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TECHNICAL MANUAL

NONDESTRUCTIVE INSPECTION METHODS

KARTA TECHNOLOGY, INC
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NAVY PERSONNEL: OPNAV Instruction 4790.2 and weapon system specific manuals take precedence over this manual.

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INTRODUCTION

1. Nondestructive Inspection (NDI) is the inspection of a structure or component in any manner that will not impair its future usefulness. The purpose of the inspection may be to detect flaws, measure geometric characteristics, determine material structure or composition, or characterize physical, electrical or thermal properties, without causing any change in the part. The NDI methods include the following:
   - Liquid Penetrant
   - Magnetic Particle
   - Electromagnetic
   - Ultrasonic
   - Penetrating Radiation
2. This publication covers the theory and general applications of the various NDI methods. For specific information on the operation or maintenance of a particular item of NDI equipment, consult the appropriate Technical Manual.
3. NDI methods in the hands of a trained and experienced technician are capable of detecting flaws or defects with a high degree of accuracy and reliability. It is important that maintenance engineering personnel are fully knowledgeable of the capabilities of each method but it is equally important that they recognize the limitations of the methods. No NDI method should ever be considered conclusive. Often a defect indication developed by one method must be confirmed by another method to be considered reliable. Furthermore, the equipment is highly sensitive and is capable of detecting discontinuities and anomalies that may be of no consequence in the service for which a component is used. Limits for acceptance and rejection are thus as much a part of an inspection as the method itself. As an example, ultrasonic inspection equipment is fully capable of detecting normal grain boundaries in some cast alloys. The inspection criteria must be designed to overlook these “normal” indications and to discriminate in favor of the discontinuities that will affect the service of the component.
4. The Office of Primary Responsibility (OPR) for this publication is the Air Force NDI Office, AFRL/MLS-OL, 4750 Staff Dr., Tinker AFB, OK 73145-3317; DSN 339-4931. All inquiries regarding either the technical content or AFTO Form 22 in accordance with T.O. 00-5-1 should be addressed to this office. Army users are invited to send comments and suggested improvements on DA Form 2028 *(Recommended Changes to Publications and Blank Forms)* directly to Commander, US Army Aviation Systems Command, ATTN: AMSAV-MC, 4300 Goodfellow Blvd., St. Louis, MO 63120-1798. Navy and Marine personnel shall submit changes/corrections to Commanding Officer Naval Aviation Maintenance Office (NAVAVNMAINOFF) (ATTN NDI PM) NAS Patuxent River, MD submit changes/corrections to Commanding Officer Naval Aviation Maintenance Office (NAVAVNMAINOFF) (ATTN NDI PM) NAS Patuxent River, MD 20670-5446; DSN 326-7934.

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SAFETY SUMMARY

INTRODUCTION

The following are general safety precautions and instructions that people must understand and apply during many phases of operation and maintenance to ensure personal safety and health and the protection of Air Force property. Portions of this may be repeated elsewhere in this publication for emphasis. Additional safety precautions are contained in AFOSH STD 91-110 and, for the Army, AR 85-10.

GENERAL CONSIDERATIONS

WARNING AND CAUTION STATEMENTS

Warning and caution statements have been strategically placed throughout this publication prior to operating or maintenance procedures, practices and conditions considered essential to the protection of personnel (WARNING) or equipment and property (CAUTION). A WARNING or CAUTION will apply each time the related procedure, practice or condition is repeated. Prior to starting any task, the WARNINGS and CAUTIONS included in the text for that task shall be reviewed and understood. The following warnings and cautions appear in the text and are repeated here for emphasis.

WARNING

Exposure to excessive X or gamma radiation is harmful to human beings. While most X-ray equipment is designed to minimize the danger of exposure to direct or stray radiation, certain precautions must be observed. Radiation protection requirements are discussed in Chapter 5, Section 9.

Prolonged direct exposure of hands to the filtered blacklight main beam may be harmful. White cotton glove liners or other suitable gloves shall be worn when exposing hands to the main beam. The temperature of some operating blacklight bulbs reaches 750°F (399°C) or more during operation. This is above the ignition or flash point of fuel vapors. These vapors will burst into flames if they contact the bulb. These blacklights SHALL NOT be operated when flammable vapors are present.

A blacklight bulb also heats the external surfaces of the lamp housing. The temperature is not high enough to be visually apparent, but it is high enough to cause severe burns with even momentary contact of exposed body surfaces. Extreme care must be exercised to prevent contacting the housing with any part of the body.

Solvents used may contain aromatic, aliphatic or halogenated compounds. Many are highly flammable while others may decompose at elevated temperatures. Keep all solvents away from heat and open flames. Vapors also may be harmful to personnel. Use adequate ventilation. Avoid contact with skin and eyes. Do not take solvents internally.

Exposure to excessive amounts of SF6 gas can cause asphyxiation by displacing oxygen in the air. Care must be taken not to release large quantities of the gas in unvented work areas. The amount leaked into the air while performing normal X-ray tube repair does not create an asphyxiation hazard. Sulphur hexafluoride, when heated, liberates hazardous fluorine gas. This possibility of producing fluorine gas exists in most X-ray tubeheads and precautions must be taken to guard against inhalation of sulfur hexafluoride released from X-ray tubes that have been energized.

CAUTION

Photochromatic lenses (lenses that darken when exposed to sunlight or ultraviolet light), and sunglasses reduce the visibility of fluorescent indications, possibility causing faint indications not to be seen. Therefore, sunglasses or glasses with photochromatic lenses SHALL NOT be worn when performing fluorescent penetrant or fluorescent magnetic particle inspections. Personnel who wear contact lens SHALL refer to the appropriate material safety data sheets (MSDS). Colored contact lenses SHALL NOT be worn when performing fluorescent penetrant or fluorescent magnetic particle inspections.

The use of visible dye penetrant is prohibited on aircraft parts (including engine) and missile parts except for those with specific engineering approval for each inspection.

Unfiltered ultraviolet radiation can be harmful to the eyes and skin. Blacklight bulbs SHALL NOT be operated without proper filters. Cracked, chipped or ill-fitting filters SHALL be replaced before using the lamp.

Dry developer particles are not toxic materials. However, like any solid foreign matter, they should not be inhaled. Air cleaners, facemasks or respirators may be required. The Base Bioenvironmental Engineer SHALL be consulted if the process generates airborne particles.

Improper cleaning procedures/materials can cause severe damage. Cleaning should be accomplished by trained and qualified personnel. For the Air Force T.O. 1-1-691 applies; for the Army, T.M. 1-1500-344-23; and for the Navy, N.A. 01-1A-509.

Waste material disposal SHALL be according to applicable directives or as specified by the local Bioenvironmental Engineer/Environmental Management Offices.

KEEP AWAY FROM LIVE CIRCUITS

Operating personnel must think safety at all times. Do not replace components or make adjustments inside equipment with the electrical supply turned on. Under certain conditions, such as residual charges on capacitors, danger may exist even when the power control is in the off position. To avoid injuries, always remove power from, discharge and ground circuit before touching it. Adhere to all lock-out/tag-out requirements.

DO NOT WEAR JEWELRY

Remove rings, watches and other metallic objects that may cause shock or burn hazards.

FINGER RINGS

Snagged finger rings have caused many serious injuries. Unless specifically allowed by shop safety procedures, remove finger rings during all maintenance activity.

GIVE CLEANERS/CHEMICALS SPECIAL CARE

Keep cleaners/chemicals in approved safety containers and in minimum quantities. Some cleaners/chemicals may have an adverse effect on skin, eyes and respiratory tract. Observe manufacturer's WARNING labels; Material Safety Data Sheet (MSDS) instructions for proper handling, storage, and disposal; and current safety directives. Use cleaners/chemicals only in authorized areas. Discard soiled cloths into safety cans. Unless otherwise indicated in the text, usage as described in this T.O. should not result in any immediate health concern. Consult the local Bioenvironmental Engineer for specific protective equipment and ventilation requirements.

COMPRESSED AIR

Use of compressed air can create an environment of propelled foreign particles. Air pressures shall be reduced to less than 30 psig and used with effective chip guarding and personal protective equipment.

PERSONAL PROTECTIVE EQUIPMENT (PPE)

Wear protective clothing/equipment (gloves, apron, eye protection, etc.) approved for the materials and tools being used. Contact supervisor for guidance. If necessary, the Bioenvironmental Engineer or the Base Safety Office should be contacted for guidance.

MAGNETIC PARTICLE INSPECTION

Magnetic particle inspection includes exposure to oils, pastes, and electrical current. Rubber insulating floor matting, rated for the voltage of the equipment being worked on, will be used in front of magnetic particle units. Use neoprene gloves during inspection process with adequate surface area exhaust ventilation as determined by the Base Bioenvironmental Engineer.

PENETRANT INSPECTION

Penetrant inspection includes the use of black light and exposure to flammable chemicals that may affect skin, eyes, and respiratory tract. Wear neoprene gloves and keep insides of gloves clean when handling penetrate materials. Chemical goggles, rubber apron, and gloves shall be worn when spraying penetrate or when processing parts. Care will be exercised when using hot black lights so as not to burn hands, arms, face, or other exposed body areas. When recommended by the Base Bioenvironmental Engineer, an approved respirator shall be worn when working in areas where adequate ventilation cannot be practically provided.

RADIOGRAPHIC INSPECTION

Nondestructive inspection radiation can be harmful to personnel. Comply with all applicable safety precautions in Chapter 6. Failure to comply may result in injury. Coordinate all operational changes with the Base Radiation Safety Officer.

CHAPTER 1
SECTION I
GENERAL INFORMATION

1 GENERAL INFORMATION

1.1 INSPECTION FACILITY

1.1.1 Introduction

This section describes a typical Nondestructive Inspection (NDI) facility. Figure 1-1 is a typical floor plan showing the minimum requirements for such a facility. A larger or modified facility may be warranted depending on the particular weapon system(s) serviced. Use of the floor plan and the associated notes should be used in conjunction with both the applicable manufacturer's installation instructions for the equipment required and the information provided in the radiation protection section of Chapter 6 of this technical order.

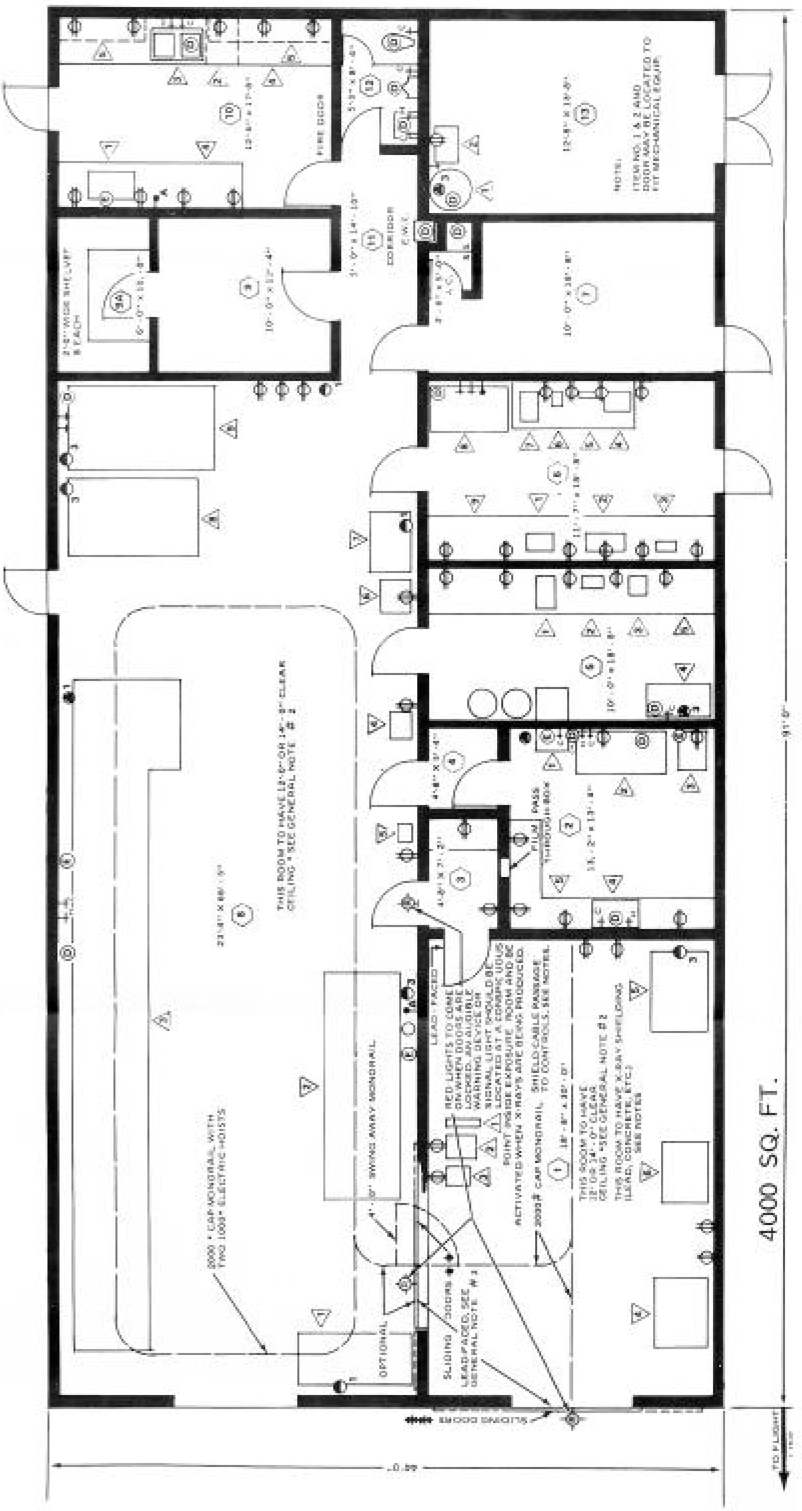


Figure 1-1. Nondestructive Inspection Facility.

1.1.2 Notes For Floor Plan

1.1.2.1 General.

a. A ceiling height of 10 feet is required throughout the facility with the exception of rooms 1, 7, 8 and 12.

b. Clear ceiling height in the X-ray exposure room (1) should be 12 feet where practical, to avoid difference in roof level. The height may be 14 feet where the using command can justify it on the basis of sizes of components to be inspected in the foreseeable future. Door and monorail between rooms 1 and 8 are optional. Where a monorail is provided, adjust the ceiling heights in both rooms to suit the monorail operation.

c. Sizes of lead-faced doors into the exposure room depend on the size of items to be inspected. They should be as small as practical for efficient operation. The door between rooms 1 and 8 can be above the floor, at any height to suit operations.

d. Materials, construction, etc. are to be in accordance with AFM 88-15.

e. Building is to be Type “N” unprotected noncombustible construction.

1.1.2.2 X-Ray and Environmental Protection.

NOTE

NAVY REQUIREMENT: Navy and Marine Corps radiographic facilities SHALL comply with NAVSEA S0420-AA-RAD-010

a. Radiation shielding, barricades and warning devices are dependent on each specific siting and operation.

b. X-ray exposure room 1 will conform to the requirements specified in the National Institute of Standards Technology (formerly National Bureau of Standards) Handbook 93, *Safety Standards for Non-Medical X-ray and Sealed Gamma-ray Sources*. (Bioenvironmental Engineers or health physicists should be consulted for help in interpreting Handbook 93 and performing shielding calculations.)

(1) Shielding will be used on the ceiling only when required by shielding calculations. When ceiling shielding is not provided, a barrier limiting access to the roof of the NDI facility will be used, with a warning light at each point of access.

(2) The design and specifications for the NDI facility will be reviewed by a Bioenvironmental Engineer or health physicist and approved by the Director of Base Medical Service prior to contract solicitation.

(3) Before a new installation is placed in routine operation, the medical service will be notified and a request submitted for a radiation protection survey by a qualified Bioenvironmental Engineer or health physicist.

(4) If use of radio-isotopes is anticipated, this should receive consideration when calculating shielding requirements.

c. Design shall show the cable passage between the exposure room and the controls outside this room. Cable passage should be “S-shaped” and provide the same level of shielding as the X-ray barrier.

d. In room 8 provide appropriate ventilation for penetrant and magnetic particle inspection processes.

e. Do not tie heating/ventilation/air conditioning return air ducts in with building system. All supply air to be exhausted to exterior (explosion proof exhaust fan).

1.1.2.3 Electrical and Mechanical.

a. Recessed lighting fixtures may be used where operationally required. Use surface mounted fixture, for economy, wherever practical. Fixtures in room 1 should be surface mounted if shielding is applied on ceiling.

b. In room 10, provide two-hour fire-rated walls and doors. All electrical wiring will meet Class I, Division II requirements.

c. Environmental control required for the entire facility with maximum relative humidity and temperature of 50 % and 75 °respectively.

d. Include necessary provisions for handling waste materials containing pollutants in drainage system.

1.1.2.4 Room Identification.

a. The following is a list of the typical rooms in the NDI facility:

1. X-ray vault
2. X-ray film processing room
3. X-ray control room
4. X-ray film process room entrance
5. Film viewing room
6. Consolidated equipment room
7. Office
8. Main inspection bay
9. Training room

9a. Shop stock and storage

10. Oil analysis lab
11. Corridor
12. Latrine
13. Mechanical equipment room

SECTION II

PERSONNEL TRAINING / QUALIFICATION / CERTIFICATION

1.2 PERSONNEL TRAINING / QUALIFICATION / CERTIFICATION.

1.2.1 Guidelines.

Only highly trained and experienced personnel can attain effective utilization of NDI. In order to qualify for the table of allowances, TA 455; commanders will insure that properly trained and qualified personnel will be available. Army commanders will insure that authorized positions are filled with qualified personnel in accordance with AR 750-1. Navy personnel must be trained according to OPNAVINST 4790.2. The formal training requirements are waived for the black lights, ultrasonic leak detector and optical equipment, provided the personnel using the equipment are properly trained in its use and the equipment is not being used to perform nondestructive inspections, such as fluorescent penetrant and magnetic particle inspections.

1.2.2 Requirements.

Formal training requirements may be met through the nondestructive inspection basic technician course conducted by Air Education and Training Command (AETC) at NAS Pensacola or through equivalent training obtained in courses conducted by industry or civilian service. For this training to be considered equivalent to that provided by the AETC NDI course, approval is required by the Air Force NDI Office, AFRL/MLS-OL, 4750 Staff Dr., Tinker AFB, OK 73145-3317; DSN 339-4931. Army personnel shall be qualified in accordance with AR 611-201. Job qualification/proficiency shall be documented per Command policy and filed in the individual’s AF Form 623 On-The-Job Training folder. For all civilian Department-of-Defense personnel and non-Department of Defense personnel performing inspections in accordance with the Technical Order: they SHALL be qualified and certified to the current National Aerospace Standard (NAS) 410, NAS Certification and Qualification of Nondestructive Test Personnel. This Requirement has been temporarily waived until 1 June 2000 for active duty, Air National Guard and AF Reserve Center civilian personnel. This requirement is still mandatory for Air Logistics Center (ALC) (DEPOT) personnel performing NDI. At a minimum, the local organization shall document its procedure on training and certifying their inspectors per MIL-STD-410. In lieu of each local unit developing a written procedure, where enough similarity exist from unit to unit, a command may develop a written procedure to be used by all units within the command.

1.2.3 Physical Requirements.

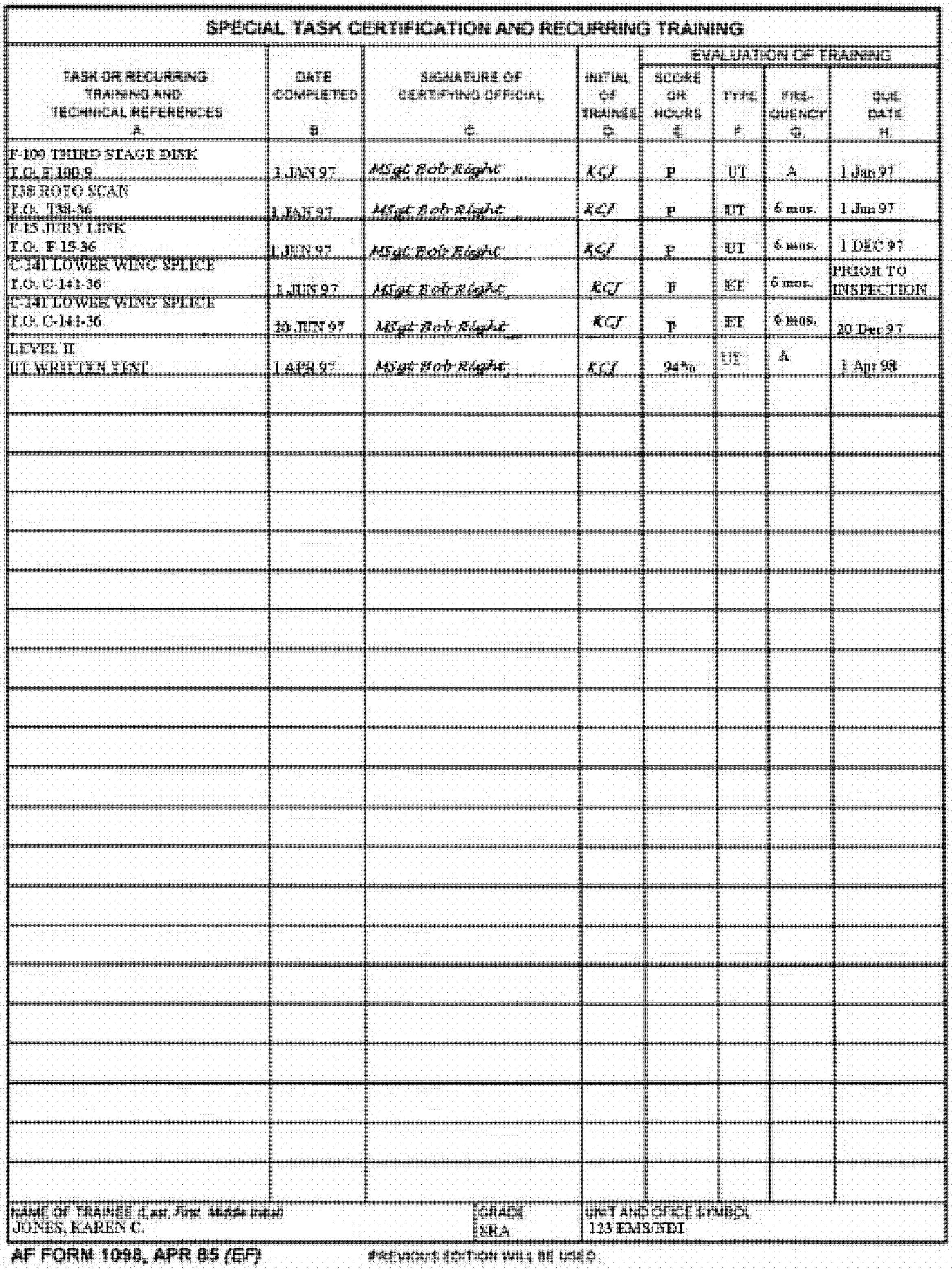
A physical examination shall assure that the applicants near vision and color perception meet the following requirements. Near vision test and color perception tests shall be administered annually.

NEAR VISION - Jaeger #1 test chart at not less than 12 inches, or equivalent as determined by medical personnel, with one eye, either natural or corrected.

COLOR PERCEPTION - Distinguish and differentiate between the colors used in the method for which certification is sought.

1.2.4 Special Task Certification and Recurring Training.

Lab supervisors SHALL identify and document critical nondestructive inspections on an AF Form 1098 (see Figure 1-2). This form should be completed to track critical inspection certification and recurring training. Identifying a critical task, which requires certification, should be done with direction from the appropriate ALC NDI Manager. Most boxes on the form are self-explanatory. The lab supervisor is the certifying official. In the columns for evaluation of training you may or may not have a score. You should have at least Pass (P) or Fail (F). Any failure of the inspector to accomplish the inspection SHALL require training before the inspector is allowed to accomplish this tasking. Block f. should be filled in by inspection method, for example ET, UT, RT. The timeline for re-occurring certification of these critical inspections SHALL be determined by the lab supervisor, inspection procedure or engineering authority. Any critical inspection task should be evaluated at least annually (A).



SPECIAL TASK CERTIFICATION AND RECURRING TRAINING

TASK OR RECURRING TRAINING AND TECHNICAL REFERENCES A.	DATE COMPLETED B.	SIGNATURE OF CERTIFYING OFFICIAL C.	INITIAL OF TRAINEE D.	EVALUATION OF TRAINING SCORE OR HOURS E.	TYPE F.	FRE-QUENCY G.	DUE DATE H.
F-100 THIRD STAGE DISK T.O. F 100-9	1 JAN 97	MSgt Bob Right	KCJ	P	UT	A	1 Jan 97
T38 ROTO SCAN T.O. T38-36	1 JAN 97	MSgt Bob Right	KCJ	P	UT	6 mos.	1 Jun 97
F-15 JURY LINK T.O. F-15-36	1 JUN 97	MSgt Bob Right	KCJ	P	UT	6 mos.	1 DEC 97
C-141 LOWER WING SPLICE T.O. C-141-36	1 JUN 97	MSgt Bob Right	KCJ	F	ET	6 mos.	PRIOR TO INSPECTION
C-141 LOWER WING SPLICE T.O. C-141-36	20 JUN 97	MSgt Bob Right	KCJ	P	ET	6 mos.	20 Dec 97
LEVEL II UT WRITTEN TEST	1 APR 97	MSgt Bob Right	KCJ	94%	UT	A	1 Apr 98

NAME OF TRAINEE (Last, First, Middle Initial)	GRADE	UNIT AND OFICE SYMBOL
JONES, KAREN C.	SRA	123 EMS/NDI

AF FORM 1098, APR 85 (EF) PREVIOUS EDITION WILL BE USED.

Figure 1-2. Example of AF Form 1098

SECTION III
REPORTING NEW OR IMPROVED NDI TECHNIQUES.

1.3 REPORTING NEW / IMPROVED NONDESTRUCTIVE INSPECTION TECHNIQUES.

1.3.1 Summary.

a. Developing new NDI techniques is expensive and time consuming. In addition, techniques and procedures can be applied to all aircraft where similar problems exist. Interchanging information on newly developed NDI techniques between operating commands will reduce maintenance costs and enhance safety.

b. This section prescribes the procedures for reporting the development of new or improved nondestructive inspection techniques. It also provides for the reporting of a NDI method application to a part or item not previously inspected by NDI methods.

c. Nondestructive Inspection Data, AFTO Form 242, permits detailed feedback and interchange of new or improved NDI techniques, procedures and applications from base level NDI laboratories to other NDI operational facilities, system/item managers and NDI program managers.

d. The Army equivalent of AFTO Form 242 is DA Form 2028 (see paragraph 1.3.4.5).

e. Navy / Marine Corps personnel use AFTO Form 242 and forward via Aircraft Controlling Custodian/Type Commander (ACC/TYCOM) to the Cognizant Field Activity (CFA).

1.3.2 Authority.

The authority for reporting new or improved NDI techniques or new applications of NDI methods is contained in AFI 21-105, Air Force Fabrication Programs.

1.3.3 Scope.

a. The procedures prescribed herein apply to all major air commands, Air National Guard and Air Force Reserve units operating NDI shops per AFI 21-105.

b. An AFTO Form 242 SHALL be submitted whenever an NDI technique is developed improved or is considered desirable and is not sufficiently described or contained in existing manuals.

c. An AFTO Form 242 SHALL NOT be used in the following cases:

  (1) Reporting minor technical inaccuracies in NDI involving the use of the same technique.

  (2) Techniques requiring the use of nonstandard equipment not listed in TA 455. However, this does not include locally manufactured shoes, holders, or wedges for use with TA 455 equipment. Reporting requirements for equipment evaluation will be provided by the AF NDI Program Manager and directed by the command NDI Program Manager.

  (3) Reporting changes or deficiencies in inspection requirements, such as contained in Dash 6 Technical Orders.

1.3.4 Responsibilities.

1.3.4.1 Initiator.

a. Any NDI technician who (a) develops an NDI technique or procedure not presently contained in the existing NDI applications manuals or other applicable T.O. manuals, (b) improves an existing NDI procedure, or (c) determines an area or condition where an NDI procedure would be advantageous will initiate an AFTO Form 242 in accordance with the instructions prescribed in subsequent paragraphs.

b. The initiator will also prepare an AFTO Form 22 in accordance with T.O. 00-5-1 to serve as a processing document for the AFTO Form 242. The AFTO Form 22 should cite the NDI applications manual (Dash 36) for the applicable weapons system or other manual in which the proposed procedure should be incorporated. On commodity items, that do not have an NDI applications manual, the applicable technical order manual containing service, operating and maintenance instructions should be cited. One copy of the applicable AFTO Form 242 will be attached to each copy of AFTO Form 22.

c. The initiator shall complete the applicable sections of AFTO Form 242 as described in paragraph 1.3.5.

1.3.4.2 Initiators Supervisor.

NOTE

The AFTO Form 22 and 242 shall be submitted to the ALC NDI Manager when the inspection technique directly involves parts that are on or associated with the weapon system. Support equipment items require only the approval of the local lab supervisor.

a. The supervisor of the person initiating the AFTO Form 242 shall review the completed form to insure that all information is included. He shall also witness a demonstration of the technique following the instructions on the AFTO Form 242 to verify the capability of performing the inspection as it is described. In addition, the supervisors will initial/date the AFTO Form 242 confirming that he/she has witnessed the inspection.

b. After approving the technique, the supervisor will submit the Forms 22 and 242 to the responsible ALC NDI Manager.

1.3.4.3 Air Force ALC NDI Program Manager.

a. The responsible ALC NDI Program Manager is responsible for ensuring the technical accuracy of the technique. He will add, revise or supplement the submitted technique as required to produce a workable procedure. He will validate the final technique and take action to include it in the appropriate technical order.

b. The manager will provide a copy of the Forms 22 and 242 to the AF NDI Program Manager.

1.3.4.4 Air Force NDI Program Manager.
The AF NDI Program Manager will distribute information copies of the approved technique to all Command NDI Program Managers as applicable.

1.3.4.5 Army Personnel.
The Army uses DA Form 2028 when developing a NDI technique or procedure not presently contained in existing manuals. AFTO Forms may be reproduced and used to supplement DA Form 2028. Send to Commander, US Army Aviation Systems Command, ATTN: AMSAV-MC, 4300 Goodfellow Blvd., St. Louis, MO 63120-1798.

1.3.5 Entries on AFTO Form 242.

NOTE

> If it is not possible to provide adequate space on a single sheet for a complete detailed description of a NDI technique, the AFTO Form 242 should be supplemented with additional sheets of plain bond paper.

Examples of AFTO Form 242 for radiographic inspection techniques and ultrasonic inspection techniques are provided for illustrative purposes (Figures 1-3). Entries for other inspection methods are similar and are described in the appropriate paragraphs. The first twelve blocks on AFTO Form 242 are used to identify the submitting command, organization and initiator, also the system, subsystem, next higher assembly, the actual part or component to be inspected and a description of the defect/condition or reason for the inspection. The instructions for completing these twelve blocks are provided in the following paragraphs:

1.3.5.1 General Information.

1.3.5.1.1 Block 1 Control Number.

A standardized number that reflects the command and organization developing the technique and method used. The control number SHALL be made up of three series of numbers and letters as follows:

a. Two digits of the calendar year with an alphabetic character designating the applicable NDI method code (Table 1-1). If more than one inspection method is used to determine the integrity of a part, and both techniques are listed on the same AFTO Form 242, use a letter for each inspection method, (i.e., 86CA) with the letter for the primary inspection method being listed first.

b. The code for the major command (Table 1-2) and the organization or unit number of the technique originator.

c. A sequential number assigned by the originating organization without regard for method of inspection or calendar year.

d. Example: Report/Control No. 97A-Q62-12
Where: 97 stands for calendar year 1997
A is the method designator for penetrant inspection
Q is Major Command Code for AMC
62 is the Unit Number, i.e., 62nd Maintenance Squadron
12 stands for the twelfth technique submitted by the 62nd MXS

Table 1-1. NDI Method Codes.

NDI Method	Method Code
Penetrant	A
Magnetic Particle	B
Electromagnetic	C
Ultrasonic	D
Radiographic	E

Table 1-2. Major Command Codes.

Major Command	Command Code
US Air Forces Europe (USAFE)	D
Air Force Materiel Command (AFMC)	E
Air Force Education and Training Command (AETC)	J
Air Force Reserve (AFRES)	M
Air Combat Command (ACC)	T
Air Mobility Command (AMC)	Q
Air Force Space Operations Command (AFSOC)	S
US Air Force Pacific (PACAF)	R
Air National Guard (ANG)	Z

1.3.5.1.2 Block 2 Organization and Base.
Example: 62 MXS, McChord AFB, WA.

1.3.5.1.2 Block 3 End Item (M/D/S).
Enter the major end item on which the part/area to be inspected is installed. Include the Mission/Designator/Series (M/D/S) or Federal Stock Class (FSC) number, as applicable.

1.3.5.1.4 Block 4 Nomenclature.
Specify the name of item/component or assembly to be inspected.

1.3.5.1.5 Block 5 Part/Assembly Number.

1.3.5.1.6 Enter part or assembly number of the item to be inspected.

1.3.5.1.7 Block 6 T.O. Number.
Enter technical order number of illustrated parts manual or service and maintenance manual that shows item/assembly to be inspected. Enter page, figure, index number and date of issue of the manual where applicable.

1.3.5.1.8 Block 7 Next Higher Assembly.
Enter name and part number of next higher assembly. If there is insufficient space, complete the entry on a continuation sheet of plain bond paper.

1.3.5.1.9 Block 8 Manufacture/Serial Number.
Enter manufacturer's name and serial number (if applicable).

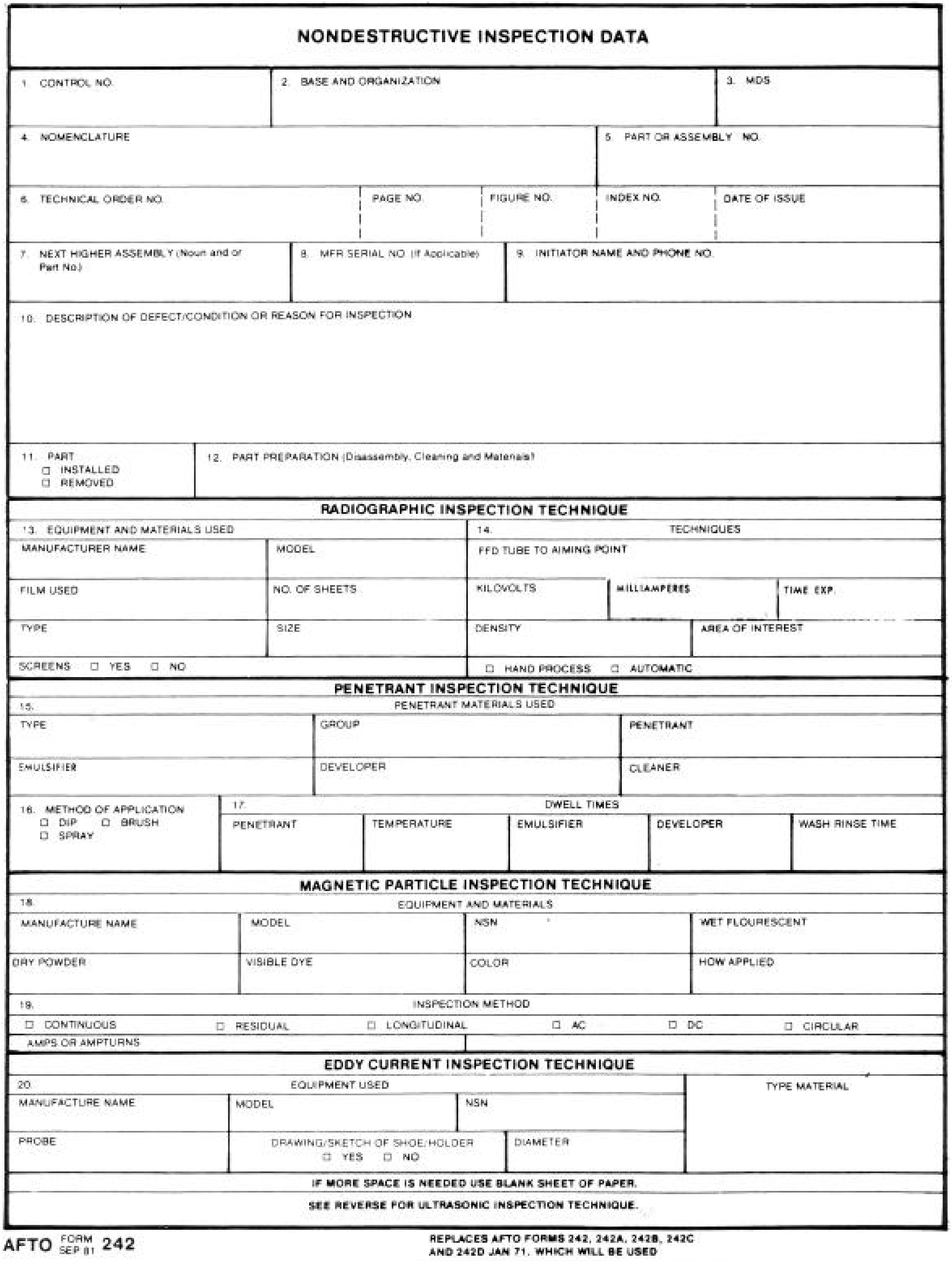
1.3.5.1.10 Block 9 Initiator and Phone Number.
Enter name, rank and phone number of initiator or person who developed the technique.

1.3.5.1.11 Block 10 Description of Defect/Condition or Reason for Inspection.
Provide a narrative description of defect/condition or reason for inspection. Narration should include location and orientation of the discrepancy.

1.3.5.1.12 Block 11
Place a check mark or an "X" in appropriate block indicating whether inspection is performed with part installed or removed.

1.3.5.1.13 Block 12 Part Preparation.

Describe any disassembly or system preparation necessary. Examples: “Remove retaining bolt P/N 1, lower inboard flaps;” or “Remove access cover number ---.” Also describe any depainting, carbon removal or other cleaning requirements.



NONDESTRUCTIVE INSPECTION DATA

1. CONTROL NO.	2. BASE AND ORGANIZATION	3. MDS

4. NOMENCLATURE	5. PART OR ASSEMBLY NO.

6. TECHNICAL ORDER NO.	PAGE NO.	FIGURE NO.	INDEX NO.	DATE OF ISSUE

7. NEXT HIGHER ASSEMBLY (Noun and or Part No.)	8. MFR SERIAL NO. (If Applicable)	9. INITIATOR NAME AND PHONE NO.

10. DESCRIPTION OF DEFECT/CONDITION OR REASON FOR INSPECTION

11. PART ☐ INSTALLED ☐ REMOVED	12. PART PREPARATION (Disassembly, Cleaning and Materials)

RADIOGRAPHIC INSPECTION TECHNIQUE

13. EQUIPMENT AND MATERIALS USED		14. TECHNIQUES		
MANUFACTURER NAME	MODEL	FFD TUBE TO AIMING POINT		
FILM USED	NO. OF SHEETS	KILOVOLTS	MILLIAMPERES	TIME EXP.
TYPE	SIZE	DENSITY	AREA OF INTEREST	
SCREENS ☐ YES ☐ NO		☐ HAND PROCESS ☐ AUTOMATIC		

PENETRANT INSPECTION TECHNIQUE

15. PENETRANT MATERIALS USED

TYPE	GROUP	PENETRANT
EMULSIFIER	DEVELOPER	CLEANER

16. METHOD OF APPLICATION ☐ DIP ☐ BRUSH ☐ SPRAY	17. DWELL TIMES				
	PENETRANT	TEMPERATURE	EMULSIFIER	DEVELOPER	WASH RINSE TIME

MAGNETIC PARTICLE INSPECTION TECHNIQUE

18. EQUIPMENT AND MATERIALS

MANUFACTURE NAME	MODEL	NSN	WET FLOURESCENT
DRY POWDER	VISIBLE DYE	COLOR	HOW APPLIED

19. INSPECTION METHOD

☐ CONTINUOUS ☐ RESIDUAL ☐ LONGITUDINAL ☐ AC ☐ DC ☐ CIRCULAR

AMPS OR AMPTURNS

EDDY CURRENT INSPECTION TECHNIQUE

20. EQUIPMENT USED			TYPE MATERIAL
MANUFACTURE NAME	MODEL	NSN	
PROBE	DRAWING/SKETCH OF SHOE/HOLDER ☐ YES ☐ NO	DIAMETER	

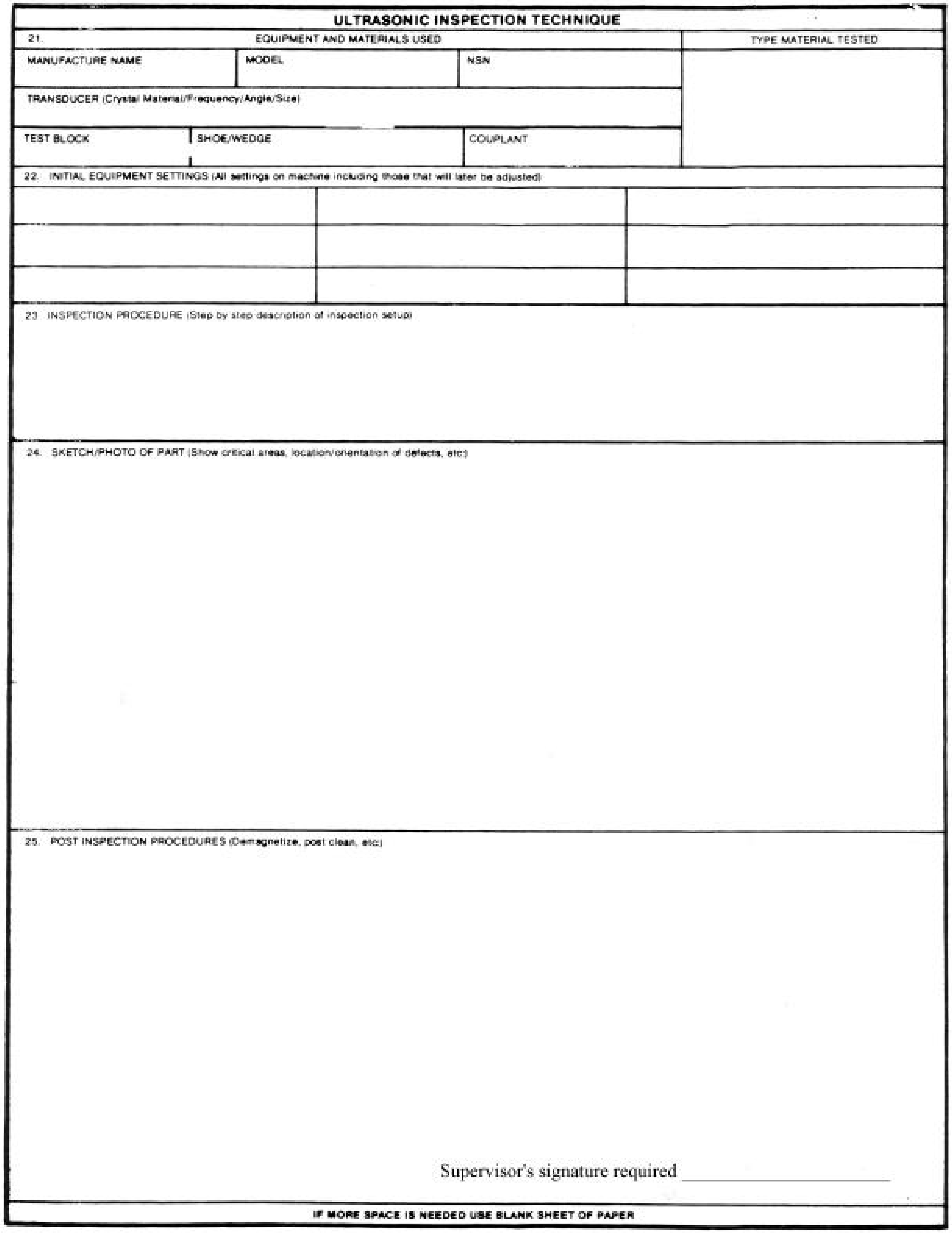
IF MORE SPACE IS NEEDED USE BLANK SHEET OF PAPER.

SEE REVERSE FOR ULTRASONIC INSPECTION TECHNIQUE.

AFTO FORM SEP 81 242

REPLACES AFTO FORMS 242, 242A, 242B, 242C AND 242D JAN 71, WHICH WILL BE USED

Figure 1-3. AFTO Form 242 (Sheet 1 of 2).



ULTRASONIC INSPECTION TECHNIQUE

21. EQUIPMENT AND MATERIALS USED			TYPE MATERIAL TESTED
MANUFACTURE NAME	MODEL	NSN	
TRANSDUCER (Crystal Material/Frequency/Angle/Size)			
TEST BLOCK	SHOE/WEDGE	COUPLANT	

22. INITIAL EQUIPMENT SETTINGS (All settings on machine including those that will later be adjusted)

23. INSPECTION PROCEDURE (Step by step description of inspection setup)

24. SKETCH/PHOTO OF PART (Show critical areas, location/orientation of defects, etc.)

25. POST INSPECTION PROCEDURES (Demagnetize, post clean, etc.)

Supervisor's signature required ____________________

IF MORE SPACE IS NEEDED USE BLANK SHEET OF PAPER

Figure 1-3. AFTO Form 242 (Sheet 2 of 2).

SECTION IV
PROCESS CONTROL OF ALL NDI METHODS

1.4 PROCESS CONTROL.

1.4.1 Reason For Process Control.

Process control is an essential ingredient in achieving irrefutable results in NDI inspections, regardless of method. A well-regimented NDI process control program will not allow conditions to develop that render inspection methods a source of misinformation. This misinformation may take two forms. The first arises when NDI has determined that a part is defective when indeed it is not (false call). This is a waste of resources and an unnecessary reduction in mission capability. The second form is the most dangerous, that is, determining a part is serviceable when in fact it is defective (a miss). Both forms of misinformation can be minimized through the implementation of effective process control.

1.4.2 Scope Of Process Control.

All aspects of these categories are interrelated. They have to be tuned to each other to achieve valid inspection results. If any one of these requirements is altered, the final outcome of the inspection will change, regardless of the inspector's proficiency.

a. Process control is a general term used to encompass the actions and documentation, required by established directives and logic, that are necessary for a nondestructive inspection (NDI) method to be effective in detecting conditions of interest (e.g., cracks, foreign objects, corrosion, alignment of parts and thickness of parts).

b. The general areas that fall within the scope of process control are as follows:

(1) Inspector training and the demonstrated practical skills of inspectors.

(2) Inspection environment; for example, temperature, specific type and levels of light, safety and human engineering.

(3) Material control; for examples, the serviceability of ultrasonic transducers, eddy current probes, penetrant materials, X-ray film and chemicals, and magnetic particle suspensions.

(4) Equipment control; for example its operational and performance capability and PMEL/user calibration.

(5) Adequate, specific inspection instructions; for example, -36, -26, and -9 technical orders.

(6) Adherence to the inspection requirements dictated by specific NDI procedures and commonly accepted basic NDI practices.

1.4.3 Scope Of Documentation Requirements.

a. The documentation requirements and process control are completed to verify conformance to established requisites in the areas described in paragraph 1.4.2. The requirements prescribed within this technical order apply to all Major Air Force Commands, Air National Guard and Air Force Reserve that use Nondestructive Inspection Laboratories per AFI 21-105. These requirements also apply to Army, Army National Guard (ARNG), and Army Reserve (USAR) units.

b. Separate documentation SHALL be maintained for each NDI method, equipment and material with established process control requirements. Process control requirements SHALL NOT be documented on the same form used for equipment maintenance. This documentation SHALL reflect, as a minimum, each element of process control with respect to required time intervals between checks, date of accomplishment for each check, condition of element checked, corrective action taken (if required), initials of person performing test, serial number or identification number of the element tested, manufacturer, lot or number if applicable, and date put into service. Unless otherwise directed, only the most recent required documentation concerning equipment/ materials needs to be maintained.

1.4.4 Responsibilities.

Each organization listed in paragraph 1.4.3a SHALL determine the method which their assigned NDI laboratories will utilize to document process control verification. Army units will maintain records of process control requirements at the unit level.

1.4.5 Suggested Documentation Method.

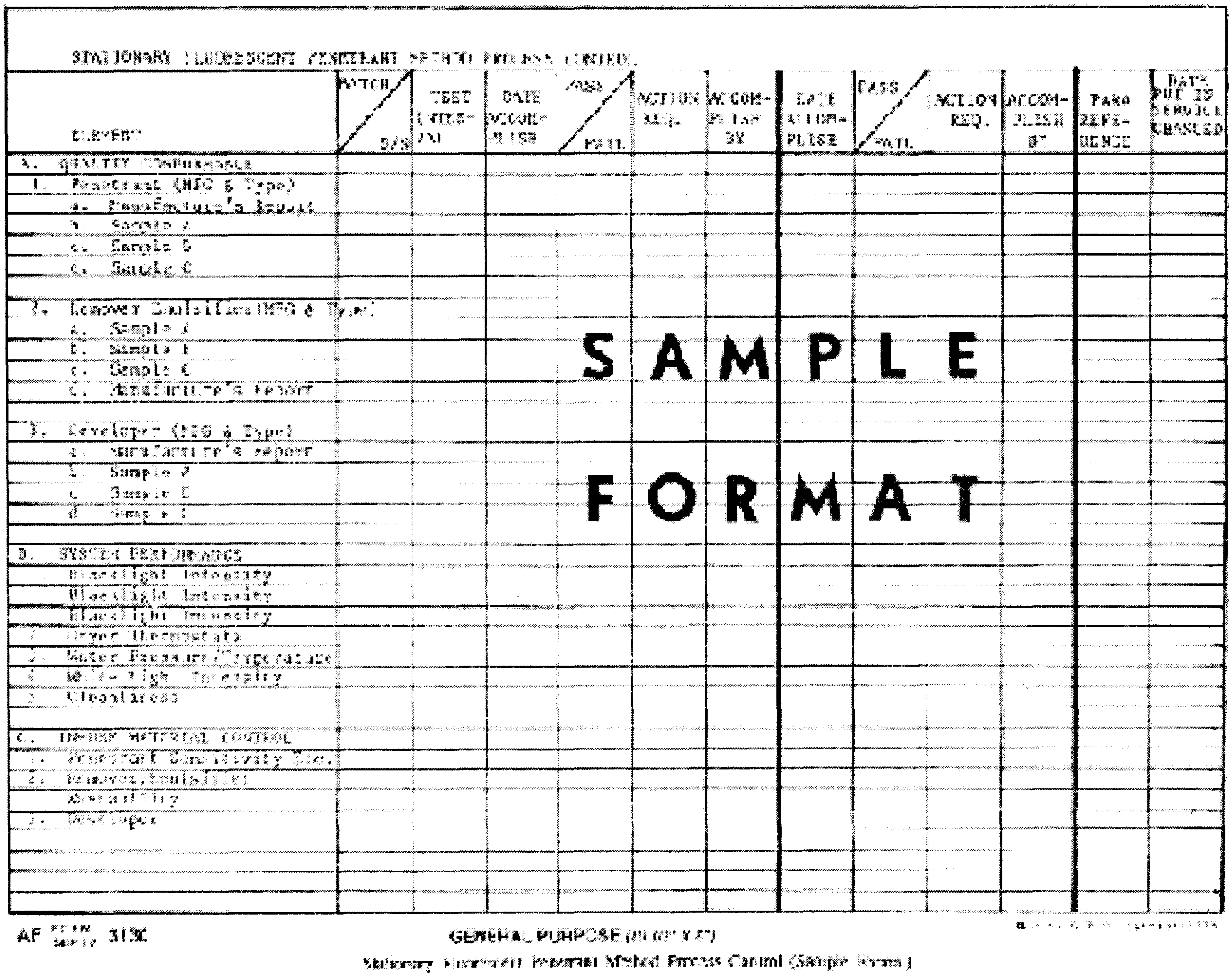
Figures 1-4 and 1-5 are examples of how process control may be documented utilizing an Air Force general-purpose form. For this example AF Form 3130 was used. The use of a general-purpose form would be relatively inexpensive and could be easily formatted to fit specific NDI method and equipment process control requirements. An alternative to the general-purpose form would be to interface process control with a computer, utilizing the PCAMS system. The Air Force NDI Program Office has authorized and highly recommends the use of this program.

Table 1-3. Frequency for Process Control

LIQUID PENETRANT	INTERVAL	PG	PARA
Crack Chrome Panels/Material Performance	Determined By Workload	1-32	1.5.4.2
Developer Specific Gravity/Water Soluble	7 Days	1-41	1.5.5.6.1
Remover Contamination Check	30 Days	1-37	1.5.5.4.1.1
Remover Performance Check	30 Days	1-37	1.5.5.4.1.2
Spray Remover Concentration Check	30 Days	1-38	1.5.5.4.2.1
Wash Nozzle Check/Spray Angle	30 Days	2-51	2.5.4.5.2.4
Penetrant Brightness/Depot; Optional Field	30 Days	1-34	1.5.5.2.2b
Penetrant Wetability/Surface Wetting	90 Days	1-34	1.5.5.2.2a
Water Content Test/Hydrophilic Remover	90 Days	1-36	1.5.5.4
Dryer Temperature	180 Days	1-25	1.5.2.10
Quality Conformance Test	(New Solution)	1-30	1.5.3.4
MAGNETIC PARTICLE TESTING	**INTERVAL**	**PG**	**PARA**
Concentration/Suspension Settling Test	Determined by Workload	1-44, 3-69	1.6.4, 3.5.6.8
Determination of Vehicle Fluorescence	In Conjunction with Suspension Settling Test	3-74	3.5.7.5.2
System Effectiveness Test	Minimum of Once Every 7 Days	1-48	1.6.10
Ambient Light Check PT & MT	60 Days	1-27	1.5.2.12c
Black Light Intensity PT & MT	Daily or Prior to Use	2-79	2.7.4.1.5
Amperage Indicator Check	6 Months	1-49	1.6.11
Quick Break	60 Days	1-50	1.6.12
WATER MPI BATH ONLY	**INTERVAL**	**PG**	**PARA**
Water Break Test	Daily	3-26	3.3.6.1
MAGNETIC PARTICLE PORTABLE	**INTERVAL**	**PG**	**PARA**
Dead Weight	30 Days	1-46	1.6.7.2c
EDDY CURRENT	**INTERVAL**	**PG**	**PARA**
Probe Sensitivity/Signal To Noise Ratio	Per Inspection Check	4-51	4.5.2.8
ULTRASONIC INSPECTION	**INTERVAL**	**PG**	**PARA**
Vertical Linearity	Determined By Lab Supervisor	1-57	1.8.2.1
Horizontal Linearity	Determined By Lab Supervisor	1-58	1.8.2.2
Sensitivity Check	Determined By Lab Supervisor	1-59	1.8.2.3

Table 1-3. Frequency for Process Control - Continued

ULTRASONIC INSPECTION (Cont.)	INTERVAL (Cont.)	PG	PARA
Resolution Check	Determined By Lab Supervisor	1-60	1.8.2.4
Dead Zone Check	Determined By Lab Supervisor	1-61	1.8.2.4.2.2
Angle Beam Point Of Incident	Determined By Lab Supervisor	1-65	1.8.2.6.2
Angle Beam Angle Determination	Determined By Lab Supervisor	1-66	1.8.2.6.3
Angle Beam Skew Angle	Determined By Lab Supervisor	1-69	1.8.2.6.7
RADIOGRAPHY INSPECTION	**INTERVAL**	**PG**	**PARA**
Safelight Fog Evaluation	Determined By Lab Supervisor	1-73	1.9.2.7
Interlock	Prior to Shift Use	6-121	6.9.7.2.7



STATIONARY FLUORESCENT PENETRANT METHOD PROCESS CONTROL

ELEMENT	BATCH / S/N	TEST (INITIAL)	DATE ACCOMPLISHED	PASS / FAIL	ACTION REQ.	ACCOMPLISH BY	DATE ACCOMPLISHED	PASS / FAIL	ACTION REQ.	ACCOMPLISH BY	PARA REFERENCE	DATE PUT IN SERVICE CHANGED
A. QUALITY CONFORMANCE												
1. Penetrant (MFG & Type)												
a. Manufacturer's Report												
b. Sample A												
c. Sample B												
d. Sample C												
2. Remover Emulsifier (MFG & Type)												
a. Sample A												
b. Sample B												
c. Sample C												
d. Manufacturer's Report												
3. Developer (MFG & Type)												
a. Manufacturer's Report												
b. Sample A												
c. Sample B												
d. Sample C												
B. SYSTEM PERFORMANCE												
Blacklight Intensity												
Blacklight Intensity												
Blacklight Intensity												
Dryer Thermostats												
Water Pressure/Temperature												
White Light Intensity												
Cleanliness												
C. IN-USE MATERIAL CONTROL												
1. Penetrant Sensitivity Etc.												
2. Remover/Emulsifier												
Washability												
3. Developer												

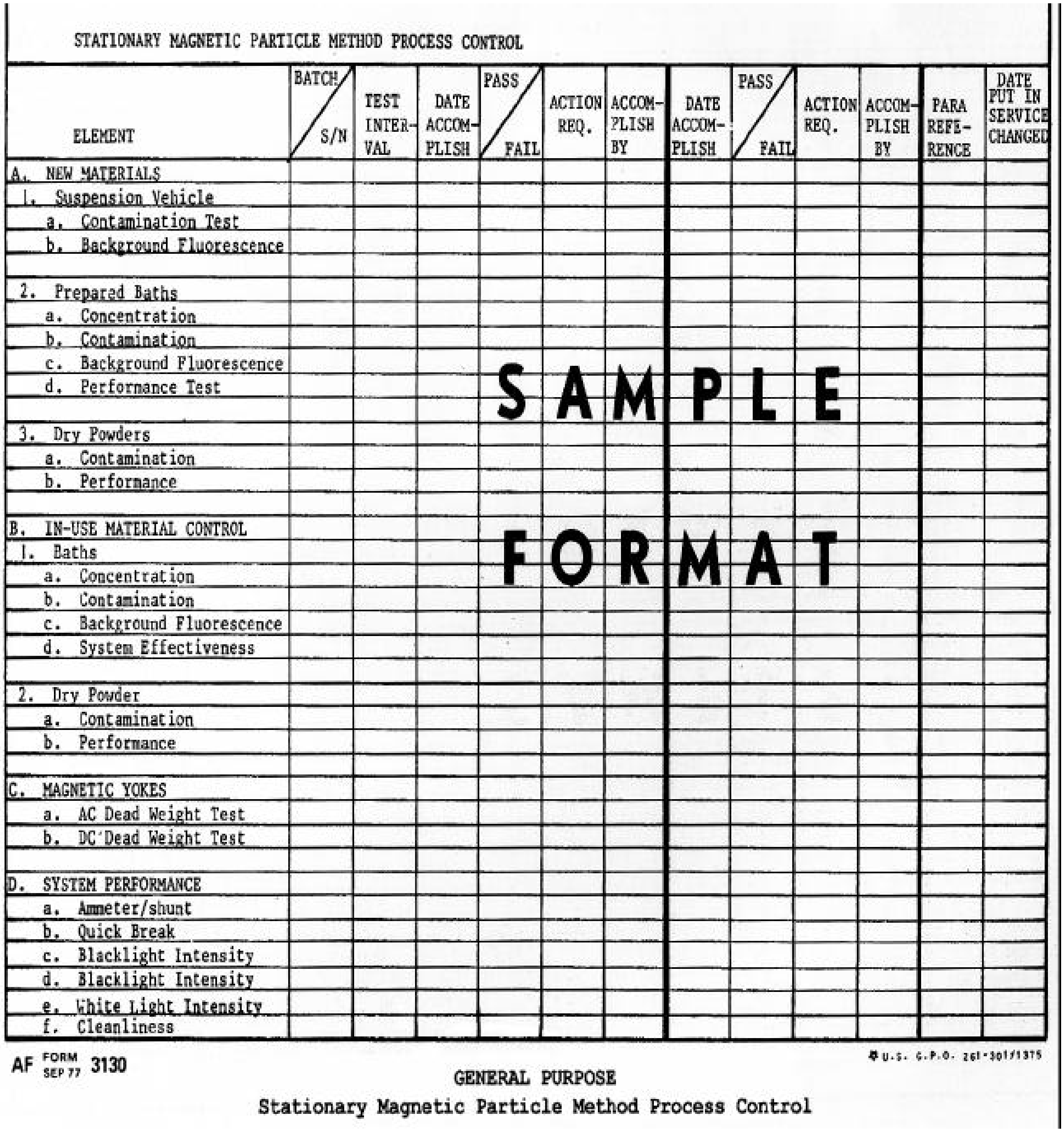
SAMPLE FORMAT

AF FORM SEP 77 3130 GENERAL PURPOSE

Stationary Fluorescent Penetrant Method Process Control (Sample Form)

H0000368

Figure 1-4. AF Form 3130 Sample Format for Fluorescent Penetrant Method Process Control



STATIONARY MAGNETIC PARTICLE METHOD PROCESS CONTROL

ELEMENT	BATCH / S/N	TEST INTER-VAL	DATE ACCOM-PLISH	PASS / FAIL	ACTION REQ.	ACCOM-PLISH BY	DATE ACCOM-PLISH	PASS / FAIL	ACTION REQ.	ACCOM-PLISH BY	PARA REFE-RENCE	DATE PUT IN SERVICE CHANGED
A. NEW MATERIALS												
1. Suspension Vehicle												
a. Contamination Test												
b. Background Fluorescence												
2. Prepared Baths												
a. Concentration												
b. Contamination												
c. Background Fluorescence												
d. Performance Test												
3. Dry Powders												
a. Contamination												
b. Performance												
B. IN-USE MATERIAL CONTROL												
1. Baths												
a. Concentration												
b. Contamination												
c. Background Fluorescence												
d. System Effectiveness												
2. Dry Powder												
a. Contamination												
b. Performance												
C. MAGNETIC YOKES												
a. AC Dead Weight Test												
b. DC Dead Weight Test												
D. SYSTEM PERFORMANCE												
a. Ammeter/shunt												
b. Quick Break												
c. Blacklight Intensity												
d. Blacklight Intensity												
e. White Light Intensity												
f. Cleanliness												

AF FORM SEP 77 3130

U.S. G.P.O. 261-301/1375

GENERAL PURPOSE

Stationary Magnetic Particle Method Process Control

Figure 1-5 AF Form 3130 Sample Format for Magnetic Particle Method Process Control.

SECTION V
PT PROCESS CONTROL

1.5 PENETRANT PROCESS CONTROL.

This section provides basic, operating and advanced level information on the procedures necessary to assure a high quality performance from the penetrant inspection system. The first part of the section discusses the reasons for process and materials control. The second part describes procedures to verify materials quality. The third part outlines review functions of the process.

1.5.1 Need For Process Quality.

NOTE

> Materials and process deficiencies are not always obvious. It is not easily determined that a penetrant has lost its ability to penetrate into a given flaw. Thus, it is necessary to periodically test the materials and to inspect the equipment and process to be sure they are functioning.

Penetrant inspection, as well as all other nondestructive inspection processes, is not a perfect process. The presence of indications confirms the existence of discontinuities in the part. However, the absence of indications does not guarantee the absence of discontinuities. Flaws can be present and not be indicated for a number of reasons. The two main reasons for discrepancies in inspection results are:

a. Substandard inspection materials due to either receipt of bad material from the manufacturer or degradation in storage or service.

b. Process deviations either in equipment, procedures, or conditions.

1.5.1.1 New Materials.

Penetrant materials are subjected to extensive testing during their formulation to assure their proper composition. However, materials that do not perform satisfactorily can still be received. Many times, the discrepancies in performance have not been detected until a number of parts have been processed. Considerable effort must then be expended to locate and reinspect the suspect parts. Unsatisfactory materials can result from a number of causes. The penetrant supplier may inadvertently omit an ingredient or a process. An ingredient with similar characteristics may be substituted if the original material is unavailable. The substitution of ingredients may occur at the penetrant formulator’s supplier. Experience has shown that all newly received penetrant materials must be tested to verify performance characteristics.

1.5.1.2 In-Use Materials.

Some inspection processes use the penetrant materials one time with no attempt to recover the excess. The materials are usually applied by spraying, and only enough material is applied to perform the test. The materials are stored in closed containers until they are used. These processes minimize the possibility of material contamination or degradation during use. More often, however, the materials are used in open tanks or open containers. When the immersion method is used, the surplus materials are allowed to drain from the part back into the tank. When the materials are applied by brushing, the brush is alternately stroking the part surface and being immersed in the container. Both methods provide numerous opportunities for contamination and deterioration. Materials handled in this manner must be checked periodically to be sure they are functioning acceptably.

1.5.1.3 Causes of Materials Degradation.

1.5.1.3.1 Materials Contamination.

Materials contamination is a primary source of degrading the performance of a penetrant system. There is a number of contaminating materials and their effect on performance depends upon the type of material. Some of the common contaminants frequently encountered are:

a. Water is probably the most common type of contaminant. It can occur by careless or improper rinsing or carry over from other parts.

b. Organic materials such as paint, lubricants, oils, greases, and sealants are another source of contamination. These materials, if not removed from parts during precleaning, can dissolve in the penetrant and react with or dilute it, so that it loses some or all of its ability to function.

c. Organic solvents such as degreaser fluid; cleaning solvent, gasoline, and antifreeze solution are common types of contaminants. These materials dissolve in the penetrant and reduce its effectiveness in proportion to the amount present. A small change in performance is usually not noticeable (5% or less of the total volume). The method of entry into penetrant is usually carry-over on the inside interior cavities of the part.

d. Dirt, soil and other insoluble solids are carried into the penetrant, emulsifier, and developer as a result of improper precleaning and carry-over from other parts. Another common source of soil contamination occurs when the dwell stations are used to store parts. Most dwell stations have drain pans, which return the effluent back to the immersion tanks. Any soil falling from unclean parts into the drain pan will be washed into the tank with the drain effluent.

e. Acid and alkaline materials are serious contaminants of penetrant solutions. They react with the penetrant to destroy fluorescence brightness even when present in fairly small quantities. They are usually residues from etching; plating or the cleaning processes.

f. Penetrant is a normal contaminant of emulsifier in the postemulsifiable process. It can be carried in on penetrant covered parts during the penetrant dwell step. As the penetrant builds up in volume, it will gradually slow the emulsifying action, and if the level becomes high enough, the emulsification process will stop.

1.5.1.3.2 Evaporation Losses.

Penetrant materials used in open tanks are continuously undergoing evaporation. The rate of evaporation is increased with warmer temperatures and large tank surfaces. Evaporation losses of penetrant result in an increase in viscosity, thus slowing penetration and emulsification. Evaporation of water washable penetrant may slow or speed washability, depending on the penetrant formula. Evaporation losses in developer solutions increase the concentration, which produces a heavier coating that may mask smaller indications. Since evaporation losses take place very gradually, performance change may become significant before it is noticed.

1.5.1.3.3 Heat Degradation.

Penetrants, especially fluorescent penetrants, are sensitive to elevated temperatures. Temperatures over 140°F (60°C) can reduce the fluorescence; and temperatures over 250°F (121°C) may destroy it completely. High temperatures also speed evaporation of the volatile components of penetrants, causing undesired performance changes. High temperatures in penetrants can occur from the following:

a. Immersion of heated or hot parts.

b. Inspection of surfaces exposed to the sun, such as flight line aircraft.

c. Improper storage before being placed in use, such as storage in direct sunlight.

1.5.1.4 Process Degradation.

Not only do materials degrade, but equipment and procedures (other elements of the process) can deteriorate also. Black light bulbs age and become dirty, reducing their output. Drying oven thermostats can be improperly set or may malfunction, resulting in excessive temperatures which may cause critical procedures to be performed incorrectly. Materials, equipment and procedures SHALL be periodically audited during their service life to assure satisfactory process performance.

1.5.1.5 Frequency of Process Control Checks.

1.5.1.5.1 Guidelines.

NOTE

> Table 1-3 establishes MAXIMUM process control intervals allowed. Laboratories shall use the guidelines listed below to establish their process control requirements and intervals.

One of the factors influencing the degradation of a penetrant process (materials, equipment and procedures) is the volume of parts being processed. The opportunities for materials contamination, drag-out, equipment malfunction, and procedure deviation are directly proportional to the number of parts being inspected. Since there is no uniformity in workload between activities, a single calendar schedule cannot be established. Each activity SHALL set inspection intervals based on their workloads. The inspection intervals SHALL be documented as shown in Chapter 1, page 1-15, paragraph 1.4.5. Guidance on inspection intervals is provided in the following paragraphs.

a. A high volume workload is considered to be a penetrant system that is in continuous use or is utilized for more than 4 hours every workday. A suggested inspection interval for materials verification of high volume penetrant systems is a daily check.

b. A medium volume workload is considered to be a penetrant system that is used daily for less than 4 hours. A weekly inspection interval is suggested for materials verification of penetrant systems processing a medium volume workload.

c. A low volume workload is considered to be a penetrant system that is used to process parts less than 3 days a week. An inspection interval of once every two weeks is suggested for materials verification of low volume workload penetrant systems.

d. In a penetrant system used occasionally with a one-week interval between uses, the minimum monthly verification requirement must apply.

1.5.1.5.2 Specific Requirements.

Equipment and process control inspection intervals vary depending upon the specific item to be checked. Many items will degrade on a time rather than a use basis. Equipment and process SHALL be inspected at weekly, monthly, quarterly or semiannual intervals as specified in ASTM 1417 or other applicable process specification.

1.5.2 Process Control Requirements.

1.5.2.1 General.

The capability and reliability of penetrant inspections depend upon the materials, equipment, and procedures. Degradation in any of the three areas will reduce the effectiveness of the process. The following paragraphs highlight some process steps requiring audit. At minimum these steps should be audited, and additional applicable steps should be added to cover specific equipment or processes as necessary.

1.5.2.1.1
Many of the listed steps are fundamental to the respective inspection processes. Therefore, an inspector can perform a self-audit by referencing the appropriate steps each time the respective processes are performed.

1.5.2.2 Cleaning / Precleaning.
Prior to application of penetrant, examine the precleaned parts using either visual or locally developed technique for the following:

a. Complete removal of coatings, soil, and contaminants, with special attention to recess and entrapment areas.

b. Verify that all cleaning process residues have been removed.

c. Verify that the parts are adequately dried, especially in recessed areas and faying surfaces.

1.5.2.3 Materials Control.

1.5.2.3.1 New Materials.
Verify that tests on new materials are being properly performed and documented (paragraph 1.5.3).

1.5.2.3.2 In-Use Materials.
Verify that tests on in-use materials are being properly performed and documented (paragraph 1.5.5).

1.5.2.4 Penetrant.
Observe the application of penetrant paying attention to the following:

a. The part temperatures are not excessive prior to penetrant application.

b. The penetrant application is properly accomplished for the method being used.

c. The entire part surface or area to be inspected is completely and evenly covered.

d. When using the immersion method parts with concave or complex surfaces are rotated in the penetrant to assure no air pockets remain.

e. Drain-dwell is accomplished in a satisfactory manner including the removal of any pooled penetrant.

f. Penetrant dwell time complies with the procedure requirements.

1.5.2.5 Lipophilic Emulsifier.
The lipophilic emulsifier process SHALL be observed and checked periodically to verify the following:

a. Method B removability tests, in-process, are being properly performed and documented (see paragraph 1.5.5.3.2).

b. The part is rapidly and completely covered with emulsifier with minimum mechanical action and no air pockets or uncoated surfaces.

c. Drain-dwell is accomplished in a satisfactory manner, including rotation of parts to avoid pooling when required.

d. Emulsifier dwell is closely timed and complies with procedure requirements.

e. No delay in moving part from emulsifier dwell station into the rinse station.

1.5.2.6 Hydrophilic Remover (Pre-RINSE).
When the hydrophilic remover method is used, the pre-rinse operation SHALL be checked or observed to verify the following:

a. The proper water pressure, waters temperature, droplet size, and spray pattern and time are employed.

b. All surfaces are adequately rinsed.

1.5.2.7 Hydrophilic Remover - (Immersion).
The following areas in the hydrophilic remover, immersion process SHALL be observed or verified:

a. In-use performance tests are properly accomplished and documented (see paragraph 1.5.5.4).

b. There is little or no floating penetrant Examine the surface of the remover with a black light for any signs of fluorescence.

c. Agitation is not excessive.

d. Parts are completely immersed and when necessary rotated to eliminate air pockets.

e. Complex shaped parts are rotated after removal to reduce pooling of remover.

f. Drain time after removal from bath is less than 30 seconds until rinsing is started.

1.5.2.8 Hydrophilic Remover - (Spray).
The hydrophilic spray remover process SHALL be observed and checked periodically to verify the following:

a. Spray remover concentration tests are being properly performed and documented.

b. Spraying is done under black light and in a shaded area.

c. The water pressure, temperature, droplet size, and spray pattern are satisfactory.

d. All surfaces of the part are sprayed to remove the surface penetrant without over-removal.

e. Part is rinsed with fresh water following the spray removal.

1.5.2.9 Rinsing.
The water rinsing process SHALL be observed and checked periodically to verify the following:

a. Rinse station is shaded from bright lights or windows.

b. Rinsing is accomplished under black light.

c. The proper water pressure, temperature, droplet size, and spray pattern are used.

d. On parts processed with lipophilic emulsifier, the entire surface shall be rapidly wetted to stop the emulsification process before attempting removal.

e. On parts processed with hydrophilic remover, the entire part is rinsed to remove all traces of remover.

f. After rinsing, the part is free of pockets or splashes of penetrant.

g. Parts not free of residual penetrant (lipophilic process) are completely cleaned and reprocessed through penetrant and emulsifier.

1.5.2.10 Drying.

NOTE

> Depots with automated and semi-automated penetrant inspection systems may exceed the 140°F (60°C) drying oven temperature while performing inspections with these systems. The temperature of the parts SHALL NOT exceed 140°F (60°C). All parts remaining at 140°F (60°C) for longer than ten minutes or exceeding 140°F (60°C) SHALL be reprocessed (cleaned and re-inspected).

The drying process SHALL be observed and checked periodically to verify the following:

a. Oven thermostat must be calibrated for accuracy and documented by the user at intervals not to exceed 180 calendar days. Calibration SHALL be accomplished per manufacturer's instructions.

b. The oven area SHALL be inspected with a black light to ensure it is clean and without fluorescent penetrant contamination.

c. Fans are working properly and airflow is not restricted.

d. All pooled rinse water removed.

e. Temperature setting at 140°F or less.

f. Parts remain in oven only until dry.

1.5.2.11 Developers.

1.5.2.11.1 General.

The developer process SHALL be observed and checked periodically to verify the following:

a. Area SHALL be inspected with a black light to ensure it is clean and without fluorescent penetrant contamination. It SHALL also be free of any other contaminant which may adversely affect penetrant inspection results (i.e., liquids, grease, excess developer, overspray, and extraneous parts and materials). Expose to black light and visually examines for any signs of fluorescence.

b. Parts are in suitable condition (e.g., dry or wet) for the developer involved.

c. Parts receive a minimum of the required dwell time after dry (water or solvent developers).

1.5.2.11.2 Dry Powder.

1.5.2.11.2.1 General.

When dry developer is used, the process SHALL be observed and checked periodically (paragraph 1.5.5.7) to verify the following:

a. Developer is dry with no clumping or fluorescent contamination.

b. Developer is loose, fluffy and pours easily.

1.5.2.11.2.2 Dip and Pour.
When dry powder developer is applied by the dip and pour method, the process SHALL be observed and checked periodically to verify the following:

a. Developer dwell area is clean and has adequate room for the parts being processed.

b. Entire part surface is covered.

c. Excess developer powder is removed without brushing or rubbing.

1.5.2.11.2.3 Fog Chamber.
When dry powder developer is applied by a fog chamber, the process SHALL be observed and checked periodically to verify the following:

a. Work and dwell areas are adequate with controls accessible for adjustment.

b. The system has an adequate reservoir with positive feed and there is no caking or uncovered pressure tubes.

c. A good fog cloud is produced with controlled air pressure.

d. Chamber or tank does not create excessive air pollution.

1.5.2.11.3 Water Suspended Developer.
When water suspended developer is applied, the process SHALL be observed and checked (paragraph 1.5.5.5) to verify the following:

a. Performance comparison tests are performed on schedule and documented (see paragraph 1.5.5.5.

b. Concentration checks are correctly performed on schedule and documented.

c. Solution is clean with no penetrant on the surface (see paragraph 1.5.5.5.2).

d. Agitation produces a uniform suspension with no caking on the bottom or in the corners of the tank (see paragraph 1.5.5.5).

e. Entire part is covered, with no water breaks or air pockets.

f. Part is drained over the tank or recovery tray to reduce drag-out losses.

g. Complex parts are rotated during drain to reduce pooling.

h. After drying, the developer coating is light and even, with no retracted areas of beading or non-wetting (paragraph 1.5.5.5.1).

i. Developer dwell time starts when the part is free of moisture.

1.5.2.11.4 Water Soluble Developer
When water soluble developer is applied, the process SHALL be observed and checked (see paragraph 1.5.5.6) to verify the following:

a. Performance comparison tests are performed on schedule and recorded (see paragraph 1.5.5.6).

b. Concentration checks should be properly performed on schedule and recorded (see paragraph 1.5.5.6.1).

c. Surface should be free of floating penetrant (see paragraph 1.5.5.6.2).

d. Solution should be clean and translucent.

e. There should be no odor and no evidence of algae, fungi, or other growth.

f. The developer should wet the part surface, with no water break areas after spray or immersion.

g. Part should be drained over the tank or recovery tray to reduce drag-out losses.

h. Complex shaped parts should be turned over or rotated during draining to remove any pools.

i. The correct developer dwell time must be used with the dwell time starting after the coating is dry.

j. After drying, the coating should be transparent and nearly invisible. In examining the part in reflected light, there should be no distinct change in sheen indicating a break in the coating.

1.5.2.12 Inspection Booth.

The inspection booth and process SHALL be observed and checked to verify the following:

a. Area SHALL be clean and of adequate size for the size and number of parts to be inspected. Booth SHALL NOT be used to store parts since non-relevant indications may be formed when parts contact extraneous penetrants.

b. Area SHALL be free of spilled penetrant and SHALL NOT fluoresce when exposed to black light.

c. Area SHALL be darkened to 2 lumens per square foot or less and SHALL be periodically checked with an accurate visible light meter for ambient light and documented at least every 60 calendar days or when a black light bulb is changed.

d. Black light bulb and filter SHALL be kept clean.

e. Intensity of the black light SHALL be checked and documented at least once each day prior to use.

f. Filters SHALL be inspected for fit and be free of cracks.

g. Black lights SHALL be positioned so they do not shine into the technician’s eyes.

h. Technicians must observe the dark adaptation eye adjustment period.

1.5.2.13 Portable Inspection Process.

NOTE

Shelf life dates on aerosol containers of penetrant inspection materials is the final date that the manufacturer will warranty its product. These products may be used after this date provided there is sufficient propellant remaining in the container and they conform to the provisions of process control. Only containers being used to perform inspections require testing.

The portable inspection process SHALL be periodically observed and checked to verify the following requirements.

1.5.2.13.1 Cleaning Precleaning.

a. Verify that coatings have been chemically removed from the surface of the area to be inspected.

b. Verify that the surface has not been sanded, blasted, scrapped, or otherwise mechanically disturbed.

c. Verify that paint stripping residues or other inorganic contaminants have been removed.

d. Verify that aerosol spray cleaner-remover is suitable for precleaning.

e. Verify that time has been allowed for the precleaning solvent to evaporate.

1.5.2.13.2 Penetrant.

a. Verify that spray nozzles are clean and free of dried or tacky penetrant.

b. Verify that the aerosol can is shaken to distribute solvents prior to spraying.

c. Verify that good spray technique is used, with the can moving smoothly at the proper distance from the part.

d. Verify that brushes, swabs, and small containers used to apply penetrant are clean and free of contaminates.

e. Verify that penetrant is applied in an even layer, not excessively thick, and free of runs.

1.5.2.13.3 Penetrant Removal.

a. Verify that initial penetrant removal is done with clean cloth, folded between wipes to provide a fresh surface during each wipe.

b. Verify that solvent is not sprayed or poured directly on the inspection area.

c. Verify that final removal is accomplished with a clean cloth, moistened (not saturated) with solvent. The cloth must be folded over with each wipe.

d. Verify that a black light is used to check for traces of residual penetrant during penetrant removal.

1.5.2.13.4 Developer.

a. Verify that can nozzles are clean and free of caked developer.

b. Verify that the can is agitated until all developer is in suspension.

c. Verify that the developer coating is not excessively thick and is applied as several thin layer passes, rather than a single layer.

d. Verify that the required dwell time is allowed after the solvent has evaporated.

e. Verify that the developer spray pattern is uniform.

1.5.2.13.5 Inspection.

a. Verify that the inspection area is shaded or shielded to reduce ambient light to acceptable levels.

b. Verify that black light intensities are within acceptable limits.

1.5.2.13.6 Postcleaning.

a. Verify that removal of developer residues is accomplished in a satisfactory manner.

b. Verify that removal of penetrant residues is accomplished in a satisfactory manner.

1.5.3 Control Of New Materials.

1.5.3.1 Newly Received Materials.

Penetrant system materials (penetrants, emulsifiers and removers, and wet and dry developers) are compounded or formulated in batches or lots. It is possible for one batch or lot among several to have characteristics that do not meet the specification requirements. Therefore, each batch or lot of penetrant, emulsifier and remover, and wet and dry developers SHALL be tested on receipt, prior to in-service use. Quality conformance tests for newly received materials are described in paragraph 1.5.3.4. The batch or lot of material can be identified by batch or lot number on each container.

1.5.3.2 Procurement provisions.

Penetrant system material procurement SHALL meet the following requirements:

a. Materials SHALL comply with the current version of ASM 2644.

b. Except for solvent removers, bidders SHALL have material listed (or approved for listing) on the most current revision of QPL-25135.

c. Contract and special purchase orders for procurement of materials SHALL require a certified test report and a quality conformance sample submitted in accordance with the latest revision of ASM 2644.

d. Materials listed on QPL-25135 and those centrally procured using generic national stock numbers (NSNs) need not comply with paragraph 1.5.3.4c.

1.5.3.3 Sampling Of Newly Received Materials.

1.5.3.3.1 General.

Two samples are required from each batch or lot of penetrant, emulsifier or remover, and/or wet and dry developer when received. If the supplier has submitted a quality conformance sample, (see paragraph 1.5.3.3.2.1), only one additional sample will be required. Either one or two samples SHALL be taken from each batch or lot of penetrant, emulsifier and remover, and wet and dry developer, when received and prior to use. One sample, either from the supplier or locally taken, will be used to verify the Quality Conformance as described in paragraph 1.5.3.4. The second sample, which may be larger than the first, will be retained by the using activities as a reference standard for periodic process performance tests.

1.5.3.3.2 Sample Sizes.

1.5.3.3.2.1 Quality Conformance Samples.

For all items except developer solids, a sample of not less than 1 quart or more than 1 gallon SHALL be taken from each batch or lot of each material. For each batch or lot of wet developers in the dry condition, a 2-pound sample SHALL be selected, and from each batch or lot of dry developer solids a 1 pound sample SHALL be selected.

1.5.3.3.2.2 Process Control Reference Sample.

These samples will be used as reference or master standards in comparing the performance of the in-use material. The sample size will depend upon the workload which determines the frequency of process control testing. A suggested sample size for high volume workload systems is 1 to 2 gallons (for all items except developer solids) from each batch or lot of materials. The suggested quantity of wet developers in the dry condition is 2 pounds with a 2 pound sample of dry developer solid. A minimum sample size for penetrant systems that have an occasional workload (see paragraph 1.5.1.5) requiring fewer process control checks, SHALL be as stated in paragraph 1.5.3.3.2.2. Each depot and base SHALL be responsible for determining the sample size required for its workload. The reference sample SHALL be large enough to permit the required process control checks during the life of the material and still have a quantity of reference sample to run a comparison check against the new materials when the old solution is finally discarded.

1.5.3.3.3 Sample Handling and Storage.

Care must be exercised in obtaining, handling, and storage of the reference samples to prevent contamination or degradation. The containers SHALL be metal or glass since many plastics are attacked by the penetrant oils and solvents. The same restriction applies to the seals or washers in the container lids. The sample containers SHALL be clean, dry, and have tight fitting lids or covers. The devices used for obtaining the sample must not contain traces of other batch or lot materials. The samples SHALL be stored in a cool area and not exposed to sunlight, black lights or high intensity white lights.

1.5.3.4 Quality Conformance Testing.

The following procedures SHALL be used to verify the quality conformance of newly received materials:

a. For materials that are not centrally procured using a generic stock number, the NDI laboratory supervisor SHALL review the test report and SHALL accomplish a system performance test comparing the newly received material against the process control reference sample (paragraph 1.5.3.3.2.2) that was used to check the in-use material (paragraph 1.5.5). Compare old penetrant to replacement.

b. The newly received material may be accepted when both the system performance test and the test report are positive. (Test reports and quality conformance tests are not required for materials centrally procured using generic national stock numbers).

c. If a test report is required but not received with the material, the NDI supervisor SHALL check with base procurement to see if a test report was received. If a test report is not available, a test sample may be sent per paragraph 1.5.3.4d or tested per paragraph 1.5.3.4e. Test reports are not required for generic National Stock Numbers (NSNs).

d. If the system performance test results are not conclusive or the test report (if required) is not available, a sample selected in accordance with paragraph 1.5.3.3.2.1 SHALL be submitted to: AFRL/MLSA Bldg 652, 2179 Twelfth Street Ste. 1, Wright-Patterson Air Force Base OH 45433-7718. AFRL/MLSA will provide the submitting field laboratory a test report with the results of the quality conformance tests and recommend acceptance or rejection of the batch or lot of materials.

e. Depots Only: Depots with appropriate analytical equipment and competent technicians to perform the required tests may test the following properties for compliance with ASM 2644 in accordance with applicable procedures referenced in the specification: flash point of penetrants and lipophilic emulsifiers, viscosity of penetrants and emulsifiers, fluorescent brightness of penetrants, thermal stability of penetrants, water tolerance of water washable penetrants and lipophilic emulsifiers, redispersibility of nonaqueous wet and aqueous suspended developers, developer fluorescence, penetrant removability, and water content of hydrophilic remover concentrate.

1.5.3.5 Unsatisfactory Materials.

NOTE

> Knowledge of problems, even relatively minor items, is essential for improvement in the NDI program, the materials specification, and qualification testing. Information copies of written correspondence concerning unsatisfactory penetrant materials SHALL be furnished to AFRL/MLSA, 2179 Twelfth Street, Ste. 1, Wright-Patterson Air Force Base, OH 45433-7718.

Unsatisfactory materials SHALL be reported in accordance with T.O. 00-35D-54 (Air Force) or AR 735-11-2 (Army). A copy of the quality conformance test report SHALL be included as substantiating data. Air Force NDI Program Office, AFRL/MLS-OL, 4750 Staff Dr., Tinker AFB, OK 73145-3317; DSN 339-4931 is the item manager for penetrant materials. They may be contacted for assistance when preparing a material deficiency report. (For Navy: Commanding Officer Naval Aviation Maintenance Office, Attn.: NDI PM, Patuxent River, MD 20670; for Army: Commander, AVSCOM, Attn.: AMSAV-MC, 4300 Goodfellow Blvd., St. Louis, MO 63120-1798).

1.5.4 Monitoring Process Performance (Stationary Inspection Units).

1.5.4.1 Description of Process Monitoring Device.

An example of a process monitoring device is the Penetrant System Monitor (PSM), also known as the “star burst” panel. The PSM is alternatively specified as Pratt and Whitney TAM Panel 146040, Sherwin Company P/N PSM-5 and Magnaflux Company P/N 198055. The panel is especially suitable for high volume, semi-automated, and fully automated depot systems. It is intended to be used as a daily or weekly monitor of the entire penetrant process. When properly used, the PSM will signal changes that would affect the integrity of a penetrant inspection process, changes that may have occurred in the materials, equipment or procedures. It is not a substitute for the cracked chrome plate panels that are used to compare the performance of the materials in terms of sensitivity.

1.5.4.1.1

The PSM is a stainless steel panel measuring 4 inches wide by 6 inches long. A chrome-plated strip runs the length while the other side is a medium roughness, grit blasted surface. The chrome-plated strip contains five, evenly spaced, crack centers. The crack centers are in circular patterns varying in size from about 1/4-inch diameter down to about 1/32-inch diameter, and are arranged in order of magnitude. The cracks radiate from the center in a star or sunburst pattern. No two panels are completely identical. Crack patterns and sizes vary from panel to panel. The panels are supplied in sets of two, with the supplier matching the panels as closely as possible. One panel is reserved for use as a “reference” or “transfer” standard while the other is the “working” panel.

1.5.4.1.2

The PSM can monitor the entire process because it can be processed directly in the working tanks along with production parts. In addition, the grit blasted strip will separately indicate the effectiveness of just the removal process steps. One disadvantage is that small or gradual changes are not readily noticed. Furthermore, as with cracked chrome plate panels, the PSM indications deteriorate with handling and repeated use. Also, the PSM panel can retain large amounts of residual penetrant, so careful and thorough cleaning is mandatory.

1.5.4.1.3

The 50µ and 30µ panels are usually used with low and medium sensitivity penetrants. The 20µ and 10µ panels are usually used with high and ultra-high sensitivity penetrants. The standard panel is the 20µ panel. After the 2.80 inch wide plate is plated and cracked, it is cut in half, lengthwise. This produces two panels containing symmetrical crack patterns in each panel. Since the cracks extend across the original panel, the two panels are provided as a set with each panel measuring 3.94 inches (100 mm) long and 1.38 inches (35 mm) wide.

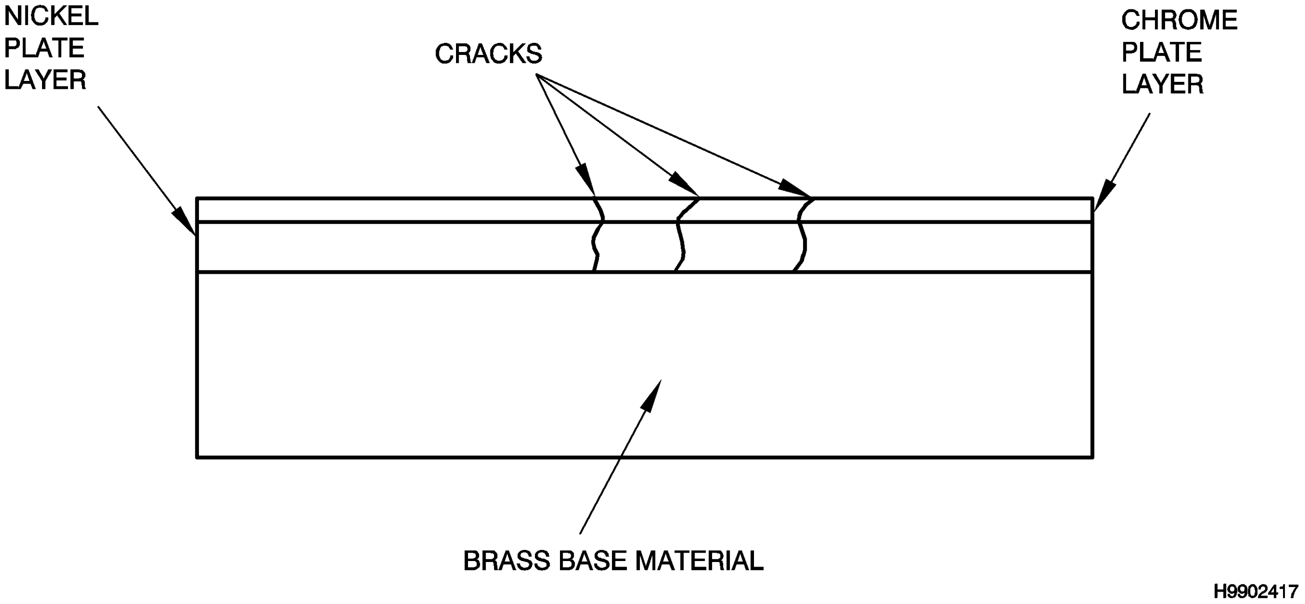


Figure 1-6. Illustration of Crack Depth in Chrome-Plated Panel

1.5.4.2 Procedure for Testing Material Performance.

NOTE

> Panels are cracked on one face only. When the penetrant materials are applied to the cracked face, surplus penetrant materials often get on the back of the panel. Penetrant materials on the back must be removed to keep from contaminating the cracked panel face.

a. Observe the following precautions when processing the cracked chrome plate panels:

(1) Do not expose the test panels to temperatures above 212°F (100°C).

(2) Use extreme care in handling and storing the panels. Do not drop, hit, or place undue mechanical stress on the test panels. Do not attempt to bend or straighten the test panels.

(3) Prior to and after each use, clean the test panels by immersion and agitation in a solvent. Cleaning with an ultrasonic solvent cleaning system can also be used. Some handling or touching of the plated surfaces is necessary, but should be kept to a minimum to reduce fingerprint contamination. After cleaning, examine the plated surfaces under a black light for evidence of entrapped residues from previous inspections. Time must be allowed after cleaning to ensure all of the solvent has evaporated from the panels before using them.

(4) The mirror surface finish and flaw shape on the test panels are not representative of normal aircraft parts. This requires special procedures when using the test panels. The main difference is the extreme care that must be taken during the surface penetrant removal step. It is very easy to remove entrapped penetrant from the test panel cracks.

b. Place a small quantity of in-process or working bath materials and reference materials in separate containers for each material. DO NOT apply the reference materials from their storage containers to avoid contaminating the entire reference sample. DO NOT apply the working bath and reference material with the same brush or swab. Any mixing of the two materials will invalidate the test results.

Prepare the reference developer sample by mixing a small batch of previously reserved developer solids in the same ratio as the solution in your tank. For example, if the solution in your tank was prepared at 1/2 lb. per gallon of water then mix the reference sample at 1/2 lb. per gallon of water. This one gallon reference sample can be used until depleted, but must be discarded when the solution in the tanks is changed, along with the remainder of your dry reference solids. The test panels should be processed side by side, and with one end slightly raised, rather than flat, on the worktable. Use the working materials on one panel and the reference materials on the other. Apply penetrant by brushing, swabbing, or flowing. Brushing or swabbing is preferred since it permits better control over the quantity of penetrant applied.

c. Penetrant dwell time of 2 or 3 minutes is usually adequate since the shallow cracks are rapidly penetrated. Apply lipophilic emulsifier by carefully flowing or pouring each material in turn on its respective panel. Hydrophilic materials are applied by immersing the panels. Emulsification or removal time is also very short, typically around 10 to 20 seconds. This will vary with different penetrant emulsifier or remover combinations. Initially, several trials should be made to determine the proper emulsification or removal time. The shortest possible time to remove the surface penetrant with the reference materials shall be used. Water washable penetrants should be washed as gently as possible under a black light. Wash time should be limited to removal of surface penetrant only. Solvent removal should be done by hand wiping with a separate dry cloth or towel on each panel. Removal of any residual penetrant should be done with the cloth or towel just lightly moistened with solvent. DO NOT saturate the cloth or towel. Care must be exercised to prevent mixing of test and reference materials during removal. DO NOT use the same cloth or towel on both panels.

d. Developer may be applied by immersion, flowing, or spraying. Ensure developers have been mixed properly (see paragraph 1.5.4.2b). Water suspended developers must be thoroughly agitated just before applying them to the panels. If water soluble developers are used, agitation is not required. Because of the shallow crack depths on the panels, volatile components of the penetrants will quickly evaporate and care must be taken when drying the panels. Minimum drying time SHALL be used to ensure the panels do not become too hot to handle with bare hands. Developer dwell time is 2 to 3 minutes after the panels are completely free of moisture.

e. Examine the panels side by side, under a black light, first noting the overall brightness and color of the indications. Then examine in detail by following individual indications across both panels. Note the presence, absence or diminishing of crack indications on the working solution panels and observe the continuity, size and color.

   (1) Any distinct difference is cause for additional testing to determine if the penetrant, emulsifier/remover, or the developer caused the difference in the indications. Perform additional tests as described in paragraph 1.5.5.

   (2) When no distinct difference is noted, system performance testing is complete.

f. The panel SHALL be cleaned as soon as possible after completing the process check. The cleaning procedures SHALL be used.

1.5.4.3 Storage of Panels.

The panels must be stored in a clean environment to retard degradation. The panels can be stored in a dry air environment or placed in mineral spirits or alcohol. If the panels are stored in mineral spirits, degreasing will be required prior to use. The panels do not have an indefinite life as penetrant and developer residues plus oxides retained in the cracks, will gradually clog or fill the cracks, thus reducing the apparent size of the indication.

1.5.5 Testing Of Material in Use.

1.5.5.1 Control Of In Use Materials.
In-use materials SHALL be periodically tested to assure they are capable of acceptable performance. Frequency of in-process testing SHALL be as determined in paragraph 1.5.1.5. Some of the in-process checks can be performed in the process tanks while others are more conveniently performed on small samples taken from the tanks.

1.5.5.2 Testing Penetrant.

1.5.5.2.1 Test the performance of the penetrant material.

a. If the penetrant performance test indicates a loss of sensitivity or brightness, use a set of clean, dry cracked chrome panels to repeat the material test procedure (paragraph 1.5.4.2) with the following changes: use reference samples of emulsifier (or remover) and developer.

b. If crack indications on the two panels show clearly visible differences in sensitivity, brightness or color, the penetrant SHALL be discarded as oil waste. If there is little or no difference in the crack indications, clean the panels and repeat the performance test procedure to test the emulsifier (or remover) or if necessary, developer. Use reference materials on both panels except for the respective working material on one panel at the appropriate point in the process.

1.5.5.2.2 Additional tests to determine the total working condition of the penetrant include.

a. Surface Wetting: Apply a small amount of penetrant to the clean, shiny surface of commercially available aluminum foil with a cotton swab. After 10 minutes observe to ensure the penetrant readily wets the surface and the penetrant film does not retract or form beads.

b. Penetrant Brightness (Depot; optional for Field):

(1) Pour 10 milliliters (ml) of Type I (fluorescent) Method A (water washable), Method B (postemulsifiable, lipophilic) or Method D (postemulsifiable, hydrophilic) in-use production line penetrant into a graduated cylinder. Allow penetrant to drain down the inside cylinder walls. Pour out excess penetrant and clean off the outside of the cylinder.

(2) Fill the graduated cylinder to the 100-ml level with an approved solvent.

(3) Stopper the graduated cylinder and invert several times to mix the contents. Do not shake or agitate vigorously.

(4) Cut filter paper into quarters and using tweezers, insert a quartered piece of filter paper into the cylinder mixture, withdraw the paper and set it aside to air dry.

(5) Discard the contents of the graduated cylinder and clean and dry the cylinder with an approved solvent (Specification O-C-265 or equal). Dry with clean filtered compressed air.

(6) Pour 10 ml of Type I (fluorescent) Method A (water washable), Method B (postemulsifiable lipophilic) or Method D (postemulsifiable hydrophilic) new (reference) penetrant into the graduated cylinder. Allow penetrant to drain down the cylinder walls. Pour out excess penetrant and clean off the outside of the cylinder.

(7) Fill the graduated cylinder to the 100-ml level with an approved solvent.

(8) Stopper the graduated cylinder and invert several times to mix contents. Do not shake or agitate vigorously.

(9) Using tweezers, insert a quartered piece of filter paper into the cylinder mixture, withdraw the paper and set it aside to air dry.

(10) When both filter papers (reference and in-use) are dry, compare the fluorescent brightness of the filter papers to each other under a blacklight. If a significant difference of fluorescent brightness is noted, the fluorescent properties of the in-use production line penetrant have deteriorated, and the fluorescent sensitivity will probably not be acceptable. Follow accepted activity standards to process and perform additional testing or to discard the contaminated/degraded material.

(11) At the conclusion of the fluorescent brightness testing, clean the cylinder with acetone (Specification 0-A-51F), rinse with water, and again clean with acetone. Dry with clean filtered compressed air.

c. Rapid Brightness Test (Field). A rough check of penetrant baths can be accomplished by comparing their appearance on an absorbent material, preferably the filter paper used in paragraph 1.5.5.2.2b above. Place a drop of the working bath penetrant on a paper towel. Place a second drop of penetrant from the reference standard near the drop from the working bath. When the two drops merge, examine under a black light for difference in color and brightness.

1.5.5.3 Testing Lipophilic Emulsifier.

Penetrant is an unavoidable contaminant of lipophilic emulsifier. It is carried into the emulsifier on the surface of parts where it dissolves and is washed off during immersion and drain. Since emulsifier and penetrant are miscible in all concentrations, even small quantities of fluorescent dye will cause the emulsifier to fluoresce. The fluorescent brightness increases with increasing dye content, but it is impossible to visually estimate penetrant contamination by observation of the tank surface.

1.5.5.3.1

Emulsifier will continue to function when contaminated with penetrant; however, when the penetrant concentration reaches a certain level, the emulsification action slows and eventually stops. The military procurement specification requires a 4 to 1 mixture of emulsifier to penetrant to leave no more residual background than the uncontaminated emulsifier.

1.5.5.3.2 Removability Test.

NOTE

Grit blasting using 100 mesh aluminum oxide grit is required only on locally manufactured panels to roughen the surface and is only required one time. Normally ultrasonic cleaning or solvent cleaning is performed after grit blasting.

a. In-use lipophilic emulsifiers SHALL be periodically tested for contamination. A two-inch by four inch, 16 gauge (0.060") annealed type 301 or 302 stainless steel panel is required. The panel SHALL be ultrasonically cleaned or vapor degreased and grit blasted on both sides using 100 mesh, aluminum oxide grit (not beads), using 60 psig air pressure, with the gun held normal to and approximately 18 inches from the panel surface. After blasting, the panel surface should be handled by the edges only and protected from contamination by wrapping in tissue paper.

b. Immerse the panel in the working penetrant bath and allow it to drain for 10 minutes at approximately a 60° (±15°) angle. At the end of the drain period apply working bath emulsifier to one half of the panel and reference standard emulsifier to the other half. Application may be either by pouring or immersion. If pouring is used, place a small quantity of both working bath emulsifier and reference standard emulsifier into separate containers that are suitable for pouring. Apply the emulsifier to the upper edge of the panel so it flows down across half of the panel face. This shall be done with the panel in an upright position. It is desirable to have the two emulsifier strips close together at the center of the panel without allowing them to contact each other. However, this is not always possible so care should be taken to keep the area of mixing to a minimum. An overlapping of the two emulsifiers of less than 1/4 inch is acceptable; however, any overlap greater then 1/4 inch will reduce the accuracy of the test, requiring the panels to be reprocessed.

c. Allow an emulsifier dwell time of 2 minutes and a wash time of 60 seconds. The water spray should be applied equally to both panel halves with the nozzle at a constant distance from the surface. The bare metal should be examined for signs of fluorescent background after the process has been applied. Developer must be applied before evaluation.

d. A distinct difference in residual background indicates excess penetrant contamination of the working bath lipophilic emulsifier. It is acceptable to extract a quantity of used emulsifier, for example 55 gallons, and replace it with fresh unused emulsifier. At least 25 to 50% of the tank volume should be extracted and replaced. This procedure SHALL be done only once before changing the entire tank. Following this procedure the emulsifier mixture shall be retested as described in paragraphs 1.5.5.3 to ensure proper functioning of the emulsifier bath.

1.5.5.4 Testing Hydrophilic Remover.

1.5.5.4.1 Immersion Baths.

NOTE

This test is valid only on new hydrophilic remover baths.

Freshly mixed (new) hydrophilic remover is characterized by a pinkish-red color that varies in intensity with the water content. There are three methods to verify initial remover concentration. The first method utilizes an instrument known as a refractometer. The refractometer measures the refraction or refractive index (Snell’s Law) of the material utilizing the refractive index scale which ranges from 0 to 320, with water having refractive index of 0. The second method that may be used is known as colorimetry. It is a procedure of chemical analysis that deals with the measurement of the light absorption by colored solutions. The fundamental principles of colorimetry state that the amount of light absorbed by a given substance in a solution is proportional to the intensity of incident light and to the concentration of absorbing material. Visual colorimetry is a simple method and is fairly precise. It matches the color of a standard solution with an unknown; when they become identical they must contain the same amount of colored substance. An instrument used to perform this task is known as a colorimeter. The final method involves the use of a hydrometer to determine the concentration by specific gravity. This method is very similar to the method used to check developer. Procedures for the refractometer and hydrometer are detailed below.

a. A refractometer is supplied in the penetrant process control kit and is the recommended method to use in determining the initial water content concentration. The refractive index and light transmission properties of removers vary from batch to batch, even with the same type and manufacturer. This makes it necessary for each NDI lab to develop a graph of concentration versus refractive index number or colorimeter reading for each batch or lot of remover.

b. When using a refractometer perform a water content test in accordance with the following procedure:

   (1) Dip the plastic rod supplied with the refractometer in the solution of new hydrophilic remover and water being tested. Do not use a metal or glass rod as it may scratch the refractometer prism face. The test solution should be well mixed for accurate results.

   (2) Raise the cover plate on the refractometer and place two or three drops of the test solution on the prism face. Close the cover plate, making certain the test solution film completely covers the prism face.

(3) Hold the refractometer close to a light source so that the light illuminates and enters the prism. A bright light is necessary. Overhead fluorescent lamps may not furnish sufficient illumination.

(4) With the cover plate contacting the prism, look through the eyepiece. Read the Brix value (refractive index units) where the bright and dark areas meet. A clearer meeting line may be created by adjusting the angle between the light source and the prism face or holding the prism face closer to the light source. Record the refractive index units. Using the manufacturer's literature, determine the concentration of the test sample from the refractive index value.

(5) When the test has been completed, clean the refractometer cover plate and prism face with a soft lint-free cloth. Place the refractometer in its own protective pouch, and return it to the penetrant test kit carrying case.

c. When using the hydrometer, perform a water content test in accordance with the following procedure:

(1) Mix a test sample of the new hydrophilic remover as recommended by the manufacturer in a 500-ml graduated cylinder or similar container.

(2) Using the hydrometer, check the concentration of the test sample by noting its specific gravity and recording this reading.

(3) Mix the working bath to the same concentration as the test sample within 5%.

1.5.5.4.1.1

A quick test to determine if penetrant is present in the remover in a large enough quantity to become a possible contaminant can be accomplished by passing a blacklight over the surface of the remover in the tank and visually examining it for signs of fluorescence.

1.5.5.4.1.2

NOTE

The immersion removal time cited is typical. Actual time will depend upon type of penetrant, type of remover, agitation and remover concentration. Actual time must be determined at each depot or base for each system involved. Trials must be accomplished using fresh or uncontaminated remover. The objective is to use the minimum time necessary to produce a background-free surface on the immersion panel when the remover is uncontaminated.

Penetrant materials used in open tanks are continuously undergoing evaporation that may increase the viscosity and also affect removability. Therefore, before changing the remover bath, perform the procedures in paragraph 1.5.5.4.1c.

A performance check to verify the concentration of used immersion hydrophilic remover baths is required. The penetrant from parts disperses in the remover, causing turbidity and a change in the refractive index. The turbidity makes a color comparison invalid and the change in refractive index is no longer a true indicator of concentration. The shift in refractive index requires developing a compensation curve for variation with penetrant concentration. Performance testing is the easiest and most practical way of determining the adequacy of a remover bath. The test involves processing two roughened panels with different removal contact times and comparing the results using the following procedure:

a. Performance Check. Use two oxide blasted, stainless steel panels as described in paragraph 1.5.5.3.2. A typical processing procedure is as follows:

(1) Immerse both panels n the working bath penetrant and allow them to drain for 10 minutes supported at an angle from the horizontal of approximately a 60° (±15°).

(2) Process the first panel through a 10-second pre-rinse, 10-second drain, 20-second immersion in remover, 5-second drain, and 10-second rinse.

(3) Process the second panel through the same cycle except double the immersion time in the remover.

(4) Examine the panels under black light.

(5) Clean the panels.

b. When the remover is fresh and uncontaminated, neither panel should exhibit any background fluorescence. As the penetrant level in the remover starts to build up, the short immersion time panel will begin to show some residual fluorescence while the longer immersion panel remains free of background. As the amount of penetrant in the remover continues to increase, the level of fluorescence on the short immersion panel stabilizes and the longer immersion panel begins to show some residual background. When the remover reaches its penetrant tolerance limit, there will be negligible difference in fluorescence background on the two panels. The remover SHALL be changed at this point. Rejuvenation by partial extraction and addition of fresh solution, as with lipophilic emulsifiers, SHALL NOT be permitted due to the inability to control concentration.

c. If the performance check in paragraph 1.5.5.4.1.2a does not indicate remover degradation, determine if penetrant is causing the background fluorescence by proceeding as follows using the same panels.

(1) Immerse both panels in the working bath penetrant and allow them to drain for 10-minutes at a 60° (±1°) angle.

(2) Process the first panel using a 10-second pre-rinse, 10-second drain, 30-second immersion in the working bath remover, 5-second drain, and a 10-second rinse.

(3) Process the second panel using the same procedures above, except using the reference remover.

(4) Examine the panels under a black light.

(5) If background fluorescence is present on both panels, the working bath penetrant is contaminated and must be replaced. If the panel processed with the reference remover is free of background fluorescence, and the other panel exhibits any background fluorescence, then the determination can be made that the working bath remover has reached its penetrant tolerance limit and SHALL be changed.

(6) Cleaning the panels is mandatory.

1.5.5.4.2 Spray Solution.

1.5.5.4.2.1
Spray remover solutions are normally only used once with the effluent being disposed of after contact with the part. Contamination of the working solution is not a problem. However, the aspirator injection system, while simple and inexpensive, requires frequent checks to assure that the proper concentration is produced. Concentration of remover in the spray SHALL be measured whenever the aspirator or water pressure valve is adjusted and at the intervals prescribed in paragraph 1.5.1.5. Measurement SHALL also be made whenever there is an unexplained change in background fluorescence.

a. Performing a check of the touch-up, spray hydrophilic remover concentration SHALL be accomplished by one of the methods explained in paragraph 1.5.5.4.1. The concentration of the spray remover is much lower than immersion baths, and the results of the check must reflect this change. Important items to remember are:

   (1) If the touch-up, spray hydrophilic remover is not of the same batch as the remover in the immersion tank, a new graph SHALL be plotted for the touch-up material.

   (2) Make sure that the temperature of the touch-up remover is within the parameters of the instrument/graph being used or compensated for.

b. The penetrant-material system concept SHALL apply to the hydrophilic remover use in the touch-up step of the penetrant inspection. The material being used in the immersion remover tank and as touch-up spray SHALL be of the same manufacturer.

1.5.5.5 Testing Water Suspended Developer.

NOTE

When taking a specific gravity reading to determine the concentration of in-use suspendible or soluble developer, the following SHALL apply: suspendible developers SHALL be thoroughly agitated immediately prior to taking the specific gravity reading; whereas, soluble developer SHALL NOT be stirred or agitated after its initial mixing.

There are a number of service factors that affect the performance of water suspended developer. Most significant are concentration changes, closely followed by contamination problems. Concentration may vary for a number of reasons. Evaporation of the water will increase the concentration, causing excessive coating thickness. Prior to using a new solution, a working level should be established by measuring the distance from the top of the tank to the solution. This working level should be maintained by the addition of water to replace evaporation losses. As parts are processed, developer is removed due to the film adhering to the surface, plus some developer is entrapped in recesses. This loss of developer is termed drag-out and, unless concentrate is added, will reduce the concentration of the developer. Reduced concentration results in thin coatings that decrease the sensitivity of the system. Inadequate agitation will allow some of the developer particles to settle out which also reduces concentration. It is also possible for the developer particles to cake on the bottom or in the corners of the tank preventing them from being suspended. The wetting agents in the developer can remove some of the entrapped penetrant causing fluorescent dye contamination. Developer solutions SHALL be periodically tested to assure acceptable performance (see paragraph 1.5.1.5 for frequency). Suspended developer baths SHALL be tested for concentration using a hydrometer. The hydrometer indicates specific gravity that is proportional to the amount of developer particles in suspension. Prior to obtaining the hydrometer reading, the working solution SHALL be filled to the proper working level, thoroughly agitated, and the tank checked for caked particles on the bottom or in the corners. Newly prepared solutions SHALL NOT be used or checked for concentration until 4 hours after mixing. This aging period is to allow the developer particles to become wetted or saturated. The solution must be stirred after the aging period. The hydrometer may be placed directly in the tank, and when floating free and not touching the tank sides, the specific gravity can be read from the scale. It may be more convenient to take a sample from the tank using a long, narrow glass container such as a graduated cylinder, which is deep enough to float the hydrometer. Figure 1-7 is a graph of specific gravity versus concentration for two water suspended developers illustrating the variation that can occur in the specific gravity's of different water suspended developers, even from the same manufacturer. The supplier can provide an accurate conversion chart for the specific developer, which SHALL be used when checking the developer concentration.

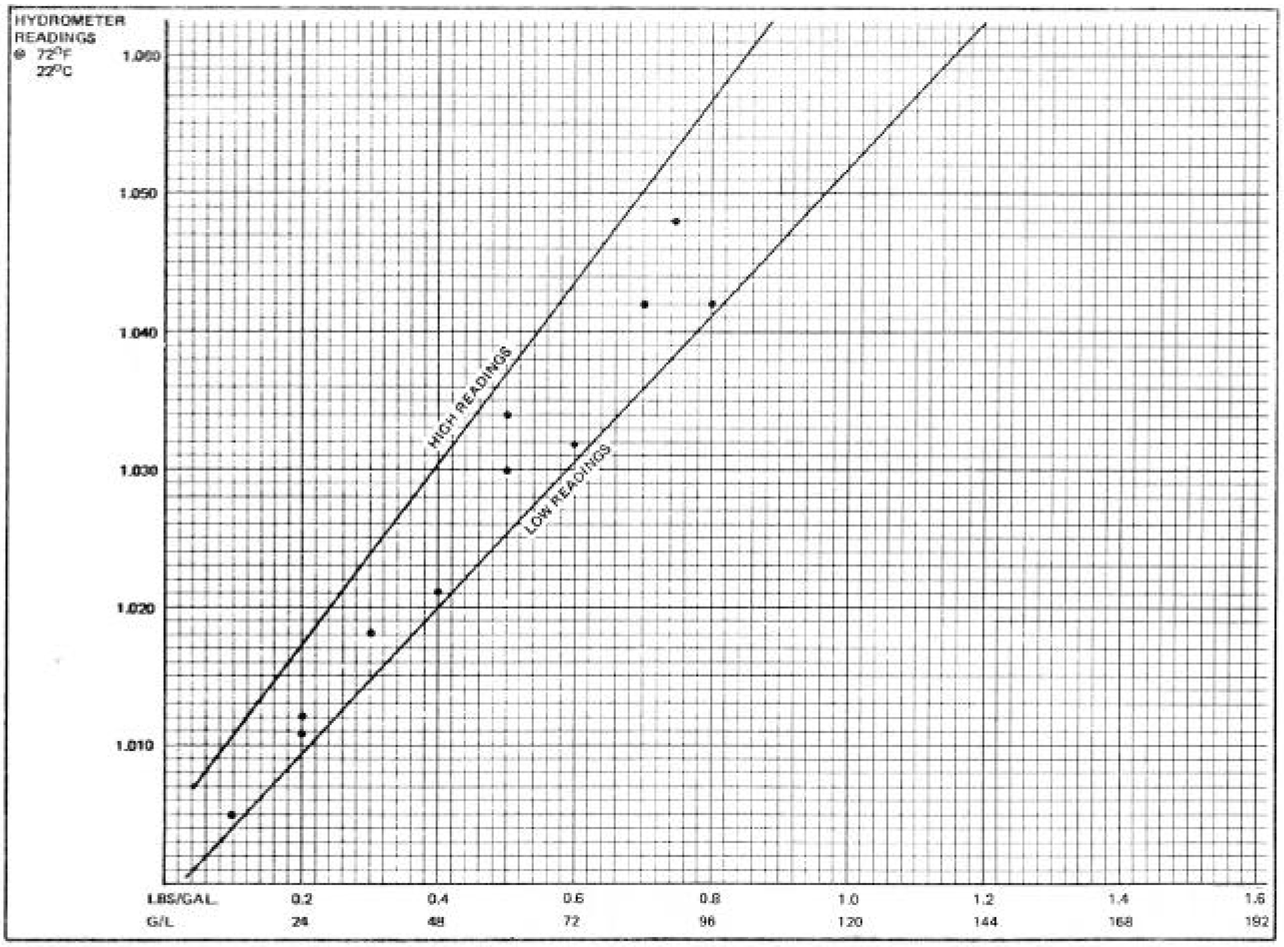


Figure 1-7. Specific Gravity Hydrometer Readings for Two Water Suspended Developers.

1.5.5.5.1
Water suspended developers do not perform properly unless they wet the part surface and form a smooth, even coating when dry. Lumpy or thick areas will hide small indications while uncoated areas will not provide developer action. Poor wetting is usually due to the addition of too much makeup water to replace drag-out losses or by contamination with oily materials which destroy wetting agents. It can also be due to developer age, since most of the newer wetting agents are biodegradable for pollution control purposes. To perform the coating test, use cracked chrome panels; ensure the panels are clean. Pour or otherwise apply some of the working bath developer and some of the reference standard developer to the cracked chrome panels and inspect for signs of not wetting, such as pulling apart or forming beads. The panel should then be dried and examined for even and complete developer coverage.

1.5.5.5.2
The developer may also become contaminated with penetrant. Fluorescent penetrant dye contamination can be checked by visual examination of the bath surface with a black light. Uncontaminated developer appears dull white while fluorescent dye contamination will show up as specks of yellow-green, floating on the top of the bath.

1.5.5.6 Testing Water Soluble Developer.
Water soluble developers reduce the number of in-service problems encountered with suspended developers since agitation is not required and the particles do not settle out. However, there are still concentration and contamination problems. Evaporation and drag-out will change concentrations during use, and the wetting agents can remove entrapped penetrant resulting in contamination. Water soluble developer SHALL be periodically tested to assure acceptable performance.

1.5.5.6.1
The concentration of water soluble developers SHALL be measured by taking specific gravity hydrometer readings. Note that the water soluble developer solution does not require agitation. There are a wide variety of materials available to formulate water soluble developers; therefore, the specific gravity hydrometer readings versus concentration will vary more than they will for the wet suspended developers. Figure 1-8 shows the concentration range (between the lines) for several water soluble developers of one manufacturer; others may even be above or below the lines. The supplier can provide an accurate conversion chart for its particular developer, which SHALL be used when checking the developer concentration.

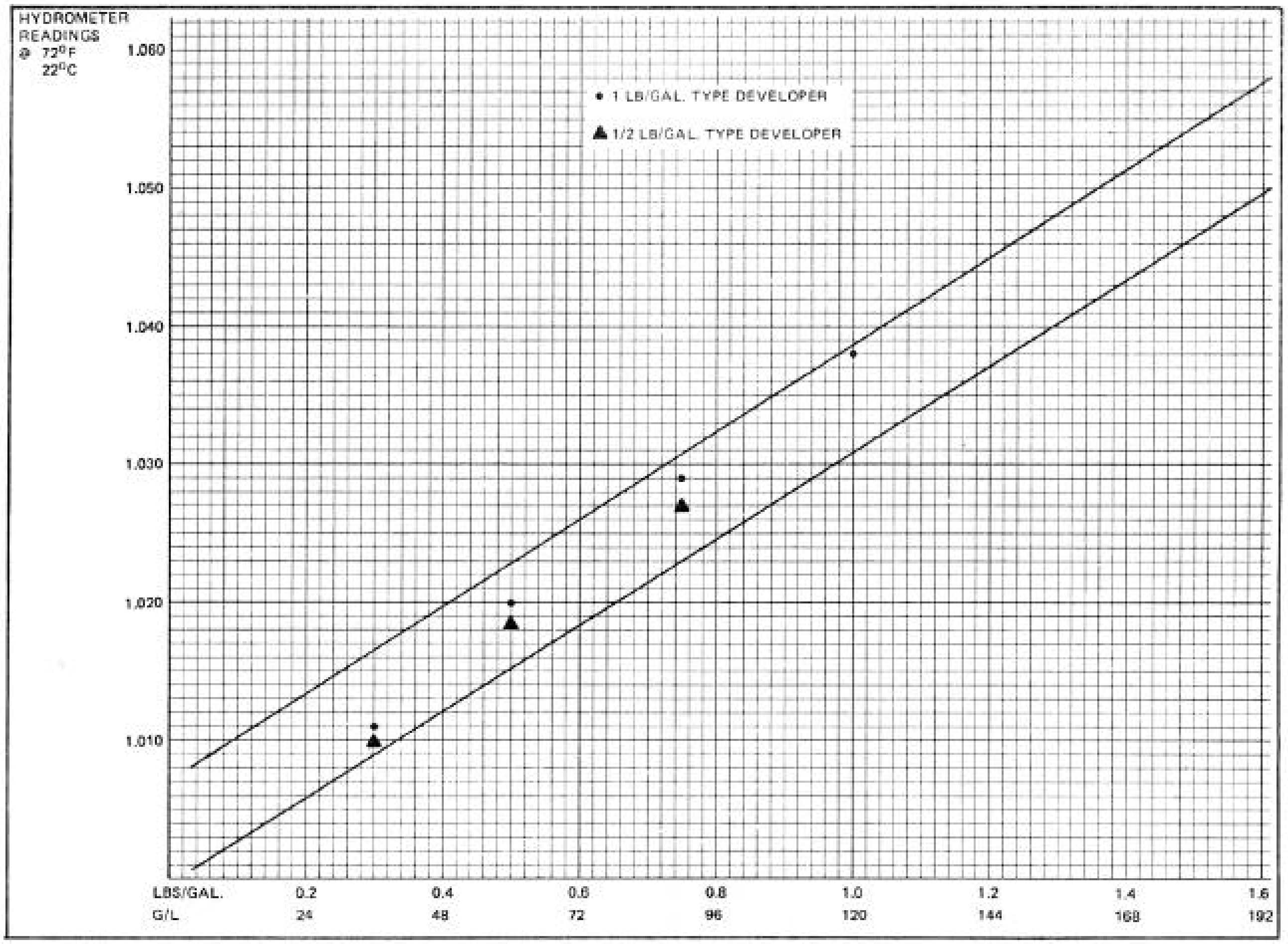


Figure 1-8. Specific Gravity Hydrometer Readings versus Concentration for One Manufacturer's Water Soluble Developers.

1.5.5.6.2
Fluorescent penetrant dye contamination can be checked by visual examination of the bath surface with a black light.

1.5.5.7 Testing Dry Developer.
Dry developers, unlike water based developers, do not have a problem with concentration changes. However, dry developers do become contaminated. Water or moisture from inadequately dried parts splashed into tanks by careless rinsing or condensation are potential sources of contamination. Dry developers can also become contaminated with penetrant when lumps of penetrant-soaked developer from heavy indications or improperly rinsed parts fall off during developer application.

1.5.5.7.1
Dry developers SHALL be periodically checked for evidence of contamination. Visually examine while stirring or mixing the dry powder. Check for evidence of clumps. It may be possible to dry the powder if the water content is low. The lumps of developer must be removed or crushed into loose flakes. If it is not possible to restore the original consistency, the developer SHALL be discarded. The test for penetrant is an examination under black light while stirring or mixing the dry powder. Penetrant contaminated dry developer SHALL be discarded.

SECTION VI

MT PROCESS CONTROL

1.6 MAGNETIC PARTICLE INSPECTION PROCESS CONTROL.

1.6.1 Purpose and Scope.

This section provides information on the procedures necessary to assure a high quality performance for the magnetic particle inspection system. This section discusses the reasons for process control, control requirements, the use of the Quantitative Quality Indicators and the system effectiveness check.

1.6.2 General.

1.6.2.1 Need For Process Control.

The presence of magnetic particle indications confirms the existence of discontinuities in the part. However, the absence of indications does not guarantee the absence of discontinuities. Flaws can be present and not be indicated for a number of reasons. The reasons for incorrect inspection results are deficiencies in either the materials used or application of the process. Of the two, the latter is far more common. These deficiencies are insidious since they may not be readily evident during the inspection of a part. It is necessary to periodically examine the materials, equipment and process parameters to be sure they are as required for adequate inspection results.

1.6.2.2 New Materials.

Magnetic particle materials are subjected to testing during their formulation to assure their proper composition. However, materials that do not perform satisfactorily can be received. If unsatisfactory material performance is not discovered until some number of parts have been processed, then extra time and expense is required to reinspect the suspect parts. Unsatisfactory materials can result from a number of causes. The cost of verifying adequate material performance is extremely low and the required tests can be performed at any field laboratory.

1.6.2.3 In-Use Materials.

Some inspection processes use the magnetic particle materials only once. In these processes the materials are usually applied by spraying or dusting and only the amount of material required for the inspection is applied. The materials are stored in closed containers until they are used. These processes minimize the possibility of material contamination or degradation during use. More often, however, the materials are used in open tanks where the excess materials are allowed to drain from the part back into the tank. This method provides numerous opportunities for contamination, deterioration and changes in concentration and such materials must be checked periodically to be sure they are functioning satisfactorily.

1.6.3 Causes of Materials Degradation.

1.6.3.1 Contamination.

Contamination is a primary source of magnetic particle bath performance degradation. There are a number of contaminants and their effect on performance can vary. Some of the common contaminants frequently encountered are:

a. Water is a common contaminant in petroleum based baths. It can occur because of condensation, leaks or moisture carryover on parts.

b. Organics such as paint, lubricants, oils, greases and sealants, are another source of contamination. These materials are usually introduced into the magnetic particle bath by parts to be inspected and can react with or dilute a bath so that it loses some or all of its ability to function.

c. Organic solvents such as degreaser fluid, cleaning solvent, gasoline and antifreeze solution, are also potential contaminants. These materials can mix with the inspection bath or float on top of it reducing the bath’s effectiveness.

d. Dirt, soil and other insoluble solids can be carried into the magnetic particle bath as a result of inadequate pre-cleaning.

e. Acidic and alkaline solutions can be a contaminant of magnetic particle baths. Acidic and alkaline solutions can be residues of previous plating, paint stripping and cleaning processes.

1.6.3.2 Evaporation Losses.

Magnetic particle bath vehicle materials used in open tanks are continuously undergoing evaporation, resulting in an increase in particle concentration. The rate of evaporation increases with warmer temperatures and larger tank surfaces. Evaporation losses take place very gradually so performance change may become significant before it is noticed.

1.6.3.3 Drag-Out.

Particle concentration is reduced when particles that adhere to parts being inspected are not returned to the suspension. Like evaporation, the resultant change occurs slowly and would probably go unnoticed until significant performance loss is experienced.

1.6.3.4 Heat Degradation.

Fluorescent dye stuffs are sensitive to elevated temperatures. Temperatures of over 140°F (60°C), can reduce the fluorescence and temperatures over 250°F (117°C), may destroy it completely. High temperatures in magnetic particle inspection materials usually occur when materials are improperly stored. A dark colored container stored in direct sunlight can reach temperatures above 140°F.

1.6.3.5 Process Degradation.

In addition to materials degradation during use, the equipment and process can deteriorate. The magnetizing equipment can loose power, black light bulbs age and become dirty and critical procedural steps may be performed incorrectly or omitted. Periodic checks SHALL be accomplished to assure satisfactory performance.

1.6.4 Frequency of Process Control.

One of the factors influencing the degradation of a magnetic particle system (materials, equipment and procedures) is the volume of parts being processed. Bath and equipment deficiencies can be expected to occur more often with increased workload volume. Since there is no uniformity in workload between activities, a single calendar schedule cannot be established. Each inspection activity SHALL set inspection intervals based on their workloads. The inspection intervals SHALL be documented as shown in Chapter 1, page 1-15, paragraph 1.4.5. (For Navy: use local form.) Guidance on inspection intervals is provided in the following paragraphs.

a. If your workload requires operation for eight or more hours each day, perform the concentration test every eight hours or each shift.

b. If your workload requires occasional or less than eight hours of operation, perform the concentration test prior to processing parts on that shift.

1.6.5 Material Requirements.

1.6.5.1 Applicability.

NOTE

Prior to bath replacement in a magnetic particle inspection unit, the equipment must be cleaned thoroughly according to the equipment maintenance manual. This does not apply to the addition of materials (either vehicle or particles) to maintain concentration.

Material tests apply to both newly received and in use materials. They are designed to assure that unsatisfactory materials do not enter the magnetic particle inspection system and that in use materials continue to perform satisfactorily.

1.6.5.2 Tests For New Materials.

New materials SHALL be subjected to the following tests, as appropriate, prior to being put into use:

a. Perform contamination/background fluorescence check on petroleum based bulk vehicle.

b. Check the concentration, background fluorescence and contamination of the bath using the settling test.

c. Perform system effectiveness test. This applies to magnetic rubber inspection materials as well as conventional magnetic particle inspection materials.

1.6.5.3 Tests For In Use Materials.

In-use materials SHALL be checked. The frequency of checking SHALL be as established per Table 1-3.

1.6.5.4 Disposition for Nonconformance.

NOTE

> Knowledge of problems, even relatively minor ones, is essential for improvement in the NDI program. Information copies of written correspondence concerning unsatisfactory magnetic particle inspection materials SHALL be furnished to Air Force NDI Program Office, AFRL/MLS-OL, 4750 Staff Dr., Tinker AFB, OK 73145-3317; DSN 339-4931 and AFRL/MLSA, 2179 Twelfth Street, Ste. 1, Wright-Patterson Air Force Base, OH 45433-7718. (For Army: Commander, AVSCOM, Attn.: AMSAV-MC, 4300 Goodfellow Blvd., St. Louis, MO 63120-1798).

Reject all materials not meeting minimum requirements. Rejected materials SHALL be reported according to T.O. 00-35D-54. (For Navy: Refer to OPNAV 4790.2 Quality Deficiency Reporting [QDR] requirements.)

1.6.5.4.1

Open tank baths SHALL be changed (replaced or replenished, as appropriate) when they do not meet minimum inspection requirements.

1.6.6 Safety Requirements.

Safety requirements SHALL be reviewed by the laboratory supervisor on a continuing basis to insure compliance with provisions contained in AFOSH Standard 91-110, section 3.2, as well as provisions of this technical order and applicable weapons systems technical orders.

1.6.7 Magnetic Particle Equipment / System Requirements.

1.6.7.1 General.

Magnetic particle equipment SHALL be maintained according to applicable technical orders, Navy Maintenance Requirements Cards (MRCs) or commercial manuals.

1.6.7.2 Equipment / System Tests.

The following minimum equipment/system tests, as appropriate, SHALL be accomplished to insure magnetic particle inspection equipment/systems meet acceptable operating standards.

a. System effectiveness check.

b. Amperage indicator check for stationary units. Perform when the system effectiveness check is failed and as established per Table 1-3 on page 1-16.

c. Dead weight check for portable induced field equipment. AC electromagnet yokes shall have a lifting power of at least 10 pounds, with a spacing of three to six inches between the legs. DC electromagnetic or permanent magnet yokes shall have a lifting power of at least 30 pounds with a two to four inch spread or 40 pounds with a four to six inch spread of the legs. Test weights should be locally manufactured from 4 inches x 1-1/4 inches SAE 4130 or SAE 4340 bar stock. A 7-inch long piece of this material will weigh approximately 10 pounds. Testing frequency shall be established as per Table 1-3.

d. Field indicator check. Perform check on in-use indicator daily or before use if used less frequently.

e. Lighting requirements.

  (1) Blacklights.

    (a) Check the intensity prior to use.

    (b) Check new black light bulb intensity prior to its being placed into service.

    (c) Check black light and filter's physical condition. Black light and filters SHALL be kept clean, free of cracks or chips, and SHALL fit properly.

  (2) Check the ambient white light background in the fluorescent magnetic particle inspection booth. It shall not exceed 2 foot candles at the inspection surface.

1.6.8 Process Requirements.

1.6.8.1 Pre Cleaning.

Prior to magnetic particle inspection examine the parts for the following:

a. Removal of oils, grease, moisture, dirt, rust, scale and loose paint.

b. Verify cleaning residues have been removed.

c. Insure parts are adequately dried, especially in recessed areas.

d. Verify all areas requiring masking and/or plugs have been covered.

1.6.8.2 Inspection Operations.

Observe the magnetic particle inspection operations being applied to assure:

a. The applicable technical data is available.

b. The appropriate magnetizing current is used (AC, DC, rectified AC).

c. The appropriate magnetic particles are used (wet, dry, visible, fluorescent).

d. The proper application of inspection media (continuous, residual).

e. The required field directions are induced.

f. The sequence of induced fields (circular versus longitudinal). Whenever practical the circular field should be induced first. This is to facilitate the demagnetization process.

g. The required magnetizing amperage is used and the part is checked for proper magnetization.

h. The black light is allowed to warm up for a minimum of ten minutes, or until the required intensity (1000 µwatts/cm2) is achieved.

i. The required demagnetization procedure is used (30 point stepdown, AC coil).

j. The adequacy of the field indicating device to determine adequacy of demagnetization.

k. The effectiveness of the demagnetization process.

1.6.8.3 Post Cleaning.

Visually inspect parts for the following:

a. Assure all inspection materials are removed.

b. Assure all masking and plugging materials are removed.

1.6.9 Quantitative Quality Indicators.

The QQIs, introduced in (chapter 3), are potentially very useful as both a process control tool and a technique development tool.

1.6.9.1 Introduction.

Quantitative Quality Indicators (QQIs) used in magnetic particle and magnetic rubber inspections are also called shims. They are used to evaluate the effectiveness of the applied magnetic fields for the two inspection methods.

1.6.9.1.1

In the absence of a cracked-part reference standard, QQIs offer a valid method of assessing the adequacy of an inspection procedure. QQIs indicate the direction and strength of the applied magnetic fields. As such they are also useful in assessing the performance of equipment and materials associated with either magnetic particle or magnetic rubber methods General Information.

1.6.9.1.2

CAUTION

Exercise care when using QQIs on curved surfaces. Excessive bending will damage a QQI beyond use.

Usually the thinner QQI will be used on curved surfaces; however they are fragile. The thicker QQI is less fragile but can still be damaged by excessive bending.

1.6.9.2 Instructions for Use.

WARNING

Cleaning solvent, MIL-C-38736, is flammable and moderately damaging to the skin, eyes and respiratory tract. To prevent injury, rubber gloves and goggles are required. Good, general ventilation is normally adequate.

NOTE

Use of a QQI will require a second magnetic particle or magnetic rubber inspection (without the QQI) if the QQI is placed in an area where an actual crack could be present.

1.6.9.2.1

The area where the QQI is to be placed shall be thoroughly cleaned and dried. Use cleaning solvent, MIL-C-38736. Place the appropriate QQI in place with the slot side against the surface of the part. In general, the 30% deep slot is adequate for most defects. For very critical inspections, the 15% deep slot may be required and for rough castings or weldments the 60% slot may be more appropriate.

1.6.9.2.2

Use a clear adhesive tape (for example, Scotch brand 191, 471 or 600 series) to hold the QQI in place. Tape should be applied to all four edges to insure good contact (no air gap) and prevent the particles from getting under the QQI. Make sure the tape does not cover the area of the QQI where the indications will form. “Super glue can provide a fixed bond, although it may be later removed by soaking in acetone.”

1.6.9.2.3

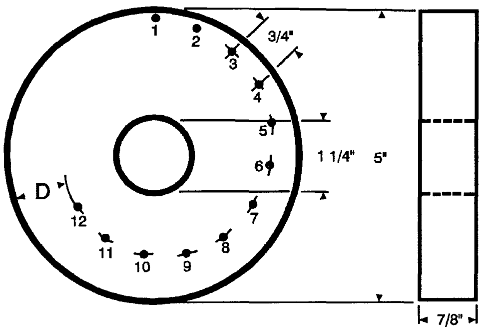
Conduct the inspection and observe the results under the appropriate lighting. Note that the QQI was designed for the continuous method and the indications may disappear when the applied field is removed. Also note that the QQI will not indicate background. The actual part must be examined to determine the amount of background present.

1.6.10 System Effectiveness Check.

The importance of this process control step is second only to having an adequate inspection procedure. The intent is to use a test specimen or set of specimens to assure that the system, i.e. equipment and materials, are capable of producing an adequate magnetic particle inspection. There is no Department of Defense standard specimen for this requirement; consequently there are a variety of ways to fulfill the requirement, each with its own applicability. It is the responsibility of each laboratory NCOIC to establish the effectiveness check that best suits the requirements for their laboratory. The following information is presented to assist these individuals in this task.

1.6.10.1 Ketos Ring.

To use the Ketos ring see Figure 1-9, for the system effectiveness check, first check the ring for residual magnetism. Apply the magnetic particle bath, wait at least 60 seconds for any indications to form, then examine the ring. If any indications are present on the outer edge, the ring must be demagnetized and the check repeated until no indications are formed. Next, inspect the ring using the wet continuous method with circular magnetization applied using the current listed in Table 1-4 through a one-inch diameter central conductor. Inspect the ring to insure the minimum number of holes listed for a given amperage is visible. Lack of this visibility may indicate a malfunctioning magnetic particle unit, a low particle concentration, or a ring that is not in the annealed condition. The cause of the malfunction SHALL be determined and corrected prior to performing additional magnetic particle inspections with the deficient system.



HOLE	1	2	3	4	5	6	7	8	9	10	11	12
DIAMETER	.07	.07	.07	.07	.07	.07	.07	.07	.07	.07	.07	.07
" D "	.07	.14	.21	.28	.35	.42	.49	.56	.63	.70	.77	.84

Figure 1-9. Ketos Ring

Table 1-4. Ring Specimen Indications

Type of Suspension	D.C. Amperage	Minimum No. of Holes Indicated
	1400	3
Non-fluorescent	2500	5
	3400	6
	1400	4
Dry Powder	2500	6
	3400	7
	1400	3
Fluorescent	2500	5
	3400	6
	A.C. Amperage	
Non-fluorescent	1000	1
Dry Powder	1000	1
Fluorescent	1000	1

1.6.10.2 QQIs.

Test specimen(s) used with QQIs offer a more versatile means of checking system performance than afforded by the Ketos ring. The specimens can be real parts or designed to be representative of the most challenging inspection to be currently performed. This combination is capable of providing an adequate check on any magnetic particle inspection system. Even though QQIs respond to the applied, not residual, field, demagnetization is necessary of the specimen(s) in order to remove the previously applied inspection media.

1.6.10.3 Cracked Parts.

The ultimate specimens for the performance tests are cracked parts. If available, they require careful handling to remain corrosion-free and retain their flaw sizes.

1.6.11 Ammeter Check.

Amperage indicator accuracy check SHALL be performed using the calibrated ammeter/shunt authorized in TA-455. Operation of the ammeter/shunt SHALL be according to the commercial manufacturer's operating instruction. DC amperage variations exceeding ±10% at reading or +60 amperes, whichever is greater, and

AC amperage variations exceeding ±10% at maximum rated unit output SHALL necessitate location the source of the difficulty and corrective action taken. The ammeter/shunt SHALL be calibrated as prescribed in T.O. 33K-1-100-1.

1.6.12 Quick Break Tester.

Check SHALL be accomplished to insure the presence of accurate decay rate sufficient for quick break magnetization. The quick break tester is authorized in TA-455. Operation fo the quick break tester SHALL be accomplished according to the commercial manufacturer's operating instructions. Test failure SHALL necessitate locating the source of the difficulty and corrective action taken. The quick break check SHALL be performed at least once each 60 calendar days.

1.6.13 Establishing a Field Indicator Reference Standard. (See Figure 1-9a.)

a. Place a small bar magnet (approximately 1 by 1/2 inch) vertically near the bottom of an 8 1/2- by 11-inch sheet of paper and trace around the magnet with a marker. (It does not matter which pole of the magnet is up.)

b. Place a new field indicator at the top of the paper with the bottom of the indicator above and in line with one pole of the magnet.

c. Slowly move the new field indicator toward the magnet until a half-scale meter reading is obtained. (If the south pole of the magnet is up, the meter needle will deflect to the right.)

d. Mark the location of this field indicator by tracing along the bottom of the indicator with a marker. Label the line with a unique letter.

e. Repeat steps b, c and d with all remaining new indicators in the NDI shop inventory. Use the same magnet at the same orientation.

f. From among the group of new field indicators tested, select the one that gave a half-scale reading at the most common position marked on the sheet of paper.

g. Label the selected field indicator as the reference standard.

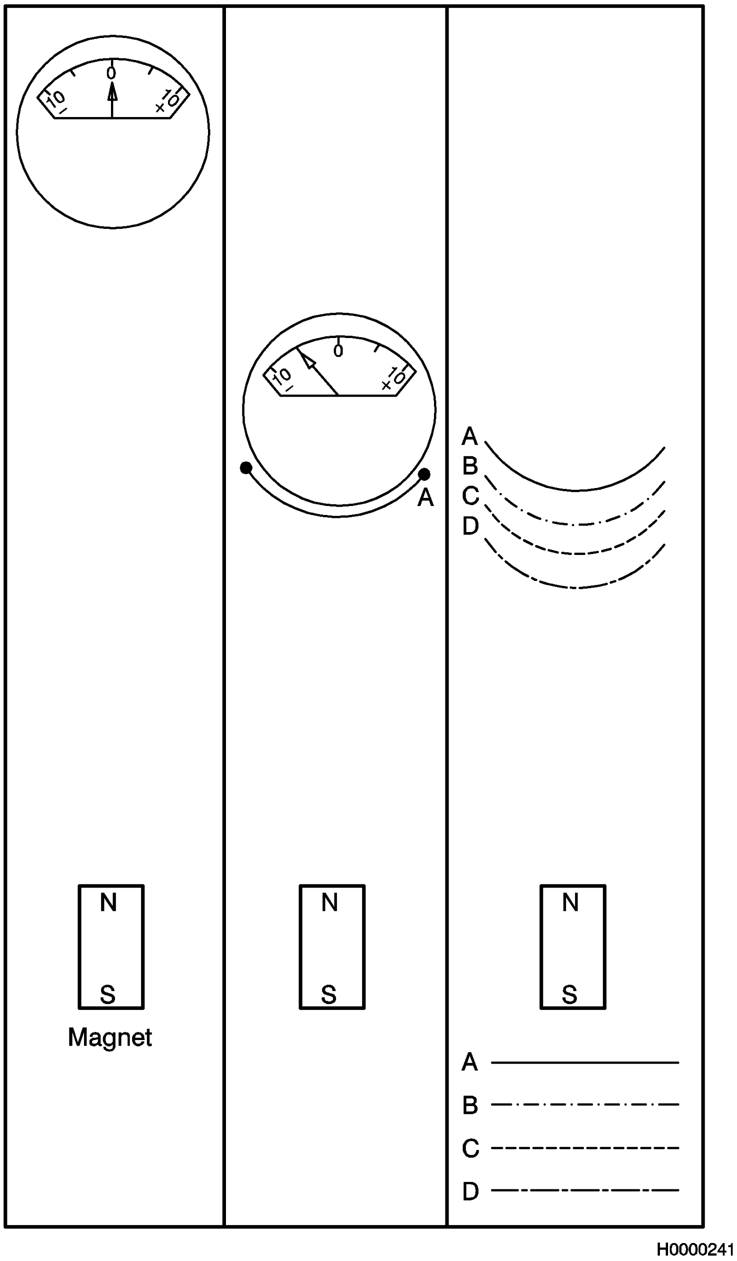


Figure 1-9a. Establishing a Field Indicator Reference Standard

1.6.14 <u>Checking the In Use Field Indicators.</u> (See Figure 1-9b.)

a. Place a small bar magnet (approximately 1 by 1/2 inch) vertically near the bottom of an 8 1/2- by 11-inch sheet of paper and trace around the magnet with a marker. (It does not matter which pole of the magnet is up.)

b. Place the field indicator reference standard on a sheet of paper with the bottom of the indicator above and in line with one pole of the magnet.

c. Move the reference standard toward the magnet until a half-scale meter reading is obtained. (If the south pole of the magnet is up, the meter needle will deflect to the right.)

d. Mark this position on the sheet of paper by tracing along the bottom with a marker.

e. Place an in-use field indicator in the exact position traced for the reference standard and note the reading.

f. Reject an in-use indicator if the meter reading obtained differs from that of the reference standard by more than two units in either direction.

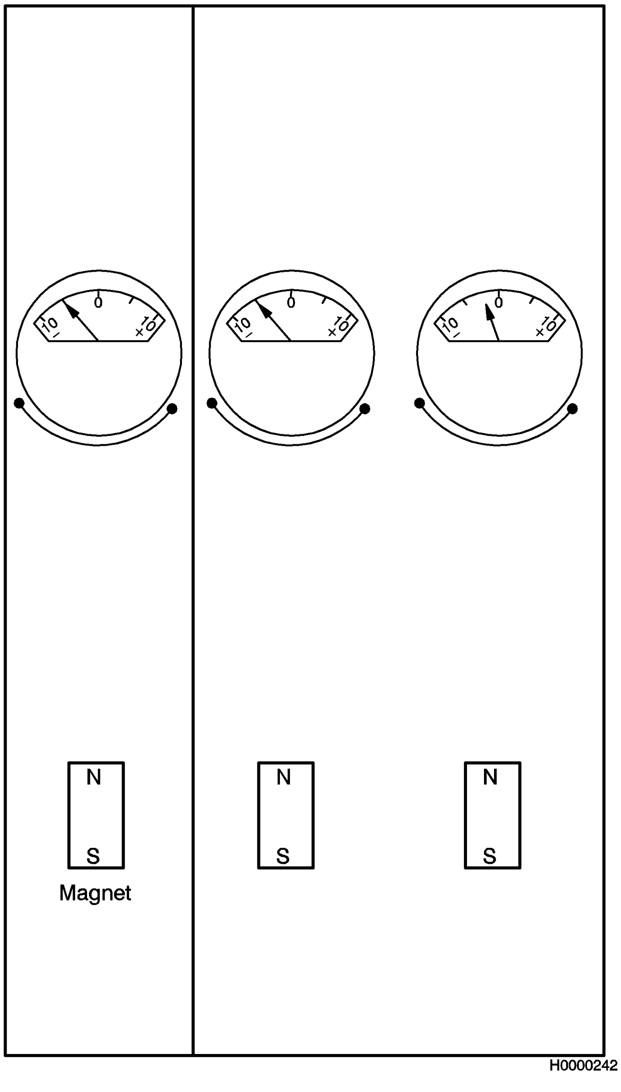


Figure 1-9b. Checking In-Use Field Indicators

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SECTION VIII

UT PROCESS CONTROL

1.8 ULTRASONIC PROCESS CONTROL REQUIREMENTS.

1.8.1 The Ultrasonic Process Control Requirements.

In the ultrasonic inspection process like the eddy current process you must know your equipment and probe or transducer or search unit is functioning properly. The following information on process control in ultrasonic testing is designed to help ensure repeatability and accuracy. All new transducers should be checked against a reference transducer of the same dimension and frequency. Only transducers in use require documentation on serviceability. For example, you may have 5 of the same transducers in stock but only be using one. The one in use should be labeled to show the required gain to achieve a 100% amplitude on a specific size flaw. If a transducer requires more gain than the reference transducer, you know it is then a suspect. This transducer can be used, providing you can still find the required defect called by the procedure. You should never have only one transducer for a specific application. A transducer element can separate from the damping material. This will cause the initial pulse to become a long ringing signal. Such a situation will cause the transducer to fail the dead zone test. The transducer must be replaced. This type of process control will help ensure quality inspections without assuming everything is working properly. Frequency of process control checks on equipment should come from the operations manual on the equipment. Frequency of transducer checks should be determined by the amount of use, which will be determined by the lab supervisor. The operator is the critical link in this process. Even if all the equipment is working properly, the inspector must follow the written procedure and use the correct standard. No deviations SHALL be made without proper engineering authority. In this chapter, the terms “reference standard,” “reference block,” “test block,” and “calibration standard” all have the same meaning as defined in the glossary. Reference standards are used by the instrument operator. Calibration of reference standards by laboratories is not required. However, to insure uniform inspection sensitivity, reference standards shall be traceable to a “master standard” in terms of discontinuity response.

1.8.1.1 Required Use.

All inspections shall include the use of one or more reference standards for setting up the inspection. In addition, all discontinuity indications shall be compared to a reference standard by comparing the signal amplitude of the discontinuity with the signal amplitude of the reference standard. This is done either in percent signal amplitude or by noting the difference in amplitude in decibels (dB) when the instrument is equipped with dB attenuation controls.

1.8.1.2 Configuration.

The reference standard may be a block containing a known size flat-bottom or side-drilled hole, machined slot or notch, or a real discontinuity of known size in the test part or a piece similar to the test part. Inspection procedures must be carefully reviewed for the following specific requirements:

a. Flat surface reference standards used for test set-up and for evaluation of discontinuity size and metal travel shall be fabricated and checked in accordance with ASTM standard practices. For more information see ASTM E127, E128, and E1158, 2nd para. 4.2.4.5.

b. Curved surface reference standards may be required when performing straight beam inspection of curved entry surfaces on cylindrical or irregularly shaped products. Special ultrasonic test blocks containing specified radii of curvature and flat-bottom holes of standard diameter shall be used. For parts with convex radii over 4 inches, use standard flat face blocks. Flat blocks may be used to inspect other curved surfaces when supported by test data showing correction factors, and must be acceptable to the responsible engineering activity.

c. Hollow cylindrical standards for inspection of hollow cylindrical parts or sections shall be fabricated in accordance with a particular specification.

d. International Institute of Welding (IIW) blocks shall be used as specified for determining certain characteristics of angle beam and straight beam search unit and may be used for distance calibrations.

e. Holes, notches, and other reflectors shall be protected against corrosion and mechanical defacing that would alter the ultrasonic echo signal. For example, it is recommended that all holes be sealed to prevent corrosion of the hole face.

f. For most inspections performed to locate cracks, an effective reference standard can be made by electric discharge machining (EDM) notches. Notches must be replicated for verification. The notch of appropriate size should be placed in the expected location of cracks (or per drawing) with the plane of the notch in the expected plane of cracks. Information on the expected location and orientation of cracks shall be obtained from the depot-level engineering activity. Other reflecting surfaces meeting the requirements of MIL-STD-2154 are permitted. All standards should be clearly identified so that the material, hole or notch size, angles and dimensions are clear.

1.8.1.3 Metal Travel Distance.

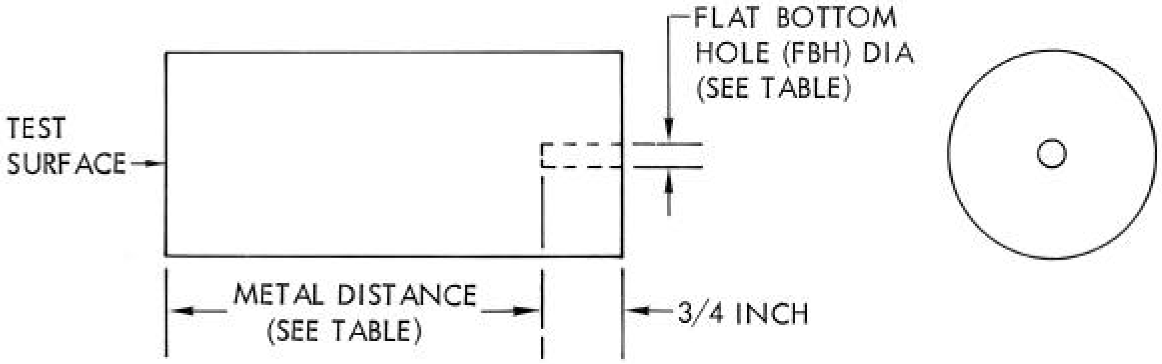
The metal travel distance (distance from sound-entry surface to a discontinuity) for the test part and the reference standard must be the same within the tolerances shown in Table 1-5; or else, as an option, distance amplitude correction could be used.

Table 1-5. Reference Standard Metal Travel Tolerances.

Metal Travel Distance to Discontinuity in Test Part (inches)	Tolerances on Metal Travel Distance to Discontinuity in Reference Standard (inches)
Up to ¼	± 1/16
1/4 to 1	± 1/8
1 to 3	± 1/4
3 to 6	± 1/2
Over 6	± 10% of metal travel

1.8.1.4 ASTM Blocks.

The ASTM test block configuration is shown in Figure 1-10. Two sets of ASTM test blocks, one for aluminum and one for steel, are included in TA 455. Two ASTM specifications cover manufacturing and verification of these reference standards. They are ASTM E 127 (aluminum test blocks) and ASTM E 428 (steel test blocks). ASTM E 428 also allows the use of reference standards of other materials such as titanium. For more information see ASTM E1158, “Standard Guide for Material Selection and Fabrication of Reference Blocks for the Pulsed Longitudinal Wave Ultrasonic Examination of Metal and Metal Alloy Production Material.



METAL DISTANCE, INCHES	1/8	1/4	1/2	3/4	1-1/2	3	3	3	6	6
FBH DIA IN 64THS INCH	5	5	5	5	5	3	5	8	5	8

Figure 1-10. ASTM Reference Blocks.

a. When applicable, Table 1-6 may be used as an aid if the required flat-bottom hole, (FBH), reference standard is not available. The second column lists relative amplitudes of echoes from successive sizes of FBHs. For example the signal from a #5 FBH is 4 dB larger than the signal from a #4 FBH, so the instrument gain would have to be decreased by 4 dB if a #4 FBH were available but a #5 FBH was the required standard. If a #5 FBH were available but a #2 FBH were required, the instrument gain would have to be increased 16 dB (7+5+4) for the inspection.

Table 1-6. Relative Signal Response from FBHs in ASTM Blocks.

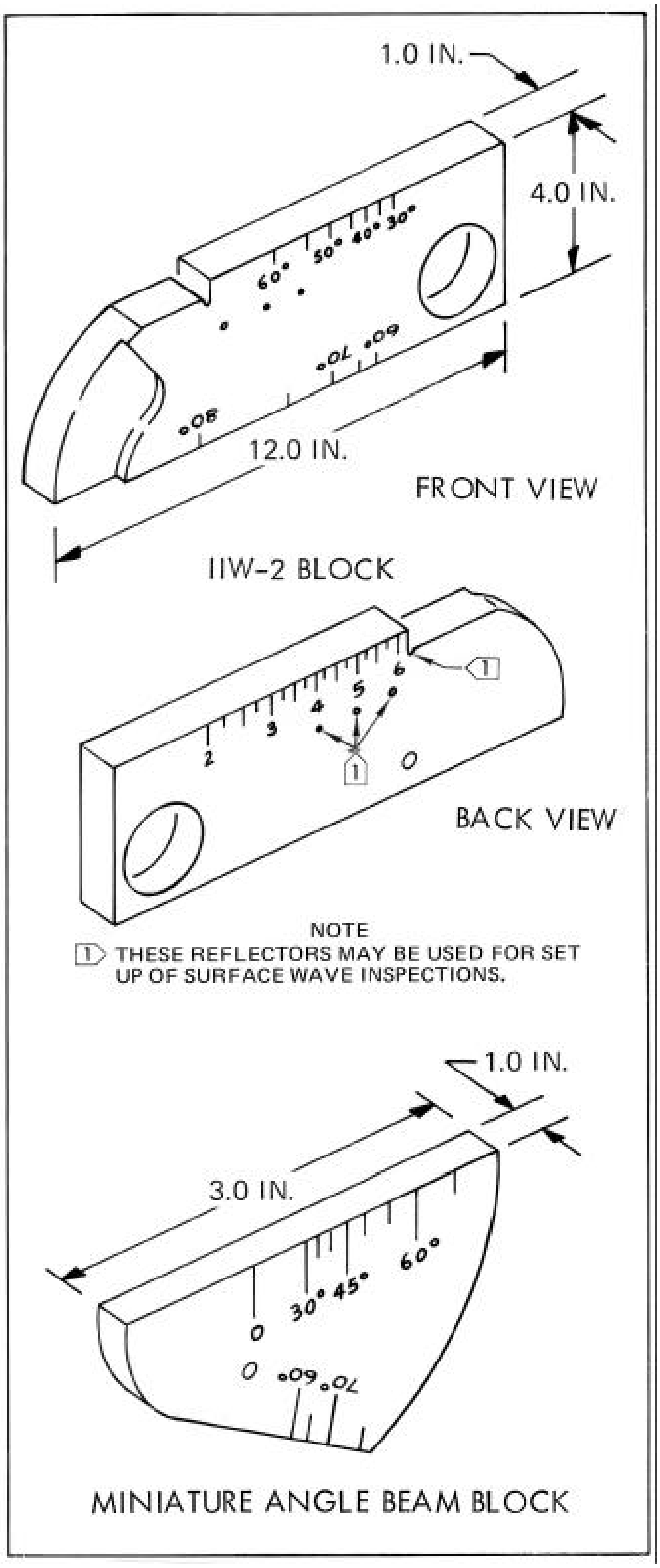
FBH Number (size in 64ths of an inch)	Difference (dBs) From previous FBH size
2	
3	7
4	5
5	4
6	3
7	3
8	2

b. Hole bottoms are checked for flatness and hole orientation is checked for perpendicularity to the block surface.

c. When FBH size is plotted versus respective ultrasonic echo amplitude for a given equipment set-up, a straight line ± 2 dB should pass through the plotted points.

1.8.1.5 Angle Beam Blocks.

There are two types of angle beam calibration blocks included in TA 455: the miniature block and the International Institute of Welding (IIW) block Type 2 (see Figure 1-11). Either of these blocks may be used to perform the following for angle beam transducers: check the refracted angle of the sound beam, check the point-of-incidence of the refracted sound beam and calibrate the sweep of the ultrasonic instrument. Note also within these paragraphs are procedures for characterizing and calibrating straight beam transducers. Angle beam blocks made of aluminum and steel are standard. Other materials may be specifically ordered. Shear wave velocities for titanium and aluminum are close so aluminum blocks may be used for shear wave inspection of titanium. However, adjustments in distance calibration may have to be made.



NOTE

1 THESE REFLECTORS MAY BE USED FOR SET UP OF SURFACE WAVE INSPECTIONS.

Figure 1-11. Angle Beam Block.

1.8.1.6 Surface Wave Reference Standard.

A variety of reflectors can be used for set up of surface wave inspections. Electrical discharge machined notches, saw cuts, chiseled notches, and drilled holes can be used. Suggested surface wave standards are the side-drilled holes or the notch in the IIW block when the search unit is placed on the large front or back surface of the block. The reflected signal from one of the holes or the notch can be compared with the reflected signals from discontinuities in test parts. Signals should be compared at equivalent travel distances (distance from search unit to reference standard reflector equal to distance from search unit to test part discontinuity).

1.8.2 Calibration of Equipment.

The most important calibration is the verification of each inspection setup through use of the applicable reference standard. It is essential that this verification be accomplished for each and every inspection. However, there are general calibration procedures that can be used to ensure that the equipment and its supporting components are within the parameters required to perform ultrasonic inspections. These procedures, which follow in the remaining paragraphs of this section, should be performed and documented at the time intervals prescribed in applicable specifications or procedures, at any time an operator suspects that there is a problem with the equipment, or at least annually.

1.8.2.1 Vertical Linearity of Instrument.

1.8.2.1.1 Limits.

a. Upper Linearity Limit is the level of vertical deflection defining the upper limit of an observed constant relationship between the amplitude of the indications on an A-scan screen and the corresponding magnitude of the reflected ultrasonic wave from reflectors of known size. The minimum acceptable limit of full screen height is 95 percent.

b. Lower Linearity Limit is the level of vertical deflection defining the lower limit of an observed constant relationship between the amplitude of the indications on an A-scan screen and the corresponding magnitude of the reflected ultrasonic wave from reflectors of known size. The maximum acceptable limit of full screen height is 10 percent.

1.8.2.1.2 Procedure for Determining Vertical Limits.

a. Use three ASTM blocks, all with 3-inch metal travel distances and one each with a 3/64, 5/64, and 8/64 inch diameter flat-bottom hole (FBH).

b. Move the search unit over the surface of the block with the 5/64 inch FBH until maximum response is obtained from the FBH. Make sure that the reject control and filters are in the "off" or minimum positions. Adjust the instrument gain control until the FBH signal is 35% of saturation on the CRT.

c. Leave the gain fixed as adjusted above in d. Maximize the FBH signal on the 3/64 and 8/64 FBH blocks. Record the FBH signal amplitudes.

d. If the instrument is linear, the signals from the 3/64 and 8/64 FBHs will be 13% ± 3% and 90% ± 5% of saturation respectively. Thus, a 3/64 FBH signal between 10% and 16% of saturation is considered linear; an 8/64 FBH signal between 85% and 95% of saturation is considered linear.

e. Instruments not linear within the above limits SHALL be repaired or replaced.

1.8.2.2 Horizontal Linearity of Instrument.

1.8.2.2.1 Definitions.

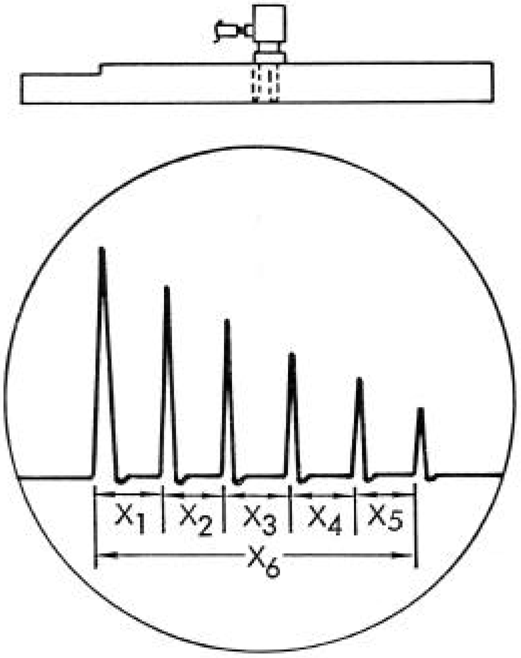
a. Horizontal Limit is the maximum readable length of horizontal deflection that is determined either by an electrical or a physical limit in the A-scan presentation of an ultrasonic testing instrument. Horizontal limit is expressed as the maximum observed deflection in inches from the left side, or the start, of the horizontal line representing the time base. The horizontal limit is full scale.

b. Horizontal Linearity Range is the range of horizontal deflection in which a constant relationship exists between the incremental horizontal displacement of vertical indications on the A-scan presentation and the incremental time required for reflected waves to pass through a known length in a uniform transmission medium. The acceptable horizontal linearity range is 85 percent of the Horizontal Linearity Range.

1.8.2.2.2 Procedure for Determining Horizontal Linearity.

In lieu of any specific linearity requirement, the horizontal linearity may be checked as follows:

a. Use the IIW block and a straight beam search unit (see Figure 1-12).



ACCEPTABLE HORIZONTAL LINEARITY INDICATED BY $X_1 = X_2 = X_3 = X_4 = X_5$ WITHIN ±3% of X_6.

Figure 1-12. Use of IIW Block Horizontal Linearity.

b. Place the search unit on the IIW block and adjust the gain, sweep, and sweep delay to obtain six back reflections on the CRT. The first back reflection should be located at the left side of the base line (the initial pulse will be off screen), and the 6th back reflection should be located at the right side of the base line.

c. Measure the distance between the leading edge of adjacent back reflections. Ideal horizontal linearity will be indicated by an equal distance between the leading edges of adjacent back reflections. If all the values are equal within ± 3% of the full scale width, the instrument is considered linear in the horizontal direction.

d. Instruments not linear within the above limits shall be repaired or replaced.

1.8.2.3 Sensitivity of Inspection System.

1.8.2.3.1 Definition.
Sensitivity is a measure of the ability of an inspection system (instrument and search unit) to detect discontinuities producing relatively low-amplitude signals because of the size, geometry or location of the discontinuities. Noise can limit detectability of discontinuities by masking their indications. Generally, sensitivity, resolution and signal-to-noise ratio are interdependent and should be evaluated under similar test conditions.

1.8.2.3.2 Procedure for Determining General Sensitivity.

NOTE

The 1 MHz and 15 MHz requirements are applicable only when these frequencies are to be used; they are not specific requirements for all instruments.

Unless otherwise specified in a detailed procedure, use ASTM reference blocks with flat-bottom holes (FBHs). Table 1-7 shows the FBH that should be detectable with the respective frequencies.

a. Select the ASTM block with the appropriate FBH at a depth of three inches.

b. Obtain a peak signal from the appropriate FBH.

Table 1-7. Minimum Sensitivity Requirements.

Frequency (MHz)	1	2.25	5	10	15
FBH Size (inch/64)	8	4	2	1	1

c. Adjust the Gain control of the instrument until the discontinuity indication is 60 percent of full screen height.

d. Note the baseline noise in the test region (adjacent to the FBH indication). The noise should be no higher than 20 percent of full screen height.

e. When a reference standard specified by a detailed inspection procedure is used, the minimum signal-to-noise ratio is also 3 to 1.

f. If the inspection system does not meet these sensitivity requirements, the search unit and/or cable SHALL be replaced and the sensitivity checked again. If the inspection system still does not meet the above requirements, the instrument SHALL be repaired or replaced.

1.8.2.4 Resolution of Inspection System.

NOTE

Before evaluating entry surface resolution, perform the distance calibration to avoid misinterpreting an indication of a multiple echo from a discontinuity as the indication of the first echo.

1.8.2.4.1 Definition.

Resolution is the minimum spacing between discontinuities for which separate and distinct ultrasonic echo signals can be obtained. Spatial resolution refers to the lateral separation of discontinuities. Depth resolution, as the name implies, refers to depth separation between internal discontinuities or a discontinuity and a boundary surface. The following procedures are concerned only with entry and back surface resolutions, which are defined as the inspectable distances nearest to the respective surfaces of the test material. Resolution shall be checked when specified and shall meet the minimum requirements as given in Table 1-8. This evaluation requires a reference standard with reference discontinuities at the respective distances from the appropriate surfaces of the standard.

NOTE

The 1 MHz and 15 MHz requirements are applicable only when these frequencies are used; they are not general requirements for all instruments.

Table 1-8. Limits of Boundary Surface Resolution.

Frequency (MHz)	1	2.25	5	10	15
Entry Surface Resolution in Aluminum (inch)	0.5	0.375	0.25	0.125	0.125
Back Surface Resolution in Aluminum (inch)	0.5	0.3	0.2	0.1	0.1

1.8.2.4.2 Checking Resolution with an IIW Block.

When no resolution is specified, the following procedures may be used to check resolution with the IIW block (see Figure 1-13).

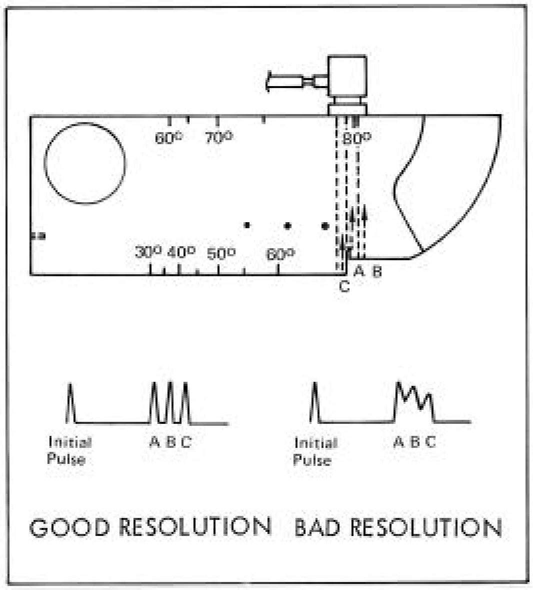


Figure 1-13. Use of an IIW Block to Check Back Surface Resolution.

1.8.2.4.2.1 Back Surface Resolution.

a. Position the search unit on an IIW block, and peak the signal from reflector A.

b. Maximize the separation of the signals from the reflectors A, B and C.

c. Evaluate the resolution by matching the signal patterns. Good resolution is indicated by the respective signals returning to the baseline.

d. If a test system with a 2.25 MHz search unit does not meet these resolution requirements, the search unit and/or cable SHALL be replaced and the resolution checked again. If the inspection system still does not meet the above requirements, the instrument SHALL be repaired or replaced.

1.8.2.4.2.2 Entry Surface Resolution (Dead Zone).

a. Position the search unit on an IIW block at P-1 or P-2 as shown in Figure 1-14. P-1 gives 0.2 inch metal travel distance to the edge of the large hole. P-2 gives 0.4 inch metal travel distance.

b. Maximize the separation between the initial pulse and the hole signal. Evaluate the signal pattern according to the criteria given in Figure 1-14.

c. Check that the hole signal is actually the indication of the first echo from the hole by noting the position of the hole signal on the calibrated distance scale of the waveform display. The distance should be the actual depth of the hole.

d. The first echo from the edge of the hole shall be completely separate from the initial pulse. The initial pulse shall return to the baseline, as shown in the “good” example of Figure 1-14, for the following conditions:

(1) 10 MHz: Good at P-1 and P-2

(2) 5 MHz: Good at P-2

(3) 2.25 MHz: Good at P-2

e. If the first echo from the edge of the hole is not completely separate from the initial pulse as required above, the search unit and/or cable SHALL be replaced and the dead zone checked again. If the inspection system still does not meet the above requirements, the instrument SHALL be repaired or replaced.

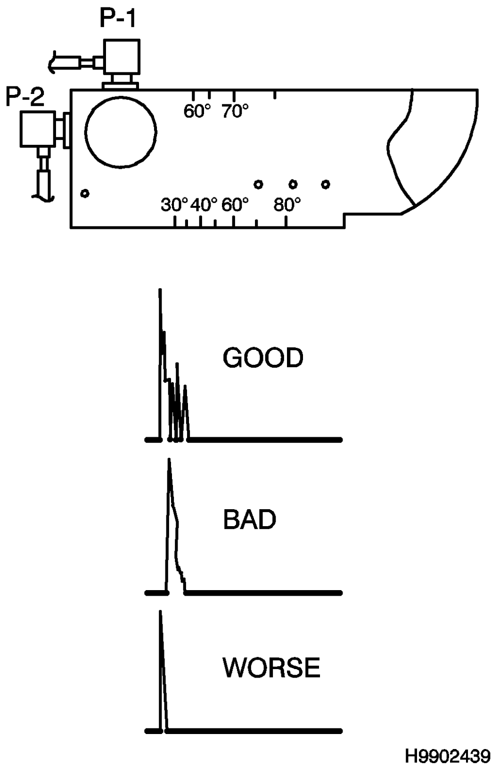


Figure 1-14. Use of IIW Block to Check Entry Surface Resolution

1.8.2.4.3 Checking Entry Surface Resolution with ASTM Blocks.

a. Use an ASTM block with a #5 FBH, or other size if specified. Choose a block with a metal travel distance according to the frequency being used (see Table 1-8).

b. Maximize the separation between the initial pulse and the hole signal.

c. Check that the hole signal is actually the indication of the first echo from the hole by noting the position of the hole signal on the calibrated distance scale of the waveform display. The distance should be the actual depth of the hole.

d. Evaluate the waveform patterns.

1.8.2.5 Distance Calibration of A Scan.

1.8.2.5.1 Straight Beam Distance Calibration for Weld Inspection (IIW Block).

a. Position the search unit on an IIW block at P-1, P-2 or P-3 as shown in Figure 1-15. This distance between multiple back reflections is as follows:

(1) 1.00 inch at P-1

(2) 4.00 inch at P-2

(3) 8.00 inch at P-3

b. Set the time base for the applicable distance calibration. Figure 1-15 shows example CRT displays for various distance calibrations.

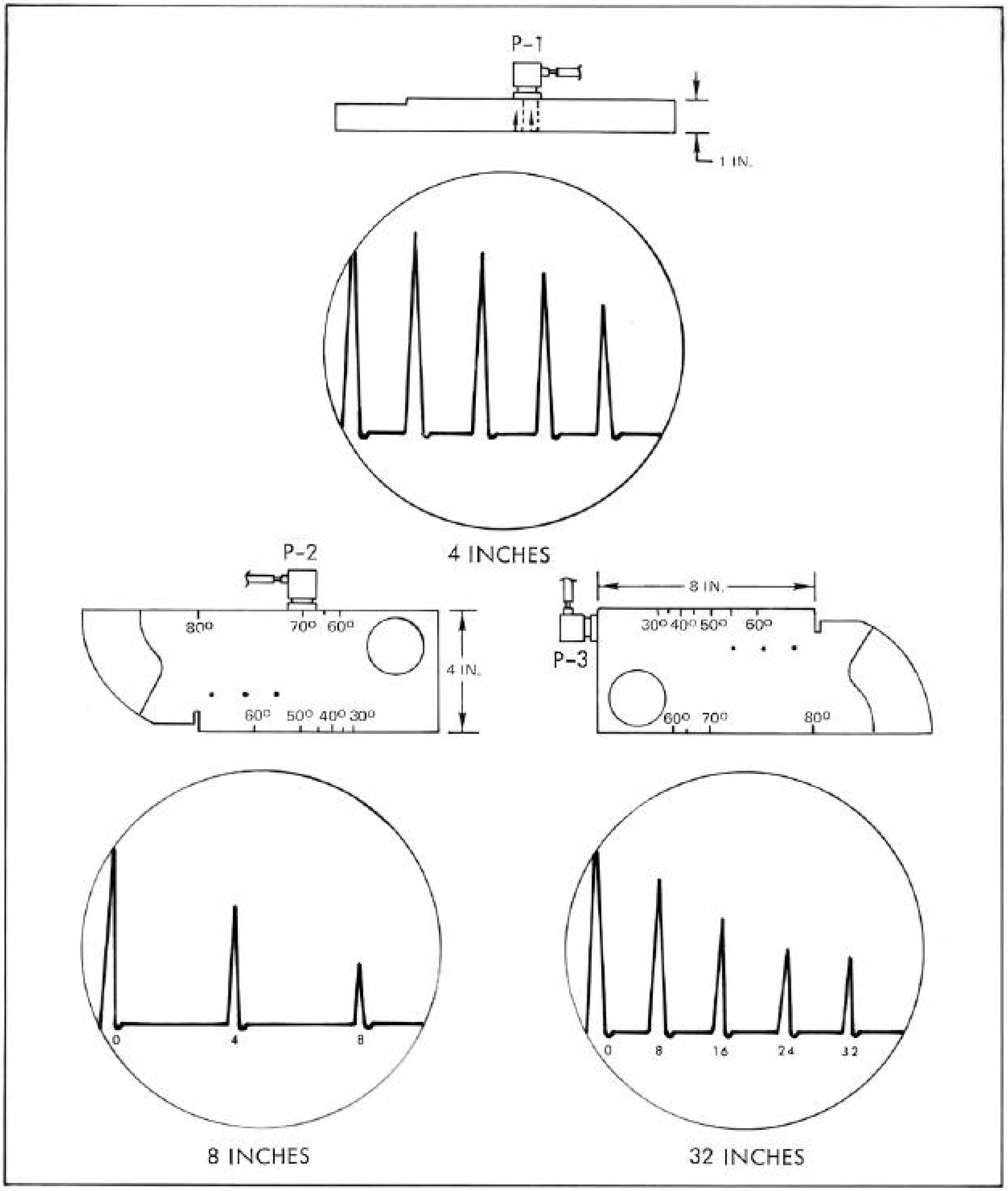


Figure 1-15. Straight Beam Distance Calibration with IIW Block.

1.8.2.5.2 Straight Beam Distance Calibration (Miniature Angle Beam Block).

a. Position the search unit on the miniature block at P-1 or P-2 as shown in. The distance between multiple back reflections is as follows: (see Figure 1-16)

b. Set the time base for the applicable distance calibration.

(1) 0.250 inch at P-1

(2) 1.000 inch at P-2

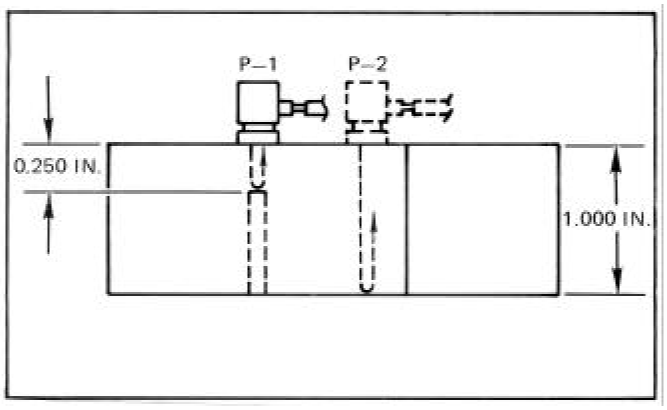


Figure 1-16. Straight Beam Distance with Miniature Angle Beam Block.

1.8.2.5.3 Straight Beam Distance Calibration (ASTM Blocks).

Distance calibration may be performed using multiple reflections from the FBHs or the back surfaces of ASTM blocks. The procedures are identical to the procedures outlined above using the IIW block and the miniature angle beam block.

1.8.2.6 Calibration of Angle Beam Transducers.

NOTE

Do to a problem with the IIW Type 1 and Type 2 aluminum reference blocks, they SHALL NOT be used for determining the point-of-incidence on shear wave search unit having a refracted angle greater than 45° (i.e., 60°, 70°, etc.) Use a steel IIW block instead.

1.8.2.6.1 Angle Beam Point Of Incidence (IIW Block).

The point-of-incidence is defined as the center point of the sound beam exiting the search unit wedge. It is usually indicated by a mark on the side of the wedge at the point where an imaginary line through the exit point of the beam intersects the side of the wedge.

a. Move the search unit back and forth from the curved surface at R-4 (see Figure 1-17) until the peak signal from R-4 is obtained.

b. The search unit point-of-incidence now coincides with the line marked "0" on the block. Mark the point-of-incidence on the side of the search unit.

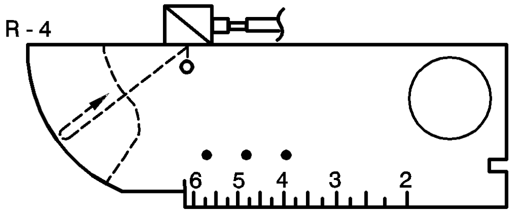


Figure 1-17. Point of Incidence Determination with IIW Block

1.8.2.6.2 Angle Beam Point of Incidence (Miniature Angle Beam Block).

NOTE

> The point-of-incidence as determined in accordance with these procedures may not correspond with the point-of-incidence placed on the search unit by the search unit manufacturer.

a. Move the search unit back and forth from the curved surface at R-2 (see Figure 1-18) the peak signal from R-2 is obtained.

b. The search unit point-of-incidence now coincides with the line marked “0” on the block. Mark the point-of-incidence on the side of the search unit.

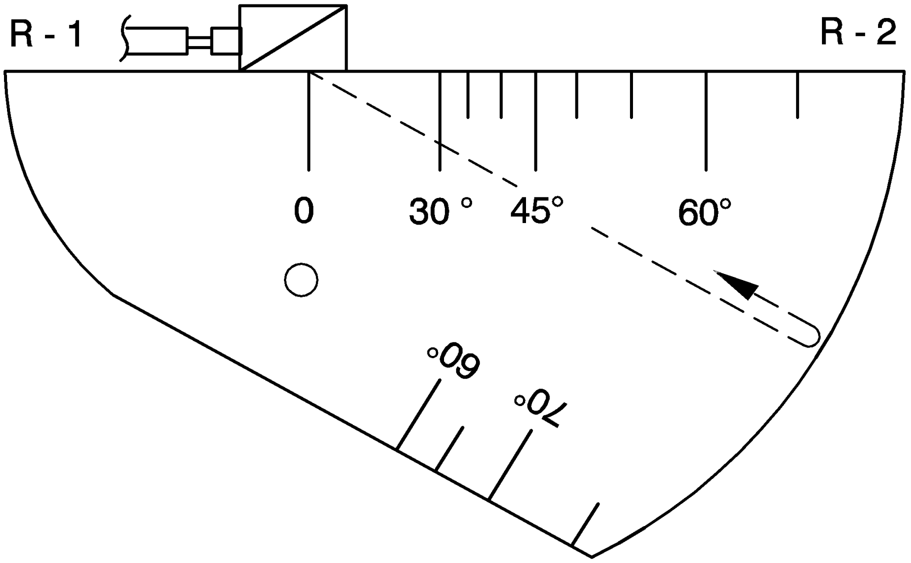


Figure 1-18. Determination of Point of Incidence with Miniature Angle Beam Block

1.8.2.6.3 Angle Beam Angle Determination (IIW Block).

a. Position the search unit on scale “A” or “B” as shown in Figure 1-19. Move the search unit back and forth until the peak signal from the hole is obtained.

b. Read the refracted angle from the position on scale “A” or “B” coinciding with the point-of-incidence. In Figure 1-19, P-1 shows 60°; and P-2 shows 45°.

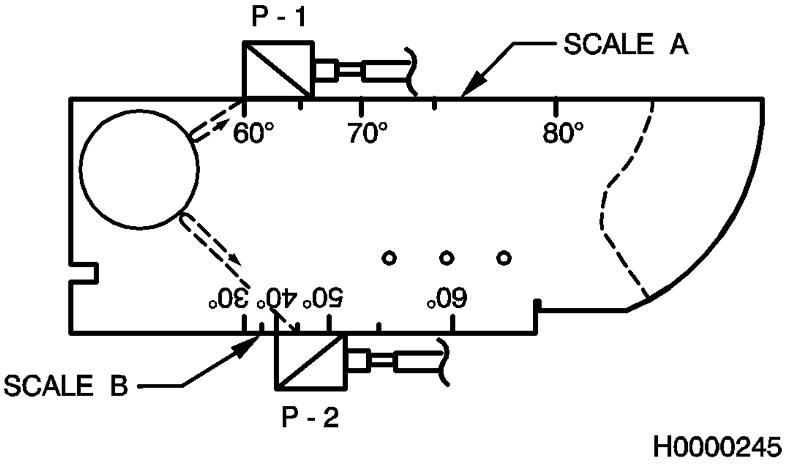


Figure 1-19. Angle Determination with IIW Block

1.8.2.6.4 Angle Beam Angle Determination (Miniature Angle Beam Block).

a. Position the search unit on scale “A” or “B” as shown in Figure 1-22. Move the search unit back and forth until the peak signal from the hole is obtained.

b. Read the refracted angle from the position on scale “A” or “B” coinciding with the point-of-incidence. In Figure 1-22, P-1 shows 45°; and P-2 shows 70°.

c. Angle beam determination can also be done with the miniature angle beam block Figure 1-22.

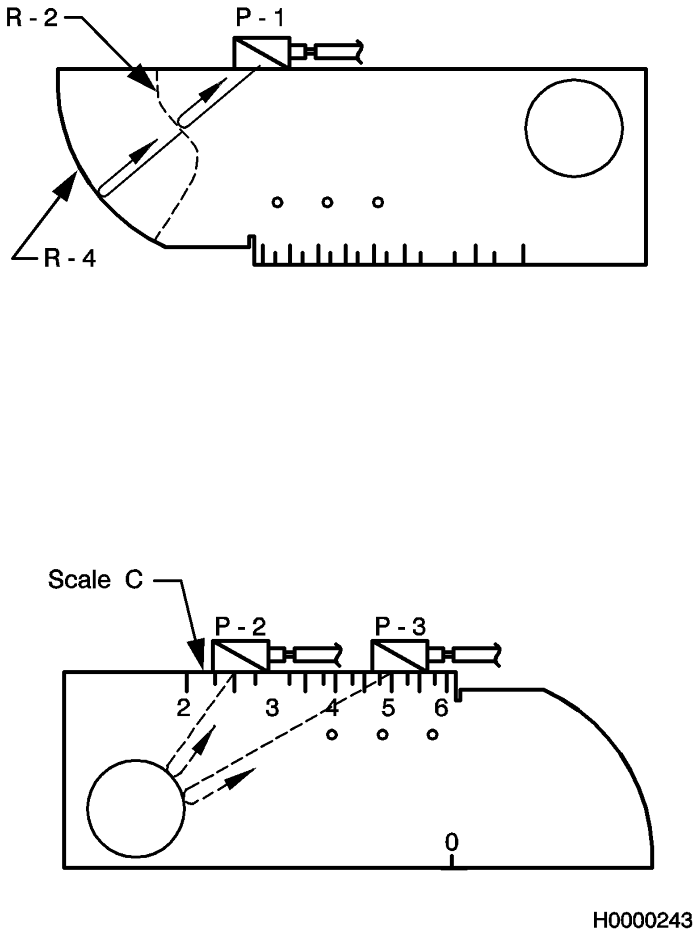


Figure 1-20. Angle Beam Distance Calibration with IIW Block

1.8.2.6.5 Angle Beam Distance Calibration (IIW Block).

The following procedure works only for a 45° angle beam.

a. Position the, search unit at P-1 as shown in Figure 1-20 and adjust the position laterally to obtain equal amplitude signals from R-2 and R-4.

b. The distance between the R-2 and R-4 signals is 2 inches. Set the time base range for the applicable distance calibration.

c. Another method is to position the search unit along scale "C" and obtain a peak signal from the hole as shown in Figure 1-20. Distance is read directly off the scale. P-2 shows 2.5 inches; P-3 shows 5 inches.

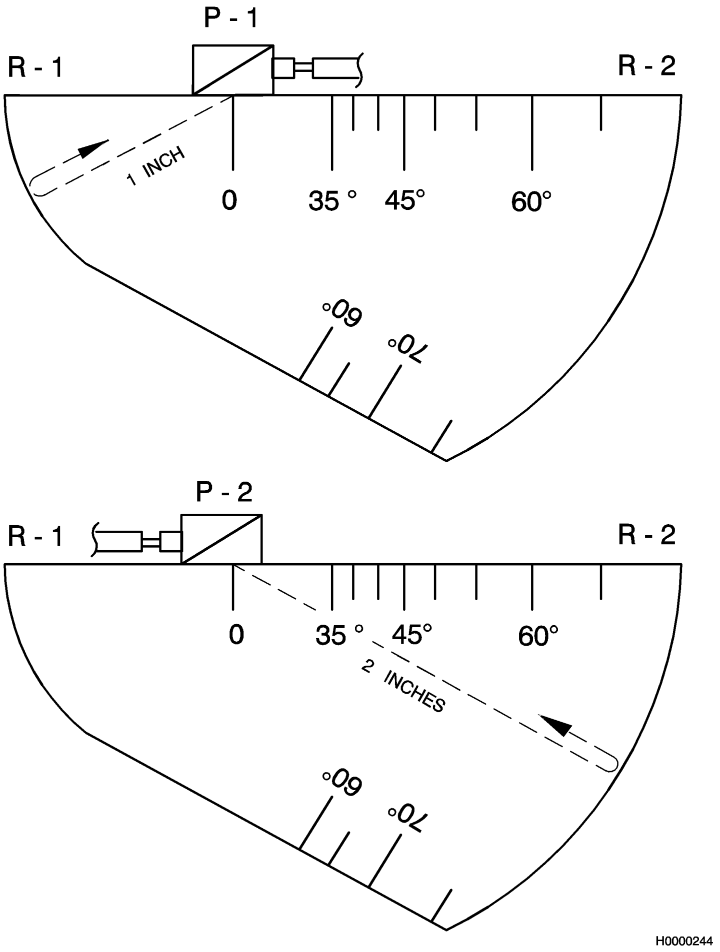


Figure 1-21. Angle Beam Distance Calibration with Miniature Angle Beam Block

1.8.2.6.6 Angle Beam Distance Calibration (Miniature Angle Beam Block).

The following procedure works only for a 45° angle beam.

a. Position the search unit at P-1 and then P-2 as shown in Figure 1-21. Obtain peak signals from R-1 and then from R-2.

b. The angle beam metal travel at P-1 is 1.00 inch; at P-2, it is 2.00 inches. Use multiple back reflections to calibrate longer distances.

CAUTION

Ensure you are using the proper transducer and standard matched for the material you wish to inspect.

EX: A = aluminum transducer
S = steel transducer

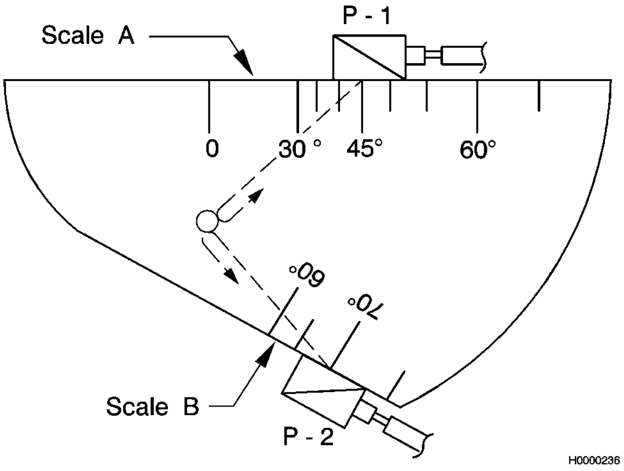


Figure 1-22. Angle Determination with Miniature Angle Beam Block

1.8.2.6.7 Determining Skew Angle.

Skew angle is a measure of the misalignment angle between the ultrasonic beam and the Search units' axis of symmetry (see Figure 1-23).

a. Place the IIW block flat on the side and adjust the Search units to maximize the echo from the other corner of the block (see Figure 1-24). The corner of the block where there are no scale engravings SHALL be used.

b. Place a protractor on the block as shown in Figure 1-24 and measure the skew angle.

c. Alternatively, any reference block having right angled edges and a constant thickness can be used for the skew angle measurement.

1.8.2.6.8 Angle Beam Transducer Parameters.

The angle of incidence and skew angle of NEW and USED ultrasonic transducers SHALL be maintained within two (2) degrees of what is required to perform an ultrasonic inspection. Transducers that do not fall within this parameter SHALL NOT be used to perform ultrasonic inspections. Transducers out of tolerance SHALL be reworked, if possible, to within parameters to extend their usefulness. The rework procedure consists of wet sanding the wear plate/wedge very slowly using 600 grit of finer sandpaper or equivalent emery cloth. Extreme care must be taken, during sanding, not to raise the temperature of the wear plate/wedge. Temperature increases will affect the acoustic impedance of the wear plate/wedge and therefore, the overall transducer sensitivity.

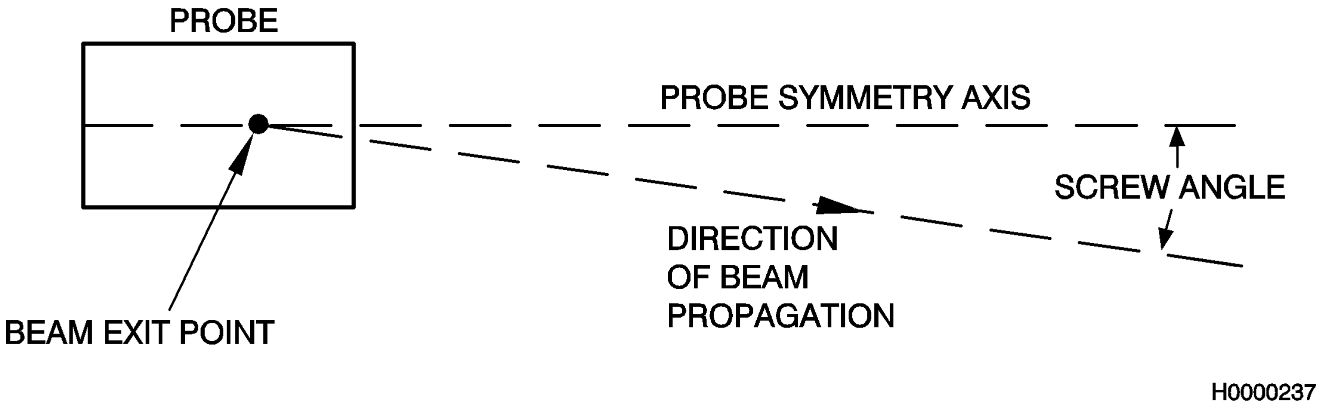


Figure 1-23. Beam Misalignment (Skew Angle)

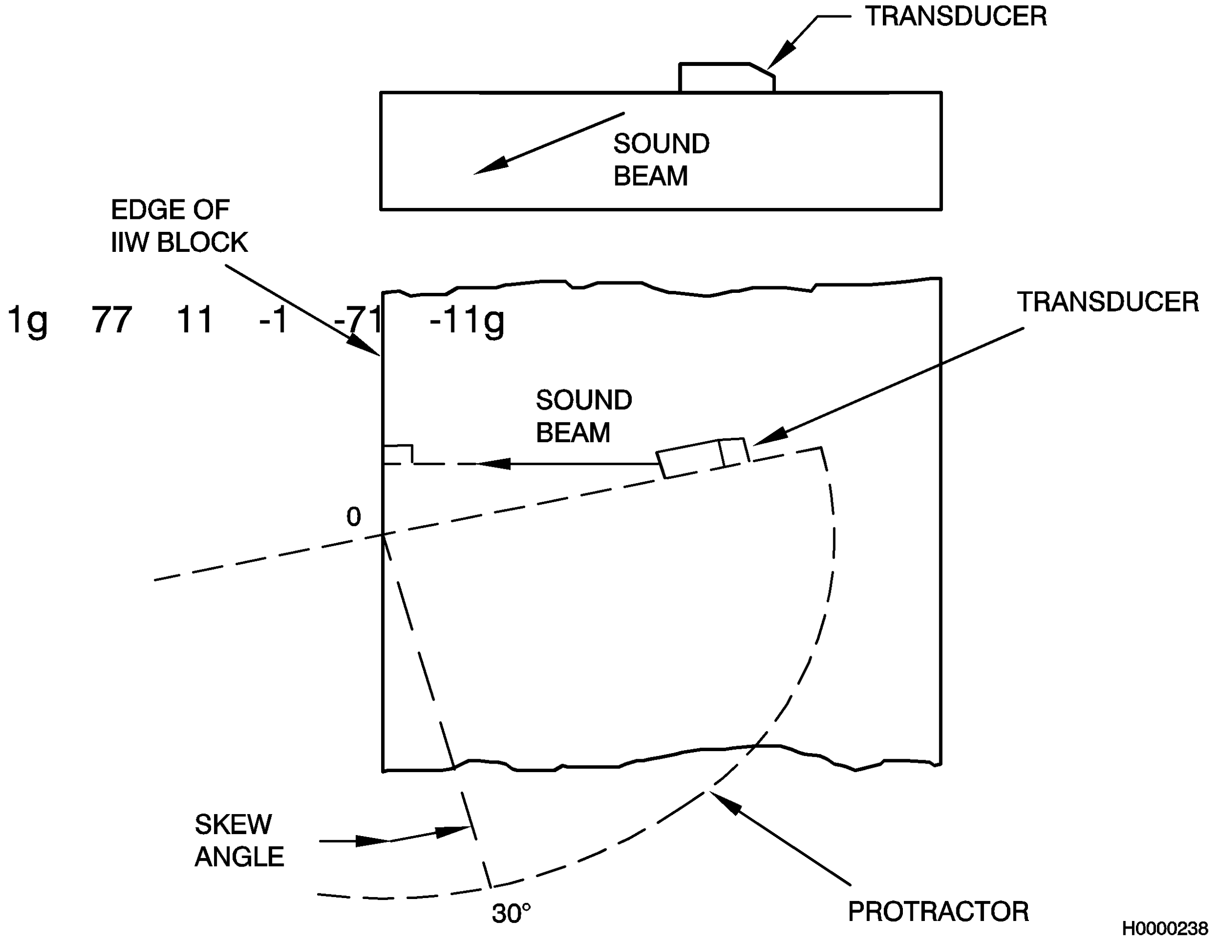


Figure 1-24. Skew Angle Measurement

SECTION IX

RT PROCESS CONTROL

1.9 PROCESS CONTROL FOR RADIOGRAPHY.

1.9.1 Scope and Purpose.

Process control for radiography or other methods of inspection means that all the variables involving, materials, equipment, personnel, and documentation are well-defined and that the features that are significant in terms of process reliability be identified so that controls can be put in place.

1.9.1.1

For radiographic inspection, control features include variations in the radiation source, voltage, current, heat removal, and geometry factors such as focal spot size, shape and location, beam collimation and direction, and source-to-object and source-to-detector distances. Variations can also occur in the object and detector area in terms of the placement of the object (and penetrameters or image quality indicators) and the detector. In the case of film radiography, the storage and handling of the film, screens, and cassettes are an important variables to be brought under control. For the most part control of these variables is dependent on the radiographic inspector and the care the inspector uses in setting up all these features. Good record keeping is important in maintaining reliability.

1.9.1.2

A major variable in the radiographic process is the processing of the film. Concentration of processing chemicals, contaminants, and temperature are important variables. A method of monitoring changes in film processing involves the processing of many control-exposed films periodically to detect changes in film density and/or contrast. This can be implemented by radiographing a step wedge at time zero; this SHALL be at the beginning of each month. The film exposed to all the various gray levels from the step wedge can be cut into strips, each strip to be processed at various times after the identical exposures. For example, strip No. 1 would be processed immediately, as the control film. Densities and contrast between selected steps can be measured with a densitometer. Periodically, once a week, another film strip shall be processed and the densities and contrasts compared to those of the control film. Major variations in the densities of the films should lead to further examination of the film processing procedure. Variations in excess of 0.3 density units from anticipated film density values would be considered a major variation (a factor of 2 in transmitted brightness). Small variations may be tolerated. The experience of several months should provide scatter data that the radiographer will recognize as acceptable. The last strip in the control exposure should be processed with the control film of the new batch to maintain continued control from month to month. In cases where films from one manufacturer are processed in another film manufacturer's recommended solutions, the period between control tests should be shortened.

1.9.1.3

The radiographic inspector should implement the control strip to detect changes in the radiographic process. If the inspector sees to it that the equipment is properly maintained, takes care to use the equipment in a repeatable manner, maintains good records, and maintains the repeatability of film processing, then the radiographic inspection process will remain in good control.

1.9.2 Radiographic Process Control Requirements.

This requirement centers around film processing however the whole x-ray process must be closely controlled to produce the expected results. X-ray is a cure all to the novice, but to the informed it is a very costly and sometime inaccurate NDI method. Every aspect of the x-ray process must be right for the quality and probability of detection to be what we want. X-ray procedures SHALL be followed precisely. Proper beam alignment, the correct film, source focal spot size, and correct exposure parameters are critical. This radiographic process has many factors that effect the quality of the final product. One you must continuously check is the manner in which the film is handled.

1.9.2.1 Process Control in the Darkroom.

For efficiency and reducing the possibility of damaging radiographic film, two distinct areas should be established within the darkroom. One area being designated the “dry area” and the other the “wet area.”

The dry area is where film is unloaded and placed on hangers, prepared to be loaded in the automatic film processor, loaded in cassettes or cut to support special inspections. No liquids or materials that could damage unprotected film should be allowed in this area. The wet area is where development chemicals are mixed, hand development is accomplished and other operations of this nature are performed. Wet hangers and other wet equipment should not be permitted out of this area of the darkroom. These two areas should be physically separated to prevent the wet chemicals, which can cause spots or other artifacts, from being accidentally transferred to the film loading areas. Most dark room equipment such as the processing tanks, dryers, and hangers are manufactured of stainless steel. The fixer solution is particularly corrosive, and most other metals are readily attacked.

1.9.2.2

If possible, the dark room should adjoin the X-ray room or radiographic work area. A film-transfer cabinet should be installed in the separating wall, particularly if a large volume of work is done. Film can be handled efficiently without interfering with darkroom processing. The film-transfer cabinet must be lead lined if it adjoins the X-ray room.

1.9.2.3

Proper ventilation SHALL be provided for the darkroom. The circulation of clean fresh air will reduce fatigue and provide a healthier atmosphere. Light-tight ventilators SHALL be installed, the number depending on the size of the darkroom.

1.9.2.4

Assuming a developing time of 5 minutes, one 5-gallon tank will develop 30 films an hour. The stop bath tank should have a capacity equal to that of the developing tank. The capacity of the fixing bath tank should be double that of the developing tank. The wash tank should hold from 20 to 25 gallons. Install the wash tank so that films are placed in the tank at the outlet end. If dark room volume requirements must be greater, use the above relationships to plan the additional facilities. The finish of the benches, walls and floor adjacent to the tanks must be adequate to protect against the action of chemical solutions and water that may be spilled on them.

1.9.2.5

Film bins are desirable since they are light-tight and close automatically. The boxes of film can be stored here in perfect safety and are readily available. For the mixing of chemicals enamel pails, several funnels and stirring rods must be provided. Where films must be dried rapidly, film drying cabinets are necessary. These dryers should have a filtered air intake, film racks, exhaust fan and heating element. It is best to wire the fan and heating elements on the same circuit so the heating element cannot be turned on without the fan.

1.9.2.6

To minimize the fogging of undeveloped radiographic film by the safelights in the darkroom the following provisions apply:

a. General illumination should be indirect.

b. Safelights should be suspended from be ceiling and SHALL be at least four feet from undeveloped/ exposed film.

c. The ceiling should be white with the walls a light color.

d. Only the minimum level of safelight needed to perform darkroom operations SHALL be allowed.

e. Only safelight filters (6B or equivalent) designated for use with industrial radiographic film SHALL be allowed.

f. The manufacturer’s recommended bulb wattage SHALL not be exceeded.

1.9.2.7

NOTE

It is extremely important that the film used for these tests never be exposed to safelight prior to the test. Therefore, if a film cassette is used, it SHALL be loaded in total darkness.

Safelights for darkroom operation, contrary to their name, contribute to unwanted densities (fog) on radiographic film. To overcome this problem, the length of time that undeveloped industrial radiographic film can safely be exposed to the level of safelight within a specific darkroom SHALL be determined. This time period is much shorter for exposed film than for unexposed. The reason for this time difference is that exposed film is approximately five times more susceptible to fog caused by safelight than film that is unexposed. The safelight fog evaluation procedure consists of two tests, the individual safelight test and the collective safelight test. These tests have a requirement to be performed separately or jointly depending upon the circumstances. The circumstances when both tests SHALL be performed are: 1) initial safelight evaluation for in-use or new darkroom facility and 2) when the periodic collective safelight tests results are unacceptable. The circumstances when the individual safelight test SHALL be performed on a single or, if the requirement dictates, all safelights are: 1) initial test, which includes all safelights; 2) a newly installed fight; 3) if any changes are made to existing lights such as bulbs, filters, position, and reflecting versus direct light function; 4) whenever filters are suspect of fading and to determine the adverse effects of crazing, scratches, and cracks; or 5) whenever a light is suspect of producing excessive safelight fog. The circumstances when the collective safelight test SHALL be performed are: 1) during the periodic requirement (safelights filters deteriorate with use. The rate of deterioration is dependent on their age, amount of use and amount of heat generated by its bulb. Therefore, a periodic test schedule SHALL be established to collectively test safelights for film fog, dependent upon their use. This test cycle SHALL not exceed one year); 2) repositioning of safelights; 3) reestablishing undeveloped film handling area; and 4) installing additional safelights. The materials and procedure that SHALL be used to establish the maximum safelight exposure period is as follows:

a. For the initial safelight evaluation radiographically expose an individual sheet of Class 4 radiographic film for each safelight that is in the dark room plus an additional sheet to approximately a 1.5 (± 0.2) HD units overall constant density. For example, if there are three safelights in the darkroom expose four separate sheets of film individually. In the case where only the individual safelight test is being performed, only radiographically expose the number of films that correspond to the number of safelights that are to be tested. If only the collective test is to be performed only radiographically expose one film. Each film that is radiographically exposed, to perform the individual or collective safelight tests, SHALL be identified so as to identify the specific safelight it was used to test or if it was used to perform the collective safelight test.

b. To perform the individual safelight test, turn off, or remove, the bulbs from all the safelights with the exception of the safelight to be tested. During the initial safelight evaluation each safelight SHALL be tested individually and collectively.

c. Turn off the safelight to be tested and ensure the darkroom is void of all ambient light.

d. While all safelights are off, and in total darkness, remove the radiographically exposed film from its envelope/cassette. Position the exposed film in direct line and perpendicular with the safelight's filter, at a maximum distance of four feet unless the distance between the normal working level and safelight is greater than four feet, in which case the test film should be placed at this measurement.

e. Cover the entire test film with an opaque Material, such as cardboard.

f. Turn-on the safelight to be tested.

g. Expose equal sections of the radiographically exposed test film to the safelight by sliding the opaque material the length of the film in 6 minute, 3 minute, 1 minute, 30 seconds, 15 seconds, 0 second time intervals, (leaving the last section unexposed to the safelight). This will result in six test film sections, each with a different safelight exposure consisting of the following: 10 minutes and 45 seconds, 4 minutes and 45 seconds, 1 minute and 45 seconds, 45 seconds, 15 seconds and 0 seconds.

h. Cover the entire test film with the opaque material, taking care not to lift the mask off of the test film, as this would result in the 0 second section being exposed to the safelight.

i. Turn off the safelight being tested.

j. Develop the film as you would normally, with the exception of it being performed in total darkness.

k. Repeat the individual safelight test procedure for each safelight, if required. Great care must be taken not to unintentionally expose test film to safelight. Undeveloped test film SHALL be maintained in a light tight container prior to it being developed and not being used to perform a safelight test.

l. Upon completing the initial individual safelight test for each safelight, perform the collective safelight test. The initial and periodic collective safelight test is similar to the individual safelight test with the exception of the following:

    (1) All safelights SHALL be turned-on during the safelight time interval exposures.

    (2) The radiographically exposed test film SHALL, be positioned in the usual area where normal undeveloped radiographically exposed film is handled. This area SHALL NOT be less than four feet from any safelight source.

m. After all test films have been developed in total darkness, read the densities of the five safelight exposed sections comparing them to the sixth section on their respective test film. The section with the least amount of safelight exposure that has a measurable density increase is the maximum time that an undeveloped radiographic film SHALL be allowed to be exposed to safelight in the darkroom.

n. If this time restriction is 4 minutes and 45 seconds or less, or not suitable for operational needs, one or more of the following actions SHALL be taken:

    (1) Replace safelight filters that are faded, cracked, are not designated for industrial radiographic film, crazed, do not fit properly, or scratched.

    (2) Replace safelight bulbs that exceed the wattage recommended by the manufacturer.

    (3) Replace safelights that are unserviceable, such as emitting ambient light.

    (4) Eliminate or reconfigure uncontrollable ambient light sources such as doorways, ventilating and heating ducts/vents, faulty film pass through box, building structural cracks, and holes around pipes and electrical wiring.

    (5) In the event that the individual safelight tests are all within an acceptable tolerance, but the collective safelight test is unacceptable, investigate, the validity of the individual safelight test and when, in fact, the results of these tests are correct, reduce the number of safelights in the darkroom. The level of safelight that SHALL be present is the minimum required to perform undeveloped film preparation/ development operations.

1.9.2.8
During the development and preparing of uncovered, undeveloped radiographic film, ambient light SHALL NOT exist in the darkroom.

CHAPTER 2
SECTION I
INTRODUCTION TO LIQUID PENETRANT INSPECTION

2 LIQUID PENETRANT INSPECTION.

2.1 INTRODUCTION.

Penetrant is used to detect discontinuities, i.e., cracks, pits, etc., open to the surface on parts made of nonporous materials. This method depends on the ability of the penetrant to enter into a surface discontinuity in the material to which it is applied.

2.1.1 GENERAL.

a. Due to its ability to inspect ferrous and nonferrous parts of all sizes and shapes, and its portability, the liquid penetrant NDI method can be used at both depot and at field repair stations. For a specific aircraft type, a technical manual on nondestructive inspection is used to define the method, technique, equipment preparation, and precautions required to perform NDI on each component of the aircraft. A separate manual is used for engines.

b. With wider use of the eddy current NDI method, liquid penetrant, long a primary NDI method, is now becoming the secondary method for many applications. This is a result of the improved sensitivity of new eddy current inspection techniques and the fact that eddy current does not require use and disposal of potentially hazardous chemicals. For batch inspection of large areas, the penetrant method is still preferred due to the shorter total process time when compared to eddy current.

2.1.2 Summary.

This section contains introductory information for management, supervisors, and non-NDI personnel. The information can also be used in the indoctrination training of beginning NDI personnel. The section provides background information and outlines the basic penetrant process. It describes the purpose and some reasons for selecting the penetrant inspection methods. Personnel qualification requirements for performing penetrant inspections are also discussed. Penetrant test equipment is briefly discussed in general terms. The capabilities/advantages and limitations/disadvantages of the process are also discussed.

2.1.3 Background.

a. Liquid penetrant inspection is one of the oldest of modern nondestructive inspection methods. It began in the railroad maintenance shops in the late 1800s. Parts to be inspected were immersed in used machine oil. After a suitable immersion time, the parts were withdrawn from the oil and the excess surface oil wiped off with rags or wadding. The part surfaces would then be coated with powdered chalk or a mixture of chalk suspended in alcohol (whiting). Oil trapped in cracks or flaws would bleed-out causing a noticeable stain in the white chalk coating. This became known as the oil-and-whiting method.

b. The oil-and-whiting method was replaced by magnetic particle inspection on steel and ferrous parts in 1930. However, industries using non-ferromagnetic metals, especially aircraft manufacturers, needed a more reliable and sophisticated tool than discolored machine oil and chalk. In 1941, fluorescent dye materials were added to highly penetrating oil to make a penetrant material. Colored dyes, primarily red, were produced a little later. Since then, a large number of penetrant systems or families have evolved. These include developments in the following: various types and concentrations of dye materials; types of penetrating oils and additives; materials and methods for removing the excess surface penetrant; and various materials and forms of developing agents.

2.1.4 Capabilities of Penetrant Inspection.

Penetrant inspection is an inexpensive and reliable nondestructive inspection method for detecting discontinuities that are open to the surface of the item to be inspected. It can be used on metals and other nonporous materials that are not attacked by penetrant materials. With the proper technique, it will detect a wide variety of discontinuities ranging in size from readily visible flaws down to the microscopic level, as long as the discontinuities are open to the surface and are sufficiently free of foreign material.

2.1.5 Basic Penetrant Process.

The basic fundamentals of the penetrant process have not changed from the oil-and-whiting days. The following provides a simplified description of the fundamentals. More explicit process details are discussed in subsequent sections. Figure 2-1 illustrates the basic principles of the penetrant inspection process.

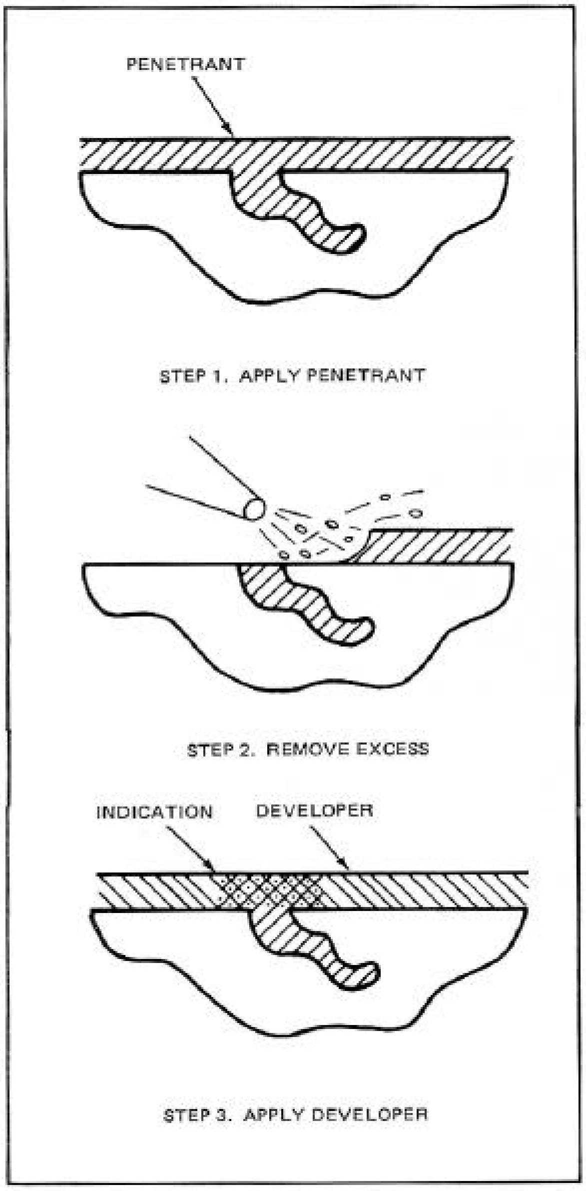


Figure 2-1. Basic Penetrant Inspection Process.

a. In Step 1, Cleaning is a critical part of the penetrant process and is emphasized because of its effect on the inspection results. Contaminants, soils or moisture, either inside the flaw or on the part surface at the flaw opening, can reduce the effectiveness of the inspection.

b. In Step 2, a penetrating liquid containing dye is applied to the surface of a clean part to be inspected. The penetrant is allowed to remain on the part surface for a period of time to allow it to enter and fill any openings or discontinuities open to the surface.

c. After a suitable dwell period, the penetrant is removed from the part surface, in Step 3. Care must be exercised to prevent removal of penetrant contained in discontinuities.

d. A material called a developer is then applied (Step 4). The developer aids in drawing any trapped penetrant from discontinuities and improves the visibility of indications.

e. The final process step (Step 5) is a visual inspection under appropriate lighting conditions to identify relevant indications.

2.1.6 Leak Detection.

Penetrant is also used to detect leaks in containers. The same basic fundamentals apply but the penetrant removal step may be omitted. The container is either filled with penetrant or the penetrant is applied to one side of the container wall. The developer is applied to the opposite side, which is visually inspected after allowing time for the penetrant to seep through any leak points. This method may be used on thin parts where there is access to both surfaces and the discontinuity is expected to extend through the material.

2.1.7 Personnel Requirements.

The apparent simplicity of the penetrant inspection is deceptive. Very slight variations in performing the inspection process can invalidate the inspection by failing to indicate serious flaws. It is essential that personnel performing penetrant inspection be trained and experienced in the penetrant process. All individuals who apply penetrant materials or examine components for penetrant indications shall be qualified as specified in Chapter 1, Section 1.2.

2.1.8 Equipment Requirements.

The equipment used in the penetrant inspection process varies from aerosol spray cans to complex automated systems. Some of the more generally used types of equipment are briefly described in the following paragraphs.

2.1.8.1 Portable Equipment.

Penetrant inspection can be performed on installed parts (e.g., on aircraft) or on parts too large to be brought to the inspection area. Penetrant materials are available in aerosol spray cans and in small containers for brush or wipe applications. Generally, portable penetrant applications are limited to localized area or spot inspections rather than entire part surfaces.

2.1.8.2 Stationary Inspection Equipment.

The type of equipment most frequently used in fixed installations consists of a series of modular workstations. At each station an inspector performs a specific task. The number of stations in a processing line varies with the type of penetrant method used. Typical stations are: dip tanks for penetrant, remover or emulsifier, and developer; drain or dwell areas; a spray wash area with a black light; a drying oven; and an inspection booth. The drain or dwell stations are roller top benches to hold the parts during the processing cycle. The usual arrangement is to position a drain or dwell station following each of the dip tanks, the wash station and the drying oven.

2.1.8.3 Small Parts Inspection Unit.

There are inspection units designed for processing small parts. The units are smaller than the general systems described in paragraph 2.1.8.2, and some of the stations serve multiple purposes. In use, the parts are loaded into wire baskets that are then batch processed through each of the stations. The wash station may contain a water-driven, rotary table with spray jets to supplement the hand held spray wand. Figure 2-2 shows a small part inspection unit.

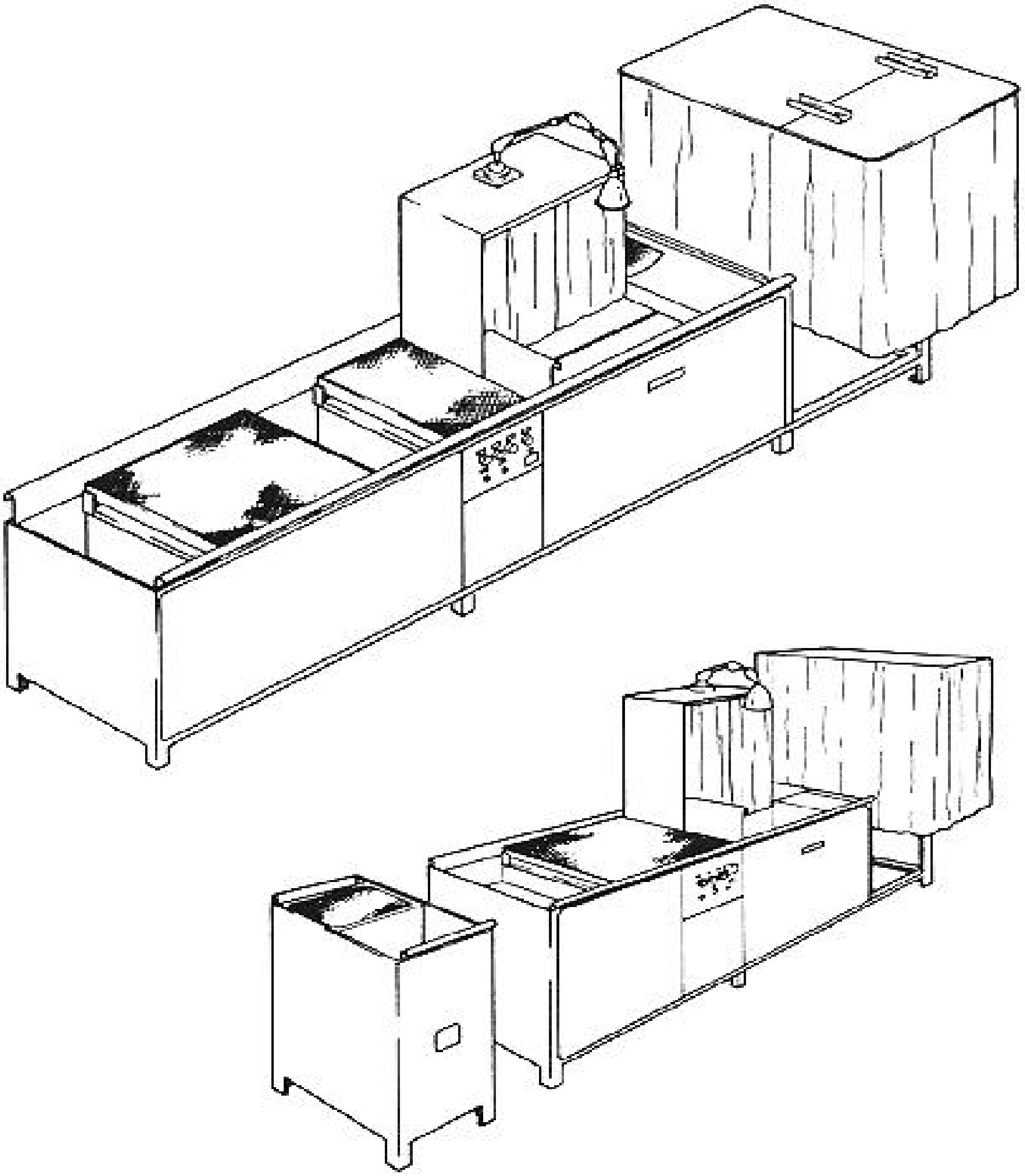


Figure 2-2. Typical Small Parts Inspection Units.

2.1.8.4 Automated Inspection Systems.

The penetrant inspection process can be adapted for use with semi and fully automated processing equipment. Semi-automated systems consist of a conveyor belt or table for moving the parts through one or more of the processing steps. Applications of penetrant, emulsifier or remover, rinse, or developer are manually performed. In fully automated systems, all of the processing steps are mechanically performed without an operator. Automated equipment allows large numbers of parts to be rapidly processed with a minimum of personnel and time. Automated equipment also provides a more uniform, though not necessarily more sensitive, testing process. The inspection interpretation can be performed manually, semi or fully automated.

2.1.9 Advantages and Capabilities of Liquid Penetrant Inspection.

a. Liquid penetrant inspection is capable of examining all of the exterior surfaces of objects. Complex shapes can be immersed or sprayed with penetrant to provide complete surface coverage. Other nondestructive methods cover a specific area or location and must then be repeated to cover other areas or locations.

b. Liquid penetrant inspection is capable of detecting very small, surface discontinuities. It is one of the more sensitive nondestructive inspection methods for detecting surface flaws.

c. Liquid penetrant inspection can be used on a wide variety of materials: ferrous and nonferrous metals and alloys, fired ceramics, powdered-metal products, glass, and some types of organic materials. Restrictions of the penetrant application are listed in paragraph 2.1.11.

d. Liquid penetrant inspection can be accomplished with relatively inexpensive, non-sophisticated equipment. If the area to be inspected is small, the inspection can be accomplished with portable equipment.

e. Liquid penetrant inspection magnifies the apparent size of discontinuities making the indications more visible. In addition, the discontinuity location, orientation, and approximate length are indicated on the part, making interpretation and evaluation possible.

f. Liquid penetrant inspection is readily adapted to volume processing permitting 100 percent surface inspection. Small parts may be placed in baskets for batch processing. Specialized systems may be semi- or fully automated to process as many parts per hour as required.

g. The sensitivity of a penetrant inspection process may be adjusted through selection of materials and technique. This allows suppression of indications from small, inconsequential discontinuities while indicating larger discontinuities of more concern. Figure 2-3 shows indications from two penetrant inspection processes of different sensitivity levels.

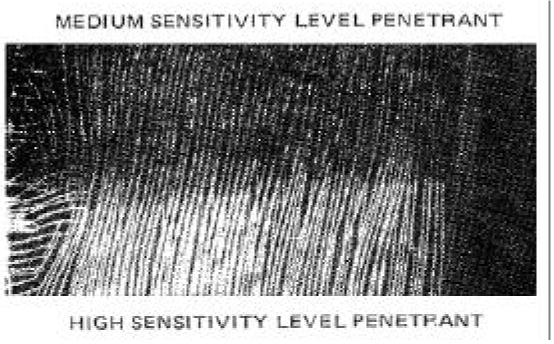


Figure 2-3. Cracked, Brittle Iron-Plated Coupon Showing the Inspection Results from Two Fluorescent Penetrant Inspection Processes of Different Sensitivities.

2.1.10 Disadvantages and Limitations of Liquid Penetrant Inspection.

WARNING

Penetrants, emulsifiers, and some types of developers have very good wetting and detergent properties. They can act as solvents for fats and oils. If they are allowed to remain in contact with body surfaces for extended periods, they may cause skin irritation.

Some penetrant materials contain volatile solvents that can be nauseating. This is especially true of the vehicles in aerosol or pressure spray cans. Recommendations of the Base Bioenvironmental Engineer and the manufacturer regarding necessary personnel protective equipment SHALL be followed when using such materials. Always use adequate ventilation, as determined by the Base Bioenvironmental Engineer, to remove noticeable vapor concentrations in confined areas.

CAUTION

Many penetrant materials are combustible, but most have relatively high flash points. They are not considered a serious fire hazard in open tanks. However, when sprayed as a fine mist, they are easy to ignite and open ignition sources must be avoided when spraying is used.

NOTE

Although advantages/disadvantages may appear straightforward, the decision to select the penetrant test method or any other NDI method is often not straightforward and depends upon a large number of factors. A thorough knowledge of the capabilities and limitations of all nondestructive inspection methods is required. Whenever possible, the decision on which method to use should be referred to the cognizant NDI engineering activity.

a. Penetrant inspection depends upon the ability of the penetrating media to enter and fill discontinuities. Penetrant inspection will only reveal discontinuities that are open to the surface.

b. The surfaces of objects to be inspected must be clean and free of organic or inorganic contaminants that will prevent the action of the penetrating media. It is also essential that the inside surface of the discontinuities be free of materials such as corrosion, combustion products, or other contaminant that would restrict the entry of penetrant.

c. Penetrants are usually oily materials with strong solvent powers and highly concentrated dyes. They will attack some non-metallic materials such as rubber and plastics. There is also the possibility of permanent staining of porous or coated materials.

d. Some penetrant materials may contain either or both sulfur and halogen compounds (chlorides, fluorides, bromides, and iodides). These compounds can cause embrittlement or cracking of austenitic stainless steels if not completely removed prior to heat treating or other high temperature exposure. Entrapped halogen compounds may also cause corrosion of titanium alloys if not completely removed after the inspection is completed and the part is subjected to elevated temperatures.

e. Most penetrant materials are oily in nature. Therefore, they must not be used on parts such as assemblies where they cannot be completely removed and will subsequently come in contact with gaseous or liquid oxygen. Oils, even residual quantities, tend to explode or burn very rapidly in the presence of oxygen. There are special oxygen compatible materials that SHALL be used if penetrant inspection is required and complete removal of the residue is not possible.

2.1.11 Limitations on Applications of Penetrant Inspection.

2.1.11.1 Flaw Location.

Penetrant inspection is applicable to all solid, nonporous materials. The discontinuities must be open to the surface of the part. If subsurface discontinuities must be detected, another inspection method must be used.

2.1.11.2 Restricted Flaw Openings.

The penetrant inspection process depends upon the ability of the penetrant to enter and exit the flaw opening. Any factor that interferes with the entry or exit reduces the effectiveness of the inspection. Organic surface coatings, such as paint, oil, grease, or resin, are in this category. Any coating that covers or blocks the discontinuity opening will prevent penetrant entry. Even when the coating does not cover the opening, the material at the edge of the opening may affect the entry or exit of the penetrant and greatly reduce the reliability of the inspection. Coatings at the edge of a discontinuity will also retain penetrant, causing background indications. An inspection method other than penetrant SHALL be used if the organic coating cannot be stripped or removed from the surface to be inspected.

2.1.11.3 Smeared Metal.

NOTE

NAVY REQUIREMENT: PMB shall not precede liquid penetrant inspection unless effective chemical etching is performed or unless specifically authorized without etching.

Mechanical operations, such as shot peening, plastic media blasting (PMB), machine honing, abrasive blasting, buffing, brushing, grinding and sanding may smear or peen the surface of metals. This mechanical working closes or reduces the surface opening of any existing discontinuities. Mechanical working (smearing or peening) also occurs during service when parts contact or rub together. Penetrant inspection may not reliably detect discontinuities when it is performed after a mechanical operation or service use that smears or peens the surface.

2.1.11.4 Porous Surfaces.

Penetrant inspection is impractical on porous materials, such as some types of anodized aluminum surfaces, and other protective coatings on other metals. The penetrant rapidly enters the pores of the material and becomes trapped. This can result in background fluorescence or color that would reduce contrast or mask any potential discontinuity indications. In addition, removal of the penetrant may not be possible after the inspection.

SECTION II

BASIC PENETRANT PROCESS

2.2 BASIC PENETRANT PROCESS.

2.2.1 Summary.

a. Removal, developers, process sensitivity, and general process steps are discussed. The advantages and disadvantages of the various penetrant processes are discussed. The various specifications and classifications which control the application of the penetrant process are also reviewed.

b. The information in this section is a brief non-technical description of penetrant and general process steps. It is intended as introductory material for management, supervisors, and other personnel who are required to know the general applications and classifications of penetrants but do not require detailed NDI information. It can also be used in the training of beginning NDI personnel. Detailed, technical information on penetrant materials and application processes is provided in subsequent sections.

2.2.2 Types of Penetrant.

2.2.2.1 General.

The penetrant inspection process detects discontinuities open to the inspection surface by trapping a very small amount of the penetrant. If a discontinuity is to be detected, the very small amount of penetrant must be highly visible. In the oil-and-whiting days, it was found that used or dirty oil was much more visible than clean machine oil. Present penetrants obtain visibility by having highly colored dyes dissolved in the penetrating vehicle or oil. The type of dye materials provides one means of classifying penetrants.

2.2.2.2 Visible Penetrant.

CAUTION

DOD prohibits the use of visible-dye penetrant on aircraft, engines and missiles, except for those parts with specific engineering approval.

Visible-dye or color-contrast penetrants contain a red dye dissolved in the penetrating oil. The visibility is further enhanced during the penetrant process by the application of a layer of white developer. The white developer provides a high contrast background for the bright red penetrant when viewed under natural or white light.

2.2.2.3 Fluorescent Penetrant.

CAUTION

DOD prohibits the use of water washable dye penetrant on aircraft, engines, and missiles, except for those parts with specific engineering approval.

Some chemical compounds have the capability of emitting visible light when exposed to near-ultraviolet light (UV-A, energy with a wavelength of 320 to 400 nanometers), commonly called black light. This property is termed fluorescence, and the materials are called fluorescent (see paragraph 2.4.4.2.6). Very small quantities of fluorescent penetrant will emit highly visible indications when exposed to black light.

2.2.2.4 Dual Mode (Both Visible and Fluorescent) Penetrant.

CAUTION

DOD prohibits the use of visible / fluorescent (dual mode) penetrant on aircraft, engines, and missiles, except for those parts with specific engineering approval.

Dual mode penetrants contain dye materials that are reddish in color under white light and fluorescent under black light. However, the intensities of the visible red color and the fluorescent color (usually orange) are less than the individual visible dye and fluorescent penetrants. The brilliance of the visible color and brightness of fluorescence are less than that obtained with the single mode visible-dye and fluorescent-dye penetrants respectively.

2.2.3 Methods of Penetrant Removal.

2.2.3.1 General.

Penetrant materials are manufactured or formulated for specific removal methods. The removal method provides another means of classifying penetrant materials. Each removal method has advantages and disadvantages, which are covered in later paragraphs.

2.2.3.2 Water Washable.

The usual liquid base or vehicle for a penetrant is petroleum oil, which is insoluble or immiscible in water. This means that the penetrant cannot be removed with water. However, there are chemical compounds called emulsifiers that can mix with oil vehicles to form a mixture that can be removed with water. When emulsified, the oil-based penetrant then can be removed with water. The chemical compound forming the emulsifiable mixture is called an emulsifying agent or an emulsifier. Water-washable penetrants contain an integral emulsifying agent when received from the manufacturer. This permits direct removal by water immediately after the penetrant dwell.

2.2.3.3 Postemulsifiable, Lipophilic Method.

Penetrants used in the postemulsifiable, lipophilic method are formulated to optimize their penetrating and visibility characteristics. They do not contain any emulsifying agent and cannot be completely removed with plain water. Removal is made possible by applying an emulsifier in a separate process step. This converts the excess surface penetrant into an emulsifiable mixture that can be removed with water. (See paragraph 2.5.5.3).

2.2.3.4 Solvent Removable.

WARNING

Solvents used may contain aromatic, aliphatic, or halogenated compounds. Aromatic compounds are characterized by a strange aroma and are formed from hydrocarbons and benzene. Aliphatic compounds are derived from fat; paraffin is an example. Halogenated compounds are materials in combination with the halogens fluorine and/or chlorine. Many solvents are highly flammable while others may decompose at elevated temperatures. Keep all solvents away from heat and open flame. Vapors may be harmful. Use adequate ventilation. Avoid contact with skin and eyes. Do not take internally.

The term "Solvent Removable" applies to the process rather than the penetrant material, since all penetrants can be removed with solvents. Usually the penetrants used in the solvent removable process are the postemulsifiable penetrants; however, water washable penetrants can also be used.

2.2.3.5 Postemulsifiable, Hydrophilic Method.

The postemulsifiable, hydrophilic method also uses penetrants requiring a separate emulsifier. The penetrants are the same as those used in the lipophilic method. The difference between hydrophilic and lipophilic methods is in the emulsifiers. Hydrophilic emulsifiers are water soluble emulsifiers and actually remove excess surface penetrant by means of a detergent action rather than an emulsification action. (See paragraph 2.5.5.4).

2.2.4 Developers.

2.2.4.1 Forms Of Developer.

There are four forms of developers in general use:

a. Dry powder

b. Water soluble

c. Water suspendible

d. Nonaqueous

2.2.4.2 Developer Application.

There are several methods of applying each form of developer, e.g., immersion, fog, air bath, electrostatic and pressure spray.

2.2.5 Classification Of Penetrant Materials And Processes.

2.2.5.1 ASM 2644 -Categories.

In ASM 2644, penetrant materials have been classified under several headings (See Table 2-1):

a. Type of penetrant (fluorescent or visible dye).

b. Method of removing excess surface penetrant.

c. Sensitivity Level of a penetrant system.

d. Form of developer.

e. Class of solvent remover.

NOTE

Form designations reflect ASM 2644, which has superseded MIL-25135. ASTM E 1417-95a did not reflect this change at the time of publication. The Specific Application categories in Table 2-1 for nonaqueous developers and solvent removers allow a manufacturer the opportunity to optimize the formulation of these products for one of their own specific penetrant systems or for a specific user need.

Table 2-1. Classification of Penetrant Materials Contained in ASM 2644.

Type	
Type I	Fluorescent Dye
Type II	Visible Dye
Type III	Dual Mode (Visible and Fluorescent Dye)
Method	
Method A	Water Washable
Method B	Postemulsifiable, Lipophilic
Method C	Solvent Removable
Method D	Postemulsifiable, Hydrophilic
Sensitivity Level	
Level ½	Very Low
Level 1	Low
Level 2	Medium
Level 3	High
Level 4	Ultra High
Developer	
Form a	Dry Powder
Form b	Water Soluble
Form c	Water Suspendible
* Form d	Nonaqueous (Wet; for Type I)
* Form e	Nonaqueous (Wet; for Type II)
* Form f	Specific Application
Solvent Remover	
Class 1	Halogenated
Class 2	Nonhalogenated
Class 3	Specific Application

2.2.5.2 Classifications in Other Documents.
The ASM 2644 classifications are referenced in process standard ASTM E 1417 (latest version), the American Society for Testing and Materials (ASTM) *Practice for Liquid Penetrant Examination*. The Type and Method classifications

and the descriptions of the first four kinds of developers are referenced in ASTM E 165, *Standard Test Method for Liquid Penetrant Examination*. The MIL-I-25135 has been superseded by an Aerospace Material Specification (AMS) 2644.

2.2.5.3 Penetrant System.

CAUTION

> The penetrant system concept does not allow the mixing together of solvents or developers from different manufacturers. For example, a qualified non-halogenated solvent remover from manufacturer A may not be mixed with a qualified non-halogenated solvent remover from manufacturer B, and a qualified water soluble developer from manufacturer C may not be mixed with a qualified water soluble developer from manufacturer D.

A penetrant system is defined as a penetrant and emulsifier together, from the same manufacturer. ASM 2644 requires that a penetrant / emulsifier combination be qualified and used together for the two postemulsifiable methods. For the water washable and solvent removable methods the penetrant system consists of the penetrant alone. Solvent removers and developers are qualified independently and may be used with any qualified penetrant system. Therefore, a qualified postemulsifiable penetrant system from one manufacturer may be used with any qualified developer; a qualified solvent removable system may be used with any qualified solvent and developer, and a qualified water washable penetrant system may be used with any qualified developer (approved for water washable systems).

2.2.5.4 Requirements.

The ASM 2644 is used to procure penetrant materials and requires manufacturers to conduct extensive tests on new formulations of penetrant materials. The test reports, plus a sample of the material, are then submitted to the Government Qualifying Agency. The Qualifying Agency reviews the reports and conducts additional tests to verify the acceptability of the material. If the candidate material(s) meets or exceeds the requirements of the specification, a letter of notification approving the material(s) for listing is issued and at the next revision, the material(s) and manufacturer are listed on the Qualified Products List, QPL-25135. All materials listed in a given classification category are considered equivalent in meeting the generic specification requirements. Consequently, any manufacturer’s penetrant system listed in the QPL, for a given type, sensitivity, and removal mode may be substituted for any other penetrant system listed to the same classification.

2.2.5.4.1 Sensitivity.

ASM 2644 requires candidate materials and systems to equal or exceed the performance of the appropriate reference system or material. Additionally, the Method D systems must be qualified with the hydrophilic emulsifier concentration at the maximum recommended by the manufacturer; this concentration is listed on the qualified products list (QPL) and shall not be exceeded. Reference materials were selected from available commercial products to represent typical examples of each classification of material listed in Table 2-1 except Dual Mode penetrants and Specific Application developers and solvent removers. There are reference fluorescent penetrants for each sensitivity level. The reference dry developer is used to process both the candidate and the reference materials except for visible penetrant systems (Type II) where the nonaqueous (wet) reference developer (Form e) is used. Two examples follow.

a. A candidate Type I/Method D/Level 3 penetrant system is processed with the reference dry developer and the brightness of the resulting crack indications are compared to the results from processing the same crack standards using the reference Type I/Method D/ Level 3 hydrophilic penetrant system (postemulsifiable reference penetrant and reference hydrophilic emulsifier) and the reference developer.

b. Any candidate developer for use with fluorescent penetrant systems is processed with the Level 4 lipophilic system and the results compared to the results from processing the same crack standards with the same reference penetrant system and the reference developer.

2.2.5.4.2 Penetrant Removability.

NOTE

> All penetrant materials, except solvent removers, used in performing penetrant inspection SHALL be listed on the QPL or SHALL be approved for listing as evidenced by a letter of notification. Refer to paragraph 2.5.6.

Qualification procedures for penetrant removability follow the same pattern as the sensitivity qualification procedures except that the reference system for all fluorescent penetrant systems is the lipophilic system for the appropriate sensitivity level. Again, the reference dry developer is used in all processes. The requirement is for a candidate penetrant system to leave no more residual penetrant than the same sensitivity level reference penetrant system. Grit blasted stainless steel panels are used for the removability tests. Background measurements taken at three spots are averaged to get a result used for comparison purposes. As an example, the Level 2 fluorescent penetrant lipophilic system is used for removability tests of all Level 2 candidate penetrant systems; the reference dry developer is applied in processing both systems.

2.2.6 Qualified Products List (QPL).

2.2.6.1 Quality of QPL Materials.

NOTE

> DOD activities SHALL perform quality conformance verification on incoming penetrant materials as described in Section 2.8.5.

Listing of materials on the QPL does not guarantee that subsequent products of the same formulation will be acceptable. Listing on the QPL merely indicates that the original raw materials, formulation and compounding practice can result in an acceptable product. There are many factors and conditions involved in compounding and manufacturing penetrants that can affect their performance. ASM 2644 includes an option for a procuring activity to contractually require a manufacturer to provide quality conformance test results and a sample of the material from the lot or batch to be supplied. The procuring activity itself has the option of performing tests to verify the conformance of a material, whether a sample and test report is or is not contractually required.

2.2.6.2 Unsatisfactory Materials.

NOTE

> Knowledge of penetrant problems, even relatively minor ones, is essential for improvement of the NDI program, the materials specification and the qualification tests. Information copies of written correspondence concerning unsatisfactory penetrant materials SHALL be submitted to AFRL/MLS-OL (Air Force NDI Office), 4750 Staff Dr., Tinker AFB, OK 73145-3317; DSN 339-4931 and AFRL/MLSA, Bldg. 652, 2179 Twelfth Street, Ste. 1. Wright-Patterson Air Force Base, OH 45433-7718.

Unsatisfactory materials SHALL be reported in accordance with T.O. 00-35D-54 (Air Force) or AR 735-11-2 (Army). A copy of the quality conformance test results SHALL be included as substantiating data.

2.2.7 Basic Penetrant Processes.

Abridged penetrant process flow charts illustrating the general process steps for the various penetrant methods are provided in Figure 2-4 through Figure 2-7. Detailed descriptions of application procedures are contained in later sections and paragraphs. The process flow charts contain reference locations for the detailed information. Since the application procedures for fluorescent penetrant (Type I) and visible-dye penetrant (Type II) are similar, the process flow charts are applicable to both types of penetrants.

2.2.8 Sensitivity.

The term "sensitivity", when used in conjunction with penetrant inspection processes refers to the ability to detect flaws. Sensitivity, when used in this context, is a relative factor. More sensitive inspection processes are capable of detecting smaller flaws than less sensitive processes. Among the several factors that influence the sensitivity of a given penetrant inspection process are the cleaning methods on the parts before the penetrant inspection, the selection of penetrant materials and the process by which the materials are used. This is not to be confused with "penetrant system sensitivity level" which is a penetrant system classification term mentioned in paragraph 2.2.5 that will be further discussed in paragraph 2.4.4.3.

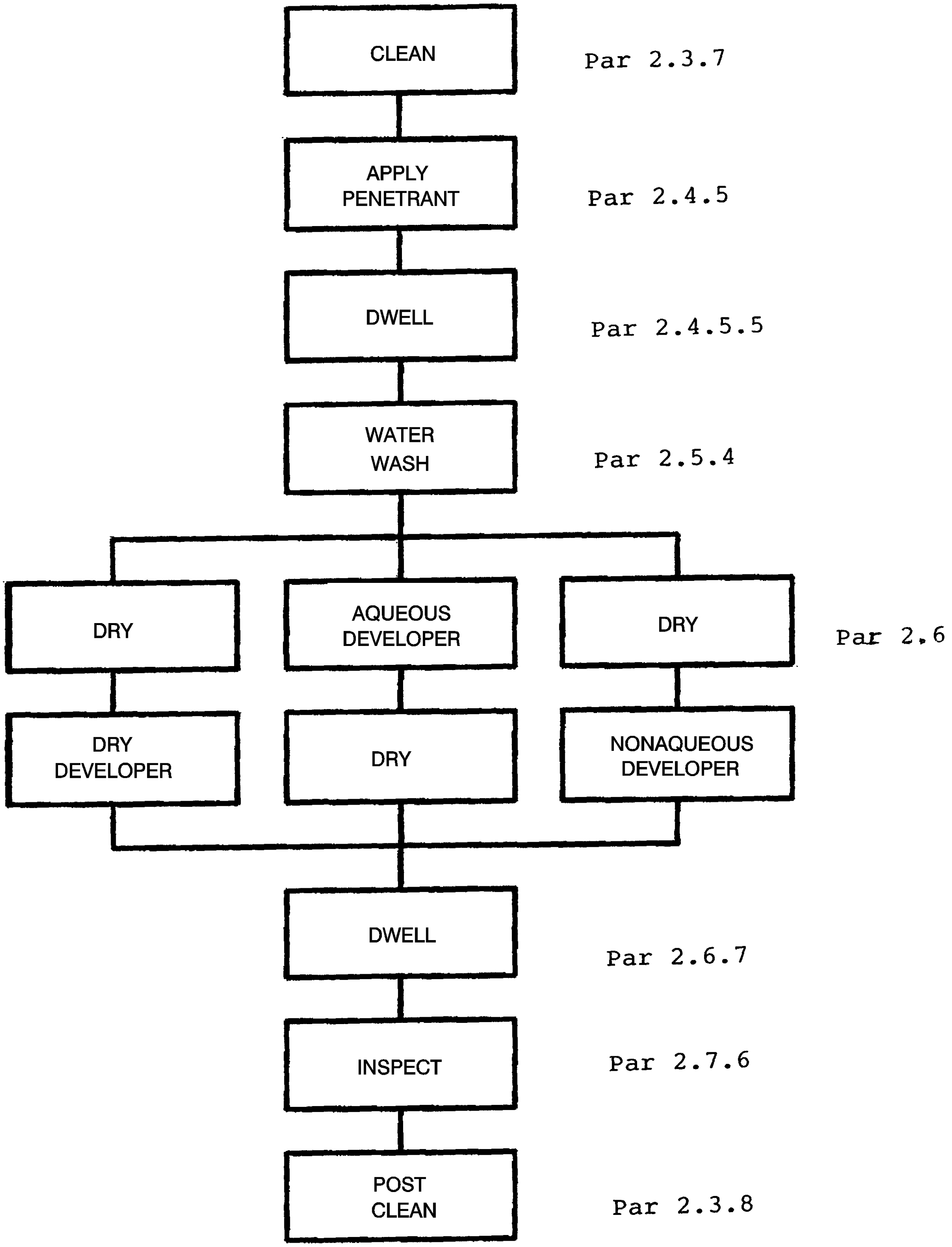


Figure 2-4. Flow Chart for Water Washable Penetrant Process (Method A).

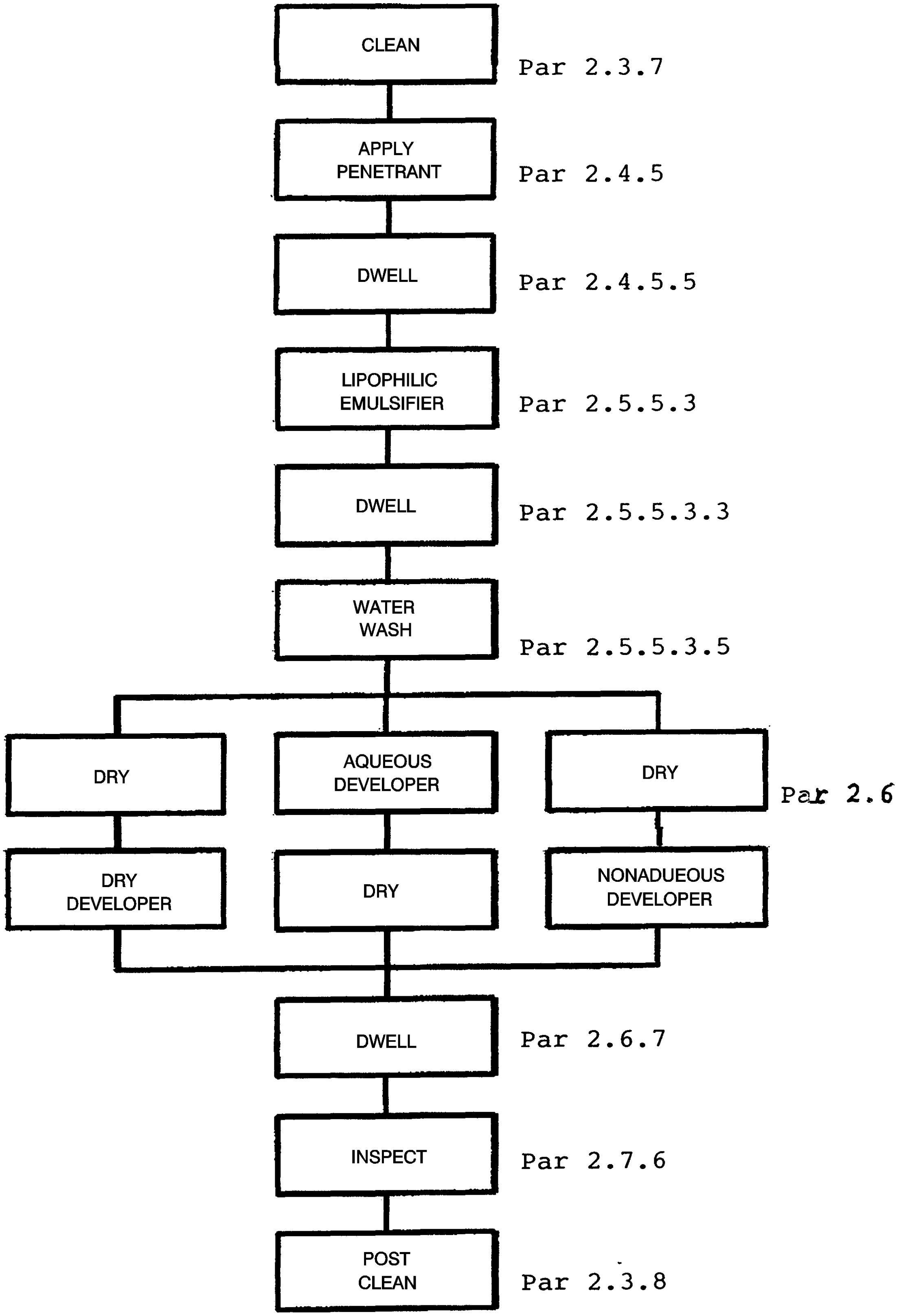


Figure 2-5. Flow Chart for Postemulsifiable, Lipophilic, Penetrant Process (Method B).

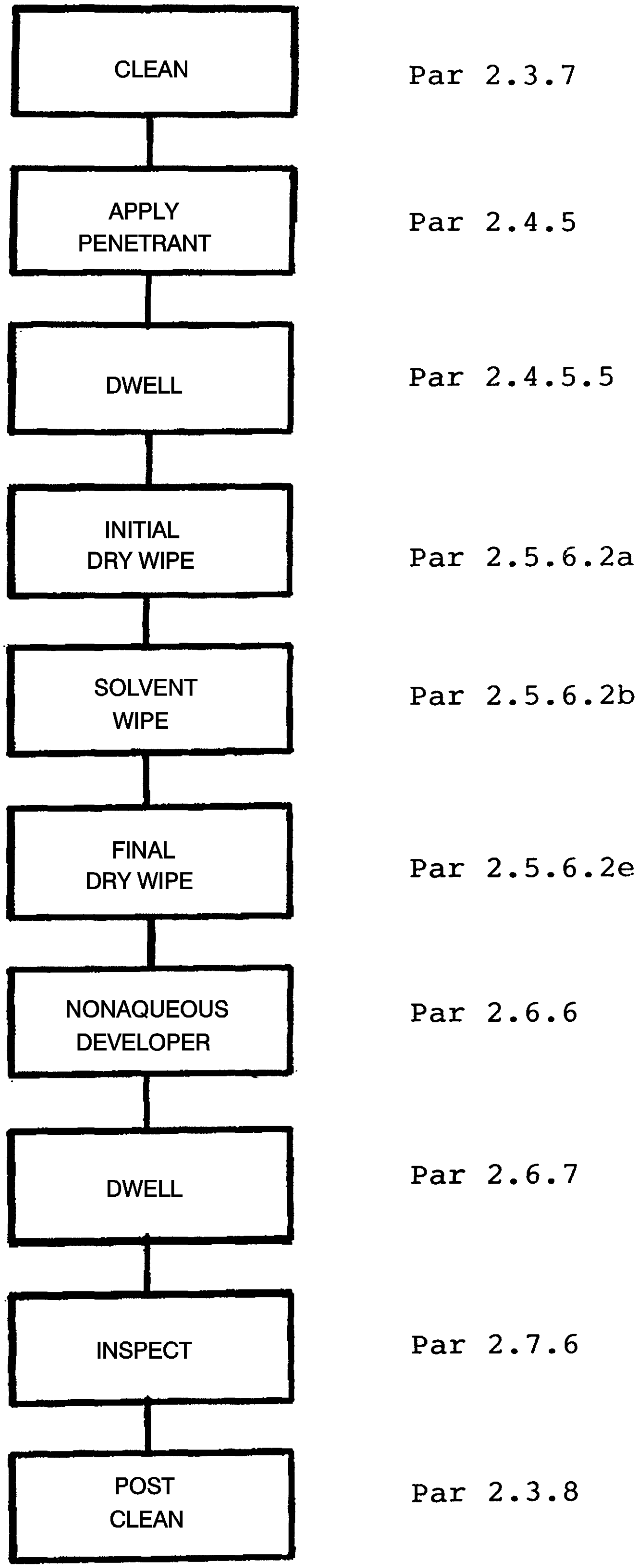


Figure 2-6. Flow Chart for Solvent Removable Penetrant Process (Method C).

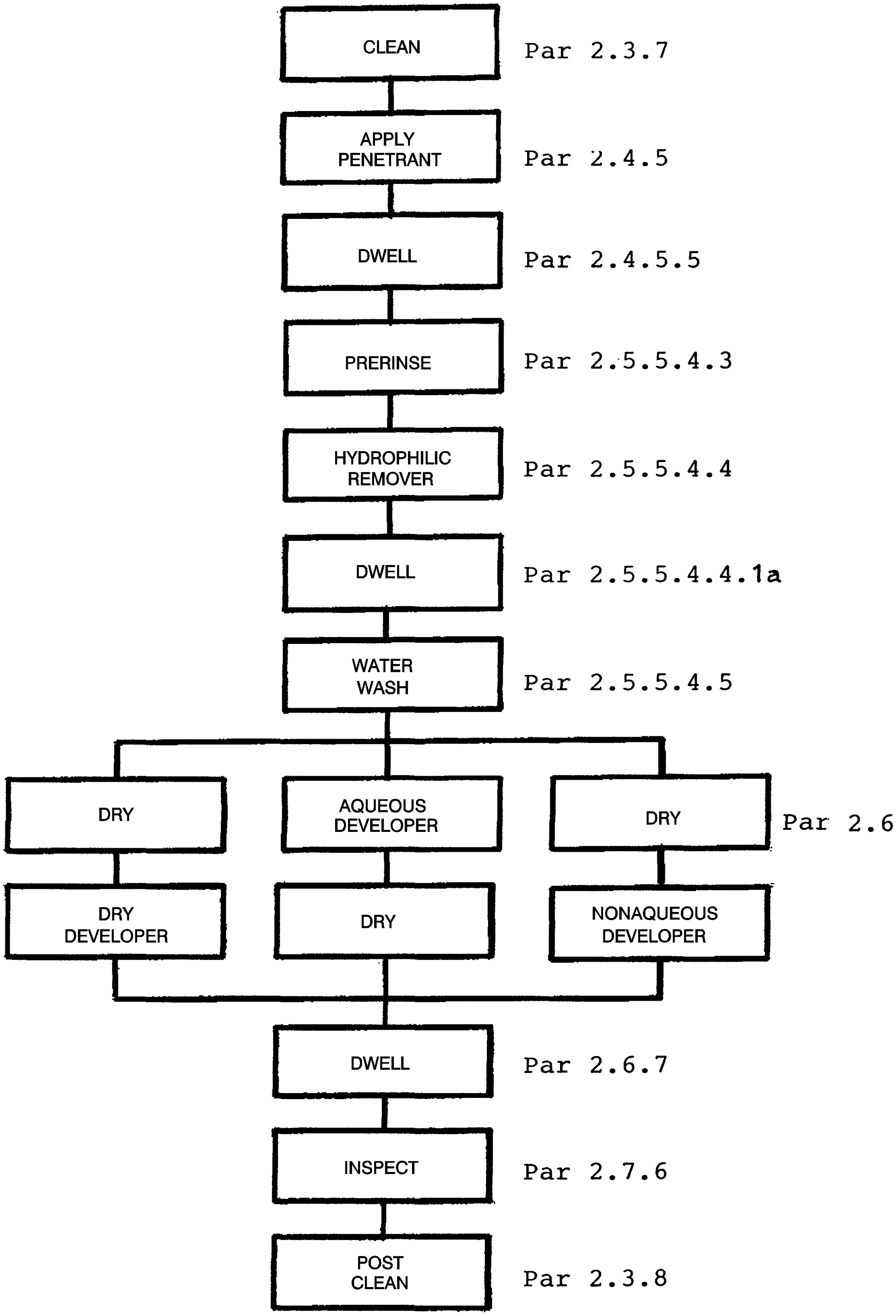


Figure 2-7. Flow Chart for Postemulsifiable, Hydrophilic Penetrant Process (Method D).

SECTION III
PRETESTING, CLEANING, PRECLEANING AND POSTCLEANING

2.3 PRETESTING, CLEANING, PRECLEANING AND POSTCLEANING.

2.3.1 Introduction.

2.3.1.1 Purpose Of This Section.
The treatment and condition of parts prior to inspection have a significant influence on the results of the inspection process. Nondestructive inspection personnel must be aware of the pre-inspection surface treatment processes and their effects on the penetrant process. This section provides the necessary background information but does not contain enough information to permit selection of a cleaning process or to perform major cleaning operations. However, there is information on pretesting and precleaning procedures which NDI personnel perform.

2.3.1.2 Definitions.

2.3.1.2.1 Pretesting.
Pretesting is done to determine the compatibility of penetrant materials with parts made of a material that has no history of being successfully inspected with liquid penetrants.

2.3.1.2.2 Cleaning.
Cleaning, is the initial removal of soil, corrosion and paint accomplished by the corrosion control or cleaning shop.

2.3.1.2.3 Precleaning.
Precleaning is the surface preparation performed by NDI personnel just prior to inspection, to remove light soils that have accumulated during service or since major cleaning.

2.3.1.2.4 Postcleaning.
Postcleaning follows penetrant inspection to remove residual penetrant materials.

2.3.2 Pretesting.

2.3.2.1 Purpose Of Pretesting.
Some nonmetallic parts, such as plastics, rubbers and plexiglass, may react with the oils and solvents contained in penetrant inspection materials. These oils and solvents can cause swelling, softening, distortion, crazing, or other surface effects resulting in damage to the part. The purpose of pretesting is to ensure that parts to be inspected will not be damaged by penetrant materials. All nonmetallic parts that have not been previously inspected, and which do not have approved technical or nondestructive inspection procedures, SHALL be pretested.

2.3.2.2 Pretesting Procedure.

NOTE

If necessary, the cognizant ALC NDI Manager or responsible engineering authority should be contacted for assistance.

Some materials may not show effects until they are subjected to service conditions (aging, cold, heat, moisture).

Pretesting SHALL be performed as follows:

a. If spare or extra parts are available, the entire surface to be inspected may be pretested. If the part to be inspected must be reused, the pretest should be performed on a small area where possible damage can be tolerated.

b. The part to be pretested SHALL be cleaned and visually examined for evidence of pre-existing damage.

c. Apply the penetrant to be used to the area selected and allow it to remain on the surface for at least twice the proposed dwell time. Wipe excess penetrant from the area and closely examine for any surface changes.

d. Repeat Step c with the remover and developer to be used, examining the part surface for any evidence of change between each process step.

e. If any evidence of adverse effects is noted, the penetrant inspection method should not be used.

2.3.3 Cleaning.

2.3.3.1 Responsibility for Cleaning.

Properly performing surface treatment operations, such as paint stripping and cleaning of military system metals and alloys, requires skill and knowledge. Improper methods, materials, or procedures can result in severe damage to surfaces and parts. Nondestructive inspection personnel are neither trained nor experienced in performing paint stripping or cleaning. Surface treatment processes SHALL be accomplished only by qualified personnel.

2.3.3.2 Need For Clean Surfaces.

The proper preparation of parts prior to inspection is critical. Successful detection of discontinuities by penetrant inspection depends upon the ability of the penetrant to enter and exit from the discontinuity, and the resulting indication must be readily distinguishable from the background. Surface conditions, such as coatings or soil contamination, can reduce the effectiveness of the inspection by interfering with the entry and exit process or producing a high residual background. Penetrant inspection is reliable only when the parts to be inspected are free of contaminants. Foreign material, either on the surface or within the discontinuity, can produce erroneous results. Any interfering conditions must be removed by proper cleaning or surface treatment prior to penetrant application.

2.3.3.3 Factors In Selecting A Cleaning Process.

CAUTION

Improper cleaning methods can cause severe damage or degradation of parts. Selection and application of cleaning processes SHALL be accomplished only by qualified personnel.

Cleaning is a broad term covering methods and materials used to remove contaminants or soils from a surface. Cleaning is routinely used for corrosion control and to prepare surfaces for other treatments. There are no special methods or materials specifically dedicated to penetrant inspection. Different materials and parts require separate or individual cleaning processes. No one cleaning method is equally effective on all contaminants. The selection of a suitable cleaning process is complex and depends on a number of factors, such as:

a. Type of soil(s) or contaminant(s) to be removed.

b. Part material. Some nonferrous metals, such as aluminum and magnesium, present problems because strong alkaline or acid cleaners attack the metals. Steels, especially in the heat treated condition, are likely to become embrittled by acid cleaners. Other metals, such as titanium and high nickel alloys, can be attacked by cleaning compounds containing halogen and sulfur compounds if they have residual cleaning compounds present and are exposed to high temperatures.

c. Part surface condition. Rough surfaces tend to hold soil, making it harder to remove.

d. Part surface accessibility and geometry. Complex shapes make it difficult to clean all of the surfaces, and soils lodged in restricted areas may escape the effects of cleaning.

e. Required degree of cleanliness as dictated by the surface treatment that will follow or what service conditions will be encountered by the cleaned part.

f. Availability and adequacy of cleaning facilities. For example, a large part cannot be placed in a small alkaline or ultrasonic cleaning tank.

2.3.4 Contaminants and Soils.

2.3.4.1 Definition of Contaminants and Soils.

In this section, the terms “contaminants” and “soils” are used interchangeably and refer to matter on a part or component that may affect the penetrant testing process. Contaminants may be intentionally applied, such as paint or corrosion prevention compounds; may result from prior processes, such as machining, heat treating, or cleaning; or may be the consequence of service, such as corrosion, carbon deposits, lubricating fluids, or dirt particles. The effects of contaminants on the penetrant inspection process depend on the type of soil and whether it is on the part surface or entrapped in a discontinuity.

2.3.4.2 Effects Of Surface Contaminants.

Contaminants that cover or bridge the surface opening of a discontinuity will prevent or reduce the formation of a penetrant indication. An indication can form only when the penetrant enters and exits the discontinuity. Any closure or reduction of the surface opening will restrict the formation of an indication.

2.3.4.2.1

Contaminants that do not bridge a discontinuity but are adjacent to the opening will also reduce the effectiveness of penetrant inspection. A common example of this condition is a painted part with a crack extending through the paint layer. While penetrant may enter and exit the defect to form an indication, the retention of penetrant in the adjacent contaminant can produce a residual background that masks or reduces the contrast of any discontinuity indication. These contaminants can also result in the formation of false indications.

2.3.4.2.2

One of the requirements for a penetrant to function is that it forms a continuous, even layer in intimate contact with the surface of the area to be inspected. This action is called surface wetting and is one of the mechanisms of penetration. Some types of contaminants prevent surface wetting thus prohibiting penetrant entry and the forming of an indication.

2.3.4.3 Effects Of Contaminants Trapped in Discontinuities.

Foreign materials that fill discontinuities will block penetrant entry and indications will not form. A common occurrence of filled discontinuities is the tire bead seat area on aircraft wheels. When cracks occur in this area, they are frequently sealed by fine rubber particles from the tire. Eddy current or visual inspection will show cracks not indicated by penetrant inspection.

2.3.4.3.1

Contaminants within, but not completely filling discontinuities, can have several types of adverse effects:

a. Some contaminants interfere with the penetrating mechanism and either prevents or reduces penetrant entry and exit from the discontinuity.

b. Contaminants within the discontinuity, that do not interfere with the penetrating mechanism, still take up physical space and reduce the volume of penetrant dye inside the discontinuity. The amount of penetrant that can enter may be insufficient to produce a noticeable indication.

c. Contaminants that are strongly acidic or alkaline, such as residues from cleaning processes, can attack the dyes. This attack can result in a loss of color or fluorescence, resulting in a less noticeable indication.

2.3.4.4 Specific contaminants And Their Effects.

2.3.4.4.1 Light Oils and Soft Films.

a. Examples of light oils and soil films are: hydraulic oils; lubricating oils; machining and cutting fluids; thin greases, such as petroleum jelly; and film corrosion preventive compounds. When present as thin films, these contaminants are easily removed by solvents. However, when they contain solid particles, such as metal chips, sand, or dirt removal is more difficult. The oily phase is readily removed, leaving the solid particles adhering to the surface. Removal of the solid particles may require a mild mechanical action, such as hand wiping, pressure spray, solution agitation or ultrasonic vibration.

b. Light oils and soft films have several adverse effects on the penetrant inspection process. They readily enter surface openings, thus reducing or preventing penetrant entrapment. Oily materials on the part surface interfere with the mechanisms causing the penetrant to enter and exit from discontinuities. Also, many oils and greases fluoresce under black light. When on a part surface, this fluorescence could obscure a discontinuity indication or produce a false indication.

2.3.4.4.2 Heavy Oils and Solid films.

a. Examples of heavy oils and solid films are viscous oils; thick greases; hard film corrosion preventative compounds; and particulate lubricants, such as graphite and molybdenum disulfide. These contaminants or soils are more difficult to remove than light oils. They require solvent or chemical action plus considerable mechanical action. Mechanical action can be solution agitation, manual scrubbing or pressure spraying. Cleaning for penetrant inspection presents special problems. The heavy oils and greases are viscous and flow very slowly; many of them have excellent penetrating ability and readily enter surface discontinuities. Removal of heavy oils requires considerable mechanical action where the forces are concentrated at the surface. Use of excessive mechanical forces to remove heavy oils and films may further aggravate problems by smearing metal over narrow discontinuities.

b. Heavy oils and solid films have the same adverse effects on penetrant inspection as light oils and soft films. They enter or bridge surface discontinuities and either prevent or reduce the amount of penetrant entrapment. Many heavy oils and semi-solid films fluoresce under black light. This fluorescence can obscure valid indications and produce false indications. Heavy oils and films on the surface of a part, even in trace amounts, interfere with the entry and exit of penetrant discontinuities.

2.3.4.4.3 Carbon, Varnish and other Tightly Held Soils.

a. Examples of origins of carbon, varnish and other tightly held soils are: partially burned petroleum and other combustion products; residues from evaporated fuel and oils; and dry film lubricants. These types of soil are very adherent and are difficult to remove. They require special cleaning compounds and processes to dissolve and loosen the soils. Strong mechanical action, such as scrubbing, pressure spray, or solution agitation is also required. Care must be used, since many of the cleaning compounds will attack some metals and alloys.

b. Tightly held soils, such as carbon, engine varnish, and other dry soils, can seriously interfere with the penetrant inspection process. They can bridge over or partially fill the discontinuity, blocking or reducing the amount of penetrant in the void. When on the part surface, they interfere with the forces or mechanism causing penetrant entry and exit from discontinuities. When dry, they tend to absorb moisture that also interferes with penetrant entry and exit. As surface contaminants, they retain the penetrant, leading to a residual background and false indications during inspection.

2.3.4.4.4 Scale, Oxides, And Corrosion Products.

a. Scale and oxides generally occur as a result of exposure to high temperatures. Scale and oxides are usually very difficult to remove and may require extreme cleaning methods, such as acid pickling, abrasive blasting or other metal removal operations. Some of these processes can have an adverse effect on the penetrant inspection process and should be avoided, (see paragraph 2.3.6). Corrosion products, particularly from stress corrosion, often occur or are lodged within discontinuities resulting in removal problems.

b. Scale, oxides and corrosion products can bridge or partially fill discontinuities restricting penetrant entry. When on the part surface, they interfere with the mechanism of penetration, impeding both penetrant entry and exit from discontinuities. They also retain penetrant on the surface, leading to a high residual background and false indications. Stress corrosion products occur within the flaws and may be impossible to completely remove. Penetrant inspection for stress corrosion cracking flaws generally requires extended dwell times to permit penetrant entry.

2.3.4.4.5 Paint and Other Similar Coatings.

Paint and similar coatings are not foreign soils since they are intentionally applied to the part surface as a smooth, continuous layer. However, they can have several adverse effects on the penetrant inspection process. Many of the coatings are elastic and do not form openings when the base metal cracks from service stress. When this occurs, the surface opening is bridged or covered, preventing penetrant entry. Paint coatings can interfere with penetrant inspection process even when they form open cracks along with the base metal. The paint surface texture is much different than bare metal, and it can interfere with the mechanisms causing the penetrant to enter and exit the discontinuity. Paint coatings, especially when they are oxidized, weather checked or cracked, can retain penetrant during removal causing a high residual background or false indications.

2.3.4.4.6 Water or Moisture.

Water or moisture on a part can occur from many sources. The most common source is the cleaning process followed by inadequate drying of the part. Water or moisture on the part surface or in the discontinuity seriously interferes with the penetration process. It is essential that water be removed not only from the part surface but also from the inside of any discontinuities that may be present. Moisture in the form of condensation from high humidity or low temperatures may occur and must be removed. An example of condensation occurrence is the spot cleaning of a local area with a volatile solvent. Rapid evaporation of the solvent may cause cooling to a temperature at which condensation occurs (dew point).

2.3.4.4.7 Residues from A Cleaning Process.

The chemicals used for cleaning solutions may contain strong alkalis and acids. If not completely removed from the part surface before penetrant inspection, they can interfere with the penetrant process in several ways. They can impede surface wetting and prevent the penetrant from evenly coating the inspection area. They also interfere with the mechanism causing the penetrant to enter and exit discontinuities. Strong alkalis and acids can decompose or degrade dyes and other chemicals in the penetrant, causing weak or faint indications. Chromate residues absorb black light, leaving less energy to excite the fluorescent dyes in the penetrant.

2.3.4.4.8

Residues from Previous Inspection. Residues from penetrant inspection can affect subsequent inspection results and the serviceability of the part. The effects of residues from previous penetrant inspections are discussed in the following paragraphs. The effects on serviceability are discussed in paragraph 2.3.8.1

2.3.4.4.8.1
If the post-inspection cleaning is inadequate, the residues must be considered as contaminants during a subsequent reinspection. Developer residues on the part surface will retain penetrant causing a high residual background that can obscure valid indications. When retained in crevices, joints or faying surfaces, developer residues will cause false indications. Developer residues also absorb and retain moisture and, if not dried, may cause corrosion of the part. Penetrant residues, if not removed from discontinuities, will dry forming a varnish-like material in the flaw. This entrapped residue may not fluoresce and will reduce or prohibit entry of penetrant during future tests of the part.

2.3.4.4.8.2

CAUTION

DOD prohibits the use of visible-dye penetrant on aircraft, engine, and missile parts, except for those with specific engineering approval.

The red dye in visible-dye penetrant acts as a filter to black light radiation. When red dye residues mix with fluorescent penetrant in a discontinuity, the fluorescent brightness can be reduced or destroyed. Visible-dye penetrant should not be used if the part may be inspected with fluorescent penetrant at some later time. If a part has been previously inspected with visible penetrant and requires reinspection, the reinspection should be done with visible-dye penetrant. If fluorescent penetrant inspection must be performed to achieve the required sensitivity, special cleaning processes should be used to insure removal of the visible penetrant residue of previous tests.

2.3.5 Cleaning Processes.

2.3.5.1 Introduction to Cleaning Processes.

The success of any penetrant inspection procedure depends upon the part surface and discontinuities being free of any contaminants or soils that might interfere with the penetrant process. There are a variety of cleaning methods which may be utilized. The methods are generic and are used principally for corrosion prevention and preparation of items for surface treatments. There are no special methods used exclusively to prepare parts for penetrant inspection. Some of the cleaning methods are discussed in the following paragraphs.

2.3.5.2 Alkaline Cleaning.

CAUTION

Some alkaline cleaning compounds will attack aluminum parts and components. Care must be used in selecting the proper cleaning process for the materials to be cleaned.

Alkaline cleaners are water solutions of chemicals which remove soils by a chemical action such as saponifying (converting chemicals into soap) or displacement rather than dissolving the soils. Cleaners of this type usually have components to aid in lifting the soils from the part surface. After displacement, the soil may be carried as a suspension in the cleaner; it may separate; or, in the case of fatty soils, it may react with the cleaner to form water soluble soaps. Alkaline cleaning is usually accomplished in immersion tanks with the solution at or near its boiling point. The cleaning action is expedited by some type of agitation. Following alkaline cleaning, parts and components must be thoroughly rinsed to remove any traces of the cleaning compound prior to penetrant inspection.

2.3.5.3 Steam cleaning.

CAUTION

T.O. 1-1-691 and NAVAIR 01-1A-509, TM 55-1500-334-23 prohibits the use of raw steam for cleaning aircraft and missile surfaces.

Steam cleaning is a form of alkaline or detergent cleaning. Diluted solutions of alkaline cleaners, detergent cleaners, or mixtures of both are injected into a live steam spray. The steam/cleaner mixture is under pressure and the jet is directed at the surface to be cleaned by a spray wand. Steam cleaning provides both chemical and strong mechanical action at elevated temperatures. Mobile steam generators permit application on parts and structures that cannot be brought into the cleaning shop.

2.3.5.4 Detergent Cleaning.
Detergent cleaners are water base chemicals called surfactants, which surround and attach themselves to particles of surface soil. The particles of soil and detergent are then washed away by solution agitation, pressure spray, or hand wiping. The action is identical to hydrophilic removers in the penetrant process described in paragraph 2.5.5.4.2. Detergent cleaners may be alkaline, acidic or neutral but must be noncorrosive to the material being inspected. The cleaning properties of detergent solutions facilitate complete removal of light soils from the part surface, preparing it for penetrant inspection.

2.3.5.5 Emulsion cleaning.
Emulsion cleaners consist of an organic solvent and a detergent in water based solution. The organic solvent may be a petroleum base liquid. The soils are removed through a combination solvent-detergent action. The cleaner is lightly alkaline and is usually sprayed on the part. Emulsion cleaning can leave a light oil film on the part surface that is the residue of the solvent. Emulsion cleaned parts must be hot water rinsed or wiped with a solvent to remove the oily residue prior to penetrant inspection.

2.3.5.6 Solvent Cleaning.
This type of process removes soils by dissolving them. Solvents can be used on oils, greases, waxes, sealants, paints and general organic matter. The resulting solution may leave a thin film or residue of an oily nature. This oily film must be removed with another solvent, vapor degreasing, alkaline or detergent cleaning prior to penetrant inspection. Solvent cleaning may be accomplished by tank immersion, but is more often applied by spraying or hand wiping when alkaline, detergent or vapor degreasing is impractical.

2.3.5.7 Vapor Degreasing.

NOTE

Methyl chloroform, the most commonly used solvent in vapor degreasers, is no longer available to government facilities because of its detrimental effect on the ozone layer. Other solvents that can be used are generally too toxic or expensive to be practical substitutes. Consequently, utilization of vapor degreasing is generally no longer available to government facilities.

2.3.5.8 Ultrasonic cleaning.
This method adds ultrasonic agitation to solvent or detergent cleaning. The agitation is the result of cavitation of the liquid when subjected to the high and low pressure (partial vacuum) of the ultrasonic waves. The formation and collapse of the cavities in the liquid provides a scrubbing action to the surface of the part. The agitation increases action of the cleaning solution and decreases cleaning time. It is particularly effective in removing contaminants trapped in discontinuities. However, its effectiveness is dependent upon the cleaning medium. It should be used with water and detergent on inorganic soils, such a rust, dirt, salts and corrosion products. It should be used with an aromatic or halogenated solvent if the soil to be removed is organic, such as oil or grease; see paragraph 2.2.3.4.

Ultrasonic cleaning has limitations: its efficiency is affected by part size, configuration, and the cleaning solution action on the soil to be removed.

2.3.5.9 Paint Removal

NOTE

> Many paint removal operations leave a thin film of dissolved or softened paint and remover chemicals on the part surface or in discontinuities. This often occurs when local or spot paint removal is performed. Care must be taken to ensure the area to be inspected is free of paint and remover residues since they interfere with the penetrant inspection process.

There are a large variety of paint coatings and finish systems in use on aircraft parts and surfaces. Some conventional coatings are readily removed using standard methods. However, advances in paint technology have resulted in finishes that can only be removed with unique materials and techniques. For conventional coatings, there are three general types of removers: solvent, bond release, and disintegrating. Some proprietary removers contain multiple types, such as solvent or disintegrating compound in combination with a bond release material.

2.3.5.10 Carbon Removal.

Carbon, varnish and other tightly held soils can present special problems in removal. The soils may have been baked at elevated temperatures to form a vitreous or glass-like coating. There are special solvent and alkaline cleaners for baked soil removal. Many of the paint removal materials and processes are used in removing carbon, varnish and other tightly held soils that are not baked.

2.3.5.11 Salt Bath.

Molten salt baths are used for removing heavy, tightly-held scale and oxide from low alloy steels, nickel and cobalt base alloys, and some types of stainless steel. Salt baths cannot be used on aluminum, magnesium, or titanium alloys. The process involves immersing the parts in molten caustic soda at about 700°F. The difference in thermal expansion between scale and base metal separates some scale and causes the remainder to crack. The molten caustic soda also chemically reacts with the scale, reducing it to lesser oxides and metals. When the part is removed from the molten salt, it is plunged into water creating a thermal shock, plus steam at the part surface which scours or blasts any remaining scale from the part.

2.3.5.12 Acid Cleaning.

NOTE

> Acid cleaning requires very careful control of procedures and solutions to prevent damage to the parts.

Solutions of acids or their salts are often used to remove rust, scale, corrosion products, and dry shop soils. The type of acid and its concentration depends on the part material and contaminant to be removed. Acid cleaners are not generally effective on oily soils. Oils and greases must first be removed by some other cleaning method so the acid can react with the scale, oxides, or other tightly held soil.

2.3.5.13 Chemical Etching.

CAUTION

> Chemical etching SHALL be done only with engineering approval and written detailed process and application instructions.

Chemical removal or etching of deformed or disturbed surface metal is necessary if flaws are to be detected by penetrant inspection. There are a number of mechanical processes that deform the surface of a part (see paragraph 2.3.6.1). The deformation is a thin layer, surface metal flow that seals or reduces the opening of discontinuities (see paragraph 2.3.6.2). The smeared metal over the surface opening prevents or severely restricts the penetrant entry into any discontinuities. Chemical etching to remove the smeared metal allows penetrant inspection to be performed. The etching is done using a mixture of appropriate acids or alkalis plus inhibitors. The type of etching solution depends on the part material and condition. Chemical etching requires very close control of the etching solution composition, process procedures, and time of contact. Minor deviations in processing parameters will result in a number of adverse effects, such as:

a. Excessive metal removal.

b. Selective etching of critical surfaces.

c. An increase in the parts susceptibility to stress corrosion.

d. Reduction of residual surface stress with a corresponding reduction in fatigue life.

2.3.5.14 Removal of Cleaning Process Residues.
Cleaning process residues are removed by rinsing with fresh water. The use of warm water and agitation followed by repeated immersions in fresh water assist in complete removal. In some cases, residues of strong alkalis and acids are subjected to a rinse with a weak neutralizing solution followed by fresh water rinses.

2.3.5.15 Summary of Cleaning Processes.
Table 2-2 is a summary of cleaning processes. Not all of the processes listed may be available at each operating location.

Table 2-2. Non-Mechanical Cleaning Processes that may be Used Prior to Penetrant Inspection.

SOLVENT MATERIALS	POLAR OR IONIZING MATERIALS
Immersion – Para. 2.3.5.6	Alkaline Cleaning – Para. 2.3.5.2
Spray – Para. 2.3.7	Steam – Para. 2.3.5.3
Ultrasonic – Para. 2.3.5.8	Detergent – Para. 2.3.5.4
	Emulsion – Para. 2.3.5.5
	Paint Removal – Para. 2.3.5.9
	Carbon Removal – Para. 2.3.5.10
	Salt Bath – Para. 2.3.5.11
	Acid Cleaning – Para. 2.3.5.12
	Chemical Etching – Para. 2.3.5.13

2.3.6 Mechanical Working Processes.

2.3.6.1 Description.
Mechanical working processes involve displacement or removal of metal on the part surface. Intense mechanical working processes (sand blast, grit blast, and wire brushing) are used to remove heavy or tenacious contaminates, such as scale or rust. The less severe mechanical working processes (tumbling, liquid honing, vapor blasting) are frequently used to remove light oxides and residual combustion products. Classification and methods of mechanical working processes are listed in Table 2-3. Metal removal methods are listed by the type of cutting action, while abrasive blast methods are categorized by the type of abrasive media.

Table 2-3. Mechanical Working Processes.

METAL REMOVAL	ABRASIVE BLASTING
Filing	Sand
Sanding	Aluminum Oxide
Scraping	Glass Bead
Milling Plastic	Media Beads
Drilling	Ligno-Cellulose
Reaming	Shot Peening
Grinding	Metallic Grit
Liquid Honing	Organic Media
Vibratory/Tumble Deburring	

2.3.6.2 Effects Of Mechanical Working.

NOTE

If a conflict arises pertaining to the proper inspection method to use following mechanical working, the appropriate engineering activity SHALL be contacted for final determination.

Mechanical working removes soils and contaminates by physical action. This physical action may also remove or deform the part surface. Deformation is in the form of metal flow or displacement on the part surface. The amount of deformation depends on the type and severity of the working plus the ductility of the part. Even a small amount of deformation, such as that caused by fine sanding or vapor blasting, may reduce the surface opening of small discontinuities. This deformation can reduce the effectiveness of the penetrant inspection process. Chemical etching (see paragraph 2.3.5.13) may be necessary when penetrant inspection is performed after a less severe mechanical working process. Severe mechanical working processes, such as metal removal, shot peening, or grit blasting, can seal or close the surface openings of large discontinuities which prevents the formation of penetrant indications. Penetrant inspection SHALL be accomplished prior to mechanical work processes, such as machining, shot peening, grit blasting, plastic media bead blasting, or coarse sanding, that severely displace surface metal. If it is not feasible to perform penetrant inspection prior to these processes, then another inspection method should be considered. An exception to this requirement is when penetrant inspection is performed to detect discontinuities formed by mechanical working, such as machining tears or grinding cracks.

2.3.7 Precleaning.

2.3.7.1 Solvent Cleaning With Aerosol Spray Cans.

CAUTION

Isopropyl alcohol and most Class 2 solvent removers are flammable.

NOTE

With the elimination of the use of 1,1,1 trichloroethane (methyl chloroform), the solvent remover in portable penetrant kits is most likely to be Class 2 (non-halogenated). Most Class 2 solvent removers are hydrocarbon solvents such as aliphatic naphtha. While they are excellent solvents, because of their high boiling point (in excess of 300°F) such Class 2 solvent removers will not rapidly evaporate at room temperature. Consequently, when used as a precleaner, care must be taken to assure there is no residual solvent remover on the part surface prior to the application of penetrant. This can be accomplished by thoroughly drying the surface with a cloth or rag or, alternatively, using a more volatile solvent such as isopropyl alcohol to remove the less volatile solvent remover.

Portable penetrant kits contain aerosol spray cans of penetrant, developer and solvent remover. The solvent remover is used in three ways: it serves as a precleaner before penetrant application; it removes the last of the excess penetrant after completion of the penetrant dwell; and serves as a postcleaner to remove residual penetrant materials when the inspection has been completed. This section deals with using the solvent as a precleaner.

2.3.7.2 Method of Applying Spray Solvent.

The method of applying spray solvent remover as a precleaner is different than when it is used to remove penetrant following penetrant dwell. When used as a precleaner, the solvent remover may be sprayed directly on the test surface. Spraying the solvent directly on the surface is not permitted when removing excess surface penetrant during a penetrant inspection process. As a precleaner, a liberal amount of solvent should be applied and the excess solvent and contaminants wiped from the test surface with a dry, lint free cloth or paper towels. The spray and wiping operation should be repeated until a clean surface is obtained. Following the, application of spray solvent, a dwell period must be allowed to permit evaporation of any residual solvent before applying penetrant.

2.3.7.3 Hazards Of Aerosol Cans.

Aerosol cans are a convenient method of packaging a wide variety of materials. Their wide use, both in industry and the home, has lead to complacency and mishandling which can be hazardous. Some of the hazards in the use of aerosol cans are discussed below:

a. The containers are gas pressure vessels. When heated the gas pressure increases. At temperatures above 120°F (49°C) the container may burst.

b. Any combustible material, regardless of flash point, can ignite with explosive force when it is finely divided and dispersed in air.

c. Penetrant materials (penetrant, cleaner/remover and developer) may contain petroleum distillates and aliphatic (kerosene, mineral spirits, etc.) or aromatic (benzene type hydrocarbon) solvents. These chemicals must be carefully used in the aerosol form to avoid health hazards.

2.3.8 Postcleaning After Penetrant Inspection.

2.3.8.1 Effects Of Inspection Residues on Subsequent Service.

Penetrant inspection residues can have several adverse effects on subsequent processing and service. Developer and penetrant residues, if not removed, have detrimental effects on the application of surface finishes such a painting, plating and anodizing. Penetrant residues in flaws or discontinuities can seriously affect weld quality if not removed prior to repair welding. Parts that will contact liquid oxygen must be given special attention. Traces of oil can cause an explosion when contacted by liquid oxygen. Developer residues can interfere with the functioning of the part if they involve a moving or wear surface. In addition, developer materials can absorb and retain moisture resulting in corrosion of the part.

2.3.8.2 Removal of Inspection Residues.

2.3.8.2.1 Developer Residue Removal.
Developers are the last material applied in the penetrant process and may be one of several forms. The form of developer applied (dry powder, nonaqueous, water suspendible or water soluble) greatly influences the method and difficulties of removal. One point common to most developers is the increase in adherence with time on the part. The longer a developer remains on a part, the more difficult it is to remove. Removal of the developer coating SHALL be done as soon as possible after completing the penetrant inspection.

2.3.8.2.1 Removal of Dry Powder Developer.
Dry powder developer adheres to all areas where applied. Some dry powder may lodge in recessed areas, faying surface joints, or crevices. Dry powder particles can be removed with a water soluble detergent wash followed by a water rinse. Dry developer particles adhering to penetrant bleed-out will be removed during the removal of residual penetrant described below in paragraph 2.3.8.2.2

2.3.8.2.1 Removal of Nonaqueous Developer.

NOTE

Spraying aerosol solvent directly on the developer without first hand wiping is not recommended. This practice spreads the developer particles over a larger area, which increases the amount of wiping that must be done. Aerosol solvent spraying may be used as a final step to remove residual or trace amounts of developer when it is not practical to use water.

Nonaqueous developer is usually applied by spraying from an aerosol can. The majority of applications involve a relatively small area. This makes it advantageous to remove by initially hand-wiping the surface with a dry cloth or paper towel to remove most of the developer. The remaining traces of developer can then be removed with a water or alcohol moistened rag or paper towel. The inspected area may contain threads, crevices, and surface recesses where wiping will not remove all of the developer particles. These areas should first be wiped to remove as much developer as possible, and then pressure sprayed with a water and detergent solution. Solvent spraying is not particularly effective, as the developer is usually insoluble. A vapor degreaser SHALL NOT be used because the elevated temperature bakes or hardens the developer coating.

2.3.8.2.1 Removal of Water Soluble Developer.
Water soluble developer is the easiest to remove. The developer coating readily re-dissolves in water. Water soluble developer should be removed by immersion or spraying with water.

2.3.8.2.1 Removal of Water Suspendible Developer.
Water suspendible developer is very similar to non-aqueous developer in removal characteristics. The best method of removal is immersion and pressure spraying with a hot detergent solution. It can also be removed with a plain water spray and hand scrubbing with a fiber bristle brush.

2.3.8.2.2 Removal of Penetrant Residues.
Removal of residual penetrant following the inspection and developer removal is almost always required. The amount of residual penetrant is small, consisting of penetrant retained in discontinuities, crevices, and part surface irregularities. Penetrant residues generally can be removed with liquid solvents and detergent or alkaline cleaning.

2.3.8.2.3 Protection Of Parts Following Penetrant Inspection.
The penetrant inspection process and subsequent removal of inspection residues leave the parts with a chemically clean surface. These surfaces, especially ferrous materials, are highly reactive and may corrode from the moisture in air. Such parts should receive a corrosion protection treatment as soon as practical, following penetrant inspection.

SECTION IV
MECHANISM, PROPERTIES AND APPLICATION OF PENETRANT

2.4 MECHANISM, PROPERTIES AND APPLICATION OF PENETRANT.

2.4.1 Summary.

This section provides basic, operating, and advanced level information on the penetrant portion of the inspection process. It explains the basic theory of penetrating action on the mechanism of penetration, describes the physical and chemical properties of penetrants and discusses their effects on the inspection process, describes methods and provides instructions on applying penetrants, and presents information and guidance on the penetrant dwell process.

2.4.2 Requirements of A Penetrant.

There are a number of characteristics desired in a material if it is to function as a penetrant. The four primary requirements are:

a. It must be capable of entering and filling surface openings even though they may be very small.

b. Penetrant in a discontinuity must resist removal during removal of the excess penetrant material on the surface of the part.

c. It must exit from the discontinuity after the surface penetrant has been removed.

d. It must present a readily visible or noticeable indication of the discontinuity.

The primary requirements listed do not include the factors of being economical, safe, and practical to use. The primary requirements, combined with the additional factors, complicate the formulation of a penetrant material. The behavior of a penetrant is controlled by a number of physical and chemical properties, many of which are conflicting. As a result, commercial penetrants are a complex mixture of chemicals that are formulated for specific performance characteristics. Unfortunately, there is no simple rule for formulating a penetrant material, nor is there a set of characteristics which, if provided, will ensure a final material that is completely satisfactory for all applications.

2.4.3 Mechanism of Penetration.

2.4.3.1 Physical Principles.

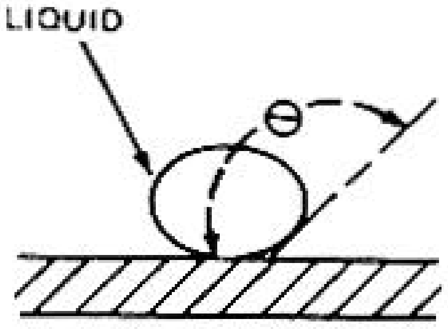
The penetrant inspection process depends on a liquid that can flow over the surface. The ability of a liquid to cover the surface of a part and enter any surface opening depends on surface tension, wetting ability and capillary action.

2.4.3.1.1 Surface Tension.

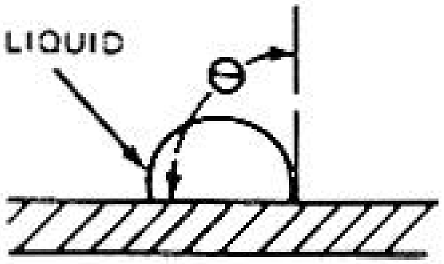
The surface of a liquid exhibits certain features resembling the properties of a stretched elastic membrane. These features are due to the cohesive forces holding the surface molecules together, hence the term “surface tension”. As an example, one may lay a needle or safety razor blade upon the surface of water, and it will lie at rest in a shallow depression caused by its weight, much as if it were on a rubber air cushion. The forces drawing surface molecules together can be very strong. These forces, or surface tension, cause a droplet of liquid to have a spherical shape. A sphere has the smallest surface for a given volume of liquid. This has a direct effect upon the ability of a penetrant to wet a surface. Surface tension usually decreases with a decrease in temperature.

2.4.3.1.2 Wetting Ability.

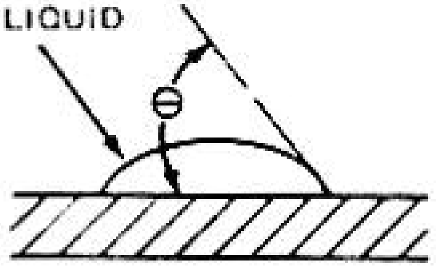
When a liquid comes into contact with a solid surface, the cohesive force responsible for surface tension competes with or is countered by the adhesive force between the liquid molecules and the solid surface. These forces determine the contact angle that the liquid forms with the surface. Figure 2-8 illustrates three examples of contact angle. Contact angle is designated by the Greek letter θ (theta). If the contact angle is less than 90 degrees, the liquid spreads over the surface and is said to “wet the surface”, or to have good wetting ability.



(a) θ GREATER THAN 90°
VERY POOR WETTING



(b) θ EQUALS 90°
POOR WETTING



(c) θ LESS THAN 90°
GOOD WETTING

Figure 2-8 The Contact Angle (θ) Is the Angle Between the Liquid and Solid Surface and is a Measure of the Wetting Ability.

2.4.3.1.3 Capillary Action.

Capillary action is associated with wetting ability. When a tube with a small inside diameter is inserted into a liquid, the liquid level inside the tubing may rise above, remain even, or be lower than the outside liquid level. If the contact angle between the liquid and the tubing wall is less than 90 degrees (the liquid wets the tube wall), the liquid will be higher in the tube than on the outside. When the contact angle is 90 degrees or greater (poor wetting and high surface tension), the liquid will not rise above the outside level and may even be depressed. Capillary rise occurs when a liquid wets the inside of a tube and the surface tension draws additional liquid into the wetted area. Figure 2-9 illustrates the effects of contact angles and capillary action.

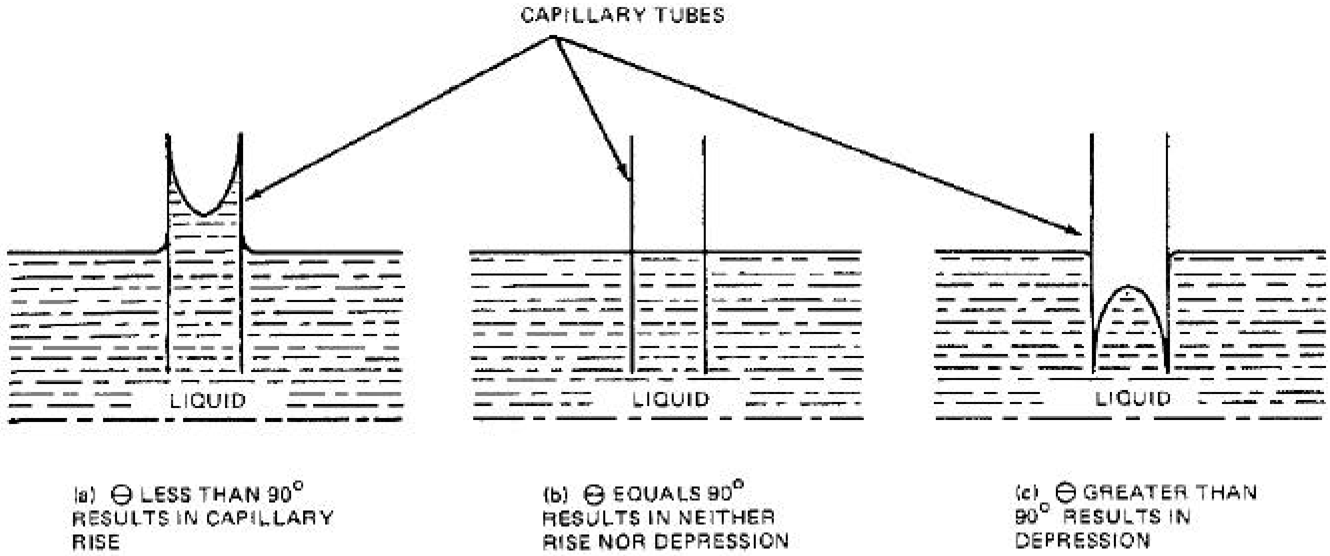


Figure 2-9. The Rise or Depression of Liquid in a Capillary Tube Depends upon the Contact Angle.

2.4.3.2 Penetrant Entry Into discontinuities.

The description of capillary action illustrates the basic principles by which a penetrant enters a small surface opening. If one end of the tube is closed, such as occurs in the case of a flaw, the capillary rise is affected by compression of the air trapped in the closed end. In addition, flaws are not capillary tubes since the sides are not parallel and are not circular. These factors allow penetrant to enter a flaw even in an inverted position, such as on a lower wing surface. The points to be remembered about penetrant entry into discontinuities are:

a. A high surface tension and small contact angle are desirable in a penetrant, however these are conflicting properties. High surface tension tends to increase contact angle and decrease wetting ability, but enhances drawing penetrant into wetted areas.

b. Capillary force increases with smaller flaws.

c. Viscosity does not affect the penetrating ability but it can affect the time required for penetration.

d. Shape of a discontinuity can affect penetrant entry.

e. Temperature affects the surface tension.

f. Roughness of the flaw walls affects penetrant entry.

g. Contamination in the flaw can affect penetrant entry.

h. Residual cleaning solution in the flaw can effect penetrant entry.

2.4.4 Penetrant Properties.

Surface tension and wetting action are only two requirements of a penetrant. In addition to penetrating ability, a satisfactory penetrant must resist removal from discontinuities when excess surface penetrant is removed, produce a noticeable indication, and be practical and economical to use. Formulation, selection, and application of penetrant materials require consideration of many physical and chemical properties. Some of these properties, other than surface tension and wetting ability, are discussed in the following paragraphs.

2.4.4.1 Physical Properties.

2.4.4.1.1 Viscosity.

Viscosity is a measure of a liquid's resistance to a change in physical shape and is related to internal friction. Viscosity varies with temperature, decreasing as the temperature is raised and increasing with lower temperatures. Viscosity has no effect on penetrating ability. Some highly viscous fluids, such as molasses, have very good penetrating ability, while some low viscosity liquids, such as pure water, have very poor penetrating ability. However, from an application viewpoint, viscosity affects the speed with which a penetrant enters a discontinuity. Viscosity also determines how much penetrant will remain on a part surface during the dwell period. High viscosity penetrants cling to the surface, requiring increased effort for removal. Very thin penetrants (low viscosity) may drain from the part surface so quickly that insufficient penetrant remains to enter into discontinuities.

2.4.4.1.2 Specific Gravity.

Specific gravity is the ratio of the density of a substance to the density of distilled water at 40°F (4°C). This is also the ratio of the weight of the substance to an equal volume of water. Specific gravity has no direct effect on the performance of a penetrant. Most commercial penetrants have a specific gravity of less than one, primarily because they are made up of organic materials having low specific gravities. For this reason, water contamination sinks to the bottom of the penetrant tank.

2.4.4.1.3 Flash Point.

Flash point is the temperature at which sufficient flammable vapor is given off a liquid to form an explosive mixture in air over the liquid. The flash point does not affect the performance of a penetrant. High flash points are desirable to reduce the hazard of fire. Penetrants and lipophilic emulsifiers meeting the requirements of ASM 2644 have a minimum flash point of 200°F (93°C) if they are to be used in open tanks.

2.4.4.1.4 Volatility.

Volatility is characterized by the vapor pressure or boiling point of a liquid. It is associated with the evaporation rate of liquids and it is desirable for penetrant materials to have a low volatility, i.e., a high boiling point. However, in the case of petroleum products, viscosity increases as the boiling point goes up. In this group of materials, the lower viscosity is preferred because they require less penetrating time. Still, for practical purposes, high volatility can be avoided before viscosity becomes a problem. High volatility results in a loss of penetrant in open tanks. In addition, a highly volatile material will dry on the part during the penetrant dwell, leaving a film that is difficult to remove. Entrapped penetrant would also have a tendency to dry or lose its liquid properties, resulting in failure to bleed back out of a discontinuity to produce an indication.

2.4.4.1.5 Fluorescent Dye Thermal Stability.

The dyes used in fluorescent-dye penetrants lose their brightness or color when subjected to elevated temperature. Loss of brightness or color also occurs at moderate temperatures, but at a slower rate. This loss is termed "heat fade". ASM 2644 specifies the maximum allowable brightness loss as a function of penetrant sensitivity. This test is performed after a penetrant has been subjected to an elevated temperature. Thermal stability is an important consideration during hot air drying before or after developer application.

2.4.4.1.6 Water Washable Penetrant Thermal Stability.

Thermal stability is the ability of water washable penetrants to resist physical changes under normal operating conditions. ASM 2644 requires water washable penetrants submitted for qualification to be thermally cycled between 0°F and 150°F for 8 hours without separation or precipitation of constituents or major degradation in performance.

2.4.4.1.7 Storage Temperature Stability.
Storage temperature stability is the ability of a penetrant to resist physical and chemical changes when stored in sealed containers at appropriate temperatures. Penetrant materials, excluding dry developer, SHALL NOT be stored in direct sunlight or at temperatures above 140°F (60°C) or below 0°F (-18°C).

2.4.4.2 Chemical Properties.

2.4.4.2.1 Chemical Inertness.

CAUTION

Penetrant materials may cause deterioration and damage to materials that react to hydrocarbons.

Penetrant materials should not react with the materials to be inspected. It is necessary that the penetrant, emulsifier and developer material be chemically inert relative to the parts being inspected. Most oil base materials meet this requirement. However, water contamination of many oils may cause the mixture to become alkaline. This is one of the reasons why water contamination must be avoided. While oily penetrant materials are generally inert to most metals, there is no one material that can be formulated for all parts. Chemical reactivity of penetrant materials must be considered whenever a new application is encountered. Some rubber (natural and synthetic) and plastic (transparent and opaque) parts are susceptible to attack by the solvents and oils in the penetrant materials. Some metals can be degraded at elevated temperatures by the trace amounts of sulfur or chlorine in conventional penetrants. Special low sulfur and low chlorine materials are available and are discussed in Section 2.8, Special Purpose Materials, paragraph 2.8.3.

2.4.4.2.2 Toxicity.
Toxicity is the measure of adverse effects on humans resulting from contact with the material. It applies to any abnormal effects ranging from nausea and dermatitis through dysfunction of major organs, such as the liver or kidneys. It is essential that penetrant materials be nontoxic. In qualifying penetrant materials for the QPL, the manufacturer must submit a certified statement identifying each ingredient in the product by a recognizable chemical or trade name. This information is evaluated for toxicity by the USAF Occupational and Environmental Health Laboratory before the material is listed as a Qualified Product.

2.4.4.2.3 Solvent Ability.
The visibility of indications depends upon the fluorescent or visible dye dissolved in the penetrant oils. The oils used in penetrants must have good solvent properties to dissolve and hold the dye in solution. It must maintain the dye in solution under the wide range of temperatures encountered during transit and storage of the penetrant. If even a small amount of separation occurs, recombination may be very difficult or not possible, resulting in decreased penetrant performance.

2.4.4.2.4 Removability.
This term describes two conflicting requirements for a penetrant: a) the ability to be removed from a surface leaving little or no residual background and b) resistance to being removed from discontinuities. In order to meet the first requirement, the penetrant must maintain the dyes in solution even when in the form of a thin film on the surface of a part and without its more volatile components that have been lost during the dwell time. This requirement is more difficult for water washable penetrants than postemulsifiable penetrants because the water washable penetrant does not receive the additional solvent or surfactant of the emulsifier/remover during the removal process. The second requirement is met by the penetrant resisting the removal process. For water washable penetrants and postemulsifiable penetrants used with a lipophilic emulsifier, this is accomplished by the formation of a gel with the penetrant/water mixture during washing that protects the penetrant in discontinuities from removal. For postemulsifiable penetrants used with a hydrophilic emulsifier (Method D), the resistance is due to the lack of diffusion of the surfactants into the surface penetrant layer, thus making only the thin surface layer emulsifiable and not the penetrant in discontinuities

beneath the layer. For solvent removable penetrants, this can be done only by minimizing the amount of solvent used during the removal process.

2.4.4.2.5 Water Tolerance.

When penetrants are used in open tanks, it is inevitable that some water contamination will occur. Postemulsifiable penetrants are inherently tolerant to water intrusion. Since they are oil based materials, any extraneous water will settle to the bottom of the tank. Although their performance is not degraded, corrosion of the tank can occur. However, water washable penetrants contain emulsifiers and will combine with water. They can tolerate the addition of small amounts of water without losing their properties. The military procurement specification, MIL-1-25135E, requires Method A penetrants to tolerate the addition of 5 percent of water, based on volume, without gelling, separating, clouding, coagulating, or floating of water on the surface.

2.4.4.2.6 Mechanism of Fluorescence.

The mechanism of fluorescence involves two factors: the atomic structure of the fluorescent material and the energy level or wave length of the radiation source. The basic component of all matter is the atom that consists of protons, neutrons and electrons. The protons and neutrons form a positively charged nucleus or core, while the negatively charged electrons circulate in orbits around the nucleus. The orbits are actually shells or rings of discrete energy levels with a definite number of electrons in each shell. A material will fluoresce only if it has a certain atomic structure: the energy holding the electrons in orbit in the outer shells must be low, and there must be vacant electron space in the outermost shell. When a photon of electromagnetic radiation from an X-ray or ultraviolet light impacts an electron in an atom of fluorescent material, the electron absorbs some of the photon energy and jumps from its natural shell to a higher energy shell. The electron is unstable in this condition and immediately returns to its natural shell or orbit. In returning to equilibrium, the electron releases its excess energy as electromagnetic radiation. The released electromagnetic energy always has a longer wavelength than the exciting radiation. Thus, ultraviolet radiation with a wavelength of 365 nm (nanometer, a unit of length) causes some fluorescing materials to release energy that has a longer wavelength of 400 to 700 nm. This is the wavelength range of visible light. The human eye is most sensitive to yellow-green light at approximately 510-560 nm in darkness. Most dyes are made to emit this range.

2.4.4.2.7 Brightness.

One of the more important factors responsible for the effectiveness of the penetrant process is the visibility of the indication. Penetrants containing fluorescent dyes are not especially visible under white light. However, when subjected to near ultraviolet (365 nm) radiation (UV-A or black light), the dyes emit visible light. Some dyes emit more visible light per unit of black light energy than others. In addition, the amount of light given off is proportional to the amount of dye in the penetrant. Brightness is a measure of the amount of visible light given off when fluorescent dye is exposed to black light. It is controlled by the particular dye’s efficiency in converting black light into visible light and by the quantity of dye dissolved in the penetrant. High efficiency dyes are brighter than low efficiency dyes.

2.4.4.2.8 Ultraviolet Stability.

Fluorescent dyes lose their ability to fluoresce after prolonged exposure to black light. Resistance to this loss is termed ultraviolet stability. ASM 2644, requires a diluted sample of fluorescent penetrant to retain a minimum brightness after a one-hour exposure to 800 $\mu W/cm^2$ (microwatts per square centimeter) of black light.

2.4.4.3 Penetrant Sensitivity

The term “sensitivity”, when used to describe a penetrant performance characteristic, is the ability to produce indications from very small, tight cracks. This ability involves both penetrating ability and brightness. The flaw opening in discontinuities is usually restricted, and the void volume is such that only a very small amount of penetrant can be entrapped. The penetrant must enter and exit the flaw with enough dye to produce a noticeable indication.

2.4.4.3.1

The qualification test for sensitivity involves a comparison of the brightness of indications produced by a candidate penetrant system (penetrant and emulsifier) versus the indications produced by a penetrant system designated as a reference standard. The test panels for visible-dye penetrants are thermally cracked aluminum blocks. The test panels for fluorescent-dye penetrants are a series of titanium or nickel alloy panels containing various sizes of laboratory generated fatigue cracks. There is only one set of the latter qualification test panels, and it is not presently possible to produce duplicate fatigue cracks with identical penetrant performance characteristics. Therefore, non-qualification sensitivity comparison tests, which are not used for qualification purposes, may be accomplished with cracked chrome plated panels.

2.4.4.3.2
Figure 2-10 illustrates the effects of different sensitivities by showing the indications produced on cracked chrome panels by penetrants of different sensitivity levels.

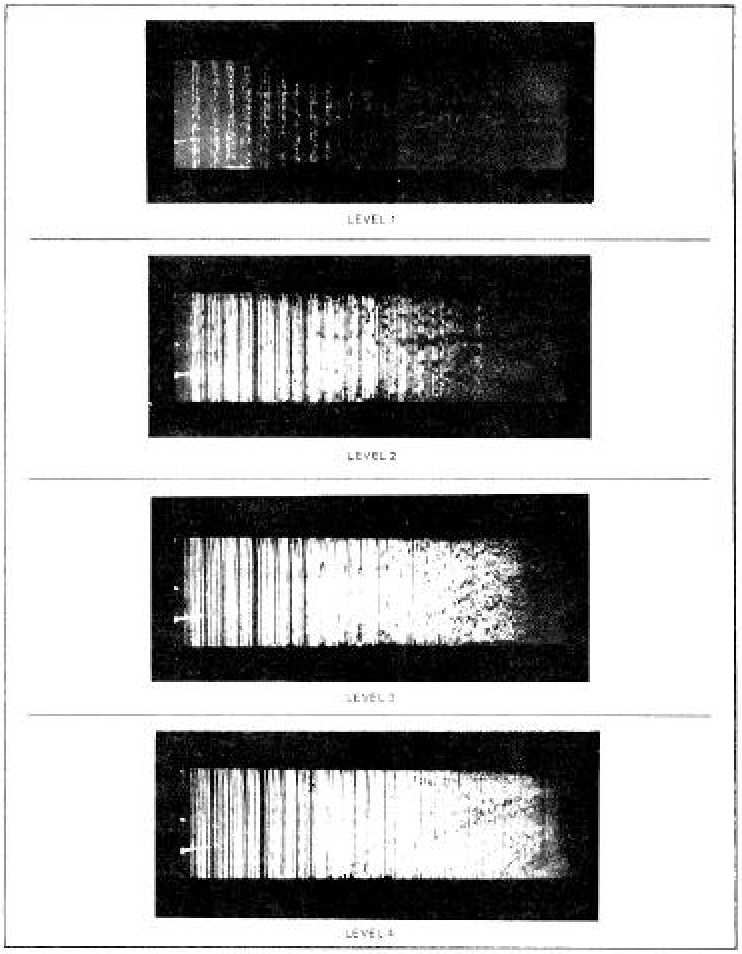


Figure 2-10. Indications Produced by Penetrants of Four Different Sensitivity Levels Using Dry Developer.

2.4.4.3.3
Selection of the sensitivity level to be used depends on a number of factors: potential flaw size, width of opening and volume of the discontinuity; part size, shape, surface finish and residual stress; allowable flaw size; and intended service of the part. The rule is to use the lowest sensitivity that will reveal the discontinuities that are large enough to affect the integrity of the part. Difficulties can be experienced if the sensitivity level is either too low or too high. Low sensitivity levels may not reveal critical flaws, while excessive sensitivity can result in an excessive residual background that would obscure any discontinuity indications or nonrelevant indications.

2.4.5 Application of Penetrant.

2.4.5.1 General.

CAUTION

Care must be taken to avoid trapping air bubbles or pockets during penetrant application to complex shaped parts by immersion. Oil and air passages and blind holes should be plugged prior to penetrant application by immersion. Remove the plugs immediately after the inspection process.

Penetrant can be applied by any of several methods: immersion or dipping, spraying, brushing, swabbing or flowing. The method to be used depends on several factors, including size, shape and configuration of the part or area to be inspected; accessibility of the area to be inspected; and availability of inspection equipment. All methods of application are acceptable provided the surface or area to be inspected is completely coated with penetrant. However, there are certain conditions that must be met for each method.

2.4.5.1.1
Immersing or dipping is the preferred method of applying penetrant when the entire surface of a part must be inspected. The method is limited by the size of the tank or penetrant container. Parts can be immersed one at a time or, if small, can be batch processed by placing them in a basket or rack. When parts are batch processed in a basket, they must be separated from each other during the immersion and dwell period. Contact between parts interferes with the formation of a smooth, even coating of penetrant.

2.4.5.1.2
Certain part conditions require special attention during application of penetrant by immersion. Parts containing concave or recessed surfaces can trap an air bubble or pocket when immersed. Air bubbles or pockets will prevent the penetrant from contacting the part surface. Complex shaped parts should be inverted or turned over while immersed to dislodge any entrapped air. Precautions must also be taken when immersing parts with air cooling or oil passages and blind holes. During immersion, the passages and holes will fill with penetrant that will bleed out during development and obscure an discontinuities in the area. In addition, it is difficult or impossible to completely remove penetrant from passages and blind holes following inspection. Therefore, oil or air cooling passages and blind holes should be plugged or stopped off with corks, rubber stoppers or wax plugs prior to immersion in penetrant. These devices SHALL be removed immediately after the inspection process.

2.4.5.2 Application by Spraying.

2.4.5.2.1 General.
Penetrant, emulsifiers or removers, and wet developers may be applied by any of several hand or automated spray methods. Spray application is especially suitable for parts too large to be immersed, conveyor lines, automated systems, on-aircraft inspections (portable), and when only a portion or local area of a large part or component requires inspection. In applying penetrant by the spray method, the requirement is to apply a thin layer that completely covers the area to be inspected. Application of penetrant by spraying has several advantages over the immersion method. It is usually more economical since large tanks of penetrant are not needed, and pooling of penetrant in part cavities is reduced. In immersion application, pooling removes substantial amounts of penetrant by drag out.

2.4.5.2.2 Air or Pressure Spray.

WARNING

Paint type respirators may be required when spraying penetrant as determined by the Base Bioenvironmental Engineer.

Atomized penetrant is very flammable.

Penetrants can be applied from most types of spray equipment using liquid pressure only, air aspiration only, or a combination. The equipment used is similar to that used in spraying paint. It consists of a supply tank, hoses, and a spray gun or nozzle. The supply tank is pressurized to force the penetrant through the fluid hose to the gun. The gun, which may be hand held or mounted in a fixture for automated spraying, is connected to an air line. The air applied to the gun converts the stream of penetrant into a spray. The air pressure, usually between 10 and 90 psig, controls the size of the spray droplets. Too low a pressure may produce a solid stream of penetrant. This would cover only a narrow area requiring many passes to coat the surface, and it also splatters the penetrant on adjacent surfaces. Too high a pressure can atomize the penetrant into a fine fog with poor covering ability and which drifts away from the part. Spray gun application, other than isolated cases, requires a spray booth and exhaust system for confining and removing the overspray.

2.4.5.2.3 Electrostatic Spray.
The equipment required for electrostatic spraying is similar to that used in air spraying. In addition, a high voltage power supply is connected to the gun. This puts a positive electrical charge on the penetrant particles as they leave the gun. The part is electrically grounded and attracts the charged penetrant particles. The attraction is strong enough to pull the particles to surfaces not in front of or perpendicular to the spray. This ability makes electrostatic spray a preferred method for automated lines where complex shaped parts are to be coated. However, coverage inside cavities is limited. An advantage of the electrostatic spray method is the large savings resulting from reduced material requirements. Electrostatic spraying deposits a thinner layer of penetrant on the part than air spraying and greatly reduces penetrant loss due to overspray. Savings of over 80% compared to immersion application have been claimed.

2.4.5.2.4 Aerosol Spray.
Penetrant packaged in aerosol containers provides a convenient method of application when portability is required. Packaging in sealed containers also eliminates contamination and evaporation of penetrant. Another advantage is that special exhaust equipment, such as used in pressure spray booths, and is not normally required as the amount of penetrant involved is small. There are disadvantages:

a. Material cost is increased by the special packaging.

b. Should not be used on large areas due to small spray pattern and high material cost.

c. Overspray coats adjacent surfaces and complicates penetrant removal.

d. Cans lose propellant and remaining penetrant must be discarded.

2.4.5.2.4.1
Penetrants, unlike nonaqueous developers, do not settle out of solution. Therefore, a mixing ball in the container is not essential. However some manufacturers buy only a single type aerosol can which is then used to package penetrant, solvent remover, or nonaqueous developer. Whether the can does or does not contain a mixing ball, it is good practice to shake the can thoroughly before spraying. This ensures an even distribution of penetrant and propellant. The propellant pressure is directly proportional to the ambient temperature. At temperatures below 60°F (15.6°C), the pressure may be too low for proper spraying. On the high temperature side, the pressure becomes excessive and may burst the container if the temperature reaches 120°F (49°C). When applying penetrant from an aerosol container, the nozzle should be held 3 to 6 inches from the part surface and the can moved in a line to completely cover the area to be

inspected. A thin, even coating with no breaks or non-wetted area is necessary. Excessive penetrant is not desirable as it tends to run or drain off the area and complicates removal. Holding the can motionless or moving it too slowly while spraying will result in an excessive layer of penetrant. Short distances between the can nozzle and the part reduce the size of the spray pattern, and produce a thick layer of penetrant in a small area. Long distances increase the size of the spray pattern, and reduce the penetrant layer thickness. There is also an increase in overspray and the possibility of uncovered areas.

2.4.5.3 Brush or Swab Application.

NOTE

Care must be taken to avoid spilling the penetrant while on or in an aircraft.

Penetrant can be applied to large parts by brushing, wiping, or even pouring from a container. The brush or swab method is most frequently used to coat a small area of a large structure. Brushing or swabbing provides control over the placement of penetrant on the desired area; improves the ability to regulate the quantity or thickness of the penetrant layer; and eliminates overspray. Any sort of brush, swab, rag, or even sponge can be used (synthetic sponges may dissolve in penetrant). The size of the brush can vary from large paint brushes down to small acid or artist brushes, depending on the size of the area to be covered. Any type of clean container can be used to hold the penetrant.

2.4.5.4 Temperature Limitations.

Penetrants may be applied over a range of ambient temperatures. However, certain limits must not be exceeded as the inspection process may be degraded. The operating range for conventional penetrants is 40°F (4°C) to 120°F (49°C). There are special penetrants formulated for hot applications exceeding these limits. They are discussed in Section 2.8, Special Purpose Materials, paragraph 2.8.4.

2.4.5.4.1 Low Temperature Limitations.

Penetrant inspection SHALL NOT be performed when the test part temperature is less than 40°F (4°C). There are several reasons for this restriction:

a. At 32°F (0°C) or less, any moisture, even from the inspector’s breath, will form ice crystals on the part, which will interfere with the penetration process.

b. The propellant pressure in aerosol containers is affected by temperature. The gas pressure decreases with lower temperatures. When the temperature drops below 60°F (15.6°C), the reduced pressure can result in an erratic spray pattern.

c. The evaporation rate of solvent cleaners and nonaqueous developers is reduced at lower temperatures. Figure 2-11 shows the evaporation or drying time for two types of nonaqueous developers at various temperatures. The graph shows a ten-fold increase in drying time between the temperatures of 60°F (15.6°C) and 0°F (-18°C).

d. The viscosity of the penetrant increases as the temperature decreases. When temperatures are between 40°F (4°C) and 60°F (15.6°C), the penetration dwell time must be increased due to the increased viscosity. Additional information on temperature-viscosity is provided in paragraph 2.4.5.5.2.5. The increase in solvent cleaner evaporation time; penetrant dwell time; and developer drying time required at temperatures lower than 40°F (4°C), makes the total inspection time far too long to be practical.

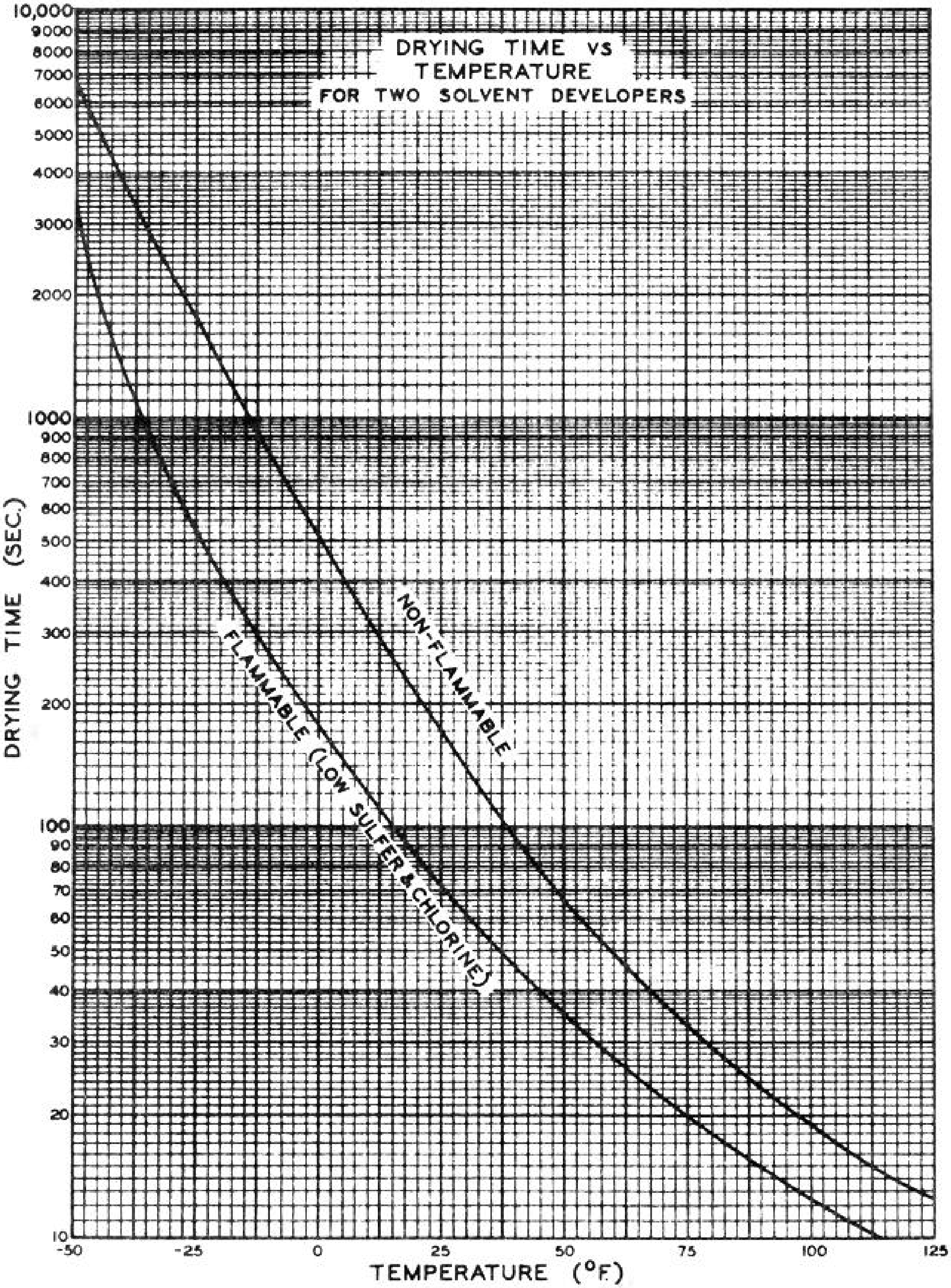


Figure 2-11. Approximate Drying Times for Two Types of Nonaqueous Developers at Various Temperatures.

2.4.5.4.2 High Temperature Limitations.

Sensitivity is improved slightly when test part temperatures are 120°F (49°C) to 150°F (65.5°C). The higher temperature evaporates some of the liquid, which increases the dye concentration and improves the visibility of indications. The elevated temperature also reduces viscosity, which speeds penetration. However, the disadvantages of elevated temperatures outweigh the advantages. At temperatures of 120°F (49°C), the volatile components of penetrants are rapidly evaporated. During penetrant dwell, the layer of penetrant is very thin and with a part temperature of more than 120°F (49°C), the loss of volatile components will drastically change the penetrants composition. Elevated temperatures also reduce visible dye color and fluorescence (heat fade), making indications less visible. Penetrant inspection SHALL NOT be performed on parts whose temperatures exceed 120°F (49°C), unless special high temperature penetrants are used. In general if a part is too hot to handle, it is too hot for penetrant testing.

2.4.5.5 Penetrant Dwell.

2.4.5.5.1 Definition.

Penetrant dwell is the total length of time the penetrant is allowed to remain on the part before removal of the penetrant. This includes immersion, soak and drain times. The purpose of dwell is to allow the penetrant to seep into and fill any surface openings.

2.4.5.5.2 Factors Influencing Penetrant Dwell.

There are a number of interacting factors that influence the length of time required for penetrant to enter and fill a surface void. Some of the factors are included in the list, which is followed by descriptions of each item.

a. Width and depth of the void.

b. Type of penetrant.

c. Part material and form.

d. Type of discontinuity.

e. Penetrant viscosity.

f. Cleanliness of the void.

2.4.5.5.2.1 Void Size.

The dwell time required for a penetrant to enter and fill a surface void depends mainly on the width of the surface opening and depth of the void. Penetrant enters and fills voids with wide openings more rapidly than those with narrow openings. Very narrow or tight flaws, such as those associated with fatigue cracking, may require 2 to 5 times the length of dwell time needed for a wider flaw caused by over-stressing. The larger void depth requires more time to fill because there is more volume of void.

2.4.5.5.2.2 Penetrant Sensitivity.

The sensitivity level of penetrants is affected by the length of penetrant dwell time. The differences in dwell times are due to the differences in surface tension, contact angle, and viscosity of the various penetrant types and sensitivities. While viscosities between manufacturers of the same type and sensitivity level vary, the combination of factors tends to stabilize dwell time for each type and sensitivity. This allows penetrants within each of the sensitivity levels to have equivalent dwell times.

2.4.5.5.2.3 Part Material and Form.

The effect of part material (steel, magnesium, aluminum, etc.) and form (castings, forgings, welds, etc.) on penetrant dwell relates to the type of flaw typically found. For example, cold shuts in steel casting tend to have tighter openings than cold shuts in magnesium castings. Therefore, the dwell time for cold shuts in steel castings is longer than the dwell time in magnesium and aluminum castings. Discontinuities occurring in forgings are tighter than in castings and require more dwell time.

2.4.5.5.2.4 Type of Discontinuity.

The various types of discontinuities differ in the width of the opening. Laps are tighter than porosity, and fatigue cracks are tighter than either laps or porosity. The required length of penetrant dwell increases as the discontinuity width decreases (surface opening becomes tighter or narrower).

2.4.5.5.2.5 Penetrant Viscosity.

Viscosity has been previously defined as the resistance of a liquid to changing shape. This resistance controls the flow characteristics of a liquid and is a major factor in the time required to enter and fill a void. Viscosity of oils, which includes penetrants, changes drastically with temperature. Oils become thin (less viscous) at high temperatures and thick (more viscous) at low temperatures. Figure 2-12 illustrates how the viscosities of a number of QPL penetrants change with temperature. The horizontal and vertical scales are spaced to show the viscosity changes as a straight line function. The chart shows that the viscosity of a high sensitivity, postemulsifiable (PE) penetrant is about 3 centistokes (cs) at 120°F (49°C) and about 75 cs at -10°F (-23.4°C), or becomes about 25 times thicker. The viscosity of visible dye is about 2 cs at 120°F (49°C) and 22 cs at -10°F (-23.5°C), which is an eleven times increase in viscosity. See ASTM D341-43 for viscosity of several QPL Penetrants.

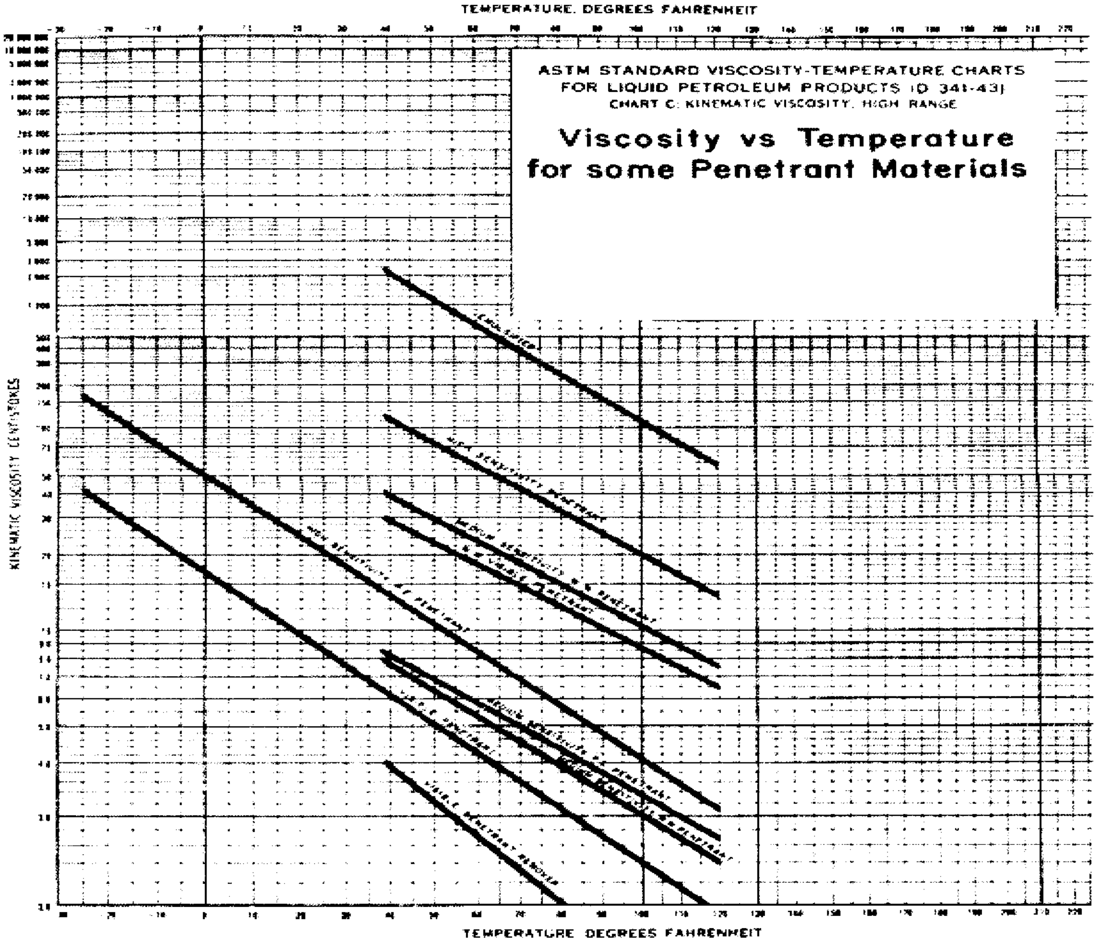


Figure 2-12. Viscosity of Several QPL Penetrants at Various Temperatures

2.4.5.5.2.5.1

The part temperature range for applying penetrants is 40°F (4°C) to 120°F (49°C). Actually, most penetrants are applied at or near a part temperature of 70°F (21.1°C). Therefore, nearly all operating instructions or procedures specifying dwell times are based on applying penetrant to a part that is at or near a temperature of 70°F (21.1°C). For high sensitivity PE penetrant, Figure 2-13 shows that the viscosity (7 cs) at 70°F (21.1°C) is twice the viscosity (14 cs) at 40°F (4°C) and about half the viscosity (3 cs) at 120°F (40°C). Other penetrants show a similar range of viscosity change with temperature. These viscosity changes are significant enough to require the adjustment of dwell times for temperature extremes.

2.4.5.5.2.5.2

NOTE

The evaporation rate of penetrant is increased at temperatures above 100°F (37.2°C). Care must be taken to prevent the penetrant from drying.

Laboratory experiments show that penetrant dwell time does not have to be changed in the same ratio as the viscosity changes. Figure 2-13 compares the minimum dwell times for the penetrants previously discussed. The high sensitivity PE penetrant, with a viscosity of 7 cs at 70°F (21.1°C), required a penetrating time of 3 minutes. At 40°F (4°C), the viscosity doubled to 14 cs, while the dwell time increased by 1.75 to 5.5 minutes. At 120°F (49°C), the viscosity drops to less than one-half (3 cs) and the dwell time is decreased by two-thirds (1 minute). The thinner visible-dye penetrant, with a viscosity of 3.6 cs at 70°F (21.1°C), required a penetrant dwell lime of 2.4 minutes. At 120°F (49°C), the viscosity was reduced by almost one-half (2.0 cs), while the required dwell was reduced to one-fifth of the time (0.5 minutes).

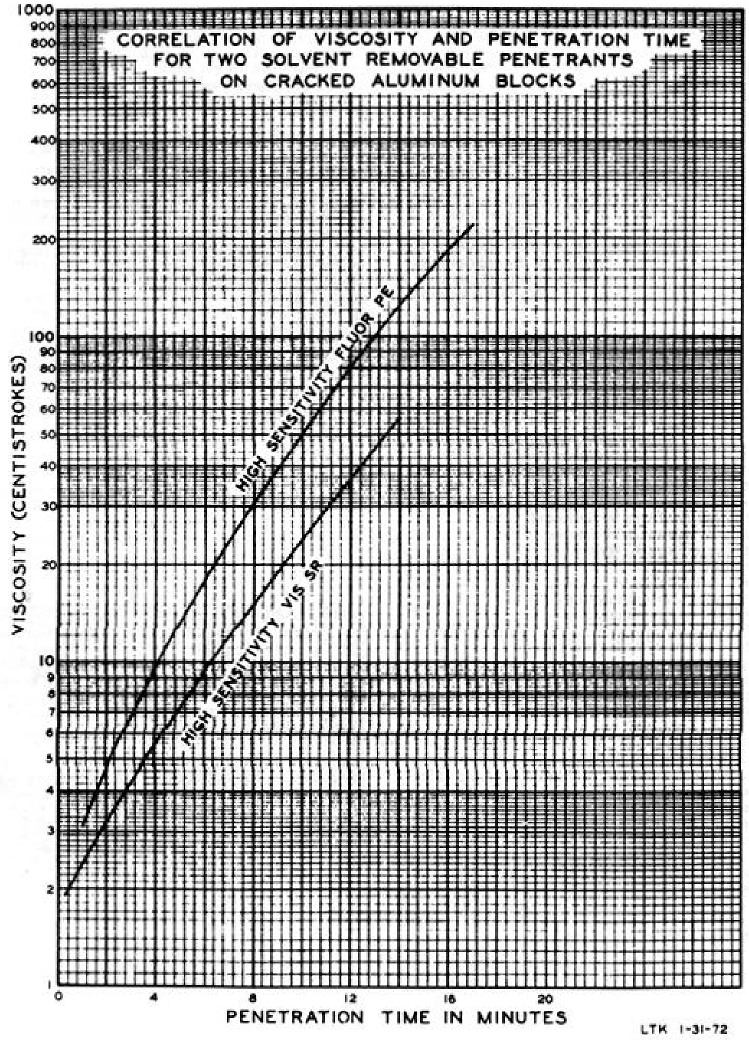


Figure 2-13. Comparison of Dwell Time versus Viscosity for Two Types of Penetrants.

2.4.5.5.2.5.4
Penetrant dwell times, which are normally based on application at room temperatures, must be adjusted to compensate for viscosity changes at other temperatures. The following factors SHALL be used to correct penetrant dwell time for temperature changes:

a. Temperatures between 60°F (15.5°C) and 100°F (37.2°C) shall be considered room temperature, so the specified dwell time SHALL be used over that range.

b. When the part ambient temperature is between 40°F (4°C) and 60°F (15.5°C), the specified dwell time SHALL be doubled.

c. When the part or ambient temperature is between 100°F (37.2°C) and 120°F (49°C), the specified dwell time MAY be reduced by half, but SHALL NOT be less than 5 minutes.

d. The minimum dwell time for service-induced flaws SHALL NOT be less than 30 minutes.

2.4.5.5.2.6 Cleanliness of the Discontinuity
Penetrant dwell times are based on clean parts without entrapped contaminants. Inspection of parts that have been in service can be complicated by the difficulty of removing all of the entrapped soil from the discontinuities. The effect of the entrapped soil on the penetrant dwell time depends upon the type and amount of soil involved.

2.4.5.5.2.6.1
If the discontinuity is full of soil that is not soluble in penetrant, penetration cannot occur. A change in penetrant sensitivity or dwell time will not help since penetrant can not enter such flaws. A discontinuity that is only partially filled with insoluble soil will produce a smaller and less visible indication. Increasing the dwell time will not improve the indication. However, a more sensitive penetrant with its higher dye content will produce a more visible indication.

2.4.5.5.2.6.2
When discontinuities contain soils that are soluble in penetrants, such as unpigmented grease, oils, cleaning solutions and other soluble organics, the situation is different. The penetrant will fill any vacant space in the discontinuity and then stop. Diffusion then begins between the penetrant and soluble soil (paragraph 2.5.5.3.1 describes the diffusion process). In a short time, the penetrant and soil become evenly mixed. This mixture will fluoresce much less and may not give a useful indication. An increase in dwell time will improve the visibility of the indication. With increased dwell time some of the soil diffuses out of the discontinuity and is replaced with pure penetrant. Using a more sensitive penetrant will improve the visibility of the indication since the higher dye content can withstand more dilution.

2.4.5.5.2.6.3
In summary, when a flaw is partially filled with an insoluble soil, an increase in dwell time will not improve the visibility of the indication. However, if the soil is soluble in the penetrant, the visibility will improve with increases in dwell time. In both cases, with insoluble and soluble soil contamination, a higher sensitivity penetrant should improve the results.

2.4.5.6 Penetrant Dwell Characteristics.

2.4.5.6.1 Dwell Modes.
There are two basic penetrant dwell modes, immersion and drain.

2.4.5.6.1.1 Immersion Dwell.
In this mode the part remains submerged in a tank of liquid penetrant for the entire dwell period. Immersion dwell can also be performed by continuously brushing with fresh penetrant throughout the dwell period.

2.4.5.6.1.2 Drain Dwell

NOTE

> The drain dwell mode SHALL be used unless the inspection instruction specifies immersion dwell.

With drain dwell, the part is first covered with penetrant by spraying, brushing or immersion. Once coated, the part is placed on a rack or rest and allowed to drain during the dwell period. Comparison tests with aluminum crack blocks and nickel-chrome penetrant panels have demonstrated the improved performance of drain dwell mode compared to that of immersion dwell mode. This improved performance is due to the changes in penetrant composition that occurs during the dwell period. The penetrant vehicle is a mixture of heavy oils that dissolve and hold the dye materials in solution; and thin or lightweight solvents or oils that reduce the viscosity of a penetrant. During the drain dwell period, the lighter weight liquids evaporate, which increases the concentration of the dye material entrapped in discontinuities. The increased dye concentration enhances the visibility of the indication. The drain dwell mode is also more economical than immersion dwell mode since the excess penetrant drains from the part and is recovered. The savings with drain dwell are two-fold, since the drained penetrant is recovered and the remaining penetrant layer is much thinner than an immersion dwell layer. The thinner penetrant layer requires less emulsifier during the removal process. Generally the immersion is momentary, but at most it should be no longer than half the total dwell period.

2.4.5.6.2 MINIMUM PENETRANT DWELL TIMES

NOTE

> Selection of a penetrant dwell time is complex and depends upon a large number of factors. A thorough knowledge of the penetrant capabilities and limitations of the penetrant system used for the type of discontinuity to be detected is required. Whenever possible, the decision of dwell time should be based upon experience of the cognizant engineering support. Documents governing dwell time should specify the mode and time of dwell.

The number of factors influencing the entry of penetrant into a discontinuity complicates setting uniform minimum penetrant dwell times. Most dwell times are based on past experience with similar parts, materials and potential flaws. The minimum dwell time for service-induced defects SHALL NOT be less than 30 minutes. There is one exception to this requirement. When stress corrosion cracking is suspected the minimum dwell time SHALL NOT be less than 240 minutes. These established minimum dwell times are based on parts having a temperature of 60°F (15.5°C) to 100°F (37.2°C). When part temperatures are 100°F (37.2°C) to 120°F (49°C), the dwell time may be reduced by half, except a minimum of 5 minutes dwell time is required. When part temperatures are between 60°F (15.5°C) and 40°F (4°C), the minimum dwell time SHALL be doubled. Penetrant inspection SHALL NOT be performed with part temperatures below 40°F (4°C) or above 120°F (49°C). For long dwell times refer to paragraph 2.4.5.6.4 for precautions to take for a successful inspection.

2.4.5.6.3 Effects Of Insufficient Dwell.

When the dwell time is too short to allow the penetrant to completely fill the discontinuity, the visibility of the resulting indication will be reduced. Figure 2-14 shows a thermally cracked, aluminum block with one half receiving an adequate dwell, and the other half an insufficient dwell. The differences in dwell times have different effects depending on the flaw size. The very small flaws are not indicated; the visibility of indications from medium size flaws is greatly reduced; and there is a slight reduction in the visibility of larger size flaw indications. If it is suspected that a part has not had an adequate dwell, the part SHALL be completely cleaned and then reprocessed through the entire inspection process.

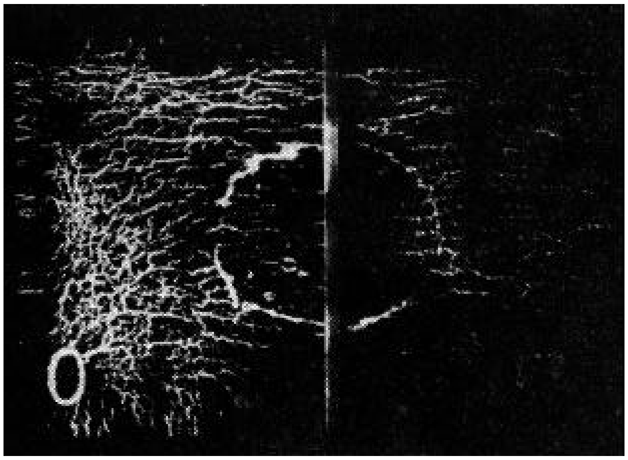


Figure 2-14. Comparison of Adequate Dwell versus Insufficient Dwell on a Thermally Cracked Aluminum Block.

2.4.5.6.4 Effects of Excessive Dwell.
Once the penetrant has completely filled a void, extending the dwell time will not improve the indication, except for contaminated flaws. Extended dwell times caused removal difficulties with older penetrants that became very viscous with longer dwell times. The newer penetrants do not have this problem, as they are required to meet a removability test after an extended dwell time. However, it is good practice to apply fresh penetrant at 60 minute intervals when long dwell times are required. When intermediate dwell times of 45 minutes or more are involved, the fresh penetrant should be applied 15 minutes before removal, or at any time the penetrant appears to be drying on the part. Application of fresh penetrant improves the rate of penetration and makes it easier to remove the excess surface penetrant at the end of the dwell period. The penetrant SHALL NOT be allowed to evaporate to the tacky or dry state while on the part. Evaporation is accelerated by temperatures above 100°F (37.2°C) or by rapid air movement. If, for some reason, the penetrant is allowed to become tacky, the part SHALL BE subjected to a complete reprocessing through the precleaning and penetrant inspection cycle. When inspections require excessively long penetrant dwell times, another inspection method, such as eddy current, may be considered to reduce inspection time.

SECTION V
PENETRANT REMOVAL

2.5 PENETRANT REMOVAL.

2.5.1 Summary.
This section provides basic, intermediate, and advanced information on the theory, methods and procedures used in removing the excess surface penetrant. The first portion of the section contains general information applicable to all removal methods. The second portion is devoted to the water washable penetrant processes and water washing or spray rinsing. The remaining portion covers the theory and procedures used in the postemulsifiable lipophilic, postemulsifiable hydrophilic and solvent removable penetrant processes.

2.5.2 Introduction.
After the penetrant has been applied and has filled any open discontinuities, the excess penetrant on the surface must be removed. Removal of the excess surface penetrant is a critical step in the inspection process. Improper removal can lead to misinterpretation and erroneous results. Excessive or over-removal will reduce the quantity of penetrant entrapped in a flaw, resulting in either a failure to produce an indication or an indication with greatly reduced visibility. Incomplete or insufficient removal will leave a residual background that may interfere with the detection of flaw indications. The term "removability" applies to the ease of removing the excess surface penetrant. Washability is

sometimes used interchangeably in commercial application; however, the materials specification and this manual will use "washability" only in the case of water washable penetrants.

2.5.3 Factors Influencing Removability.

2.5.3.1 Part Surface Condition.

The surface condition of the part has a direct effect on removability. Smooth, polished surfaces such as chromium plated panels can be easily processed by any of the removal methods with no residual background. As the surfaces become rougher, such as chemically etched or sand blasted parts, the removal of surface penetrant becomes more difficult. Rough surfaces reduce removability in two ways: the roughness restricts the mechanical force of the spray rinse in the indentations or low points and prevents the emulsifier from evenly combining with the surface penetrant. It is not always possible to produce a background-free surface on rough parts. The wash or emulsification time required for a completely clean surface may result in removal of some of the penetrant entrapped in flaws. In this case, the wash or emulsification time must be shortened, leaving some residual background. The amount of residual background must be limited to allow any flaw indications to be visible through the background.

2.5.3.2 Part Shape or Geometry.

The part shape and geometry may indirectly affect removability by causing a thicker layer of penetrant to accumulate during the dwell period and restricting accessibility to the test surface by the spray rinse. One of the factors involved in removing excess surface penetrant is the mechanical action or force of the spray rinse. When parts contain surfaces where the spray cannot directly strike the surface, such as concave or recessed areas, holes, and screw threads, the removal time is increased in these local areas. Also, the thickness of the penetrant layer in these inaccessible areas is usually greater than that on the adjacent surfaces. This is due to the tendency of the penetrant to drain and collect in these areas. For example, during the dwell period the penetrant will drain from the top or crown of a thread and will flow into the thread root area. The increased layer thickness in the thread root requires a longer removal time than the thin layer at the thread crown. The inaccessible surfaces usually have thicker layers of penetrant and require additional removal time. Care must be exercised to prevent over-removal on the accessible surfaces with thinner penetrant layers, while trying to adequately clean the thicker penetrant layer from an adjacent inaccessible surface.

2.5.3.3 Flaw Size and Shape.

Flaw size and shape complicate the removal process. Narrow, deep flaws, while requiring long penetrant dwell times, provide a relatively large reservoir to hold entrapped penetrant. The narrow surface opening reduces both the diffusion rate of emulsifier into the flaw and the mechanical force of the spray rinse on the entrapped penetrant. The result is that narrow, deep flaws produce highly visible indications with a minimum of removal problems.

2.5.3.3.1

The removal process becomes slightly more critical when narrow, shallow flaws are present. Narrow, shallow flaws do not have a large reservoir to hold entrapped penetrant. The visibility of an indication depends on the amount of penetrant that exits from the flaw. If the flaw is shallow, only a small amount of penetrant is available, and the indication may be faint. Over-removal of any entrapped penetrant will reduce the visibility of an already faint indication. In addition, a small amount of residual background (insufficient removal) will obscure faint indications.

2.5.3.3.2

Broad, shallow flaws are defined as those with the surface opening equal to or greater than the depth. They present the most critical case for penetrant removal. The opening does not reduce the force of the spray rinse, nor does it restrict the emulsification rate, and entrapped penetrant is easily removed. Extreme care must be used during penetrant removal if broad shallow flaws are likely to be present.

2.5.3.4 Type Of Penetrant.

Penetrant materials vary widely in their ease of removal. There are differences in removability between the various penetrant types, classes, and sensitivity levels. Also, similar penetrants provided by different manufacturers vary in removability. One penetrant characteristic affecting removability is the viscosity. High viscosity (thick) penetrants are more difficult or more slowly removed than low viscosity (thin) penetrants. The penetrant system sensitivity level also affects removability. Higher system sensitivity level penetrants contain more dye per unit volume, and trace quantities of residual penetrant will produce a higher background than the same quantity of a penetrant system with a lower sensitivity level. It is necessary to remove more of the residual high sensitivity penetrant to produce an equivalent background.

2.5.4 Removal of Water Washable Penetrant, Method A.

2.5.4.1 General Description.

Water washable penetrants are penetrants that contain an emulsifying agent. The excess surface penetrant is removed with a water spray following the penetrant dwell period. The water washable penetrant is converted into small suspended oil droplets by the mechanical force of the water spray. A separate process step of applying emulsifier is not required. Water washable penetrants are often called "self-emulsifying" and are one of the most widely used non-destructive inspection methods. Water washable penetrants exist in all penetrant system sensitivity levels.

2.5.4.2 Removal Procedure.

Water washable penetrant is removed after penetrant dwell by subjecting the part to a water spray wash. The spray wash may be a hand-held nozzle, a semi-automatic system, or a fully-automated system. Care must be exercised to prevent over-removal since the penetrant entrapped in discontinuities contains an emulsifying agent and is easily removed. Removal is controlled by length of wash time and the wash must be stopped when an acceptable background is reached. Figure 2-15 shows cracked chrome panels following different wash times. Insufficient wash, optimum wash, and excessive wash are shown. The smooth surface of the chrome plated panel is deceptive. If the surface were rougher, some residual background may have been retained on the optimum-wash sample. Water washing of fluorescent penetrant SHALL be accomplished under black light. The wash station should be in subdued light, if possible (20 lumens). Details on water washing are provided in paragraph 2.5.4.5.

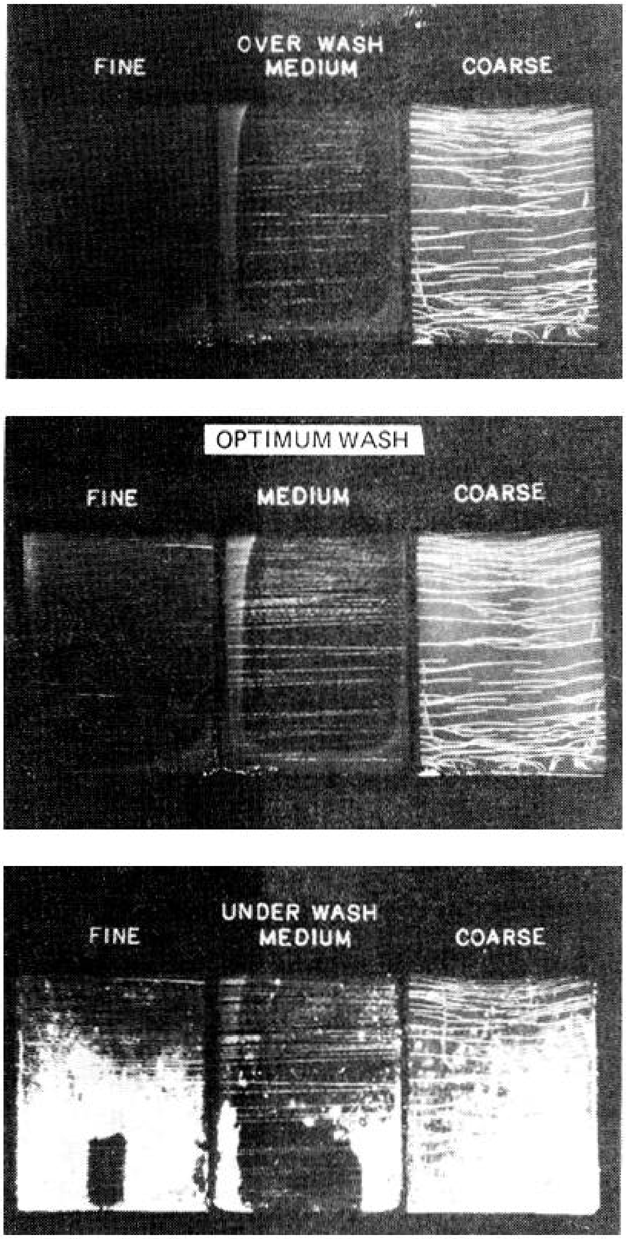


Figure 2-15. Cracked Chrome Panels Showing Effects of Insufficient Wash, Optimum Wash and Excessive Wash.

2.5.4.3 Advantages Of Water Washable Penetrant, Method A.

a. Elimination of the separate emulsification process step results in the following cost savings:

(1) The cost of the combined penetrant emulsifying agent is less than the total cost of separate penetrant and separate emulsifier.

(2) A separate tank or station for emulsifier is not required.

(3) Cost of automating is reduced.

(4) Process flow time, especially on volume production, is reduced.

b. The emulsifiable mixture is easily removed from complex shaped parts, making it advantageous for use on threads and keyways.

a. The variables associated with controlling emulsifier dwell time are eliminated.

2.5.4.4 Disadvantages Of Water Washable Penetrant, Method A.

a. There is no control over the diffusion or emulsified layer. Penetrant entrapped in flaws contains emulsifying agent, making it susceptible to removal by over-washing. It is also easily removed from broad, shallow flaws.

b. Water rinse time is critical and must be carefully controlled.

c. Residual background is higher than that from the same sensitivity level postemulsifiable penetrant system.

d. The penetrant emulsifying agent mixture is susceptible to water contamination.

e. Treatment/disposal of large quantities of rinse water contaminated with water washable penetrant.

2.5.4.5 Water Washing or Spray Rinsing.

2.5.4.5.1 General.

Water washing or spray rinsing is usually accomplished in a stationary rinse tank, which is provided with a hose, nozzle, drain, and in the case of fluorescent penetrant, a black light. Figure 2-16 is a typical wash station with a good spray shown. The rinsing procedures used for removal of water washable penetrant, Method A, and postemulsifiable penetrant, Method B (after emulsification) are almost identical. The difference is in controlling the rinse time. Rinse times for Method A penetrants are very critical as the entrapped water washable penetrant can be removed from discontinuities if the time is not controlled. Entrapped postemulsifiable penetrants that have not been diffused with emulsifier resist removal, and rinse times are not as critical. The conditions and procedures described in the following paragraphs are applicable to both water washable and postemulsifiable penetrants.

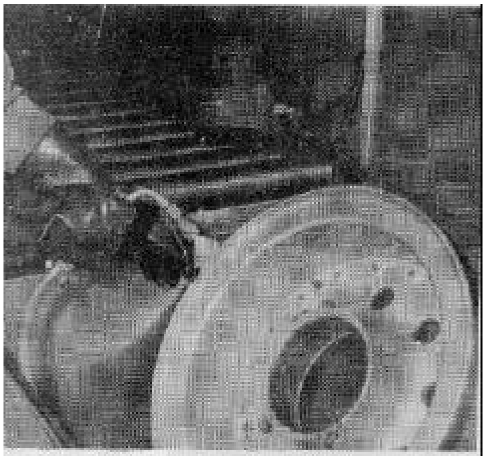


Figure 2-16. A Typical Wash or Rinse Station.

2.5.4.5.2 Factors Influencing Effectiveness of Spray Rinse.

2.5.4.5.2.1 Size of Water Droplets.
Removal of excess surface penetrant depends upon the mechanical force of the water impacting the part surface. The impact force consists of the droplet mass and velocity at impact. The two factors are related, and increasing either will produce a higher mechanical force. There are limits on both size and velocity; the latter is derived from the water pressure. If the droplet is small or if the pressure is too high, the result will be a fog or mist with little removal ability. On the other hand, a solid stream of water, as shown in Figure 2-17, is not desirable either because it covers only a small area at one time and is actually one large continuous drop.

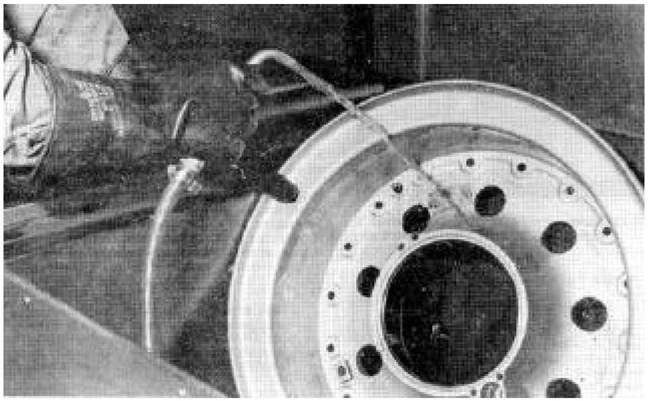


Figure 2-17. An Improper Washing Procedure.

2.5.4.5.2.2 Water Pressure.
The effect of water pressure is straight-forward. Increased water pressure increases the speed of removal. However, excessive pressure can atomize the water into a fog that is useless for removal. Normal line pressure, approximately 10 to 35 psig, is acceptable and is generally used. Water pressures in excess of 40 psig or injection of compressed gases or air into the water system SHALL NOT be used.

2.5.4.5.2.3 Water Temperature.
The temperature of the rinse water will affect the washability. Some penetrant-emulsifier combinations may form a gel with water temperatures of 50°F (10°C) or less. This gel can be removed but requires longer wash times. Other penetrant emulsifier combinations have reduced removability at elevated temperatures, above 110°F (43°C). The effect of temperature on washability depends upon the penetrant formulation, which varies between suppliers. Penetrant-emulsifier combinations meeting specification requirements are washable in the temperature range of 50°F (10°C) to 100°F (38°C). Hot water, 120°F (49°C) or above SHALL NOT be used.

2.5.4.5.2.4 Spray Angle.

NOTE

Water nozzles that are capable of producing spray patterns such as solid streams or a fine mist SHALL NOT be used. Rinsing dye penetrant from the surfaces of parts SHALL be accomplished with a fan-shaped, coarse spray.

The angle of spray may be varied over a wide range with only slight effects on the removal time. When the angle is close to perpendicular (80 to 90 degrees), the droplets will rebound into the on-coming water, diverting the fresh droplets, which reduces the scrubbing action. The scrubbing action is also reduced when the spray is close to parallel with the part surface (10 to 20 degrees), since there is little energy transfer at the point of impact. Generally, an angle of 45 to 70 degrees is most effective.

2.5.4.5.3 Recommended Procedure.
Washing is best accomplished with a fan shaped, coarse spray with a temperature range of 60°F (15.5°C) to 100°F (37.8°C), and line pressure water not to exceed 40 psig. The wash time will depend upon the surface roughness of the part. Water washable penetrant can easily be over-washed and wash time must be closely controlled. Washing of fluorescent penetrant SHALL be done under a black light in a semi-darkened area and the washing stopped when a low background level is reached. If small defects must be detected in parts with rough surfaces, some residual background may be necessary.

2.5.5 Removal of Postemulsifiable Penetrant, Methods B and D.

2.5.5.1 Introduction.
Postemulsifiable penetrants are oil based vehicles containing highly visible colored or fluorescent dyes. They are formulated to optimize their penetration and visibility capabilities. They differ from water washable penetrant in that they resist removal by water washing since they do not contain an emulsifier. A separate process step of emulsification is required for removal. This is done by one of two methods: lipophilic process or hydrophilic process.

2.5.5.2 Derivation of the Names Lipophilic and Hydrophilic.
The words, "lipophilic" and "hydrophilic", like many other chemical and medical terms, have their basis in Greek word elements: "lipo" comes from the Greek word for oil or fat, whereas "hydro" is from the Greek word for water. "Philio" means a fondness or affinity for, borrowed from the Greek word "philos" for loving. Thus, lipophilic is an oil or fat based material, and hydrophilic is a water based solution. In this chapter, the word "emulsifier" will be used when referring to lipophilic material and the word "remover" will be used when discussing hydrophilic material. This is a practice generally used by industry.

2.5.5.2.1 Lipophilic versus Hydrophilic Processes.
Details of the two processes are discussed below. Some basic differences are summarized as follows:

a. Lipophilic emulsifier is supplied in a ready to use liquid, whereas hydrophilic remover is supplied as a liquid concentrate that has to be diluted with water.

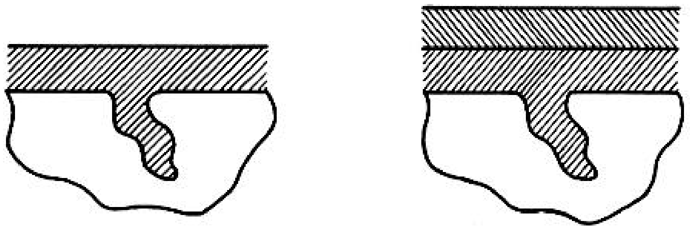
b. The hydrophilic process requires an additional pre-rinse step following the penetrant dwell period.

c. The methods of applying the emulsifier and remover differ. Parts are dipped into lipophilic emulsifier and then immediately removed to drain. Parts either are immersed into hydrophilic remover for the entire removal time or are subjected to a spray of remover for the specified time.

d. The modes of action by which the emulsifier and remover remove the excess penetrant differ. This is also why the application methods differ as explained in the previous paragraph.

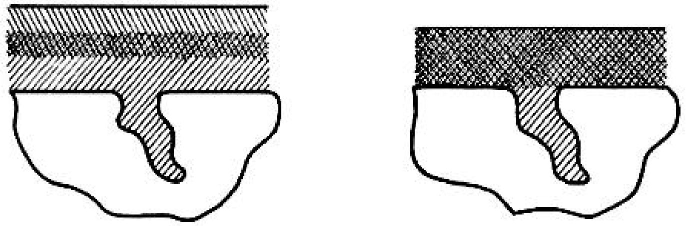
2.5.5.3 Lipophilic Emulsifier Process, Method B.

2.5.5.3.1 Mode of Action.
Diffusion into the oil-base penetrant is the primary action. Diffusion is the intermingling of molecules or other particles as a result of their random thermal motion. If two miscible (capable of being mixed) liquids or gases are placed in a container, they will eventually mix into a uniform solution. For example, if a sugar solution (a heavy solution) is placed in the bottom of a glass, and plain water (lighter medium) is placed on top, the sugar will migrate across the boundary. After a period of time, the entire quantity of liquid will reach a nearly uniform concentration. This is what happens when emulsifier is applied to a layer of penetrant on a part (see Figure 2-18).



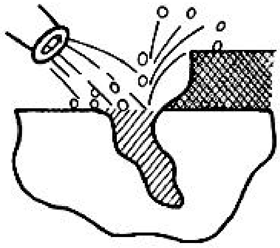
A. APPLY PENETRANT

B. APPLY EMULSIFIER



C. DIFFUSION

D. DIFFUSION COMPLETE



E. RINSING

Figure 2-18. Diffusion of Emulsifier into Penetrant during the Lipophilic Emulsifier Dwell.

2.5.5.3.1.1
The physical action of the penetrant/emulsifier mixture draining from a part removes some of the excess penetrant. The remainder of the surface penetrant is removed as the penetrant/emulsifier mixes with water during the spray rinse and drains away. Generally oil and water do not mix, that is, they are immiscible. However, this is not always the case. If equal amounts of oil and water are placed in a bottle, they will immediately separate into two distinct layers. If the bottle is shaken, the oil will form into globules, which are dispersed throughout the mixture. When the bottle is allowed to rest, the globules will rise to the surface and reform into a separate oil layer. The process of the globules combining to form this layer is called coalescence. If the amount of oil is small compared to the quantity of water, and the bottle is violently shaken, the oil will be broken into very small droplets. On standing, most of the droplets will coalesce at a slower rate than previously described. However, some of the very small droplets will remain suspended in the water giving it a cloudy or milky appearance. Depending on the droplet size, it may require an extremely long time for separation to take place. This cloudy water mixture is called a colloidal suspension and the process by which it is formed is termed emulsification. Certain chemicals have the ability to combine with oily materials to form an easily emulsifiable mixture. This is the case when an emulsifier is applied to a penetrant on a part. The penetrant is oil that repels water and resists removal. However, when combined with an emulsifier, the resulting colloidal mixture can be removed with a water spray.

2.5.5.3.2 Application of Emulsifier.
Lipophilic emulsifier is used as supplied by the manufacturer. It usually is applied by dipping or immersing the part in a tank of emulsifier. Application by spraying or flowing the emulsifier is not recommended. The two major problems with spraying are the difficulty in applying a uniform thickness and the difficulty of applying enough emulsifier without the mechanical force of the spray scrubbing the penetrant layer. There are a few automated systems where the emulsifier is applied as a fog. Emulsifier SHALL NOT be applied by brushing or wiping. Brushing or wiping produces an uncontrolled and uneven mixing action.

2.5.5.3.3 Emulsifier Drain / Dwell.
When the part surface has been coated with emulsifier, the part SHALL be removed from the liquid and allowed to drain. The part SHALL NOT remain in the emulsifier during the dwell period. Care must be exercised to prevent pooling in cavities during the dwell. Immersion dwell would nullify one of the modes of emulsifier action. It was once thought that emulsification occurred only through the chemical action of diffusion. It is now recognized that two modes are involved. The first mode occurs as the emulsifier drains from the part surface during the dwell period. As the emulsifier drains, the movement carries with it considerable surface penetrant. This scrubbing or mechanical action reduces the amount of penetrant to be emulsified and also initiates the chemical or diffusion action. Without this mixing action, emulsifier dwell time might be as long as ten or twenty minutes.

2.5.5.3.3.1

CAUTION

When a number of parts are being inspected, they SHALL be processed one at a time through the emulsifier, emulsifier dwell and wash steps unless they are small enough to be batch processed. Excessive dwell will occur when emulsifier is applied to a number of parts and they are then individually washed.

After emulsifier has been applied and the part is draining, a period of time is allowed for diffusion. During diffusion, a water removable colloidal mixture is being formed. This is the emulsifier dwell time and is one of the most critical factors in the lipophilic process. A timing device is required to control this process. The objective is to stop the diffusion when the emulsifier has just reached the part surface and before it diffuses into any penetrant entrapped in a discontinuity. Penetrant without emulsifier resists removal. If the dwell time is too long, the emulsifier will diffuse into entrapped penetrant that is easily removed causing loss of sensitivity and missed flaws. If the time is too short, the thin layer of surface penetrant not emulsified will cause an excessive background that can obscure a discontinuity indication. A number of factors, which influence the dwell times, are discussed in the following paragraphs.

2.5.5.3.3.2
Although emulsifier dwell time is critical for most defects, the large number of influencing factors makes it impossible to develop a general dwell timetable. Optimum emulsifier dwell time must be determined on each part by experiment. Even here, dwell times may require adjustment to compensate for local conditions. At the extreme, dwell times may range from 10 seconds to 5 minutes; however, typical dwell times are less than 1 minute. Under no circumstances shall the emulsifier dwell time exceed 5 minutes. The lipophilic emulsion step does not tolerate deviation from the optimum dwell time. A relatively short over-emulsification time of 10 seconds on a 1 minute dwell period can result in failure to indicate small flaws. Figure 2-19 are cracked chrome plate panels showing the effects of insufficient, optimum and excessive emulsifier dwell.

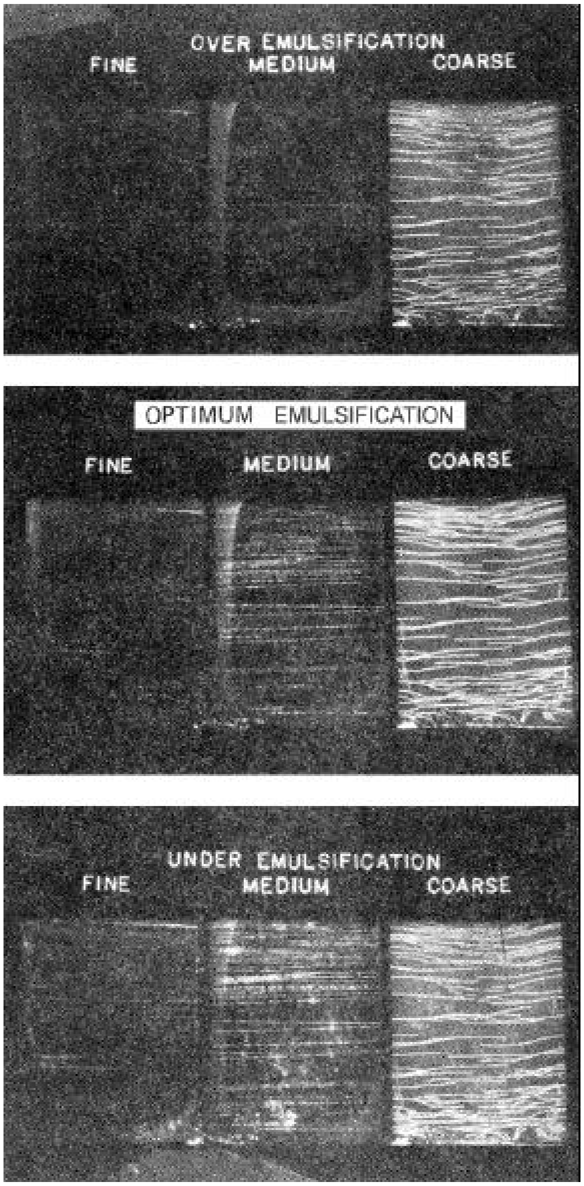


Figure 2-19. Results of Insufficient, Optimum and Excessive Lipophilic Emulsifier Dwell Time.

2.5.5.3.4 Factors Influencing Dwell Time.

2.5.5.3.4.1 Part Surface.

Very smooth polished surfaces retain only a thin layer of penetrant and requires a relatively short emulsifier dwell period. On the other hand, longer emulsifier dwell times are required for rough surfaces such as sand castings that retain a thicker layer of penetrant which dictates a longer time for the emulsifier to diffuse to the bottom of the surface indentations.

2.5.5.3.4.2 Flaw Type.

Tight flaws, with significant depth relative to flaw width, are more tolerant to longer emulsification dwell time than are wide, shallow flaws. The diffusion rate of even the more active emulsifiers is slowed down when diffusing into constricted or narrow openings. The diffusion rate on wide, shallow flaws is not slowed, and it is easy to over-emulsify. Flaw depth is a determining factor for both narrow and wide flaws. Flaws with some depth provide a large reservoir to entrap penetrant and some over-emulsification can be tolerated. When shallow flaws must be detected in parts with rough surfaces, some under-emulsification or residual background may be necessary.

2.5.5.3.4.3 Emulsifier Types.
There are at least two general types of emulsifiers. The two general types are similar in composition with the principal difference being viscosity. However, viscosity and diffusion rates are related and viscous materials diffuse slowly, while thinner, less viscous emulsifiers diffuse more rapidly.

2.5.5.3.4.4 Penetrant Dwell Time.
Long penetrant dwell times permit more penetrant to drain from the part, resulting in a thinner surface layer. Since diffusion rate for a given emulsifier is constant, the emulsifier dwell time required is proportional to the thickness of the penetrant layer, i.e., thicker layers require more emulsification dwell time, and thinner layers require less time.

2.5.5.3.4.5 Penetrant Contamination.
As parts are processed, the emulsifier becomes contaminated with penetrant from both the initial immersion and the drain cycle. While penetrant and emulsifier are soluble in all combinations, the gradual increase of penetrant in the emulsifier slows the emulsification action. With combined build-up, the mixture will eventually stop functioning as an emulsifier. The slowing action due to penetrant contamination is very gradual, and at concentrations of less than 25%, penetrant in emulsifier is not noticeable for practical purposes.

2.5.5.3.5 Water Rinsing the Emulsified Layer.
When diffusion of the emulsifier has reached the desired end point, further diffusion is stopped by spraying with water. The same water spray serves to remove the emulsified penetrant surface layer. Details of the water spray wash are given in section 2.5.4.5. One variation in technique is the initial requirement to rapidly and lightly water spray the entire surface at the end of the emulsification dwell period, without regard for removal of the emulsified layer. This stops the diffusion process and eliminates excessive emulsifier dwell on one surface, while removing penetrant from an adjacent surface. The emulsified surface layer can be removed after the entire surface has been wetted and the diffusion process has been stopped. Postemulsifiable penetrant entrapped in flaws and not diffused with emulsifier is relatively resistant to water spray and rinse time is not critical. However, excessive spray pressure or hot water can remove entrapped penetrant and must be avoided.

2.5.5.3.6 Insufficient or Excessive Emulsification.
The part SHALL be completely reprocessed if, during or after the rinse step, it is suspected that a too short (insufficient emulsification) or too long (excessive emulsification) dwell time has occurred. Correction of dwell time cannot be made by immersing in penetrant or emulsifier. The part must be cleaned to remove all residual penetrant and reprocessed through the entire process.

2.5.5.4 Hydrophilic Remover Process, Method D.

2.5.5.4.1 Introduction.
The objective in both the lipophilic and the hydrophilic methods is the removal of excess surface penetrant without removing any of the penetrants entrapped in discontinuities. However, the hydrophilic method is completely different from the lipophilic method. The differences are in the materials, mechanism or mode of action, and the procedures used. The removal of excess surface penetrant using hydrophilic removers can be accomplished using immersion or spray techniques. A combination of both immersion and spray is most often used in hand lines and is recommended.

2.5.5.4.2 Mechanism or Mode of Action.
Hydrophilic removers are basically detergent/dispersant concentrates consisting of water soluble chemicals, usually non-ionic surface active agents called surfactants. They are supplied as concentrated liquids and are mixed with water either before or during the removal process. The surface active agent in the remover displaces a small quantity of penetrant from the surface and disperses or dissolves it, preventing it from recombining with the remaining penetrant layer. Unlike lipophilic emulsifier, hydrophilic remover is immiscible with penetrant and diffusion does not occur. All of the removal action takes place at the exposed surface, and penetrant just below the surface is not involved until it becomes exposed. Gentle agitation of the liquid helps remove the displaced penetrant and allows fresh remover to

contact the remaining penetrant layer. The action stops when the part is withdrawn from the remover, unlike lipophilic emulsifiers that become active only after withdrawal and during drainage. Figure 2-20 illustrates hydrophilic remover action.

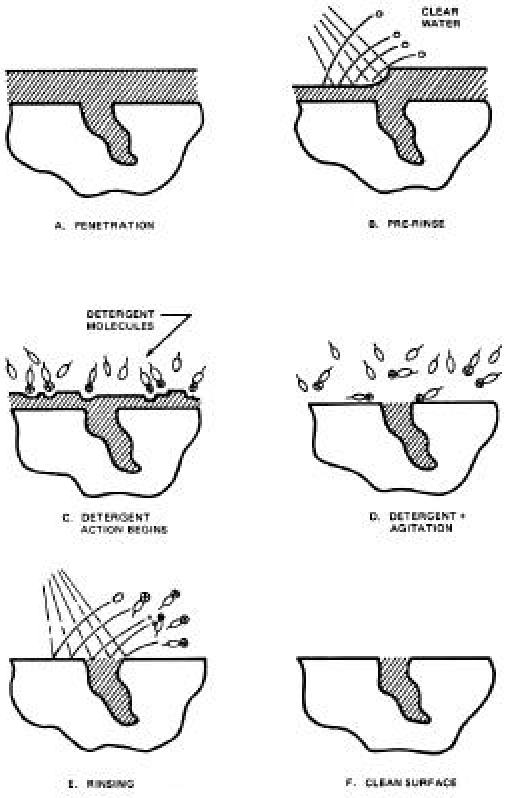


Figure 2-20. Action of the Hydrophilic Process.

2.5.5.4.3 Pre Rinse.

2.5.5.4.3.1 Description.
The clean, preclean, penetrant application and penetrant dwell steps are identical in both the lipophilic and hydrophilic methods. However, the processes diverge with the pre-rinse step in the hydrophilic method. The part is subjected to a plain water spray following the penetrant dwell when using the hydrophilic method. The mechanical action of the water spray removes over 80 percent of the excess surface penetrant, leaving only a very thin uniform layer of surface penetrant on the part which helps optimize the removal process. It reduces the amount of remover consumed, and in immersion set-ups, minimizes contamination of remover due to penetrant carry-over. It also reduces remover contact time since, in general, contact time is about 50 percent less when the pre-rinse step is used. This pre-rinse step cannot be used in the lipophilic process, as the oil base emulsifier does not tolerate water.

2.5.5.4.3.2 Pre-Rinse Procedure.
The pre-rinse step SHALL be used since it improves the efficiency of the process and minimizes hazardous waste. The pre-rinse cycle SHALL be a coarse spray of plain water for 30 to 120 seconds, at a pressure as low as practically possible, not to exceed 40 psig, with a water temperature of 50°F (10°C) to 100°F (38°C). The objective is to reduce the amount of surface penetrant, while leaving only a thin layer remaining on the part.

2.5.5.4.4 Application of Remover.
The removal of excess surface penetrant using hydrophilic removers can be accomplished through the use of either immersion or spray technique, or a combination of both. Each technique offers certain advantages along with disadvantages that are discussed in the following paragraphs.

2.5.5.4.4.1 Immersion Technique.

a. Procedure. The primary advantage of the hydrophilic immersion technique compared to the spray technique, is its effectiveness on hollow or complex geometry parts where the configuration interferes with the spray impinging on the part surface. In use, the part or parts are immersed in the remover tank while still wet from the pre-rinse. The principal mode of action is a detergent mechanism. A slight agitation is necessary to bring fresh solution in contact with the surface. Agitation can be movement of the part through the solution, but is most usually produced by an air manifold in the bottom of the tank. Excessive agitation that is evidenced by foaming SHALL be avoided. Time of immersion depends on a large number of factors and will vary between 30 seconds and 2 minutes. The maximum time of 2 minutes is seldom necessary, except on very rough surfaces or when remover is depleted.

b. Remover Concentration. Each penetrant manufacturer has its own formulation that varies in aggressiveness. The concentrations of hydrophilic emulsifier (in water) used for qualification are identified in the Qualified Products List (QPL) and should not be exceeded without approval from the cognizant engineering authority. Caution must be exercised when changes in suppliers are involved because the required concentration may change. Penetrant and remover are qualified as a system (see paragraph 2.2.5.3) and SHALL NOT be interchanged.

c. Penetrant Tolerance. One of the disadvantages of the hydrophilic immersion technique is the remover's limited tolerance to penetrant contamination. As parts are processed, the amount of penetrant in the remover gradually increases. If the removal process is closely timed, penetrant contamination will reach a point where a distinct performance change occurs. The amount of penetrant causing this performance change is called the remover's penetrant tolerance point or level. The amount of penetrant that can be tolerated is directly related to the concentration of the remover and sensitivity level of the penetrant. Typical tolerance levels for a remover concentration of 33% is 5% to 6% for a Sensitivity Level 3 penetrant and 3% to 4% for a Sensitivity Level 2 penetrant.

d. Bath Appearance. A freshly mixed remover bath is a transparent or clear, pink solution. During use, as penetrant is removed from the parts and retained, the bath becomes turbid or cloudy with distinct color change. As additional parts are processed and the penetrant tolerance point is approached, globules of penetrant will rise to the surface, and then slowly disperse back into the mixture. This effect is not usually noticed in an agitated bath, but is visible when the agitation is shut off. When the penetrant tolerance point is reached, the penetrant will remain floating on the surface. A characteristic of the bath is that the excess penetrant does not spread across the surface, but collects at the sides. The remover will continue to function in this condition, but at a very reduced rate. A problem with using the remover after the penetrant tolerance point is reached, in addition to the longer removal time, is the tendency of the floating penetrant to deposit on the part as it is withdrawn from the solution. This results in an objectionable background. If the bath is to be used after the tolerance point is reached, the majority of the floating penetrant should be removed. This can be done by wiping the tank edges with absorbent newspaper, paper towels, or rags.

2.5.5.4.4.2 Hydrophilic Spray Technique.

a. Procedure. Hydrophilic remover can be applied by spraying the part with a mixture of water and remover. This method of application has several advantages: it does not require a separate tank; it works well on simple contoured parts; and it can be easily automated. The procedures and equipment are identical with those used in spray rinsing, (see paragraph 2.5.4.5). The usual concentration range is

1% to 5% remover to water by volume. The recommended concentration for manual spray operations is 1% by volume, and in no case shall the concentration of remover exceed 5%.

b. Equipment. A practical and efficient way of handling the low remover concentrations is by continuously metering the remover directly into the stream of water. This can be done with an aspirator device that employs the water flow to create a vacuum (Bernoulli effect), drawing up the concentrate directly from the container. The method is inexpensive and only requires a minimum of equipment and provides intermittent, on/off operation. A disadvantage of this system is the variation in concentration with water pressure. This requires the careful control of water pressure as well as the mixing ratio. The most commonly used system is the installation of a three-way valve on the water rinse or wash line. The aspirator is connected to one side; fresh or plain water to the second; while the third position is off. This allows the existing wash tank to be used for both spray removal and fresh water rinsing.

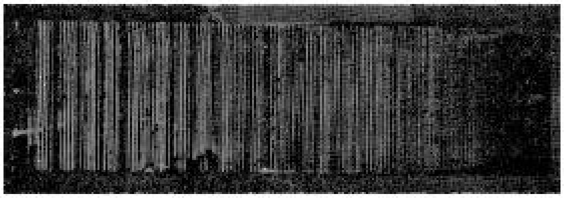
c. Removal Mechanism. The modes of action are the same for both hydrophilic immersion and spray remover techniques. However, the mechanism of spray removal is complicated by the relation between the chemical and mechanical action. As the spray water pressure is increased, the rate of removal also increases. A common misconception is that the increased rate of removal is due solely to the greater mechanical action. The higher water pressure actually increases both mechanical and chemical action. As the water pressure increases, more solution contacts the surface per unit of time, thereby increasing the chemical action.

2.5.5.4.5 Water Rinse.

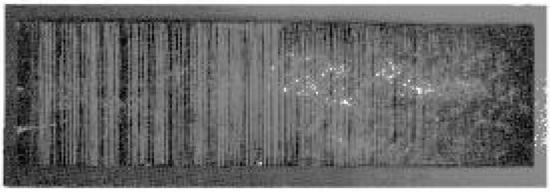
Following the penetrant removal step, the part SHALL be subjected to a plain water rinse or wash. The purpose is to remove any remover residues that could contaminate the developer or interfere with the development process. The rinse step is a water spray in the station or tank used for the pre-rinse. The process step is not critical and requires very few controls. The cycle SHALL be a plain water spray of 30 to 60 seconds duration using a pressure of 10 to 35 psig and a water temperature between 50°F (10°C) to 100°F (38°C). Rinsing of fluorescent penetrants SHALL be accomplished under a black light. Further details of water spray removal are given in section 2.5.4.5. One of the advantages of the hydrophilic technique is the ability to do touch-up removal on local areas after the initial application of the water rinse. After touch-up, the part SHALL be fresh water rinsed.

2.5.5.5 Summary Comparison of Lipophilic and Hydrophilic.

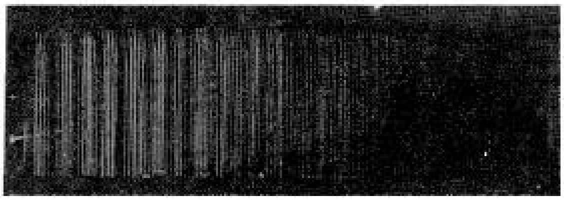
A comparison of the physical, chemical and application differences between the lipophilic and hydrophilic techniques is set out in Table 2-4. The hydrophilic method has the ability to remove surface penetrant with reduced effect on penetrant entrapped in a crack. This ability results in several benefits compared to the lipophilic method. A major advantage of hydrophilic removers is the increased process tolerance, i.e.; (hydrophilic) removal time is not as critical as (lipophilic) emulsification dwell. Additional (hydrophilic) removal times of 1 or 2 minutes have little effect on penetrant entrapped in a discontinuity, while additional (lipophilic) emulsification times as little as 10 or 15 seconds can seriously degrade a flaw indication. Figure 2-21 is a cracked chrome plated panel that has been processed to show the effects of optimum, insufficient and excessive hydrophilic removal. The cracks in the panel are progressively smaller from left to right in the figure.



OPTIMUM REMOVAL



UNDER REMOVAL



OVER REMOVAL

Figure 2-21. The Effects of Optimum, Insufficient, and Excessive Hydrophilic Removal.

2.5.5.5.1

Another advantage of hydrophilic remover is its relative insensitivity to removal of penetrant entrapped in a discontinuity. This permits complete removal of fluorescent background in most cases. In contrast, when using lipophilic emulsifier on slightly rough surfaces, it is desirable to leave a faint residual background when maximum sensitivity is required. The reduction of background fluorescence with the hydrophilic technique improves the contrast, making faint indications easier to see. The hydrophilic method also allows spot or touch-up removal on local areas during the final clear water rinse. This cannot be done with the lipophilic method, since the oil base emulsifier will not tolerate water. The use of hydrophilic emulsifiers also provides better control, handling and recycling of the penetrant effluent. This can significantly decrease waste water treatment costs and minimize water pollution.

Table 2-4. Comparison of Hydrophilic versus Lipophilic Methods.

Hydrophilic	Lipophilic
1. Supplied as a concentrate	1. Supplied as a ready to use fluid
2. Water base when mixed	2. Oil base
3. Low viscosity 9 to 12 cs	3. High viscosity 35 to 120 cs
4. Limited penetrant tolerance	4. Miscible with penetrant in all concentrations
5. Miscible with water in all concentrations	5. Limited water tolerance
6. Applied as dip or spray	6. Applied as a dip
7. Action: Dip-detergent with scrubbing wash	7. Action: Diffusion activated by scrubbing
8. Reduced drag-out	8. Critical emulsion time

2.5.6 Removal of Penetrants with Solvent, Method C.

2.5.6.1 General.

All oil based penetrants are soluble in a large number of organic liquids. However, postemulsifiable penetrants are most frequently used in Method C. As discussed in the note after paragraph 2.3.7.1, the majority of solvent removers are Class 2 (non-halogenated), and they can be further subdivided on the basis of their flash points or boiling points. For almost all solvent removers, removal of the excess surface penetrant is accomplished through dissolving and dilution. The exception to this is when an aqueous based detergent mixture is used as a solvent remover. When higher boiling point solvents are used, care must be taken to control the amount of solvent applied to the surface. Excess solvent can strip penetrant from defects or dilute the penetrant in a defect with the result of producing dim, fuzzy indications.

2.5.6.1.1

The selection of a suitable solvent remover depends on a number of factors. The most significant factors are the evaporation rate (boiling point), flammability and cost. Solvency is a factor but becomes significant only when the removal process allows excess solvent to remain on the surface of the part, thus diluting penetrant that is trapped in defects. For smooth surfaces, high boiling points solvents can be used with minimal concern since residual solvent can be easily wiped from the surface with a dry cloth. The higher boiling point solvents are also less flammable than the lower boiling point materials. For rougher surfaces, caution is required with the use of the higher boiling point materials; the lower boiling point solvents may be more appropriate since any residual solvent would evaporate before it could dilute the penetrant in a flaw. With the lower boiling point solvents, however, safety (flammability) may be a concern. If that is the case, then the halogenated solvent removers may be used although the cost will be high. HCFC 141b is one approved halogenated solvent: it is found in several qualified products.

2.5.6.2 Application Procedure.

NOTE

The solvent-cleaner SHALL NOT be applied directly onto the inspection area to remove excess penetrant.

The use of high sensitivity, postemulsifiable penetrant with the solvent removal method will produce indications form small, tight flaws. However, improper application procedures will seriously degrade the indications. The use of excess solvent will remove or dilute entrapped penetrant resulting in a failure to produce a visible indication.

a. Following the penetrant dwell period, the surface SHALL be wiped with a clean, dry rag or paper towel to remove the major portion of surface penetrant. The proper procedure is to make only a single pass and then fold the rag or towel over to provide a fresh surface for each succeeding wipe.

b. When the surface penetrant has been reduced to a minimum with dry rags or towels, any residual penetrant is removed with a fresh rag or towel moistened with solvent. The amount of solvent applied to the rag or towel is critical. The cloth or towel should only be lightly moistened with the application of a mist of solvent to the cloth. The cloth SHALL NOT be saturated either by immersion in liquid solvent or spraying on excessive solvent.

c. A black light SHALL be used to examine the part surface during the intermediate and final wiping stages. The surface of the rag SHALL also be examined with the black light after the final solvent wipe. If the rag shows more than a trace of penetrant, it SHALL be folded to expose a clean surface, remoistened with solvent, and again wiped across the part.

d. This procedure SHALL be repeated until the rag shows little or no trace of penetrant.

e. Finally the part be wiped with a clean dry rag to remove any residual solvent on the surface.

SECTION VI
DEVELOPERS

2.6 DEVELOPERS.

2.6.1 Summary.

This section covers the development process. Development follows penetrant application, dwell, and removal of excess surface penetrant. The section contains basic, intermediate, and advanced information on the process theory, materials, and application procedures. The first portion is introductory in nature, discussing the functions and required properties of developers. The second portion is devoted to the mechanisms and theory of developers. The third portion covers drying of the part after surface penetrant removal or application of a water base, aqueous, developer. The fourth portion describes the materials and application procedures for dry, aqueous and nonaqueous developers. The section concludes with a comparison of the various types of developers.

2.6.2 Fundamentals.

2.6.2.1 Functions Of A Developer.

The basic function of all developers is to improve the visibility of the entrapped penetrant indication. The improvement in visibility is achieved through a number of mechanisms that include the following:

a. Assist in extracting the entrapped penetrant from discontinuities.

b. Spread or disperse the extracted penetrant laterally on the surface, thus increasing the apparent size of the indication.

c. Improve the contrast between the indication and the background.

2.6.2.2 Self Development.

CAUTION

Self-development SHALL NOT be used in aircraft and engine maintenance inspection where service-induced flaws must be detected.

Self-development is the formation of an indication without the application of a developer material. All penetrants are capable of some degree of self-development since they will exude from a discontinuity and spread over the surface. The critical factors are the size and volume of the discontinuities that must be detected. A relatively large volume of entrapped penetrant is required, and self-development is not reliable in detecting small tight flaws.

2.6.2.3 Mechanisms of Developer Action.

2.6.2.3.1 Capillary Action.

Just as capillary action draws penetrant into a crack, it draws penetrant back out of a crack into the small spaces between developer particles.

2.6.2.3.2 Adsorption versus Absorption.

Developer action involves adsorption and absorption. Adsorption refers to the collection of a liquid on the outer surface of a particle due to adhesive forces. This action contributes to the developer particle build-up at a crack as the particles adhere to the exuded penetrant. Absorption refers to the blotting action that occurs when a liquid merges into an absorbent particle. The mechanism of development is a combination of both adsorption and absorption (see Figure 2-22).

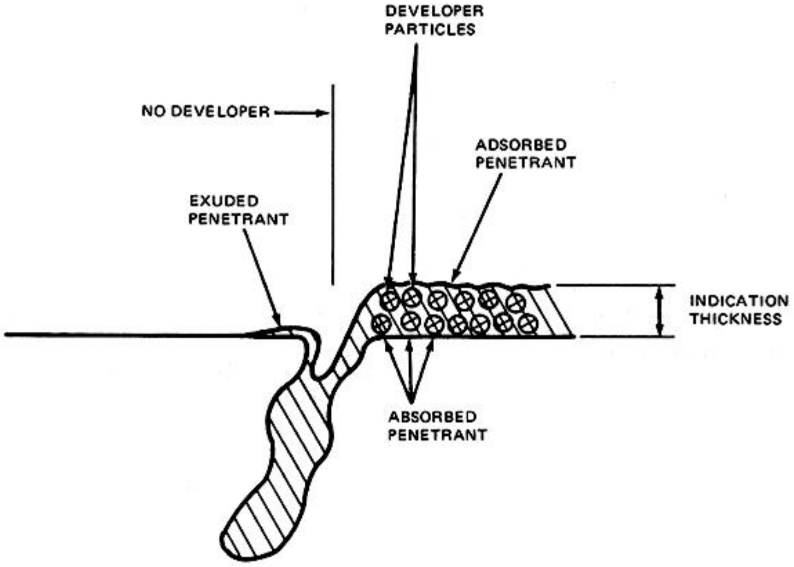


Figure 2-22. The Effects of a Developer.

2.6.2.3.3 Scattering Of Light.

The developer particles scatter both the incoming ultraviolet light and the exiting visible light. This property enhances the brightness of a fluorescent indication by causing more of the ultraviolet light to be absorbed by the penetrant and more of the visible (fluorescent) light to escape the penetrant layer and reach the inspector's eye.

2.6.2.3.4 Contrast Enhancement.

Developers improve the visibility of indications by providing a contrasting background. They reduce reflections from a part surface and appear blue-black under black light. The blue-black color provides a high contrast with the fluorescent yellow-green penetrant indication. Water suspended and some nonaqueous developers produce a solid white coating which provides a contrasting background for red visible-dye penetrant.

2.6.2.3.5 Solvent Action.

Nonaqueous developers contain solvents that hold the developer particles in suspension. When sprayed on the part, the solvent combines with any entrapped penetrant, diluting it. This increases the volume and reduces the viscosity of penetrant that exudes from the discontinuity, thus improving the visibility of the indication. Nonaqueous developers are capable of providing the highest sensitivity of any of the developer forms.

2.6.2.4 Drying the Test Part.

2.6.2.4.1 Purpose and Methods.

After removal of excess surface penetrant, the parts must be dried before applying nonaqueous or dry developer. When aqueous developers are used, the drying is done after application of the wet developer. Drying can be accomplished in a number of ways:

a. Ambient or room air. Parts can be dried by allowing the parts to set in still air. The length of time required for this method depends upon temperature and humidity of the air and is usually too long to be used for drying wet developer.

b. Warm air blowers. Warm air blowers are often used on large parts that cannot be oven dried. The method may not uniformly dry wet developers.

c. Recirculating air ovens. The most frequently used method of drying parts is with a recirculating hot air oven. It provides a rapid means of properly drying parts and wet developer; is adaptable to production; and permits control of the temperature.

2.6.2.4.2 Time Temperature Effects.

NOTE

Depots with automated and semi-automated penetrant inspection systems may exceed the 140°F (60°C) drying oven temperature while performing inspections with these systems. The part temperature SHALL NOT exceed 140°F (60°C). All parts remaining at 140°F (60°C) for longer than ten minutes or exceeding 140°F (60°C) SHALL be reprocessed (cleaned and reinspected).

When drying test parts in a recirculating oven, both time of exposure and dryer temperature must be carefully controlled. The minute quantity of penetrant entrapped in discontinuities can be subject to dye degradation and/or large evaporation losses. Fluorescent dyes experience heat fade or permanent loss of fluorescence at elevated temperatures. Heat fading starts at about 140°F (78°C) and increases rapidly with increased temperatures and time. Evaporation loss can decrease the small amount of penetrant entrapped in a discontinuity to such a low level that it will not contact the developer on the surface and an indication will not form. The effects of drying temperature and time are more severe when a dry developer is used. Aqueous or wet developers are applied before heat and may retain contact with the penetrant during the drying cycle. The base vehicle of the developer tends to mix with the penetrant in the defect. The evaporating action of the base vehicle helps to draw the penetrant from the defect to form the indication. Figure 2-23 compares proper versus excessive drying of Sensitivity Level 3 penetrant prior to applying dry developer. Drying was at 150°F (66°C) for ten minutes. The fine indications are the first to disappear.

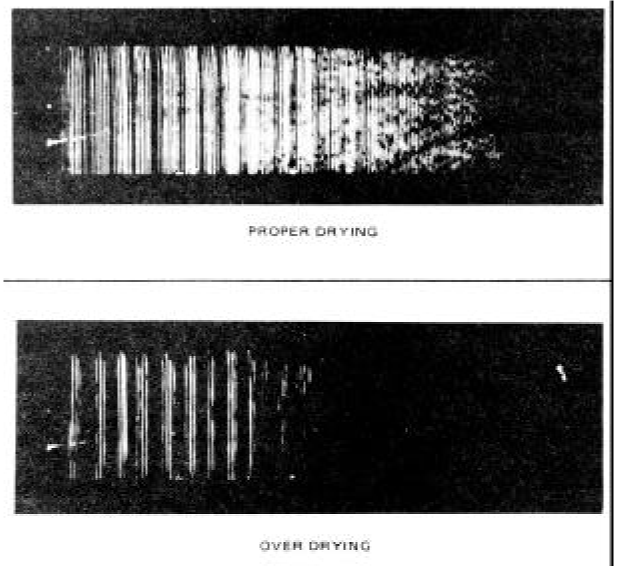


Figure 2-23. The Effect of Proper versus Excessive Drying.

2.6.2.4.3 Procedure.

It is easy to monitor and control oven temperature, but almost impossible to monitor test part temperatures. Another complicating factor is the rate at which parts heat. Thin areas will dry and reach oven temperature before thick sections become warm. The procedure is to set the oven temperature at 140°F (60°C) or less, and to remove the parts from the oven as soon as they are dry. Parts SHALL be separated with an air space between them. If the part temperature reaches and remains at 140°F (60°C) for over ten minutes, the inspection sensitivity can be reduced. As a guideline remove the parts while they are warm but can still be handled with bare hands. This is a temperature of about 120-125°F (49-52°C).

2.6.3 Dry Developer.

2.6.3.1 Description.

Dry developers are characterized by their fluffy nature and low bulk density, i.e.; one pound of dry developer occupies 2 or 3 times the volume that would be required for wet developer powders. Dry developers can be used with any type of fluorescent penetrant but not with any visible-dye penetrant. They are loosely held on the part surface by adhesion. Dry developer particles are generally white. When the dry developer is applied to part surfaces, the coating layer is very thin and uniform. In fact, dry developers leave very little visible trace, but their presence becomes readily obvious when a finger or rag is wiped across the surface. Dry developers SHALL NOT be used with visible-dye penetrants since they do not provide adequate contrast.

2.6.3.2 Application.

WARNING

Dry developer particles are not toxic materials; however, like any solid foreign matter; they should not be inhaled. Air cleaners, face masks, or respirators may be required. The Base Bioenvironmental Engineer SHALL be consulted if the process generates airborne particles.

NOTE

Dry developers SHALL NOT be applied to a part until the surface and any discontinuities are thoroughly free of moisture. The presence of even a little moisture will interfere with the developer action and small flaws may be missed.

Dry developers can be applied in a number of ways:

a. Blowing the powder on with a bulb type blower.

b. Immersing the part in a container of dry particle powder.

c. Pouring the powder over the parts.

d. Using a dust or fog chamber where the particles are blown into an air suspension.

e. Spraying with an electrostatic system or a low pressure flock gun.

2.6.3.2.1

After application, the excess developer should be shaken off or removed with a hand air bulb or squeeze blower. The developer particles are not loosely held but care should be taken to not remove them during handling. Wiping, brushing, or compressed air in excess of 5 psig SHALL NOT be used. Care must be taken to prevent contamination of the dry developer. The two most frequent contaminants are water or moisture and penetrant. Water in dry developer comes from parts that have not been completely dried or from careless splashing during the wash step. Water or moisture contamination will cause the dry developer to form lumps or to cake, thus reducing its effectiveness. Penetrant contamination occurs when particles of penetrant-soaked developer fall from poorly washed parts or heavy indications. Penetrant contamination will cause false indications either on the part being processed or on subsequent parts.

2.6.4 Water Suspended (Wet-Aqueous) Developer.

2.6.4.1 Description.

NOTE

> Developing action in wet suspended developers will not start until all the absorbed and adsorbed water has been driven off. Developer dwell time SHALL NOT begin until the part is completely free of moisture.

Water suspended developers consist of inert particles in a water suspension. The particles are insoluble in water and when dry, are highly adsorptive and absorptive. The developers are supplied as either concentrated liquid or dry, bulk powder and must be mixed with water prior to using. In addition to the developer particles, they contain chemical dispersing agents to reduce the tendency of the developer particles to stick together or form clumps. Wetting agents are added to provide complete and thorough coverage of the parts. Corrosion inhibitors are added to protect the part from corrosive attack. Finally, biocides are added to provide a reasonable tank life by delaying bacterial growth. When applied, water suspended developers evaporate very slowly at room temperature and require a hot air oven for proper drying.

2.6.4.2 Preparation.

Wet suspended developer is always used in stationary systems due to the requirement for a drying oven. Wet developer concentrates should be mixed with water in the proportions recommended by the manufacturer. The concentrations vary between types and manufacturers. The measured quantity of powder or liquid concentrate is added to the water while stirring constantly, until a smoothly mixed suspension is obtained. A newly mixed batch of suspended developer should stand for 4 or 5 hours before use to allow the developer particles to wet out.

2.6.4.3 Application.

Wet suspended developers are applied by spraying, flowing or immersion. Wet developer, since it has a water base, can be applied to parts still wet from penetrant removal. When the part has been thoroughly covered with the developer solution, it is allowed to drain for a short time, (wet suspended developer drain SHALL NOT exceed 30 seconds) and then placed in a drying oven.

2.6.4.4 Advantages.

Water suspended developers have several attributes which produce greater sensitivity than possible with dry developer:

a. The coating is in more intimate contact with the part surface, and the layer is thicker than that of dry powder, resulting in increased extraction and the formation of brighter indications.

b. Water suspended developers produce a readily visible coating that shows the extent of coverage.

c. Water suspended developers do not give off any solvent vapors or obnoxious dust and do not require expensive exhaust and ventilating equipment.

d. Properly applied, water suspended developers can achieve a sensitivity very close to that obtained with non-aqueous wet developers.

2.6.4.5 Disadvantages.

a. Water suspended developer particles are insoluble and heavier than water, causing them to rapidly settle to the bottom. Frequent agitation or stirring is required to maintain a uniform concentration.

b. The dried coating thickness of wet suspended developer is critical. If the coating thickness is excessive, the layer can reduce or mask the visibility of flaw indications. The thickness of the dried developer layer depends upon the concentration of developer in the water. Figure 2-24 shows the results of having optimum versus excessive thickness of developer layer on a cracked aluminum panel.

c. The liquid developer is mobile on the part surface before drying, and it may flow into and collect in cavities or recesses, leaving an excess of developer. This local build-up can be reduced by careful handling and positioning of the part.

d. Even though the water suspendible developers contain a biocide, eventually bacterial growth will occur. Bacterial growth is evidenced by foul odors, discoloration and/or foreign material in the suspension. Once bacterial growth is noticed the suspension must be discarded and the tank completely disinfected before mixing a new suspension.

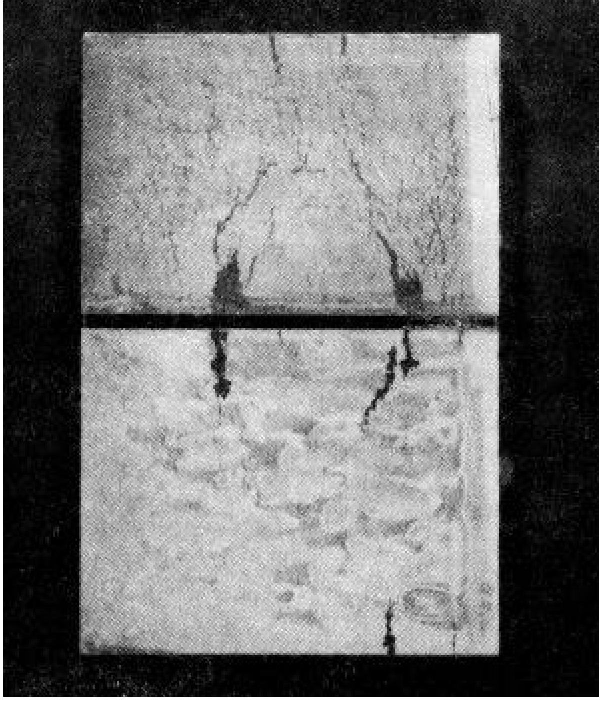


Figure 2-24. Cracked Aluminum Panel Comparing Results with an Optimum Thickness Layer (Top) to an Excessive Layer (Bottom) of Developer.

2.6.5 Water Soluble Developer.

2.6.5.1 Description.

Water soluble developers contain developer particles, wetting agents, corrosion inhibitors and biocides. They differ from wet suspended developer since the particles dissolve in water to form a clear, lightly tinted solution. During the drying process, the developer particles crystallize out of solution as the water evaporates. The resultant coating is a thick, readily visible white. The dry layer is thicker than wet suspended developer coating, and much thicker than a dry developer coating.

2.6.5.2 Preparation.

Wet, soluble developers are supplied as dry powders and must be dissolved in water before use. The proportions of dry powder to water depend upon the type of developer and the manufacturer. The manufacturer’s recommendations on concentration SHALL be followed. In making up the bath, the dry powder must be stirred into the water until it has completely dissolved. Since the developer particles are dissolved in the solution, agitation is not required after the developer has been initially mixed with water.

2.6.5.3 Application.

CAUTION

Water soluble developers SHALL NOT be used on parts processed with water washable, Method A, fluorescent penetrants or any visible-dye penetrants, unless specifically authorized

NOTE

Wet, soluble developer in open immersion tanks is subject to evaporation. As the water evaporates, the developer concentration increases. A solution concentration level should be established and maintained by the addition of water and dry powder.

The developer may be applied by spraying, flowing, or immersion. If the immersion process is used, the part should not remain in the solution any longer than required to provide complete coverage. The developer may be applied to parts while they are still wet from the water wash after penetrant removal. Care must be exercised to prevent entrapment of soluble developer in the part cavities or concave surfaces (pooling). The developer should wet the part surface with no water break areas after application. After the developer is applied, the parts must be oven dried, since room temperature evaporation is too slow. The developing action does not start until the developer is dry.

2.6.5.4 Advantages.

a. The primary advantage of water soluble compared to water suspended developer is the elimination of the need for agitation to keep the particles in suspension.

b. The coating does not produce streaks or runs that often occur with wet suspended developers.

c. The developer particles, being soluble in water, are very easy to remove during postcleaning.

2.6.5.5 Disadvantages.

NOTE

Water soluble developers are subject to bacterial growth. The susceptibility is dependent on the geographical area and the type of local water. The first indication can be a foul odor or visible growth.

a. Water soluble developers contain wetting agents that can act as penetrant removers and must be carefully used. This removal action is accelerated with water washable penetrants. Therefore, water soluble developers SHALL NOT be used on parts processed with water washable penetrant.

b. Even though a thick, white coating is produced, water soluble developers do not function well with visible-dye penetrants. Water soluble developer SHALL NOT be used with visible-dye penetrants.

c. Like the wet suspendible developers, the biocides in water soluble developers only delay bacterial growth. The water soluble developers must be discarded when bacterial growth is noticed and the tank or container completely disinfected prior to mixing a new solution.

2.6.6 Nonaqueous Solvent Suspended Developers.

2.6.6.1 Description.

Nonaqueous solvent suspended developers are supplied in the ready to use condition and contain particles of developer suspended in a mixture of volatile solvents. The solvents are carefully selected for their compatibility with the penetrants. Solvent developers also contain surfactants and dispersants whose functions are to coat the particles and reduce their tendency to clump or collect together. Solvent developers are the most sensitive form of developers due to the solvent action contributing to the adsorption and absorption mechanisms. In many cases where tight, small flaws occur, the dry and aqueous developers do not contact the entrapped penetrant. This results in the failure of the developer to create the necessary capillary and surface tension forces that serve to pull the penetrant from the flaw. The nonaqueous developer solvents enter the flaw and dissolve into the penetrant. This action increases the volume and reduces the viscosity of the penetrant. The manufacturer must carefully select and compound the solvent mixture. Either excessive or inadequate volatility and solubility will adversely affect the performance of the developing action. High volatility reduces the time for the developer to function before it evaporates, while low volatility increases the drying time. Low solubility reduces the penetrant dissolving action, so the extraction of the penetrant from the flaw will not be enhanced.

2.6.6.2 Application.

Nonaqueous wet developers are always applied by spraying. Proper spraying produces a thin, uniform layer that is very sensitive in producing indications. Dipping, pouring or brushing are not suitable for applying solvent suspended developer. Dipping and pouring increases the time the solvent is dissolving and diluting the entrapped penetrant so that much of it ends up in the unevaporated liquid developer layer. During the drain, the penetrant will flow from the flaw site, and any indications that do form will be weak and badly distorted. Application of solvent developer by brushing will leave streaks and distort and smear flaw indications into unrecognizable forms. Nonaqueous wet developer SHALL be applied only as a fine spray or mist.

2.6.6.2.1

NOTE

Excessive thickness of developer SHALL NOT be used. Parts that have received excessive developer SHALL be completely reprocessed.

Spraying of nonaqueous developer is most often done with pressurized, aerosol containers. There are a few production lines that use pressure pots and spray guns. Electrostatic spraying is possible but is seldom used due to the poor throwing power of the spray. Like dry powder developers, solvent developers SHALL NOT be applied to a part until the surface and any discontinuities are thoroughly free of moisture. The presence of any moisture will interfere with the developer action and small flaws may be missed. Prior to spray application, the container SHALL be agitated. Nonaqueous wet developer is usually a suspension and the particles settle out in a matter of minutes. The spray can or gun must be held far enough from the surface to produce a light, moist film. Liquid flow on the part surface must be avoided. The recommended technique is to apply a very thin, dry layer and build up the thickness with several passes rather than applying a single, wet pass. The optimum coating thickness depends on the penetrant system type (i.e. visible or fluorescent dye) and must be judged from its appearance, based upon prior experience. Type I penetrant systems, the luster or surface texture of the part surface should not be completely hidden. If the metallic luster cannot be seen, the developer layer is too thick, and small indications may be masked or too widely spread to be easily seen. At the thin end of the optimum thickness range, there should be sufficient developer on the part surface to be clearly visible. Coatings that are too thin may not extract a sufficient amount of entrapped penetrant to form an indication. Also, too thin of a coat does not allow the penetrant to spread and magnify the indication. For Type II penetrant systems, a thicker coating is required to provide a solid white background to contrast with the visible indication color.

2.6.6.3 Advantages.

a. They are packaged in portable aerosol containers.

b. They are volatile and fast drying in the air, thus eliminating the need for a drying oven.

c. They are sealed in their containers and are not recovered after their initial use, which eliminates any degradation, by contamination.

d. When proper techniques are used, they provide a smooth, even layer of developer whose thickness can be controlled by the operator.

e. Nonaqueous wet developers can be used with both fluorescent and visible-dye penetrants.

f. Nonaqueous wet developers are capable of producing the highest level of sensitivity of any of the developer forms due to their solvent action.

2.6.6.4 Disadvantages.

WARNING

Nonaqueous wet developers contain solvents that can be relatively flammable, and when used in confined locations, present a health hazard. Caution must be exercised to prevent ignition and to avoid inhalation of the vapors.

a. The developer particles are suspended in the solvent and tend to rapidly settle out. Agitation prior to and during application is required.

b. The portable aerosol containers have a small spray coverage that makes coating of a large surface very time consuming. The aerosols are best limited to small, local areas.

c. There is a gradual loss of pressure over a period of time and occasionally there are leakers due to improper sealing. When the pressure is lost the can and its remaining contents must be properly discarded.

d. If the nozzle is not free of dried developer particles, spray patterns can be very erratic. It is necessary to clean the nozzle after every use by inverting the can and pressing the spray nozzle until only propellant escapes.

2.6.7 Developer Dwell.

2.6.7.1 Minimum Dwell Time.
Extraction of the penetrant entrapped in a flaw is a function of time and volume of available penetrant. Time must be allowed for the developer to assist in drawing some of the entrapped penetrant from the flaw and spreading it on the part surface to form the indication. The length of developing time varies widely with a number of influencing factors. The development time SHALL be at least one-half of the penetrant dwell time, and SHALL NOT start until part is completely free of moisture.

2.6.7.2 Maximum Dwell Time.

NOTE

The maximum dwell times specified are based on small discontinuities. Medium or large discontinuities, which develop faster, will be blurred at these maximum dwell times. However, medium or large discontinuities contain enough penetrant to form an observable indication even though it is blurred. Indications from small discontinuities may be missed if the maximum dwell times are exceeded. To increase penetrant system capability, parts should be viewed periodically during developing.

Over-development, i.e., too long a development time, is possible and must be avoided. Developer action starts when the developer is completely dry and continues until all of the available penetrant is extracted. An indication will gradually form, reach a maximum resolution point (bright and sharp), and then begin to degrade. The lateral diffusion of penetrant over a period of time can be so great that the indication becomes indistinct. Medium size or large discontinuities will appear as a smear or blob of penetrant. Small indications are especially critical, since the small amount of penetrant may not be observed when it diffuses. The maximum developer dwell time SHALL NOT exceed the following, unless otherwise specified in a written inspection procedure:

a. Nonaqueous developer – 30 minutes

b. Aqueous developer – 1 hour

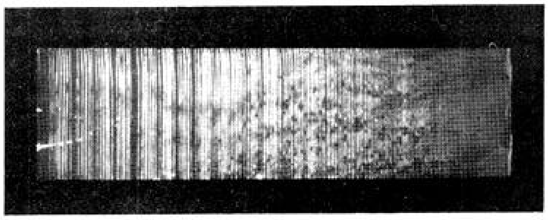
c. Dry developer – 2 hours

2.6.7.3 Comparison of Developers.

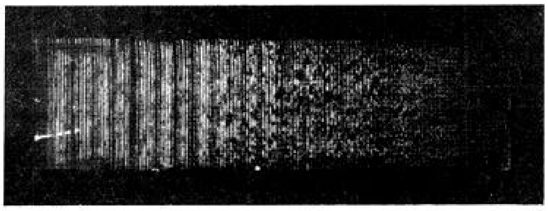
The relative sensitivities of penetrant inspection with various forms of developer are influenced by a number of factors. The method of applying the developer produces a range of sensitivities for each of the developer forms. Table 2-5 lists some of the common forms of developer, plus the application method, arranged in order of decreasing sensitivity. This is the sensitivity order most generally accepted. It is recognized that solvent suspended developers applied by spraying produce the highest sensitive penetrant system. Industry agreement on the developer sensitivity order ends at this point. The type of test sample, type of flaw, flaw size and shape, type of penetrant, method of removal, and drying procedures will affect the sensitivity of the penetrant system. The number of variables involved has resulted in conflicting reports on the relative performance of dry versus water based (suspended and soluble) developers. It is agreed that, when properly applied, the water base developers form a coating with a finer matrix of developer particles that are in more intimate contact with the part surface, than is possible with dry developers. The opposing argument is that an uneven coating of water based developers can mask indications. There is agreement that water soluble developers should not be used on water washable penetrant. Figure 2-25 contains photographs of a single cracked chrome plated panel that has been processed with four forms of developer using application methods available to base level NDI laboratories.

Table 2-5. Developer Forms and Application Methods in Decreasing Order of Sensitivity.

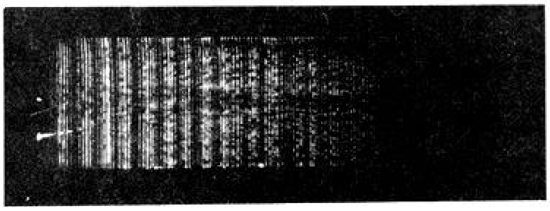
Developer Form	Application Method
1. Non-aqueous wet (solvent suspended)	Spray
2. Water suspended	Spray
3. Water suspended	Immersion
4. Water soluble	Spray
5. Water soluble	Immersion
6. Dry powder	Dip and pour
7. Dry powder	Electrostatic spray
8. Dry powder	Fluidized bed
9. Dry powder	Air agitated dust cloud



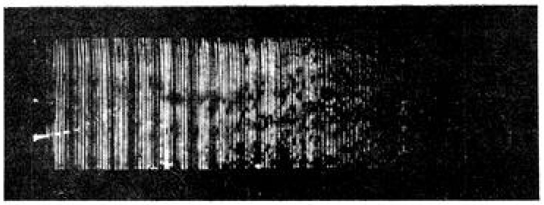
a. SOLVENT DEVELOPER, SPRAY



b. WATER SOLUBLE DEVELOPER, IMMERSION



c. WATER SUSPENDED DEVELOPER, IMMERSION



d. DRY DEVELOPER, IMMERSION

Figure 2-25. Comparison of Four Forms of Developer on a Cracked Chrome Plated Panels.

SECTION VII
INSPECTION AND INTERPRETATION

2.7 INSPECTION AND INTERPRETATION.

2.7.1 Summary.

Detection of flaws by the penetrant inspection method depends upon many factors, chiefly, among which are the selection of the appropriate materials and process, the proper application of the chosen process, the quality of lighting during the examination and the ability of a technician to detect flaw indications. This section provides basic, intermediate, and advanced information on the requirements for a reliable inspection and describes the appearance of indications from various types of flaws. The section covers four topics: general requirements, personnel requirements, lighting requirements and guidance on flaw interpretation.

2.7.2 General.

a. The purpose of the penetrant inspection process is to detect flaws that will affect the integrity of a part. Many of these flaws may be very small. All of the penetrant materials, procedures, and process controls are oriented to producing valid indications from surface discontinuities. The inspection or examination step is one of the most important and frequently the least controlled of all the process steps. Marginally controlled inspection or examination conditions will degrade the entire penetrant process. Maximum benefits can only be obtained when all aspects of the process (e.g., personnel training and qualification, lighting and inspection environment) receive equal management emphasis.

b. The apparent simplicity of the penetrant process is misleading. While the penetrant process is relatively straightforward, the testing depends upon following very carefully prepared processes. Modern penetrant systems are the result of very modern chemical technology. The penetrant inspection process requires diligent care from the initial step to the process completion. An improper or marginal process step may not be recognizable in the inspection booth. As a result, a serious flaw may not be indicated. Many times, the first indicator of process degradation occurs during an individual process step. For example, an excessive emulsification time or an improper water-spray pattern can be identified at the time of the respective process steps, but the consequent removal of penetrant from a defect would go unnoticed.

2.7.3 Personnel.

a. Personnel, who are responsible for processing of parts through one or more of the penetrant process steps, even though they do not inspect or interpret indications, SHALL have a basic knowledge of the process theory, practical aspects, and equipment operation. They SHALL be aware of the process control requirements and of the effects of improper procedures or degraded materials on the formation of indications.

b. Personnel responsible for inspecting processing parts though one or more of the penetrant process steps and for interpreting and evaluating penetrant indications SHALL have a detailed knowledge of the theory, practical aspects, and application procedures for the major penetrant processes. They SHALL be capable of performing all of the process steps, performing materials and process control tests, and providing technical guidance to operators and trainees. In addition, they SHALL have knowledge of the potential types of discontinuities peculiar to the part being inspected, be familiar with the appearance of penetrant indications of those discontinuities, and have experience in interpretation and evaluation of indications. It is essential for an inspector to gain experience by working with other individuals who possess the required skill before being assigned interpretation responsibilities.

c. All personnel performing any of the penetrant process steps SHALL be qualified in accordance with Chapter 1, Section 1.2.

2.7.4 Lighting.

2.7.4.1 Black Light.

2.7.4.1.1 Characteristics.

Ultraviolet light is electromagnetic radiation with a wavelength ranging between X-rays and visible light. It is not visible to the human eye. The ultraviolet range is usually divided into three bands: A) soft ultraviolet or long wavelength (UV-A), 320 to 400 nm, which is commonly called black light; b) medium wavelength (UV-B), 270 to 320 nm, which is used for examining minerals and in suntan lamps; and c) hard ultraviolet or short wavelength (UV-C), 4 to 270 nm, which is used in germicidal or sterilizing lamps. Black light has the smallest band width of the ultraviolet range and is just below visible wavelength range of 400 to 700 nm. Figure 2-26 is the electromagnetic spectrum showing the relatively small band of black light used in fluorescent penetrant inspection. Black light is near the violet end of the visible light range (near 400 nm).

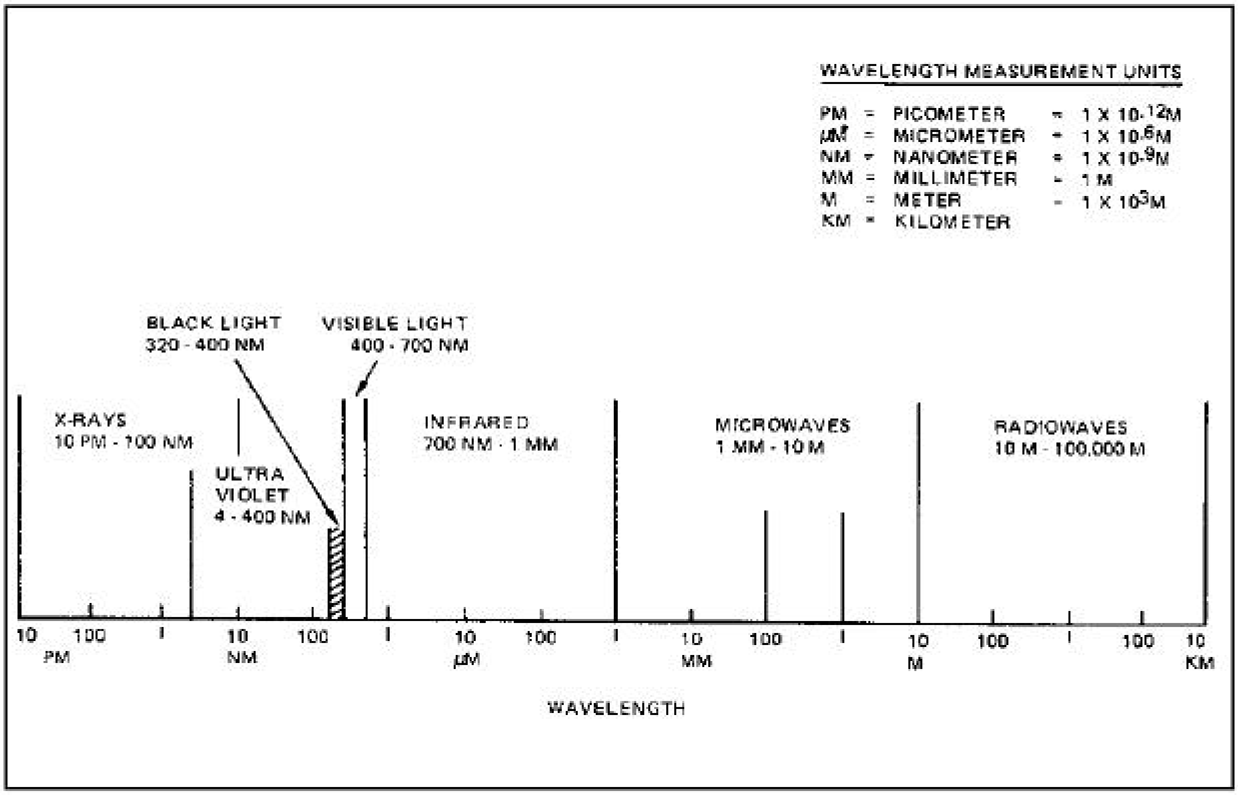


Figure 2-26. Electromagnetic Spectrum Shows the Relatively Narrow Band of Black Light.

2.7.4.1.2 Interaction with Fluorescent Materials.

NOTE

Some optical plastics used in eyeglass lenses can fluoresce; causing a loss of eye sensitivity when exposed to ultraviolet light. UV goggles should be worn over such glasses to block the black light.

When fluorescent materials are energized by ultraviolet radiation, visible light is emitted. The color of the emitted light depends upon the material. Each type emits a specific wavelength ranging from violet (400 nm) to red (700 nm). Factors in selecting a fluorescent dye are the color emitted and the intensity of emitted fluorescent light. The most frequently used dyes emit a yellow-green light in the wavelength band of 510 to 560 nm. This color is chosen since the human eye has its highest response to wavelengths in the 550 nm range. Figure 2-27 shows the relative response of a typical human eye to various wavelengths of visible light under two different lighting conditions. Curve A at 100 lumens (100 foot-candles) is typical of a well lighted inspection bench. Curve B at 2 lumens (2 foot-candles) is the maximum white light level allowed in a fluorescent penetrant inspection booth. Under the darkened condition, the sensitivity of the eye increases about 30 times and shifts slightly to the blue region. At a light level of 2 lumens, it is possible for the eye to see some light wavelengths below 400 nm and above 700 nm.

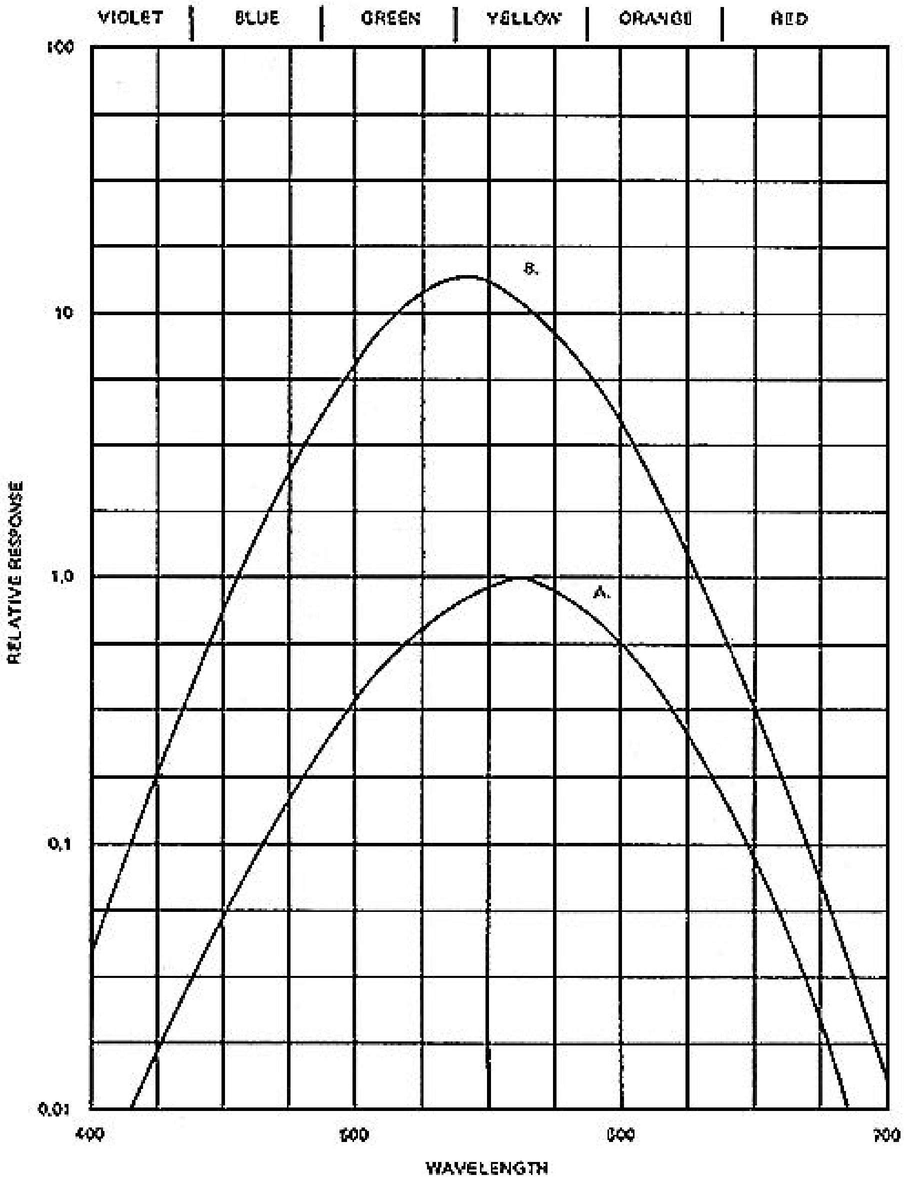


Figure 2-27. Relative Response of Typical Human Eye to Visible Light of Various Wavelengths.

2.7.4.1.3 Sources.

2.7.4.1.3.1 Incandescent and Carbon Arc Systems.
Electric current heating a tungsten element to incandescence is the typical visible light bulb familiar to everyone. The wavelength of the associated electromagnetic radiation is generally in the visible and infrared range. It is characterized by large amounts of heat (infrared) and visible light. Electric current arcing between two carbon electrodes generates a high quantity of electromagnetic radiation in the carbon arc lamp. The radiation spans a range of wavelengths from about 10 nanometers to over 10 micrometers. This covers the entire ultraviolet and visible light ranges and a portion of the infrared range. However, little if any useful ultraviolet radiation is produced. In addition, the lamps require a high electrical power supply and are very bulky or large due to the need for electrode drive mechanisms. Incandescent and carbon arc systems are not used for fluorescent penetrant inspection.

2.7.4.1.3.2 Low Pressure Fluorescent “BL” Bulbs.
Low pressure, fluorescent bulbs are similar to standard fluorescent tubes. However, instead of an inert gas, the tube contains metallic mercury. When an electric current is applied, the mercury vaporizes and emits hard (deeply penetrating) ultraviolet radiation with a wavelength of about 254 nm. This wavelength is not useful for fluorescent penetrant inspection. Therefore, the inside of the tube is coated with a phosphor that is activated by the hard ultraviolet and emits black and visible light in the wavelength range of 320 to 440 nm. The amount of useful black light at 365 nm is relatively small. However, there is a large amount of both harmful short wavelength black light, (below 320 nm) and visible light, (above 400 nm) that is emitted through the phosphor. Some of these undesirable wavelengths are removed by the use of filters. While this reduces the unwanted radiation, it also reduces the already low amount of useful 365 nm black light. In addition, fluorescent black light bulbs, because of their configuration, cannot be easily focused and their intensity per unit area is below that of other type of bulbs. Thus, fluorescent “BL” black lights SHALL NOT be used for detecting fluorescent indications.

2.7.4.1.3.3 Fluorescent “BLB” Bulbs.
Most fluorescent black lights do not produce an output sufficient to meet the requirements of ASTM 1417.

2.7.4.1.3.4 Mercury Vapor Bulbs.
High pressure, mercury vapor bulbs are the most common sources for black light. They are preferred for fluorescent penetrant inspection because they have an acceptable output at a reasonable distance from the bulb. They can be focused to increase their intensity over a localized area. They are available in a wide range of sizes from a 2-watt pencil type to a 400-watt floodlight. The smaller sizes, less than 100 watt, SHALL NOT be used for penetrant inspection unless specifically authorized. The most frequently used size is the 100-watt bulb that is mounted in a variety of fixtures or housings and is fairly portable. The bulbs are purchased from a lamp manufacturer, and the fixtures or holders are provided by the penetrant supplier. Figure 2-28 shows a typical 100-watt black-light source; the base contains a transformer

Figure 2-28. Portable 100-Watt Black Light.

2.7.4.1.3.4.1
A cross section of a typical mercury vapor arc discharge bulb is shown in Figure 2-29. The high pressure component is a quartz tube containing some mercury plus a small amount of neon gas. When the lamp is first turned on, the mercury is condensed as a liquid and an arc between the electrodes cannot be generated. This is the reason for the neon gas. A small amount of current, limited by the resistor, causes a discharge from the starting electrode through the neon gas. This glow is sufficient to vaporize the mercury, which then allows the arc to pass between the main electrodes. This starting procedure requires from 5 to 15 minutes to fully vaporize the mercury and produce full output of black light. Some blacklights may be warmed-up in 2-3 minutes. Refer to the owners manual the light you are using. Black lights SHALL NOT be used for inspection before the required intensity at the inspection surface (paragraph 2.7.4.1.5) is achieved.

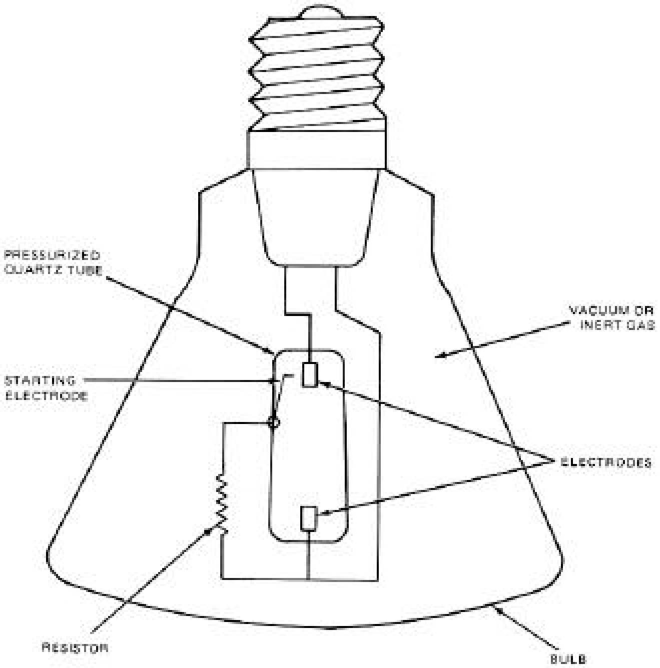


Figure 2-29. Cross-Section of a Typical High Pressure, Mercury Vapor Arc Bulb.

2.7.4.1.4 Black Light Fixtures.

CAUTION

Black light bulbs SHALL NOT be operated without filters. Cracked, chipped or ill-fitting filters SHALL be replaced before using the lamp. High intensity "super" black lights that use bulbs with integral filters SHALL have a splash guard attached to the front of the lamp housing to prevent accidental implosion of the bulb. This splash guard SHALL be the manufactured item.

A high pressure, mercury vapor, black light bulb requires a housing, filter, regulating ballast or transformer and connecting cables or wires. The housing, which may be metal or plastic, serves several functions:

a. Hold and protect the bulb.

b. Hold and support the filter.

c. Prevent leakage of unwanted visible light.

d. Permit directing the beam on the surface to be inspected.

e. Provide a means for handling the bulb.

2.7.4.1.4.1
The filter is a special material that prevents the passage of short wavelength ultraviolet and long wavelength visible light. The filter transmits ultraviolet between 320 nm and 400 nm. This wavelength causes maximum florescence of the penetrant dyes. Black lights used for penetrant inspection SHALL have a peak wavelength between 340 and 380 nm. Figure 2-30 shows the transmission characteristics of Kopp 41 filter glass. Filters for penetrant inspection can be either a smooth or fluted surface. The fluted surface provides a slightly larger focused spot than a smooth surface filter. A current regulating ballast or transformer is required for proper functioning of the bulb.

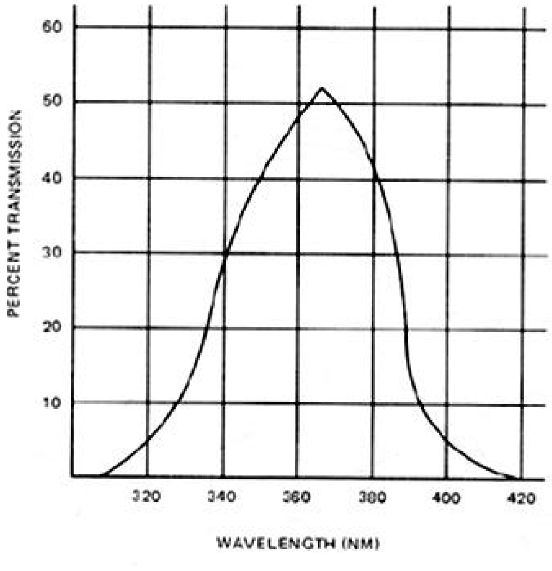


Figure 2-30. Transmission Curve for Kopp 41 Glass.

2.7.4.1.5 Intensity Requirements.

The adequacy of a black light source for fluorescent penetrant inspection is determined by measuring the intensity of the black light at a distance of 15 inches from the front or outside surface of the black light source filter. This intensity SHALL be at least 1000 microwatts/square centimeter (µW/cm^2), and sources providing less than this intensity SHALL NOT be utilized. The actual intensity needed at the surface of the part will vary depending upon the ambient light conditions and size of the suspected indication. Table 2-6 indicates the intensity of black light required under varying ambient light levels. Refer to paragraph 2.7.4.2.2 for measuring the ambient light. When performing portable fluorescent penetrant inspection, a dark colored canvas or photographers black cloth SHALL be used to darken the area during the examination. Values of 3,000 µW/cm^2 can be achieved with acceptable black light sources by moving the source closer than 15 inches to the part, yet leaving sufficient space to observe the specific area of interest. The part has been moved closer to the black light to increase the intensity. Modern fluorescent penetrant testing has improved significantly due to the increase in black light intensities, as well as the formulation of brighter fluorescent penetrants. This has greatly improved the sensitivity and reliability of the penetrant process.

Table 2-6. Empirical Black Light Intensity Requirements at Various Ambient Light Levels.

		Minimum Intensity (µW/cm^2)	
Ambient Light (Lumens) (1 Lumen = 1 Foot-Candle)	Inspection Conditions	Fine Cracks (20 microns wide)	Coarse Cracks (50 microns wide)
0.01 to 2	Fully darkened inspection booth	1000	1000
2 to 10	Dim interiors such as warehouses or storage areas	1000	1000
20 to 40	Well lighted (bright) interiors	5000	1000
900 to 1000	Outdoors, cloudy day	More than 20,000	
3000 to 7000	Outdoors, direct sunlight	More than available	

2.7.4.1.6 Measurement of Black Light Intensity.

2.7.4.1.6.1 Measurement Devices.

Ultraviolet light is electromagnetic energy and is measured in units of energy; hence the watts per square meter or microwatts per square centimeter, where one watt per square meter (W/m^2) equals 100 microwatts per square centimeter (µW/cm^2). For measurement purposes, the ultraviolet spectrum is divided into three bands: UV-A, UV-B and UV-C (see paragraph 2.7.4.1.1). Care must be exercised to assure the instrument is designed for the black light (UV-A) or 365-nm band. This meter is filtered to respond to 365 nm and comes with a multiplier screen to extend the scale. Digital radiometers are also available. The digital radiometers are easier to use than the meter instrument. Examples of digital radiometers are shown in Figure 2-31.

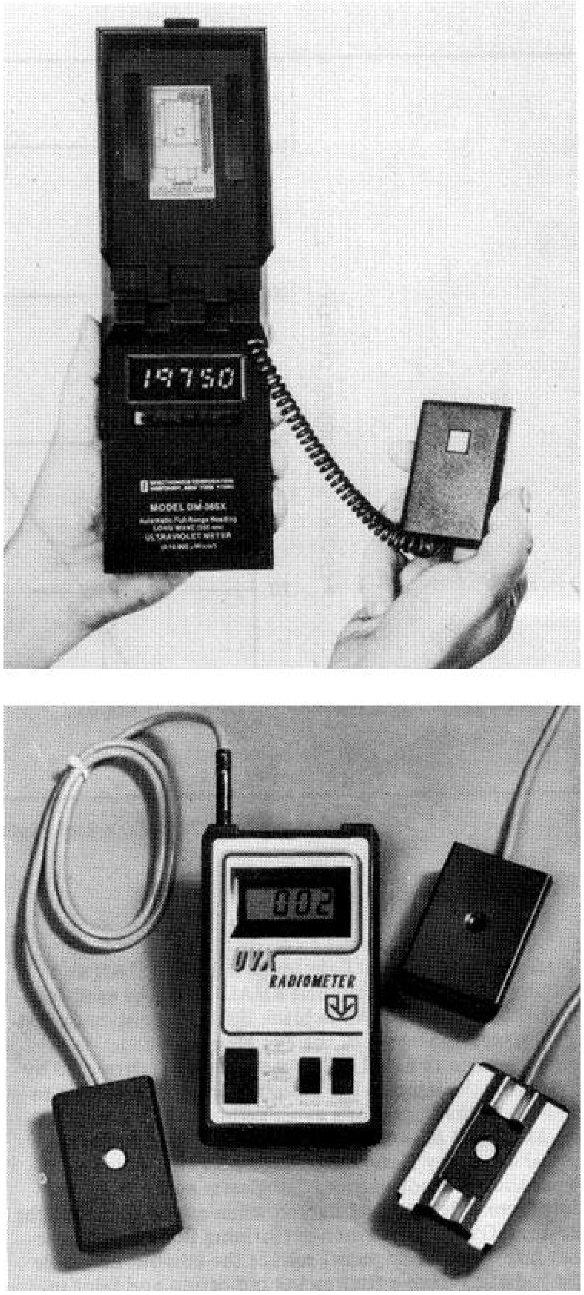


Figure 2-31. Examples of Digital Radiometers.

2.7.4.1.6.2 Guidelines for Measurements.

Some instruments have selectable ranges, and the proper range for the intensity being measured must be used. The range selector may be changed while under the black light. The sensing element should be at the location and orientation of the part surface to be inspected. Some instruments have detachable sensors that may be placed directly on the part surface. White light does not affect the reading of the instrument.

2.7.4.1.7 Variables in Black Light Sources.

a. Manufacturing Variations. Black light bulbs are manufactured for other industrial applications. Nondestructive inspection, NDI, uses only a small portion of the production. The primary users do not require a specific output or consistency between bulbs. Consequently, new bulbs can vary by as much as 50% in their initial output. This means that with two new bulbs, one may have an intensity that is double that of the other without either being defective. New black light bulbs SHALL be tested for output before being used. Intensity of new bulbs SHALL be at least 1000 µw/cm2 at a distance of 15 inches from the outside face of the filter.

b. Line Voltage Variations. Black light intensity varies almost linearly with line voltage. A common misconception is that the black light ballast or transformer will regulate line variations. This is not true. Below approximately 90 volts, the lamps will not sustain the mercury arc and the lamp will extinguish. It will not restart until it has cooled. Black light lamps should be connected to stable power sources. If none are available and line voltage fluctuates, a constant potential transformer should be used.

c. Service and Aging Variations. During use, dust and dirt will collect on both the bulb face and filter. Even small amounts will reduce the intensity and, if allowed to build up, can result in a 10-fold decrease. The bulb face and filter SHALL be kept clean. The output of black light bulbs will vary due to changes in operating characteristics. As the bulb ages, the intensity will gradually decrease. Operating hours will decrease output. Of greater significance is the number of bulb starts. A single start can equate to 2 or 3 hours of continuous use on operating life. Black lights that will be used periodically during the day should be allowed to remain on until their last use of the day. This practice will extend the useful bulb life.

2.7.4.1.8 Black Light Hazards.

WARNING

Prolonged direct exposure of hands to the filtered blacklight main beam may be harmful. Suitable nonfluorescent gloves SHALL be worn when exposing hands to the main beam for extended periods (e.g.: exceeding two hours per day).

The temperature of some operating black light bulbs reaches 750°F (399°C) or more during operation. This is above the ignition or flash point of fuel vapors. These vapors will burst into flame if they contact the bulb. These black lights SHALL NOT be operated when flammable vapors are present.

The bulb temperature also heats the external surfaces of the lamp housing. The temperature is not high enough to be visually apparent, but is high enough to cause severe burns with even momentary contact of exposed body surfaces. Extreme care must be exercised to prevent contacting the housing with any part of the body.

2.7.4.1.9 Black Light Physiological Effects.

WARNING

Unfiltered ultraviolet radiation can be harmful to the eyes and skin. Black light bulbs SHALL NOT be operated without filters. Cracked, chipped, or ill-fitting filters SHALL be replaced before using the lamp.

NOTE

Contact lenses, sunglasses and glasses with photochromic lens that darken when exposed to sunlight SHALL NOT be worn when performing fluorescent penetrant inspection. Sunglasses reduce the amount of visible light radiating from a fluorescing indication and faint indications may not be seen. Photochromic lens will darken when exposed to black light and will reduce the ability to see small indications.

Black light properly filtered is not harmful. The output of a black light bulb is principally at 365 nm and the amount of radiation at shorter wavelengths rapidly falls off. The amount of radiation emitted at or below 320 nm is less than 1 percent. However, this quantity is enough to require a filter since ultraviolet radiation below 320 nm can be hazardous and may cause permanent effects. Germicidal, sun tanning and mineral light bulbs that emit short and medium wavelength ultraviolet SHALL NOT be used for penetrant inspection. While black light does not cause lasting effects, some layers of the eye have a tendency to fluoresce when radiated. This can usually be corrected by positioning the lamp so the radiation is not directed or reflected into the inspector's eye, or the inspector can wear UV goggles.

2.7.4.2 Ambient Visible Light.

2.7.4.2.1 Requirements.
Inspection of a part for fluorescent penetrant indications with a black light SHALL always be done under the lowest possible level of ambient light. This increases the contrast between the light emitted from the indication and the background. A low level of visible ambient light is critical for maintaining the sensitivity of the inspection. Ambient light in stationary inspection system booths SHALL NOT exceed 2 lumens per square foot (lm/ft^2) of white light (1 lm/ft^2 equals 1 foot-candle). If a stationary black light booth is not adequate or appropriate, other provisions must be made.

2.7.4.2.2 Measurement.
Visible light is measured easily by using photometers or light meters. The light meter responds to electromagnetic energy with wavelengths of approximately 380 to 750 nm. This range extends into the longer wavelength black light and shorter wavelength infrared ranges. Precise measurement is possible with filters that exclude black light and infrared. The unit of measurement is the foot-candle. Another term often used to measure light intensity is the lux, which equals 1 lumen per square meter of surface area. One foot-candle equals approximately 10 lux.

2.7.4.3 White Light.
For inspecting parts that have been processed with visible-dye penetrant (Type II), the lighting system in the viewing area shall provide at least 100 foot-candles (1000 lux) of visible white light at the examination surface. Refer to paragraph 2.7.4.2.2 for measuring the intensity of white light.

2.7.5 Inspection Conditions.

2.7.5.1 Dark Adaptation.
The human eye becomes many times more sensitive to light under dark conditions. This increased sensitivity gradually occurs when the light conditions change from light to dark. When first entering a dark area from a lighted area, little or nothing can be seen. The pupil of the eye must widen to admit more light, and the mechanism of vision slowly changes. Full sensitivity or dark adaptation requires about 20 minutes. A dark adaptation time of 5 minutes is usually sufficient for penetrant inspection with black light. An inspector entering a darkened area SHALL allow at least 5 minutes for dark adaptation before examining parts. The human eye contains a protective mechanism that further complicates dark adaptation. The pupil of the eye responds very rapidly to bright light. A very short bright light exposure cancels the slowly acquired dark adaptation. Time for dark adaptation must be allowed whenever an inspector enters the darkened station or is exposed to ambient light. A timer capable of measuring this time period should be visibly or audibly available within the darkened area.

2.7.5.2 Cleanliness.

The inspection area and the hands and clothing of the inspector SHALL be clean and free of extraneous penetrant material. Non-relevant indications may be formed when parts contact extraneous penetrants. In addition, the fluorescence from the penetrant will raise the ambient light level, thus reducing sensitivity.

2.7.6 Inspection, Interpretation and Evaluation.

2.7.6.1 General.

Inspection is the process of detecting an indication. Interpretation is the process of determining whether an indication is relevant, non-relevant or false. Evaluation involves assessing a relevant indication to determine its cause and type (if it is a defect or flaw) and reporting its category, location, and approximate size.

2.7.6.1.1

A distinction must be made between relevant indications, non-relevant indications, discontinuities, and flaws or defects. A relevant indication is one resulting from a discontinuity. Non-relevant indications can result from an intentional change in part shape such as threads or small radii, or may be caused by improper or careless processing procedures. Non-relevant indications are of concern because they may mask or cover a true discontinuity indication. A discontinuity is an unintentional change in part surface or physical condition such as tooling marks, scratches or gouges, cracks, seams, laps, and porosity. A discontinuity may or may not affect the serviceability of the part. If the discontinuity reduces or interferes with the serviceability, it is classified as a flaw or defect. It is possible for a part to contain multiple indications that may be any combination of non-relevant discontinuities not affecting serviceability, and defects requiring corrective action.

2.7.6.1.2

The decision to classify the porosity as acceptable is based on the evaluation of the porosity size and density versus the accept/reject criteria of the specification for the inspection of the part. NDI personnel must be capable of interpreting indications and evaluating discontinuities in accordance with the specifications and procedures for the inspection process in use. They are not normally responsible for disposition decisions on flawed parts, but they must report the type, location and approximate size of any flaws present. Acceptance, rework or repair, and rejection limits are contained in the repair manuals and are the responsibility of the applicable work center.

2.7.6.2 Classification of Discontinuities.

There are a number of ways of classifying discontinuities, such as appearance of the indication, its cause, material, and service conditions. The method of classification used depends upon the test method, the use of the parts, and the original designer. Many of the NDI application manuals, which are usually prepared by the original manufacturer, contain several discontinuity classifications in the same manual.

2.7.6.2.1 Appearance of Indications.

The appearance of penetrant indications is influenced by the size and shape of the discontinuity, the type of penetrant system and processing technique, and the type of developer and the length of developer dwell. These factors hold true for all types and forms of material and apply to both large and small parts.

2.7.6.2.1.1 Continuous Linear Indications.

Linear penetrant indications are caused by discontinuities such as cracks, seams, or laps. The width and brightness of the indication depend upon the volume of entrapped penetrant. The indication may be fairly straight or may have some curvature depending on how the discontinuity was formed. Also, the edges may be jagged or smooth, where the discontinuity meets the part surface. Figure 2-32a shows the surface appearance and a cross-section through a linear discontinuity with a large reservoir. Figure 2-32b is a narrow or tight linear discontinuity.

2.7.6.2.1.2 Intermittent Linear Indications.

Intermittent linear indications are caused by the same discontinuities that form continuous linear indications. However, either a subsequent process or service use has partially sealed the surface edges. This occurs in forging laps or where the part has been subjected to a mechanical smearing action. A sub-surface discontinuity that does intermittently breaks the surface for its entire length or a partially filled seam will also produce an intermittent linear indication as shown in Figure 2-32c.

2.7.6.2.1.3 Round or Dot Indications.
Rounded indications are characterized as having a length and width of approximately equal dimensions. Porosity or relatively small areas of unsoundness in metal components usually form rounded indications. However, the actual surface opening may be irregular in shape. Deep discontinuities, such as weld crater cracks, may appear rounded due to the large volume of entrapped penetrant. Figure 2-32d illustrates the appearance of large and small rounded indications.

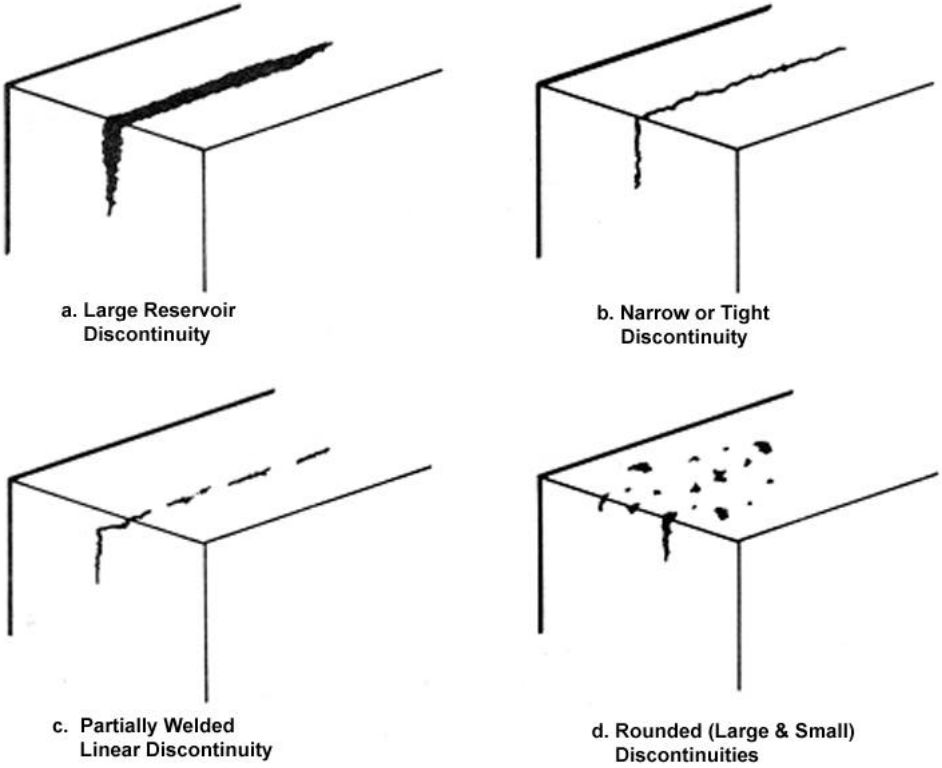


Figure 2-32. Typical Penetrant Indications.

2.7.6.2.2 Manufacturing Discontinuities.
Many discontinuities result from the manufacturing and repair processes. These will probably be detected each time the part is reinspected. The NDI inspector must, therefore, be familiar with their appearance and cause, in order to make valid interpretations of inspection results. Some of the common types of manufacturing discontinuities are described and illustrated in the following paragraphs.

2.7.6.2.2.1 Porosity.
Porosity is common to all cast parts, particularly aluminum and magnesium. Porosity occurs when gases are entrapped in the molten metal during pouring and solidification and may also occur during welding. It does not always break the surface, and internal porosity is not detected by penetrant inspection. Porosity can be very small and distributed throughout the material, in which case it is called microporosity. Microporosity may or may not cause a penetrant indication. When it does, it produces an overall background. The larger pores are called macroporosity. In castings, porosity is not usually considered a defect, unless it is extensive enough to cause a structural weakness or allow the leakage of a fluid intended to be contained by the casting.

2.7.6.2.2.2 Inclusions.
Inclusions are particles of foreign material, usually slag, oxides, sulfides or silicates trapped in the metal during solidification. If the material is mechanically worked into plate, sheet or bar, the inclusions will be elongated by the forming operations. They are not usually at the part surface but may become exposed by subsequent machining. Since inclusions are solid foreign matter, they will not form penetrant indications unless the foreign material is porous. Inclusions are considered defects only when they are open to the surface, have a measurable length, and are located in a critical area.

2.7.6.2.2.3 Seams.
Seams occur in rolled bar stock or parts machined from bar stock. They are inclusions, porosity, or more commonly, metal folds that have been elongated by the rolling process during fabrication. They are long, straight discontinuities that run parallel to the direction of mechanical working. If the seams contain foreign material, they may produce no indications, or very faint indications. They may be classified as defects depending on size and location.

2.7.6.2.2.4 Forging Laps.
Forging laps are formed when a portion of the metal is creased and folded over during the forging operation. They produce a wavy, irregular, linear indication. The indication may be faint or intermittent, since the lap breaks the surface at an angle and the edges may be partially welded. They may or may not be considered a defect, depending on size and location.

2.7.6.2.2.5 Flash-Line Cracking.
Forging flash is the line of excess metal extruded into the space at the junction between the top and bottom dies. Cracking can occur when this excess metal is removed causing the linear type of indications. The cracking always occurs along and within the trimming marks.

2.7.6.2.2.6 Extrusion Tears.
Extrusion involves forcing a metal through a die to produce a desired shape. The process is similar to squeezing tooth paste out of a tube. If the die lip has a nick, burr or lump of oxide, the die can produce tears in the extruded part. Extrusion tears are usually short linear defects perpendicular to the extrusion direction.

2.7.6.2.2.7 Thermal Cracks.
When metals are subjected to a high temperature, localized stresses can occur due to unequal heating or cooling; restricted movement within the part; or unequal cross-section. Cracking will occur when the stresses exceed the tensile strength of the material. There are several types of thermal cracking depending upon the heating process.

2.7.6.2.2.8 Grinding Cracks.
Grinding of hardened surfaces frequently introduces surface cracks. These thermal cracks are caused by localized over-heating due to insufficient or poor coolant; improper grinding wheel; too rapid feed or too heavy a cut. The cracks are shallow and sharp at the root; generally occur at right angles to the direction of grinding; and usually but not always, occur in multiples. Grinding cracks are considered defects since they reduce the fatigue strength.

2.7.6.2.2.9 Heat Treat Cracks.
Heat treat or quench cracks form as a result of unequal heating or cooling within a part. The cracks are deep, usually forked, and seldom form a pattern. These cracks are considered defects.

2.7.6.2.2.10 Weld Cracks.
Welds can contain a number of discontinuities detectable by penetrant. They may be due to lack of penetration, lack of fusion, heating or quenching cracks in the weld bead and heat affected zone, and grinding cracks occurring during removal of the weld crown. Crack-like discontinuities are considered defects. Two typical examples are, weld grinding cracks; and, shrinkage or quench crack.

2.7.6.2.3 Service Induced Discontinuities.
The most frequently encountered service discontinuities detected by penetrant inspection are fatigue cracks. Stress corrosion and overload cracking is also common. Overload fractures occur when the stress exceeds the tensile strength

of the part. This is greater than the yield point, and the fracture is accompanied by some distortion. Cracks caused by overloading are relatively large and are further magnified by distortion, making them easy to detect visually without penetrant inspection.

2.7.6.2.3.1 Fatigue Cracks.

Fatigue cracks are caused by repeated or cyclic loads that are below the yield strength of the metal. They initiate after a large number of load cycles usually at a surface imperfection such as a pit, scratch, tool mark, or at sharp change in cross-section. The initial crack is very small and forms a quarter or half arc around the initiation point and then stops. After an additional number of load cycles, the crack grows slightly. This growth-arrest cycle produces a characteristic pattern on the fracture face, termed clam shell or beach mark pattern. Fatigue cracks have many common features. They occur in regions of high stress; are perpendicular to the direction of principal stress at their origin; and are transgranular. Figure 2-33 is a good example of a fatigue crack. Transgranular means the cracking progresses through or across the grains of metal rather than around them. Fatigue cracking occurs on a wide variety of parts and is considered a defect. It will continue to grow in-service, and the rate of growth increases as it becomes larger.

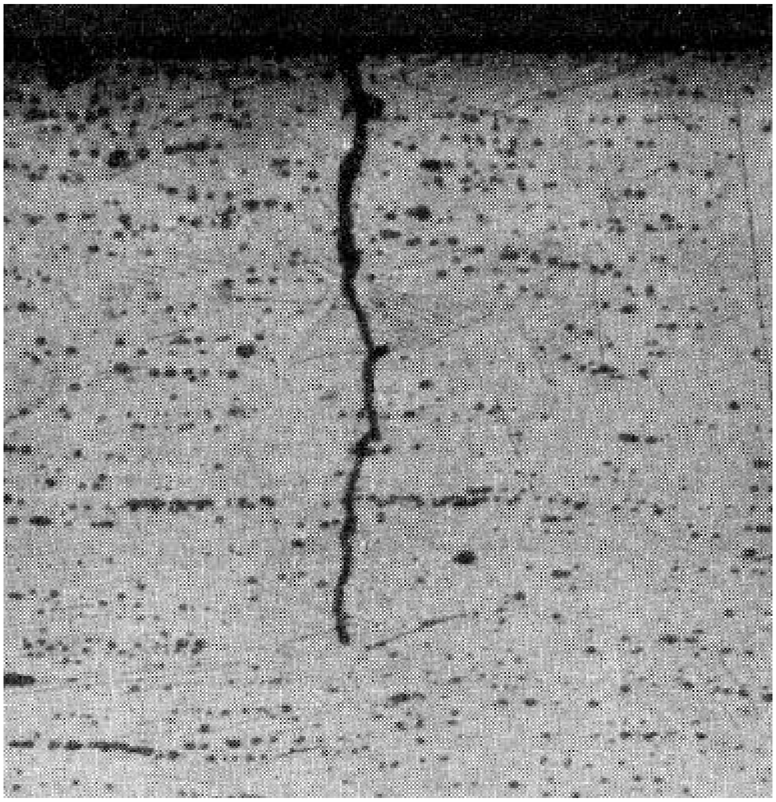


Figure 2-33. Micrograph of a Cross-Section through a Fatigue Crack Showing the Transgranular Progression.

2.7.6.2.3.2 Stress Corrosion Cracks.

Stress corrosion cracking is caused by a combination of stress and corrosion action. The stress may be either from service loads or a residual stress in the part. The residual stress can cause cracking of a part that has never been in service. Stress corrosion cracks have many of the characteristics of fatigue cracks. They occur in high stress areas at right angles to the stress and will grow in-service. Stress corrosion cracking may form a network of fine spider web-like cracks on the part surface. Penetrant indications of stress corrosion cracks can also appear identical to indications of fatigue cracks. Figure 2-34 shows stress corrosion crack indications in a wheel. It is not always possible to distinguish between fatigue cracks and stress corrosion cracks from their surface appearance. Metallurgical examination is required to identify stress corrosion from fatigue cracks, since cross-sectioning will show stress corrosion cracks to be between the metal grains, intergranular, while fatigue cracks are transgranular breaks through the metal grains. Figure 2-34 is a micrograph of a cross section through a stress corrosion crack. As with fatigue cracks, it is important to know the history or circumstances associated with the occurrence of the stress corrosion cracking. Depending upon the service of the part, fatigue cracks may be free of contamination and may be easily detected with penetrant testing or they may be filled with contamination or under such high residual compressive stress that they are impossible to detect with penetrant. Stress corrosion cracks may have very little or a lot of corrosion products trapped in the cracks. The amount of corrosion product present significantly affects the detectability of this type of cracking. As with fatigue cracks, certain types of stress corrosion cracking may not be detectable with penetrant methods. Extended dwell times may also be required to detect stress corrosion cracking.

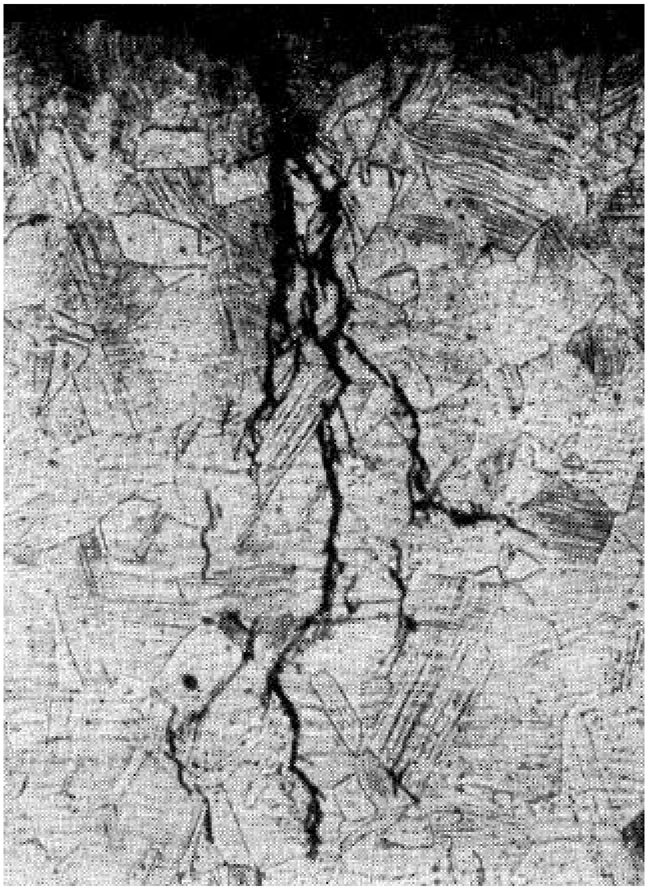


Figure 2-34. Micrograph of a Cross-Section through a Stress Corrosion Crack.

2.7.6.2.3.3 Corrosion.

The penetrant inspection method is occasionally used to detect corrosion. Corrosion usually attacks the material at the grain boundaries faster than at the interior of the grains and forms a network of very fine cracks. In the early stages, the cracks are visible only under 10X or greater magnification. Penetrant indications of intergranular corrosion appear as a residual background that can only be resolved under magnification. Developer is not used when evaluating a penetrant indication using a magnifying glass (see paragraph 2.7.6.3). Penetrant inspection is often used to monitor the surface for adequacy of corrosion removal by grinding. Caution must be exercised, since the mechanical removal causes smearing which may obscure indications of remaining corrosion attack (see paragraph 2.3.6.2). In monitoring corrosion grind-out areas, a developer is not used. Following removal of excess surface penetrant, the area is examined using a low power magnifying glass (3X to 5X). The examination should be repeated after a minimum 5 minute dwell in lieu of developer. When the corrosion is no longer detected, the inspection process SHALL be repeated using nonaqueous developer.

2.7.6.3 Evaluation of Indications.

Indications can be indistinct and blurred while still being highly visible. The following method may be used to verify and evaluate the type of indication. Carefully wipe the indication area once with a fast drying solvent such as light naphtha, xylene, methylene chloride or isopropyl alcohol. After the solvent has evaporated, spray a very light layer of solvent developer over the area and watch the indication as it begins and continues to develop. If it does not reappear, wipe again with solvent and examine the bare surface with a 3X to 5X magnifying glass. Evaluation of penetrant indications with a magnifying glass should be accomplished with the developer removed. Developer will blur and enlarge the indication. The initial evaluation should be done at low magnification (3X to 5X) with higher magnification (10X) used only after the indication has been located. If no penetrant bleed-out or surface imperfection can be seen, the original indication could have been non-relevant, possibly due to improper processing.

2.7.6.4 Photography of Indications.

2.7.6.4.1 General.

Photography is a good method of producing a permanent record of penetrant indications. Photographs provide a very descriptive record since they show both the indication size and location on the part. They are permanent, reproducible to some extent, and the required equipment is available. Photographing penetrant indications is slightly different that normal photography and requires care, practice and a series of trial and error exposures to produce an optimum photograph. It is also very difficult to produce identical photographs when there is a time lapse between exposures. Photographs made at different times will vary due to a number of factors, such as changes in part position, camera position, black light intensity, or changes in film processing or development.

2.7.6.4.2 Camera Equipment.

When photographing penetrant indications, which are generally very small, the camera must be held close to the object. This requires, at a minimum, a set of close-up lenses. Extension tubes or a bellows attachment also permits close-up photographs. Photographing fluorescent indications requires time exposures, a tripod or other means of holding the camera steady, and a cable release shutter.

2.7.6.4.3 Filters.

Photographic emulsions or films have a higher response to ultraviolet than the human eye. When photographing fluorescent indications, the ultraviolet light must be removed or filtered to obtain a usable photograph. The basic filter used is a No. 2B. (The name Wratten is often associated with the filter numbers, after the man who devised the numbering system.) The 2B filter will absorb the invisible ultraviolet while passing the visible blue light. This approach, when used with color film, provides a photograph representative of what the eye sees. Color balance will be normal and the part will appear as a blue outline with the fluorescent indication appearing as bright yellow-green as normally seen. With black and white film, the part will be outlined and the indication will appear as a white line or dots. Some developers form a bright background that will decrease the contrast between the part and indication. This can be compensated for by using a 2E filter. The 2E filter reduces the background brightness without reducing the indication brightness. When using a 2E filter and color film, the color balance will shift and the photograph may be more yellow than desired. For black and white photography, Nos. 3, 4, 8 or 15 may be used to improve the contrast of the indication, but these filters will transmit only the light from the indication, and the part outline will not be visible. The white light can be flashed during the black light exposure to provide an outline of the part. Alternatively, to show the part, double expose the film using white or visible light for the second exposure. When using the double exposure procedure for black light photography, the white light exposure should be 1/3 or less of the normal exposure. This will make the part appear dark as it would in the normal inspection station. If a normal exposure were used, the contrast between the part and the indication would be largely lost.

2.7.6.4.4 Film Types.

All types of color and black and white film Including Polaroid can be used. Slow film speed will increase contrast and decrease grain effects.

2.7.6.4.5 Camera Positioning.

Penetrant indications are usually small. On large parts, it may not be possible to include the entire part in the photograph and still get acceptable detail on the indication. The camera must be moved in close to the indication, showing just enough of the part to adequately identify the location of the indication. When photographing penetrant indications, a through-the-lens viewing system is preferred. Cameras with a separate viewing lens will not include the exact area when making close-up photographs. This parallax problem must be compensated for by shifting the viewer aiming spot the distance between the lens and viewer opening.

2.7.6.4.6 Lighting.

The maximum possible amount of black light energy must be used to reduce exposure time. The usual procedure is to use two black light lamps placed at equal distances on each side of the indication and position the camera in the middle. This procedure provides equal light intensity across the length of the indication. The black light lamps must be positioned so that neither the direct beams, nor reflections from them, enter the camera. Tubular (fluorescent) black light bulbs emit more visible blue light than high pressure, mercury bulbs. Therefore, a No. 2E filter will produce a more natural photograph when fluorescent black lights are used.

2.7.6.4.7 Light Meters.

Photographic light meters may be used to estimate exposure criteria when photographing fluorescent indications but they are not precise. Normal photographic exposure meters respond to black light to a greater degree than does the human eye. The exposure meter must be equipped with the same ultraviolet absorbing Filter that is used on the camera. The level of light emitted by fluorescing indications is low and a sensitive meter must be used. A meter with a narrow angle aperture is better than a wide angle type because most black light lamps are spot type sources, and there are wide variations in intensity over the part surface. Meter readings will be influenced by the size of the fluorescing indication. The meter readings will be correct or slightly over-exposed when the indications are large and emit considerable light. On average size indications, the meter reading will be correct or slightly under exposed. In general, it is wise to assume the meter reading is only a starting point. Light meters provide a more consistent and accurate reading when photographing visible dye indications. White developer backgrounds may result in a meter reading calling for a slight under exposure. This can be compensated for by slightly increasing the exposure.

2.7.6.4.8 Lens Opening, Exposure and Bracketing.

Close-up photography requires care in selecting the lens opening to obtain an acceptable depth of field. Depth of field is the distance range that is in focus. Lens openings are called F-stops with larger numbers indicating a smaller lens opening. As the lens opening increases (smaller F-stop numbers), the depth of field decreases. Always use the smallest lens opening (largest F-stop number) possible to get an acceptable depth of field to keep the entire part in focus. The lens opening number should be higher than F5.6 for most close photography of this type as stated. Stop numbers of F6 or smaller will result in portions of the picture being out of focus. Close-up photography of fluorescent indications may require a number of exposures to obtain optimum results. Therefore, with black and white film, three exposures should be made: The first at the meter indicated F-stop number; the second at two F-stop numbers under the meter reading; and the third at two F-stop numbers over the meter indicated number. A fourth exposure may be required at an intermediate setting. With color film, the same three exposure procedure should be used to obtain a usable quality picture. However, it is recommended that the lens openings be adjusted at one stop intervals with allowance for indication size as discussed above. With very large or very small indications, the optimum lens opening may be three or four F-stop numbers off the indicated value. If an exposure meter is not available, the chart in Table 2-7 can be used a guide to estimate the exposure starting point.

Table 2-7. Typical Photographic Exposure Settings for Fluorescent Indications

(Film Speed: ASA 64; Filter: Wratten 2B).

Defect Description	Black Light Intensity ($\mu W/cm^2$)	Lens Opening	Time(sec)
Large and bright	1100	F11	16
Large and bright	500	F11	60
Average (turbine blades)	1200	F11	16
Very small (20µm, cracked chrome plate panel	1100	F8	120

2.7.6.4.9 Instant Cameras.
Instant cameras can be used for photographing indications. There are a few guidelines to be followed:

a. The camera should not be hand held due to the long exposures. A steady support, such as a tripod or a camera stand, must be available. Some of the instant cameras do not have a tripod socket and a special mounting clamp or fixture must be used.

b. Close-up lens plus a mounting ring or adapter to hold them on the camera lens must be available. The lenses must be capable of providing a focus with camera-to-subject distances of 5 to 24 inches.

c. The same filters that are used with conventional films must be used, namely the Wratten 2B or 2E for fluorescent indications and the No. 66 filter for visible dye indications. It is also necessary to place an identical filter over the camera electric eye or exposure meter, when the camera contains an automatic shutter control.

d. The lens opening on instant cameras is not usually controllable by the photographer. They are usually small enough to produce a usable area of sharp focus even when using color film.

e. Shutter speeds on instant cameras are usually controlled by the electric eye. The shutter will stay open until enough light has entered the camera to make the picture. This feature is very useful in indication photography, since it largely automates the exposure. For fluorescent photography, the "lighten-darken" control should be set one or two marks toward darken. This will produce a picture where the part is apparently dark, but still has a visible outline and the indications are bright. This produces a picture of what is visually seen in the darkened inspection booth.

f. Instant color film requires a slightly different technique than other films. When photographing fluorescent indications with 2B and 2E filters, set the built-in meter to one mark lighter than normally recommended. Less exposure will not make the part visible. When developing color pictures of fluorescent indications, develop for two-thirds to three-fourths of the recommended time. Over-developing will result in a general blue background; under developing will produce a reddish-brown background.

g. Notes:

    (1) Tubular (fluorescent) black light sources give less satisfactory instant pictures than high pressure, mercury bulbs.

    (2) Use as much light as possible. Automatic shutters are not as reliable under low light as in normal light.

    (3) Exposure times of 10 seconds to 3 minutes can be considered normal.

2.7.6.5 Other Methods for Developing and Recording Indications.

a. Video Camera Systems. Readily available hand-held video camera systems with very low light capability are extremely useful for showing penetrant indications. The low light sensitivity allows records of indications to be made without the high light levels and extreme exposure times often required with conventional photographic film methods. Many of the video camera systems are equipped with automatic focusing, exposure, and zoom control. The camera can be hand held or positioned on a tripod. With a hand-held camera, the indication and part can be viewed from a variety of angles. The video tape record is easily viewed on a monitor and can be copied for distribution.

b. Film-type developers. Permanent records can also be made using strippable coating developers.

c. Laser scanning with a variety of computer driven, data retrieval systems are being developed for the inspection of large critical parts.

d. Digital computerized pattern-recognition systems are being developed to record flaws as variations to a recognized pattern. Some types of pattern recognition systems are able to discriminate between linear, crack-like indications and rounded, non-critical indications.

SECTION VIII
SPECIAL PURPOSE MATERIAL

2.8 SPECIAL PURPOSE MATERIALS.

2.8.1 Summary.

NOTE

The materials described in this section are not covered by the military specification on penetrant materials.

There are a number of penetrant materials that are different than the materials described in the previous sections. These materials are formulated for special applications and purposes. This section describes these special purpose materials and discusses the reasons for their use. Application procedures are not covered. The procedures vary widely between materials and manufacturers. Each of the manufacturers provides detailed application procedures for the particular material when it is procured.

2.8.2 Oxygen Compatible Penetrants.

2.8.2.1 General.

Oxygen has a high degree of chemical reactivity. It will explosively react or combine with a large number of materials. This includes traces or residues from normal penetrant inspection materials. There are special cleaning procedures to be used on parts and components that will be contacting gaseous or liquid oxygen. Simple disassembled parts can be penetrant inspected and sent to the cleaning shop for complete removal of residual inspection materials in the usual manner. Difficulties are encountered with assembled parts (on or off of aircraft) and complex shaped parts containing crevices, recessed areas, or faying surfaces where inspection materials become trapped and are not easily removed by cleaning. Such items should be inspected by another nondestructive test method or special penetrant materials used, which do not react with oxygen. There are liquid oxygen (LOX) compatible materials available by special order. These materials are mainly intended for use on space vehicles and can be used on aircraft when required.

2.8.2.2 Requirements for Lox Compatible Materials.

Testing for LOX compatible materials involves dropping a weight on the material in a liquid oxygen environment. If the material is not compatible (i.e., will readily burn in an oxygen rich atmosphere), it will cause an audible explosion, a visible flash in a darkened room, discolor the impact surface, or leave evidence of charring. There are two ways of avoiding a LOX reaction from penetrant materials:

a. Completely remove all conventional inspection material residues.

b. Use only process materials that are inert in an oxygen environment.

This is not simple, since the penetrant system must still be capable of detecting very small flaws. Normal penetrants are designed to resist removal from cracks and crevices and the organic dyes are oxygen reactive.

2.8.2.3 Lox Compatible Penetrant Types.

There are three approaches used in formulating LOX compatible penetrant systems:

a. Use of materials that are soluble in water and lend themselves to complete removal during postcleaning.

b. Use of materials that are completely volatile and evaporate from the parts without leaving a residue.

c. Use of non-reactive liquids that maintain the dyes in solution and are completely wetted by the liquid at all times.

2.8.2.3.1 Water Base Lox Compatible Penetrants.

There are dyes and developer materials that are soluble in water. Water base penetrants, if their water content is high, are LOX insensitive. However, when the water evaporates, the residues can become LOX sensitive. Water base penetrant systems have been approved for some LOX related applications since their residues are water soluble surface agents similar to detergents. Approval for LOX applications is based on their ease of removal from surfaces and flaw entrapment using plain water.

2.8.2.3.2 Volatile Penetrants.

There is a class of dyes that sublimes at room or up to temperatures in the range of 130° to 200°F (50° to 90°C). These and other materials will fluoresce from a discontinuity and will dissipate entirely from the flaw on setting or when the part is slightly heated. The materials have been used in formulating volatile penetrant systems. The problems to be considered are:

a. Even though the materials evaporate from a surface or flaw, there is still the possibility of them re-depositing at another location.

b. Determination of 100% dissipation as judged by the disappearance of an indication does not mean a residual-free surface or crack.

2.8.2.3.3 Non-Volatile Lox Penetrants.

Another method of formulating penetrants that are not LOX-reactive is to dissolve the dye in a non-reactive, non-volatile liquid or vehicle. The liquid serves to quench the reactivity of the dye and, since it is non-volatile, does not produce a reactive residue. Water based penetrants described in paragraph 2.8.2.3.1 do not meet this criteria, since they evaporate, leaving a reactive residue. There are some useful fluorinated hydrocarbon liquids, commonly called fluorocarbon or fluorolube oils that may be employed as penetrants. Fluorolube oils are quite non-volatile and are non-reactive with LOX. They also act to quench any LOX reactivity of dye that is dissolved in or wetted by the fluorolube oil. Unfortunately, they are not good solvents for fluorescent dye. One particular LOX compatible penetrant utilizes a volatile solvent, methylene chloride, to dissolve the dye and mixes this solution with fluorolube oil. This produces a high dye content with the LOX reactivity quenched by the non-volatile fluorolube oil.

2.8.3 Low Sulfur, Low Chlorine Penetrant Systems.

NOTE

Low sulfur and low halogen penetrant material requirements are not covered by the military specification on penetrant materials.

There is considerable concern over the effects of small quantities of sulfur and halogens present in penetrant materials. This concern is due to the increased use of high temperature alloys such as nickel and cobalt-base alloys, austenitic stainless steel, and titanium in aircraft and engines. These alloys are susceptible to hydrogen embrittlement, intergranular corrosion, and stress corrosion. Small amounts of sulfur and halogens, principally chloride, remaining on the alloys during service will increase their susceptibility to attack. Sulfur and halogens are not essential compounds in penetrant materials, nor are they deliberately added. They are usually introduced as contaminants in the raw materials. There is considerable difference of opinion as to the allowable limits of these contaminants. Nuclear and boiler codes specify from 0.5% to 1% by weight as the maximums. Many of the QPL materials will meet at least the upper limit. The position is similar to that for LOX compatible materials. Namely, there is no requirement for special penetrants, if the part to be inspected is disassembled and can be sent to the cleaning shop for the removal of all inspection residues. The aircraft or engine manufacturer's recommendations should be followed for on-aircraft and assemblies.

2.8.4 High Temperature Penetrant Materials.

Standard penetrant materials are limited to temperatures of 120°F (49°C) (see paragraph 2.4.5.4). There are special penetrant systems formulated for use above 120°F (49°C). These special high-temperature penetrants contain visible and fluorescent dyes that resist heat degradation. The vehicles and solvents are carefully chosen to remain liquid and resist evaporation at the operating temperature. The nonaqueous wet developer must be modified since standard developer will peel or curl on hot surfaces. The upper temperature limits are in the range of 350°F (177°C) to 400°F (204°C). Typical applications for high temperature penetrant systems are the inspection of live steam valves and lines and intermediate weld beads prior to laying down a covering bead.

2.8.5 Dye Precipitation Penetrant Systems.

NOTE

Dye precipitation penetrant systems are not covered by the military specifications on penetrant materials.

Dye precipitation penetrant systems are commonly referred to as high resolution penetrants. The penetrant contains a high concentration of either visible or fluorescent dye dissolved in a highly penetrating, volatile solvent. The penetrant is usually applied by brushing on the surface to be inspected. The penetrant will enter any discontinuities and, during the dwell period, the solvent evaporates, precipitating the dye as a solid that fills the discontinuity. After removal of the excess surface penetrant, and when using a two-step development process, a very thin layer of solvent developer is sprayed on the surface. The developer re-dissolves the solid penetrant dye entrapped in the flaw, expands its volume, and extracts it from the flaw. It is possible to build the indication to any desired size and resolution by applying additional thin coats of solvent developer. When the indication reaches the desired size, it is fixed by applying a layer of plastic developer. The plastic developer allows the developer coating with the embedded indication to be removed or stripped from the part. There is also a one-step developer that provides the same results. Dye precipitation penetrant systems are extremely sensitive.

2.8.6 Reversed Fluorescence Method.

The reversed fluorescence method is similar to a photographic-negative of the standard fluorescent penetrant inspection. A standard visible-dye penetrant is applied to the surface to be inspected and after the dwell, the excess is removed in the normal manner. A special developer, containing a low intensity fluorescing dye and a relatively small amount of developer powder, is applied by spraying under a black light. The entire surface will fluoresce, except for the flaw, which appears as a dark line where the penetrant has quenched the fluorescent dye.

2.8.7 Thixotropic Penetrant.

A thixotropic material is one that changes form or structure as a function of time or shear stress. Thixotropic penetrants are applied as a solid or gel and then change to a liquid after application. They are used when it is difficult to apply the penetrant as a liquid. One example is a high temperature penetrant in the form of a crayon or stick used to inspect welds before they have cooled.

2.8.8 Dilution Expansion Developers.

Dilution-expansion developers differ from the conventional powder type developers in that they do not utilize the absorption-adsorption action of powder particles. In fact, powder particles are not required and may even interfere with the action of dilution-expansion developers. The action of dilution-expansion developer is to dissolve the exuded and exposed layer of entrapped penetrant and disperse it in the thicker layer of developer. Dilution-expansion developers have a layer thickness equivalent to that of conventional powder developers.

2.8.9 Plastic Film Developers.

Plastic-film developers form a dry, flexible layer that can be peeled or stripped to provide a record of indications on test surfaces. The most frequently used plastic film developers are two-part systems. The first part provides developer action while forming a white, reflecting background. The second part forms a clear layer that freezes the indication and provides film strength and some flexibility. The layers combine and can be removed from the part as a thin film and maintained as a record of the indication.

CHAPTER 3
SECTION I
INTRODUCTION TO MAGNETIC PARTICLE INSPECTION

3 MAGNETIC PARTICLE INSPECTION.

3.1 INTRODUCTION.

This section explains magnetic particle inspection, its purposes, and capabilities. This method is used for detecting discontinuities in ferromagnetic parts. The part is magnetized by using an electrical current that induces a magnetic field in the part. A discontinuity, which crosses the magnetic field, creates north and south poles on either side of the defect area. When magnetic particles are applied to the part, the poles attract the particles and an indication of the discontinuity is formed. Magnetic field characteristics are described, as well as the various techniques and equipment used to magnetize and demagnetize components under inspection.

3.1.1 Purpose Of MPI.

NOTE

The terms MPI, MPT and MT are used interchangeably in this chapter.

Magnetic particle inspection (MPI) or magnetic particle testing (MPT or MT) is a nondestructive inspection method used to reveal surface and near sub-surface discontinuities in ferromagnetic materials. It consists of three basic steps:

a. Establish a suitable magnetic field in the part.

b. Apply magnetic particles to the surface of the part.

c. Examine and evaluate any particle accumulations on the surface of the part.

3.1.2 Limitation of Magnetic Particle Inspection.

Magnetic particle inspection can detect discontinuities only in parts made of ferromagnetic materials. The magnetic particle inspection method will detect surface discontinuities, including those that are too fine to be seen with the naked eye and those that lie slightly below the surface.

3.1.3 Discontinuity versus Defect.

Discontinuities may exist in raw materials, be formed during processing or fabrication of parts, or result from service use. Discontinuities are considered defects only if their existence is detrimental or harmful to the usefulness of the parts.

3.1.4 Magnetization.

a. A part is said to be magnetized when it is ferromagnetic and contains a magnetic field. An electric current can be used to create or induce magnetic fields in ferromagnetic materials. The direction of the magnetic field is perpendicular to the direction of the magnetizing current. The current direction is selected to induce a magnetic field that is transverse to the orientation of a suspected discontinuity. The strength and distribution of the field are varied by the changing the nature of the magnetizing current. Understanding how different types of current can change the magnetization within a part is necessary for the proper application of magnetic particle testing.

b. When a surface or near-surface discontinuity interrupts the magnetic field in a ferromagnetic material, some of the field is forced out into the air above the discontinuity resulting in a leakage field. The size and strength of the leakage field depend on the size and proximity to the surface of the discontinuity. The discontinuity is detected by the use of finely divided ferromagnetic particles that are applied to a part's surface and are attracted to the leakage field. This collection of particles indicates the presence and location of the discontinuity.

3.1.5 Basic Terminology.

The following terms and definitions are basic to an understanding of the MPT method.

a. Coercive Force. The negative or reverse applied magnetizing force (H) necessary to reduce the residual magnetizing force (B) to zero in a ferromagnetic material, after magnetic saturation has been achieved. The magnitude and direction of this force are represented by the line OG in Figure 3-16.

b. Direct Contact Magnetization. Use of current passed through the part via contact heads or prods to produce a magnetic field.

c. Ferromagnetic. A term that describes a material that exhibits both magnetic hysteresis and saturation, and whose magnetic permeability is dependent on the magnetizing force present. In magnetic particle testing, we are concerned only with ferromagnetic materials.

d. Field, Circular Magnetic. The magnetic field surrounding the flow of electric current. For magnetic particle testing, this refers to current flow in a central conductor or the part itself. It is best characterized as having no magnetic poles present.

e. Field, Longitudinal Magnetic. A magnetic field that results in magnetic poles. An example would be the field that exists in a bar magnet.

f. Field, Magnetic. The term used to describe the volume within and surrounding either a magnetized part or a current-carrying conductor wherein a magnetic force is exerted.

g. Field, Magnetic Leakage. The magnetic field outside of a part resulting from the presence of a discontinuity, a change in magnetic permeability, or a change in the part's cross-section.

h. Flux Density, Magnetic (B). The strength of a magnetic field, expressed in flux lines per unit cross-sectional area.

i. Flux Lines or Lines of Force. A conceptual representation of magnetic flux that can be illustrated by the line pattern produced when iron filings are sprinkled on paper laid over a permanent magnet

j. Hysteresis, Magnetic. The behavior of ferromagnetic materials that results from both the retentivity and the coercive force being greater than zero.

k. Induced Current Magnetization. Use of current induced in a part to produce a magnetic field.

l. Magnetizing Current (I). The flow of either alternating or direct current used to induce magnetism into the part being inspected.

m. Magnetizing Force (H). The magnetizing field applied to a ferromagnetic material to induce magnetization.

n. Magnetic Permeability (μ). The ease with which a ferromagnetic part can be magnetized. It is equal to the ratio of the flux density (B) produced to the magnetizing force (H) inducing the magnetic field. It changes in value with changes in the strength of the magnetizing force. A metal that is easy to magnetize, such as soft iron or low carbon steel, has a high permeability or is said to be highly permeable.

o. Residual Magnetism. The magnetic field that remains in the parts when the external magnetizing force has been reduced to zero.

p. Retentivity. The property of a material to remain magnetized after the magnetizing force has been removed. Metals, such as hard steel with its high percentage of carbon, which retain a strong magnetic field after removal of the magnetizing current have high retentivity, or are said to be highly retentive.

q. Saturation, Magnetic. The level of magnetism in a ferromagnetic material where the magnetic permeability is equal to 1. This is characterized as that level where an increasing in magnetizing force (H) results in no greater increase in magnetic field (B) than would occur in a vacuum or air.

3.1.6 Magnetic Field Characteristics.

3.1.6.1 Horseshoe Magnet.

A familiar type of magnet is the horseshoe magnet as shown in (See Figure 3-1). This is a permanent magnet and possesses only residual magnetism. It will attract ferromagnetic materials to its ends or poles between which a leakage field occurs. By convention, these ends are commonly called “north” and “south” poles, indicated by N and S on the diagram. Continuous magnetic flux lines, or lines of force in leakage fields, flow from the north to the south pole. These same flux lines continue through the magnet. In an ideal horseshoe magnet, the flux lines leave only at the poles and consequently an external magnetic force capable of attracting magnetic materials exists only at the poles. This is an example of a longitudinal magnetic field. In a real horseshoe magnet very small discontinuities are distributed throughout creating small, weak and very localized leakage fields distributed over the surface of the magnet.

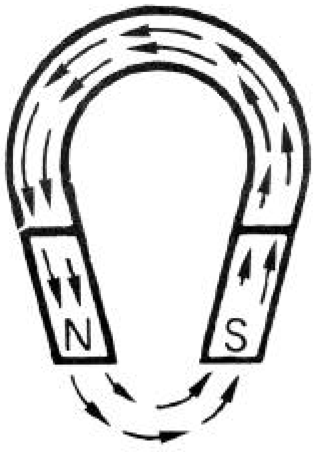


Figure 3-1. Horseshoe Magnet.

3.1.6.1.1

If the shape of an ideal horseshoe magnet is changed as shown in Figure 3-2, the ends will still attract other magnetic materials. However, if the ends of the magnet are fused or welded into a continuous ring as shown in Figure 3-3, the magnet will no longer attract or hold exterior magnetic materials. This is because the north and south poles no longer exist; thus a large leakage field does not exist. The magnetic field will remain as shown by the arrows, but there is no attraction for external ferromagnetic materials. This is an excellent example of a circular magnetic field. The change in magnetic field from longitudinal to circular by fusing the ends of the magnet is caused by the elimination of the large north and south poles present in the horseshoe magnet.

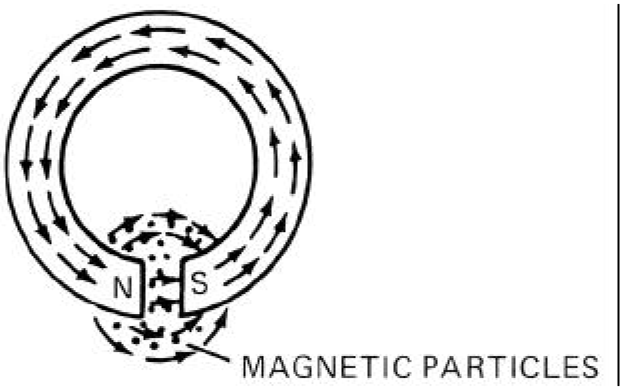


Figure 3-2. Horseshoe Magnet with Poles Close Together.

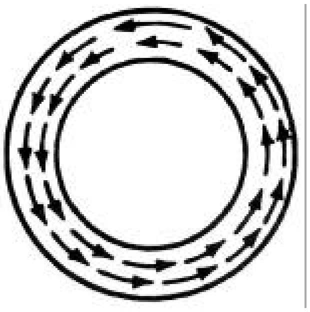


Figure 3-3. Horseshoe Magnet Fused into a Ring.

3.1.6.1.2
A transverse crack in the fused magnet or circularly magnetized part (see Figure 3-4) will create a leakage field with north and south poles on either side of the crack. Some of the magnetic flux (lines of force) will exit the metal and form a leakage field. Magnetic materials or particles will be attracted by the leakage field created by the crack, forming an indication of the discontinuity in the metal part. This is the principle whereby magnetic particle indications are formed.

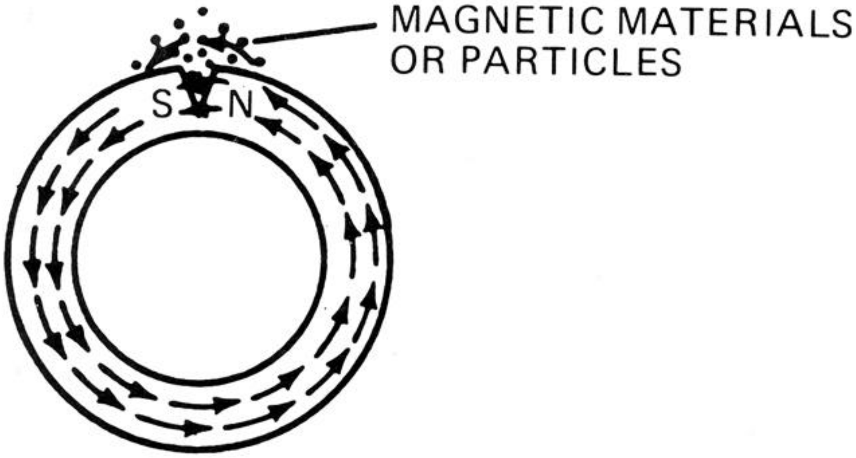


Figure 3-4. Crack in Fused Horseshoe Magnet.

3.1.6.2 Bar Magnet.

3.1.6.2.1
If the shape of the magnet is straightened, as shown in Figure 3-5, a bar magnet is created. The bar magnet has poles at either end and magnetic lines of force that flow through the length of it and return around the outside of it. Magnetic particles will be attracted only to the poles (in the ideal case). Such a piece is said to have a longitudinal field, or to be longitudinally magnetized.

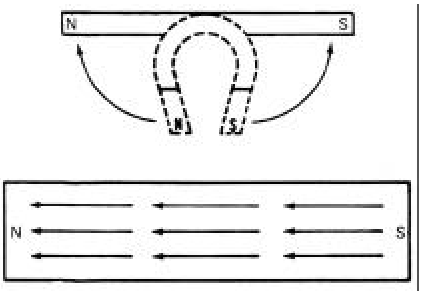


Figure 3-5. Horseshoe Magnet Straightened to Form a Bar Magnet.

3.1.6.2.2
A transverse slot or discontinuity in the bar magnet that crosses the magnetic flux lines will create north and south poles on either side of the discontinuity (see Figure 3-6). The resulting leakage field will attract magnetic particles. In a similar manner, a crack, even though it is very fine, will create magnetic poles as indicated in Figure 3-7. These poles will also produce a leakage field that can attract magnetic particles. The strength of the leakage field will be a function of the number of flux lines (i.e. the strength of the internal field), the depth of the crack, and the width of the air gap at the surface. The strength of this leakage field, in part, determines the number of magnetic particles that will be gathered to form indications. Clear indications are found at strong leakage fields, while weak indications are formed at weak leakage fields.

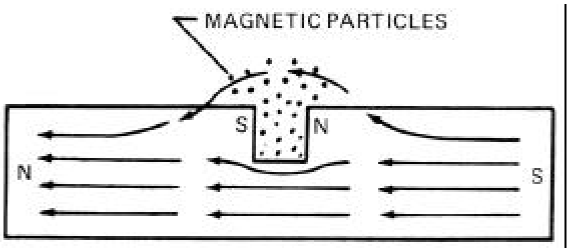


Figure 3-6. Slot in Bar Magnet Attracting Magnetic Particles.

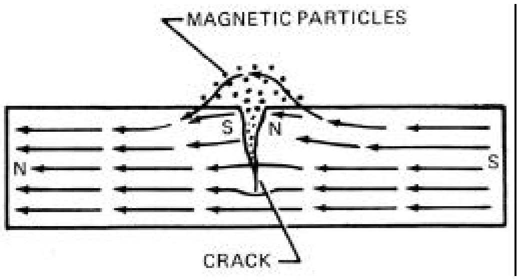


Figure 3-7. Crack in Bar Magnet Attracting Magnetic Particles.

3.1.6.3 Electricity and Magnetism.

Electric current can be used to create or induce magnetic fields in parts made of ferromagnetic materials. Magnetic lines of force are always aligned at right angles (90°) to the direction of electric current flow. It is possible to control the direction of the magnetic field by controlling the direction of the magnetizing current. This makes it possible to induce magnetic lines of force so that they intercept defects at right angles.

3.1.6.4 Magnetic Attraction.

Magnetic attraction can be explained using the concept of flux lines or lines of force. Each flux line forms a closed continuous loop, which is never broken. For a circularly magnetized object, the flux lines are wholly contained in the object (ideal case). No external magnetic poles are present and therefore there is no attraction for other ferromagnetic objects. For a longitudinally magnetized object, the flux lines leave and enter at magnetic poles. The flux lines always leave a ferromagnetic material at right angles to the surface. They always seek the path of least resistance, i.e. maximum permeability and minimum distance. When a piece of soft iron is placed in a magnetic field it will develop magnetic poles. These poles will be attracted to the poles of the magnetic object that created the initial field. As it approaches closer to the source original field, more flux lines will flow through the piece of iron, thus creating stronger magnetic poles and further increasing the attraction. This concentrates the lines of flux into the easily traversed (high permeability) iron path rather than the alternative low permeability air paths. This is magnetic attraction and is the reason magnetic particles concentrate at leakage fields. The leakage field is established across an air gap of relativity low permeability at the discontinuity. Since they offer a higher permeability path for the flux lines, the magnetic particles are drawn to the discontinuity and bridge the air gap to the extent possible.

3.1.6.5 Effects Of Flux Direction.

The magnetic field must be in a favorable direction, with respect to a discontinuity, to produce an indication. When the flux lines are parallel to a linear discontinuity, the indications formed will be weak. The best results are obtained when the flux lines are perpendicular (at right angles) to the discontinuity. Note: When an electrical magnetizing current is used, the best indications are produced when the path of the magnetizing current is parallel to the discontinuity.

3.1.6.6 Circular Magnetization.

A circular magnetic field always surrounds a current carrying conductor, such as a wire or a bar (see Figure 3-8). The direction of the magnetic lines of force (magnetic field) is always at right angles to the direction of the magnetizing current. An easy way to remember the direction of magnetic lines of force around a conductor is to imagine that you are grasping the conductor with your right hand, so that the extended thumb points parallel to the electric current flow. The fingers then point in the direction of the magnetic lines of force. Conversely, if the fingers point in the direction of current flow, the extended thumb points in the direction of the magnetic lines of force. This is called the right hand rule.

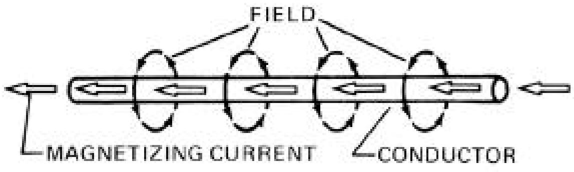


Figure 3-8. Magnetic Field Surrounding an Electrical Conductor.

3.1.6.6.1

Since metals are conductors of electricity, an electric current passing through a metallic part creates a magnetic field as shown in Figure 3-9. The magnetic lines of force are at right angles to the direction of the current. This type of magnetization is called circular magnetization because the lines of force, which represent the direction of the magnetic field, are circular within the part.

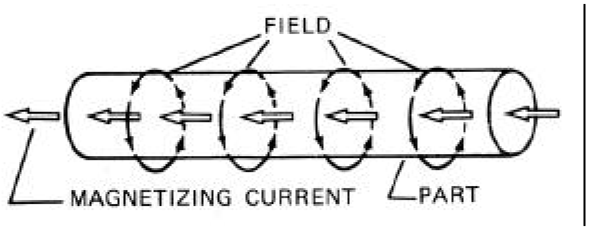


Figure 3-9. Magnetic Field in Part used as a Conductor.

3.1.6.6.3 Circular Magnetization with Inspection Equipment.
One method of creating or inducing a circular field in a part with stationary MPT equipment is to clamp the part between two contact plates and pass current through the part as indicated in Figure 3-10. A circular magnetic field is created within the part. If a longitudinally aligned crack or discontinuity exists within the part, a leakage field will be established at the site of each crack or discontinuity. The leakage field will attract magnetic particles to form an indication of the discontinuity.

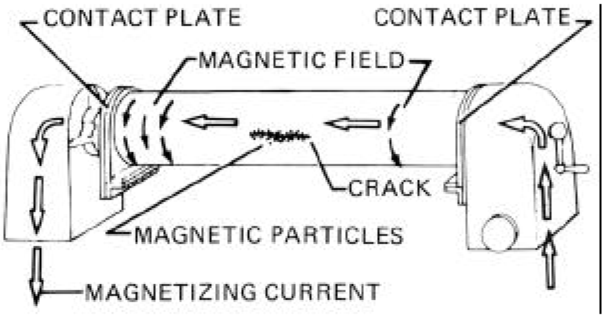


Figure 3-10. Creating a Circular Magnetic Field in a Part

3.1.6.6.3.1
For hollow or tube-like parts, it is important to inspect both the inside and outside surfaces. When such parts are circularly magnetized by passing the magnetizing current through the part, the magnetic field on the inside surface is negligible. To understand this, consider that a circular field exists externally to the net current flow only, not internally as well. To produce a magnetic field on both surfaces of the part, a separate conductor, such as a copper rod, is positioned inside the hollow part. Since a circular magnetic field surrounds such conductors when an electric current is passed through them, it is possible to induce a satisfactory magnetic field that is strongest on the hollow part's inside surface. This situation is illustrated in Figure 3-11 and Figure 3-12.

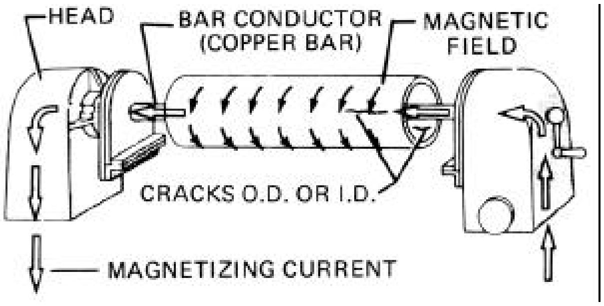


Figure 3-11. Using a Central Conductor to Circularly Magnetize a Cylinder.

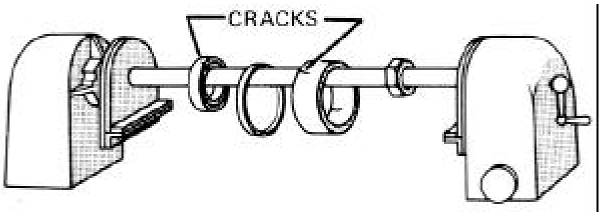


Figure 3-12. Using a Central Conductor to Circularly Magnetize Ring-Like Parts.

3.1.6.7 Longitudinal Magnetization.

Electric current can also be used to create a longitudinal magnetic field in a test part with a current carrying encircling coil. Application of the right hand rule to any segment of a coiled conductor will show that the field within the coil consists of contributions from each turn of the coil and is aligned lengthwise as indicated as shown in Figure 3-13.

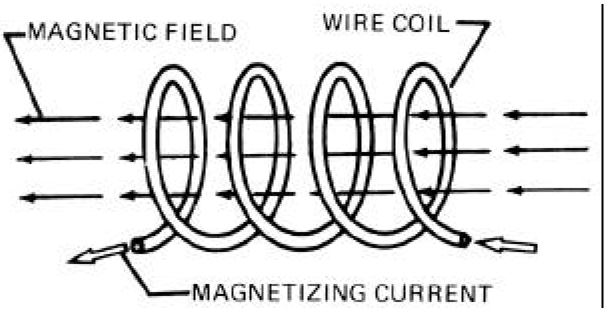


Figure 3-13. Magnetic Lines of Force (Magnetic Field) in a Coil.

3.1.6.7.1

In Figure 3-14a. If a part is placed inside a coil; the magnetic lines of force created by the coil are aligned along the longitudinal axis of the coil. If the part is ferromagnetic, the high permeability concentrates the lines of flux within the part and induces a strong longitudinal magnetic field.

3.1.6.7.2 Longitudinal Magnetization with Inspection Equipment.

Inspection of a cylindrical part using longitudinal magnetization is shown in Figure 3-14b. When a transverse discontinuity exists in the part, as in the illustration, a magnetic leakage field is formed at the crack location. This attracts magnetic particles, forming an MPI indication of the transverse discontinuity. Compare Figure 3-14b with Figure 3-10, and note that in both cases, a magnetic field has been induced in the part that is at right angles to the defect. This is the most desirable condition for reliable inspection.

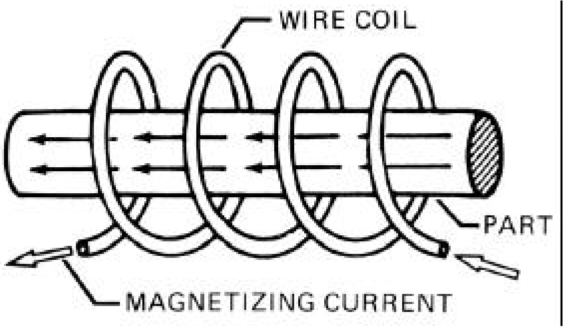


Figure 3-14a. Longitudinal Magnetic Field Produced in a Part Placed in a Coil.

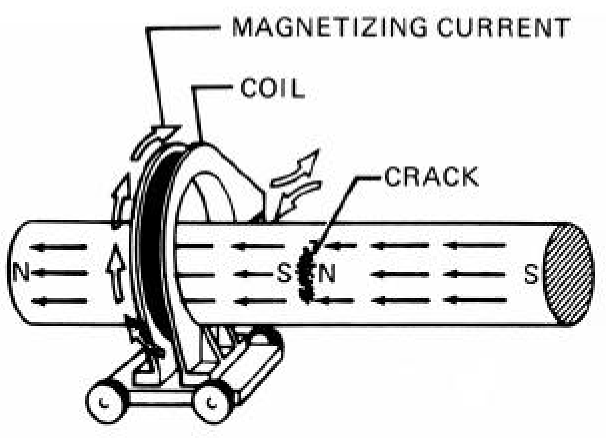


Figure 3-14b. Longitudinal Field produced by the Coil Generates an Indication of Crack in Part.

3.1.6.8 Multi-Directional Magnetic Field.

Two separate fields, having different directions, cannot exist in a part at the same time. However, two or more fields in different directions can be imposed upon a part sequentially in rapid succession. When this is done, magnetic particle indications can be formed when discontinuities are located favorably with respect to the directions of any of the applied fields, and will persist as long as the rapid alternations of field direction continue. This enables the detection of defects oriented in any direction in one operation. The indications must be viewed when the fields are being applied because they are weakly held after the current is discontinued and can be easily dislodged.

3.1.6.9 Parallel Current Induced Magnetic Field.

If a ferromagnetic bar is placed alongside, and parallel to, a conductor carrying current, a field will be set up in the bar that is more transverse than circular (see Figure 3-15). Such a field is of very little use for magnetic particle testing. Operators have tried to use this method as a substitute for a headshot for the purpose of producing circular magnetization. The field produced is not circular and is extremely limited in the transverse direction when inspecting for defects such as seams. Furthermore, the external field around the conductor and the bar can attract magnetic particles and produce confusing backgrounds.

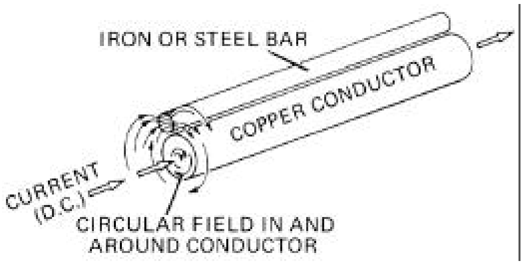


Figure 3-15. Field produced in a Bar by a "Parallel" Current

3.1.7 Current Sources For Generation Magnetic Field.

There are specific types of current used in magnetic particle testing. They are Straight Direct Current (DC); Single Phase Alternating Current (AC); Three Phase AC; Half Wave Rectified Alternating Current (HWRAC or HWDC); Full Wave Rectified AC; and Three-Phase Full Wave Rectified AC (commonly known as DC). Of these, three types of magnetizing current are most often used in magnetic particle inspection. Only one type is generally best suited for each type of inspection to be performed. Alternating current (AC) is preferred for the detection of surface discontinuities. Direct current (DC), full-wave direct current, or half-wave direct current (HWDC) can be used for both surface and subsurface discontinuities.

3.1.7.1 Alternating Current (AC).
Alternating current, which is single phase when used directly for magnetizing purposes, is taken from commercial power lines or portable power sources and is can be 50 or 60 Hertz. Magnetizing currents up to several thousand amperes are used, derived from step-down transformers connected to common line voltages, e.g., 115, 230, or 460 volts.

3.1.7.2 Direct Current (DC).
Rectified alternating current is by far the most satisfactory source of direct current. By the use of rectifiers, commercially available single and three phase AC can be converted to a unidirectional current. Rectified three phase AC is equivalent to straight DC, but exhibits a slight ripple.

3.1.7.3 Half Wave Rectified Single Phase Alternating Current (HWDC).
Half-wave rectified single phase AC results in a pattern of unidirectional current flow made up of positive half cycles of the original AC waveform. The negative (reverse) half of each cycle is completely blocked out. The result is a pulsating unidirectional current. That is, the current rises from zero to a maximum and drops back to zero (replicating the AC's half cycle), is blocked during the reverse cycle (no current flows), and then repeats the first half cycle. This type of current is also called Half-Wave Direct Current (HWDC).

3.1.7.4 Full Wave Rectified Single Phase Alternating Current (FWDC).
This pulsating unidirectional current is sometimes used in MPT for certain special purpose applications. In general, however, it possesses no advantage over single-phase half-wave rectified waveforms. Because of its extreme "ripple," it is not as satisfactory as rectified three phase current when DC is required. Further, it is more costly since it draws a higher average current from the AC line than does rectified half-wave AC for a given magnetizing strength.

3.1.7.5 Induced Current Magnetization.
When direct current in a circuit is instantly cut off, the field surrounding the conductor collapses, or falls rapidly to zero. If an electrically conductive ferromagnetic material is present in such a field, the collapse of that field will induce a current in the material the same direction as present in the neighboring conductor before cut-off. This phenomenon can be used to solve specific magnetizing problems that have no other practical solution. A useful application of the collapsing field technique has been found in the inspection of ring-shaped parts, such as bearing races, without the need to make direct contact with the surface of the part. Regardless of the type of magnetizing current employed, whether DC, AC, or half-wave, the induced current technique is usually faster and more satisfactory than the contact method. Only one operation is required, and the possibility of damaging the part due to arcing is completely eliminated since no external contacts are made on the part.

3.1.8 Ferromagnetic Material Characteristics.
All ferromagnetic materials, after having been magnetized, will retain some residual magnetic field. The strength and direction of the residual field depend upon all the magnetizing forces applied since the material was last demagnetized and the retentivity of the material. The manner in which ferromagnetic materials respond to magnetizing forces is most often portrayed in a plot of the flux density (B) as a function of the magnetizing force (H). The flux density (B) is the number of magnetic lines of flux that are formed per cross-sectional area as a result of the magnetizing force (H). For an encircling coil, the magnetizing force is the accumulative effect of each turn of the coil and the current passing through it. Therefore, H equals the current passing through the coil, multiplied by the number of turns in the coil. Figure 3-16 shows a typical B-H curve for a ferromagnetic material starting in a demagnetized condition and then cycled to saturation in two opposite directions.

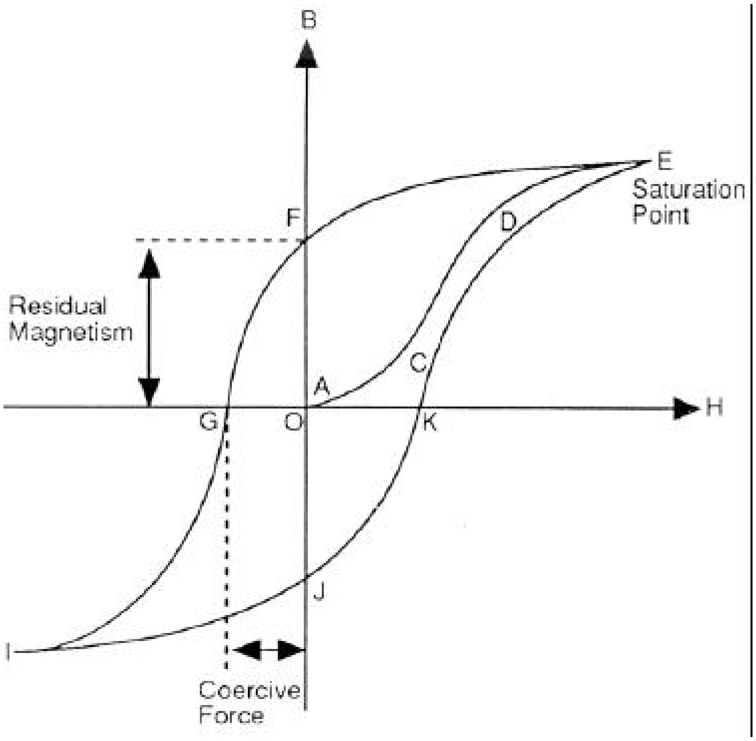


Figure 3-16. Hysteresis Curve for a Ferromagnetic Material

3.1.8.1 Hysteresis Curve.

The magnetic field within an unmagnetized piece of steel is zero. As the magnetizing force (H) is increased from zero, the flux density (B) within the part will also increase from zero. The curve from points A to E in Figure 3-16 illustrates this behavior. In the region of point E, the flux density increases up to a point and then tends to level off; this condition is called magnetic saturation and for a magnetically saturated ferromagnetic material, the relative permeability (µ) is approximately equal to 1. When the magnetizing force is reduced to zero the flux density does not return to zero. Instead, the flux density returns to a value shown at point F in Figure 3-16. This is the amount of residual magnetism resulting from the applied magnetizing force (H) that reached the point E in the hysteresis curve. As the magnetizing force (H) is increased from zero in the opposite direction, the flux density (B) will decrease to zero, as shown at point G in Figure 3-16, and then start to increase to point I. The magnetizing force (H) represented by the distance OG on the H axis in Figure 3-16 is called the coercive force. It represents the strength of the magnetizing force (H) required to reduce the flux density (B) to zero in a saturated ferromagnetic material. A further increase in the magnetizing force (H) to the point I results in saturation of the material in a direction opposite to that represented by point E. Reduction of the magnetizing force (H) to zero from point I will reduce the flux density (B) to the value represented by point J. Application of a magnetizing force (H) in the original direction will change the flux density (B) as shown in the portion JK of the hysteresis curve. Increasing the magnetizing force (H) sufficiently will return the material to saturation as illustrated at point E.

3.1.8.2 Magnetic Domains.

The behavior of ferromagnetic materials resulting in properties evidenced by hysteresis curves can be explained in terms of magnetic domains. Domains are small regions within a ferromagnetic material that have a permanent magnetic flux density (B) that is not equal to zero. In a completely demagnetized ferromagnetic material, the domains are randomly oriented resulting in an overall flux density of zero. When saturated, the domains are all aligned in the direction of the applied field. When the applied field is removed, after saturation, some domains return to their previous orientation but most remain aligned in the direction of the previously applied field. This results in the residual magnetism observed in ferromagnetic fields. The magnetic behavior then is a result of behavior of the domains within the ferromagnetic material. Magnetization is the alignment of domains in a single direction; demagnetization is a randomization of the alignment of the domains resulting in a zero net residual magnetism.

3.1.8.3 Demagnetization.

Ferromagnetic materials subjected to magnetic particle inspection are usually demagnetized following their inspection. The problem of demagnetization may be easy or difficult depending on the type of material, part geometry, and magnetic field orientations used. Demagnetization involves subjecting a magnetized part to a continuously reversing magnetic field that gradually decreases in strength. This action reduces the strength of the residual magnetic field in the part. Although some residual magnetization will remain, this method can reduce the residual magnetic field to acceptable levels. Note that materials heated above their Curie temperature become non-magnetic, thus offering another method of demagnetization.

3.1.8.3.1

There are a number of methods of demagnetization available with varying degrees of effectiveness. They can be explained with the hysteresis loop shown in Figure 3-16. Nearly all are based on the principle of subjecting a part to a continually reversing magnetic field that gradually reduces in strength down to zero. This is illustrated in Figure 3-17. The waveform is shown at the bottom of the graph of the reversing current used to generate the hysteresis loops. As the current diminishes in value with each reversal, the loop shrinks and traces a smaller and smaller path.

3.1.8.3.2

The waveform at the upper right of Figure 3-17 represents the flux in the part as indicated on the diminishing hysteresis loops. Both current and flux waveforms are plotted against time, and when the current reaches zero the residual field in the part will also have approached zero. Precautions to be observed in the use of this principle are:

a. Be certain that the magnetizing force is high enough at the start to overcome the coercive force, and to reverse the residual field initially in the part.

b. The decrease between successive reductions of current is small enough so that the reverse magnetizing force will be able, on each cycle, to reverse the field remaining in the part from the previous reversal.

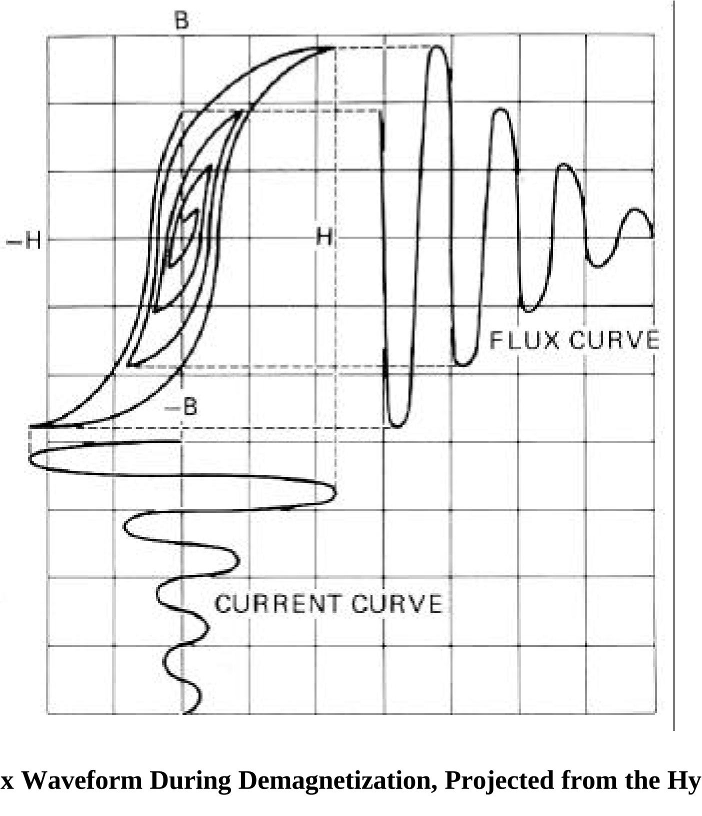


Figure 3-17. Flux Waveform During Demagnetization, Projected from the Hysteresis Loop.

3.1.8.3.3

Frequency of reversals is an important factor affecting the success of this method. With high frequency of current reversals, the field generated in the part does not penetrate deeply into the part section since penetration decreases as frequency increases. At a frequency of perhaps one reversal per second, penetration of even a large section is probably near 100%. For moderate sized parts, the 50 or 60 hertz commercial frequencies of alternating current give quite satisfactory results.

3.1.8.4 Limitations of Demagnetization.

"Complete" demagnetization is usually not possible, even though it is often specified. All practical demagnetization methods leave some residual field in the part. Therefore, demagnetization is either the best effort that existing means permit or reduction in magnetism to a residual level considered permissible in the particular part involved. It is extremely difficult to bring the steel back to the original zero point by any magnetic manipulation. In fact, it is so difficult that for all practical purposes, it may be said that the only way to completely demagnetize a piece of steel is to heat it to its Curie temperature or above, and cool it with its length directed east and west in order to avoid magnetization by the earth's field. This method of demagnetization is never used because it is not only impractical but such heating will alter the properties of the part.

3.1.8.4.1

It must be remembered that the earth's magnetic field can determine the lower limit of practical demagnetization. Long parts, or assemblies of long parts, such as welded tubular structures, are especially likely to remain magnetized, at a level determined by the earth's field, in spite of the most careful demagnetization technique.

3.1.8.4.2

Many articles and parts become quite strongly magnetized from the earth's field alone. Handling of parts, such as transporting from one location to another, may produce this effect. Long bars, demagnetized at the point of testing, have been found magnetized at the point of use. It is not unusual to find that steel aircraft parts are magnetized after having been in service for some time, even though they may never have been near any intentionally produced magnetic field. Parts may also become magnetized by being near electric lines carrying heavy currents, or near some form of magnetic equipment.

3.1.8.4.3

The limits of demagnetization may be considered to be either the maximum extent to which the part can be demagnetized by available procedures, or the level to which the terrestrial (earth's) field will permit it to become demagnetized. These limits may be further modified by the practical degree or limit of demagnetization that is actually desired or necessary.

3.1.9 Magnetizing Equipment.

3.1.9.1 General.

Selection of magnetic particle inspection equipment must consider the type of current to be used and the location and nature of inspection. Magnetic particle inspection equipment must provide a rapid and convenient means for magnetizing each part in a reliable and reproducible manner.

3.1.9.2 Stationary Equipment.

A variety of stationary, bench-type MPT units are available, with many characteristics that fit different testing requirements. The smaller size units are used for small parts easily transported and handled on the unit by hand. The larger ones are used for heavy parts such as long engine crankshafts, where handling must be by crane. Such units are made to deliver AC or DC with various types of current control.

3.1.9.3 Mobile Equipment.

Mobile magnetic particle equipment delivering AC or half-wave DC magnetizing currents up to 6000 amperes are available. Such equipment is used when it is necessary to conduct inspections in another shop area or in the field. This type of equipment is sturdy and well suited for both fabrication and overhaul inspections.

3.1.9.4 Portable Equipment.

CAUTION

Contact prods shall not be used on aerospace components or parts, and SHALL be labeled: NOT FOR AIRCRAFT USE.

Portable MT units are manufactured in a variety of sizes, shapes, voltages, and current outputs. Portable equipment operates on the same principle as stationary equipment. However, the compactness allows areas to be inspected where larger equipment may prohibit access. Portable equipment is usually operated on 110 or 220 volt AC and is rated between 200 and 1000 amperes. Portable equipment can be either AC, or a combination of AC and halfwave DC. Portable equipment is suitable for examining small areas in large components where suspected cracks may be found. For example, critical engine mount fittings and landing gear assemblies, which are difficult to inspect in stationary units, can be examined quickly with minimum disturbance and with attention concentrated on points most subject to cracking. Portable equipment can be moved to large items in need of magnetic particle testing and inspections can often be performed without disassembly.

3.1.9.5 Contact Prods.

CAUTION

When parts are being magnetized by the use of spring loaded contact clamps to generate circular magnetization, the contact clamps shall not conduct more than 800 amperes.

When a part is too large to fit into a stationary unit, or if only mobile or portable equipment is available, then the part, or areas of the part, can be magnetized using cables and two hand-held prods. The current passing between the two contact prods creates a circular field. Great care must be used to prevent local overheating, arcing, or burning the surface being inspected, particularly on high-carbon or alloy materials where hard spots or cracks could be produced.

3.1.9.6 Contact Clamps.
Contact clamps can be used with cables instead of contact prods, particularly when the parts are relatively small in diameter. Parts, like engine mounts and tubular structures, are inspected by positioning the clamps so that current passes through the area under inspection. Care must be used to avoid burning of the part under the contact clamps. Burning and heating may be caused by dirty contacts, insufficient contact clamp pressure, or excessive currents. Cracks may be produced as a result of the transient heating.

3.1.9.7 Hand probe Or Yoke.
For occasional inspections of small parts and localized inspection of large parts, magnetic hand probes or yokes are often adequate and easy to use. Probes or yokes are able to put a strong magnetic field into that portion of the part that lies between the poles of the probe or yoke. Hand probes or yokes can be excited by either AC or DC electrical currents, or they can be a permanent magnet.

3.1.9.8 Electromagnetic Probe or Yoke.
Electromagnetic probes or yokes are U-shaped cores of soft iron with a coil wound around the base of the U (see Figure 3-18). When alternating current or rectified alternating current is passing through the coil, the core is magnetized. This produces an electromagnetic probe or yoke that functions similarly to a permanent horseshoe magnet. A probe or yoke may be used to induce only a longitudinal field in a part. No electrical current passes through the part.

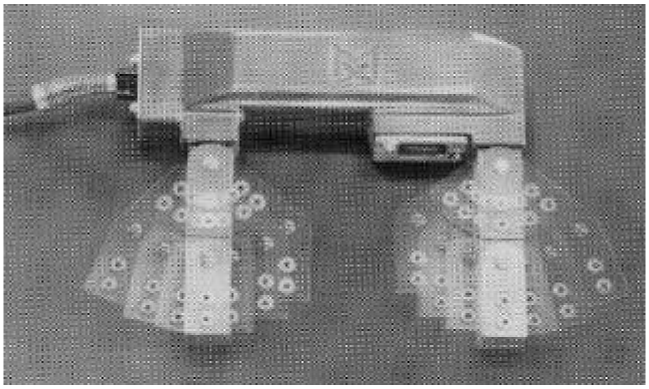


Figure 3-18. Electromagnetic Probe or Yoke

3.1.9.9 Alternating Current (AC) Yoke.
Alternating current, which is single phase when used directly for magnetizing purposes, usually has a frequency of 50 or 60 Hertz. The AC longitudinal magnetizing field induced in the part is restricted to the surface due to its skin effect. AC provides a very desirable field for maintenance and overhaul inspection work due to it's high sensitivity to surface defects. The peak AC current produces a surge peak in the magnetic field that is well above the average DC current required to develop a field of equivalent strength.

3.1.9.9.1
AC magnetic fields form eddy currents that tend to guide or restrict the magnetic lines of flux into a narrow pattern between the poles. Another by-product is a vibratory action at the work piece, which adds mobility to the inspection particles to form larger and more distinct build up of particles at the defect.

3.1.9.9.2
An AC magnetic field can be used when it is necessary to discriminate between surface indications and subsurface defects that might be revealed with a DC magnetizing field. Yokes utilizing AC magnetization also have the additional advantage that they can be readily used for demagnetization.

3.1.9.10 Direct Current (DC) Yoke.
An electro-magnet powered by DC provides a very strong magnetic field. However, being a constant field and lacking any vibratory action, it is sometimes difficult to gather enough particles at the defect to form a visible indication. To overcome this difficulty, full-wave or half-wave rectified single-phase alternating current is used. This adds mobility to the magnetic inspection particles comparable to that produced by AC.

3.1.9.11 Permanent Magnet Yoke.
Permanent magnets can be used to magnetize parts for MPT. This method of magnetization has severe limitations and is properly used only when these limitations do not prevent the formation of satisfactory leakage fields at discontinuities.

3.1.9.11.1
Permanent magnets create longitudinal fields. The poles created on the parts can result in confusing particle indications. Control of field direction is possible only over a limited area. A permanent bar magnet, set on end on the surface of a steel plate, creates a radial field in the plate around the pole at the end of the bar as shown in Figure 3-19. The flux of this field leaves the plate surface at some distance from the point of contact to return to the pole at the opposite end of the magnet. Cracks crossing such a field pattern can be indicated provided the field produced in the plate is sufficiently strong. When the poles of a permanent magnet yoke are placed upon the surface of a steel plate or part, the field travels through the object from one pole of the yoke to the other. The flux generally follows along a straight line drawn between the poles, and is strongest near the poles of the yoke and weakest at the point midway between the poles. The magnetic field strength within the part depends on the strength of the yoke magnetization and the distance between the poles. Cracks at right angles, or nearly so, to this line can be indicated, provided the field

strength is adequate. Outside this limited area, the field spreads out, and cracks favorably located with respect to field direction may or may not be shown, again depending on the place where they occur. Figure 3-19 illustrates the uses of permanent magnets for magnetization of parts. This method of magnetization should be used only by experienced operators who are aware of and understand the limitations of the technique.

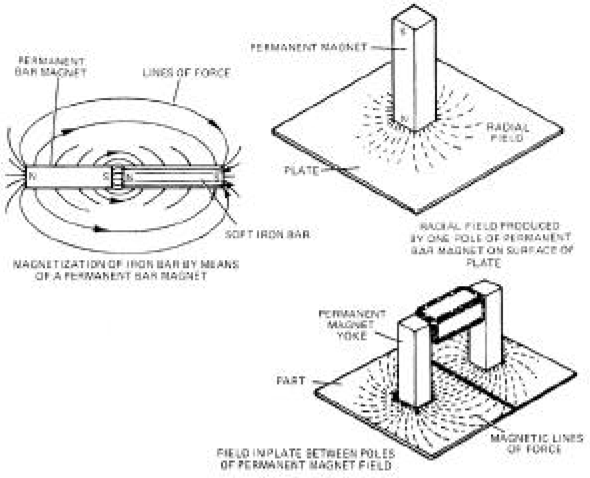


Figure 3-19. Magnetization with a Permanent Magnet

3.1.9.11.2
Some of the other drawbacks to the use of permanent magnets are:

a. The strength of the field is not continuously variable.

b. Large areas or masses cannot be magnetized with enough strength to produce satisfactory crack indication

c. It may be difficult to remove a strong magnet once it is in contact with the part.

3.1.9.12 Special Purpose Equipment.
Special units are those, which have been specifically designed to take, care of unusual situations where standard units are inappropriate. They may be special as to the method of magnetization or particle application, or be designed to handle unusual size, shape, or number of parts. They may or may not be automatic. Special units can be further broken down into two groups:

a. Special-purpose units are those that are built to do a single testing job. This special job may be a variation in magnetization technique, in the way the magnetic particles are applied, or in the way parts are handled. They may be for a single-purpose in which case they are to test a single type of part and no other possibly by a special processing technique. They may be general-purpose, in which case they are designed to apply a special magnetization or processing technique to a variety of parts.

b. Automatic units are those in which part or all of the handling and processing steps are performed automatically. Either single-purpose or general-purpose units may be partly or entirely automatic. Even standard units, by addition of standard accessories, may be made automatic in some of their functions. The principal purpose of automatic units is to speed up the inspection cycle. This is accomplished through automation of one or more of the important steps involved in any given testing operation.

3.1.9.12.2 Multidirectional Magnetization.
Complex-shaped parts can be sometimes inspected rapidly with equipment capable of producing magnetic fields in two mutually perpendicular directions in rapid succession. For large parts such as shipyard castings, the equipment produces three phase full wave rectified AC and rapidly switches it between several different magnetizing modes. An alternate approach, used for smaller parts, is to use each of the three phases, either rectified or unrectified, for a separate magnetizing mode. Such equipment can then apply up to three magnetizing modes in rapid succession to a part.

3.1.9.12.2.1
The multidirectional units produce the multidirectional magnetization effect by rapidly changing the magnetizing directions. For equipment utilizing the switched mode of operation, the switching can be on the order of 0.1 seconds. For the other type of equipment, the magnetizing modes are out of phase by 120 degrees. For 60-Hertz current this is equivalent to switching magnetization directions in less than 0.006 seconds. These units are capable of producing indications of discontinuities with widely differing orientations in a single operation, thus saving the time to conduct two or more separate inspections with different magnetic field excitation setups. It is not possible to estimate the required magnetizing currents before hand to produce the required magnetic field strengths and directions. Consequently, sensors must be used to determine the resulting strength and orientation of the magnetic fields in order to develop valid inspection techniques with multidirectional magnetization methods.

3.1.9.12.3 Induced Current Magnetization.
When inspecting ring-like parts for defects in a circumferential direction, the induced current technique can sometimes be used to good advantage. As an example, a ring-shaped part is placed inside and concentric to a magnetizing coil being excited with AC (see Figure 3-20). A laminated ferromagnetic core is placed inside the part and parallel to the axis of the coil in order to concentrate the magnetic field. The time-varying AC induces eddy currents in the test piece, which in turn induce a circular magnetic field within the test part. Such a field is used to detect circumferential defects within the test part.

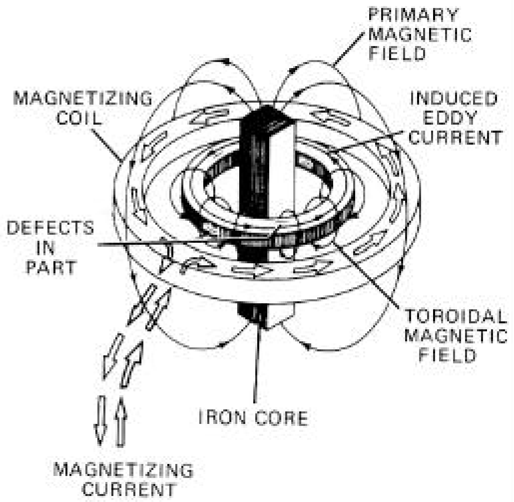


Figure 3-20. Current and Field Distribution in a Bearing Race being magnetized by the Induced Current Method

3.1.9.12.3.1
The core piece used should be laminated and made of low retentivity iron. If the part is ring-shaped, the core length should be approximately equal to the ring diameter or longer, but never less than six inches, and must be centered in the part. For a disc-shaped part with no bore, shorter core pieces should be placed on either side of the disc so that they are parallel to the axis of the part. In some cases it is advantageous to shape the ends of the core pieces adjacent to the part to facilitate bath application. Since the induced current method does not require contacting the part, there is no danger of local part overheating.

3.1.9.12.4 Hand-Held Coil.
For longitudinal magnetization of shafts, spindles, rear axles, and similar small parts, the hand-held AC coil offers a simple and convenient method of inspecting for transverse cracks. Parts are magnetized and demagnetized with the same coil.

3.1.9.12.5 Demagnetizing Equipment.
The most common type of demagnetizing equipment consists of an open, tunnel-like coil through which AC is passed at the line frequency, usually 60-Hertz. The larger type equipment is frequently placed on its own stand, incorporating a track or carriage to facilitate moving large and heavy parts through the demagnetizing equipment. The demagnetizing equipment can also include tabletop units, yokes, or plug-in coils that are more suited for the demagnetization of small parts. However, the large stationary type equipment is preferable when geometrically complex parts are involved. The use of demagnetization and demagnetization equipment s discussed in detail in Section 6.

SECTION II
PRE- AND POST-MPI CLEANING & PRE-MPI DISASSEMBLY

3.2 PRE- AND P0ST-MPI CLEANING & PRE-MPI DISASSEMBLY.

3.2.1 Pre-Inspection Cleaning.

3.2.1.1 Definition.
Pre-cleaning is the removal of all foreign material (paint, grease, oil, corrosion, layout dye, wax crayon markings, etc.) which may interfere with magnetic particle testing that has accumulated since the general cleaning operation but prior to inspection.

3.2.1.2 Necessity for Pre-Inspection Cleaning.
Parts or surfaces should be clean and dry before they are subjected to any magnetic particle inspection process. The cleaning process used must not reduce the effectiveness of the inspection process that follows. The cleaning process is required to remove all contaminants, foreign matter, and debris that might interfere with the application of current or the movement of the magnetic particles on the test surface. Note, however, that thin coatings such as cadmium, chromium or paint, if in good condition, will not interfere with the inspection process and do not necessarily have to be removed.

3.2.2 Considerations when selecting A Cleaning Process.
No single cleaning method can assure removal of all types of contaminants. Most methods are limited to the removal of only a few types of contaminants. Further, some cleaning methods require equipment that may not be adaptable to the specific job conditions, i.e., such as cleaning large parts or cleaning in place on an aircraft. Finally, some processes may cause corrosion of the part to be inspected. The cleaning process must then be chosen with knowledge of the contaminant, the alloy and the accessibility of the part to be inspected.

3.2.3 Typical Cleaning Methods.

CAUTION

Improper cleaning procedures/materials can cause severe damage. Cleaning should be accomplished by trained and qualified personnel. For Air Force personnel, T.O. 1-1-691 applies. For Navy personnel, use NA 0l-lA-509. For Army personnel, use TM1-1500-344-23.

Residues from cleaning processes can remain on the part surface and become contaminants. Paint removers can leave sticky residues that either trap particles or contaminate recirculating baths.

Section 3 of Chapter 6 contains a detailed discussion of cleaning methods. The following is a brief summary.

a. Alkaline cleaners are non-flammable water solutions containing alkaline detergents that can remove certain types of oils by saponifying (converting the oil to soap) or displacement. They can be used hot or cold, as a dip or as a spray.

b. Solvent cleaners dissolve oil, wax, grease and some other contaminants. They can be applied by spraying, wiping, or dipping. Solvent cleaners are an efficient and practical means of removing light preservatives and soil from parts taken out of storage for magnetic particle inspection prior to use. This also includes light soils that accumulate during transit and handling from the cleaning shop, but prior to being subjected to the inspection process.

c. Mechanical methods, such a wire brushing or abrasive blasting, can be used to remove rust or other corrosion deposits. These methods, if used improperly, can damage parts and conceal discontinuities and should only be used as directed.

d. Paint removers can be a solvent, bond release agent, softening agent or combination.

e. Steam cleaning is a form of alkaline or detergent cleaning and can remove loosely bound inorganic contamination and many organic contaminants from the test surfaces.

f. Ultrasonic cleaning combines solvent or detergent cleaning with very vigorous mechanical action to loosen contaminants.

3.2.4 Surface Preparation.

3.2.4.1 Considerations when using The Dry Powder MPI Technique.
In general, the smoother the surface of the part to be tested and the more uniform its color, the more favorable are the conditions for the formation and the observation of the powder pattern. This applies particularly to inspections being made on horizontal surfaces. For sloping and vertical surfaces, the dry powder may not be held on a very smooth surface by a weak leakage field. The surface should be clean and dry and free of oil and grease. The dry particles will stick to wet or oily surfaces and not be free to move over the surface to form indications. This may completely prevent the detection of significant discontinuities by obscuring the flaw indications with a heavy background. On surfaces that have been cleaned of grease by wiping with a rag soaked in a high boiling point solvent, such as naphtha, a thin film of unevaporated solvent often remains that is sufficient to interfere with the free movement of the magnetic particles. This film can be removed by wiping the surface with a clean, dry cloth, flushing with a low boiling point solvent, or dusting the surface with chalk or talc from a shaker can, and then wiping the surface with a clean dry cloth. An initial application of the dry magnetic powder itself, followed by wiping, can also provide a surface over which a second application of powder will move readily.

3.2.4.1.1
Any loose dirt, paint, corrosion or scale can be removed with a wire brush, by shot or grit blasting, or other means. If cleaning is done with shot or grit blasting, there is a peening effect, especially on softer steels, which may close up fine surface discontinuities. The effect is more pronounced with shot than with grit, but if these cleaning methods are used the operator should be aware of the danger of missing very fine cracks. A thin, hard, uniform coating of corrosion or scale will not usually interfere with the detection of any but the smallest defects.

3.2.4.1.2
Paint or plating on the surface of a part has the effect of making a surface defect behave like a subsurface defect. The relative thickness of the plating or paint film and the size of the defects sought, determine whether or not the coatings should be stripped. The dry method is more effective than the wet method in producing indications through such non-magnetic coatings. If fine cracks are suspected, the surface should be stripped of the coating if its thickness exceeds 0.003 inch. Most coatings of cadmium, nickel or chromium are usually thinner than this, and the plating makes an excellent background for viewing indications. Hot galvanized coatings are thicker than 0.003 inch, and in general should be removed before inspections. Broken or patchy layers of heavy scale or paint also tend to interfere by holding powder around the edges of the breaks or patches and should be removed if they are extensive enough to interfere with the detection of discontinuities.

3.2.4.1.3
When preparing for contact testing, nonconductive coatings shall be removed from the contact areas.

3.2.4.2 Considerations when using The Wet Suspension MPI Technique.
In general the same requirements apply for the wet method as for the dry technique. Dirt, corrosion, loose scale or paint and oil or grease should be removed. When preparing for contact testing, nonconductive coatings shall be removed from the contact areas. The test surface should be free of contaminants that can dissolve into the inspection bath. Such dissolved contaminants can become concentrated in a recirculating test bath and increase its viscosity, or its background fluorescence, or both. This will gradually retard the forming of indications, and make fluorescent indications increasingly hard to see. Insoluble particulate contaminants on the surface, such as corrosion, sand, and grit can accumulate in a recirculating wet bath to the point where they interfere with the formation and visibility of indications, and force the bath to be discarded sooner than normal.

3.2.4.2.1
Further problems can arise with the wet method of inspection if surface contaminants are present. Moisture on the test surface can be emulsified into an oil bath and cause the magnetic particles to coagulate and settle out of the bath, where they are no longer available to form indications. Oil or grease can harm aqueous inspection baths in two ways. First, their presence on the test surface can either prevent the bath from wetting and covering the entire surface, or can cause the bath to peel off the surface, stripping any indications off with it. Second, the oil can be emulsified in an aqueous bath, and again coagulate the magnetic particles.

3.2.4.3 Plugging and Masking.
When it is possible for the inspection media to become entrapped or to damage components, plugging and/or masking SHALL be employed. Plug small openings and holes with hard grease or similar nonabrasive readily soluble material. This prevents the accumulation of the magnetic particles and carrier liquid where it cannot be completely and readily removed by conventional cleaning and air blasting.

3.2.5 Post Inspection Cleaning.

CAUTION

All plugs and masks shall be removed after post-inspection cleaning.

3.2.5.1 Necessity for Post Inspection Cleaning.

3.2.5.1.1 Particles.
The magnetic particle inspection process leaves behind at least a scattering of magnetic particles that are abrasive. This may or may not be harmful to the later reuse of the part subjected to the inspection process. Where this slight residue cannot be tolerated, it must be removed. When its presence makes no difference, post-inspection cleaning can be eliminated. Dry magnetic particle inspection leaves only the particles behind. These particles are fairly coarse, quite abrasive, and probably magnetically bonded to the test surface. The wet method magnetic particles are much finer than the dry method magnetic particles (0.0002 inch instead of 0.002 inch to 0.006 inch in diameter), and they are

softer though still somewhat abrasive. On highly polished surfaces, residual powder from the bath can contribute to rapid corrosion.

3.2.5.1.2 Vehicle.
The wet method inspection process will normally leave the carrier liquid or vehicle on the test surface. If the vehicle is oil, it can be removed by vapor degreasing or solvent cleaning. If the vehicle is water, the residue will consist of wetting agents and water soluble corrosion inhibitors, which may be removed with a plain water rinse or spray. Regardless of the type of vehicle used, the part should be cleaned as soon as possible after inspection and demagnetization.

3.2.5.2 Methods.

CAUTION

Post-cleaning methods that use water can cause corrosion of the test surfaces if the water is not promptly removed. Thoroughly dry off the surfaces by wiping, heating or blowing off with properly regulated compressed air.

Regardless of whether the wet or dry visible or fluorescent magnetic particle inspection process is used, once the carrier liquid or vehicle is removed, the requirement for removal of the magnetic particles is the same. Thoroughly demagnetize the part, and then remove the magnetic particles by wiping or scrubbing. Cleaners or detergents cannot break the magnetic attraction. The particles cannot be dissolved from the surface, as they are a ferrous oxide. Mechanical scrubbing or detergent washing may be necessary. Solvents may be used to remove the residue, and in some cases the use of ultrasonic cleaning has been successful.

3.2.5.3 Requirements Following Post Inspection Cleaning.
After inspection by the wet method using a petroleum distillate as the bath liquid, the surfaces of parts are left vulnerable to corrosion. The bath vehicle is, by specification, free of any residual non-volatile material, and when it dries it leaves no protective film. Every effort shall be taken to clean a part and apply a protective finish as soon as possible after the inspection. When water is the vehicle of the bath, the dried film on the surface of a part consists of the various conditioners that have been used in the bath formulation in addition to the residual magnetic particles. One of the conditioners is a corrosion inhibitor, so that some corrosion protection is afforded by this inhibitor after testing. However, this is by no means permanent and a protective finish should be applied as soon as possible.

3.2.5.3.1
In the event a functional material, such as oil, grease or anti-seize compound, is removed from the part to facilitate inspection, the same material shall be reapplied after the part has been inspected.

3.2.6 Disassembly Requirements.

3.2.6.1 Requirements.
It is usually preferable to disassemble parts before inspection for the following reasons:

a. Disassembly makes all surfaces and areas accessible.

b. Boundaries between two magnetic pieces, or between a magnetic and a non-magnetic piece, will create a leakage field that may confuse inspection.

c. It is usually easier to handle disassembled parts.

3.2.6.2 Considerations.
If the critical area of an assembly is completely accessible for inspection without any disassembly, and if the inspection medium (magnetic powder or paste) can be removed after inspection, then it is acceptable to inspect those area or parts in place without disassembly. For example, steel propeller blades may be inspected in the blade area when they are in place on the aircraft, but to inspect the shank area, which is concealed by the hub, it is necessary to disassemble.

SECTION III
MAGNETIC PARTICLE INSPECTION TECHNIQUES

3.3 MAGNETIC PARTICLE INSPECTION TECHNIQUES.

3.3.1 General.

a. Magnetic particle inspection is a method of nondestructive testing that uses very small ferromagnetic particles to reveal discontinuities in parts capable of being magnetized. Magnetizable parts are those parts made of metals classed as ferromagnetic. To find flaws in metals that are not ferromagnetic, such as aluminum, titanium, brass, etc., other inspection methods must be used.

b. This section includes a description of the types of electric currents used; the various techniques, procedures and equipment used to magnetize parts; and the kinds of magnetic particles available for either wet or dry application. Special magnetization techniques are also included.

3.3.2 Factors determining the choice Of Technique.
The choice of technique for a particular magnetic particle inspection depends upon:

a. The type of discontinuity or defect being sought.

b. The part's material, shape, and size.

c. The magnetic particle inspection equipment available.

3.3.3 Technique Variations.
The following points must be considered and the appropriate alternatives selected in order to achieve a particular inspection result. A discussion of each alternative and the effect that it has upon the results of the inspection will follow.

a. Type and amount of electric current to be used for magnetization.

b. The direction of the resultant magnetic fields obtained using these currents.

c. The kind of magnetic particles to be used, i.e., wet or dry.

d. How the inspection media is to be applied.

3.3.4 Types Of Electric Current.
Commonly, three types of electric current are used in magnetic particle inspection: alternating current (AC), direct current (DC), and half-wave direct current (HWDC). Alternating current is used for the detection of surface discontinuities only, whereas direct or half-wave direct currents are used for both surface and subsurface discontinuities.

3.3.4.1 Alternating Current (AC).
The use of alternating current in magnetic particle inspection is effective only for the detection of surface discontinuities that comprise the majority of service-induced defects. Fatigue, overload and stress corrosion cracks are examples of cracks usually open to the surface.

3.3.4.1.1
The shallow penetration of AC fields into the part at the usual power line frequencies of 50 and 60 Hertz precludes the use of AC for the detection of subsurface discontinuities. The shallow penetration is due to a skin effect. The skin effect is the crowding of magnetic flux or electric current outward and away from the part center. The crowding phenomenon is caused by self-induced flux or currents that reduce the interior density of the flux or current. The skin effect is the reason AC is recommended when inspecting for service-induced surface defects. However, the skin effect of AC is less at lower frequencies, resulting in deeper penetration of the lines of force. At 25 Hertz, the penetration is considerably deeper, and at frequencies of 10 Hz and less, the skin effect is almost nonexistent.

3.3.4.1.2
The alternating currents used in magnetic particle inspection have low excitation voltages. Currents, from stationary equipment, range from about 100 amperes to 10,000 amperes depending upon the test part and the magnetization technique. The high currents are obtained using step-down transformers that reduce line voltages to about 20 volts. Lower amperages are available from hand-held devices that operate from standard 115-volt outlets. Alternating current (AC) and half-wave direct current (HWDC) are obtained from single-phase systems or from one phase of three-phase systems. Full-wave direct currents (DC) are usually obtained from three-phase systems using full-wave, three-phase bridge rectifiers.

3.3.4.1.3
If the defects sought are at the surface, AC has several advantages. The rapid reversal of the field imparts mobility to the particles, especially to the dry powders. The "dancing" of the powder helps it to move to the area of leakage fields and to form stronger indications. This effect is less pronounced in the wet technique.

3.3.4.1.4
Alternating current has another advantage in that the magnetizing force is determined by the value of the peak current (at the top of the sine wave of the cycle). The peak current is 1.41 times greater than the current value read on the meter. Alternating current meters read more nearly the average current for the cycle rather than the peak value. To get equivalent magnetizing effect from straight DC, more power and heavier equipment are required. Thus AC equipment for a given output of magnetizing force can be lighter and less costly, and better adapted for portability.

3.3.4.2 Direct Current (DC).
Magnetic fields produced by direct current penetrate deeper into a part than fields produced by alternating current, making possible the detection of subsurface discontinuities. For longitudinal magnetization DC magnetizes the entire part's cross-section more or less uniformly. For direct contact (circular) magnetization a straight-line gradient of strength (from a maximum at the surface to zero at the center) is experienced. Direct current generally is used with wet magnetic particle techniques. In the presence of DC fields' dry powder particles are relatively immobile and tend to remain wherever they happen to land on the surface of a part. This is in contrast to what happens with dry powder particles in the presence of AC or HWDC fields. In these fields the particles have mobility on a surface due to the pulsating character of the fields. Particle mobility aids considerably in the formation of particle accumulations (indications) at discontinuities.

3.3.4.2.1
Pure direct current can be obtained from automotive type storage batteries. Today this technique is seldom used except occasionally in emergencies when a battery may be used to power a hand-held magnetizing device. The disadvantages of using batteries are their weight, when a number of them must be used to obtain high currents, the frequent charging and maintenance required, and their limited life and replacement cost.

3.3.4.2.2
The prevailing approach for obtaining direct current for magnetic particle inspection is through rectification of alternating current using solid state rectifiers. A rectifier (diode) is a device that allows electric current to flow through it in only one direction. By proper connection of rectifiers, the back and forth flow of alternating current is converted to a current flow in only one direction. This is a form of direct current. A rectifier circuit, which converts both alternations (back and forth flow) of the alternating current to one direction of current flow, is called a full-wave rectifier.

3.3.4.2.3
Single-phase alternating current can be rectified using a full-wave rectifier circuit to obtain direct current for magnetic particle inspection. Single-phase rectification, however, is seldom used to obtain direct current, except in the case of small hand-held magnetizing devices. Since three-phase power is so readily available in industry, direct current for magnetic particle inspection units is usually obtained using three-phase full-wave rectifiers.

3.3.4.3 Comparison Of Results Using Different Types Of Current.
Figure 3-21 is a comparison of indications of the same set of fine surface cracks on a ground and polished piston pin, obtained by using 60 cycle AC, DC from storage batteries (straight DC), and DC from rectified three-phase 60 cycle AC respectively. Four values of current were used in each case with a central conductor to magnetize the hollow pin. The indications produced with AC are heavier than the DC indications at each current level, although the difference is most pronounced at the lower current values. Straight DC and rectified AC are comparable in all cases. The AC currents are meter (R.M.S. or Root Mean Square) values, so that peak of cycle currents, and therefore magnetizing forces, are 1.41 times the meter reading shown.

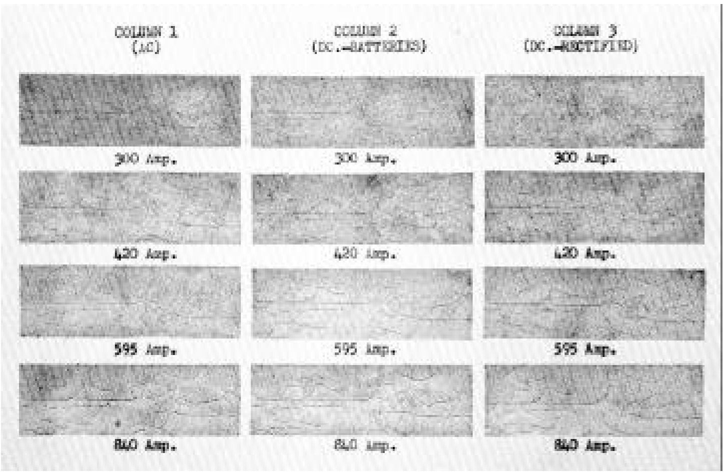
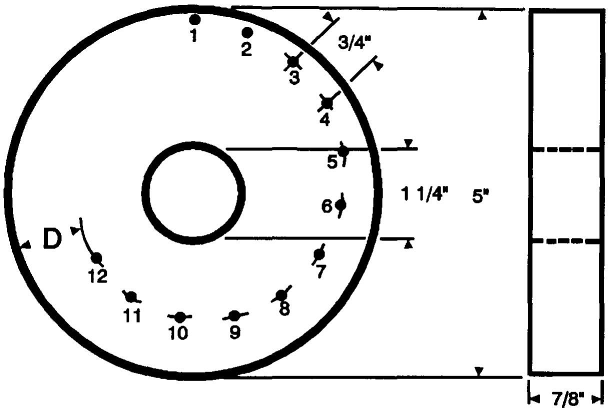


Figure 3-21. Comparison of Indications of Surface Cracks on a Part Magnetized with AC, DC and Three Phase Rectified AC

3.3.4.3.1
Another comparison can be made using the Ketos ring specimen, the drawing for which is shown in Figure 3-22. The specimen, made of unhardened (annealed) tool steel (0.40 percent carbon), is 7/8 inch thick. Holes, 0.07 inch in diameter and parallel to the cylindrical surface, are located at increasing depths below the surface.



HOLE	1	2	3	4	5	6	7	8	9	10	11	12
DIAMETER	.07	.07	.07	.07	.07	.07	.07	.07	.07	.07	.07	.07
" D "	.07	.14	.21	.28	.35	.42	.49	.56	.63	.70	.77	.84

Figure 3-22. Drawing of a Tool Steel Ring Specimen (Ketos Ring) with Artificial Sub-Surface Defects

3.3.4.3.2
For the inspection of finished parts, such as the machined and ground shafts and gears, direct current is frequently used. Although AC is excellent for the location of fine cracks that actually break the surface, DC is better for locating the very fine non-metallic stringers that can lie just under the surface.

3.3.4.3.3
These comparisons point up the importance of choosing the right current type to give the best indications possible, and show how the choice will vary, depending upon the nature and location of the defects sought.

3.3.4.3.4
Half-wave current provides the greatest sensitivity for detecting discontinuities that lie below the surface, particularly when using dry powder and the continuous technique. The pulsation of the half-wave current vibrates the magnetic particles, thereby aiding their migration across a surface to form indications at discontinuities. This particle mobility, which is very pronounced when dry magnetic powder is used, contrasts with the relative immobility of the powder when pure direct current is used. There is some skin effect when half-wave current is used, due to the pulsating magnetic fields produced by this current. However, the effect on field penetration is small at the usual frequencies of 50 and 60 Hertz.

3.3.5 Particles.

3.3.5.1 Description.

The particles used in magnetic particle testing are made of ferromagnetic materials, usually combinations of iron and iron oxides, having a high permeability and low retentivity. Particles having high permeability are easily attracted to and magnetized by the low-level leakage fields at discontinuities. Low retentivity is required to prevent the particles from being permanently magnetized. Strongly retentive particles will cling together and to any magnetic surface, resulting in reduced particle mobility and increased background accumulation.

3.3.5.2 Types.

Magnetic particles may be applied as a dry powder or wet suspension, in the latter case using either water or a high flash point petroleum distillate as a suspension vehicle. Dry powders are available in various colors so the user can select the color that contrasts best with the color of the surfaces upon which they are used. Colors for use with ordinary visible light are red, gray, black or yellow. Red and black colored particles are available for use in liquid suspensions and visible light. Fluorescent yellow-green particles are used only in liquid suspensions.

3.3.6 Suspensions.

CAUTION

> The use of water suspensions SHALL be carefully controlled to prevent corrosion and provide wetting of ferromagnetic aerospace components. This requires weekly monitoring of corrosion inhibitor and wetting agent concentrations.

3.3.6.1 Water Suspensions.

Wetting agents and corrosion inhibitors SHALL be used with water suspensions. Usually the magnetic particle concentrates provided include the correct amount of wetting agent and corrosion inhibitor for initial use. However, these materials are available separately so the concentrations can be maintained or adjusted to suit the particular conditions. If no corrosion can be tolerated, a higher concentration of corrosion inhibitor is used. Acidity should be checked weekly. The pH of the water bath shall be 6 to 10. If the parts being inspected have a residual solvent film, more wetting agent is required so the parts' surfaces will be completely wetted. Breaking of the bath into rivulets as it is applied over a part is an indication of a need for additional wetting agent or part cleaning. A water break test shall be conducted daily using a clean specimen or part having the smoothest surface finish to be inspected. The specimen should be flooded with the bath and examined once flooding is stopped. If a smooth continuous film of bath forms over the entire surface, sufficient wetting agent is present. If the film breaks, wetting agent is inadequate if the part is not clean. Before adding wetting agent make certain the specimen or part is clean. Reference shall be made to the manufacturer's recommendations for the correct quantity of wetting agent to be added.

3.3.6.2 Petroleum Distillate Suspensions.

No additives other than the magnetic particles themselves are used with petroleum distillate suspensions. Petroleum distillate recommendations are included in other publications or specifications.

3.3.7 Methods of Particle Application.

3.3.7.1 Dry Particles.

Magnetic particles in dry form may be applied by hand, using rubber squeeze bulbs or plastic squeeze bottles equipped with perforated caps, similar to an ordinary salt shaker but with smaller holes. The objective is to lay down a light cloud of powder on the part being inspected; this is usually accomplished by using a combination of bulb squeezing and tossing of the powder toward the area being inspected.

3.3.7.2 Wet Particles.

Many techniques are used to apply liquid suspension magnetic particles. They range from simple hand pouring of the suspension onto a part to large industrial systems in which the suspension is applied automatically, either by dumping or spraying. The most common technique for application is through the use of a hand-held nozzle and recirculating pump on stationary units. Occasionally small, hand-held, lever-operated sprayers are used. Aerosol-type containers similar to those used for spray painting are also available.

3.3.8 Techniques for Current/Particle Application.

Two processing techniques are used in magnetic particle inspection. The approach to use in a given case depends upon the magnetic retentivity of the part being inspected and the desired sensitivity of the inspection to be made. Highly retentive parts may be inspected using what is called the residual technique. The other technique, continuous, must be used on parts having low retentivity. For a given magnetizing current or applied magnetizing field, the continuous approach offers the greatest sensitivity for revealing discontinuities.

3.3.8.1 Residual Technique.

In the residual inspection technique, magnetic particles, either as a dry powder or in a liquid suspension, are applied after the parts have been magnetized. This technique is used only when parts are magnetized with DC and when parts have sufficient retentivity to form and retain adequate magnetic particle indications at discontinuities. This technique can be used with both longitudinal and circular magnetization with either direct contact or central conductor application. Usually it is limited to the search for discontinuities open to the surface such as cracks. Residual inspection permits the magnetizing of parts at one time and the application of magnetic particle media at some subsequent convenient time. When a central conductor is used, inspection of holes or bores is facilitated since inspection takes place after removal of the central conductor.

3.3.8.1.1 Magnetic Writing.
Care must be taken in the handling of parts that have been magnetized, particularly parts having smooth or machined surfaces, to avoid their being rubbed together or against other ferromagnetic parts. Such rubbing may produce localized magnetized areas on surfaces of parts that will attract and hold magnetic particles. Magnetic particle indications produced on these areas are non-relevant and are called magnetic writing. An inspector may notice that magnetic writing indications are not as sharp as those produced at surface cracks and is cautioned against misconstruing such indications as being caused by subsurface discontinuities. Whether an indication is caused by magnetic writing or by a subsurface discontinuity can be determined by demagnetizing and reprocessing the part. Demagnetizing will remove the magnetic writing. If the indication returns after demagnetizing and reprocessing, it is an indication of a discontinuity at or near the surface.

3.3.8.1.2
Currents used with the residual technique need be only great enough to magnetize the part sufficiently to show the type of discontinuity being sought. Some gross discontinuities may require only weakly magnetized parts, and others, being more difficult to find, may require the maximum residual field obtainable. The residual magnetic field retained in a part is always less than the applied magnetic field strength that produced it. A maximum residual field strength results when the magnetization level within the part reaches magnetic saturation. The use of magnetizing currents greater than those needed to produce the maximum saturation field strength, are of no value with the residual technique.

3.3.8.1.3
Inspector experience with typical parts that have discontinuities is very helpful to determine what current levels should be used to inspect a part using residual magnetism. In the absence of such experience, an inspector should first determine whether or not a part could be inspected using the residual approach. Any part to be inspected must be retentive enough so that magnetic particle indications will be formed at discontinuities in the parts. A rough determination of a part's retentivity can be made by magnetizing the part in a coil with the maximum DC current available. If, after magnetization, the part will lift and hold an ordinary steel paper clip, chances are good the part is retentive enough for residual inspection. If the part will not hold a paper clip, residual techniques may still be possible. The part could still be retentive enough to be inspected residually, depending upon the nature of the discontinuities expected to be found. In this case, the inspector must resort to testing of the part, or parts, using the continuous technique, inspecting for indications at discontinuities, then removing these indications and reapplying the magnetic particle media to see if residual indications are produced. The current used to form the indications found with the continuous technique will give an inspector some indication of the current level needed for residual inspection.

3.3.8.1.4
The application of magnetic particle media for residual inspection is simply a matter of covering the area to be inspected. Care should be taken with a liquid suspension to ensure that the parts are adequately covered using low velocity streams or sprays, and that the parts are positioned to take advantage of any particle flow resulting from drainage on a part's surface. Some parts may need a longer drain time than others, since on smooth surfaces indications may be slower in forming. In some cases, on bearing rollers for example, formation of fine indications may be enhanced by immersing the magnetized part in liquid media for a considerable time. This permits time for the leakage fields to attract and hold the maximum number of particles resulting in an increase in sensitivity.

3.3.8.1.5
Care must be taken when applying dry magnetic powders to parts that have been magnetized to avoid getting too much powder on a part's surface. A combination of a light blowing and tossing action is needed, either from a hand-held container or a pressurized powder blower. Additional care is also required when removing any excess powder from a surface so as not to hinder formation of indications or remove indications already formed. The use of dry powder with the residual technique has several disadvantages. It is more difficult to apply to interior surfaces of a part than is a liquid suspension and it is more difficult to completely cover a part in a short time.

3.3.8.1.6
Liquid suspensions may be applied by stream, spray, or immersion of the part in a tank containing the media. Extra care is required when using the immersion technique, particularly with parts that have smooth surfaces, to avoid removing any indications by the rapid removal of a part from the bath. To ensure uniform concentration the

suspension must be continuously agitated. The concentration must be maintained within specified limits. Too weak a particle concentration will produce weak indications, and in borderline cases may cause fine discontinuities to go undetected. Equally undesirable, too heavy a concentration produces heavy background accumulations that reduce contrast.

3.3.8.1.7
Most magnetic particle indications produced using the residual technique appear quickly on a part. Longer times are required when discontinuities are extremely fine. Formation of the indications can sometimes be speeded up by holding the part in a position that will allow residual suspension drainage to flow across the suspected areas. In the case of a cylindrical part, it would be held in a near vertical position allowing the drainage flow across circumferential (transverse) cracks.

3.3.8.1.8
Although the residual technique is not as widely used today as the continuous technique, it does have some advantages that make it attractive in some circumstances. The residual approach is capable of close control, and of giving uniform results to a greater degree than the continuous technique.

3.3.8.2 Continuous Technique.
The continuous technique is used primarily with liquid suspensions although occasionally dry powder is more appropriate. This technique requires that the magnetizing force be present while the liquid suspension is present on the part in sufficient quantity for the particles to be highly mobile. When the current is on, the maximum flux density will be created in the part and the maximum leakage flux will be present at a discontinuity to attract the magnetic particles to form an indication. To leave the current on for long periods of time is not practical or necessary in most instances. However, when using dry particles and either AC or HWDC as the magnetizing current, the current is sometimes kept on for minutes at a time. The heavy current required for proper magnetization can cause overheating of parts and contact burning or damage to the equipment if allowed to flow for any appreciable time. In practice, the magnetizing current is normally on for only a fraction of a second at a time since the real requirement is that a sufficient number of magnetic particles have been applied and are in the magnetized zone. These particles must be free to move while the magnetizing current flows. The bath ingredients are so selected and formulated that the particles can and do move through the film of liquid on the surface of the part and form strong, readable indications. This is one reason why the viscosity of the bath and bath concentration are so important, since anything that reduces the number of available particles or slows their movement will impede the build-up of indications.

3.3.8.2.1
The reason for greater sensitivity for the continuous method is simple and basic. When the magnetizing force is applied to a ferromagnetic part, the flux density rises. Its value or intensity is derived from the strength of the magnetizing force and the material permeability of the part. When the magnetizing force is removed, the residual magnetism in the part is always less than the field present while the magnetizing force was acting. The difference depends on the retentivity of the material. Consequently, the continuous technique, for a given value of magnetizing current, will always be more sensitive than the residual technique. The continuous technique can be faster than the residual since the indication starts to form at the time of magnetization, whereas the residual method requires magnetization and then application of particles, plus the added time for indications to build up if immersion is used. Parts made of low retentivity materials, such as low carbon steel must be inspected using the continuous technique since residual leakage fields at discontinuities in these materials are too weak to produce good magnetic particle indications. It is frequently used with AC on such materials because the alternating current field produces excellent mobility of the particles.

3.3.8.2.2
Liquid suspensions are usually used with the continuous technique. The exception is when small, subsurface defects must be found. In this case, under some conditions, a dry particle continuous technique can produce slightly greater sensitivity. Timing of the liquid suspension application and the magnetizing current is critical to form good indications. The area of the part to be inspected must be completely flooded with suspension and then the current SHALL be applied at least twice in rapid succession. Turning off or diverting the suspension flow before the final applications of current ensures that the force of the flow will not interfere with the formation of indications. Extra care

must be taken with parts having low retentivity to minimize the risk of washing away an indication. On larger parts where the entire area of interest cannot all be flooded simultaneously, additional "shots" of current SHALL be applied immediately after the suspension application hose is moved away from each point of application. In addition to the minimum required current applications one or two current applications just before stopping the suspension application, if the equipment duty cycle permits, will help small indications to form.

3.3.8.2.3
It should be noted that the continuous technique requires more attention and alertness on the part of the inspector than does the residual. Careless handling of the suspension-current application sequence can interfere seriously with the results. Normally the duration of the magnetizing shots will vary from one-half second to 1 or 2 seconds, depending on the difficulty involved in showing the condition of interest. In some instances, when large forgings or steel castings are to be inspected with manual suspension application, the magnetizing current may be left on from 5 to 10 seconds during which time the part may be repeatedly swept with the suspension spray. The magnetizing field is maintained for a second or two after the final spray has ceased or been diverted.

3.3.9 Magnetic Field.

3.3.9.1 Direction.

The proper orientation of the magnetic field in the part, in relation to the direction of the defect, is a more important factor than the value or amount of the magnetizing current. For reliable inspection, the magnetic lines of force should be at right angles to the defect to be detected. If the magnetic lines of force are parallel to the defect there will be little magnetic leakage at the defect, and therefore, if any indication is formed it is likely to be extremely small.

3.3.9.2 Amplitude.

3.3.9.2.1 Rule Of Thumb.

ASTM E 1444, as did its predecessor MIL-STD-1949, suggests that sufficient magnetic field is present when an applied peak tangential field strength of 30 to 60 Gauss (Oersted) can be measured on the surface of the part where indications are expected to form. A recent study using DC magnetizing current confirmed that this field strength can produce good indications from small defects, with field strengths at less than this range, detectable indications can be produced. Other studies have suggested that while good to excellent indications of defects may be produced with a tangential field in the range of 30 to 60 Gauss (Oersted) and higher, the background produced from acceptable surface roughness may reduce the visibility of such indications. All studies agree that the “rule of thumb” formulae for estimating magnetizing currents, contained in ASTM E 1444 and reproduced in this section, will usually produce field strengths well in excess of 30 to 60 Gauss (Oersted) with the concurrent risk of producing a background that can hide defect indications.

3.3.9.2.2 Recommended.

The most direct way of determining the magnetic field strength required would be to use a specimen representative of the parts to be inspected with a defect representative of those to be found. The specimen would be magnetized at sequentially higher field strengths until a good indication of the defect was formed without an excess of background from surface conditions. This magnetic field strength could then be measured and used for parts that are similar to the specimen utilized. Since suitable specimens are seldom available, an alternative is to use the techniques discussed in the following paragraphs to simulate a defect and measure the necessary magnetic field strengths.

3.3.9.3 Measurement.

The measurement of magnetic flux or field strength, either within a part or at the part's surface, is extremely difficult. There are several practical methods or devices. These methods or devices have limitations. They do serve a purpose in technique development if their limitations are understood.

3.3.9.3.1 Hall Effect Gauss / Tesla Meter.

This is a portable, hand-held digital instrument that can be used to measure magnetic-field strength. It applies a current to a Hall-effect probe or sensor and amplifies the output voltage that is proportional to the magnetic flux density that is present at the sensor and is at right angles to the applied current. It can be used in establishing MT testing procedures to indicate magnetic-field direction and to measure both applied and residual fields. One limitation is that it measures only the flux passing through the probe or sensor (Figure 3-23) and does not measure the field at or below the part surface.

a) Tangential
b) Normal
(The arrow represents an external magnetic leakage field B_L at the point of measurement.)

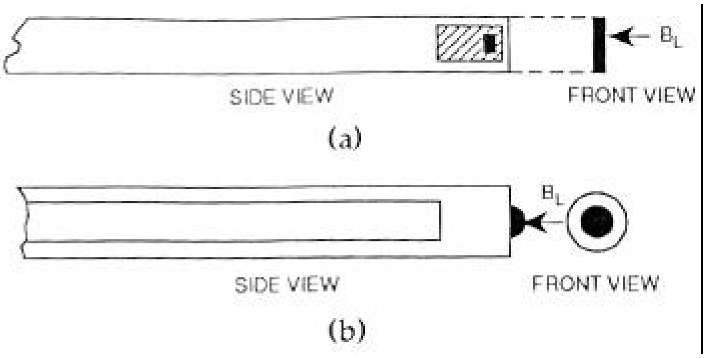


Figure 3-23. Hall-Effect Sensors.

3.3.9.3.2 Quantitative Quality Indicator (QQI).
The QQI is a small, thin, metal shim, made of a low carbon steel, that contains artificial defects for establishing or verifying MPI techniques. Examples of QQIs are illustrated in Figure 3-24. The artificial defects are formed by an etching process that can produce very narrow (0.005 inch) flaws with tightly controlled depths, typically 15%, 30% and 60% of a QQI's thickness. The thickness is either 0.002 or 0.004 inch. The basic QQI shim satisfies most needs because its circular and crossed-bar flaw configuration is suitable for longitudinal and circular fields. The bars in the cross are 0.25 inch long, while the circular slot is 0.5 inch in diameter. The circular flaw is especially useful in balancing multi-directional fields. The miniature shim is designed for small areas on a test part; each circle is 0.25 inch in diameter. The QQI with three concentric circular flaws with different depths (typically 20%, 30% and 40% of shim thickness) may be used for more quantitative assessment of a magnetic field; the diameters of the circles are 0.25, 0.375 and 0.5 inch in diameter. The linear shim is 2 inches long by 0.4 inch wide; it may useful in covering a curved area of a part, such as a radius.

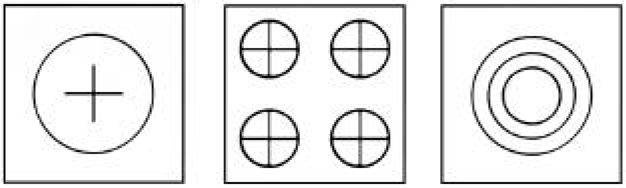


Figure 3-24. Shim-Type Magnetic Flux Indicators

3.3.9.3.2.1
QQIs are intended for use with the continuous method only. If a Gauss/Tesla meter is available, readings for both circular and longitudinal fields can be made at the point of QQI attachment. Once the readings are recorded for a part, it may be quicker to use the meter instead of a QQI to ensure sufficient field strength when the same type of part is inspected later.

3.3.9.3.2.2 Advantages of the QQI.

a. Only device able to demonstrate adequacy and balance of multidirectional magnetization.

b. Quantitative to some extent.

c. Ultra-high permeability. Virtually no rententivity.

d. Can bend in one direction to conform to very tightly curved surfaces. The 0.002” thick QQIs can conform to radii down to about 1/8”.

e. Can be re-used with careful application and removal practice.

3.3.9.3.2.3 Disadvantages of the QQI.

a. Parts must be clean and dry for application.

b. Usefulness readily destroyed with careless handling.

c. Not well adapted to dry powder applications.

d. Physical size limits application to some areas.

3.3.9.3.2.4 Application of the QQI.

To be effective, the QQI must be placed flaw side down and in intimate contact with the part surface. Also, it must be emphasized that since the QQI responds to the field in its immediate vicinity, indications can be produced in the QQI when no other ferromagnetic material is present. Obviously, the primary rule of assuring that the part is ferromagnetic before attempting an inspection applies with the use of QQIs.

3.3.10 Sensitivity Level.

Any factor that affects the formation of magnetic indications at a discontinuity affects the sensitivity of that magnetic particle inspection. Three of the most important factors are the field direction, current level and control of the magnetic particle inspection media.

3.3.10.1 Current Level.

The formation of magnetic particle indications at discontinuities depends upon the strength of the corresponding leakage fields. Since the leakage fields result from the field generated by the magnetizing current, the greater the magnetizing current, the greater will be the strength of the leakage fields. Thus, the sensitivity of a magnetic particle inspection is directly related to the exciting current. A current level that is too low produces leakage fields too weak to form readily discernible indications; and a current level that is too high creates a heavy background accumulation of particles which masks an indication. In circular magnetization, a high current level may also burn the contact points of a part.

3.3.10.2 Inspection Media.

Sensitivity level is affected not only by the current amperage, but also by the kind of magnetic particle inspection media, its control and its applications.

3.3.10.2.1

Liquid suspensions, because of the smaller particle sizes, are the most sensitive for the detection of surface discontinuities. Dry powders can be better for detecting subsurface defects. Fluorescent materials have a higher apparent sensitivity than do those used with visible light, such as the black and red particles.

3.3.10.2.2

Inspection of parts made of materials only moderately retentive requires careful control of the way the inspection media is applied. Usually, maximum sensitivity is obtained by applying the media while a part is being magnetized and ending it before the magnetizing field is removed. This is also true in the case of automatic wet-method inspection in which the main bath stream is shut off shortly before the magnetizing current is ended; to avoid washing off indications already formed.

3.3.10.2.3
Particle concentration in the baths must be closely controlled if maximum sensitivity is to be obtained. Sensitivity is lowered if concentrations are too low due to the lack of sufficient magnetic particles to be readily discernible. If concentrations are too high, fine indications may be masked by heavy background accumulations.

3.3.10.2.4
Contaminants, particularly in wet baths, can result in lowered sensitivity. Lubricating oils and greases for example, cause a blue background fluorescence that reduces contrast, causing fluorescent particle indications to be less visible.

3.3.10.2.5
Sensitivity of dry powders depends upon the type of powder selected, how carefully it is applied, and its color. Most powders are made for general use and have a wide mix of particle sizes, so as to favor the detection of both fine surface and deep subsurface discontinuities. A powder color is usually selected which will provide the best color contrast with the color of the surface upon which it is being used. Care is needed in applying the powder. A light tossing and air-blowing action is needed to allow the particles to migrate to and be held by the leakage fields at discontinuities. Excessive application of powder can cause indications to be lost in background accumulation.

3.3.10.2.6
The dry powder method is superior for locating defects lying wholly below the surface because of the high permeability and the favorable elongated shape of the particles. These form strings in a leakage field and bridge the area over a defect.

3.3.10.2.7
However, when the problem is to find very fine surface cracks, there is no question as to the superiority of the wet method, regardless of the form of magnetizing current used. In some cases, direct current is selected for use with the wet method to obtain the advantage of improved indications of discontinuities that lie just below the surface, especially on bearing surfaces and aircraft parts. The wet method offers the advantage of easy complete coverage of the surface of parts of all sizes and shapes. Dry powder is often used for very local inspections.

3.3.11 Circular Magnetization.

3.3.11.1 General.

Circular magnetization is used for the detection of radial discontinuities around edges of holes or openings in parts. It is also used for the detection of longitudinal discontinuities, which lie in the same direction as the current flow, either in a part or in a part that a central conductor passes through.

3.3.11.1.2
A circular magnetic field is generated in a part whenever an electric current is passed through it or through an electrical conductor that passes through the part. The circular field around the inside of the part will be wholly contained within the part in the case of a concentric cylinder. No magnetic poles will be produced on the part. Poles will be produced if the part is not a concentric cylinder, is irregularly shaped, or the path of the current flow is not located on the part's geometric axis. The magnetic poles in these cases are caused by a relatively small portion of the magnetic flux that passes out of the part and into the air that surrounds the part. The no pole condition in a concentric cylinder occurs both while the magnetizing current is flowing and after current flow ceases. The part is thus residually magnetized, but since no magnetic poles exist, the part appears to be in an unmagnetized state. However, if the part is cut into, such as when a keyway is made, some of the field will pass out and over the cut, producing opposite magnetic poles on each side of the cut. Such poles can hold chips or metal that can interfere with subsequent machining operations or damage bearing surfaces. Care is needed in the case of circular magnetization, which may not be detectable, and appropriate means to ensure demagnetization must be taken.

3.3.11.1.3 Two techniques can be used to produce circular magnetization in a part:

a. Direct Contact (Head Shot) Technique: Electric current is passed through the part itself.

b. Central Conductor Technique: Electric current is passed through a central conductor that into an opening in the part. These techniques are discussed in more detail below.

3.3.11.2 Direct Contact (Head Shot) Technique.

This technique produces circular magnetization by passing electric current through the part itself. Direct contact to parts is generally made by placing them between clamping heads. Lead faceplates and/or copper braid pads must be used to prevent arcing, overheating, and splatter. Wetting of the contact plates with the suspension vehicle before current application helps prevent overheating. On large parts, current contact is sometimes made by clamping lug-terminated cables to the part using ordinary C-clamps. Regardless of how it is made, the electrical contact should be as good as practicable. This will minimize any heating or arcing at the juncture. This requires that the contact surfaces be clean and free of paint or similar coatings and have adequate pressure applied to achieve good mechanical and electrical contact over a sufficient area of the part's surface. Any excessive heating at the contact points may burn the part, affect its temper, finish, etc.

3.3.11.3 Central Conductor Technique.

This technique produces circular magnetization by passing electric current through a conductor that has been placed coaxially in an opening, frequently in the center of a part. A magnetizing field does exist outside a central conductor carrying current, so the walls surrounding a central conductor become magnetized making possible the detection of discontinuities that parallel the central conductor. Central conductors are any conductive material such as a copper bar or cable placed in the center of the part to be magnetized. The central conductor technique SHALL be used if longitudinal discontinuities on the inside of tubular or cylindrically shaped parts are to be detected. Theoretically, the magnetic field is zero on the inside surface of such parts unless a central conductor is used. The direct contact technique may not produce reliable results in this case, particularly if the part is a concentric tube or cylinder with good current contact at each end. Either the central conductor or the direct contact technique can be used to detect discontinuities on the outside surfaces of such parts. Because the circular field around a central conductor is at right angle to the axis of the conductor, the central conductor technique is very useful for the detection of discontinuities that lie in a direction generally parallel with the conductor. The central conductor technique is also very useful for detecting discontinuities, usually cracks, which emanate radially from holes. A part having a hole or opening that is to be inspected for inside and outside discontinuities is usually positioned with the central conductor centered coaxially in the hole or opening. On very large parts having large openings the central conductor maybe located close to the inside surface and several inspections made around the inside periphery of the opening. Placing the conductor close to the inside surface reduces the current requirement since the strength of the circular field increases with decreased distance from the conductor.

3.3.11.4 Selection of Current Level.

3.3.11.4.1 General.

A number of factors must be considered when determining what current amperage to use for circular magnetization. Some of the more important of these factors are:

a. The type of discontinuity being sought and the expected ease or difficulty of finding it.

b. The part's size, shape and cross-sectional area through which the current will flow.

c. The amount of heating that can be tolerated in the part and at the current contact areas.

3.3.11.4.1.1

Another factor is the relationship between the current and the leakage fields at the surface of the part. The magnetizing force at any point on the outside surface of a part through which electric current is flowing will vary with the current. The greater the current, the greater will be this magnetizing force. Inside the part, just under the point on the surface, the magnetic flux density will be the product of this magnetizing force and the magnetic permeability of the part at that point. It is this magnetic flux density which determines the leakage field strength at discontinuities. Thus, current is directly related to the strength of leakage fields at discontinuities, and it is these leakage fields that capture and hold magnetic particles. The more difficult the discontinuities are to detect, the weaker the leakage fields will be for a given current level. A higher current will be required to form discernible magnetic particle indications. At the same time, leakage fields from minor surface variations can attract and hold the magnetic particles, forming a background that makes indications of true discontinuities less distinct. Increasing the magnetizing force or current will also increase the intensity of this background. The proper magnetizing force or current is then one strong enough to produce indications of the discontinuities that must be detected and yet is not too strong so that the background masks the indications sought.

3.3.11.4.2 Direct Contact.

A problem arises when deciding what current is to be used for a given part, particularly when the part has a complicated shape. A rule of thumb from ASTM E 1444 suggests currents from 300 to 800 amperes per inch of part diameter when the part is reasonably uniform and cylindrical in shape. Except for some special alloys the use of current values in the upper half of this range will result in excessively high field strength thus impeding the detection of discontinuities. Generally, the diameter of the part SHALL be taken as the largest distance between any two points on the outside circumference of the part. However, as a starting point, use the lower limit of such rules of thumb as the initial magnetization current level. From this point, either with use of a gauss meter or shim indicators, the correct current level can be found.

3.3.11.4.2.1

The use of the rule-of-thumb for excitation currents is fairly straightforward in the case of uniform cylindrically shaped parts. On parts having complicated shapes, such as irregular forgings, machinery parts, weldments or castings, the use of any rule-of-thumb is often not practical. In these cases the inspector must rely on judgment and past experience and aids such as the shims or gauss meter previously discussed, to help in the selection of the optimum current level. Experience with similar parts, which do have discontinuities, is especially helpful in this respect.

3.3.11.4.3 Central Conductor.

Induction current requirements using a central conductor will depend upon the part's size and the diameter of the opening through which the conductor is to be located. In the case of a centrally-located conductor, suggested currents from an old “rule of thumb” may range from 100 amperes per inch of hole diameter to as much as 1000 amperes per inch, depending upon part material and the nature of the suspected discontinuities. Keep in mind that the magnetizing field strength around a central conductor decreases with distance away from the conductor. The strongest flux field is present at the inner surface of the hole through which the central conductor passes as shown in Figure 3-25.

Not only discontinuities that are parallel with the central conductor are detectable using the central conductor technique, but radial discontinuities at the ends of holes and openings can be detected, since some portion of the magnetic lines of force will intercept these discontinuities.

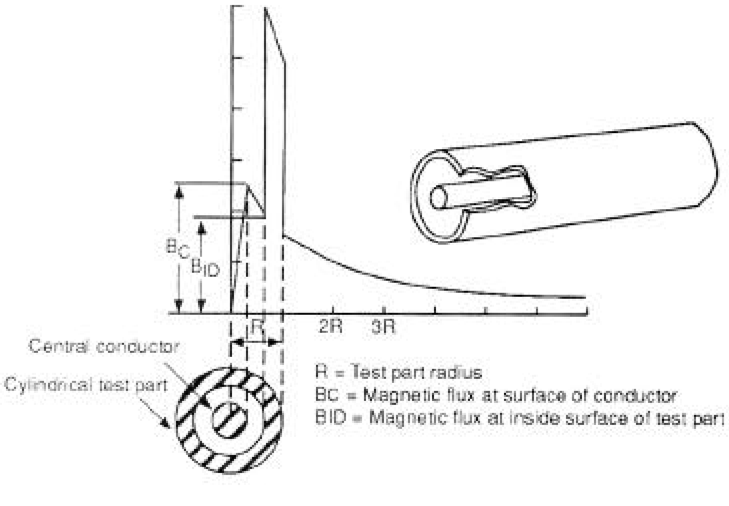


Figure 3-25. Magnetic Flux Distribution in a Central Conduction and a Cylindrical Test Part

3.3.11.4.3.1
When using a central bar conductor, alternating current is only to be used when inspecting for surface discontinuities on the inside circumference of the part. If only the inside surface is to be inspected, the diameter shall be the largest distance between two points, 180 degrees apart, on the inside circumference. Otherwise the diameter shall be determined as indicated in paragraph 3.3.11.4.2. The central bar conductor should have an outside diameter as close as practically possible to the inside diameter of the hole of the part that is being inspected.

3.3.12 Longitudinal Magnetization.

3.3.12.1 General.

A part is said to have been longitudinally magnetized when the field in it is approximately parallel with a major axis. A part magnetized in a coil, for example, will be longitudinally magnetized in a direction approximately parallel with the coil axis. A characteristic of a part that is magnetized longitudinally will be the appearance of opposite magnetic poles, north and south, at the extreme ends of the part. The existence of the poles is a disadvantage when magnetizing and inspecting because much of the leakage flux from the pole-ends is not parallel with the part surface. This reduces the magnitude of flux that is parallel, thereby weakening the leakage fields at discontinuities in the end regions. The use of pole pieces as described in paragraph 3.3.12.6.3.7, overcomes this weakening effect in many cases. The poles are an advantage in demagnetizing since they make it easy to detect magnetized parts and to confirm removal of the residual fields after demagnetizing procedures.

3.3.12.1.1
Longitudinal magnetization is used for the detection of circumferential discontinuities that lie at approximately right angles to a part's axis. Circumferential discontinuities around a cylinder for example, are detected by magnetizing the cylinder longitudinally in a direction parallel with its axis. A portion of the longitudinal field will cross the discontinuities creating leakage fields that can capture and hold magnetic particles to form indications at the discontinuities.

3.3.12.2 Coil Shot Technique.

The usual way to longitudinally magnetize a part is by placing the part in a rigid coil on a stationary magnetic particle inspection unit. The part may be laid on the bottom inside of the coil where the field is strongest, or the part may be supported in the coil by the contact heads of the unit. Special supports are provided on some inspection units for long heavy parts, permitting rotation of parts for inspection. Coils are usually mounted on rails permitting movement along a long part for multiple inspections (multiple coil shots). Because the effective field extends only 6 to 9 inches on either side of a coil, multiple inspections are needed on long parts.

3.3.12.3 Cable Wrap Technique.

Cable wrapping a coil around large or heavy parts is another method of producing longitudinal magnetization. Flexible, insulated copper cable is used. A cable-wrapped coil is connected to a magnetic particle mobile or portable power pack or it can be connected to the contact heads of a stationary inspection unit. The type of power source to be used will depend upon the kind and level of current needed to accomplish the particular desired inspection, both magnetizing and demagnetizing.

3.3.12.3.1
Cable lengths used to connect cable-wrapped coils must be kept as short as practical to minimize cable resistance losses and obtain higher magnetizing currents. In the case of AC, and to some extent half-wave DC, in addition to cable resistance, there is the inductance of the coil circuit which further reduces current flow. Twisting or taping the coil cable leads together aids in reducing the inductance of the coil circuit. Coil inductance increases directly with the coil opening area and increases as the square of the turns in the coil. Keeping each of these factors as small as practical, particularly when using AC, assures the maximum current will be obtainable from the power supply. To help keep coil current losses low, cable coils should be wrapped directly on a part or on some insulating material only a little larger than the part. Multiple inspections along a long part, using a coil of only a few turns (3 to 5) is preferably to using a coil of many turns over the length of the part. The latter is occasionally done in some cases where performing multiple inspections is not possible or when a power pack having the required output voltage and current capacity is available.

Finally, any cables and cable leads used with and for cable-wrapped coils must have good quality electrical connections. Poor connections result in overheating and reduced coil amperage.

3.3.12.4 Electromagnet Technique.

Parts can be magnetized longitudinally by placing them between the pole pieces of a pair of electromagnets with the fields of the two electromagnets being directed in the same direction through the part.

3.3.12.5 Yoke Technique.

Still another method is the magnetizing of parts between the feet of yoke or probe.

3.3.12.6 Selection of Current Level.

3.3.12.6.1 General.

A number of factors must be considered when determining current levels for longitudinal magnetization of parts. Some of the more important factors are:

a. The coil diameter and the number of turns.

b. Cross-sectional area of the part and the coil.

c. The length to diameter (L/D) ratio of the part.

d. The size, shape, and composition of the part.

e. The orientation of the part within the coil.

f. The kind of discontinuities being sought and their ease of detection.

3.3.12.6.1.1

The magnetizing field strength in the center of the magnetizing coil increases with the current passing through the coil and is proportional to the number of turns. The field strength decreases if the coil radius is made larger.

3.3.12.6.1.2

Rule-of-thumb formulas have been developed to help determine the amount of amperage required to induce an adequate longitudinal magnetic field in a part. These formulas apply particularly well to cylindrically shaped parts and are explained with examples shown in the following paragraphs. However, as discussed previously, blind adherence to these “rules of thumb” can result in overmagnetization with a subsequent loss of inspection sensitivity.

3.3.12.6.2 Cross Sectional Area.

It is critical to determine the relationship between the cross-sectional area of the part and the cross-sectional area of the coil(s). This relationship/ratio will determine whether the part can be inspected within a coil of a given diameter by lying the part in the bottom or next to the side of the coil wall, or by centering the part in the coil, and which formula will be used for estimating the amperage required. The cross-sectional area for the part and coil are determined as follows:

$A = \pi r^2$

Where: A = Cross-sectional Area

$\pi = 3.1416$

r = radius (1/2 of the diameter). The diameter of the part shall be taken as the largest distance between any two points on the outside circumference of the part.

Example: A 12-inch diameter coil is to be used to inspect a part having a 2-inch diameter.

Area of Coil (12" diameter)	Area of Part (2" diameter)
$A = \pi r^2$	$A = \pi r^2$

$A = \pi(6)^2$ $A=\pi(1)^2$
$A = 113$ sq. inches $A = 3.14$ sq. inches

3.3.12.6.2.1
When the cross-sectional area of the part is less than one-tenth of the cross-sectional area of the coil, the part should be magnetized lying in the bottom of the coil.

3.3.12.6.2.2
When the cross-sectional area of the part is greater than one-tenth of the cross-sectional area of the coil, the part must be magnetized in the center of the coil.

3.3.12.6.2.3
When using a cable wrap or when the cross-sectional area of the part exceeds one-half of the cross-sectional area of the coil, the part should be centered in the coil and the formula for high fill factor coils SHALL be used for estimating the required amperage.

3.3.12.6.2.4
Table 3-1 lists the diameter of the largest part that can be magnetized lying in the bottom of a coil or placed next to the coil wall for some typical coil sizes. For any given coil diameter, parts with diameters larger than those listed must be magnetized by some other method, such as centering them in the coil, using a cable wrap, or using a larger coil.

Table 3-1. Coil Size vs. Maximum Diameter for Parts Magnetized in Bottom of Coil.

Coil Diameter (inches)	Maximum Part Diameter (inches)
8	2.5
12	3.8
15	4.8
18	5.7
20	6.3
24	7.6

3.3.12.6.3 Calculating Coil Current.
Two rule-of-thumb formulas have been developed for use in estimating the coil current levels to be used for longitudinal magnetization. One formula is for a part centered in the coil and the other for a part lying in the bottom of the coil. These formulas apply to cylindrical and irregularly shaped parts and at one time were thought to estimate the required current to within 10%. Recent studies show that in almost all instances they overestimate the required current by at least 50%. They use the part length-to-diameter (L/D) ratio. The useful magnetizing field produced by an encircling coil extends approximately 6 to 9 inches to either side of the coil. For parts longer than the effective field distance, one or more inspections are required along the length of the part. When repositioning these longer parts in the coil, allow a 3-inch effective field overlap. The formulas are intended for part with a L/D ratio between 3, and 15. For inspecting parts having L/D ratios of 3 or less, see paragraph 3.3.12.6.3.7. For parts with a L/D ratio greater than 15, use 15 as the value for the ratio.

3.3.12.6.3.1 Formula for Part Lying in Bottom of Coil.
The following formula can be used when the cross-sectional area of the part is less than one-tenth the cross-sectional area of the coil(s) and SHALL be used whenever the part is lying in the bottom of the coil, or is placed next to the coil wall during magnetization. If the part has hollow portions, replace D with D_{eff} (see paragraph 3.3.12.6.3.4).

$$I = \frac{KD}{NL}$$

Where:

I = Current through coil (amperes)
K = 45,000 (a constant, ampere-turns)
L = Length of the part (inches)
D = Diameter of the part (inches)
N = Number of turns in coil

Example: Determine the current required to longitudinally magnetize a steel part 10 inches long with a diameter of 2 inches using a 12 inch diameter coil having 5 turns. (See paragraph 3.3.12.6.2 to determine cross-sectional area ratio between part and coil.)

Substituting the known values and doing the calculations gives:

$$I = \frac{45000 \times 2}{5 \times 10}$$

I = 1800 amperes

Table 3-2 gives typical currents for a five turn coil with the parts lying in the bottom of the coil or held next to the coil wall.

Table 3-2. Typical Coil-Shot Current for a Five-Turn Coil with Part in Bottom of Coil.

Part Length in Inches (L)	Part Diameter in Inches (D)	L/D Ratio	Ampere-Turns Required	Amperes Required
12	3	4	11,250	2,250
12	2	6	7,500	1,500
16	2	8	5.625	1,125
10	1	10	4,500	900
18	1 ½	12	3,750	750
14	1	14	3,214	643

3.3.12.6.3.2

Formula for Part in Center of Coil. This formula SHALL be used when the cross-sectional area of part is greater than one-tenth and less than one-half of the cross-sectional area of the coil(s).

$$I = \frac{KR}{N(6(L / D) - 5)}$$

Where:

I = current through the coil amperes)
K = 43,000 (Constant) (ampere-turns)
R = Radius of coil, (inches)
N = Number of coil turns
L = Length of part (inches)
D = Diameter of part (inches)

The term 6(L/D)-5 is called the effective permeability.

Example: Determine the current needed to longitudinally magnetize a l2 inch long part with a diameter of 4 inches and using a 5 turn, 12 inch diameter coil. (See paragraph 3.3.12.6.2 to determine the cross-sectional area ratio between the part and the coil). If the part contains hollow portions, D should be replaced with D_{eff} (see paragraph 3.3.12.6.3.4).

Substituting known values gives:

$$I = \frac{43000 \times 6}{5(6(12/4) - 5)}$$

I = 3969 amperes

3.3.12.6.3.3 Formula for Cable Wrap or High Fill-Factor Coils.
When using a cable wrap or when the cross-sectional area of the part is greater than one-half of the cross-sectional area of the coil, the following formula SHALL be used for estimating the current required to longitudinally magnetize a part centered in the coil. If the part has hollow portions, replace D with D_{eff}, in the formula (see paragraph 3.3.12.6.3.4).

$$I = \frac{K}{N((L/D) + 2)}$$

Where:

I = Current through the coil (amperes)
K = 35,000, a constant (ampere-turns)
N = Number of coil or cable turns
L = Length of the part (inches)
D = Diameter of the part (inches)

Example: Determine the required current to longitudinally magnetize a part 12 inches long with a 4 inch diameter using the cable wrap technique with a 3 turn wrap.

Substituting known values gives:

$$I = \frac{35000}{3((12/4) + 2)}$$ I = 35000/3(12/4 + 2)

I = 2333 amperes

3.3.12.6.3.4 Formula for Hollow Parts or Parts Having Hollow Portions.
If a part has hollow portions, replace the diameter (D) with the effective diameter (D_{eff}), which is calculated using:

$$D_{eff} = 2\left(\frac{A_t - A_h}{\pi}\right)^{\frac{1}{2}}$$

Where:

D_{eff} = Effective Diameter (inches)
A_t = Total cross-sectional area of part (square inches)
A_h = Area of part hollow sections of part (square inches)
π = 3.1416

Example: What would the effective diameter be for a cylindrical part 10 inches long that has a 2 inch outside diameter with a 0.125 inch wall thickness (see Figure 3-26).

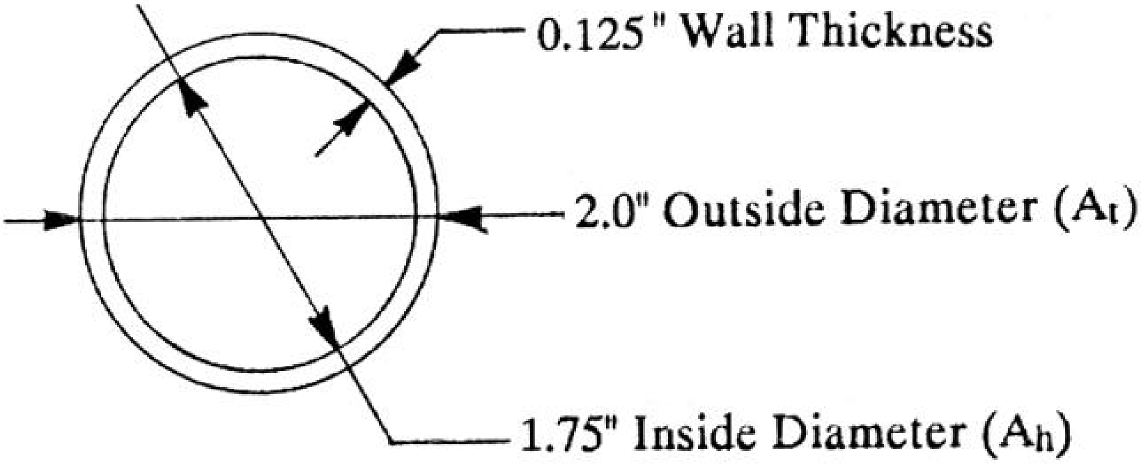


Figure 3-26. Calculating Effective Diameter

To find A_t, calculate the cross-sectional area of the outside diameter of the part as follows:

$A_t = \pi r^2$
$A_t = \pi(1)^2$
$A_t = 3.1416$ sq. inches
To find A_h, calculate the cross-sectional area for the inside diameter of the part (the part's hollow portion) as follows:

$A_h = \pi r^2$
$A_h = \pi(0.875)^2$
$A_h = 2.40$ sq. inches

Insert the results for A_t and A_h into the formula to find D_{eff}.

$$D_{eff} = 2\left(\frac{3.1416 - 2.40}{3.1416}\right)^{\frac{1}{2}}$$

$D_{eff} = 0.97$ inch

To calculate the current required to longitudinally magnetize the part in the above example, use the formula from paragraph 3.3.12.6.3.1 (for the part in the bottom of a 12 inch diameter coil with 5 turns), except replace D with $D_{eff.}$ (0.97):

$$I = \frac{KD}{NL}$$

$$I = \frac{45000 \times 0.97}{5 \times 10}$$

I = 873 amperes

3.3.12.6.3.5
Table 3-3 compares the differences in the current required to longitudinally magnetize the solid and hollow parts in the examples of paragraphs 3.3.12.6.3.1 and 3.3.12.6.3.4 above. The only difference in the two parts is that one was hollow and the other was solid. If the effective diameter D_{eff} had not been considered, the current for the hollow part would have been over-estimated by 927 amperes. This additional amperage would certainly result in excessive background and possibly false indications from over-magnetizing the part.

Table 3-3. Comparison of Coil Amperages for Solid vs. Hollow Parts

	Solid Part	Hollow Part
Part Length	10 inches	10 inches
Part Diameter	2 inches	2 inches
Coil Description	5-turn, 12-inch diameter	5-turn, 12-inch diameter
Amps Required	1800	873

3.3.12.6.3.6
The inspector should be cautioned that when using the above rule-of-thumb formulas, the part length used in the L/D ratio is the part dimension measured in the direction of the coil axis and the diameter is the dimension measured in the plane of the coil. For example, a 2-inch diameter steel bar 10 inches long will have an L/D ratio of 5 when the bar is placed in the coil with its axis parallel with that of the coil. If the bar is placed in the coil so that the bar and coil axis are at right angles to each other, the L/D ratio will be only 0.2, a figure which, if used, would indicate the need for impracticably high amperages.

3.3.12.6.3.7
If the need arises to inspect parts having L/D ratios of 3 or less, the effective L/D ratio must be increased by placing the part between two pole pieces while it is being magnetized. The length dimension for the L/D ratio then becomes the length of the two pole pieces plus the part length. Such pole pieces must make good contact on each side of the part and must be made of ferromagnetic material. Solid steel pole pieces may be used when direct current is used in the coil and the continuous method of inspection is used. If the continuous method is used with either AC or half-wave DC current in the coil, the pole pieces must be made from laminated magnetic material similar to the silicon steel legs of a hand probe with articulated legs. This is also true for residual inspection. Pole pieces must be made from the proper material if residual inspection, or the wet continuous method of inspection with AC or half-wave DC, is to be used.

3.3.12.6.4 Cable Wrap Coil.
Cables used are commonly 2/0 or 4/0 AWG (American Wire Gage), flexible stranded, insulated copper cable. The number of turns used is kept low, from 3 to 5 turns to minimize cable resistance in the case of DC and coil impedance when AC is used.

3.3.12.6.4.1
Multiple inspections spaced approximately 15 to 18 inches along the length of a long part are preferable to one inspection using one long coil of many turns. Cable lead lengths between the power source and coil wraps must be kept as short as practical so that maximum amperages are produced in the coil. When AC is being used, and to some extent with half-wave DC, available amperages can be increased by twisting or taping together the cable lengths between the coil and the power supply. This reduces the coil-circuit impedance the same way that reducing turns on the coil does and makes it possible for more AC current to flow in the coil circuit. The total length of the cable together with the resistance of its connections determines the DC amperage obtainable in the coil. The longer the cable and the poorer the electrical connections, the less will be the DC and the half-wave DC amperages that can be obtained. Increased cable resistance also lowers available AC current, but in the case of AC, the impedance of the coil and coil length circuit has a much greater effect than does resistance in lowering and limiting available AC current.

3.3.12.6.4.2
Much of the information contained in paragraphs 3.3.12.6.2 through 3.3.12.6.3.6 on solenoid coils also pertain to cable wrapped coils. The rule-of-thumb given in paragraph 3.3.12.6.3.1 for a part lying in the bottom of a coil may be used to estimate the current requirement. However, since the cables are likely to be closely placed around the part, the full current will not be required. Sometimes less than one half of the estimated current will be sufficient.

3.3.12.7 Applications.
Longitudinal magnetization is used to inspect ferromagnetic components having material permeabilities of about 500 or greater. This includes most steel alloys. (See Table 3-4). A simple test to determine whether or not a part is sufficiently magnetic is to place a permanent magnet against a part to be tested. If the attraction of the magnet can be felt, the part is sufficiently magnetic for magnetic particle inspection.

Table 3-4. Relative Permeabilities for Some Ferromagnetic Materials.

Ferromagnetic Materials	Relative Permeability*
Iron (99% annealed in H)	200,000
Iron (99.8% annealed)	6,000
Iron (98.5% cold rolled)	2,000
Nickel (99% annealed)	600
Cobalt (99% annealed)	250
Steel (0.9% Carbon)	100

+ **Excerpt from Nondestructive Testing Handbook, Vol. 6, American Society for Nondestructive Testing, 2nd Ed., 1988.**

*Relative to air, which has a permeability of 1.0

3.3.12.7.1
Discontinuities detected by the longitudinal method are those which lie generally in a direction transverse or crosswise to the direction of the applied field. The depth at which a discontinuity can be detected depends upon the size and shape of the discontinuity relative to: (1) the size of the cross section in which it is located; (2) the length to diameter ratio (L/D) of the part; and (3) the strength of the applied magnetizing field. For a given coil and coil current amperage, the smaller the L/D ratio, the lower will be the magnetic flux density in the part, and the weaker will be the leakage fields over discontinuities. In other words, the smaller the L / D ratio, the greater the coil current amperage must be to produce the same flux density or field strength in the part. Coil amperages become impracticably large for L/D ratios of 3 or less. Small L/D ratios of 3 or less can be effectively increased by using pole pieces of magnetic material (refer to paragraph 3.3.12.6.3.7), one on each side of a part. All three pieces must be lined up in the direction of the applied field or coils axis. Very long parts having L/D ratios greater than 15 should receive multiple inspections along the length of a part. The most effective field in a part extends about 6 to 9 inches on each side of a coil. For multiple inspections, a coil must be repositioned at intervals of from 15 inches to 18 inches along the part. Rule-of-thumb formulas for estimating current longitudinal magnetization using coils, for parts having L/D ratios up to l5, and diameters not exceeding about 1/10 that of the coils, are given in paragraph 3.3.12.6.3.

3.3.12.7.2
Longitudinal magnetization of coated parts may be accomplished depending upon the kind and thickness of the coating. Metallic plating generally should not exceed 0.005 inch in thickness unless it is known that the discontinuities being looked for can be detected through greater thicknesses. Nonmetallic coatings such as paint or other protective coatings require removal only if they are excessively thick or damaged to the extent that particles can be trapped mechanically. Any oil or grease must be removed since such materials contaminate the liquid media. Any loose scale or rust must also be removed from parts before inspection since they also can interfere with formation of indications and are a contaminant in a liquid bath.

3.3.12.7.3

Inherent with longitudinal magnetization when using a coil is the difficulty in producing good indications near the ends of the part. This difficulty is caused by the leakage field that emanates from the magnetic poles generated at the part ends. Longitudinal magnetization of a cylindrical part in a coil will produce free magnetic poles at the end of the part. The direction of the magnetic field within the part will be in the same direction as the magnetization force generated by the coil. However, since the flux lines are continuous, the flux lines that traverse from one pole to the other within the part must return outside the part, and in doing so travel in a direction opposite to the applied magnetizing force. This results in a reduction in field strength at the surface of the part and is called free pole demagnetization. The inspection of areas near the ends of such parts is improved when the quick break in the magnetizing current is used. The resulting rapid decay of the field generates a pulse of induced current in the same direction as the original magnetizing current, which in turn produces a strong surface residual field over most of the length of a part. Parts must be moderately retentive for this type of residual inspection, and their shape must be generally cylindrical and have no long slots or cuts that would interrupt an induced current path around in the part near its outer surface. It must be mentioned that the use of yokes or field flow magnetization will also assure an adequate inspection of the ends of generally cylindrical objects.

3.3.13 Equipment.

A variety of equipment is available which can be used for either circular or longitudinal magnetization. The equipment ranges in size from small, general-purpose portable units capable of being carried by hand to large, custom-built stationary units with separate power supplies.

3.3.13.1 Stationary Equipment.

A typical stationary horizontal wet magnetic particle inspection unit of intermediate size is shown in Figure 3-27. The unit has two contact heads for either direct contact or central conductor, circular magnetization using a copper rod between the heads, or a cable connected to a contact block between the heads. Many of the units contain a coil used for longitudinal magnetization. The coil and one contact head are movable on rails. The other contact head is fixed; the contact plate on it, being air cylinder operated, provides a means for clamping the part. The unit has a self-contained power supply with all the necessary electrical controls. Magnetizing currents are usually three phase full-wave DC or AC depending upon usage requirements. The units are made in several different sizes to accommodate different length parts and with various maximum output currents. A full-length tank with pump, agitation and circulation system for wet inspection media is located beneath the head and coil mounting rails. A hand hose with nozzle is provided for applying the bath. On special units automatic bath application facilities are provided.

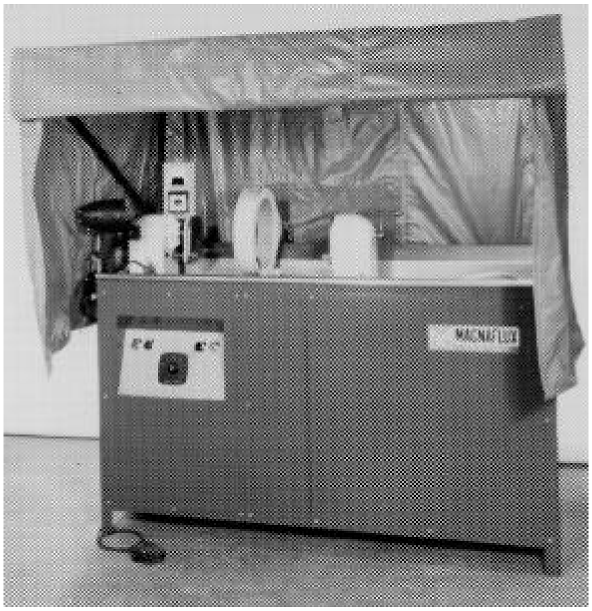


Figure 3-27. Stationary Wet Magnetic Particle Inspection Unit

3.3.13.2 Mobile Equipment.

Mobile inspection units are available in several sizes ranging from 2000 to 6000 amperes of AC and half-wave DC outputs. The units have remote current output, ON/OFF and MAG/DEMAG controls that permit one-man operation at the site of inspection. The units are used with either rigid or cable-wrapped coils for longitudinal magnetization and demagnetization. Cables connected to a part or passing through it is used for circular magnetization or demagnetization. Mobile units can be easily moved to any inspection site where suitable line input voltages and current capacity are available.

3.3.13.2.1

CAUTION

Prods SHALL not be used to inspect aerospace components.

Both half-wave DC and AC outputs are included in most mobile and portable units to increase their versatility. Half-wave DC current and dry magnetic powder make the best combination for detecting subsurface flaws in welds, particularly when used with the prod method of inspection. Half-wave DC is also useful for detecting subsurface discontinuities when the wet method is used. The use of alternating current is limited to the detection of discontinuities that are open to the surface, such as cracks, and for demagnetizing parts.

3.3.13.3 Portable Equipment.

A small portable unit that can be hand-carried is shown in Figure 3-28. These units have both AC and half-wave DC outputs and must be used with portable or cable-wrapped coils for longitudinal magnetization. The units usually have a remote ON/OFF control permitting a one-man operation. They can be used wherever an adequate 115-volt AC power source exists.

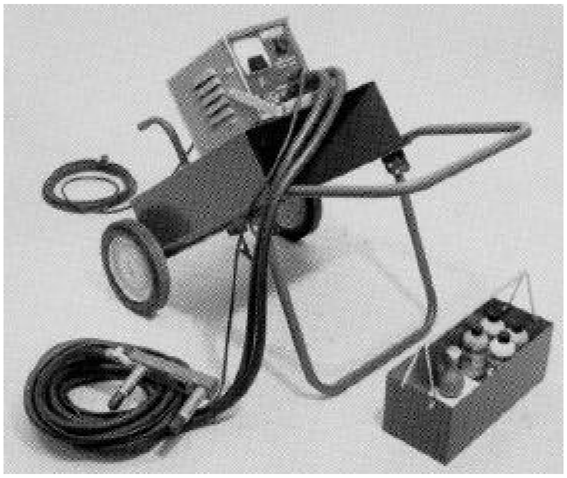


Figure 3-28. AC/HWDC Portable Power Pack

3.3.14 Special Methods.

3.3.14.1 Summary.

Many parts, because of their small L/D ratio, shape, complicated geometry, or the location and kind of discontinuities, require specialized techniques to obtain a good magnetic particle inspection. One of the techniques uses the fields generated by induced currents in a part, which are produced by rapidly varying longitudinal fields. Another specialized technique uses magnetic flakes in viscous slurry, taking advantage of the difference in light reflection from flakes that have become reoriented by leakage fields at discontinuities. Another technique uses a diluted silicone rubber containing black magnetic particles for the inspection of the interior or otherwise difficult to view surfaces. The liquid rubber is catalyzed, placed against the surface to be inspected and held in place with the appropriate dams and fixtures. Applied magnetic fields cause the particles to migrate to defect locations while the rubber is cured. After cure, the rubber material, which has formed a replica of the surface against which it was placed, is viewed under low power magnification for the indications formed during the inspection. Multidirectional magnetization can be very effective in detecting randomly oriented discontinuities quickly. The technique energizes two or more magnetizing circuits in different directions very rapidly (almost simultaneously) resulting in a reduction of testing time and part handling.

3.3.14.2 Induced Current Magnetization.

3.3.14.2.1 General.

A varying magnetic field in any conducting metal generates electrical current in that metal. The amplitude of the current can be reduced by increasing the length of the current path by a cut, an insulated joint, or a deep surface indentation. The amplitude will also depend upon the size and shape of the cross section through which the magnetic field varies the rate of variation in flux lines per second, and the electrical conductivity of the metal. A single pulse of induced current will flow around in the part, at right angles to the magnetic field, when the magnetic field strength is changed. When the magnetic field is varying in a continuous manner, as it does in the case of alternating or half-wave DC fields, a continuing succession of induced current pulses are produced. These induced current pulses are often referred to as eddy currents.

3.3.14.2.1.1

The process of inducing high amplitude eddy currents in a part to be inspected can also introduce stray eddy currents in adjacent metallic components. The effect of stray eddy currents in a metal is twofold.

a. Heat is generated whenever an electric current flows in a conductor because of resistance. The generation of such heat is of little consequence in magnetic particle inspection because of the relatively short duration of the current flows.

b. The second effect of stray eddy currents is important in magnetic inspection. The magnetic fields resulting from the stray eddy currents is in opposition to the magnetic fields which produce them, resulting in either a reduction of the amplitude of inducing alternating magnetic fields or a decrease in decay rate for an inducing field generated by a collapsing DC current. Either condition results in a reduction in amplitude of the induced current in the part to be inspected. Precautions must be taken to minimize the generation of any induced stray eddy currents in metals in contact with or in the immediate vicinity of the part to be inspected. Any pole pieces should be made of laminated silicon transformer steel or low carbon steel with a low magnetic retentivity. Any part supports or contact plates should be split or cut partially through in such a manner as to produce as long a current path as practical. In some cases part supports, in addition to being split, are made of nonmagnetic metals such as brass or stainless steel, which are also poor electrical conductors. This also reduces the stray eddy currents generated in them.

3.3.14.2.1.2
Induced current magnetization is used for the detection of circumferential defects in rings, discs, and cylinders. The advantages of using the induced current method are:

a. No current contact need be made on a part.

b. Strong fields are generated in a part by the induced currents.

c. Parts with L/D ratios of less than one can be inspected without the need for extremely high coil currents.

3.3.14.2.1.3
Induced current techniques require that the part be circular in shape and have no deep radial cuts or slits which would prevent the generation of an induced current around in the part. It is the circular field produced by such an induced current that generates the leakage fields at circumferential discontinuities. Circumferential discontinuities, in order to be detected using the induced current method, must be at or very near the surface of a part. The circular magnetic fields generated by induced currents tend to be crowded toward an outer surface. Circular, disc, or cylindrically-shaped parts, which are retentive, may be inspected residually using a single pulse of induced current such as obtained when DC current in a coil is suddenly interrupted allowing the coil field to rapidly collapse to zero. Parts having a low retentivity must be inspected using the continuous method and AC or half-wave DC current in the coil. The repeated induced current pulse generated by each cycle of these currents is responsible for the formation of the indications at discontinuities. For parts with smooth surfaces, care is required when handling the parts after inspection to prevent mechanical loss of the indications. Washing action is much less of a problem with parts having rougher surfaces, as indications are held by both mechanical and magnetic bonds.

3.3.14.2.2 Technique.
Parts to be inspected using the induced current method must be positioned with their axis parallel with that of the coil, or coils. Two coils, one on each side of a part, may be used when the part's diameter is larger than that of the coils. The coils in this case must be connected electrically; assuring that the coil fields will be in the same direction through the central region of the part. If the part is retentive and is to be inspected residually, DC current is used in the coil. The power pack supplying the DC to the coil must have quick break electrical circuitry so as to obtain a rapid collapse of the coil field. Alternating or half-wave DC current must be used in the coil with the continuous method when a part is made of steel having a low retentivity.

3.3.14.2.2.1
The longitudinal flux density in a part and the rate of decay or collapse of this flux determines the magnitude of the induced current that will be generated in the part. The higher the coil amperage, the higher will be the coil field strength and the higher the flux density in a part up to a coil amperage which produces magnetic saturation in the part. The flux density and thus the induced currents in short cylinders having an L/D ratio of less than 3 or 4, can be increased by placing the part between two laminated pole pieces while being magnetized. Induced currents in ring-shaped parts, such as bearing races, can be increased by placing a laminated core or pole piece in the ring while it is

being magnetized. The laminated core in this case increases the total flux threading the ring. It should be remembered when using the induced current method, that any means used to increase the flux in the direction of the coil field through the part, will increase the magnitude of the induced currents, up to the point of magnetic saturation.

3.3.14.2.2.2

Magnetic flux through the center region of disc-shaped parts which have a small bore hole, or none at all, can be increased by placing a laminated core centered against each side of the disc. Another variation for the use of a laminated core is in the inspection of holes in large parts suspected of having circumferential discontinuities. In this case the magnetizing coil is placed around one end of the core and the other end is used as a probe for placement in the hole. Alternating current is used to energize the coil. In operation the core is placed in a hole and, while the coil is energized, liquid magnetic particle media is sprayed around the inside surfaces of the hole. Before withdrawing the core from the hole, the coil is de-energized so as not to demagnetize the area around the hole. When demagnetization of the area is wanted, the core is simply removed from the hole while the AC current is flowing.

3.3.14.2.3 Selection of Current Level.

No rule-of-thumb formulas have been developed for the induced current method of magnetization. Lacking any other information upon which to select a current level, the rule-of-thumb formulas given in paragraph 3.3.12.6.3 may be used to obtain trial amperages for parts having L/D ratios up to 15. Part diameters, which approach, or are greater than that of the coil and are very short in length, for example, disc-shaped parts will usually require laminated cores to be used, so the rule-of-thumb coil formulas are not applicable. The formulas were developed for the determination of coil amperages, which will produce a longitudinal flux density of 70,000 lines per square inch in a part. The rate of change or rate of collapse of this longitudinal flux produces an induced current in the part, which in turn results in leakage fields at the discontinuities.

3.3.14.3 Slurry.

A magnetic particle testing material is available that supplements both wet and dry magnetic particle testing materials. This material formulation uses selected magnetic particles dispersed in a viscous, oily vehicle which results in slurry having the consistency of paint. The material is brushed on a surface to be inspected until the magnetic particles are evenly and thoroughly distributed. A magnetic field is generated in the test part through conventional AC or half-wave DC magnetizing techniques. Any discontinuities show as contrasting black indications on a gray background. Alternating current fields using a yoke or probe are capable of revealing very fine surface discontinuities using this slurry technique.

3.3.14.3.1

The slurry, being a viscous liquid applied by brush, has the advantage over dry powder of eliminating any hazard to adjacent equipment by airborne magnetic particles. Another advantage is that the slurry can be applied and used successfully on vertical or overhead surfaces, on wet (even underwater) or dry surfaces and over scaly, plated or painted surfaces if the coatings are not too thick.

3.3.14.3.2

The slurry concentration can be varied to suit particular inspection requirements. The material is brushed evenly on a part, much as paint would be, prior to magnetization of the part. If needed the material can be brushed repeatedly permitting magnetization in various directions. The oily vehicle used in the slurry mixture is nondrying, and the slurry can be removed using dry rags, paper towels, or prepared cleaning solvents.

3.3.14.4 Magnetic Rubber.

Magnetic rubber formulations using finely divided magnetic particles in a silicone rubber base are used for the inspection of holes and other surfaces which are not easily accessible. The liquid silicone rubber mixture is poured into holes or against the surface of the magnetic parts to be inspected. Curing time for silicone rubbers varies from about 10 to 30 minutes, depending upon the particular silicone rubber, the catalyst, and the amount of catalyst used to produce the curing reaction.

3.3.14.4.1
While the rubber cures, the surface inspected must stay in the required magnetized state. This can be accomplished using a permanent magnet, a direct current yoke, an electromagnet, or some other suitable means. Whatever method of magnetization is used, the leakage fields at any discontinuities on the surfaces inspected must be maintained long enough to attract and hold in position the magnetic particles until a partial cure takes place. A two-step magnetizing procedure has been developed. The first magnetization is accomplished for a short time in one direction, followed by a second at 90° to the first for the same length of time. This procedure must be repeated for whatever period of time is needed until the cure prevents particle mobility. Magnetization in two directions 90° apart assures formation of indications at discontinuities in all directions.

3.3.14.4.2
After curing, the rubber plugs, which are exact replicas of the surfaces, are removed and visually examined for indications, which will appear as black lines against the gray or yellow background of the silicone rubber. Location of any discontinuities or other surface imperfections can be determined from the location of the indications on the plugs. The magnetic rubber inspection method is covered in detail in Section 9.

SECTION IV
PORTABLE MPI TECHNIQUES

3.4 PORTABLE MAGNETIC PARTICLE FIELD INSPECTION TECHNIQUES.

3.4.1 General.

a. Portable induced field inspection equipment is generally referred to as either a probe or a yoke. These terms are synonymous and differ only due to manufacturer's nomenclature. This category of inspection equipment is described here in conjunction with the techniques for their use and application.

b. Magnetic yokes are small and easily portable. They are easy to use and are adequate when testing small castings or machine parts for surface cracks and for weld inspection. They induce a strong magnetic field into that portion of a part that lies between the poles or legs of the yoke. The induced field flows from one leg of the yoke to the other regardless of the style or leg configuration. Yokes or probes are available with either fixed or articulated legs as shown in Figure 3-29.

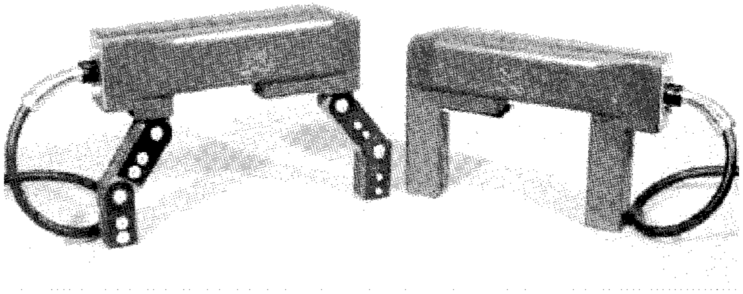


Figure 3-29. Portable Induced Field Inspection Equipment

c. Either dry powder or wet magnetic particles may be used in conjunction with a yoke for the detection of discontinuities. Yokes are available for operation from a 115 volt, 60-hertz AC outlet, or from a 12 volt DC battery. A permanent magnet yoke is also available, permitting inspections to be performed without the use of electric current.

d. Deleted.

3.4.2 Capabilities and Limitations.

a. The units are designed for simplicity, ease of handling, and operation by one person. They may be used on machine-finished surfaces, as well as castings and weldments fabricated in a variety of configurations. The units induce a strong magnetic field at the surface of the part being inspected. Since no current is flowing through the part being subjected to inspection is impossible to overheat or burn the part. The flexibility of a yoke with articulating legs is greatly increased permitting inspections to be performed on parts of varied configurations.

b. Yokes or probes are limited to the detection of surface and near surface discontinuities only. They should not be used for deep-seated, subsurface discontinuities due to the limited penetration of the induced magnetic field. Because of their size they cannot be used with a 100% duty cycle. Rather, they are limited essentially to spot-checking and occasional sample testing rather than continuous production testing. Under optimum operating conditions, the fixed leg yoke has a limited inspection area governed by the distance between and immediately surrounding the legs. The moveable or articulated leg yoke can inspect either a larger area (legs apart) or detect finer discontinuities by concentrating the magnetic field in a smaller area (legs closer together).

3.4.3 Equipment.

3.4.3.1 General.

Yokes or probes are essentially U-shaped laminated cores of soft iron with a coil wound around the base of the U. When electrical current is passing through the coil, the two ends of the core are magnetized with opposite polarity and the combination is an electromagnet similar to a permanent horseshoe magnet.

3.4.3.2 Fixed Leg Yoke.

A fixed leg yoke is shown in Figure 3-29. The legs are spaced approximately 5 inches apart providing a usable magnetic field of approximately 25 in^2. Fixed leg probes can be used on flat, contoured, or irregular surfaces. However, the fixed leg position might preclude their use on some parts of a complex configuration unless special pole pieces are available to adapt the legs to the part's surface.

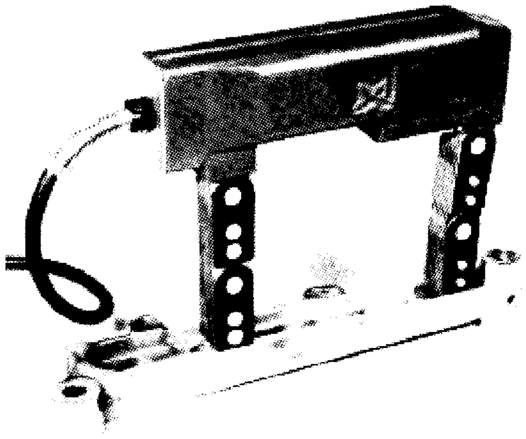


Figure 3-30. Leg Positions of Articulated Leg Yoke (Sheet 1 of 3)

3.4.3.3 Articulated Leg Yoke.

An articulated or movable-leg yoke (also shown in Figure 3-30) contains all the features of a fixed-leg yoke. They are, however, more versatile in their use and application because of the movable legs. Figure 3-30 shows articulated-leg yokes with the legs in normal, decreased, and extended positions. The legs may be moved to the decreased or extended positions to obtain optimum contact assuring a better induced magnetic field. When in the extended position, the area of the usable magnetic field is increased though the field strength is weaker. The discontinuities being sought must be larger. When in the decreased position, the area of the usable magnetic field is decreased and the magnetic field is increased, permitting the detection of finer discontinuities. Movable-leg yokes are more suitable for demagnetization than fixed-leg yokes. The space between the poles or legs can be adjusted such that the parts to be demagnetized pass snugly between them to obtain maximum demagnetization.

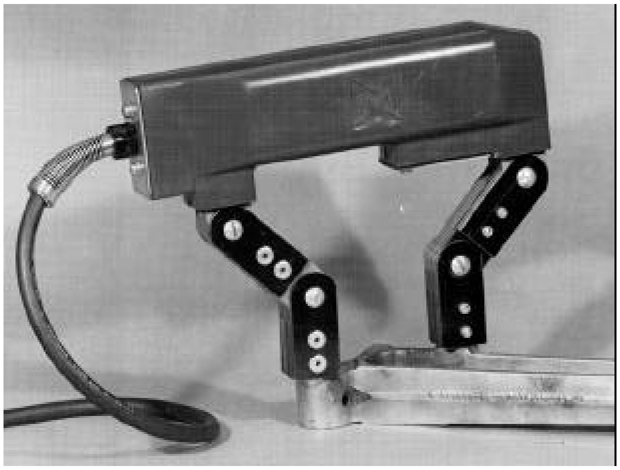


Figure 3-30. Leg Positions of Articulated Leg Yoke (Sheet 2 of 3)

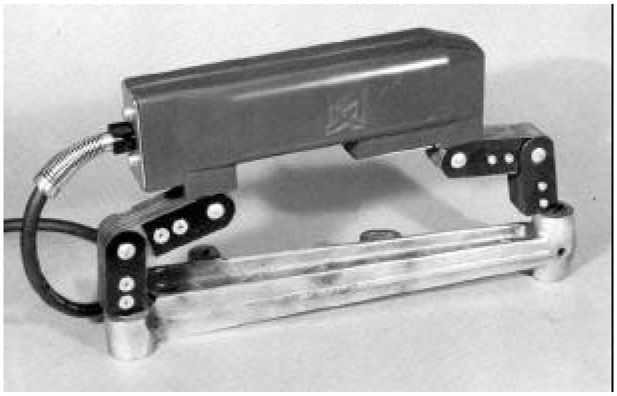


Figure 3-30. Leg Positions of Articulated Leg Yoke (Sheet 3 of 3)

3.4.4 Technique.

3.4.4.1 Magnetizing Source.

Both AC and DC current can be used for electromagnetic yokes. The design of a particular yoke will determine which of the two is the appropriate current.

3.4.4.2 Alternating Current (AC).

An alternating current magnetizing field induced in a part concentrates at the surface layers of the material, and produces a surface longitudinal field. AC provides a very desirable and useful field. Polarity reversal at the 60-hertz rate produces a noticeable surge peak reflected in the magnetic field. Eddy currents are a by-product of AC, which tend to guide the field basically between the poles. The vibratory action of AC adds significantly to the magnetic particle mobility enhancing the formation and build-up of larger and sharper indications at discontinuities. Yokes magnetizing with AC can be readily used for demagnetizing. Because of the reversing nature of AC, the residual method of inspection cannot be used when AC is used for magnetism.

3.4.4.3 Direct Current (DC).

Direct current provides a constant, strong magnetic field. Magnetic particle mobility is minimal and the gathering of magnetic particles at a discontinuity is quite difficult because the vibratory action of an AC field is missing. Direct current induced fields can be successfully applied to small parts. Surface and near subsurface defects can be revealed. The residual method of inspection may be used with direct current, but alternating current must be used for demagnetizing.

3.4.4.4 Pulsed Direct Current.

Pulsed direct current combines the strong magnetic field of direct current with the particle mobility of alternating current. Pulsed direct current is produced by rectifying single-phase alternating current. This pulsating direct current pulses at a rate and level to produce a noticeable surge peak in addition to providing the necessary vibratory action for magnetic particle mobility. Even though pulsed, the direct current aspect permits the residual method of inspection to be used.

3.4.4.5 Permanent Magnet.

When permanent magnets are placed on a ferromagnetic surface, the magnetic field travels through the surface from one pole to the other. The flux field will be relatively straight along a line between the poles and strongest near the poles. Field strength will vary and be weakest at a point midway between the poles. The actual field strength at any point will depend upon the strength of the magnet and the distance between the poles.

3.4.4.6 Field Direction.

Regardless of the current selected, AC or DC, or the position of the legs, the magnetic flux field induced in a test surface always traverses a path in the same direction, from one pole or leg to the other. The yoke is therefore oriented in a transverse direction to the discontinuities being sought to obtain optimum results.

3.4.4.7 Current / Particle Application.

Magnetic particles may be applied either dry or in suspension in a liquid carrier. The part may be magnetized first and the particles applied after the magnetizing force is removed (residual method of inspection applicable to DC or specially designed AC units only), or the particles may be applied while the magnetizing force is still acting (continuous method of inspection). In order to select the proper variations to obtain optimum results, the inspector must understand the variations and how each affects the desired end result.

3.4.4.8 Dry powder / Wet Suspension.

The type of magnetic particles to be used is a choice primarily between the dry and the wet method, and secondarily among the various colors that are available, including fluorescent colors. The decision is influenced principally by the following considerations:

a. Size of the discontinuity. Dry powder is excellent for surface defects of moderate size. The wet method is usually best for very fine and shallow defects.

b. Convenience. The wet method offers the advantage of easy, complete coverage of the surface of parts of all sizes and shapes. Dry powder is more often used for very local inspections.

3.4.4.8.1

Selection of the color of particles to use is essentially a matter of securing the best possible contrast with the background of the surface of the part being inspected. The differences in visibility among the black, gray, red, and yellow particles are considerable on backgrounds which may be dark or bright, and when viewed in various kinds of light, may be difficult to see. If some difficulty is experienced in seeing indications, the inspector should try a different color of powder. In the case of the wet method, the ultimate in visibility and contrast is obtained by the use of fluorescent particles. The fluorescent wet method has been used in constantly increasing numbers of inspection applications for many years, principally because of the ease of seeing even the faintest indications.

3.4.5 Applications.

Hand-held yokes, because of their compact size, low voltage requirements, and minimal weight, are versatile, general-purpose magnetic particle test equipment. They may be used at an inspection facility where parts are brought for inspection, or they may be taken to the inspection site. They are used to test large castings and weldments, assembled and welded structures, or component parts of assemblies without the necessity of disassembly. Yokes are used on parts subject to arc burns, in the detection of surface cracks in welds and castings, and to locate fatigue cracks of large assemblies that may not be conveniently inspected with either mobile or stationary equipment. Where no source of electric current is available or where because of fire or explosive hazard the use of electric current is not permitted, a permanent magnet yoke is available for inspection. One typical application of yokes is shown in Figure 3-31. The yokes SHALL be able to pass the equipment/system tests in paragraph 1.6.7.2c.

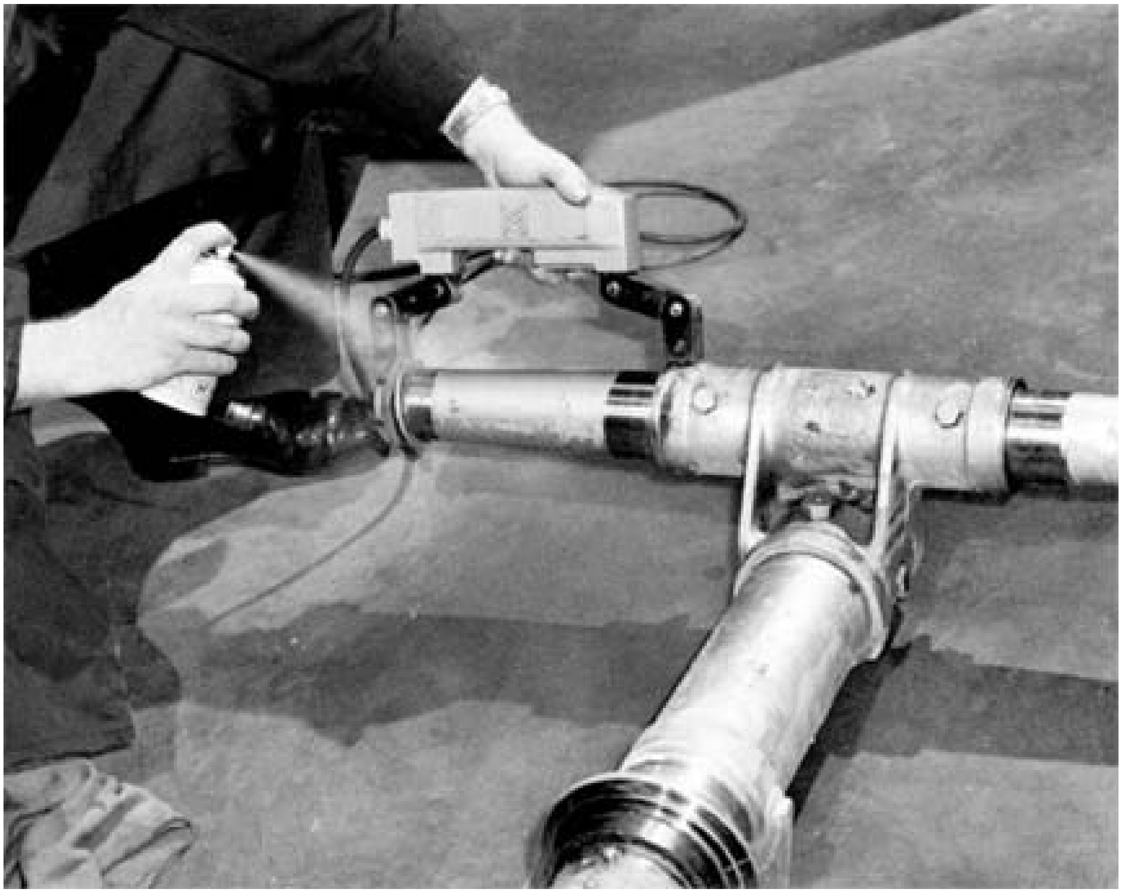


Figure 3-31. Field Inspection of Nose Wheel Strut

SECTION V

MPI MATERIALS AND RESPECTIVE METHODS

3.5 MAGNETIC PARTICLE INSPECTION MATERIALS AND RESPECTIVE METHODS.

3.5.1 General.

a. An important consideration in the magnetic particle testing process is the use of the proper type of materials to secure the best possible indications of the particular type of defect being sought under a given condition. The choice of which materials to use is important, since the appearance of the particle patterns at discontinuities will be affected by this choice, even to the point of whether or not a pattern is even formed. Since the results of magnetic particle tests depend on the interpretation of the particle pattern, the appearance of this pattern is of fundamental importance. The reproducibility of results by inspectors at different locations is dependent on the same type of particles being used by each inspector, and the same magnetizing procedure.

b. There are two basic classes of magnetic particles available for use, wet and dry. The wet method particles use a liquid vehicle for suspension; the dry method particles are borne by air. Either water or oil may be used as a vehicle for the wet method. The particles are colored to give good color contrast with the surface being inspected. The wet particles are best suited for the detection of fine surface cracks such as fatigue cracks. They are usually used with stationary equipment where the bath can be reused until it becomes contaminated. For field applications, aerosol cans of magnetic wet bath are available. Dry particles are more sensitive for detecting defects beneath the surface and are usually used with portable equipment.

3.5.2 Particle Properties and Their Effects.

3.5.2.1 Description.

The particles used in the magnetic particle inspection process are finely divided ferromagnetic material, usually combinations of iron and iron oxides. Properties of these particles include the size, shape, density, magnetic properties, mobility and color. These properties may vary depending on the application.

3.5.2.2 Size.

It is self-evident that size plays an important part in the behavior of magnetic particles in a magnetic field, which can be quite weak at a discontinuity. A large heavy particle is not likely to be arrested and held by a weak field when such particles are moving over a part surface. On the other hand, very fine powders will be held by very weak fields, since their mass is very small. Consequently, extremely fine particles may adhere to the very weak leakage fields caused by acceptable surface and/or material variations. Particle size has a profound effect upon mobility. (Refer to paragraphs 3.5.2.7.1 and 3.5.2.7.2.)

3.5.2.2.1 Dry Powders.

In general, for the dry powders, sensitivity to very fine defects increases as particle size decreases, but with definite limitations. If the particles are extremely small, on the order of a few microns, they behave like a dust. They accumulate and adhere even on very smooth surfaces. The particles will adhere at any damp or slightly oily area, whether or not leakage fields exist. Extremely fine powders, though undoubtedly sensitive to very weak fields, are not desirable for general use because they do leave a heavy, dusty background. In some special applications, particles of a specific size range are used. For instance, where it is desired to detect only rather large, coarse discontinuities, only large-sized particles are used. However, most dry ferromagnetic powders used for detecting discontinuities are mixtures of particles in a range of sizes. The smaller particles add sensitivity and mobility, while the large particles not only aid in locating large defects, but also by a sort of sweeping action, counteract the tendency of the fine ones to leave a dusty background. Thus, by including a wide size range, a balanced powder with sensitivity over most of the range of sizes of discontinuities is produced.

3.5.2.2.2 Wet Method Visible Materials.

When the ferromagnetic particles are applied as a suspension in some liquid medium, much finer particles can be used. The upper limit of particle size in most wet method visible materials used for magnetic particle testing purposes is in the range of 20 to 25 microns (about 0.0008 to 0.0010 inch). Particles larger than this are difficult to hold in suspension, and even the 20 to 25 micron sizes settle out of suspension rather rapidly and are left behind as the suspension drains off. Such particles often line up in what are called drainage lines to form a watermark that could be confused with indications of discontinuities.

3.5.2.2.2.1

In the case of the finer particles, the stranding due to the draining away of the liquid occurs much later, giving the particles mobility long enough to reach the influence of leakage fields and accumulate to form the indications. The minimum size limit for particles to be used in liquid suspensions is indeterminate. Ferromagnetic materials commonly used include some exceedingly fine particles. In actual use, however, particles of this size never act as individuals. Because they are magnetized in use, they become actual tiny magnets. Under conditions of quiet settling in a suspension, these particles are drawn together as a result of their retained magnetism to form clumps or aggregates of particles. These aggregations then tend to act as a unit when they are applied to the surface of parts for magnetic particle testing. The speed and extent to which this process takes place increases with the retentivity of the particle material. Agitating the suspension breaks up the aggregates, but they begin to form again as soon as agitation ceases. This happens when the suspension has been applied over the surface of the part, since the particles act as agglomerated units of varying size, and not as individual particles.

3.5.2.2.2.2 Advantages of an Agglomeration of Fine Particles.

This agglomeration of fine particles into larger clumps is advantageous as long as the size of the aggregate does not become larger than the limit mentioned in paragraph 3.5.2.2.2. Individual particles of exceedingly small size move very slowly through the liquid of the suspension under the influence of leakage fields at discontinuities. Unless special techniques are used, exceedingly small size particles are not particularly useful for the location of very fine cracks until the process of agglomeration into somewhat larger units has taken place. In practical applications this process takes place while drainage of the suspension from the surface of the part is occurring. As the agglomeration proceeds the clumps formed will vary in size, and since these clumps act as individual units, the effect is that of a particle size range from very fine to relatively coarse.

3.5.2.2.3 Fluorescent Wet Method Materials.

Paragraph 3.5.2.2.2 applies primarily to magnetic particles that have not been treated with fluorescent pigments. Fluorescent particles (or even colored visible particles) must be compounded and structured to produce a pigmented or colored coating that will not readily separate from the ferromagnetic core.

3.5.2.3 Shape.

The shape of the magnetic particles used for magnetic particle testing has a strong bearing on their behavior in locating defects. When in a magnetic field the particles tend to align themselves along the lines of force. This tendency is much stronger with elongated or rod-like particles than with more compact or globular shapes because the long shapes develop stronger polarity. Due to the attraction exhibited by opposite poles, the north and south poles of these tiny magnets arrange themselves into strings of particles, north pole to south pole, much more readily than do globular shapes. The result is the formation of stronger patterns in weak leakage fields, as these magnetically formed strings of particles bridge the discontinuity. The superior effectiveness of the elongated shapes over the globular shapes is particularly noticeable in the detection of wide, shallow discontinuities, or of those discontinuities, which lie wholly below the surface. The leakage fields at such defects are more diffuse, and the formation of strings due to the stronger polarity of the elongated-shaped magnetic particles makes for more visible indications in such cases.

3.5.2.3.1 Dry Powders.

In the case of the dry powders, there is another effect from the shape of the particles, which must be taken into account. Dry particles are applied to the surfaces of parts by means of plastic powder bottles, rubber squeeze bulbs, or by the use of compressed air guns. The ability to flow freely and to form uniformly dispersed clouds of powder that will spread evenly over a surface is a necessary characteristic for rapid and effective dry powder testing. A powder composed only of elongated shapes tends to gather together in container, and to be ejected in uneven clumps. When a powder behaves in this manner, the inspection becomes extremely slow and difficult. On the other hand, globular-shaped particles flow freely and smoothly under similar conditions. A dry powder must have free-flowing properties for easy application, yet have optimum shape for the greatest sensitivity for the formation of strong indications. These two opposing needs are met by blending particles of different shapes. A fair proportion of rod-like particles must be present for a sensitive blend. A sufficient proportion of more compact shapes must be present in order to have a powder that will flow well for easy and uniform application

3.5.2.3.2 Wet Method Materials.

In the case of particles for the wet method of inspection, the individual particles are kept dispersed by mechanical agitation until they are applied to the surface of the magnetized part. Therefore, no need exists to incorporate unfavorable shapes merely for the purpose of improving the flow of the particles. Long, slender particles, with otherwise desirable characteristics, could be used exclusively.

3.5.2.3.2.1

Because wet method particles are suspended in a liquid medium, which is much denser and more viscous than air, they move in the leakage fields much more slowly than the dry powders. Therefore, they accumulate much more slowly at discontinuities. In the vicinity of leakage fields, they can be seen to line up to form minute elongated aggregates. Even the unfavorable aggregate shapes, formed by simple agglomeration in suspension, will line up into magnetically held elongated aggregates under the influence of local, low-level leakage fields. This effect contributes to the high sensitivity of the fine particles comprising wet method materials.

3.5.2.4 Density.
Most ferromagnetic materials have fairly high densities. The densities of the materials in common use vary from around 5 to nearly 8 times the density of water. Large, heavy particles will settle out of a suspension faster than either smaller and/or lighter particles. This constitutes one more reason for requiring magnetic particles to be small. The density of many ferromagnetic particles is lowered somewhat by compounding or coating them with pigment with densities lower than that of the particles; with the obvious advantage of the particles remaining suspended longer than uncoated particles. This is true of both the dry, pigmented powders, and the fluorescent particles in liquid suspension.

3.5.2.5 Permeability.
Magnetic particles used for magnetic particle testing should have as high a permeability and as low a retentivity as possible. This is so they can be readily magnetized by the low-level leakage fields that occur in the vicinity of a discontinuity and can be drawn by these fields to the discontinuity itself to form a visible indication. However, there is little connection between permeability and sensitivity for magnetic powders. For instance, the iron-based dry-method powders have permeabilities that are higher than the oxides used in the wet method. Yet a typical dry powder has less ability in detecting the extremely fine surface cracks than the wet-method particles. This is because the higher permeability is insufficient to overcome the handicaps of the other less desirable characteristics of the dry powders. Unless all other factors are in the proper range for the application at hand, high permeability alone is of little value.

3.5.2.6 Coercive Force.
As a general principle, low coercive force and low retentivity are desirable properties for magnetic particles. If these values were high in a dry powder, the particles would become magnetized during manufacture or in first use, and thus become small, strong, permanent magnets. Once magnetized, their tendency to be controlled by the weak fields at discontinuities would be overshadowed by their tendency to stick magnetically to each other and to the test surface. This acts to reduce mobility of the powder, and also to form a high level of background that obscures defect indications.

3.5.2.6.1
Wet method particles that could become strongly magnetized because of high coercive force would also form this same objectionable background. In addition, such particles would stick to any iron or steel in the tank or plumbing of an inspection unit, and cause heavy settling-out losses that would have to be made up by frequent additions of new particles to the bath. Another undesirable feature displayed by highly retentive wet method particles is their tendency to clump together quickly in large aggregates on the test surface. Excessively large clumps of material have low mobility and indications are distorted or obscured by the heavy, coarse-grained backgrounds. Therefore, particles having high coercive force and retentivity are not desirable for wet method use either.

3.5.2.6.2
Both theory and experience have shown that low coercive force and retentivity are advantageous. But low does not necessarily mean minimum or none. Dry powders with some residual magnetism appear more sensitive, especially in the diffuse leakage fields formed by defects lying wholly below the surface. The reason may be that the small amount of polarity established in weakly magnetized, elongated particles aids in lining them up into strings when the leakage fields from discontinuities act upon them. The action is similar to that of the compass needle swinging in the very weak field of the earth. Similarly, wet-method particles benefit from higher-than-minimum values of retentivity and coercive force. These ultra-fine particles begin to collect at discontinuities as soon as they are applied to the test surface, when the agitation, which had been present in the bath, ceases. With insufficient retained magnetism; the particles remain fine and migrate very slowly through the liquid, due to the weak leakage fields, and the viscosity of the liquid suspending medium. The indications of discontinuities will build up, but very slowly, taking as long as five to ten seconds. On the other hand, if excessively magnetized particles are used; the test surface is covered with large immobile clumps as soon as the bath is applied. Particles having intermediate magnetic properties collect into clumps more slowly while the indications are forming. The leakage field, strongest at the actual discontinuity, draws particles toward it, while the particles themselves are constantly enlarging due to agglomeration. At the same time they sweep up the ultrafine particles as they move toward the defect. In this way all the magnetic fields present work together.

3.5.2.7 Mobility.

When magnetic particles are applied over the surface of a magnetized part, they must move and gather at a discontinuity under the influence of the leakage field to form a visible indication. Any factor that interferes with this required movement of the particles will have a direct effect on the sensitivity of the powder and the test. Conditions promoting or interfering with mobility are different for dry and wet method materials.

3.5.2.7.1 Dry Powders.

Dry powder should be applied in such a way that the particles reach the magnetized surface in a uniform cloud with a minimum of motion. When this can be done, the particles come under the influence of the leakage fields while suspended in air, and have three-dimensional mobility. This condition can be approximated when the magnetized surfaces are vertical or overhead. When the particles are applied on a horizontal or sloping surface they settle directly to the surface and do not have the same degree of mobility. Mobility can be achieved in this case by tapping or vibrating the part, which jars the powder loose from the surface and permits it to move toward the leakage fields. When AC, or half-wave rectified AC (pulsating DC) are used for magnetization, the rapid variation in field strength while the current is on imparts a vibratory motion to the magnetic particles on the surface of the part. This gives the particles excellent mobility for the formation of indications. The coatings applied to some of the dry-method powders to give color to the indications also reduce friction between particles and the surface of the part, aiding mobility.

3.5.2.7.2 Wet Method Materials.

The suspension of particles in a liquid, which may be water or a petroleum distillate, allows mobility for the particles in two dimensions when the suspension is flowed over the surface of the part, and in three dimensions when the magnetized part is immersed in the suspension. Wet method particles readily settle out of suspension. To be effective, the magnetic particles must move with the liquid and reach every surface that the liquid covers without settling out somewhere along the way. Particles settle out of suspension at a rate that is directly proportional to their size and their density and inversely proportional to the liquid's viscosity. While it must be balanced off against many other properties, mobility is one of the factors which is important to wet method results. The viscosity of the suspension medium is also important to mobility. In thicker liquids the magnetic particles migrate to the leakage field more slowly. If the suspension liquid is too viscous and the magnetizing cycle too short, the indication may not form adequately. As a practical rule for sensitive inspection, the viscosity of the suspension medium should not exceed 3 centistokes.

3.5.2.8 Visibility and Contrast.

These are important properties that have a great deal to do with making a magnetic powder suitable for its intended purpose. Size, shape, and magnetic properties of a particle may be adequate, but if the indication is not visible to the inspector the inspection fails.

3.5.2.8.1

Visibility and contrast are promoted by choosing colors of particles that are easy to see against the color of the surface of the test part. The natural color of the metallic powders is silver-gray. The colors in the iron oxides commonly used as the base for the wet method materials is limited to black and red. Visibility against certain colors can be increased by coloring the powder particles in some way. By use of pigments the silvery iron particles are colored white, black, red or yellow, all with comparable magnetic properties. One or another of these colors gives good contrast against the surfaces of most of the parts that are tested. Among the dry powders, the gray-white powder gives good contrast against the surfaces of many test parts. It fails to give good visibility, however, against the silver-gray of a sand- or grit-blasted surface, or against bright machined or ground surfaces. Choice of colors must be made by the inspector to provide the best possible visibility against the surfaces of the test part under the conditions of shop lighting that prevail. Similarly, the choice of either the black or the red wet method material is made to suit particular lighting conditions.

3.5.2.8.2

In some cases it has been found advantageous to coat the part being tested with a color to improve contrast. Chalk or whiting, in alcohol, has been used in the past for the inspection of large castings and weldments, when lighting conditions were poor in the areas where the inspection was being conducted. Aluminum paint has been similarly used.

Color contrasting is rarely used today, because the fluorescent materials now available solve the problem in a much better way.

3.5.2.8.3

The ultimate in visibility and contrast is achieved by coating the magnetic particles with a fluorescent pigment (usually available in wet method materials only). The search for indications is conducted in total or semi-darkness, using ultraviolet light to activate the fluorescent dyes used. When indications glow in the dark it is almost impossible for an inspector not to see them. Magnetically, these fluorescent materials are less sensitive than uncoated particles, but this reduction in magnetic sensitivity is more than offset by the fact that patterns of particles can be readily seen even when only a few such particles make up the indication. A fluorescent indication easily visible under black light is often quite impossible to see when viewed in white light. The advantage in visibility and contrast of the fluorescent materials is so great that they are being used in a very high percentage of all applications.

3.5.2.9 Dry Versus Wet.

The choice between the dry and wet methods is influenced principally by the following:

a. Type of Defect (surface or subsurface). For subsurface defects the dry powder is usually more sensitive.

b. Size of Surface Defect. The wet method is usually best for very fine and shallow defects.

c. Convenience. Dry powder with a portable half-wave unit, for instance, is easy to use on large parts in the shop or for field inspection work.

The dry powder method is superior for locating defects lying wholly below the surface because of the high permeability and the favorable elongated shape of the particles. These form strings in a leakage field and bridge the area over a defect. AC with dry powder is excellent for surface cracks, which are not exceedingly fine, but it is of little value for defects lying even slightly below the surface. When the requirement is to detect very fine surface cracks, the wet method is considered superior regardless of the form of magnetizing current used. In some cases, direct current is considered advantageous for use with the wet method to get better indications of discontinuities that lie just below the surface. The wet method offers the advantage of easy complete coverage of the surface of parts of all sizes and shapes. Dry powder is often used for spot inspections.

3.5.2.10 Visible Versus Fluorescent.

Selection of the color of particles to use is essentially a matter of obtaining the best possible contrast with the background of the surface of the part being inspected. The differences in visibility among the black, gray, and red particles are considerable on backgrounds which may be dark or bright and which may be viewed in various kinds of light. Black stands out against most light colored surfaces, gray against dark colored ones. Red is more visible against silvery and polished surfaces especially when the lighting is from incandescent lamps. If the indication is hard to see, the inspector should try some other color of powder. In the case of the wet method, the ultimate in visibility and contrast is obtained by the use of fluorescent particles. The fluorescent wet method has been used in constantly increasing numbers of inspection applications for many years, principally because of the ease of seeing the faintest indication.

3.5.3 Media Selection.

NDI laboratory generated results SHALL include supplemental information requesting that the following be included on the purchase order or contract.

a. Suspension vehicle for magnetic particle inspection SHALL comply with DOD-F-87395. Table 3-5.)

Table 3-5. Requirements for Magnetic Particle Wet Method Oil Vehicle (DOD-F-87395)

Test	Requirement		Specification/ Standard
	Minimum	Maximum	
Flash Point, °C(°F)	94(200)	—	ASTM D 93
Odor	—	None	DOD-F-87395
ASTM Color	—	1.0	ASTM D 1500
Background Fluorescence	Less than the standard		DOD-F-87395
Viscosity Centistokes	—	3.0	ASTM D 445
Particulate Matter, mg/L	—	0.5	ASTM D 2276
Total Acid Number, mg KOH/L	—	0.015	ASTM D 3242

b. Magnetic particles SHALL comply with ASTM E 1444 and the specific aerospace material specification (AMS). (see Table 3-6)

Table 3-6. Procurement Data for Magnetic Particles per ASTM E 1444

Type of Particles (Specification Title)	Specification
Magnetic Particle Inspection Material, Dry Method	AMS 3040
Magnetic Particles, Wet Method, Oil Vehicle	AMS 3041
Magnetic Particles, Wet Method, Dry Powder	AMS 3042
Magnetic Particles, Wet Method, Oil Vehicle Aerosol Canned	AMS 3043
Magnetic Particles, Fluorescent, Wet Method, Dry Powder	AMS 3044
Magnetic Particles, Fluorescent, Wet Method, Oil Vehicle	AMS 3045
Magnetic Particles, Fluorescent, Wet Method, Oil Vehicle, Aerosol Canned	AMS 3046

3.5.4 Current / Particle Application Techniques.

The part may be magnetized first and particles applied after the magnetizing force has been turned off (the residual method); or the part may be covered with particles while the magnetizing force is still present (the continuous method). With parts having high retentivity, a combination of these methods is sometimes used. The choice between the residual and the continuous method is a relatively easy one.

3.5.4.1 Residual Method.

3.5.4.1.1 Description and Use.

In the residual method, parts are magnetized and the magnetic particles are then applied. This method can be used only on parts having sufficient retentivity. The magnetic field they retain must be sufficiently strong to produce leakage fields at discontinuities, which in turn will produce readable indications. The method in general is reliable only for the detection of surface discontinuities. Since hard materials which have high retentivity are usually low in permeability, higher than usual magnetizing currents may be necessary to obtain a sufficiently high level of residual magnetism. The difference in the behavior between hard steels and soft steels is usually not very serious, if only surface discontinuities are sought.

3.5.4.1.2 Dry Versus Wet.

Either the dry or the wet method for particle application can be used in the residual method. With the wet method, the magnetized parts may be immersed in an agitated bath of suspended magnetic particles, or they may be flooded with bath by a spray. In these circumstances a favorable factor occurs that affects the strength of indications. This factor is the time of immersion of the part in the bath. By leaving the magnetized part in the bath or under the spray for a considerable time, the leakage fields have time to attract and hold a maximum number of particles even at fine discontinuities. This produces an increase in sensitivity over the mere flowing of the bath over the surface of the part as it is being magnetized by the continuous method. It should be noted, however, that the location of the discontinuity on the part as it is immersed affects particle buildup. Build-up will be greatest on horizontal upper surfaces, and less on vertical surfaces or horizontal lower surfaces. Also, rapid withdrawal from the bath or spray can wash off indications held by extremely weak leakage fields, and care must be exercised in this part of the process. The residual method, either wet or dry, has many attractive features and finds many applications, even though the continuous method has the inherent advantage of greater sensitivity.

3.5.4.2 Continuous Method.

The reason for greater sensitivity for the continuous method is straightforward. When the magnetizing force is applied to a ferromagnetic part, the field rises to a maximum. Its value or intensity is derived from the strength of the magnetizing force and the material permeability of the part. When the magnetizing force is removed, the residual magnetism in the part is always less than the field present while the magnetizing force was acting. The amount of difference depends on the retentivity of the material. The continuous method, for a given value of magnetizing current, is always more sensitive than the residual as determined by the strength of field in the part. Techniques have been developed for the continuous method, which make it faster than the residual. The indication is produced at the time of the two magnetization shots and the sixty second migration of the magnetic particles as the residual vehicle drains from the part. The residual method requires two steps, magnetization and application of particles, plus the added time for indications to build up if the immersion method is used. The continuous method is preferred unless special circumstances make the residual method more desirable.

3.5.4.2.1

The continuous method is the only effective one to use on low carbon steels or iron having little retentivity. It is frequently used with AC on such materials because the alternating current field produces excellent mobility of the particles. With the wet method the usual practice is to flood the surface of the part with the bath, then simultaneously terminate bath application and apply the magnetizing current momentarily. Thus the magnetizing force acts on the particles in the film of the bath as they are draining over the surface. Strength of the particle bath has been standardized to supply a sufficient number of particles in the film to produce good indications with this technique. It should be noted that the continuous method requires more attention and alertness on the part of the inspector than does the residual method. Careless handling of the bath/current application sequence can seriously interfere with reliable results.

3.5.4.2.2

Probably the highest possible sensitivity obtainable for very fine defects is achieved by immersing the part in the wet bath, magnetizing the part for a short time while immersed, and continuing to magnetize while the part is removed from the bath and while the bath drains from the surface.

3.5.5 Dry Powder Magnetic Particles.

CAUTION

Dry powder method SHALL NOT be used on aerospace vehicles or aerospace parts without specific approval of the appropriate engineering authority for the individual inspection requirements.

3.5.5.1 General.

The dry powder method is used for the inspection of welds and castings where the detection of defects lying wholly below the surface is considered important. The particles used in the dry method are provided in the form of a powder. They are available in red, black, yellow, and gray colors. The magnetic properties, particle size and shape, and coating method are similar in all colors making the particles equally efficient. The choice of powder is then determined primarily, by which powder will give the best contrast and visibility on the parts being inspected and the degree of sensitivity desired.

3.5.5.2 Advantages and Limitations.

The dry powder method has good and bad features. The advantages and disadvantages, which may influence its use for a specific application, are summarized in the following list.

a. Excellent for locating defects wholly below the surface and deeper than a few thousandths of an inch.

b. Easy to use for large objects with portable equipment.

c. Easy to use for field inspection with portable equipment.

d. Good mobility when used with AC or half-wave (HW).

e. Not as messy as the wet method.

f. Equipment may be less expensive.

g. Not as sensitive as the wet method for very fine and shallow cracks.

h. Not easy to cover all surfaces properly, especially of irregularly shaped or large parts.

i. Slower than the wet method for large numbers of small parts.

j. Not readily usable for the short, timed shot technique of the continuous method.

k. Difficult to adapt to a mechanized test system.

3.5.5.3 Powder Selection by Visibility and Contrast.

Selection of the color of particles to use is essentially a matter of obtaining the best possible contrast with the background of the surface of the part being inspected. The differences in visibility among the black, gray, yellow, and red particles are considerable on backgrounds which may be dark or bright, and which may be viewed in various kinds of light. If difficulty is experienced in seeing indications, the inspector should try a different colored powder. Available colors for powders for the dry method are:

a. Gray Powder is a general-purpose high contrast powder and by far the most widely used of the dry powders. It is effective on dark surfaces, whether black, gray or rust colored.

b. Black Powder is especially designed for use on light colored surfaces. It is dust-free as well as the most sensitive of the dry powders. Its higher sensitivity is because it contains the highest proportion of magnetic material of all the dry powders.

c. Red Powder is a dark reddish powder used on light colored surfaces as is the black powder. However, since the black powder on a silvery or polished surface is sometimes hard to see, the red color may offer a better contrast, particularly under incandescent lighting where the red color stands out.

d. Yellow Powder is pale yellow powder featuring fair sensitivity and good contrast on dark colored surfaces.

3.5.5.4 Surface Preparation.

In general, the smoother the surface of the part and the more uniform its color, the more favorable are the conditions for the formation and the observation of indications. This statement applies particularly to inspections being made on horizontal surfaces. For sloping and vertical surfaces, the dry powder may not be held on a very smooth surface by a weak leakage field. The surface should be clean, dry, and free of grease. The dry particles will stick to wet or oily surfaces resulting in reduced particle mobility. On surfaces that have just been cleaned of grease by wiping with a rag soaked in a petroleum distillate, a thin film of unevaporated solvent can remain that is sufficient to interfere with the free movement of the powder. This thin film can be removed by dusting the surface with chalk or talc from a shaker can, then wiping the surface with a clean dry cloth. An initial application of the dry magnetic powder followed by wiping often will give a surface over which a second application of powder will move readily. Vapor degreasing, if available; will give a dry, oil-free surface.

3.5.5.4.1

Any loose dirt, paint, rust or scale must be removed. If cleaning is accomplished with shot or grit blasting, there is a peening effect, especially on softer steels, which may close up fine surface discontinuities. The effect is more pronounced with shot than with grit, but if these cleaning methods are directed, the inspector should be aware of the danger of missing very fine cracks. A thin, hard, uniform coating of rust or scale will not usually interfere with the detection of any but the smallest defects. The inspector should be aware of the smallest size defect he is to consider, in order to judge whether or not such a coating of rust or scale should be removed.

3.5.5.4.2

Paint or plating on the surface of a part has the effect of making a surface defect appear like a subsurface one. The relative thickness of the plating or paint film and the size of the defects sought determine whether or not the coatings should be stripped. The dry method is more effective in producing indications through nonmagnetic coatings than the wet method, but if fine cracks are expected, the surface SHALL be stripped of the coating if its thickness exceeds 0.003 inch. Most coatings of cadmium, nickel or chromium are usually thinner than this, and the plating makes an excellent background for viewing indications. Hot galvanized coatings are thicker, and in general, should be removed before testing, unless only gross discontinuities are important. Broken or patchy layers of heavy scale also interfere with their tendency to mechanically hold powder around the edges of the breaks or patches, and SHALL be removed if they are extensive enough to seriously interfere with the detection of discontinuities.

3.5.5.5 Applying the Powder.

A few rules for the application of dry powder will make the process of testing easier and more effective. The dry particles are heavier and individually have a much greater mass than the very fine particles of the wet method. If they are applied to the surface of a part with any appreciable velocity, the fields at the discontinuities may not be able to stop and retain them. This is especially true when vertical or overhead surfaces are being examined. The powder should reach the surface of parts as a thin cloud with practically zero velocity, drifting to the surface, so that leakage fields have only to hold it in place. For vertical and overhead surfaces, the fields must overcome the pull of gravity, which tends to cause the particles to fall away. Since the dry particles have a wide range of sizes, the finer particles will be held under these conditions, unless the leakage fields are extremely weak. On horizontal surfaces this problem is minimized. The usual mistake is to apply too much powder. Once on the horizontal surface of a part, the powder has no mobility (unless AC or HWDC is being used) and too heavy an application tends to obscure indications. If the part can be lifted and tapped, the excess powder will fall away and indications will be more readily visible. The excess powder can also be gently blown away with an air stream not strong enough to blow off magnetically held particles forming an indication.

3.5.5.6 Applicators.

Various devices have been used to make proper powder application easy. One of the most widely used is shown in Figure 3-32. The squeeze bottle is light and easy to use. With some practice, by a combination of shaking as with a salt shaker, and a squeeze on the bottle, powder can be ejected with minimum velocity. Practicing with the bottle on a sheet of white paper will train the inspector to produce an even, gentle overall coverage. A powder gun or blower improves application, especially on vertical and overhead surfaces. The powder gun throws a cloud of powder at low velocity, much like a very thin paint spray. When held about one foot from the surface being inspected, a very light dusting of powder permits easy observation of the formation of indications. On horizontal surfaces the excess of powder is blown away with a gentle air stream from the blower. Two push-button valves on the blower gun control the flow of powder or clean air. Less powder is used with the gun, which helps to assure better inspection. A more elaborate gun-type powder blower has a motor-driven compressor integral with a powder container and air-powder mixer. A multichannel rubber hose connects to the gun. A work light is contained in the gun tip to illuminate the inspection area. A trigger on the gun controls the discharge of the powder-air mixture and blow-off air. More elaborate production systems have been built using this same principle of operation. In these cases, the discharge nozzles are mechanically controlled, as is the movement of parts through the machine. Spent powder is automatically retrieved and reused.

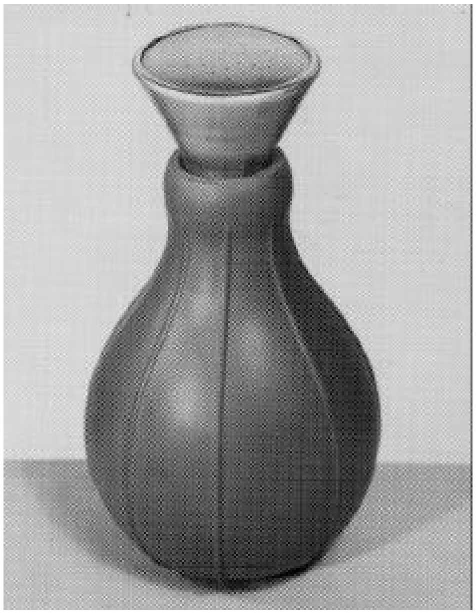


Figure 3-32. Squeeze Bottle Applicator

3.5.5.7 Effects Of Part Surface Condition / Orientation.

Clean, smooth surfaces are best for successful dry powder testing when the surface is horizontal. If the surface is rough, powder tends to gather and be held mechanically in depressions on the rough surface. A stronger stream of air than normal may be required to blow off this loose powder. Care must be taken in the inspection of such rough areas (for example, a rough weld bead) so that weakly held indications are not also blown away. By watching the area very carefully while applying powder and blowing off the excess, weak indications can often be seen as the powder shifts. For very critical inspections, the weld bead is sometimes machined away. Indications of discontinuities, which are below the surface, are more readily formed on the smooth machined surface of the weld. If the surface being tested is vertical or even at an angle to the horizontal, an extremely smooth surface becomes a disadvantage, since the dry powder tends to slide off easily, and weak leakage fields may not be able to hold it in place. Under these circumstances, a slightly roughened surface give better results.

3.5.5.8 Inspection Technique Variables.

The two basic inspection variables to be considered are the types of current to be used, and the current/particle application technique. The type of current is dictated by the location of the defects, whether they are on the surface of the part, or located wholly below the surface. The choice of current is between AC and some form of DC. If the defect is on the surface, either AC or DC may be used, and the choice is determined by other considerations. If the defect lies below the surface, AC SHALL NOT be used.

3.5.5.8.1 Current.

AC versus DC is the first basic choice to be made, since the skin effect of AC at 50 or 60 hertz limits its use to the detection of defects that are on the surface, or only a few thousandths of an inch below it. However, the skin effect of AC is less at lower frequencies, resulting in deeper penetration of the lines of force. At 25 hertz the penetration is deeper, and at frequencies of 10 hertz and less, the skin effect is almost nonexistent. If the defects sought are on the surface, AC has several advantages. The rapid reversal of the field imparts mobility to the particles. The dancing of the powder helps it to move to the area of leakage fields and to form stronger indications. Alternating current has another advantage. The magnetizing effect is 1.41 times that of the current read on the meter. To get equivalent magnetizing effect from DC more power and heavier equipment is required.

3.5.5.8.1.1
DC on the other hand, magnetizes the entire cross section uniformly in the case of longitudinal magnetization and with a field that varies linearly from a maximum at the surface to zero at the center of the bar, for direct contact (circular) magnetization. The types of DC are straight DC from batteries; full wave rectified three phase AC, and full wave and half-wave rectified single phase AC.

3.5.5.8.1.2
For the inspection of finished parts, such as the machined and ground shafts and gears of precision machinery, DC is frequently used. Although AC is excellent for the location of fine cracks that actually break the surface, DC is better for locating very fine nonmetallic stringers lying just under the surface. It is usually important to locate such stringers in parts of this type, since they can initiate fatigue failures. These comparisons point up the importance of choosing the right current type to give the best indications possible, and show how the choice will vary, depending upon the nature and location of the defects sought.

3.5.5.8.2 Current / Particle Application Technique.
The use of dry powder with residual inspection has several disadvantages; it is more difficult to apply to interior regions of a part than is wet media; it is more difficult to completely cover a part in a short time; and removal of powder from a part can be a problem.

3.5.5.9 Inspection Guidelines.
Proper illumination and good eyesight are the principal requirements for observing the presence of indications on the surface of parts. Selection of the best color powder for contrast against the surface is an aid to visibility. Last, but certainly not least, the magnetization must be sufficient to generate a useable leakage field at the location of discontinuities but not excessive to where the background degrades the contrast of any indications formed. On the large discontinuities, dry powder build-up is often very heavy, making indications stand out clearly from the surface. For finer cracks the build-up is less, since fewer particles are held by the leakage field. For extremely fine cracks, some form of the wet method, which is more sensitive to very fine discontinuities, should be used.

3.5.5.9.1
The same requirements for proper inspection of surfaces apply for the detection of subsurface discontinuities. The depth below the surface and the size and shape of the discontinuity determine the strength and spread of the leakage field. A proficient inspector will observe the surface as the powder is allowed to drift onto it, and will see faint but significant tendencies of the powder to gather. Often indications are seen under these conditions, but are no longer visible when more powder has been applied, the excess blown off, and the surface then examined for indications. Standardized techniques for careful and proper application of the powder can help assure the required sensitivity is achieved where similar assemblies are repetitively tested.

3.5.5.9.2
Indications are held at the defect by the residual field for highly retentive steels. In low carbon steels, the retentivity is very low. On these steels it is important to perform the inspection while the magnetizing current is on and the powder is being applied, since indications may not remain in place after the current is turned off. This is particularly true on vertical and overhead surfaces, where gravity plays a part in causing particles to fall away if lightly held. However, inspection requirements for the higher retentive steels often require the detection of very small defects. Even though the residual field may be high in such steel, the leakage fields for small defects will also be small and therefore the indications are not held at the surface very well.

3.5.6 Wet Visible Particles.

CAUTION

The wet visible method SHALL NOT be used on aerospace vehicles or aerospace vehicle parts without specific approval of the appropriate engineering authority for the individual inspection requirements.

3.5.6.1 General.

Wet method magnetic particles are fundamentally similar to each other, once they are dispersed in the suspending liquid. In past years, the most common form of the material concentrate was a paste. Today, however, the pastes have been almost exclusively reformulated and produced as dry powder concentrates. These powders incorporate the needed materials for dispersion, wetting, corrosion inhibition, etc. The powders are much easier to use, as they need merely to be measured out and added directly to the agitated bath. The agitation system of the modern magnetic particle units will pick up the powder and quickly disperse it in the bath.

3.5.6.2 Advantages and Limitations.

As is true of every process, the wet method has both good points as well as less favorable characteristics. The more important good points of the wet method, which constitute the reason for its extensive use, as well as the less attractive characteristics are tabulated as follows:

a. It is the more sensitive method for very fine surface cracks.

b. It is the more sensitive method for very shallow and fine surface cracks. It quickly and thoroughly covers all surfaces of irregularly shaped parts, large or small, with magnetic particles.

c. It is the faster and more thorough method for testing large numbers of small parts. The magnetic particles have excellent mobility in liquid suspension.

d. It is easy to measure and control the concentration of particles in the bath, which makes for uniformity and accurate reproducibility of results.

e. It is easy to recover and re-use the bath.

f. It is well adapted to the short, timed shot technique of magnetization for the continuous method. It is readily adaptable to automatic unit operation.

g. It is not usually capable of finding smaller defects lying wholly below the surface if more than a few thousandths of an inch deep.

h. It is messy to work with, especially when used for the expendable technique, and in field testing. A recirculating system is required to keep the particles in suspension.

i. It sometimes presents a post-inspection cleaning problem to remove magnetic particles clinging to the surface.

3.5.6.3 Particle Selection by Visibility and Contrast.

The need to meet a variety of conditions for successful magnetic particle testing has resulted in the development of different materials to obtain this result. The most commonly used materials, black and red, oil and water suspendible are listed below with the special characteristics of each.

3.5.6.3.1 Black Powder Concentrate.
This is available as an oil- or water-suspendible dry powder. It is especially suited for finding fine cracks on polished surfaces, such as bearings or crankshafts. It is the most sensitive of the non-fluorescent wet method powders for such applications.

3.5.6.3.2 Red Powder Concentrate.
This is available as a reddish brown oil- or water-suspendible powder. The red color gives improved contrast and visibility in situations where the contrast of the black powder is poor. This color tends to be more visible than the black under incandescent light.

3.5.6.3.3 Suspension Characteristics.
Wet method particles may be suspended either in water or in a petroleum distillate. Water is initially cheaper, but additions SHALL be made before it is a suitable medium for suspending the wet magnetic particles. Wetting agents, anti-foaming materials, corrosion inhibitors, suspending and dispersing agents are all necessary and must be carefully controlled. In order to assure proper control of the various conditioners, water as a suspending liquid SHALL NOT be used unless adequate process control capabilities are present.

3.5.6.4 Particles.
Dry material concentrates to be used for water suspension must contain all of the extra ingredients necessary to make the finished suspension. Cost of the concentrates is comparable for water or oil suspension.

3.5.6.4.1
The need to incorporate all of the special ingredients for water or oil suspension into the concentrate necessitates two separate and distinct products. Water-suspendible concentrates cannot be used in oil. The various additives are insoluble in oil and will not disperse the particles in an oil bath. The additions made to the concentrates intended for oil suspension are not soluble in water. However, with suitable water conditioners, some of the oil-suspendible concentrates can be used in water.

3.5.6.4.2
One outstanding characteristic of wet visible method particles is their extremely small size. These very fine particles do not act as individuals but agglomerate into groups. Dry concentrates are almost always formulated to include all required constituents.

3.5.6.5 Vehicle.
The bath liquid or vehicle may be either a petroleum distillate or water. Both require conditioners to maintain proper dispersion of the particles and to permit the particles mobility to form indications on the surfaces of parts. These conditioners are usually incorporated with the powders.

3.5.6.5.1
Petroleum distillates were the first choice as a suspension liquid. Significant characteristics for a suspension vehicle are low viscosity, odorless, low sulfur content and a high flash point. The specifications for a suitable vehicle are given in Table 3-5. Of these properties, viscosity is probably the most important from a functional standpoint. High viscosity will retard the movement of particles under the influence of leakage fields, thus slowing the build-up of particles to form indications.

3.5.6.5.2
Lighter distillates have even lower viscosities than those used, but they have other properties undesirable in a magnetic particle bath. For example, lower initial boiling points accompany the lower viscosities and this results in faster evaporation losses. In addition, a lower flash point also accompanies the lower viscosity with the resulting increase in fire hazard. Inhalation of fumes from a light distillate can impair an inspector’s health. The odor of distillate can be a distraction for the inspector and is associated with color and sulfur content.

3.5.6.5.3
The advantages of water instead of oil for magnetic particle wet method baths are lower initial costs, lower viscosity (about 1 centistoke), non-flammability and ready availability. The disadvantages of water include potential corrosion, electrical conductivity, freezing and the requirement for more conditioners to assure adequate particle function.

3.5.6.5.4
Water baths without auxiliary heating can be used only in shop areas where the temperature is above freezing. Use of anti-freeze liquids is not feasible because the viscosity of the bath then exceeds the maximum allowable. Because the detergents that assure wetting of surfaces can cause foaming of the bath, circulation systems must be designed to avoid air entrapment or other conditions that produce foam. Anti-foaming agents help minimize this tendency, but are not 100% effective.

3.5.6.5.5
Since water is a conductor of electricity, units in which it is to be used are designed to isolate all high voltage circuits in such a way as to avoid all possibility of an inspector receiving a shock. The equipment SHALL be thoroughly and positively grounded. Corrosion of parts of the units can occur if proper provision is not made to avoid this. However, units designed to be used with water as a suspension liquid are safe for the inspector and minimize the corrosion problem. There is no restriction as to the water that is used for the bath, as there is in the case of oil. Ordinary tap water is suitable, and hardness is not a problem, since the mineral content of the water does not interfere with the conditioning chemicals necessary to prepare the bath.

3.5.6.5.6

NOTE

The use of water bath suspension is not recommended for field NDI laboratories unless adequate base laboratory facilities exist to test the serviceability of the wetting agents, dispersing agents, corrosion inhibitors, anti-foam agents, and other additives that are required in the water suspension. Where water is used baths SHALL be carefully controlled to prevent corrosion and assure adequate wetting of parts to be inspected. This requires weekly monitoring of corrosion inhibitor and wetting agent concentration.

Wetting agents and rust inhibitors must be used with water-type wet baths. Usually the magnetic particle concentrates provided include the correct amounts of wetting agent and corrosion inhibitor for initial use. However, these materials are available separately so concentrations can be maintained or adjusted to suit the particular conditions. Reference SHALL be made to the manufacturer's recommendations for the correct quantity of wetting agent to be added.

3.5.6.6 Suspension Preparation.

3.5.6.6.1 Tank Inspection and Cleaning.
When a new unit is being installed or after dumping a dirty bath from a unit in use, the agitation/circulation system must be inspected and cleaned as necessary to insure that it is not contaminated with dried particles or dirt.

3.5.6.6.2 Vehicle.
Fill the tank with oil or water as required, and operate the agitation system to make sure it is functioning properly. If petroleum based bulk vehicle is used, the following check SHALL be performed on bulk vehicles prior to formulating the inspection bath to prevent unsatisfactory bulk magnetic particle vehicle from being introduced into the magnetic particle inspection system.

a. Loosen cap, cover, seal, or plug on the bulk vehicle container.

b. Leave the container undisturbed for at least one (1) hour.

c. Remove cap, cover, seal, or plug from the bulk vehicle container. Obtain a clean glass tube of sufficient length to reach from the bottom of the bulk vehicle container to at least six (6) inches above the container opening when tube is held in the vertical position.

d. Place thumb over one end of the glass tube. Insert the other end of the glass tube slowly in a vertical position into the bulk vehicle. Insure that the tube is all the way to the bottom of the container.

e. Release thumb on upper end of the glass tube for five (5) to ten (10) seconds, then replace thumb over end of glass tube. Remove glass tube slowly from the bulk vehicle maintaining its vertical position.

f. Prior to removing thumb from the end of the glass tube, observe the level of contamination in the glass tube. Water and other contaminants should be evident in lower portion of the glass tube, if present. (At depot facilities, if the vehicle is suspected, the contents of the glass tube may be sent to the depot chemical laboratory for analysis).

g. If contaminants are evident in the bottom of the container, siphon off the good vehicle to within two inches of contamination level.

h. See paragraph 3.2.5.1.2 for disposition instructions of contaminated bulk vehicle.

3.5.6.6.3 <u>Particle Concentration</u>.

NOTE

Prior to adding the magnetic particles to the vehicle they SHALL be demagnetized to eliminate any agglomeration that might have developed during storage because of magnetization.

The strength of the bath is a major factor in determining the quality of the indications obtained. Too heavy a concentration of particles gives a confusing background and excessive adherence of particles at external poles, reducing the visibility of indications of very fine discontinuities. Add magnetic particles to obtain a suspension concentration as follows:

a. <u>Visible</u> magnetic particle bath concentrations: 1.2 to 2.4 milliliters (ml) of particles per 100 ml of vehicle.

b. <u>Fluorescent</u> magnetic particle bath concentrations: 0.1 to 0.4-ml/100 ml.

These ranges are rather broad for uniform results and should be reduced by the individual laboratories for their specific requirements. The optimum range for most magnetic particle bath concentrations is 1.5 to 2.0 ml/100 ml for <u>visible</u> particles and 0.15 to 0.20 ml/100 ml for <u>fluorescent</u> particles.

3.5.6.6.4 <u>Dry Powder Concentrate</u>.

Measure out the required amount of powdered concentrate and pour it directly into the bath liquid in the tank. The agitation system should be running and the concentrate poured in at the pump intake, so that it will be quickly drawn into the pump and dispersed. The new pre-wet concentrates will disperse very quickly even through the large volume of bath in large units. After 10 minutes of operation the bath strength should be checked with a settling test. The amount of settled material should check approximately with the volume requirements in paragraph 3.5.6.6.3.

3.5.6.6.5 <u>Paste Concentrate</u>.

The procedure is similar to that followed with the dry powder concentrates, except that the paste must be weighed instead of measured. It is transferred to a mixing cup or bowl, bath liquid is added little at a time, and mixed until a smooth thin slurry has been produced. This slurry is then poured into the tank at the point where the agitation system will pick it up and disperse it. After agitating 10 minutes the strength should be checked by the settling test as in the case of the dry powder concentrate.

3.5.6.7 Suspension Maintenance.

As the suspension bath is used for testing, it will undergo changes due to use. Some of these changes are:

a. Drag-out of magnetic particles, by mechanical and magnetic adherence to parts.

b. Drag-out of liquid due to the film that adheres to the surface of parts.

c. Loss of liquid by evaporation.

d. A gradual accumulation of contaminants: shop dust, dirt from parts not properly cleaned, lint from wiping rags, and oil from parts that carry a residual film of oil.

e. Miscellaneous objects and materials which are dropped into the tanks.

f. Dilution/contamination of the bath from wet test pieces, dripping overhead pipes, and moisture condensation.

3.5.6.7.1

The magnetic particles are considerably heavier than the vehicle in which they are suspended. When the agitation system is shut off, the particles rapidly settle out. It is important that all particles be in suspension before conducting any inspections or concentration tests. When the agitation system has been off for 4 or more hours, the agitation system SHALL be turned on for at least 30 minutes before conducting an inspection. This agitation time varies with the downtime due to compacting of the particles from their own weight. If the machine has been off for 30 to 60 minutes, a 10-minute agitation is usually adequate. If the unit has been off for a week or more, 60 minutes of agitation plus supplemental stirring may be necessary. Concentrate should be added when the particle concentration is low. Evaporation or liquid drag-out SHALL be watched, and volume maintained when the level drops appreciably. Loss of liquid may be either by drag-out or by evaporation, and corrective measures are different for these two types of loss. To make up for evaporation loss, only additional oil or water is required. To make up for the drag-out loss, the addition of bath liquid and particles is required.

3.5.6.7.2

It is difficult to know what the cause of volume loss actually is in any given case. For a unit in constant use, it can be assumed that more than 50% of the loss is due to drag-out. For a unit used only occasionally, loss by evaporation is likely to be the major cause. Actually the problem is not serious, because with constant use the accumulation of dirt, scraps, lint, etc. requires the dumping of the tank and a new bath before loss of liquid becomes serious. Magnetic particle content is of most critical importance and SHALL be carefully watched at all times.

3.5.6.7.3

Dirt accumulation in the bath can usually be observed in the settling test for magnetic particles. Dirt, lint, etc. are usually lighter and settle later. Dirt, lint, etc. are often seen as a second layer on top of the particles or as a nonfluorescent band or strip in the particle layer. For particle determination, this layer of dirt must be carefully excluded from the total volume read. When the contamination exceeds 30% of the volume of the particle layer, formation of proper indications will be impeded, and the bath SHALL be dumped and a new one made up. This may occur as often as once a week when a unit is in constant use. The layer of dirt and the vehicle immediately above it SHALL NOT fluoresce. If oil is used as a suspension, it must be considered a petroleum product and disposition of the bath must conform to all applicable regulations.

3.5.6.8 Suspension Settling Test.

NOTE

> The difference between milliliters (ml) and cubic centimeters (cc) in this case is negligible and the two terms are used interchangeably for this paragraph. The magnetic particle bath SHALL only be agitated in the magnetic particle machine's holding tank when it is necessary to perform a magnetic particle inspection or meet process control requirements.

The following procedure shall be used to determine the concentration of magnetic particles and to check for the accumulation of dirt or other contaminants in a suspension. The equipment required is a 100 cubic centimeter (cc) or 100 milliliter (ml) pear-shaped, graduated centrifuge tube and stand (see Figure 3-33).

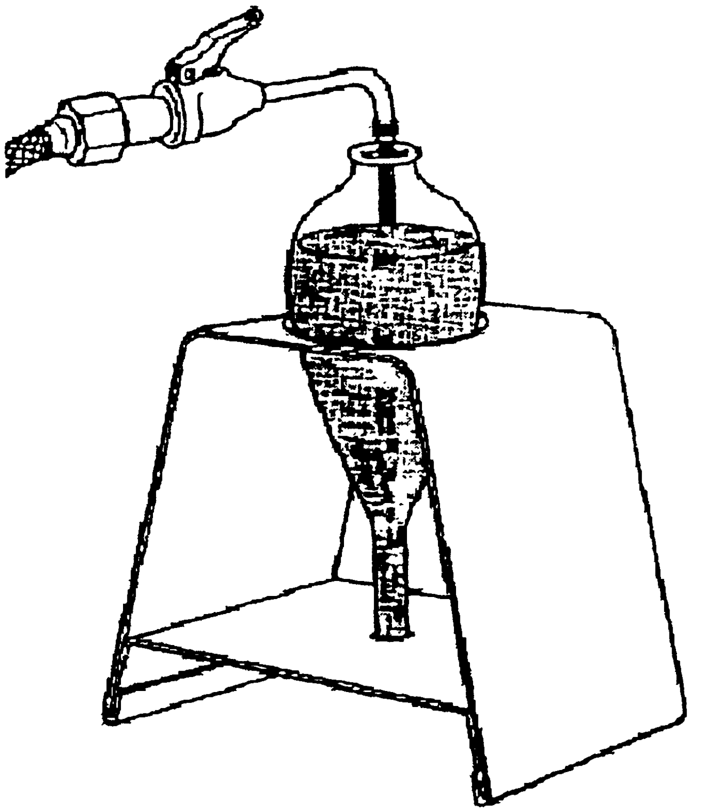


Figure 3-33. Filling Centrifuge Tube from Hose

a. Thoroughly agitate the suspension.

b. Run suspension through the hose and nozzle for at least 1 minute. This is to assure the suspension in the hose is fresh and agitated.

c. Fill the 100 cc (100 ml) centrifuge tube with agitated suspension using the hose.

d. Demagnetize the suspension in the tube to reduce clumping.

e. Place the centrifuge tube in its nonferromagnetic stand and allow settling on a vibration free surface for 1 hour for oil baths and 30 minutes for water baths. Inspections or Process Control Inspections CANNOT BE ACCOMPLISHED prior to the full 1 hour time limit. The suspension concentration must be within T.O. limits prior to use.

f. Observe the total level of settled particles at the end of the settling period. The graduated cylinder reads directly in milliliters. The level of contaminants must be subtracted from the total level to obtain the concentration of particles (see paragraph 3.5.6.6.3).

g. If the level or concentration of magnetic particles is above or below the range required, correct by adding vehicle or magnetic particle powder respectively. Repeat step a. through f. after making corrections.

h. Return contents of centrifuge tube to the unit suspension tank, and clean the tube prior to next test. Dirt in the bath will also settle out and usually show as a separate layer on top of the particles. The layer of dirt and lint is usually easily distinguishable, since it is of a different color and texture from the particles. The layer of dirt and lint is usually easily distinguishable, since it is of a different color and texture from the particles. Also easily distinguishable are iron peening shot and blasting grit; both will settle faster and lie beneath the magnetic particles. The concentrates to be added per gallon of bath, and the volume of solid materials, which settle out when the bath is made up with these amounts of concentrates, should conform with the manufacturer's data supplied with the concentrate.

3.5.6.9 Preparation of Part Surface.
In general the same requirements apply for the wet method as for the dry technique. Dirt, corrosion, loose scale, and oil or grease SHALL be removed. The oil bath will dissolve oil or grease but this builds up the viscosity of the bath and shortens its useful life. With a water bath, oil on the surface of the part makes wetting more difficult, although the conditioners in the bath are usually sufficient to take care of a slight amount of oil. Excessive oil on part surfaces contaminates the water bath. Paint and plated coatings, if over 0.003 inch thick, may have to be stripped. Tests have shown that nonmagnetic coatings of any kind, in excess of 0.003 inch in thickness, can seriously interfere with the formation of magnetic particle indications of small discontinuities.

3.5.6.10 Application of Suspension.
Many ways are used to apply magnetic particles in vehicle carriers. The methods range from a simple pouring of a bath onto a part, to large industrial systems in which the bath is applied automatically, either by immersion or flooding, then recirculated or reused. Occasionally small hand-held, lever-operated sprayers are used.

3.5.6.10.1
Prepared bath is widely available in aerosol cans. Such cans, usually containing oil-based baths, are very convenient to use for spot-checking, or small area tests in the field. They are often furnished in kits, including a permanent magnet or electro-magnet yoke, which makes a portable package for small field testing jobs or for maintenance testing around the shop. Various sizes of ordinary pressurized paint spray tanks equipped with special guns are used, particularly with water-type baths. Aerosol containers SHALL be checked for residual magnetism prior to being used to perform an inspection and, if necessary, demagnetized to less than two increments on the magnetic field indicator. This is necessary to preclude the magnetic particles from agglomerating and not being expelled from the container.

3.5.6.10.2

NOTE

Shelf life dates on aerosol containers of magnetic particle materials is the final date that the manufacturer will warranty its product. These products SHALL be used after this date provided there is sufficient propellant remaining in the container and they pass the system effectiveness check. Only containers being used to perform inspections require testing.

One method practiced, mostly on small parts, is where the parts are magnetized one at a time, then placed in a tray and immersed in a tank containing an agitated bath of magnetic particles. The parts must be placed in the tray so they do not touch each other; or else non-relevant indications from magnetic writing may be produced at the points of contact. Haphazard loading into a basket for immersion application SHALL NOT be permitted. Both the concentration of the bath and the immersion time affect the production of indications. If the leakage field at the discontinuity is weak, prolonged immersion permits more particles to come into the influence of the field and makes the indication more visible.

3.5.7. Wet Fluorescent Method.

3.5.7.1. General.

When exposed to near ultraviolet light (blacklight), fluorescent magnetic particles emit a highly visible yellow-green color. Indications produced are easily seen, and the fluorescent particles give much stronger indications of very small discontinuities than do the non-fluorescent magnetic particles. The differences between the wet visible method and the wet fluorescent method are comparatively minor regarding suspension characteristics, maintenance and application, as well as the inspection variables and demagnetization techniques. The following applies only to the wet fluorescent method.

3.5.7.2. Advantages and Limitations.

Fluorescent particles have one major advantage over the untreated or visible particles. That is their ability to give off a brilliant glow under blacklight. This brilliant glow serves three principal purposes:

a. In semi- or complete darkness even very minute amounts of the fluorescent particles are easily seen, having the effect of increasing the apparent sensitivity of the process, even though magnetically the fluorescent particles are not superior to the uncolored particles.

b. Even on discontinuities large enough to give good visible indications, fluorescent indications are easier to see and the chance of the inspector missing an indication is reduced, even when the speed of inspecting parts is increased.

c. Concurrent with the greater visibility of indications formed by fluorescent particles, the background caused by excessive magnetization is also more severe. Consequently, greater care must be exercised in selection of the particle concentrations and magnetization levels for the inspection with fluorescent particles.

3.5.7.2.1.
The fluorescent particle method is faster, more reliable and more sensitive to very fine defects than the visible colored particle method in most applications. Indications are easier to detect, especially in high volume testing. In addition, the fluorescent method has all the other advantages possessed by the wet visible suspension technique.

3.5.7.2.2.
The wet fluorescent method also shares the disadvantages found with the wet visible method. In addition, there is a requirement for both a source of blacklight, and an inspection area from which the white light can be excluded. Experience has shown that these added requirements are more than justified by the gains in reliability and sensitivity.

3.5.7.3. Inspection Materials.

There is no difference between the fluorescent and non-fluorescent materials as far as the vehicle requirements. Petroleum distillates must meet the same specifications as listed in Table 3-5, with one additional requirement. The vehicle itself must not fluoresce strongly.

3.5.7.3.1.
The particles for this method are magnetically the same as the visible type, but they must carry the fluorescent dye and the binding material that holds the dye and particle together as a unit. This coating of the particles could make them less effective in producing indications. However, fluorescent particle indications require only a small fraction of the particles, as compared to the non-fluorescent type, to be easily visible. Thus, the overall effect is a significant increase in sensitivity.

3.5.7.3.2.
Fluorescent particles are supplied primarily as a dry concentrate, incorporating all the ingredients necessary for use in oil or water, as appropriate.

3.5.7.3.3.
It is of importance that the bond between the fluorescent dye or pigment and the magnetic particle is able to resist the vigorous agitation it receives in the pump circulation and the solvent attack from the suspension fluid. If the dye separates from the magnetic particle, the dye tends to cling to the surfaces of the part, independent of any magnetic attraction, thus increasing the background against which indications must be viewed. At the same time the magnetic particles that are held magnetically at indications have lost some or all of their fluorescing ability, reducing their visibility.

3.5.7.3.4.
The need to provide successful magnetic particle testing under varying conditions has resulted in the development of different materials to accomplish this result. These fluorescent materials are readily available in a dry concentrate powder form suitable for use in water and/or oil suspensions. Prepared oil-based baths are also available in aerosol-type cans and bulk quantities.

3.5.7.4. Suspension Preparation.
Except as described in the following subparagraphs, the details of suspension preparation are the same as for the wet visible non-fluorescent particles (see paragraph 3.5.6.6).

3.5.7.4.1.
A fluorescent background check shall be accomplished on vehicle material used in the fluorescent magnetic particle inspection method if conformance to DOD-F-87935 is in question. One procedure for checking the background is as follows:

a. Obtain a clean glass tube of sufficient length to reach from the middle of the bulk vehicle container to at least six (6) inches above the container opening when it is in the vertical position.

b. Insert the tube slowly into the bulk vehicle.

c. Place thumb over protruding end of the glass tube and remove the tube from the container.

d. Illuminate vehicle in the glass tube with a black light in a darkened area.

e. If vehicle does not fluoresce, proceed with its use. If the vehicle fluoresces, determine the fluorescence in accordance with the appropriate section of DOD-F-87935. Dispose of vehicle not conforming to DOD-F-87935.

3.5.7.5. Suspension Maintenance.
The rules are identical with those described in paragraph 3.5.6.6 for the wet visible non-fluorescent particles. However, there are three additional sources of deterioration that can occur in a bath of fluorescent particles, and that require discarding of the bath when the condition becomes excessive.

3.5.7.5.1. Deterioration of Suspension.

a. The first source of deterioration is the separation of the fluorescent pigment from the magnetic particles. Such separation causes a reduction of fluorescent brightness of indications and an increase in the overall fluorescence of the background. When this occurs to a noticeable degree, the bath SHALL be changed. This condition is difficult to detect in the settling test but can be observed by directing a blacklight at the settling tube after the normal settling period. Refer to paragraph 3.5.7.5.2 for additional steps to aid interpretation of observations. Noticeable fluorescence of the solution with a reduced fluorescence of the particles signifies separation. Observation by the inspector in the way the bath performs is another method of detecting separation.

b. A second source of deterioration of the bath of fluorescent particles is the accumulation of non-fluorescent magnetic dust or dirt in the bath. When there is a considerable amount of finely divided magnetic material in the dust carried by the air, this material will accumulate in the bath along with other dust and dirt. In a bath of wet visible non-fluorescent particles this does no specific harm until the accumulation of total dirt is excessive. In the case of fluorescent particles, it tends to decrease the brightness of the indication. The fine magnetic material is attracted to indications along with the fluorescent particles, and it takes very little of such non-fluorescent material to significantly reduce the brightness or visibility of the indication.

c. A third source of deterioration of the fluorescent particle bath is the accumulation of fluorescent oils and greases from the surfaces of tested parts. This accumulation, in time, builds up the fluorescence of the liquid vehicle to the point where it interferes with the visibility of fluorescent particle indications.

3.5.7.5.2. Determination of Vehicle Fluorescence.

The settling test for particle concentration can be used to also judge vehicle fluorescence and is readily performed at a stationary unit. It is not as accurate as the laboratory test but is reasonably quantitative and reproducible. It can be easily standardized with the material in use, and is quite satisfactory as a daily guide for the inspector. The following procedure SHALL be used in performing the vehicle fluorescence test after the steps in the settling test have been completed (see paragraph 3.5.6.8).

a. Illuminate the suspension in the centrifuge tube with black light in a darkened area. Only the particle layer should fluoresce. Dirt, lint, etc. will usually settle more slowly than the particles and may be seen as a nonfluorescent band or strip toward the top of the particle layer. For particle concentration determination, this layer of dirt must be carefully excluded from the total volume read. Dirt accumulation that exceeds 30% of the total volume of the particle layer can impede the formation of indications, requiring replacement of the bath.

b. Fluorescence in the liquid may indicate bath breakdown (fluorescent pigmentation being stripped from the magnetic particles or fine magnetic particles remaining suspended in the vehicle). If the vehicle fluoresces excessively, place the centrifuge tube in its stand (which must not be ferromagnetic) with a horseshoe magnet in contact with the centrifuge tube (see Figure 3-34) and let sit on a vibration free surface for 1 hour for oil baths and 30 minutes for water baths. Illuminate the vehicle in the centrifuge tube with black light in a darkened area. If the vehicle's fluorescence is reduced or eliminated the cause of the fluorescence is fine magnetic particles remaining suspended. If the level of fluorescence remains at the same level, the fluorescent pigmentation has been stripped from the magnetic particles.

c. If it is determined that the cause of the vehicle's fluorescence is stripping of the pigmentation, the suspension SHALL be replaced if it is serious enough to interfere with the results of the system effectiveness check using the Ketos ring.

d. If it is determined that the cause of the excessive suspension fluorescence is fine magnetic particles remaining in the vehicle, and they are of a volume to interfere with the results of the system effectiveness check using the Ketos ring an effort may be made to remove them from the holding tank's magnetic particle bath. This can be done with magnets. The magnetic particle bath in the magnetic particle machine's holding tank should be allowed to rest (not agitated) for forty (40) minutes. Place the magnets in the magnetic particle bath, taking care not to place them so deep that they will attract the particles that have settled out of suspension. The length of time or number of times that the magnets will have to be cleaned of particles and submerged is dependent upon the seriousness of the problem. The bath SHALL be able to pass the system effectiveness check, after the removal of as many suspended particles as possible or be replaced.

e. If a magnet was used to remove fine magnetic particles from suspension in the centrifuge tube, the suspension SHALL be demagnetized prior to being poured back into the magnetic particle machine.

f. The inside of the centrifuge tube SHALL be cleaned to eliminate any residual fluorescence remaining after each use.

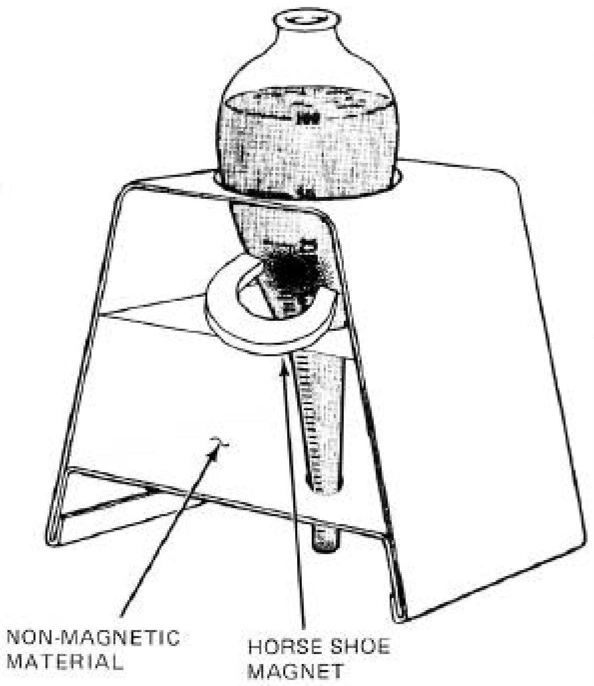


Figure 3-34. Drawing Fine Magnetic Particles from Vehicle with Horseshoe Magnet

3.5.7.6 Surface Preparation.

The removal of surface oil and grease becomes very important in the cleaning of part prior to wet fluorescent magnetic particle inspection. Most petroleum distillates, lubricating oils, and greases fluoresce. Such materials must be kept out of the testing bath because of the increase in background fluorescence that they produce.

3.5.7.7 Application of Suspension.

Application of the suspension using fluorescent magnetic particles is identical with the procedure described in detail for the wet visible method.

3.5.7.8 Blacklight Information (See Penetrant Chapter).

3.5.7.8.1 Ambient Light Requirements.

Inspection booths of a stationary fluorescent magnetic particle system SHALL NOT exceed 2 lumens per square foot (lm/ft^2; 1 lumen per square foot equals 1 foot-candle) of ambient light. For portable applications it is not always possible to achieve ambient light levels as low as this. As the ambient light level is increased, the intensity of black light must also be increased. When performing portable fluorescent magnetic particle inspections, a dark colored canvas or photographers black cloth SHALL be used to darken the area of interest to the lowest possible ambient light levels during the inspection.

3.5.7.8.2 Measurement.

The measurement of visible light intensity is easily accomplished by using solid-state photometers. Measurements of visible light are keyed to the response of the visual system of a standard human observer. The unit of energy for visible light is the lumen-hour and represents the amount of energy in the visible light spectrum distributed in a specific way that is related to the response of the standard human eye. The energy flux, that is the energy per unit of time, then is the lumen. The units of measurements for visible light intensity are foot-candles where one foot-candle equals one lumen per square foot. Another term often used is lux, which equals one lumen per square meter. The conversion between the two terms is 1 foot-candle equals approximately 10 lux.

3.5.7.9 Dark Adaptation.

The human eye becomes much more sensitive to light under dark conditions. This increased sensitivity gradually occurs when the light conditions change from light to dark. When entering a darkened area from a lighted area, little or nothing can be seen at first. The pupil of the eye must widen to admit more light. The time required for the eye to adjust to darken condition depends upon the overall health and age of the individual. Full sensitivity or dark adaptation requires about 20 minutes. A dark adaptation time of 5 minutes is usually sufficient for magnetic particle inspection with black light. An inspector entering a darkened area SHALL allow at least 5 minutes for dark adaptation before examining parts. Once dark-adapted, the pupil of the eye responds very rapidly to bright light. A very short bright light exposure cancels the slowly acquired dark adaptation. Time for dark adaptation must be allowed whenever an inspector enters the darkened booth or is exposed to a bright light. A timer capable of measuring this time period should be available within the darkened area.

3.5.7.10 Cleanliness.

The inspection area as well as the hands and clothing of the inspector should be clean and free of extraneous fluorescent materials. Nonrelevant indications may be formed when parts contact extraneous fluorescent materials. In addition, the fluorescence from this material will raise the ambient light level, thus increasing the amount of blacklight necessary to produce a visible indication of a small defect.

SECTION VI
DEMAGNITIZATION

3.6 DEMAGNETIZATION.

3.6.1 General.

a. Any ferromagnetic material subjected to magnetic particle inspection requires demagnetization. When performing magnetic particle inspection of aircraft parts, it is essential to demagnetize them. The inspector should understand the reasons for this step, as well as the problems involved and the available means for solving them.

b. The earth's magnetic field can contribute to the difficulty of demagnetizing parts. A long part to be demagnetized should be placed so that its principal axis is in an east-west direction. A long part lying in a north and south direction can never be demagnetized below the level of the earth's field. Rotating the part or structure on its east-west axis while demagnetizing often helps reduce the field in transverse members that are not lying east and west. Vibration of the structure during the demagnetization process is also helpful under these circumstances. Complete removal of all magnetic fields is virtually impossible.

3.6.2 Purpose.

Ferromagnetic materials retain a certain amount of residual magnetism (or remnant field) after application of a magnetizing force. This does not affect the mechanical properties of the part. However, a residual field can impede the operation of some parts as well as affect the operation of adjacent equipment that are sensitive to low level stray magnetic fields.

3.6.3 Principles Of operation.

Demagnetization may be accomplished in a number of different ways. The method used depends upon the electrical power and equipment available, the degree of demagnetization required and the skill of the inspector.

a. One of the simpler methods subjects the magnetized part to a magnetizing force that continually reverses its direction. At the same time, this force is gradually decreased in strength. As the decreasing magnetizing force is applied, first in one direction and then the opposite direction, the magnetization of the part is decreased. This decreasing magnetization is accomplished by smaller and smaller hysteresis loops created by the application of decreasing current as shown in Figure 3-35. The smaller the hysteresis loop produced the more demagnetization that has been accomplished.

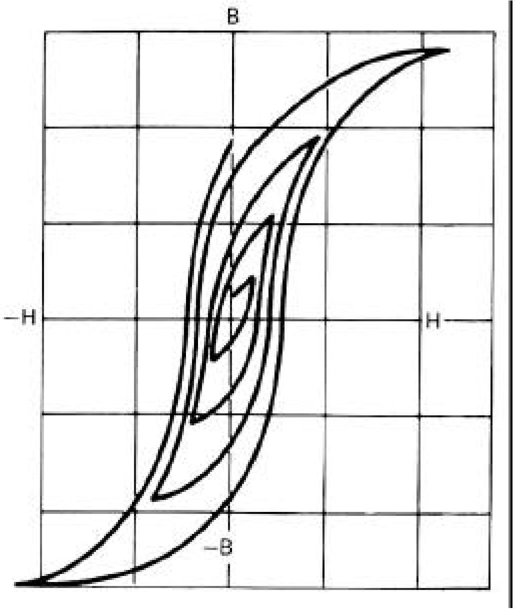


Figure 3-35. Hysteresis Loops Produced During Demagnetization

b. For all practical purposes the only way to completely demagnetize a part is to heat it to its Curie point or above.

c. Under normal conditions, a part is considered to be satisfactorily demagnetized if, when checked with a field indicator, the magnetic field is at or below 3 units on a gaussmeter or 2 units on a field indicator.

3.6.4 Requirements.

Aircraft ferromagnetic parts require demagnetization principally to prevent magnetic flux from affecting instrumentation. There are several additional reasons supporting the requirement for demagnetization.

3.6.4.1 Situations Requiring Demagnetization.

Demagnetization is required when the residual field in a part:

a. May interfere with subsequent machining operations by causing chips to adhere to the surface of the part or the tip of a tool that may become magnetized from contact with the magnetized part. Such chips can interfere with smooth cutting by the tool, adversely affecting both part surface finish and tool life.

b. May interfere with electric arc or electron beam welding operations. Residual magnetic fields may deflect the arc or electron beam away from the point at which it should be applied.

c. May interfere with the functioning of the part itself after it is placed into service. Magnetized tools, such as milling cutters, hobs, etc., will hold chips and cause rough surfaces, and may even be broken by adherent chips at the cutting edge.

d. Might cause trouble on moving parts, especially those running in oil, by holding particles of metal or magnetic testing particles - for instance, on balls or races of ball bearings, or on gear teeth.

e. May prevent proper cleaning of the part after inspection by holding particles magnetically to the surface of a part.

f. May interfere with subsequent magnetization requirements.

g. May hold particles that interfere with later applications of coatings such as plating or paint.

3.6.4.2 Situations Not Requiring Demagnetization.
Demagnetization is not usually required when:

a. The parts are not aircraft parts and have low retentivity. In this case, the residual field is low or disappears after the magnetizing force is no longer acting. An example is low-carbon plate such as that used for low strength weldments, tanks, etc.

b. The material in question consists of non-aircraft structural parts such as weldments, large castings, boilers, etc., where the presence of a residual field would have no effect on other components or the proper service performance of the part.

c. If the part is to be subsequently processed or heat-treated and in the process will become heated above the Curie point, or about 770°C (about 1418°F). Above this temperature steels become nonmagnetic, and on cooling are completely demagnetized when they pass through the reverse transformation.

d. The part will become magnetized anyway during a subsequent process, for example, when held in a magnetic chuck.

e. A part is to be subsequently magnetized in another direction to the same or higher level at which it was originally magnetized, for example, between circular and longitudinal magnetization for magnetic particle inspection.

f. The magnetic field contained in a non-aircraft finished part is such that there are no external leakage fields measurable by ordinary means, i.e., the field produced during magnetic particle inspection with circular magnetization.

3.6.4.2.1
The requirement cited in paragraph 3.6.4.2e is sometimes a cause of confusion. A residual magnetic field in a ferromagnetic material exists because there is a preferred orientation of the magnetic domains caused by a previously applied magnetic field. A residual magnetic field perpendicular to a previously established residual field can only be produced by application of a magnetic field in the perpendicular direction strong enough to rotate the domain 90 degrees. Because the preferred orientation of the domains has been rotated 90 degrees, the previous residual field no longer exists. For this reason, longitudinal magnetization, strong enough to produce indications of discontinuities in a part that previously had a residual circular magnetic field, reduces the circular residual field to zero. If the magnetizing force is not of sufficient strength to establish the longitudinal field, the strength SHALL be increased, or other steps taken to insure that a residual longitudinal field actually has been established. For example, a large part having a large L/D ratio may require multiple longitudinal shots along its length to eliminate the circular field. Rotation of the preferred orientation of the magnetic domains also occurs when a circular residual field is produced in a part with an existing residual longitudinal field.

3.6.4.2.2
If the two fields, longitudinal and circular, are applied simultaneously, an applied field results that is a vector combination of the two in both strength and direction. If the magnitude of this resultant applied field is large enough, then a residual field will be produced in this same direction. If, however, the fields are induced sequentially the last field applied, if strong enough to produce a residual field, will eliminate the residual field from the previous magnetization. A convenient method of assuring reduction of a residual magnetic field in one direction and establishing a field in a perpendicular direction is to slightly increase the magnetizing force of the second shot.

3.6.5 Methods.

3.6.5.1 General.

Alternating and direct currents are used in demagnetizing aircraft parts after magnetic particle inspection. Although direct current can be used for demagnetization, alternating current demagnetization has been found to be more convenient. Since alternating current does not penetrate very deeply below the surface of magnetic materials, some parts may be difficult to demagnetize completely using alternating current. This is particularly true with large heavy parts, and may also be the case with parts of unusual shape. Direct current can be used to demagnetize if there is provision for current decay or reduction and a means for reversing the direction of the current. Demagnetization accomplished in this manner with direct current is the most complete and effective possible.

3.6.5.1.1

To demagnetize with direct current, the part is placed in a coil connected to a source of direct current. The current is adjusted to a value at least as great as that used to magnetize the part and a shot of current is given at this initial value. The direction of the current is then reversed the value reduced, and a shot of current given at the new value. This process of reversing and reducing the current is continued until a very low value is reached. The part is now effectively demagnetized.

3.6.5.1.2

Paragraph 3.6.8.6 indicates that parts with a circular field do not have magnetic poles. This lack of measurable poles, providing no discontinuities are present, makes it impossible to check the magnitude of residual circular magnetization with the conventional residual field indicator. A common and recommended practice on aircraft parts is to magnetize the part longitudinally after it has been circularly magnetized. The difficult to measure circular field is then replaced by an easy to measure longitudinal field.

3.6.5.2 AC Demagnetization.

Separate AC Coil. The most common and convenient method of demagnetizing small to moderate sized parts is by passing them through an open tunnel-type coil, through which alternating current at line frequency (usually 50 to 60 hertz) is passing. Another practice is to pass the 50 or 60 hertz AC through a coil with the part inside the coil, and gradually reduce the current to zero. In the first case, the reduction of the strength of the reversing field is obtained by withdrawal of the part axially from the coil (or the coil from the part) and for some distance beyond the end of the coil (or part) along that axial line. In the second case, the gradual decay of the current in the coil accomplishes the same results. This method of demagnetization is particularly suitable for large numbers of relatively small parts.

3.6.5.2.1 Stationary MPI Unit.

Stationary magnetic particle testing equipment often has demagnetization capabilities. If so equipped, AC current may be passed directly through the part or through the coil on the magnetizing unit. For demagnetization of parts, the alternating current is reduced to zero automatically by built-in means of step-down switches or variable transformers for older equipment, or solid state devices for newer equipment. The step-down feature permits the demagnetization of parts without removal from the magnetizing equipment. This procedure is more effective on long, circularly magnetized parts than the separate coil method, but does not overcome the lack of penetration due to skin effect unless frequencies much lower than 60 hertz are used.

3.6.5.3 DC Demagnetization.

Demagnetizing by the direct current reversing step-down feature is essentially identical in principle to the AC method. Modern stationary DC magnetizing equipment usually incorporates this capability. The use of DC current permits a more even and complete penetration of even large cross sections. The DC current flows in one direction for a short time, it then is slightly reduced in magnitude, and completely reversed in direction. The process of automatically reversing and reducing the current is continued until the current reaches zero and the part is effectively demagnetized. This method of demagnetizing is very effective although it does require large, heavy equipment. It is especially effective in removing circular fields when the current can be passed through the part and works well with a central conductor, when applicable. Small parts can be placed in a standard coil and larger parts can be cable-wrapped for their full length, as induction loss is not present with DC.

3.6.6 Equipment and Procedures.

3.6.6.1 Stationary Unit.
Magnetic particle inspection equipment which magnetizes with AC or DC is used to demagnetize parts after inspection, depending upon the demagnetization features included in the equipment and the size and shape of the part.

3.6.6.1.1
The most common type of stationary demagnetizing equipment consists of an open coil through which alternating current at line frequency, usually 50 to 60 hertz, is used. The demagnetizing coil may be equipped with a stand or may be constructed and placed on a bench. Usually larger sizes also have a track or carriage on which parts can be placed to facilitate handling.

3.6.6.1.2
To use a demagnetizer coil, such as that illustrated in Figure 3-36, the part is placed in the coil and the current turned on. While the current remains on, the part is slowly withdrawn from the coil a distance of 4 to 5 feet before the current is shut off. The axis of the part should be parallel to the axis of the coil for regularly shaped parts. On complex parts, more complete demagnetization is sometimes possible if the part is rotated and turned end for end. For best result the diameter of the demagnetizer coil should be just large enough to accommodate the part. However, for practical purposes one or two sizes of coils will satisfactorily serve an inspection facility. When demagnetizing, small parts in a large coil, keep the parts close to the inside wall or corner of the coil since the demagnetizing forces are strongest in that area.

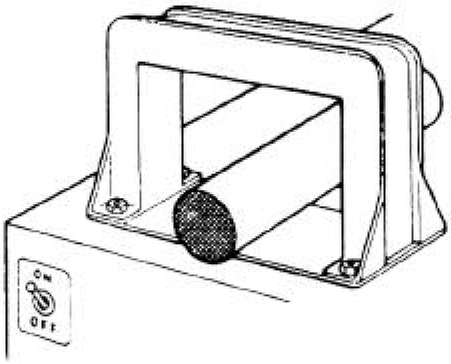


Figure 3-36. Part in Demagnetizing Coil.

3.6.6.1.3
Some stationary AC equipment with a coil on rails has a toggle switch, which enables the inspector to turn the current on in the coil, and leave it on. This coil then becomes a demagnetization coil when a part is drawn through it while the current is flowing. It is important to remember that the part must be drawn completely out of the magnetic field of the coil before the current is shut off.

3.6.6.1.4

CAUTION

Care must be used in demagnetizing small parts using machines equipped with "step-down" demagnetizers, which do not have adjustable current tap switches. A small part such as a bolt being circularly demagnetized with this equipment may be overheated with the initial high current steps.

NOTE

Circular demagnetization is particularly effective on parts of complicated shape, such as multiple throw cranks or coil springs.

This same equipment will also have a rheostat or current control switch which enable the inspector to select different magnetizing current levels as well as initial demagnetizing current levels. These switches may be provided with a motor drive. When equipment with a motor driven switch is used for demagnetization, the inspector places the part in the equipment and presses the demagnetization switch which causes the motor to drive the switch contactor from maximum to minimum current positions, giving a shot at each successively lower current value. This effectively demagnetizes the part and can be used either by passing the current through the coil on the equipment (longitudinal demagnetization), or by passing the current through the part itself (circular demagnetization). This process is referred to as "step-down" demagnetization.

3.6.6.1.5

Two methods are used to circularly demagnetize parts: the direct contact and central conductor methods. The method used depends upon the part's size, shape, and the method used to magnetize it. Generally the same method used to magnetize is used to demagnetize a part. Though the methods used may be the same, the kind of current required to demagnetize may differ from that used to magnetize. For example, parts having large cross sections, which have been magnetized using AC, may require step-down reversing DC to demagnetize them. The use of reversing DC overcomes the lack of field penetration, which occurs with AC.

3.6.6.1.6 Direct Contact Demagnetization.

Demagnetization using the direct contact method is accomplished by alternately reversing and reducing the current in a part. The part may be clamped between contact heads on a stationary unit having provision for demagnetization, or cables may be connected to it and to a suitable demagnetizing current power supply. Starting with a current amperage greater than or equal to that which was used for magnetizing, the current is reduced to either zero or a very low amperage. Either AC or reversing DC may be used depending on the size, shape, and retentivity of the part. The AC demagnetization is usually less time consuming and is satisfactory for many small to medium-sized parts. However, for large parts or parts having thick cross sections, step-down reversing DC is required. A step-down reversing DC demagnetization is usually completed in about 30 seconds - one second per step. The one second at each step allows time for the field in the part to reach a steady state, at which time induced currents become zero, permitting maximum penetration of the field into the part. This can easily be done using a continuously variable auto-transformer or electronic decay circuitry to reduce the AC current to zero.

3.6.6.1.6.1

Parts having a complicated geometry or that have been magnetized using more than one current path through the part, may not be completely demagnetized in one demagnetizing cycle. The same number of demagnetizing cycles may be needed, and through the same current paths, as were used for magnetizing. Quite often with small, low retentivity parts, instead of such repeat demagnetization on the same part, a satisfactory and quicker demagnetization can be obtained using coil demagnetization with AC or reversing DC.

3.6.6.1.7 Central Conductor Demagnetization.

The information contained in paragraph 3.6.6.1.6 and paragraph 3.6.6.1.6.1 also applies to central conductor demagnetization. Demagnetizing currents should start from the same or slightly higher amperages than were used for magnetizing. Placement of the central conductor or threaded-cable configuration should be the same as that used for magnetization. Sometimes different central conductor locations or configurations must be used and be determined by experiment.

3.6.6.1.7.1

To circularly demagnetize a part by direct contact, clamp the part between the contact heads. Demagnetization is accomplished by automatically passing shots of decreasing current through the part. Care must be taken not to demagnetize very small parts between the heads because the high initial current can overheat the parts. If longitudinal demagnetization is desired the coil is then placed in position with the part still clamped in the heads. The same general procedure is followed, except that the demagnetizing current passes through the coil instead of the part.

3.6.6.2 Mobile.

Mobile equipment used for magnetization can also be used for demagnetization. Demagnetization is performed by selecting a current output equal to or greater than the one that was used when magnetizing the part. Cables are either formed into a coil of three or four turns, or wrapped around the part three or four times. The cables are then connected to the output terminals. On units without a demagnetization cycle, initiate the magnetizing cycle and pass the part through the coil or pass the coil over the part, leaving the current on until the coil and part are well separated (approximately 4 to 5 feet). On units incorporating a demagnetization capability, place the part in the coil, and initiate the demagnetization cycle that starts the automatic step-down of the applied current.

3.6.6.3 Portable.

Portable equipment, other than hand probes or yokes will usually supply both alternating current and half-wave direct current. Demagnetization with this equipment and cables is done using alternating current as follows:

a. Make a coil of three or four loops of cable. Adjust the alternating current output to a higher level than was used in magnetizing the part. Place the coil around the part and turn on the current. Then withdraw the coil four or five feet from the part and turn off the current.

b. Alternatively, make a coil of three of four loops of cable around the part. Adjust the alternating current output to a higher level than was used in magnetizing the part. Turn on the current. Then withdraw the part from the coil for four or five feet along the centerline of the coil and turn off the current.

3.6.6.4 Hand Probe or Yoke.

Hand probes or yokes, either AC or DC; provide a portable means for demagnetizing when other methods are impractical. In some cases they are more effective than coil-type demagnetizers are, because the field of the probe or yoke can be concentrated into a relatively small area. For probes with adjustable legs the space between the poles should be such that parts to be demagnetized will pass between them as close as possible. With AC flowing in the coil of the probe, parts are passed between the poles and withdrawn (as shown in Figure 3-37). On large parts, the probe is placed on the part and is moved around as it is slowly withdrawn. This method of demagnetizing is very effective. When the probe incorporates a DC magnetization capability, it can be used for DC demagnetization as well.

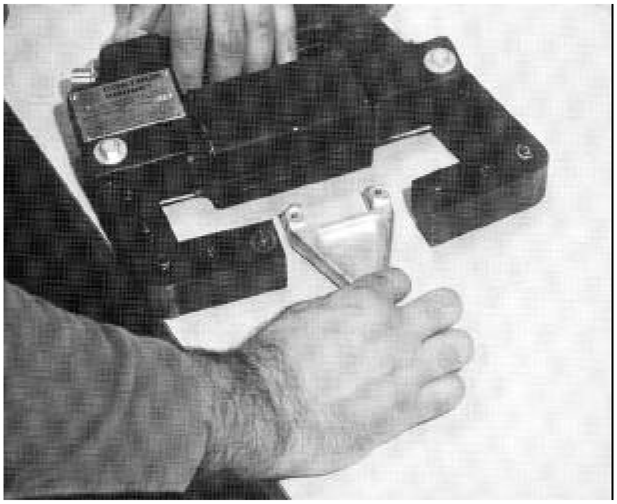


Figure 3-37. Non-Contact Demagnetization

3.6.7 Limitations.

a. When steel is heated it passes through its Curie point, approximately 770°C (or about 1418°F) for soft steels. Above the Curie point it is no longer ferromagnetic. When the steel cools to room temperature in the absence of a magnetic field it will contain no residual magnetism. Other means of demagnetizing always leave some residual field. Complete demagnetization is not possible even though it is often specified.

b. The earth's field will always affect the residual magnetism in a ferromagnetic part and will often determine the lower limit of practical demagnetization. Long parts, or assemblies of long parts, such as welded tubular structures, are especially likely to remain magnetized, at a level determined by the earth's field, in spite of the most careful demagnetizing technique.

c. Many articles and parts become quite strongly magnetized from the earth's field alone. Transporting parts from one location to another may produce this effect. Long bars, demagnetized at the point of testing, have been found magnetized when delivered to the point of use. It is not unusual to find that parts of aircraft, automotive engines, railroad locomotives, or in fact, any parts made from steel of fair retentivity, are quite strongly magnetized after having been in service for some time, even though they may never have been near any artificially produced magnetic field. Parts also become magnetized by being near electric lines carrying heavy currents, or near some form of magnetic equipment.

3.6.8 Special Techniques.

Where the size, shape or method of magnetization of a part make demagnetization difficult, there are several techniques, which may be used effectively. Through the use of the techniques that follow, most difficult parts can be demagnetized to the extent required for service.

3.6.8.1 General.

a. Sometimes parts that are difficult to demagnetize can be effectively demagnetized by striking the part with a hammer during the demagnetizing operation. To use this technique, the part is placed in the demagnetizing coil and the current is turned on. The part is then hammered with a rubber mallet and withdrawn from the coil field while the hammering is continued. Care must be taken that the part is not damaged by the hammering.

b. Demagnetizing coils sometimes work better if they are positioned so that the path of the part, as it is drawn through the coil, is in an east-and-west direction rather than north-and-south. This is particularly true for long parts that may be influenced by the earth's magnetic field.

c. Sometimes the residual field from heavy parts can best be removed by a technique known as the transient method of demagnetization. To perform this technique, the part is placed in the demagnetizing coil and the current turned on and off five to ten times. The current is then turned on and left on while the part is withdrawn from the magnetic field of the coil.

3.6.8.2 Short Parts.

When a short part is being demagnetized in an AC coil by the method of withdrawing the part along the line of the axis of the coil, it is helpful to rotate the part both around the axis parallel to and transverse to the coil's axis. This should be accomplished while the part is in the coil as well as during the entire time of withdrawal. This procedure is also effective in demagnetizing short, hollow or cylindrical parts. A short part with an L/D ratio of one or less can sometimes be better demagnetized by placing it between two pole pieces of soft iron of similar diameter but longer than the part. This combination is then passed through the coil as a unit. It has the effect of increasing the L/D ratio and facilitates the removal of the field in the part.

3.6.8.3 Ring Shaped Parts.

For the demagnetization of ring-shaped parts an effective method is to pass a central conductor through the ring. The central conductor is energized with AC, and the current caused to decay to zero by means of either a step-down switch or a stepless current control. The latter method of decay can be much more rapid (down to a few seconds) than the step-down switch. This method can also be used with reversing, decaying or step-down DC as well.

3.6.8.4 Long Parts.

Long parts, such as rods, bars, and tubes may retain an objectionable amount of residual magnetism from the earth's magnetic field. As the earth's field extends from the north to the south pole, it is desirable to demagnetize these types of parts by withdrawing from an AC coil in an east-and-west direction. This will minimize the effect of the earth's field on the residual magnetism in the parts.

3.6.8.5 Large Structures.

Frequently, large structures such as engine mounts may require demagnetization and demagnetizing coils of suitable size may not be available. In such case each individual extension from the structure, such as the legs of a mount, should be placed within the coil as close to the wall as possible and withdrawn. The structure should then be reversed. The other end is then brought close to the face of the coil and rotated, so that all parts of the structure are passed across the open face of the coil. The entire structure is finally withdrawn four to five feet from the coil before it is shut off. In handling such tubular structures, it is important that they be moved to and from the coil in an east-and-west direction.

3.6.8.6 Removal of Longitudinal and Circular Fields.

In considering the problem of demagnetization, it is important to remember that a part may retain a strong residual field after having been circularly magnetized, and yet exhibit little or no external evidence of such a condition. Such a field is difficult to remove, and there is no easy way to check the success of demagnetization. There may be local poles on a circularly magnetized piece at projecting irregularities or changes or sections, and these can be checked with a field indicator. However, to demagnetize a circularly magnetized part, it is often better to first convert the circular field to a longitudinal field. The longitudinal field does possess external poles, is more easily removed, and the extent of removal can be easily checked with a field indicator.

3.6.9 Measuring Residual Leakage Field Intensities.

Leakage field intensities can be measured by quantitative or comparative methods. Quantitative measurements usually involve the use of instruments in conjunction with search coils, probes, or Hall-effect cells. Such instruments are classified as laboratory equipment and are not generally found in field locations. For purposes of determining the effectiveness of demagnetization efforts, residual field intensities are measured by comparative methods.

3.6.9.1 Field Indicator.

The field indicator, a pocket instrument, is used to determine the comparative intensity of leakage fields emanating from a part. A typical field indicator is shown in Figure 3-38. The theory of operation is quite simple.

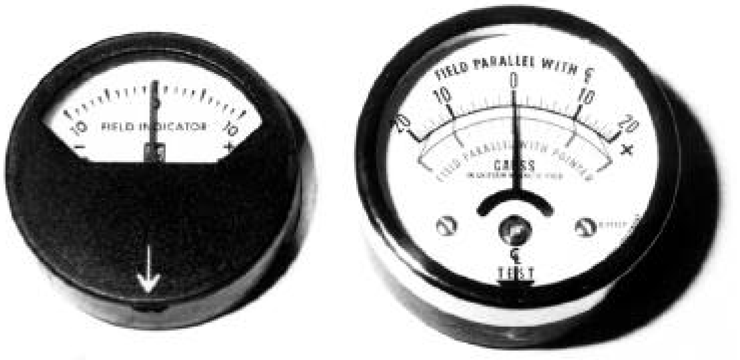


Figure 3-38. Typical Field Indicators

3.6.9.1.1

When a field indicator is placed in a magnetic field, it responds to that portion of the magnetic field that passes through the sensing element of the indicator. The indicator responds to the magnetizing force of the leakage field passing through its sensing element, rather than the flux density in the part from which the leakage field emanates. When measuring the strength of the leakage field emanating from a part, the indicator senses only the field at some distance from the part. This distance is from the center of the sensing element to the bottom of the indicator when it is placed on the part's surface. The flux density of the field in the part will be greater than indicated by the field indicator. How much greater will depend upon the permeability of the part, shape of the part, and the effect of distance from the part to the sensing element in the indicator. Since these variables have an effect on determining flux density, it is recommended that the field indicator be used only as a comparative indicator of the flux leakage from a part. The sensing element in newer indicators is of a ceramic-like material, which is very resistant to demagnetization. The indicator, however, must still be kept away from fields that are strong enough to damage the needle because of rapid or violent deflection beyond full-scale reading. Therefore, field indicators being used in support of magnetic particle inspections SHALL be kept away from this area of influence. Field indicators, SHALL NOT be stored within the influence of magnetizing or demagnetizing magnetic flux.

3.6.9.1.2 Deleted

Figure 3-39. Deleted

3.6.9.1.3 Deleted

Figure 3-40. Deleted

3.6.9.2 Compass Indicator.

A compass is sometimes used for indicating the presence of external leakage fields. A compass can be placed upon a nonmagnetic surface and a magnetized part (aligned due east and west) moved slowly toward the east or west side of the compass case. The presence of an external leakage field from the part can cause the compass needle to deviate from its normal north-south alignment. However, demagnetized parts will cause the needle to deviate from its normal position if the compass case is not approached from an easterly or westerly direction. The theory of operation is very similar to that for the field indicator since the compass needle is a permanent bar magnet.

3.6.9.3 Steel Wire Indicator.

A piece of iron or steel wire can be fashioned into a fair detector when nothing else is available. By forming a loop at one end of a piece of tag wire approximately 6 inches long, it can be suspended from a second wire supported in the horizontal plane. The part in question is then brought into contact, near the free end of the vertically suspended wire. The presence of leakage fields will cause the wire to deviate from its normal vertical position as the part is slowly withdrawn in a horizontal direction. Care must be taken to demagnetize the vertically suspended wire between each test. Small pieces of tag wire about 1 inch long can also be used to indicate the presence of leakage fields. The piece of demagnetized wire is placed upon a horizontal nonmagnetic surface, and the part in question is placed on top of it. If the piece of tag wire can be lifted off the surface as the part is slowly raised, the leakage fields are excessive.

3.6.9.4 Other Detection Methods.

Another method of testing for demagnetization is to use a piece of steel feeler stock in a few thousandths of an inch thick and test if the feeler stock is attracted by the part. A small piece of iron or steel, such as a ferromagnetic paper clip, can be suspended on a string near the test part to determine if it is attracted to the part.

SECTION VII

DISCONTINUITIES AND THEIR MPI INDICATIONS

3.7 FORMATION OF DISCONTINUITIES AND THEIR MPI INDICATIONS.

3.7.1 Iron and Steel Manufacturing Processes.

Knowledge of iron and steel manufacturing processes is necessary to enable an inspector to interpret and evaluate magnetic particle indications. It is not possible in this manual to explain all of the processes used in the manufacture of iron and steel parts, but a brief review will explain how some discontinuities are formed.

3.7.1.1 Purpose of Processing.

Iron ore is converted into metal by heating it in a furnace. When it is liquid or molten it can be poured into molds and allowed to cool and solidify. In the molten state it is possible to remove impurities and also to add other elements to form alloys. These additions, along with other appropriate metal processing steps, impart desirable properties to the finished metal that can make it:

Harder
Softer
Tougher
Stronger
Easier to machine
Resistant to heat
Resistant to corrosion

3.7.1.2 Ingot Production.

After melting, purifying and alloying the iron or steel, the molten metal is poured into an ingot mold where it is allowed to solidify. Most impurities rise to the top of the ingot before the metal is completely solid. However, some of the foreign materials can become trapped within the ingot during solidification. Because such entrapment is usually concentrated near the top, the ingot is cropped to remove most of the impurities.

3.7.1.3 Primary and Secondary Processing.

Ingots undergo primary processing to form the metal into basic shapes according to end-product requirements. Secondary processing is subsequently used to manufacture the final products. Figure 3-41 is a pictorial story of steel processing which shows in sequence the principal stages or operations where defects may be created, and indicates the defects most likely to be found in the material as it leaves each stage. This illustration should be studied in conjunction with the text in this section.

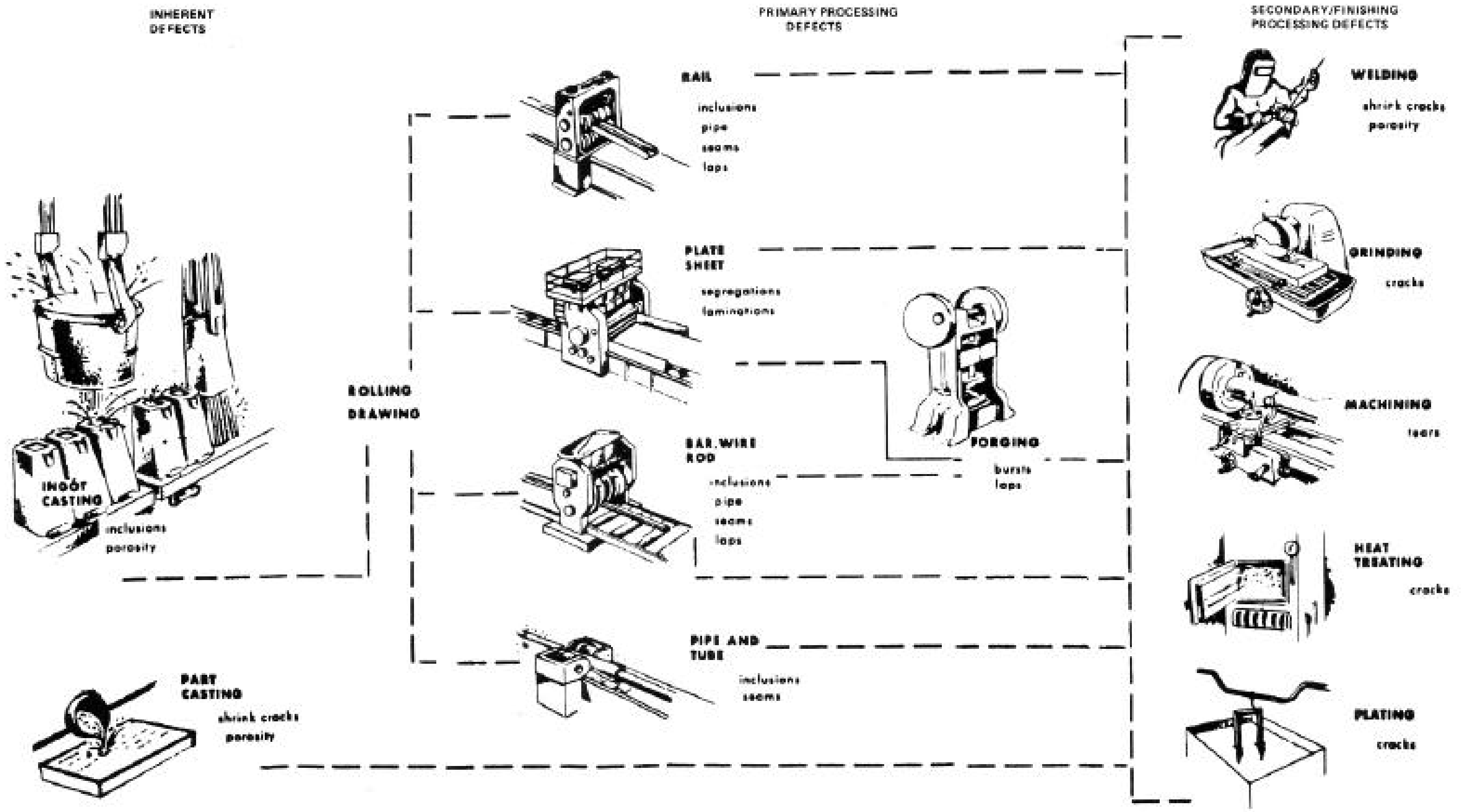


Figure 3-41. Sequence of Steel Processing Stages, Indicating the Principle Operations and the Defects Most Likely to be found in the Material after Each Process

3.7.2 Definition of Terms.

The magnetic particle inspector must understand the distinctions between discontinuity, indication and defect.

3.7.2.1 Discontinuity.

A discontinuity is an interruption in the normal physical structure or properties of a part. Discontinuities may be cracks, laps in the metal, folds, seams, inclusions, porosity, and similar conditions. A discontinuity may be very fine or it may be quite large. A discontinuity may or may not be a defect; that is it may or may not affect the intended use of the product or part. A discontinuity, which would be a defect in one part, may be entirely harmless in another part designed for a different service.

3.7.2.2 Indication.

An indication is an accumulation of magnetic particles being held by a magnetic leakage field to the surface of a part. The indication may be caused by a discontinuity or it may be caused by some other condition that produces a leakage field or it may be caused by mechanically held particle accumulation.

3.7.2.3 Defect.

A defect is a discontinuity that interferes with the intended use of a part.

3.7.3 Basic Steps of Inspection.

Magnetic particle inspection can be divided into these three basic steps:

a. Producing an indication on a part.

b. Interpreting the indication.

c. Evaluating the indication.

3.7.3.1 Producing an Indication.

In order to produce a proper indication on a part, it is necessary to have some knowledge of the principles of magnetism, the materials used in inspection, and the technique employed. Since these subjects have been covered in previous sections of this manual, observance of the procedural steps therein should insure that a proper indication is produced.

3.7.3.2 Interpreting the Indication.

After the indication is created, it is necessary to interpret that indication. Interpretation is the determination of what caused that indication. Knowledge of metal processing is often invaluable in identifying the cause of an indication.

3.7.3.2.1

Indications caused by a discontinuity at the surface of the part are characterized by particles that are tightly held to the surface by a relatively strong magnetic leakage field. The particle accumulation has well defined edges and there is a noticeable "build-up" of the particles. This build-up consists of a slight mound or pile of particles, which on deep surface cracks is sometimes high enough above the surface of the part to cast a shadow. If such an indication is wiped off the discontinuity can usually be seen.

3.7.3.2.2

Indications caused by a discontinuity below the surface are characterized by a broad and fuzzy looking accumulation of particles. The particles in such an indication are less tightly held to the surface because the leakage field is weaker.

3.7.3.2.3

The difference in appearance between indications of surface and subsurface discontinuities is clearly shown in Figure 3-42 and Figure 3-43. Notice the sharpness and definition of the accumulation of magnetic particles in Figure 3-42. The pattern in Figure 3-43 is much broader than that in Figure 3-43 and is quite typical of the indications formed over subsurface discontinuities.

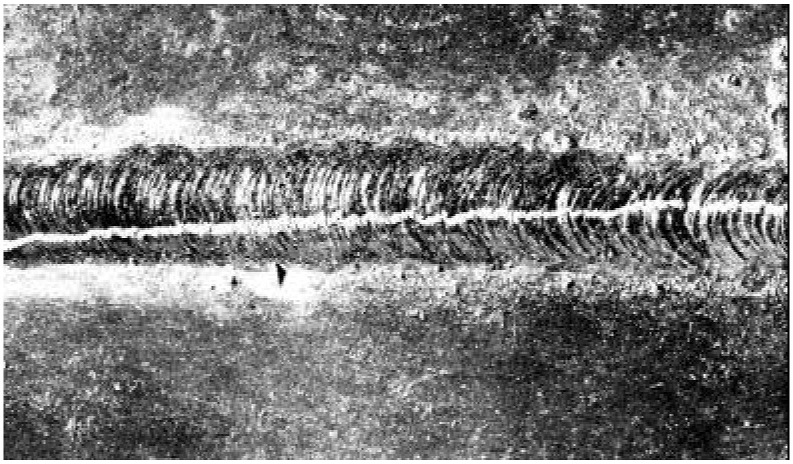


Figure 3-42. Sharp, Well Defined Indication of Surface Discontinuity in a Weld

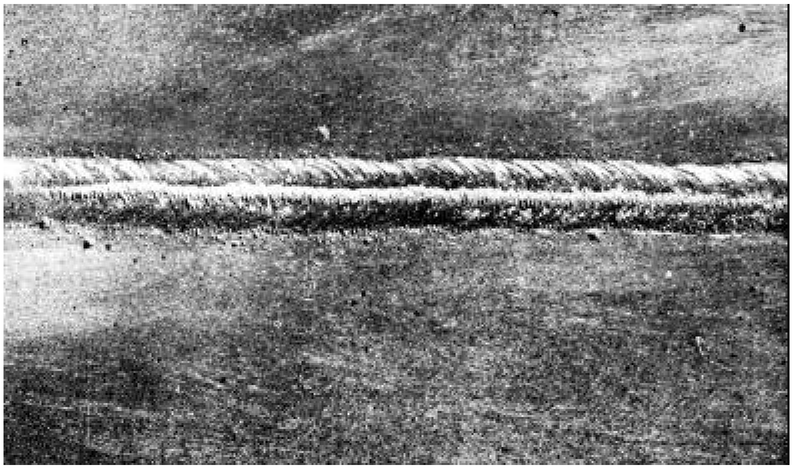


Figure 3-43. Broad Indication of Subsurface Discontinuity in a Weld

3.7.3.3 Evaluating The Indication

Finally, after the indication has been formed and has been interpreted, it must be evaluated. Evaluation is the determination of the consequences of the presence of the discontinuity. This includes determining if the discontinuity is a defect and if so, can the part be reworked or repaired, or must the part be scrapped.

3.7.3.3.1

Generally, an inspector has fairly detailed guidance concerning the interpretation and evaluation of indications included with the procedure by which the inspection was done. In the event such guidance is not available, the following basic considerations may be used in conjunction with the inspector's knowledge and experience to help in the evaluation of indications.

a. A discontinuity of any kind lying at the surface is more likely to be harmful than a discontinuity of the same size and shape which lies below the surface.

b. Any discontinuity having a principal dimension or a principal plane which lies at right angles or at a considerable angle to the direction of principal stress, whether the discontinuity is surface or sub-surface, is more likely to be harmful than a discontinuity of the same size, location, and shape lying parallel to the stress.

c. Any discontinuity that occurs in an area of high stress must be more carefully considered than a discontinuity of the same size and shape in an area where the stress is low.

d. Discontinuities that are sharp, such as grinding cracks or fatigue cracks are severe stress raisers and are more harmful in any location than rounded discontinuities such as scratches.

e. Any discontinuity that occurs in a location close to a keyway or fillet must be considered to be more harmful than a discontinuity of the same size and shape which occurs away from such a location.

3.7.3.3.3 Magnetic Discontinuities.

Magnetic discontinuities in the part under examination will produce indications. These discontinuities may not always be associated with physical discontinuities. Magnetic discontinuities may be caused by:

a. An actual physical discontinuity at or near the surface of a part, which may have been present in the original metal, or may have been produced by subsequent forming, heating, or finishing processes or service use. (See Figure 3-44)

Figure 3-44. Typical Magnetic Particle Indications of Cracks

b. Actual physical discontinuities which are, however, present by design, as for example, an interference or close fit between two members of an assembly. Figure 3-45 illustrates this condition.

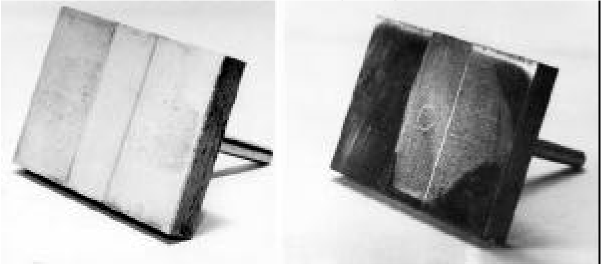


Figure 3-45. Magnetic Particle Indication of a Forced Fit

c. A weld between two dissimilar ferromagnetic metals having different permeabilities; or between a ferromagnetic metal and a non-magnetic material. Indications may be produced at such a point even though the joint is perfectly sound. Such an indication may be produced in a friction or flash weld of two dissimilar metals. (See Figure 3-46)

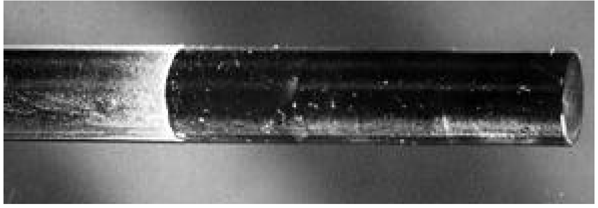


Figure 3-46. Magnetic Particle Indication at the Weld between a Soft and a Hard Steel Rod

d. The junction between two ferromagnetic metals by means of non-magnetic bonding materials, as in a brazed joint. An indication will be produced though the joint itself may be perfectly sound. (See Figure 3-47)

Figure 3-47. Magnetic Particle Indication of the Braze Line of a Brazed Tool Bit

e. Segregation of the constituents of the metal, where these have different permeabilities, as for example, low carbon areas in a high carbon steel, or areas of ferrite, which is magnetic, in a matrix of stainless steel which is austenitic and therefore non-magnetic. Another example would be in the weld zone and/or the heat-affected zone in welds between details of the same alloy. (See Figure 3-48.)

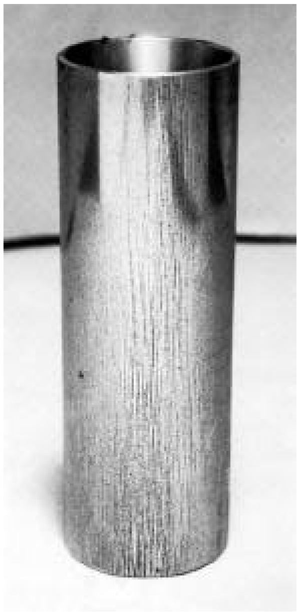


Figure 3-48. Magnetic Particle Indications of Segregations

3.7.4 CLASSES OF DISCONTINUITIES.

There are a number of ways of classifying discontinuities that occur in ferromagnetic materials and parts.

a. One broad grouping is based on location - surface or subsurface. The ability of magnetic particle inspection methods to find members of these two groups varies sharply. But beyond this, the classification is too broad to be very useful.

b. Another possible system is to classify discontinuities by the processes that produce them. Although such a system is too specific to be suitable for all purposes, it is used extensively. We speak of forming defects, welding defects, heat-treating cracks, grinding cracks, etc. Practically every process, from the original ore refinement to the last finishing operation, can and does introduce discontinuities which magnetic particle testing can find. It is therefore important that the nondestructive testing engineer or inspector be aware of all of these potential sources of defects.

3.7.4.1 Conventional Classification System.

For many years it has been customary to classify discontinuities according to their source or origin in the various stages of production of the metal, its fabrication, and its use:

a. Inherent: Produced during solidification from the liquid state.

b. Processing: Primary.

c. Processing: Secondary, or finishing.

d. Service.

A discussion of each class with detailed examples is given below.

3.7.4.1.1 Inherent Discontinuities.

This group of discontinuities is present as the result of its initial solidification of metal from the molten state, before any of the operations to forge or roll it into useful sizes and shapes have begun. The names of these inherent discontinuities are given and their sources described below.

a. Pipe. As the molten steel, which has been, poured into the ingot mold cools, it solidifies first at the bottom and walls of the mold. Solidification progresses gradually upward and inward. The solidified metal occupies a somewhat smaller volume than the liquid, so that there is a progressive shrinkage of volume as solidification goes on. The last metal to solidify is at the top of the mold, but due to shrinkage there is not enough metal to fill the mold completely, and a depression or cavity is formed. This may extend quite deeply into the ingot (See Figure 3-49.) After early breakdown of the ingot into a bloom (see Glossary), this shrink cavity is cut away or cropped. If this is not done completely before final rolling or forging into shape, the unsound metal will show up as voids called "pipe" in the finished product**.** Such internal discontinuities, or pipe, are obviously undesirable for most uses and constitute a true defect. Special devices ("hot tops") and special handling of the ingot during pouring and solidification can control the formation of these shrink cavities.

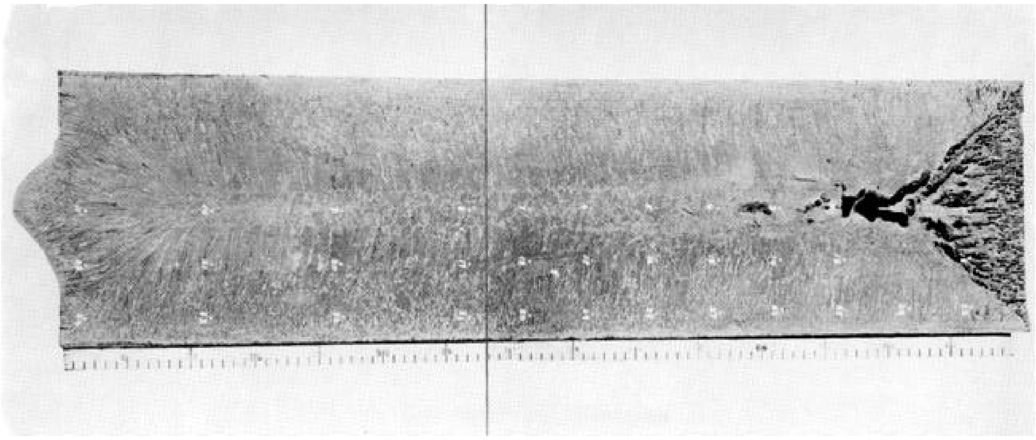


Figure 3-49. Cross-Section of Ingot Showing Shrink Cavity

b. Blowholes. As the molten metal in the ingot mold solidifies there is an evolution of various gases. These gas bubbles rise through the liquid and small percentage escape. The remainder is trapped as the metal freezes. Most of these, usually small, will appear near the surface of the ingot; and some, often large, will be deeper in the metal, especially near the top of the ingot. Many of these blowholes are clean on the interior and are fused shut into sound metal during the first rolling or forging of the ingot; but some, near the surface, may have become oxidized and do not fuse. These may appear as seams in the rolled product. Those deeper in the interior, if not fused in the rolling, may appear as laminations.

c. Segregation. Another action that takes place during the solidification is the tendency for certain elements in the metal to concentrate in the last-to-solidify liquid, resulting in an uneven distribution of some of the chemical constituents in the ingot. Various means have been developed to minimize this tendency, but, if for any reason, severe segregation does occur, the difference in permeability of the segregated areas may produce magnetic particle indications. Segregation can adversely affect physical properties as well as contribute to the formation of defects later in the processing cycle.

d. Nonmetallic Inclusions. Nonmetallic inclusions are usually oxides, sulfides or silicates. They can be introduced by the use of dirty raw materials, crucibles or rods. Other contributing factors can be faulty linings and poor pouring practices. The inclusions can form stringers during subsequent rolling operations. These stringers can affect the physical properties of the materials and are usually considered defects. See Figure 3-50 for an example of an indication of nonmetallic inclusions.

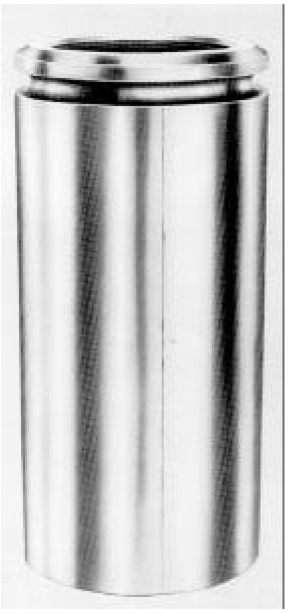


Figure 3-50. Magnetic Particle Indication of a Sub-Surface Stringer of Non-Metallic Inclusions

e. Internal Fissures. Because of the stresses set up in the ingot as the result of shrinkage during cooling, internal ruptures may occur which may be quite large. Since air does not reach the surfaces of these internal bursts, they may be fused during rolling or other forming operations and leave no discontinuity. If there is an opening from the fissure to the surface, however, air will enter and oxidize the surfaces. In this case fusion does not occur, and they will remain in the finished product as discontinuities.

f. Scabs. When liquid steel is first poured into the ingot mold there is considerable splashing or spattering up and against the cool walls of the mold. These splashes solidify at once and become oxidized. As the molten steel rises and the mold becomes filled, these splashes will be reabsorbed to a large extent into the metal. But in some cases they will remain as scabs of oxidized metal adhering to the surface of the ingot. These may remain and appear on the surface of the rolled product. If they do not go deeply into the surface they may not constitute a defect, since they may be removed by machining. Figure 3-51 illustrates this condition on a rolled bloom.

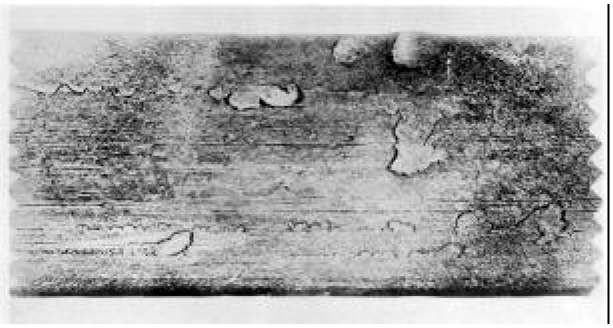


Figure 3-51. Scabs on the Surface of a Rolled Bloom

g. Ingot Cracks. Surface cracking of ingots occurs due to surface stresses generated during cooling of the ingot. They may be either longitudinal or transverse, or both. As the ingot is formed into billets by rolling, these cracks form long seams. Inspection of billets for seams of this type with magnetic particles is now common practice in modern mills. Detection at this point permits removal of the seams by flame scarfing, chipping or grinding without waste of good metal. If not removed before further rolling these seams appear, greatly elongated, on finished bars and shapes, often making them unsuitable for many purposes.

3.7.4.1.2 Primary Processing Discontinuities

When steel ingots are worked down into usable sizes and shapes, such as billets and forging blanks, some of the above described inherent defects may appear. But the rolling and forging processes may themselves introduce discontinuities that also may constitute defects. Primary processes are those, which work the metal down, by either hot or cold deformation, into useful forms such as, bars, rod and wire, and forged shapes. Casting is another process usually included in this group. Even though it starts with molten metal it results in a semi-finished product. Welding is included for similar reasons. A description of the discontinuities that can be introduced by these primary processes follows:

a. Seams. Seams in rolled bars or drawn wire are usually highly objectionable. As previously described, seams may originate from ingot cracks. Conditioning of the billet surfaces by scarfing, grinding or chipping can eliminate the cracks before final rolling is performed. But seams can be introduced by the rolling or drawing processes themselves. Laps can occur in the rolling of the ingot into billets as the result of over-filling of the rolls. This produces projecting fins, which on subsequent passes are rolled into the surface of the billet or bar. In similar fashion, under-fills in the rolling process may on subsequent passes be squeezed to form a seam, which often runs the full length of the bar. Seams derived from laps will usually emerge to the surface of the bar at an acute angle. Seams derived from the folds produced by an under-filled pass are likely to be more nearly normal to the surface of the bar. Seams or die marks may also be introduced in the drawing process due to defective dies. Such seams may or may not make the product defective. For some purposes, such as springs or bars for heavy upsetting, the most minute surface imperfections (or discontinuities) are cause for rejection. For others, where machining operations are expected to remove the outer layers of metal, shallow seams will be machined off. (See Figure 3-52 and Figure 3-53.)

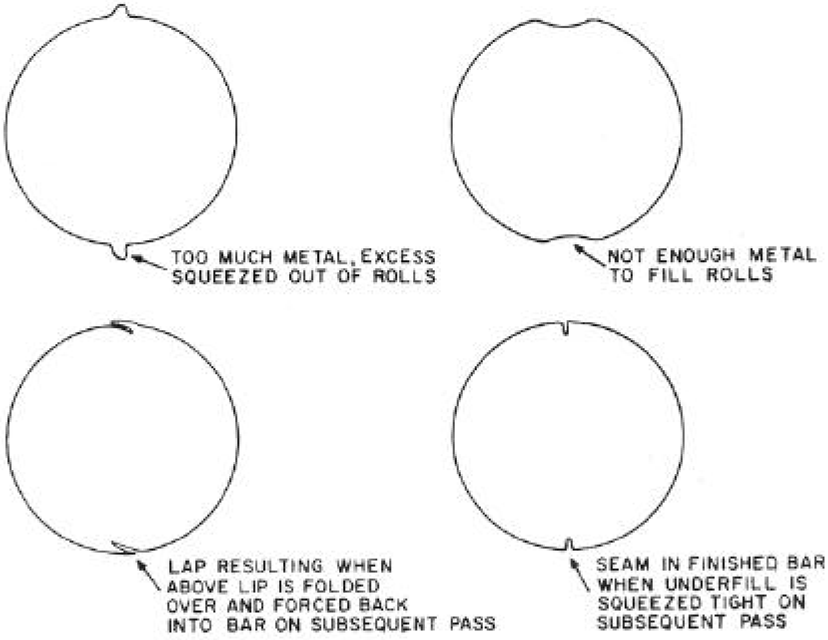


Figure 3-52. How Laps and Seams Are Produced from Over-Fills and Under-Fills

Figure 3-53. Magnetic Particle Indication of a Seam on a Bar.

b. Laminations. (See Figure 3-54.) Laminations in rolled plate or strip are formed when blowholes or internal fissures are not fused during rolling, but are enlarged and flattened into sometimes quite large areas of horizontal discontinuities. Laminations may be detected by magnetic particle testing on the cut edges of plate. The laminations do not give indications on plate or strip surfaces, since they are internal and parallel to the surface. Ultrasonic mapping techniques are used to define them.

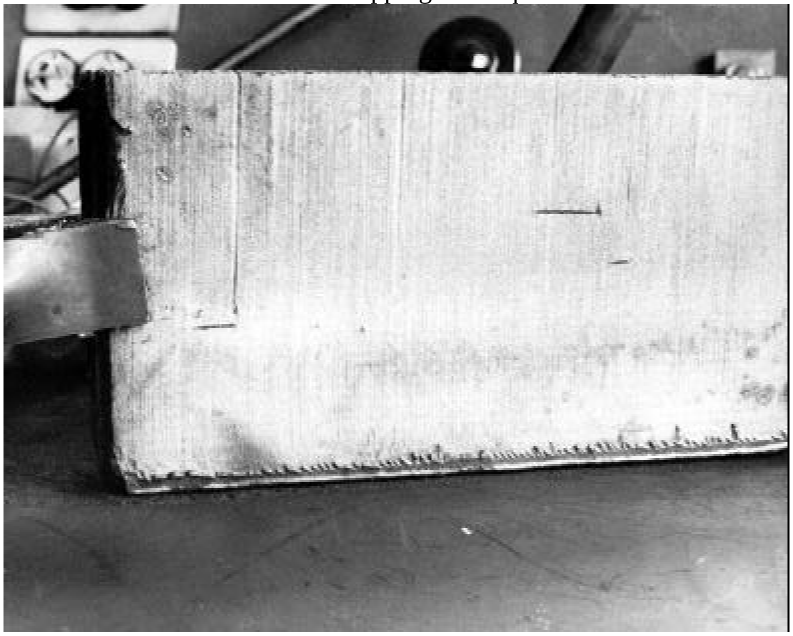


Figure 3-54. Magnetic Particle Indications of Laminations Shown on Flame-Cut Edge of Thick Steel Plate.

c. Cupping. This is a condition created in drawing or extruding when the interior of the metal does not flow as rapidly as the surface. Segregation in the center of the metal usually contributes to this occurrence. The result is a series of internal ruptures that are severe defects whenever they occur. They may be indicated with magnetic particles if the ruptures are large and are near the surface of the part. The cupping problem can be minimized by changing die angles. (See Figure 3-55.)

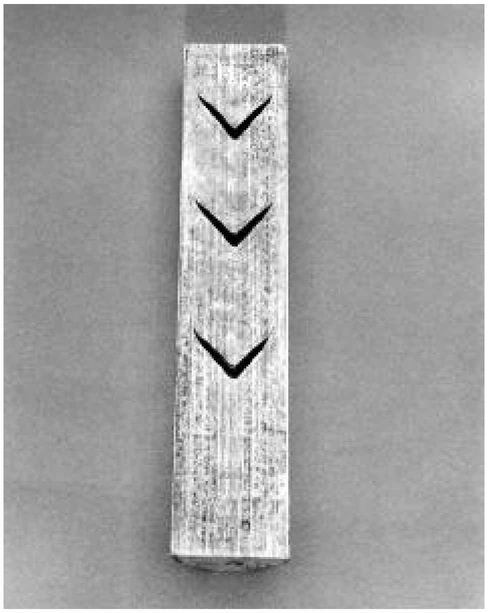
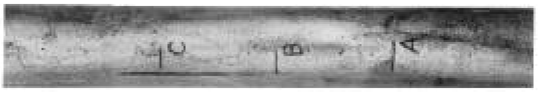
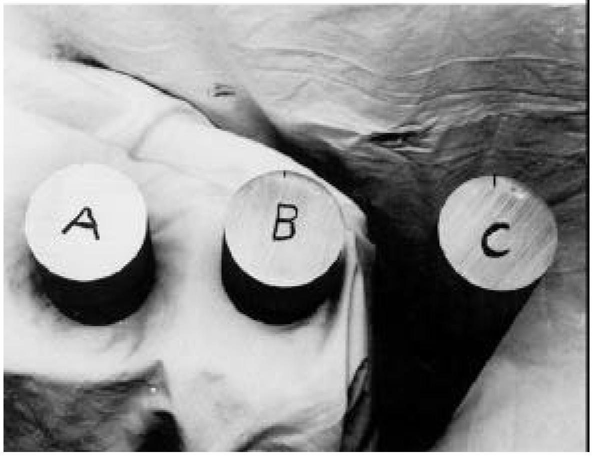


Figure 3-55. Section through Severe Cupping in a 1 3/8-Inch Bar.

d. Cooling Cracks. When alloy and tool steel bars are rolled and subsequently run out onto a bed or table for cooling, stresses may be set up due to uneven cooling which can be severe enough to crack the bars. Such cracks are generally longitudinal, but not necessarily straight. They may be quite long, and usually vary in depth along their length. Figure 3-56 shows the magnetic particle indications of such a crack, and also sections through the crack at three points to illustrate the variation in crack depth. The magnetic particle indication varies in intensity, being heavier at points where the crack is deepest.



(a) Surface Indications



(a) Surface Indications.
(b) Cross-Section Showing Depth.

Figure 3-56. Magnetic Particle Indications of Cooling Cracks in an Alloy Steel Bar.

e. Hydrogen Flakes. Flakes are internal ruptures that may occur in steel as the result of internal stresses from metallurgical changes and decreased solubility of hydrogen from excessively rapid cooling. Flakes usually occurring in fairly heavy sections and certain alloys are more susceptible than others. Figure 3-57 shows magnetic particle indications of flakes that have been exposed on a machined surface. Since these ruptures are deep in the metal - usually half way and more from the surface to the center of the section they will not be shown by magnetic particle testing on the original surface of the part.

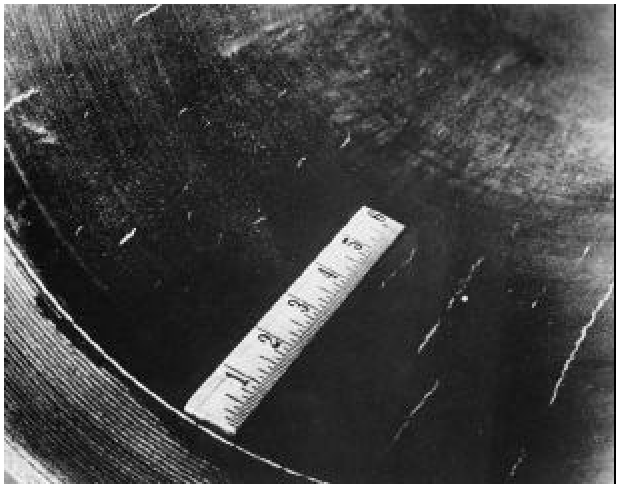


Figure 3-57. Magnetic Particle Indications of Flakes in a Bore of a Large Hollow Shaft.

f. Forging Bursts. When steel is worked at too high a temperature it is subject to cracking or rupturing. Too rapid or too severe a reduction of section can also cause bursts or cracks. Such ruptures may be internal bursts, or they may be cracks at the surface. Cracks at the surface are readily found by magnetic particle testing. If interior, they are usually not shown except when they have been exposed by machining. (See Figure 3-58.)

Figure 3-58. Magnetic Particle Indications of Forging Cracks or Bursts in an Upset Section Severe Case.

g. Forging Laps. As the name implies, forging laps or folds are formed when, in the forging operation, improper handling of the blank in the die causes the metal to flow so as to form a lap, which is later squeezed tight. Since it is on the surface and is oxidized, this lap does not weld shut. This type of discontinuity is sometimes difficult to locate, because it may be open at the surface and fairly shallow, and often may lie at only a very slight angle to the surface. In some unusual cases it also may be solidly filled with magnetic oxides. (See Figure 3-59 and Figure 3-60.)

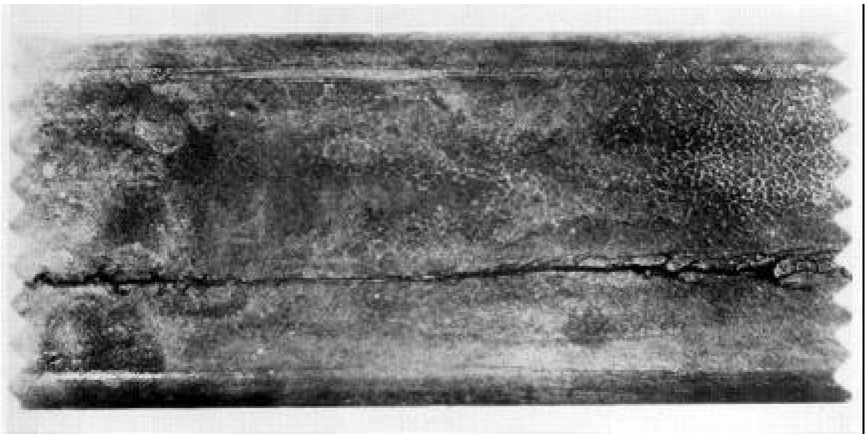


Figure 3-59. Surface of a Steel Billet Showing a Lap.

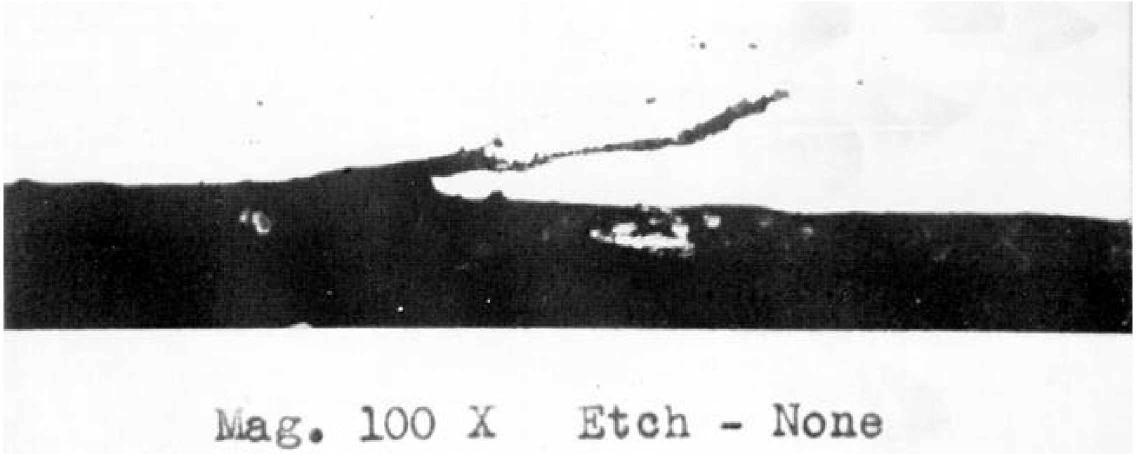


Figure 3-60. Cross-Section of a Forging Lap (Magnified 100X).

h. Burning. Overheating of forgings, to the point of incipient melting, results in a condition which renders the forging unusable in most cases, and is referred to as burning. However, the real source of the damage is not oxidation, but the material becoming partially liquefied due to the heat at the grain boundaries. Burning is a serious defect but is not generally shown by magnetic particle testing.

i. Flash Line Tears. Cracks or tears along the flash line (see Glossary) of forgings are usually caused by improper trimming of the flash. If shallow they may "clean up" during machining. Otherwise they are considered defects. Such cracks or tears can easily be found by magnetic particles. (See Figure 3-61.)

Figure 3-61. Magnetic Particle Indication of Flash Line Tear in a Partially Machined Automotive Spindle Forging.

j. Casting Defects. Steel and iron castings are subject to a number of defects which magnetic particle testing can easily detect. Surface discontinuities are formed in castings due to stresses resulting from cooling, and are often associated with changes in the cross section of the part. These may be hot tears or they may be shrinkage cracks that occur as the metal cools down. Sand from the mold can be trapped by the hot metal and form sand inclusions on or near the surface of castings. Gray iron castings may be quite brittle, and can be cracked by rough handling. (See Figure 3-62.)

(a) Surface Indications of an Internal Shrink Cavity

Figure 3-62. Magnetic Particle Indications of Defects in Castings.

k. Weld Defects. A variety of discontinuities may be formed during welding. Some are at the surface and some are in the interior of the weldment. Some of the defects peculiar to weldments are lack of penetration, lack of fusion, undercutting, cracks in the weld metal, crater cracks, cracks in the heat affected zone, etc.

3.7.4.1.3 Secondary Processing or Finishing Discontinuities.

In this group are those discontinuities associated with the various finishing operations after the part has been rough-formed by rolling, forging, casting or welding. Discontinuities may be introduced by machining, heat treating, grinding and similar processes. These are described below:

a. Machining Tears. These are caused by dragging of the metal under the tool when it is not cutting cleanly. Soft and ductile low carbon steels are more susceptible to this kind of damage than are the harder, higher carbon or alloy types. Machining tears are surface discontinuities and are readily found with magnetic particles.

b. Heating Treating Cracks. (See Figure 3-63.) When steels are heated and quenched to produce desired properties for strength or wear, cracking may occur if the operation is not correctly suited to the material and the shape of the part. Most common are quench cracks, caused when parts are heated to high temperatures and then suddenly cooled by immersing them in some cool medium, which may be water, oil or even air. Such cracks often occur at locations where the part changes cross-section or at fillets or notches in the part. The edges of keyways and the roots of splines or threads are likely spots for quench cracks to occur. Cracks may also result from too rapid heating of the part, which may cause uneven expansion at changes of cross-section, or at corners where heat is absorbed more rapidly than in the body of the piece. Corner cracking may also occur during quenching, because of more rapid heat loss at such locations. Heat treating cycles can be designed to minimize or eliminate such cracking, but for critical parts, testing with magnetic particles is a safety measure usually applied, since such cracks are serious and their detection presents no difficulty.

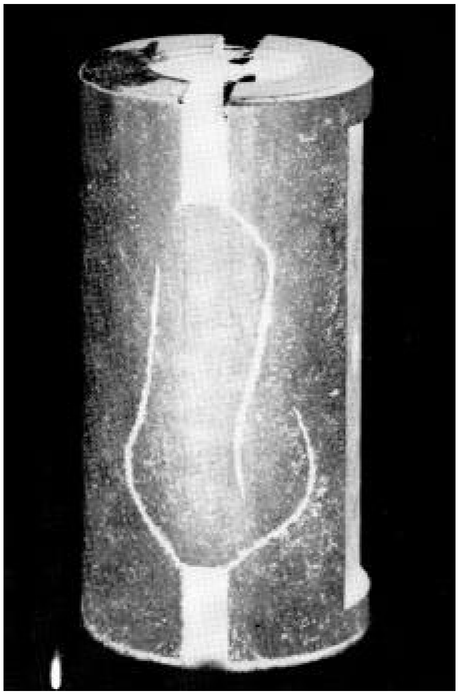


Figure 3-63. Magnetic Particle Indications of Quenching Cracks Shown with Dry Powder.

c. Straightening Cracks. The process of heat treating often causes some warping of the part due to non-uniform cooling during quenching. A hardened shaft, for example, may come from the heat treat operation not quite straight. In many cases these can be straightened in a press, but if the amount of bend required is too great or if the shaft is too brittle, cracks may be formed. Again, these are very readily found with magnetic particles

d. Grinding Cracks. Surface cracking of hardened parts, as the result of improper grinding is frequently a source of trouble. Grinding cracks are essentially thermal cracks. They are caused by stresses set up by local heating under the grinding wheel. They are avoidable by using proper wheels, proper cuts, and proper coolants. They are sharp surface cracks and they are easily detected with magnetic particle inspection. Such surfaces usually crack severely and extensively, as illustrated in Figure 3-64 and Figure 3-65.

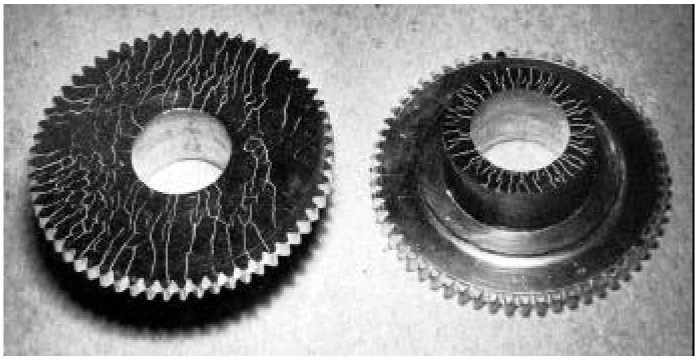


Figure 3-64. Fluorescent Magnetic Particle Indications of Typical Grinding Cracks.

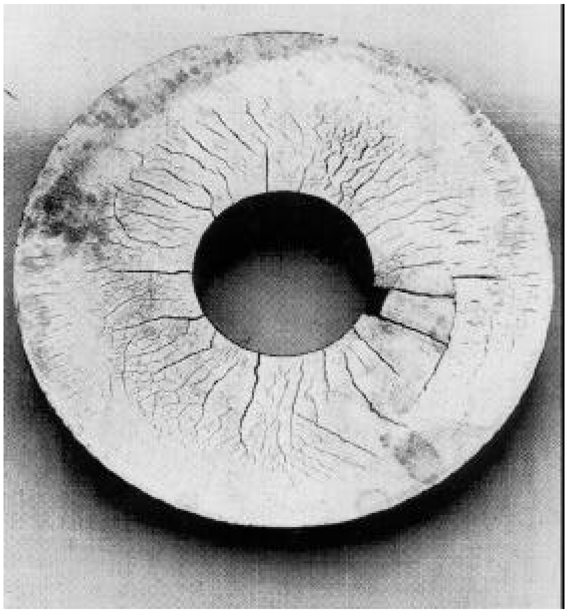


Figure 3-65. Magnetic Particle Indications of Grinding Cracks in a Stress-Sensitive, Hardened Surface.

e. Etching and Pickling Cracks. Hardened or cold worked parts, that contain high internal and external residual stresses, may crack if they are pickled or etched in acid. Acid attack of the surface layers of the metal gives the internal stress a chance to be relieved by the formation of a crack. Before this action was fully understood the heat treatment of the part was often blamed for the cracking. The heat treat operation did, however, deserve some of the blame by leaving the part with high residual stresses.

f. Plating Cracks. Plating can introduce high residual stresses at the plated surface and thus create the potential for cracking. The hot galvanizing process itself may also produce cracks in surfaces containing residual stresses by the penetration of hot zinc into the grain boundaries. Copper penetration during brazing may result in similar cracking if the parts contain residual stress. (See Figure 3-66.)

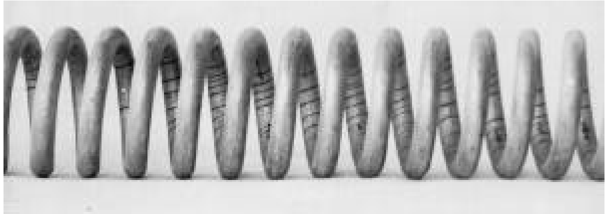


Figure 3-66. Magnetic Particle Indications of Plating Cracks.

3.7.4.2 Service Cracks.

NOTE

When performing magnetic particle inspection on landing gear parts the paint SHALL be removed.

The fourth major classification of discontinuities comprises those that are formed or produced after all fabrication has been completed and the part has gone into service. The objective of magnetic particle testing to locate and eliminate discontinuities during fabrication is to put the part into service free from defects. However, even when this is accomplished, failures in service still occur as a result of cracking caused by service conditions.

a. Fatigue Cracks. As a source of discontinuities, the phenomenon of fatigue is a prolific one. Fatigue strength will eventually develop cracks, and finally fracture. Fatigue cracks, even very shallow ones, can readily be found with magnetic particles. (See Figure 3-67 and Figure 3-68.)

Figure 3-67. Magnetic Particle Indication of a Typical Fatigue Crack.

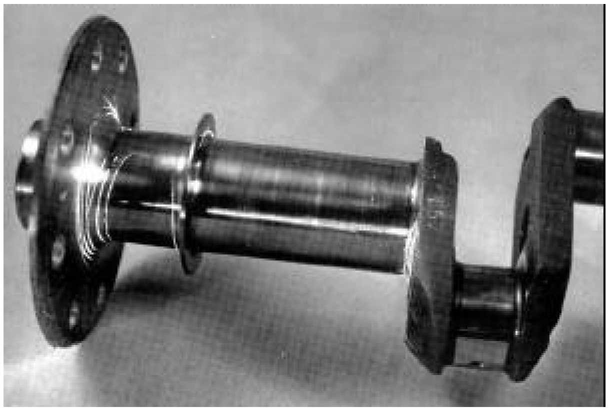


Figure 3-68. Fluorescent Magnetic Particle Indications of Cracks in Crankshaft of Small Aircraft Engine Damaged in Plane Accident.

b. Stress Corrosion Cracks. Parts that are under either residual or applied tensile stress and are exposed to a corrosive environment may develop stress corrosion cracking. The primary role of corrosion in this cracking mode is to produce hydrogen. The hydrogen migrates to the tip of a stress corrosion crack where its presence increases the stresses at the tip, thus driving the crack even deeper. When corrosion is added to a fatigue-producing service condition, this type of service failure is called corrosion fatigue.

c. Overstressing. Parts that are stressed beyond the level for which they were designed can crack or break. Such over-stressing may occur as the result of an accident; or a part may become overloaded due to some unusual or emergency condition not anticipated by the designer; or a part may be loaded beyond its strength because of the failure of some related member of the structure. After complete failure has occurred magnetic particle testing obviously has no application with regard to the fractured part. But other parts of the assembly that may appear undamaged may have been overstressed during the accident or overloading from other causes. Examination by magnetic particle testing is usually carried out in such cases to determine whether any cracks have actually been formed.

3.7.4.3 Other Sources of Discontinuities.

In this chapter an attempt has been made to familiarize the reader with most of the common sources of discontinuities that can occur in iron and steel. Actually the list given here is incomplete. But the inspector working with magnetic particle testing will encounter these discontinuities which have been described more frequently than those from less common conditions. He will often have the metallurgical laboratory of a support organization available for consultation, and the metallurgist will usually be able to assign a cause to an indicated discontinuity and assess its importance.

3.7.5 Non-Relevant Indications.

3.7.5.1 Nature and Type.

NOTE

It is easier to distinguish between relevant and nonrelevant indications when fluorescent rather than visible magnetic particles are used.

It is possible to magnetize parts of certain shapes in such a way that magnetic leakage fields are created even though there is no discontinuity in the metal at that point. Such indications are sometimes called erroneous indications or false indications. They should be called "non-relevant indications" since they are actually caused by distortion of the magnetic field. They are true indications but, since there is no unintentional interruption of the material, they do not affect the usefulness of the part. It is important that the inspector know how and why these non-relevant indications are formed and where they can occur.

3.7.5.2 Classes.

3.7.5.2.1 Magnetic Writing.

This is a condition caused by a piece of steel rubbing against another piece of steel that has been magnetized. Since either or both pieces contain some residual magnetism the rubbing or touching creates magnetic poles at the points of contact. These local magnetic poles are usually in the form of a line or scrawl, and for this reason the effect is referred to as magnetic writing. In Figure 3-69 the part in the top view is magnetized with a circular field. If another part made of magnetic material is rubbed against or comes into contact with the magnetized part, as in the second view, a weak field will be induced into the smaller part. After the smaller part has been removed, the circular field in the original part will be altered or distorted to some extent as shown in the bottom view. Since there is no force to change the direction of the altered field, there will be some leakage at the point of distortion that will attract magnetic particles.

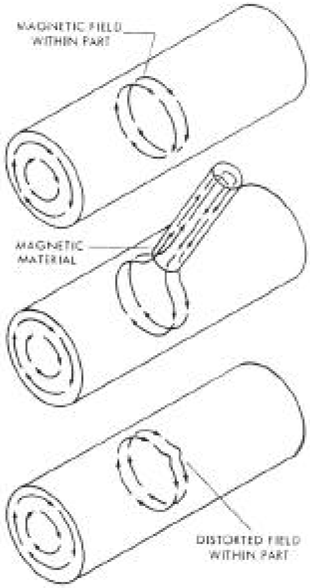


Figure 3-69. Creation of Magnetic Writing

3.7.5.2.2 Longitudinal Magnetization.

When a part is longitudinally magnetized in a coil, there are always magnetic poles at the ends of the piece. Magnetic material such as chips or magnetic powder or paste will be attracted to these poles. The same situation occurs when a yoke is used to create a magnetic field; poles are induced on the part in the areas where the yoke touches the part.

3.7.5.2.3 Cold Working.

Cold working consists of changing the size or shape of a metal part without raising its temperature before working. When a bent nail is straightened by a carpenter with a hammer, the nail is being cold worked. Cold working usually causes a change in the permeability of the metal where the change in size or shape occurs. The boundary of the area of changed permeability may attract magnetic particles when the part is magnetized.

3.7.5.2.4 Hard or Soft Spots.

If there are areas of a part which have a different degree of hardness than the remainder of the part, these areas will usually have a different permeability. When a part with such areas of different permeability is inspected with magnetic particle inspection, the boundaries of the areas may create local leakage fields and attract magnetic particles to form indications.

3.7.5.2.5 High Temperature Exposure.

a. Boundaries of Heat Treated Sections. Heat treating a part consists of heating it to a high temperature and then cooling it under controlled conditions. The cooling may be relatively rapid or it may be done quite decrease the hardness or the grain size of the metal by varying the temperature and the rate of cooling. On a cold chisel the point is hardened to cut better and to hold an edge. The head of the chisel, which is the end struck by the hammer, is kept softer than the cutting edge so that it won't shatter and break. The edge of the hardened zone frequently creates a leakage field when the chisel is inspected with magnetic particle inspection.

NOTE

Delta Ferrite is brittle and has historically been considered a defect in applications such as aircraft that are exposed to tensile and cyclic loading. While the presence of delta ferrite does not indicate an actual defect, such a region would be a preferential crack initiation area.

b. Delta Ferrite. Delta Ferrite is a ferromagnetic phase of steel that occurs at elevated temperatures. This phase primarily occurs at normal temperatures because of rapid cooling after prolonged exposure to high temperatures. A concentrated region of delta ferrite may cause non-relevant indications along the regions boundary due to the magnetic disturbance caused by its presence.

3.7.5.2.6 Abrupt Changes of Section.

Where there are abrupt changes in section thickness of a magnetized part, the magnetic field may be said to expand from the smaller section to the larger. Frequently this creates local poles due to magnetic field leakage or distortion. If a part, as shown in Figure 3-70, is magnetized in a coil, poles are set up at each end and some leakage occurs at A and B. Also, the change of section at C is quite abrupt and there may be a leakage across this corner as shown. These leakage fields will attract magnetic particles, thereby creating an indication. The indications formed at A and B are usually very easily interpreted; that at C may be more difficult to recognize as being non-relevant. If the indication is continuous around the shaft, it should be suspected as being caused by the shape of the part rather than by a discontinuity. The non-relevant indication at C will usually be "fuzzy" like an indication, which is produced by a defect beneath the surface. If there is a crack or discontinuity in that area, it will usually produce an indication that is sharper and it probably will not run completely around the part.

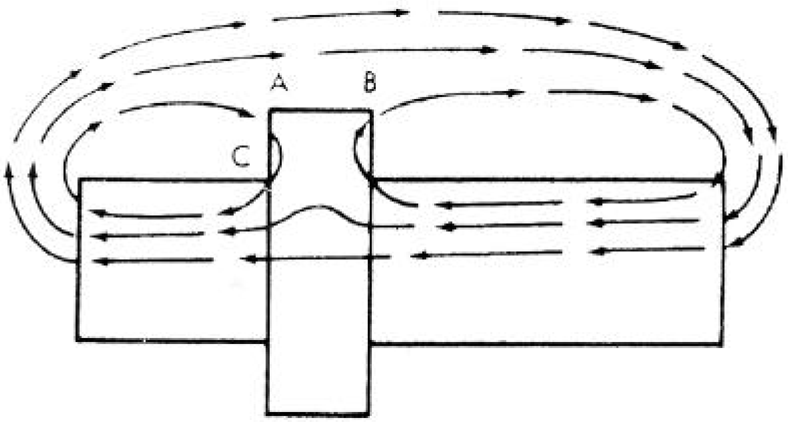


Figure 3-70. Local Poles Created by Shape of Part

3.7.5.2.6.1
On parts with keyways, a circular magnetic field can also set up non-relevant indications as in Figure 3-71. Particle accumulations may occur at A where there are leakage fields. A keyway on the inside of a hollow shaft may also create indications on the outside as indicated at area B in Figure 3-72.

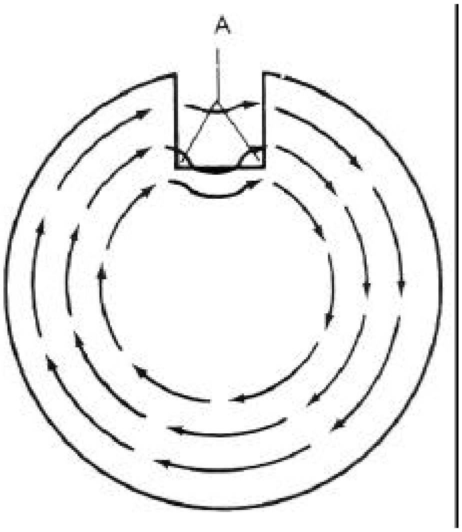


Figure 71. Concentration of Field in a Keyway

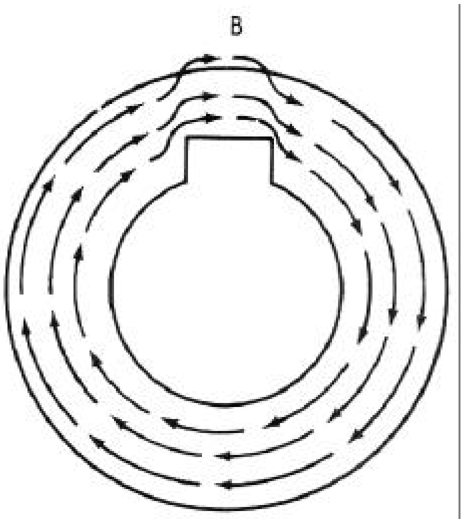


Figure 3-72. External Leakage Field created by an Internal Keyway

3.7.5.2.6.2
The gear and spline shown in Figure 3-73 were magnetized circularly by passing current through a central conductor. The reduced cross section created by the spline ways constricts the magnetic lines of force and some of them break the surface on the outside diameter. Particles gather where the magnetic lines of force break through the surface thereby creating indications.

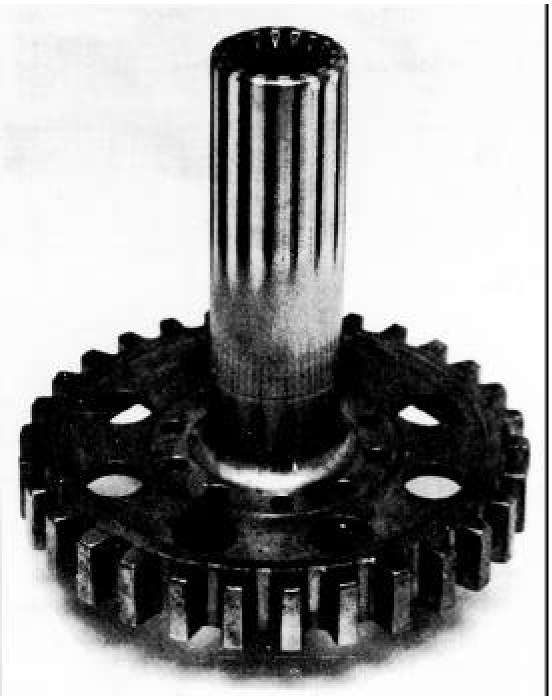


Figure 3-73. **Non-Relevant Indications of Shaft Caused by Internal Spline**

3.7.5.2.6.3
Figure 3-74 shows a non-relevant indication on the under side of a bolt head. The indication here is caused by the slot in the head.

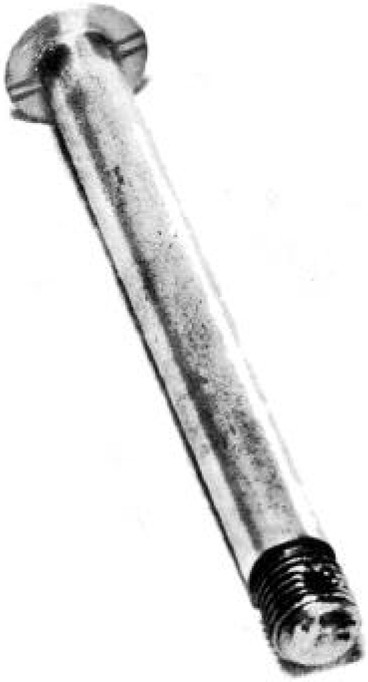


Figure 3-74. Non-Relevant Indications under the Head Created by Slot in Bolt

3.7.5.3 Interpretation and Elimination of Non-Relevant Indications.

3.7.5.3.1 Interpretation.

It may at first appear to the inspector that some types of non-relevant indications discussed and illustrated in the preceding material would be difficult to recognize and interpret. For example, the non-relevant indications shown in Figure 3-73 and Figure 3-74 may look like indications of subsurface discontinuities. However, there are several characteristics of non-relevant indications, which will enable the inspector to recognize them in the example cited and under most other conditions. These characteristics of non-relevant indications are:

a. On all similar parts, given the same magnetizing technique, the indications will occur in the same location and will have identical patterns. This condition is not usually encountered when dealing with real subsurface defects.

b. The indications are usually uniform in direction and size.

c. The indications are usually "fuzzy" rather than sharp and well defined.

d. Non-relevant indications can always be related to some feature of construction or cross section, which accounts for the leakage field creating the indication.

3.7.5.3.2 Elimination of Non-Relevant Indications.

Although non-relevant indications can be recognized in most cases, they do tend to increase the inspection time, and under certain conditions may mask or cover up indications of actual defects. Therefore, it is desirable to eliminate them whenever possible.

3.7.5.3.2.1

In most cases non-relevant indications occur when the magnetizing current is higher than necessary for a given part. Consequently, these indications will disappear if the part is demagnetized and re-inspected using a sufficiently low magnetizing current. Under most conditions the value of magnetizing current which is low enough to eliminate non-relevant indications will still be sufficient to produce indications at actual discontinuities. This will be true where the non-relevant indication is magnetic writing, and for several other types, but may not hold where there are abrupt changes of section. It is therefore desirable to determine whether the non-relevant indication was caused by an abrupt change of section before re-inspecting.

3.7.5.3.2.2

The proper procedure is to demagnetize and reinspect using a lower value of magnetizing current, repeating the operation with still lower current if necessary until the non-relevant indications disappear. Care must be taken not to reduce the current below the value required to produce indications of all actual discontinuities. Where there are abrupt changes of section two inspections may be required: one at fairly low amperage to inspect only the areas at the change in section; the other at a higher current value to inspect the remainder of the part. Another solution is to use AC magnetization for inspection. AC magnetization responds less to changes in cross section than DC magnetization and is acceptable when it is not necessary to inspect for subsurface defects.

SECTION VIII
METHODS OF RECORDING MPI INDICATIONS

3.8 METHODS OF RECORDING MPI INDICATIONS.

3.8.1 General.

The full value of magnetic particle inspection can be realized only if records are kept of parts inspected and the indications found. The size and shape of the indication and its location on the part should be recorded along with other pertinent information, such as rework performed or disposition. The inclusion of some visible record of the indications on a report makes the report much more complete.

3.8.2 Types Of Records.

The simplest record is a sketch of the part showing location and extent of the indications. On large parts it may be sufficient to sketch only the critical area. Other types of records include preserving the actual indication on the part (where the part is to be kept for reference), transferring the indication from the part to a record sheet or report, and photographing the indication. These last three methods will be discussed in this section.

3.8.2.1 Preserving Indications on A Part.

3.8.2.1.1 Fixing Indications with Lacquer.

One of the advantages of magnetic particle inspection is that the indication is formed directly on the part at the exact spot of the magnetic leakage field. This makes it possible to retain the part itself for record purposes, but it is necessary to fix or preserve the indication on the part, so that the part can be handled and examined without smudging or smearing the indication. One method of fixing the indication semi-permanently on the part is by using clear lacquer. In order to do this the part must be dry; if the wet method has been used to develop the indication, the vehicle should be allowed to evaporate. Normal evaporation can be accelerated by heating the part and is usually sufficient for water; it is also possible to flow on isopropyl alcohol or other solvent that will evaporate rapidly and leave the indication dry on the part. For an oil vehicle, use of a solvent is almost necessary to provide a dry indication in a reasonable time. It is usually desirable to thin out the clear lacquer by adding lacquer thinner. The lacquer should either be sprayed on the part or flowed on since brushing would smear the indication.

3.8.2.1.2 Applying Transparent Tape.

It is also possible to preserve an indication on a part by covering it with transparent pressure sensitive tape (such as Scotch brand). This method is not as neat looking as the lacquer method but it is easier to apply. Before applying the tape, the vehicle used in the wet method should be removed in the same manner as when using lacquer.

3.8.2.2 Tape Transfers.

An accurate record of an indication can be obtained by lifting the particles forming the indication from the part with transparent pressure sensitive tape (such as Scotch brand) and then placing the tape on stiff white paper. The procedure for taking tape transfers is simple and can be accomplished quickly and accurately with a little practice. If a report is being made and it is necessary to duplicate the indication, mount the tape transfer on a sheet of clear plastic and use a standard duplicating process or prepare a photographic negative and contact print. When tape transfers are taken of indications, it is customary to sketch the part and locate the position of the preserved indication on the sketch.

3.8.2.2.1 Dry Particle Indications.

If the indication is formed of dry powder particles, excess powder should be removed from the surface by gentle blowing. Use a piece of tape larger than the indication and gently cover the indication with the tape. Gentle pressure should be applied so that the adhesive will pick up the particles; do not press too hard or the indication will be flattened too much and the tape may be difficult to remove. Carefully lift the tape from the part and press it onto the record sheet or report. Note that tape preserved indications are usually a little broader than indications on the part because of the flattening effect of the tape. It is easier to remove the tape if a corner of it is not pressed to the part; this leaves a tab for easy removal.

3.8.2.2.2 Wet Particle Indications.

If the indication is formed of particles used with the wet method, it is necessary to dry the surface of the part before applying the tape as described in paragraph 3.8.2.1.1.

3.8.2.2.3 Fluorescent Indications.

Tape transfers can be taken of fluorescent particle indications, but there are some disadvantages to the process. Such preserved indications usually must be viewed under black light to properly interpret them since the number of particles in the suspension is much less than when using visible particles. Some transparent tape is fluorescent and the fluorescence of the tape may mask the fluorescence of the indication.

3.8.2.2.4 Alginate Impression Compound Method.
The alginate impression compound method of "lifting" magnetic particle indications is a method of securing indications in areas that are inaccessible and cannot be viewed with a black light.

3.8.2.2.4.1
Alginates are hydrocolloid polysaccharides derived from seaweed kelp. Compounds such as those used for making dental impressions are based on mixtures of potassium alginate, calcium sulfate, sequestering agents such as sodium phosphate and fillers such as silica, diatomaceous earth, or calcium carbonate. When the compound is mixed with the correct amount of water it forms a soft paste which sets up to a rubbery solid in three to four minutes. This rubbery material or gel has the property of accurately conforming to and taking an impression of the surface to which it is applied and also absorbing or lifting traces of particulate material from the surface. This latter property is the basis for its use as an indication lifting material.

3.8.2.2.4.2 Transfer Of Magnetic Particle Crack Indications to Alginate Impression Compound.

a. Perform the magnetic particle inspection of the area of interest in the usual manner.

b. The part does not have to be dried before taking an impression.

c. Using the plastic scoop and water measuring container, follow the directions given on the can of powder and mix the powder with water to obtain a smooth creamy paste.

d. Transfer the paste immediately to a piece of thin polyethylene film and then apply the paste to the inspecting area. Gently press against the film to obtain a uniform contact of the paste against the inspection area. Avoid excessive working of the paste to avoid smearing of the indication. The plastic film prevents the paste from sticking to the hand. For cavities such as holes, the paste can be applied without the polyethylene film to form a plug when set.

e. After the paste has set to a rubbery gel in about 3-4 minutes, gently remove the replica from the metal part and examine under ultraviolet light. The replica may be photographed with ultraviolet light it desired.

3.8.2.3 Photographing Indications.
Photographs of indications can also be taken to be used for records. Enough of the part should be shown to make it possible to recognize the part and the position of the indication. It is helpful to include in the picture some common object to show the size of the part. Sometimes this can be done with a finger pointing at the indication or by placing a ruler along the part to show relative size. In photographing indications on highly polished parts, care must be taken to avoid highlights or reflections that may hide indications. Taking photographs of fluorescent indications calls for special photographic techniques, refer to the penetrant chapter, Chapter 2, of additional information.

SECTION IX
MAGNETIC RUBBER INSPECTION METHOD

3.9 MAGNETIC RUBBER INSPECTION METHOD.

3.9.1 Description.

a. Magnetic rubber inspection (MRI) is an extension of magnetic particle inspection and is a nondestructive inspection technique used for detecting cracks or other flaws on or near the surface of ferromagnetic materials. Its principal applications are in certain problem areas, such as, (l) areas having limited visual accessibility (inside holes, tubes, etc.); (2) coated surfaces, (3) complex shapes or poor surface conditions, and (4) inspection for defects that require magnification for detection and interpretation. Magnetic rubber inspection involves the use of a material consisting of magnetic particles dispersed in a room temperature curing silicon rubber. The material is catalyzed, applied to the test surface, and the area to be inspected is magnetized, causing the particles to migrate through the rubber and accumulate at discontinuities on the surface. Following cure, the solid replica casting is removed from the part and examined for indications.

b. The magnetic principles discussed in Section 1 of this chapter apply equally to Magnetic Rubber Inspection.

3.9.2 Safety Precautions.

a. General safety precautions are applicable to magnetic rubber inspection. The silicon rubber, dibutyltin dilaurate, stannous octoate, cure stabilizers, cleaners, and release agents are or can be skin and eye irritants, skin sensitizers (causing allergic reactions), and inhalant and ingestion hazards. For specific information concerning any of the materials used as magnetic rubber, magnetic rubber catalysts, release agents, or cleaners consult the Material Safety Data Sheets, or contact the appropriate Safety Officer. Silicon oil is an ingredient in the material and can result in very slippery surfaces, especially floors, if not well controlled.

b. When performing magnetic rubber inspection on aircraft using electromagnets to magnetize, the aircraft SHALL be grounded.

3.9.3 Gel Time, Pot Life and Cure Time.
Gel time is defined as the time from the addition of the catalyst to when the viscosity starts to noticeably increase. Pot life refers to the time from the addition of the catalyst to when the material can no longer be poured and magnetization must be completed. Cure time is the time to completely cure.

3.9.4 Magnetic Rubber Inspection Procedure.

WARNING

Cleaning solvent ML-C-38736 contains aromatic naphtha, ethyl acetate, methyl ethyl ketone, and isopropyl alcohol. Cleaning solvent is flammable. Vapors may be harmful. Use with adequate ventilation. Avoid contact with skin and eyes.

CAUTION

Areas to be magnetic rubber inspected must be free of grease, oil, dirt and other foreign matter which could cause false or confusing indications or could prevent the base material from curing.

NOTE

Prior to the initial inspection remove, as much as possible, corrosion, sealant, loose paint, and other foreign material from the inspection area.

a. Obtain the required materials and equipment. Refer to Table 3-7 and Table 3-8.

Table 3-7. Magnetic Rubber Equipment.

Electromagnetic yokes, fixed or articulated leg (same as used for magnetic particle inspection
Permanent bar magnets
Soft iron pole pieces
Stereo zoom microscope (7-10X) with light
Dial probe gaussmeter
Electronic gaussmeter

Table 3-8. Magnetic Rubber Inspection Materials.

Base material
Dibutyltin Dilaurate and Stannous Octoate catalysts.
Sealing compound (putty for forming dams)
Aluminum or plastic sheet material for forming dams
Lubricant (release agent) to aid in the removal of replicas from holes
Paper cups in which to mix magnetic rubber material
Tongue depressors for mixing the material
Isopropyl alcohol for cleaning replicas
Hypodermic disposable syringe for applying the rubber mixture to the inspection area

b. Prepare part for magnetic rubber inspection as follows:

(1) Using cheesecloth or equivalent moistened with cleaning solvent MIL-C-38736 or equivalent, remove grease, oil, dirt, lint, and similar contaminants from the area to be inspected.

(2) Remove paint topcoat or fuel tank coating, as appropriate, and primer coat and/or plating as required.

CAUTION

If a delay is expected that would leave any area of steel in a bare metal state for over 1 hour, coat the area with corrosion preventive compound, Mil-C-16173, Grade 3. The exterior topcoat or fuel tank coating shall be removed from the surfaces of holes to be inspected.

The primer coat may be left on unless a specific procedure requires that it be removed or unless the total thickness of the primer plus plating is greater than 0.005 inches.

NOTE

When building dams, make certain they are small enough to allow magnets or the legs of an electromagnet to span the reservoir. Magnets or the legs of an electromagnet should never be placed into the uncured magnetic rubber.

Using the procedures and materials as discussed above, virtually any area or configuration can be prepared for magnetic rubber inspection. Upside-down surfaces may be inspected by building a reservoir beneath the test area and pressure filling with magnetic rubber. This type of reservoir must be provided with a vent hole to prevent air entrapment.

(3) Prepare a dam around the surface or hole to be inspected. Examples are shown in Figure 3-75. Use tape, aluminum foil, special sealing putty and specially made dams (singly or in combination) to form a reservoir to hold the magnetic rubber.

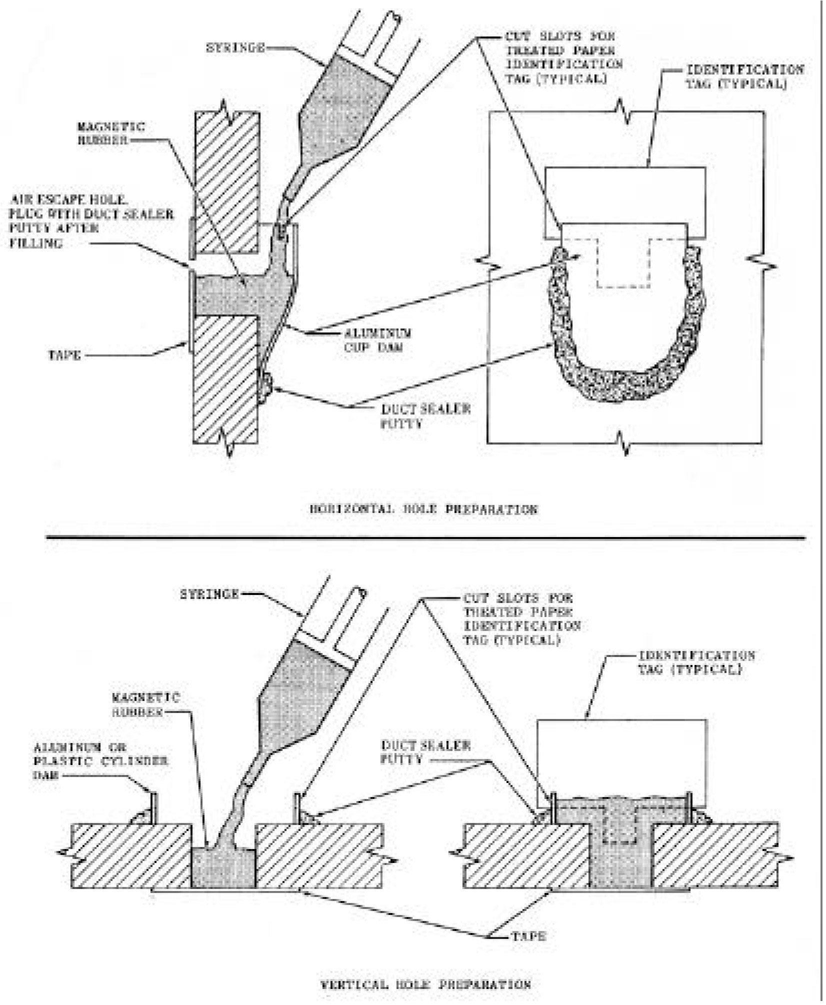


Figure 3-75. Preparation for Magnetic Rubber Inspection

NOTE

Permanent bar magnets usually are made of ALNICO 8 material, are 1 inch in diameter and are either 4 or 8 inches long. The field strength of a permanent bar magnet is **not** related to its length. Usually field strength of over 1000 gauss is adequate for most magnetic rubber inspections and most new permanent magnets will be much stronger than that. Bar magnets should be tested periodically using a gaussmeter to assure the field strength is adequate.

It is acceptable to put two or more shorter magnets together to make a longer magnet for those few inspections where the magnet is placed with its side against the part being magnetized and the specified magnet length is not available.

Step c through h are for the premagnetizaion set-up and adjustment. Magnetization will be conducted after addition of the magnetic rubber.

c. Select method of magnetization. Magnetism may be applied with portable electromagnets (yokes), permanent magnets, or conventional magnetic particle inspection equipment. In areas of limited accessibility, steel extensions or pole pieces are used to transfer magnetism into the inspection area. Permanent magnets are useful in certain specialized applications, such as threaded bolts, gears, or other small parts whose shape makes magnetization difficult with an electromagnet. The magnetic fields produced in large parts by permanent magnets are often quite low and unpredictable; therefore, they should not be used on such parts, unless a specific procedure has been developed and verified. Central conductors are best suited for fastener and attachment holes particularly when there are multiple layers of materials.

d. Select the method of magnetic contact. Field strength is greatly reduced when there is poor contact between the magnet and the test piece. To improve contact, auxiliary pole pieces are useful as illustrated in Figure 3-76. These may be machined from soft iron and attached to the poles of magnets. Pole pieces should be designed to have the least reduction in cross-section, consistent with space requirements.

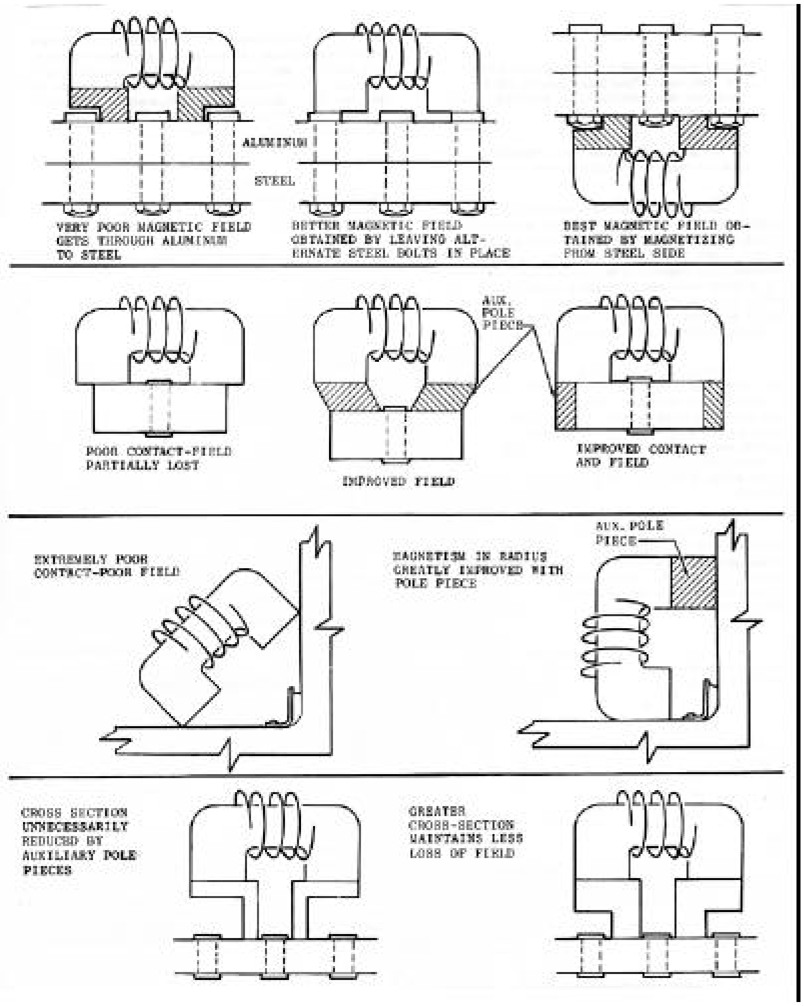


Figure 3-76. Using Pole Pieces to Improve Magnetic Contact.

e. Determine the magnetic field requirements. The magnetic field recommendations (field strength and duration) for inspection of holes and surfaces are shown in Table 3-9. Note that these are recommended starting points; actual requirements are those that produce acceptable inspection replicas.

Table 3-9. Magnetic Field Strength and Duration Recommendations.

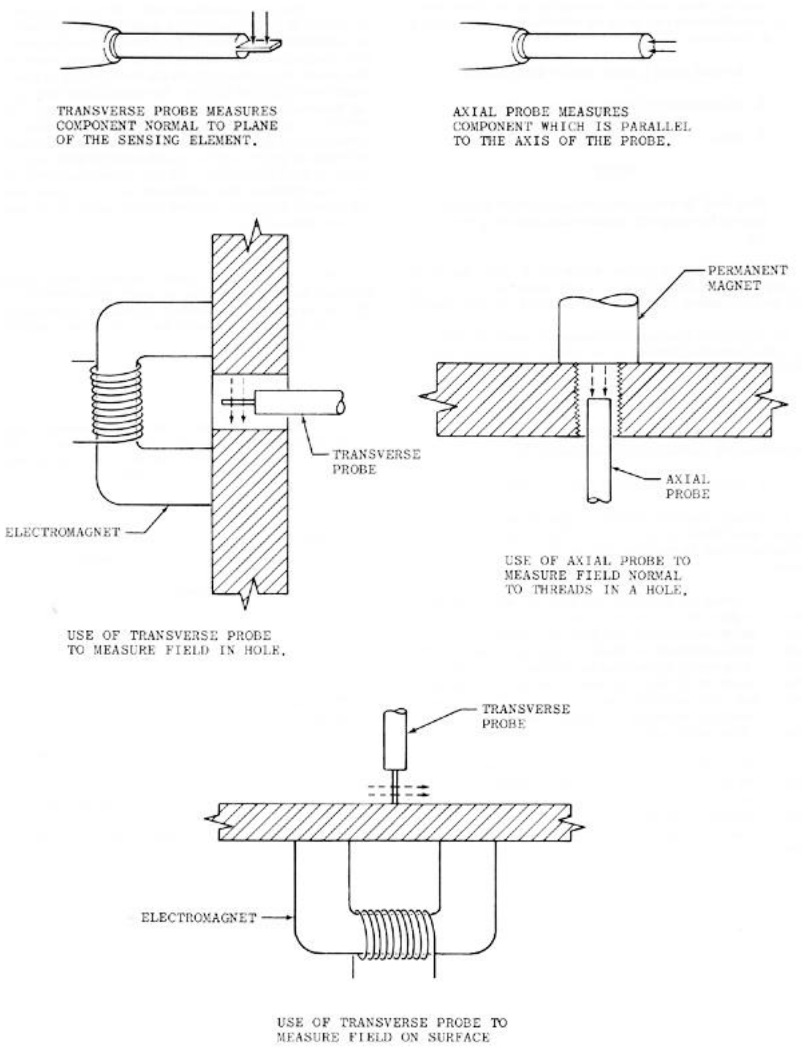
INSPECTION AREA	FIELD STRENGTH (GAUSS)	MAGNETIZATION DURATION, EACH DIRECTION (SECONDS)
	50 to 75	15
Hole (bare)	25 to 50	30
	15 to 25	120
	15- to 200	30
	100 to 150	90
Surface (bare)	50 to 100	300 (5 minutes)
	40 to 50	450 (7 1/2 minutes)
	20 to 40	900 (15 minutes)

f. Determine the direction of the field. Since cracks and other flaws are displayed more strongly when they lie perpendicular to the magnetic lines of force, the magnetism should be applied from two directions to increase reliability. Usually this is accomplished by magnetizing in one direction and then rotating the magnetization source 90 degrees and magnetizing again. When the direction of a suspected defect is known, such as in thread roots, only one magnetizing direction is required.

g. Measure the magnetic field strength using a dial probe or a gaussmeter as follows:

  (1) The dial-probe is used by placing the probe into the test hole or on the test surface and slowly rotating the probe counterclockwise. The maximum dial reading is the magnetic field strength.

  (2) The gaussmeter has interchangeable probes to permit measurement of the magnetic field either parallel or perpendicular to the axis of the probe. The probe is placed in the hole or on the surface as shown in Figure 3-77.



TRANSVERSE PROBE MEASURES COMPONENT NORMAL TO PLANE OF THE SENSING ELEMENT.

AXIAL PROBE MEASURES COMPONENT WHICH IS PARALLEL TO THE AXIS OF THE PROBE.

USE OF TRANSVERSE PROBE TO MEASURE FIELD IN HOLE.

USE OF AXIAL PROBE TO MEASURE FIELD NORMAL TO THREADS IN A HOLE.

USE OF TRANSVERSE PROBE TO MEASURE FIELD ON SURFACE

Figure 3-77. Typical Use of Gaussmeter Probes.

h. Adjust the magnetic field strength.

(1) Electromagnets. The magnetic field strength is adjusted to the recommended value from Table 3-10 by adjusting the control knob of the magnetization power supply. The control knob reading and the position of magnet and pole pieces are noted so that these settings can be repeated when final magnetization is performed after addition of the rubber formulation.

Table 3-10. Cure Times for Different Quantities of Catalyst.

CATALYST	DROPS PER 30 CC OF MAGNETIC RUBBER BASE	ESTIMATED POT LIFE	ESTIMATED CURE TIME
Stannous octoate	2	7 minutes	30 minutes
Dibutyltin dilaurate	2	7 minutes	30 minutes
Stannous octoate	1	10 minutes	60 minutes
Dibutyltin dilaurate	1	10 minutes	60 minutes

(2) Permanent Magnets. Appropriate bar magnets are placed to obtain the field strengths recommended by Table 3-9.

i. Mix, measure and deaerate (only if bubbles in replica are a problem) magnetic rubber base material as follows:

(1) Mixing. The magnetic rubber base material must be thoroughly mixed prior to use. Materials that have settled should be agitated on a mechanical shaker (paint shaker or equivalent). . Steel balls may be placed in the container containing the magnetic rubber to facilitate thorough mixing. Prior to measuring or weighing a quantity of magnetic rubber, it should be thoroughly mixed with a wooden tongue depressor or a spatula. Mixing should continue until the material contains no streaks or color variations.

(2) Measuring. The magnetic rubber base material may be weighed or measured volumetrically into paper cups or other suitable containers. One gram of magnetic rubber base material is equal to one cubic centimeter (cc) of base material. The number and size of the batches measured must be based on the area to be inspected. Do not measure more material per batch than can be poured and magnetized within the pot life of the formula selected. To determine the pot life at the time of inspection, measure a small trial batch and time the pot life in the mixing cup before the inspection batch is mixed and poured.

(3) Deaerating. For the inspection of horizontal holes or upside down surfaces, the magnetic rubber base material is placed in a vacuum chamber and pumped down to 25 to 30 inches of mercury for one to two minutes. This will remove excess air and help prevent the formation of bubbles on the upper surfaces of the cured replicas.

NOTE

The magnetic rubber will begin to thicken when curing agents are added. Therefore, magnetization must begin immediately and the entire batch must be magnetized before the pot life of the formula has expired.

Magnetic rubber material, catalyst addition, and cure time are based on a room temperature of 76°F. The cure times are very unpredictable when the temperature is below 60°F or over 90°F.

When inspecting holes with scored surfaces, holes that are deep and of small diameter or unusual configuration, the inspection area may be coated with a thin layer of petrolatum to aid in removal of replica.

j. Add to the magnetic rubber base material the correct number of drops of both catalysts using the criteria in Table 3-10.

k. Using a tongue depressor or equivalent, thoroughly stir the mixture. Avoid whipping air into the mixture.

l. Using the mixing container or a syringe, fill only the number of holes or other test areas that can be magnetized within the pot life. Following fill, all vent holes should be sealed with putty to prevent the continual flow of rubber.

NOTE

Holes in steel having high retentivity may be magnetized by a "residual" method. Using this method, the hole is filled with magnetic rubber and is magnetized with an electromagnet at the maximum field obtainable for a period of about one-second. This should establish a residual field of 25-100 gauss. This field must stay undisturbed for 30 to 60 seconds (depending on the level of residual magnetism). Do not magnetize the hole in a second direction nor magnetize any other hole on the same test part until the 30 to 60 seconds have elapsed.

m. Magnetize each test area according to the pre-magnetization setup established in steps c through h.

n. Identify each replica by recording the following data on an identification tag, or on an individual bag (for storing replica after cure).

(1) Aircraft serial number and/or part number.

(2) Hole number or other inspection area identification.

(3) Date.

NOTE

Care must be exercised to avoid excessive disturbance of the magnetic rubber when inserting the tag.

o. Allow magnetic rubber to cure for the time specified. Avoid movement of the part and contamination of the magnetic rubber by foreign matter.

p. Determine that the magnetic rubber is cured (tack-free) by lightly touching the replica or the material remaining in the mixing container.

q. Remove each replica as follows:

(1) Remove the magnets if applicable.

(2) Remove tape, aluminum dam, duct sealer putty, and/or central conductor and dam assembly.

(3) Gently remove replica from test area.

r. Visually examine replicas for overall condition and proper identification. A 7X to 10X stereo microscope and illuminator SHALL be used for microscopic examination as follows:

(1) Adjust the illuminator so that the light does not produce a glare on the surface of the replica. A good stereo microscope with excellent light gathering characteristics and a strong light projected at a shallow angle is generally sufficient for this work. Experience has proven that an improper microscope or lighting may result in small cracks going undetected. The inspector may check the adjustment of the illuminator periodically on a replica that is known to display a faint crack indication.

(2) Hold the replica with finger tips and focus by lowering or raising the replica beneath the microscope lens (rather than raising or lowering the lens itself) This allows the inspector to view the replica at various angles and to scan the entire area of interest.

(3) Evaluate the magnetism level. Although magnetic rubber responds satisfactorily to a wide range of magnetism, the reliability is increased if the optimum level is used. Too little magnetism will result in faint indications that are easily missed. Too much magnetism darkens the background so that indications might be hidden. The experienced inspector can determine if the magnetism level is satisfactory. Adequate magnetism on the replica of a hole is indicated by a dark "halo" at the pouring spout or corner. Adequate magnetism on flat surfaces and areas of gentle contour is indicated by darkness in the rough areas of the replica. On very smooth surfaces, external "penetrameter type" indicators such as staples, nickel foil or other magnetic material may be taped to the part to indicate magnetism.

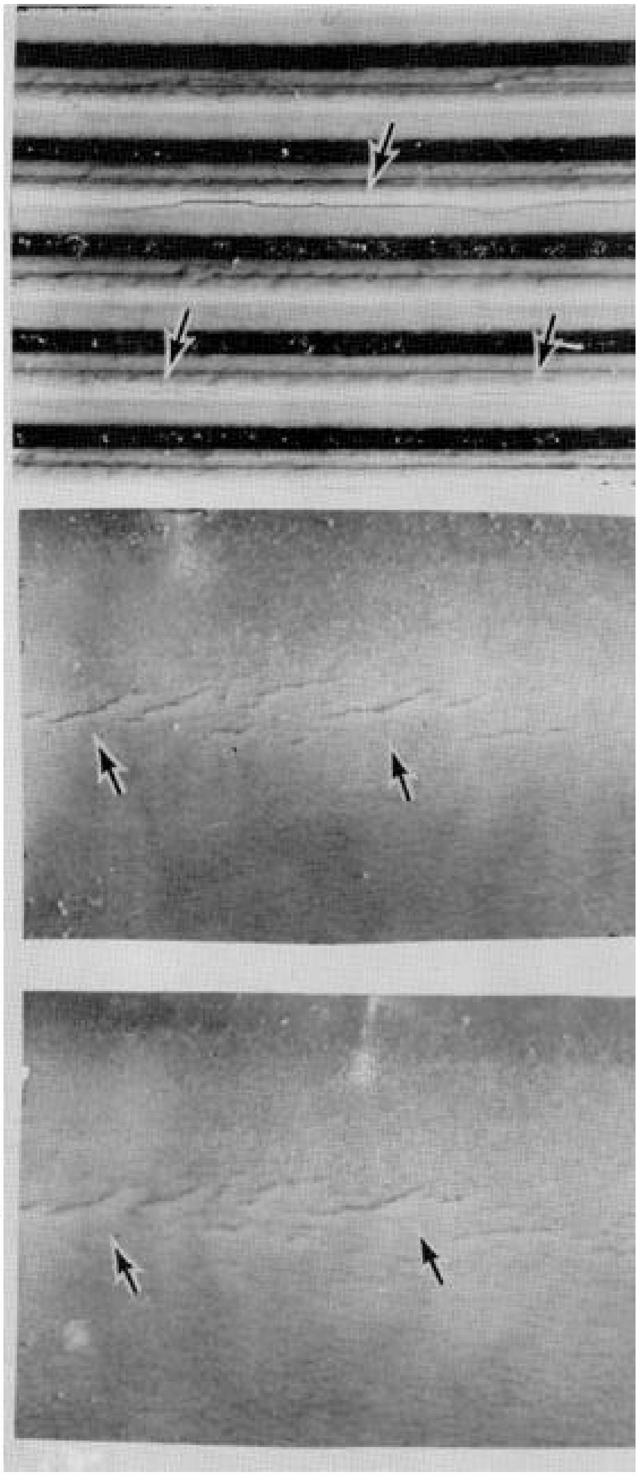
(4) Evaluate replica quality. Replicas that contain excessive air bubbles, debris, or poorly mixed rubber are difficult to interpret and should be recast. Examples of poor replica quality and other false indications (artifacts) are included in Figure 3-78 illustrating typical examples of crack indications, discontinuities and other surface conditions.

(5) Classify each replica according to the severest indication detected (See Table 3-11):

(6) Surface defects. A replica may show obvious surface defects (tool marks, corrosion pitting, etc.) that are not attracting magnetic particles. The inspector is not responsible for identifying this type of defect unless the procedure specifically requires such identification. The inspector may identify gross surface defects, but replicas will be classified “A” or “B” only when there are visible magnetic indications present. A replica classified as “C” may show surface defects.

s. Resolve “B” indications. The following methods will be attempted in order until the “B” indication is resolved to either an “A” or a “C”:

(1) Reinspect. Correct any technique or procedural errors. Clean the inspection area down to bare metal if necessary. Vary inspection technique as appropriate.

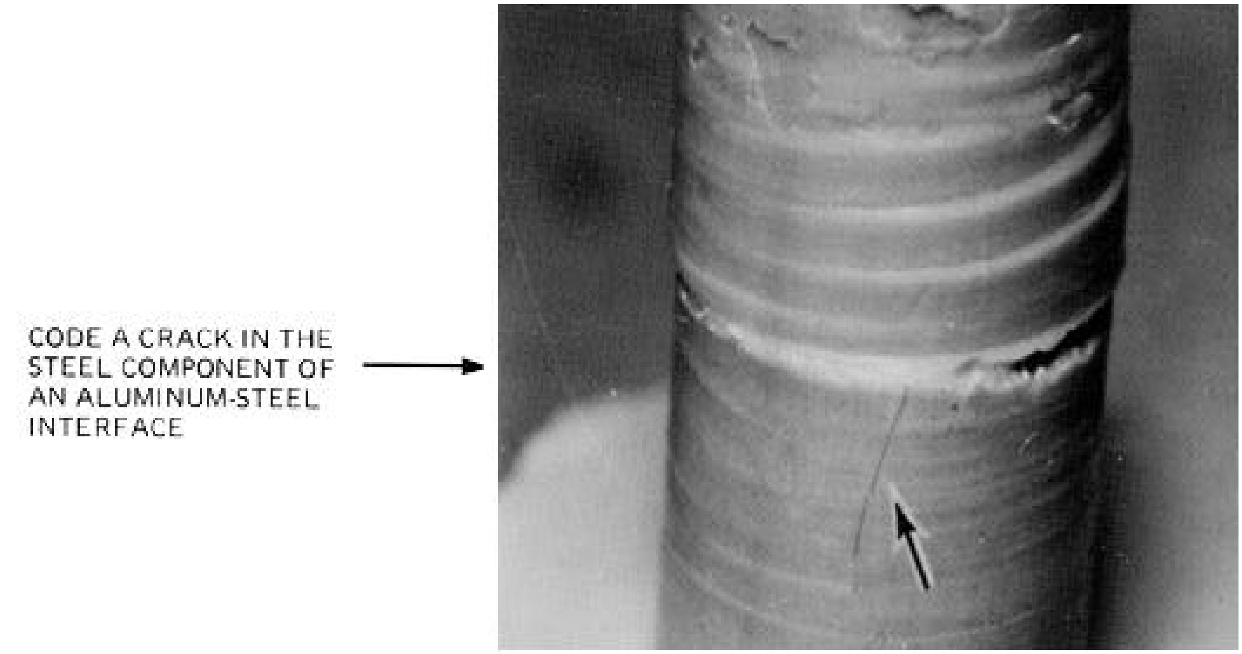


CODE A CRACKS IN ROOTS OF THREADS

MULTIPLE CODE A CRACK IN AN UNCOATED FLANGE CORNER RADIUS

SAME FLANGE AS SHOWN IN PRECEDING VIEW, EXCEPT THAT CRACKS ARE SHOWN BENEATH PAINT. NOTE FUZZINESS OF INDICATIONS AS COMPARED TO BARE SURFACE INDICATIONS SHOWN ABOVE.

Figure 3-78. Magnetic Rubber Replicas (Sheet 1 of 6).



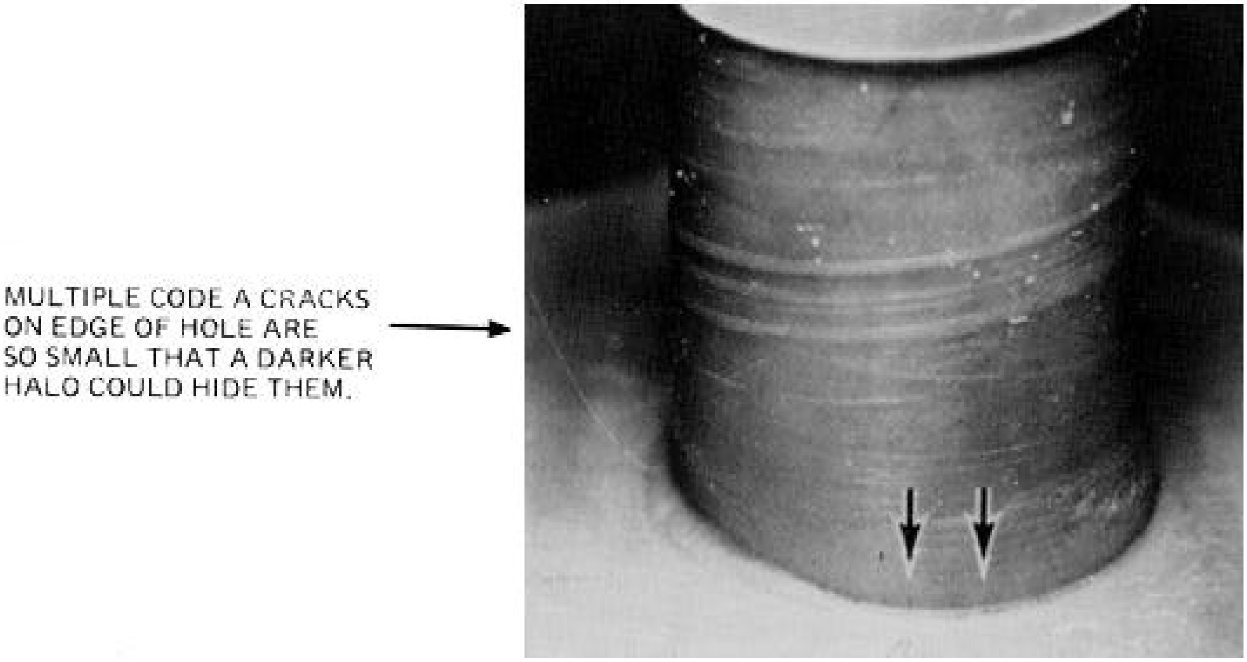
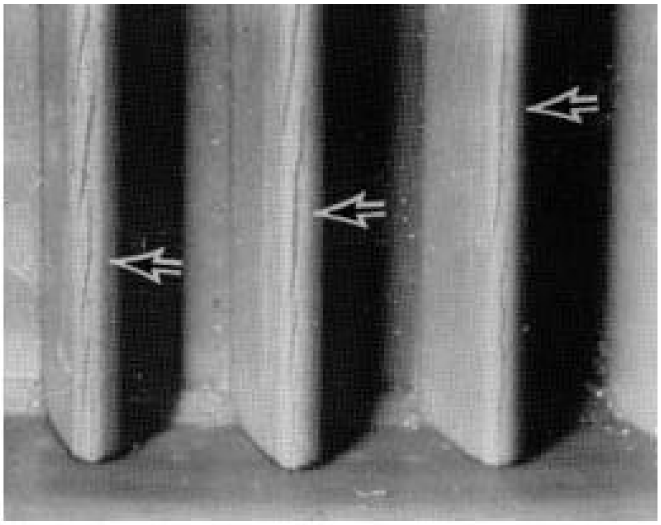
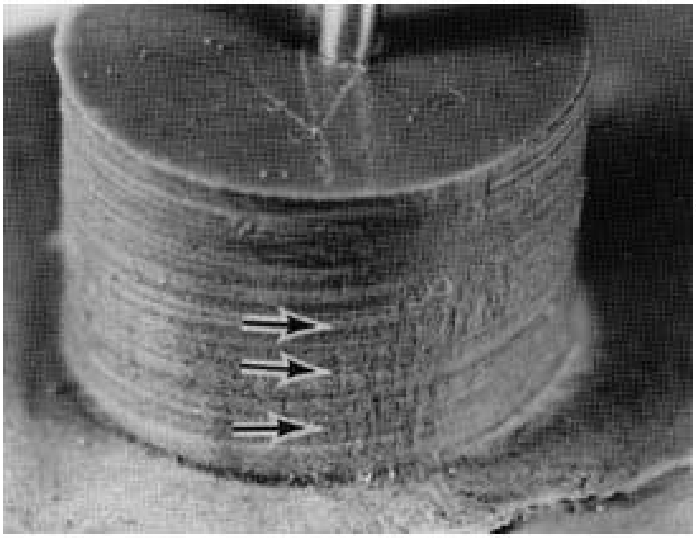


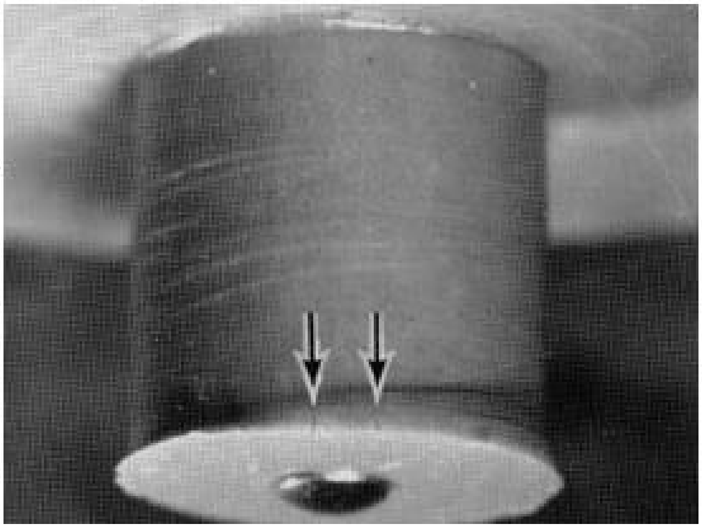
Figure 3-78. Magnetic Rubber Replicas (Sheet 2 of 6).



CODE A CRACKS IN ROOTS OF GEAR TEETH.



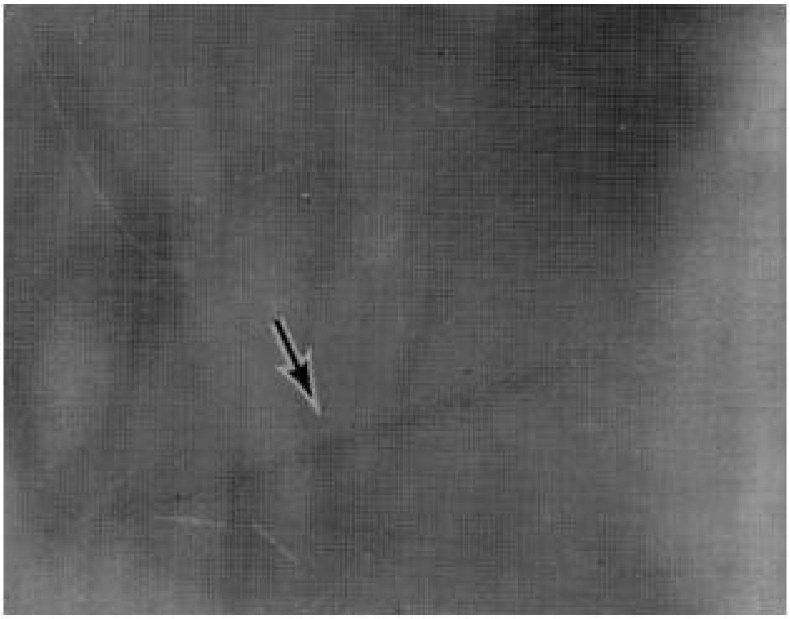
MULTIPLE CODE B INDICATIONS IN SURFACE ROUGHNESS OF HOLE. IT IS DIFFICULT TO DISTINGUISH SMALL DISCONTINUITIES FROM SURFACE ROUGHNESS. RECAST WITH LESS MAGNETISM AND/OR SMOOTH HOLE.

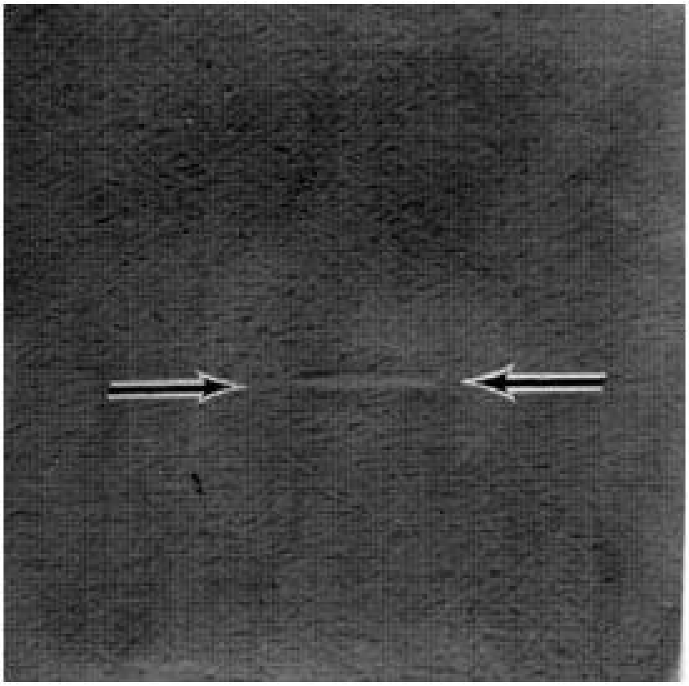


CODE B INDICATION ON TAPED SIDE OF HOLE. THIS HOLE SHOULD BE RECAST FROM OPPOSITE SIDE TO SEE IF INDICATION TRAVERSES CORNER.

Figure 3-78. Magnetic Rubber Replicas (Sheet 3 of 6).

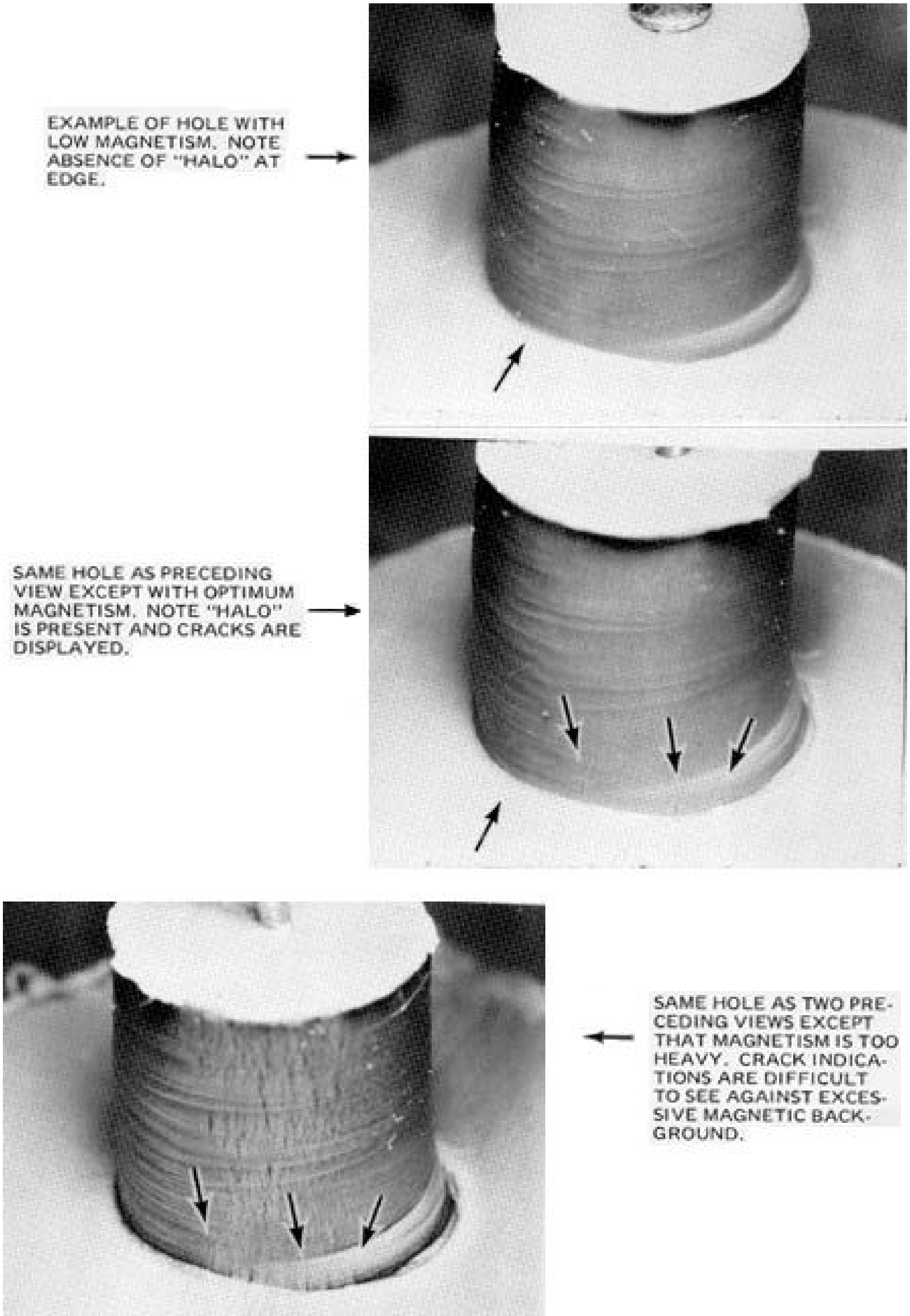
CODE B INDICATION APPEARS TO BE SUBSURFACE. SUCH INDICATIONS ARE HAZY AND DIFFUSE.





SUBSURFACE CRACKS ARE SOMETIMES DISPLAYED AS WHITE INDICATIONS. SUCH INDICATIONS MAY ALSO RESULT WHEN SURFACE CRACKS ARE UNDER-MAGNETIZED.

Figure 3-78. Magnetic Rubber Replicas (Sheet 4 of 6).



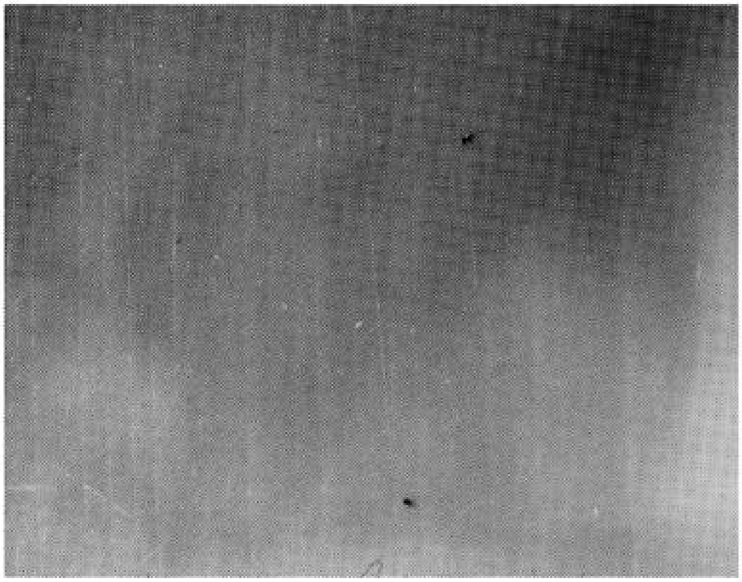
EXAMPLE OF HOLE WITH LOW MAGNETISM. NOTE ABSENCE OF "HALO" AT EDGE.

SAME HOLE AS PRECEDING VIEW EXCEPT WITH OPTIMUM MAGNETISM. NOTE "HALO" IS PRESENT AND CRACKS ARE DISPLAYED.

SAME HOLE AS TWO PRECEDING VIEWS EXCEPT THAT MAGNETISM IS TOO HEAVY. CRACK INDICATIONS ARE DIFFICULT TO SEE AGAINST EXCESSIVE MAGNETIC BACKGROUND.

Figure 3-78. Magnetic Rubber Replicas (Sheet 5 of 6).

EXAMPLE OF SURFACE WITH LOW MAGNETISM. NOTE ABSENCE OF MAGNETIC BACKGROUND.



SAME SURFACE AS PRECEDING VIEW WITH MAGNETISM TOO HEAVY. SMALL INDICATIONS WOULD BE LOST IN HEAVY MAGNETIC BACKGROUND.

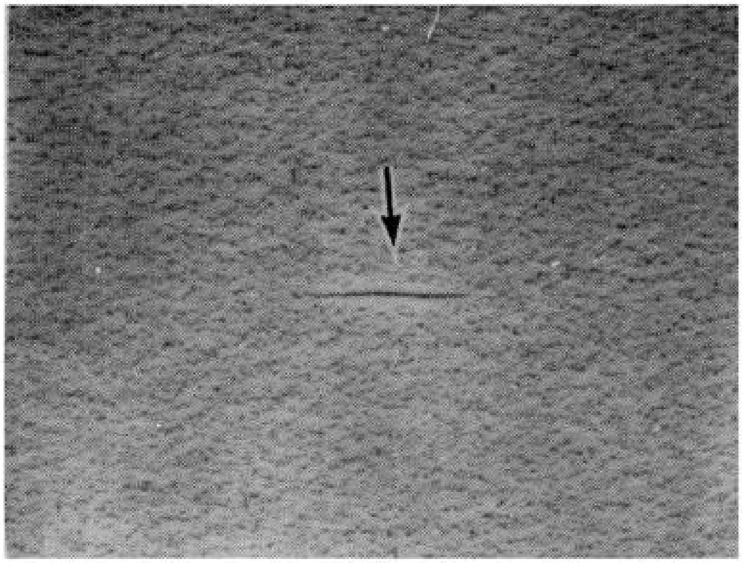


Figure 3-78. Magnetic Rubber Replicas (Sheet 6 of 6).

Table 3-11. Magnetic Rubber Indication Codes.

INDICATION CODE	INDICATION DESCRIPTION
A	A positive, definite indication. An “A” indication clearly contrasts with the background replica material. It may apply to surface defects other than cracks. All “A” indications are to be reported to engineering, along with orientation and length.
B	A fuzzy, unclear indication. A “B” indication can be due to improper inspection technique or procedure, a dirty inspection area, or a subsurface defect. A “B” indication is a temporary classification that has to be resolved to either an “A” or a ”C” indication.
C	The replica is clear of any defect indications.
SD	A surface defect. This classification will be used only in those critical inspections where the inspector is required to identify surface defects such as corrosion pitting, tool marks, scratches, gouges, machine tears or chatter marks.

(2) Rework inspection area and reinspect. For material removal limits refer to the appropriate technical documentation. Remove only the material amount required to resolve the defect indication.

(3) Contact the appropriate engineering function if the material removal limits are reached before the defect indication is resolved.

t. Surface finish visual inspection. After all “A” and “B” indications have been resolved (replicas from the last inspection of the area are classified as “C”), the inspection area is ready for appropriate personnel to evaluate the surface finish and configuration. The last replica may be examined in lieu of the actual surface. If no additional rework is performed, the last inspection (paragraph v below) is not required.

u. Final inspection. The area will be inspected, if required by appropriate engineering directive, when additional metal removal is performed to correct conditions noted in the surface finish visual inspection.

3.9.5 Post Inspection Procedures.

WARNING

Cleaning solvent ML-C-38736 contains aromatic naphtha, ethyl acetate, methyl ethyl ketone, and isopropyl alcohol. Cleaning solvent is flammable. Vapors may be harmful. Use with adequate ventilation. Avoid contact with skin and eyes.

a. Demagnetize parts until the residual magnetism is less than two divisions on the magnetic field indicator.

b. Clean parts with cleaning solvent.

c. Restore finish in accordance with the appropriate engineering directives.

d. Reinstall parts removed in accordance with applicable technical manual.

CHAPTER 4
SECTION I
INTRODUCTION TO EDDY CURRENT INSPECTION

4 EDDY CURRENT INSPECTION.

4.1 INTRODUCTION.

This method is used detect discontinuities in parts that are conductors of electricity. An eddy current is the circulating electrical current induced in a conductor by an alternating magnetic field. When eddy currents encounter an obstacle, such as a crack, the surrounding currents become distorted. This change is detected on a meter or other type of display.

4.1.1 Definition of Eddy Currents.

Eddy currents are electrical currents induced in a conductor by a changing magnetic field. The eddy currents are circular in nature, and their paths are oriented perpendicular to the direction of the magnetic field. Eddy current nondestructive inspection can determine some properties of materials, locate discontinuities, and measure dimensions. The eddy currents are usually generated by the flow of alternating or otherwise varying electric currents in coils placed near an electrically conductive part. Figure 4-1 illustrates eddy currents flowing in various configurations.

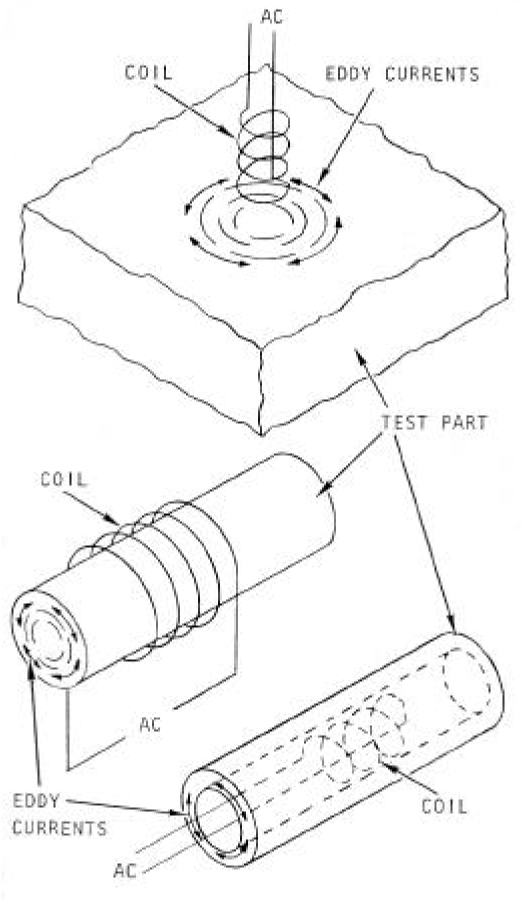


Figure 4-1. Generation of Eddy Currents in Various Part Configurations.

4.1.2 Inspection with Eddy Currents.

The eddy currents induced in an electrical conductor vary in magnitude and distribution in response to specimen properties such as electrical conductivity, magnetic permeability, geometry and discontinuities as well as inspection parameters such as the coil-to-specimen separation (also called lift-off or fill-factor, depending on the type of coil used) and coil assembly design. A consequence of this is that often the eddy current inspection for one condition, i.e. presence of discontinuities, can be hampered by variations in properties not of concern, i.e. specimen geometry. In most cases the effects of variations in properties not of interest can be minimized or suppressed. Minimization or suppression of unwanted eddy current responses is essential to the conduct of an effective inspection and will be discussed in a later section of this chapter.

4.1.3 Eddy Current Inspection Techniques.

A wide variety of eddy current inspection techniques have been developed. Test frequencies, coil arrangements, data analyses, and data displays are some of the parameters which define a technique. When the ferromagnetic properties of the specimen are of interest, magnetoinductive testing is the more correct term; for the purposes of this chapter eddy current inspection will be the term of choice.

4.1.4 Inspection Applications.

In most cases, the properties that are detectable by eddy current testing are of little interest by themselves. However, in many cases they correlate to characteristics that are of interest, such as the presence of defects, heat treat condition or coating thickness. Some of the characteristics that eddy current techniques can detect and/or measure are presented in Table 4-1, categorized according to the actual material property or inspection parameter measured.

Table 4-1. Common Applications of Eddy Current Inspection.

Electrical Conductivity	Magnetic Permeability*	Geometry	Material Discontinuities	Lift-Off or Fill-Factor
Alloy Sorting Heat-Treat Condition Heat Damage Plating Thickness Cladding Thickness	Alloy Sorting Heat-Treat Condition Case Depth Plating Thickness	Metal Thickness	Cracks Segregation Seams Inclusions Corrosion Porosity Carbon Fiber breakage	Insulation Thickness Nonmetallic Coatings Thickness Proximity Gage Diameter (e.g., of bar stock with encircling coil)

* Ferromagnetic Materials Only

4.1.5 Electrical Conductivity.

Electrical conductivity is a measure of the ability of electric currents to flow in a material. The conductivity of a material can depend on a material's heat treat condition, chemical composition, and the presence of cracks or other discontinuities. Therefore, eddy current inspection can be used to detect variations in alloy composition, hardness (heat treat condition), thermal exposure and a wide variety of flaw conditions. For example, the electrical conductivity of aluminum alloys is significantly influenced by heat treat condition. Consequently, it is often possible to use eddy current testing to determine if a part of a known aluminum alloy has been properly heat treated or has been exposed to temperatures that can degrade the heat treat condition. The dependence of conductivity on chemical composition can also allow eddy current inspection to sort between different alloys. Eddy current inspection is also able to detect the localized variation in conductivity associated with the presence of a discontinuity.

4.1.6 Magnetic Permeability.

For ferromagnetic materials (see Chapter 3 for a discussion of ferromagnetic materials), the relative magnetic permeability is the principal property that affects eddy current response. The relative permeability depends on a wide variety of parameters; alloy composition, degree of magnetization, heat treat and residual stress, just to name a few. In many cases, variations in permeability due to non-flaw conditions mask effects from discontinuities or other conditions of interest. As will be discussed later, there are some situations where the permeability in the area of interest is not an interfering parameter and eddy current inspection can be successfully applied.

4.1.7 Geometry.

Geometric features such as edges, curved surfaces, changes in thickness, and non-conductive coatings (such as paint) on surfaces affect the distribution and strength of eddy currents. The eddy current response as a probe approaches an edge is known as edge effect and appears similar to a response from a crack. Similarly, curved surfaces and non-conductive coatings can vary the distance between the probe coil and the part. These changes are known as lift-off, and the consequent effects on the eddy current signal are called lift-off effects. Lift-off usually cannot be completely prevented; therefore compensating for some lift-off is part of the calibration procedure for most eddy current inspections. Part thickness variations can also produce an interfering response in some eddy current inspections when the thickness is in the range of the depth of penetration of the eddy current field (see paragraph 4.2.3.2).

4.1.8 Lift off And Fill Factor.

The effects of lift-off are mentioned in a later section and can be exploited if the measurement of coating thickness is desired. Changes in lift-off can be calibrated to allow measurements of nonconductive coating thicknesses. Fill-factor applies to parts passed through an encircling coil and, in a manner similar to lift-off, can be used to gauge some dimensions.

4.1.9 Flaw Detection.

When eddy currents are induced in a metal in the region of a crack or other flaw, the eddy current flow is distorted. The distortion results in a localized decrease in electrical conductivity. In this manner an eddy current inspection is able to detect cracks or other flaws.

4.1.10 Components of an Eddy Current Inspection System.

In its simplest form, an eddy current inspection system consists of the following components: (1) an oscillator, (2) a coil assembly, (3) a bridge circuit, (4) signal processing circuits, and (5) a readout. A block diagram of an inspection system is shown in Figure 4-2 with the coil applied to a test part. Systems may be constructed for multiple purposes or for very specialized functions. In general, instruments designed for specific tasks, such as measuring coating thickness or electrical conductivity, are easier to calibrate and operate than general purpose instruments but also are limited to their designed application.

4.1.10.1 Oscillator.

The oscillator provides an alternating current of one or more frequencies to the test coil. The frequency used is determined by the intent of the inspection and the material being inspected. Frequencies used for eddy current inspection range from less than 50 Hz to greater than 6 MHz.

4.1.10.2 Coil Assembly (Probe).

The coil assembly induces eddy currents into the part being inspected and detects changes in eddy current flow. For some applications, a single coil is used for both functions. More commonly, multiple coils are employed in an assembly. A common configuration has one coil inducing the eddy current flow and separate coils used as detectors. Another configuration uses one coil as both an inducer and a detector on the test part.

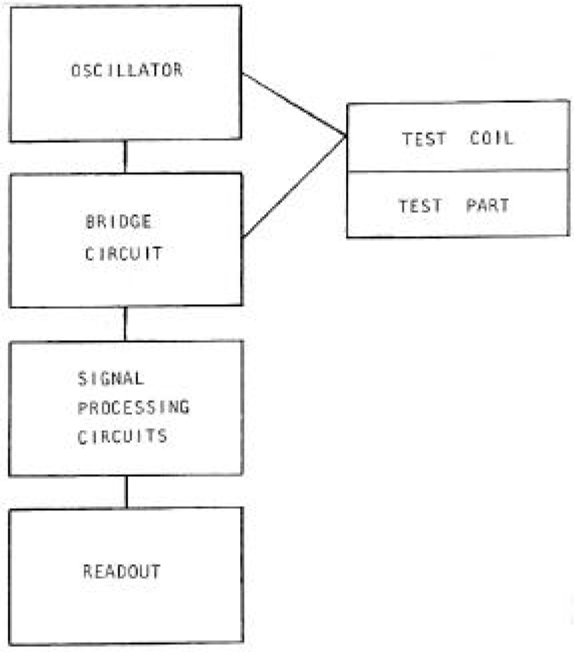


Figure 4-2. Block Diagram of Eddy Current Inspection System.

4.1.10.3 Bridge Circuit.

The bridge circuit converts changes in eddy current magnitude and distribution into signals that are ultimately processed and displayed. A common mode of operation is to have the output of the bridge equal zero for a “good” or ‘“non-flaw” condition. Presence of a flaw or an “other-than-good” condition results in an unbalance of the bridge, thus producing a relatively small signal. This signal becomes the input to subsequent circuits.

4.1.10.4 Signal Processing Circuits.

The processing of the signal from the bridge circuit depends on the type of information to be displayed. Simple eddy current devices can be built which detect and amplify the signal or convert the signal into digital format (i.e., a conductivity value). More sophisticated systems can process the complex electromagnetic signal into signal amplitude and signal phase, and provide filtering to suppress unwanted signals. Details of the processes are discussed further in later sections.

4.1.10.5 Output Display.

Eddy current test data can be presented as an analog or digital meter readout, a strip chart, an X-Y recorder plot, an oscilloscope display or a video screen presentation. Meters are suitable for performing specific types of tests such as crack detection, alloy sorting, coating thickness, or other types of testing that require a measurement of signal amplitude only. Strip charts, X-Y recorders and digital storage allow the signal amplitude to be displayed and correlated with some other parameter such as time or position. Eddy current instruments with a 2 dimensional graphical display are used where both the eddy current signal amplitude and phase must be measured. These are becoming the most common instruments available and provide the inspector with the greatest capability in interpreting the results of an eddy current inspection. They are also very portable and can be battery operated, but are a few pounds heavier than those with a meter display.

4.1.11 Limitations of Eddy Current Method.

There are several limitations to the eddy current inspection method. First, it is limited to electrically conductive materials or materials with electrically conductive components such as carbon fiber re-enforced composites. Second, flaws parallel to the surface inspected are difficult to detect. The most serious limitation, however, is the necessity to be able to prevent or suppress eddy current responses to non-flaw conditions. This becomes a particularly difficult problem with ferromagnetic materials.

SECTION II
FACTORS EFFECTING EDDY CURRENTS

4.2 GENERATION OF AND FACTORS AFFECTING EDDY CURRENTS.

4.2.1 Generation of Eddy Currents.

4.2.1.1 Primary Electromagnetic Field.

Eddy currents are generated when a varying magnetic field penetrates an electrically conductive material. The usual source of the varying magnetic field is the electromagnetic field produced by a coil carrying an alternating electric current. This field is called electromagnetic because it has both electric and magnetic field components; however only the magnetic component is involved in the generation of eddy currents. The rate at which the electromagnetic field varies is called the frequency. The strength of the electromagnetic field at the surface of the conductor depends on the coil size and configuration, the amount of current through the coil, and the distance from the coil to the surface.

4.2.1.2 Induction of Eddy Currents.

As the electromagnetic field from a coil penetrates a conductor, it generates eddy currents parallel to the surface of the part and at right angles to the direction of the applied field (Figure 4-3). The frequency of eddy current flow is the same as the electromagnetic field.

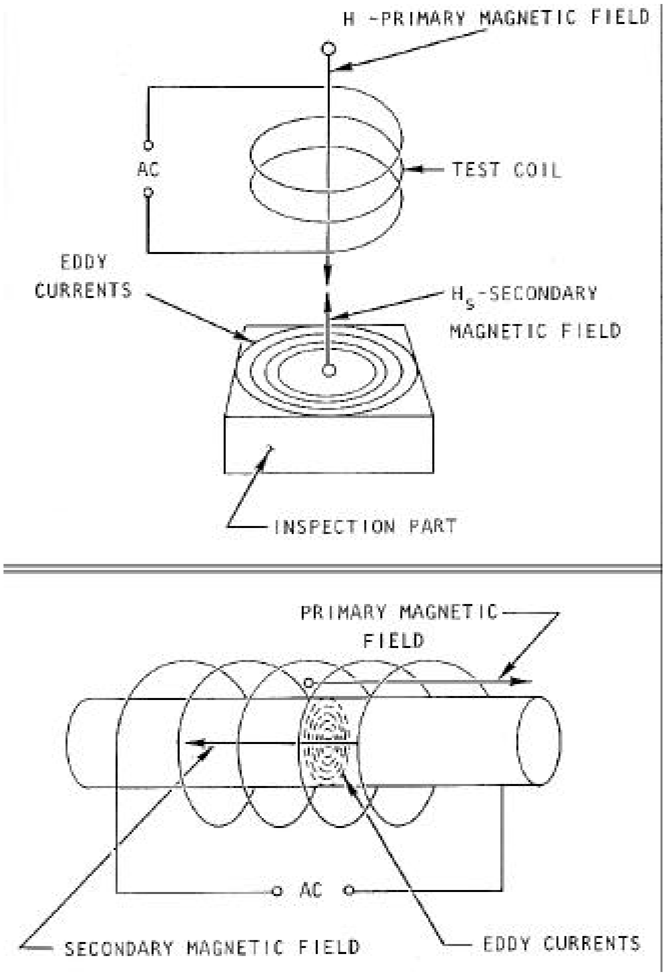


Figure 4-3. Primary and Secondary Magnetic Fields in Eddy Current Inspection.

4.2.1.3 Secondary Electromagnetic Field.

Eddy currents also generate an electromagnetic field. This field, called the secondary electromagnetic field, opposes the primary electromagnetic field (see Figure 4-3) and is a consequence of Lenz's Law. Lenz's Law, as applied to this case, states that induced currents (eddy currents) act to reduce the magnitude of the inducing current. The opposition of the secondary field to the primary field decreases the overall electromagnetic field strength and reduces both the current flowing through the coil and the resultant eddy currents. Changes to the properties of the inspection article produce changes to the eddy currents and thus their secondary magnetic fields. In this manner, changes in the inspection article produce effects that can be detected by monitoring either the source of the primary electromagnetic field or the overall electromagnetic field.

4.2.2 Variables Affecting Eddy Currents.

The generation and detection of eddy currents in a part are dependent upon the design of the inspection system (coil assemblies), material properties of the part, and the test conditions. The inspection systems, including coil assemblies, are discussed in Section 4.4. Material properties and inspection conditions that influence eddy current response are summarized in Table 4-2.

Table 4-2. Material Properties and Inspection Conditions Influencing Generation of Eddy Currents.

Material Properties	Inspection Conditions
Electric Conductivity	Frequency
Magnetic Permeability	Coupling or Lift-Off
Geometry	Coil Current
Discontinuities	Coil Design

4.2.2.1 Material Properties.

4.2.2.1.1 Electrical Conductivity.

Electrical conductivity is a measure of the ease with which electrons (and thus eddy currents) can move within a material (see paragraph 4.1.5). Good conductors of electricity have electrons that are not tightly bound in the atomic lattice or crystal structure and are relatively free of obstacles to the movement of those electrons. Metals have greater conductivity than nonmetals, but even within metals there is a wide range of conductivity.

4.2.2.1.1.1 Factors Affecting Electrical Conductivity.

A perfect lattice is one in which there is no interruption in the orderly arrangement of the atoms making up the material. This situation offers the fewest obstacles to electron flow and therefore the highest conductivity. Any irregularity or distortion of the atomic lattice impedes the flow of electrons. Sources of such impediments include atoms of alloying elements and grain boundaries (where lattice mismatches occur because of differing crystalline orientations). Further impediments are created when heat treat processes precipitate alloying elements at grain boundaries to increase strength. Cold working also creates impediments to electron flow by its disruption of the lattice structure. Most importantly for NDI, cracks and other discontinuities also impede electron flow.

4.2.2.1.1.2 Measurement of Resistivity.

Electrical resistance is a measure of the resistance to the flow of electric current in a conductor. Resistance depends on the length and area of the current path, and the conductivity of the conductor. Resistance is commonly measured in ohms. If a material allows one volt (electric potential) of driving force to push one ampere of current through a conductor, the electrical resistance of the conductor is defined as one ohm of resistance. Resistivity is a material parameter independent of the size of a material sample and is related to resistance as shown in the second equation of paragraph 4.2.2.1.1.3 below. Resistivity is defined as ohms per unit of length per unit of cross-sectional area.

4.2.2.1.1.3 Measurement of Conductivity.

Electrical conductivity is the reciprocal of electrical resistivity. The reciprocal of the "ohm" is commonly called the "mho". Conductivity is commonly expressed in units of mhos per unit length such as mho/inch or mho/meter. The relationships between conductivity, resistivity and resistance are expressed by the following equations:

$\sigma = L/RA = 1/\rho$; therefore, $R = \rho L/A$

Where:

σ = electrical conductivity (mhos/unit-length)
L = length
R = resistance (ohms)
A = cross-sectional area
ρ = resistivity (ohms–unit-length)

* See Table 4-3 for more aluminum alloy materials.
** Values represent averages taken from literature.

4.2.2.1.1.4 Conductivity based on %IACS.

An alternative way of expressing conductivity is as a percent of the conductivity of a known material. The International Electrotechnical Commission has designated the conductivity of a specific grade of high purity copper to be the standard for this alternative method with a conductivity of 100 percent. It is called the International Annealed Copper Standard (IACS). The conductivity’s of all other metals are then expressed as a percentage of this standard. Average values of conductivity of some commonly used engineering materials are listed in Table 4-3.

Table 4-3. Conductivity's of Some Commonly Used Engineering Materials.

Material	Conductivity Megaohms/Inch**	Conductivity (%IACS)	Temperature (°F)
Aluminum Base*			
1060-0	0.913	62.0	69
2014-T6	0.589	35.5 - 41.5	68
2024-T3	0.174	28.5 - 32.5	68
2024-T851	0.589	36.0 - 42.5	—
5052-0	0.516	33.6 - 37.6	68
6061-T6	0.589	40.0 - 48.0	68
7075-T6	0.442	30.5 - 36.0	68
Copper Base			
99.9%, Annealed	1.473	100.0	68
Cartridge Brass, Annealed	0.412	28.0	68
Aluminum Bronze - 5%, Annealed	0.250	17.0	68
Phosphor Bronze - 5%, Annealed	0.221	15.0	68
Magnesium Base			
Pure, Annealed	0.560	38.0	68
K60A-0	0.442	30.0	68
AZ31B-T5	0.273	18.5	70
Nickel Base			
A, 99.4%	0.265	18.0	68
Monel 400	0.053	3.6	68
Inconel 600	0.025	1.7	70
Stainless Steel			
304	0.353	2.4	70
430	0.423	2.9	70
Titanium Base			
Ti-55A	0.045	3.1	—
6Al-4V	0.015	1.0	—
8A1-1Mo-1V	0.013	0.87	—

4.2.2.1.1.5 Effect of Conductivity on Eddy Currents.

The distribution and intensity of eddy currents in non-ferromagnetic materials is strongly affected by electrical conductivity. In a material of relatively high conductivity, strong eddy currents are generated at the surface. In turn, the strong eddy currents form a strong secondary electromagnetic field opposing the applied primary field. As a result the strength of the primary field decreases rapidly with increasing depth below the surface. In poorly conductive materials, the primary field generates small amounts of eddy currents, which produce a small opposing secondary field. Therefore, in highly conductive materials, strong eddy currents are formed near the surface, but their strength reduces rapidly with depth. In poorly conductive materials, weaker eddy currents are generated near the surface, but they penetrate to greater depths. The relative magnitude and distribution of eddy currents in good and poor conductors are shown in Figure 4-4.

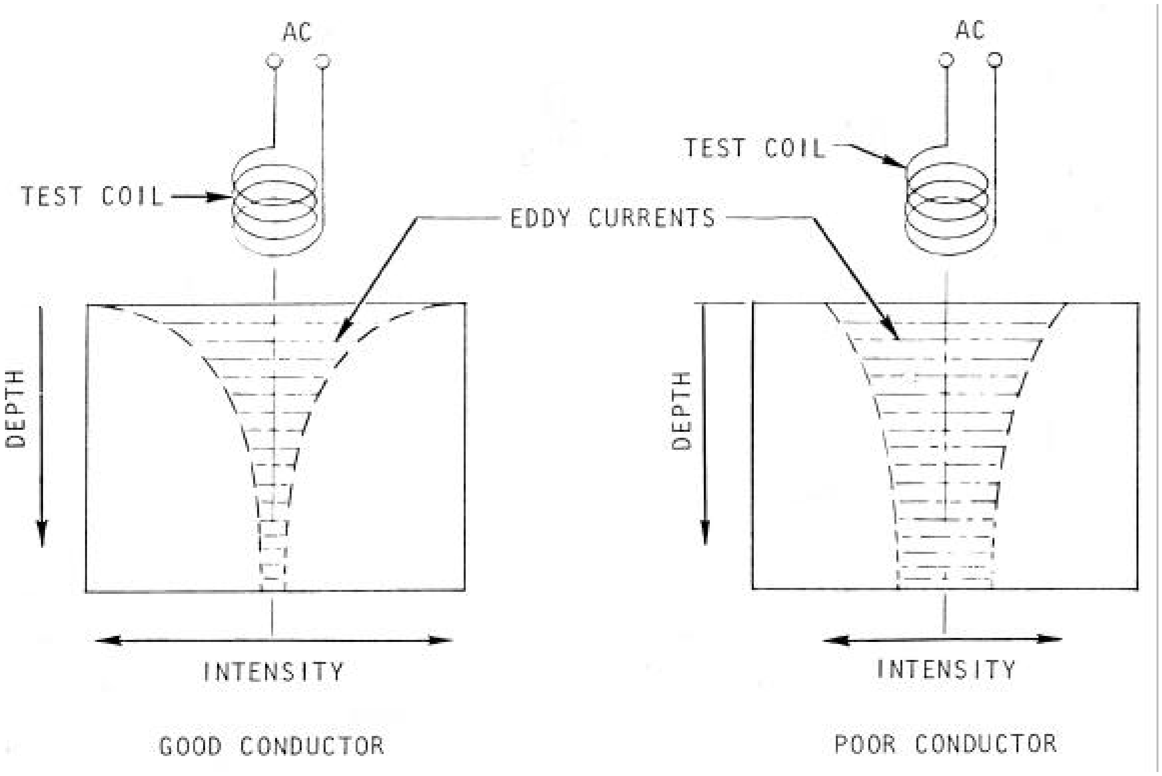


Figure 4-4. Relative Magnitude and Distribution of Eddy Currents in Good and Poor Conductors.

4.2.2.1.2 Permeability.

In a ferromagnetic material, as compared to a non-ferromagnetic material, the primary field results in a much greater internal field because of the large relative magnetic permeability. The increased field strength at the surface results in increased eddy current density. The increased eddy current density generates a larger secondary field that rapidly reduces the overall field strength a short distance from the surface. Consequently, the effective depth of penetration during eddy current inspection is much less in ferromagnetic materials than in other conductive materials. The high relative magnetic permeability acts as a shield against the generation of eddy currents much below the surface in a ferromagnetic part. Thus, eddy current testing of ferromagnetic parts is usually limited to testing for flaws or other conditions that exist at or very near the surface of the part. The relative effects of permeability variations on the depth of penetration and the intensity of the eddy currents are shown in Figure 4-5.

4.2.2.1.3 Geometry.

Eddy currents, as generated by most eddy current inspection techniques, occupy a volume in a conductive material that is relatively small. As indicated in Figure 4-4 and Figure 4-5, the volume is approximately conical and not very deep. The maximum diameter will be on the order of twice the diameter of the driving coil and the depth is estimated by the equation discussed in paragraph 4.2.3.3. Part geometry only becomes significant when this volume exceeds the volume available within the part. This happens when the thickness of the region of the part inspected is less than the effective depth of this conical volume or when an area near edges of the part is inspected.

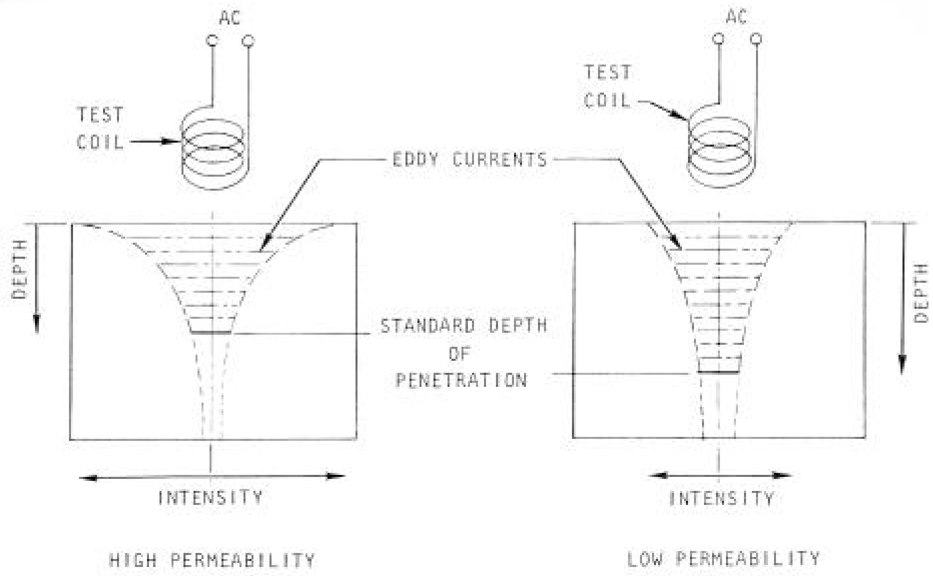


Figure 4-5. Relative Magnitude and Distribution of Eddy Currents in Conductive Material of High and Low Permeabilities.

4.2.2.1.4 Material Thickness.

In a part, such as sheet material, in which the thickness is less than the effective depth of penetration, the overall electromagnetic field is not zero at the back surface. As the back surface gets closer to the front surface, the overall field at the back surface increases; and as the back surface gets further from the front surface the overall field decreases. This provides a mechanism for thickness gauging of thin materials. Furthermore, a material of either lower or higher conductivity at the far side will change the magnitude and distribution of the eddy currents as shown in Figure 4-6. This provides a means for thickness gauging of thin, conductive coatings on substrates that are either more or less conductive than the coating.

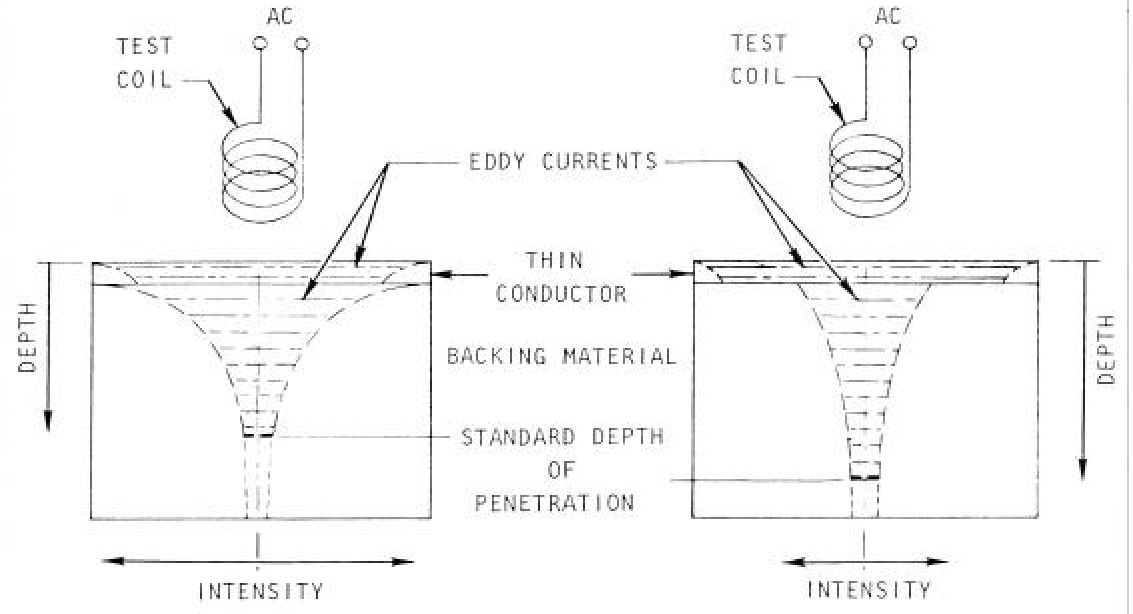


Figure 4-6. Distribution of Eddy Currents in Thin Conductors Backed by Materials of Different Conductivity's.

4.2.2.1.5 Edges (Including Corners and Radii).

For most eddy current techniques, the flow is circular parallel to the surface of the part. If the flow of eddy currents intercepts an edge, corner, or radius of the part, the circular pattern is disrupted and the eddy currents are confined to a smaller volume. This action changes the magnitude and distribution of the eddy currents and is known as edge effect (see Figure 4-7). As illustrated, the current density will be slightly greater at the edge of the part than at the interior. This will result in a slight increase in sensitivity to discontinuities located at the edge.

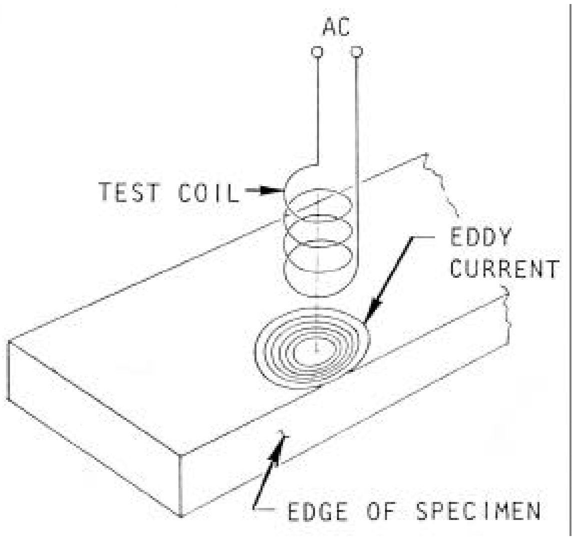


Figure 4-7. Distortion of Eddy Current Flow at the Edge of a Part.

4.2.2.1.6 Discontinuities.

Discontinuities in an electrically conductive material can also change the circular eddy current flow pattern as shown in Figure 4-8. Discontinuities include cracks, inclusions, voids, seams, pits, laps, and numerous other inhomogeneities related to the production, fabrication and use of metallic parts. The change in the magnitude and distribution of the eddy currents is roughly proportional to the size of the discontinuity intercepted by the eddy currents. Because of the weaker eddy currents at increasing depths beneath the surface, the eddy current response to flaws at or near the surface is greater than the reaction from same size flaws at greater depths.

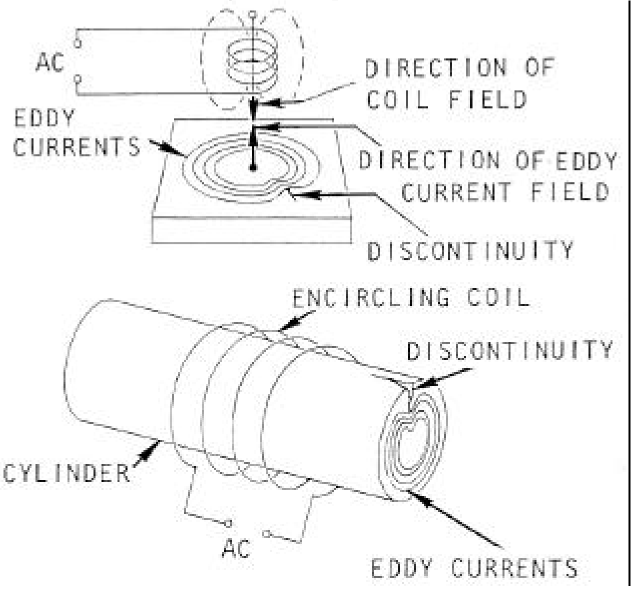


Figure 4-8. Effect of Discontinuities on Distribution of Eddy Currents.

4.2.2.2 Effects Of Inspection Conditions on Eddy Currents.

4.2.2.2.1 Frequency.

The magnitude of the induced eddy currents in the part increases as the frequency of the inducing current increases. In turn, the higher intensity eddy currents generate a stronger opposing magnetic field, reducing the penetration of the primary field. Therefore, all other factors remaining constant, higher frequencies result in shallower depths of penetration as shown in Figure 4-9.

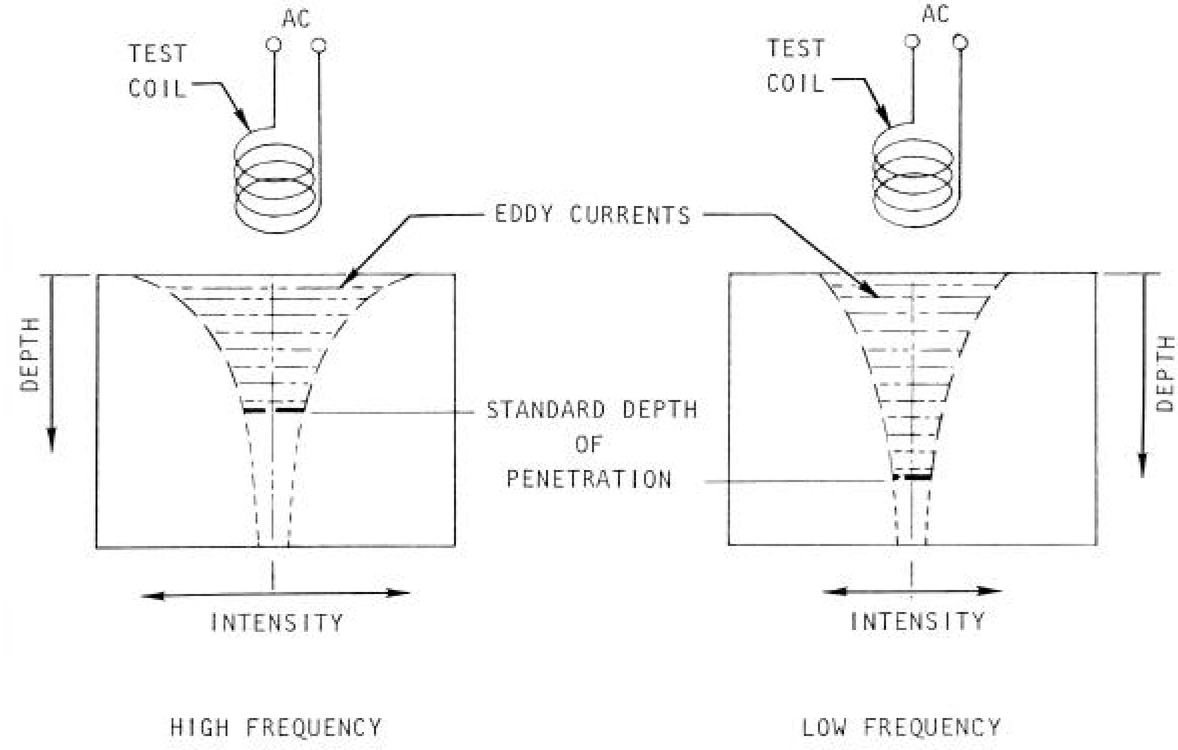


Figure 4-9. Relative Effect of Frequency on Depth of Penetration.

4.2.2.2.2 Electromagnetic Coupling.

The interaction between the primary electromagnetic field, generated by the coil and the inspection article is referred to as electromagnetic coupling. Because the field decreases in strength with increasing distance from the coil, resultant eddy currents at the surface of the part will also decrease in intensity. An electrical engineering term that could also be used is inductive coupling.

4.2.2.2.3 Lift-Off.

As an eddy current probe is brought near a conductive part, a change in the detected signal will be noted. With the probe near a part, a pronounced signal change will be observed in response to a small change in distance between probe coil and part. This effect is termed lift-off. The signal change occurs because the intensity of the eddy currents in the part decreases considerably with a slight increase in coil-to-part spacing. This condition is demonstrated in Figure 4-10. Calibrated measurements of lift-off can be used to determine the thickness of nonconductive coatings on conductive parts.

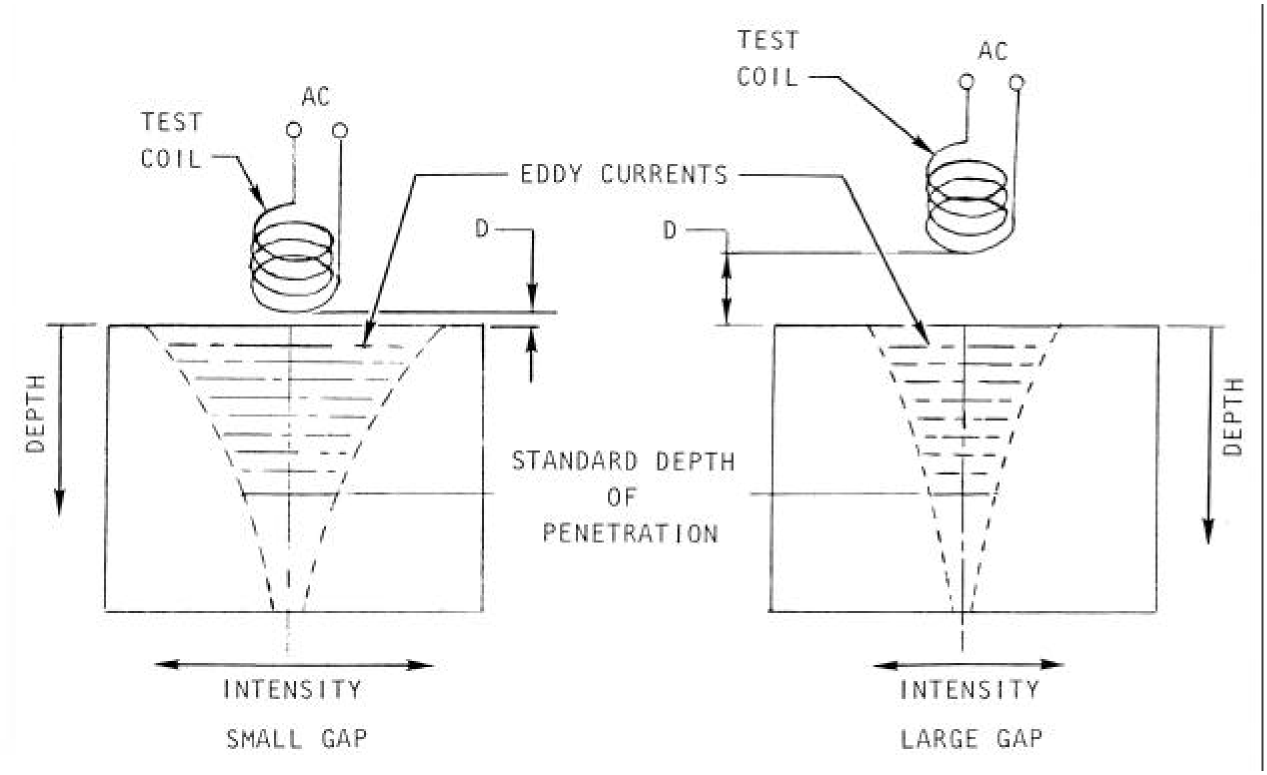


Figure 4-10. Relative Intensity of Eddy Currents with Variations in Lift-Off.

4.2.2.2.4 Fill Factor.

When an encircling coil is used to inspect a cylindrically shaped part, the degree of magnetic coupling is dependent upon the difference between the internal diameter of the coil and the external diameter of the part. This effect is termed fill-factor (see Figure 4-11) and is designated by the ratio of the squares of the diameters as follows:

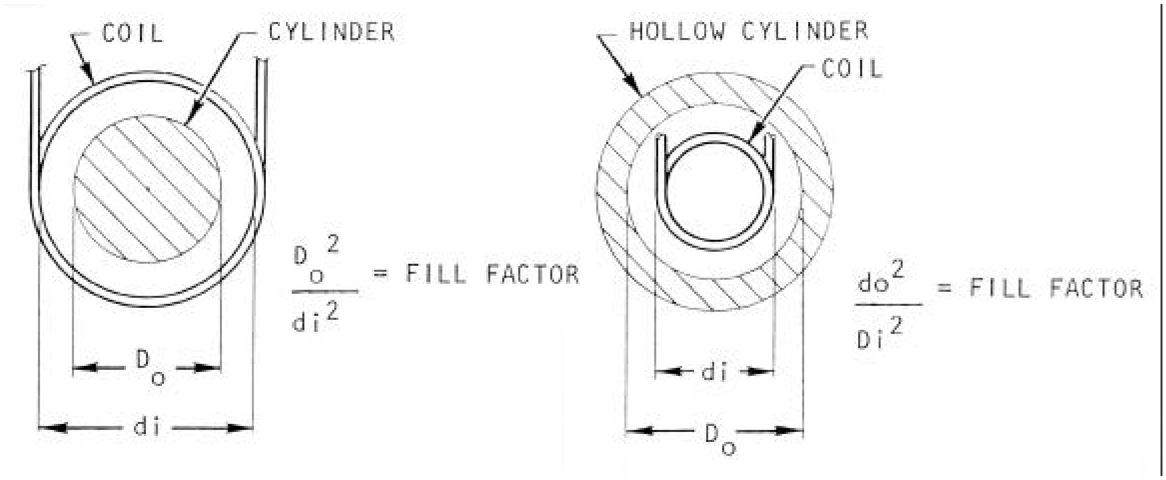


Figure 4-11. Fill-Factor.

$N=(D_0/d_i)^2$
Where:
N = Fill factor
D_o = Outside diameter of test part
d_i = Inside diameter of coil

For example, if an encircling coil with an internal diameter of 2.25 inches were used to inspect 2.00-inch diameter rod, the fill factor would be:

$$N=(D_0/d_i)^2 = (2.00 / 2.25)^2 = (0.889)^2 = 0.79.$$

4.2.2.2.4.1

For internal coils, electromagnetic (inductive) coupling is determined by the air gap between the external diameter of the coil and the internal diameter being inspected. Fill-factor is again calculated using the above formula, but in this case "d_i" is the inside diameter of the part and "D_o" is the outside diameter of the coil placed in the part. For example, if a coil with an external diameter of 1.5 inches is used to inspect tubing with an internal diameter of 1.6 inches, the fill factor is given by:

$$N = (1.5/1.6)^2 = (0.9375)^2 = 0.88.$$

4.2.2.2.5 Coil Current.

With all other factors constant, an increase in current flowing through the coil results in a higher magnetic field strength (H) applied to the inspection part in accordance with the following equation:

$$H = 4 (3.14) N I/10 L = 4 (3.14) n I/ 10$$

Where:
H = Magnetic field along axis of coil (oersteds)
N = Number of turns
I = Coil current (amperes)
L = Length of coil (cm)
n = Number of turns per unit length $= N / L$

4.2.2.2.6 Temperature.

The temperature at which an inspection is performed affects both the electrical conductivity and the ferromagnetic properties of the inspection article. Electrical conductivity generally decreases with increasing temperature, and conversely increases with decreasing temperatures. The reduction at higher temperatures occurs because of the scattering of conduction electrons by atoms moving with increased thermal oscillations. Temperature effects on the ferromagnetic properties of a material are generally negligible with one exception. Above a specific temperature called the Curie temperature, (about 1400 ° F) ferromagnetic properties disappear. However, rarely is eddy current inspection performed above this temperature. Because of the thermal effects on conductivity, increasing temperature of the inspection article slightly decreases the intensity of eddy currents at the surface of a part and slightly increases the depth of penetration. Temperature variations also affect the inductance of the coil. The main concern is that temperature changes that occur during the eddy current test can produce responses that could either mask or be mistaken for flaws or variability in properties of interest such as coating thickness or conductivity. Therefore, during inspections, time should be allowed for the test system and the test part to stabilize to the ambient temperature.

4.2.3 Intensity And distribution Of Eddy Currents.

4.2.3.1 Intensity at Surface.

The magnitude of the eddy currents at the surface of the inspection part is related to a combination of variables. One of these variables, the test system, is discussed in section 4.4. The other test variables and their influence are summarized in Table 4-4. In general, any change in a parameter that would tend to increase the intensity of surface eddy currents would also increase eddy current response to material properties immediately adjacent to the surface of an inspection part.

4.2.3.2 Depth of Penetration.

The intensity of eddy currents decreases exponentially with depth in a material. The intensity at any given depth is affected by the same variables that influence the surface intensity of eddy currents, although not always in the same manner or by the same amount. To put it another way, the depth of penetration of a specific intensity of eddy currents is affected by the variables, as indicated in Table 4-4. Generally, any parameter that increases the depth of penetration would provide an equivalent eddy current response at a greater depth in a test part.

4.2.3.3 Standard Depth of Penetration.

Three of these variables (conductivity, relative magnetic permeability, and frequency) are used to define the standard depth of penetration. Standard depth of penetration is the depth below the surface of the inspection article at which the magnetic field strength, or the intensity of the induced eddy currents, is reduced to 36.8 percent of the value at the surface. (0.368 = 1/e, where e = 2.71828, the base of natural logarithms). The standard depth of penetration is expressed by the following formula:

$$\delta = K_A / (\pi\ f\ \mu\ \sigma)^{½}$$

Where:

δ = One standard depth of penetration (inches)
π = 3.14
f = frequency (Hertz)
μ = relative magnetic permeability (1.0 for nonmagnetic material)
= Conductivity (%IACS)
$K_A = 46.12$

Example: Copper at 1KHz: $\delta = 46.12 / (3.14 \text{ x } 1000\ \textit{Hz} \text{ x } 1\ 100)^{1/2} = 0.008$ *inches.*

4.2.3.3.1

Because the depth of penetration is related only to a percentage of surface field strength or surface eddy current intensity, test variables that affect the strength of the field applied to the surface are not included. Therefore, coil configuration, size and current, and magnetic coupling are not considered in this formula. These variables affect the absolute magnitude of the eddy currents at a specified depth but not the standard depth of penetration.

Table 4-4. Effect of Changes in Test Variables on the Surface Intensity and Depth of Penetration of Eddy Currents.

Test Variable	Change in Variable	Effect on Surface Intensity	Effect on Depth of Penetration
Conductivity	Increase	Increase	Decrease
	Decrease	Decrease	Increase
Relative Magnetic Permeability	Increase	Increase	Decrease
	Decrease	Decrease	Increase
Geometry of Part	—	Variable	Variable
Discontinuity	—	Variable	Variable
Frequency	Increase Decrease	Increase Decrease	Decrease Increase
Electromagnetic Coupling	Increase	Increase	None
	Decrease	Decrease	None
Coil	Increase	Increase	None
Current	Decrease	Decrease	None
Temperature	Increase	Decrease	Increase
	Decrease	Increase	Decrease

4.2.3.3.2 Effective Depth of Penetration.

Effective depth of penetration is the depth in the inspection article at which the magnetic field strength or the intensity of the induced eddy currents is reduced to 5 percent of the value at the surface. This depth is approximately 3 times the standard depth of penetration. The effective depth of penetration is used to determine test frequency when working with thin materials, so the overall electromagnetic field does not extend beyond the back surface of the test part so that thickness variation effects can be suppressed.

4.2.3.3.3 Temperature Effects.

For most applications, temperature is not a major factor in determining depth of penetration. However, if necessary the effects of temperature would be included as adjustments to the values for conductivity and relative magnetic permeability used in the formula to calculate the standard depth of penetration.

SECTION III
ANALYSIS OF EDDY CURRENT SIGNALS

4.3 ANALYSIS OF EDDY CURRENT SIGNALS.

4.3.1 Overview of Signal Detection, Processing and Display.

4.3.1.1 Signal Sources.

Changes in an electrically conductive material close to a coil containing an alternating current can affect the resultant electromagnetic field from that coil. These material changes can be detected by monitoring the alternating current in the coil or using a separate sensing coil to monitor the resultant electromagnetic field. Changes so detected are the eddy current inspection signals. These signals can be analyzed for information relevant to the inspection being conducted.

4.3.1.2 Signal Detection.

A simple but effective signal detection technique is to use a bridge circuit as illustrated in Figure 4-12. With current flowing through the test coil and the coil positioned on a flaw-free or reference area, the variable impedance Z_1 can be adjusted so that zero current flows through the amplifier. This adjustment is termed either “balancing” or “nulling” the bridge. When the coil is placed on a flawed or damaged area, the resultant change in current through the coil “unbalances” the bridge and current flows through the amplifier. This current is the inspection signal. The signal has the same frequency as the current through the coil. The phase and amplitude of this signal contains information on the condition that caused the bridge unbalance.

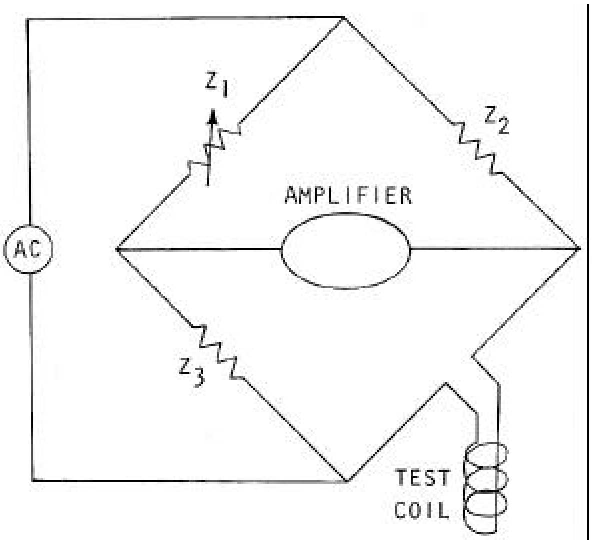


Figure 4-12. Simplified Bridge Circuit

4.3.1.3 Signal Analysis.

In the simplest type of instrumentation, analysis of the signal consists of measuring the change in magnitude of the current flowing through the bridge. Changes in the magnitude of the alternating current are amplified and converted to a direct current for display or readout. In more sophisticated instrumentation, both amplitude and phase are measured

4.3.1.4 Displays.

The method by which eddy current signals are presented is dictated by the type of information required and the complexity of the instrumentation. When only signal amplitude is measured, meters, alarm signals, or recorders are commonly used. When both amplitude and phase information are to be displayed, a cathode ray tube or some other two dimensional display device is normally used.

4.3.1.4.1 Amplitude Display.

Meters may be analog (needle moving over a fixed numerical scale) or digital. Audible or visual alarms may be set to trigger when the signal amplitude exceeds a predetermined threshold. A recorder presents a continuous record of the signal amplitude during an inspection for subsequent analysis.

4.3.1.4.2 Impedance Plane Display.

Defects or other variations in material characteristics will alter the strength and distribution of an induced eddy current flow. Changes in the eddy current flow will result in changes in the inducing coil or sensor coil currents. These changes can be expressed as an apparent change in the coil’s electrical impedance. This makes it possible to associate changes in material properties with specific changes in the apparent impedance of either the excitation or sensor coils. The two-dimensional display that permits this is the most commonly used and is called an impedance plane display. The usefulness of impedance plane displays will be discussed later starting with paragraph 4.3.2.5.

4.3.2 Impedance.

Impedance is the opposition to current flow and is a two dimensional parameter consisting of resistance and reactance. Resistance is the opposition to the flow of both direct and alternating current. Reactance is the opposition to flow of alternating current only. Reactance can be either capacitive or inductive. Both resistance and reactance are measured in ohms. Of primary interest in eddy current inspection are resistance and inductive reactance, the latter due to inductance of a coil. Capacitive reactance becomes significant in only a few cases and will be discussed later. The impedance of a test coil is related to the current flow in and voltage drop across the coil as follows:

$Z = E / I$

Where:

Z = Impedance of coil (ohms)
E = Voltage drop across the coil (volts)
I = Current through coil (amperes)

4.3.2.1 Resistance.

When AC or DC flows through a purely resistive element (i.e., a straight section of wire or a carbon resistor) of an electrical circuit, the impedance is resistance only and is expressed as:

$R = E / I$

Where:

R = Resistance (ohms)
E = Voltage drop across the resistor (volts)
I = Current flowing through circuit (amperes)

In an AC circuit containing resistance only, the voltage and the current are in phase. The term "in phase", when used to describe the relationship between the voltage and current, indicates that changes in current occur at the same time and in the same manner (direction) as changes in voltage. Figure 4-13 is an example of two quantities that are in phase.

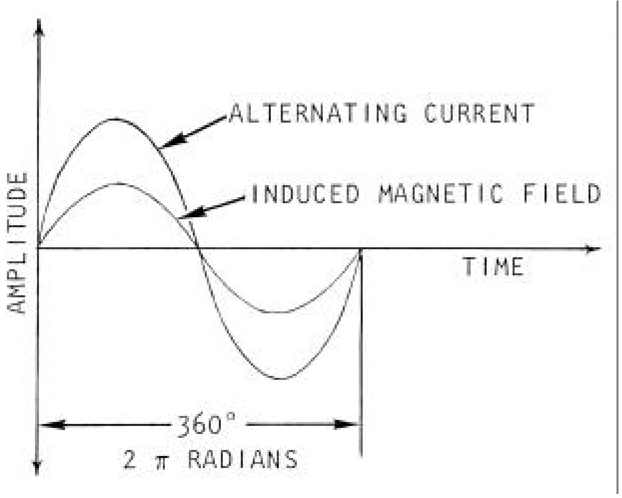


Figure 4-13. Sinusoidal In-Phase Variation of Alternating Current and Induced Magnetic Field.

4.3.2.2 Inductance.

The inductance of an eddy current probe is the result of magnetic field effects of the alternating electric current in the probe. Inductance is a measure of the capability of a circuit to induce current flow in another circuit. It is proportional to the ratio of the magnetic flux (ϕ) linking (encircling) a circuit to the current (I) that produced the flux. When the flux from one inductor is linked to (passes through) another inductor, the inductance is called mutual inductance (M). An electrical transformer is an example of a device where M is a significant parameter. For eddy current testing, we consider only the inductance of a single circuit element, specifically the coil used to sense changes in eddy current flows in test specimens. This inductance is called self-inductance (L).

4.3.2.2.1 Self Inductance.

Self-inductance (L) is expressed in henrys. A henry is the inductance by which one volt is produced across a coil when the inducing current is changed at the rate of one ampere per second. A formula for self-inductance expressed in these terms is as follows:

$$L = E / (\Delta I / T)$$

Where:

L = Inductance (henrys)
E = Induced Electromotive Force (volts)
ΔI = Change in Current (amperes)
T = Time (seconds)

4.3.2.2.1.1

Because the henry is such a large unit, inductance is more commonly expressed in terms of millihenrys (1/1000 henry) or microhenrys (1/1,000,000 henry). Typical coils used in eddy current inspection have self-inductances in the range of 10 to several hundred microhenrys.

4.3.2.2.1.2

The inductance of a coil depends upon the number of turns in the coil, the size of the coil, the permeability of the material within the coil (i.e., the core of the coil), and total magnetic flux through the coil. An alternate method of expressing self-inductance (L) is:

$$L = n\,\phi / I$$

Where:

L = Inductance (henrys)
n = Number of turns in coil
ϕ = Magnetic flux (webers)
I = Current through coil (amperes)

4.3.2.2.2 Inductive Reactance.

The measure of the amount of opposition or resistance (ohms) to alternating current flow due to inductance in a coil is called inductive reactance. Inductive reactance is dependent upon the value of the inductance of the coil and the frequency of the alternating current. The inductive reactance increases as the inductance or frequency increases. This can be stated by the following equation:

$$X_L = 2\,\pi\,f\,L$$

Where:

X_L = Inductive reactance (ohms)
f = frequency (Hertz)
L = Inductance (henrys)

4.3.2.2.2.1

The inductive reactance results from the electromotive force generated across a coil by the alternating current. The instantaneous value of this induced voltage increases and decreases as the rate of change of the applied alternating current increases and decreases as shown in Figure 4-14. The voltage is at its maximum value when the rate of current change is at its maximum; this occurs when the current value is at zero. Conversely, the voltage is zero when the rate of current change is zero; this occurs when the current is at its maximum value. Considering 360 degrees to be one complete cycle, the induced voltage leads the current (i.e., is out of phase with the current) by 90 degrees as illustrated in Figure 4-14. The induced voltage is in opposition to the electromotive force applied to the coil, reducing the amplitude of the resultant current.

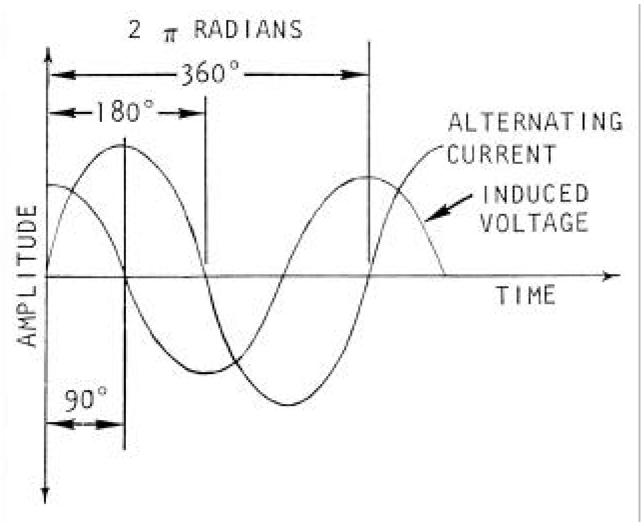


Figure 4-14. Sinusoidal Variation of Alternating Current and Induced Voltage in a Coil

4.3.2.3 Combining Out Of Phase Quantities.

A real coil has a resistive component of the impedance in addition to the inductive reactance. They can be combined to describe the net impedance. A coil can be considered to be a resistor in series with an inductor. Applying an alternating current to this series circuit will result in two voltages, one across the resistor and another across the inductor. The net voltage across the combination of the resistor and inductor, i.e. across a real coil, will be the combination of the two voltages. The voltage across the resistor will be in phase with the current while the voltage across the inductor will lead the voltage across the resistor by 90 degrees. The combination of the two voltages, as illustrated in Figure 4-15, results in a voltage that will be out of phase with the current but not by a full 90 degrees.

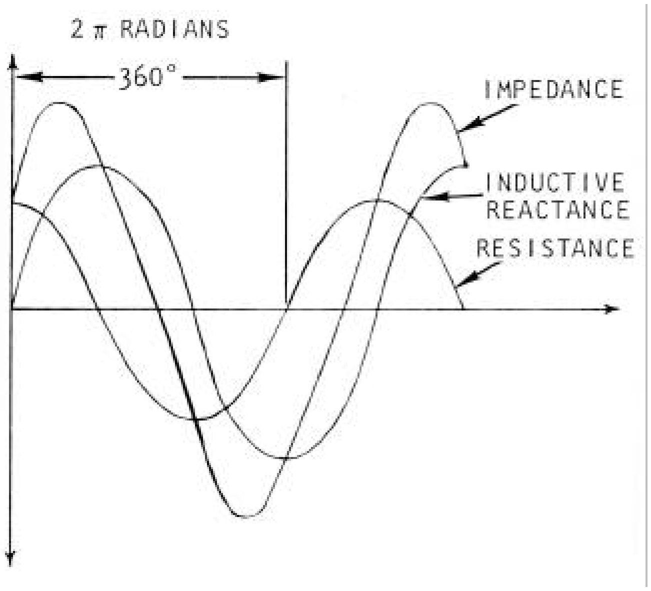


Figure 4-15. Combining of Out-of Phase Voltages

4.3.2.3.1 X-Y Plot Representation.

Another way to illustrate the combination of out-of-phase quantities in a coil is illustrated in Figure 4-16. Here the two voltages drop; one across the resistor (V_R) and the other across the inductor (V_L) are plotted at right angles to each other. This represents the two quantities being 90 degrees out of phase. The combination of the two quantities is represented by the diagonal line OA that is at the angle θ with respect to the voltage drop across the resistor.

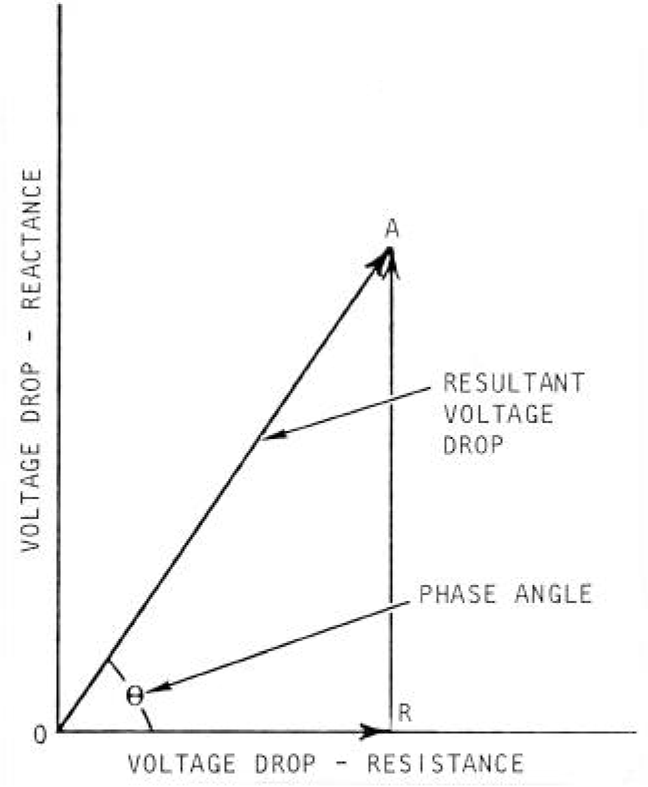


Figure 4-16. Vector Diagram Showing Relationship between Resistance, Reactance, and Impedance.

4.3.2.4 Impedance Plane Representation.

Just as the two voltages can be combined to produce the net voltage across a coil as illustrated in Figure 4-17; the resistive and inductive impedance components can be combined to produce the net impedance of a coil. In Figure 4-16, inductive reactance (X_L) is plotted on the y-axis and resistance (R) is plotted along the x-axis. These two values define the impedance that is represented by the vector OA. The value of the angle θ for the net impedance is the same as the angle θ illustrated in Figure 4-17 for the net voltage. This is important because it shows that the impedance of a coil can be displayed as the combination of two out-of-phase voltage drops. The amplitude of the impedance may be determined from the known values of resistance and inductive reactance according to the following formula:

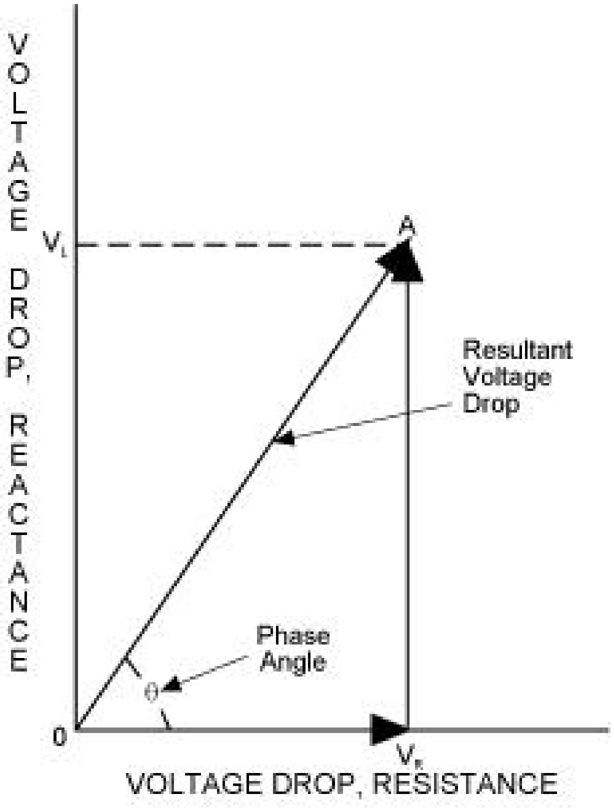


Figure 4-17. Diagram Showing Relationship of Voltage Drops across Coil Resistance and Coil Reactance

$Z = \sqrt{X_L{}^2 + R^2}$

Where:

Z = Impedance magnitude (ohms)
X_L = Inductive reactance (ohms)
R = Resistance (ohms)

The phase angle (θ) of the impedance can be calculated from the values of resistance and inductive reactance as follows:

$\tan \theta = X_L / R$

Where:

θ = Phase angle (degrees)
X_L = Inductive reactance (ohms)
R = Resistance (ohms)

4.3.2.5 Impedance Changes.

The impedance of a coil appears to change when it is placed adjacent to an electrically conductive or ferromagnetic part. The eddy currents induced in the part produce a secondary magnetic field that opposes the primary field. This opposing field also induces a current flow in the coil in opposition to the primary current. If the part is not ferromagnetic, the net magnetic field resulting from the combination of the primary and secondary fields is decreased in magnitude, as is the current flow in the coil. This is equivalent to decreasing the inductance and increasing the resistance of the coil. If the part is ferromagnetic, the net magnetic field is increased because of the magnifying effect of the relative magnetic permeability, but the current flow in the coil is decreased because of the opposing effect of the secondary magnetic field from the induced eddy currents. This is equivalent to increasing both the inductance and resistance of the coil. In this manner changes in a part that affect either the strength of the magnetic field at the surface of the part or the strength and distribution of the eddy currents in the part, change the apparent impedance of the test coil(s). These variations in current flow, both phase and amplitude, can be detected, amplified, displayed and analyzed as eddy current test results. The amplitude and phase changes in the signals can be related to changes in the parts inspected.

4.3.3 Impedance Diagrams.

4.3.3.1 Purpose.

The impedance diagram shows how changes in eddy current test variables change the apparent impedance of a coil. Typical variables displayed are electrical conductivity, relative magnetic permeability, fill-factor or lift-off, part thickness, and test frequency. Impedance diagrams are very useful for determining optimum inspection parameters and understanding eddy current results when more than one variable is changing.

4.3.3.1.1

The vector representation of inductive reactance on the y-axis and resistance on the x-axis of Figure 4-16 is the basis of the impedance diagram. Let the point A represent the impedance of a test coil while on a part. If the probe is moved to a place on the part with a flaw, the impedance will change. This new impedance can be represented by the point B, as shown in Figure 4-18. Each change in the impedance will create a new point on the diagram.

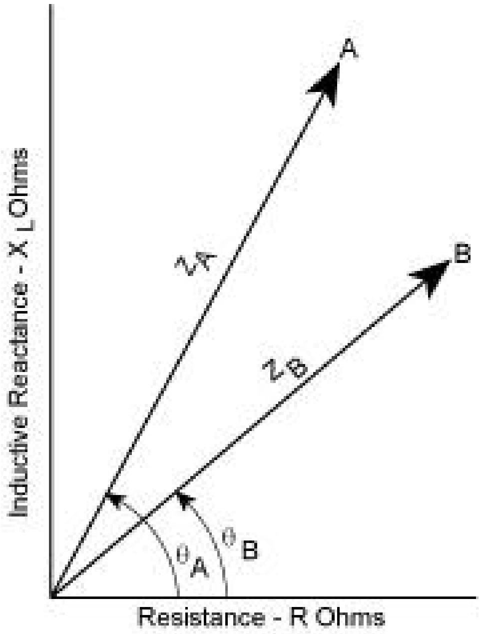


Figure 4-18. Vector Representation of Impedance

4.3.3.2 Development of an Impedance Diagram.

To make the impedance diagram into a useful tool for understanding eddy current testing, it is necessary to systematically change a single test parameter such as conductivity, and observe the changes in the impedance. Using an eddy current instrument with a two dimensional graphical display (such as the NORTEC-19E^{II}, MIZ-12, MIZ-17, or MIZ-20), a surface probe, a piece of ferrite (a nonconductive, ferromagnetic ceramic) and several nonmagnetic metal specimens representing a range of conductivity’s from low (titanium, Inconel) to high (copper, silver), approximate impedance diagrams can be developed and demonstrated. The specimens must have clean, flat, and bare surfaces. When the eddy current probe is held away from the part (in the air) and the instrument is nulled, an indication (spot) will appear on the display. The spot (null point) can be repositioned near the upper left hand corner of the display, as indicated by point A in Figure 4-19. The null point in air will be used as a point of reference for the rest of the diagrams. Next, the ferrite specimen is used to establish the direction of inductive change. Place the probe on the ferrite and adjust the phase control so that the change from air to ferrite is vertical (parallel to the y-axis). When the probe is placed on the copper specimen, the point will move to a new location on the screen, represented by point I in the figure. As the probe is lifted from the specimen, the point will move back to the air null point (A), as shown in Figure 4-19. The path that the indication follows as the probe is moved onto and off the specimen is called the lift-off trace/line.

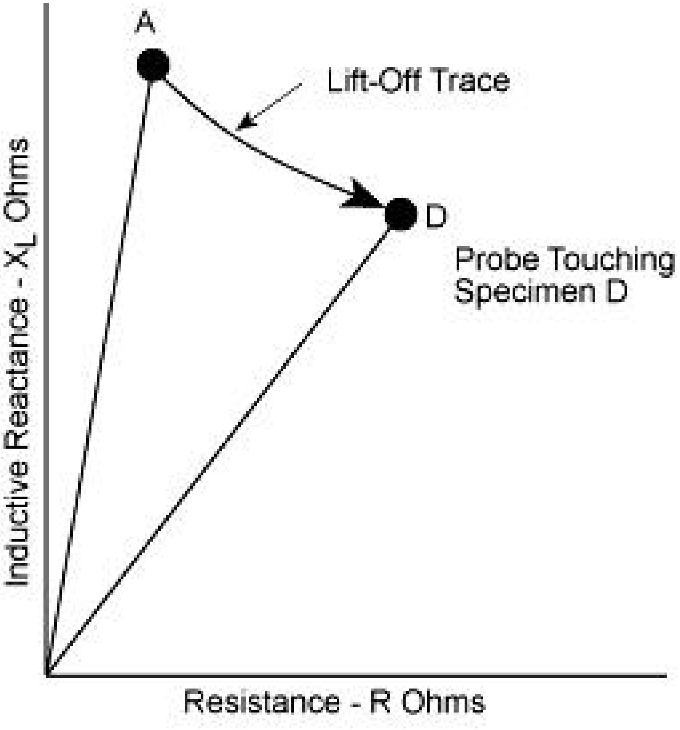


Figure 4-19. **Vector Representation of an Impedance Change Due to Lift-Off.**

4.3.3.2.1
The gain and phase controls can be adjusted to place point I anywhere on the display. Because copper has high conductivity, it will be convenient to adjust the gain to put point I in the lower part of the screen, as shown in Figure 4-20. When the probe is placed on the other metal samples, the respective impedance points (B through H in Figure 4-20) are recorded. Note that for each of the different materials, the point will be located at a different location on the screen (i.e., each different specimen has a different impedance). Each line from the null point A, to the impedance point for a particular specimen represents a lift-off trace. If a smooth curve is drawn from the null point (A) through each of the impedance points (B through I), a conductivity curve will be formed. The point on the curve closest to the air null point represents the material with the lowest conductivity (titanium, for example). The point on the curve farthest from the air null point represents the material with the highest conductivity (high purity copper). This diagram also shows the relative conductivity's of the other specimens.

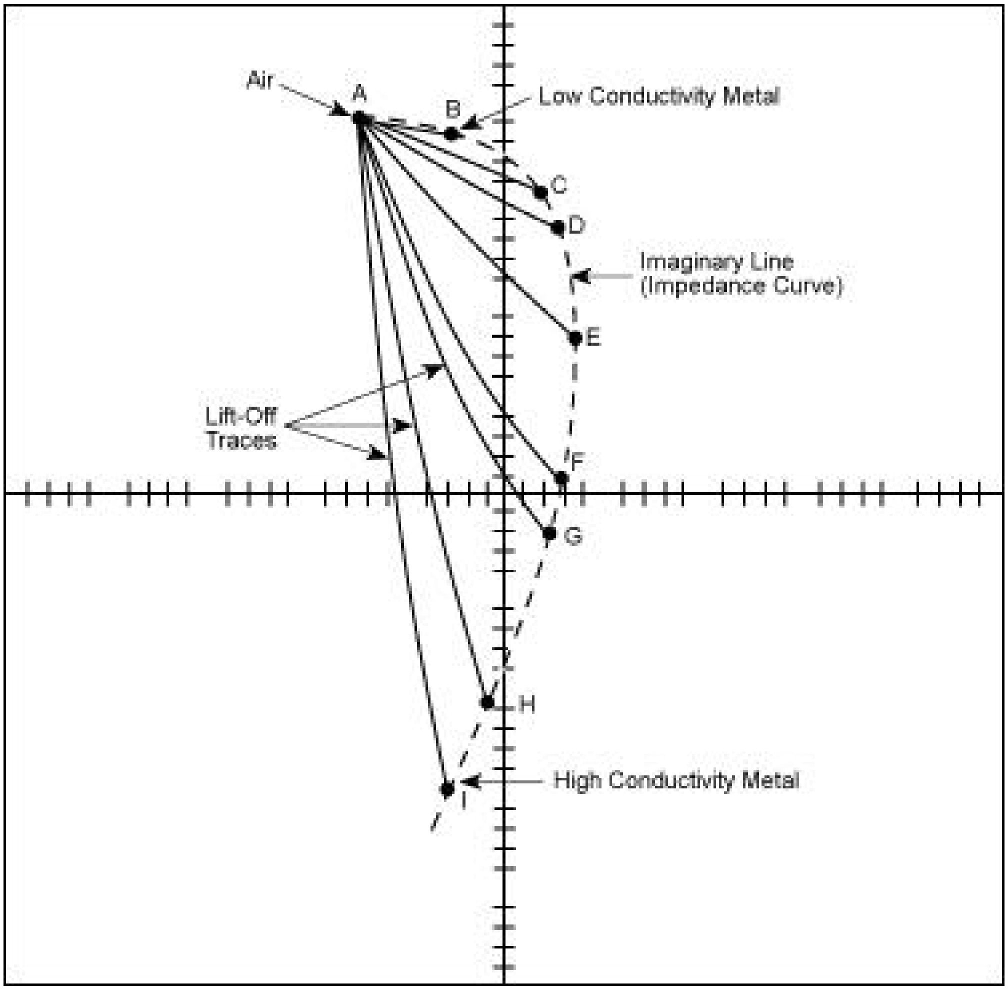


Figure 4-20. Impedance Diagram Illustrating Effects of Variable Conductivity

4.3.3.3 Typical Uses.

The impedance diagram shown in Figure 4-20 illustrates that the conductivity curve can be used to measure the relative conductivity of an unknown material by comparing the position of its indication on the conductivity curve to the positions of indications from known materials. Notice also that the lift-off lines are in a different direction than the conductivity line. Changes in conductivity and lift-off are said to have different phase angles. This phase angle difference is further illustrated in Figure 4-21.

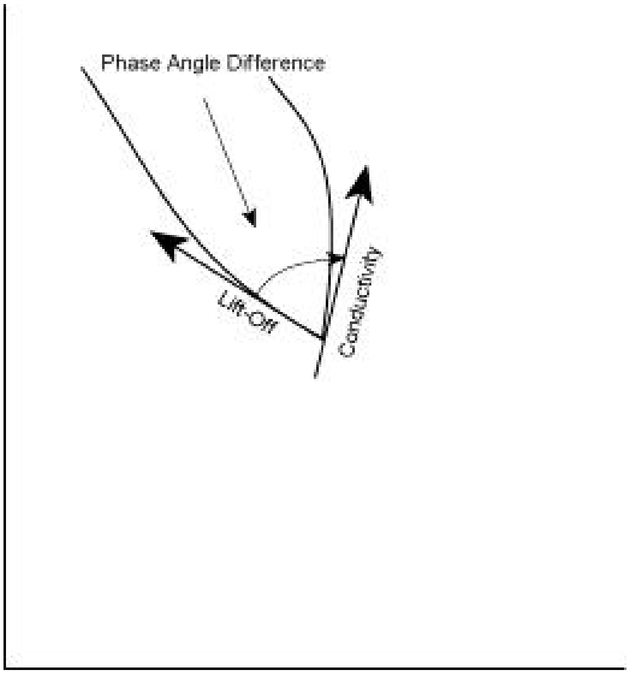


Figure 4-21. Phase Angle Difference between Lift-Off and Conductivity.

4.3.3.3.1
The lift-off curve can be used to measure the thickness of non-conductive coatings on a conductive surface. This is done by comparing the length of lift-off line for an unknown coating thickness to the lengths of lift-off lines for known thicknesses.

4.3.3.4 Normalization of Impedance.

To illustrate general principles of eddy current inspection or to present data in a universal form independent of specific coil impedance values, impedance diagrams are usually normalized. In normalization, the inductive reactance and the resistance of the coil on the part are divided by the value of the inductive reactance of the coil in air. Therefore, the vertical axis of the impedance diagram equals the relative inductive reactance ($X_{L,N}$) of the test coil; and the horizontal axis of the impedance diagram equals the relative resistance (R_N) of the test coil.

4.3.3.4.1
Normalization is a convenient method to allow comparisons of eddy current data from a large number of tests using different probes and materials. The shapes of the impedance diagrams remain the same. However, the air null point A in Figure 4-22 through Figure 4-23 becomes 1 on the y-axis of the impedance diagram after normalization. The impedance diagrams in this manual will all be represented by the normalized reactance ($X_{L,N}$) on the y-axis and normalized resistance (R_N) on the x-axis.

4.3.3.5 Effects Of Test Part Properties and Inspection Parameters on Impedance Diagrams.

4.3.3.5.1 Conductivity and Frequency.

An identical diagram could be developed to show the effect of changing frequency. One point on the curve would be established by nulling the probe in air and placing the probe on a specimen. Then, other points would be obtained by changing the test frequency, nulling the probe in air again, and placing the probe on the same specimen. After the data is normalized, a plot would be created. With increasing frequency the impedance of the probe on the specimen would move in the same direction as an increase in conductivity of the specimen. A decrease in frequency would cause the probe impedance to move in the same direction as a decrease in conductivity. The relationship between conductivity and frequency allows experience obtained from the eddy current inspection of one alloy to be transferred to the inspection requirements for an alloy of different conductivity by changing the frequency of inspection. As an example, an eddy current inspection for cracks in aluminum alloy 7075-T6, with a conductivity of about 30% IACS uses a frequency of 200 kHz. To perform a comparable inspection on a titanium alloy, TI 6-4 with a conductivity of about 1% IACS, a frequency of about 6 MHz would be required.

4.3.3.5.2 Lift Off.

As a test coil is moved away from a part (increasing lift-off) the coupling between test coil and inspection part is decreased. The magnitude of the impedance change for a specific change in an inspection variable is also decreased. For probe coils, the dotted lines connecting points representing the same material properties but with various amounts of lift-off have some curvature as evidenced in Figure 4-22. The line ABC represents the increase lift-off for material 1. Line DEF represents the increase in lift-off for material 2. The line from point A to point D represents the increase in conductivity of material 2 compared to material 1 at one lift-off value. With more lift-off, lines BE and CF are increasingly shorter, indicating a smaller indicated change in the conductivity.

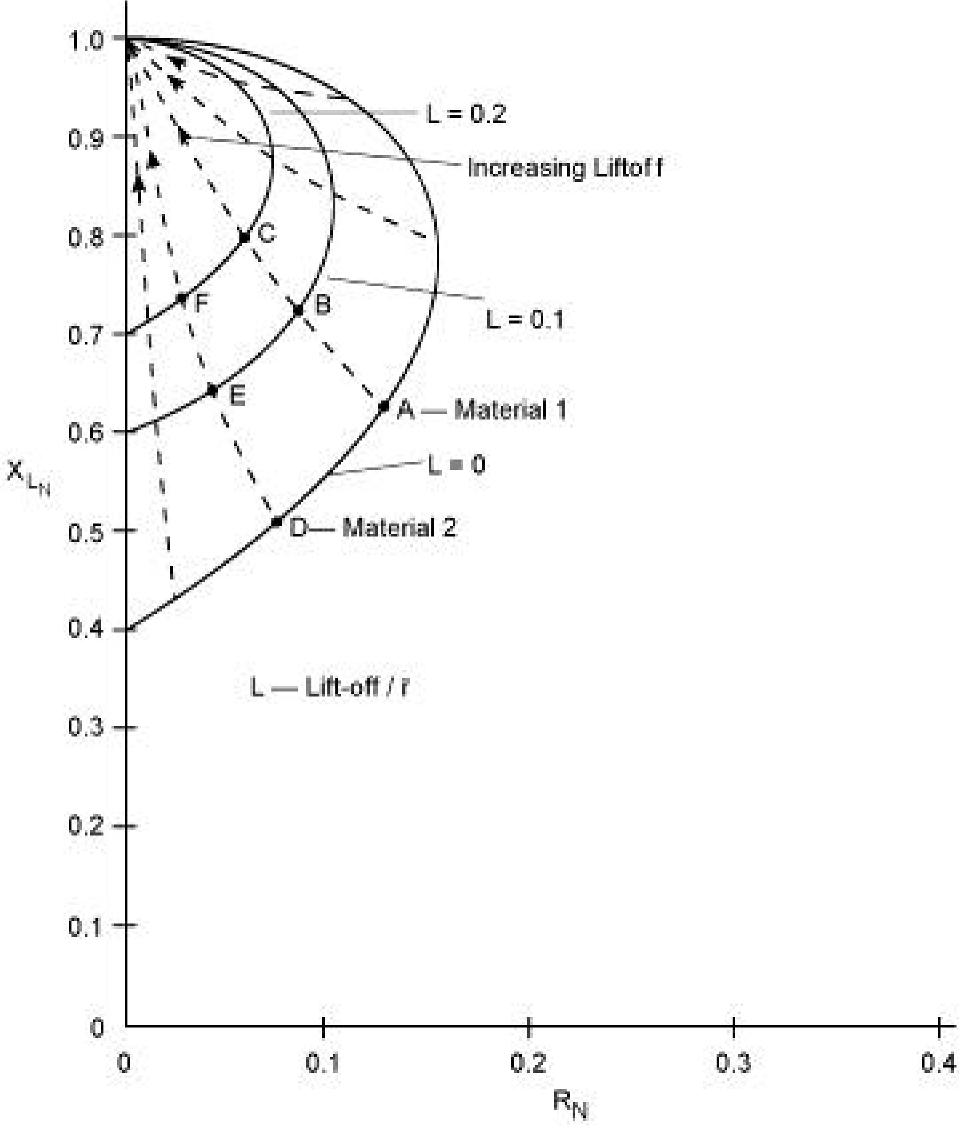


Figure 4-22. Impedance Diagram Showing the Effect of Lift-Off.

4.3.3.5.3 Relative Magnetic Permeability.

Although increases in conductivity of an inspection part or the test frequency result in a decrease in the normalized impedance of a test coil, an increase in magnetic permeability results in an increase in impedance.

4.3.3.5.4 Thickness Variations.

When the part thickness is less than the effective depth of penetration of the test coil at the inspection frequency employed, the impedance curve departs from the conductivity curve as shown in (Figure 4-23) Typically, there is an increase in the resistive component of the impedance with thinner parts, as compared to parts that have thicknesses equal to or greater than the effective depth of penetration (see paragraph 4.2.3.3.2). As the thickness of the parts increase and approach more closely the effective limit of penetration, the curve tends to spiral as it approaches the end point (T=1) on the conductivity curve, where T equals the ratio of the specimen thickness to the effective depth of penetration in that specimen.

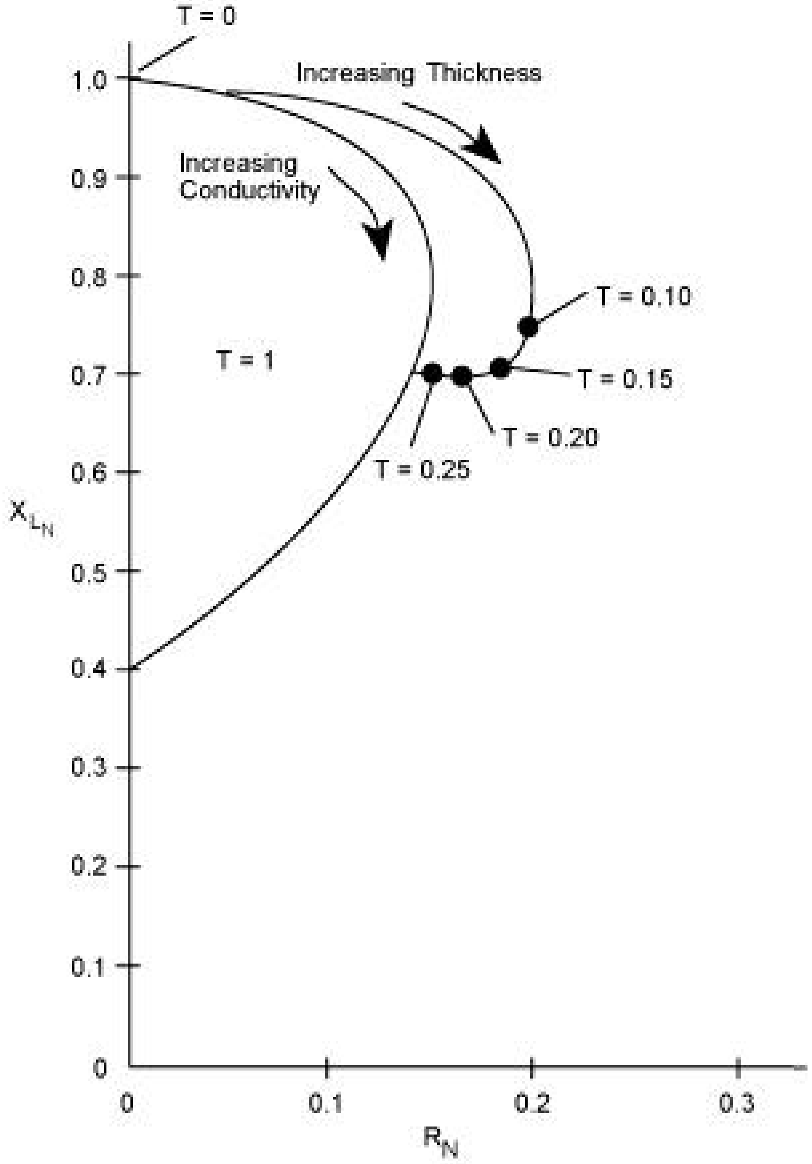


Figure 4-23. Impedance Diagram Showing the Effect of Specimen Thickness.

4.3.3.5.5 Conductive Layers.

The impedance curve for thin conductive layers on a substrate of different conductivity is also represented as a deviation in the impedance curve for conductivity. The impedance for the layered material departs from the conductivity curve at the value corresponding to the substrate conductivity and forms a loop that rejoins the conductivity curve at the conductivity of the metal in the outer layer. Increasing thickness of the outer layer corresponds to a clockwise direction along the loop. The point at which the loop rejoins the curve represents the effective depth of penetration in the coating.

4.3.3.5.6 Cracks, Lift Off and Conductivity.
The impedance changes due to surface cracks of different depths. The change for cracks will lie between the lift-off and conductivity (σ). As the crack depth increases the response moves further from lift-off and closer to decreasing conductivity (σ).

4.3.4 Heat Treat Condition or Hardness.
Heat treating (or age hardening) a metal changes its hardness and its electrical conductivity. Just as above, the aluminum alloys have been the most investigated for the hardness/conductivity effect. Again, the impedance change is along the conductivity curve in the range of 25% IACS to 65% IACS.

4.3.4.1 Temperature
Changing the temperature of a part changes its electrical conductivity. All metals become less conductive as temperature rises. This would be seen on the impedance plane as a movement along the conductivity curve toward the zero (air) end of the curve. For aluminum alloys, conductivity decreases about 1% IACS for a 20^{O} F increases in temperature (see Figure 4-24).

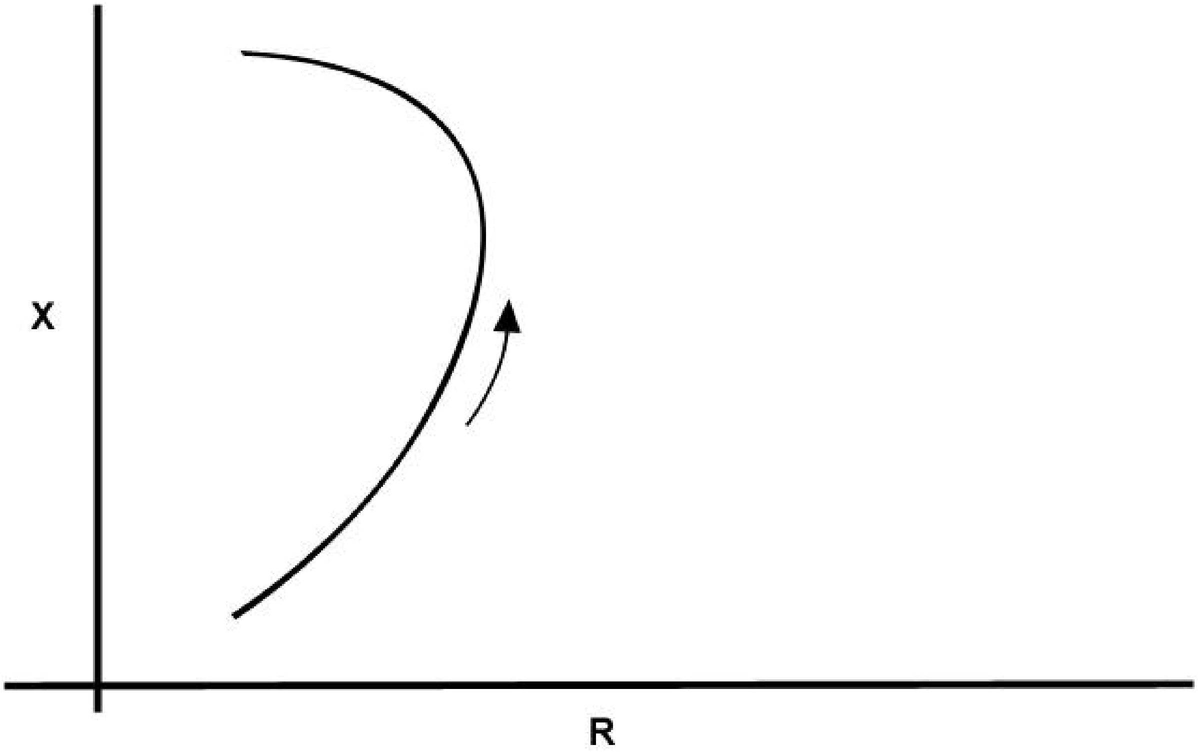


Figure 4-24. Effect of Temperature Increase

If a conductivity meter is being used to check for proper alloy or heat treat condition, the temperature of all parts and calibration standards must be the same and kept constant. A change in temperature could be interpreted as a change in alloy or hardness, since all three factors may change the conductivity of a metal.

4.3.4.2 Crack Detection, Nonferromagnetic Materials
As discussed previously, the amplitude of the response from a surface crack increases as the crack gets deeper. When the crack reaches three standard depths it is interrupting essentially all of the eddy current flow and no increase in

amplitude is seen as it gets still deeper. Besides an amplitude increase for deeper cracks, the phase angle of the crack indication changes. A shallow crack interrupts little of the eddy current flow, so the amplitude of its signal is small. Also, it is essentially a surface condition, so the direction (phase) of the signal response is very close to that of lift-off (see Figure 4-25).

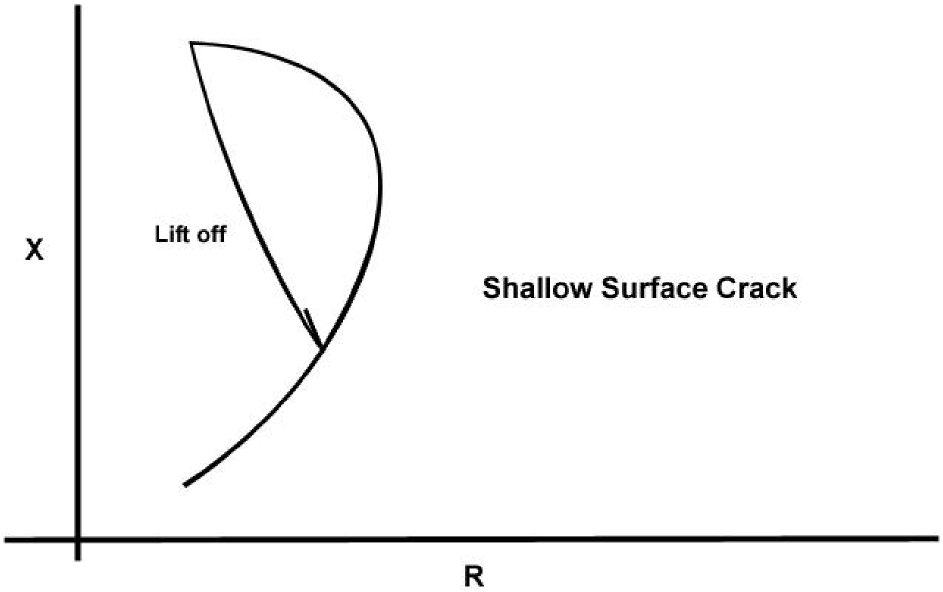


Figure 4-25. Shallow Surface Crack

4.3.4.2.1
A deeper crack interrupts more of the eddy current flow, so its signal has greater amplitude. Since it extends well below the surface, the direction (phase) of its signal is farther away from lift-off (see Figure 4-26.)

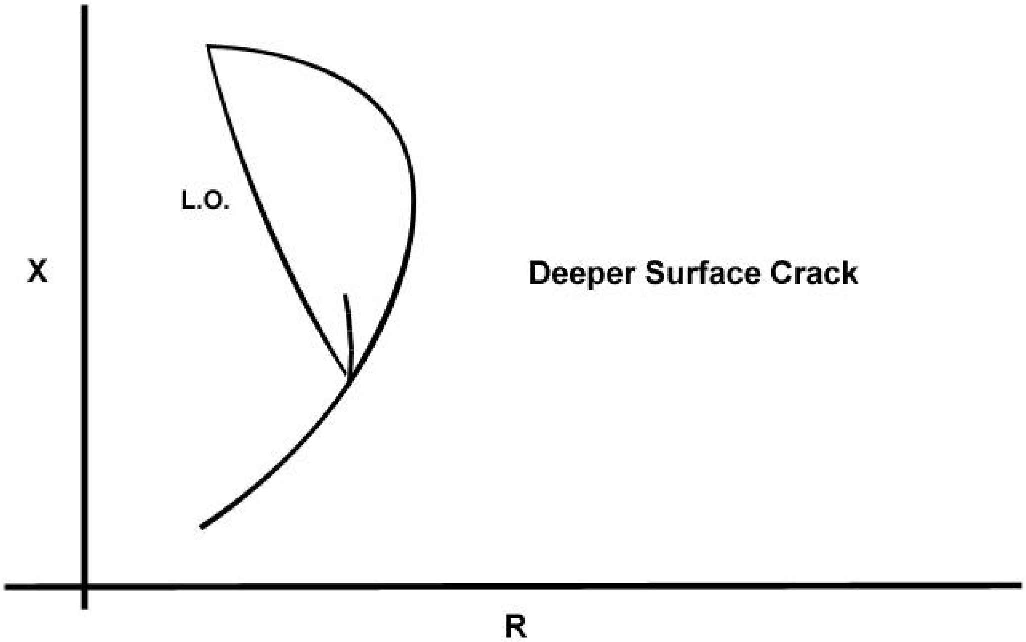


Figure 4-26. Deeper Surface Crack

4.3.4.2.2

The three standard depths crack has the largest amplitude response. Since its interrupts the eddy currents as far down in the metal of the test can sense, it looks like a change in the bulk property of area of lower conductivity, and the crack signal direction (phase) is along the conductivity curve (see Figure 4-27).

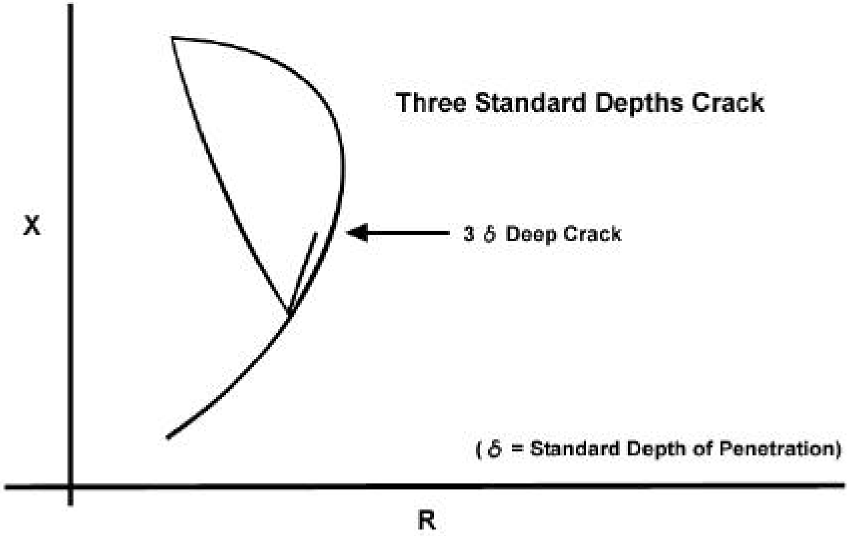


Figure 4-27. Three Standard Depths of Penetration.

4.3.4.2.3

It is obvious that making the 3 standard depths crack deeper will not change the response signal, since there is no more eddy current flow for it to interrupt. However, there will be a change in its signal if we submerge it below the surface. First, eddy currents will flow over the top of the crack (at the surface), it will therefore not be blocking as much of the EC flow, and the amplitude of the signal must decrease. Second, the crack is now farther away from the surface so its phase angle must be still farther away from lift-off (see Figure 4-28).

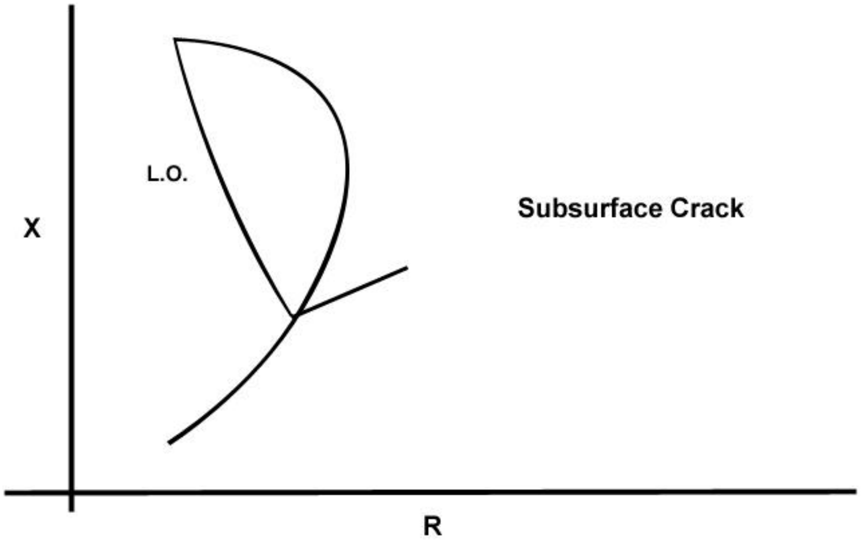


Figure 4-28. Subsurface Crack

4.3.4.2.4
This same effect continues as the crack is submerged deeper under the surface. The more subsurface the crack goes the less of the eddy current flow is interrupted, which decreases the amplitude of the crack response. And the farther away from a surface effect the signal amplitude gets smaller and the phase angle rotates clockwise, away from lift-off (see Figure 4-29).

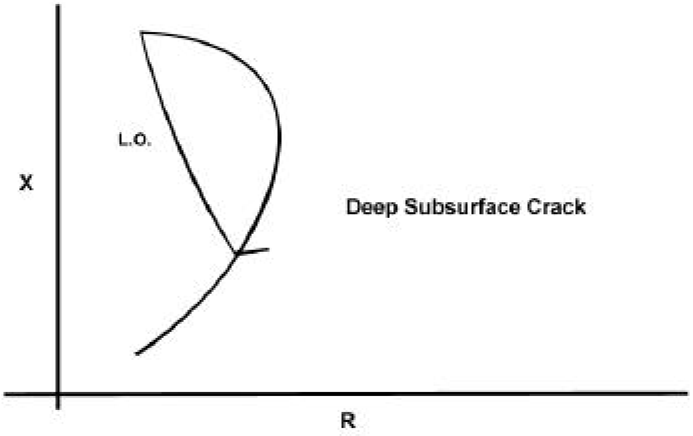


Figure 4-29. Deep Subsurface Crack

4.3.4.2.5
Another explanation for this phase angle shift is that changes in the eddy current field take time to travel any distance. Changes at the surface of the part are seen immediately by the coil, while disturbances to the field at some depth in the part require some travel time to return to the surface where they are seen by the coil. Electrically, this is described as phase lag at depth, and the amount of phase lag is 1 radian (57^{O}) per standard depth of penetration (see Figure 4-30).

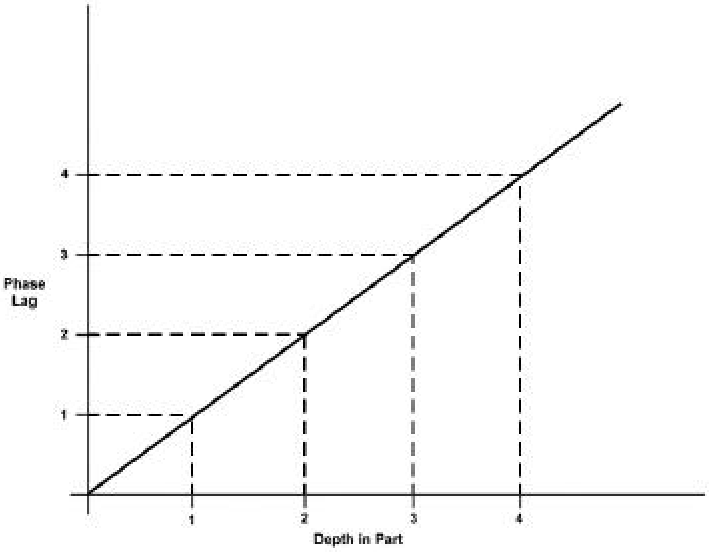


Figure 4-30. Depth in Part

This phase lag from the lift-off (surface) signal may be used to measure the depth of defects, and this effect is put to good use in tube testing. The phase angle of a defect signal correlates to defect depth.

4.3.5 Impedance Plane Analysis.

Most eddy current inspection applications have two major problems to overcome. The first is to ignore changes in parameters not of interest during the test; an example is lift-off variation while inspecting for cracks. The second is to recognize valid indications while other changes are occurring. Another way of stating this is that variations in a parameter such as lift-off should not be mistaken for valid defect indications and valid defect indications should not be hidden by changes in parameters such as lift-off. Impedance plane analysis, also called phase analysis, is a tool that is effective in solving these problems.

4.3.5.1 Phase Adjustment.

In eddy current instruments with two dimensional displays, the signals displayed can be rotated to align the direction of changes caused by the variable of no interest with the horizontal (or vertical, if so desired) axis as shown in Figure 4-31. This is also called phase adjustment and its purpose is to position the response associated with lift-off variations in a direction that does not interfere with the interpretation of responses from variables of interest. The effectiveness of this technique increases as the phase difference between lift-off and the variable of interest increases from 0° to 90°.

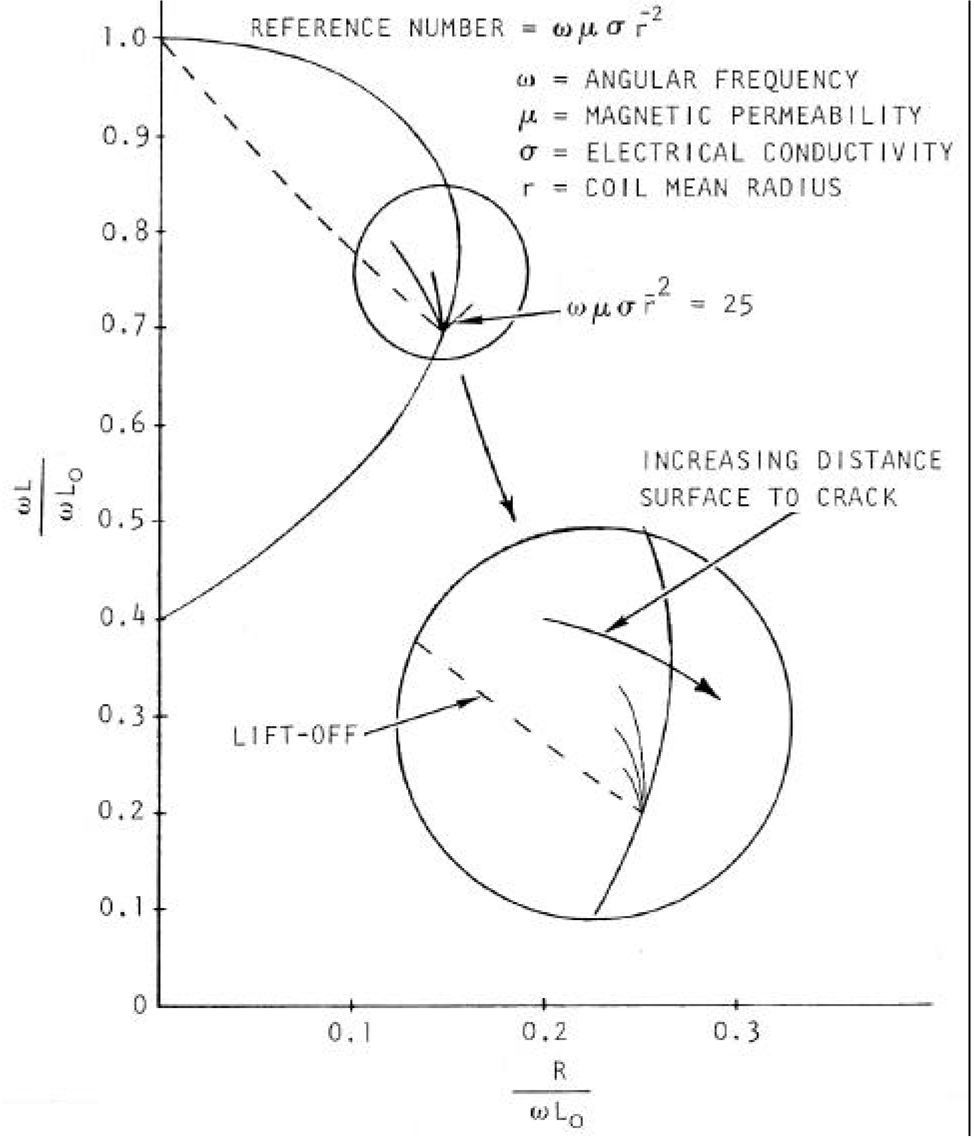


Figure 4-31. Impedance Diagram Showing the Effect of a Crack.

4.3.5.2 Operating Point.

The operating point, or null point, is that point in the impedance plane at which the eddy current instrument is nulled. For instrumentation with two dimensional displays, the operating point is usually the "good" or reference condition. For instrumentation with one dimensional or meter displays, this would be unsatisfactory because any change in the specimen would cause an unbalance of the bridge circuit with a subsequent indication displayed on the meter. It would be impossible to discriminate against any variable affecting the impedance of the test coil. Consequently, the operating point is displaced from the point representing null for a "good" condition.

4.3.5.3 Suppression Techniques.

Suppression techniques are used to eliminate or reduce instrument response to one or more inspection variables to permit better identification of changes in the parameters of interest during eddy current inspection. When the display is rotated as previously indicate, lift-off variations produce little or no signals in the vertical direction. Even though the crack signal is predominately horizontal, it has a significant vertical component. This vertical component can be amplified independently and monitored visually or electronically. A box gate is a rectangle whose position, height and width can be adjusted to selectively monitor a portion of the impedance plane. In the example shown, defect indications will enter the box gate over a fairly large area of lift-off conditions while the slight vertical component of these lift-off responses remains outside.

4.3.5.3.1 Ferromagnetic Materials.

Variability in permeability can make the eddy current inspection of ferromagnetic materials difficult. Permeability and lift-off have approximately the same direction of impedance change in unmagnetized ferromagnetic materials; but there can be very large variations in permeability that are very difficult to compensate for. Magnetic saturation can be employed to overcome the difficulties presented by permeability effects. In this technique, the material is magnetically saturated by a high DC magnetic field. This reduces the permeability to about 1 and makes it a constant. This results in a relatively low conductivity material, essentially non-ferromagnetic, for eddy current inspection applications.

4.3.5.3.2 Phase Discrimination.

Each of the eddy current inspection variables (lift-off conductivity, thickness, permeability, and flaws) has a characteristic effect on the net impedance of a coil. The display of the impedance curves caused by changes in the inspection variables can be of great assistance in determining the cause of a change.

4.3.6 Modulation Analysis.

Another technique that is useful in separating signals of interest from other signals relies on an analysis of signals as a function of time. Occasionally the suppression techniques discussed previously aren't sufficient to separate small defect signals from other non-essential signals. A straightforward procedure often used is to scan the part and display the resultant signals as a function of time or position on the part. These signals can be considered a modulation of the eddy current frequency and as such have frequency characteristics themselves. Often, the characteristics can be correlated to the presence of defects.

4.3.6.1 Frequency Response.

Frequency response analysis is the most common form of modulation analysis. During eddy current inspection, the impedance of the test coil remains constant provided there is no change in inspection conditions or material properties. When variations in impedance do occur, the rates of change in the impedance and resultant eddy current signal are proportional to the rates at which material properties are changing and the scanning speed. Consequently, a small crack would provide a rapid change in impedance during scanning and a corresponding high frequency eddy current signal. These signals can be viewed on a video display or a strip chart recorder as a function of time. Figure 4-32 illustrates the effect on amplitude as a result of encountering different kinds of material variations when scanning at a constant speed. A fast signal change is often a good indicator of a small flaw or an abrupt change in material characteristics; a slow signal change usually indicates a gradual change in dimensions, lift-off or some other property.

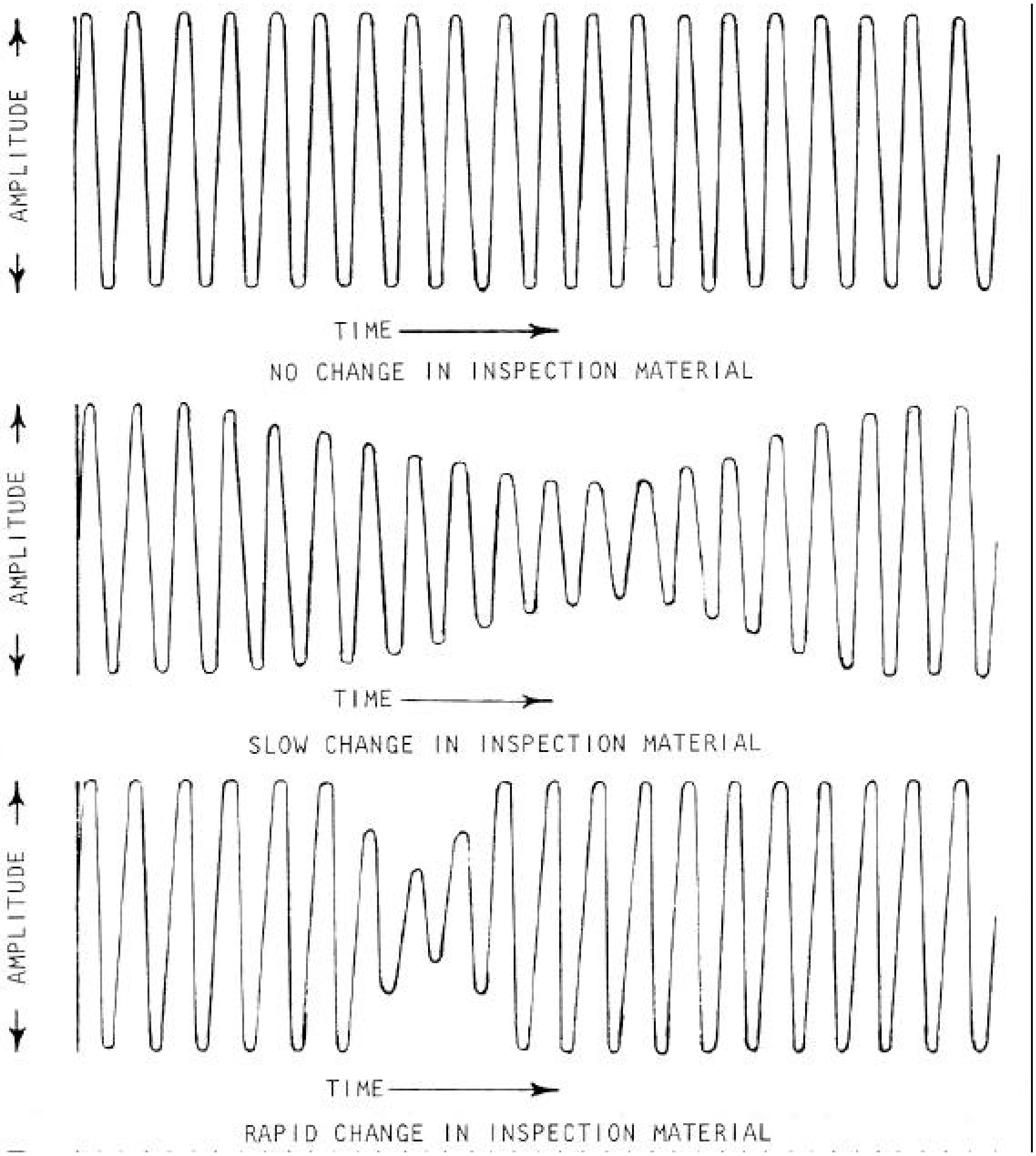
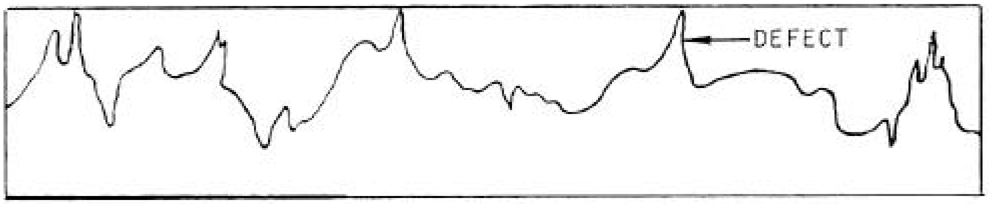


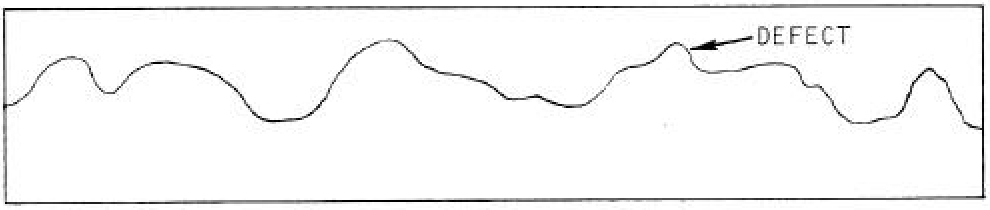
Figure 4-32. Effect of Material Variables on Magnitude of Alternating Current in Test Coil with Constant Scanning Speed.

4.3.6.2 Filters.

Filtering is often used to improve the signal-to-noise ratio in the eddy current signal display as illustrated in Figure 4-33. Three types of filters can be used; the high-pass, the low-pass, and the band-pass. High pass filtering removes the low frequency components of the eddy current signal from the bridge. This type of filtering can eliminate the effect of gradual variations in conductivity or dimensions on the eddy current inspection response. Low pass filtering removes rapid (high frequency) response from electronic noise and from harmonic frequencies related to variations in magnetic permeability. Band pass filters allow a response over a specific range of frequencies and suppress frequencies above and below this range.

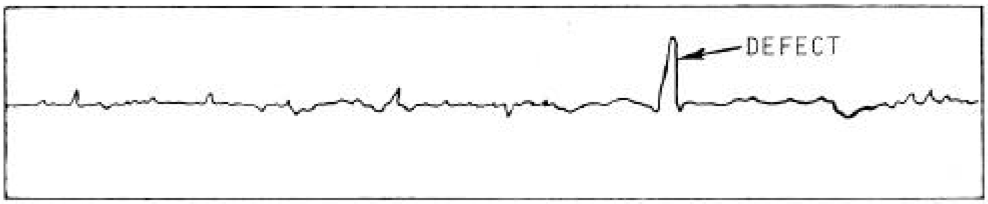


UNFILTERED DC SIGNAL



LOW PASS FILTERED DC SIGNAL

HIGH PASS FILTERED DC SIGNAL



BAND PASS FILTERED DC SIGNAL

Figure 4-33. Illustration of the Effects of Different Filters on the Eddy Current Signal.

SECTION IV
TEST SYSTEMS AND SUBSYSTEMS

4.4 TEST SYSTEMS.

4.4.1 Eddy Current Systems.

Eddy current systems generally consist of three subsystems. One is the probe or probe subsystem. Second is the eddy current instrument. The third is the accessory subsystem. Scanners and recorders are included in items considered accessories.

4.4.2 Probes (Coil Assemblies) - General.

4.4.2.1 Purpose.

Eddy current probes consist of one or more coils designed to induce eddy currents into a part being inspected and detect changes within the eddy current field. A fundamental consideration in selecting an eddy current probe is its intended use. A small diameter probe or narrow encircling coil will provide increased resolution of small defects. A larger probe or wider encircling coil will provide better averaging of bulk properties with a loss in sensitivity to small defects. Also the probe or coil must match the impedance range of the eddy current instrument with which it is to be used.

4.4.2.2 Classification of Probes.

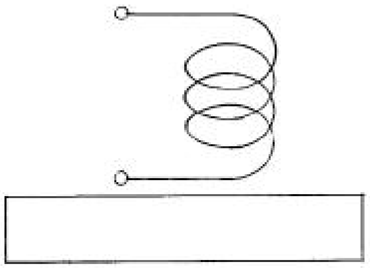
Eddy current probes and coils can be classified by mode of operation, application, or geometry.

4.4.2.3 Mode of Operation.

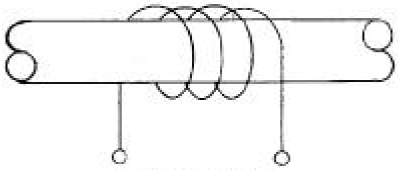
There are three general modes of operation for eddy current coil assemblies; absolute, differential, or driver/receiver (also called reflection). Absolute probes consist of a single coil and interrogate the area immediately adjacent to the coil. They may have other discrete electrical elements such as capacitors included in the probe housing for matching to specific equipment requirements. Differential probes, on the other hand, consist of two or more coils and operate by comparing the response of one coil to the response of another coil. Normally, one coil is used for interrogating the area of interest on the part while another coil is responding to an adjacent area on the same part or an area on a known good part being used as a reference standard. The usual equipment connections to the differential probe allow subtraction of the response of the reference coil from the response of the interrogating coil. Driver/receiver probes can have a wide variety of configurations but all have a driver coil physically separate from one or more receiver coils. The driver coil is used to induce the eddy current flow in the part. A common configuration for the receiver coils is for one receiver coil to be adjacent to the part inspected and the other to be removed from the part (but still within the probe housing and near the driver coil). The eddy current instrument is adjusted for zero output for this condition. Then as the area interrogated by the first coil changes, the eddy current instrument output changes in a manner that can be related to the change in the area inspected.

4.4.2.4 Method of Application.

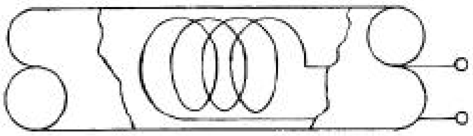
Eddy current probes can also be classified by the method of application. The most common application is the contact or surface probe used for flat or relatively flat surfaces of a part. Eddy current probes used to encircle a part are called encircling coils. Eddy current probes completely encircled by the part are called ID coils or bobbin coils. Through transmission probes, which utilize a coil on each side of a part (a sheet of aluminum for instance) is another method of application. All of these probe applications can be operated in absolute or differential modes (Figure 4-34 through Figure 4-36).



Surface Coil



Encircling Coil



Inside Coil

Figure 4-34. Basic Coil Configurations.

Figure 4-35. Typical Eddy Current Test Probes

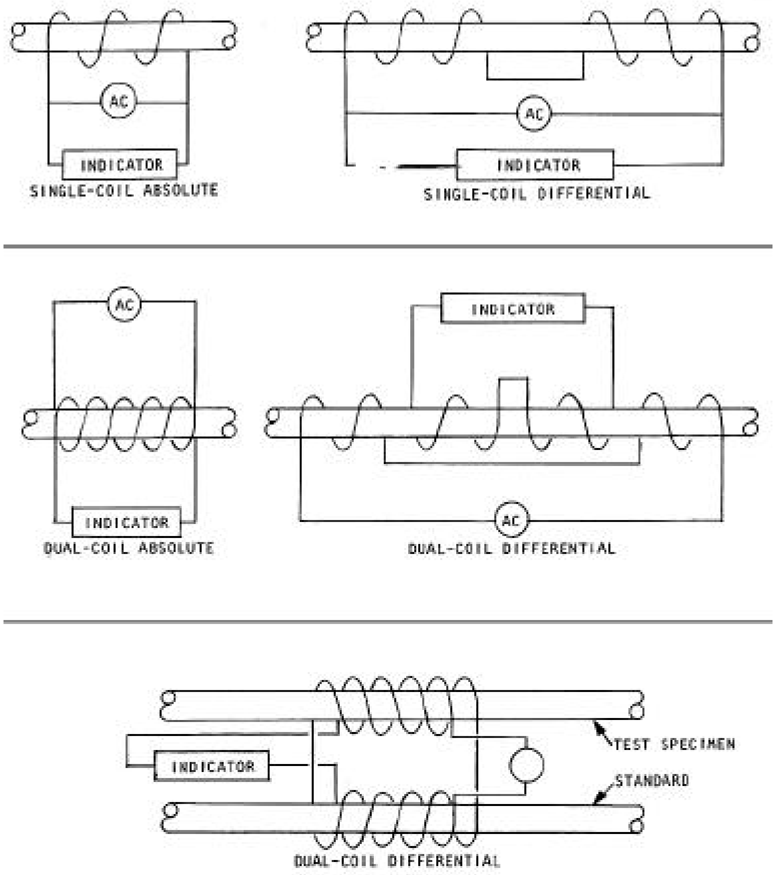


Figure 4-36. Single and Double Test Coil Configurations – Encircling Coils

4.4.2.5 Configuration.
Eddy current probes can also be classed according to the shape or some other prominent feature of the probe. Very thin probes are called pencil probes. Probes with special electromagnetic shielding are called shielded or focused probes. Probes used in rivet or boltholes are called bolt hole probes. Certain types of probes with shaped ferrite cores may be referred to as E-core, U-core, and pot or cup core probes.

4.4.2.6 Applications And Limitations - Surface Probes.
Most eddy current testing in the field is accomplished with surface probes. The surface probe is used on plate, sheet, irregularly shaped parts and in holes. The extent of the area to be tested by the probe is controlled by the coil diameter and by the presence of coil shielding. When the area to be scanned is large, pancake-type surface coils or overlapping multi-coil probes can be used to reduce the time required to inspect the part. When small flaws must be detected, coils as small as 1/32 inch in diameter can be used to examine limited areas.

4.4.2.7 Applications and Limitations - ID Coils.
An inside diameter (ID) coil may be used on tubes, pipes, or other cylindrical parts where the geometry is regular and the interior is accessible. The ID coil should nearly fill the part opening in order to provide a high fill factor for maximum test sensitivity. The use of ID coils can be restricted by bends or non-uniform diameters.

4.4.2.8 Applications And Limitations - Encircling Coils.
Encircling coils are used primarily for inspecting rods, tubes, cylinders, or wire in manufacturing applications. With both encircling and inside coils the entire circumference of the specimen is evaluated at one time. Consequently, while the axial location of defects (along the part length) can be determined, circumferential location (around the part) cannot be defined.

4.4.2.9 Probe Design Considerations.

Eddy current probes have several conflicting requirements. First, they must be a reasonable match to the electrical impedance requirements of the instrument to which they are connected. Also, the coils need to be sized for the flaw size to be detected with smaller flaws requiring smaller coils.

4.4.3 Eddy Current Instruments.

4.4.3.1 Functions.

The eddy current test instrument performs three basic functions. First, it generates the alternating current that induces the eddy current flow in the part to be inspected. Second, it processes the responses to the induced eddy current flow. Third, it displays the responses in a manner to aid interpretation.

4.4.3.2 Current Generators.

The current generator is usually a variable frequency oscillator operated at a single frequency for any given inspection. Useful frequencies can extend from less than 50 Hz to over 6 MHz. Newer instruments have provisions of providing multiple frequencies to the test coil(s), either sequentially or simultaneously.

4.4.3.3 Processing.

The processing function of the eddy current instrument includes a number of subfunctions. Most instruments include some form of a balancing or compensating circuit which is adjusted to provide essentially a zero output for non-flaw conditions. The simplest form of balancing circuit is a bridge circuit which is discussed more fully in subsequent paragraphs. The signal from the bridge circuit is amplified before proceeding to the detector and/or analysis circuitry. Signals can be analyzed for their amplitude and phase contents. The output from the analysis circuits may be further filtered to assist interpretation before display.

4.4.3.4 Display Methods.

The primary display method of most eddy current devices is either one dimensional, such as a meter, or two dimensional, such as a CRT or an LCD screen. The outputs can also be transferred to X-Y recorders, strip chart recorders, magnetic storage media or even computers to both generate inspection records as well as aid in the analysis of the eddy current signals.

4.4.3.5 General Eddy Current Instrumentation Requirements.

Eddy current instrumentation is the core of an eddy current system, whether the system is a simple instrument/coil combination or a fully automated scanning inspection station. In order to assure reliable operation, the instrumentation must have the capabilities described below.

4.4.3.6 Sensitivity.

The sensitivity to find the size and types of flaws to be detected.

4.4.3.7 Low Noise.

The noise should be low enough so that the signal from the smallest flaw to be found (or smallest calibration flaw) is at least three times the noise level of the instrumentation.

4.4.3.8 Response Time.

The response time of the circuitry must be fast enough to process and display signals at the required scanning rate.

4.4.3.9 Selectivity.

The instrumentation should be immune to external sources of electromagnetic interference.

4.4.3.10 Stability.

The instrumentation should be drift free during the required testing period.

4.4.3.11 Ruggedness.
The instrumentation must be capable of operating in the test environment. This may include a variety of environmental extremes of temperature, humidity, dust, and vibration.

4.4.3.12 Specific Instrumentation Requirements.
Choice of an eddy current test instrument must take into account the type of flaw to be detected, the permeability of the material (nonferromagnetic or ferromagnetic), type of probe to be used, display method (meter, CRT, digital display, recorders, etc.), test frequency, and signal processing requirements, portability, if needed, and any accessories to be used.

4.4.3.13 Instrumentation components.
In general most eddy current instruments consist of an oscillator, a bridge circuit or similar null balancing system, and a variety of other circuits for processing and display of the eddy current signal. Depending upon the complexity of the instrumentation and the requirements of the test, the following components will be present.

4.4.3.14 Variable Grequency Oscillator.
A basic eddy current instrument, while operating at a single frequency during a particular test, usually has an operating frequency range that is adjustable to meet a large variation of inspection situations. Low frequencies increase depth of penetration and consequently would be used for subsurface flaw detection or in high conductivity materials. Higher frequencies limit depth of penetration and thus are used for low conductivity materials as well as for detecting smaller flaws. Some instruments also incorporate a fine adjustment of frequency as a mechanism for suppressing lift-off. These instruments incorporate the probe coil in parallel with a capacitor as one leg of a bridge. The coil/capacitor combination is resonant near the intended operating frequency. The frequency selected for operation is off-resonant enough to where lift-off causes less of an impedance change than caused by a defect and the impedance change for increasing lift-off is opposite to that for a defect.

4.4.3.15 Bridge Circuit.
A basic bridge circuit is shown in Figure 4-37. In this example, a voltage is applied at points E_1 and E_2 to the bridge containing impedances Z_1, Z_2, Z_3, and Z_4. Z_1 and Z_4 are fixed impedances of the same value; Z_3 is an adjustable impedance; and Z_2 the unknown or test probe impedance. Initially, Z_3 is adjusted so that no current flows through the amplifier. This means the voltage at points A and B is the same and the bridge is said to be balanced or nulled. Any change in impedance of Z_2, the test probe impedance, will result in a current change through the leg of the bridge and consequently a change in the voltage at point B. A current will then flow through the amplifier, since a voltage or potential difference exists between points A and B. The bridge is now said to be unbalanced. The bridge can again be balanced by adjustment of Z_3 and the change in the test probe impedance, Z_2, may be determined by measuring the change in Z_3 required to rebalance the bridge. The bridge circuit in an eddy current test instrument is termed an impedance bridge since the circuit contains both resistive and reactive elements. Impedance Z_2 in Figure 4-37 would consist of the eddy current test coil. Other reactive elements, inductors, and capacitors may be included in the impedance bridge depending upon the specific design and function. However, the basic principle is that a change in impedance of the test coil results in an unbalance of the bridge circuit. The output (unbalance) from the bridge circuit can be amplified, processed and displayed.

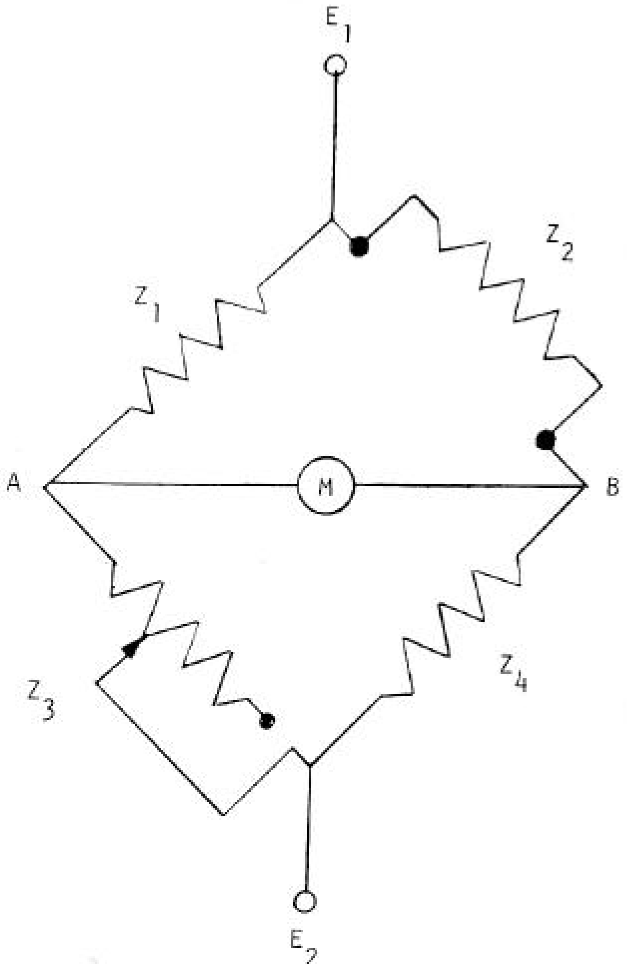


Figure 4-37. Basic Bridge Circuit.

4.4.3.16 Amplification Circuits.
The unbalance in the bridge circuit due to an impedance change at the test probe results in a change in signal amplitude, signal phase or both. These signal changes must be amplified, detected or demodulated, and processed for presentation on the output device (meter, scope, or recorder, etc.). The flaw signal may be only several microvolts in amplitude and may require amplification of one thousand to one million times for further processing and display. The frequency content of the flaw signal can range from very low (essentially DC) to the maximum operating frequency of the eddy current instrument. This defines the distortion-free frequency response of the amplifier. The amplifier must also be very stable with very little drift in order to maintain the required sensitivity and calibration throughout the duration of the test.

4.4.3.17 Special Circuits And Processes.
A wide variety of electronic techniques have been developed for particular inspection problems in eddy current testing. The circuits used depend upon the type of output, the type of flaw to be detected, or when a particular test variable (such as lift-off) must be suppressed in order to detect other conditions. The following circuits are commonly used by many eddy current test instruments.

4.4.3.18 Amplitude Detection.
If an eddy current system is required which only needs to detect signal amplitude changes without the use of phase information, amplitude detection with a simple diode type detector can be used. The diode rectifies the bridge output to

produce a variable amplitude direct current signal. This is the most common type of detection on meter types of eddy current instruments.

4.4.3.19 Phase Detection.

If an eddy current system is to be used to detect a variety of flaw conditions, phase angle measurements may be needed to determine the nature of the flaw condition. The information in the impedance diagram illustrates this fact. Decrease of conductivity (i.e., cracks) and permeability changes could produce the same signal amplitude, and it would be difficult to differentiate between cracks and normal permeability changes in a part. However, the phase angle of a conductivity change is very different from a permeability change if the correct test frequency is chosen. Using phase detection techniques, it becomes a simple matter to detect the difference between permeability variations and cracks. This also applies to determining the depth of a flaw which is phase sensitive or separating lift-off effects from flaw conditions. Phase sensitive detectors use a variety of techniques such as phase splitters, phase shifters, averaging, half-wave and full-wave detection, sampling, and subtractive and additive techniques. The presentation of the impedance plane on waveform display eddy current instruments utilize two phase sensitive detectors to provide horizontal and vertical phase detection. This information is combined to produce a dot or point on the screen which represents the relative phase and amplitude of an eddy current signal. Some types of meter instruments utilize an adjustable phase control or phase gate to allow only signal detection at a particular phase angle of interest.

4.4.3.20 Multifrequency Technique.

A single test frequency can provide phase and amplitude information for one material condition. If a variety of conditions are to be detected, there must be a frequency for each condition. Multifrequency eddy current systems, for example, can be used to detect the cracks in the presence of geometric changes in a complex part. Each condition to be suppressed must produce significant impedance changes for one frequency and less significant changes for the other frequencies used in the inspection. An example would be using a dual frequency inspection for subsurface corrosion while compensating for lift-off. A low frequency would be selected that would allow sufficient penetration to detect the corrosion. Lift-off responses would also be present from this frequency. A higher frequency would then be used that would respond to lift-off and not have sufficient penetration to respond to the corrosion. In this simple example, lift-off could be compensated for. The analysis of these signals can become extremely complex. Presently most multifrequency testing is limited to dual frequency testing and some three frequency testing. This technique is also used in tube testing to discriminate between ID and OD defects in tubing.

4.4.3.21 Pulsed Eddy Current Techniques.

The pulsed eddy current technique is a non continuous wave test technique and also has multifrequency characteristics. The width of the pulse establishes the lower frequency limit while the sharpness of the pulse corners establish the upper frequency limit.

4.4.3.22 Eddy Current Instrument.

Table 4-5 lists current eddy current instruments and their applications, features and limitations. Figure 4-38 through Figure 4-40 show examples of eddy current equipment.

Table 4-5. Eddy Current Instruments – Applications, Features and Limitations.

	General	Features			
Instrument	Application	Type	Frequency	Output	Limitations
Hocking UH-B Locator	Cracks and flaws in magnetic and nonmagnetic material; general purpose sorting.	Impedance (Amplitude only)	200 kHz 2 MHz 6 MHz	Meter	Single coil testing; no phase analysis; no low frequency capability.
Staveley NDT-19e	Flaw detection; conductivity and thickness measurement; multi-layer inspections; dual frequency mixing	Impedance Amplitude & Phase	Freq 1 = 50 Hz - 2 MHz; Freq 2 = 100 Hz - 1 MHz; Dual Freq: variable	Impedance plane display; recorder; external printer	
Staveley NDT-19eII	NDT-19e plus semiautomatic bolthole scanner				
Zetec MIZ-20A	Flaw detection, conductivity; thickness measurement; multi-layer inspections	Impedance Amplitude & Phase	50 Hz - 2 MHz, variable	Impedance plane display; recorder; external printer	No signal mixing (single frequency); no digital conductivity display
Physical Acoustics PD-214	Flaw detection, conductivity, thickness measurement, bolt hole scanner, probe characterization, C-scan, waterfall presentation	Impedance Amplitude & Phase	50 - 3 MHZ	Impedance display RS232 output Floppy disk external printer	
Zetec MIZ-22	Flaw detection, conductivity; thickness measurement; multi-layer inspections	Impedance Amplitude & Phase	Freq 1 = 100 Hz - 2 MHz; Freq 2 = 100 Hz - 1 MHz; Dual Freq: variable	Impedance plane display; recorder; external printer	

Figure 4-38. NDT-19eII Eddy Current Instrument.

Figure 4-39. Hocking Locator UH-B Eddy Current Instrument.

Figure 4-40. ZETEC MIZ-22 Eddy Current Instrument.

4.4.3.23 Presentations And Displays.

The output from an eddy current instrument may be read on a meter, impedance plane display, or recorder, depending upon the type of information required from the test. An analog (pointer) type meter is the simplest type of output indicator. An output consisting of amplitude and phase is called an impedance plane display, and can be displayed on either a cathode ray tube (CRT) or a digital display.

4.4.3.24 Meters.

Many of the portable flaw and conductivity testers use a meter that essentially indicates the degree of bridge unbalance in terms of amplitude. Depending upon the instrument circuitry, phase differences may also be displayed on a meter. Most eddy current instruments contain built-in output meters specifically designed or selected for use with the particular circuitry involved. The meter should have a speed of response sufficient to detect the discontinuities of interest at the highest expected scan speed. However, the meter should be sufficiently damped so that "noise" indications do not confuse the inspector, but not damped to the point that information of interest may be missed. Optimum meter response is a balance between speed of response and damping.

4.4.3.25 Cathode Ray Tube (CRT) Display.

The cathode ray tube (CRT) is a device for display and measurement of electrical phenomena. The CRT consists of four basic parts: a glass envelope, and electron gun, a means of deflecting or controlling the electrons produced by the gun, and a screen which transforms the electrical energy of the electrons from the gain into light. The screen consists of a phosphor coating on the inside face of the glass envelope (tube). When electrons strike the screen, light is generated. The relative length of time that the screen continues to glow or give off light after the electrons have gone is termed persistency. Generally, CRT persistency is on the order of 0.1 to 1 second. Storage oscilloscopes contain extremely long persistency CRTs, on the order of many minutes. Storage oscilloscopes are used in most CRT type eddy current equipment. A CRT output is used on eddy current instruments where impedance plane analysis techniques are required in order to separate test variable.

4.4.3.26 Digital Display.

Some eddy current equipment provides waveform output on a two dimensional display of small, square spots called pixels. Light is generated on such a screen by applying a small voltage to the individual pixels. A wave form is created by energizing the pixels that are needed to shape the appropriate waveform. Since the persistency of a digital display is controlled by an applied voltage rather than by electron impact with a phosphor coating, the persistency can be controlled by the operator. In general, the lighted pixel will remain lighted until the operator "erases" them by turning off the voltage to the pixels.

4.4.3.27 Impedance Plane Display.

Some eddy current equipment uses the vector point display technique of displaying information on a screen. Signal phase and amplitude are directly presented for analysis of the eddy current information. The display consists of a point of light rather than a waveform. Changes in the test article relative to the reference standard will cause the point of light to move. Movements of the point of light can be analyzed to determine which test variable (conductivity permeability or dimension) causes the change.

4.4.3.28 Linear Time Base Display.

Some types of eddy current test equipment use a linear time base display. The display's vertical signal, i.e., the phase shift, is received from the test coil. The display's horizontal signal, i.e., time, is received from a timing voltage. The timing voltage is adjusted to the frequency or period of the generator and provides a linear horizontal sweep of the vertical input voltage. A change in reactance of the test coil result, in a phase change of the voltage across one of the bridge circuit arms (vertical signal). This phase change is evidenced by a shifting (along the horizontal baseline) of the waveform. During operation, the timing or sweep voltage is used to adjust the display to show the desired number of waveform cycles (usually one). Generally control is also included in order to control the horizontal position of the waveform on the screen.

4.4.3.29 Recorders.

Recorders are used primarily in testing where the test coil or the test parts are moving relative to one another. Many newer applications using a test fixture and a mechanical scanner to move an eddy current probe across a specific area of a part can utilize a recorder to map the flaw indications in a part. Modulation analysis testing is an example of an older test technique that uses a recorder. A recorder for eddy current applications may be any of several types; however, the strip chart recorder is probably the most common. Other types of "pen and ink" and thermal recorders, as well as various "plotters", can also be used. Some of the newer eddy current instruments provide means of storing information on digital media. This is particularly useful where down time is important, since testing can be accomplished as rapidly as possible, and the information stored on tape for later analysis. When selecting a recorder for use with a particular eddy current instrument, several factors must be considered: impedance match between recorder and instrument; frequency response of recorder; recorder sensitivity (voltage range); and response time.

SECTION V
GENERAL APPLICATIONS

4.5 GENERAL APPLICATIONS — FLAW DETECTION.

4.5.1 Requirements For Eddy Current Flaw Detection.

4.5.1.1 Field Application.

Eddy current techniques are particularly well suited for detection of service-induced cracks in aircraft related materials in the field. Eddy current equipment is very portable, with many systems utilizing battery power. Eddy current inspection has greatest application for inspecting small localized areas where possible crack initiation is suspected rather than for scanning broad area of metal for randomly oriented cracks. In some instances, however it is more economical to scan relatively large areas with eddy current rather than to strip surface coatings, inspect by another method, and then refinish.

4.5.1.2 Sensitivity And Reliability Of Crack Detection.

In establishing eddy current procedures for crack detection, the following factors must be considered:

a. Location and size of cracks to be detected.

b. Type of material to be inspected.

c. Accessibility of inspection area.

d. Test system capabilities.

4.5.1.3 Flaw Detection.

Service-induced cracks in aircraft structures are generally caused by fatigue or stress corrosion. Both types of cracks initiate at the surface of a part. If this surface is accessible, either by direct surface contact or by penetration of the eddy current field through the material, eddy current inspection can be performed with a minimum of part preparation and a high degree of sensitivity. Unlike penetrant inspection, eddy current inspection can usually be performed without removing such surface coatings as primer, paint, and anodic film.

4.5.1.4 Inspection Material.

The material from which the inspection part is fabricated is of primary importance in determining the possibility of eddy current inspection and the limitations involved. The conductivity and magnetic permeability influence frequency requirements, instrument choice, signal-to-noise ratio, and resulting sensitivity and reliability of inspection. For example, aluminum, a material of intermediate conductivity, can be inspected for discontinuities up to 1/8" below the surface with modern instruments capable of operation at 1 KHz frequency. Titanium, a lower conductivity metal, would require higher frequencies in the range of 1 MHz to obtain optimum sensitivity. If surface cracking is to be detected in ferromagnetic material, a high frequency can be utilized to limit penetration and thus eliminate permeability problems (i.e. noise) common to ferromagnetic material testing.

4.5.1.5 Accessibility.

Most of the eddy current equipment presently available for use in the field is of the small, portable, battery powered type. This instrumentation permits operation in relatively tight quarters. However, eddy current inspection is only feasible for surface or near surface conditions because of its limited depth of penetration. For this reason, direct access to the surface to be inspected is usually preferred. Inspection from the opposite surface is limited to materials with low conductivity and magnetic permeability of 1. Sufficient freedom of movement must be available in the area to be inspected to allow positioning and movement of the probe to detect or measure the specified variable. The inspection area must be visible to enable the inspector to determine the position of the probe. Alternatively, a special probe, a fixture, or a guide can be used to position and hold probes in the required location. The extent of disassembly required for inspection should be defined in applicable written procedures.

4.5.2 Test Systems.

4.5.2.1 Crack Detection.

The test system for crack detection includes the probe (or probes), the eddy current instrument, any additional recording or measuring instruments, and calibration standards. For most crack detection applications, general purpose probes manufactured for the specific test instrument should be employed. A wide variety of eddy current units are fabricated for general purpose or specific applications. General purpose instruments are used for flaw detection. For some field applications, a small, lightweight, battery-powered meter output instrument is desirable. More critical inspections may require detailed phase and amplitude information which is most easily obtained with the scope type of eddy current instrument. Also the storage scope-type of instrument and magnetic tape recording systems are very useful for automated, high scan speed testing.

4.5.2.2 Probe Selection.

The primary consideration in selecting an eddy current probe is the type of inspection being performed. To detect small cracks, a probe coil of small diameter with a ferrite core is desirable to concentrate the induced field into a small volume. A small crack has a proportionately greater effect on a small probe field than on a large probe field. In general, cracks whose lengths are less than half the diameter of the coil are difficult to detect. In the event encircling coils or inside coils are used, short or narrow coils are preferred for inspection of small localized conditions. Spacing of the coils must be considered when determining the resolution required. The coil or probe must match the frequency range and output impedance of the instrument being used. In general, cracks whose lengths are less than half the diameter of the coil, are difficult to detect and will indicate a 50% decrease in amplitude.

4.5.2.3 Probe Housings.

The housing for most general purpose surface probes are cylindrical in configuration and from 1/8 to 3/8 inch in diameter. Probes can be shielded with either mu metal or ferrite to concentrate the field. When defect detection around fasteners, in radii, or adjacent to edges is required, it is often advantageous to have a pointed or small rounded tip at the end of the probe. The pointed end allows the probe to be inserted closer to the inspection surface, or edge, and permits better visibility of probe coil position. The advantages of a pointed probe for these applications are illustrated in Figure 4-41. For inspection of bolt holes, special probes are manufactured that permit contact with the side of the hole at any desired level in the hole. For inspection areas where accessibility is a problem, or where probe positioning is critical, it is often desirable to fabricate a special probe housing as an aid in performing the inspection. The use of special housings can greatly decrease the loss of sensitivity associated with probe wobble and lift-off during scanning. When large quantities of parts are to be inspected, special probes present a distinct advantage if they enable per unit inspection time to be reduced. Test procedures and Technical Orders for the eddy current inspection of specific aircraft components may specify the design and use of special fixtures when required.

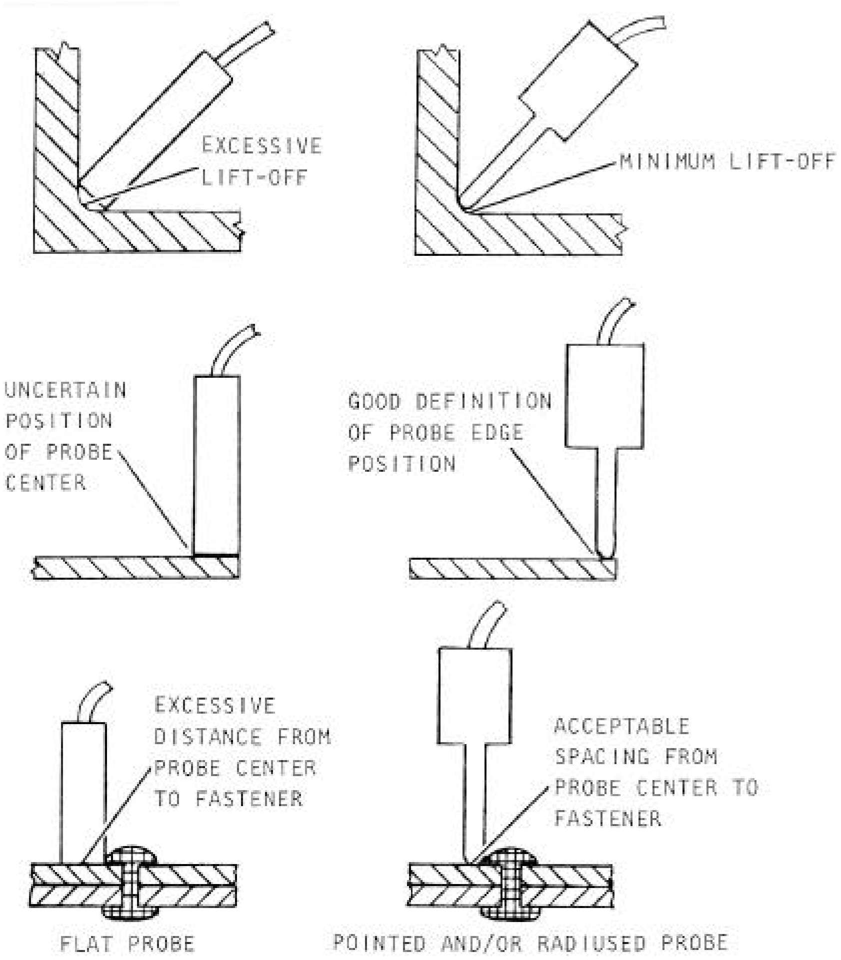


Figure 4-41. Advantages of Pointed and Radiused Probes for Eddy Current Inspection.

4.5.2.4 Probe Types.
The most common type of eddy current probe used in field applications is the absolute probe. The absolute probe contains a single coil that is placed in contact with or adjacent to the part being inspected. Since any changes in the area interrogated by the coil produce a response, absolute probes can be used to measure specific materials properties such as electrical conductivity and magnetic permeability. Differential probes contain two or more coils and are intentionally designed to produce a response when changes are sensed by the active coil only. Consequently, if the differential probe has two coils mounted side by side, gradual changes in electrical conductivity or magnetic permeability would be sensed by two coils simultaneously and no response would occur. On the other hand, if an abrupt change in conductivity should occur, localized to where it can be sensed by only one coil at a time, then there would be a response. Cracks cause a localized conductivity change and consequently can be readily detected by differential probes in the presence of slowly varying changes in electromagnetic properties or conditions that would cause interfering responses in absolute probes.

4.5.2.5 Sensitivity.
The ability of an eddy current instrument to detect small variations in test coil impedance is a measure of its sensitivity. This quality is interrelated with the properties of the test coil and the operating frequency. Therefore, instrument sensitivity to a particular flaw condition or material property should be established from calibration standards representing this condition.

4.5.2.6 Frequency Requirements.
As the eddy current test frequency is increased for a specific eddy current application, the eddy currents are confined to a smaller volume adjacent to the inspection probe coil. This concentration increases the proportion of generated eddy currents intercepted by a small crack or other defect. Higher frequencies should then provide better response to the smallest defects. This statement holds in general, but other conditions may limit the sensitivity when using higher frequencies. In some instruments, high induction losses limit instrument output at these higher frequencies. Lower frequencies may be required for increased penetration to detect subsurface or far surface flaws. Optimum sensitivity to cracks or other flaws generally occurs in specific frequency ranges for each combination of metal, flaw size and flaw depth. Operating frequency ranges can be established for each application by using the calculated depth of penetration using the conductivity and permeability of the material. These calculations should be confirmed with the use of calibration standards which simulate the anticipated flaws to be detected.

4.5.2.7 Resolving Power.
The ability of a test system to separate the signals from two indications that are close together is defined as resolving power. This property plus sensitivity must be considered in every flaw evaluation situation. Probe design, test frequency, and instrumentation design are all factors in determining the resolution of an eddy current system.

4.5.2.8 Signal To Noise Ratio.
As the gain of a test system is increased, a background of electrical noise will be observed. This may be represented by erratic meter movement, excessive background signals on a waveform display, or excessive, random patterns on a recorder. This "noise" can be the result of random variations in the electrical system of the test instrument, normal variations in material properties, or stray electrical signals from other electrical devices. Signal-to-noise ratio is not a function of the instrument alone, but is also dependent on lift-off, surface finish, and conductivity and permeability variations within the inspection part. In order for an eddy current test instrument or any other electrical test instrument to be useful, it must provide flaw signal information that is greater than the background noise of the test system. Otherwise the inspector could not see the difference between the flaw signal and the background noise. For maximum reliability in eddy current inspection, a high signal-to-noise ratio is desired. Unless the signal from the crack or other flaw for which inspection is performed is significantly greater than the signals from electronic noise and from material and test variables for which inspection is not being performed, the desired signals may be lost in the noise. No specific signal-to-noise ratio is mandatory, but a minimum of 3-to-1 is desirable for flaw detection.

4.5.2.9 Signal To Noise Ratio And Sensitivity.
As the required crack size to be detected is decreased, the gain or sensitivity of the eddy current instrumentation must be increased to provide readable indication from small cracks. The higher gain results in greater indications from small cracks. The higher gain also results in greater response from variables other than cracks and the noise level

increases. This decreases the signal-to-noise ratio, making it more difficult to observe the small flaw indication. The decrease in signal-to-noise ratio lowers the reliability of the inspection. Therefore, an increase in gain will increase the amplitude of the flaw signal as well as increase the level of noise. Thus, useful sensitivity must be measured in relation to the noise of the test system.

4.5.2.10 Influence Of Frequency On Noise.

Increasing the operating frequency for eddy current inspection improves the sensitivity to near-surface defects but also tends to increase noise from surface related factors such as lift-off scratches, rough surface, and probe wobble.

4.5.3 Lift Off Effects.

4.5.3.1 Sources Of Lift Off Variations.

During eddy current inspection, changes in spacing between the probe coil and the inspection surface cause variations in test coil impedance. These changes in lift-off result from surface roughness, slight contour changes, probe wobble, probe bounce, and inconsistent thickness of nonmetallic coatings, such a paint, primer, and anodic coatings. The magnitude of impedance changes resulting from small amounts of lift-off variations can exceed the response from a relatively large crack. Consequently, some means of eliminating or separating this effect must be provided.

4.5.3.2 Lift Off Suppression.

One option for eliminating lift-off effects from the variable to be measured is the use of impedance plane analysis, where the phase direction of the response from the desired variable is separated from the phase direction of signals caused by lift-off variations. This type of analysis can be performed using any of the waveform display instruments that provide amplitude and phase of the signal. The small, meter readout type battery-powered instruments provide only a total amplitude measurement and require some means of lift-off suppression. For these instruments, lift-off compensation is obtained by selection of an off null operating point. The off null operating point is selected to provide equal current flow (meter reading) with the probe on bare metal and at a designated amount of liftoff. Eddy current inspection using small amounts of lift-off compensation or adjustment is also termed intermediate layer technique. The amount of lift-off adjustment is selected to minimize any surface roughness or variation in coating thickness on the part.

4.5.4 Lift Off Compensation Methods.

4.5.4.1 Impedance Plane Analysis Instruments.

Instruments that present the phase and amplitude of the signal on a CRT have phase rotation controls which allow the eddy current signal to be rotated until the phase is in a particular orientation. For instance, the phase can be rotated until the lift-off signals move in a horizontal motion, with increasing lift-off represented by movement to the left on the screen. Flaw signals or loss of conductivity will generally be in a vertical direction. The phase angle and amplitude of an indication will depend upon the depth of the flaw and the frequency of the test.

4.5.4.2 Meter Type Instruments.

Meter type instruments utilize frequency selection, off-null settings, and other electrical compensation procedures to minimize lift-off. The frequency selected provides the same meter response when the probe is in contact with bare metal or separated from the metal by a nonconductive shim (usually paper or plastic) equal in thickness to the expected maximum variation in gap between the probe and the metal. For a specific amount of lift-off adjustment, more than one frequency or operating point may be available. For maximum sensitivity to surface or near surface cracks, the lift-off compensation point occurring at the highest frequency should be used.

4.5.4.3 Lift Off Effects On Sensitivity.

As lift-off increases, sensitivity of the eddy current system decreases. The magnitude of the response from a crack or other defect decreases continuously as the distance between the cracked metal and the probe increases. The typical effect of increasing lift-off on crack response is shown in Figure 4-42. The magnitude of the total response obtained from two cracks is plotted against the controlled thickness of an intermediate layer between the probe and the part.

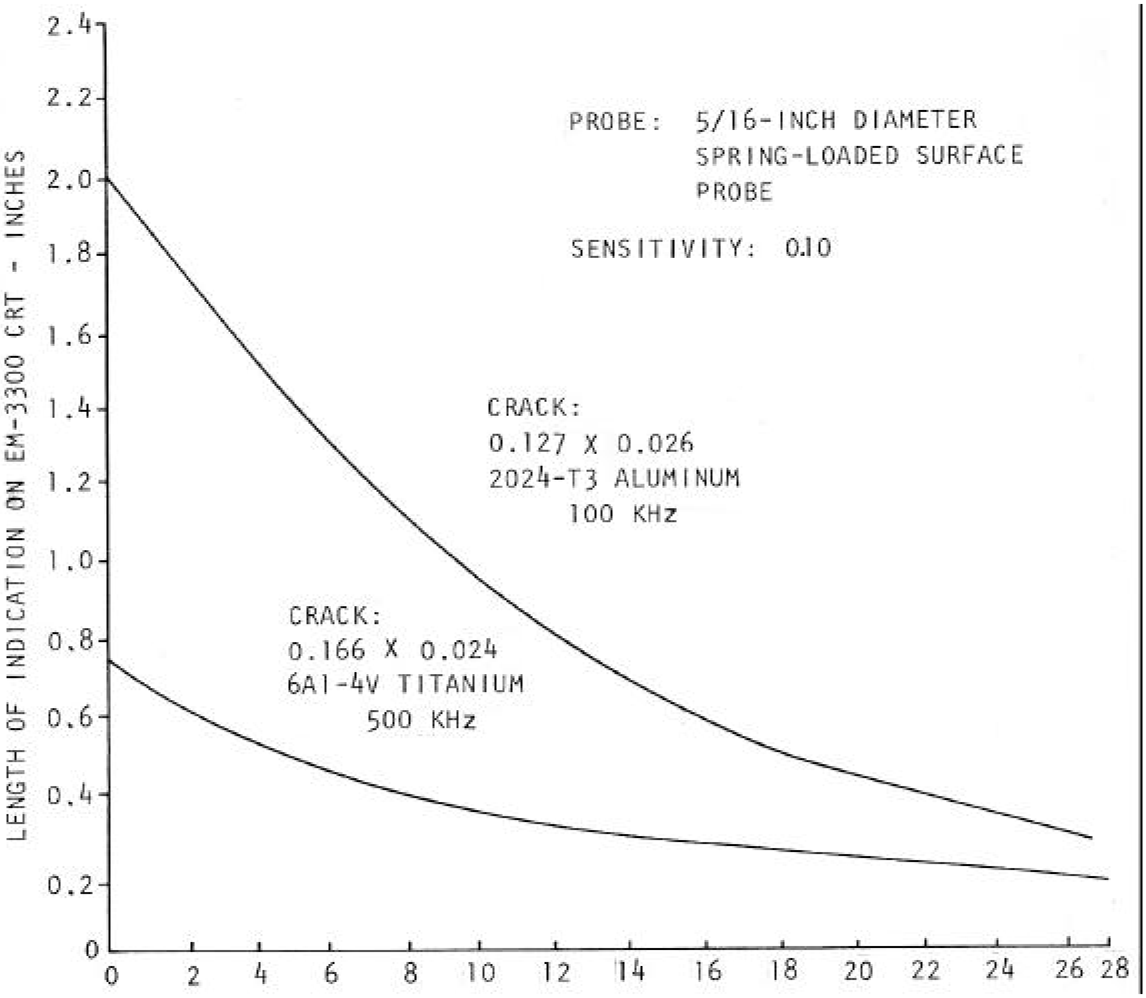


Figure 4-42. **Decrease in Crack Response with Increasing Lift-Off.**

4.5.4.4 Lift Off Compensation Effects On Sensitivity.

Lift-off must be minimized or compensated for in order to maintain a known level of sensitivity during an eddy current inspection. A meter type of eddy current instrument requires some form of lift-off adjustment. Otherwise, slight variations in lift-off would provide strong signals which would completely mask the response from cracks. The magnitude of crack response is considerably reduced by lift-off compensation. The reduction in sensitivity depends upon the particular eddy current system in use. Each system must be calibrated for the particular application.

4.5.4.5 Phase Response From Cracks.

Difference in phase between lift-off response and crack response is essential for the detection of cracks in most applications of eddy current inspection. Depending upon the location of the impedance of the signal on the impedance diagram, the phase angle between lift-off and crack response can be very small. This makes it very difficult to detect the difference between lift-off and probe motion from crack indications. Referring to Figure 4-42, as lift-off increases and/or the frequency decreases, the impedance of the system approaches the air null point, the phase angle between lift-off and the conductivity line decreases. By maintaining a high fill-factor or low liftoff and operating at a high enough frequency, a crack indication (loss of conductivity) can be easily distinguished from lift-off signals because of the larger phase angle. These relationships, as seen on an impedance plane analysis eddy current instrument, are shown in Figure 4-43 for aluminum, titanium and steel alloys. As crack depth increases, the phase angle approaches more closely the phase angle for conductivity changes.

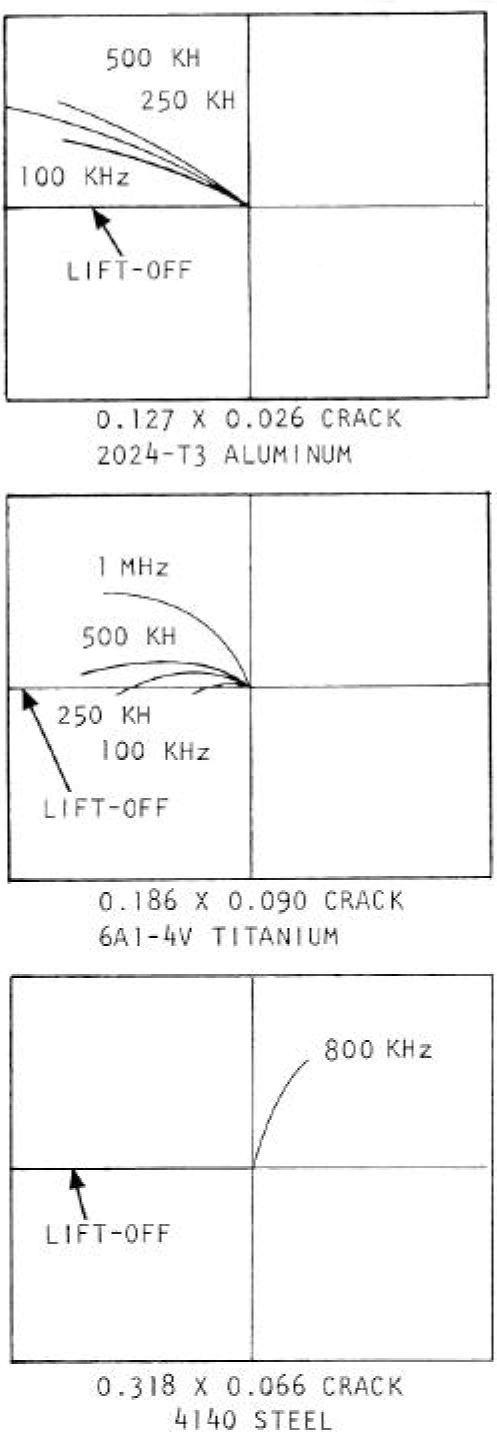


Figure 4-43. Phase Relationship Between Lift-Off and Crack Response for Various Materials and Frequencies.

4.5.4.6 Probe Wobble.

In performing manual eddy current inspection with a surface probe or pencil probe, it is usually impossible to maintain the probe at the same angle, with respect to the inspection surface, as position is changed. In some instances, holders may be fabricated to guide the probe and hold the angular relationship with the inspection surface. The angular change between the probe and the inspection surface is termed probe wobble. Probe wobble results in changes in lift-off as shown in Figure 4-44. The amount of lift-off obtained because of changes in probe angle depends on the diameter and shape of the probe tip. Rounded tips of small diameter cause less lift-off than flat tipped probes with larger diameters or impedance display instruments, lift-off effect can be lessened by changing the vertical to horizontal sensitivity ratio.

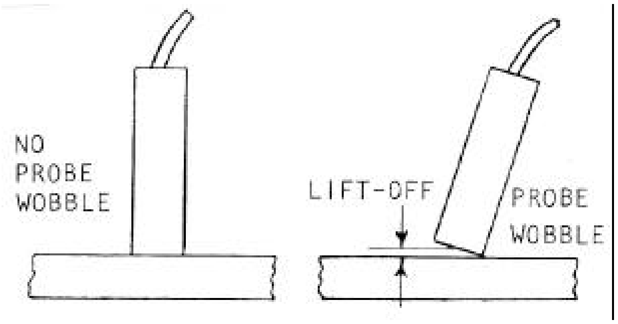


Figure 4-44. Lift-Off Resulting from Probe Wobble.

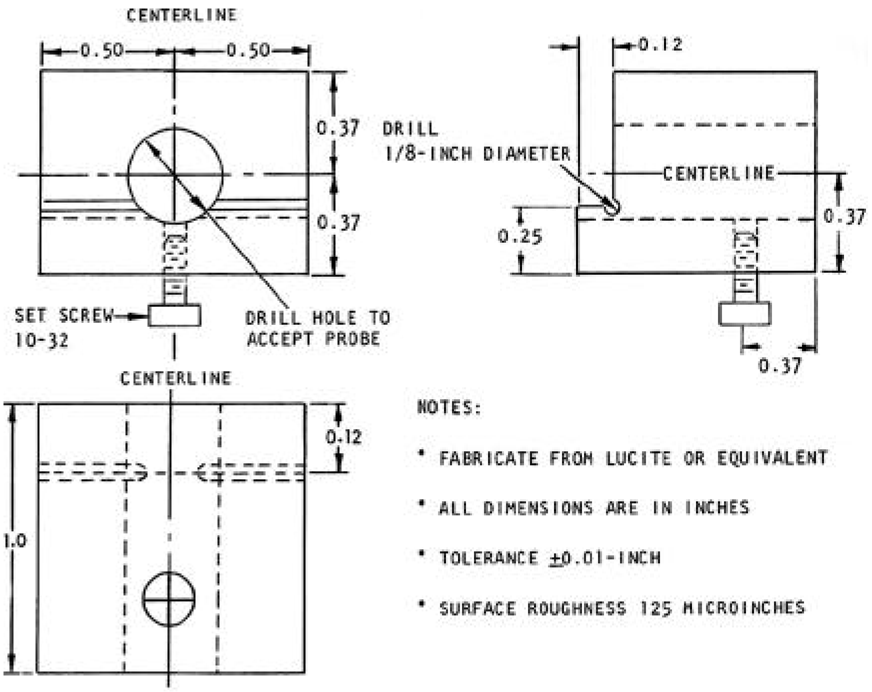
4.5.5 Effects Of Crack Location On Detectability.

4.5.5.1 Crack Location And Orientation.
To provide the optimum sensitivity and reliability for crack detection, the maximum information should be available regarding the expected crack. Often, this information is provided from previous history of cracks in the designated locations. In other cases, such information may be determined from knowledge of stress distribution during service. Increasing definition of crack location and orientation permits the inspector to reduce his inspection time. For manual eddy current inspection, reduction in scanning time provides less operator fatigue and consequent improvement in inspection reliability.

4.5.5.2 Cracks At Part Edges.
The edge of a part can be represented as an infinitely large crack and, consequently, produces a strong signal during eddy current inspection. The problem in inspecting part edges for cracks is separation of crack response from the strong edge response (edge effect).

4.5.5.3 Inspection At Part Edges.
Two approaches can be used to inspect for cracks at part edges. The first method is to null the instrument with the probe at the edge of the part. Then, usually with a non-conductive fixture or some other method, the probe is maintained at the edge as it is scanned along the edge. If this position can be maintained, the inspection can be done with greater sensitivity than is possible with the same instrument and probe away from the edge. The second approach is to use a shielded probe, thus minimizing response from edges.

4.5.5.4 Fixtures And Holders For Edge Inspection.
One of the simplest methods for eddy current inspection adjacent to a linear edge of a part is to tape or hold a straight edge at a predetermined distance from the edge. Nonmetallic straight edges should be used for this purpose. A simple fixture which can assist in positioning the probe adjacent to an edge is shown in Figure 4-45. This fixture maintains the probe center 1/8 inch from the edge, but closer edge inspection can be obtained by varying the position of the drilled hole.



NOTES:

- FABRICATE FROM LUCITE OR EQUIVALENT
- ALL DIMENSIONS ARE IN INCHES
- TOLERANCE ±0.01-INCH
- SURFACE ROUGHNESS 125 MICROINCHES

Figure 4-45. Edge Probe Guide.

4.5.5.5 Curvature.

When small diameter pencil probes are employed, curvature has minimal effect on crack response. This is due to the minimal lift-off effect of the small size of the probe tip. For most applications involving inspection of curved surfaces with small diameter pencil probes, flat standards can be satisfactorily used for curved surfaces in establishing sensitivity requirements.

4.5.5.6 Subsurface Flaw Detection.

Increasingly, applications arise where it is desired to inspect for cracks initiating beneath an accessible surface. This could be a crack initiating on the opposite side of the accessible surface, in the structure contacting the opposite surface of a accessible surface, or beneath a conductive coating or plating. Eddy current inspection can be a powerful tool for the detection of subsurface flaws.

4.5.5.7 Impedance Plane Analysis Of Subsurface Flaws.

If the required frequency is used with impedance plane analysis instrumentation, eddy current penetration to the flaw area can be obtained. The phase and amplitude information received from the flaw can be directly related to the flaw depth.

4.5.5.8 Meters For Subsurface Flaw Detection.

In most instances, eddy current inspection employs meter type instruments to detect cracks initiating at an accessible surface. Meter type instruments are very successfully used for surface eddy current inspection. They can be very useful for measuring depths of indications which are open to the surface being tested. Due to the inability of most meter type instruments to be calibrated or metered for phase information, it is almost impossible to obtain accurate information which can be related to buried flaw depth and size. With some meter instruments, the amplitude response with flaw depth is non-linear. That is, as the depth of the flaw increases, the meter response can increase or decrease unpredictably. The limited frequency range of most meter type instruments prevents them from being utilized over a wide range of material thickness and conductivity ranges.

4.5.5.9 Detection of Cracks Under Metallic Coatings.

The detection of cracks under metallic plating and coating is similar to detection of subsurface flaws. The magnitude of the total response consistently decreases with increasing coating thickness. With meter type instrumentation with a constant frequency test system, the thickness of plating or coating through which cracks can be detected decreases with increasing plating conductivity and/or magnetic permeability. In general, decreasing frequency permits detection of larger cracks under thicker coatings because of the increased depth of penetration. Detection of cracks under metallic coatings with phase analysis instrumentation using the impedance plane diagram can be performed with more accuracy and sensitivity than with meter instruments because phase information can be measured. Recent research has shown that multifrequency eddy current systems may find application for detecting and measuring cracks under metallic coatings.

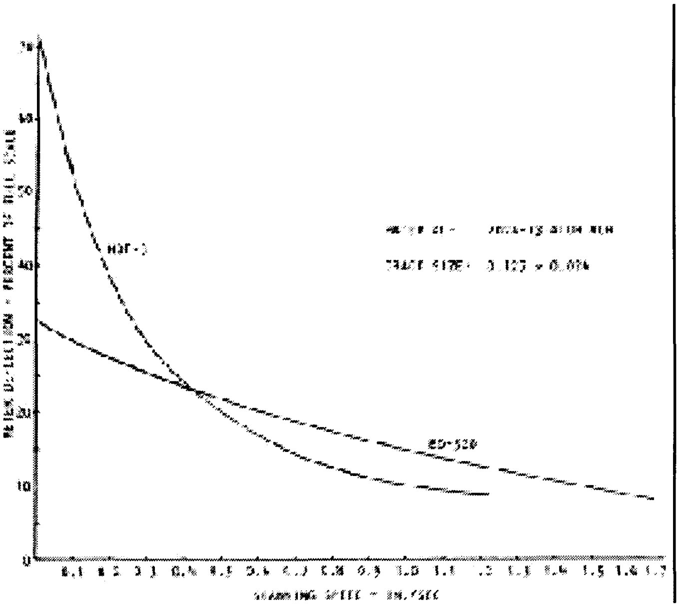
4.5.6 Effects of Scanning Techniques on Detection.

4.5.6.1 Inspection Technique.

Consistent positioning of the probe in relation to edges and interfaces during calibration and scanning should be established to ensure maximum response from flaws with minimum interference from other sources of indications. If conditions are known to exist which may result in false indications or which could mask true indications from flaws, these conditions should be noted in the procedure and a means of interpreting or evaluating the false indications provided. In performing eddy current inspection of an area, the distance between scans or between measurements must be selected to ensure complete coverage for the minimum size flaw or variation in properties to be detected. In determining maximum distance between scans, consideration must be given to the change in magnitude of flow response as the probe coil center position increases in distance from the center of the crack.

4.5.6.2 Scanning Speed.

The scanning speed employed in eddy current inspection for cracks is related to the type of equipment utilized and the inspection technique. Slowest scanning speeds are necessary when the inspector is required to read a meter while manually directing the probe in the specified scanning pattern. The rate of scanning is primarily determined by the damping of the instrument meter. Meter damping prevents excessive vibration and oscillation of the meter needle and provides errors in instruments readings. The damping effect reduces the



H0000349

Figure 4-46. Effect of Scanning Speed on Meter Deflection from a Crack magnitude of crack response as scanning speed is increased. The reduction in needle deflection with increased speed of scanning is shown in Figure 4-46. Manufactures may produce equipment manuals that suggest a fast scanning speed, however, scanning speeds using manual scanning techniques SHALL not exceed 1/4 to 1/2 inch per second.

4.5.6.3 Automatic or Semi Automatic Equipment.

Automatic eddy current equipment in conjunction with high speed recorders is capable of operation at extremely high speeds. The upper limits of scanning speed are based on the operating frequency and the sampling rates of the recorder or readout. The principal use for automated eddy current equipment by the military is for the inspection of bolt holes. In this application, rotational speeds of 100 rpm can be obtained by the inspection system.

4.5.6.4 Use of Recorders or Oscilloscopes.

The use of recorders or oscilloscope (CRT) type eddy current instruments permits increasing the speed of manual scanning to the limits imposed by the reaction time of these instruments. Generally, other restrictions related to guiding the probe in the prescribed scanning pattern become the controlling factor when recorders or oscilloscopes are employed.

4.5.6.5 Scanning Pattern.

The scanning pattern required for eddy current inspection is based upon the possible initiation site of the crack, the orientation of the cracks, and the size of the cracks which must be detected. If cracks initiate from an edge in thin material (0.050 inch or so), eddy current inspection is usually limited to a single scan of the edge. For thicker materials, scans might be required on both surfaces adjacent to the edge and one or more scans of the material between the edges. When cracks initiate beneath the heads of nonremovable fasteners, the pattern usually consists of a single scan around the protruding head of the fastener to detect cracks growing outward from the hole. If cracks can occur at a variety of positions and orientations, as is possible on flat surfaces, in radii, and on cylindrical surfaces, scanning must be performed in a manner which will assure detection of the smallest cracks required to be found. For these types of inspection areas, the direction of scanning, the number of scans, and the distance between scans should be specified.

4.5.7 Reference Standards For Cracks.

NOTE

The AF general purpose eddy current standard, NSN 6635-01-092-5129, P/N 7947479-10, SHALL be the common standard used to perform eddy current inspections on aluminum components within the Air Force unless otherwise specified by the cognizant weapon system engineering authority. See Figure 4-47 through Figure 4-49. Figure 4-50 is the Navy version of this standard. The Navy Eddy Current Reference Standard Kit, Part Number NRK-3AST, consists of (1) Aluminum, Part Number NRK-3A, 7075-T651 top & middle layer, 7075-T73 bottom layer; (1) Steel, Part Number NRK-3S, 4340 alloy all three layers and (1) Titanium, Part Number 6AL4V alloy all three layers.

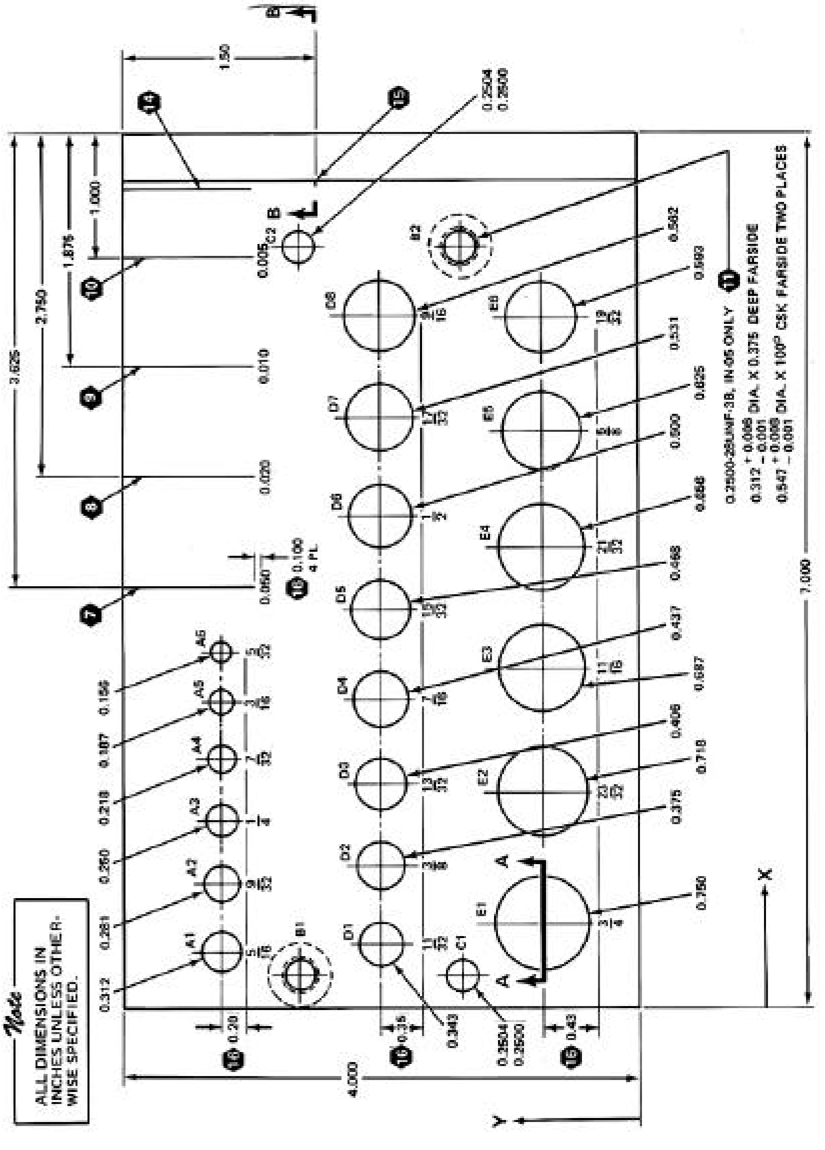


Figure 4-47. Air Force General Purpose Eddy Current Standard.

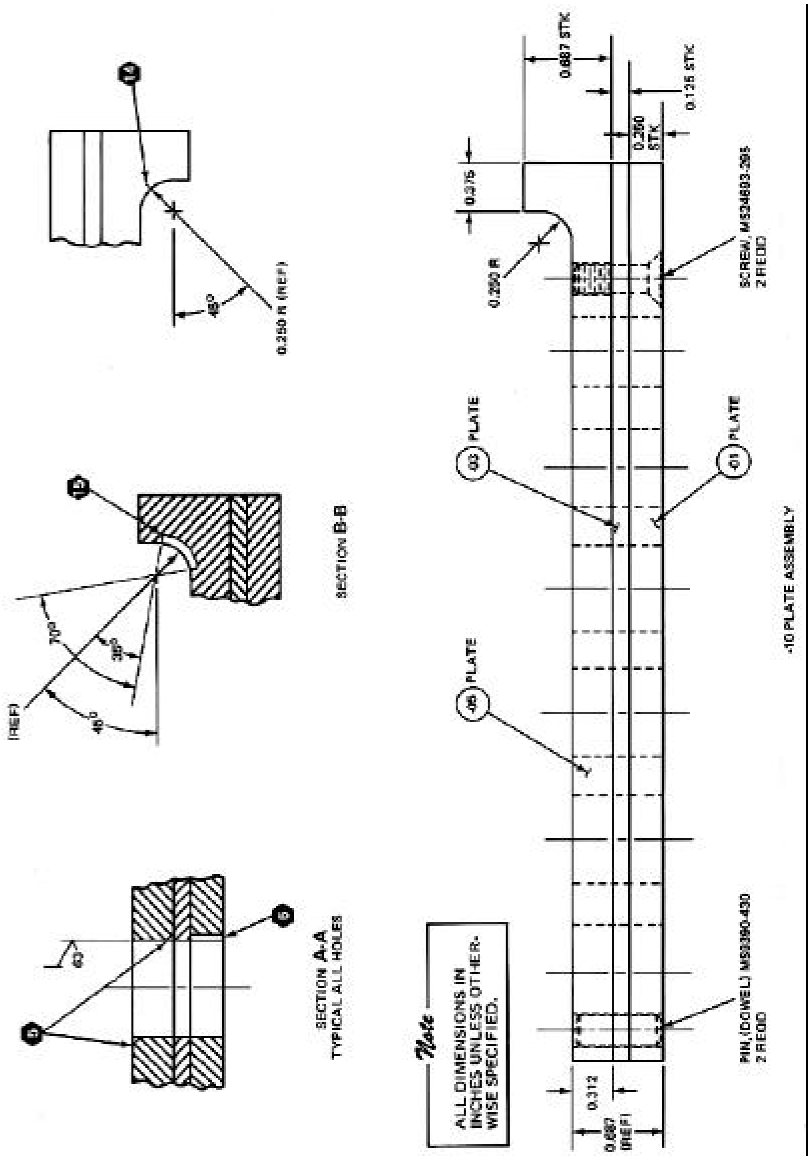


Figure 4-48. Air Force General Purpose Eddy Current Standard.

Note

1. INTERPRET THIS DRAWING PER MIL-STD-100.

2. IDENTIFY PART PER MIL-STD-130.

3. BREAK SHARP EDGES EXCEPT AT HOLES AND REMOVE BURRS.

❹ FINISH: ANODIZE AL ALY PARTS PER MIL-A-8625, TYPE II, CLASS I.

❺ ELOX SLOT, 0.030 X 0.030 X 0.004 ± 0.001.

❻ ELOX SLOT, 0.020 X 0.250 X 0.004 ± 0.001.

❼ ELOX SLOT, 0.050 X 1.000 X 0.004 ± 0.001.

❽ ELOX SLOT, 0.020 X 1.000 X 0.004 ± 0.001.

❾ ELOX SLOT, 0.010 X 1.000 X 0.004 ± 0.001.

❿ ELOX SLOT, 0.005 X 1.000 X 0.004 ± 0.001.

⓫ THREADS PER MIL-S-7742.

12. SURFACE ROUGHNESS $^{63}\sqrt{}$ MAX. ALL OVER PER ANSI B46.1-1978.

⓭ THE EDDY CURRENT METHOD IS USED TO DETECT CRITICAL CRACKS ORIGINATING IN HOLES OF LOWER WING SKIN OF ALL AIRCRAFT.

⓮ ELOX SLOT, TAPERED 0.200 AT EDGE CORNER TO 0.000 X 1.000 X 0.004 ± 0.001.

⓯ ELOX SLOT, 0.050 DEEP X 0.004 ± 0.001 AND PERPENDICULAR TO THE RADIUS.

⓰ MECHANICAL ETCH NUMBERS 0.093 HIGH AS SHOWN.

17. ALL DIMENSIONS IN INCHES UNLESS OTHERWISE SPECIFIED.

Drilling Legend

QUANTITY REQUIRED		6	2	2	8	6			
HOLE DIAMETER		~	~	~	~	~			
POSITION		HOLE SYMBOL							
X →	Y ↑	A	B	C	D	E	F	G	H
0.437	3.250	A1							
0.983	3.250	A2							
1.498	3.250	A3							
1.982	3.250	A4							
2.435	3.250	A5							
2.856	3.250	A6							
0.250	2.625		B1						
6.094	1.375		B2						
0.250	1.375			C1					
6.094	2.625			C2					
0.500	2.000				D1				
1.125	2.000				D2				
1.781	2.000				D3				
2.468	2.000				D4				
3.186	2.000				D5				
3.936	2.000				D6				
4.717	2.000				D7				
5.529	2.000				D8				
0.687	0.750					E1			
1.718	0.750					E2			
2.718	0.750					E3			
3.686	0.750					E4			
4.623	0.750					E5			
5.529	0.750					E6			

PARTS LIST

QTY	NOMENCLATURE	PART NO.	MATERIAL/SPECIFICATION
2	SCREW	MS24693-295	
2	PIN	MS9390-430	
1	PLATE	-05	AL ALY PL 0.687 THK QQ-A-250/12. CMPSN 7075, CONDTN T6
1	PLATE	-03	AL ALY SH 0.125 THK QQ-A-250/12 CMPSN 7075, CONDTN T6
1	PLATE	-01	AL ALY PL 0.250 THK QQ-A-250/12 CMPSN 7075, CONDTN T6
	PLATE ASSY	-10	

Figure 4-49. Air Force General Purpose Eddy Current Standard.

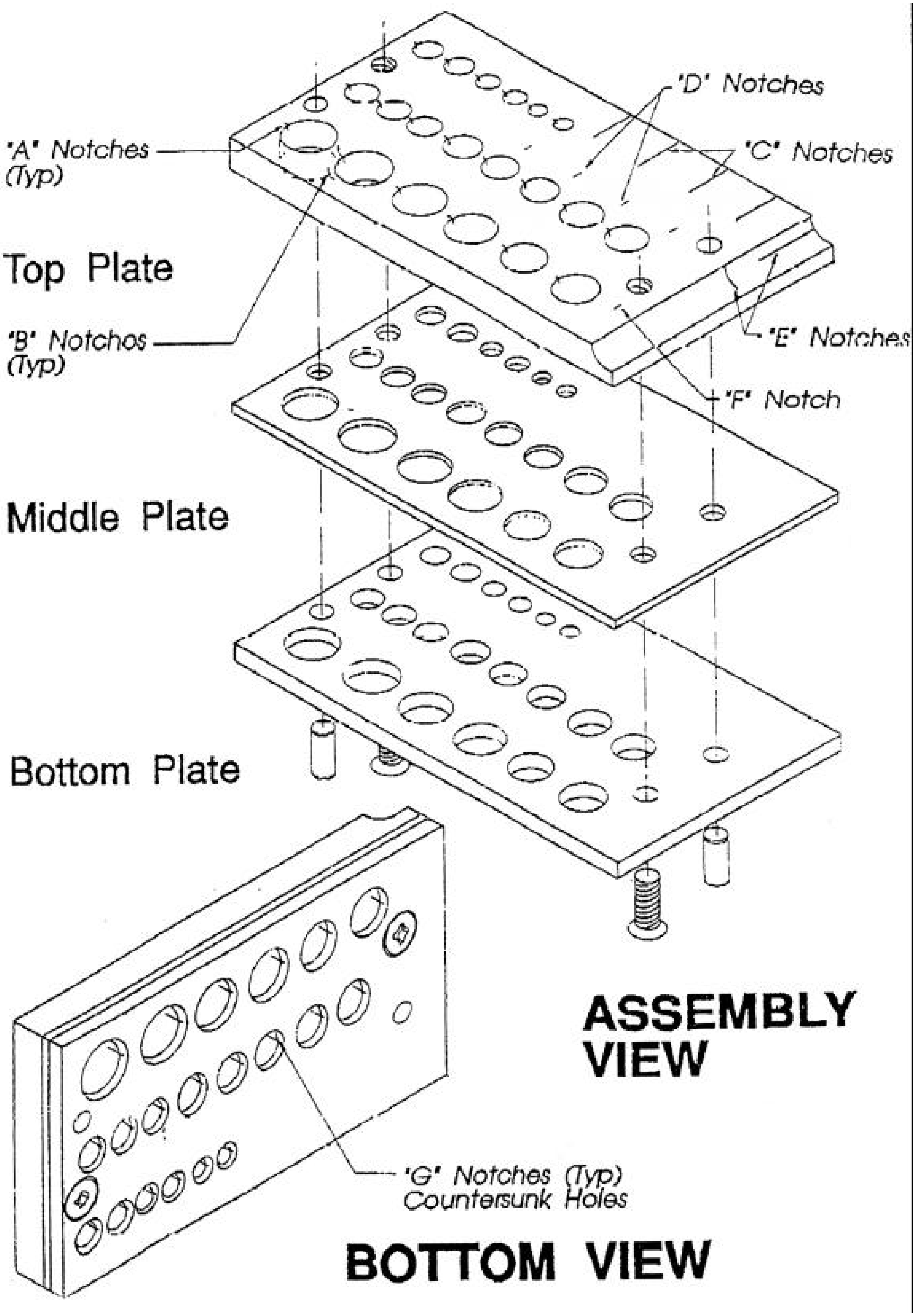


Figure 4-50. Navy Eddy Current Reference Standard

4.5.7.1 Cracks As Reference Standards.

When calibrating an eddy current instrument for detection of cracks, some means must be provided to assure that the sensitivity of the test system is sufficient to detect the smallest required crack size. Ideally, the best standard would be a section of the same material containing a crack of this minimum size. Cracks of specified sizes are difficult to obtain. With few specimens to choose from, such situations are rare. Fatigue cracks of specified size can be grown under laboratory conditions, but this method is extremely expensive. The length of the crack along the surface and its width at the surface are easily measurable. The depth of the crack is generally unknown and must be approximated or assumed from other data. Because of difficulty in obtaining actual cracks for reference standards, a number of other standards may be used. These standards are discussed below.

4.5.7.2 Requirements For Reference Standards.

The primary requirement for eddy current reference standards is that they provide uniformity of response which can be related to the condition or material property to be detected or measured. Two fundamental ideas are assumed by uniformity of response. First, this means that all tests can be done with the same sensitivity or that different levels of sensitivity can be compared on a quantitative basis. Second, standards fabricated to a specific design should be stable devices able to provide a repeatable response within certain specified limits. To be useful for flaw size and type evaluation, the reference standard must relate to the flaw to be detected. By means of correlation data, prior history or investigation, the response from the reference standard must relate to the response from the condition or material property of the part. To permit fabrication of standards at a number of locations, material, alloy, temper and dimensional tolerances which will provide the required response should be defined in the applicable Technical Order for the test being performed. Methods of fabrication which utilize simple tools should be specified when adequate uniformity and sensitivity can be obtained. Ideally, when an instrument has been adjusted for a specified response from the standard, a signal of approximately the same amplitude and phase (where applicable) should be obtained from the condition or material property with an eddy current instrument and probe of the same general type.

4.5.7.3 Standards For Specific Tests.

Calibration standards must be designed for the specific material property or condition being tested. Specific standards are required for each type of test being performed. Calibration standards used to sort alloys must meet very specific conductivity requirements. Calibration standards for measuring coating thickness of conductive coatings would not be suitable for measuring coating thickness of paint or other nonconductive coatings or for detecting cracks around rivet holes. Drilled holes or EDM (electrical discharge machining) notches in an aluminum block should not be used to test for material thickness or alloy composition of titanium or stainless steel parts.

4.5.7.4 Artificial Defects For Standards.

Due to the difficulty of obtaining the types and sizes of real flaws in parts for use as calibration standards, a variety of artificial flaws have been developed to simulate the real flaws. Fatigue cracks have been grown under laboratory conditions, but reproducible sizes in sufficient quantity for standards are impractical. Artificial flaws, such as drilled holes, EDM notches, saw cuts, two surfaces clamped together to simulate a crack, or chemically produced conditions to simulate pits or corrosion, can be produced in a variety of ways. Ideally an artificial flaw will produce an eddy current response identical to the response from a real flaw of the same size, orientation, and location. This ideal is seldom achieved with artificial flaws. Estimation of flaw size from the response to artificial flaws must be based upon correlating previous known flaw sizes with the response from the artificial flaws. To maintain the quality of this correlation, it is necessary to carefully specify the material properties and fabrication process of the artificial defect standard.

4.5.7.5 Simulated Conditions For Standards.

When using eddy current techniques to measure conductivity, coating thickness, permeability, alloy sorting, and hardness, standards can usually be obtained which represent the materials and conditions being tested. These standards are used for direct comparison to the response seen on the part being tested. Great care must be exercised in handling these types of calibration standards. Scratches, dents, distortion, oxidation, or other conditions can alter the calibration standards making them useless for comparison and calibration purposes. In order to protect the quality of reference standards, a primary standard and secondary standards will be utilized. The primary standards are usually maintained under laboratory storage conditions and may be traceable to the National Bureau of Standards, ASTM (American Society for Testing Materials) or similar agency. The secondary standard, are compared to the primary standard for response; the secondary standards are said to be traceable to the primary standard. The actual testing in the field environment utilizes the secondary standards, and the secondary standards are periodically compared to the primary standard to assure integrity.

4.5.7.6 Drilled Holes.

Drilled holes are not recommended to be used as calibration standards. However, drilled holes provide a relatively simple means of fabricating simulated defects in nonferromagnetic metals. To obtain the most consistent response, holes should be drilled completely through the part or beyond the effective depth of penetration of the eddy currents. A variety of diameters may be used to assess the range of sensitivity of an inspection with a minimum of expense and effort. The main disadvantage of the drilled hole for a calibration standard is that larger drilled holes do not always produce an eddy current signal with the same characteristics of a crack. Hole diameters smaller than the probe diameter produce signals similar to a small crack. Estimation of actual crack size shall be based upon comparison to an approved standard.

4.5.7.7 Drilled Holes In Ferromagnetic Steel.

Drilled holes in steel do not exhibit consistent responses and are difficult to relate to crack size. The variation in response can be attributed to the lack of penetration of the eddy current signal in ferromagnetic material. With few exceptions, drilled holes should not be used for calibration standards for eddy current tests of ferromagnetic materials.

4.5.7.8 EDM Notches.

Electrically discharged machined (EDM) notches, in a variety of sizes, shapes and locations, can be placed in almost all metals. The width of the notch can be held to as small as 0.003 inch, and although far greater in width than most cracks, this method provides a narrower slot, or notch, than all other fabricating techniques such as saw cuts. Similar responses are obtained on real cracks. Eddy current meter response can often be nonlinear. This means that as the flaw depth increases, the meter needle may increase or decrease. This is due to the changing phase of the eddy current signal with depth; the meter is sensitive to only one phase angle and is not uniformly responsive to all phase angles presented by the EDM notch. The same situation applies to real flaws in a test part. Linear response can be expected with the meter when EDM notches and flaw size and depth are less than the probe diameter.

4.5.7.9 EDM Notches In Ferromagnetic Steel.

The eddy current signal does not penetrate well in ferromagnetic materials because of the shielding effect of the high magnetic permeability. EDM notches are useful as examples of flaws open to the surface of a part. Surface breaking cracks are best detected by using a very high frequency (500 KHz and greater) which is not meant to penetrate deeply into the part. Under these conditions the test provides very high sensitivity to surface flaws in ferromagnetic materials. Likewise the test provides little if any information on flaw depth.

4.5.7.10 Saw Notches.

Probably the simplest method of preparing eddy current standards is by means of a jeweler's saw. With a 7/0 blade, notches as narrow as 0.007 to 0.008 inch can be made in the edge of a standard. Circular jeweler's slotting saws are also available for other notch locations. Phase response is similar to that obtained from cracks. However, as notch width increases, the similarity to a crack decreases.

4.5.7.11 Machined Notches.

Calibration standards utilizing machined notches can be used under some tests conditions. However, the response of a particular probe size and frequency to the notch must be evaluated for its applicability for a test situation.

4.5.7.12 Choosing Reference Standards For Cracks.

As previously discussed, the primary requirement for eddy current reference standards is that they provide uniformity of response that can be related to the minimum size crack to be detected. To various degrees, several types of reference standards may meet this criteria. Consequently, such factors as cost, ease of fabrication, availability, and field application become prime considerations. Table 4-6 tabulates the various types of reference standards and indicates the advantages and disadvantages of each, and makes recommendations as to the applicability of each as crack reference standards.

Table 4-6. Eddy Current Reference Standards for Cracks.

Type of Standard	Advantages	Disadvantages	Recommendations
Drilled Holes	Ease of fabrication Relatively easy to obtain good dimensional tolerances	Maximum response difficult to detect Negative and/or positive responses (with some instruments)	Not recommended for reference standards.
EDM Notches	Good dimensional tolerances Response similar in phase to a crack	Cannot be fabricated in the field Relatively expensive	Best small crack standard for aluminum, titanium, and steel
Sawed Notches	Ease of fabrication in the field	Dimensional tolerances cannot be precisely controlled in the field	Sometimes satisfactory for large crack standards Can be used to check instrument operation and relative response
Slots in Foil, Razor Cuts			Not recommended for small crack standard
Machined Notches	Less expensive to fabricate than EDM notch	Response varies with type of probe Cannot be fabricated in the field	Large notches not recommended for small crack standard Can be used to check instrument operation and relative response
Induced Fatigue Crack	Gives crack response	High cost Hard to control size	Critical applications when cost is justified

4.5.8 Evaluation Of Crack Indications.

4.5.8.1 Acceptance Rejection Criteria.

In most cases, the depth of flaws detected by eddy current inspection cannot be directly measured. In almost all cases, the eddy current signal of the flaw must be compared to the eddy current signal produced by the calibration standard. The relationship between response to the standard and the corresponding response to the defect size must be established prior to the test and should be considered an essential part of the calibration process. Prior to the start of any test, the maximum flaw size allowed should be defined by the test specification or applicable Technical Order, and the calibration process should confirm that the test can be conducted with the required sensitivity.

4.5.8.2 Conditions Affection Flaw Evaluation.

Inspection for cracks, measurement of conductivity, or hardness can often be complicated by the surface damage, and manufacturing processes. Included in this category are scratches, gouges, pitting, and metal smearing. Severe damage may require refinishing of the area prior to inspection, inspection at a lower sensitivity, or selection of another test method.

4.5.8.3 Metal Smearing.

Flowing of surface metal may result from machining operations, abrasion during service, or by deformation during assembly or disassembly of an aircraft or component. The depth of smearing in nonmagnetic materials and its metallurgical effects will rarely exceed 0.002 to 0.003 inch. At normal crack detection frequencies, the metallurgical changes created by smeared metal may not affect eddy current response. However, metal build-up and depressions associated with the smearing create changes in lift-off. With meter type instruments this change may exceed lift-off compensation and cause irrelevant indications. With impedance plane analysis instruments detection of flaws will not be affected, if sufficiently separated in phase angle from the lift-off angle. In ferromagnetic steel, eddy current penetration is very shallow, and any blemish of the surface increases the difficulty of inspection.

4.5.8.4 Scratches, Gouges, And Pitting.

Scratches, gouges, and pits may result in eddy current signals similar in magnitude to those from cracks. As test frequencies increase, the sensitivity to scratches tends to increase, because the eddy current field is more concentrated at the surface.

4.5.8.5 Compensation Of Meters For Surface Conditions.

Because eddy current inspection is sensitive to a number of material and inspection conditions, many indications require additional investigation to separate cracks from other variables. In some cases when testing with meter type instruments, separation of cracks from increases in lift-off may be obtained by changing the amount of lift-off adjustment. Increasing the amount of lift-off adjustment or intermediate layer reduces the signal from lift-off or reverses its direction. Reduction of the amount of lift-off adjustment increases the magnitude of the response from lift-off.

4.5.8.6 Rate Of Deflection.

Rapidity of response with a meter or impedance plane display instrument is also a means of evaluating indications. When traversing a crack, a quick rapid deflection is obtained. Variations in conductivity, gradual thickness changes, out-of-round holes, and variations in edge-to-probe spacing provide a slow, gradual change in measured response. The inspector should be aware of the rate of change in response from cracks, as contrasted to the rate of signal change from slow changing material properties or test conditions.

4.5.8.7 Estimation Of Crack Size.

Cracks have the three dimensions of length, width, and depth. All three of these dimensions have an effect on the eddy current response from the flaw. In general, the length of the flaw can be related to the distance over which a signal above a specified level is obtained. When the crack is perpendicular to the surface, the approximate depth of the crack can be determined from the eddy current indication. With meter type instruments this will usually be related to the signal amplitude. With impedance plane analysis instruments the depth can be determined by the phase angle and amplitude of the indication. When using a meter type instrument to measure small cracks, amplitude correlates better with crack area rather than crack depth. The width of the crack also influences the magnitude of the indication. With impedance plane analysis instruments, the signal shape, phase, and amplitude can be used to estimate the depth and area of the crack. Generally, the crack dimension of greatest interest is the depth. With meter type instruments this is the most difficult dimension to measure, and estimation of crack size should only be applied to those situations where crack geometry is similar and considerable data has been developed relating crack size to meter response. With impedance plane analysis instruments, crack depth measurements in nonferromagnetic materials can be performed when based upon the phase response.

4.5.9 Effect Of Scan Rate And Pattern.

4.5.9.1 Meter Instruments.

When manual scanning is performed using meter type instruments without a recorder, the amplitude of response decreases with increasing scanning speed because of the damping effect of the meter. In the same manner, the ends of a crack can be established by the point at which the amplitude of deflection falls below a predetermined level. Mechanized scanning rates with meter instruments and recorder output are limited to the response rate of the recorder. Scan speeds must always be maintained below the maximum response of the detection system in order for the system sensitivity to remain linear and within calibration.

4.5.9.2 Impedance Plane Analysis Instruments.
The speed of manual scanning with impedance plane analysis instrumentation does not affect signal response because the system response time is not limited by the response of a meter movement.

SECTION VI
SPECIFIC APPLICATIONS

4.6 SPECIFIC APPLICATION — FLAW DETECTION.

4.6.1 Fastener Holes Removable Fasteners.

4.6.1.1 Cracks In Fastener Hole Walls.
A common application of eddy current inspection in aircraft structures is the detection of cracks in fastener hole walls. These cracks are usually generated by fatigue, stress corrosion, or a combination of fatigue and corrosion. The progress of these cracks is often slow in the initial stage and early detection can prevent possible catastrophic failure.

4.6.1.2 Fatigue Cracks.
Fatigue cracks are usually caused by repeated cyclic loading of a structure at levels of stress less than that required for visible deformation. Because stress is concentrated at areas of localized weakness, such as holes, fatigue cracks often initiate at such points. The cracks usually propagate normal to the direction of the maximum applied tensile stress.

4.6.1.3 Stress Corrosion Cracks.
Stress corrosion cracks occur under the combined influence of a tensile stress and a corrosive environment on a material susceptible to stress corrosion cracking. The tensile stress may result from either an applied stress or a residual stress. Moisture in the air combined with a sufficiently corrosive environment may create stress corrosion cracking in some instances.

4.6.1.4 Fatigue And Corrosion Cracks.
Cyclic fatigue in the presence of corrosion cracks can cause rapid growth of cracks.

4.6.1.5 Hole Wall Finish And Dimensions.
The hole wall finish and dimensions strongly influence both the occurrence and the detectability of cracks in fastener holes. Hole wall damage such as scratches, chatter and grooves created during manufacturing can create additional stress concentrations at the hole wall and provide preferred sites for crack initiation. Loose fitting bolts caused by oversize or out-of-round holes allow movement in the area of the hole and allow fatigue action. These same conditions can influence the reliability of inspection. During inspection, severe damage to the hole wall results in strong eddy current indications that may not be separable from crack indications. Excessive lift-off from out-of-round conditions can also mask indications from cracks. All of these conditions can be created during manufacturing processes on the hole or as a result of fatigue action during service and from bolt removal.

4.6.1.6 Edge Effects.
Many cracks in fastener holes occur at or near the edge of the hole. Adjoining structures, non-uniform countersink and deburring radii, and damage at the hole edges increase the background noise and decrease the signal-to-noise ratio. This leads to a general loss of detection of cracks at the edge of holes. Further effects on crack detectability result from the presence of other metals adjacent to the hole edge. Countersunk surfaces also limit eddy current inspection by manual techniques adjacent to hole edges.

4.6.1.7 Fastener Hole Inspection Equipment.
A considerable number of fastener holes are still inspected manually using meter type instruments and a standard bolt hole probe. For some bolt hole inspections, recorders are used in conjunction with the instrument. Increased use is being made of automatic scanning equipment. This equipment provides a hand held scanning unit which drives a

probe in a helical pattern through the length of the hole. This equipment maintains a constant speed of revolution. Results can be retained on a strip chart recorder or displayed on a storage oscilloscope. For most applications, no additional equipment is required. Occasionally, a special shim is necessary to provide a flat surface on which to position the probe stop or scanning unit to maintain good alignment between the probe and the hole**.**

4.6.1.8 Lift Off Compensation.

The lift-off adjustment for bolt hole inspection is dependent upon the surface quality and dimensions of the hole. Optimum lift-off adjustment is that which just suppresses lift-off variations within the hole, but does not provide excessive compensation. Excessive lift-off compensation can reduce sensitivity and increase noise related to changes in lift-off less than the amount of adjustment. When using unshielded probes, specific amounts of lift-off adjustment can be obtained by using a shim between the coil of the bolt hole probe and the hole wall. The thickness of the shim must equal the amount of lift-off adjustment desired and must be relatively tough to prevent tearing during insertion and removal of the probe. Flexible plastic or Teflon tape can be used for this purpose. Lift-off adjustment is usually performed in the hole at a point at least 1/4 inch from the edge or at the center if the part thickness is less than 1/2 inch thick. The practice of performing a lift-off adjustment by pushing the coil away from the hole wall can lead to indefinite amounts of lift-off adjustment and should be used only with caution. More tolerance in lift-off adjustment settings is permissible when using automatic scanning equipment or shielded probes.

4.6.1.9 Sensitivity Settings.

The sensitivity settings are based upon response to a specified reference standard. A wide variety of test standards are employed for bolt hole inspection. They include cracked parts, electrical discharge machined notches, notches cut with a jeweler's saw, differences in conductivity standards, and a multitude of other standards with larger notches and/or cracks. Each individual procedure usually specifies the standard to be used and the required response in terms of meter deflection or indication size on a recorder, strip chart, or scope. When it is necessary to find small flaws and the possibility exists that different types of probes (coil size and frequency) may be used, it is preferable to use a reference with the same approximate dimensions as the flaws to be detected such as the jeweler saw cuts or electrical discharge machined notches. Standards which affect a large volume of metal such as the conductivity standards and large notches do not provide consistency of response from the same crack for all probes.

4.6.1.10 Meter Testing And Scanning Speed.

Scanning speed and pattern must be considered in the calibration procedure with meter equipment. Since the probe response with manual scanning will not be the same as that during mechanized scanning, calibration SHALL be performed at the same scanning rate employed during inspection.

4.6.1.11 Bolt Hole Preparation.

NOTE

Inspection must not be performed on holes which are offset at interfaces. Holes in mating surfaces must be realigned prior to eddy current inspection or redrilled to a larger diameter which is concentric through the mating parts.

Prior to performing bolt hole inspection, all foreign material must be removed from the hole. Foreign material can include sealant, lubricants, metal slivers and paint chips. Usually this material can be removed using cotton swabs and a suitable solvent. Holes which are severely damaged during service or during fastener insertion or removal may require reaming prior to eddy current inspection.

4.6.1.12 Manual Bolt Hole Scanning Procedures.

Manual scanning of bolt holes is performed at specified levels throughout the depth of the hole. Inspection is usually initiated with the probe core positioned immediately within the upper or lower edge of the hole so that the outside edge of the core is even with the surface of the part. The probe core position is adjusted to the specified level below the collar of the probe and the probe inserted into the hole until the probe collar rests against the surface of the part If inspection is performed for fatigue cracks parallel to the length of the hole, the inspector observes the meter for any rapid deflection and return of the needle. Occasionally, intergranular stress corrosion can occur along a plane roughly parallel to the part surface. When this type of flaw occurs, needle deflection may be relatively slow.

4.6.1.13 Scan Pattern.

The distance between scans or the scanning increment is determined by the minimum crack size required to be detected. For detection of small cracks, the distance between scans should not exceed 0.060 inch. The scanning procedure is repeated after setting the probe coil at each scanning position until the entire length of the hole has been inspected. When inspecting multiple layers, inspection should be performed in the materials of both layers adjacent to each interface. When the specific interface position between layers of similar material is not known, its position may be established by running the probe down past the interface and marking the position of maximum deflection.

4.6.1.14 Automatic Bolt Hole Scanning.

Automatic bolt hole scanning should be accomplished in accordance with the scanner manufacturer's recommendations for operation and the applicable T.O. covering the particular test to be performed.

4.6.1.15 Evaluation Of Indications.

Beneath the rough surface of many bolt holes, numerous indications are obtained from causes other than cracks. Indications should therefore be examined carefully to establish if indications could be from cracks or if they are attributable to other causes. Evaluation can be made on the basis of direction of deflection and rate of deflection.

4.6.1.16 Indications On Meter Instruments.

Meter deflections obtained during scanning of a hole in a part may be compared to the meter response from the standard reference. The direction of deflection should be the same for both the reference and the standard. The rate of deflection and return to nominal reading is rapid for both cracks in the inspection part and the standard when scanning is performed at recommended speed. Indications from out-of-round conditions, wide grooves, and changes in chemical composition are relatively slow. Caution must be exercised when inspecting for lamellar conditions because the response is not typical of fatigue cracks. The magnitude of response at various amounts of lift-off adjustment can also aid in screening out indications from rapid changes in lift-off.

4.6.1.17 Indications On Storage Oscilloscope Or Strip Chart Recorder.

The use of a strip chart recorder or storage oscilloscope for recording indications during manual scanning of fastener holes makes evaluation less subjective. Comparison of rate of deflection from indications in the hole and the reference can be observed at the same time.

4.6.1.18 Indications From Automatic Scanner.

The controlled rate of scanning obtained with the automatic scanning unit provides additional improvement in ease of evaluation. Because of the small scanning increment (pitch of scanner screw), any crack of significant size will be detected during at least three consecutive revolutions of the scanner. This should result in three or more evenly spaced indications on the strip chart recorder or storage oscilloscope. If crack-like indications are observed, inspect the hole visually to determine if the indications are due to obvious deformations such as metal tears or gouges. Gouge indications, while cyclic in nature, are generally easily recognized due to the fact that such indications usually appear 180 degrees opposite in phase or polarity to crack or slot indications. Additionally, a gouge indication will usually not be as sharply peaked as an indication from a crack or slot. Careful study must be made of such indications to ensure that they do not mask an indication of a crack at the bottom of the gouge.

4.6.2 Openings, Large Holes, And Cutouts.

4.6.2.1 Location And Orientation Of Cracks.

An opening or cutout in a stressed aircraft part serves as a stress riser and a potential source of fatigue cracks and/or stress corrosion cracks. Fatigue cracks initiate at the edges of an opening, hole, or cutout and grow away from the edge at right angles to the direction of stress. Stress corrosion cracking usually occurs in sections subject to either an applied or residual tensile stress. The direction of tensile stresses can often be defined by engineering stress analysis or from the history of previous cracking in the part. This application covers openings for doors and accesses in aircraft skins, cutouts at part edges, and attachment holes too large for bolt hole probes.

4.6.2.2 Inspection Requirements.
If inspection is required only for large cracks (greater than approximately 1/4 inch in length) adequate inspection can usually be performed without special equipment or fixturing. For such cracks, inspection can be performed sufficiently far enough from the edge to avoid interference from edge effects. To detect small cracks, a relatively constant probe-to-edge distance must be maintained. For maximum reliability, a fixture or probe guide is used to establish probe positioning.

4.6.2.3 Probe To Edge Spacing.
When inspecting for small cracks initiating from edges, probe-to-edge spacing can become a concern. There are two basic approaches for inspecting at part edges. In addition to these two approaches, selecting other parameters that minimize the volume of material sensed by the probe will improve the inspection results. Increasing the frequency of the eddy current generating source; reducing the physical size of the eddy current generating source; and reducing the physical size of the coil allow inspection closer to the edge because of the reduced volume of material sensed and result in greater sensitivity to small flaws. Probe-to-edge spacing becomes even more of a concern when the edge of the part is in contact with a ferromagnetic part such as a bearing or bushing. Again, minimizing the volume of material sensed by the probe will optimize the eddy current inspection of such a geometry.

4.6.2.4 Fixtures And Guides.
The simplest eddy current inspection scanning guide is a section of thin flexible plastic cut to conform to the inspection area with allowance for probe positioning. Such a guide can be easily prepared from used X-ray film. The flexibility permits fitting of the guide to compound curvatures. It is necessary that the edge used to guide the probe be smooth to allow steady movement at a constant distance from the edge of the opening. The guide can either be held in place or taped in the required position. Another type of probe guide which can be used for small openings, including holes with bushings, consists of a circular insert which fits into the hole and has a larger diameter at one end to provide the required offset distance from the edge of the hole. Probe guides should be constructed to provide the required offset from the edge for a specified type of probe and should not interfere with movement of the probe.

4.6.3 Fastener Holes Nonremovable Fasteners.

4.6.3.1 Inspection Application.
If a fastener cannot be removed from a hole because of fastener type or location, inspection can be performed around the fastener to detect cracks growing from beneath the fastener head or nut. The size of cracks detectable is dependent upon the distance which must be maintained between the probe and the edge of the fastener. In many respects, this application is similar to inspection for cracks at the edge of openings and cutouts. Large low frequency probes and sliding reflectance probes can also be scanned over countersunk fasteners and identify cracks at the 1st, 2nd and 3rd layer.

4.6.3.2 Probe To Fastener Spacing.
If only required to detect relatively large cracks, such a those extending between two fasteners, eddy current inspection can usually be performed sufficiently distant from the fastener heads to eliminate their effect on eddy current response. When small cracks must be detected, the probe must be positioned closer to the edge of the fastener, and the probe to fastener distance must be held constant during scanning. When fasteners fabricated of magnetic materials such as steel are used in nonmagnetic parts, a relatively large spacing, usually a minimum of 1/8-inch, must be employed. Also, shielded probes can be used to minimize the distance between the probe and the fastener, allowing inspection near to the fastener.

4.6.3.3 Scanning Guides For Nonremovable Fasteners.
For nonferrous (nonmagnetic) fasteners, the head of the fastener may be used as a probe guide. Only those fasteners which protrude from the surface of the part and are concentric with the hole can be used as guides. For fasteners with heads not concentric with the holes, such as hexagonal and serrated heads, a collar fitted to the fastener head can be used as a scanning guide. Most shielded probes can be scanned around steel fasteners without requiring a collar. Templates must be positioned concentric to the fastener head to assure relatively consistent meter response from defect-free material as the probe is guided around the fastener.

4.6.3.4 Probe Selection.

As with many other flaw detection applications, the use of small diameter, radiused probes is recommended. These probes permit better visibility of probe coil location and permit more flexibility in establishing spacing between the probe and the fastener. Radiused probes are also less susceptible to liftoff variations with changes in probe to surface angle than flat surface probes.

4.6.3.5 Standards For Nonremovable Fastener Holes.

Whenever possible, the standards for inspecting around the heads of nonremovable fasteners should duplicate as closely as possible the conditions of the inspection area. If cracked specimens representing the minimum crack size to be detected are not available, sawed notches or EDM slots cut at the edges of holes in the reference standard can be employed. Material, geometry, hole size, and fastener type, and installation should be the same for the reference part as for the inspection area, unless prior correlation with other available references has been established. Duplication of part geometry in the reference minimizes differences in response between references and cracks in the part.

4.6.4 Fillets And Rounded Corner.

4.6.4.1 Crack Occurrence.

Repeated bending loads applied to fillets and radii (rounded corners) of a part can lead to fatigue cracks. Fatigue cracks usually lie parallel to the radius. In formed radii, cracking usually occurs near the center of the radius where maximum thinning is obtained. In machined fillets or radii of extruded shapes where part thickness is greater at the center of the radius, fatigue cracks are more likely to occur at the tangent point of the radius. Stress corrosion cracking can sometimes occur in the radii and fillets of machined parts where tensile stresses are applied or areas of residual tensile stresses are exposed. Stress corrosion cracking is often promoted by the collection of moisture in these fillets and radii.

4.6.4.2 Equipment Requirements For Fillets And Radll.

In general, no special equipment is required for the inspection of fillets and radii. Adequate inspection can be performed using eddy Current instruments with a radiused tip probe or an equivalent test system. The radius of the probe tip must be less than the radius of the fillet to be inspected to ensure relatively constant contact between probe and part and thereby avoid excessive changes in lift-off. For inspection of the edges of radii or fillets, a thin plastic straight edge is desirable to maintain Probe-to-edge spacing in the fillet. Occasionally, a fixture similar to those employed for the bead seat radii in wheels can be employed for fillets and radii. Fixtures decrease inspection time and assure complete coverage.

4.6.4.3 Reference Standards For Fillets.

The best reference standard for any part is one that represents the configuration of the part to be tested. Therefore, it is preferable to have a standard of the same material, finish, and radius as the fillet to be tested. An EDM notch representing the smallest crack required to be detected should be placed in the radius. Flat standards can be used if a standard of the required configuration is not available. Response from flat standards differs very little from response from cracks or slots in fillets or curved surfaces if a radiused probe is used. Slots at edges are not interchangeable with slots located away from the edge.

4.6.5 Corrosion.

4.6.5.1 Types Of Corrosion.

Corrosion is the deterioration of metals by chemical action. Corrosion occurs where two different metals are in contact via a conducting material. For corrosion to occur, electrons must be moved from one metal to another. This movement can occur through any conductive material, including air, water, or conductive adhesives. As a solution's conductivity increases, its potential to cause corrosion increases. Thus, corrosion is more prominent in humid or saline environments. Although corrosion may be classified in many ways, for purposes of detection, five principal forms are considered: (1) uniform etch, (2) pitting, (3) intergranular attack, (4) exfoliation, and (5) stress corrosion cracking.

4.6.5.2 Uniform Etch.

Uniform etch (corrosion is characterized by a general overall reduction in thickness of the metal in which some areas may be corroded more rapidly than others. This form of corrosion is readily detectable by visual means on exposed surfaces. Corrosion of inaccessible surfaces of thin metal structures is detectable with eddy currents if access is available to the uncorroded side. Detection of this type of corrosion then becomes a matter of thickness measurement with some variations expected because of small areas with increased corrosion or the presence of metallic materials at the far surface.

4.6.5.3 Pitting.

Small localized areas of corrosion are termed pitting. Pitting can vary from pinpoint size to relatively large areas. The detection and measurement of corrosion pits must take these possible variations into account.

4.6.5.4 Intergranular Attack.

In some materials, including many structural aluminum alloys, corrosion occurs preferentially along grain boundaries. Although slight amounts of corrosion pitting may be observed at the surface, the extent of damage is not readily observable by visual means because of the small crack-like penetrations. This type of attack is particularly applicable to aluminum alloys.

4.6.5.5 Exfoliation.

Exfoliation corrosion initiates along grain boundaries parallel to the surface and propagates from these initiation sites. The corrosion products force the metal upward resulting in blistering and flaking of the metal. This corrosion form is most prevalent in structural aluminum alloys such as 7075-T6.

4.6.5.6 Stress Corrosion Cracking.

The combination of a constantly applied residual or applied stress and a corrosive (environment can lead to stress corrosion cracking in many high strength metals. The sustained stress can result from heat treating, machining, forming, shrink fits, welding, and assembly mismatch. Depending on the type of metal and the corrosive environment, stress corrosion cracking may or may not be associated with other forms of corrosion. This form of corrosion is primarily a crack and its detection has been covered under applications related to crack detection.

4.6.5.7 Test System Requirements for corrosion Detection.

The test system requirements for corrosion detection depends on the type and depth of corrosion for which inspection is performed. For uniform etch corrosion and for large pits, thickness measuring systems provide optimum delectability. For small pits and small areas of exfoliation or intergranular attack, the inspection requirements become similar to those for subsurface flaws. Instrumentation and probes with a broad selection of operating frequencies may be needed to cover the wide range of material types and thicknesses. Impedance plane analysis equipment can be used for corrosion detection and has many advantages for these applications. Battery operated impedance plane analysis, equipment allows this equipment to be used in most field situations.

4.6.5.8 Frequency selection.

The choice of frequency depends on the type of corrosion to be detected and the thickness of the material through which inspection is being performed. Higher frequencies favor resolution of small pits or small areas of intergranular corrosion or exfoliation. Lower frequencies increase the depth of penetration.

4.6.5.9 Probe Selection.

The probe must match the frequency at which the inspection for corrosion is performed. When more than one model of probe is operable at the inspection frequency, part and probe geometry are the determining factors in probe selection. For narrow contact areas, a smaller diameter probe may be advantageous. Larger diameter probes provide for greater averaging of thickness and provide somewhat better sensitivity in thicker areas.

4.6.5.10 Calibration Standards.

Because of the unique action of each type of corrosion and its effect upon conductivity, calibration standards must be fabricated form the same alloy, temper, and thickness as the material being inspected. When faying surfaces are involved in corrosion detection, the standard should be built up to simulate the joint including nonconductive shims for gap, paint and primer thickness. Standards for pitting may also be used for exfoliation and intergranular attack. Standards should also have approximately the same curvature as the part.

4.6.5.11 Inspection Procedure-Corrosion Dectection.
Detection of corrosion with eddy current techniques is applied to aircraft skins when corrosion may occur on inaccessible interior surfaces. Corrosion usually results in areas where moisture is entrapped. If relatively uniform thinning is expected, corrosion detection may be simply a matter of thickness measurement. In most instances, corrosion is confined to smaller localized areas of relatively small diameter. As skin thickness increases, sensitivity to small areas and shallow depths of corrosion is reduced.

4.6.5.12 Part Preparation.
Prior to inspection, all foreign material should be removed from the area to be inspected. Any roughness, sharp edges, or protrusions that could damage the probe or cause errors in readings should be removed by light sanding within the limits of the applicable T.O.'s. The locations of all fasteners, edges and changes in structure on the far side of the inspection surface should be established and marked with an approved removable marker to aid in the interpretation of inspection results. Paint removal is not required if it is relatively uniform and not loose or flaking.

4.6.5.13 Inspection Procedures.
Because of the wide variety of corrosion attack, inspection shall be performed in accordance with the applicable T.O.

SECTION VII
CONDUCTIVITY MEASUREMENT

4.7 SPECIFIC APPLICATION — CONDUCTIVITY MEASUREMENT.

4.7.1 Relationship Of Mechanical Properties And Conductivity.

4.7.1.1 Structure Of Metals.
The atoms of a chemical element have a nucleus or center with a positive charge. Around each nucleus are orbiting electrons. Each element has a different size nucleus surrounded by a characteristic number and arrangement of orbiting electrons. The distribution and number of the outermost electrons determine the properties of the element, including its metallic or nonmetallic nature. In a crystalline solid the atoms are stacked in orderly arrangement called lattices.

4.7.1.2 Mehcanical Properties.
The physical properties of a metal are related to the binding energy between the atoms. Yield strength, tensile strength and fatigue strength are determined by resistance to plastic deformation. Plastic deformation is permanent distortion of the metal and results from shearing along layers of atom. Plastic deformation is made easier by the presence of localized imperfections in the lattice. These lattice imperfections are called dislocations and are present in great numbers in all commercial metals and alloys. If the resistance to movement of the dislocations can be increased, the strength of the metal can be increased.

4.7.1.3 Conductivity Of Metals.
Metals are good conductors of electricity. Conductivity is dependent on the arrangement of atoms in each metal lattice and the distribution and energy of the electrons surrounding each atom. Any variation in the structure of metals that affects the electronic structure and energy of the atoms changes the conductivity of the metal. For simplicity, a decrease in conductivity may be associated with obstacles in the path of electron flow through a metal. The obstacles to electron flow may be caused by lattice distortions resulting from dislocations, missing atoms (lattice vacancies), foreign atoms, or grain boundaries. The presence of particles of different composition also restricts the flow of electrons, a greater number of smaller particles offering more resistance than fewer larger particles.

4.7.1.4 Pure Metals.

A pure metal is one composed entirely of a single element. These metals are rarely used in structural applications and are usually difficult to prepare because of problems in removing all traces of other elements.

4.7.1.5 Mechanical Properties Of Pure Metals.

Pure metals have relatively low resistance to deformation because there are few mechanisms to prevent the movement of dislocations through the metal. Two conditions can add to the strength of pure metals. Yield strength, which is a measure of the first detectable plastic deformation, can be increased very slightly by decreasing grain size. A grain is a small volume of the metal with the same three dimensional repetitive pattern of atoms. Most engineering metals are made up of a large number of grains fitted together along grain boundaries usually not visible to the unaided eye. Difference in lattice orientation in adjoining grains provides increased resistance to dislocation movement. A second strengthening mechanism for pure metals is cold working. Cold working multiplies the number of dislocations, and interaction between dislocations on different lattice planes increases the resistance to further deformation.

4.7.1.6 Conductivity Of Pure Metals.

Conductivity of pure metals is very high. As the purity of the metal decreases, conductivity is reduced. The normal flow of electrons is decreased by scattering and interaction with the impurities.

4.7.1.7 Alloys.

Most engineering metals are alloys. An alloy is formed by adding one or more metals or non-metals to a base metal to form a metal of desired properties. Alloying elements are usually added during melting of a base metal and the quantities added are specified over a percentage range. The alloying elements can be in one or more forms in the solidified state depending on the amount added and the rate of cooling from the melting temperature. Some elements may occupy lattice positions normally occupied by atoms of the base metal. The alloy thus formed is called a substitutional solid solution. Very small atoms such as those of carbon, nitrogen and hydrogen take up positions between the base metal atoms to form interstitial solid solutions. This action can actually change the lattice structure, an example being the addition of carbon to iron to form a steel. Alloying elements can also form new lattice structures which are continuous throughout the metal or distributed as small particles of various sizes throughout the metal. The distribution of the alloying elements is dependent on the amount of alloying elements that are added in relation to the amount that can be tolerated in the lattice of the base metal and their change in solubility with temperature.

4.7.1.8 Alloy Effects On Mechanical Properties.

All of the alloying element distributions increase the resistance of a metal to deformation. Increased strength results from the interference of the alloying atoms of particles formed by the alloying atoms with the movement of dislocations or by the generation of new dislocations. This distribution can often be modified by heat treatment.

4.7.1.9 Alloy Effects On Conductivity.

The conductivity of a metal is decreased as increasing amounts of alloying elements are added. Even small amounts of foreign atoms can greatly reduce conductivity. Some alloying elements have a much greater effect on conductivity than others. Generally, atoms that most severely differ in size and electron distribution from the base metal cause the greatest decrease in conductivity. The lattice distortion caused by the alloying atoms and particles of different chemical composition inhibits the flow of electrons through the lattice. Because of variations in chemical composition resulting from the tolerances in alloy additions, a conductivity range rather than a specific conductivity value is obtained for each alloy

4.7.1.10 Heat Treatment.

The properties of metals can be altered by changing the number and distribution of dislocations, alloying atoms, and particles of different composition. These changes can be accomplished through various types of heat treatment. The three principal types of heat treatment are: (1) annealing, (2) solution heat treatment, and (3) precipitation heat treatment or artificial aging.

4.7.1.11 Annealing.

In annealing, the metal is heated to a sufficiently high temperature to remove the effects of cold working by redistribution of dislocations and, in some instances, by the formation of new stress-free grains (recrystallization).

During the annealing of alloys, the temperature is selected sufficiently high to permit the alloying atoms to migrate readily. However, this selected temperature is sufficiently below that of maximum solubility to favor the formation of separate particles and compounds by the alloying atoms. Slow cooling from the annealing temperature encourages even more alloying atoms to move from their random position in the base metal lattice to aid in the growth of larger secondary compounds.

4.7.1.12 Annealing Effects On Mechanical Properties.

Annealing removes many of the obstacles to plastic flow, such as interacting dislocations and the numerous individual alloying atoms ind fine particles that normally resist plastic deformation. These processes generally result in metals of lower strength and greater ductility after annealing.

4.7.1.13 Annealing Effects On Conductivity.

The annealing process reduces obstacles to electron flow. Therefore, annealing improves the conductivity of a metal. Increased annealing times favors more complete diffusion and greater coalescence and growth of particles with associated increase in conductivity.

4.7.1.14 Solution Heat Treating.

The minimum number of alloying atoms will occupy lattice sites of the base metal when a temperature slightly below melting point is reached. In interstitial solid solutions, the maximum number of atoms will occupy interstatial positions. As temperatures are lowered, the atoms of many alloying elements will tend to diffuse together and form separate compounds or regions with a different lattice. If the metal is cooled sufficiently rapidly, the atoms do not have time to diffuse and are held in their original lattice positions (retained in solution). The process is called solution heat treating. Any delay in rapid cooling (delayed quench) or a slow rate of cooling will permit an increased amount of diffusion and reduce the number of alloying atoms held in solution.

4.7.1.15 Solution Heat Treating Effects On Mechanical Properties.

The alloying atoms retained in base metal lattice positions by solution heat treating present obstacles to dislocation movement. The resistance to plastic deformation increases the strength of the metal. In many instances, more than one alloying element contributes to the higher strength of alloys. Slow rates of cooling from solution heat treating temperatures or too low a solution heat treating temperature can reduce the strength of the heat treated alloy.

4.7.1.16 Solution Heat Treating Effects On Conductivity.

The distortion and stresses established by the substitution of alloying atoms for those of the base metal reduce the conductivity of the metal. The greater the number of solute atoms of a specific material, the greater the reduction in conductivity. The presence of lattice vacancies caused by solution heat treating also disrupts the electronic structure of an alloy and contributes to lower conductivity. The conductivity is not lowered as much if solution heat treat temperatures are low or cooling from solution heat treat temperatures is excessively slow. Poor solution heat treat practices such as these permit too many atoms to come out of solution or form secondary particles.

4.7.1.17 Precipitation Heat Treatment.

If an alloy has been solution heat treated to retain atoms in the same lattice occupied at high temperature, properties can be further modified by a precipitation or aging treatment. During a precipitation treatment, an alloy is heated to a temperature which will allow alloying atom diffusion and coalescence to form microscopic particles of different composition and lattice structure within the metal. The number, size, and distribution of the particles is controlled by the time and temperature of the aging process. Temperatures are much lower than those required for solution heat treating or annealing. Lower temperatures and shorter times result in smaller particle sizes. Higher temperatures favor the formation of fewer but larger particles.

4.7.1.18 Precipitation Treatment Effects On Mechanical Properties.

Precipitation or aging treatments are generally designed to increase the strength of alloys, particularly the yield strength. The strengthening is accomplished by the formation of small particles of different composition and lattice structure from the original lattice. The small particles provide obstacles to the movement of dislocations in which planes of atoms slip one over the other causing plastic deformation. Greatest strengthening usually occurs at a specific range of particle size for a particular alloy system. In many cases, aging is performed under conditions designed to provide a specific combination of strength and ductility or corrosion resistance. As aging increases beyond the optimum time or temperature, particle size increases and gradual softening occurs. When material has been aged for an excessive time or at too high a temperature, it is said to be over-aged.

4.7.1.19 Precipitation Hardening Effects On Conductivity.
The removal of foreign atoms from the parent lattice during precipitation hardening removes much of the distortion of the electron distribution in the lattice. This action favors the movement of electrons through the metal and results in higher conductivity. As increased amounts of foreign atoms are removed from solution and particle growth occurs during over-aging, conductivity continues to increase.

4.7.1.20 Measurement Of Mechanical Properties.
The most common method of determining the strength of metals is by means of a tensile test. In the tensile test, a specimen is cut from the metal to be tested, machined to a specified configuration, and tested to failure by application of a known tensile force. The stress at which a known amount of plastic deformation occurs and the breaking stress can then be determined. Many other destructive type tests can be performed to establish such properties as impact resistance, notch sensitivity and fatigue strength. All of these methods require destroying a section of the part to be tested and involve considerable time and expense

4.7.1.21 Hardness Testing.
An approximate measure of strength of metals may be established by hardness testing. Hardness is usually determined by the resistance of a metal to penetration by a rounded or pointed indenter pressed into the surface with a known static force. Measurement of hardness is based on the depth of penetration of the indenter or the plane area of the indentation. For many metals, correlation has been established between hardness and tensile strength. Hardness supplies no information regarding ductility although portable hardness testers are available, access and geometry often limit their use.

4.7.1.22 Conductivity And Mechanical Properties.
The same variables of chemical composition, heat treatment, and metal working which determine the mechanical properties of a metal also establish its electrical conductivity and magnetic permeability. As a result, correlation has been obtained between electrical conductivity and mechanical properties. This correlation does not mean that the conductivity value of a metal will reliably measure its mechanical properties. However, for some metals, deviation of the measured conductivity from a specified conductivity range or excessive variation in conductivity within a given part or specimen indicates a probable deviation in properties. This deviation may be detrimental to the performance of the metal and requires additional engineering investigation using hardness testing and other forms of testing to determine the magnitude of the deviation and disposition of the parts.

4.7.1.23 Requirement For Application.
Application of conductivity measurement for correlation with mechanical properties requires a clearly defined difference in conductivity ranges between the various alloys, tempers, or heat treatments involved. Differences in conductivity and/or permeability exist between alloys of many metals including aluminum, copper, magnesium, steel, and titanium. Not all alloys in each system are separable because of overlapping conductivity ranges. Even when overlapping conductivity ranges for two materials occur, separation of the two is possible if it is known that in the particular lot of material being tested, one material has Conductivity in the upper end of the total range and the second material is in the lower end of the range. Some metals have clearly defined differences in conductivity or permeability between the standard heat treat tempers. This situation exists for most structural aluminum alloys, many magnesium alloys, some copper alloys, and various steels. Little or no difference in conductivity is noted between the various heat treat conditions of titanium alloys with one or two exceptions.

4.7.1.24 Measurement Of Conductivity.

Absolute values of conductivity are usually determined by measuring the resistivity of a metal under very closely controlled laboratory conditions. Conductivity is calculated as the reciprocal of resistivity as follows:

C=1/R

Where:

C = Conductivity mhos/inch

R = Resistivity ohm.inch

Conductivity can be converted to % IACS units as described in section 4.2.2.1.1.3

4.7.1.25 Field Measurement Of Conductivity.

For determination of electrical conductivity under production and field conditions, eddy current instrumentation is employed. The eddy current instruments are calibrated against standards of known conductivity. When available, instruments designed specifically for measurement of conductivity are used. These instruments measure conductivity directly in % IACS.

Table 4-7. Electrical Conductivity Ranges for Aluminum Alloys

Alloy and Temper	Electrical Conductivity (%IACS)	
	Minimum	Maximum
1100 (All tempers)	57.0	62.0
2041-0	48-5	51.5
2013-T3XX	31.5	35.0
2041-T4XX	31.5	35.0
2013-T6XX	37.0	41.5
2024-0	45.5	50.0
2024-T3XX	28.0	33.0
2024-T4XX	28.5	32.5
2024-T6XX	35.0	41.0
2024-T8XX	36.00	42.5
2219-0	43.0	46.0
2219T3XX	27.0	31.0
2219-T62X	31.0	35.5
2219-T8XX	31.0	35.5
3003-0	44.5	50.0
6061-0	47.0	51.0
6061-T4XX	35.5	41.5
6061-T6XX	40.0	45.0
7075-0	44.0	48.0
7075-T6XX	30.0	35.0
7075-T73X	38.0	42.5
7075-T76X	36.0	39.0
7079-0	44.0	47.0
7079-T6XX	30.0	35.0
7079-T6XX	30.0	35.0
7178-0	43.0	47.0
7178-T6XX	29.0	34.0
7178-T76	35.0	39.0

4.7.1.26 Conductivity Of Aluminum Alloys.

Conductivity measurement is applied most often to aluminum alloys. This application results from the extensive use of aluminum alloys in the aerospace industry and the wide variation in the electrical conductivity and mechanical properties between different alloys and heat treatment. For most aluminum alloys in common usage, specific conductivity ranges have been established for each alloy and temper. Table 4-7 lists the conductivity ranges for most of the aluminum alloys commonly used in aircraft structural applications. These values represent a composite of values obtained from various airframe manufacturers and Government agencies. The ranges include all values obtained for standard heat treatments except for extreme values obtained from one or two sources which were clearly outside the ranges of all other lists. If a measured conductivity value for an aluminum alloy and temper is outside of the applicable range, its mechanical properties should be considered suspect. Measured conductivity values should be in accordance with Mlt,-H-6088 or a suitable ASTM standard.

4.7.1.27 Heat Treatment Effects On Aluminum conductivity.

An aluminum alloy has the highest conductivity and lowest strength when it is in the fully annealed temper. After quenching from the solution heat treating temperature, the strength is increased and the conductivity decreased. Many aluminum alloys are unstable for a considerable period of time after solution heat treatment even if held at room temperature during this time, a certain amount of atom migration takes place to initiate the formation of submicroscopic particles. This process, sometimes called natural aging, increases the strength of the alloy but has either no effect on conductivity or a slight decrease in the conductivity value. Some aluminum alloys remain unstable for such long periods after quenching that they are never used in the solution heat treated condition (7075 is an example). If a solution heat treated alloy is precipitation hardened by heating at relatively low temperature (generally 200-450°F), alloying atoms form small particles. At a critical size and distribution of particles, the strength of the aluminum alloy reaches a maximum. Conductivity increases during the precipitation hardening or artificial aging process. If aging is carried on beyond the point where optimum strength is obtained, strength will decrease, but conductivity will continue to increase.

4.7.1.28 Discrepancies In Aluminum Alloy Heat Treatment.

Variations from specified heat treating practice can result in aluminum alloys with strengths below required levels. Heat treat discrepancies include deviations or misapplication of the following processes:

a. Solution heat treating temperature

b. Solution heat treating time.

c. Quenching practice.

d. Aging temperature.

e. Aging time.

f. Annealing temperature and time.

g. Uncontrolled temperature application

4.7.2 Applications Of conductivity Measurement.

4.7.2.1 Separation Of Alloys And Tempers.

Conductivity measurement can be used to separate mixtures of two or more alloys and/or tempers. Separation is possible when the electrical conductivity of each grouping is clearly different. The process of separation may be accomplished with an instrument calibrated in %IACS.

4.7.2.2 Magnetic Materials.

Use of general purpose instruments may be extended to the separation of magnetic materials where the product of permeability and conductivity of each of the alloys is clearly different. Conductivity meters will not measure the conductivity of magnetic materials.

4.7.2.3 Typical Application.

Eddy current techniques are used to separate metal parts or raw materials of similar geometry which have lost alloy and/or temper identification and have become mixed in manufacture or storage. Such procedures can be applied at any stage in the processing, storage, or service of the material.

4.7.2.4 Control Of Heat Treatment.

The relationship between electrical conductivity and heat treat condition has permitted the use of eddy current techniques for checking the adequacy of heat treatment in aluminum alloys. In this application, conductivity measurements by eddy current techniques are used to supplement a minimum amount of tensile testing and/or hardness testing. Eddy current conductivity measurements are particularly valuable for determining the uniformity of heat treatment of large and complex aluminum alloy structures when tensile specimens are not obtainable and part geometry limits accessibility for hardness testing. Adequacy of heat treatment of aluminum alloys is determined by conformance of the material to the pre-established conductivity ranges. This method of heat treat control has been applied extensively to aluminum alloys. Eddy current (electromagnetic) techniques are used also for evaluation of heat treatment of steels. Generally, more sophisticated instrumentation is employed for steels, but general purpose instruments can be used for many applications. Acceptance standards are usually employed for eddy current inspection of steel. Conductivity measurement is applied to a lesser degree for heat treat control of copper and magnesium alloys. Eddy current techniques can be employed for heat treat control in any alloy system where consistent but different conductivity ranges or permeability values occur with the various heat treating conditions. Conductivity measurement has not been established as a method of determining heat treat response in titanium alloys. Differences in conductivity between various heat treat conditions for most titanium alloys are insufficient to permit determination of temper.

4.7.2.5 Determination Of Heat And Fire Damage.

A common application of conductivity measurement in field applications is the determination of heat and/or fire damage to aircraft structures. Because of the extensive use of aluminum alloys for aircraft structures and their sensitivity to mechanical property losses at relatively low temperatures, greatest experience and data have been generated for these materials. Heat and fire damage to other metals can be detected if temperatures become high enough to affect both conductivity and/or permeability and mechanical properties. For aluminum alloys, damage is detected as deviations in conductivity from the specified range for the alloy and temper being inspected. Heat and fire damage usually vary over a part because of nonuniform application of heat. Nonuniform heat application, in turn, results in variations in electrical conductivity. Unless the temperature and time of heat application is known, or testing is performed on a number of parts with the same history of heat application, quantitative values of mechanical properties cannot be established from the electrical conductivity values.

4.7.3 Test Equipment.

4.7.3.1 Direct Conductivity Measurement.

To determine conductivity directly, eddy current instruments are available which provide a value of conductivity in % IACS. These instruments do not cover the entire conductivity range. The most common range of instrument coverage is approximately 8 to 110 % IACS. Although instruments with other conductivity ranges are available, they have more limited application and are not generally available at field bases. % IACS measuring instruments usually require only two standards of known conductivity for calibration. US Navy unit - .5-105% with variable frequency.

4.7.3.2 General Purpose Equipment.

If direct conductivity measuring equipment is not available, general purpose eddy current equipment may be adapted for measuring conductivity. Use of general purpose equipment requires a larger number of standards to establish a calibration curve. The number of standards necessary for a conductivity measuring application is determined by the range of conductivity to be covered and the accuracv required. General purpose equipment can also be employed in a go, no-go function to separate metals above and below a specified conductivity value. A standard representing the minimum acceptable or rejectable conductivity must be available.

4.7.3.3 Equipment For Magnetic Materials.

Impedance plane analysis instruments can be used to measure the conductivity of ferromagnetic materials because the permeability and conductivity can be separated in phase. Meter type conductivity measurement equipment generally available at field level can not separate conductivity from permeability variations. However, the combination of conductivity and permeability, in many cases, can be related to variations in alloy, temper and strength. General purpose meter type instruments can then be used to separate or grade various levels of properties. The number of standards required depends on the number of categories of materials to be established.

4.7.4 Effects Of Variations In Material Properties.

4.7.4.1 Conductivity.

Conductivity variations can occur in metals as a result of improper heat treatment or as a result of exposure to excessive temperatures during service and cold working. These are the conditions for which eddy current inspection is usually performed. Conductivity variations can stem from other sources. Separation of elements during solidification of metals can lead to either localized or uniform differences in conductivity. For instance, a variation in conductivity can exist with increasing depths beneath the part surface particularly in heavier sections which have not been worked extensively. Slight differences in heat treating time, temperature, or quenching rates imposed by limitations in heat treating facilities or changes in part configuration also lead to variations in conductivity of a part. Localized cold working of metals when not followed by heat treatment to relieve residual stress can reduce electrical conductivity. Many of the variations are considered normal to the processing of the parts and the conductivity lies within the acceptable range for the alloy specification and temper. Conductivities outside the specified range for a given alloy and temper should be considered unacceptable and further investigation should be performed using hardness testing techniques.

4.7.4.2 Clad Materials.

Cladding will affect the measured conductivity of the base metal. The degree to which the cladding will affect the value obtained depends on the conductivity of the cladding, the thickness of the cladding, and the operating frequency. Present applications are usually limited to Alclad aluminum alloys in the range of 0.050 to 0.080 inch thick using conductivity meters with operating frequencies of 60 KHz. Special conductivity ranges are required for clad aluminum alloys. The thicknesses of cladding, which are usually based on a percentage range of the overall thicknesses, can vary slightly because of normal tolerances. At 60 KHz, conductivity readings from aluminum alloys less the 0.050 inch in thickness are affected by both cladding and part thickness. Eddy current testing of modern complex cladding systems is still in an experimental stage for the most part.

4.7.4.3 Magnetic permeability.

Direct meter measurement of electrical conductivity is applicable to nonmagnetic materials with a relative magnetic permeability of one or nearly one. If magnetic permeability exceeds one, it will produce a bridge unbalance in the meter system which can not be separated from the conductivity measurement and erroneous readings will be obtained. For this reason, conductivity of steels, nickel, and other magnetic materials can not be determined with conventional eddy current conductivity meters. Some stainless steels (400 series) are essentially nonmagnetic in the annealed condition, but slight amounts of cold working or exposure to extremely low temperature can cause transformation to a magnetic structure. Impedance plane analysis equipment can readily separate magnetic permeability and conductivity, allowing an accurate measurement of conductivity of ferromagnetic materials.

4.7.4.4 Geometry.

Any change in part configuration that affects distribution or penetration of eddy currents will result in erroneous electrical conductivity readings. The following sources of error are included in these categories:

a. Proximity to part edges or adjoining structure.

b. Metal thickness less than the effective depth of penetration in the metal.

c. Excessive curvature of part surface.

4.7.4.5 Metal Thickness.

If metal thickness is less than the effective penetration of the eddy currents, the measured conductivity will differ from the true value. Note that the effective penetration depth is approximately three times the standard depth of penetration. With meter equipment it is important to determine the operating frequency of the instrument. The operating frequency must not exceed the effective penetration depth of the material being tested. Impedance plane analysis equipment has a very wide range of operating frequencies, and the frequency can be adjusted to limit penetration to less than the effective depth. The standard depth can be determined by using the equation in section 4.2.3.3.1. Special sliderules are available for calculation of depth of penetration. Effective depth is approximately three times greater than the standard depth calculated by this equation. The material thickness must be greater than the effective depth or errors in conductivity measurement will occur.

4.7.4.6 Edge Effects.

If the electromagnetic field of the probe is affected by the geometry of the edge of the part, an error will occur in the measurement of the conductivity. The probe should be located several probe diameters away form the nearest edge or transition boundary.

4.7.4.7 Curvature.

Lift-off effects caused by the probe-to-curve surface fit-up will cause an error in the conductivity measurement. On curved surfaces, the smallest practical probe should be used to minimize lift-off effects.

4.7.5 Effects Of Variations In Test Conditions.

4.7.5.1 Frequency.

Because frequency affects distribution of eddy currents within the test part, it affects the minimum thickness which can be measured without special adjustments. Higher frequencies permit measurement of thinner metals without compensation for thickness. Frequencies that provide less than 3 standard depths of penetration in the metal being tested are necessary for reasonably accurate conductivity measurement. However, the higher frequencies are more strongly affected by localized variations in conductivity or by conductive coatings and cladding on metals. Excessively high frequencies should not be used for conductivity measurements.

4.7.5.2 Probes For conductivity Measurements.

With instruments designed for conductivity measurement, probes are carefully matched to the instruments and are usually obtained from the instrument manufacturer. Probes for conductivity measuring instruments are larger than those normally employed for defect detection. This design provides for averaging of conductivity over a relatively large area. Probes are designed with plastic or ceramic shoes to prevent damage to the coil. With continued use, wear on the face of the probe reduces the coil-to-surface distance, and calibration cannot be obtained. As wear occurs, the probe shoe must be changed and the instrument recalibrated.

4.7.5.3 Lift Off Effects On conductivity.

Meter type conductivity measuring eddy current instruments often have a pre-set lift-off adjustment. The lift-off adjustment is usually set during calibration of the instruments. Applicable maintenance manuals describe the procedures that can be performed by trained NDI personnel. With probe wear and changes in instrument electrical components over a period of time, lift-off adjustment can change. Therefore, when conductivity measurements are to be performed on rough surfaces or through thin nonconductive coatings, lift-off adjustment should be checked prior to performing the measurements. After calibrating an instrument against the conductivity standards, lift-off adjustment should be checked against a specimen with conductivity representative of the test part. Lift-off greater than the amount of preset lift-off adjustment (if any) results in errors in conductivity reading.

4.7.5.4 Temperature Effects On Conductivity Measurements.

Higher temperature increases the thermal activity, of the atoms in a metal lattice. The thermal activity causes the atoms to vibrate at a high amplitude about their position in the lattice. This thermal vibration of the atoms increases the chances of a collision with electrons in the material. This increases the resistance to electron flow, thereby lowering the conductivity of the metal. Lower temperatures reduce thermal oscillation of the atoms resulting in an increased electrical conductivity. The conductivity of standards is usually determined at a specific temperature; 68°F (20°C) is most commonly used. Typical conductivity values and allowable conductivity ranges are also established at approximately this temperature. If all instrument calibration and conductivity measurements could be performed at this temperature, errors in conductivity measurement related to temperature variation would not occur and/or temperature compensation would not be required. In field applications, testing temperatures can conceivably be anywhere in the range of 0°F to 120°F. Unless precautions are taken in selection of standards, calibration of the instrument, and testing, errors will occur in the measured conductivity values. Two ways in which erroneous readings may be obtained are:

a. Difference in temperature between standards and test part.

b. Difference in temperature at which conductivity of the standard was originally established and the temperature at which instrument calibration and conductivity measurements are performed.

To prevent errors from differences in temperature between standard and test part, the instrument and standards should be allowed to stabilize at the test part temperature before calibration and conductivity measurements are performed. In no instance should measurements be taken if part and standards temperature differ by more than 10°F. Even though standards and test part are at the same temperature, error in determining conductivity values occurs when the measuring temperature differs from the temperature at which the conductivity of the standards was originally established. The magnitude of the error becomes larger as this difference in temperature increases.

4.7.6 Conductivity Reference Standards.

4.7.6.1 Number of Standards Required.

For calibration of eddy current conductivity meters, at least two calibration blocks with accurately determined conductivity values must be available. When using general purpose instruments, the number of standards may vary from two to several depending on the inspection purpose and the accuracy required.

4.7.6.2 Conductivity Range.

The conductivity range of the standards must be within the range of the instrument and cover the range of conductivity values to be measured. Preferably, the calibration blocks should have the same change in resistivity with temperature as the test parts

4.7.6.3 Size Of conductivity Standdards.

For convenience of transportation and storage, conductivity standards are usually kept relatively small. Standards must have sufficient size to prevent edge effects or thickness from having a bearing on conductivity readings. These requirements can be satisfied by requiring length and width to be 1 inch greater than the probe diameter and the thickness greater than 3.5 times the standard depth of penetration at the test instrument frequency. Standards should be flat, have a surface finish of 63 RMS or better, and be free of any coatings.

4.7.6.4 Accuracy Of Standards.

Standards used for calibrating instruments immediately prior to measuring conductivity should be accurate within ±0.5% IACS of the nominal value. A second set of standards accurate within 0.35% IACS should be periodically made available for checking the performance of instruments and field calibration standards. Standards should be traceable to the National Bureau of Standards. Standards are available from manufacturers of eddy current conductivity instruments.

4.7.6.5 Stability Of Standards.

Many standards, particularly those of aluminum alloys, are subject to metallurgical changes if exposed to excessively high temperature, and thermal shock from sudden changes in temperature. Surfaces of standards can also corrode if exposed to moisture or other hostile environments. Damage caused by rough handling can also lead to error in conductivity readings. For these reasons standards should be transported and stored in dry, clean, protected areas not subject to excessive temperatures.

4.7.7 Inspection Procedures.

4.7.7.1 Conductivity Procedure Requirements.

Procedures for conductivity measurement should take into account the varieties of environments and test part conditions which might be encountered. In preparing for conductivity measurement, the following steps should be considered:

a. Background and objectives of the inspection.

b. Equipment requirements.

c. Part preparation.

d. Instrument calibration.

e. Conductivity measurement procedures.

f. Acceptance/rejection criteria.

4.7.7.2 Background And Objectives.

An understanding of the problem that initiates a conductivity measurement requirement enables the inspector to better interpret inspection results and handle unexpected test conditions. The purpose of the test can be separation of mixed or improper alloy, determination of improper heat treatment, and detection of heat or fire damaged material. The types of material involved and the location of the inspection should be specifically established. Heat and/or fire damage may be confined to a portion of a part and may vary in the degree of damage. These variables must be considered during conductivity measurement.

4.7.7.3 Part Preparation.

As with all types of eddy current inspection, areas on which conductivity measurement is to be performed must be free of any sharp slivers or foreign material that could damage a probe or cause lift-off changes. Such conditions can be removed with fine emery paper or other approved means. Conductivity measurements can be performed through nonconductive coatings that have thicknesses equal to or less than the amount of lift-off adjustment on meter type equipment. Both the thickness and uniformity of the coating thickness and the amount of lift-off adjustment provided should be checked prior to measuring conductivity through nonconductive coatings. If lift-off adjustment cannot be obtained, correction factors can be determined for uniform coatings by establishing the change in conductivity readings caused by the coating and adding this change to each of the measured values. Nonuniform coatings in excess of lift-off adjustment must be removed prior to measuring conductivity. Excessively rough surfaces should be smoothed with emery paper to provide a surface finish 250 RMS or better before performing conductivity measurements.

4.7.7.4 Calibration For Measuring Conductivity Values.

NOTE

US Navy - PD-214 Follow instructions in the: instruments' conductivity program.

To calibrate a general purpose instrument for measuring conductivity directly, the following procedures should be followed:

a. Select a sufficient number of standards to obtain a smooth continuous curve over the range of conductivity to be measured. The actual number of samples will depend on the expected range to be measured and the accuracy required.

b. Adjust the instrument for lift-off, if applicable, and a standard representing approximately mid-range of the conductivities to be measured.

c. Determine the meter or scope readings corresponding to each of the intermediate standards and record the conductivity value.

d. Note each of the values on a graph with meter or scope readings on the vertical axis and conductivity values on the horizontal axis.

e. Construct a smooth curve through all the points. The curve should increase or decrease smoothly throughout the range with no minimum or maximum values. This curve is then be used to measure conductivity with the specific instrument and probe.

4.7.7.5 Calibration For Separation Of Mixed Alloys.

To calibrate the general purpose instruments for separating two groups of materials with different conductivities, the instrument is set to obtain readings at one end of the scale for one group of material, and the other end of the scale for the second group of material. Lift-off is usually set on a specimen representing the group with the lower value of conductivity or permeability.

4.7.7.6 Calibration Check.

Calibration or standardization should be checked approximately every 10 minutes during continual use and whenever abnormal values are obtained. Whenever an instrument is found to be out of calibration, all measurements performed since the previous calibration verification should be rechecked.

4.7.7.7 Acceptance/Rejection Criteria.

Acceptance/rejection criteria can be found in the applicable T.O. or material specification. Acceptable conductivity ranges for many aluminum alloys are shown in Table 4-7.

SECTION VIII
THICKNESS MEASUREMENT

4.8 SPECIFIC APPLICATION — THICKNESS MEASUREMENT.

4.8.1 Criteria for Application.

4.8.1.1 Types Of Measurements.

In general, three types of thickness measurement may be performed by eddy current techniques. The total thickness of thin metallic products such as foils, strip and sheet, may be determined when the thickness dimension is less than the effective depth of penetration of eddy currents in the material. A second category of thickness measurement includes the measurement of metallic plating or coating on a conductive or magnetic base. Subcategories of plating and coating measurements can be established on the basis of the relative conductivity or permeability of the plating and the base metal on which it is plated. Typical subcategories of plating measurements include the following:

a. Low conductivity plating on high conductivity base.

b. High conductivity plating on low conductivity base.

c. Low permeability plating on a high permeability base.

d. High permeability plating on a low permeability base.

The terms high and low are relative and are not meant to indicate specific values. The third category of measurement is the determination of nonconductive coating thickness on a metallic base. This application can also be extended to measure the total thickness of thin nonconductive materials that are accessible from both sides.

4.8.1.2 General Limitations of Plating Thickness Measurement.

The use of eddy current techniques for thickness measurement is confined to thin materials. This limitation results from the inability of the eddy current field to penetrate deeply into conductive materials. The effective depth of penetration, and therefore the thickness that can be measured, decreases as the conductivity and/or permeability of the metal increases. To determine the thickness of plating or coatings on metallic substrates, a difference must exist in conductivity or permeability between the surface material and base material. Increased sensitivity is obtained, as the differences between plating and substrate conductivity or permeability become larger. For nonconductive coatings, the sensitivity improves with increasing frequency. Larger probe diameters provide greater sensitivity for measurement of thicker plating. A summary of the effects of an increase in material properties and inspection variables on the sensitivity and range of thickness measurements is presented in Table 4-8.

Table 4-8. Effects of Material and Inspection Variables on the Sensitivity and Range of Thickness Measurements.

Variable Increased	Sensitivity of Measurement	Range of Measurement
Conductivity	Increases for thin metallic parts and plating. Increases throughout effect range for nonconductive coatings.	Decreases for metallic materials. Increases for nonconductive coatings.
Permeability	Increases for thin metallic parts and plating. Decreases for thick metallic parts and plating. Increases throughout for nonconductive coatings.	Decreases for metallic materials. Increases for nonconductive coatings.
Frequency	Increases for thin metallic parts and plating. Decreases for thicker metallic parts and plating. Increases throughout the effective range for nonconductive coatings.	Decreases for metallic materials. Increases for nonconductive coatings.
Probe Diameter	Increases for thicker metallic parts and plating and throughout effective range for nonconductive coatings.	Increases for metallic parts, plating, and nonconductive coatings.

4.8.1.3 Test Systems.

A wide variety of specialized equipment is manufactured for thickness measurement. Many such instruments are optimized for one or two types of applications. Examples include instruments designed to measure nonconductive coatings on nonmagnetic metals or instruments for measuring nonmagnetic plating on a magnetic substrate. Because of limited requirements, such specialized equipment is usually not available for use in the field. In most cases, general-purpose instruments may be adapted for thickness measurement. Many of the meter type instruments can be used for a wide variety of thickness measurement operations. Impedance plane analysis equipment is very useful for thickness measurement. Phase change is more nearly linear with increasing depth of penetration, thereby providing more consistent sensitivity and accuracy over the entire range of measurement.

4.8.1.4 Thickness Measuring Procedures.

Before thickness measurement can be performed, the eddy current measurement procedures should be carefully established and proven to ensure accuracy and reliability. Curves should be prepared to relate instrument readings to known thickness standards. A sufficient number of samples within the thickness range to be measured must be used in preparing the curves to ensure that a smoothly increasing or decreasing curve will be obtained. The type and number of standards necessary for instrument standardization must be defined. The limitations of the procedures in terms of material and dimension applicability must be established and noted in the procedures. Because instrument settings for a specific inspection may vary slightly with test conditions, different probes, and variations between instruments, specific instrument settings are not usually provided for these applications.

4.8.2 Measurement of Total Metal Thickness.

4.8.2.1 Applications of Total Thickness Measurement.

The primary use of eddy current techniques for measuring the total thickness of metal parts is to detect corrosion on the far sides or between layers of structure. However, this technique can also be employed to establish the thickness of thin sheet, to determine wear or thinning of sheet materials and to measure thickness, erosion, or corrosion of tubing walls. Thickness measurement with eddy currents is generally used when mechanical methods of measurement cannot be utilized and ultrasonic equipment is not available or applicable or if very thin materials are to be measured.

4.8.2.2 Total Thickness Limitations.

The accuracy and range of metal thickness measured with eddy currents are dependent upon the electromagnetic properties of the material and the test system. Increasing conductivity and magnetic permeability increase accuracy in measuring very thin specimens, but decrease the effective range of measurement and the accuracy at greater depths. Therefore, at a specified frequency, greater thicknesses of metals with low conductivity and/or low magnetic permeability can be measured than can be measured in materials of high conductivity and/or high permeability.

4.8.2.3 Frequency Effects In Total Thickness Measurement.

Just as decreasing frequency increases the depth of penetration of eddy currents in a conductor, decreasing frequency also increases the thickness of a metal that can be measured by eddy current inspection techniques. Higher sensitivity is obtained for the thinnest specimens with the higher frequency. For greater thicknesses (over 0.050 inch), the lower frequency provides greater sensitivity and greater overall penetration. Sensitivity in any thickness range can be determined by the plot. The greater the slope of the plotted line, the greater the sensitivity. Optimum frequency can be estimated by calculating one standard depth of penetration.

4.8.2.4 Effects Of Probe Construction.

Probes designed specifically for thickness measurement have air cores and are generally larger in diameter than the ferrite core probes used for flaw detection. Larger diameter probes average thickness measurements over a larger area. Smaller diameter probes and probes with ferrite cores reduce the area of measurement and therefore can be used in smaller areas and closer to edges. The larger air core probes can provide greater sensitivity for thickness measurements than the ferrite core pencil probes.

4.8.2.5 Operating Procedures for Total Thickness Measurement.

All thickness measuring should be performed in accordance with pre-established procedures. In general, these procedures will include the following steps:

a. Prepare part for thickness measurement.

b. Establish the presence of geometrical factors, which will limit or restrict thickness measurement.

c. Select appropriate test system, probe, and operating frequency.

d. Develop or verify a calibration curve and calibrate the test system using the specified standards.

e. Perform thickness measurements at designated points

f. Record thickness and report all rejectable values as required by the written procedure.

4.8.2.6 Prepare Part for Thickness Measurement.

Many thickness measurements must be performed through nonconductive coatings such as paint or anodic coatings. Lift-off compensation must be used during the calibration. Any loose foreign material should be removed from the surface where thickness is being determined. Any sharp edges, protrusions, or chemical, which is potentially damaging to the probe, should be removed.

4.8.2.7 Presence of Geometrical Limitations.

Prior to measuring thickness by eddy current techniques, the presence and position of any structural features that could restrict accessibility or reduce accuracy of measurement must be established. Thickness measurement must be performed sufficiently far away from fastener and other conductive objects to prevent its influencing the meter reading. Limited access may restrict the type of probe to be used. In most cases, written inspection procedures will define geometrical limitations.

4.8.2.8 Selection of Test System.
The test system selected for thickness measuring must be based on thickness measuring requirements, frequency of the eddy current instrument, and the types of probes available.

4.8.2.9 Selection of Test Frequency for Thickness Measurement.
For each thickness measurement task to be performed by eddy current techniques there is an optimum frequency or range of frequencies that will provide optimum sensitivity at the depth to be measured. The product of the material conductivity in percent IACS and the relative magnetic permeability is plotted along the vertical axis, and frequency in kilohertz is plotted along the horizontal axis. Lines representing optimum thicknesses are plotted on the graph. To determine the recommended frequency, the product of material conductivity and relative permeability of the material to be measured is found on the vertical axis. Follow this point horizontally to the diagonal line representing the thickness to be measured. The recommended frequency is found on the horizontal axis by extending a line vertically downward from the established point. Considerable variation from this frequency value will still provide sufficient sensitivity for most applications. When in doubt, the adequacy of a frequency may be determined by establishing a trial calibration curve.

4.8.2.10 Calibrate Instrument.
Because the general-purpose instruments are not specifically designed for thickness measuring, correlation must be established between instrument readings and thickness dimensions. Therefore, the thickness range over which measurements are to be performed should be defined as closely as possible to minimize the number of data points to be established. Where applicable, lift-off compensation should be employed to minimize the effects of variations in surface finish on thickness readings.

4.8.2.11 Record Thickness and Report Rejectable Values.
Most written procedures provide acceptance limits for the thickness dimension. When a rejectable value is obtained, it is advisable to recheck the calibration of the instrument against the standards. The written procedure usually provides methods for reporting rejectable values.

4.8.2.12 Standards for Total Thickness Measurement.
The standards used for calibration in total thickness measurement must have the same electrical conductivity, magnetic permeability, and geometry as the material being measured. The same electrical conductivity is usually obtained by requiring the standards to be fabricated from the same alloy and temper as the inspection material. In magnetic materials, permeability can vary to such a degree within a single alloy and temper that selection of representative standards can be difficult. The high permeability of iron and ferromagnetic steel restricts the use of eddy current thickness measurement to very thin metals. The curvature of the standards should be the same as the part being inspected. All standards should be uniform in thickness and the accuracy of the standard thickness should be at least 10 times that required for the accuracy of the thickness measurement. For example if thickness measurement is required to the nearest 0.001 inch, the standards should be accurate to the nearest 0.0001 inch. All standards should be clearly identified with alloy, temper and thickness.

4.8.2.13 Accuracy of Thickness Measurement.
The accuracy obtained in total metal thickness measurement varies widely depending on material properties, thickness, frequencies employed, and system noise level. With higher frequencies (500 KHz and up) and thin materials (0-010 inch and less), thicknesses may be measured to the nearest 0.0001 inch. As frequencies are lowered and thicknesses increase, accuracy decreases. For maximum accuracy, variations in lift-off, conductivity, geometry and magnetic permeability must be reduced to the lowest possible level.

4.8.2.14 Application of Conductive Coating Measurement.
Eddy current inspection techniques are commonly used to measure the thickness of conductive platings on metallic materials. These measurements may be used as a process control to determine that the proper thickness of platings or conductive coatings has been applied to a substrate. The thinning of such platings and coatings, because of erosion or corrosion, can also be established. Eddy current methods have also been employed to determine the presence and thickness of surface layers which have been altered in composition from the metal deeper within the part. This application includes the measurement of carburized cases in steel and the depth of oxygen or hydrogen contamination

of the surface layers of titanium alloys. The absorption of carbon into the surface layers of steel effectively lowers the magnetic permeability. The solution of hydrogen and oxygen in the surface of the titanium alloy lowers the conductivity of the surface. The amount of surface contamination can be measured by measuring the changes in permeability and conductivity.

4.8.2.15 Effects Of Material Properties on Plating Thickness Measurements.
Although the depth of penetration of eddy currents in metals decreases with increasing electrical conductivity, lack of penetration for measuring plating thickness is seldom a problem. Plating and coating thicknesses rarely exceed 0.005-0.010 inch and in many instances are less than 0.003 inch thick. The sensitivity of inspection is controlled to a large measure by the difference in conductivity and/or magnetic permeability between the base metal and the plating. Coating or plating thickness measurement is considered feasible if the product of conductivity and permeability for the base metal and the coating have a ratio of 1.5 or greater or 0.67 or less. Sensitivity increases as the difference in the conductivity or permeability value between coating and substrate increases. Therefore, a rough determination of sensitivity can be obtained from an impedance curve, which shows the positions of substrates and coating at the frequency and probe size used for inspection.

4.8.2.16 Effect Of Test Conditions on Plating Thickness Measurement.
Normally, the frequencies employed for plating thickness measurement are relatively high, 100 KHz and greater. In specialized equipment, frequencies as high as 6 MHz are available. These frequencies provide high sensitivities for very thin coatings. As the Conductivity differences between plating and base metal decrease, the frequency may be either increased or decreased as necessary, to obtain equivalent sensitivity for the thickness to be measured. Considerable latitude from these approximate values may be exercised in choosing the actual operating frequency. If doubt exists, a trial calibration curve should be prepared. To reduce the effects of surface roughness and variations in nonconductive coatings, lift-off compensation (intermediate layer technique) should be employed. Generally, 0.002 to 0.003-inch lift-off compensation is sufficient unless very rough surfaces are present in the test area. An increase in probe diameter and the use of air cores rather than ferrite cores has the effect of increasing measuring sensitivity and extending the depth to which accurate plating thickness measurement can be performed.

4.8.2.17 Procedures for Plating Thickness Measurement.
A written procedure should be established for each application of eddy current inspection techniques for plating thickness measurement. Each procedure should include the following steps:

a. Define the objective of the plating or coating thickness measurement. The type of base metal and plating should be included in the procedure.

b. Clean any foreign material from the inspection area. Even though lift-off compensation is employed, excessive build-up of foreign material in excess of lift-off adjustment could lead to significant errors.

c. Select the test system, instrumentation, and probe that will perform the thickness measurement to the required accuracy.

d. Develop or verify calibration curve and standardize the test system using the specified standards. A calibration curve must be available for each combination of instrument and probe

e. Perform plating thickness measurements at the designated points. The probe should be held against the part with constant pressure. When available, spring loaded probes can be used to aid in maintaining constant pressure. For curved surfaces, a fixture may be used to maintain the probe normal to the surface. Plating thickness measurements should be made in areas where the readings are not affected by adjoining structures, edges, or variations in total plating plus substrate thickness that are within the effective limit of penetration. At least three readings should be taken at each measurement position to ensure accurate and repeatable values. The calibration of the instrument should be periodically checked against the standards to guard against instrument drift.

f. Check all measured values against the tolerances specified by the written procedure. All abnormal values should be reported as required by the procedure.

4.8.2.18 Plating Thickness Reference Standards.

Reference standards for plating thickness measurements must have the same electrical conductivity, magnetic permeability, and geometry as the part. These requirements apply to both the base material and the plating. Electrical conductivity and magnetic permeability for the base material are usually obtained by using the same alloy and temper for the standards as used in the part. Particular care should be taken in processing the materials to ensure that similar properties are obtained. The surface finishes of the part and standard should also be alike. To obtain the same electrical conductivity, magnetic properties, and surface finish for plating on the parts and reference standards; the plating must be performed in baths of similar composition and subject to similar controls. If the plating on the part is stress-relieved prior to thickness measurement, the references should receive the same treatment. Several methods of determining plating thickness on reference standards can be used. One of these is to carefully measure the thickness prior to plating and again after plating. The difference represents the thickness of the plating (plating is applied to one side only). A second method is to measure the plating on an adjacent section of the standard by removal of a rnetallographic specimen. The total thickness of the plating plus substrate must exceed the effective depth of penetration in the part. A total thickness of 2.5 to 3 combined standard depths of penetration is usually considered sufficiently thick. This thickness may be determined by adding the standard depth of penetration in the plating and the substrate at the frequency used. For example, if approximately 0.003-inch thick sliver plating on aluminum is to be measured at 200 KHz, the minimum total thickness can be determined as follows:

a. The standard depth of penetration of silver at a frequency of 200 KHz is 0.007 inch. Therefore, the 0.003-inch of silver in the plating represents 0.4 standard depth of penetration.

b. The 2024-T3 aluminum base material must be at least 2.5 - 0.4 = 2.1 standard depths of penetration.

If the conductivity and magnetic permeability of a metal are known, the standard depth of penetration can be determined.

4.8.3 Measurement of Nonconductive Coatings.

4.8.3.1 Nonconductive Coatings.

A wide variety of nonconductive coatings are applied to military hardware. Primers, paints, and plastics and sealants are widely used to protect metals from corrosion. Anodic coatings are used on metals, particularly aluminum, to prevent surface deterioration. Other oxide coatings provide protection against heat or wear. Boron epoxy laminates increase stiffness and strength. To control the thickness of such nonconductive coatings or to measure their loss during service, eddy current inspection techniques have been employed with a high degree of accuracy.

4.8.3.2 Basis for Measurement of Nonconductive Coatings.

The determination of thickness of nonconductive layers or materials is a relative measure of the magnetic coupling between the probe and the underlying conductive material. In other terms, the thickness of a nonconductor is a direct measurement of lift-off or the spacing between the probe and the conductor. Because the properties (electrical conductivity, magnetic permeability, and geometry) of the underlying materials affect the signal detected by the probe, they must be constant or their variation minimized by instrument adjustment. Three requirements for measurement of nonconductive coatings by eddy current techniques are: (1) the nonconductive coating must be in intimate contact with a conductive material; (2) the thickness of the coating must be less than the effective range of the varying magnetic field generated by the probe; and (3) the thickness of the substrate must be at least 2.5 times the standard depth of penetration at the frequency employed.

4.8.3.3 Impedance Effects of Nonconductive Coatings.

NOTE

US Navy: follow PD-214 instructions for nonconductive coating thickness measurement.

When an eddy current probe is placed on bare metal, the impedance of the coil is changed by an amount that is dependent on the frequency of the oscillating current, the conductivity, magnetic permeability, and geometry of the test part, and the geometry and construction of the test coil. When impedance measuring eddy current instruments are used, the measurement of nonconductive coating thickness is determined from variation in current or voltage across the coil as the coil impedance changes due to increase or decrease in lift-off.

4.8.3.4 Influence Of Material Properties and Frequency.
Increases in the conductivity or magnetic permeability of the base metal or in the operating frequency improve the sensitivity of the thickness measurement of nonconductive coatings.

4.8.3.5 Test Systems for Nonconductive Coating Measurement.
Nonconductive coating thickness can be measured with almost any eddy current inspection system. Sensitivity is limited by the frequency obtainable with available test instruments. Accuracy and range of measurement are increased with increasing frequency. The size and construction of available probes, and instrument circuit design affect the accuracy of measurement. Accuracy decreases with increases in coating thickness. Sometimes probes are spring-loaded to prevent variations in readings caused by inconsistent pressures.

4.8.3.6 Procedures for Measuring Nonconductive Coatings.
The following steps should be followed in performing thickness measurements of nonconductive coatings or the total thickness of nonconductive materials.

a. Establish the range of thickness to be measured and the accuracy required.

b. Select test system capable of performing required thickness measurement to specified tolerances.

c. Prepare the part or area for thickness measurement.

d. Prepare calibration curve or verify calibration curve with existing standards. A calibration curve is required for each combination of instrument and probe and for each base metal.

e. Perform thickness measurement.

4.8.3.7 Standards for Measurement of Nonconductive Coatings.
Standards for measurement of nonconductive coatings may be obtained from a number of sources. Layers of paper, plastic, and tape are three of the most available standards. Standards should be uniform in thickness and conform to the surface of the bare metal representing the part to be measured. When standards are stacked layers of material, no gaps or pockets should exist between the layers. Standards can also be actual sections of parts with known thicknesses of the nonconductive coating applied. These standards usually require more effort and expense to prepare. When possible, standards should be measured to an accuracy 10 times greater than the accuracy required for the measurement of the nonconductive coating. This may not always be possible under field conditions.

SECTION IX
ADVANCES IN ELECTROMAGNETIC TEST METHODS

4.9 ADVANCES IN ELECTROMAGNETIC TEST METHODS.

4.9.1 General Improvements.

4.9.1.1 Impedance Plane Eddy Current Test Equipment.

A significant increase in testing capability has been realized by the upgrading of existing test techniques with newer instrumentation. The use of modern impedance plane equipment has greatly increased the flaw analysis capability of the inspection process.

4.9.1.2 Digital Equipment.

The use of digital test equipment, along with digital computers to process and analyze data, has provided significant reduction in the noise levels. This has effectively increased the sensitivity of the flaw detection process.

4.9.1.3 Mechanical Scanning.

Increased use of mechanical scanners to control probe movement has increased the detection capability of many test methods. Repeatability of testing is also enhanced by mechanical scanning. A mechanical scanner can provide testing of difficult to reach areas of parts. Remote video cameras can also be incorporated with a mechanical scanner to provide visual coverage during the testing of inaccessible areas.

4.9.1.4 Data Management.

Mechanical scanners controlled by computers or other microprocessors provide data management and increased assurance of proper coverage of the part being tested. Fastener hole inspection is a specific example of a test method that has been significantly improved by the use of mechanical scanning and computer data management. Improved record keeping along with the ability to analyze data are among the benefits to be realized by better data management.

4.9.1.5 Improved Calibration Standards.

Improved calibration standards are required to meet the need for increased sensitivity and improved flaw discrimination. Improved test methods are capable of discriminating between actual flaws and fabricated discontinuities. Artificial flaws such as drilled holes and EDM notches are not sufficiently "real". In some cases the artificial flaw may not respond with the same phase as an actual flaw. More and more testing procedures require the calibration standard to contain actual fatigue cracks rather than EDM notches or other artificial flaws.

4.9.2 Techniques Available For use.

4.9.2.1 Mulitfrequency Testing Techniques.

Multifrequency techniques have found a variety of applications in which several material properties are changing at the same time. A single frequency test signal is composed of phase and amplitude; therefore, only two variables such as the phase and amplitude of a signal response from a crack can be measured. If the wall thickness of a part is also changing, this variation could affect the phase or amplitude of the crack signal. By the use of multiple frequency techniques, multiple variables can be selectively detected and analyzed during the same test. For example, this allows dimensional and/or permeability variations to be filtered out during the testing process.

4.9.2.2 Dual Frequency Testing.

If only two frequencies are used, one frequency channel can operate in the differential probe mode and the other frequency channel can operate in the absolute mode. With this setup the differential mode can be used to detect discrete indications such as small cracks and holes, and the absolute mode can be used simultaneously to record wall thickness or other dimensional changes in the test part.

4.9.2.3 Pulsed Eddy Current Testing.

Conventional multifrequency systems usually utilize two or three frequencies. Additional frequencies require very complex multiplex mixing systems to analyze the information from the test. A variety of experimental techniques have utilized the multifrequency characteristics of a short electrical pulse to achieve the same type of results as the multifrequency test technique. In principle, this technique is advantageous in that it requires simpler electronics to process the data. It can potentially generate higher frequencies than fixed frequency systems. This would allow testing of thinner materials, and materials with very low electrical conductivity (high resistivity). The eddy current pulse can also be a very short, high voltage pulse that can be used to momentarily produce magnetic saturation in a ferromagnetic part. This will allow detection of subsurface flaws in ferromagnetic materials.

4.9.2.4 Low Frequency Eddy Current Inspection.

In the past most eddy current testing utilized test frequencies of 10 kHz to 1 MHz. Improved equipment and data processing techniques now allow the use of test frequencies as low as 55 Hz. Along with impedance plane equipment to measure signal phase, this has provided a means for testing multilayer materials and thick materials. Detection of deep subsurface cracks, cracking in intermediate layers of material, and corrosion on the backside of a material are possible.

4.9.2.5 Barkhausen Noise Testing Of Ferromagnetic Materials.

Abnormal stresses induced by shot peening, other cold working processes, and grinding burns affect the structural properties of a material and can lead to flaw growth and part failure. In ferromagnetic materials, these processes affect the ease with which the magnetic domains in the surface of the material can be moved. In unmagnetized ferromagnetic material, the magnetic domains are randomly oriented. If the material is subjected to a magnetic field, the magnetic domains tend to align themselves in the direction of the magnetic field. When the domains move to align themselves, electrical pulses are generated during the domain movement. This is called Barkhausen noise. This electrical noise can be detected and measured by Hall effect sensors. If the material is free of abnormal stresses, the domains are relatively free to move and little Barkhausen noise is generated. Areas of tensile stress parallel to the applied magnetic field cause an increase in Barkhausen noise. Examples of applications of this test method are ferromagnetic engine components and landing gear. Barkhausen noise measurements are also used to detect the quality of drilling and reaming of holes in ferromagnetic material.

4.9.3 Developmental Techniques.

4.9.3.1 Metal Thickness Measurements.

A wide range of thickness can be measured with low frequency eddy current test equipment.

4.9.3.2 Metal Spacing.

The spacing of metal sheets separated by a nonconductive adhesive layer can be successfully measured by using an eddy current frequency for which the thickness of both metal sheets is less than or equal to three times the corresponding standard depth of penetration.

4.9.3.3 Alpha-Case on Titanium.

Oxygen diffusion from the surface of titanium alloys, known as alpha-case, can lead to surface embrittlement and cracking. This condition can be detected using high frequency (frequencies above 500 kHz) eddy current testing.

4.9.3.4 Titanium Aluminide.

Brazed honeycomb panels formed from titanium alloys and 3003 aluminum create a brittle intermetallic titanium aluminide at the braze interface. The thickness of this interface is critical to the integrity of the structure. While eddy current methods show promise of measuring the interface thickness, further testing is required to produce reliable measurements.

4.9.3.5 Magneto Optic Imaging (MOI).

Corrosion in aircraft structures is difficult to detect with existing NDI techniques, particularly in combination with moisture entrapment. Magneto-optic imaging, also referred to as magneto-optic/eddy current imaging, has been identified as a potential candidate NDI technique which may be more reliable than the currently mandated eddy current inspection technique. MOI may also reduce inspection time and associated costs, and may have unique capabilities to solve special inspection problems. Magneto-optic imaging depends on the ability of certain materials to rotate the plane of polarization of light in the presence of a magnetic field. This (Faraday) effect is used to detect disturbances in the magnetic field produced by passing an alternating current in a thin planar foil of doped yttrium iron garnet. When the foil is placed near the surface of a metallic test object, eddy currents are produced which modify the magnetic field in the foil. When defects or other material discontinuities, such as rivets or holes, divert the otherwise uniform flow of electric current near the surface of the test piece, magnetic fields perpendicular to the surface of the test piece are produced which can be imaged in real time by an appropriately designed optical system. Since the system provides optical information, the results can be videotaped for analysis and permanent documentation.

4.9.3.5.1

The MOI NDI technique is based on the Faraday magneto-optic effect. When light passes through a polarizer, the wave motion of the light is altered to produce motion in one plane perpendicular to the propagating light wave. When the polarized light then passes through a magneto-optic material in a direction parallel to an applied magnetic field, the plane of polarization is rotated an angle theta (θ) as shown by the arrows. This design uses a reflector, which causes the light to pass through the sensor twice, thereby doubling the rotation angle of the polarized light caused by the magnetic field.

4.9.3.5.2

A 1992 study sponsored by the United States Federal Aviation Agency (FAA) evaluated the performance of a commercially available MOI system. The purpose of the study was to compare the effectiveness of the MOI system with conventional eddy current methods of detecting corrosion in aircraft test panels, previously identified by eddy current scanning. The study indicated that MOI might not be able to detect gradual differences in thinning that are less than ten percent of base metal thickness. Also, with MOI it appeared to be more difficult to provide quantitative estimates of remaining thickness than is the case with eddy current scanning. On the other hand, MOI visualization of the extent of corrosion was simple and free of the labor intensive point-by-point mapping required by eddy current scanning. Other recent studies conducted by various aircraft manufacturers have demonstrated the potential for MOI to detect cracks in both prepared samples and samples extracted from aging aircraft. MOI also appears to have an advantage over conventional eddy current NDI for the detection of linear cracks under thick (greater than 0.005 inches) paint and coatings. Development and application studies using MOI are continuing, and this technique may find specific applications to NDI of aircraft structures in the near future.

4.9.4 Application of Advanced Techniques.

Several of the advanced techniques and processes discussed above do not have fully developed and recognized test procedures, process controls, and qualification procedures. Specific application of these processes and techniques shall be in accordance with approved procedures and engineering approval.

CHAPTER 5
SECTION I
GENERAL ULTRASONIC PRINCIPLES

5 ULTRASONIC TESTING.

This method uses ultrasound to detect internal discontinuities. Ultrasound can be used on most all materials and locate very small defects. It can be used to measure the overall thickness of a material and the specific depth of a defect. The part needs little or no preparation. However, knowledge of the internal geometry of a part is very critical to interpretation of any defect signal.

5.1 GENERAL ULTRASONIC PRINCIPLES.

NOTE

Whenever possible, definitions are taken from ASTM E1316, Standard Terminology for Nondestructive Examinations. Section 1, Ultrasonic Examinations.

5.1.1 Characteristics of Ultrasonic Energy.

5.1.1.1 Definition—Ultrasonic.

The term *ultrasonic* pertains to sound waves having a frequency greater than 20,000 Hz.

5.1.1.2 Characteristics of Sound.

The transmission of ultrasound is characterized by periodic vibrations of a particle or small volume element of matter. As a particle is displaced from its rest position by any applied stress, it moves to a maximum distance away from its rest position (this is called a maximum displacement). The particle then reverses direction and moves past its rest position to a maximum position in the negative direction (a second displacement). The particle then moves back to its rest position that completes one cycle. This process continues until the source of vibration is removed.

a. The term "period" indicates the amount of time it takes to complete one cycle.

b. The term "velocity" indicates the distance traveled per unit time (second).

c. The term "frequency" indicates the number of complete cycles that occur in one second. The term "Hertz" indicates cycles per second.

d. The term "wavelength" is the distance a wave travels while going through one cycle. Wavelength is defined by the formula:

λ(lambda) = v/f
Where:
λ = wavelength (normally inches or centimeters)
v = velocity (inches or centimeters per second)
f = frequency (Hertz)

5.1.2 Generation and Receiving of Ultrasonic Vibrations.

Ultrasonic vibrations are generated by applying high-frequency electrical pulses to a transducer element (piezoelectric element) contained within a search unit. The transducer element transforms the electrical energy into mechanical energy (ultrasonic energy). The transducer element can also receive ultrasonic energy and transform it into electrical energy (reverse piezoelectric effect). (See Figure 5-1) Ultrasonic energy is transmitted between the search unit and the test part through a coupling medium, such as oil, grease, water, penetrant emulsifier, water soluble gels, or other approved couplants (see Figure 5-2). The purpose of the couplant material is to eliminate air at the interface. Since air has a very high acoustic impedance, it is a poor transmitter of ultrasound, and therefore is not a good coupling medium. The couplant material shall not be injurious to the material to be inspected.

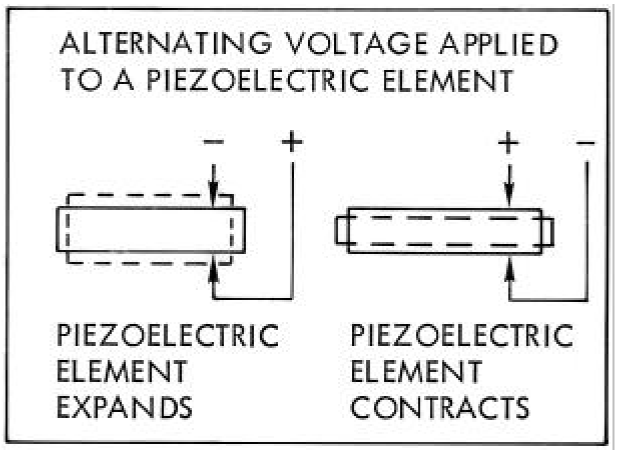


Figure 5-1. Generation of Ultrasonic Vibrations

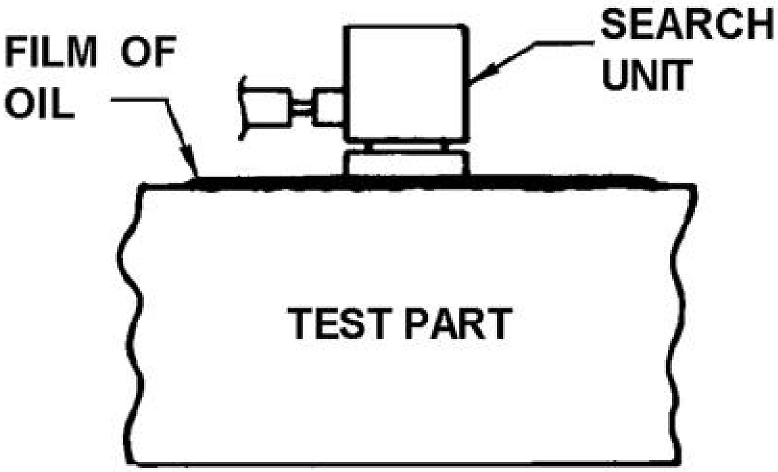


Figure 5-2. Coupling of Search Unit to Test Part for Transmission of Ultrasonic Energy.

5.1.3 Basic Ultrasonic Inspection.

5.1.3.1 Methods.

5.1.3.1.1 Contact Inspection.

Contact Inspection is the method in which the search unit makes direct contact with the material, with a minimum couplant film as (see Figure 5-2). Viscosity and surface wetting of the couplant must be sufficient to maintain good ultrasonic energy transmission into the part.

5.1.3.1.2 Immersion Inspection.

Immersion Inspection is an examination method where the search unit and the material are submerged in a tank of water (Figure 5-2 and Figure 5-3), or a water column is maintained between the search unit and material. The water shall be free of visible air bubbles and other foreign material that could interfere with ultrasonic tests. If necessary, a suitable corrosion inhibiting agent and a wetting agent shall be added to the water to inhibit corrosion and to reduce the formation of air bubbles on the material and the transducer. The inhibiting and wetting agents shall have been previously determined to be suitable for the materials to be inspected.

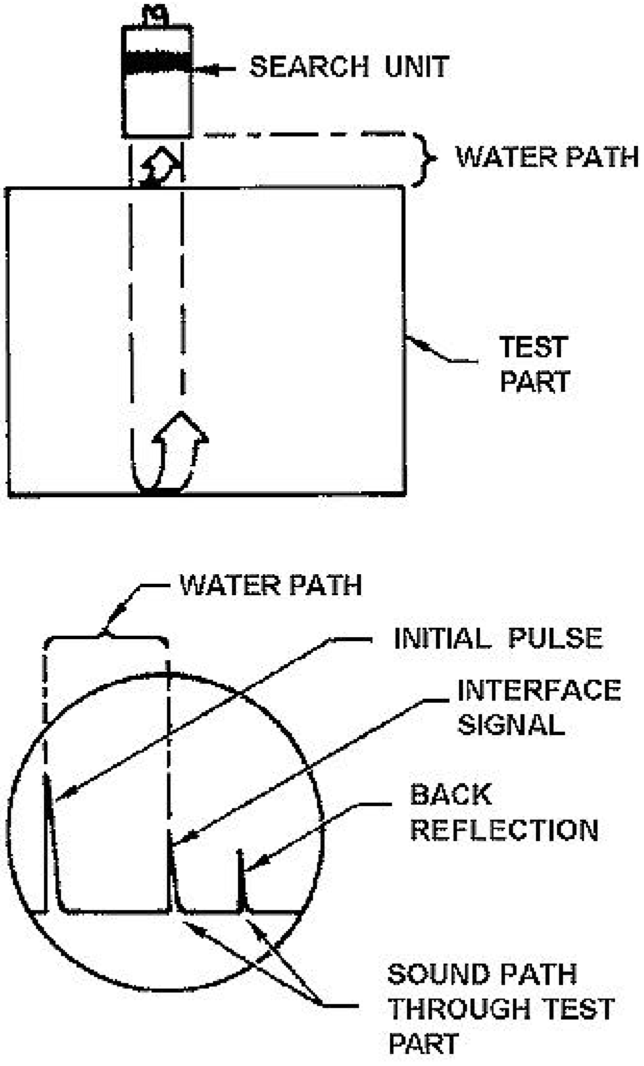


Figure 5-3. Immersion Method.

5.1.3.2 Ultrasonic Reflections.

Ultrasonic sound beams have properties similar to light beams. For example, when an ultrasonic beam strikes an interrupting object, sound beam energy is reflected from the surface of the interrupting object. The angle of incidence is equal to the angle of reflection (see Figure 5-4.).

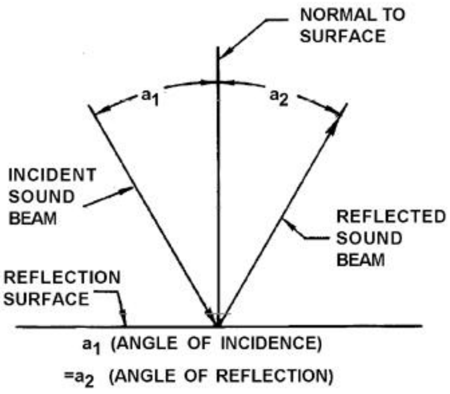


Figure 5-4. Ultrasonic Reflection.

5.1.3.3 Data Presentation Methods.

There are three methods of data presentation used for ultrasonic inspection: A-scan, B-scan and C-scan. "A-Scan" is the method of data presentation in the form of a horizontal baseline that indicates distance/time and that deflects vertically to indicate amplitude of electrical signals corresponding to ultrasonic pulses and echoes. The upper half of Figure 5-5 represents an A-scan display corresponding to the contact inspection shown in the lower half of the figure. A-scan presentations are the most popular presentation, and are commonly referred to as distance-amplitude presentations.

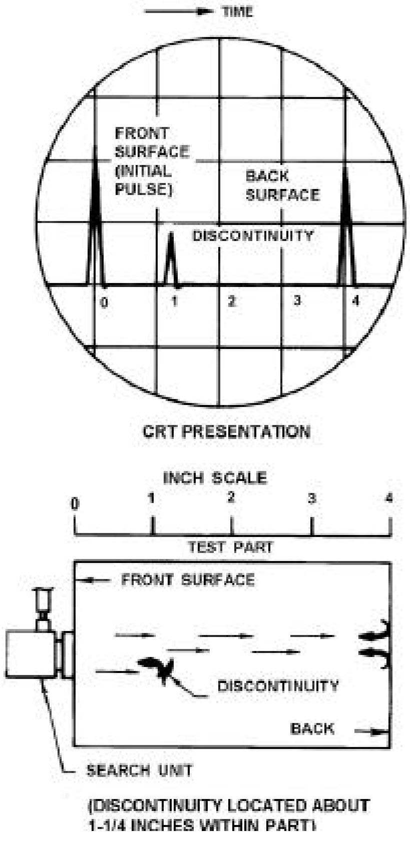


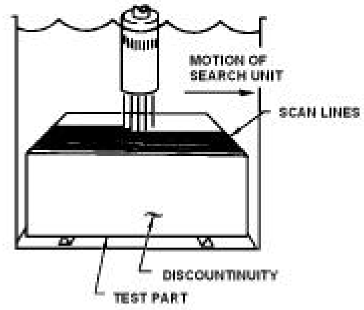
Figure 5-5. Typical A-Scan Display for Contact Inspection.

5.1.3.3.1 B-Scan.

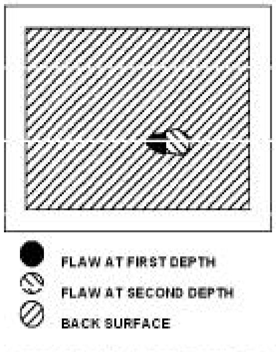
This is a means of data presentation that provides a cross-sectional view of the test piece under the scan path of a search unit. This requires a device that transfers the movement of the search unit to the sweep of the video display while the distance/depth information from the ultrasonic beam is used to vertically position the sweep to indicate the relative positions of part surfaces and internal discontinuities. This method of presentation is rarely used.

5.1.3.3.2 C-Scan.

This is a means of data presentation, which provides a plan view of the material and discontinuities therein. This is accomplished by coupling a selected (electronically gated) output of an A-scan presentation to a x-y recorder or a video display. Discontinuities are indicated at positions corresponding to the actual x-y locations of the discontinuities in the part (see Figure 5-6). Devices to track and relay search unit position to the recorder or display are required. The video displays, usually in color, are produced after the analog signal is converted to digital data. The display can be adjusted so that the colors represent different depths or thickness if several gates are used. Alternatively, the signal amplitude is displayed in various colors.



A. INSPECTION SET-UP



B. VIDEO DISPLAY/PRINTED OUTPUT

Figure 5-6. Typical C-Scan Inspection and Presentation.

5.1.3.4 Relationship of A Scan Waveform Display to Distance.

In a test part containing a discontinuity, ultrasonic energy is reflected as echoes from the discontinuity and the back surface of the test part. Referring back to Data Presentation Method, there are three methods of data presentation used for ultrasonic inspection: A-scan, B-scan and C-scan. Notice the positions of the displayed signals on the cathode ray tube (CRT) in relation to the actual positions of the test-part front surface, discontinuity, and back surface. The distance along the CRT base line is proportional to the distance to the discontinuity and back surface in the test part. In Data Presentation Methods, there are three methods of data presentation used for ultrasonic inspection: A-scan, B-scan and C-scan. The signals on the CRT were adjusted to position the initial pulse, on the grid marked “0” and the back surface signal on the grid marked “5”. The discontinuity then appeared just to the right of the grid marked “1”. The adjustment of the signals on the CRT was accomplished by varying two controls on the instrument: the Sweep Delay and the Sweep Length or Range. The adjustment made each space between the vertical grid lines on the CRT equivalent to 1 inch in the test part. Further information on operation of the ultrasonic equipment is contained in section 5.2.

5.1.4 Ultrasonic Vibration Modes.

Sound energy is propagated in a material by the vibration of particles in the material. Ultrasonic energy is transmitted from one particle to another. The direction in which the particles vibrate in relation to the direction of the ultrasonic beam propagation is dependent on the mode of vibration.

5.1.4.1 Longitudinal Waves.

Waves in which the particle motion of the material is essentially in the same direction as the wave propagation are called longitudinal waves. Longitudinal waves are also known as compressional waves or "L" waves (see Figure 5-7). Longitudinal wave inspections are also called straight beam inspections.

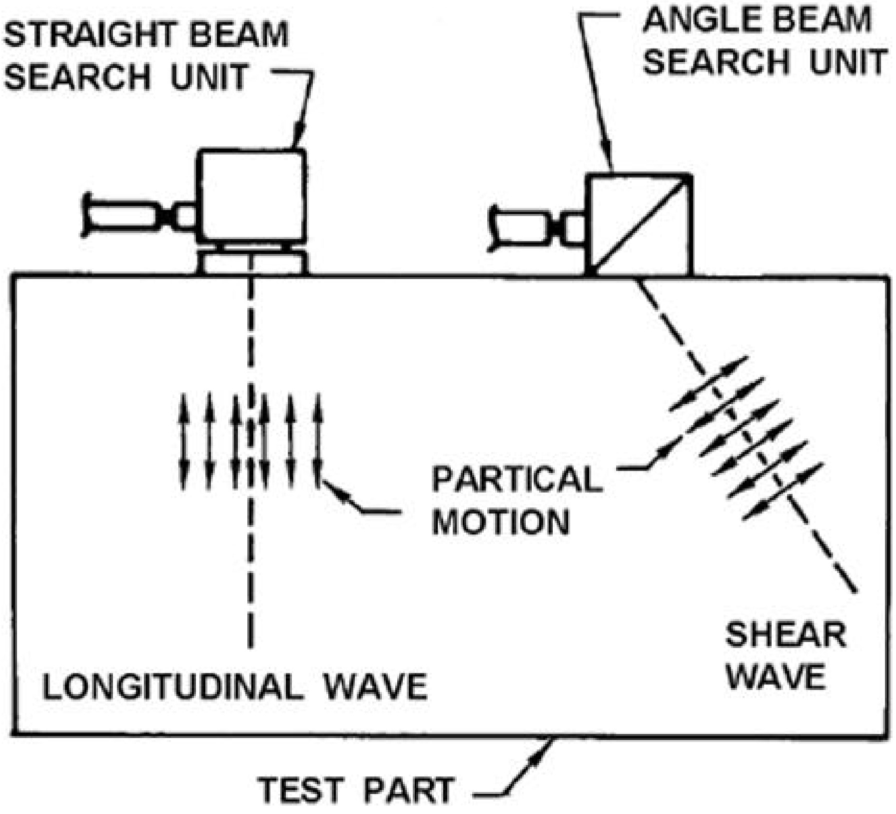


Figure 5-7. Longitudinal and Shear Wave Modes

5.1.4.2 Shear Waves.

Shear waves denote wave motion in which the particle motion is perpendicular to the direction of propagation (see Figure 5-7). Shear waves travel at approximately one half the speed of longitudinal waves. Shear waves are introduced into a test part by tilting the search unit to change the incident angle and a portion of the longitudinal wave generated by the search unit is mode-converted into shear wave at the entry surface. When using the contact method, angle beam search units are used. This type of search unit consists of a transducer element mounted on a plastic wedge, so that ultrasonic waves enter the test part at an angle. Shear waves are also known as "S" waves. Air and water will not support shear waves. Shear wave inspections are also called angle beam inspections.

5.1.4.3 Surface Waves.
Surface waves are those waves in which the particle motion is elliptical in a plane parallel to the propagation direction and perpendicular to the surface. Surface waves, or Rayleigh waves, are created at the second critical angle (see paragraph 5.1.5.2). Surface waves are confined to a thin layer up to one wavelength thick on the free boundary of a solid. A free boundary is a surface bounded by a gas. Figure 5-8 shows an angle beam search unit containing a steeply angled wedge. The steep angle causes the longitudinal beam in the wedge to strike the test surface at an angle that results in conversion to the surface mode of sound travel. Surface waves will travel around curves. Reflections occur only at sharp corners on the surface. The energy of surface waves decays rapidly below the surface of a test part as shown in Figure 5-9. Surface waves are therefore most suitable for detecting surface flaws (stress risers), such as cracks and machining lines. Surface waves may also be used to detect discontinuities lying slightly below the surface (about one-half wavelength in depth). Surface waves travel at about 90 percent of the velocity of shear waves.

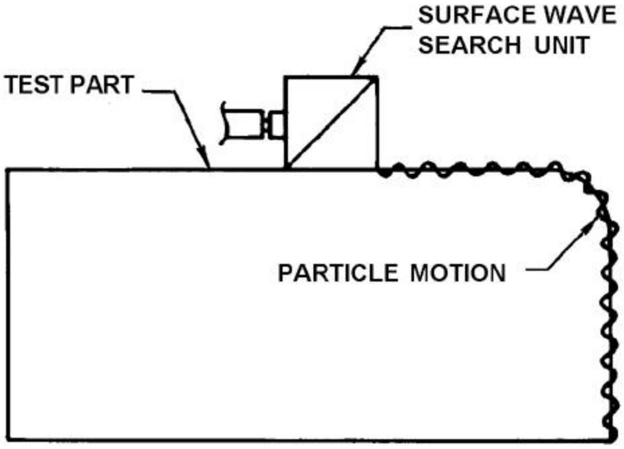


Figure 5-8. Surface Wave Mode

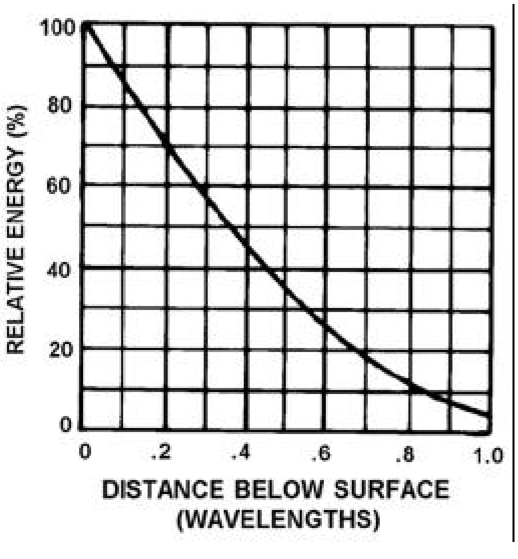


Figure 5-9. Distribution of Surface Wave Energy with Depth

5.1.4.4 Lamb Waves.

Lamb waves, also known as plate waves, propagate within thin plates, a few wavelengths thick. Lamb waves may be generated in an infinite variety of modes whose velocity is dependent on the incident angle, the frequency, the plate thickness, and the properties of test material. Calculation of Lamb wave modes is complex, and is generally not required. However, when Lamb waves are generated in material thinner than one wavelength, the velocity can be determined by noting the relative positions of the echoes as a function of distance.

5.1.5 Refraction and Mode Conversion.

5.1.5.1 Snell's Law.

When a sound beam passes from one medium into another with a different sound velocity, at an angle not normal to the interface separating the two media, refraction (a change in propagation direction) occurs (see Figure 5-10). The incident and refracted angles follow Snell's law:

$$\frac{\sin \phi_1}{\sin \phi_2} = \frac{v_1}{v_2}$$

Where:

ϕ_1 (phi) = angle between the normal to the interface surface and the incident sound beam
ϕ_2 = angle between the normal to the interface surface and the refracted sound beam
v_1 = velocity of incident sound beam
v_2 = velocity of refracted sound beam

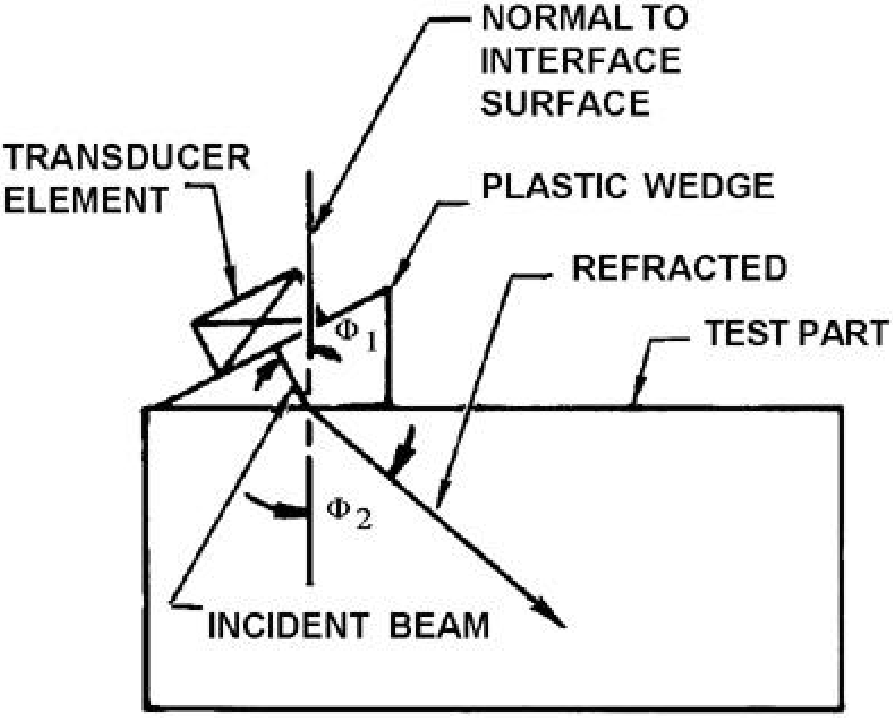


Figure 5-10. Sound Beam Refraction.

5.1.5.2 Multiple Refracted Beams.

When an incident longitudinal beam is normal to the test part surface ($\phi_1 = 0°$), the longitudinal sound beam is transmitted straight into the test part and no refraction occurs. When the incident angle is other than normal, refraction and mode conversion occur. A portion of the longitudinal incident beam is refracted into one or more wave modes traveling at various angles and intensities depending on the incident angle of the longitudinal beam. The angles of the refracted beams are determined by Snell's law. Figure 5-11 shows the relative energy for shear, longitudinal, and surface wave beams in steel for different incident angles of longitudinal waves in plastic. The curves shown were obtained using plastic wedges on steel. Similar shaped curves can be obtained for other test materials, such as aluminum and titanium. Similar curves can also be generated for the immersion mode of inspection with the plastic replaced by water. Refraction angles are greater with water than plastic.

a. The incident angle at which the refracted angle for longitudinal waves reaches 90 degrees is called the first critical angle. At incident angles equal to or greater than this critical angle, longitudinal waves no longer exist in the material. Beyond this angle, only shear waves remain in the test material.

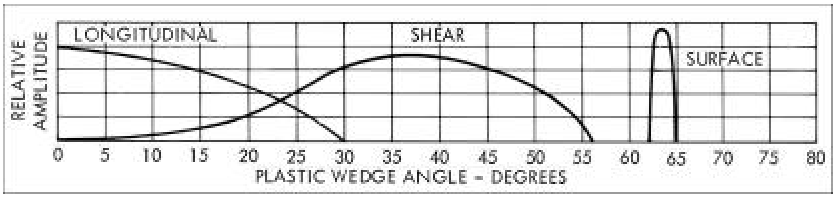


Figure 5-11. Relative Amplitude in Steel of Longitudinal, Shear and Surface Wave Modes with Changing Plastic Wedge Angle.

b. The incident angle at which the refracted angle for shear waves reaches 90 degrees is called the second critical angle. At incident angles equal to or greater than this, shear waves are no longer generated in the material. Instead, surface waves are propagated along the surface of the material.

c. Figure 5-11 shows the first critical angle in plastic for steel is approximately 30 degrees; the second critical angle is approximately 56 degrees.

d. Incident angles useful for shear-wave NDI fall between the two critical angles.

5.1.5.3 Obtaining the Required Refracted Beam.

Field NDI personnel are responsible for using the correct refracted beam angle for a particular application. The specific procedure details the correct refracted beam angle. However, it is important for the field NDI inspector to know how the correct angle was obtained. Snell's law is the tool for determining wedge angles for contact testing, or the angle of incidence in water for immersion testing. The following example shows how Snell's law is used to determine the angle of incidence in plastic needed to generate 45-degree shear waves in aluminum:

ϕ2 = 45°; sin 45° = 0.707
v1 = velocity of longitudinal wave in plastic wedge = 1.05 x 105 in/sec (from Table 5-2)
v_2 = velocity of shear waves in aluminum = 1.22 x 10^5 in/sec (from Table 5-2)

$$\frac{\sin\phi_1}{\sin\phi_2} = \frac{v_1}{v_2}\ ;\ \frac{\sin\phi_1}{0.707} = \frac{1.05\text{x}10^5}{1.22\text{x}10^5} \text{ or } \sin\phi_1 = \frac{(0.707)(1.05\text{x}10^5)}{1.22\text{x}10^5} = 0.608$$

Therefore, ϕ_1 = 37.5° (from Table 5-1)

NOTE

Then determining an angle, use the angle having the sine value closest to the calculated sine value. For example, if sin ϕ_1 = 0.591, Table 5-1 shows sin 36° = 0.5878 and sin 37° = 0.5984. Since 0.5878 is closer to 0.591, select 36°.

Table 5-1. Trigonometric Sines of Angles.

Angle (Deg)	Sine	Angle (Deg)	Sine	Angle (Deg)	Sine	Angle (Deg)	Sine
0.0	0.0000	24.0	0.4067	48.0	0.7431	72.0	0.9511
0.5	0.0087	24.5	0.4147	48.5	0.7490	72.5	0.9537
1.0	0.0175	25.0	0.4226	49.0	0.7547	73.0	0.9563
1.5	0.0262	25.5	0.4305	49.5	0.7604	73.5	0.9588
2.0	0.0349	26.0	0.4384	50.0	0.7660	74.0	0.9613
2.5	0.0436	26.5	0.4462	50.5	0.7716	74.5	0.9636
3.0	0.0523	27.0	0.4540	51.0	0.7771	75.0	0.9659
3.5	0.0610	27.5	0.4617	51.5	0.7826	75.5	0.9681
4.0	0.0689	28.0	0.4695	52.0	0.7880	76.0	0.9703
4.5	0.0785	28.5	0.4772	52.5	0.7934	76.5	0.9724
5.0	0.0872	29.0	0.4848	53.0	0.7986	77.0	0.9744
5.5	0.0958	29.5	0.4924	53.5	0.8039	77.5	0.9763
6.0	0.1045	30.0	0.5000	54.0	0.8090	78.0	0.9781
6.5	0.1132	30.5	0.5075	54.5	0.8141	78.5	0.9799
7.0	0.1219	31.0	0.5150	55.0	0.8192	79.0	0.9816
7.5	0.1305	31.5	0.5225	55.5	0.8241	79.5	0.9833
8.0	0.1392	32.0	0.5299	56.0	0.8290	80.0	0.9848
8.5	0.1478	32.5	0.5373	56.5	0.8339	80.5	0.9863
9.0	0.1564	33.0	0.5446	57.0	0.8387	81.0	0.9877
9.5	0.1650	33.5	0.5519	57.5	0.8434	81.5	0.9890
10.0	0.1736	34.0	0.5592	58.0	0.8480	82.0	0.9903
10.5	0.1822	34.5	0.5664	58.5	0.8526	82.5	0.9914
11.0	0.1908	35.0	0.5736	59.0	0.8576	83.0	0.9925
11.5	0.1994	35.5	0.5807	59.5	0.8616	83.5	0.9936
12.0	0.2079	36.0	0.5878	60.0	0.8660	84.0	0.9945
12.5	0.2164	36.5	0.5948	60.5	0.8714	84.5	0.9945
13.0	0.2250	37.0	0.6018	61.0	0.8746	85.0	0.9962
13.5	0.2334	37.5	0.6088	61.5	0.8788	85.5	0.9969
14.0	0.2419	38.0	0.6157	62.0	0.8829	86.0	0.9976
14.5	0.2504	38.5	0.6225	62.5	0.8870	86.5	0.9981
15.0	0.2588	39.0	0.6293	63.0	0.8910	87.0	0.9986
15.5	0.2672	39.5	0.6361	63.5	0.8949	87.5	0.9990
16.0	0.2756	40.0	0.6428	64.0	0.8988	88.0	0.9994
16.5	0.2840	40.5	0.6496	64.5	0.9026	88.5	0.9997
17.0	0.2924	41.0	0.6561	65.0	0.9063	89.0	0.9998
17.5	0.3007	41.5	0.6626	65.5	0.9100	89.5	1.0000
18.0	0.3090	42.0	0.6691	66.0	0.9135	90.0	1.0000
18.5	0.3173	42.5	0.6756	66.5	0.9171		
19.0	0.3256	43.0	0.6820	67.0	0.9205		
19.5	0.3338	43.5	0.6884	67.5	0.9239		
20.0	0.3420	44.0	0.6947	68.0	0.9272		
20.5	0.3502	44.5	0.7009	68.5	0.9304		
21.0	0.3584	45.0	0.7071	69.0	0.9336		
21.5	0.3665	45.5	0.7133	69.5	0.9367		
22.0	0.3746	46.0	0.7193	70.0	0.9397		
22.5	0.3827	46.5	0.7254	70.5	0.9426		
23.0	0.3907	47.0	0.7314	71.0	0.9455		
23.5	0.3987	47.5	0.7373	71.5	0.9483		

Table 5-2. Ultrasonic Properties of Materials

MATERIAL	VELOCITY (10^5 inches/sec)			WAVE LENGTH (inches)												ACOUSTIC IMPEDANCE (10^4 lb/in^2 – sec)
	Longitudinal Waves	Shear Waves	Surface Waves	Longitudinal Waves				Shear Waves				Surface Waves				
				1MHz	2.25 MHz	5MHz	10MHz	1MHz	2.25 MHz	5MHz	10MHz	1MHz	2.25 MHz	5MHz	10MHz	
METALS:																
Aluminum 1100 – 0	2.50	1.22	1.14	0.250	0.111	0.050	0.025	0.122	0.054	0.024	0.012	0.114	0.051	0.023	0.011	2.45
Aluminum 2014–T4	2.46	1.22	1.10	0.246	0.109	0.049	0.025	0.122	0.054	0.024	0.012	0.110	0.049	0.022	0.011	2.49
Beryllium	5.02	3.43	3.10	0.502	0.224	0.101	0.050	0.343	0.152	0.069	0.034	0.310	0.138	0.062	0.031	3.32
Brass, Naval	1.76	0.83	0.77	0.176	0.078	0.035	0.017	0.083	0.037	0.017	0.008	0.077	0.034	0.015	0.008	5.13
Bronze, Phosphor, 5%	1.39	0.88	0.79	0.139	0.062	0.028	0.014	0.088	0.039	0.018	0.009	0.079	0.035	0.016	0.008	4.44
Copper	1.84	0.89	0.76	0.184	0.081	0.037	0.018	0.089	0.040	0.018	0.009	0.076	0.036	0.015	0.008	5.96
Lead, Pure	0.85	0.28	0.25	0.085	0.038	0.017	0.009	0.028	0.012	0.006	0.003	0.025	0.011	0.005	0.003	3.60
Lead, Antimony, 6%	0.85	0.32	0.29	0.085	0.038	0.017	0.009	0.032	0.014	0.006	0.003	0.029	0.013	0.006	0.003	3.36
Molybdenum	2.48	1.32	1.22	0.248	0.110	0.050	0.025	0.132	0.059	0.026	0.013	0.122	0.054	0.024	0.012	9.04
Nickel	2.22	1.17	1.04	0.222	0.099	0.045	0.022	0.177	0.052	0.023	0.012	0.104	0.046	0.021	0.010	7.05
Inconel, Wrought	3.08	1.19	1.10	0.308	0.136	0.061	0.031	0.119	0.053	0.024	0.012	0.110	0.049	0.022	0.011	9.18
Monel, Wrought	2.38	1.07	0.77	0.236	0.105	0.047	0.024	0.107	0.048	0.021	0.011	0.077	0.034	0.015	0.008	7.56
Silver – 18Ni	1.82	0.91	0.66	0.182	0.080	0.036	0.018	0.091	0.040	0.018	0.009	0.066	0.029	0.013	0.007	5.74
Iron	2.32	1.27	1.10	0.232	0.103	0.046	0.023	0.127	0.056	0.025	0.013	0.110	0.049	0.022	0.011	6.45
Iron, Cast	1.89	0.95		0.189	0.084	0.039	0.019	0.095	0.042	0.019	0.010					5.30
Steel, 302	2.23	1.23	1.23	0.223	0.099	0.045	0.022	0.123	0.055	0.025	0.012	0.123	0.055	0.025	0.012	6.35
Steel, 347	2.26	1.22		0.226	0.100	0.045	0.023	0.122	0.054	0.024	0.012					6.35
Steel, 410	2.91	1.18	0.85	0.291	0.129	0.058	0.029	0.118	0.052	0.024	0.012	0.085	0.038	0.017	0.008	8.05
Steel, 1020	2.32	1.28		0.232	0.103	0.046	0.023	0.128	0.057	0.026	0.013					6.45
Steel, 1095	2.32	1.26		0.232	0.103	0.046	0.023	0.126	0.056	0.025	0.013					6.53
Steel, 4150, Rc 14	2.31	1.10		0.231	0.103	0.046	0.023	0.110	0.049	0.022	0.011					6.52
Steel, 4150, Rc 18	2.31	1.25		0.231	0.103	0.046	0.023	0.125	0.056	0.025	0.012					6.53
Steel, 4150, Rc 43	2.31	1.26		0.231	0.103	0.046	0.023	0.126	0.056	0.025	0.013					6.51
Steel, 4150, Rc 64	2.30	1.09		0.230	0.102	0.046	0.023	0.109	0.048	0.022	0.011					6.46
Steel, 4340	2.30	1.26		0.230	0.102	0.046	0.023	0.126	0.056	0.025	0.013					7.24
Titanium, 150A	2.40	1.23	1.10	0.240	0.107	0.048	0.024	0.123	0.055	0.025	0.012	0.110	0.049	0.022	0.011	3.94
Tungsten	2.04	1.13	1.04	0.204	0.091	0.041	0.021	0.113	0.050	0.023	0.011	0.104	0.046	0.021	0.010	14.20
NON–METALS:																
Air	0.13			0.013	0.006	0.003	0.001									0.00047
Water	0.59			0.059	0.026	0.012	0.006									0.212
Motor Oil, SAE20	0.68			0.068	0.030	0.014	0.007									0.214
Transformer Oil	0.54			0.054	0.024	0.011	0.005									0.181
Bakelite	1.02			0.102	0.045	0.020	0.010									0.515
Lucite	1.06	0.50		0.106	0.047	0.021	0.011	0.050	0.022	0.010	0.005				0.005	0.448
Plastic, Acrylic Resin	1.05	0.44		0.105	0.046	0.021	0.010	0.044	0.020	0.009	0.004					0.456
Plexiglass	1.09			0.109	0.048	0.022	0.011									0.494
Teflon	0.57			0.057	0.026	0.011	0.006									0.426
Quartz, Natural	2.26			0.226	0.100	0.045	0.023									2.16
Fused Quartz	2.33	1.48	1.33	0.233	0.104	0.047	0.023	0.148	0.066	0.030	0.015	0.133	0.059	0.027	0.013	1.85
Pyrex	2.20	1.35	1.23	0.220	0.097	0.044	0.022	0.135	0.060	0.027	0.014	0.123	0.055	0.025	0.012	1.77
Plate Glass	2.28	1.36	1.24	0.228	0.100	0.045	0.023	0.135	0.060	0.027	0.014	0.124	0.055	0.025	0.012	2.06

5.1.6 Ultrasonic System Variables.

An ultrasonic inspection is affected by several variables. The ultrasonic inspection system consists of the instrument, search unit, wedges or shoes, coupling medium, etc. Discussion of variables related to the test part and to discontinuities follows in the paragraphs describing system variables. It is important that the operator be familiar with and recognize the effects of all these variables.

5.1.6.1 Frequency.

For flaw detection using the contact method, frequencies between 2.25 and 10 MHz are commonly used. The higher frequencies in this range provide greater sensitivity for detection of small discontinuities, but do not have the penetrating power of the lower frequencies. The higher frequencies are also more affected by metallurgical discontinuities in the structure. Signals from these discontinuities can often interfere with the detection of relevant discontinuities, such as small cracks. The size of the defect that must be detected should be the prime consideration when selecting the frequency. If the defect size of interest is large, a low frequency, such as 2.25 MHz, can be used for greater penetration if required. Under favorable conditions, defects must have at least one dimension equal to or greater than ½ the wavelength in order to be detected. For example, straight beam inspection of aluminum (1100-0) at 2.25 MHz with a wavelength of 0.111 inch requires a defect be 0.066 inch or larger in order to be detected. At 5 MHz, the minimum defect size is 0.025 inch. At 10 MHz, it is 0.012 inch.

5.1.6.1.1 Frequency Bandwidth.

The above discussion on frequency pertains to the peak frequency used in an inspection. In all cases, the ultrasonic instrument and search unit produces a band of ultrasonic energy covering a range of frequencies. The range is expressed as bandwidth. Ultrasonic inspection procedures can be sensitive to frequency. Therefore, the inspection results can be affected by variation in the bandwidth of the inspection system. For example, certain inspections use loss of back reflection as criteria for rejection. Frequencies that are too high can lead to diminished or complete loss of back reflection due to the sound being scattered by a rough inspection surface, large grain structure in the test material, or small irrelevant discontinuities. In other words, improper choice of peak frequency and bandwidth of the inspection system (instrument and transducer) can produce irrelevant indications that affect inspection results. Both the instrument and the transducer affect the bandwidth of the inspection. Therefore, it is important to have a reference standard of the same material manufactured with the same manufacturing process and having the same surface conditions as the test part, so the inspection results will be the same for different inspection systems. Instruments are constructed to pulse the search unit, and measure the response in different ways with respect to bandwidth. Some instruments use a broadband pulser and a broadband amplifier. With these instruments, the bandwidth is controlled by the search unit. A given search unit has a maximum response at the natural resonant frequency of the transducer element. However, the element will also respond at other frequencies. The search unit response to these other frequencies is controlled by its internal construction. Modern instruments are designed to be operated in either narrow band or broad band modes to accommodate a variety of transducers. A broader bandwidth means better resolution; and a narrow bandwidth means greater sensitivity. Ultrasonic systems are generally designed with respect to bandwidth to provide a reasonable compromise between resolution and sensitivity.

5.1.6.2 Sound Beam Characteristics.

The sound beam does not propagate uniformly through the volume defined by the straight-sided projection of the transducer face. Side lobes exist along the outer edges of the beam near the transducer face, and sound intensity is not uniform throughout the beam.

5.1.6.2.1 Dead Zone.

In contact scanning, there is an area beneath the search unit in which there can be no inspection. When a transducer is excited, it vibrates for a finite amount of time during which it cannot act as a receiver for a reflected echo. If a defect were close to the surface, the reflected sound would arrive back at the transducer while it is still transmitting. A dead or no-inspection zone is inherent in all ultrasonic equipment. In some types of equipment, the dead zone is not obvious because the length of the transmitted pulse can be electronically suppressed. The dead zone can be estimated experimentally. Generally, the shorter the pulse length, the shallower the dead zone will be.

5.1.6.2.2 Near Field.

Extending from the face of the search unit is an area characterized by wide variations in sound beam intensity. This area is called the near field (Fresnel zone) as shown in Figure 5-12. The length of the near field, can be calculated by the following equation:

$$N = \frac{D^2}{4\lambda} = \frac{D^2 f}{4v}$$

Where:

N = near field length (inches)

D = diameter of transducer element in a round search unit or maximum diagonal of transducer element in a rectangular or square search unit (inches)

λ = wavelength of sound in the test material (inches)

f = frequency (Hertz)

v = velocity (inches per second)

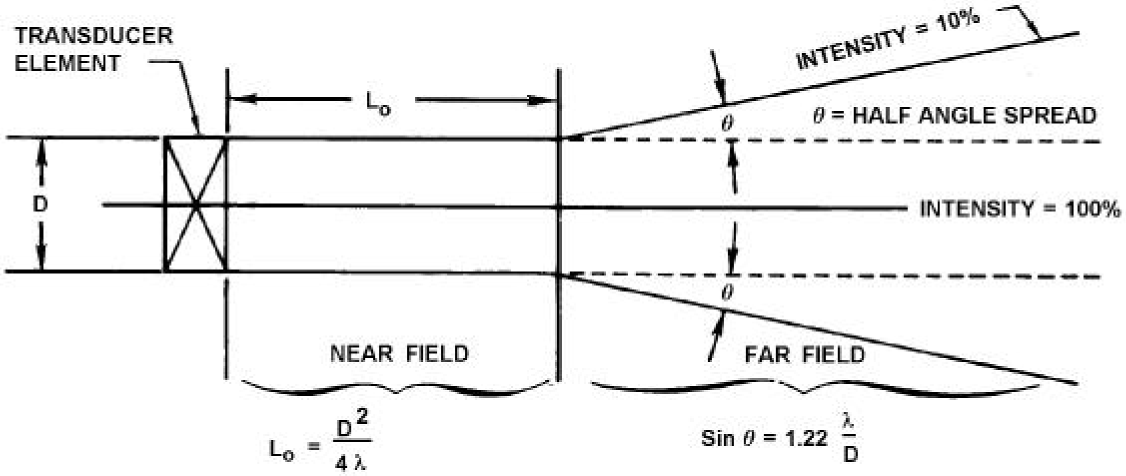


Figure 5-12. Schematic Presentation of Sound Beam.

The smaller the transducer element diameter or the lower the frequency, the shorter the near field will be. Due to inherent amplitude variations inspection within the near field is not recommended without careful calibration on reference flaws within the near field.

5.1.6.2.3 Far Field.

The zone beyond the near field is called the far field (see Figure 5-12). In the far field (Fraunhofer zone) the intensity of the sound beam falls off exponentially as the distance from the face of the search unit increases.

5.1.6.2.4 Distance versus Amplitude.

NOTE

The important thing to remember is that wide variations in amplitude from discontinuities can occur when inspecting in the near field. It is always best to compare discontinuity signals with signals from reference standards, such as flat-bottom holes, having the same metal travel distance as the discontinuity.

Figure 5-13 is a typical curve of amplitude response versus distance from the transducer face.

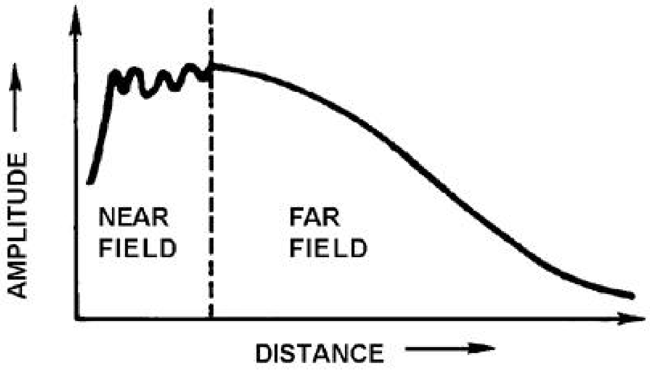


Figure 5-13. Amplitude Response Curve of Typical Search Unit.

5.1.6.2.5 Beamspread.

In the near field the sound beam propagates straight out from the face of the search unit. In the far field the sound beam spreads outward and decreases in intensity with increasing distance from the central axis of the beam, as shown in Figure 5-13 At a given frequency, the larger the transducer element, the straighter the sound beam, and the smaller the transducer element, the greater the beamspread. Also there is less beamspread for the same diameter transducer elements at higher frequencies.

The half angle of the beamspread θ (theta) is calculated as follows:

$$\sin\theta = 1.22\frac{\lambda}{D}$$

Where:

λ = wavelength (inches)

D = transducer diameter (inches)

Example: Given 2014-T4 aluminum being tested with a ¼-inch diameter unit at 5 MHz, what is the half angle of the beam spread?

D = ¼ inch (0.25 inch)

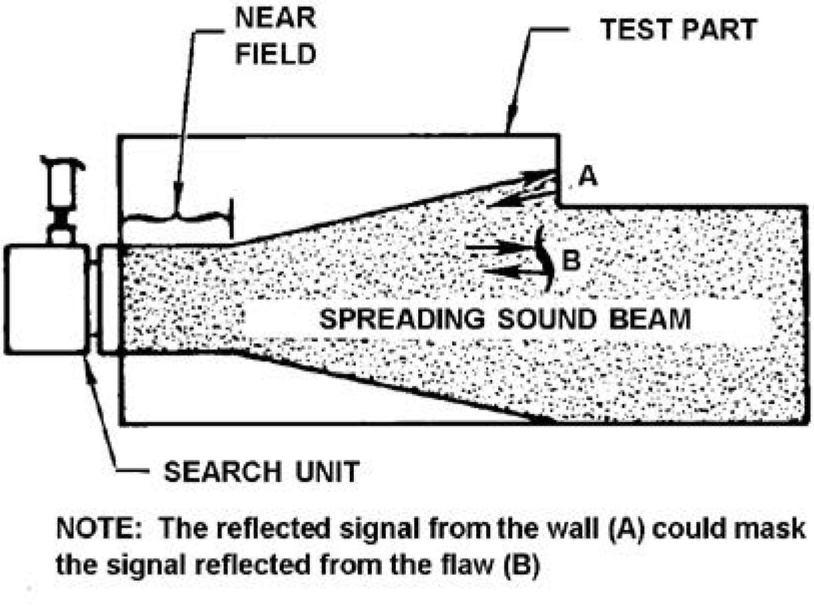
λ = 0.049 inch (from Table 5-1)

$$\sin\theta = (1.22)\frac{0.049}{0.25} = 0.2391$$

θ = 14° (from Table 5-1)

5.1.6.2.5.1

Beam spread is important to consider, because in certain inspection applications the spreading sound beam can reflect off of walls or edges and cause confusing signals on the A-scan presentation. For example, see Figure 5-14.



NOTE: The reflected signal from the wall (A) could mask the signal reflected from the flaw (B)

Figure 5-14. Example of Beam Spread Causing Confusing Signals.

5.1.6.2.5.2
In addition to the main sound beam pattern discussed above, there is also a small amount of side lobe energy, as shown in Figure 5-15. Some of the effects of this side lobe energy are discussed in paragraphs 5.1.7.1 and 5.3.6.5.3. Due to side lobes, the efficiency of a transducer is reduced, and the actual useable width of a sound beam near the face of the transducer is less than the physical width of the piezoelectric element.

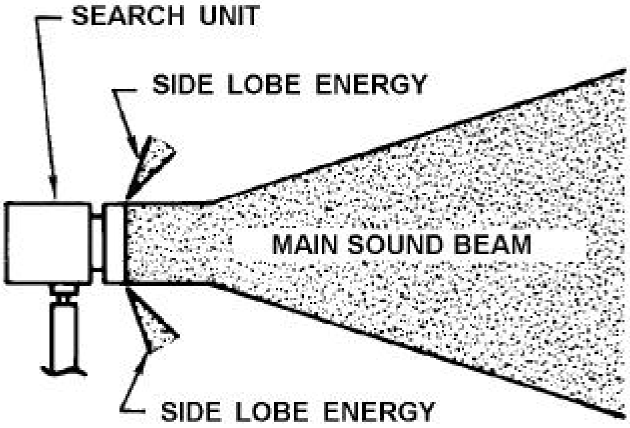


Figure 5-15. Main Sound Beam and Side Lobe Energy.

5.1.6.2.6
Focused Sound Beams. On some immersion inspections or special contact tests with a water delay column, a focused sound beam is used (see Figure 5-33). As shown in Figure 5-16, the focusing is produced by using a search unit containing a plastic acoustic lens on the face of the transducer element. The acoustic lens causes the sound beam to converge as the sound travels away from the transducer. Due to refraction at the plastic-water interface, a peak in amplitude is obtained at the focal point. The amplitude decreases rapidly on each side of this point. This type of search unit has a high sensitivity for discontinuities located at the focal point distance due to the concentration of energy at this focal point, but the depth of material that can be inspected in any one scan is limited. Beam shaping, which "tucks in" the side lobes can also be accomplished by using an acoustic lens without creating a focused transducer.

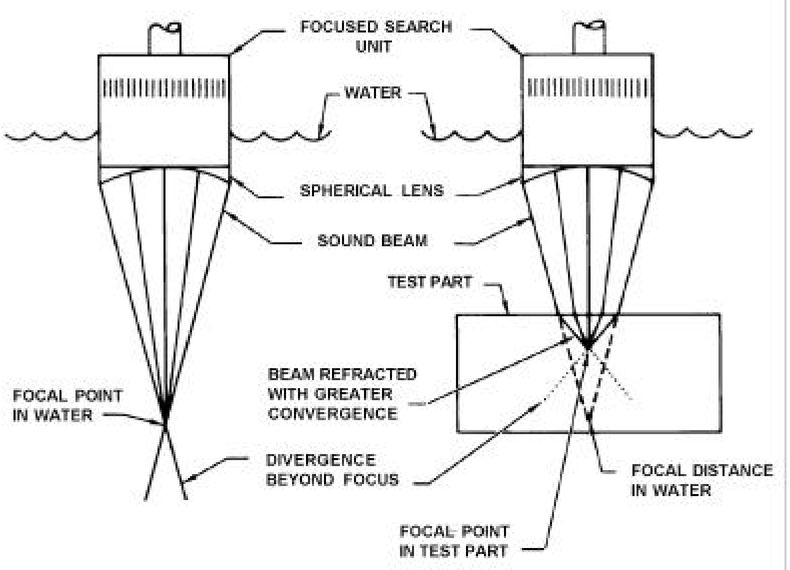


Figure 5-16. Focused Sound Beams

5.1.7 Test Part Variables.

5.1.7.1 Surface Condition.
Rough surfaces and surfaces with loose or pitted paint, scale, or corrosion distort ultrasonic inspection results, and can prevent a meaningful inspection due to scattering of the sound beam and/or poor coupling. This can cause:

a. Insufficient ultrasonic energy reaching discontinuities within the part.

b. Loss of resolving power due to an increase in the length of the dead zone caused by a lengthening of the front surface echo. This is caused by reflections of side lobe energy. On smooth surfaces, the side lobe energy is not normally reflected back to the search unit, and, therefore, does not interfere with inspection.

c. Beam divergence, or widening of the sound beam within the test part.

To minimize these effects, the sound entry surface and the back surface of a test part shall be free from loose, heavy or uneven scale, machining or grinding particles, or other loose foreign matter. As required, clean parts before ultrasonic inspection. Current specifications require surface finish of 250 microinches or better; a finish of 125 micro inches is preferred.

5.1.7.2 Geometry of the Part.
The position and shape of the sides and walls of the part can affect the test. A back surface not parallel to the front surface can cause reflections at other than normal angles, and thus mode conversion in the part; this can cause confusing indications or complete loss of back reflection.

5.1.7.2.1 Flat Sound-Entry Surfaces.
In the case of test parts with parallel front and back surfaces, it is often required to monitor the back reflection signal in order to evaluate the material and/or assure ultrasonic energy is passing through the part. Any loss of back reflection may be cause for rejection unless it can be shown that the loss of back reflection is due to a non-parallel back surface or back surface roughness. If back surface roughness is found to be the cause of the back reflection loss and cannot be eliminated, the entire test item shall be inspected with another technique to assure conformance to the applicable specification or test procedure.

5.1.7.2.2 Curved Sound-Entry Surfaces.
If the test specimen surface is curved beyond certain limits, a plastic shoe is required to match the search unit face to the curved surface (see paragraph 5.2.2.9).

5.1.7.2.2.1
For a concave surface, the sound beam tends to be focused as it passes into the test part (see Figure 5-17). Depending on the depth in the part, discontinuity signals can be increased in amplitude over signals received from an equivalent discontinuity in a part with a flat sound entry surface.

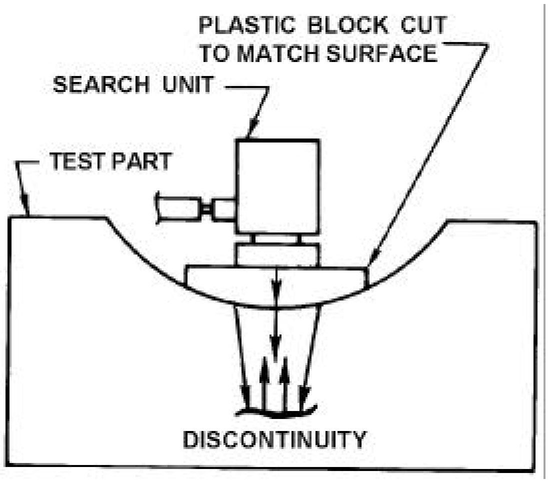


Figure 5-17. Concave Sound Entry Surface.

5.1.7.2.2.2

For a convex surface, the acoustic power that reaches an internal discontinuity is reduced by refraction at the test surface (see Figure 5-18). Signals received from a discontinuity have less amplitude than signals received from the same size discontinuity in a test specimen with a flat sound entry surface.

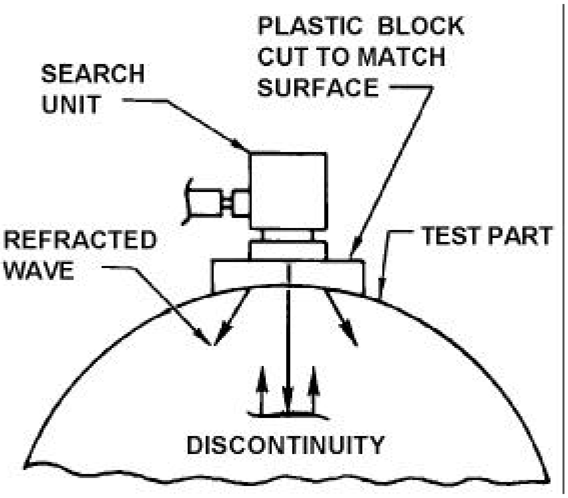


Figure 5-18. Convex Sound Entry Surface.

5.1.7.2.2.3

NOTE

The following paragraph and Figure 5-17 and Figure 5-18 are applicable when shoes are made of plastic, as is most common. However, shoes may be fabricated from the same material as the test part. If this is done, the sound will propagate straight into the test part. Refraction does not occur, because the velocity in the shoe equals the velocity in the test part. For immersion techniques, no shoe is required, but refraction will be greater than illustrated in Fig. 5-18 and 5-19.

Because of the variation in a signal due to curved surfaces, it is best to have a curved surface reference standard for set up of the test. The curved surface of the reference standard should be similar to the curved surface of the test part. Specifically, when performing straight beam inspection on curved surfaces of cylindrical or irregularly shaped products, special ultrasonic test blocks, containing specified radii of curvature and flat-bottom holes of standard diameter may be required. For inspecting parts with convex surfaces or radii up to 4 inches (8-inch diameter), blocks conforming to the applicable specification or procedure shall be used. For parts with convex radii over 4 inches, use standard flat face blocks. For more information see ASTM standout E1315 for steel blocks (Ultrasonic examination of steel with convex cylindrically curved entry surfaces.)

5.1.7.3 Internal Mode Conversion.

A frequently misinterpreted form of mode conversion found in the field is shear wave converted to longitudinal. For example, on an H-3 sleeve and spindle inspection using a 45 ° transducer to inspect a large radius or bore, a nonrelevant indication occurs in the area of interest as a result of this conversion. At a certain transducer position, part of the shear wave will convert to longitudinal as it reflects from the bore. This longitudinal wave will travel at double the velocity of the shear wave and will be reflected to the surface, then back to the bore. It then returns to the transducer to cause a nonrelevant indication that is similar to a crack indication. In this case, finger damping the part surface where the longitudinal wave reflects off of the part surface in front of the transducer will identify the indication as nonrelevant.

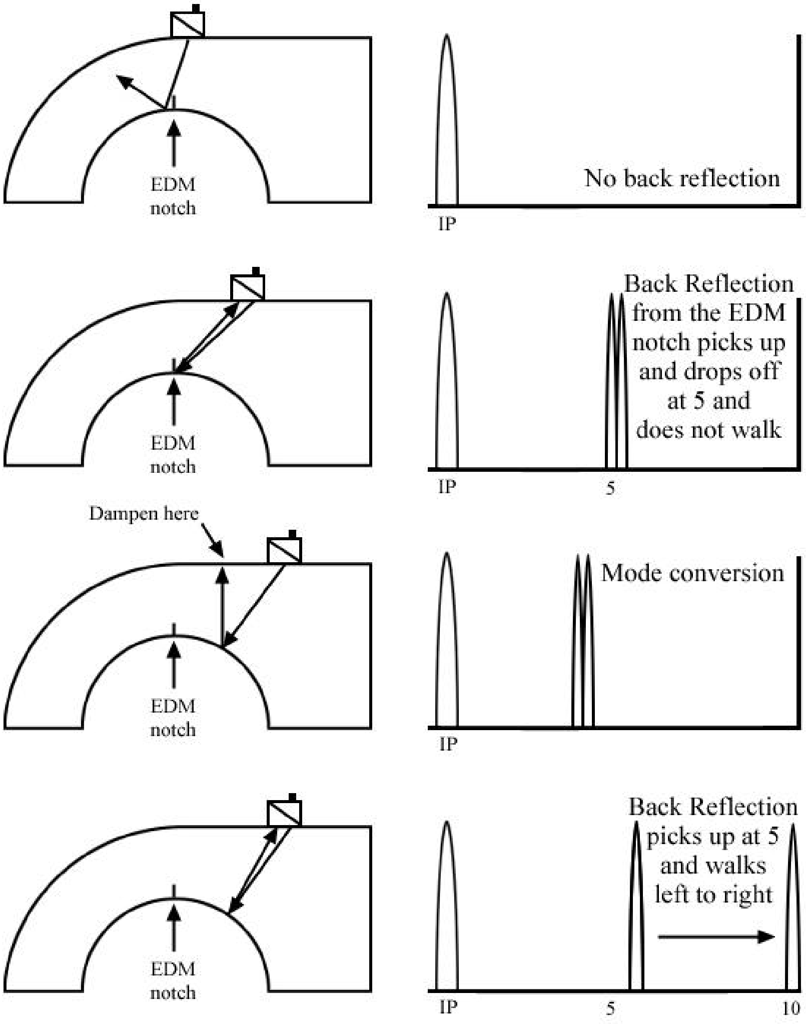


Figure 5-19. Example of Mode Conversion

5.1.7.4 Internal Structure.
Discontinuities inherent in the test article, such as grain boundaries, affect the ultrasonic test by scattering the ultrasonic energy. This reduces the energy available for finding detrimental discontinuities and causes “noise” in the waveform presentation. Effects on an inspection increase as the frequency is increased and are most noticeable in materials with relatively large grain size. In certain applications, the loss in ultrasonic energy caused by internal scattering can be measured to evaluate metallurgical structures.

5.1.8 Discontinuity Variables.
Ultrasonic beams can be reflected at various angles at the discontinuity interface and can also spread or focus depending on the shape of the discontinuity.

5.1.8.1 Size and Shape.
When discontinuities smaller than the sound beam are oriented with one surface perpendicular to the incident sound beam, the amplitude of a reflected ultrasonic beam from a discontinuity increases as the area of the surface normal to the incident sound beam increases. An irregularly shaped or round discontinuity reflects sound energy at many angles; thus, a flat discontinuity perpendicular to the sound beam reflects the greatest amount of sound energy back to the search unit.

5.1.8.2 Orientation.
For discontinuities with surfaces oriented at angles other than perpendicular to the sound beam, only a portion (if any) of the sound beam is reflected back to the search unit. If discontinuities are suspected to be located at angles other than parallel to the entry surface, consider angle beam inspection or straight beam inspection from another surface (if the discontinuity is expected to be parallel to that surface). To help in detecting discontinuities oriented at angles to an incident straight beam, it is helpful, when geometry permits, to monitor the back surface reflection. A sudden decrease in back reflection when scanning may indicate a discontinuity or possibly a number of small discontinuities. If a discontinuity signal is observed which is proportional to the loss in back reflection, the discontinuity is probably flat and oriented normal to the incident sound beam. If the discontinuity signal is small in relation to the loss of back reflection signal, the discontinuity is probably turned at an angle to the incident sound beam or is rounded. A decrease in back reflection accompanied by multiple discontinuity signals or a general increase in the noise level may indicate the presence of multiple discontinuities.

5.1.8.3 Acoustic Impedance.
When an ultrasonic beam strikes a boundary between two different materials, part of the energy is transmitted to the second medium and a portion is reflected. The percentage of sound energy transmitted and reflected is related to the ratio of the acoustic impedances of the two materials. Acoustic impedance can be calculated as follows:

$Z = \rho v$
Where: Z = acoustic impedance of a material
ρ (rho) = material density
v = velocity of sound in the material

5.1.8.3.1
Table 5-2 includes acoustic impedance values for several materials. Acoustic impedance can be used to calculate the theoretical reflected and transmitted energy for an interface. The greater the difference in acoustic impedance across the interface, the greater amount of sound reflected. The theoretical reflection at a water-steel interface is 88 percent; at a water-aluminum interface it is 72 percent. However, the actual reflection often differs significantly from the calculated theoretical reflection. Surface roughness is one of the variables besides acoustic impedance that affects the percentage of reflection. The acoustic impedance of the discontinuity material in relation to the acoustic impedance of the test part is important. The reflections from an air interface such as a crack or void are large due to the acoustic impedance ratio. If a discontinuity had acoustic impedance close to the acoustic impedance of the test material, the acoustic impedance ratio would be small, and very little reflection would occur. The following formula is used to determine the amount of reflected energy that occurs at an interface.

$$R = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2 \times 100$$

Where:

R = percentage of energy reflected at the interface.
Z_2 = acoustic impedance of the discontinuity
Z_1 = acoustic impedance of the test material

Example: A tungsten inclusion is found in a piece of titanium. How much energy will be reflected at the interface if 100% of the sound energy strikes the tungsten?

Known from: Table 5-2

Acoustic impedance of tungsten (Z_2) = 14.20 (10^4 lb/in^2 - sec)
Acoustic impedance of titanium (Z_1) = 3.94 (10^4 lb/in^2 - sec)

Solution:

$$R = \left(\frac{14.20 - 3.94}{14.20 + 3.94}\right)^2 \times 100 = \left(\frac{10.26}{18.14}\right)^2 \times 100 = (0.5656)^2 \times 100 = 0.32 \times 100 = 32\%$$

Therefore, 32% of the energy will be reflected at the interface by the tungsten inclusion. A crack would reflect virtually 100% of the energy because it is filled with air.

SECTION II
ULTRASONIC EQUIPMENT AND MATERIALS

5.2 ULTRASONIC EQUIPMENT AND MATERIALS.

5.2.1 Basic Ultrasonic Instruments.

5.2.1.1 General Description.

All ultrasonic instruments basically perform the functions of generating, receiving and displaying pulses of electrical energy that have been converted to and from pulses of ultrasonic energy by a transducer/search unit attached to an instrument. By properly adjusting an instrument an operator can measure the amplitude of displayed pulse signals and determine the time/distance relationships between generated and received signals. Detailed instructions for operation of individual models shall be obtained by consulting the operating and maintenance manual for the specific instrument being used.

5.2.1.2 Physical Characteristics of Instrument Controls.

The physical nature of the instrument controls varies with the type and age of the instrument. Older instruments have rotary knobs for fine adjustments, slide switches for coarse adjustments and screwdriver rotary controls for infrequent adjustments of waveform position and visibility. Newer instruments have push buttons or a sealed membrane keypad both to select the desired control from a displayed menu and to make the respective adjustments (see Figure 5-20). Alternatively, some menu driven instruments have a single rotary ("smart") knob for making adjustments after a control has been selected from the menu.

Figure 5-20. Typical Portable Ultrasonic Instruments

5.2.1.3 Waveform Display Controls.
An ultrasonic instrument may have one of several types of waveform display: traditional cathode ray tube (CRT), liquid crystal display (LCD), or electroluminescent display. Controls affecting the waveform display are discussed below.

5.2.1.3.1 Scale Illumination.

CAUTION

With a CRT, if the intensity is allowed to remain at a high level for long periods, it is possible to permanently burn the display.

The horizontal and vertical scales are illuminated in various ways. On some instruments the scales are scribed on the faceplate and cannot be illuminated. On a CRT the brightness control for the scales may be integrated with a rotary power switch or may be a separate control. Other types of display may simply have an on/off switch for illumination control.

5.2.1.3.2 Waveform Positioning.
The events in an ultrasonic inspection are related to time that is referenced to the pulses produced by the instrument. Figure 5-21 illustrates time as seen on a display: a horizontal line called the time base or baseline. Time starts at the left end of the time base and progresses to the right. The horizontal line appearing on a display is called the sweep.

The sweep, included within the “frame” in Figure 5-22, is a visual presentation of a portion of the time base. Some instruments, such as those with a CRT display, have the following controls to properly align the baseline on the display screen.

Figure 5-21. Time Base.

a. Horizontal. The horizontal control should be adjusted so that the horizontal baseline (sweep) begins at the left edge of the display.

b. Vertical. The vertical control should be adjusted so that the horizontal time base is at zero position of the vertical scale.

5.2.1.3.3 Waveform Visibility.

a. Intensity. On a CRT the intensity of the waveform should be adjusted to produce the minimum brightness that makes the waveform clearly visible.

b. Background lighting. On some displays the background lighting can be continuously adjusted from 0-100 percent for optimum waveform visibility.

c. Contrast. This is another continuously adjustable control that is used in conjunction with background lighting to produce optimum waveform visibility.

d. Focus. On a CRT the focus is adjusted until the baseline is sharp and clear.

e. Astigmatism. On a CRT this is used in conjunction with the focus control to sharpen the peaks of the waveform after the baseline is focused.

5.2.1.3.4 Type of Waveform.

a. RF (Radio-Frequency display, non-rectified). This type of waveform has the baseline at 50 percent of full screen height and shows the full waveform with both the positive and negative peaks. Although this type of waveform contains all of the signal information, it is not normally used for inspections. It is often used when developing inspection procedures to choose which of the other types of waveforms (listed below) should be used for a particular inspection.

b. FW (Full-Wave rectified video display). This type of waveform shows the positive peaks and the negative peaks, but the negative peaks are reversed and made positive.

c. HW+ or HWP (Positive Half-Wave rectified video display). This type shows only the positive peaks.

d. HW- OR HWN (Negative Half-Wave rectified video display). This type shows only the negative peaks.

5.2.1.3.5 Video Filtering.

Some instruments provide varying degrees of filtering of the rectified waveforms. Filtering smoothes out the waveform, but some loss of information occurs. With minimum filtering, the presentation has greater resolution and signal definition. Video filtering may also affect the vertical linearity of the instrument.

5.2.1.3.6 Sweep Delay.

The Sweep Delay control determines what part of the time base is viewed on the display. Figure 5-22 shows a time base with an area circled to frame the portion of the time base that an inspector wants to view on the instrument display. Adjustments to the Sweep Delay move the frame to the desired portion of the time base, that is, Sweep Delay delays the start of the sweep with respect to the start of the time base.

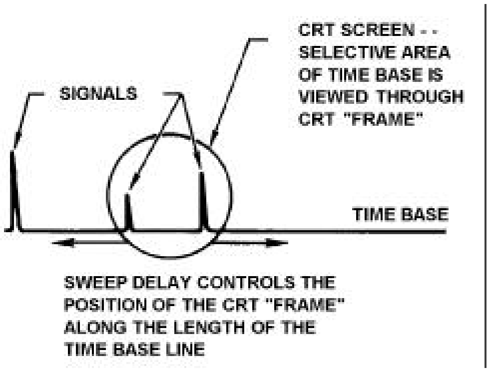


Figure 5-22. Relationship of CRT Sweep to Time Base.

5.2.1.3.7

To see how the Sweep Delay works, consider the inspection shown in Figure 5-23. Under certain control settings (or immersion testing) an instrument with a CRT might have a sweep appear as in Figure 5-24 showing only the front surface and discontinuity signals. By adjusting the Sweep Delay to move the "frame" to the right along the time base, the display shown in Figure 5-25 is obtained. Note that the front surface signal now appears on the far left and the back surface signal can now be viewed also. The distance between the front surface and the discontinuity signals has not changed from Figure 5-24.

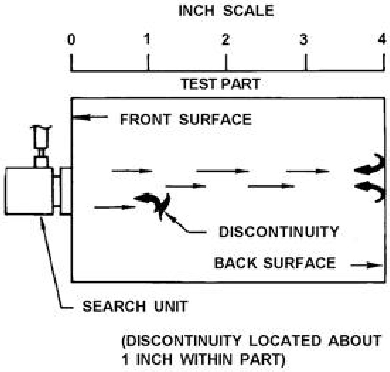


Figure 5-23. Ultrasonic Contact Inspection.

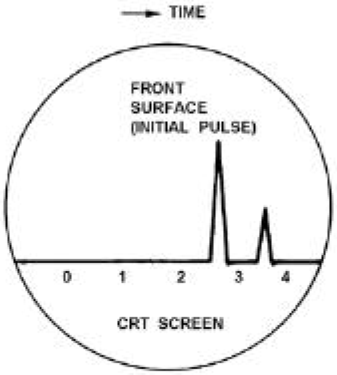


Figure 5-24. CRT Display Before Adjusting Sweep Delay.

5.2.1.3.8 Sweep Length/Range.

The Sweep Length/Range control determines how much time/distance is represented by the sweep on the display. In Figure 5-25, if the Sweep Length/Range is adjusted to decrease the time/distance represented (that is, the sweep length/range), the spacing between the signals will increase, as seen in Figure 5-26. Note that the front surface signal did not move; only the distances between the front surface signal and the other signals increased. Referring back to Figure 5-23, the four-inch length of the test part and the one-inch depth of the discontinuity are represented by the signals in Figure 5-26 at “4” and “1” respectively. In other words, the Sweep Length/Range control is used to calibrate the time base to the test part using the horizontal scale on the display.

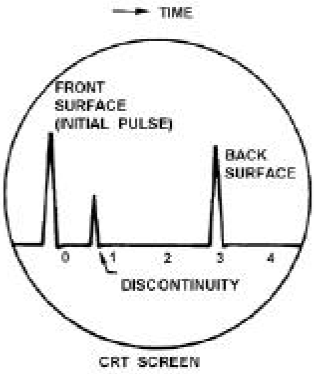


Figure 5-25. CRT Display After Adjusting Sweep Delay.

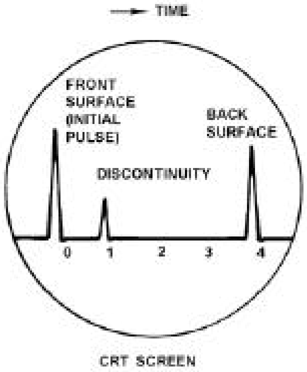


Figure 5-26. Effect of Sweep Length on CRT Display.

5.2.1.3.9 Zero or Zero Offset.
Some newer instruments have a Zero or Zero offset control that is a fine-delay control used to compensate for transducer face-plate wear. In shear-wave inspection, this control can be used to compensate for the distance the sound beam travels in a plastic wedge.

5.2.1.3.10 Velocity.
On some instruments an inspector can enter the velocity of sound in the test material (if known), then enter the thickness of the test part. Then, the horizontal scale of the display will be automatically calibrated to provide the depth of any discontinuity that may be detected in that particular test part.

5.2.1.4 Pulser / Receiver Controls.

5.2.1.4.1 Pulse Repetition Rate (Rep Rate).
On some instruments, the Pulse Repetition Rate is set automatically with the sweep controls. Other instruments allow changing the repetition rate with a separate control or menu selection. The repetition rate is the actual number of ultrasonic pulses per second generated by the instrument; that number can be set from hundreds to thousands. The Pulse Repetition Rate must be high enough so that several pulses are transmitted in the time it takes for the search unit r to move a distance equal to the size of the smallest defect that must be found. The higher the rate, the faster the scanning speed can be while still maintaining the required sensitivity. The maximum Rep Rate is the rate beyond which unattenuated echo signals occur on the display from an earlier pulse; this is called "wrap around" and is recognized by the occurrence of unexplained signals on the display which disappear if the Rep Rate is decreased while the search unit is held motionless on the test part. Some instruments include an automatic override to set the Rep Rate at a reduced value if the inspector tries to set it manually above a value that is compatible with the sweep settings.

5.2.1.4.2 Pulse Controls.
On some instruments the following controls are automatically set to default values when a new setup is initiated or when other interactive controls are adjusted. Adjustments of the following controls (if permitted) should be made to more clearly define the discontinuity indications.

NOTE

> Minimum pulse length, (maximum damping) is obtained with the load resistance as small as possible for the circuitry. Load resistance selections may range from 16 ohms for maximum damping to 500 ohms for maximum pulse length (minimum damping).

a. Pulse Length (Damping). The Pulse Length or Damping control is used to adjust the time duration of the high-frequency pulse applied to the search unit. The length of the initial pulse should be kept to a minimum, and increased only to gain signal strength when required; excessive pulse length can obscure signals from discontinuities close to the inspection surface (poor near-surface resolution). A short pulse length provides the best near-surface resolution.

b. Pulse Voltage. This control determines the amplitude of the generated initial pulse. Some instruments have incremental voltage adjustments; for example, from 40 to 400 volts in 5-volt increments. Other instruments have adjustments for only low, medium or high voltages.

c. Pulse Width. Some instruments generate a square pulse as opposed to a spike pulse. The Pulse Width control sets the width of the square pulse, usually in nanoseconds. The effect of the Pulse Width is similar to the Damping control, although the electronic nature of each is different.

5.2.1.4.3 Receiver Gain Control.

NOTE

The decibel is to express the relationship between two signal amplitudes: Number of dB = $20\log_{10}(A_2/A_1)$ where A_2 and A_1 are the two amplitudes that are being compared. Thus, dB is proportional to the logarithm (base 10) of the ratio of the two amplitudes. Figure 5-27 shows the relationship of dB to the amplitude ratio. For every 6 dB increase in Gain, the amplitude of a signal doubles. Thus, with an 18 dB increase, a signal would have eight times the original amplitude. Conversely, the signal amplitude is cut in half with a decrease in Gain of 6 dB.

The Gain control is used to adjust the amplitude (height) of signals on the waveform display. Normally a positive increase in the Gain control will increase the amplitude of the signals. However, on a few instruments the control is actually an Attenuation control, with which a positive adjustment will decrease the amplitude of the signals. Some instruments will have both Gain and Attenuation controls. On most instruments the Gain control is calibrated in terms of the decibel (dB). Where it is not, uncalibrated slide switches or rotary knobs may be used.

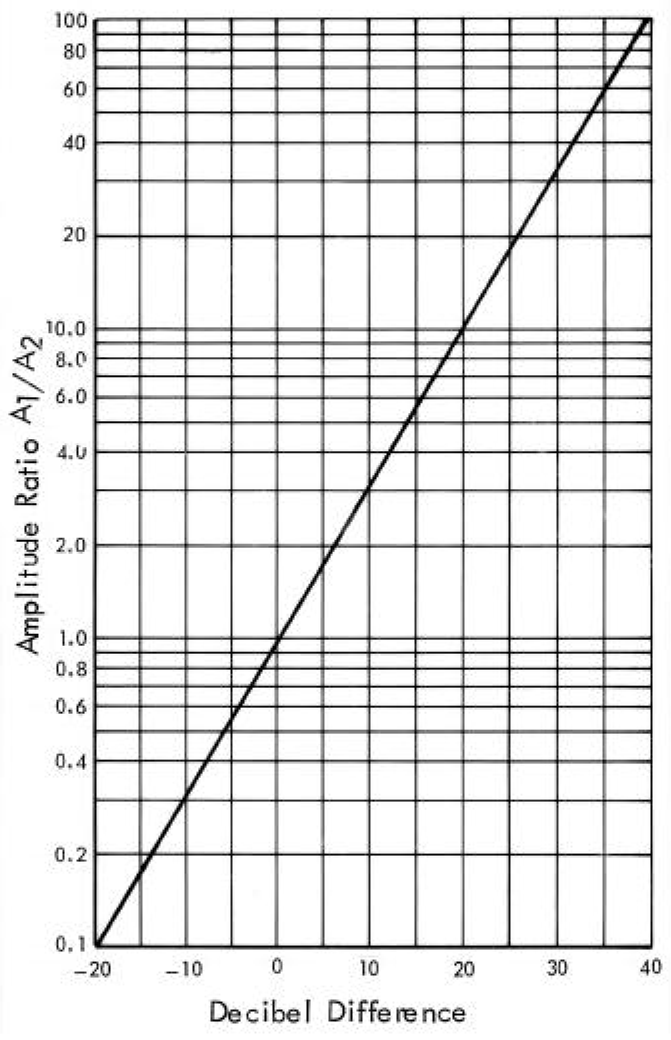


Figure 5-27. Decibel-to-Amplitude-Ratio Conversion Chart.

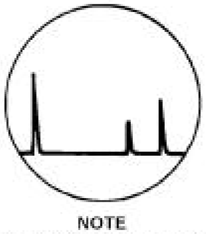
5.2.1.4.4 Reject.

CAUTION

The Reject control, even if it is linear, should be used with discretion, because even small signals may be important when interpreting waveform displays. Reject should not be used unless directed by the inspection procedure.

The Reject control is used to attenuate low-level irrelevant signals and noise signals on the waveform display. This permits easier interpretation of echo signals. Most newer instruments have linear Reject controls, which eliminate the low-level signals without affecting the amplitude of the relevant echo signals. On older instruments Reject also reduces the amplitude of the relevant signals. Figure 5-28. illustrates the effect of the linear Reject control.

WITHOUT REJECT



NOTE
WITH REJECT - SMALL BASE
LINE SIGNALS HAVE BEEN
CLIPPED OFF PRESENTING
A CLEANER BASE LINE

Figure 5-28. Reject Control

5.2.1.4.5 Frequency.

The Frequency control allows the inspector to select the frequency corresponding to a search unit or to select the broadband mode to cover all frequencies. The selection that gives the best echo signal is normally used.

5.2.1.4.6 Single/Dual Search unit.

This control configures the search unit -cable receptacles for single-element search unit, dual-element search unit or two separate search unit (for through-transmission inspection). The Dual position of the control is used for both dual-element- search unit and two- search unit inspections; in these cases some instruments specify one receptacle as transmitter and the other as receiver. For single-element- search unit inspections, only one receptacle is used. Consult the instrument manual or procedure for the appropriate use of the receptacles.

5.2.1.4.7 Electronic Distance Amplitude Correction (DAC).

Depending on the instrument, DAC may also be called STC (Sensitivity Time Control), TCG (Time Corrected Gain), TVG (Time Varied Gain) or if electronic gates are used, DAG (Distance Amplitude Gate). DAC electronically compensates for material attenuation that causes different size echoes from equal-size reflectors located at varying metal-travel distances from the search unit. After DAC is applied over a particular thickness, all the echoes from reflectors of equal size and at the same orientation within that thickness will be of the same amplitude. Consult the operating manual for the instrument being used or the specific inspection procedure for instructions for adjusting the DAC controls.

5.2.1.5 Flaw Gates.

A gate is an electronic feature that allows an inspector to monitor for discontinuities within specific zones of the test part. A gate appears on the display as a short horizontal sweep segment above the baseline. The gate can be adjusted so that any signal that appears within the limits of the gate will energize an audible or visual alarm, alerting the inspector to a possible flaw that needs to be investigated further. Information about signals within a gate also may be recorded or displayed in C-scan format on a video monitor, from which the image data subsequently may be saved on a hard or floppy disk. Controls for the gate on the display are as follows.

5.2.1.5.1 Gate Start.

This control is similar to the Sweep Delay and is used to adjust the location of the leading edge of the gate on the display.

5.2.1.5.2 Gate Width/Length.

This control is similar to Sweep Length/Range and is used to adjust the width of the gate or the location of the trailing edge of the gate.

5.2.1.5.3 Threshold/Alarm Level.

This control adjusts the vertical position of the gate (accept/reject level). Only signals that exceed the level of the gate cause an alarm or a record to be made.

5.2.2 Search Units / Transducers.

CAUTION

Search units are fragile. They shall be handled with care. Sharp blows, caused by dropping a search unit or banging a search unit against a surface, can cause extensive damage.

5.2.2.1 General Search Unit Construction.

Search units are available in a great variety of shapes and sizes. Figure 5-29 schematically shows the basic parts of a typical straight beam search unit used for contact inspection, while Figure 5-30 schematically shows an angle beam search unit. The backing material, shown in Figure 5-29, serves to damp the ringing of the transducer element after it is excited. This affects the resolution of an inspection as explained in paragraph 5.2.2.2.b. The plastic wedge, shown in Figure 5-30 serves to transmit longitudinal waves to the test part surface where mode conversion occurs. Refracted longitudinal, shear, or surface waves (depending on the angle of the plastic wedge) are generated in the test part.

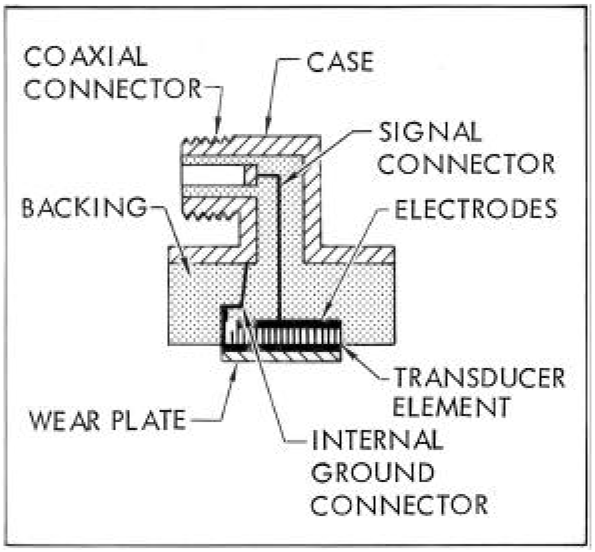


Figure 5-29. Straight Beam Contact Search Unit.

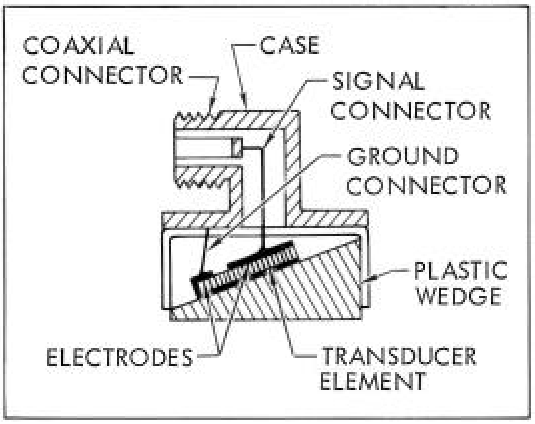


Figure 5-30. Angle Beam Contact Search Unit.

5.2.2.2 <u>Effect of Search Unit on Inspection System Performance</u>.

a. <u>Sensitivity</u>. Sensitivity is the ability of an inspection system to detect small discontinuities. It is generally rated by the ability to detect a specified size and depth flat-bottom hole in a standard test block. Sensitivity is unique to each combination of search unit and test instrument. The same model instruments and search units of the same size, frequency, material, and manufacturing do not always produce identical indications. For this reason, all inspections must be set up using a series of reference standards.

b. <u>Resolution</u>. Resolution refers to the ability of an inspection system to separate signals from two interfaces close together in depth. An example of two such signals is the front surface signal and the signal from a small discontinuity just beneath the surface. The damping or backing material (see Figure 5-29) affects the time required for the transducer to stop "ringing" after being excited by a pulse from the test instrument. Low damping causes high "ringing" resulting in a wide, high-amplitude front surface signal. This would cause a long dead zone. Signals from discontinuities just beneath the front surface would be masked by the front surface signal.

5.2.2.3 Search Unit Shape and Size.
The variety of sizes and configurations of search units that can be used is almost endless. Faces can be round or rectangular. Search units' 1/8-inch diameter and smaller have been used. For field inspection, the maximum search unit size will generally not be over 3/4-inch diameter.

5.2.2.4 Dual Search Units.
Dual search units are used primarily in applications where good near-surface resolution is required. Ultrasonic thickness measurement instruments as discussed in Section 5.5, commonly use dual search units. Figure 5-31 depicts operation of a typical dual search unit. The spaces under the transducer elements are usually filled with plastic material that serves as a delay line. Thus, the initial pulse will not interfere with any echoes from near surface effect on the sound beam. Dual search units are also used in angle beam inspection. Figure 5-32 shows two types of angle beam dual search units.

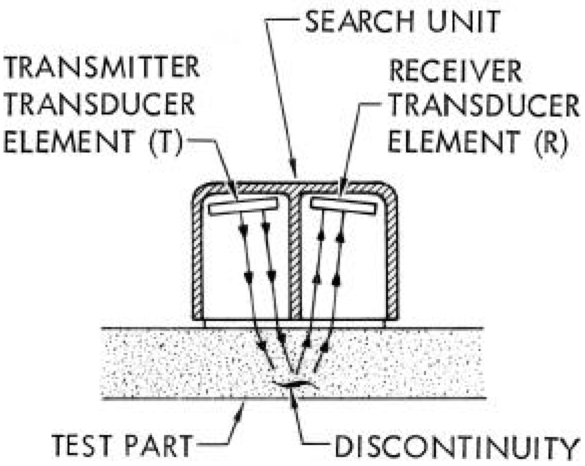


Figure 5-31. Dual Search Unit Operation.

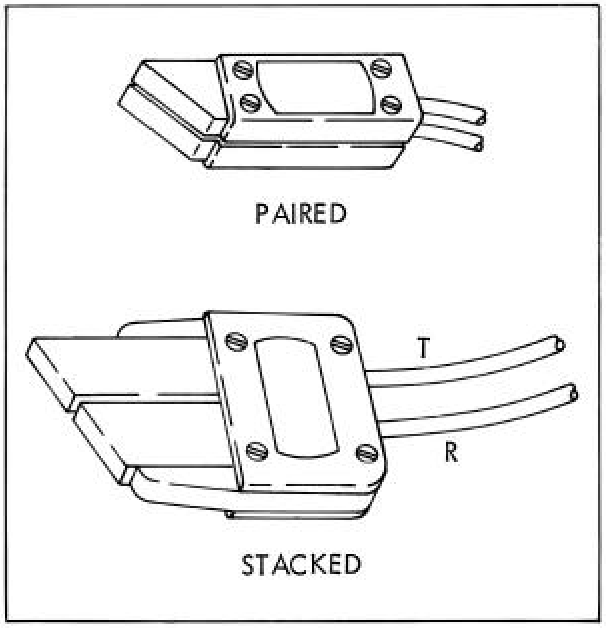


Figure 5-32. Angle Beam Dual Search Units.

5.2.2.5 Wear Faces.

Search units are often fabricated with removable plastic or rubber wear faces. These faces improve coupling on rough surfaces and prevent wear of the search unit face. However, the flexible wear faces reduce the amount of power available from the search unit.

5.2.2.6 Delay Lines.

A search unit may have a solid or a fluid delay line.

5.2.2.6.1 Solid Delay Line.

A solid delay line may be an integral part of the search unit or may be removable. An integral delay line is bonded to the transducer element. A removable delay line requires a couplant between it and the transducer face. Various lengths of removable delay lines can be interchanged and can be replaced when worn. Delay lines improve near-surface resolution.

5.2.2.6.2 Fluid Delay Line.

Some search units are equipped with water delay columns. An example is shown in Figure 5-33. The water column also permits the use of focused search units. The delay line can either have an open bottom requiring a rapid flow of water to maintain coupling, or it can be equipped with a thin membrane at the bottom. The form is common in large automated scanning systems. The membrane is usually punctured in the middle to provide a slow flow of water for coupling. Water delay lines with flowing water are also called "bubblers" or "squirters". A variety of sizes are used.

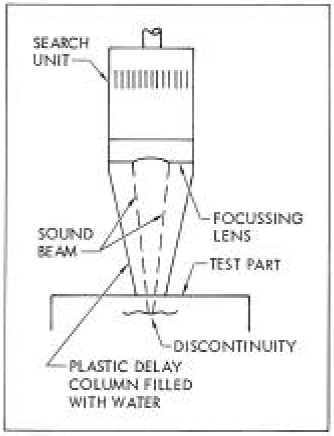


Figure 5-33. Water Delay Column Search Unit.

5.2.2.7 Wheel Search Units.

A wheel search unit consists of a flexible tire filled with liquid and containing one or more transducer elements. As shown in Figure 5-34, sound is transmitted through the liquid, the tire, and to the part through a thin couplant film between the tire and the part. Wheel search units can be made to transmit the sound beam in several different directions and modes. Wheel search units are not normally used for field NDI.

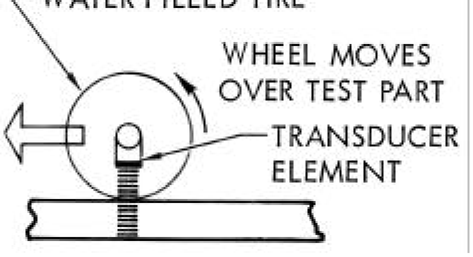


Figure 5-34. Wheel Search Unit.

5.2.2.8 Collimators.
Search units can be equipped with collimators to reduce the size of the sound beam entering the test part. The collimator may be a solid cone (usually acrylic plastic) bonded to the face of the search unit. This type of collimator reduces the diameter of the sound beam entering the test part to the diameter of the tip of the cone. The cone also acts as a delay line and can result in better near surface resolution and broadens the beam spread (see 5.1.6.2.5). However, this type of collimator reduces the energy entering the test part. Hollow cylindrical collimators may also be used in immersion inspections in which the collimator is attached to an immersion search unit to control the beam shape.

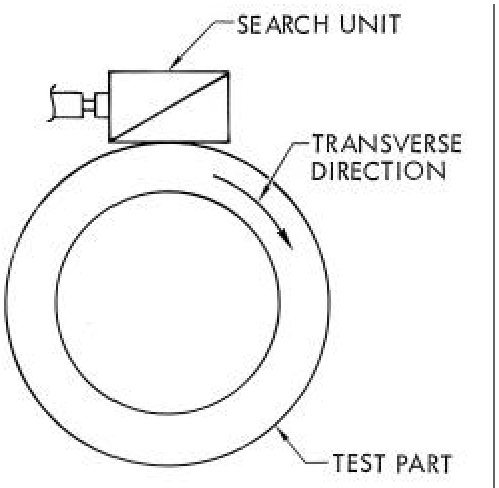
5.2.2.9 Search Unit Wedges and Shoes.

5.2.2.9.1 Reasons For Use.

a. Wedges and shoes are used to adapt search units for angle beam and surface wave inspections and for inspecting parts with curved surfaces. Normally search units are purchased with built-in wedges for angle beam and surface wave inspections on either flat or curved surfaces. When ordering search units, simply add appropriate requirements for the required refracted angle, the material to be inspected, the radius of curvature of the inspection surface and the direction of the ultrasonic beam with respect to the curvature. If necessary, straight beam search units can be adapted for use in angle beam and surface wave inspections by using wedges fabricated in accordance with paragraph 5.2.2.10.

b. If flat probes are used on convex surfaces, the ultrasonic energy transmitted into the part is drastically reduced, because only the center of the search unit makes good contact with the part. Flat search units of small size (1/4-inch or less diameter or width) can be used in some cases on convex surfaces (Figure 5-35) down to 1.4-inch radius. However, loss of power results due to the smaller contact area.

c. Inspections performed with flat-faced search units on curved surfaces will be hindered by the tendency of the transducer to rock (see Figure 5-35). This varies the angle of the incident and refracted sound beam and causes problems in interpretation. These inspection techniques are not recommended.



NOTE
FLAT SURFACE OF SEARCH UNIT MAKES
SEARCH UNIT UNSTEADY, COULD
CAUSE ROCKING BACK AND FORTH.
THIS CHANGES INCIDENT AND
REFRACTED ANGLES.

Figure 5-35. Angle Beam Inspection of Curved Surface Using Flat Search Unit.

5.2.2.9.2 Guidelines for Use of Curved Wedges and Shoes.

a. Required for all convex surfaces with a radius of curvature of 1.5 inches or less. Recommended for all convex surfaces with a radius of curvature between 1.5 and 4.0 inches.

b. Required for all concave surfaces with a radius of curvature of less than 4 inches.

5.2.2.10 Design And Fabrication Of Wedges And Shoes.

CAUTION

Excessive heat generated during fabrication (machining or sanding) of acrylic plastic wedges and delay elements can significantly increase the attenuation of ultrasound in this material.

a. Plastic wedges and shoes can be fabricated from polystyrene, Lucite or other acrylic plastic (Item A, Type 1, Grade C plastic of Federal Specification L-P-391). Before using a plastic, a sample shall be checked to insure that sound can be transmitted through the material. Some plastics will scatter ultrasonic energy. The sample shall be at least as thick as the wedge or shoe to be fabricated. Check the sample using straight beam inspection and note the back reflection signal. If a strong back reflection (at least 100% of saturation) cannot be obtained, new material must be procured. The sample shall be checked using the highest frequency that will be used with the completed wedge or shoe.

b. Angle beam wedges may be fabricated according to Figure 5-36 or Figure 5-38. The wedge in Figure 5-36 has provisions built in for mounting the straight-beam search unit, while the wedge in Figure 5-38 requires a coupling fixture (Figure 5-37) for mounting the straight-beam search unit. Similar fixtures may be procured or locally manufactured. The incident angle, f_1, for each wedge shall be determined from Snell's law using the respective velocities of the wedge and the test material and the refracted angle, f_2, required by the inspection procedure. Table 5-3 contains values for f_1 calculated for listed refracted angles in six materials.

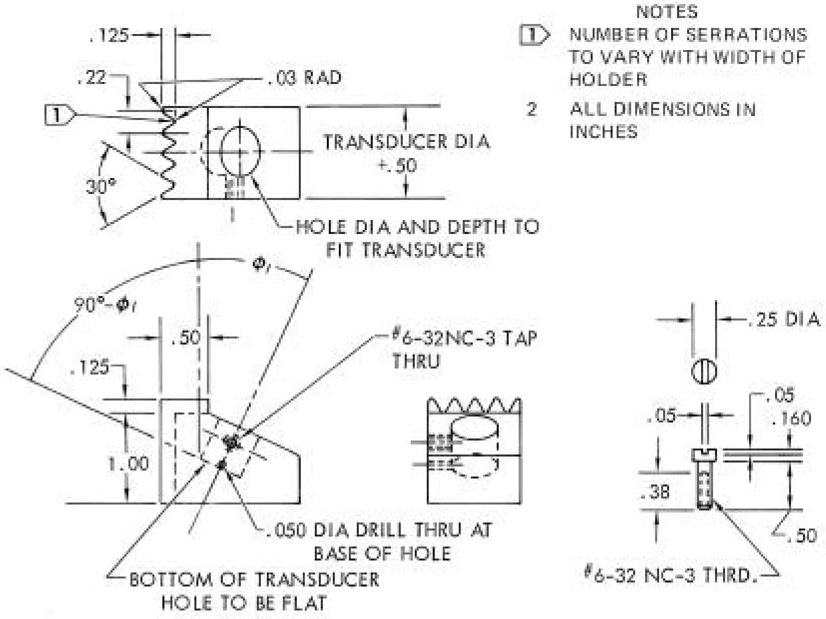


Figure 5-36. Angle Beam Wedge with Hole for Mounting Search Unit.

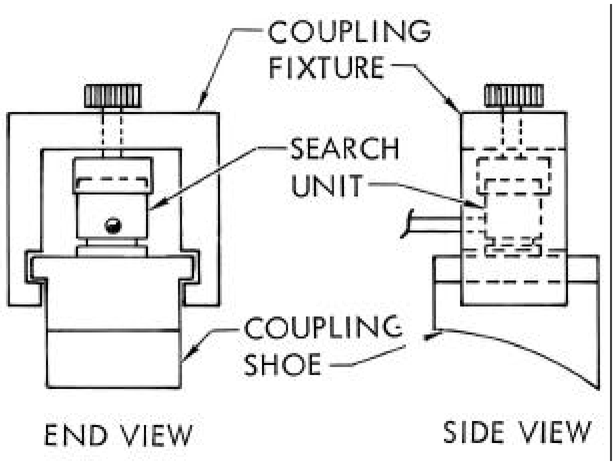


Figure 5-37. Use of a Coupling Fixture to Hold Search Unit on Shoe.

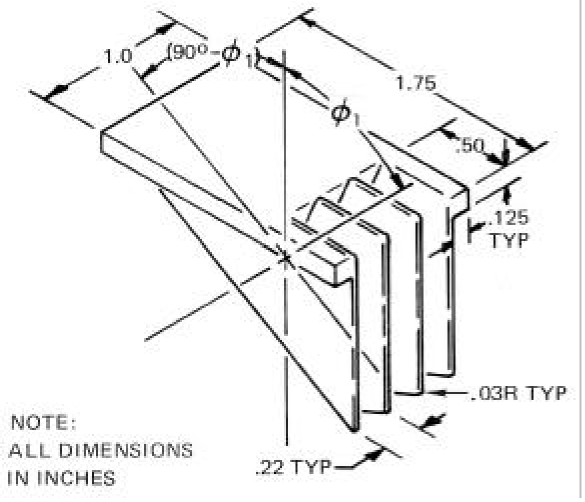


Figure 5-38. Angle Beam Wedge Requiring a Coupling Fixture.

Table 5-3. Incident Angles in Plastic for Refracted Shear Wave Angles in Test Materials.

Incident longitudinal wave angle in plastic (degrees)								
Refracted shear wave angle in test materials (degrees)	Steel	Stainless Steel 302	Stainless Steel 410	Ti 150A	Al 1100-0	Al 2014-T4	Inconel Wrought	Magne -sium AM 35
20	16.4	17.0	17.8	17.0	17.1	17.1	17.6	17.1
21	17.2	17.9	18.7	17.9	18.0	18.0	18.5	18.0
22	18.0	18.7	19.5	18.7	18.8	18.8	19.3	18.8
23	18.8	19.5	20.4	19.5	19.7	19.7	20.2	19.7
24	19.6	20.4	21.3	20.4	20.5	20.5	21.1	20.5
25	20.4	21.2	22.2	21.2	21.3	21.3	21.9	21.3
26	21.2	22.0	23.0	22.0	22.2	22.2	22.8	22.2
27	22.0	22.9	23.9	22.9	23.0	23.0	23.7	23.0
28	22.8	23.7	24.8	23.7	23.9	23.9	24.5	23.9
29	23.6	24.5	25.7	24.5	24.7	24.7	25.4	24.7
30	24.4	25.3	26.5	25.3	25.5	25.5	26.2	25.5
31	25.2	26.2	27.4	26.2	26.3	26.3	27.1	26.3
32	26.0	27.0	28.2	27.0	27.2	27.2	27.9	27.2
33	26.8	27.8	29.1	27.8	28.0	28.0	28.8	28.0
34	27.5	28.6	30.0	28.5	28.8	28.8	29.6	28.8
35	28.3	29.4	30.8	29.4	29.6	29.6	30.5	29.6
36	29.1	30.2	31.7	30.2	30.4	30.4	31.3	30.4
37	29.8	31.0	32.5	31.0	31.2	31.2	32.1	31.2
38	30.6	31.8	33.4	31.8	32.0	32.0	33.0	32.0
39	31.3	32.5	34.2	32.6	32.8	32.8	33.8	32.8
40	32.1	33.4	35.0	33.4	33.6	33.6	34.6	33.6
41	32.8	34.2	35.9	34.2	34.4	34.4	35.5	34.4
42	33.6	34.9	36.7	34.9	35.2	35.2	36.3	35.2
43	34.3	35.7	37.5	35.7	36.0	36.0	37.1	36.0
44	35.0	36.5	38.3	36.5	36.7	36.7	37.9	36.7
45	35.8	37.2	39.2	37.2	37.5	37.5	38.7	37.5
46	36.5	38.0	40.0	38.0	38.3	38.3	39.5	38.3
47	37.2	38.7	40.8	38.7	39.0	39.0	40.3	39.0
48	37.9	39.5	47.5	39.5	39.8	39.8	41.1	39.8
49	38.5	40.2	42.4	40.2	40.5	40.5	41.9	40.5
50	39.3	41.0	43.2	41.0	41.3	41.3	42.6	41.3
51	40.0	41.7	43.9	41.7	42.0	42.0	43.4	42.0
52	40.6	42.4	44.7	42.4	42.7	42.7	44.2	42.7
53	41.3	43.1	45.5	43.1	43.5	43.5	44.9	43.5
54	42.0	43.8	46.3	43.8	44.2	44.2	45.7	44.2
55	42.6	44.5	47.0	44.5	44.9	44.9	46.4	44.9
56	43.3	45.2	47.8	45.2	45.6	45.6	47.1	45.6
57	43.9	45.9	48.5	45.9	46.2	46.2	47.9	46.2
58	44.5	46.5	49.2	46.5	26.9	26.9	48.5	26.9
59	45.1	47.2	49.9	47.2	47.6	47.6	49.3	47.5
60	45.7	47.8	50.7	47.8	48.2	48.2	50.0	48.2
61	46.3	48.5	51.4	48.5	48.9	48.9	50.6	48.9

Table 5-3 Continued

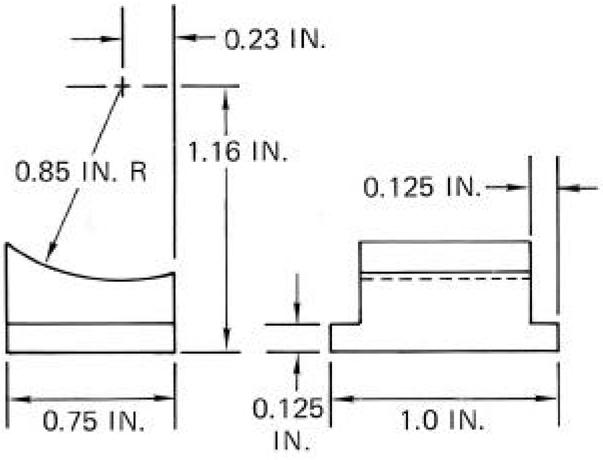
	Incident longitudinal wave angle in plastic (degrees)							
Refracted shear wave angle in test materials (degrees)	Steel	Stainless Steel 302	Stainless Steel 410	Ti 150A	Al 1100-0	Al 2014-T4	Inconel Wrought	Magne-sium AM 35
62	46.9	49.1	52.0	49.1	49.5	49.5	51.3	49.5
63	47.4	49.7	52.7	49.7	50.1	50.1	52.0	50.1
64	48.0	50.3	53.4	50.3	50.7	50.7	52.6	50.7
65	48.5	50.9	54.0	50.9	51.3	51.3	53.3	51.3
66	49.0	51.4	54.7	51.4	51.9	51.9	53.9	51.9
67	49.5	52.0	55.3	52.0	52.5	52.5	54.4	52.5
68	50.0	52.5	55.9	52.5	53.0	53.0	55.1	53.0
69	50.5	53.0	56.5	53.0	53.5	53.5	55.6	53.5
70	51.0	53.5	57.0	53.5	54.0	54.0	56.2	54.0
71	51.4	54.0	57.6	54.0	54.5	54.5	56.7	54.5
72	51.8	54.5	58.1	54.5	55.0	55.0	57.2	55.0
73	52.2	54.9	58.6	54.9	55.5	55.5	57.7	55.5
74	52.6	55.3	59.1	55.3	55.9	55.9	58.2	55.9
75	53.0	55.8	59.6	55.8	56.3	56.3	58.6	56.3
76	53.3	56.1	60.0	56.1	56.7	56.7	59.1	56.7
77	53.7	56.5	60.5	56.5	57.1	57.1	59.5	57.1

c. Note the serrations on the wedges in Figure 5-36 and Figure 5-38. These serve to dampen and scatter reflected sound that does not initially enter the test part. The serrations, therefore, reduce spurious signals.

d. The configurations of the wedges in Figure 5-36 and Figure 5-38 may be modified as required to take care of special geometry situations. In all cases, wedges shall be fabricated to provide the proper refracted angle for the desired mode of vibration. In addition, they shall provide for transmission of sound into the test part at the locations required to cover the areas of suspected flaws.

e. Figure 5-37 shows how the coupling fixture is used with the wedge in Figure 5-38. A few drops of couplant material is needed between the search unit and any wedge to ensure good sound transmission.

f. Figure 5-39 shows a typical shoe used for curved surfaces. This example may be used as a guideline for fabrication of shoes for curved surfaces. Dimensions may be changed to accommodate the specific part to be inspected.



NOTE
DIMENSIONS MAY BE CHANGED TO ACCOMODATE THE CONFIGURATION TO BE INSPECTED AND PROVIDE THE PROPER SOUND ENTRY ANGLES.

Figure 5-39. Typical Curved Surface.

g. Although shoes for curved surfaces are usually fabricated from acrylic plastic, sometimes shoes are fabricated from the same material as the test part. With shoes of the test part material, the sound beam travels straight into the test part from the shoe; refraction does not occur.

h. The radius of curvature of each shoe should match the radius of curvature of the test part. Small changes in the curvature of the shoe can be accomplished on the test part by inserting number 400 or finer grit sandpaper between the shoe and the test part and then sliding the shoe across the sandpaper. Major shaping of a shoe should be done in a machine shop, because the shoe cannot be held steady enough by hand.

i. In some cases, when using plastic shoes for angle beam inspection on curved surfaces, the portion of the sound beam away from the beam center may produce unwanted longitudinal and/or surface waves as shown in Figure 5-41. This effect increases with decreasing radii of curvature. Also, when using large angles (70° or larger) for inspecting cylindrical shapes in the longitudinal direction, interfering surface waves can be generated. These waves leave the shoe on both sides at an angle to the longitudinal direction (see Figure 5-40). In these cases, it is not desirable to adapt the shoe to a close fit with the part. The shoe should be made so that only the central portion of the beam centers the test part. As an option, slots may be cut in the bottom surface of the shoe. The slots should be oriented perpendicular to the direction of propagation of the unwanted surface waves and located away from the exiting beam center (see Figure 5-42). The dimensions of the slots should be about 1/8 inch wide by 1/8 inch deep.

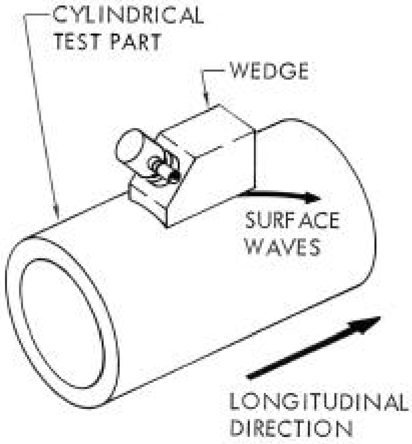


Figure 5-40. Generation of Unwanted Surface Waves during Inspection of Cylindrical Part in the Longitudinal Direction.

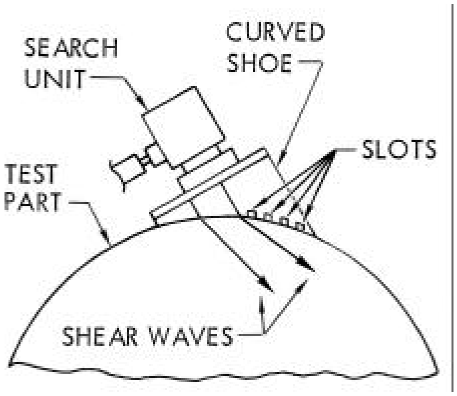


Figure 5-41. Slots in Shoe to Eliminate Unwanted Surface Waves.

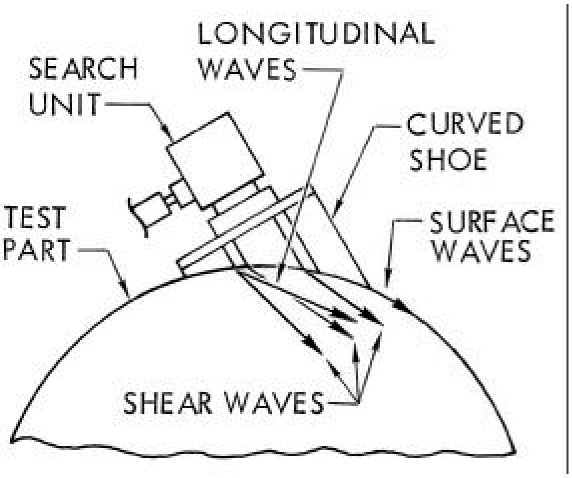
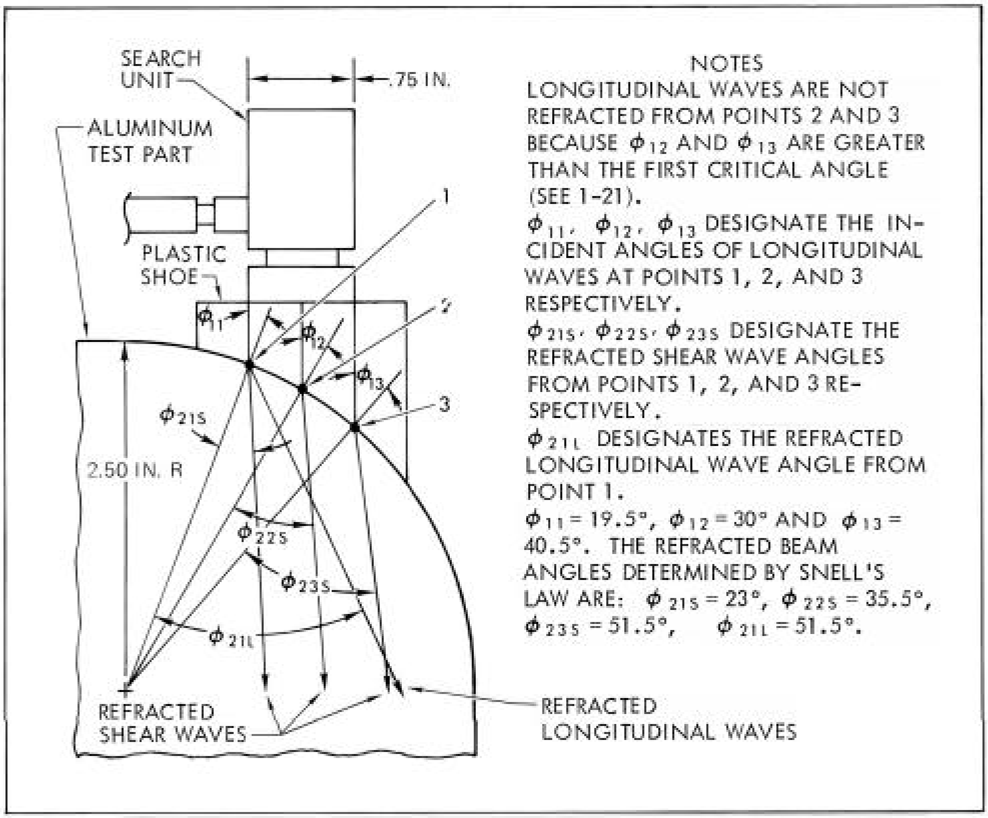


Figure 5-42. Generation of Unwanted Longitudinal and Surface Waves on Curved Surface.

NOTE

Unwanted surface waves can be detected by noting additional unexpected signals on the waveform display. If these signals can be damped and traced to their source using an oil-wetted finger as explained in 5.3.3.3, unwanted surface waves are being generated.

j. When designing shoes for curved surfaces, the sound beam path in the shoe and the test part must be considered in order to assure coverage of the area of interest within the test part. Generally the sound beam path in the shoe can be considered to be a straight projection of the face of the search unit; in almost all cases the sound travel in the shoes will be in the near field, characterized by no beam spread (see paragraph 5.1.6.2.2 and Figure 5-12). The beam path in the part can be obtained by using Snell's Law to determine the refracted angle at various points across the sound beam where it enters the test part surface (see paragraph 5.1.5.1 and Figure 5-43).



NOTES

LONGITUDINAL WAVES ARE NOT REFRACTED FROM POINTS 2 AND 3 BECAUSE ϕ_{12} AND ϕ_{13} ARE GREATER THAN THE FIRST CRITICAL ANGLE (SEE 1-21).

ϕ_{11}, ϕ_{12}, ϕ_{13} DESIGNATE THE INCIDENT ANGLES OF LONGITUDINAL WAVES AT POINTS 1, 2, AND 3 RESPECTIVELY.

ϕ_{21S}, ϕ_{22S}, ϕ_{23S} DESIGNATE THE REFRACTED SHEAR WAVE ANGLES FROM POINTS 1, 2, AND 3 RESPECTIVELY.

ϕ_{21L} DESIGNATES THE REFRACTED LONGITUDINAL WAVE ANGLE FROM POINT 1.

$\phi_{11} = 19.5°$, $\phi_{12} = 30°$ AND $\phi_{13} = 40.5°$. THE REFRACTED BEAM ANGLES DETERMINED BY SNELL'S LAW ARE: $\phi_{21S} = 23°$, $\phi_{22S} = 35.5°$, $\phi_{23S} = 51.5°$, $\phi_{21L} = 51.5°$.

Figure 5-43. Example of Determining the Sound Beam Path in a Test Part with a Curved Surface.

k. With certain inspection setups, particularly when using shoes to generate straight beams in parts with curved surfaces, multiple reflections from the shoe-to-test part interface can interfere with the inspection. To avoid this, the shoe shall be made thick enough to avoid interference with the intended inspection application. Consider the inspection setup shown in Figure 5-44. It is important only that the inspector be able to recognize and identify indications on the waveform display. Reflections caused by the shoe are easily recognized simply by raising the shoe off the surface of the material. If the indications remain on the screen, the plastic shoe is the cause. Slotting the shoe as shown in Figure 5-41 may reduce or eliminate such interference signals. It is not necessary for the operator to calculate the sound paths to and from various reflectors. However, it is important the operator know how to recognize nonrelevant indications from the reflectors and minimize their cause.

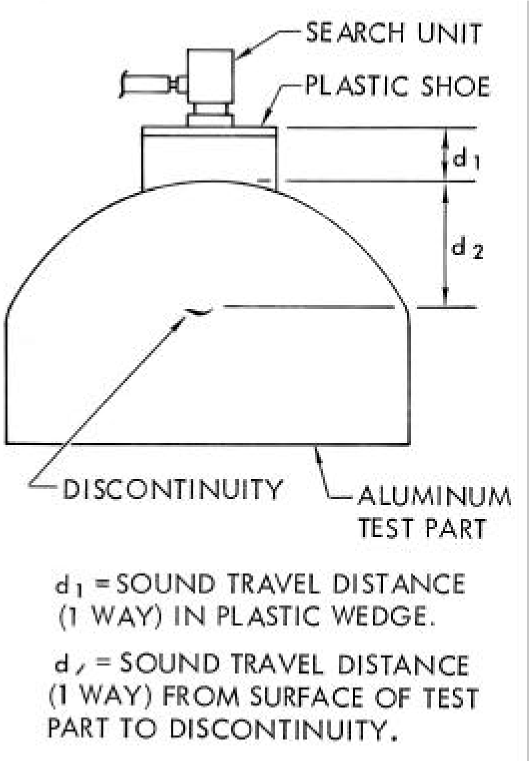


Figure 5-44. **Straight Beam Inspection of Test Part with Curved Surface.**

5.2.3 Couplants.

CAUTION

Glycerin, silicones, and graphite greases shall not be used as couplants unless authorized by specific engineering approval.

5.2.3.1 Properties.

A thin film of liquid couplant material is required between the search unit and the test part in order to displace air at the interface. This allows transmission of ultrasonic energy into the test part. Any liquid that will transmit ultrasonic energy and meets the following requirements may be used.

a. Able to wet both the face of the search unit and the test part.

b. Is not corrosive or toxic.

c. Can be applied and removed easily.

d. Is homogeneous and free of bubbles.

e. Is viscous (adheres well) enough to prevent rapid flow off the test part.

5.2.3.2 Types.

Typical couplant materials include water, oil, grease, commercial gels and penetrant emulsifier. A guide for selection of couplant materials for use at room temperature on various surfaces is given in Table 5-4. Other couplants of similar viscosities may also be used. For overhead or vertical surfaces, higher viscosity materials may be used.

Table 5-4. Couplant Materials for Contact Inspection.

Approximate Surface Roughness (microinches, μ in)	Couplant Material
4-100	SAE 10W motor oil
50-200	SAE 20-20W motor oil
100-400	SAE 30W motor oil
250-700	SAE 40W motor oil
700-over	Cup grease

SECTION III
ULTRASONIC TECHNIQUES

5.3 ULTRASONIC TECHNIQUES.

5.3.1 Guidelines for Inspector Familiarization.
Familiarization with the methods and equipment can be obtained by:

a. Performing the familiarization tests included in the instrument manuals.

b. Performing the calibration procedures given in Section 5.2.

c. Making distance amplitude correction curves and establishing transfer on some specimens as described in paragraph 5.3.5.3.1..

d. For surface wave familiarization, perform the tests given in paragraph 5.3.3.3.3.

All these familiarization tests and procedures should be followed in detail by the new operator. It is recommended that the procedures be run through several times. The operator should experiment with various combinations of specimens and search units to become familiar with different ultrasonic inspection procedures and equipment.

5.3.2 Contact and Immersion.
Ultrasonic inspections can be separated into two basic categories: contact inspection and immersion inspection (paragraph 5.1.3). Immersion inspections are no longer confined to a tank of water in a laboratory or factory. Bubblers, squirters, or water columns enables the use of immersion techniques with portable ultrasonic scanning equipment in field inspections.

5.3.3 Common Inspection Methods.

5.3.3.1 Straight Beam Method.

5.3.3.1.1 General.
This method uses longitudinal waves (paragraph 5.1.4.1).

5.3.3.1.2 Limitations.

5.3.3.1.2.1 Dead Zone.

The dead zone interferes with contact inspection of near-surface regions of parts. When required, the coverage of a straight beam inspection in near-surface regions can be extended by several different methods, such as the following:

a. Inspect the part from opposite sides. The dead zone, which is not inspected from the first side, is covered when inspecting from the second side (see Figure 5-45).

b. Use a dual search unit (see paragraph 5.2.2.4).

c. Use a delay line contact search unit (see paragraph 5.2.2.6).

d. Use an immersion inspection method.

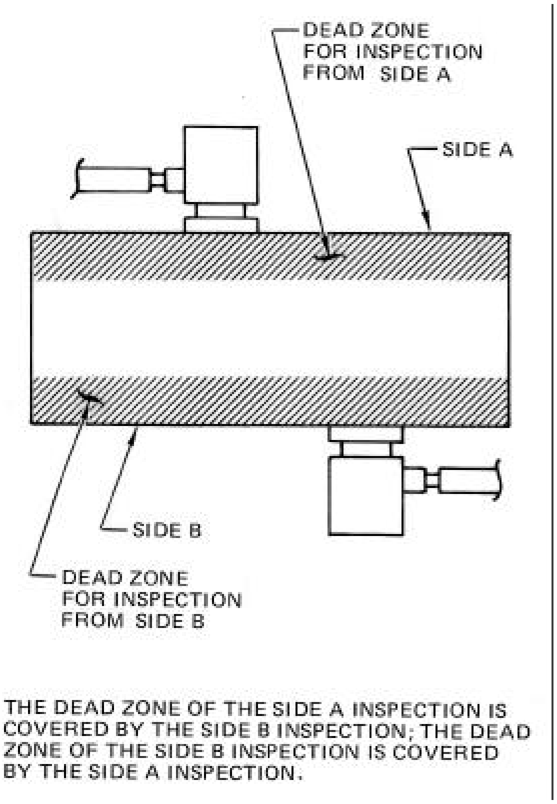


Figure 5-45. Inspection of Test Part Opposite Sides to Provide Coverage of Dead Zone Areas.

5.3.3.1.2.2 High Attenuation.

In some cases, when inspecting thick sections, the sound energy in the part drops below useable levels. If this happens, inspecting from opposite sides can help, since only half the section thickness needs to be covered in a single inspection. If inspecting from two sides, the zones must overlap by a minimum of 1/2". The limitation of high attenuation may also be alleviated by using the through-transmission technique.

5.3.3.1.3 Through-Transmission Technique.

Most straight beam methods are applied using the pulse-echo technique in which the transmitting and receiving search unit or units are placed on the same surface. Certain applications use the through-transmission method in which the transmitting search unit is placed on one surface and the receiving search unit is placed on the opposite surface. In the through-transmission method, discontinuities block the passage of sound. This results in a reduction of the received signal (see Figure 5-46). With this method, echoes from the discontinuities cannot be seen on the display. Therefore, depth information on the discontinuities cannot be determined.

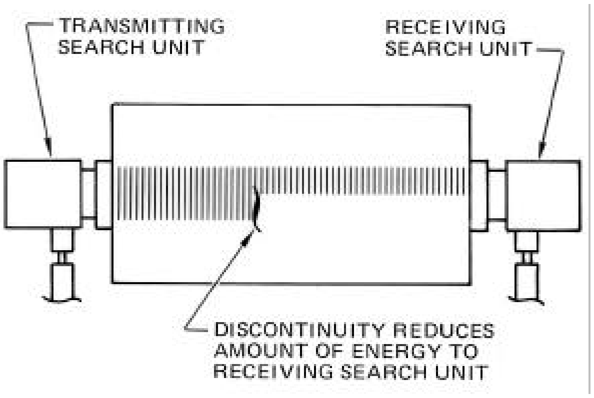


Figure 5-46. Through-Transmission Inspection.

5.3.3.1.3.1

NOTE

A major problem with through-transmission testing is maintaining alignment of the transducers. Misalignment can reduce the amplitude of the received signal. Anything causing the received energy to suddenly drop can be misinterpreted as a defect.

The through-transmission method can be applied to thick materials, and is useful when insufficient energy is obtained with the pulse-echo method. The through-transmission method can also be used to advantage on thin test parts when the dead zone prevents a complete inspection with the pulse-echo method.

5.3.3.1.4 Applications.
The straight beam method is used to detect discontinuities with at least one surface oriented parallel to the test surface. Typical discontinuity examples are laminations, corrosion, high-and low-density inclusions, porosity, forging bursts, and cracks. Applications of the straight beam method depend upon the test part geometry.

5.3.3.2 Angle Beam Method.

5.3.3.2.1 General.
This method generally uses shear waves (paragraph 5.1.4.2) refracted in the test part at angles of 30 to 70 degrees.

5.3.3.2.2 Applications.
Angle beam methods are used extensively for field nondestructive inspection (NDI) and can provide for inspection of areas with complex geometry or limited access. This is because angle beams can travel through a material by bouncing from surface to surface. Useful inspection information can be obtained at great distances from the search unit. Angle beam inspections are particularly applicable to inspections around fastener holes, inspection of cylindrical components, examination of skins for cracks and inspection of welds (see Figure 5-47) shows typical angle beam inspections.

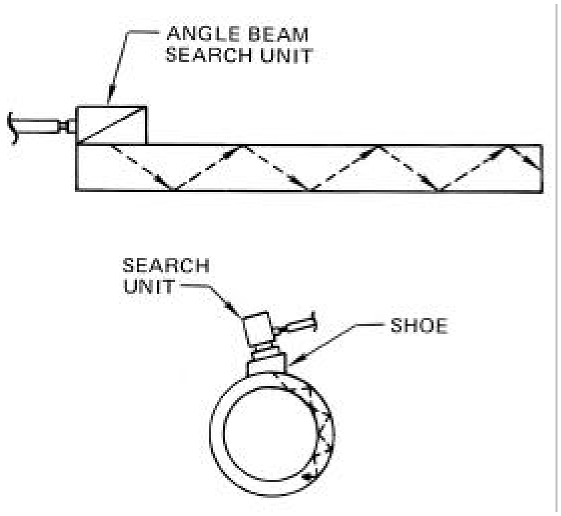


Figure 5-47. Angle Beam Inspection.

5.3.3.2.3 Multiple Search Units.

Most angle beam methods use a single search unit with one transducer element for transmitting and receiving ultrasonic energy. Special applications may utilize dual angle-beam search units (see Figure 5-32) or two or more angle beam units, one for transmitting, the rest for receiving.

5.3.3.3 Surface Wave Method.

NOTE

When surface waves are used to inspect painted surfaces, the technician should exercise caution during set up and interpretation due to the possibility of surface reflection from scratches and breaks in the painted surface. Rough surfaces or liquid on the surface attenuate surface waves. The area in front of the search unit must be kept free of all but the minimum amount of couplant needed for the inspection.

5.3.3.3.1 General.

This method uses surface/Rayleigh waves that are refracted in the test part at an angle of 90 degrees. This method works only for contact inspection since the part surface along which the surface wave propagates must be bounded by air.

5.3.3.3.2 Applications.

Surface wave inspections can be utilized in many field NDI applications involving surface cracks or slightly sub-surface discontinuities. On smooth surfaces, sound energy can travel long distances with little energy loss. Surface waves travel around curved surfaces. They reflect at sharp edges (radius less than one wavelength). Even at the sharp edges, complete reflection does not occur. Weak signals pass around the edges shows a typical surface wave inspection.

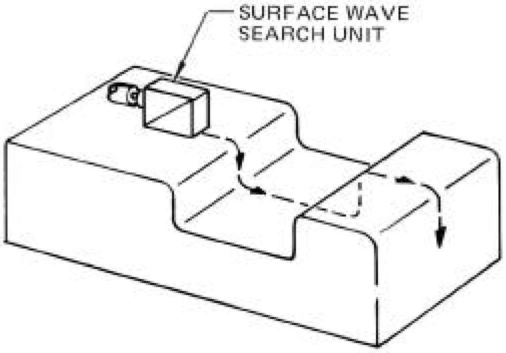


Figure 5-48. Surface Wave Inspection

5.3.3.3.3 Surface Wave Familiarization.

a. Use a miniature angle-beam block. Attach a 2.25 MHz surface wave search unit to the ultrasonic instrument.

b. Position the search unit at P-1 as shown in Figure 5-49. Adjust the sweep and gain to obtain a signal from corner C.

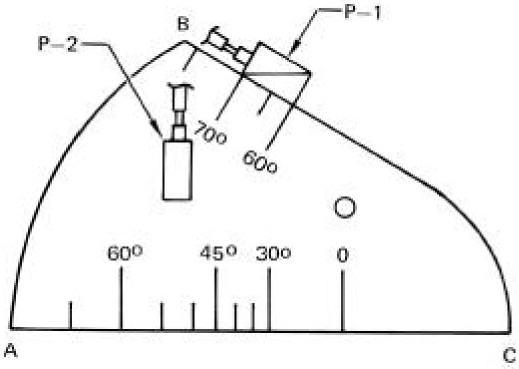


Figure 5-49. Surface Wave Familiarization.

c. Moisten a finger with oil and move it across the surface from the search unit toward corner C. Note that the corner signal is damped until the finger moves beyond the corner.

d. Move the search unit away from corner C toward corner B as shown in Figure 5-49. Note that the corner C signal moves to the right along the time base.

e. Position the search unit at P-2 as shown in Figure 5-49. Orient the search unit perpendicular to edge AC. Adjust the sweep and gain to obtain a signal from edge AC.

f. Rotate the search unit and note that the signal from the edge decreases as the search unit is rotated away from the normal to the edge. This illustrates that surface waves should always be directed perpendicular to the expected plane of cracks (see Figure 5-50).

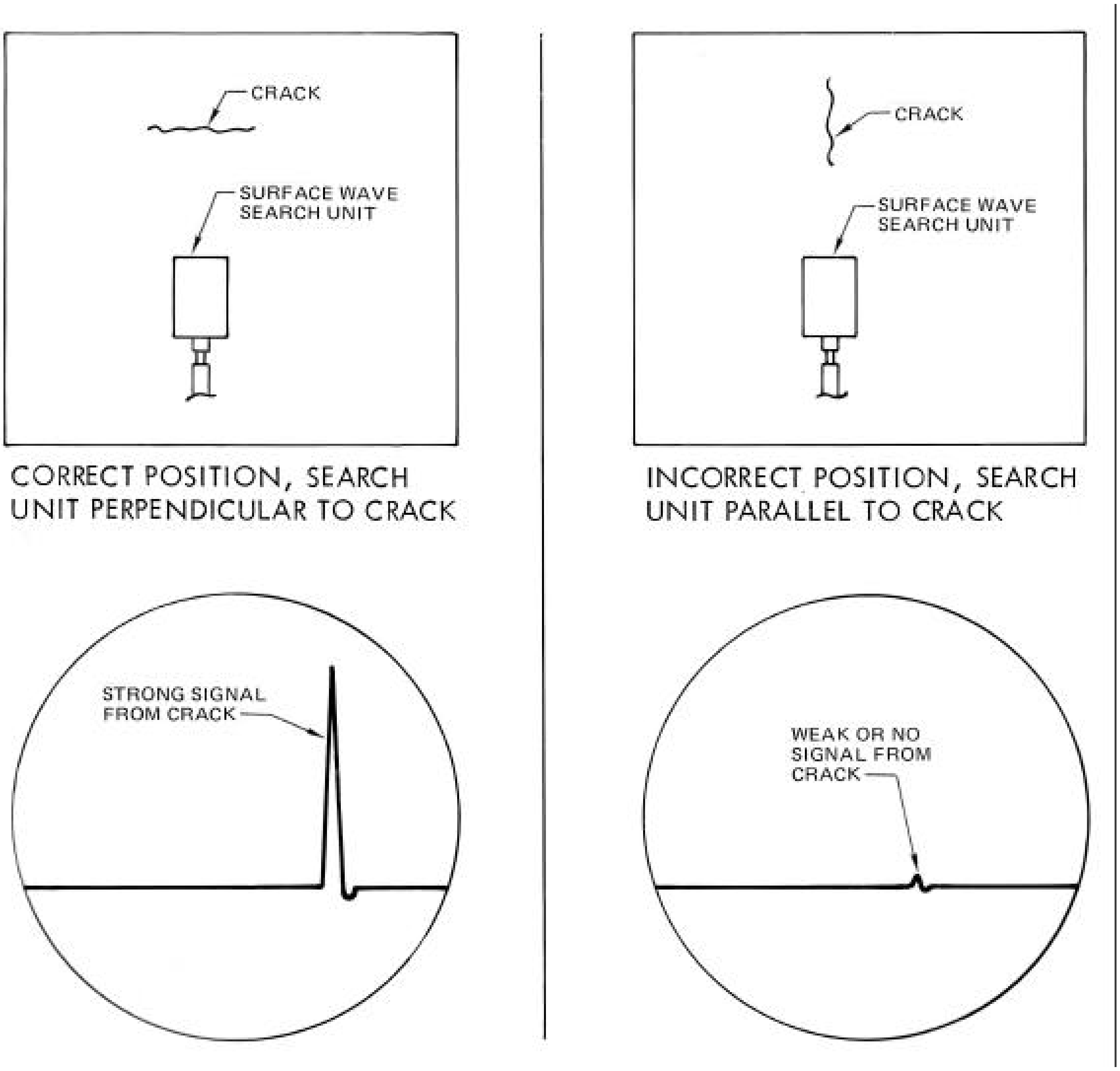


Figure 5-50. Correct and Incorrect Search Unit Orientation for Finding Cracks with Surface Waves.

5.3.3.4 Lamb Wave Method.

If the thickness of a test part is less than one wavelength of the sound introduced at the appropriate incident angle, lamb waves (paragraph 5.1.4.3) travel between the two parallel surfaces of the part. This is a special method that is not widely used.

5.3.4 Distance Amplitude Correction (DAC).

5.3.4.1 General.

When inspecting thick material, a DAC curve should be used to compensate for change in sensitivity with changing metal travel distance. Many instruments have DAC features built in. If this is the case, follow the instructions in the operator's manual for establishing a DAC curve. Otherwise, procedures for establishing DAC curves are given below.

5.3.4.2 Straight Beam DAC.

a. Connect the search unit and instrument to be used in the inspection. Turn the reject control to its minimum position.

b. Use all of the ASTM blocks with #5 FBHs that cover the range of metal travel distance to be used in the inspection. For example, for inspecting a 2 inch specimen, use the inspection blocks with 1/8, 1/4, 1/2, 3/4, 1-1/2, and 3 inch metal travel; for inspecting a 1-1/2 inch specimen, use the blocks with 1/8, 1/4, 1/2, 3/4 and 1-1/2 inch metal travel; for inspecting a 5 inch specimen, use the 1/8, 1/4, 1/2, 3/4, 1- 1/2, 3, and 6 inch metal travel blocks.

c. From this group of blocks select the one with the longest metal travel distance. Place the search unit on the part and adjust the time base using the delay and/or sweep controls until the peak of the initial pulse is positioned on the 0 or first scale marker. Move the search unit until the maximum reflected signal from the FBH is obtained. Position this reflected signal on another scale marker that will represent the metal travel distance to the FBH without moving the initial pulse from the 0 marker. If, for example, the largest block selected had a 3-inch metal travel distance, the signal from the FBH could be positioned on the 6 or 9 scale marker to allow accurate measurement of the distance below the surface for any indication. If the signal were positioned on the 9 scale marker, each scale marker would represent 1/3 inch of metal travel distance.

d. Place the search unit on each block and adjust the position of the search unit to obtain a maximum signal from the respective FBH. Note which block produced the largest FBH signal.

e. With the search unit on the block, which gives the maximum signal from the FBH, adjust the gain to bring the signal amplitude to 80% of saturation.

f. Without changing the gain, sweep, or sweep delay, measure the maximum signal amplitudes from the FBHs on the other test blocks. The height of each signal may be marked on the display face with a grease pencil. Drawing a smooth curve through these points produces the DAC curve on the face of the display. Figure 5-51 shows a typical DAC curve.

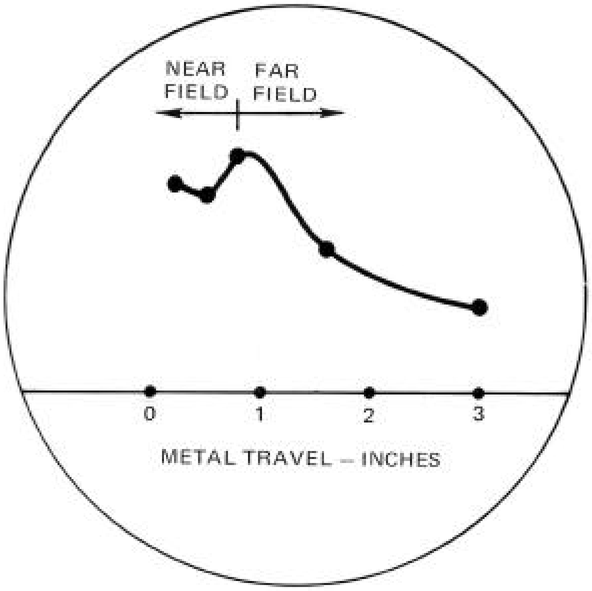


Figure 5-51. Typical Straight Beam DAC Curve.

5.3.4.3 Angle Beam DAC.

a. Connect the instrument and search unit to be used in the inspection. Turn the reject control to its minimum position.

b. Use an IIW block. Place the search unit at P-1 as shown in Figure 5-52 and maximize the signal from the flat-bottom hole face. Adjust the signal to bring the signal to 80% of saturation. Using a grease pencil, mark the position of the signal peak on the display.

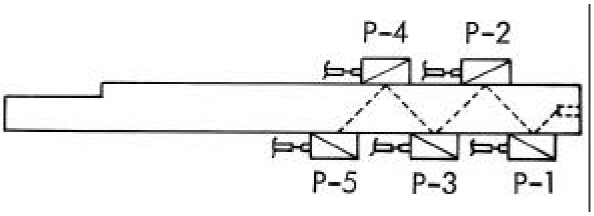


Figure 5-52. Search Unit Positions on IIW Block for Angle Beam DAC.

c. Position the search unit at P-2, P-3, P-4, and P-5. Without changing the gain, sweep, or sweep delay, maximize the signal from the hole at each point.

d. Mark the peak positions on the display. Draw a smooth curve between the points marked on the display. Figure 5-53 shows a typical angle beam DAC curve.

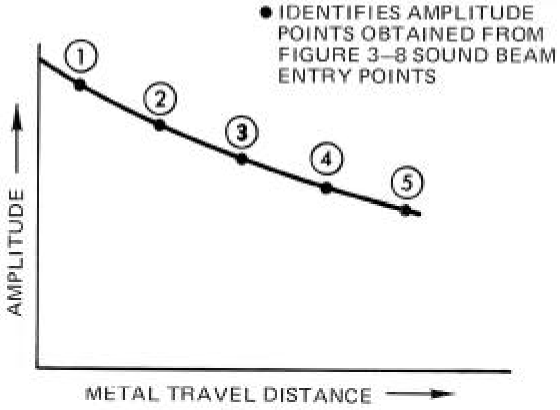


Figure 5-53. Typical Angle Beam DAC Curve.

5.3.4.4 Surface Wave DAC.

DAC is usually not necessary for surface wave inspections, because the search unit can generally be moved back and forth from a discontinuity to maximize the signal. If a DAC curve is needed for a surface wave inspection, it can be easily established. The search unit is placed at a few points at different distances from the reference standard reflector. At each point, the peak amplitude is measured and marked on the display. A smooth curve is then drawn through the points as in the straight beam and angle beam procedures.

5.3.5 Transfer.

5.3.5.1 Description.

Transfer (attenuation correction) refers to methods used to compensate for differences in ultrasonic transmission characteristics between the test part and the reference standard. For example, the surface condition of the reference standard and test part may differ, and/or the internal structures (grain size, etc.) may differ. Such differences cause the signal from a discontinuity in the test part to differ from the signal from the same size discontinuity in the reference standard. In order to obtain consistent results from ultrasonic inspections, it is necessary to correct for these differences by using transfer.

5.3.5.2 General Procedure.

a. Transfer shall be accomplished by noting the dB or gain difference in the responses received from reflectors in the reference standard and the part or piece of material to be inspected.

b. Use the echo signals from the same type of reflector in both the reference standard and the test part to establish transfer. For example, use back surfaces, flat-bottom holes, side-drilled holes or "V" notches (for angle beam inspections). If possible, a minimum of four reflections from different locations in the part or piece of material to be tested shall be noted, and the lowest response shall be used for comparison with the response from the reference standard. In practically all cases, any alteration of the test part is prohibited. Therefore, transfer must be accomplished using reflectors already included in the test part. Typical reflectors are the back surface or a fastener hole.

5.3.5.3 Examples.

5.3.5.3.1 Straight Beam Inspection of A Two- Inch Plate.

a. Suppose that a specification requires that any material with a discontinuity signal greater than the signal from a 5/64- inch diameter FBH is unacceptable. The inspection is set up by establishing a DAC curve in accordance with paragraph 5.3.4.2. Use ASTM blocks with 5/64-inch diameter FBHs and metal travel distances of 1/8, 1/4, 1/2, 3/4, 1-1/2, and 3 inches. Assume the curve shown in Figure 5-52 is obtained. Note that the 1/8-inch point is not shown. This is because the dead zone extends beyond 1/8 inch. Note that the near field appears to end around 3/4 inch.

b. After constructing the DAC curve, the amount of transfer is established through use of back surface reflections. The search unit is placed on the 1-1/2 inch metal travel ASTM standard as shown in Figure 5-54. This gives 2-1/4 inch metal travel to the back surface. The gain control is set to bring the back surface signal to the DAC curve as shown in Figure 5-55. This gain setting is maintained, and the search unit is placed on the test part. Assume the first signal shown in Figure 5-57 is obtained. This is 50% lower or 6 dB lower than the DAC curve at the 2-inch metal travel distance. This is the amount of transfer; the amount by which the gain must be increased after calibration.

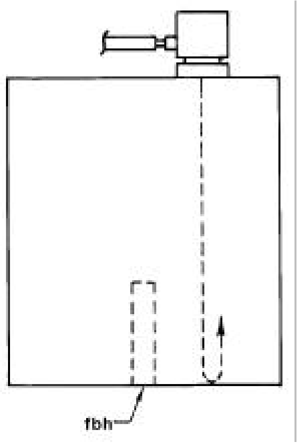


Figure 5-54. Search Unit on ASTM Block for Determining Transfer Amount.

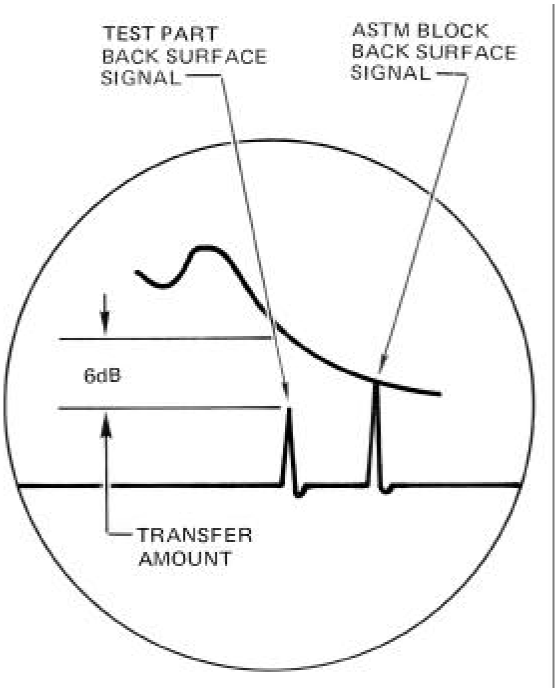


Figure 5-55. ASTM Block and Test Part Back Surface Signals.

c. The search unit is now placed on the ASTM block with 1-1/2 inch metal travel distance to the FBH. The signal from the FBH is maximized, and the gain is adjusted to bring the signal to the DAC curve level. Transfer is now applied by increasing the gain setting to double the amplitude. On an instrument with dB gain controls, this is easily accomplished by adding 6 dB to the gain or subtracting 6 dB of attenuation. On an instrument without dB controls, the gain must be increased to double the amplitude of a signal on the display. A correct way of doing this is as follows:

(1) Place the search unit on the 3-inch travel distance block and adjust the position for maximum signal from the FBH. Note the amplitude of the signal. (It should be close to 30% of full screen height.)

(2) Increase the gain until the amplitude of the signal is doubled (to 60% if it was 30% before. The gain is now set for evaluation of discontinuities in the test part. Any discontinuity signal that exceeds the DAC curve is cause for rejection.

NOTE

Doubling the gain by doubling the signal (from 50% of saturation to 100% of saturation) from the FBH in the 1-1/2 inch metal travel distance ASTM block would be improper; the 100% of saturation signal is in a possible nonlinear area of the display. Signals at levels above 90% of saturation shall not be used for applying transfer.

d. The gain setting obtained after applying transfer is used for evaluation of discontinuities in the test part. It is advisable to perform the initial inspection using an even higher gain setting. This provides for more reliable detection of discontinuities. When discontinuities are found, the gain is reduced to the level established by the transfer technique. At this gain setting, any discontinuity signal that exceeds the DAC curve is cause for rejection.

e. Note that in the above example, the metal travel distances to the back surface of the reference standard and the test part were not equal. By using the DAC curve in establishing the transfer, this difference was corrected.

5.3.5.3.2 Angle Beam Inspection for A Skin Crack.

Use a reference standard configuration as shown in Figure 5-56. Reference standard should be same thickness and material as skin to be examined. Specify size of saw cut. The inspection is set up using the saw cut to establish the sensitivity. Any discontinuity having a signal exceeding 25% of the saw cut signal is cause for rejection. Transfer is established as follows:

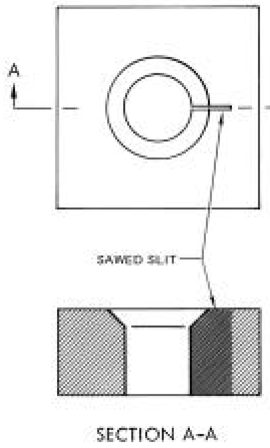


Figure 5-56. Reference Standard for Inspection for Cracks in Skin.

a. Place the search unit on the reference standard as shown in Figure 5-57 and position to obtain a maximum signal from the top corner of the wall of the fastener hole. Adjust the gain to bring the signal to 50% of saturation.

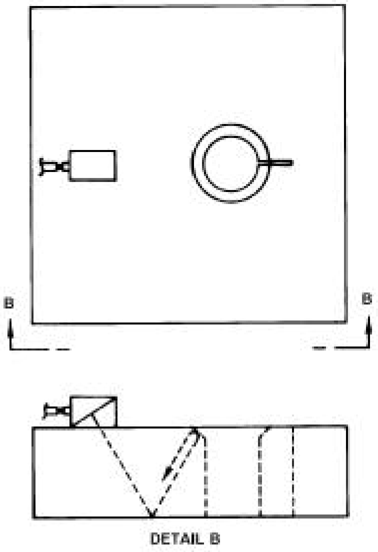


Figure 5-57. Positioning Search Unit for Establishing Transfer.

b. Place the search unit on the skin, and maximize the signal from the same size fastener hole as in the standard by adjusting the position of the search unit. Do not change the gain setting used for the fastener hole in the standard.

c. Suppose the signal obtained from the fastener hole in the skin is 80% of saturation. This is an increase of 60% (4 dB) of the signal from the reference standard fastener hole (30 = 60% of 50). This is the amount of transfer, the amount by which the rejection (alarm) level has to be raised.

d. Place the search unit back on the reference standard to obtain the signal from the saw cut. Increase the gain until the signal is at some convenient level, for example, 80% of saturation. At this gain 20% of full scale would be the rejection level, since any signal exceeding 25% of the saw cut signal is cause for rejection. However, this rejection level must be increased to 32% of full scale by the amount of transfer (60% or 4 dB). Therefore, any discontinuity that exceeds 32% of saturation is cause for rejection. As in the previous example (paragraph 5.3.5.3.1), the initial scanning is performed at a higher gain setting.

5.3.5.3.3 Straight Beam Technique of Transfer Applied to Angel Beam Inspection.
The technique given in paragraph 5.3.5.3.1 for transfer for a straight beam inspection may also be used for angle beam inspections. A straight beam search unit is used to determine the amount of transfer. This amount of transfer is then applied to the angle beam inspection. When using this method, the following conditions must be met.

a. The frequency of the straight beam search unit shall be approximately double the frequency of the angle beam search unit. For a 2.25 MHz angle beam search unit, use a 5 MHz straight beam search unit. For a 5 MHz angle beam unit, use a 10 MHz straight beam search unit.

b. The back surface of the standard and the test part must be located in the far field of the straight beam search unit.

c. The back surfaces of the reference standard and the test part must be parallel with the front surfaces.

5.3.5.4 Transfer Limits.
When using the transfer technique, if the signal from the test part is less than 25 percent (-12 dB) or more than 60 percent (+4 dB) of the signal from the reference standard (see Figure 5-58), the reference standard may be of the wrong material, heat treat condition and/or surface condition. If the signal from the test part is not within the above limits, another reference standard should be tried, or the prime depot should be contacted.

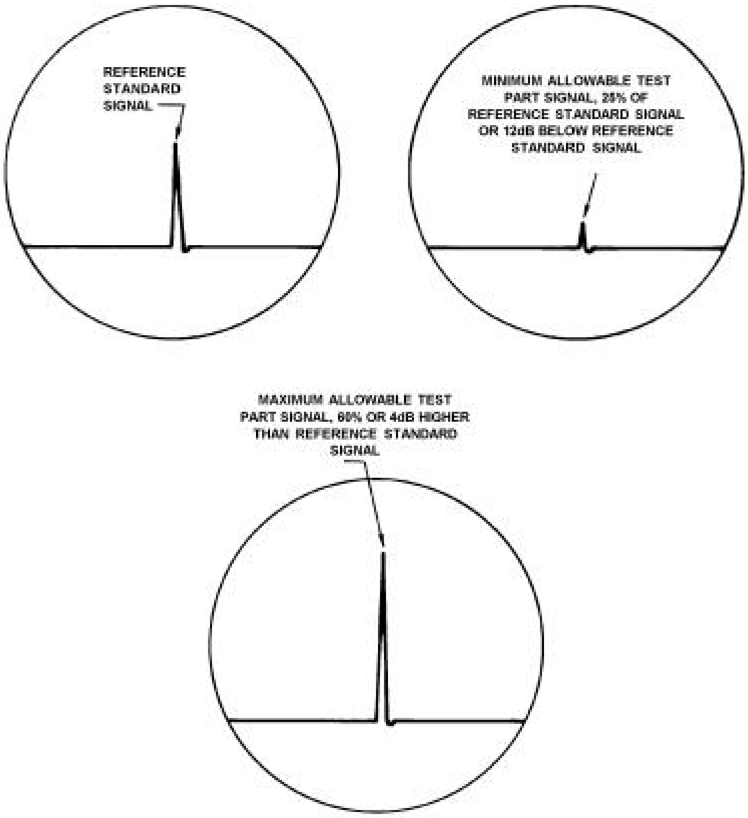


Figure 5-58. Transfer Limits.

5.3.6 Evaluation of Discontinuity Indications.

When a discontinuity indication is found, it is desirable to learn as much as possible about the discontinuity (or discontinuities). Information on the location, size, orientation and spacing helps in determining the seriousness of a discontinuity.

5.3.6.1 Location.

The location is determined by noticing the position of the indication on the waveform display and comparing this position to the positions of indications from known reflectors, such as the front and back surface. This is simple for straight beam inspections and is explained in paragraph 5.1.3.4. For angle beam methods the position is determined by first determining the angle of the refracted beam and then performing distance calibration. With this information, the beam path and distance to the discontinuity in the test part can be determined. It is often helpful to use a cross-sectional sketch of the test part and draw the beam path on the sketch. For surface wave inspections, the location of a discontinuity is easily determined by wetting a finger with oil and then moving the finger along the test part surface away from the search unit. Surface waves will be damped by the finger, and the discontinuity signal will be reduced in amplitude until the finger moves just past the discontinuity. By noting when the discontinuity signal first starts to increase in amplitude, the location of the discontinuity is determined. A distance calibration can also be easily set up for surface waves. The search unit is placed on the test part at a known distance away from a reflector, such as an edge of the test part; or the search unit can be placed at a known distance from a reflector on the IIW block.

5.3.6.2 Size.

The size of a small discontinuity (less than the diameter of the sound beam) is estimated by measuring the maximum signal amplitude produced by the discontinuity. Information on sound beam diameter is contained in paragraph 5.1.6.2.5. In general, the amplitude from a small discontinuity is proportional to the cross sectional area of the discontinuity if the discontinuity is oriented normal to the sound beam. Since natural discontinuities usually have irregular shapes and rough surfaces, determination of the actual size of small discontinuities in general may not be possible with ultrasonics. Therefore, estimating the size of small discontinuities by comparing their signal amplitude with the signal amplitude of reference standard discontinuities is subject to errors. When making such comparisons (only to be used for rough estimates) the transfer technique should be used (see paragraph 5.3.5). If, after applying transfer, the test part discontinuity signal is as large or larger than the signal from the reference standard discontinuity, it can be concluded that the test part discontinuity is at least as large as the reference standard discontinuity. The transfer technique adjusts for differences in material attenuation, not for differences in discontinuity surface irregularities. Estimating the size of discontinuities larger than the sound beam is done by moving the search unit over the discontinuity and mapping the extremities of the discontinuity. The outer edges of a discontinuity can be estimated by noting the positions of the center of the search unit when the signal amplitude from the discontinuity is reduced to 1/2 its peak value. This procedure estimates the projected area of discontinuities in a plane perpendicular to the incident sound beam.

5.3.6.3 Orientation.

In evaluating discontinuities it is helpful, if possible, to evaluate the discontinuities from several different directions. This can be accomplished by using a combination of angle and straight beam methods, and/or sound entry from different surfaces. Inspecting in these various directions reveals more about the discontinuity. The direction where the highest amplitude signal is obtained is most nearly perpendicular to the plane of the discontinuity for equivalent distances. If the discontinuity signal changes very little with changing direction, the discontinuity is probably rounded. The sound scattered from a rounded discontinuity is independent of the incident direction. A flat discontinuity gives a maximum reflection when the incident sound beam is perpendicular to the discontinuity.

5.3.6.4 Spacing.

Closely spaced small discontinuities may produce multiple indications that are often accompanied by the loss of back reflection. Figure 5-60 shows an example of how large grain size porosity can each produce multiple indications and reduce the amplitudes of back-reflection multiples. It is necessary to change the A-scan settings to check for both the effects, because the back surface signal probably saturates the display at the gain setting that shows the multiple indications. By lowering the gain and lengthening the sweep range, the decreasing amplitude of multiple back reflections is observed. The rate of decrease in the amplitudes of the back reflection signals will be greater than for an area with no discontinuities.

5.3.6.5 Types Of Indications.

Several different types of indications will be encountered in ultrasonic inspections. Some of these indications can cause confusion, resulting in false conclusions. It is important that the operator be familiar with paragraphs 5.1.6 through 5.1.8.3 and the additional information below. This will help the operator in evaluating inspection results and avoiding erroneous conclusions.

5.3.6.5.1 Loss of Back Reflection And / Or Multiple Indications.

Loss of back reflection with no other indication can be caused by a number of factors such as the following:

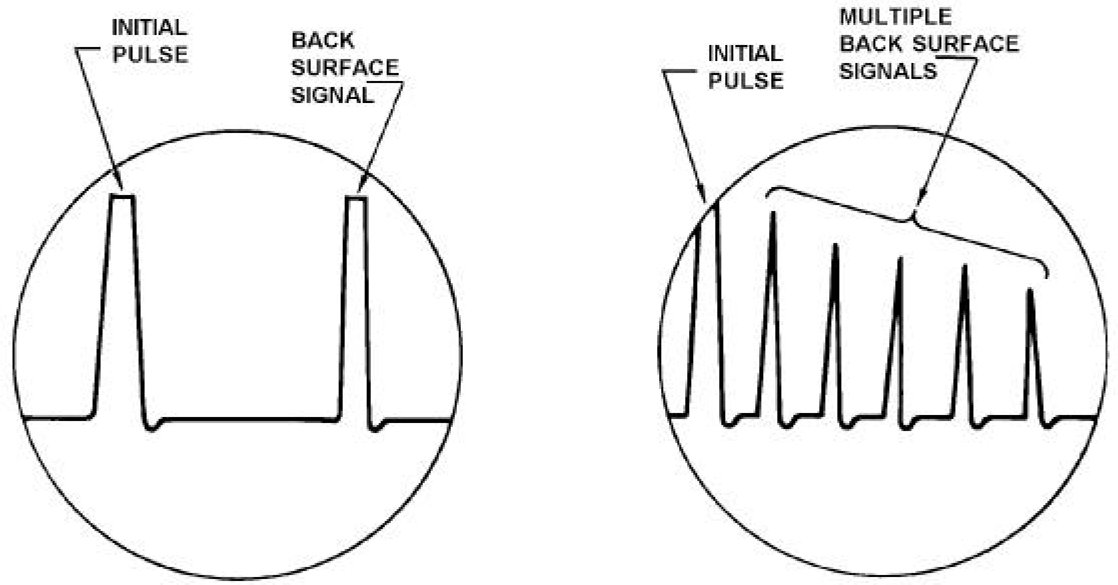
a. Large grain size

b. Porosity

c. Dispersion of precipitated particles in the material.

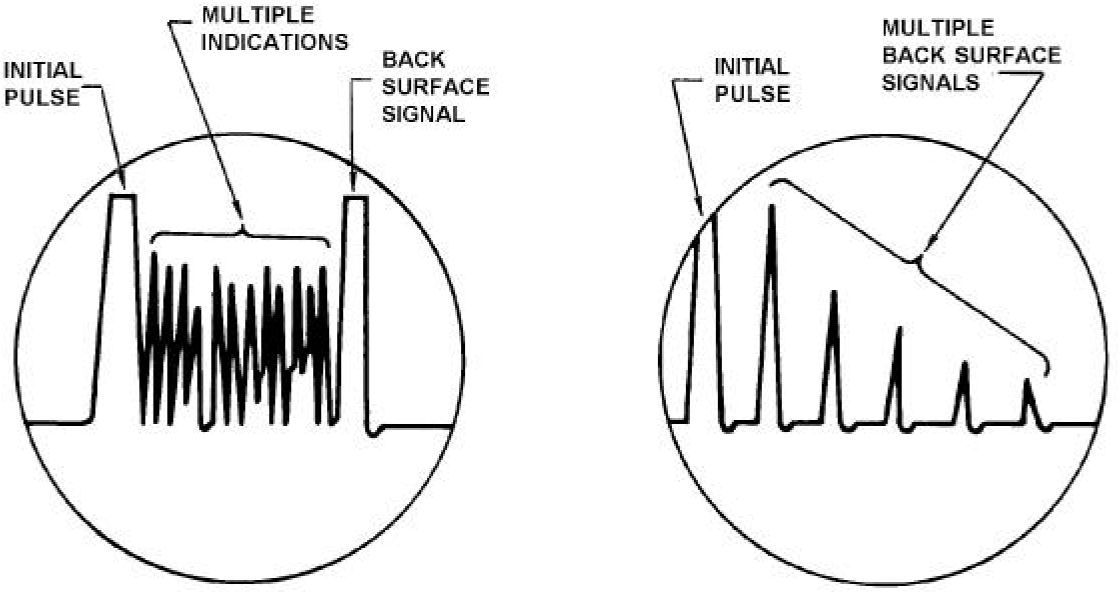
d. Overheated structure

However, these features may produce multiple indications as well (Figure 5-59). Lowering the frequency will generally reduce the multiple indications. When either multiple indications and/or loss of back reflection is noted, the test part should be compared with the reference standard using transfer in accordance with paragraph 5.3.5. The results should be evaluated in accordance with the limits in paragraph 5.3.5.4.



SOUND TEST PART

SOUND TEST PART



TEST PART WITH POROSITY OR LARGE GRAIN SIZE

TEST PART WITH POROSITY OR LARGE GRAIN SIZE

Figure 5-59. Example of Multiple Indications and Decrease in Multiple Back Reflections Caused by Large Grain Size or Porosity.

5.3.6.5.2 Delaminations.

When inspecting either metal parts fabricated from sheet or plate, or nonmetallic composite parts, delaminations can be detected by noting what appears to be a reduction in the distance between back reflection multiples as shown in Figure 5-60. Actually the signals indicate multiple echoes from the delamination instead of the back surface.

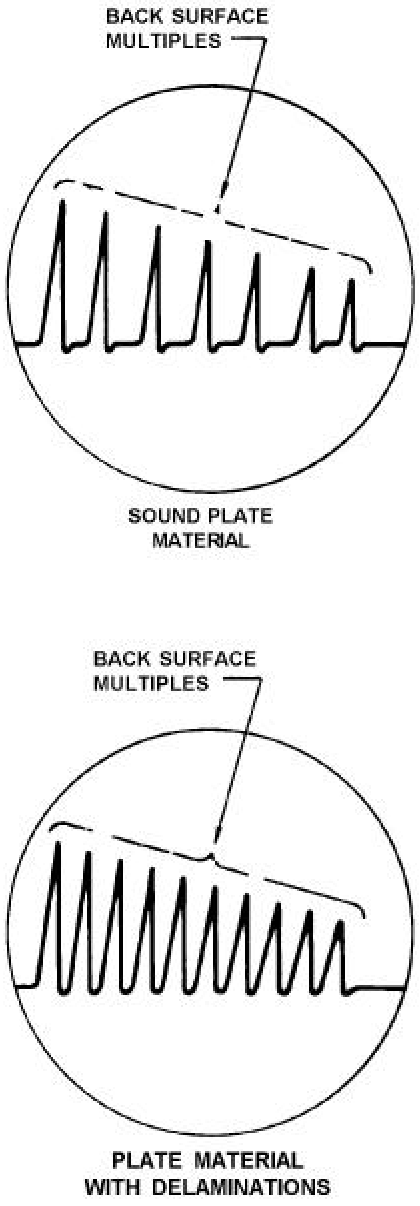


Figure 5-60. Effect of Delaminations in a Plate on Multiple Back Surface Signals.

5.3.6.5.3 Surface Wave Indications in Straight Beam and Angle Beam Inspections.
Surface waves can be generated when using straight beam search units. This is due to the side lobe energy (see Figure 5-15). Surface waves have also been observed in some inspections using angle beam search units. These surface waves can cause signals from edges of the test part, which can be mistaken for a discontinuity. These signals (shown in Figure 5-61) are easily identified by varying the distance between the search unit and the part edge and watching the signal move. The surface wave signal will move toward the initial pulse as the search unit is moved toward the edge.

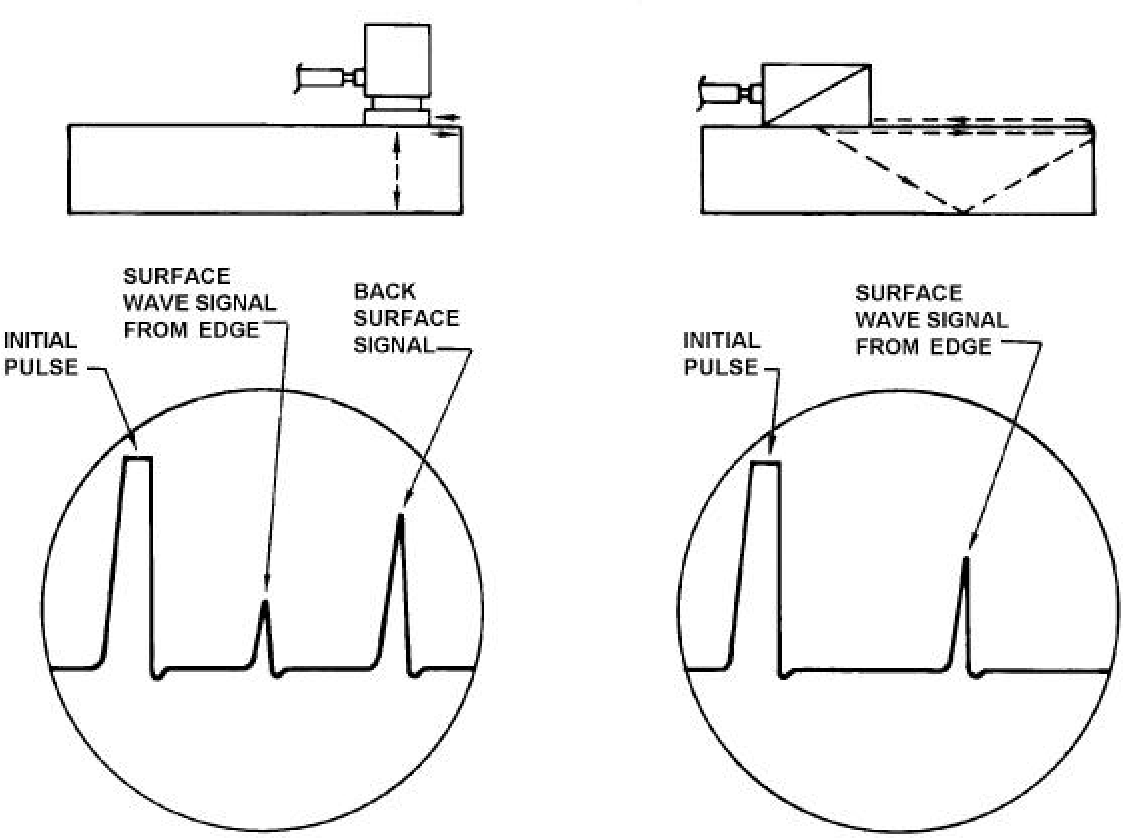


Figure 5-61. Irrelevant Surface Wave Signals

5.3.6.5.4 Parallel Boundaries.

When using straight beam inspection near a boundary parallel to the sound beam axis, the spreading sound beam results in reflections and mode conversion at the boundary (see Figure 5-14). These reflections from the boundary interfere with the main sound beam and can greatly reduce the sensitivity for detecting discontinuities close to or coming from the boundary. Such a case could occur when inspecting a bolt. As the search unit is moved closer to the boundary, the sensitivity is further reduced. When inspecting close to a boundary, it is therefore necessary to use a reference standard with the reference discontinuity located at the boundary. An example of such a discontinuity is a lateral saw cut (see Figure 5-62). Flaws close to boundaries are better located by using, when possible, angle beam techniques (see Figure 5-63).

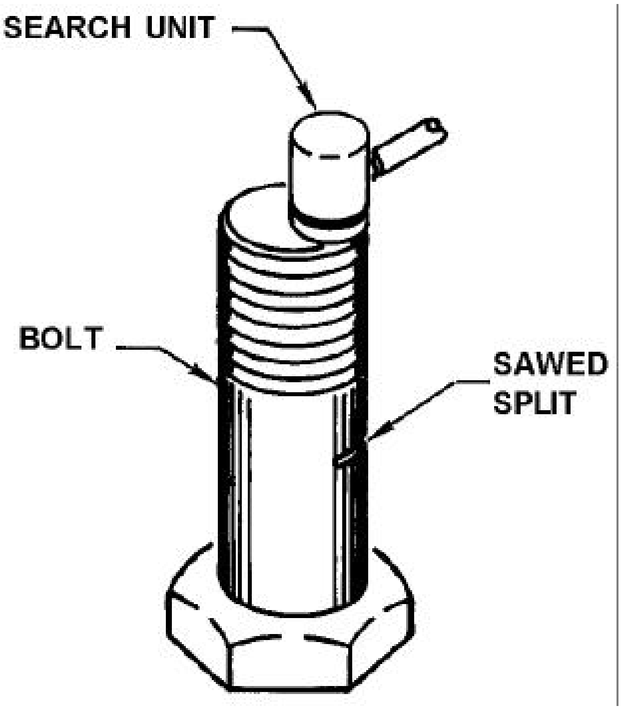


Figure 5-62. Reference Standard for Inspection of a Bolt.

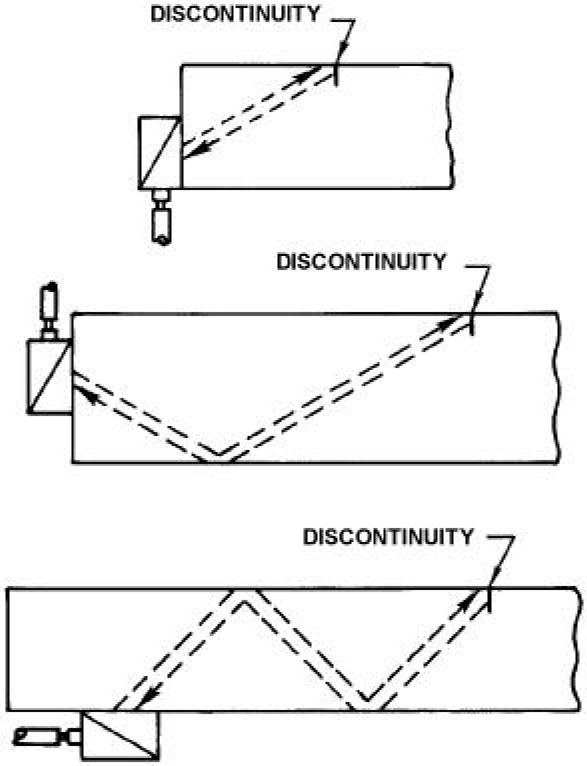
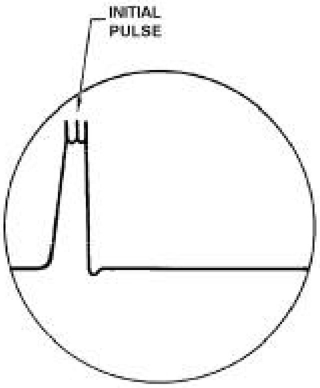


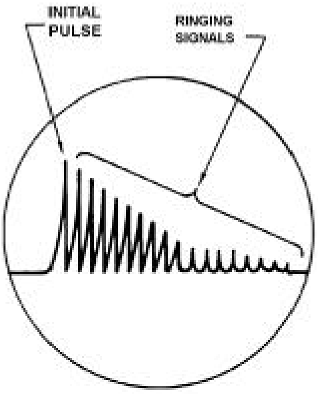
Figure 5-63. Angle Beam Technique for Locating Discontinuities at Boundaries.

5.3.6.5.5 Loose Transducer Element.

A transducer element can separate from the damping material in a search unit. This will cause the initial pulse to become a long ringing signal (see Figure 5-64.). Such a situation will cause the search unit to fail the dead zone test. When this happens, the search unit must be replaced.



NORMAL TRANSDUCER ELEMENT



LOOSE TRANSDUCER ELEMENT

Figure 5-64. Example of Ringing Signals Due to a Loose Transducer Element.

5.3.6.5.6 External Noise.

Noise can be indicated on the waveform display when disturbances are created by such sources as follows:

a. Nearby operation of electrical machinery or radio or radar transmitters.

b. Machining on the test part (grinding, cutting, filling, etc.) during the inspection.

c. Ground loop.

Noise from causes listed above are more likely to be encountered when using equipment with a broadband receiver amplifier and/or long cables between the search unit and the instrument. Sometimes a double shield on the cable as, shown in Figure 5-65, will help reduce this noise. In this case, the ground electrode of the transducer element is not connected to the metal case of the search unit and the external shield of the connecting cable. The ground electrode is connected to the instrument ground via a second internal shield of the cable. Ground loops are created when instruments, cables, alarm boxes, etc. are not grounded to a common ground point. Also a good earth ground is essential, not only for preventing stray electrical interference, but also for safety reasons. If a ground loop is suspected, tie all grounds together, and connect them to a good earth ground. Portable a/c. units can be operated with constant voltage transformers, and if electrical interference on the a/c. circuit is suspected, special transformers are available to block such interference.

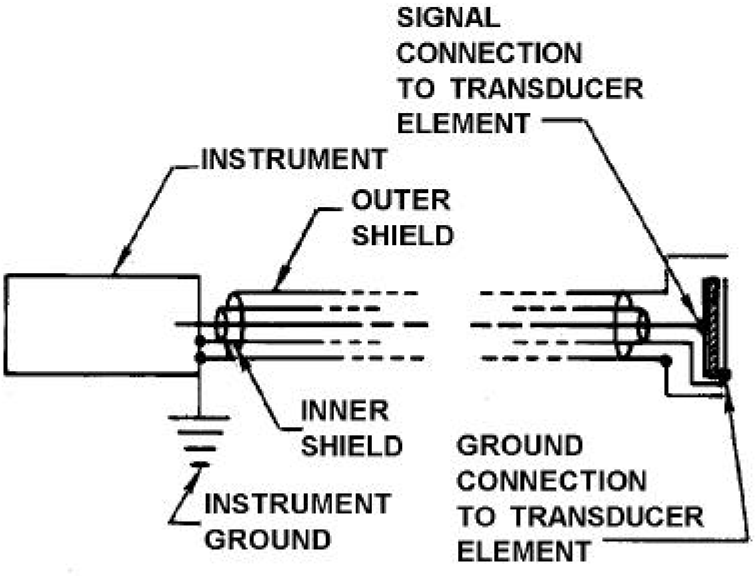


Figure 5-65. Double Shield for Reducing External Noise Signals.

5.3.7 Technique Development.

For most applications ultrasonic techniques used in the field are established at the depot or ALC. In certain situations it may be necessary to develop a technique in the field. If such a need arises, the following information will aid in developing the required techniques. The information may also lead to a better understanding of established techniques.

5.3.7.1 Information Required.

When establishing an ultrasonic inspection technique, it is first necessary to obtain as much information as possible about the test part. Information required is as follows:

a. Type of material to be inspected, and heat treatment.

b. Surface condition.

c. Accessibility

d. Shape/geometry of test part.

e. Type of discontinuity to look for.

f. Expected location of discontinuity.

g. Expected orientation of discontinuity with respect to sound path.

h. Acceptance/rejection criteria.

i. Inspection method required.

j. Inspection zones, if applicable.

5.3.7.1.1

Information on many of the above items can be obtained by visual examination of the test part and study of applicable manuals and drawings. Examination of failed parts is helpful for obtaining information on the location of and type of discontinuity causing failure.

5.3.7.2 Defining the Technique.

The information required by paragraph 5.3.7.1, along with the information in this chapter, is used to establish the technique variables. In addition, if welds are to be inspected, refer to T.O. 00-25-224. Items that need to be defined are listed below and described in more detail in the subsequent paragraphs.

a. Inspection surfaces.

b. Mode(s) of inspection: longitudinal, shear and/or surface wave, contact or immersion.

c. Scanning plan

d. Reference standard(s).

e. Transfer method.

f. Frequency.

g. Search unit.

h. Requirements for special wedges or shoes.

i. Surface preparation required and method to be used.

j. Couplant.

5.3.7.2.1 Inspection Surfaces, Scan Plan and Mode(s).

The expected location and orientation of discontinuities, along with accessibility of the inspection area, are used to help define which surfaces will be used for sound entry, the mode(s) of sound energy that will be used and the scanning procedure. The sound should be directed normal to the expected plane of the largest surface of the discontinuity. Therefore, straight beam inspection would be used to locate laminar discontinuities, and angle beam inspection would be used to locate internal discontinuities that are not parallel to the inspection surface. The beam angle should be chosen to be perpendicular to the largest surface of the discontinuity. In the case of discontinuities at the inspection surface, surface wave inspection may be a better choice.

5.3.7.2.2 Reference Standard.

The reference standard should be fabricated from material with the same acoustic properties as the test part. When possible, the reference standard should be of the same alloy, heat treat condition, same hot/cold working condition, and surface condition as the test part. The transfer technique (paragraph 5.3.5) should be used to compensate for differences between the reference standard and the test part. The geometry of the reference standard should match the geometry of the test part so that the sound path will be the same. The simulated discontinuities should be in accordance with the applicable specification for the test part. Refer to MIL-STD-2154 for general information.

5.3.7.2.3 Frequency.

The frequency is selected based upon the acceptance criteria and the acoustic properties of the test part. A good rule to remember is, “Use the highest frequency that will provide the necessary depth of penetration”. When geometry permits, the test part shall be checked at the intended frequency to verify that a strong back reflection is obtained. The frequency also should be appropriate for detecting the minimum size discontinuity anywhere in the test part (see paragraph 5.4). Frequencies of 2.25 MHz, 5 MHz and 10 MHz are popular inspection frequencies. When using both angle beam (either refracted shear or longitudinal wave) and straight beam (longitudinal wave) methods, the frequency used for the angle beam shear wave inspection should be about one-half the frequency used for the straight beam inspection. This provides approximately the same wavelength for both the longitudinal and shear waves. Refracted longitudinal wave inspection should be at the same frequency used for straight longitudinal wave inspection.

5.3.7.2.3 Search Unit.
The search unit is selected based on the requirements for mode, frequency, beam direction and beam size. The part geometry and the limitations on accessibility to the inspection surface determine if special wedges or shoes are required. Refer to paragraphs 5.2.2.9 through 5.2.2.10 for information on shoes and wedges.

5.3.7.2.5 Surface Preparation.
The sound entry surface is visually examined to determine if any special preparation is required to provide a suitable condition for ultrasonic inspection. The surface finish should be 250 microinches or smoother as explained in paragraph 5.1.7.1. Painted surfaces can normally be inspected without removing the paint if the paint is uniform and is tightly adhered to the part surface. Loose or uneven, patchy paint shall be stripped prior to ultrasonic inspection.

5.3.7.2.6 Couplant.
The couplant is selected based upon the surface condition; the surface orientation and the information in paragraph 5.2.3.

SECTION IV
ULTRASONIC INSPECTION OF BONDED STRUCTURES

5.4 ULTRASONIC INSPECTION OF BONDED STRUCTURES.

5.4.1 Introduction.

5.4.1.1 Definition.
A bonded structure is one consisting of two or more components adhesively bonded together. The structure can be all metallic or nonmetallic, or it can consist of both types of material. A bonded structure can contain honeycomb or other type of light-weight core. Sheets of metal or nonmetal can be bonded together to provide the appropriate thickness. Carbon/epoxy composites are bonded structures although the individual layers are only a few thousands of an inch thick and essentially lose their individual identity in the curing process. However, separations (delaminations) do occur between layers as a result of external impacts with foreign objects.

5.4.1.2 Variables Applicable to Bonded Structures.
Because of the many configurations and types of bonded structures, there are many variables to consider when performing NDI.

a. Probe-side skin material and thickness.

b. Adhesive type and thickness.

c. Underlying structure -- core material, thickness of core, cell size, and thickness of cell wall; far-side skin material and thickness; quantity, thickness and material of doublers; attachments of closure members; foam adhesive; steps in skins; internal ribs; and makeup of nonmetallic composite laminates (material, number of layers and layer thickness).

d. Accessibility -- one skin or both skins.

All of these variations complicate the application of ultrasonic inspection methods. A method, which works well on one part or in one area of the part, may not be applicable for different parts or different areas of the same part.

5.4.1.3 Special Requirements.

a. Because of the many inspection configurations, each application must be examined in detail. The advantages and limitations of each inspection method must be considered, and reference standards (representative of the structure to be inspected) must be ultrasonically inspected to verify proposed techniques. Scanning speeds must be identical on both the standard and the test part. Scan line indexing must be no larger than half the width of the smallest rejectable discontinuity.

b. Complete information on the internal configuration of the bonded test part must be obtained by the operator. Drawings should be reviewed; and, when necessary, radiographs should be taken. Knowledge of details such as the location and boundaries of doublers, ribs, etc. is required for valid interpretation of ultrasonic inspection results. The boundaries of internal details should be marked on the test part using a grease pen or other easily removable marking.

c. This section does not include all the information required to establish techniques. Detailed techniques for specific structures should be obtained from the applicable NDI manual or from the prime depot level engineering activity. In addition, further information on the operation of specific instruments should be obtained from the applicable equipment manuals.

5.4.2 Reference Standards.

5.4.2.1 Configuration.
Reference standards should:

a. Be similar to the test part with respect to material, geometry, and thickness. (This includes closure members, core splices, stepped skins, and internal ribs similar to the test part if bonded areas over or surrounding base details are to be inspected.)

b. Contain bond(s) of good quality except for controlled areas of unbond fabricated as explained below.

c. Be bonded using the adhesive and cure cycle prescribed for the test part.

The reference standard may be a duplicate of the test part except for the controlled areas of unbond. As an option, simple test specimens which represent the respective different areas of the test part and contain controlled areas of unbond may be used.

5.4.2.2 Defect Types.
Defects may be separated into five general types to represent the various areas of bonded sandwich and laminate structures. The five general types are:

a. Type I: Unbonds or voids in an outer skin-to-adhesive interface.

b. Type II: Unbonds or voids at the adhesive-to-core interface.

c. Type III: Voids between layers of a laminate.

d. Type IV: Voids in foam adhesive or unbonds between the adhesive and a closure member at core-closure member joints.

e. Type V: Water in the core.

5.4.2.3 Fabrication of Reference Standards.

a. The reference standards shall contain unbonds equal to the sizes of the minimum rejectable unbonds for the test parts. Information on minimum rejectable unbond sizes for test parts shall be obtained from the prime depot level engineering activity.

b. Producing unbonds by use of grease, vinyls, and other foreign material not covered below is prohibited. One or more of the following techniques shall be used in fabricating reference defects. Since bonding materials vary, some of the methods may not work with certain materials.

(1) Standards for Types I, II, III and IV unbonds may be prepared by placing discs of 0.006 inch thick (maximum) Teflon sheets over the adhesive in the areas selected for unbonds. For Type II unbond, place the Teflon between the core and adhesive. Assemble the components of the standard and cure the assembly.

(2) Types I, II and III standards may also be produced by cutting flat-bottomed holes of diameter equal to the diameter of the unbonds to be produced. The holes are cut from the backsides of bonded specimens, and the depths are controlled to produce air gaps at the applicable interfaces (see Figure 5-66). When using this method, patch plates may be bonded to the rear of the reference standard to cover each hole and seal the reference standard.

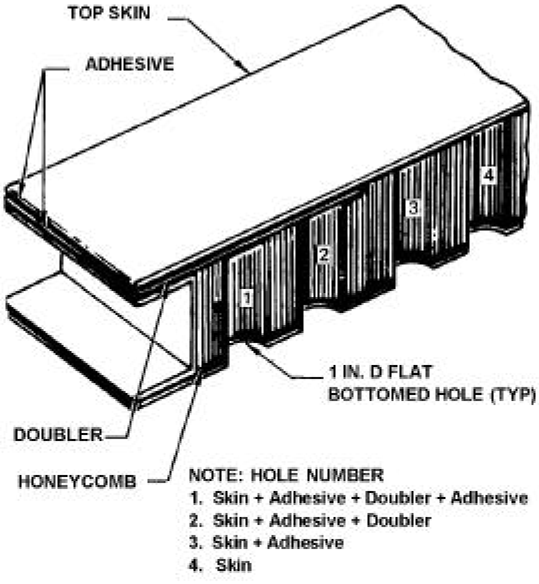


Figure 5-66. Example of Reference Standard for Types I and II Unbonds.

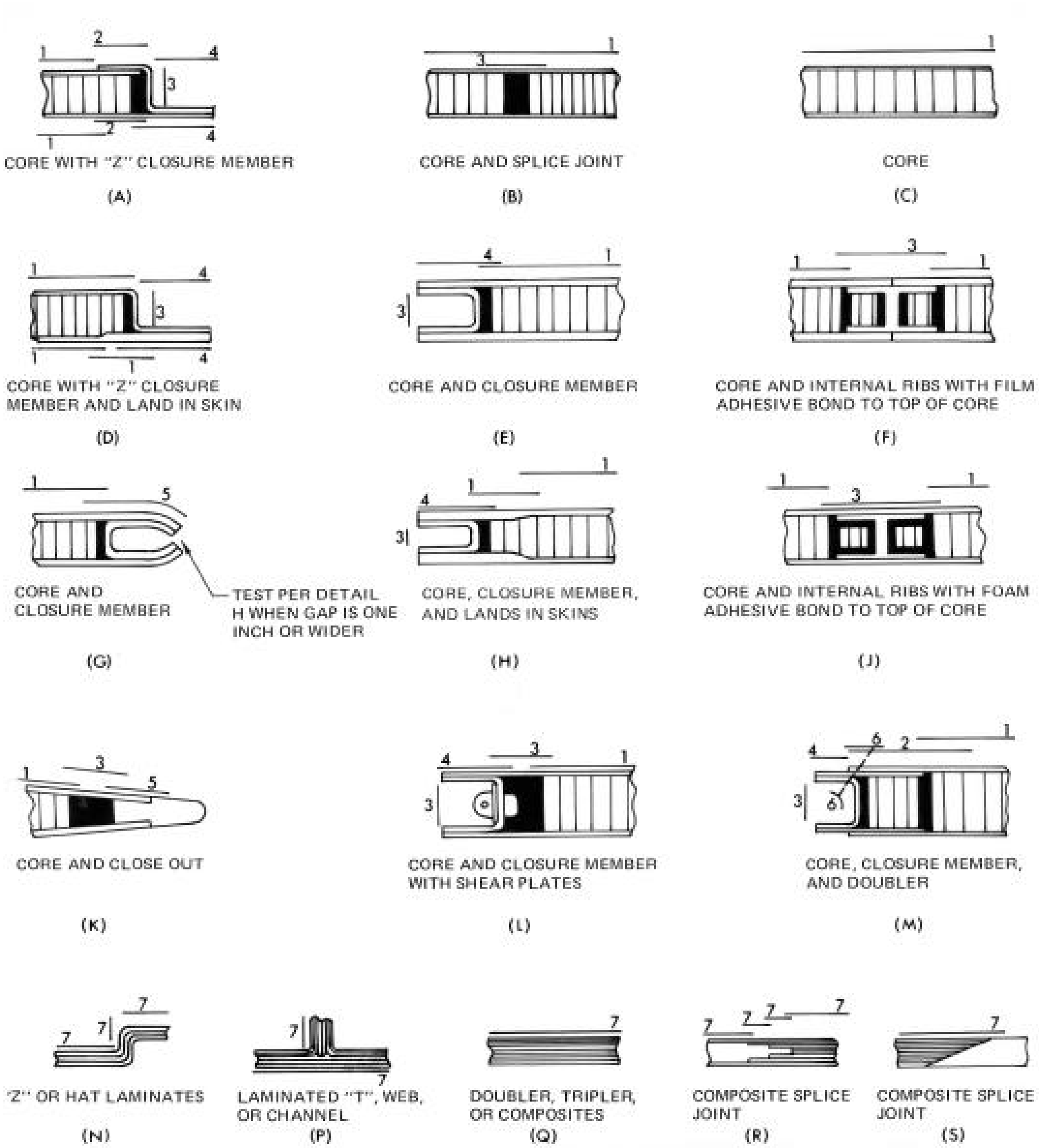
(3) Type II standards may be produced by locally undercutting (before assembly) the surface of the core to the desired size unbond. The depth of undercut shall be sufficient to prevent adhesive flow, causing bonds between the undercut core and the skin.

(4) Type IV standards may be produced by removing adhesive in selected areas prior to assembly.

(5) Type V standards may be produced by drilling small holes in the back of the standard and injecting varying amounts of water into the cells with a hypodermic needle. The small holes can then be sealed using a small amount of water-resistant glue or adhesive.

5.4.3 Inspection Coverage.

Examples of bonded structures along with suggested inspection coverages are shown in Figure 5-67. Table 5-5 lists the ultrasonic inspection methods applicable to the numbered coverages shown in the figure. Due to access limitations, it will not be possible in many cases to apply the inspections in all the areas shown. These coverages and associated methods are guidelines only. Details of inspection coverage and inspection methods for a particular assembly shall be obtained from the applicable NDI manual or the depot engineering activity.



NOTES:

1. THE NUMBERED LINES SURROUNDING EACH VIEW INDICATE THE SCAN PLANES. THE NUMBER ON EACH LINE IS USED TO DETERMINE THE ACCEPTABLE INSPECTION METHODS BY REFERRING TO TABLE 4-7.
2. WHERE SURFACES ARE SYMMETRICAL, THE COVERAGE ILLUSTRATED SHALL BE CONSIDERED TYPICAL FOR BOTH SIDES.
3. SHADED AREAS (■) REPRESENT FOAM ADHESIVE.
4. WHEN THE SAME METHOD(S) ARE SPECIFIED IN MORE THAN ONE SCAN PLANE, CALIBRATION SHALL BE VERIFIED FOR EACH PLANE.

Figure 5-67. Bonded Structure Configurations and Suggested Inspection Coverages.

Table 5-5. Ultrasonic Inspection Methods for Bonded Structures.

Scan Line Number (Fig. 5-82)	Applicable Methods	
1	Near-Side Skin-to-Core a. Pitch/Catch b. Mechanical Impedance Analysis c. Resonance d. Eddy-sonic e. Through-transmission f. Pulse-echo g. Ringing	Core Damage a. Mechanical Impedance Analysis b. Through-transmission c. Pulse-echo Far-Side Skin-to-Core a. Mechanical Impedance Analysis b. Through-transmission
2	Near-Side Skin-to-Core a. Resonance c. Mechanical Impedance Analysis b. Through-transmission c. Ringing Core Damage a. Mechanical Impedance Analysis b. Through-transmission	Far-Side Skin-to-Core a. Mechanical Impedance Analysis b. Through-transmission
3	a. Resonance b. Mechanical Impedance Analysis	c. Ringing
4	a. Resonance b. Ringing	c. Through-transmission d. Damping
5	a. Resonance	b. Ringing
6	a. Through-transmission (with fluid delay lines)	
7	a. Resonance b. Mechanical Impedance Analysis	c. Through-transmission d. Ringing

5.4.4 Inspection Methods for Bonded Structures.

Table 5-6 lists ultrasonic bond inspection methods along with advantages and limitations of each method. Additional information on each method is provided in the following paragraphs.

Table 5-6. Ultrasonic Inspection Methods for Bonded Structures.

	INSPECTION METHOD			
	Through Transmission	Pulse-echo	Ringing	Damping
Advantages	Applicable to structures with multiple layers, with or without honeycomb. Detects unbonds between any layer or in honeycomb. Detects small defects (larger than the diameter of receiving search unit).	Applicable to honeycomb structures with thick or thin skins. Detects small unbonds (search unit diameter and smaller).	Applicable to complex shapes. Detects small near-surface unbonds (larger than diameter of search unit).	Applicable to multi-layered structures with thick or thin sheets. Detects unbonds between any layers. Detects small unbonds (larger than diameter of search unit.
Limitations	Access to both sides of part required. Does not determine layer position of unbonds. Alignment of search units is critical. Couplant is required. Inspection rate is slow.	Inspection from both sides required. Does not detect far-side unbonds. Applicable only to honeycomb sandwich structures, usually those with single-layer skins. Couplant is required	Applicable only to near-surface unbonds. Works best on unbonds between top sheet and adhesive layer, may miss unbonds on other side of adhesive. Works best on metals. Couplant required.	Applicable only to laminated (non-honeycomb) structures. Access to both sides is required. Does not determine layer position of unbond. Couplant is required.
	Resonance	Pitch/Catch	MIA	Eddy-Sonic
Advantages	Locates layer position of unbonds. Applicable to laminate or honeycomb structures. Applicable to complex shapes.	No couplant required, potential for faster scanning. Special displays make interpretation easier.	No couplant required. Can be used on irregular or curved surfaces. Most effective on honeycomb structures: skin-to-core disbonds and core defects.	No couplant required, potential for faster scanning.
Limtations	Inspection required from both sides of honeycomb structures. Couplant required.	Reduced effectiveness for unbonds greater than 0.80 inch below inspection surface. Access to both sides of honeycomb required. Probe is directional with respect to locating boundaries of unbonds.	Reduced effectiveness on purely laminated structures.	Works only on metals. Reduced effectiveness for unbonds farther from inspection surface and for low conductivity metals (titanium).

5.4.5 Methods Used With Basic Ultrasonic Instruments.

5.4.5.1 Through-Transmission Method.

The principle of this method is shown in Figure 5-68. Delaminations in either skin, unbonds between skin and core, and core damage prevent the transmission of sound to the receiving search unit. The minimum size flaw that can be detected is proportional to the size of the receiving search units. The received signal does not have to disappear completely to indicate a flaw. Any flaw large enough to lower the received signal noticeably can be detected. Care must be taken to move both transducers in tandem; otherwise, misaligned transducers will generate false indications.

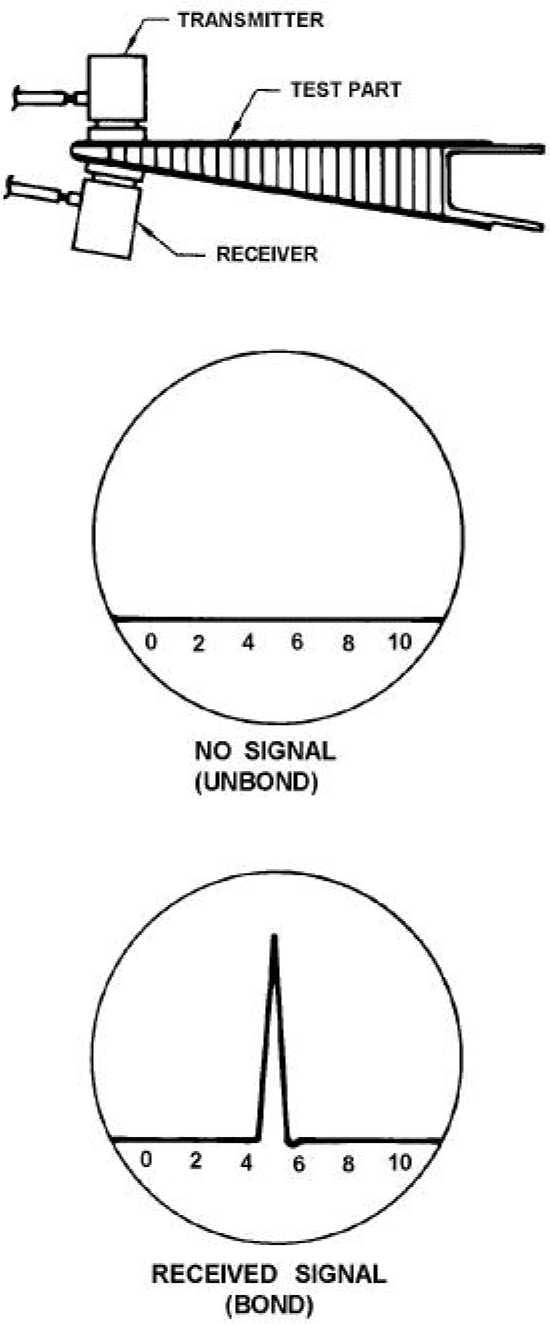


Figure 5-68. Through-Transmission Method.

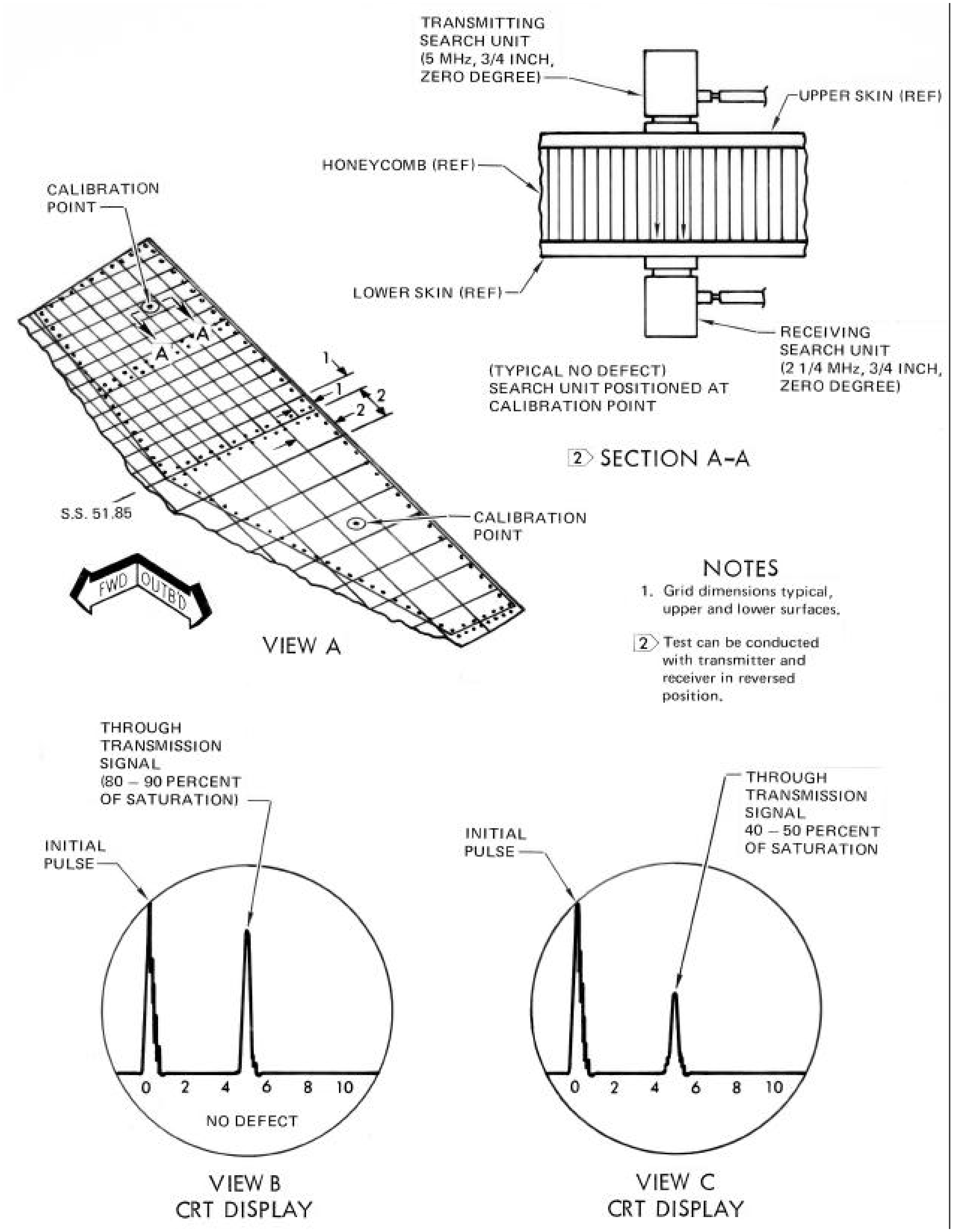
5.4.5.1.1

Figure 5-69 is an example of an inspection of a stabilator. The structure is an aluminum honeycomb sandwich structure. Grids are marked on the surfaces to aid in maintaining transmitter/receiver alignment; mapping boundaries of suspected flaws and assuring complete inspection coverage. The grid sizes are proportional to the critical flaw size of the respective zones. During the inspection one search units is placed in the center of a grid square and the other is manipulated to maximize the received signal. (See View B in Figure 5-70). Each square is inspected in turn. If the through-transmission signal falls below 50 percent of saturation view C couplant and search unit alignment should be checked. If there is a definable area where the signal is less than 50 percent, mark the boundary (at the centerline of the receiving search unit) where the signal equals 50 percent according to the procedure in View D.

Figure 5-69. Typical Through-Transmission Inspection of a Stabilator.

5.4.5.2 Pulse Echo Method.

Figure 5-71 shows the basic principle of this method, which employs an angle beam search unit because straight beam search units may produce multiple echo signals from the layers that would interfere with echo signals from the core. This method is applicable only to honeycomb structures and is best applied to structures with single-layer skins (see Figure 5-71, detail C) when the through-transmission method cannot be used. Straight beam search units may provide better results on structures with multi-layer skins. This method should be used as a backup to methods associated with dedicated bond inspection instruments discussed below. Angle beam search units producing refracted angles of 30 to 90 degrees may be used. The angle selected should be the one that produces the maximum signal response from the back of the core.



NOTES

1. Grid dimensions typical, upper and lower surfaces.

2. Test can be conducted with transmitter and receiver in reversed position.

Figure 5-70. Procedure for Through-Transmission Inspection of a Stabilator (Sheet 1 of 2).

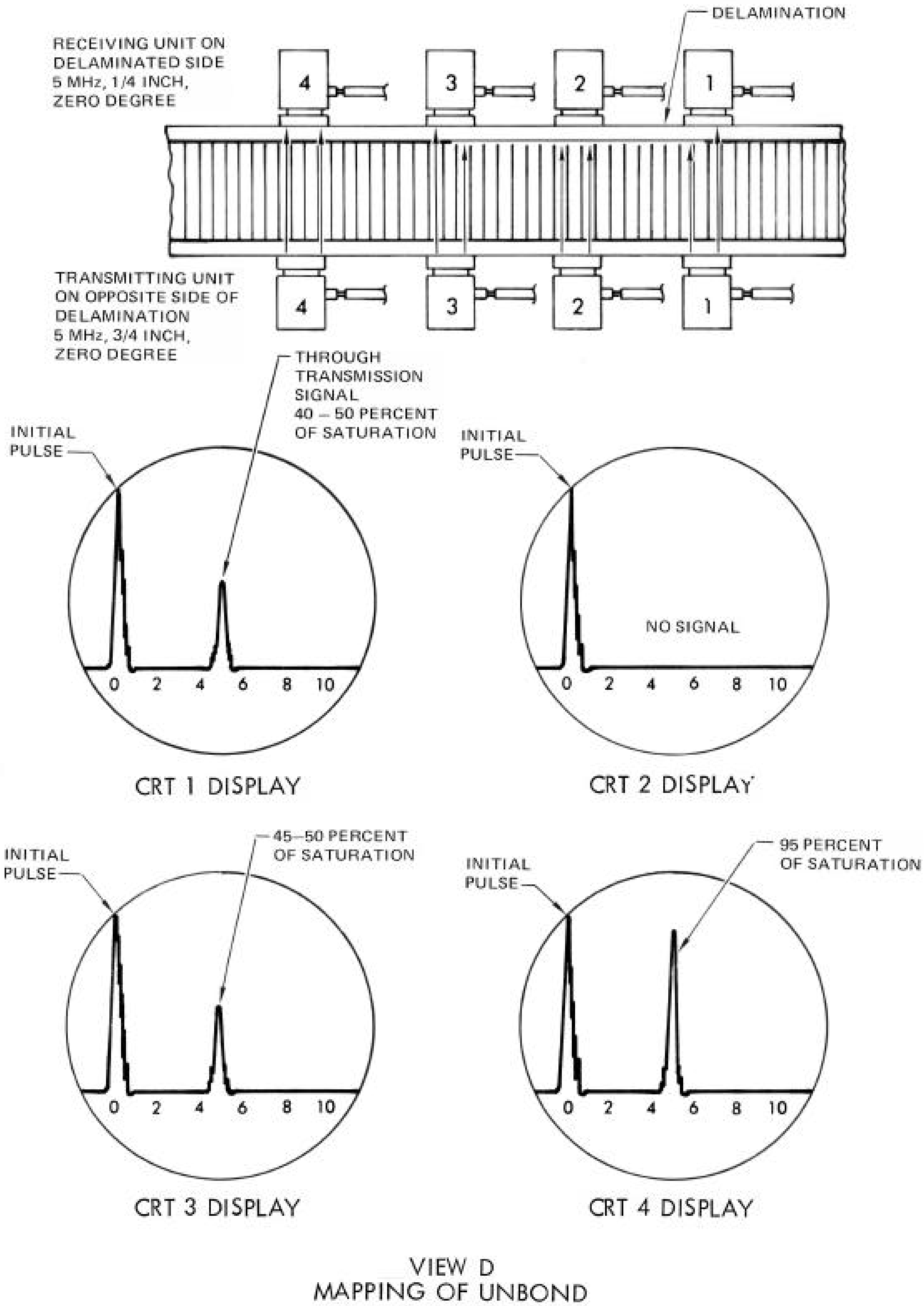
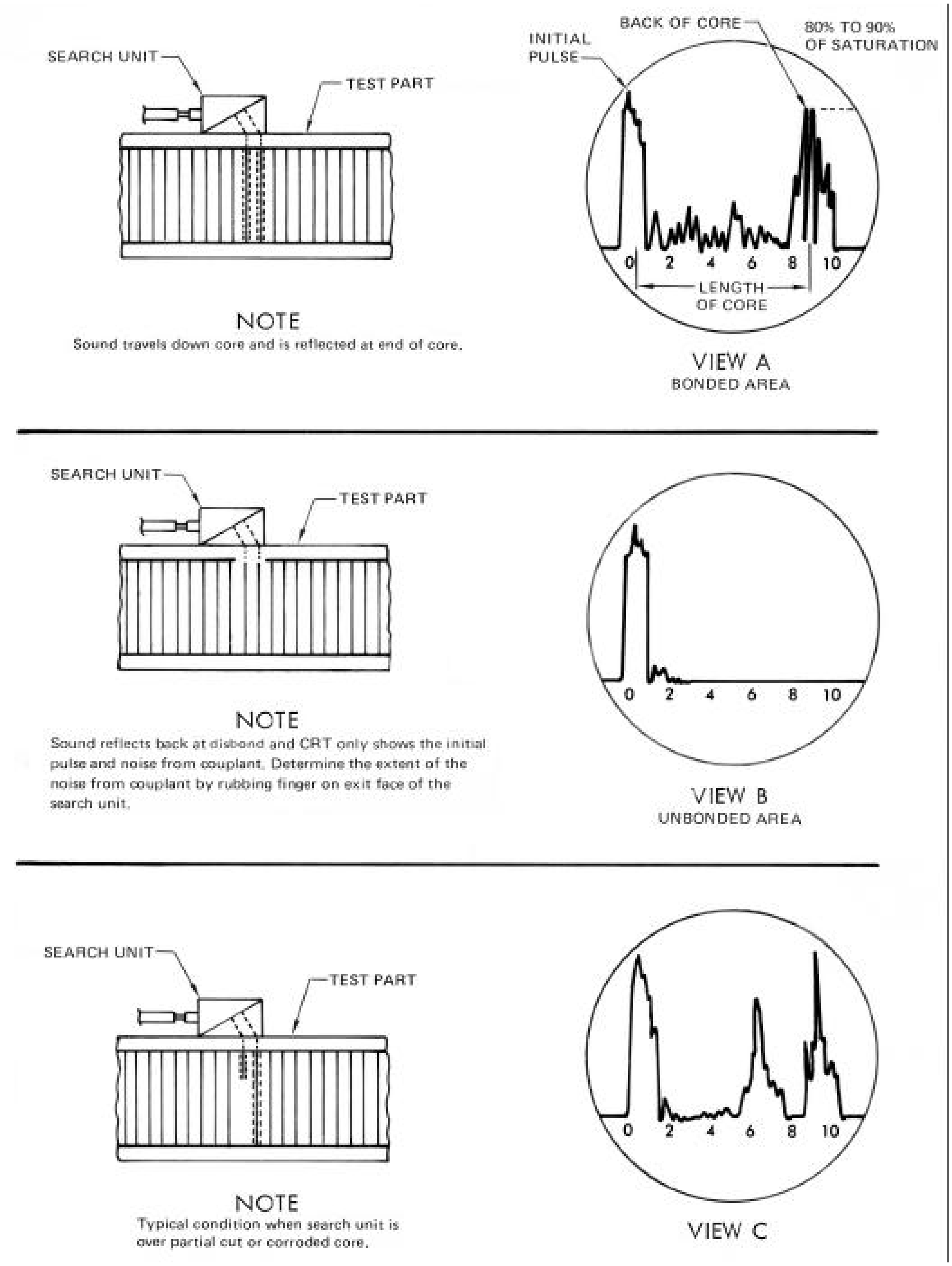


Figure 5-70. Procedure for Through-Transmission Inspection of a Stabilator (Sheet 2 of 2).



NOTE
Sound travels down core and is reflected at end of core.

NOTE
Sound reflects back at disbond and CRT only shows the initial pulse and noise from couplant. Determine the extent of the noise from couplant by rubbing finger on exit face of the search unit.

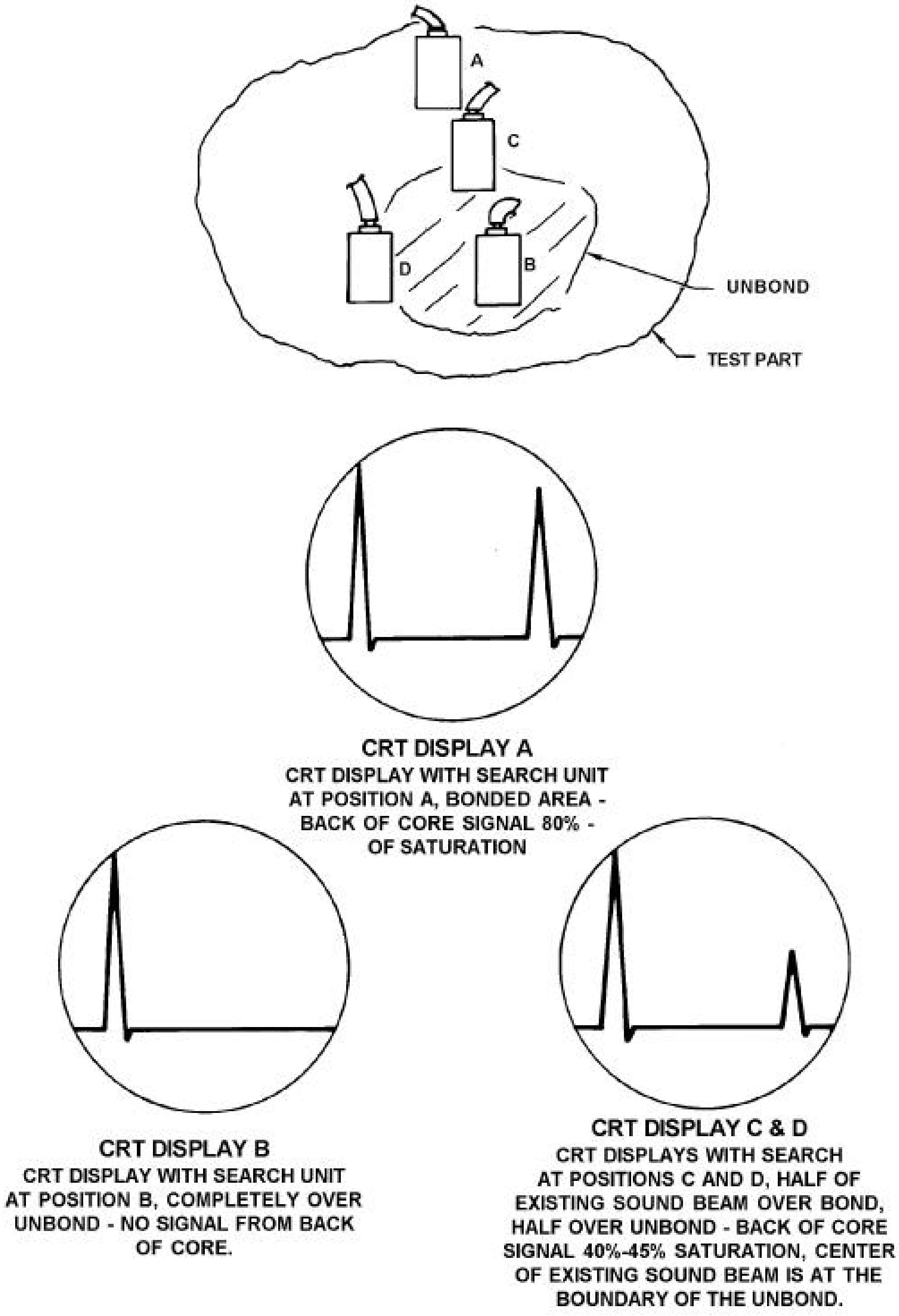
NOTE
Typical condition when search unit is over partial cut or corroded core.

Figure 5-71. Pulse-Echo Method.

5.4.5.2.2

This method can detect near-skin-to-core unbonds and broken or corroded core. Unbonds will cause a complete loss of the signal from the back of the core (Figure 5-71, View B). Broken or corroded core will reduce or completely eliminate the signal from the back of the core and may produce an echo signal (Figure 5-71, View C).

5.4.5.2.3
Indications may be mapped by marking the boundaries where the back echo signal drops below 50 percent of the amplitude obtained in a good area (see Figure 5-72).



CRT DISPLAY A
CRT DISPLAY WITH SEARCH UNIT AT POSITION A, BONDED AREA - BACK OF CORE SIGNAL 80% - OF SATURATION

CRT DISPLAY B
CRT DISPLAY WITH SEARCH UNIT AT POSITION B, COMPLETELY OVER UNBOND - NO SIGNAL FROM BACK OF CORE.

CRT DISPLAY C & D
CRT DISPLAYS WITH SEARCH AT POSITIONS C AND D, HALF OF EXISTING SOUND BEAM OVER BOND, HALF OVER UNBOND - BACK OF CORE SIGNAL 40%-45% SATURATION, CENTER OF EXISTING SOUND BEAM IS AT THE BOUNDARY OF THE UNBOND.

Figure 5-72. Mapping of Unbonds, Pulse-Echo Method.

5.4.5.3 Ringing Method.

Figure 5-73 shows the principle of this method. The A-scans in the figure represent the outline of multiple echo signals from the skin that cannot be individually resolved. This method is most sensitive to unbonds between a single layer of skin and the adhesive layer. An unbond between the adhesive and the core or another layer of skin or a doubler will often not produce a ringing signal, because the adhesive bonded to the top sheet dampens the signal. Because of this limitation, it is recommended that this method be applied only when one of the other methods is not applicable. A good application for this method is the inspection of core-to-closure-member bonds.

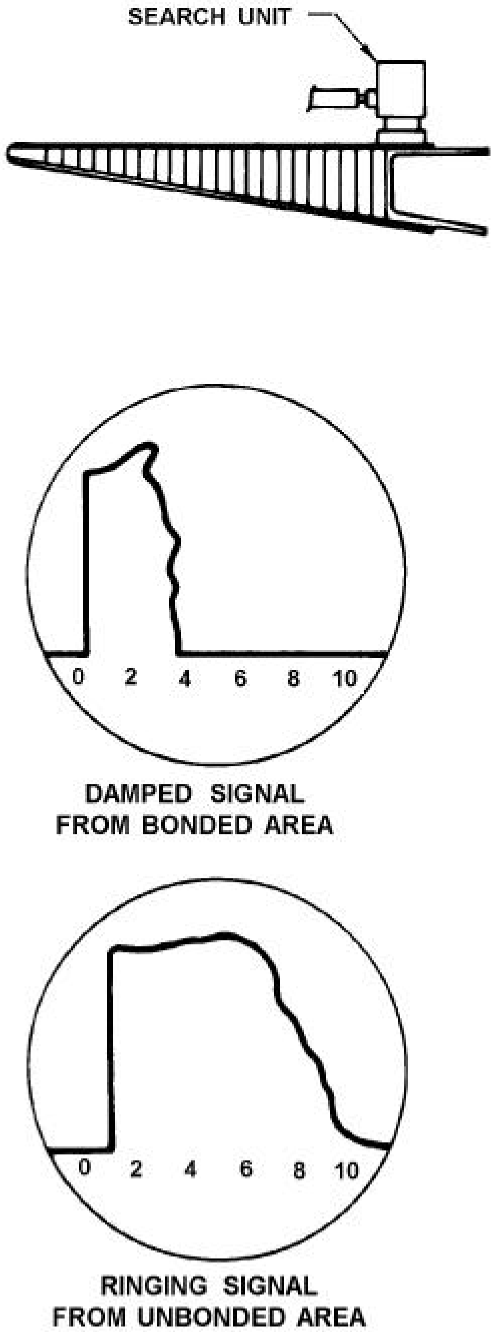


Figure 5-73. Ringing Method.

5.4.5.4 Damping Method.

This method, illustrated in Figure 5-74, is effective for laminate, doubler, and skin-to-closure-member bonds when access to the backside is available. If the inspector can dampen the multiple echoes from the far side of the bonded structure with a wet finger, then the bond is good. Otherwise the sound is being reflected by an unbond and is not reaching the far surface, so it cannot be damped. Unbonds equal to or larger than the size of the search unit are easily detected.

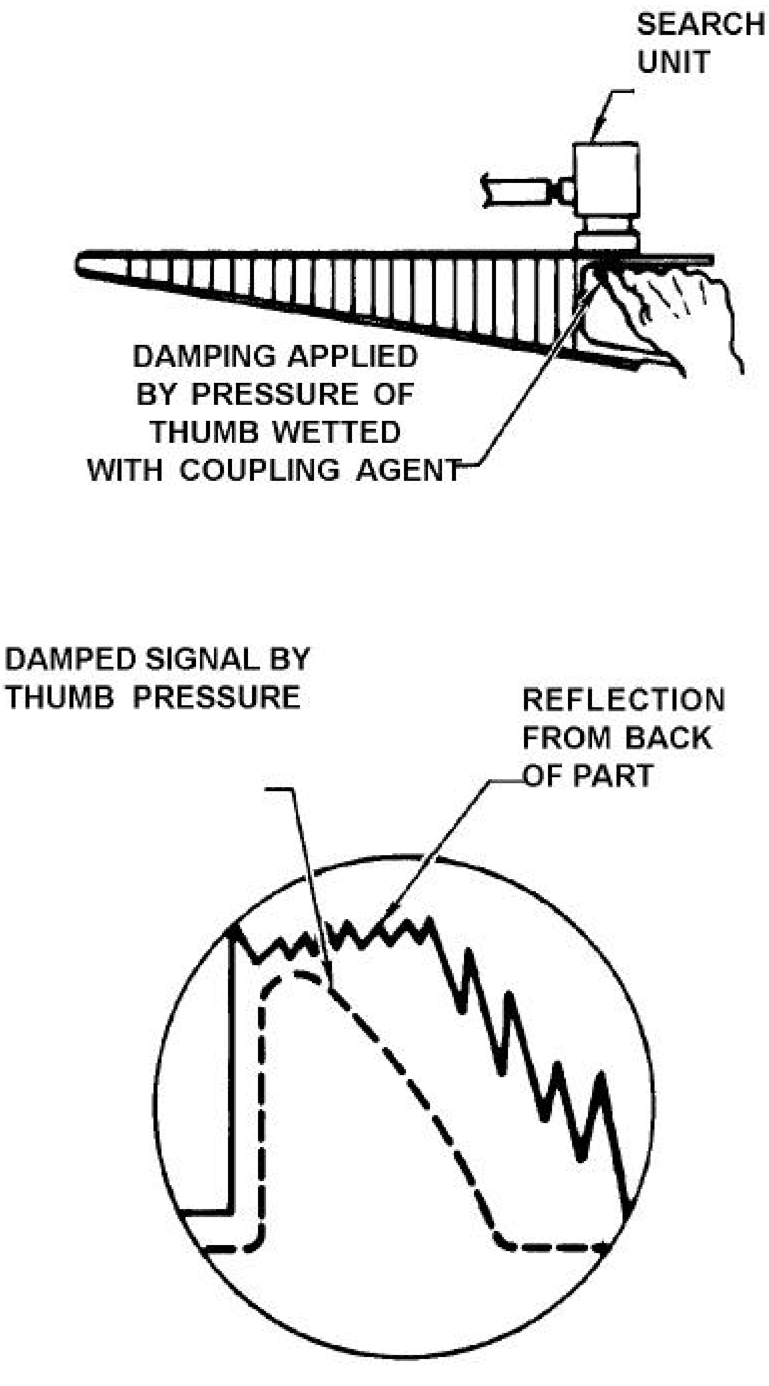
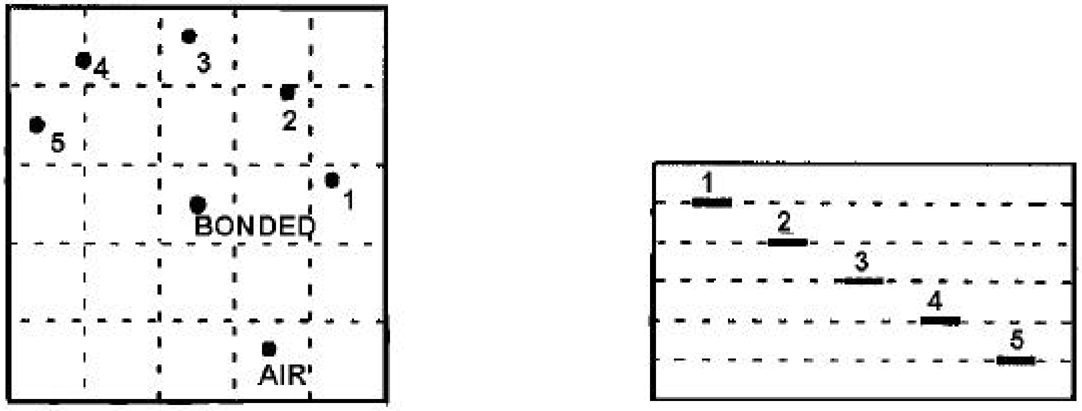


Figure 5-74. Damping Method.

5.4.6 Methods Associated With Instruments Dedicated to Bond Inspection.
Refer back to the bottom half of Table 5-6 for a summary of these methods, which are described in detail below.

5.4.6.1 Resonance Method.
An appropriate ultrasonic contact probe is placed on a test sample with couplant and is driven at its resonance frequency by an oscillator in the instrument. The detector in the instrument measures the phase and amplitude components of the electrical impedance of the probe, which are affected by changes in the acoustic impedance of the test part. The acoustic impedance of a part is altered by a lack of bond or a delamination. Bonded laminates act like a thin plate, which vibrates and generates a standing wave. Changes in the effective thickness caused by the unbonds or delaminations will significantly affect the phase and amplitude of the acoustic wave in the part. With the resonance method the instrument indicates the probe's impedance with a "flying" spot on an ultrasonic impedance plane display. Amplitude changes in impedance are indicated by the radial distance of the spot from the center of the display (null reference point), and changes in the phase are indicated by the rotation of the spot around the center null point. Figure 5-75A is an example of an ultrasonic impedance plane display which shows the spot positions corresponding to different depths of unbonds (delaminations) in the bonded laminate in Figure 5-75B. The laminate is an example of a typical reference standard that would be used for calibration. The positions can be gated, so that a disbond produces an alarm, or the display can be monitored to determine between which layers a disbond occurs. The resonance mode works very well for detecting disbonds at metal/metal, metal/composite and composite/composite interfaces, for finding delaminations within composite materials, and for detecting skin-to-core disbonds in honeycomb sandwich structures.



A) RESONANCE DISPLAY OF UNBONDS IN LAMINATE SHOWN AT RIGHT

B) MULTI-LAYERED LAMINATE WITH UNBONDS

Figure 5-75. Resonance Method.

5.4.6.2 Pitch/Catch Impulse Method.
A pulse of a single ultrasonic frequency is transmitted into the part by one while a second transducer, mounted about 3/4 inch away in the same probe assembly, receives the returned signal. Contact with the part is made through 1/4-inch diameter nylon wear tips on spring-loaded metal rods attached to the respective transducers. The ultrasound travels through the material between the two probe tips. The received signals are displayed in various ways depending on the instrument: a) amplitude and phase components are displayed on separate meters, b) the resultant signal activates light-emitting-diode (LED) display or c) the phase and amplitude components are combined to position a "flying" spot on an impedance plane display. The first type of display is the old style used on the Sondicator, The box in the middle of the display in Figure 5-76 is the gate that sets off an alarm if the spot lands inside, indicating a disbond.

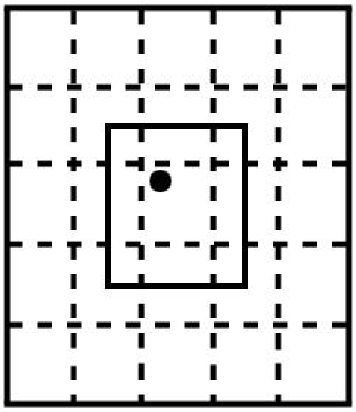


Figure 5-76. Impedance Plane Display of a Pitch/Catch Impulse Method.

5.4.6.2.1

The pitch/catch impulse probe is directionally sensitive such that both active tips must be over the same condition of bond for unambiguous signal interpretation. For example, Figure 5-77 shows the proper way to align the active tips for precise mapping of unbonds.

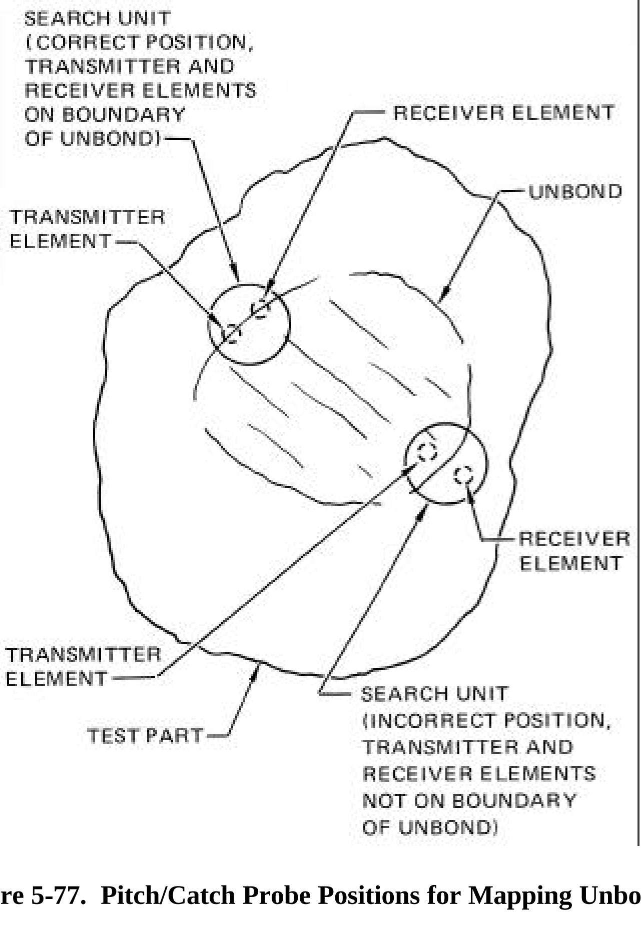


Figure 5-77. Pitch/Catch Probe Positions for Mapping Unbonds.

5.4.6.2.2

Some pitch/catch instruments permit the operator to select the frequency, while in others the frequency is fixed. Typically, selectable frequencies range from 2.5 to 70 kHz; the frequency providing the largest received signal, due to maximum flexure in the layer being tested, is chosen for the inspection. A typical fixed frequency is 25 kHz. The low frequencies eliminate the need for liquid couplant between the transducer and the test part. On some instruments, a variable time gate is used to select the part of the received pulse that has the greatest change in amplitude when the probe is scanned from a bonded area to an unbonded area. The amplitude will be larger over the unbond versus a bonded area because the motion of the layer is restricted over a bonded area and energy is lost into the second layer. The pitch/catch modes work on composite delaminations, skin-to-core unbonds, metal-to-metal unbonds and skin-to-core disbonds. The method tends to lose its effectiveness if the material thickness between the probe and the disbond/delamination exceeds 0.08 inch of aluminum or 0.30 inch of nonmetallic composite. In addition, the minimum dimension of a detectectable flaw is greater than or equal to the probe tip spacing.

5.4.6.3 Pitch/Catch Swept Frequency Method.

Instead of a single frequency, each pulse contains a range of frequencies, for example, 20 to 40 kHz or 30 to 50 kHz. Ultrasonic plate or Lamb waves are generated in the part. These waves are attenuated by coupling into the second layer in well bonded joints. In an unbond region the waves travel with very little attenuation or leakage into the second layer and produce larger indications. Both the swept and impulse techniques will find similar types of defects. However, with the swept technique, calibration interpretation of the signals may be easier because both the amplitude and phase signals are simultaneously displayed in the form of circular patterns on one X-Y active screen. Figure 5-78 shows instrument displays corresponding to three situations detected with the Pitch/Catch Swept-Frequency Method.

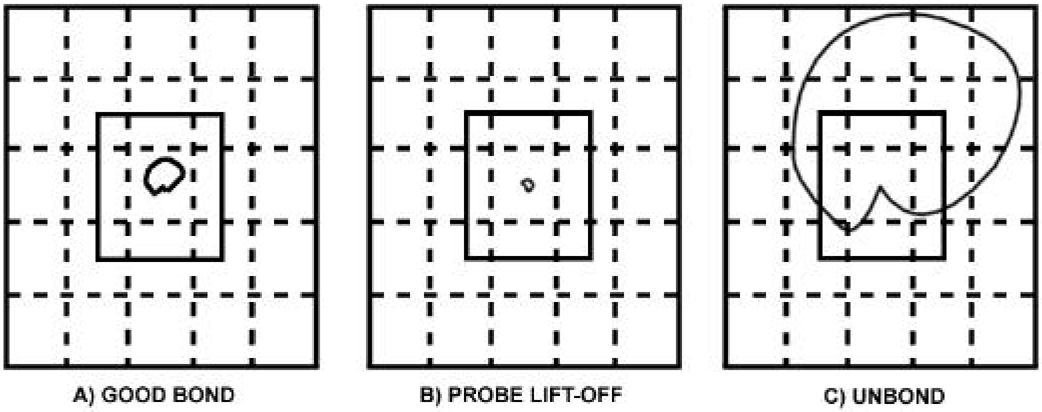


Figure 5-78. Pitch/Catch Swept-Frequency Signal Patterns.

5.4.6.4 Mechanical Impedance Analysis (MIA) Method.

The driver portion of a single-tip dual-element probe generates low-frequency sound waves that transfer to mechanical movements in the test material. The stiffness and mass of the material are measured by the receiving sensor and displayed in terms of both phase and amplitude values. The receiver element at the bottom of the probe has its loading affected by the part stiffness which changes from very high over bonded regions to low over unbonded regions. Since the measurements are a comparison of stiffness, results are better on stiff structures. Flexible composites would not have much change in stiffness from bonded to unbonded areas. The MIA mode does not require couplant and has a small contact area so it can be used on irregular or curved surfaces. The MIA technique seems most suitable for detecting damage associated with honeycomb core such as skin-to-core disbonds severely corroded aluminum core, and buckled or crushed core. However, disbonds and delaminations also can be detected with this method. Figure 5-79 shows typical positions of indications produced with the MIA method. During an inspection only the "flying" spot would be present on the display. The gate box can be positioned anywhere on the display; the appropriate position is determined during calibration. Figure 5-80 illustrates an instrument that is capable of operating in all four modes (resonance, pitch/catch impulse, pitch/catch swept-frequency and mechanical impedance). The alignment problem is normally solved be gridding off the inspection area and keeping the inspection area down to a manageable size. If the area is very large special fixtures are normally manufactured to hold both transducers and keep them aligned.

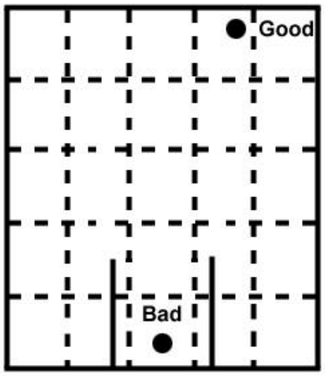


Figure 5-79. **Mechanical Impedance Analysis Display.**

5.4.6.5 Eddy-Sonic Method.

Since this method is based on the generation of eddy currents in the test part, it will work only on metal structures. The instrument sends electrical pulses, with frequencies in the low kilohertz range, to a coil in the probe. The resultant pulsating magnetic field produces eddy currents in the part; the eddy currents cause the part to vibrate, and a microphone on the axis of the coil detects the sonic vibrations. Unbonds cause changes in the vibrational response of the part. The detected changes produce an indication on a meter or an LED array. The probe usually has a mechanical lift-off adjustment that sets the air gap between the coil and the test surface to minimize the noise produced by probe scanning. This method works best on metallic honeycomb structures with thin skins (0.062 inch or less). Other methods do as well on such configurations, and because the eddy-sonic is rather limited in its application, it is not commonly used.

NOTE

For a reliable bond inspection, the inspection surfaces of the test part must be free of loose paint and foreign matter.

CAUTION

Gradual changes in indications on an instrument display should be evaluated to see if the part thickness is changing. If the part thickness has changed, recalibration is required. When possible, scanning should be performed in directions of constant thickness.

Figure 5-80. Typical Multiple Mode Bond Tester.

SECTION V
ULTRASONIC THICKNESS MEASUREMENT

5.5 ULTRASONIC THICKNESS MEASUREMENT.

NOTE

State-of-the-art instruments provide highly accurate thickness measurements from 0.005 inch up to several inches. These instruments not only measure thicknesses in inches/mm, but can also determine the velocity of the material under test.

5.5.1 Applications.

Examples of applications for ultrasonic thickness measurement are as follows:

a. Checking part thickness when access to the backside is not available.

b. Checking large panels in interior area where a conventional micrometer cannot reach.

c. Maintenance inspections for checking thickness loss due to wear and/or corrosion.

5.5.2 General Principles.

Two basic methods of measuring thickness ultrasonically are the pulse-echo method and the resonance method.

5.5.2.1 Pulse-Echo Method.

The pulse-echo method is now the most commonly used ultrasonic thickness measurement method. This method uses the basic principle defined by the following equation:

$d = vt$

Where:

d = distance (inches)
v = velocity (inches per second)
t = time (seconds)

The ultrasonic instrument measures time between the initial front and back surface signals or between successive multiple back reflection signals. Since the velocity for a given material is a constant, the time between these signals is directly proportional to the thickness. Calibration procedures are used to obtain a direct readout of test part thickness. Depending on the instrument and material under test, ranges from 0.005 inch to several feet can be measured with pulse-echo thickness measurement instruments. The accuracy depends on the surface condition, the search unit and the instrument. On smooth surfaces (63 microinches or less) maximum accuracy of ±0.0001 inch can be obtained on the lower ranges for some digital-readout instruments. On other ranges ±0.5% of full scale is a typical accuracy.

5.5.2.2 Resonance Method.

This method uses an instrument which applies continuous (as opposed to pulsed) electrical energy to the search unit. The frequency of this energy is continuously changing. Therefore, the wavelength of the sound transmitted by the search unit is continuously changing also, but it is changing inversely in proportion to the velocity of the material being tested ($\lambda = v/f$). When the search unit is coupled to a test part, and when one of the transmitted wavelengths is a multiple of the thickness of the part, the piezoelectric element in the search unit vibrates with a higher amplitude. When this occurs, the transducer is said to be in resonance with the part. If the instrument is calibrated on a reference standard so that the peaks in the transducer element vibration amplitude correspond to known reference thicknesses, the instrument will indicate unknown thickness of a test part. Resonance equipment has been largely replaced by pulse-echo equipment. For this reason, the resonance method will not be discussed further in this chapter.

5.5.3 Equipment and Materials.

5.5.3.1 Instruments.

Some instruments are designed specifically for thickness measurements. However, a basic ultrasonic instrument can also be used for thickness measurements. Most instruments of both kinds have a digital display to provide the thickness being measured. Detailed operating instructions shall be obtained by consulting the manual for the specific instrument being used.

5.5.3.2 Search Units.

Search units recommended by the instrument manufacturer shall be used with the thickness measurement instruments. A narrow dead zone and a good resolution are required for measurements in the lower ranges (thin materials). Therefore, dual search units and/or search units with plastic delay lines are used (see paragraphs 5.2.2.4 and 5.2.2.6.). Instruments dedicated to thickness measurements often are supplied with compatible search units. With a dual search unit, the ringing of the transducer element is not detected by the instrument. Therefore, received signals close to the initial pulse can be clearly resolved. A plastic delay line bonded to the face of the transducer element separates the initial pulse from the front surface signal; this improves near-surface resolution (shortens the dead zone). For measurements in the higher ranges (thick materials), a conventional straight beam contact search unit may be used.

5.5.3.3 Reference Standards.

Reference standards are required to calibrate the instruments prior to the inspection. This calibration is performed by the instrument operator; calibration by laboratories is not generally required. For the thickness measurement instruments, check the operator's manual to see if one or two reference standards are required. If two are required it is best to have one 50-90% of the nominal thickness to be measured and one 110-150% of the nominal thickness to be measured. Only one reference standard is required when using a basic pulsed instrument for thickness measurement. Direct, accurate readings of thickness can be obtained only when the acoustic velocity in the reference standards is equal to the acoustic velocity in the test part. For this reason, the material and heat treat condition of the reference standards should be the same as the test part. If reference standards of a different material or heat treat condition is used; the resultant thickness readings must be corrected by a correlation factor. The correlation factor may be established in two ways:

a. Use the ratio $\frac{v_2}{v_1}$ when the velocities of the test part and reference standard are known.

Where:

v_2 = acoustic velocity in the test part material
v_1 = acoustic velocity in the reference standard material

Example: Assume the calibration blocks are made of 2014-T4 aluminum and the test part material is 410 stainless steel.

v_2 = longitudinal wave velocity in 410 stainless steel
= 2.91×10^5 inches/sec from Table 5-2.
v_1 = longitudinal wave velocity in 2014-T4 aluminum
= 2.46×10^5 inches/sec from Table 5-2

$$\frac{v_2}{v_1} = \frac{2.91 \times 10^5}{2.46 \times 10^5} = 1.18 = \text{the correction factor.}$$

All readings on the test part are now multiplied by 1.18 to obtain the actual thickness.
If a test part reading is 0.110 inch, correct this by multiplying by the correction factor:

0.110 inch x 1.18 = 0.130 inch = the actual test part thickness

b. Use the ratio $\frac{d_2}{d_1}$ when one area of the test part is accessible for direct measurement.

Where:

d_2 = the thickness of an area of the test part as measured by mechanical or optical means

d_1 = the thickness of the same area as indicated by the ultrasonic instrument calibrated on material similar to the test part

Example: Assume an area of a test part is measured with a micrometer and is 0.167 inch thick (d_2 = 0.167 inch). This same area is measured with ultrasonic instrument and gives a reading of 0.133 inch (d_1 = 0.133 inch).

c. $\frac{d_2}{d_1} = \frac{0.167}{0.133} = 1.25 =$ the correction factor.

d. All ultrasonic readings on the test part are now multiplied by 1.25 to obtain the actual thickness. If another area of the test part gives an ultrasonic reading of 0.200 inch, correct this by multiplying by the correction factor:

0.200 inch x 1.25 = 0.250 inch = the actual test part thickness.

5.5.3.3.1

Flat surfaced reference standards may be used for measurements on convex radii of curvature as small as one inch and concave radii of curvature as small as three inches. Test parts with radii smaller than one inch convex or three inches concave, require reference standards with curved surfaces with radii equal to the test part radii, ±10%. In addition, shoes are required (see paragraphs 5.2.2.9.2 and 5.2.2.10).

5.5.3.3.2

The surface finish of reference standards should be 63 microinches or better if maximum accuracy is to be obtained. Surface roughness introduces errors as shown Table 5-7.

5.5.3.3.3

The thickness of reference standards shall be measured by mechanical or optical means. The maximum tolerance for these measurements shall be one-half the tolerance permitted for the ultrasonic thickness measurements on the test part. For example, assume a test part thickness will be measured within ±0.005 inch. The reference standards must then be measured within ±0.0025 inch. If the test part measurement tolerance is not specified, the reference standards should be measured within ±0.0005 inch or one-half the instrument tolerance, whichever is greater.

Table 5-7. Measurement Error Introduced by Surface Roughness of Reference Standard or Test Part.

Surface Finish (microinches)	Measurement Error (inch)
0-63	0.0005
63-125	0.002
125-250	0.005
250-500	0.010
500-20000	0.020

5.5.3.3.4

If there are two or more areas on the test part of different thickness (within paragraph 5.5.3.3 limits) which can be measured both ultrasonically and mechanically or optically, these areas may be used as the standards.

5.5.4 Test Part Preparation.

5.5.4.1 Surface Contamination.

All foreign matter that might interfere with the thickness measurements shall be removed. Examples of such matter are loose scale, paint, dirt, and rust. For maximum accuracy, paint should be removed in the area to be measured. Paint can introduce errors in the measurements up to three times the maximum thickness of the paint. Metallic plating on the surface of the test part (Cr, Cd, Ni, etc.) will not significantly affect the accuracy of the readings; this plating is usually relatively thin (0.0005 inch).

5.5.4.2 Surface Roughness.

The surface finish of the test part affects the accuracy of the reading as shown in Table 5-7. If the surface of the test part is pitted or irregular, consistent readings will not be obtained. Variations as great as the depth of the pits or irregularities will be introduced. If permitted by the applicable manual or the prime depot, local areas may be sanded to provide smooth surface for increased accuracy in the thickness measurements.

5.5.5 Special Considerations.

5.5.5.1 Corrosion Pitting.

The effect on thickness measurements of corrosion pits on the back surface of the test part depends on the size of the pits and the size of the search unit. The depth of large pits (search unit diameter or greater) can be measured by subtracting minimum readings from maximum readings obtained on adjacent areas of the test part. Smaller pits will generally cause a broadening of the back surface reflection signals and sometimes a reduction in amplitude, due to scattering of the sound beam. These effects can be observed on instruments equipped with waveform displays. Smaller pits also lower the average thickness readings of the test part.

5.5.5.2 Curved Surfaces.

Measurements of curved surfaces require reference standards in accordance with paragraph 5.5.3.3.1. In addition, for convex radii less than one inch or concave radii less than three inches, shoes are required to adapt the search unit to the curved surface. In addition, detailed procedures for taking the measurements must be obtained from the applicable NDI manual or the depot level engineering activity. On all curved surfaces, it is recommended that an instrument with a waveform display be used. Small-diameter search units (1/4 inch or less) are also recommended. When making a measurement on a curved surface, the back surface signals should be maximized by rocking the search unit on the surface until the back surface signals peak and the thickness reading is at a minimum. The minimum thickness reading should be recorded as the test part thickness.

5.5.6 Calibration and Measurement.

NOTE

> Accurate thickness measurements require that the reference standards and the test part have temperatures equal within 10°F. Calibration shall be performed in the same physical location as the measurements on the test part. Adequate time should be allowed for the reference standards to reach the test part temperature. When using puls-eco or resonance method to measure thickness of materials, exact horizontal linearity of equipment is crucial and must be checked prior to calibration and measuring thicknesses. See process control chapter for procedures.

If only a basic ultrasonic instrument is available and no specific instructions are given, the following procedure may be used.

a. Obtain two reference standards in accordance with paragraph 5.5.3.3.

b. Select a search unit that will resolve the back surfaces of the reference standards.

c. Decide which divisions on the horizontal scale of the display graticule would be convenient locations for the echo signals from the back surfaces of the references. For example, if the reference standards are 0.25 and 0.5 inch thick, scale divisions at 2.5 and 5.0 could be used, or for better resolution 5.0 and 10.0 could be used. In the first case, each major division on the scale equals 0.1 inch. In the second case, each major division equals 0.05 inch. In general, each major division equals 0.1 of the thickness for which the echo signal is placed at division 10.

d. Obtain an echo signal from the thinner reference standard and adjust the instrument Delay control to position the signal at the chosen scale division.

e. Obtain an echo signal from the thicker reference standard and adjust the instrument Range control to position the signal at the chosen respective scale division.

f. Repeat paragraphs d and e until no further adjustment is necessary. Always place the same vertical position of the signals at the respective divisional markings; that is, place the point where the signal breaks the baseline, crosses the 10 percent vertical-scale line or any other convenient vertical-scale line.

g. Place the search unit on the test part and obtain a signal. Read the thickness from the horizontal scale of the display, using the same vertical location on the signal that was used when placing the signals from the reference standards. On parts with irregular or pitted surfaces, take several readings and record the average. If the surface is curved, see paragraph 5.5.5.2 for additional instructions. As required, multiply the readings by a correction factor (see paragraph 5.5.3.3).

h. The calibration should be rechecked each one-half hour during continuous use. If it is determined that the instrument is out of calibration, all measurements made since the last satisfactory calibration should be repeated after correcting the calibration.

SECTION VI

ULTRASONIC LEAK TESTING

5.6 ULTRASONIC LEAK TESTING.

5.6.1 Introduction.

NOTE

Std cm^3/s is a unit of gas leakage rate. One std cm^3/s means that one cubic centimeter of gas at atmospheric pressure (14.7 pounds per square inch) and standard temperature (20°C) passes through the leak each second. A leakage rate may also be expressed in the derived SI units of pascal cubic meters per second Pa•m^3/s). Adding the unit of pressure, pascal provides a valid leakage rate without having to convert to atmospheric pressure conditions. 1 Pa•m^3/s = 10 std cm^3/s.

a. Gas leakage of flow greater than about 0.1 standard cubic centimeters per second (std cm^3/s) produces ultrasonic energy with frequencies in the range of 30,000 to 50,000 Hz under most conditions. The gas leakage can be out of a pressure system or into a vacuum system. The ultrasonic leak detector utilizes a probe containing a microphone sensitive to this range of ultrasonic frequencies. The ultrasonic energy from leakage is detected. Background noise at other frequencies does not affect the detector.

b. Ultrasonic energy in this relatively low-frequency range of 30,000 to 50,000 Hz travels easily through air. The leak detector can therefore detect leakage with the probe located away from the leak. The maximum detection distance depends on the leakage rate. A leakage rate of 0.1 std cm^3/s can be detected 2 feet away, and a leakage rate of 10 std cm^3/s can be detected 20 feet away. Larger leakage rates can be detected at even greater distances. For most cases, 0.1 std cm^3/s is the minimum detectable leakage rate.

c. The ultrasonic leak detector is used also with a contact probe. This probe is placed on the test assembly and is used to locate internal malfunctions, such as internal bypassing of hydraulic actuators and leaking valves. Under certain conditions, this probe can also be used for detecting incipient bearing failures in rotating equipment. However, extensive calibration is required; and this application (detecting incipient bearing failures) is not generally practical for field use.

d. Typical applications for the ultrasonic leak detector on aircraft systems include locating leaks during fuel system pressurization tests, locating leaks in bleed air and air conditioning systems, and identifying internal leaks in hydraulic system.

5.6.2 Equipment.

a. The ultrasonic leak detector consists of the instrument, a set of earphones, two probes, and a rubber probe extension. The ultrasonic energy detected by the probe is converted into audible signals by the instrument. These signals are heard by way of a speaker on the face of the instrument or earphones plugged into the instrument. The earphones are used in noisy locations. The received signals are also indicated on a meter on the face of the instrument. A volume control on the instrument adjusts the sensitivity.

b. Complete details on one type of detector including calibration and maintenance procedures are contained in T.O. 33D9-84-30-1. Technicians should check the maintenance and testing procedures outlined in the specific technical order/manual for the particular model being used.

5.6.3 Calibration and Testing.

Equipment set up, calibration, and maintenance shall be performed in accordance with the equipment manual. The following is an example calibration. The calibration and equipment checking procedures given in the following are intended to be performed by the equipment operator. Figure 5-81 is an example of an inspector doing leak testing.

Figure 5-81. Leak Testing

5.6.3.1 TESTING FOR EXTERNAL GAS LEAKAGE WITH THE STANDARD PROBE.

NOTE

Use of the earphones is mandatory in areas where the background noise might interfere with hearing noise from the speaker. Use of the earphones is recommended for all tests.

a. Connect the probe to the instrument.

b. If in a noisy area, wear the earphones and attach the earphone connector to the instrument.

c. Set the volume control to its minimum position.

NOTE

During this step, the probe should be pointed away from the assembly to be tested and away from any other possible leak sources. If no background noise is audible or the meter indicator does not move past zero, replace the batteries and repeat the check for background noise and meter indication movement. If noise and meter indication movement is still not noted, the instrument is not functional and must be repaired or replaced. Repair should be performed by the PMEL.

d. Turn the instrument on and increase the volume control until the meter indication moves slightly ahead from zero and a slight background noise is heard from the speaker or the earphones.

e. Use a 500-milliliter polyethylene bottle (NSN 6640-314-2097). Hold it about arm's length away from the probe with the bottle nozzle facing the probe opening. Rapidly squeeze the bottle and note the meter reading. The meter reading should be at least 70. If it does not, the instrument is not functioning properly and must be turned into the PMEL for repair and calibration.

f. Search for leaks by pointing the probe at the test assembly and moving the probe around suspected leak areas. Note fluctuations in meter readings and volume from the speaker or earphones. When fluctuations are noted, maximize the meter reading by moving the probe and pointing it straight at the suspected leak area. The leak will generally be located in front of the probe when the meter reading and volume is at a maximum.

g. To locate the leak, attach the rubber extension to the probe. This increases the directional response characteristics of the probe. Keep the probe pointed in the direction where the meter indication and noise is maximized and move the probe toward the test assembly. Where the extension tip meets the test assembly with maximum meter reading and noise is the leak location. It may be necessary to lower the volume control to keep the meter reading on scale as the probe is moved closer to the test assembly.

NOTE

Under certain conditions background noise detected by the instrument can prevent the detection of relevant leakage. This background noise can result from many types of air movement (wind, running of air motors or air cooled motors, running aircraft engines, operating pneumatic systems, etc.).

h. The leakage rate may be estimated by moving the probe away from the leak to the maximum detection distance (leakage just indicated, slight increase in meter indication and noise level from normal background with the probe pointed to maximize the leak indication). The leakage rate can then be approximated by the following:

Leakage Rate (std cm^3/s) = Detection Distance (feet)/2.
For example, assume the maximum detection distance is 1 foot.
Then:
Leakage Rate = 1/2 = 0.5 std cm^3/s.

5.6.3.2 Testing For Internal Leaks with Contact Probe.

a. Perform step a. through e. in paragraph 5.6.3 to verify proper operation of the equipment. Use the standard probe for these steps. If the equipment is not operating properly, it must be replaced or repaired by the PMEL.

b. Connect the contact probe to the instrument. Place the tip of the probe firmly against the test assembly on a surface close to the suspected location of internal leaks. The tip of the probe should be pressed normal to the surface (see Figure 5-82). Move the probe from spot to spot over the test assembly and note increases in the meter reading and noise from the earphones or speaker. Noise indications not observed at similar locations in an assembly known not to be leaking indicate internal leaks in the test assembly. By moving the probe to where the maximum noise and meter reading is obtained, the location of the leak can be estimated.

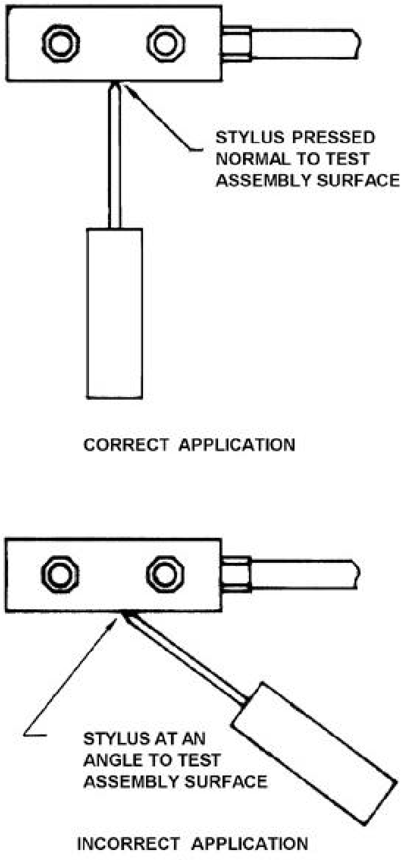


Figure 5-82. Correct and Incorrect Application of Leak Testing Contact Probe.

CHAPTER 6
SECTION I
RADIOGRAPHIC INSPECTION

6 BASIC FUNDAMENTALS OF RADIOGRAPHIC INSPECTION.

6.1 INTRODUCTION.

6.1.1 General.

This chapter will provide guidance for radiographic inspection. Additional helpful material is cited in the form of references, primarily books and standards. The references are listed at the end of this chapter.

6.1.1.1 Basics of Radiographic Inspection.

X and gamma radiographic inspection uses the penetrating abilities of electromagnetic radiation to examine the interior of objects. Three prime factors determine the amount of information that radiography can provide about an object.

a. The composition of the object.

b. The product of the density and the thickness of the material making up the object.

c. The energy of the X or gamma rays incident upon the object.

Discontinuities within the object can cause localized changes in the first two characteristics above and thus, become detectable.

6.1.1.2 General Nature Of X and Gamma Radiation.

X-rays and gamma rays are forms of electromagnetic radiation, as are visible light, ultraviolet light, infrared radiation, microwaves and radio waves. All together these types of radiation make up the electromagnetic spectrum. (Figure 6-1). Electromagnetic radiation is dualistic; that is, it exhibits some characteristics of a wave and some characteristics of a particle. In this case the particle is called a photon, which is a quantum of light. Depending upon the application, X-rays may exhibit more wave-like behavior or more quantum-like behavior.

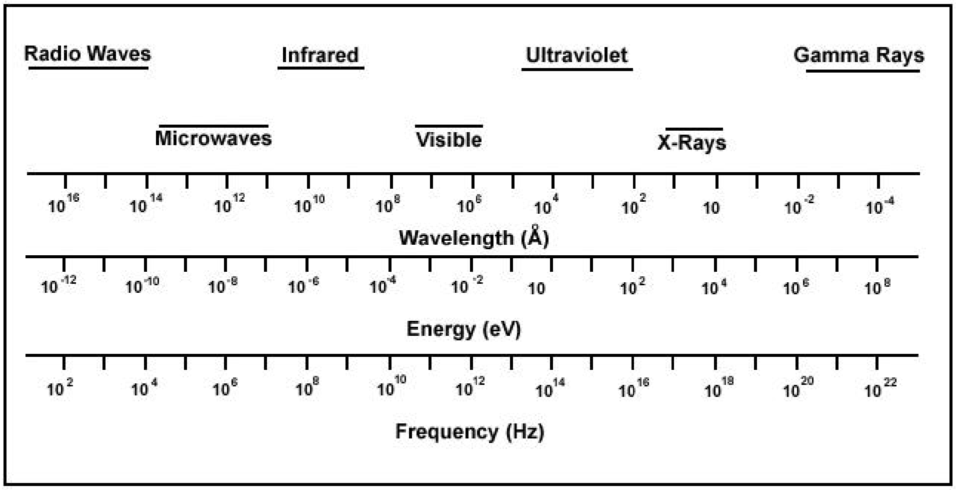


Figure 6-1. Electromagnetic Spectrum.

6.1.1.2.1

WARNING

Exposure to excessive X or gamma radiation is harmful to human beings. While most X-ray equipment is designed to minimize the danger of exposure to direct or stray radiation, certain precautions must be observed. Radiation protection requirements are discussed in Section 9.

The most distinguishing characteristic of X-rays is their short wavelength. The penetrating ability of X-rays is directly proportional to their energy, which in turn, is inversely proportional to their wavelength; that is, the shorter the wavelength, the higher the energy; the longer the wavelength, the lower the energy. Short wavelength X-rays are commonly described as "hard" while long wavelength X-rays are referred to as "soft."

6.1.2 Properties of X-Rays and Gamma Rays.

There are several properties which X-rays and gamma rays possess which make them useful for radiographic inspection. X-rays and gamma rays are the same form of energy as visible light; both are part of the electromagnetic spectrum. Like light, both are refracted when they pass through glass, such as a lens, or any other medium. However, the amount of refraction of X or gamma rays using visible-light optics is so slight as to be unnoticeable. X-rays can be focused, but the techniques are so cumbersome that in normal NDI applications X-rays are not focused. Although the properties of X and gamma rays and visible light are theoretically similar, the differences in application make it most convenient to consider X and gamma rays as being different, since their observable effects are quite different from those of light. This is noted particularly in the ability to penetrate matter. Some general properties of X and gamma rays may be summarized as follows:

a. They are invisible to humans.

b. They propagate in straight lines in free space.

c. In special cases they are reflected, diffracted, refracted, and polarized as is light, but to a much smaller degree.

d. They propagate at a velocity of 3x108 meters per second as does light.

e. They consist of transverse electromagnetic vibrations as does light.

f. X-rays have energies between roughly 1KeV and 50MeV.

g. X-rays for NDI are produced by the interaction of high-energy electrons or ions with matter.

h. Gamma rays are produced in nuclear transformations, such as radioactive decay.

i. X-rays and gamma rays expose (darken) photographic film.

j. They stimulate fluorescence and phosphorescence in some materials.

k. They are capable of ionizing gases and changing the electrical properties of some liquids and solids.

l. They are able to damage and kill living cells and to produce genetic mutations.

m. They are differentially absorbed or scattered by different media.

n. X-rays may be diffracted by the crystalline, structure of materials which acts like a grating.

o. They do not affect fuel cells or munitions.

All of these properties contribute in some degree to the understanding of the radiographic process. Most important of these in terms of usefulness to NDI are the differential absorption of radiation in matter and the ability of radiation to expose film. In the remainder of this chapter the term "X-rays" will be more prevalent since that form of radiation is most used. Except where noted the discussion will also apply to gamma rays.

6.1.2.1 Differential Absorption in Matter.
A material discontinuity, such as a void or change in configuration, (see Figure 6-2) changes the effective thickness of a material, and thus changes the degree of radiation absorption. Since all radiation that is not absorbed or scattered within a material is transmitted, the amount of transmitted radiation varies with localized changes in effective material thickness.

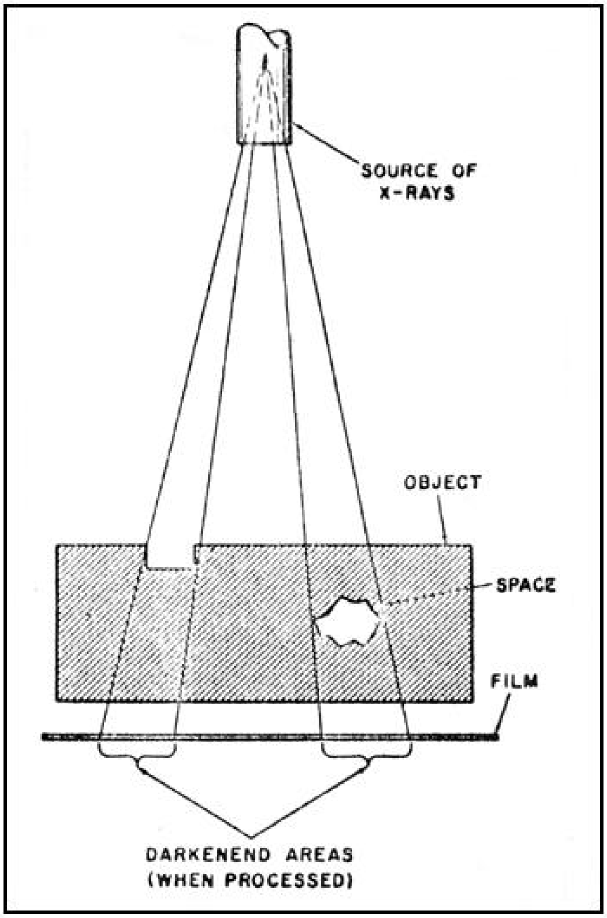


Figure 6-2. Diagram of Radiographic Exposure.

6.1.2.1.1
It is the transmitted radiation intensity that is generally used to find a material defect. If the material discontinuity represented in Figure 6-3 were a foreign material inclusion, it also would cause a change in the apparent composition of the material and again result in a change in the transmitted radiation intensity. The degree of this change would be dependent on the relative effects of the base material and the included material on the incident radiation.

6.1.2.1.2

NOTE

Although radiography will reveal the interior of opaque objects, it cannot detect all types of irregularities or discontinuities. Small defects in thick objects such as fine cracks or indentations are difficult to detect. In applying radiography as an inspection method, the sensitivity of the method must be kept in mind. The limitations of radiography will become more apparent in subsequent discussions.

Some voids are difficult to detect, because they present a very slight change in material thickness to a beam of radiation. A most important example of this type of defect is the crack. A crack represents a tear or rupture within a homogeneous material. If a crack is open, that is, the opening is wide, (see Figure 6-3a) it appears to the radiation beam as a significant change in effective material thickness and is thus readily detected. However, if a crack is under compression and is very tight as illustrated in Figure 6-3b, then its detection may become very difficult, if not impossible, because the apparent change in material thickness is negligible. It is important to note that crack orientation also has a very significant effect on the detectability of the crack with radiation. In Figure 6-3b, if the crack were oriented parallel with the radiation beam, the effective change in material thickness would be enough to make the crack easily detectable. However, in most situations the probability of aligning a beam with a tight crack is low, so other NDI techniques must be relied upon as backups. The problems associated with crack detection will be dealt with at length in later paragraphs.

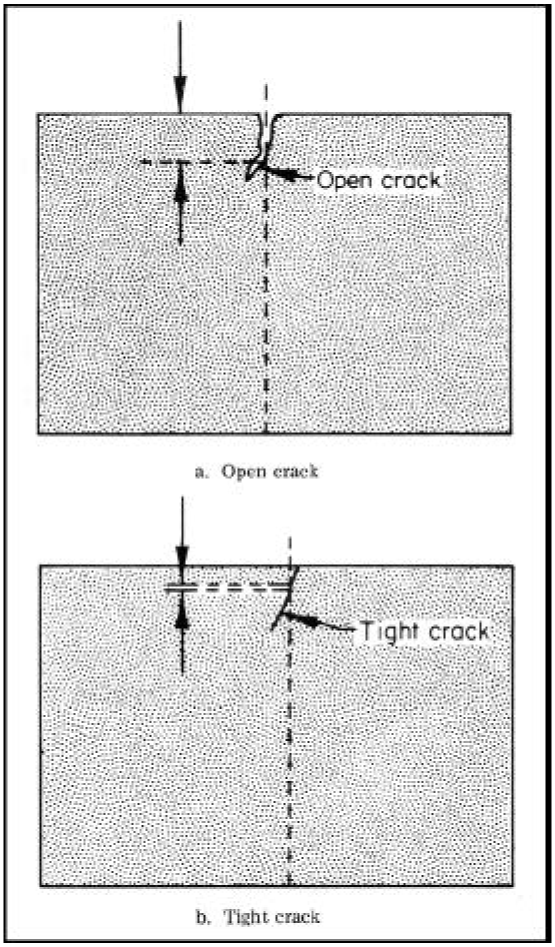


Figure 6-3. Effect of Change in Thickness of Cracks.

6.1.2.2 Exposure of Film.

In their action on photographic film, X-rays differ from ordinary light. Examination of microscopic sections through the sensitive layer of exposed films has shown that X-rays, unlike light, produce an equal distribution of grains of reduced silver throughout the whole thickness of the layer whereas light produces an effect mainly on the surface of the emulsion. Consequently, a greater blackening of the emulsion can be produced by increasing the thickness of the emulsion and by coating both sides of the base of X-ray film. This darkening effect may then be used to obtain a photographic record, or radiograph, which is produced by the passage of X-rays or gamma rays through an object and onto a film. Thus a radiograph is a shadow picture of an object and its interior; dark regions on the film represent the more penetrable regions of the part and lighter areas on the film represent the more dense areas of the part. Film may be coupled with various screens to improve the image and reduce problems associated with scattered radiation.

6.1.2.3 Summary.

Radiography satisfies the three primary requirements of any nondestructive inspection:

a. There is an energy form that can be usefully produced in a controlled manner.

b. This energy form is capable of interacting with material in a manner that causes a change in the energy form, but not in the material.

c. After such interaction the energy form may be detected and may be interpreted to define what material condition produced the observed result.

6.1.3 Where To Use Radiography.

6.1.3.1 Basic Guidelines.

There are some basic guidelines that may be used to determine situations to which radiography is applicable.

a. The defect, which is of interest, must cause a detectable change in apparent thickness, density or composition of the test material.

b. The material should be reasonably homogeneous, so that an indication of a defect may be recognized.

c. The configuration of the part to be tested, or the area that surrounds it, must be such that access to both sides is available.

d. The defect to be detected must be properly oriented in the path of the radiation beam.

6.1.3.2 Limitations.

Radiography is not a cure-all and should be used only when the above conditions are satisfied. Multiple film techniques and other special methods, which will be covered in Section V, make radiography a versatile tool for material evaluation.

6.1.3.3 Typical Examples.

a. Radiography is a useful nondestructive inspection method for detecting internal discontinuities in many materials.

b. Radiography may be applied to the inspection of castings, welds, and assembled components. Various metals, both ferrous and nonferrous, as well as non-metallics, such as ceramics and plastics, can successfully be inspected.

6.1.4 Unique Properties of Gamma Rays.

6.1.4.1 General.

Gamma-ray radiography is basically the same as X-ray radiography. Differences in material properties and effects between X-rays and gamma rays are largely a matter of degree. The major advantage of using gamma rays is the fact that gamma ray sources are small and provide access to small spaces, thereby simplifying exposure technique. Exposure periods are, however, generally longer with gamma ray sources.

6.1.4.2 Sources Of Radiation.

Many atoms exhibit a property called radioactivity, which is a phenomenon of spontaneous disintegration or decay. This characteristic is believed to be caused by the instability of the complex structure of the atom under the action of the electric, magnetic and gravitational forces existing within. Radium is one of the elements with a natural unbalance that releases energy in the form of gamma rays to achieve a more stable condition. In addition to the gamma rays, some alpha particles (helium nuclei) and beta particles (electrons) are allowed to escape. The alpha and beta particles are readily absorbed, but the gamma rays are more penetrating since their energy extends above 1,000,000 electron volts (eV). This energy release is uncontrolled and is a result of forces in the atom. Many of the atomic structures can be artificially made to release energy by subjecting them to strong fields of neutrons generated in nuclear reactors. These neutron fields add energy to the atom, which upsets the balance within the nucleus and causes the atom to emit one or more types of energy. Cobalt is one element commonly made artificially radioactive and used in NDI since the energy it releases is a very penetrating form of gamma rays. An example of nuclear disintegration and the release of energy is shown in Figure 6-4.

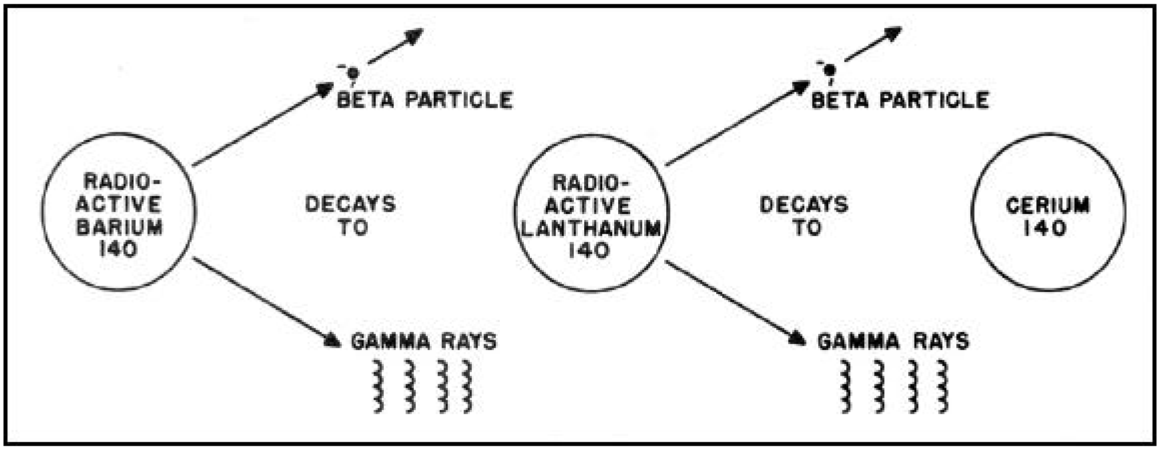


Figure 6-4. Diagram of Nuclear Disintegration.

SECTION II
X-RAY GENERATORS

6.2 X-RAY GENERATORS.

6.2.1 Definition.

X-ray generators are man-made electronic devices designed to produce X radiation. Many types of X-ray generators may be obtained commercially. X-ray equipment may be either portable or stationary. Portable X-ray generators are used for inspection of test objects that are either impossible or very difficult to transport. Stationary X-ray generators are used in shielded facilities where the objects to be tested can be readily transported to the X-ray equipment.

6.2.2 Basic Requirements for Production of X-Rays.

X-rays are produced when some form of matter is struck by a rapidly moving electron. To accomplish this, three basic requirements must be met.

6.2.2.1 Supply Of Electrons.

There must be a supply of the electrons. Fortunately, they can be supplied by simply raising the temperature of a suitable material. An electron source is readily obtainable in as much as all matter is generally considered to be composed of electrons and other minute particles. All that is necessary is to sufficiently heat the proper material. As the temperature rises, the electrons become more and more agitated until finally they escape or "boil off" the material, surrounding it in the form of an electron cloud (see Figure 6-5). This is known as thermionic emission. In an X-ray tube the heated material is known as the filament, which is similar to the filament in a light bulb. Just as in a light bulb the filament is heated by passing electrical current through it.

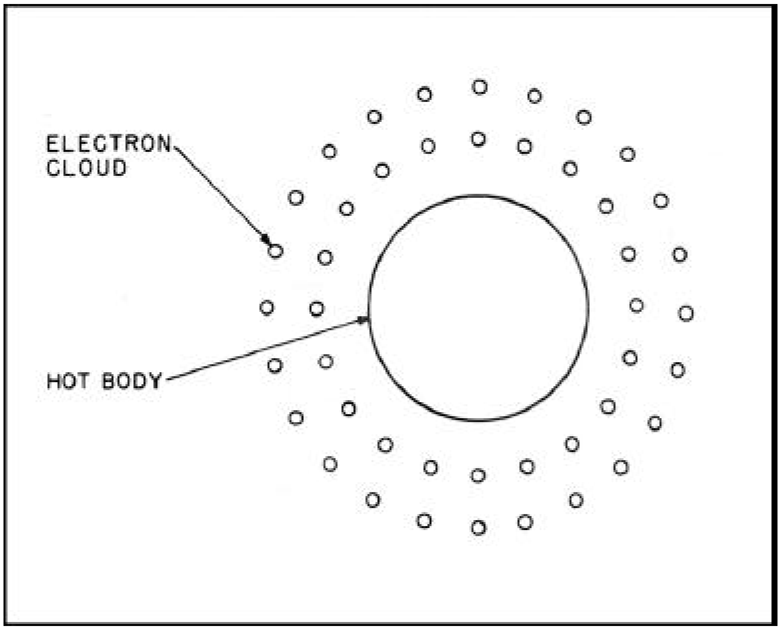


Figure 6-5. Electron Cloud.

6.2.2.1.1

This cloud of electrons simply hovers around and returns to the emitting substance unless some external action or force pulls it away.

6.2.2.2 Movement of the Electrons.

Movement of the emitted electrons is the second step in producing X-rays. This movement is brought about by the repelling and attracting forces inherent in electrical charges. The fundamental law of electrostatics states that like charges repel each other and unlike charges attract each other. Electrons are negative charges, thus repel each other. However, a stronger attracting force is needed to accelerate the electrons to a higher velocity. Therefore, a strong opposite (positive) charge is used to move the electrons from one point to another. It is important that this movement is conducted in a good vacuum, otherwise the electrons collide with air molecules and lose energy through ionization and scattering. In an X-ray tube the anode is given a positive charge with respect to the filament, which is part of the cathode.

6.2.2.3 Impingement of Electrons on a Target.

6.2.2.3.1 Continuous X-Ray Spectrum.
Merely generating electrons in a vacuum and setting them in motion is not sufficient to create X-rays. It is necessary also that the electrons strike some target substance. In an X-ray tube the target is the anode. When the electrons bombard the target, they are brought to an abrupt halt. Unfortunately most of the electrons' kinetic energy is converted into heat which must be dissipated by the target material. Only a small percentage of the energy available in the electron beam is converted into X-ray photons which can have energies ranging from zero to a maximum which is determined by 1) the original kinetic energy of the electrons and 2) by how rapidly the electrons are decelerated. This process produces the continuous portion of the X-ray spectrum and is known either by the German term *Bremsstrahlung*, meaning braking radiation, or by the term white radiation (see paragraph 6.5.3). X-rays are produced regardless of the material bombarded, whether it is a solid, liquid or gas. In the X-ray tube a solid material is used for the target. The higher the atomic number of the target material the higher the efficiency of X-ray production.

6.2.2.3.2 Characteristic X-Ray Spectrum.
In addition to the white radiation, there are several characteristic peaks in a typical X-ray spectrum. These intensity spikes are caused by interaction between the impinging stream of high-speed electrons and the electrons that are bound tightly to the atomic nuclei of the target material. If the atom is considered as a planetary system with the nucleus of protons and neutrons at the center of the system and the electrons moving in orbits around the nucleus, modern physics predicts that the orbital electrons near the nucleus will have very well-defined energies, with electrons in different orbits having different energy levels. If an electron from an external beam collides with one of these orbital electrons with sufficient energy to knock it out of its orbit, an electron from a higher energy level would, after a time, drop down to fill the void and restore atomic stability. When that electron drops to the lower energy level, it gives off a photon with energy equal to the difference in energy levels. Since these energy levels depend strictly upon the particular atom, the radiation emitted is called characteristic radiation. The characteristic radiation emitted by the target material is superimposed upon the continuous spectrum. A typical X-ray spectrum of radiation generated by an X-ray tube would appear as shown in Figure 6-6. The K and L series of characteristic radiation designates the radiation emitted from different electron orbits around the nucleus of the atom. As energy levels increase, electrons are dislodged from the various orbits with the K series being the closest to the nucleus.

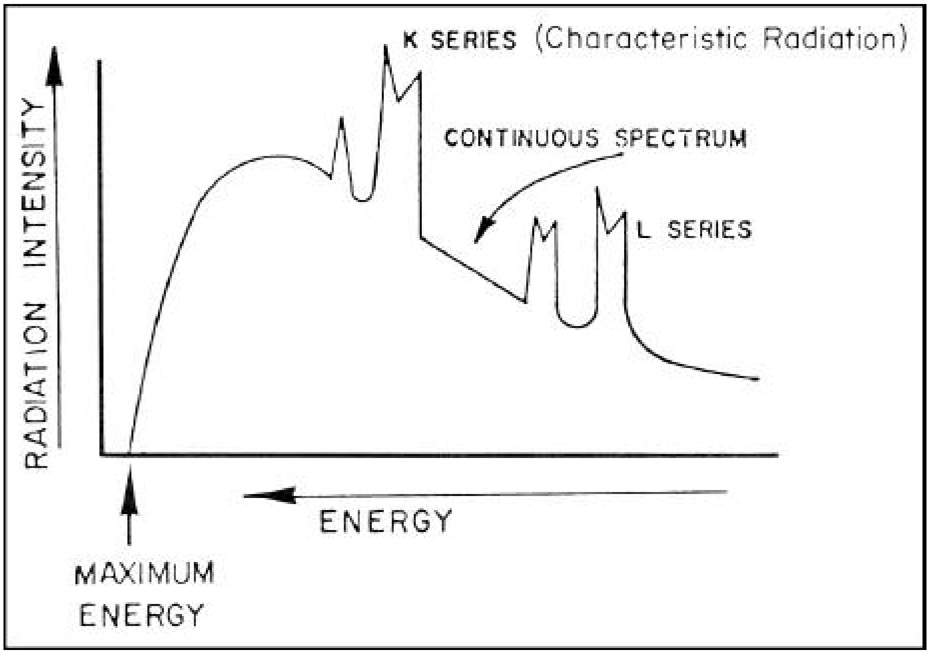


Figure 6-6. Typical X-ray Spectrum.

6.2.3 Effects Of Voltage and Amperage on X-Ray Production.

6.2.3.1 Effect Of Voltage.

In different equipment, different methods are used to accelerate the electrons. In the smaller X-ray generators, up to and including two million volt units, acceleration is accomplished with transformers to step up the incoming power line voltage and apply it between the anode and the cathode of the X-ray tube. Since the X-ray generators operate at very high voltages, the unit kilovolt (kV) is used to designate one thousand volts. As the kilovoltage (the potential that causes the electrons to accelerate) is changed, the kinetic energy of the moving electrons is changed, altering the energy of the resulting X-radiation. As the kilovoltage is increased, the efficiency of converting the electrical energy into X-rays is increased. Therefore, when kilovoltage is changed, the penetrating capability of the generated radiation is changed, and the quality of radiation is altered due to the efficiency of electrical energy converted into X-rays. Selecting the proper kilovoltage is very important in industrial radiographic applications.

6.2.3.2 Effect Of Amperage.

Amperage is a measure of the amount of electrical current applied to the filament. It is also a direct measurement of the number of free electrons available in the X-ray tube and is independent of variations in kilovoltage. Thus the quantity of X-radiation is in direct relation to the filament current. Typically, the amount of current is small, so the unit milliampere (mA), milliamp for short, is used to designate one one-thousandth of an ampere. The effect of milliamp changes on the radiation output is shown in Figure 6-7.

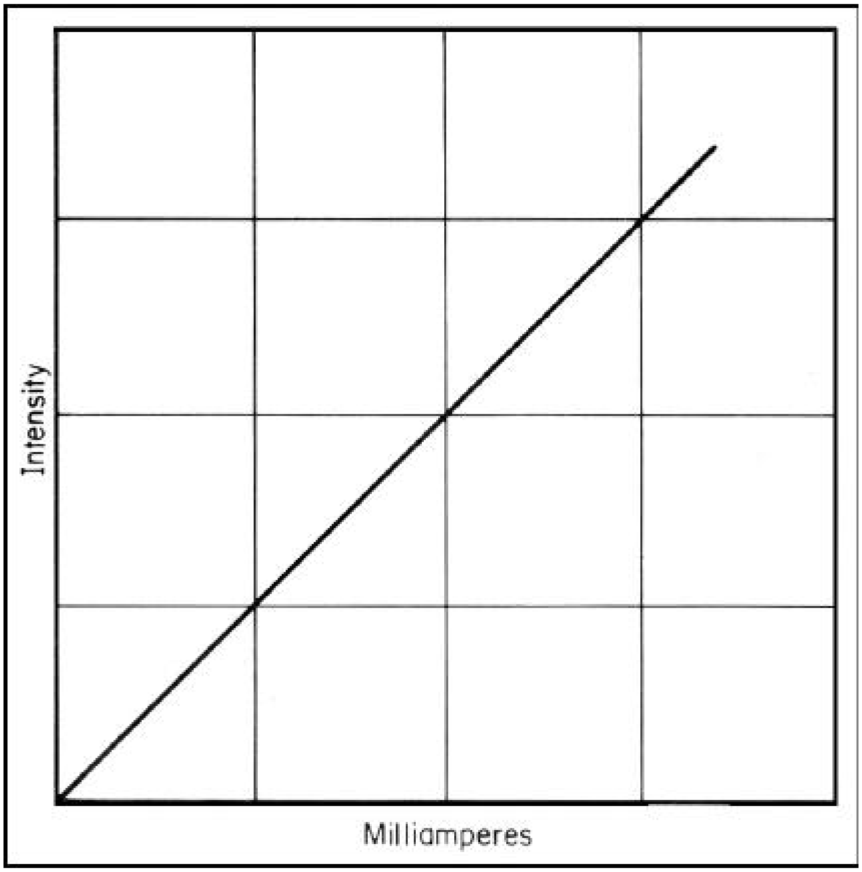


Figure 6-7. Effect Of Filament Current on Radiation Quantity.

6.2.4 X-Ray Generators.

6.2.4.1.1 Tank Type X-Ray Generators.

Tank-type units are usually small and light in weight for ease of portability. The entire high voltage circuit is housed in a single housing, which is commonly known as the tubehead in portable X-ray units. This arrangement avoids having to transmit high voltage from the high voltage transformer to the X-ray tube by means of insulated conductors. The housing contains the X-ray tube, the high voltage transformer, and the filament transformer. Electrical insulation is usually by transformer oil or compressed insulating gas. The control box is a separate unit that can be positioned at some remote distance to protect the operator from radiation. Different circuit designs are used in various tank-type generators.

6.2.4.1.2 Separate component Units.

Separate component units are those units where the transformers are separated from the X-ray tube. The high voltage and filament connections are made between the transformers and the X-ray tube through insulated cables. These units offer the advantage of ease of positioning the X-ray tube. The tube is contained in a protective housing with adequate insulation for the high voltages to be applied to the tube. These separate component units are usually fixed installations and parts to be inspected are transported to the X-ray equipment. Size or weight of this equipment is not of importance because they are usually intended for radiography in a shielded facility.

6.2.4.2 Components and Properties of an X-Ray Tube.

The X-ray tube houses the cathode (negative terminal) and the anode (positive or ground terminal) under high vacuum. Traditionally the tube has been a glass envelope with a reduced thickness at the window, the point where the X-rays exit, to reduce X-ray absorption. The high vacuum reduces the problem of the electrons colliding with, and being absorbed by, molecules of air and provides electrical insulation between the cathode and anode. In some designs a beryllium window is incorporated to further reduce absorption of the X-ray beam, particularly the lower energies. In many applications glass envelopes are being replaced by metal-ceramic envelopes. These tubes usually involve a metal cylinder with a ceramic disk at each end to hold and insulate the cathode and anode assemblies. The metal-ceramic tube is more durable than the glass tube and is less susceptible to thermal and mechanical shock.

6.2.4.2.1 Cathode.

A structure known as the cathode serves as the electron source. (See Figure 6-8). Actually, it is a filament or coil of thoriated tungsten wire that emits electrons when heated to a high temperature. But because the filament gives off electrons in all directions, some means must be used to focus them on a target. A reflector or focusing cup within the cathode structure, into which the filament is centered, serves to focus the electron beam much as light is focused by a flashlight reflector.

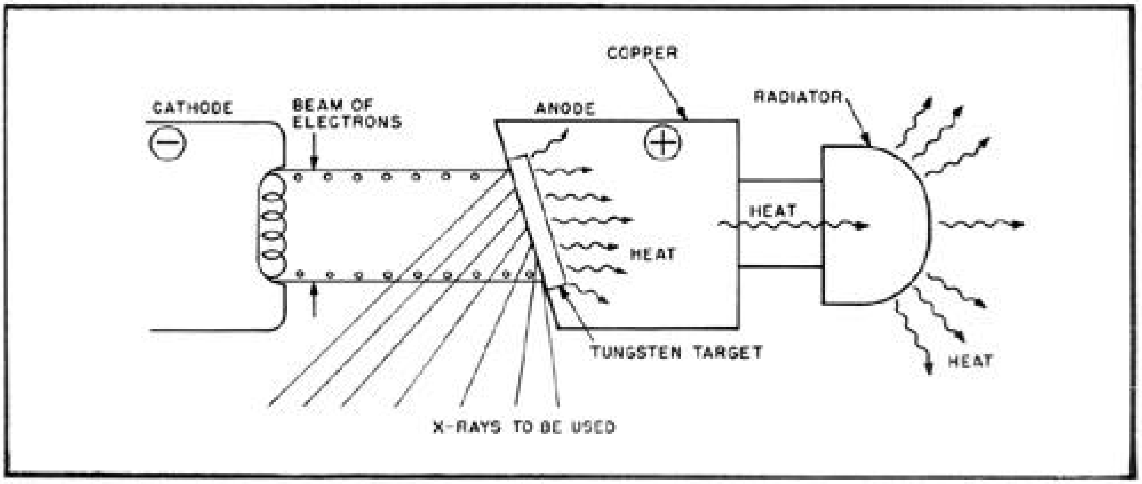


Figure 6-8. Fundamentals of X-Ray Tube.

6.2.4.2.2 Anode.

As mentioned previously, there must be a target for the electron beam to strike before X-rays are actually produced. In radiographic tubes the target material is generally made of tungsten. The choice of tungsten as a target for industrial radiography is based on four material characteristics:

a. High atomic number (74). The higher the atomic number of a material the more efficient is the conversion from electrical energy into X-ray energy.

b. High melting point (690°F*). Most of the energy in the electrons bombarding the target is dissipated in the form of heat. The extremely high melting point of tungsten permits operation of the target at very high temperatures.

c. High thermal conductivity. Permits rapid removal of heat from the target, allowing maximum energy input for a given area size.

d. Low vapor pressure. This reduces the amount of target material vaporized during operation.

6.2.4.2.2.1

The tungsten target material is usually imbedded into a massive copper rod. Copper is an excellent thermal conductor and is used to remove the heat from the target for dissipation by air, oil, or water cooling, depending on tube design and operation. The target and its copper support are the anode. To produce X-rays it must be at a positive potential (voltage) with respect to the cathode in order to attract the electrons available at the cathode.

6.2.4.2.3 Focal Spot.

The focal spot is the area of the target that is bombarded by the electrons from the cathode. The shape and size of the focusing cup of the cathode and the length and diameter of the filament all determine the size and shape of the focal spot. The size of the focal spot has a very important effect upon the quality of the X-ray image. The smaller the focal spot the better the detail of the image. The electron stream from the filament is focused as a narrow rectangle on the anode target. The typical target face is made at an angle of about 20 degrees to the cathode. When the rectangular focal spot is viewed from below, in the position of the film, it appears more nearly a small square. Thus, effective area of the focal spot is only a fraction of its actual area (see Figure 6-9). By using the X-rays that emerge at this angle, a small focal spot is created, improving radiographic definition. Because the electron stream is spread over a greater area of the target, heat dissipation by the anode is improved.

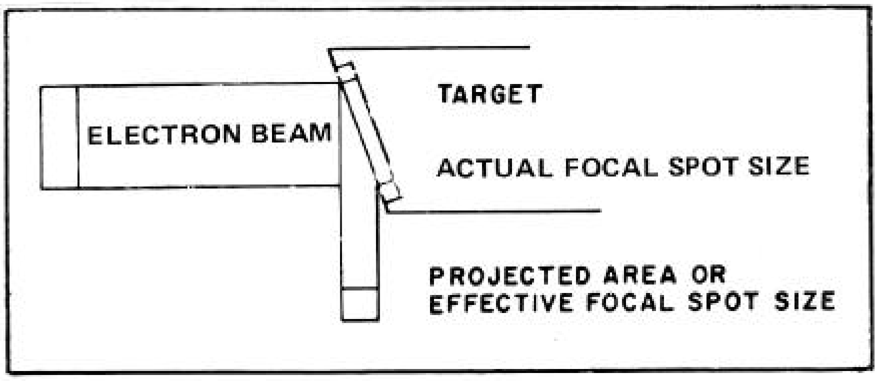


Figure 6-9. Effective Focal Spot Size.

6.2.4.2.4 Inherent Filtration.

Inherent filtration is the filtration or reduction in radiation energy due to absorption by the material necessary to provide the vacuum, the electrical insulation, and mechanical rigidity of the X-ray tube. In construction of some glass X-ray tubes, the port is reduced in thickness to provide less inherent filtration. In some other tubes the port is made of beryllium which is a light metal of low atomic number and low X-ray absorption. Because of tremendous pressures exerted by the atmosphere on large evacuated containers, X-ray ports must be designed with sufficient thickness to withstand these pressures without implosion. In center-grounded X-ray equipment, it is also necessary to provide gas (e.g., sulfur hexafluoride, SF_6) and solid insulation for electrical isolation of the X-ray tube. Excessive inherent filtration reduces the X-ray output as well as the radiographic contrast on equipment of a given rating. In normal practice it is acceptable to tolerate inherent filtration equivalent to 1 mm of aluminum up to 100 kVp (kilovolts peak); 3 mm of aluminum up to 175 kVp; 5 mm of aluminum equivalent up to 250 kVp; and higher filtration in 1,000 to 2,000 kVp units. Inherent filtration above these tolerances reduces contrast, and hence, sensitivity of radiographic inspection, and as a result, limits the sensitivity of inspection, especially on thin sections and light alloys. For this reason, during radiographic inspections using kilovoltage of 150 or less, the tubehead shall be configured so that generated radiation will travel from the target through a beryllium window without passing through any media other than air or insulating gas.

6.2.4.2.5 Cooling Requirements.

The product of mA and kV equals watts of electrical power in the electron beam striking the X-ray target. One watt of electrical power is equal to one volt-ampere. Therefore, in an X-ray tube operating at 10 mA (or 0.01 amperes) and 140 kV (140,000 volts), 1400 watts of electrical power are in the electron beam. Only a very small amount of the energy in the electron beam is converted into X radiation. This ranges from about 0.05 percent at 30 kV to approximately 10 percent in the MeV energy range. Most of the electron beam energy is converted into heat. This generation of heat in the X-ray tube target material is one of the limiting factors in the capabilities of the X-ray tube. It is necessary to remove this heat from the target as rapidly as possible. Various techniques are used for removal of heat. In some instances, the target is comparatively thin, and a suitable oil is circulated on the back surface to remove heat. Others (where the anode is being operated at ground potential) use water-antifreeze mixture to conduct heat away from the target. Most X-ray targets are mounted in copper, using the copper as a heat sink. Some units have no external method of heat removal, but depend upon heat dissipation into the atmosphere by fins of a thermal radiator. Some totally enclosed tubes depend upon the heat storage capacity of the anode structure to absorb the heat generated during X-ray exposure. This heat is then dissipated after the unit is turned off. These units usually have a duty cycle as a limiting factor of operation that is dependent upon the heat storage capacity of the anode structure and the rate of heat dissipation by thermal radiation. The rate of heat removal from the X-ray target is the primary limiting factor in X-ray tube operation.

6.2.4.3 Types Of X-Ray Tubes.

6.2.4.3.1 Directional Tubes.

In directional X-ray tubes, the anode is set at an angle to the electron beam. When the high-speed electrons strike the target, X-radiation is generated in a solid spherical pattern. The massive anode functions as an absorber for the radiation traveling into the anode. In most X-ray tubes, lead-absorbing materials are used to restrict the exiting radiation to a cone-shaped field passing through a window. The shielding reduces the leakage radiation hazard to personnel, and prevents additional scattered radiation from surrounding materials and areas. In some portable equipment, shielding of the X-ray tube has been omitted for the advantage of lightweight. In some very high-energy units such as betatrons and linear accelerators, the target is comparatively thin and offers little absorption to the very high-energy radiation being generated. The radiation beam from the front of the target is shielded to provide a directional pattern, conical in shape.

6.2.4.3.2 Rod Anode X-Ray tubes.

These tubes are designed to produce a radiation beam in a circular pattern. These tubes are used for circumferential radiography, particularly weldments in pipe. By use of an absorbing sleeve the circular radiation pattern can be reduced to a directional beam.

6.2.4.4 Intensity Distribution of an X-Ray Beam.

6.2.4.5 Heel Effect and Beam Coverage.

For simplicity's sake, most literature states that the intensity of radiation of the primary beam is constant. This is not quite correct. There is a variation in intensity due to the angle at which the X-rays are emitted from the focal spot. This is called the heel effect (see Figure 6-10).

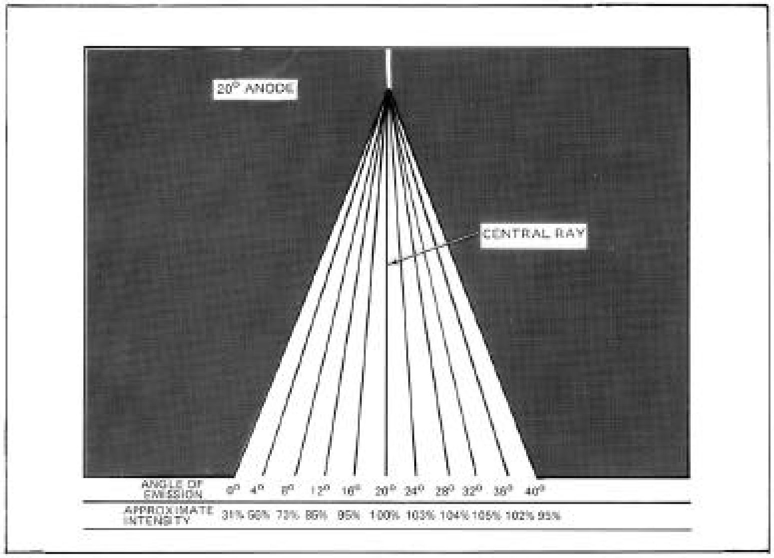


Figure 6-10. Variation of Intensity in the Primary Beam Due to the Heel Effect.

6.2.4.5.1

The intensity of the beam diminishes fairly rapidly from the central ray toward the anode side and increases slightly toward the cathode side. In general practice the heel effect is not evident, provided the maximum lateral dimension of the object to be radiographed is less than half the source-to-film distance (SFD). In other words, coverage of a 14 by 17inch film requires an SFD of approximately 36 inches to provide a field intensity of plus or minus 12 percent over the whole film. This is based upon using part of the radiation field within a cone having a 30-degree included angle. (The source for an X-ray tube is the focal spot.) For a single exposure of larger areas requiring multiple films, the SFD must be increased. For example, to determine the SFD to cover an area that fits within a circle with a diameter of 56 inches, do the following calculation:

$$\mathrm{SFD} = \frac{\mathrm{R}}{\mathrm{Tan}\theta}$$

θ equals the half-angle of the cone = 15 degrees
Tan 15 = 0.268
R = one-half the diameter = 28 inches

Therefore, $\mathrm{SFD} = \frac{28}{0.268} \approx 104.5\ \text{inches}$

If the SFD is limited, the radius of beam coverage can be calculated by rearranging the formula:

$$R = \mathrm{Tan}\theta \times \mathrm{SFD}$$

Using the same cone half-angle of 15 degrees, Tan θ = 0.268
Assume SFD is limited to 60 inches

$$R = 0.286 \times 60 \approx 17\,\mathrm{inches}$$

If an area larger than a 34-inch diameter circle needs to be radiographed, more than one setup must be used.

6.2.4.5.2 Beam coverage.

The greater the field size available from an X-ray unit, the greater its radiographic inspection capacity. Except at extremely high voltages, the X-ray beam has an angle of coverage that is a function of the X-ray target angle, the geometry of the focal spot and the X-ray port size. As indicated in the discussion of heel effect in the previous paragraph, the physical size of the field of uniform intensity increases directly with the distance from the target to the film. However, the beam intensity decreases proportionally with the square of the distance, so the exposure (the product of amperage and time) must be increased to produce equivalent density on the radiograph. If a technique has been established but the situation requires a different SFD, Table 6-1 gives some multiplication factors for calculating new exposure times to be used with the original kV and mA values.

Note

To change the SFD from any given distance to any desired distance, locate the given distance on top of the chart. Then read down the left side of the table to the desired distance. The original exposure should be multiplied by the number common to both the given column and the desired row to get the new exposure. This chart may be used for distance changes providing the kV and mA levels are not changed.

Table 6-1. Exposure-Time Correction Factors for Different Source Film Distances.

Desired Distance (Feet) Given Distance (Feet)

↓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1	0.25	.11	.06	.04	.03	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	
2	4	1	.44	.25	.16	.11	.08	.06	.05	.04	.03	.03	.02	.02	.02	.02	.01	.01	.01	.
3	9	2.3	1	.56	.36	.25	.18	.14	.11	.09	.07	.06	.05	.05	.04	.04	.03	.03	.02	.02
4	16	4	1.8	1	.64	.44	.33	.25	.20	.16	.13	.11	.09	.08	.07	.06	.06	.05	.04	.04
5	25	6.3	2.8	1.6	1	.69	.57	.4	.31	.25	.21	.17	.15	.13	.11	.10	.09	.08	.07	.06
6	36	9	4	2.3	1.4	1	.73	.56	.44	.36	.30	.25	.21	.18	.16	.14	.12	.11	.10	.09
7	49	12.3	5.4	3.1	2	1.4	1	.77	.60	.49	.40	.34	.29	.25	.22	.19	.17	.15	.14	.12
8	64	16	7.1	4	2.6	1.8	1.3	1	.80	.64	.53	.44	.38	.33	.28	.25	.22	.20	.18	.16
9	81	20.3	9	5.1	3.2	2.2	1.7	1.3	1	.81	.67	.56	.48	.41	.36	.32	.28	.25	.22	.20
10	100	25	11.1	6.3	4	2.8	2	1.6	1.2	1	.83	.69	.59	.57	.44	.39	.35	.31	.28	.25
11	121	30.2	13.4	7.6	4.8	3.4	2.5	1.9	1.5	1.2	1	.84	.72	.62	.54	.47	.42	.37	.34	.30
12	144	36	16	9	5.8	4	2.9	2.3	1.8	1.4	1.2	1	.85	.73	.64	.56	.50	.44	.40	.36
13	169	42.2	18.8	10.6	6.8	4.7	3.4	2.6	2.1	1.7	1.4	1.2	1	.86	.75	.66	.58	.52	.47	.42
14	196	49	21.7	12.3	7.8	5.4	4	3.1	2.5	2	1.6	1.4	1.2	1	.87	.77	.68	.61	.54	.50
15	225	56.2	25	14	9	6.3	4.6	3.5	2.8	2.2	1.9	1.6	1.3	1.1	1	.88	.78	.69	.62	.56
16	256	64	28.4	16	10.2	7.1	5.2	4	3.2	2.6	2.1	1.8	1.5	1.3	1.1	1	.89	.79	.71	.64
17	289	72.2	32.1	18.1	11.6	8	5.9	4.5	3.6	2.9	2.4	2	1.7	1.5	1.3	1.1	1	.89	.80	.72
18	324	81	36	20.2	13	9	6.6	5.1	4	3.2	2.7	2.3	1.9	1.6	1.4	1.3	1.1	1	.89	.81
19	361	90.2	40.1	22.6	14.4	10	7.4	5.6	4.5	3.6	3	2.1	1.8	1.6	1.4	1.2	1.1	1.1	1	.90
20	400	100	44.4	25	16	11.1	8.2	6.3	4.9	4	3.3	2.8	2.4	2	1.8	1.6	1.4	1.2	1.1	1

6.2.5 Practical Considerations When Choosing Equipment.

6.2.5.1 Choice of Radiation Energy.

The relation of X-ray voltage to the penetration for steel or other common materials depends upon the density of the material and the absorption characteristics of the material in the X-ray beam. In general, Table 6-2 can be used as a guide for applying X-rays to inspection problems, assuming average radiographic results are expected. It is necessary to establish lower limits as well as upper limits on material thickness because using voltages higher than what is required to penetrate a given thickness will reduce the radiographic contrast.

Table 6-2. Appropriate Radiation Energies for Radiography of Steel.

Kilovoltage Range	Material Thickness
5-50 kV*	Extremely thin, such as foil up to 1/8 in.
50-150 kV	1/8 to 3/4 in. steel
100-200 kV	1/4 to 2 in. steel
200-400 kV	3/4 to 3 in. steel
1000 kV	1 to 5 in. steel
2000-6000 kV	2 to 8 in. steel
15-24 MeV	3 to 18 in. steel
* This energy range is also useful for composite structures. **Note** that for X-ray energies of 15 kV or less, scatter in the air path may be a problem.	

6.2.5.2 Choice of Equipment.

The equipment choice should depend upon the circumstance under which radiographic inspection is to be conducted and the technique requirements.

6.2.5.2.1 Choice of Tube Type.

The choice of a directional or a rod anode tube type should depend upon the type of radiographic inspection conducted. Circumferential specimens, such as pipe weldments, are compatible with the rod anode radiation. It should be noted that scattered radiation is greater with the rod anode and additional personnel protection is often necessary. The directional X-ray tubes restrict the radiation to a smaller area and have a comparatively smaller focal spot resulting in better quality radiographic images.

6.2.5.2.2 Choice of Window.

When the X-ray absorption of a test object is low, lower energy radiation is required. To take advantage of the higher contrast provided at lower energies, an X-ray tube with a beryllium window should be used since beryllium transmits the low energy radiation. Up to 150 kVp the beryllium window offers advantages. Above 150 kVp the typical glass window should prove satisfactory. Therefore, radiographic inspections using 150 kVp or less SHALL use a beryllium window X-ray tube. The beryllium window and the resultant soft (low energy) spectrum SHALL also be used for the inspection of composite laminates. For example, a graphite-epoxy composite laminate 0.100-inch thick might require the use of an X-ray energy in the order of 10-20 kV for optimum sensitivity. (Reasonable exposures with standard portable X-ray equipment are often difficult below 25-30 kV.) It should be noted that, at X-ray energies of 15 kV or less, the air between the source and object would scatter the X-rays. If the X-ray equipment will operate that low, one way to displace the air is to stuff a helium-filled plastic bag between source and object.

6.2.5.2.3 Choice Of Focal Spot Size.

X-ray tubes are available with different focal spot sizes. The focal spot in an X-ray tube is the area of the target that produces the primary X-ray energy. (See Figure 6-9). The actual size of the focal spot is determined by the electron bombardment pattern on the target. The minimum size of this area is limited by the melting point of the target material and the concentration of the bombarding electrons per unit area. Tungsten is most often used as target material because of its high melting point, 6098 ° F, and high efficiency of x-ray production. An effort is made in X-ray tube design to achieve the smallest possible focal spot consistent with voltage and current required, melting temperature of the target material, and field coverage needed. The smaller the focal spot size, the sharper the radiographic image. It is normal to expect a focal spot size of the order of 2 to 10 mm (millimeters), in the voltage range of 100 to 2,000 kVp. For special application, equipment with focal spots less than 1 mm in diameter are available. X-ray tubes with dual focal spots are often used so the operator can choose the focal spot size and operational conditions compatible with the demands of inspection quality. New X-ray machines are also available with focal spots called mini-focus (spot size in the range of 0.2 to 1 mm) and micro-focus (spot size in the range of 0.002 to 0.025 mm). These new small focal spot X-ray units provide excellent image sharpness and can also be used to enlarge the X-ray image geometrically.

6.2.5.3 Equipment Protective Devices.

X-ray apparatus must be not only safe to use, but it must also be protected against damage through inadvertent misuse. To accomplish this objective, X-ray equipment should have protective devices as discussed in the following paragraphs.

6.2.5.3.1

The overload thermal circuit breaker usually incorporated in the main line switch, provides protection to the equipment should a component failure be encountered. This protection assures that the thermal circuit breaker will disconnect the unit from the power supply before extensive damage is done to the control or X-Ray head.

6.2.5.3.2

The over voltage protection circuit can be accomplished either by spark gaps set to arc at the over voltage point, or by means of a voltage sensitive relay in the control circuit of the high voltage section. Sometimes both methods are used since it is possible that under extreme conditions of surges the over voltage relay circuit may not react. This eliminates the possibilities of voltage damage due to operator carelessness or component failure.

6.2.5.3.3

There is also the possibility of inverse voltage damage in a high voltage X-ray circuit. This becomes a problem when the line conditions vary widely, as is possible when using X-ray equipment in shop, field or factories. A circuit called the inverse voltage suppressor, consisting of a resistor and rectifier network in the primary winding of the transformer, is used to protect X-ray equipment under these conditions.

6.2.5.3.4

An over-current fuse is used in the control circuit of the filament supply to prevent damage to the tube due to incorrect usage of the equipment or component failure. The alternative is to design components in which the combination of variables will not result in damage to the unit. This is not desirable when attempting to achieve maximum utility in a design.

6.2.5.3.5

Using the maximum safe working temperature of materials results in maximum efficiency from those materials. Therefore, it is necessary to prevent over-temperature to materials such as oil and solid insulation used in high voltage X-ray circuits. To accomplish this, an over-temperature thermostat installed in the X-ray head prevents damage to those materials.

6.2.5.3.6

When using gas as insulation material, it is also necessary to provide pressurestats in the X-ray head to prevent operation and consequent damage to the equipment should the gas pressure be below the safe level for insulation of the high voltage parts. Flow switches and pressurestats in the oil and water circulators are also used to prevent operation of the X-ray unit when proper cooling is not available for the unit. The degree of dependability of the equipment will be determined by the type of protection provided in the unit.

6.2.6 Considerations When Operating X-Ray Equipment.

6.2.6.1 Effect Of Focal Spot Size.

The area, or focal spot size, bombarded by the electrons affect the heat dissipation capabilities of the anode. This limits the tube rating or the milliamperes at which the tube may be safely operated.

a. Heat Dissipation. The method of removing heat from the X-ray tube anode affects the tube ratings. An X-ray tube dependent upon convection cooling has a lower limit of operation than the same tube where water or some other coolant is used to conduct heat away from the focal spot.

b. Operational Considerations. When a new X-ray tube is put into operation, it requires a warm-up period. A new tube may have been stored for a period of time and a very small amount of gas may have been released into the very high vacuum by the metallic parts within the tube. These gases can be driven back into the metal components by operating the tube at low kilovoltage and slowly heating the anode to high temperatures. Therefore a new X-ray tube should be energized at low kilovoltage, and the kilovoltage slowly increased until maximum rating has been obtained. The same procedure should be used when a unit has not been operated for 30 days or more.

6.2.6.2 Recalibration.

Recalibration should be accomplished when either a new tube or new components have been installed in an X-ray generator. Quite often technique charts need slight changes to compensate for the new conditions. This may be due to large quantities of tungsten that have been deposited on the inside walls of an old tube that increased the inherent radiation filtration. Differences in the filtration of different windows in the X-ray tubes may cause some small variations in radiation output. Due to the special equipment required to re-calibrate, this procedure is not normally performed at field level. Recalibration is desirable to insure that X-ray tube output falls within the tolerances specified in the manufacturers operations and maintenance manual. Failure to calibrate may result in over or under exposure of radiographs when following X-ray exposure techniques provided in the various aircraft/engine NDI inspection technical orders.

6.2.6.3 Tube Ratings.

Several variables affect the maximum rating of an X-ray tube. These should be carefully inspected to assure the X-ray tube rating is not exceeded. Some of the more important variables to be considered are listed below.

a. Focal Spot Size. The size of the focal spot usually dictates the milliamperes that can safely be conducted across the X-ray tube.

b. Method of Cooling. The method of heat removal from the anode affects the length of time the tube may be operated under a standard operating condition. The operation is extended by the use of external coolant.

c. Type Of Circuit. The type of circuit design used in the X-ray generator affects tube rating. Where self-rectified circuitry is used, the inverse voltage applied to the x-ray anode limits the operation of the tube. Usually, the maximum operating conditions are much greater where full wave circuitry is used, in comparison to self-rectified generators.

SECTION III
ISOTOPE RADIATION SOURCES

6.3 ISOTOPE RADIATION SOURCES.

6.3.1 Energy Spectra.

Radioactive nuclei emit gamma rays with discrete energy levels and a spectrum consists of a series of very sharply defined energies. As the atomic nucleus of a particular radioactive isotope disintegrates, well-defined decay schemes are followed. Further, it is important to be able to express the source strength and rate of decay.

6.3.2 Source Strength.

A new international unit for source strength is the Becquerel (Bq). The Becquerel is defined as one disintegration per second. Therefore, 1 curie (Ci) = 3.7×10^{10} Bq. The unit Becquerel has no relationship to the source volume or the quantity or type of energy of the radiation emitted. This term only has meaning when the particular radioactive isotope is known. For example, five Becquerels of cobalt-60 are not equivalent to five curies of iridium-192 because of different energy levels and decay schemes.

6.3.3 Focal Spot Size.

For isotopes the physical size of the radioactive source can be thought of as the “focal spot”. Since the Becquerel only relates the number of disintegrations per second, this unit has no relationship to the volume of mass or size of the radioactive source. The term "specific activity" is used to define the quantity of radioactivity of one gram of the substance and is expressed as Becquerels per gram. For a particular number of Becquerels, the dimensions of the radioactive source are governed by its specific activity. For radiographic applications a small source size is desirable to produce images with good resolution or sharpness, just as a small focal spot in an X-ray tube is required for high resolution radiographs. Large sources produce geometric distortion resulting in radiographs with poor definition. Effort is constantly being devoted to producing radioactive isotope sources with high Becquerel strengths in small volumes of material. Some special sources are stated as high specific activity, indicating a high radiation output relative to the source size. Nevertheless, in most isotopes the source size exceeds the focal spot size in X-ray tubes.

6.3.4 Decay Characteristics.

As radioactive material decays, there are a fewer number of unstable atoms left to decay and as time passes the radioactive material is becoming less and less radioactive. Different isotopes have different decay rates. If a single atom of an isotope existed, it would be impossible to predict at what moment in time it might disintegrate. But if large numbers, of atoms exist, it is possible to measure the lapse of time required for one atom out of every two to disintegrate. This is called the half-life of an isotope. The half-life is defined, as the time required for an isotope to decay to one-half of its original radioactivity.

6.3.5 Isotope Sensitivity.

WARNING

The radiation levels at the surface of the shielded container are hazardous to personnel over prolonged periods of contact.

CAUTION

Undeveloped film shall not be stored in the immediate area of the shielded container.

Radiographic definition obtained with isotope sources is usually of lower quality than that obtained with X-rays because of:

a. Focal Spot Size. Usually isotope sources have a larger focal spot size than X-ray tubes in order to have a sufficient quantity of radiation to prevent very long exposure times.

b. Fixed Radiation Energy. Isotopes emit radiation with an energy characteristic of that particular radioactive material. Therefore, the operator has no choice of radiation energy, and it is not always possible to select the radiation energy compatible with the absorption characteristics of the part being inspected.

c. Exposure Techniques. Exposure times are important and often isotopes are weak in radiation output, and source-to-film distances must be decreased to reduce exposure times. This leads to poor definition.

6.3.6 Isotope Cameras.

Isotopes emit their radiation continuously and cannot be shut off or stopped like an X-ray generator. These isotopes are stored in a radiation shielded container to reduce the radiation to a level safe for unprotected personnel when not making radiographic exposures. The shielded container must be designed so that the radioactive isotope can be remotely positioned for the radiographic exposure. Many schemes have been devised for remote handing of isotopes. Source holders, commonly called isotope cameras, generally are of two typical designs. The simplest cameras are designed for direct beam radiography, and the source is only allowed to produce a restricted conical direct beam. The container itself is used to absorb radiation that in not emanating from the window or port. Some units are designed so that opening and closing can be accomplished at a remote distance. The other types of isotope cameras are normally used for circumferential radiography. These are devised to move the source from its shielded container to a point some distance away and then, upon completion of exposure, return the source to the container. In the latter types of cameras the radiation is being emitted in all directions.

6.3.7 Maintenance.

NOTE

In the event of any malfunction, the appropriate equipment service manual shall be consulted.

All man-made radioactive isotopes are under the jurisdiction of the Nuclear Regulatory Commission (NRC). A license is required to purchase and use these isotopes. The Air Force possesses a Master Materials License from the NRC. In order to obtain sources at base level, contact the base Radiation Safety Officer (RSO). Normally the base RSO is the Bioenvironmental Engineer (BEE). The base RSO will help obtain a permit from the USAF Isotope Committee, the regulatory body within the Air Force. Each permit will give specific requirements for any radioactive isotope used for radiography.

SECTION IV
RADIOGRAPHIC FILM

6.4 FILMS, FILM HOLDERS AND SCREENS.

6.4.1 Films.

6.4.1.1 Function.

Films can be used as a recording medium because their emulsions are sensitive to the quantity and the energy of electromagnetic radiation over a wide spectral range. In the photographic process, the electromagnetic radiation of the visible spectrum is focused by a lens upon the film surface to record the variations of light intensities and form an image. In radiographic applications, the radiation is of such high energies they cannot be focused by a lens. In radiography, a shadowgraph of the test object is formed by recording the variations in radiation quantities caused by absorption and scattering by the test specimen. After final processing, film that has been exposed with X or gamma rays is called a radiograph; film exposed by using a radioisotope may be called a gammagraph. The term radiograph is used throughout this chapter. Films are an excellent recording medium with a very high signal-to-noise ratio and high amplification. Real-time, radioscopic electronic devices cannot match the excellent recording characteristics of film. This section describes how films work, reviews how films respond to radiation, and discusses radiographic paper.

6.4.1.2 General Theory of Industrial Radiographic Film.

Films consist of a base material coated with an emulsion containing the radiation-sensitive silver-halide crystals, which are usually silver bromide. Most modern films have a polyester base which is either transparent or has a slightly blue tint. The polyester is very durable, does not absorb water or processing chemicals, and is dimensionally stable dries easily, and will not support combustion. Figure 6-11 shows schematically the structure of radiographic films.

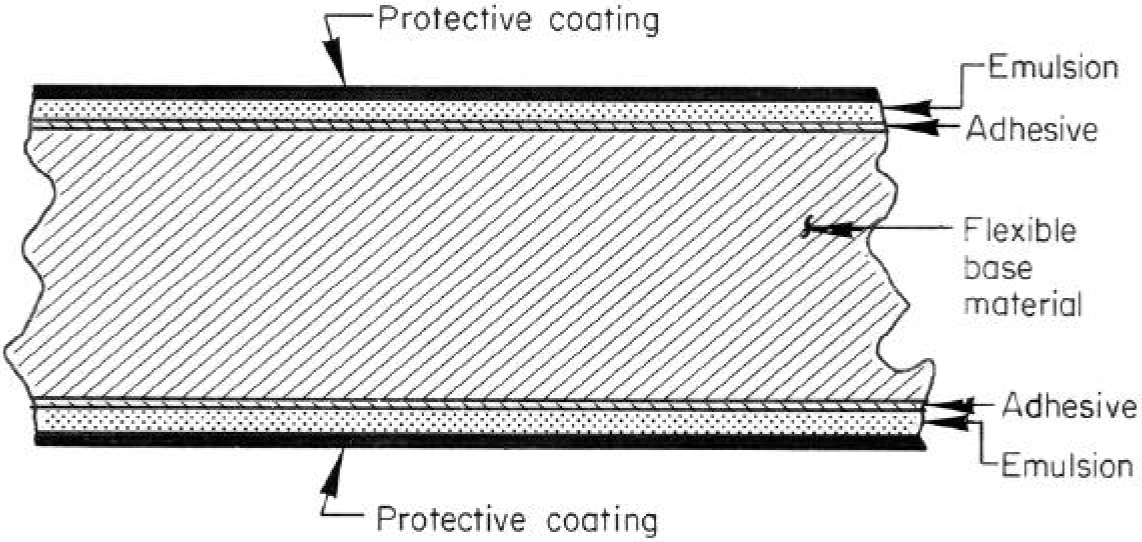


Figure 6-11. Sketch of Cross Section of X-Ray Film

6.4.1.2.1 Emulsion.

The emulsion consists of a gelatin material containing an even distribution of the radiation-sensitive silver bromide crystals or grains. This emulsion is coated on the polyester base in very thin layers, usually about 0.001 inch in thickness. Most X-ray films have double emulsions, i.e., are coated on both sides of the base material. Since the thin support material offers very little absorption to the X-rays normally used for industrial applications, the double emulsions essentially reduce exposure requirements to one-half that required for a single emulsion. However, some films, intended for radiography in which visibility of the smallest detail is required, have emulsion only on one side.

6.4.1.2.2 Latent Image.

The latent image is formed by interactions of the electromagnetic radiation with the silver bromide crystals. When solid silver bromide is formed in the manufacture of film, the silver atoms give up an orbital electron to a bromine atom. Since the silver atoms have given up an electron, they have a positive electrical charge and are silver ions (Ag+). The bromine atoms have acquired this negative electron and have become bromide ions (Br-). The silver bromide crystal is a cubical array of the silver and bromine ions. The cubical crystalline structure of the silver bromide crystal is not perfect; if it were, the photographic process could not exist. Within the crystal lattice structure are extra silver ions called interstitial ions; these do not occupy a lattice position in the crystal. There are also foreign molecules or dislocations (distortions) of the crystal array within the crystal, all of which form latent image sites.

6.4.1.2.2.1

The accepted theory of the formation of the latent image (that is, an image which may be revealed by development) in a photosensitive emulsion is based upon the Gumey-Mott concept of exposure. It is theorized that the formation is a two-step process. The electromagnetic radiation ejects an electron from the negatively charged bromine ion in the crystalline structure, thus converting the ion into a bromine atom. The free electron can travel within the crystal to a dislocation or other latent image site where it is trapped, establishing a negative electrical charge at that point. This negative electrical charge attracts one of the positively charged interstitial silver ions to the latent image site. When the silver ion reaches the image site, its positive charge is counteracted by the negative electron and it becomes neutralized and exists as a silver atom. The latent image site is now electrically neutral. The process may be repeated several times, adding silver atoms to the latent image site in the crystal. These few silver atoms act as a catalyst to the reducing action of the developer, thus making the entire emulsion grain susceptible to conversion to metallic silver in development.

6.4.1.2.3 Development.

The developing agent selectively reduces those crystals containing latent images into black metallic silver but has a much smaller effect on those crystals that have not been exposed. The metallic silver is opaque and forms the radiographic image.

6.4.1.2.4 Image Quality.

Microscopic variations in the response of film to the incident radiation produce effects of considerable practical significance. The number of sites at which the silver atoms can respond to the radiation vary in location throughout the emulsion and are inversely proportional to the size of the silver bromide grains. Thus, after exposure to radiation, the density of the image will vary. The larger the number of sites activated by radiation, the larger the number of silver atoms per unit area, and, from statistics, the smaller the density variations. The practical factors are:

a. Graininess. The graininess of the film is the visual impression of non-uniformity of density in a radiographic image. In general, graininess increases with increasing film speed and with increasing energy of the radiation. Apart from the visual appearance of graininess, the effect may be subjected to physical measurements in which case the property measured is referred to as "granularity." This latter term has been adopted as an expression for physical measurements of the statistical fluctuations of density over the area of a photographic emulsion. Granularity measurements are obtained by scanning a sample of emulsion by a small spot of light (diameter of the order of 0.08 mm) and recording the resulting irregular fluctuations of the transmitted light. (See Reference 8).

b. Signal-to-Noise Ratio. The accidental variation in image density makes it more difficult to identify the deliberate variation in image density that results from use of the film. The relationship between the two density variations is known as the signal-to-noise ratio. For threshold visibility of detail, this ratio must be at least 5.

6.4.1.3 Types Of X-Ray Films.

Various types of X-ray films are available that vary in signal-to-noise ratio, speed of response to radiation, and graininess. It is most appropriate to classify X-ray film in relation to their signal-to-noise ratios. Very fine-grained films have a very high signal-to-noise ratio, require comparatively large quantities of radiation for exposure and produce images with excellent resolution of detail. In the choice of a particular film, a tradeoff must be made between resolution and speed of exposure. The criticality of an inspection will determine this tradeoff. Some commonly used X-ray films are classified as follows:

a. Class 1: This class has the highest signal-to-noise ratio and includes such films as Agfa D2, Kodak Type R, and Fuji IX 25. These are, considered high detail resolution films and should be employed when the most sensitive radiograph is desired.

b. Class 2: This class is considered as high in signal-to-noise ratio and includes such films as Agfa D4, Kodak Type M, and Fuji IX 50.

c. Class 3: These films have a moderate signal-to-noise ratio and include Agfa D5, Kodak Type T, and Fuji IX 59 with screen.

d. Class 4: These high-speed films, by comparison, are considered to have a low signal-to-noise ratio and include Agfa D7, Kodak Type AA, and Fuji IX 100.

6.4.1.3.1.1

This classification differs from others because it is based upon the signal-to-noise ratio rather than speed. Figure 6-12 is a bar chart showing the relationships of signal-to-noise ratios, film speed, and detail resolution capabilities of the different film classes. Table 6-3 and Table 6-4 are a more detailed guide to film classification. It is not inclusive of all the film types or manufactures that may be authorized for use since manufacturers may introduce new films from time to time. Specific inspection instructions may specify film other than what is listed. Each manufacturer has a particular designation for films. Small variations may be noted in film speed and contrast of the films made by the different manufacturers within a particular class.

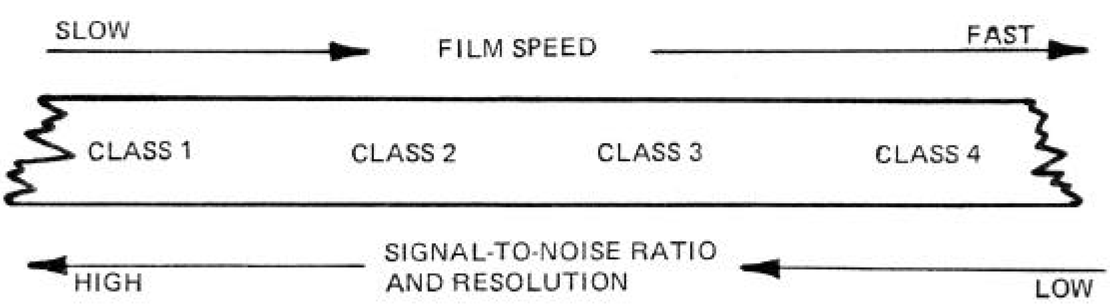


Figure 6-12. Relationship between Signal-to-Noise Ratios and Speeds of Film.

NOTE

These classifications are for the film system, that is, the film plus the associated film-processing requirements according to the criteria established by the manufacturers of the film and processing chemicals.The classifications previously listed in T.O 33B-1-1 approximately corresponds to the new film system classifications as follows:

a. Class 1 ð ASTM Class Special
b. Class 2 ð ASTM Class I
c. Class 3 ð ASTM Class II
d. Class 4 ð ASTM Class III
e. Exceptions include films followed by an arrow (á); they are the equivalent of one class higher in the new system classification compared to the previous T.O. 33B-1-1 classification.

Table 6-3. Film Classes.

	System Class			
Manufacturer	**Special**	**I**	**II**	**III**
Agfa	D2	D3 D4 D5(á)	D7 (á)	D8
Fuji	IX25	IX 20 IX 50 IX 80	IX 100	IX 150
Kodak	DR	M MX 125 T (á)	AA400 (á)	CX

The following table includes the ISO speed and signal-to-noise ratio for each film type.

Table 6-4. Speed and Signal to Noise Ratio.

	Class											
	Special			I			II			III		
Man-ufacturer	**Type**	**Speed**	**S/N**	**Type**	**Speed**	**S/N**	**Type**	**Speed**	**S/N**	**Type**	**Speed**	**S/N**
Agfa	D2	40	371	D3 D4 D5(á)	64 100 200	294 232 169	D7 (á)	320	142	D8	400	114
Fuji	IX25	50		IX 20 IX 50 IX 80	25 100 200		IX 100	320		IX 150	500	
Kodak	DR	32	378	M MX 125 T (á)	80 125 200	320 220 209	AA400 (á)	320	140	CX	400	124

6.4.1.3.2

As an example of the effect of signal-to-noise ratios caused by film grain size, Figure 6-13 shows a microdensitometer trace across the radiographic images of a series of small wires made through one inch of aluminum. All exposure parameters were a constant except exposure time, which was varied to compensate for the three different film speeds. The ratios between the trace amplitudes for the wires and the respective backgrounds indicate the signal-to-noise ratios for Class 1, Class 2, and Class 4 radiographic films. Note the higher frequency content of the Class 1 film, indicating its greater detail resolution capability.

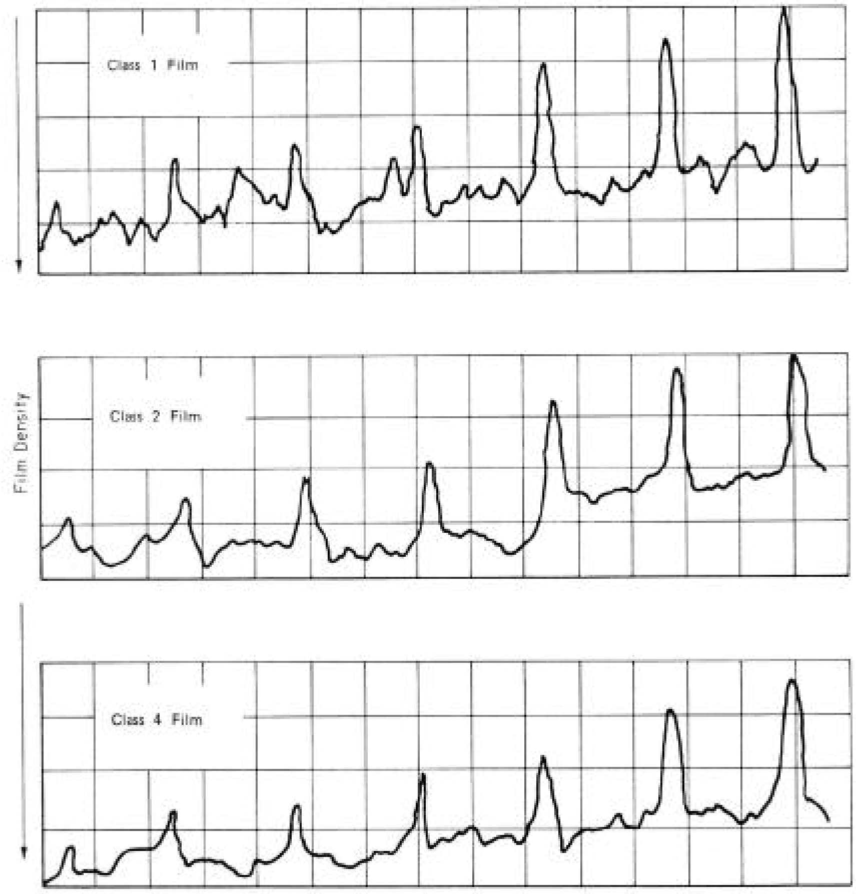


Figure 6-13. Microdensitometer Tracings of Images of DIN Wire Penetrameters.

6.4.1.3.3

Another way to classify film is according to film speed. Table 6-5 lists the approximate relative speeds of radiographic films exposed to radiation energies between 100 and 150 keV.

Table 6-5. Relative Speeds of X-ray Films Exposed at 100 kVp.

Film Designation	Relative Film Speed*
Agfa	
D8	3.7
D7	2.7
D6R	1.5
D5	1.7
D4	1.0
D3	0.75
D3 (single coat)	0.28
D2	0.28
Kodak	
AA	3.1
T	2.07
B	2.0
M	1.0
R	0.4
R (single coat)	0.2
Fuji	
IX150	3.6
IX100	2.0
IX80	1.0
IX59	.8
IX50	0.5
IX29	0.4
IX25	0.36
* Film speed numbers should be compared only within a single manufacturer.	

6.4.1.4 Film Density.

The characteristic curves (see Paragraph 6.4.1.6) are used to relate the action of exposure to radiation on a film, which becomes apparent in varying degrees of blackening in the processed film. In photographic usage, density is a measure of the degree of blackening of the processed film caused by exposure to radiation. The term exposure as used in this section refers to the amount of radiation energy reaching a particular area of the film. It could be expressed as ergs per square-centimeter, but is more convenient for practical use when expressed in terms of dimensionless relative units, one particular exposure value being used as a reference for other exposures. Film density is the logarithm of the reciprocal of the fraction of light transmitted through the film with respect to the light incident on the film:

$$D = \log \frac{I_0}{I_t}$$

Where:

D = film density.
I_0 = original light intensity falling upon one surface of film.
I_t = light intensity transmitted through the film.

For example, an increase in the amount of blackening from one area of a particular film to another that reduces the proportion of the incident light transmitted from 50 to 25 percent would cause the film density to change from 0.3 to 0.6.

6.4.1.4.1

Table 6-6 shows more examples of typical relationships between light transmission and density. A typical density used in practical radiography is 2.0 and represents one- percent transmittance.

Table 6-6. Relationship of Light-Transmission to Film Density.

Transmittance (I_t/I_0)	Percent Transmittance $(I_t/I_0) \times 100$	Opacity (I_0/I_t)	Film Density $\text{Log}_{10}(I_0/I_t)$
1.00	100	1	0
0.50	50	2	0.3
0.25	25	4	0.6
0.10	10	10	1.0
0.01	1	100	2.0
0.001	0.1	1,000	3.0
0.0001	0.01	10,000	4.0

6.4.1.5 Logarithms for Density and Exposure Calculations.

Logarithms are used extensively in X-ray exposure calculations and in the measurement of X-ray film density. Therefore, it is required that radiographers be sufficiently familiar with logarithms so that they can perform some simple calculations. A brief review of logarithms and their use is therefore included here. More detail can be found in various handbooks and intermediate mathematics texts. Logarithms are used because they provide a convenient method of handling very large ranges of numbers, and they reduce calculations involving multiplication and division to addition and subtraction. The logarithm is the power (or exponent) to which the base must be raised to give the original number. Logarithms may be taken from any base; however, most calculations in radiography involve either the base 10 or the base e (2.718). Logarithms to the base 10 are indicated by "log *x*," and logarithms to the base e are denoted by "ln *x*." For the moment, let us consider logarithms to the base 10: log 100 = 2, because $10^2 = 100$. Similarly, the logarithm of 1,000 is 3 or: log 1,000 = 3, since $10^3 = 1{,}000$. The logarithms of all numbers that are integer powers of 10 (i.e., 10, 100, 1,000, etc.) are whole numbers (1, 2,3, etc.). Logarithms of other numbers are decimal numbers and are found in tables of logarithms or calculated on some hand calculators. A table of four-place logarithms to the base 10 is given in Table 6-8. The logarithm is made up of two basic parts, the "characteristic", which is the number before the decimal point and the "mantissa", which is the number after the decimal point. The characteristic indicates the order of magnitude of the number x; for example, numbers 10 through 99 have a characteristic of 1. Characteristics for other ranges are given in Table 6-7. The mantissa is determined by the digits of the number. In Table 6-8, the mantissa of 328, for example, is found by going to the number 32 along the left hand side and looking across that row under the column marked "8." We see in the table that the mantissa of 328 is given as 5159. What is the logarithm of 328? From Table 6-7, it can be seen that the characteristic of 328 would be 2. Therefore, log 328 is equal to 2.5159.

Table 6-7. Characteristics of Logarithms

Number	Characteristic
1	0
10	1
100	2
1,000	3
10,000	4

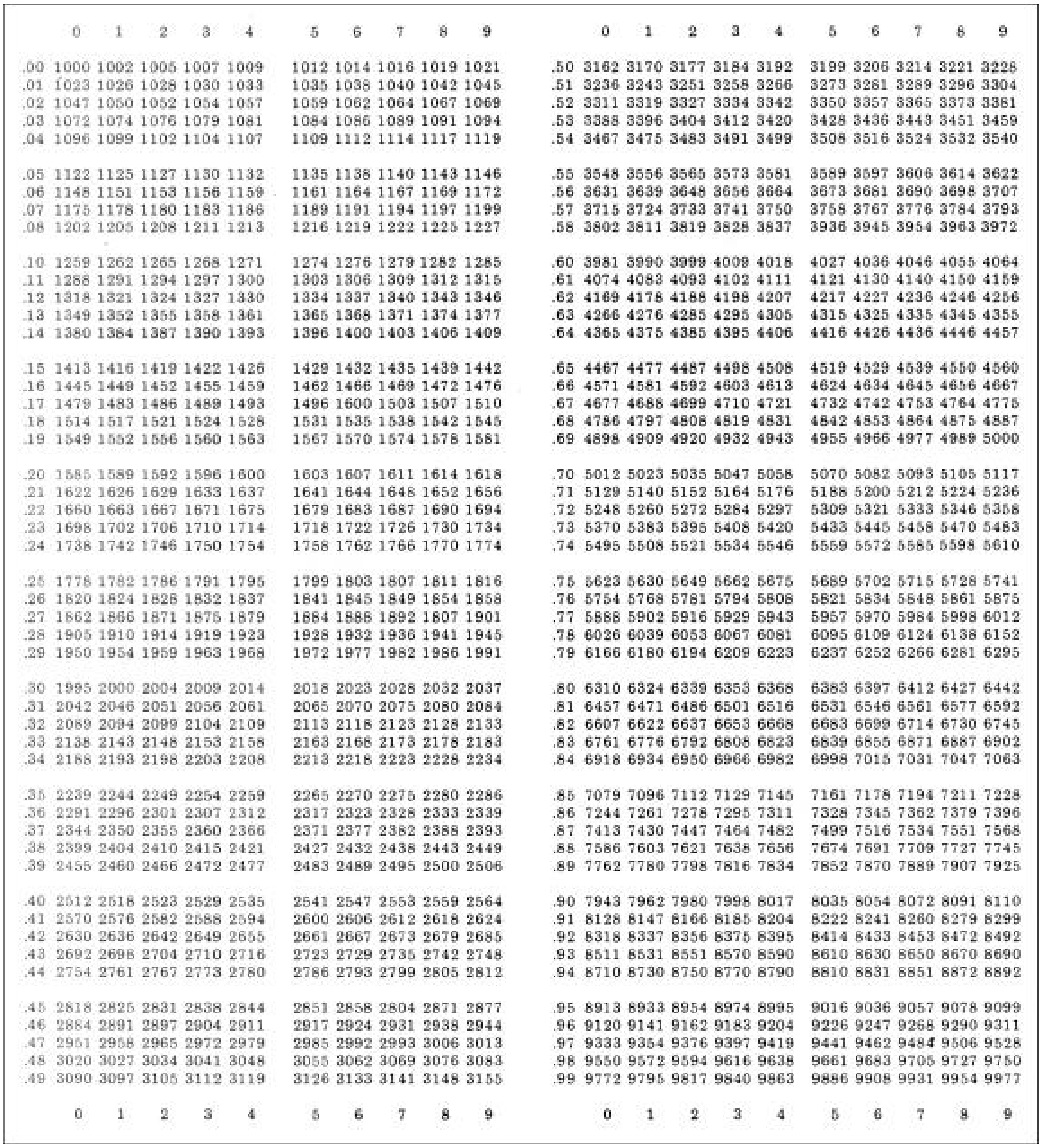
Note: The value of the characteristic is one less than
the number of digits in the number.

Table 6-8. Four-Place Logarithms to the Base 10.

N	0	1	2	3	4	5	6	7	8	9		0	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846
16	2041	2048	2095	2122	2148	2175	2201	2227	2253	2279	61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340
41	6128	6138	6140	6160	6170	6180	6191	6201	6212	6222	86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440
43	6335	6345	6355	6365	6375	6484	6493	6503	6513	6522	89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773
50	6990	6908	7007	7016	7024	7033	7042	7050	7059	7067	95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996
N	0	1	2	3	4	5	6	7	8	9	N	0	1	2	3	4	5	6	7	8	9

*Interpolation in this section of the table is inaccurate.

Table 6-9. Antilogarithms.



	0	1	2	3	4	5	6	7	8	9
.00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021
.01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045
.02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069
.03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094
.04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119
.05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146
.06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172
.07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199
.08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227
.10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285
.11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315
.12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346
.13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377
.14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409
.15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442
.16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476
.17	1479	1483	1486	1489	1493	1496	1600	1503	1507	1510
.18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545
.19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581
.20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618
.21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656
.22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694
.23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734
.24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774
.25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816
.26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858
.27	1862	1866	1871	1875	1879	1884	1888	1892	1807	1901
.28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945
.29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991
.30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037
.31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084
.32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133
.33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183
.34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234
.35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286
.36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339
.37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393
.38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449
.39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506
.40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564
.41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624
.42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685
.43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748
.44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812
.45	2818	2825	2831	2838	2844	2851	2858	2804	2871	2877
.46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944
.47	2951	2958	2965	2972	2979	2985	2992	2993	3006	3013
.48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083
.49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155
.50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228
.51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304
.52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381
.53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459
.54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540
.55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622
.56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707
.57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793
.58	3802	3811	3819	3828	3837	3936	3945	3954	3963	3972
.60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064
.61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159
.62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256
.63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355
.64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457
.65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560
.66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667
.67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775
.68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887
.69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000
.70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117
.71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236
.72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358
.73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483
.74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610
.75	5623	5630	5649	5662	5675	5689	5702	5715	5728	5741
.76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875
.77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012
.78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152
.79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295
.80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442
.81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592
.82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745
.83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902
.84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063
.85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228
.86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396
.87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568
.88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745
.89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925
.90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110
.91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299
.92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492
.93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690
.94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892
.95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099
.96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311
.97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528
.98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750
.99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977
	0	1	2	3	4	5	6	7	8	9

Table 6-10. Effect of Relative Exposure on Film Sensitivity.

Change in Relative Exposure	Change in Density
0.5 to 1.0	0.3 to 0.7
1.0 to 1.5	0.7 to 1.5
1.5 to 2.0	1.5 to 3.0

6.4.1.5.1
Logarithms provide a convenient method of multiplying and dividing. To multiply two numbers, you take the logarithms of both numbers and add them to get the logarithm of the product. To obtain the product, you then take the antilogarithm of this sum. The antilog is the inverse function of the log. In other words, the antilog of x is equal to 10^x. Table 6-11 lists the antilogs for mantissas of 0.000 to 0.999. The value of x is then obtained by properly placing the decimal point according to the characteristic of the sum of the logarithms.

Example: Multiply 20 times 8 using logarithms.

(1) Take the log of 20: log 20 = 1.3010

(2) Take the log of 8: log 8 = 0.9031

(3) Take the sum of these logarithms: 1.301 + 0.9031 = 2.2041

(4): Take the antilog of the sum:
The antilog of 0.2041 = 1600
The characteristic of 2 indicates a number between 100 and 999.

Therefore the answer is 160.

This of course is the answer that we expected. In this example, the regular mathematical calculation is simpler. However, with very large numbers, the use of logarithms significantly simplifies calculation.

6.4.1.5.2
Division is accomplished by taking the difference between the logs of the two numbers.

Example: 6/73 = antilog (log 6 - log 73).

6.4.1.5.3
In radiography, logarithms find particular use in the preparation of exposure charts and in film characteristic curves which plot film density against relative exposure as explained in paragraphs 6.4.1.6. Logarithms to the base 10 may be converted to natural logarithms by the equation $\ln x = 2.3 \log x$.

6.4.1.6 Characteristic Curve.
The characteristic curve is the response of a type of film to radiation of a particular energy. It is obtained by plotting the film-image density against the logarithm of relative exposure. Since density is a logarithm, log-log scales are used for the plot. Log-log scales not only make interpretation of the graph easier, but also the all important values of relative exposure can be derived easily by subtracting one logarithm value from another. Study of Figure 6-14, shows that at low exposures, a large change in exposure is needed to produce a significant change in density. As the relative exposure increases, the film emulsion becomes more sensitive and the same exposure change produces a greater density difference. The gradient (slope) of the curve in Figure 6-14 increases with increasing exposure. At very high values the gradient may start to decrease; that is, the film again becomes less sensitive. However, this effect, although common with medical film, is not often encountered in industrial radiography. The term used to refer to the gradient of the characteristic curve is "film contrast."

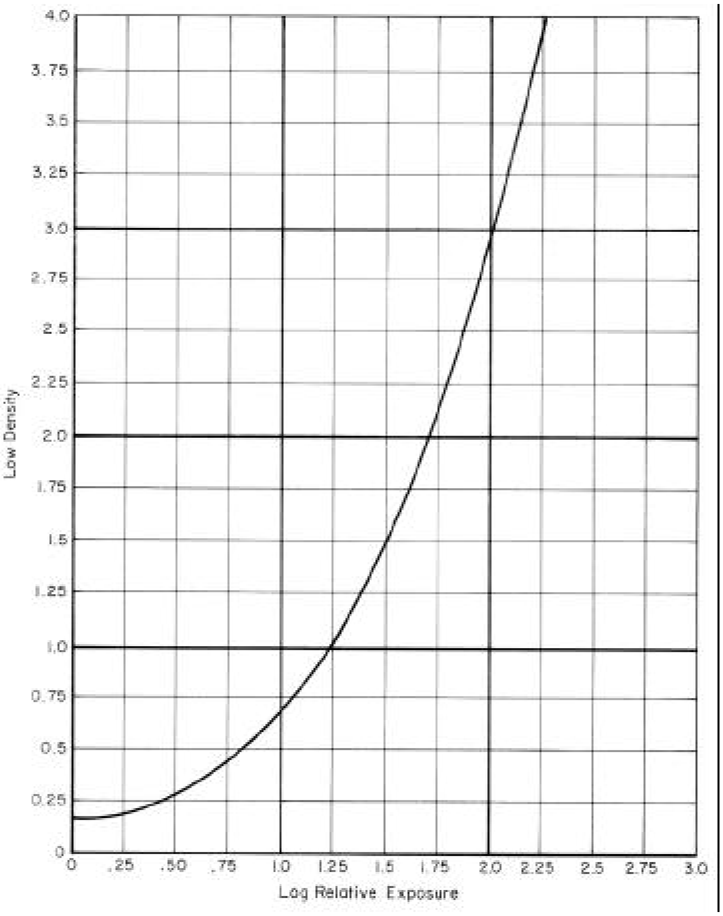


Figure 6-14. Typical Characteristic Curve

6.4.1.6.1
The significance of the characteristic curve is that it shows that, within limits, a dense film is more sensitive to small variations in exposure than a light film. Therefore, the dense film better shows small changes in subject contrast due to discontinuities and geometric changes in the part. Characteristic curves can also be used to calculate exposure changes needed to optimize a technique when altering film type or desired density.

6.4.1.7 Film Speed.
Film speed is a factor in determining the amount of radiation that a film must receive to obtain a given density. This speed is usually measured relative to some standard. Generally, film speed varies with film grain, the larger grain film being faster and the smaller grain film being slower. While film speed is sometimes an important consideration for economy, normally the prime consideration is resolution of details. High-speed films, i.e., films with low signal-to-noise ratios, should only be used when they are capable of meeting the resolution requirements of the inspection. Where high-detail resolution is required, the slower, higher signal-to noise ratio films should be used without exception.

6.4.1.8 Film contrast.
Film contrast is a measure of the difference in film density due to exposure to different amounts of radiation. When exposed beneath a step wedge, a film with low contrast would show only minor changes in image density between one step and another. A film with high contrast exposed under identical conditions would show sharply graduated changes in image density between steps. The efficiency with which the emulsion responds to an increment in exposure varies with the absolute value of the exposure. If a radiograph has high contrast, small differences in light transmission are high and readily discerned by the eye; thus the image will reveal small discontinuities in the subject. The consequence

is that a film makes more visible small discontinuities in the specimen when the image is dense. Image densities of 2.0 or more are usually recommended or required for high sensitivity to discontinuities in critical areas of parts. This will be discussed further in a later section. Film contrast should be distinguished carefully from subject contrast (a flat sheet specimen will give negligible contrast with any film). Subject contrast is affected by X-ray kilovoltage or gamma-ray characteristics.
In summary, the overall image contrast with any given specimen will depend upon:

a. Kilovoltage of X-ray beam or characteristics of gamma radiation.

b. Type of screens used.

c. Image density.

d. Processing conditions.

e. Film contrast.

6.4.1.9 Latitude.

The film characteristic that is the reverse of contrast is film latitude. The higher the contrast, the smaller the latitude; the lower the contrast, the greater the latitude. Latitude is, therefore, the range of radiation intensities that a film is capable of recording. Latitude is also the term used to indicate the range of material thicknesses that can be visualized in the final image. Often in the radiography of castings or circular rods, where it is necessary to visualize a large range of thicknesses, wide latitude is desirable.

6.4.1.10 Storage of Unexposed Film.

Film emulsions are sensitive to heat, humidity, and certain chemical fumes. Because of this harmful effect, unexposed film should be stored in a cool (below 75°F), dry (relative humidity below 60 percent) area remote from stray background radiation. It is possible to refrigerate films for additional protection, but if this is done, the film shall be brought to ambient temperatures before use. Film emulsions are also pressure sensitive and film packages shall be stored on edge rather than flat. X-ray film is sensitive to the cosmic radiation that exists everywhere. This radiation will cause fogging. Fog is the darkening of the radiograph by scattered radiation, exposure to light, or pre-exposure to radiation. It can also be caused by over-development or aging. It should be noted that fog brings no information to the film and merely creates a high background that reduces contrast and image visibility. The very high-speed films, being more sensitive to exposure, are more susceptible to fogging than the slower emulsions.

6.4.1.11 Expiration Dates of Radiographic Film.

An expiration date is marked on the film boxes at the time of manufacture. To prevent exceeding the expiration date, film should be ordered in quantities such that long-term storage is not necessary. The inventory of film should be rotated in such a manner as to use the older film first. Film that exceeds its “shelf life” date shall not be put in salvage. Its usability will be verified by first processing an unexposed sheet to determine clearing and fog level. Then, if the clearing and fog level are satisfactory, make a radiograph of a step-wedge and penetrameters to determine the sensitivity and contrast of the film in question. If these limits are acceptable, continue using the film and extend its shelf life by six months, utilizing AF Form 2032. At the end of the extended period re-verify the film using the aforementioned procedure. If the film does not meet acceptable quality levels, use the film for training, for clearing the automatic film processor, for detection of foreign objects, or should the quantity warrant ship it to the Air Education and Training Command (AETC) at NAS Pensacola for use at the NDI Technical Training School. For Navy and Marine Corps send film to NAVAL AIR Technical Training Center (NATTC) ATTN: NDI School, 230 Chevalier Field AVE, Pensacola, FL 32508. If after a one-year period past its original shelf life the film is not used, it will be considered unacceptable for crack detection and will be utilized for the alternate purposes mentioned. X-ray films present no greater fire hazard in storage in the X-ray laboratory and filing room than an equal quantity of paper records. There is no necessity for expensive vaults, equipped with elaborate fire protection devices. The storage area must be kept reasonable clean.

6.4.1.12 Film Identification.
It is necessary to identify exposed film so as to be able to identify its subject. Methods are:

a. Lead lettering.

b. Lead tape inscribed with ballpoint (low energies only).

c. Metal die stamp to impress the film (after processing).

d. Stick-on labels (after processing).

e. Thin lead sheet impressed with metal die stamps.

6.4.2 Cassettes and Film Holders.

NOTE

Films should not be left in cassettes or film holders more than 24 hours, due to interaction between films and lead screens.

Cassettes and film holders are used to protect the film from light exposure while the film is being transported and while it is being exposed. These film holders are of various designs made to hold the various film sizes.

6.4.2.1 Film Cassettes.
The term cassette is usually applied to rigid film holders. Cassettes have a bakelite or magnesium front to allow transmission of the X-rays; the back contains a lead foil lining to absorb the back-scattered radiation. Cassettes are normally used with calcium tungstate or lead screens. They provide uniform compression on the film and screens to assure good physical contact between the film and screen for ultimate in image sharpness. Cassettes are comparatively heavy and somewhat difficult to handle.

6.4.2.2 Cardboard Holders.
Cardboard holders are used extensively in industrial radiography. These are simply a heavy Kraft paper envelope between hinged cardboard covers. The back has a lead foil lining to absorb back-scattered radiation. Always place the holder with the "tube side" marking toward the radiation source. If the holder position is reversed, the radiation is filtered by the lead foil backing and will result in images of lower density. The cardboard holders are economical and durable. Lead screens can be inserted into the envelope with the film for making lead screen radiographs. Intimate film-screen contact is normally accomplished by placing the object to be inspected on the cardboard holder.

6.4.2.3 Flexible Film Holders.
Flexible film holders are used where it is necessary to contour the film to accomplish good film-to-test-object contact. However, sharp bends should be avoided. These holders are made of a lightproof flexible material. Lead screens with a rubber or vinyl backing are available to permit contouring and flexible positioning of the film for exposure.

6.4.2.4 Vacuum Cassettes.
Vacuum cassettes are especially useful when used in conjunction with lead or fluorescent screens. The air is pumped out of these cassettes, insuring intimate film-screen contact. They are very flexible, allowing the film to be positioned in a confined space.

6.4.2.5 Application of Cassettes and Film Holders.
Plain film holders are generally used to radiograph thin sections of materials at low kilovoltage, 150 kVp or lower. The sensitivity is reduced when using plain holders on thick sections due to backscatter. Using film holders with a lead sheet backing will reduce the backscatter. At kilovoltages lower than 30 kVp, standard film holders cannot be used

because the cardboard will show on the radiograph. For lower kilovoltages, holders can be made from vinyl or Mylar materials. A lead sheet can be taped to the back to reduce backscatter. Film holders can be taped in place or secured in any way that will not affect the radiograph adversely. Cassettes give better film-to-screen contact and are often used without a screen. Lead screens can be used with film holders but care must be taken to maintain even film-to-screen contact. In any critical exposure the use of cassettes is recommended.

6.4.2.6 Labeling Of Film Holders.

Do not at any time write information using a ballpoint pen or other sharply pointed writing instrument on the surface of any cassette or film holder. Film artifacts will be produced which will affect radiographic interpretation. If identification is required use self-adhering labels on which the necessary information is recorded before applying to the cassette.

6.4.2.7 Bending or Kinking of Film Holders.

Do not bend or kink the film holders unless absolutely necessary for placement of film for exposures. Artifacts may be produced which could impair interpretation of the radiograph. Use smaller or custom shaped film for better fit to part if required.

6.4.2.8 Preparation of Film Holders.

a. Remove other materials from the workspace.

b. Before loading the film holder open it and examine for cleanliness and light leaks. Discard any film holders that are physically damaged beyond repair. Many light leaks may be repaired with black photographic tape. Remove any lint or dust with a clean cloth. Do not blow the dust out since moisture may lodge on the holder and be transferred to the film

c. Place the film selected and film holder in a convenient location in the darkroom. If screens are used, place them in a handy spot to simplify loading of the film holder.

d. If a screen is used, place it in the film holder face upwards so it will contact the film.

6.4.2.9 Loading Of Film Holder.

NOTE

Do not allow the film to slide into the holder pocket. Scratches from the holder, screen or paper may result.

The procedure that follows covers only one type of film holder. Different film holders vary in the method of locking and opening but the same procedure will apply except for these details.

a. Open the inner folded cover all the way.

b. Withdraw the film from the film box with paper cover in place. Handle the film only at the edges with light finger pressure.

c. Grasp one side of the paper cover to open it. Place the film so the free end is against the rear edge of the holder. Lower the film slowly and allow the film to fall gently into the holder and remove the paper.

d. Refold the inner paper cover.

e. Close the holder cover taking care that the lead screen on the cover enters the holder pocket without binding. Some holders may not have a lead screen on the cover. In this case when the use of the screen is desired, place it in the holder pocket face downward.

f. Lower the holder cover and fasten the locking device. If the holder has a spring back, turn the latch to lock the holder.

6.4.2.10 Prepackaged Film.

X-ray film suppliers offer X-ray film in prepackaged, flexible envelopes or in rolls. The prepackaged film eliminates the film loading operation in the darkroom. They are available with double films loaded in the same package, and with a lead compound screen absorber incorporated in the package. They are convenient to use and are preferred for many industrial applications. Prepackaged film is especially convenient for field inspection.

6.4.3 Screens.

In industrial radiographic applications, screens are often used in direct contact with the X-ray film. The term screens refers to a layer of a material whose purpose is to increase the imaging radiation impinging on the film and/or decrease the scatter radiation reaching the film. There are two types of intensifying screens, fluorescent and lead.

6.4.3.1 Fluorescent Screens.

6.4.3.1.1 Principles.

The fluorescent screens are made of calcium tungstate crystals or other crystals of chemical salts that fluoresce (emit visible light) when bombarded by X-rays. These materials have the ability to convert X radiation into electromagnetic photons in the visible light of ultraviolet spectrums. The light emanating from the fluorescent screen exposes the film emulsion and supplements the original X radiation. Fluorescent screens can reduce the quantity of radiation necessary to produce a given film density by a factor of 8 to 100. However, they also cause image noise and unsharpness because of the spreading effect of the visible light emitted from the screen. Fluorescent screens produce radiographic images of inferior quality. For this reason, their use is usually limited to those situations where exposure speed is more important than image quality, or where the radiation quantity available is inadequate to perform the task. Whenever there is a need to perform a radiographic inspection using a combination of screens and film, they SHALL be of the same plane dimensions and in close contact with each other during exposure.

6.4.3.1.2 Care.

Fluorescent light from intensifying screens obeys all the laws of visible light and cannot pass through opaque bodies, as do X-rays. To avoid extraneous shadows caused by absorption of the fluorescent light by foreign matter during exposure, do not allow dust and dirt particles to collect between film and screen surfaces. Stains upon the screens must also be avoided. Make every effort to keep the screens clean. Calcium tungstate screens may be stored in the processing room but away from chemicals and other sources of contamination.

6.4.3.2 Lead Screens.

6.4.3.2.1 Description and Use.

Lead (Pb) foil and lead oxide screens are used extensively in industrial radiographic operations. When used properly they improve the image contrast and final radiographic sensitivity. The thin lead oxide screens used in light-tight, prepackaged film envelopes are very thin, usually less than 0.001 inch. Their primary function is to intensify the image.

Lead screens consist of a sheet of lead alloy (94 percent lead, 6 percent antimony) mounted on a cardboard or plastic base. They are generally used in pairs, one on each side of the film. Typically, the front screen is 0.005 inch thick and the rear screen is 0.010 inch thick. Below 100 kVp, the attenuation of the primary beam through the front screen will increase exposure time, and it is not until the kVp exceeds 160 that any significant reduction in exposure results. Sample results are shown in Table 6-11. However, the quality of the image is improved at all kVp settings.

Table 6-11. Sample Result.

Source Power	Relative Exposure Times for Equivalent Density Under Standard Conditions	
	Without Screens	With Lead Screens
120 kVp	1.0	1.0
150 kVp	1.0	0.7
200 kVp	1.0	0.5
Iridium 192	1.0	0.25
Cobalt 60	1.0	0.50
NOTE: The results were obtained with a 0.004-inch front screen and a 0.006-inch back screen.		

6.4.3.2.1.1

Lead screens should be used whenever they improve radiographic quality. Because of the resulting improvement in radiographic quality, lead screens are generally preferred to calcium tungstate screens. Whenever there is a need to perform a radiographic inspection using a combination of screens and film, they SHALL be of the same plane dimensions and in close contact with each other during exposure.

6.4.3.2.2 Effects. Lead screens in direct contact with film have two effects:

a. They intensify incident radiation. Incident radiation with energies above 88 keV eject photoelectrons from the atoms of the lead. These photoelectrons act on the emulsion in the same way as the primary radiation beam.

b. They improve clarity by absorbing scattered radiation of longer wavelengths.

6.4.3.2.3 Selection of Screen Relative to Radiation Energy.

Lead screens are available in various thicknesses and should be chosen according to the radiation energy being used. At energies less than 125 keV, very thin front lead screens are used to filter scattered radiation. With X-ray energies ranging from 125 to about 250 keV, it is common to use a front lead screen of 0.005-inch thickness and a back lead screen of 0.010-inch thickness. In some instances where scattered radiation is very high, such as in the radiography of thick sections of graphite, a 0.010 lead front screen is used to increase the absorption of the scatter. When the X-ray energies exceed 250 keV, thicker lead screens are appropriate. Usually 0.010 front and back screens are used at 250 to 400 keV for energies in the MeV ranges lead screens on the order of 0.050 are often used. There is no fixed rule for the lead screen thickness appropriate for a particular energy level, but generally speaking, the lead thickness of the screen is increased as the radiation energy increases.

6.4.3.2.4 Care.

CAUTION

Hydrogen peroxide or other common cleaning agents should never be used for this purpose because their chemical composition will cause fogging of the sensitive film emulsions.

Do not touch sensitive surfaces of the screens because fingerprints and dust particles may show in the radiograph and interfere with accurate interpretation. X-ray screens are given a special waterproof protection coating to both sides. If the surfaces accidentally acquire markings, wash with mild soap and water, and dry thoroughly with a soft cloth. Since the intensifying action of a lead foil screen is caused by the electrons emitted under X-ray or gamma ray excitation, and because of the high electron absorption in light materials, the surface must be kept free from dirt and lint which will produce light densities on the radiograph. Remove grease and lint from the surface of lead foil screens with a solvent such as isopropyl alcohol. If more thorough cleaning is necessary, rub screens gently with the finest grade of steel wool. Films may be fogged if left between lead screens longer than is reasonably necessary, particularly under conditions of high temperature and humidity. When screens have been freshly cleaned with an abrasive, this effect will be increased. It is best to delay the use of freshly cleaned screens at least 24 hours.

6.4.3.2.5 Precautions.

Lead screens must be used with great care. Common problems are:

a. A fuzzy image results from lack of intimate contact between the screens and film.

b. Dark lines on the image can result from scratches on the screens.

SECTION V
INTERACTION OF RADIATION WITH MATERIAL

6.5 INTERACTION OF RADIATION WITH MATERIAL.

6.5.1 Absorption Mechanisms.

Absorption of gamma or X radiation by materials requires detailed consideration. These radiation photons are electromagnetic waves of energy, have no mass or electrical charge, and can penetrate the densest materials. These waves are dimensionally so short that they have wavelengths less than the electron spacing in the atoms and therefore have the capability of traveling through the atomic structure. The absorption of the photons is a result of the photon either striking an electron or entering the nuclear field of the atom. The energy lost by a radiation beam as it travels through matter is due to interactions of the photons with matter. In these interactions the energy of the photon is transferred principally through three processes. These are photoelectric absorption, Compton effect and pair production. (See Figure 6-15.) At extremely high photon energies a small amount of absorption is due to the photodisintegration process, but this is of little consequence in radiographic applications. Most of the radiation absorption is due to interactions of the photons with electrons in the atoms of the absorbing material. Therefore, an absorber may be judged somewhat in relationship to the electron density of the absorber, or approximately the number of electrons in the radiation beam path. The parameters that contribute to this electron density are the atomic number, the density, and the thickness of the absorber. The atomic number is the number of protons in the nucleus of the particular atom, and material density (usually expressed as grams per cubic centimeter) is related to the number of atoms that are compacted in a given material volume. The thickness of the absorber can be mechanically measured. Atomic number, material density, and absorber thickness combine to present an absorber value to the radiation. The radiation photons interact with the atoms in the absorber in different manners, depending upon the energy or wavelength of the photon.

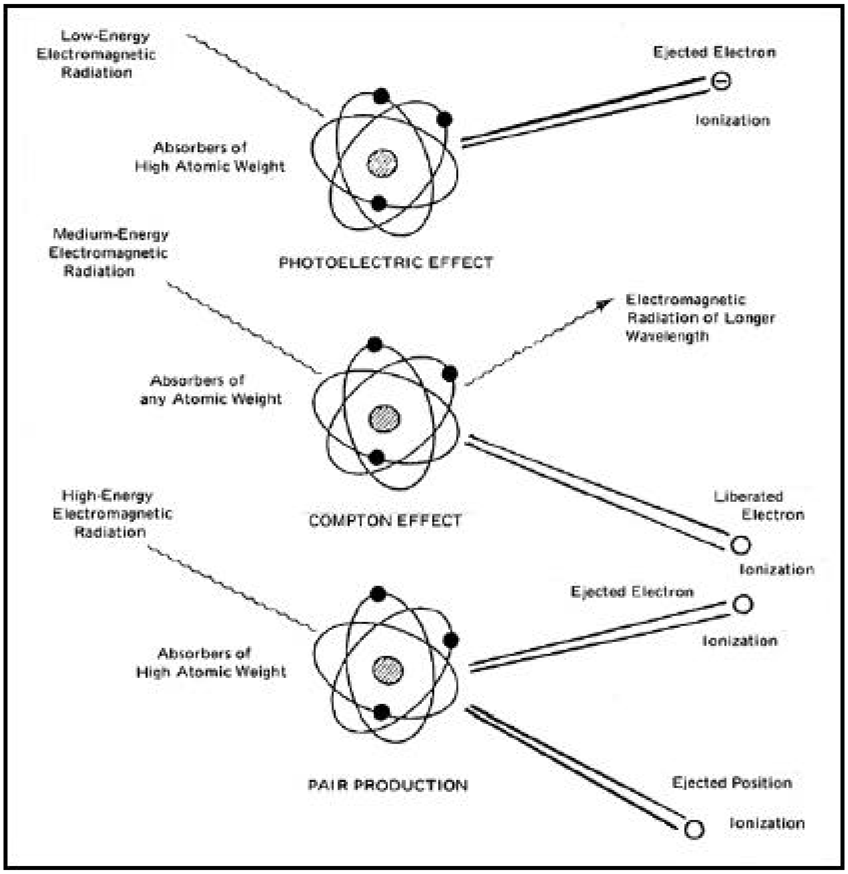


Figure 6-15. Illustration of Various Radiation Absorption Interactions.

6.5.1.1 Photoelectric Absorption.

When the photons have energies of 100 keV or less, they are readily absorbed by the electrons in the orbital shells of the atoms of the absorber. The energy of the photon is transferred to the electron; often dislodging it from its orbit and the remainder of the energy in the photon is used to give the electron kinetic energy or velocity. These ejected electrons are called photoelectrons and the process is known as photoelectric absorption. The moving electrons then lose their energy, producing ion pairs. It should be noted that the radiation photon has given up all of its energy and no longer exists. This mechanism of absorption has a very high probability for very low energy radiation and accounts for the major absorption of radiation when photon energies are 100 keV and less.

6.5.1.2 Compton Effect.

When the photon energies are in the 100 keV to 10 MeV range, all of the energy is not required to dislodge an orbital electron and accelerate it by induction of kinetic energy. In this case the photoabsorption can occur, but the photon continues at some different path and at a reduced energy level, due to the loss of energy to the electron. By this mechanism of absorption, the path of the photon is altered and its energy decreased. This mechanism of absorption is referred to as Compton effect. Compton effect accounts for the major absorption of radiation in the energy range between 100 keV and 10 MeV.

6.5.1.3 Pair Production.

When photon energies exceed 1.02 MeV, their energy can cause pair production. In this event the high-energy photon is disintegrated by the nuclear field surrounding the nucleus of the atom. The energy of the photon converts into an electron-positron pair. The positron has the same mass as an electron and is of equal, but opposite charge. It may be noted that in this absorption mode, the energy of the massless photon is converted to mass. Einstein's equation states that energy equals mass times the square of the velocity of light ($E = mc^2$). If this equation is used it can be found that the mass of an electron is equivalent in energy to a 0.51 MeV photon. This explains the requirements for a photon to have energy of at least 1.02 MeV before pair production can occur. Additional energy above the 1.02 MeV causes the pair of particles to have kinetic energy or velocity. The position may cause ionization or it may combine with an electron, causing annihilation and emission of two gamma photons of 0.51 MeV per photon. These lower energy photons may subsequently interact by either the photoelectric or Compton effect absorption modes.

6.5.1.4 Significance of Absorption Mechanisms.

With three different absorption mechanisms it is evident that an absorber, when bombarded by photons of electromagnetic radiation, has absorption characteristics highly affected by photon energy. Figure 6-16 is a graph illustrating the three major modes of absorption and how they contribute to the total absorption in the element iron with its atomic number of 26. It should be noted from Figure 6-16 that nearly all of the absorption of radiation below 100 keV is due to the photoelectric effect. This absorption is highly dependent upon the atomic structure and the binding energies between the electrons and the nucleus. Therefore, the atomic number of the material will greatly affect radiation absorption by the photoelectric effect. When radiation energy is between 100 keV and about 10 MeV, absorption is almost entirely due to Compton effect and atomic number is no longer the major criteria of absorption; instead, material density is the major controlling factor. It should also be noted that in the energy range between 10 and 100 keV, radiation absorption is very sensitive to keV changes: a unit change in keV will cause three units of change in the atomic absorption coefficient. For energies between 200 keV and about 3 MeV a unit change in keV will only cause half a unit change in the atomic absorption coefficient, so the absorber is much less sensitive to changes in radiation energy. When the radiation energy is between 3 and 30 MeV, the atomic absorption coefficient is for practical purposes unchanged.

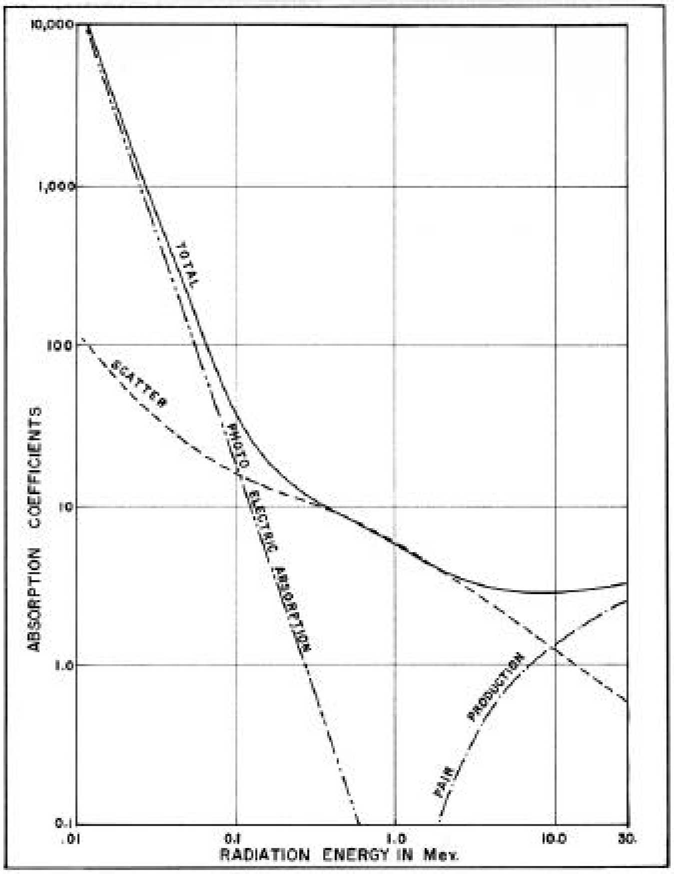


Figure 6-16. Absorption Coefficients for Different Modes of Absorption in Iron.

6.5.2 Real Life Absorbers.

In industrial applications test specimens are being bombarded by the radiation photons which are absorbed and scattered, and in the process electrons are ejected from the atoms of the test material. These absorbers are not ideal; they do not act as an ideal absorber in that they do not attenuate radiation in accordance with theoretical physics. Electrons degenerated scattered photons, characteristic radiation from the test material, and some of the primary beam is all present on the film side of the test object simultaneously. The classical attenuation equation does not consider all these various components, so it is not strictly applicable in actual radiographic practices.

6.5.3 White Spectrum.

Radiation generated by an X-ray tube contains various energies and therefore is referred to as white radiation (see Figure 6-17). The X-rays are a continuous spectrum and the beam is selectively attenuated as it passes through an absorber. The low energy radiation is highly absorbed by the first few layers of the absorber medium and the spectral distribution is altered by this selective absorption. Thus, as the white radiation is being absorbed by an absorber it more nearly approaches monochromatic radiation. Figure 6-17 shows a semi-logarithmic graph of the absorption of a monochromatic beam and a multi-energy beam of white radiation. For approximate estimations of effective X-ray attenuation coefficients, it may be assumed that the average energy of an X-ray beam is about 50 percent of the peak operating kilovoltage for glass window tubes and 30 percent for beryllium window X-ray tubes.

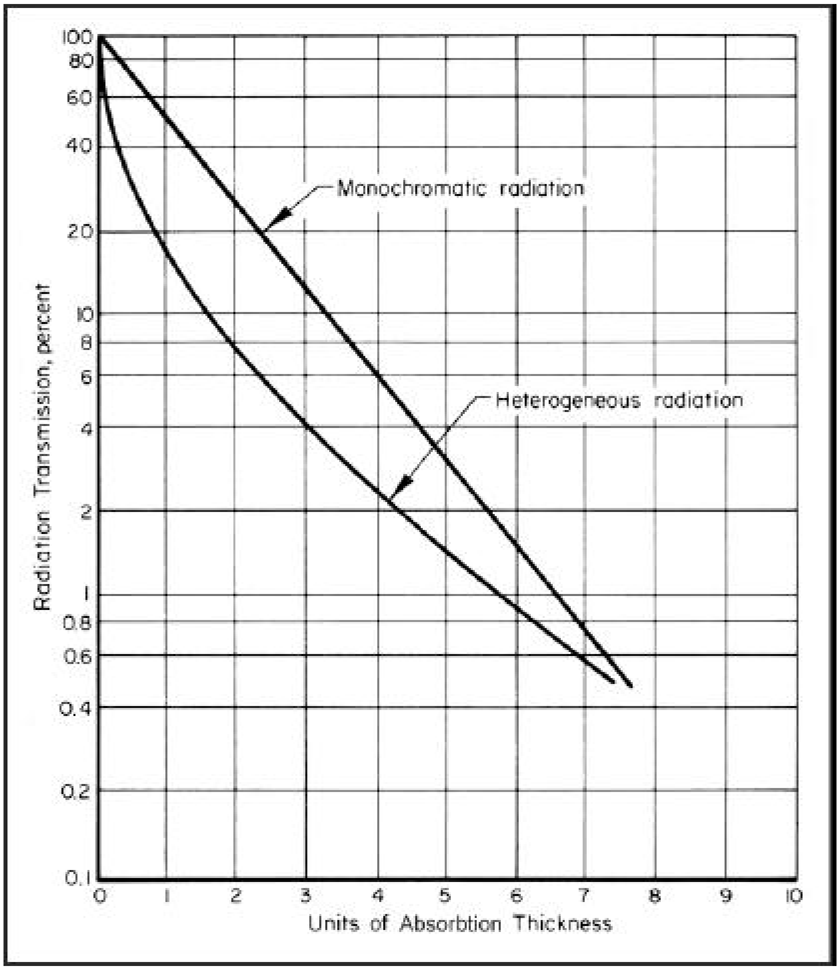


Figure 6-17. Absorption Curves of Monochromatic and Multi-Energy Radiation.

6.5.3.1 Scatter Radiation.

6.5.3.1.1 Description.

When high-energy electromagnetic radiation bombards matter, some of the radiation photons are scattered by electrons, a process called the Compton effect. If the photon has a greater quantity of energy than necessary to eject an electron from its orbital path, it continues to travel with a loss of energy at some angle to its original path. The photon energy must be reduced to a very low value before complete annihilation is possible by photoelectric absorption. In low atomic number materials the photon direction is changed with little loss of energy and its energy must be reduced to a very low energy to be absorbed completely. Thus, a single photon may be scattered many times, losing all semblance of its original path. If this scattered photon strikes the film, it reduces the image definition since it exposes the film at a spot other than directly under the point where it first entered the test material. High atomic number materials rob the photon of greater amounts of its original energy and also have much higher photoelectric absorption values. These more quickly reduce the photon energy to the point where the photon is completely absorbed. For these reasons, low atomic number materials transmit larger quantities of scattered radiation than high atomic number materials. In actual radiographic practices, low atomic number materials should be removed from the beam to the extent possible, to prevent scattering of the primary beam. Wood, concrete or other low atomic number materials in the radiation beam should be covered with lead or a high atomic number material to reduce the scatter. In actual practice this means that tables, floors or walls that are behind/beside and close to the test part should be covered with lead.

6.5.3.1.2 Scatter Build Up.

The scattering is due to photon collision with electrons in their path. As material thicknesses increase up to a critical thickness, the amount of scattered radiation emanating from the material increases. If additional thicknesses of material are added, the scattered radiation generated in these added layers have insufficient energy to penetrate the material between them and the film. The amount of scattered radiation emanating from the back of a part being inspected increases with part thickness up to a total which varies with radiation energy. Since absorption due to the Compton effect decreases with increasing radiation energy, less scattering occurs at higher radiation energy levels. Build-up scatter radiation can introduce contrast problems in the radiography of low atomic number materials such as graphite, plastics, and magnesium. A simple test to reveal the scatter build-up in a test specimen can be made. Choose a radiation source-to-film distance of three or four feet, make two identical exposures — one with the test specimen at the X-ray source and one with the specimen at the film. Differences in the densities after processing can be credited to scatter radiation.

6.5.4 Diffraction Patterns.

In the radiography of very coarse grain structure materials, such as Inconel and cast irons, diffraction patterns are often revealed in the radiographic image. These patterns are due to the selective diffraction and absorption by the atoms of a definite pattern in the crystal structure. The definitive pattern of the atoms of a crystal can be aligned with the X-ray beam at a particular angle so that the radiation is altered in its direction of travel and concentrated upon the film as a linear indication. These crystalline diffraction patterns are superimposed upon the radiographic image and make interpretation very difficult. Often these dense, sharp lines caused by the crystal diffraction are interpreted as internal cracks. If uncertainty exists as to interpretation of a particular indication, a second radiograph can be made at a slightly different angle (less than 10 degrees difference). It is unlikely the crystal causing the diffraction pattern would be located to precisely the same relative position as to cause the diffracted line to strike the film in the same relative position. Changes in radiation energy will also affect diffraction patterns. Often by changing the operating kilovoltage the problem of diffraction patterns can be reduced.

6.5.5 Material Contrast.

6.5.5.1 Material Contrast Factor.

In consideration of the above discussion on radiation absorption, the most important variable that can be controlled by the radiographer in industrial X-ray inspection is the kilovoltage. The amount of radiation absorbed by the part being inspected depends on the atomic number, density, and thickness of the material. The radiographer cannot change these factors, but can change the energy of radiation. In the attenuation equation, $\ln(-\mu x) = I_T/I_0$, it can be visualized that the linear attenuation coefficient (μ) can be changed by changing radiation energy. This in turn will change the ratio I_T/I_0 or the percent radiation transmitted through a part of thickness, *x*. In industrial radiographic applications, the difference in thickness (often due to discontinuities) is the actual parameter from which interpretation is made. Therefore, the greater the change in the radiation transmitted due to a particular change in material thickness, the more obvious is the thickness change revealed in the final image. This radiation difference due to material thickness change is called the material contrast. The material contrast is a function of the absorption characteristics of the part being inspected and the radiation energy level. When measurements have been made and a numerical value has been established, it is called the material contrast factor.

6.5.5.2 Percent Radiation Transmission.

When monochromatic radiation is used, the percentage of radiation transmission can be calculated from the formal laws of attenuation. Since this condition seldom exists in actual practice, the percent of radiation transmitted must be empirically measured. When the proper recorder is used, the actual measurements will include the scattered radiation as well as the transmitted primary beam, both of which can be expected to expose a film or interact with any other recorder in a typical industrial radiographic set-up.

SECTION VI
SPECIAL RADIOGRAPHIC TECHNIQUES

6.6 SPECIAL RADIOGRAPHIC TECHNIQUES.

6.6.1 Introduction.

The previous sections of this chapter have been primarily concerned with conventional film radiography. While film radiography offers a very versatile tool for the detection and identification of material discontinuities, there are a variety of special techniques that may be employed to extend the capabilities of conventional radiography. Special techniques may be placed into two broad categories. The first relates to radiographic techniques with a specific objective of extending the capabilities of the inspection method in general. This first category would include such techniques as multi-thickness, multiple film, triangulation, thickness measurement and stereo (three-dimensional techniques). The second category relates to special imaging methods, such as radioscopy with techniques such as image intensifiers, or X-ray vidicon, photoradiography, Polaroid radiography, photothermographic film and radiographic paper. Special radiographic methods that are not included in authorized inspection manuals SHALL NOT be used without written approval of the appropriate depot engineering activity.

6.6.2 Special Purpose Techniques.

6.6.2.1 Multi Thickness Techniques.

Most real life situations involve the radiography of parts of widely varying thicknesses and sometimes of two or more materials. If it is possible to concentrate on one area with a nearly constant thickness, optimization of image density is straightforward. Often, however, it is necessary to obtain an acceptable exposure for two or more difference thicknesses on the same image. Small thickness variations, for example, of 0.8 to 0.6 inches, can lead to large variation in density, from 1.2 to 1.7 respectively. The aim is to insure that all areas of interest have densities that are not so low so as to lose film contrast and not so high that they cannot be evaluated. An acceptable range of densities is 1.0 to 3.5. The procedure recommended during technique development is to identify the thickest area of interest, and then from exposure charts and trial-and-error, determine the exposure and kilovoltage that gives a density of 1.0. A trial shot will then show the density of the image of the thinnest area of interest. There are three possible courses of action:

a. If the density of the image of the thinnest section is approximately 3.5 and the image can be satisfactorily interpreted, the technique is optimized.

b. If this density is too low, the exposure should be increased to raise the average density of thick and thin areas.

c. If the density of the thinnest section is too high, the range of thicknesses is too great for satisfactory imaging. One solution is to raise the kilovoltage substantially, as this reduces contrast one of thin areas. A better solution is to load the cassette with two films of different speed and expose them simultaneously (see paragraph 6.6.2.2.). In the latter case, care is needed to insure that an acceptable image density is obtained for all areas of interest.

6.6.2.2 Multiple Film Techniques.

Multiple film techniques permit the inspection of multi-thickness components with a single radiographic exposure. Since the major expense associated with radiographic inspection can be attributed to setup, it is desirable to image a multi-sectional component in a single exposure, rather than set up an exposure for each cross section of the component. Multiple film techniques permit this objective to be achieved. For example, a cassette may be loaded with both Class 1 and Class 3 film to provide wide latitude. The faster Class 3 film provides a readable density film for the thicker sections of the component inspected, while the slower Class 1 film may provide the appropriate film density for the thinner sections of the component. Thus, in a single radiographic exposure, two images may be generated which cover the required latitude for the inspection of a multi-thickness component. With very complex parts, it is even possible to use three films and cover a very wide latitude. Several parameters must be considered in the choice of a multiple film technique. In addition to the exposure parameters that are always of concern in radiographic inspection, the radiographer must be concerned with the choice of film to be used and the combination of these films with various screens. Lead screens have a definite effect on the quality of a radiographic image. First, lead screens are very dense, and they preferentially absorb the lower energy scattered radiation. This reduces the fog on the final image and provides a higher contrast, higher quality image. Secondly, at energies above 125 kVp, lead screens provide a definite intensification. This intensification is due to the efficient conversion of X-ray photons into electrons in lead foils. These electrons in turn expose the X-ray film and thus provide intensification in the final image. These properties of lead screens may be useful in developing a multiple film technique. The film combination selected is based on the range of thicknesses that must be covered in a single exposure. The simplest multiple film techniques employ two different films, such as a Class 1 and a Class 2 film, to provide a range of densities for the inspection of an object. The exposure is then determined that provides the best combination of contrast and sensitivity in the two films. In double-film radiography it should be recognized that the film nearest the X-ray source acts as an absorber and the underneath film receives less exposure than the source side film. This absorption effect is of considerable magnitude at low kilovoltages and decreases with increased radiation energies. The choice of film positions will affect the range of materials that can be visualized in a single exposure. Once a technique with a particular film combination has been established, care must be used to assure that the same film is always placed in the same position in the film holder. If the positions of the films are inadvertently switched, the resulting densities in the final images will be different than expected. Two films of the same class may be loaded in a film holder and exposed at the same time to effectively reduce exposure time by one-half. The two films are then interpreted by superimposition in front of the illuminator.

6.6.2.3 Multiple Film Techniques with Lead Screens.

The above combinations of films can be used for radiography of multi-thickness materials, but the optimum in image quality may not be attained. Therefore, the use of lead screens may be introduced to help regulate the relative speeds of the films used. As an example, assume that the combination of a Class 1 and a Class 2 film could not provide the required latitude for a given component. Lead screens could be used to increase the latitude of the total exposure. Most lead screens consist of thin lead foils backed on one side by cardboard, rubber, or vinyl. With this configuration, lead screens have a filtration effect on the films that are beneath them and intensification effect on those films that face the foil-coated side. If a combination of Class 1 and Class 2 film is used and insufficient latitude is provided, the latitude may be increased by placing the faster Class 2 film on top with a backed 0.005-inch lead screen between the two films with the lead screen in contact with the Class 2 film. This increases the latitude through two effects. First, the lead foil intensifies the top Class 2 film and second, the lead acts as a filter, slowing the response of the Class 1 film. Thus, over all the latitude of the exposure is increased. If on the other hand, the latitude was excessive with the two films and no screens; the opposite effect can be achieved by placing the slower film on top and the faster film on the bottom, with lead screens in between facing the slower film. This combination speeds up the slower film by intensification and slows down the faster film by filtration. Thus, the total latitude is reduced. When only a slight increase in latitude is required, two sheets of the same film type may be employed and lead screens may be used as described above to achieve a relative speed difference between the two films. There is no end to the combinations that may be employed in multiple film radiography. Using the principles that are outlined above, any capable radiographer should be able to accommodate a wide variety of complex components with a multiple film exposure. Experience provides the required proficiency.

6.6.2.4 Triangulation.

In some cases, it is desirable to know the location of a given discontinuity relative to one of the plane surfaces of the object. If repairs are to be made, it is desirable to know from which surface the repair should be started. A single radiograph will not reveal this information. This information can be obtained by making a double exposure with suitable markers placed on the object. Markers are placed on both the source side and on the film side. Two exposures can be made on one film where discontinuity is very prominent or on two separate films that can later be superimposed. These radiographs can be used for measurement purposes to obtain the desired information. (See Figure 6-18.)

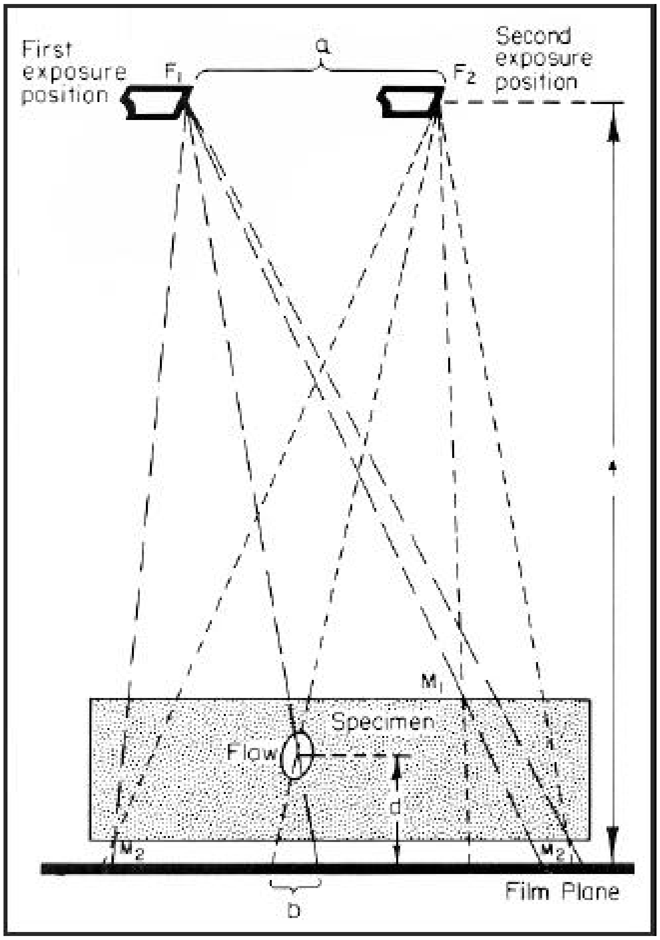


Figure 6-18. Triangulation Technique Used to Determine Flaw Depth in an Object

6.6.2.4.1

In this method, small lead markers usually in the form of triangles are attached to the two surfaces of the object, one set of three or four markers on the source side and one set on the film side. If two separate exposures are to be made, each film must be carefully aligned with the object so that both films occupy the same position. After the markers are positioned, one exposure is made with the normal source, object, and film position. A second exposure is made with all conditions the same between the object and film with the exception that the source is shifted 10 to 45 degrees from the initial position. The greater the shift, the greater the accuracy of determining the position of a given discontinuity from one of the object's surfaces.

6.6.2.4.2

If the discontinuity is sufficiently prominent, both exposures may be made on the same film. The distance of the discontinuity above the film in either case is given by the following expression:

$$d = \frac{bt}{a + b}$$

Where:

d = distance of discontinuity above film plane
a = distance of the source shift
b = change in position of discontinuity image on radiographs
t = source film distance

6.6.2.4.3

In some cases, it is sufficient to know which of the two surfaces of the object is nearest to the discontinuity. In this case, the shift of the discontinuity and marker images are measured. If the shift of the discontinuity image is less than one-half the shift of the markers that are on the source side of the object, then the discontinuity is nearer to the film. If the shift is greater than one-half, the discontinuity is nearer the markers on the source side of the object.

6.6.2.5 Thickness Measurement.

Sometimes it is impossible to determine the thickness of an object using conventional mechanical measurement techniques. In these instances, a special radiographic technique for the measurement of material thickness may be employed. Although the mathematical development of a relationship between film density and the thickness of an absorber is too complex for practical use, an empirical method of thickness measurement has proven useful. By imaging the object of interest and a step wedge of the same material on a single film, it is possible to obtain a good estimate of the thickness of the material section. It is imperative that the composition and structure of the step wedge be the same as that of the material being measured if any accuracy is to be achieved. Thickness is determined by measuring the resultant film density and finding the step on the wedge that is nearest to that density. For best results, the section of interest and the step wedge should be placed as close to one another as possible to avoid variations in the uniformity of the radiation beam. This technique may also be employed to measure void dimensions (parallel to the beam direction).

6.6.2.6 Stereo (Three Dimensional Techniques).

Objects viewed with a normal pair of eyes appear in their true perspective and correct spatial relationship because of a property of the eyes, which is called stereoscopic vision. That is, each eye receives a slightly different view and the two images are combined by interpretation to give the impression of three dimensions. A single radiographic image does not possess perspective. Therefore it does not give the impression of depth. However, some estimate of depth can be judged from detail observed by an experienced radiographer. The mechanics of stereoradiography are relatively simple. Two radiographs are made from two positions of the X-ray tube. These positions can be thought of as the "left eye" and the "right eye." As a matter of fact, the two positions represent the distance between the eyes. A so-called stereoscope is used to view the images (See Figure 6-19). Each eye sees only one image but the brain blends these two images into one.

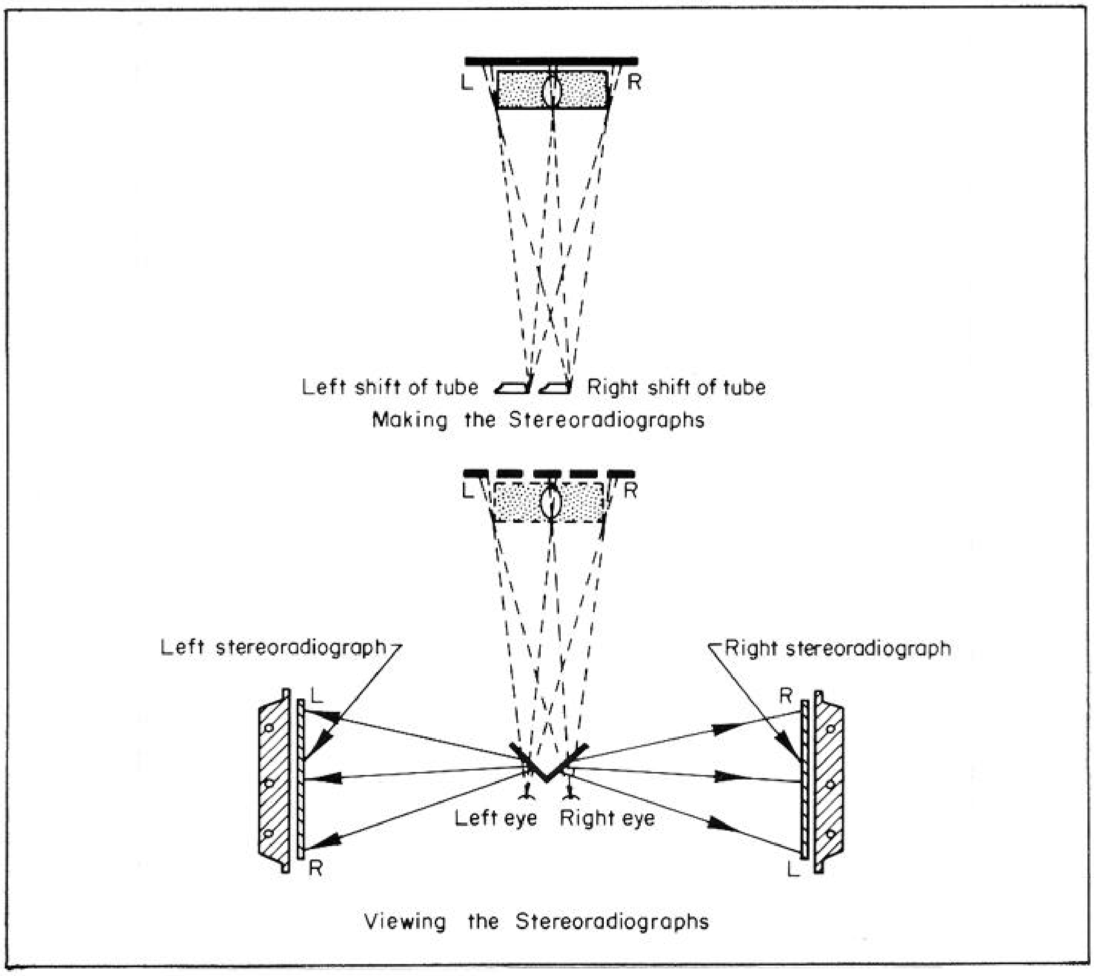


Figure 6-19. Sketch Showing Procedure for Making and Viewing Stereo Radiographs.

6.6.2.6.1.1
It should be remembered that the radiographic image produced does not define the surfaces of the object as in a photo or by direct vision. This is because no radiation is reflected from the surface as under normal optical means. Therefore, in order to obtain apparent depth it is usually necessary to define the surfaces of an industrial object by means of an X-ray attenuating marker such as a very coarse, high-absorption mesh or grid. These grids can be easily constructed by using 1/16-inch solid lead solder. Such grids, especially on objects with plane surfaces, should be placed on both the source and the film side.

6.6.2.6.1.2
It is important that in taking the radiographs, the distance of shift of sources be approximately one-tenth the focal film distance. Also, in viewing the resultant radiographs, each film must be positioned so as to duplicate the exact conditions of exposure. That is, the eyes of the viewer should be in the same relative position as the focal spot of the X-ray tube or source. This positioning is facilitated by placing a different lead marker on each of the two films. The eyes will then see a true representation of the part just as the X-ray tube saw the actual part.

6.6.2.6.1.3 Stereo radioscopic methods can also be used to present stereo images in real time.

6.6.2.7 Geometric Magnification.
For some applications it is desirable to magnify the radiographic image. This can be done optically after the radiograph is taken, or it can be done during the radiographic process by using geometric magnification. This is

particularly effective when X-ray sources with small focal spots are used (mini-focus and micro-focus sources as described in paragraph 6.2.5.2.3). Geometric enlargement can be realized by moving the radiographic object away from the detector, toward the radiation source. Moving their inspection object halfway between the X-ray source and detector produces a magnification factor of two. If the object is closer to the X-ray source (say 1/10th of the source-detector distance, then the magnification is ten times. Useful radiographic images have been produced with small microfocus sources with geometric magnifications of 10X or more. Although this discussion has covered geometric magnification using only a film detector, this special method can be used with any imaging detector, including radioscopic detectors, as discussed in the next sections. Recognize that as magnification increases the inspected volume of the object decreases. Therefore, more radiographic views may be needed for a complete inspection.

6.6.3 Special Imaging Methods.

Conventional film radiography has its own capabilities and its own limitations. The capabilities of film radiography have been covered thoroughly in the previous sections. Consider some of the limitations of film radiography. Film takes a long time to process, and the results of the inspection cannot be known until the film is processed. Therefore, in some situations, a need exists to provide more rapid means of imaging. There are many alternatives to the use of conventional film for recording radiographic images. These include fluoroscopy, electronic imaging systems, Polaroid radiography, radiographic paper, and photothermographic film. The following paragraphs discuss the advantages and capabilities of these imaging systems. Most provide for more rapid imaging than is available using conventional film radiography. However, each of these methods also has its own limitations. Special imaging methods that are not included in authorized inspection manuals SHALL NOT be used without written approval of the appropriate depot engineering activity.

6.6.3.1 Radioscopy.

The oldest non-film imaging method involves the use of fluorescent screens to produce a visible image. These phosphor screens fluoresce (emit visible light) in proportion to the amount of radiation striking them. Thus, an instantaneous visible image is produced, and the results may be instantly read using a now outdated method called fluoroscopy. Modern, prompt-view or real-time radioscopic systems make use of closed-circuit television systems to bring these images out to a safe viewing location, where a bright television image can be viewed. Radioscopy is defined in ASTM standards as "the electronic production of a radiological image that follows very closely the changes with time of the object being imaged" (see reference 9). For tutorial information about radioscopy, see reference 10.

6.6.3.2 Fluorescent Screens.

The light-emitting fluorescent screen can be viewed directly to see the prompt X-ray image. However, this method is rarely used now because closed-circuit television methods can provide a safer, more efficient environment to view the low-light level signal from the fluorescent screen. The fluorescent screen light signal can be detected by sensitive television cameras such as the image orthicon. In some systems, the weak light signal from the fluorescent screen is amplified by using a light-image intensifier tube between the fluorescent screen and the television camera.

6.6.3.3 Image Intensifiers.

Image intensifiers are specially designed evacuated electronic tubes that intensify the image on a very fine grain fluorescent screen. The input signal, fine grain screens that are used in image intensifiers do not produce sufficient light to be viewed and employed for direct fluoroscopy. Therefore, an image intensification system is employed as shown in Figure 6-20. The fluorescent screen is backed by a photo-emissive layer that produces electrons in proportion to the number of visible light photons emitted by the fluorescent screen. A series of focusing and accelerating electrodes propel these electrons toward a second and much smaller fluorescent screen. This second screen has very high detail resolution. This screen is typically viewed by a light-sensitive vidicon or other television camera and displayed on a television monitor. The image intensifier provides the immediate imaging capability of the fluorescent screen while providing higher brightness and detail resolution in a safe area remote from the radiation. However, resolution is still less than that obtained with Class 4 radiographic films. Also, no permanent record is provided unless a photograph or video tape is made. The X-ray image intensifier is widely used as part of a radioscopic X-ray inspection system. Other radioscopic systems are described in reference 10.

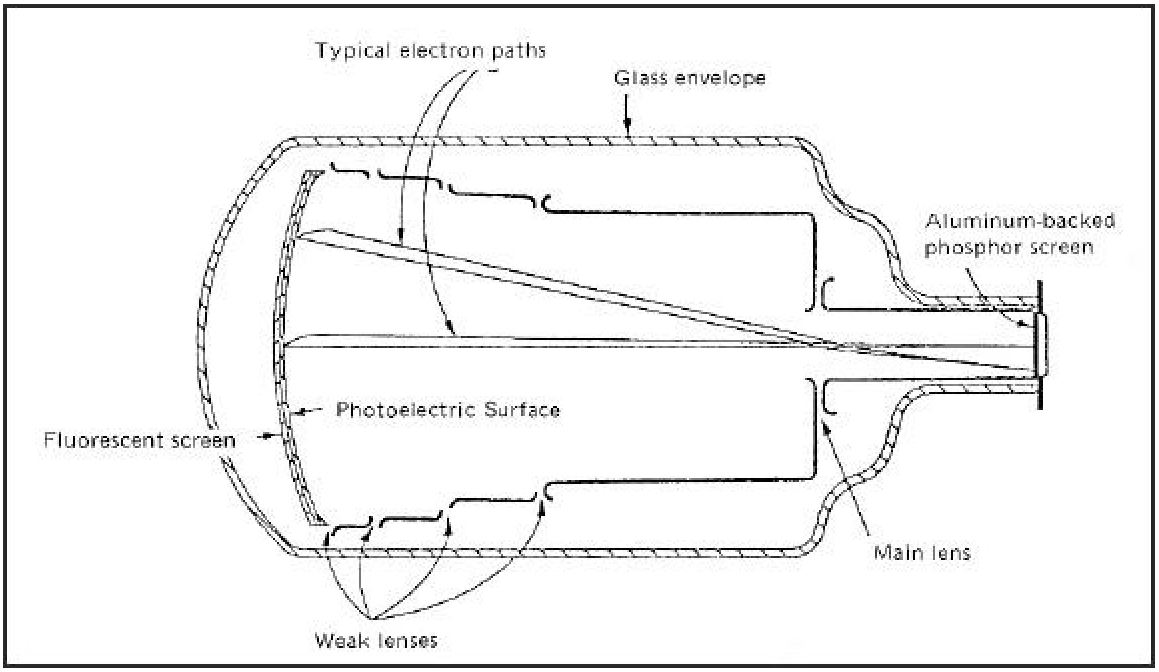


Figure 6-20. Typical Image Intensifier Tube.

6.6.3.4 X-Ray Vidicon.

The X-ray vidicon system consists of a specially designed television camera that is directly sensitive to X-rays. It has a specially coated face that is capable of imaging X-radiation, because, its electrical resistance changes with radiation, a phenomenon called photoconductivity. This small area coating provides very fine resolution. The results of this type of inspection are displayed on a television monitor. The sensitive area of the television vidicon tube is generally very small, on the order of 3/8 by l/2 inch. When this small area is viewed on a 17-inch television monitor, a magnification of 30 times results, thus very high detail resolution is accomplished. These systems are used primarily for the inspection of very fine detail, such as in the inspection of microelectronic circuits. This system is capable of resolving wires as small as 0.001 inch in diameter.

6.6.3.5 Stereoradioscopy.

Stereo imaging can be done in real-time, using microfocus X-ray sources, geometric magnification and radioscopic systems (see paragraph 6.6.3.1). The stereo pair images can be obtained using only minimal movement of the microfocus X-ray source when geometric magnification is used. This stereo pair imaging can be done by magnetic movement of the X-ray tube electron beam. The two stereo views, obtained at TV field rates (1/60 second), can be combined electronically into a stereo pair image for 30-frames/second viewing. An observer, wearing special polarizing glass and looking at the television stereo image through a 1/60 second changing polarizing filter, will see a stereo, radioscopic image.

6.6.3.6 Photoradiography.

Photo radiography is a combination of radioscopy and photography. In this method, the image of a fluoroscopic or image intensifier output screen is photographed by a conventional camera on small or miniature-type film rather than by direct contact. This method has the advantage over fluoroscopy in that the film has the property to integrate and react to the total light emitted by the screen during the time of exposure, whereas the integration time of the eye is relatively short. Furthermore, the resultant film can be viewed with transmitted light and the photographic process can be used to enhance the contrast of the fluorescent image. This method has been used to limited extent for the examination of propellant grains, die and precision castings, and similar parts and assemblies when a large number of parts of the same configuration and size are inspected. Airframes have been inspected for component shift and material changes by using photoradiography. The system has limitations since all fluorescent screens commonly used are grainy. In addition, there is loss of definition through the lens of the camera. The main advantage of the system is the economy resulting from the use of smaller size film. The image can be enlarged for viewing by a magnifying system or by projection. In general, this system permits radiographic sensitivity of about four to five percent. The photoradiography accessory is available as an assembly and usually consists of a light-tight hood, a fluorescent screen or image intensifier assembly and the camera. Various type cameras are available, some, of which employ sheet film and others using 70-mm roll film.

6.6.3.7 Polaroid Radiograph.

If a convenient, permanent image is needed and the time required for conventional film radiography is prohibitive; an alternate may be radiography with other film. One of these is Polaroid radiography. Just as Polaroid photography facilitates very rapid development of photographic images, there are available Polaroid X-ray films which provide the same advantages. These require the special Polaroid film holders and a film processor if the larger sizes are used. In some cases the typical Polaroid 4- by 5-inch adapter can be used. Polaroid radiographic films are used just as regular films are used in conventional film radiography. They have their own characteristic curves and an appropriate exposure technique should be used. However, after the exposure has been made, rather than process the films by conventional techniques, they are dry developed as a Polaroid photograph is, and results are available after about one minute. Presently available Polaroid films provide for either viewing by reflected or transmitted light. Polaroid radiographs provide nearly instant interpretation and also provide a permanent image. However, Polaroid radiographs are low in contrast and detail resolution compared to conventional film. Polaroid radiographs can be made to establish the geometrical alignment of the X-ray beam with the part before a typical film radiograph is exposed. This technique is useful in those cases where critical alignment is required.

6.6.3.8 Photothermographic Film.

The photothermographic process uses a special "dry silver" film which is heat processed, eliminating the need for chemical processing. The film is sensitive to visible green light. Therefore, to produce the image, rare earth phosphor intensifying screens are placed in intimate contact with the film. When struck by X-rays, the screens fluoresce, forming an image on the film. Since the film itself is insensitive to X-rays, care must be taken to assure that the coated side of the film is in direct contact with the coated side of the screen during the exposure. Since this film is dependent upon the screens for forming the latent image, only screens approved by the film's manufacturer SHALL be used. To aid in maintaining the necessary contact, vacuum cassettes SHALL be used for holding the film and screens, unless an approved procedure states otherwise. Photothermographic film less sensitivity than Class 4 films; therefore, it is not suitable for most critical applications and SHALL NOT be used for critical crack detection. Photothermographic film is processed by exposing the film to heat in a special thermal processor. The heat causes the latent image in the silver halide grains to form in the reducible silver salts. This process is very fast; typically requiring is to 20 seconds to process a 14- by 17-inch film. During this process the radiograph is also stabilized, requiring no additional processing. The image produced should remain stable for years under normal storage conditions. However, exposure of the film to bright light for several days could cause some discoloration of the white background.

6.6.4 Computed Tomography (CT).

Computed Tomography (CT) is a radiation inspection method that can provide quantitative density and geometric images of thin cross sections of an inspection object. The method, adapted for nondestructive testing after extensive use in medical radiology, employs a computer to reconstruct an image of a cross-sectional plane through the object. CT inspection of a tree, for example, would look very much like the surface of a tree stump, showing the varying density of the winter and summer wood rings and an accurate representation of the tree growth rings. CT information is derived from a large number of observations of radiation intensity over many different viewing angles. Using CT, one can, in effect, slice open the test object, examine its internal features, perform dimensional inspections and identify any material or structural anomalies that may exist. As compared to conventional radiography, a major advantage of CT inspection is that internal structures are not hidden or shadowed by other structures that may be in the beam path. In addition, CT inspection can provide quantitative information about density variations and spatial locations within the inspected material. An obvious disadvantage is that currently used CT image reconstruction methods require full access to the inspected part; a full 180 degrees of data must be collected by the scanner. In addition, the inspection object must be small enough to fit in the CT handling and scanning system. Systems large enough to handle missiles up to 9 feet in diameter are in use. Additional information is available from reference 12.

6.6.5 Neutron Radiography.

6.6.5.1 Description.
Neutrons are useful for radiography because the attenuation of thermal neutrons is very different from that of X-rays. In general terms, the attenuation pattern is reversed in that many light materials (e.g., hydrogen, lithium, boron) have high attenuation of thermal neutrons while many heavy materials (e.g., bismuth, lead) are relatively transparent. Therefore, in this sense, neutron radiography can serve as a complementary inspection technique to X radiography. The advantages of thermal neutron radiography include excellent sensitivity to materials containing low atomic number elements (particularly hydrogen, lithium, and boron), some additional high attenuation materials (examples include silver, cadmium, indium, and gold), and rare earth elements (particularly samarium, gadolinium, and dysprosium).

6.6.5.2 Applications.
Sensitivity to low atomic number materials opens up neutron inspection to a variety of applications involving water, explosives, fluids, rubber, plastics, and corrosion products (usually a hydroxide). An example of this type of inspection is neutron radiography of small explosive devices in metal cases to assure the presence of the explosive. Lead-covered explosive lines represent such an example. Inspection applications involving materials like cadmium have been demonstrated in the nuclear industry for cadmium reactor control materials. Cadmium plating inspection can also be considered. A major application involving rare earth materials is the inspection of investment-cast turbine blades to detect residual ceramic core left in cooling passages after leaching.

6.6.5.3 Disadvantages.
Disadvantages of neutron radiography include the relatively high cost and additional radiation safety problems. Where high volume applications exist, for example turbine blade inspection, cost need not be a prohibitive factor. The additional radiation safety issues arise mainly from the generation of radioactivity in the inspection sample. These problems are rare and where they exist are usually easily handled by shielding and/or short waiting-time periods for the activity in the sample to decay.

SECTION VII
EFFECTIVE RADIOGRAPHIC INSPECTIONS.

6.7 EFFECTIVE RADIOGRAPHIC INSPECTIONS.

6.7.1 Introduction.
This section describes the factors that determine whether or not a particular radiographic inspection is sufficiently sensitive to detect small defects. Sensitive radiography requires maximum subject contrast resulting from correct kilovoltage and alignment of the beam with the plane of the likely flaw; a sharp image due to good geometry and control of secondary radiation; and optimum density to give good film contrast. Each of these factors is described in turn and, finally, a description is given of quantitative transformations to allow exposure and density changes with a minimum of experimentation.

6.7.2 Factors Affecting Image Quality.

6.7.2.1 Radiation Energy.
The radiation energy chosen must be compatible with absorption of the subject. For low-absorbing subjects, low energy radiation produces final radiographic images with good contrast. Conversely, for inspection of thick, highly absorbing subjects, the radiation must have sufficient penetrative capability to produce an image within a reasonable period of time. For high contrast, 96 to 99 percent of the incident radiation should be absorbed by the subject. Increasing kilovoltage reduces contrast because the quantity of radiation at any given energy increases and, perhaps more importantly, the proportion of radiation with a short wavelength (high energy) increases disproportionately. Figure 6-21 shows these two relationships. High energy radiation can penetrate the subject more readily and thus reduces subject contrast. Figure 6-22 shows the effect on the final image of low or high contrast. The right diagram in Figure

6-22 shows that, for a given subject, a doubling of kilovoltage increases transmitted radiation 15 to 30 times. This example shows the disproportionate effect a small kilovoltage change can have upon a particular inspection.

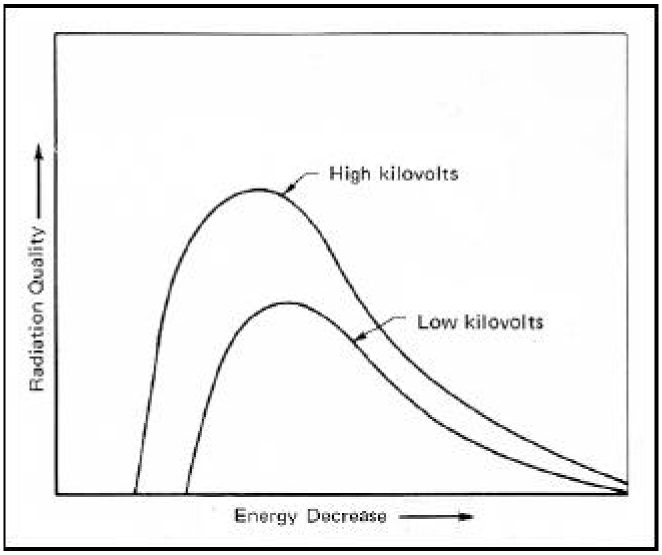
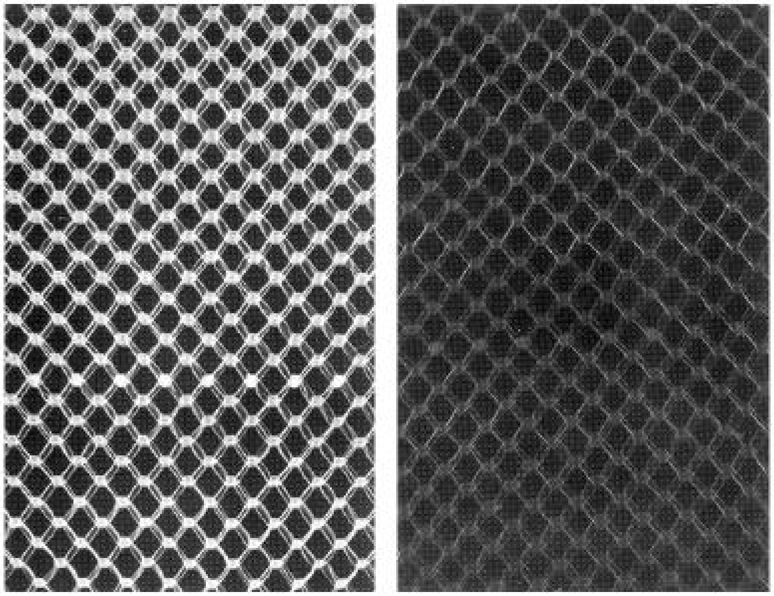


Figure 6-21. Effect of Kilovoltage on Transmitted Radiation Output.



a. 38 kVp, 5 minutes

b. 80 kVp, 5 seconds

Figure 6-22. Radiographs of Honeycomb Showing Effect of Kilovoltage on Contrast.

6.7.2.1.1

If industrial radiographic applications were to use monochromatic radiation and if there was no scattering to be considered, the radiation absorption could be mathematically calculated with high precision using the classical attenuation equation. However, in normal applications, it is not possible to calculate the right kilovoltage to be used for a particular inspection because this optimum condition does not exist. The best initial approach is to use past experience. Table 6-12 indicates approximate radiation energies compatible with various subjects.

Table 6-12. Approximate Radiation Energies Compatible with Various Absorbers.

Radiation Source, kVp	Aluminum or Other Light Metals	Steel
2-25	0.001-0.11 in.	0.001-0.01
25-50	0.1-0.75 in.	0.01-0.125
50-150	0.5-3 in.	0.125-0.75
100-250	2-8	0.125-1.75
150-400	3-12	0.375-3 in.
IrŸ192		0.625-4 in.
CsŸ137		0.75-4 in.
1 mev		1.5-5
CoŸ60		1.5-7
8-12 mev		3.12
24 mev		3.18

6.7.2.1.2

It should be noted that, as the radiation energy increases, the differences between absorbing materials become less pronounced than at lower energies. Due to the photoelectric absorption, the atomic number of an absorber has a large effect upon radiation absorption at energies of 100 kV or less. At high energies in the 1 MeV range, the material density becomes the major controlling factor in determining radiation absorption. A 10 percent change in radiation energy has a very definite effect at low energies. In the MeV energy ranges, this same percent change in energy can hardly be detected in transmission characteristics.

6.7.2.2 Radiation Quantity.

An alteration in the filament current (ma) produces a direct change in the quantity of radiation emitted but has no effect upon the radiation energy. Further more, filament current (ma) and time are usually interchangeable. That is, the product of milliamperage and time is constant for the same photographic effect. This is known as the reciprocity law and is valid for X-ray and gamma exposures, with or without lead screens, over the range of radiation intensities and exposure times used in industrial radiography with one exception. This exception is the use of fluorescent screens; their use is discussed in the section entitled films, film holders and screens. For very low or high intensities, the reciprocity law fails because of changes in the efficiency of the response of the film emulsion to unit radiation. If high production radiography were required, then a source with a high radiation output would be economical. Usually, the high-output equipment requires a source with a comparatively large focal spot. Therefore, rate of radiation output is often directly related to focal spot size, and the unsharpness due to geometry can become detrimental to image quality.

6.7.2.3 Exposure Geometry.

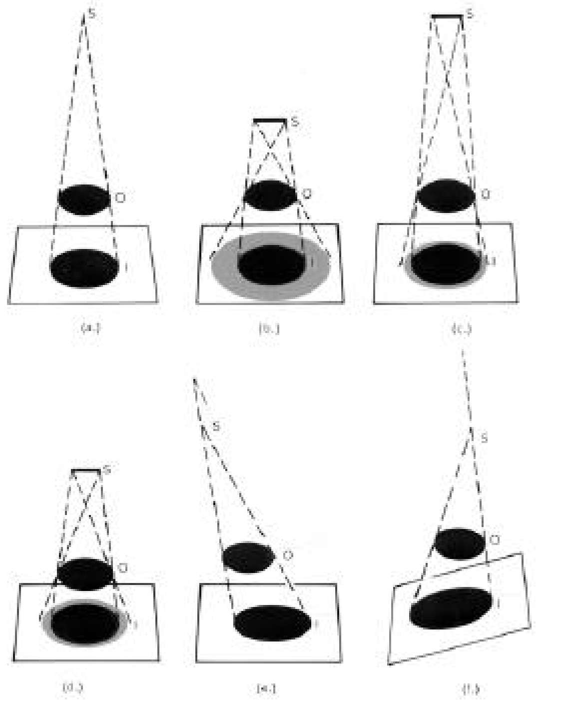
The geometrical setup used to produce a radiographic image is an important factor that contributes to final image quality. Geometrical relationships affect the image sharpness and help control image distortion.

6.7.2.4 Image Distortion.

The central ray of the X-ray source should be aligned perpendicular to the part being radiographed, and the film should be located in the same plane as the part. This positioning projects the image of the part upon the film in the true shape of the object. Any deviation from these relative positions of source, object and film will produce images with some degree of distortion. Alignment is particularly critical for crack detection. Since discontinuities revealed in radiographic images are usually identified by their shape, images free of distortion are very important in radiographic interpretation. Where complex structures are encountered in aircraft inspection, it is often impossible to locate the parts in the most desirable position, and sometimes inspection is facilitated by planned distortions. Interpretation of distorted images is not impossible, but the film reader needs to visualize mentally the geometry of exposure and substitute visualization of the distorted image with the projection of the image by the radiation source. This ability requires practice and experience.

6.7.2.5 Image Unsharpness.

Image unsharpness is the term usually applied recognizing the fact that there is always unsharpness to some degree and that perfect image sharpness is unattainable. The amount of geometric image unsharpness is due to size of the source of radiation and relative distances as shown in Figure 6-23. The distance on the film over which an edge is spread is known as the penumbral shadow or the geometrical unsharpness, U_g. The value of U_g does not enter into other computations; it sets the upper limit for Ft/d. The value must be determined experimentally. The equation to determine unsharpness is:



S REPRESENTS THE SOURCE, O REPRESENTS THE OBJECT BEING RADIOGRAPHED, AND I IS THE IMAGE PLANE. (a) OPTIMUM GEOMETRIC FIDELITY CONDITION. (b) EFFECT OF POOR F/d RATIO WITH LARGE PENUMBRAL SHADOW. (c) CONDITION IMPROVED BY INCREASING SOURCE-TO-OBJECT DISTANCE. (d) SAME CONDITION ACHIEVED BY DECREASING PART THICKNESS OR DISTANCE FROM OBJECT TO FILM. (e) AND (f) ILLUSTRATE THE EFFECT OF GEOMETRICAL MISALIGNMENT.

Figure 6-23. Possible Geometric Distortions.

$U_g = Ft/d$

where:

F = maximum dimension of the focal spot
t = distance from the source side of the test object to the film
d = distance from the source to object

6.7.2.5.1

In considering geometrical unsharpness, recognize the value of new microfocus X-ray sources and the potential for geometric magnification. Figure 6-24 is a nomogram to assist in solving this equation for various geometrical conditions. An example of its use follows, but note that 3 out of 4 terms in the equation must be known before it can be used.

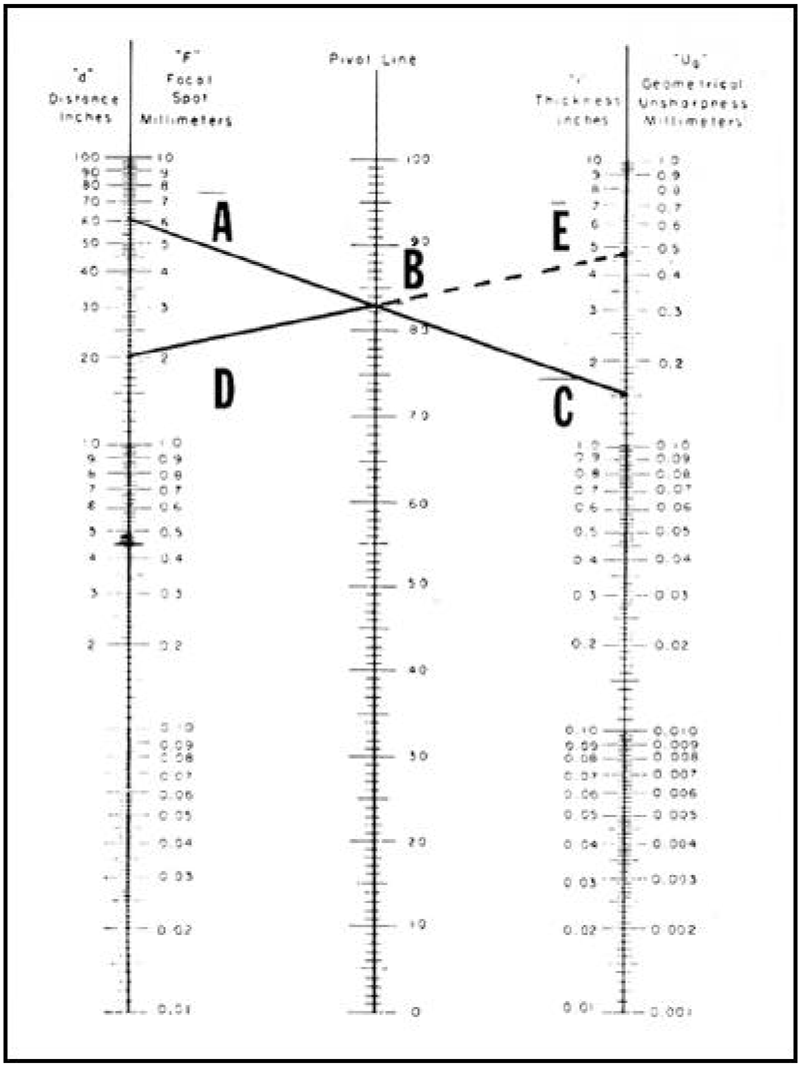


Figure 6-24. Nomogram to Assist in Solving Equation $U_g = Ft/d$.

6.7.2.5.2
Suppose that a specimen having a maximum thickness of 1.5-inch (t) is to be radiographed at 20-inch source-to-film distance (d) using a source of effective focal size 6mm. The need is to establish an approximate value for U_g. The steps in using the nomogram are:

a. Plot the points A and C that represent the known value of F and t. The pivot line is intersected at B.

b. Plot a line joining point D (the value of d) and B. The extension of this line at E gives the value of U_g (0.47mm).

6.7.2.5.3
It should be remembered that unsharpness of the radiographic image is also affected by the characteristics of the X-ray film. Therefore, the total image sharpness may be controlled by either geometrical unsharpness or film unsharpness. Whichever unsharpness value is the greater will control the total image unsharpness. In a given situation, the

geometric unsharpness that can be tolerated sets the lower limit for the adjustable parameter. Further demands on sharpness are paid for in intensity. The unsharpness is inversely proportional to the source-object distance, whereas the intensity is inversely proportional to the square of this distance. Thus, the trade-off of intensity for sharpness is not an equitable one. Nonetheless, this uneven exchange is necessary in many cases because it is very important to achieve good geometric definition. The basic principles of shadow formation must be given primary consideration to insure satisfactory sharpness and low distortion of radiographic images. Distortion cannot be entirely eliminated since some of the test object will be further away from the film than others and radiation from any source cannot be made ideally parallel; images will always be less than perfect. In summary then, five general rules can be stated which promote quality assurance from geometric considerations.

a. The X-rays should proceed from as small a local spot as other considerations will allow.

b. The distance between the source and the object should be as great as practical.

c. The film should be as close as possible to the object being radiographed.

d. The central beam should be as nearly perpendicular to the film as possible.

e. As far as the shape will allow, planes within the specimen plane of interest should be parallel with the film.

6.7.2.6 Film Placement.

After the film and film holder have been chosen, the film position in relation to the part must be considered. In production radiography of small parts, this is a simple matter of laying the parts on the film holder. With complex structures, film positioning is not usually as simple. A few rules can be of assistance in such inspection situations.

a. Always position the film as close to the area of interest as possible.

b. Attempt to locate the film so that the plane of the area of interest and the film are perpendicular to the radiation beam. This is to prevent distortion in the final image.

6.7.2.6.1

In positioning the film, care should be used to prevent sharp bends in the film or applying pressures to the film holder that can produce pressure marks or crimp marks (artifacts) on the final image. In radiography of curve surfaces, the source and film should be positioned, if possible, to take the best advantage of the inverse square law and to prevent as much distortion as possible. Flexible film holders should be used in order to place the film as near as possible to the surface of the test object. It may be noted in Figure 6-25 that the distance from source to the entire surface of the film is nearly constant and the thickness of the test object is also a constant to the path of radiation. This preferred positioning is not always possible, but it should be used when practical.

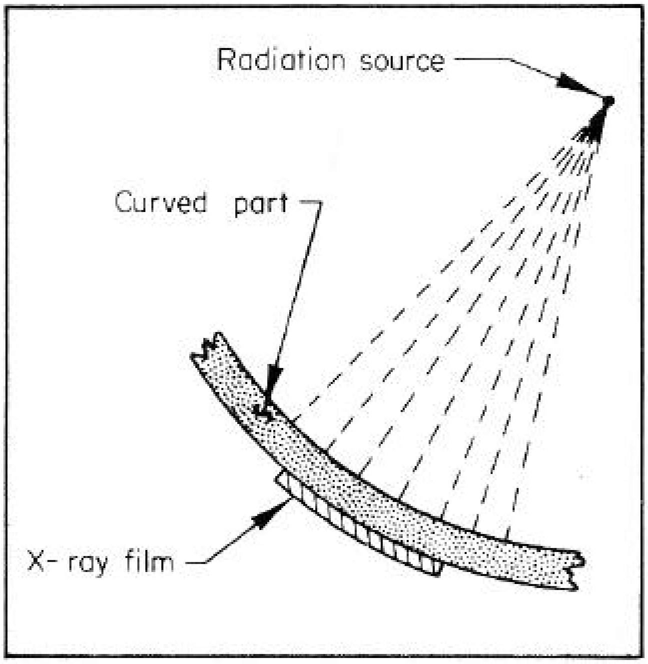


Figure 6-25. Preferred Geometry for Radiography of Curved Surfaces.

6.7.2.7 Focal spot size.

The ideal would be to have a pin point source of radiation. Though microfocus tubes approach it, in actual practice this is impossible, and radiation sources have finite dimensions. The actual focal spot size in an X-ray tube is the projected area being bombarded by electrons from the heated filament; in gamma radiography, it is the radioactive pellet. To reduce the apparent size, the X-ray target is positioned at some small angle, and from the position of the X-ray film the area appears as the projection of this focal spot on the film plane. This projection is referred to as the effective focal spot. Focal spot sizes must increase with increasing kilovoltage rating to prevent the melting of the target material. Radiation is being emitted from the entire area of the effective focal spot. These various radiation are projected at different angles through the test object and spread the image of a sharp edge over a finite distance on the film. Examples of the formation of shadow projections are shown Figure 6-23. What has been said about focal spot size in X-ray tubes also applies to gamma radiography where the pellet of radioactive material functions as the focal spot. The relatively large size of the pellets accounts for the inferior definition obtained with gamma radiographs.

6.7.2.8 Source To Film Distance.

The sharpest image would be formed by having a source-to-film distance (SFD) so great that the rays would be parallel at the film plane (see Figure 6-23). However, since radiation intensity or quantity is diminished in relationship to the inverse square of the distance, the radiation quantity available to expose the film would be very small, and exposure times would become impractical. Therefore, in the production of the radiographic image, economics and practicability must be considered. It is recommended that the longest practical SFD be used for critical exposures to improve image sharpness. If the source to film distance is changed, the following formula can be used to correct the exposure. Because an increase in distance causes a decrease in beam intensity as explained in the next paragraph, only the intensity is changed. Do not change the kilovoltage when correcting for SFD changes.

The formula is: $\frac{T_2}{(D_2)^2} = \frac{T_1}{(D_1)^2}$ $\quad T_2 = T_1\left(\frac{D_2}{D_2}\right)^2$ or $\frac{T_1(D_2)^2}{(D_1)^2}$

Where:
T1 = Original Exposure (MAS).
T2 = New Exposure (MAS).
D1 = Original Distance (SFD).
D2 = New Distance (SFD).

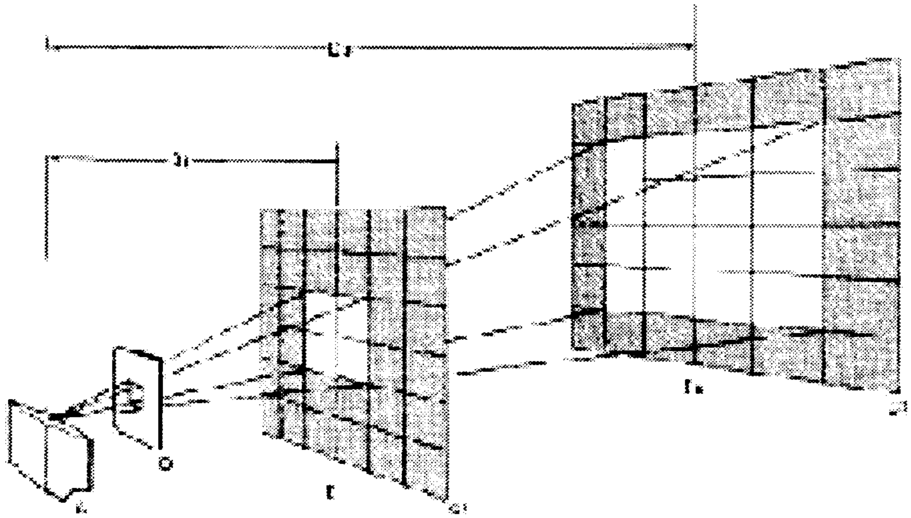
For example, a technique calls for exposing a part at 36 inches using 300 mas. However, the tube head needs to be moved to make a 48 inch SFD, what would the new exposure be?

Substituting:

Cross multiplying gives (T2) * (1296) = (300) * (2304) or T2 = (300 * 2304)/1296.
Solving, T2 = 533 MAS, which would be our new exposure.

6.7.2.9 Inverse Square Law.

When the X-ray tube output is held constant or when a particular radioactive source is used, the radiation intensity reaching the specimen is governed by the distance between the tube (or source) and the specimen, varying inversely with the square of this distance. The explanation below is in terms of X-rays and visible light but applies with equal force to gamma rays as well. Since X-rays conform to the laws of light, they diverge when they are emitted from the anode and cover an increasing larger area with lessened intensity as they travel from their source. This principle is illustrated by Figure 6-26.



H0000348

Figure 6-26. Inverse Square Law Diagram

6.7.2.9.1

In this example it is assumed that the intensity of the X-rays emitted at the anode (A) remains constant, and that the X-rays passing through the aperture (B) cover an area 4 square inches on reaching and recording surface (C_1), which is 12 inches (D) from (A). Then when the recording surface (C_1) is moved 12 inches farther from the anode to (C_2), so that the distance between (A) and (C_2) is 24 inches (2D) or twice the distance between (A) and (C_1); the X-rays will cover 16 square inches, an area of 4 times as great as that at (C_1). It follows, therefore, that the radiation per square inch on the surface at (C_2) is only one quarter that at the level (C_1). Thus the exposure that would be adequate at (C_1) must be increased 4 times in order to produce at (C_2) a radiograph of equal density. In practice this can be done by increasing the time or increasing the milliamperage. Mathematically the inverse square law is expressed as follows:

$$\frac{I_1}{I_2} = \frac{(D_2)^2}{(D_1)^2}$$

where I_1 and I_2 are the intensities at distances D_1 and D_2 respectively.

Example: An intensity of 2 mR was measured at 40″ from the source. What would be the intensity reading at 30 inches, and at 20 inches? When determining unknown distances do not forget to take the square of the predetermined value for D_2.

6.7.2.10 Source/Defect Orientation.

Radiography can be used quite reliably to detect cracks provided certain stringent criteria are met. It is very easy to produce an apparently high quality radiograph that does not show an existing crack or with a crack indication so faint it can barely be seen. The resolution of cracks depends upon total density change and film/subject contrast. The human eye can detect density changes of 0.02 H & D units, however to detect cracks a density change of 0.05 H & D units is more reasonable. There are several factors that produce density changes on X-ray film. The primary factor in the case of crack detection is a change in thickness or mass between the crack and part being inspected. A general rule is the crack must be at least 2 percent of the part thickness if it is to produce a readable indication. This rule has variables that influence film density changes, and in some cases as little as a 1 percent thickness change will produce a visible indication. In other instances, a crack exceeding 5 percent of the part thickness may not produce a readable density change. Regardless of total density change across an indication, if contrast is not high, crack indications can be missed. Example: A change in density of 0.05 H & D units can be easily seen if it is an abrupt change. Conversely, a change or 0.25 H & D units (5 times 0.05) is difficult to see if it is a gradual change over an area (i.e., gradual increase, increase over 1/2 inch width as opposed to a 1/8 inch width).

6.7.2.10.1

When an X-ray tube focal spot is centered directly over a crack whose depth is parallel to the beam (X-ray beam and crack plane coincide), the film density change will be a function of the ratio of crack depth to metal thickness. Indications of narrow cracks with parallel sides will appear as fine dark lines with high contrast. Wide cracks with sloping sides will result in broader indications of lower contrast. Figure 6-27 is a sketch illustrating the film density changes between two different width cracks when the X-ray tube is centered over the crack origin. The stress on a part will effect crack width. Example: compressive stress in the lower wing surface of an aircraft on the ground tends to reduce, crack width. The compressive stress is due to the weight of the structure, engines, ordnance pylons, etc. Jacking the aircraft to place the lower surface in neutral stress or in tension is frequently done to enhance detection of small cracks. One general characteristic of cracks and their indication is the tendency for them to curve or deviate from a straight line. An apparent exception is a very short crack or a crack between two adjacent fasteners, but even here, when the indication is examined under magnification there will be some edge jaggedness or change in edge appearance.

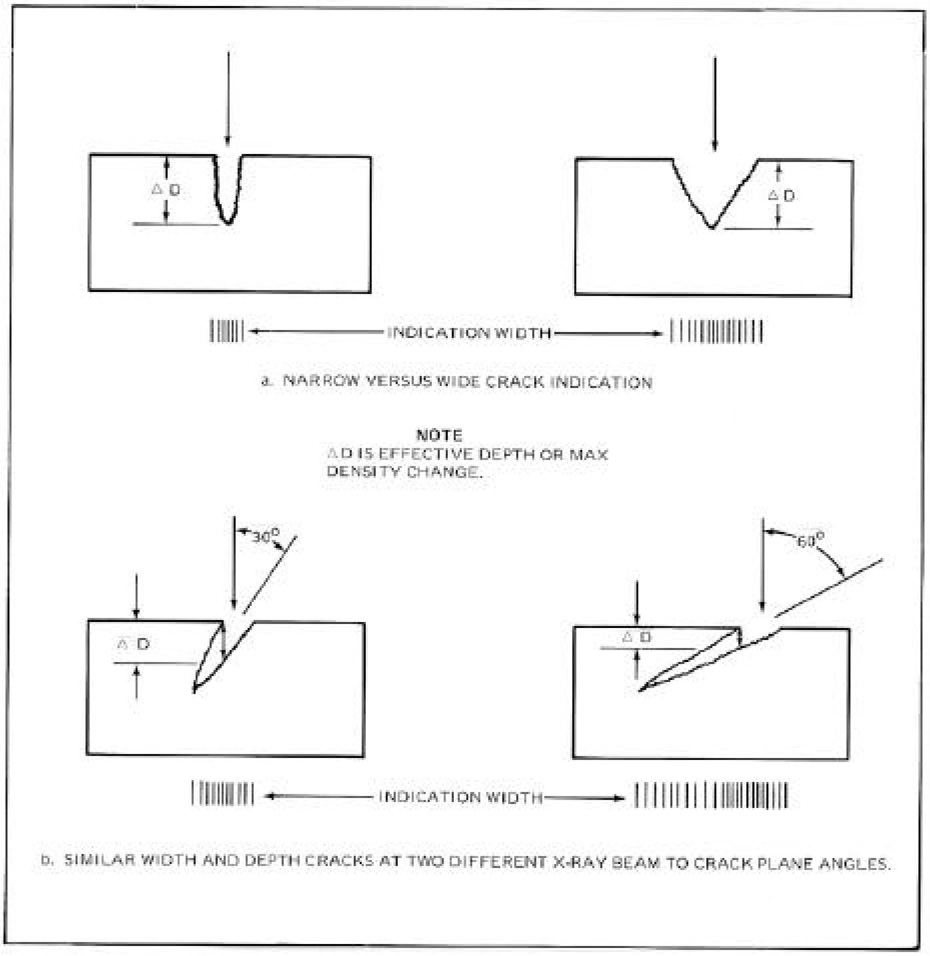


Figure 6-27. **Density Changes Due to Varying Crack Widths and Intersection Angles.**

6.7.2.10.1.1
Obtaining parallelism between X-ray beam and crack plane is difficult to achieve. Cracks do not always initiate at the expected origin and often are not perpendicular to the part surface. When the X-ray beam passes through a crack at any angle other than directly along the crack plane, both the width of the crack and the intersect angle determine the density change and indication contrast. Figure 6-27 shows two cracks of approximately the same width and depth but with different angles of X-ray beam to crack plane intersection. As the angle between the x-ray beam and crack plane increases, both film density change and contrast decreases. The film indication becomes broad, and more diffuse until it blends into the background and is no longer discernible.

6.7.2.10.1.2
Detection of cracks depends upon crack width, depth, total metal thickness and angle of intersection. When only the intersection angle varies, it becomes a matter of statistics or probability. Table 6-13 reflects the probability of detecting a crack at various intersect angles. The table indicates the probability of detecting a crack with an intersect angle of 9' is 75 percent. Conversely, the chances of missing a crack with a 9° intersect angle is 25 percent or 1 out of 4. When developing X-ray procedures to be used for detection of cracks, the maximum angle of intersection is 5°, which corresponds to an 85 percent probability of detection. The preferred limit is 2 1/2° corresponding to 90 percent detection probability.

Table 6-13. Correlation between Beam Divergence and Crack Detectability.

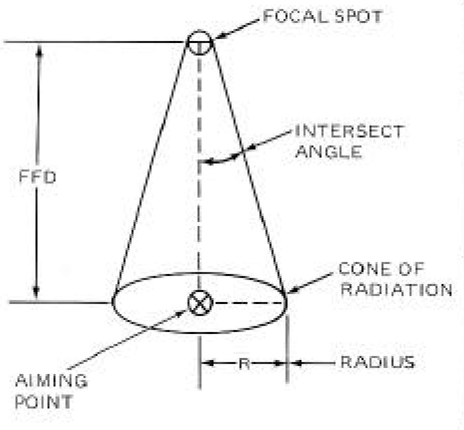
Beam to Crack Angle (Degree)	Probability of Crack Detection (Percent)
0	96
3	89
6	82
9	75
15	48
21	30
27	23
45	4

6.7.2.10.1.3

A 2 1/2° or 5° intersect angle X-ray beam will not project over the surface of a 14 inch by 17 inch film at normally used focal spot to film distances (FFDs). The entire film will be exposed but only a small cone of radiation will be within the desired or allowable intersect angle limits. Table 6-14 reflects the radiation cone coverage at various intersect angles and FFDs. The table can be used to determine the necessary FFD when developing procedures. Example: A 12 inches long splice plate must be inspected for cracks. From Table 6-13, a 72-inch FFD is required to be within the 5° intersect angle limit (6.3 inches on either side of the aiming point). Cracks occurring further than 6.3 inches from the aiming point will produce indications with reduced film density change and contrast an there is a greater chance of not detecting them. This emphasizes the need for information on crack location and orientation before developing an X-ray procedure, plus the requirement for accurate tubehead alignment during equipment set-up.

Table 6-14. Radiation Cone Radii at Various Intersect Angles and FFDs.

	RADIUS of CONE (inches)				
FFD	2 1/2°	5°	7 1/2°	10°	Intersect Angle
36"	1.57	3.15	4.74	6.35	
48"	2.10	4.2	6.32	8.46	
60"	2.62	5.25	7.9	10.58	
72"	3.14	6.3	9.48	12.7	
84"	3.67	7.35	11.06	14.8	



6.7.2.11 <u>Scattered Radiation</u>.

Whenever X-rays interact with material, one or more of the following will occur, absorption, scattering or penetration. In industrial radiography, scattered radiation can present a problem since it has the ability to expose the X-ray film without contribution to image information. Exposure due to scatter is usually referred to as fog and it substantially reduces the image contrast. Scattered radiation can have three different sources (see Figure 6-28). One source of scatter can be the area around the test or other objects that may be in the radiation beam. This is usually referred to as reflective scatter. A second source is scatter radiation from objects behind the film. This is usually referred to as backscatter radiation. The third source of scatter radiation is the test object itself. This scatter can obliterate the object's edges and is called "undercutting." The amount of scatter radiation is affected by the radiation energy and the atomic number of the element doing the scattering. Low atomic number materials scatter radiation to a greater degree than materials with high atomic numbers.

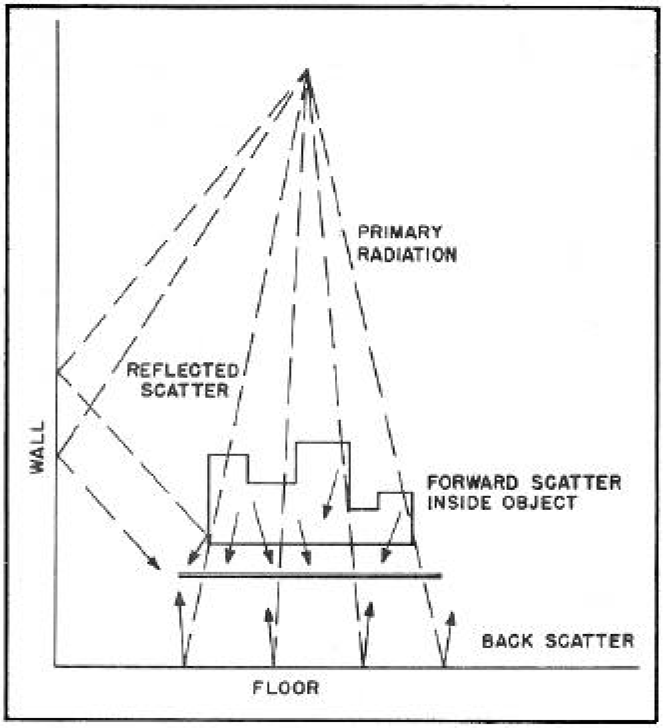


Figure 6-28. Sources of Scatter Radiation.

6.7.2.11.1

Several techniques can be used to reduce the amount of scatter. Radiographic cones or masks can be made of lead or other high absorbing materials to reduce the radiation area to only the area necessary for exposure. Lead in many different forms can be placed behind the X-ray film and test object to reduce excessive backscatter. Lead foils may be placed between the test object and the X-ray film to absorb some of the scattered radiation before they expose the film. These act as scatter filters since they permit the higher energy image forming radiation to be transmitted to the film and at the same time absorb the lower energy scattered radiation. Their function is described more fully in the section entitled films, film holders, and screening, but note that filters in this position will reduce subject contrast. In some cases, the scatter problem can be of such a magnitude that special techniques must be applied. Masking the part is often required because of large variation in thickness-and thus differences in absorption lead to scatter from excessive radiation transmitted through thin sections. Figure 6-29 shows how a lead sheet could be used for masking. In this case, the object was a steel hub without the lead sheet (1 /8 inch thick) definition was poor due to internal scatter.

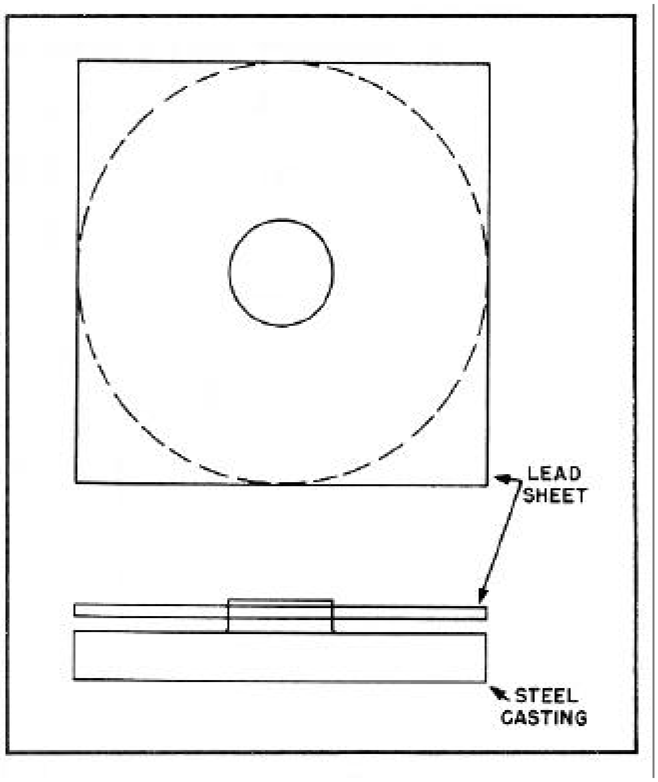


Figure 6-29. Masking to Avoid Scatter.

6.7.2.11.2
The control of scatter requires common sense and ingenuity. A concrete, wood or composition floor will generate enough back-scattered radiation to fog a film. Film holders should always be laid on or backed with a sheet of 1/8-inch lead. The backing should be as large as the primary radiation field. This thickness of lead is enough for radiation generated up to 300 kVp, except where fluorescent screens are in use, 1/4 inch should be used. The Potter-Bucky Grid is a device especially constructed to absorb object scatter radiation. Effectively, this grid is made somewhat like a Venetian window shade; it consists of strips of material comparatively transparent to radiation and strips of lead. The strips of lead absorb object scatter radiation at angles other than the direct beam. To prevent the lead strips from being revealed in the image, the grid is moved during exposure so the image of the lead strips is actually distributed over the entire image but does not show detail. These Potter-Bucky Grids are usually used in industry for radiography of low atomic materials where scatter is a problem of considerable proportions, especially in medicine.

6.7.2.12 Effect Of Processing.
Processing variables, especially development time, also affects density and film contrast through their effect upon the slope of the characteristic curve. Tests with a typical industrial film showed that as development time was reduced, the effect was to produce a family of characteristic curves displaced to the right. That is, the log relative exposure needed to produce a standard density increased as development time decreased. There were other effects too. Figure 6-30 shows that an optimum development time maximized the slope of the characteristic curve (and thus film contrast) at only slight cost in fogging.

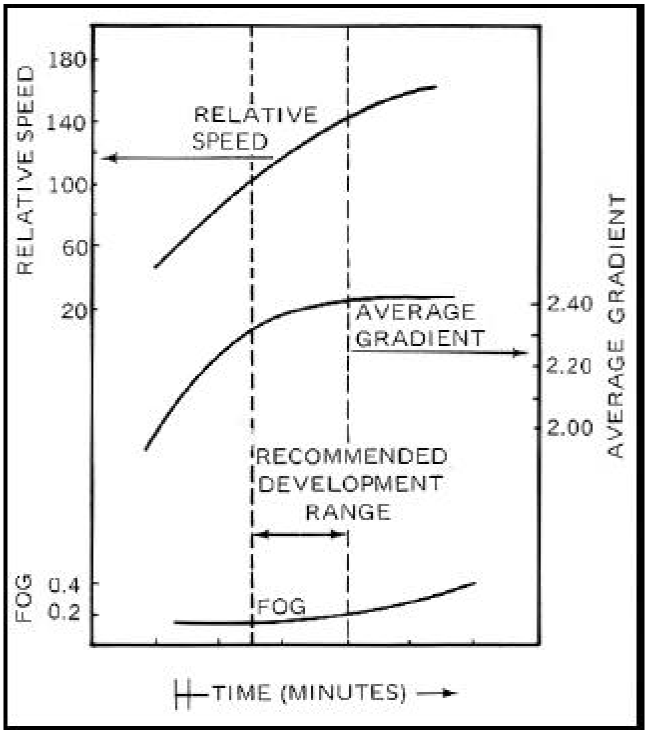


Figure 6-30. Effect of Development Time upon Film Speed, Contrast and Fogging.

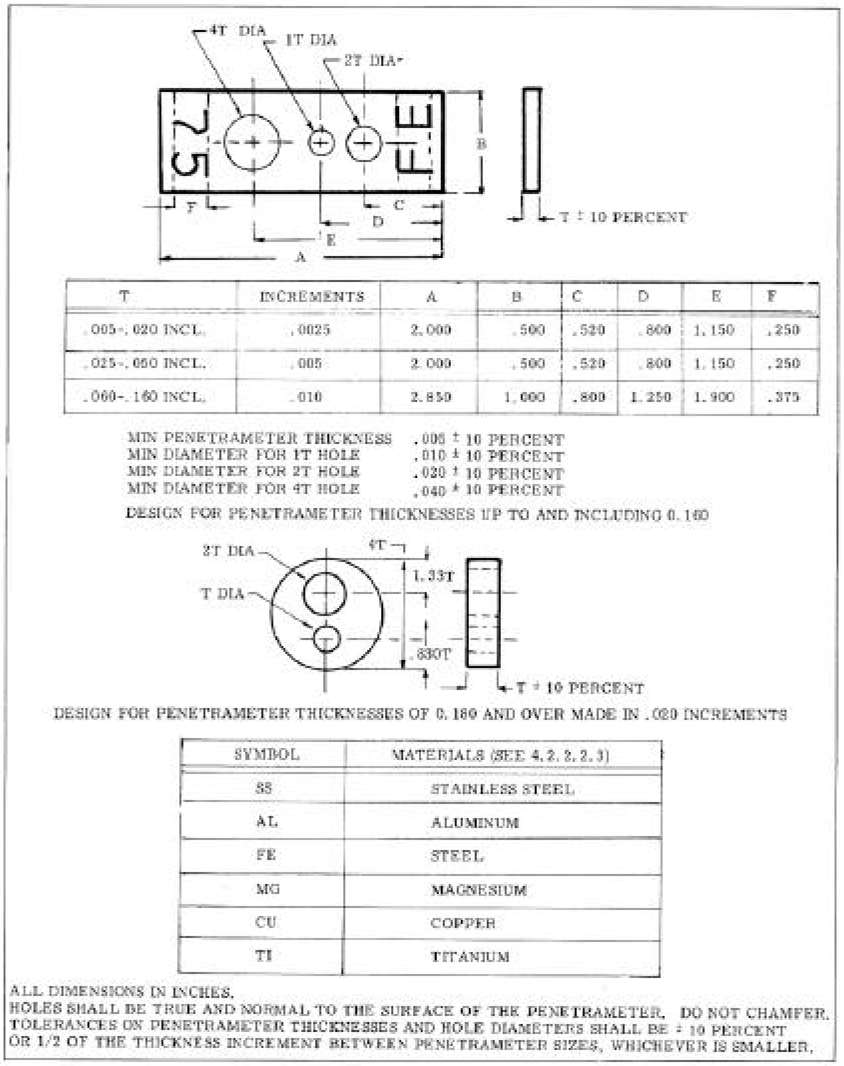
6.7.3 Radiographic Sensitivity.

6.7.3.1 Penetrameters.

CAUTION

Use the IQI specified in the technique. Consult with the appropriate ALC NDT Level III for instructions if the IQI identified in the technique is not available. IQI's are not generally required for inspection for the presence of debris, for proper assembly of components, for dissimilar material inspection, for honeycomb structures, or for the presence or absence of material.

There is a need to be able to qualitatively define how sensitive a radiographic image is. The devices that achieve this aim are known as penetrameters. Another description is image quality indicators (IQI). By whatever name, they provide an indication of what the film reader can be expected to see in the actual part being inspected. A wide range of penetrameters is specified for use by various industries. ASTM plaque-like type penetrameters (or as now more commonly called image quality indicators) are described in Ref. 13. Wire penetrameters, particularly useful for weld inspection, are described in Ref. 14. In their current form, penetrameters are a small plaque, fabricated of the same material as that being radiographed. The thickness of the penetrameter is a known percent of the test object thickness. Holes in the penetrameter are of diameters 1T, 2T, and 4T when T equals penetrameter thickness. Thickness visualization of these holes can be related to the sensitivity of the radiographic image. A typical penetrameter is shown in Figure 6-31.



T	INCREMENTS	A	B	C	D	E	F
.005-.020 INCL.	.0025	2.000	.500	.520	.800	1.150	.250
.025-.050 INCL.	.005	2.000	.500	.520	.800	1.150	.250
.060-.160 INCL.	.010	2.850	1.000	.800	1.250	1.900	.375

MIN PENETRAMETER THICKNESS	.005 ± 10 PERCENT
MIN DIAMETER FOR 1T HOLE	.010 ± 10 PERCENT
MIN DIAMETER FOR 2T HOLE	.020 ± 10 PERCENT
MIN DIAMETER FOR 4T HOLE	.040 ± 10 PERCENT

DESIGN FOR PENETRAMETER THICKNESSES UP TO AND INCLUDING 0.160

DESIGN FOR PENETRAMETER THICKNESSES OF 0.180 AND OVER MADE IN .020 INCREMENTS

SYMBOL	MATERIALS (SEE 4.2.2.2.3)
SS	STAINLESS STEEL
AL	ALUMINUM
FE	STEEL
MG	MAGNESIUM
CU	COPPER
TI	TITANIUM

ALL DIMENSIONS IN INCHES.
HOLES SHALL BE TRUE AND NORMAL TO THE SURFACE OF THE PENETRAMETER. DO NOT CHAMFER.
TOLERANCES ON PENETRAMETER THICKNESSES AND HOLE DIAMETERS SHALL BE ± 10 PERCENT
OR 1/2 OF THE THICKNESS INCREMENT BETWEEN PENETRAMETER SIZES, WHICHEVER IS SMALLER.

Figure 6-31. Penetrameter Information.

6.7.3.1.1
The penetrameter has lead numbers permanently attached to indicate the material thickness on which the penetrameter is to be used. In Figure 6-31, the ID number indicates the penetrameter is for use on a 0.750-inch test object. The thickness (T) of the penetrameter is normally made to be 2 percent of the test object thickness. Therefore the penetrameter with an ID of 6.0 inches would be 0.120 inch thick. Except in some special instances, plaque penetrameters less than 0.005 inch in thickness are not available. Therefore, in normal operation, the 0.005-inch penetrameter is used on test objects whose thickness may be 0.25 inch or less.

6.7.3.2 Contrast Sensitivity.
The penetrameter material thickness is added to the thickness of the test object. This increase in thickness causes more radiation being absorbed, and the penetrameter outline is seen on the final image as a less dense area. This change in film density due to the additional radiation absorption is a measure of the image contrast. The human eye is normally used as a detector in reading radiographic images, and the eye responds to differences in the quantity of light being transmitted through the film due to the density differences. It is usually assumed that under practical industrial film inspection conditions the human eye is capable of just detecting density differences of LD = 0.02 which corresponds to a light transmission difference of 4.72 percent. Since density differences of 0.02 are considered just barely discernible, good practice is to strive for a density difference of 0.08 to assure good visualization of discontinuities.

6.7.3.3 Detail Sensitivity.

CAUTION

In aircraft radiographs, penetrameters must always be removed from the specimen after inspection.

Detail sensitivity of the radiographic image is revealed by the capability of visualizing the penetrameter holes. When the 2 percent penetrameter is used on the test object, it is usually required that the 2T penetrameter hole be visible. If the 2T hole can be seen, the image is said to have 2 percent radiographic sensitivity. The film reader can then assume the capability of seeing any discontinuity that represents a 2 percent dimensional change of the object total thickness. The 1T hole does not represent 1- percent image sensitivity because the thickness of the penetrameter has not been reduced to 1 percent of the test object thickness. Calculations reveal that visualization of the 1T hole in a 2 percent penetrameter actually reveals 1.4- percent image sensitivity. Resolution of the holes in the penetrameter is a combined measure of image sharpness and contrast and is thus a measure of the image quality, but note that the regular and expected outline of the holes is more readily seen than a crack line. The penetrameter should not be placed over an area of interest, since the penetrameter or the lead identification numbers, may hide discontinuities. In some cases, the penetrameter cannot be placed on the actual test specimen. In these instances, it is acceptable to place the penetrameter on a separate block of the same material and of the same thickness as the specimen. In penetrameter placement, it should be remembered that the purpose of the penetrameter is to reveal the image quality to the film reader, it should therefore be placed in the least advantageous position. However, the density should not vary more than +30, or -15, percent from the area of interest. The plaque penetrameters suffers from a number of disadvantages, the most serious of which is the minimum thickness of 0.005 inches. MIL-STD-00453 provides additional information on the use of penetrameters. The preceding actions have shown that effective radiographic inspection requires techniques that have optimum geometry, film choice, contrast and density. Subsequent paragraphs explain how characteristic curves and technique charts can provide quantitative data to permit precise adjustments.

6.7.3.4 Exposure Factor.

The exposure factor is a quantity that combines milliamperage (X-ray) or source strength (gamma rays), time and distance. Radiographic techniques are sometimes given in terms of kilovoltages and exposure factor, or radioactive isotope and exposure factor. In such a case, it is merely necessary to multiply the exposure factor by the square of the distance to be used in order to find; for example, the milliampere-minutes or millicurie hours required.

6.7.3.5 Radiographic Contrast.

Contrast in a radiograph is the difference in the resultant density that is produced for a given change of X-ray or gamma ray absorption. It is affected by many factors, some of which must be a compromise. Thus, operator judgment again becomes important. The choice of X-ray equipment is one of the most important of these considerations. The shorter the effective wavelength of the X-rays the greater the penetrating power. Also, the higher the kilovoltage on the tube, the shorter the effective wave length of the generated radiation. As a result, the higher the x-ray tube voltage, the greater the penetrating power of generated X-rays. This is true for steel with X-rays generated below 8 to 10 MeV, for aluminum up to 20 to 22 MeV, and for lead up to only 2 to 3 MeV. See Table 6-15.

Table 6-15. Relative Absorption of Materials

Material	Kilovoltage	Exposure Time	Thickness
Lead	200 kVp	1 min	1/16"
Copper	200 kVp	1 min	1/2"
Steel	200 kVp	1 min	3/4"
Titanium	200 kVp	1 min	1"
Aluminum	200 kVp	1 min	4"
Magnesium	200 kVp	1 min	5"

6.7.3.5.1
If the penetrating power of the radiation is great, it can be seen that each increment of thickness in the object will absorb less of the total than if the penetrating power of the radiation is lower. And, conversely, it follows that if low kilovoltage is utilized; less of the total radiation will be transmitted through the object. Each small change in absorption due to thickness of material will then cause a relatively large change in transmission. Thus, the lower the voltage used, the greater the radiographic contrast. Therefore, kilovoltage may be lowered to perform an inspection, but SHALL NOT be increased above the level prescribed in the specific inspection instructions without cognizant engineering approval.

6.7.3.6 Subject Contrast.
Subject or object contrast must also be considered by the radiographer. At X-ray voltages from 30 kVp to 5 MeV, aluminum has a lower absorption per unit thickness than steel. Therefore, it takes a greater thickness change of aluminum to cause a given change in X-ray transmission than with steel. Hence, it follows that aluminum has less object contrast than steel. Figure 6-32 shows graphically the change in thickness versus the change in transmitted radiation. In the radiographic process, these differences in object contrast are, however, partially compensated for because lower energy radiation (longer wavelength) can be used to examine a given thickness of aluminum than for the same thickness of steel. In general, a 1- percent change of thickness will produce sufficient density change on film to be visible when viewed on most metal subjects. But with magnesium and lighter metals, it is difficult to record 2 percent thickness change. Thus, object contrast is a somewhat limiting factor in light metals and material with both low density and atomic number. See Figure 6-33 for the relations between X-ray absorption of steel, aluminum and magnesium.

NOTE

It is recommended that on light materials the radiographer should use lower kilovoltage and, consequently, longer exposure time than he would on heavier materials.

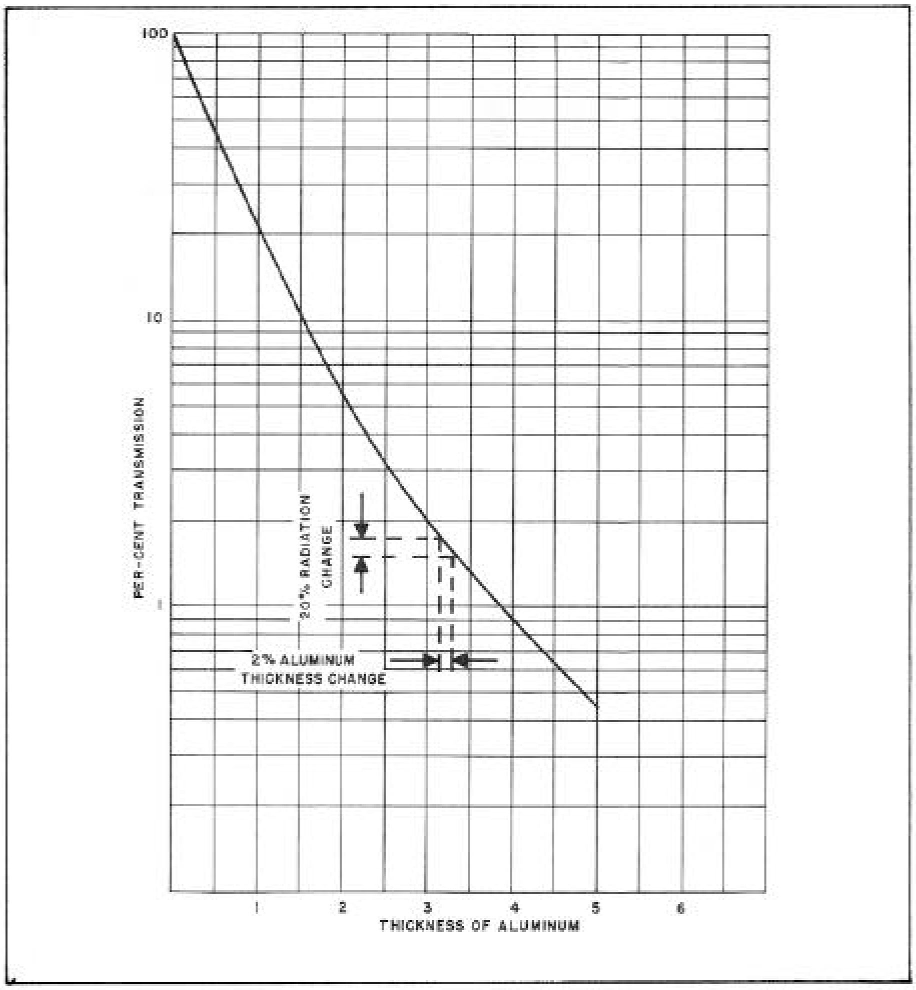


Figure 6-32. Radiation Transmission versus Thickness of Aluminum at 150 kVp.

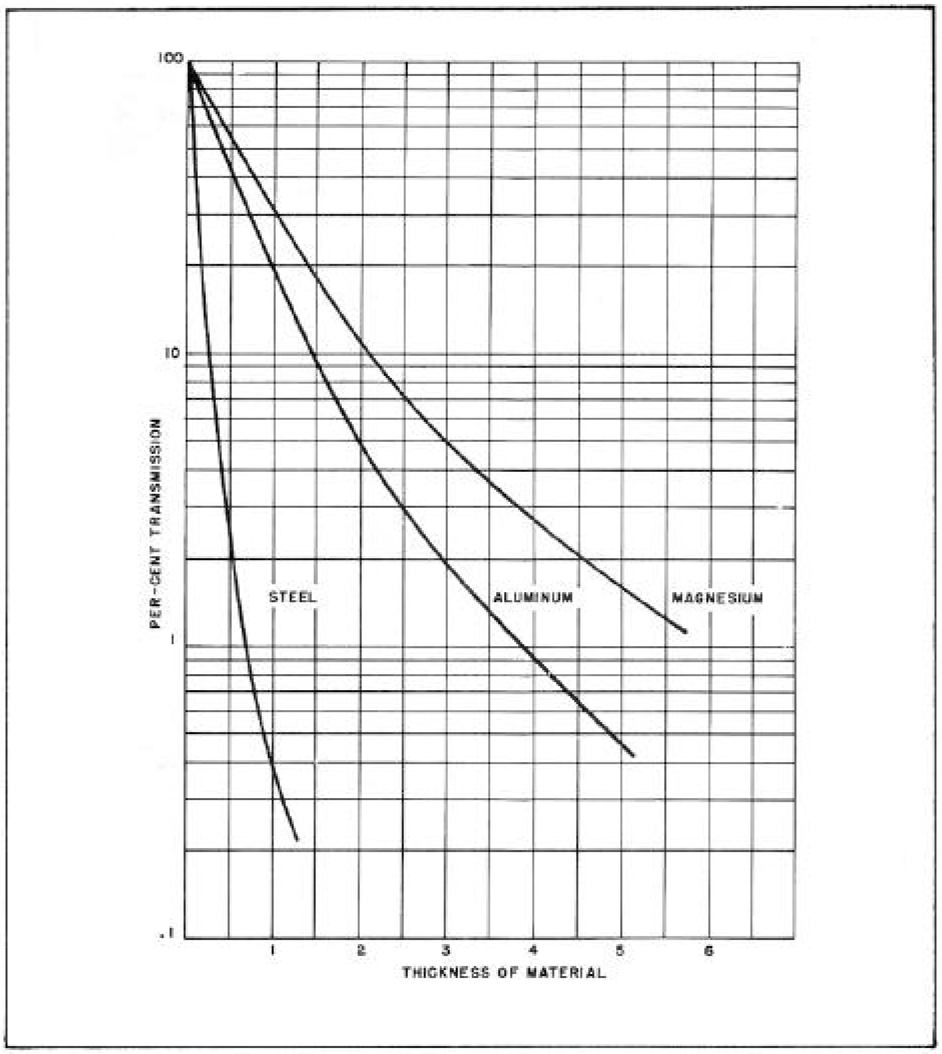


Figure 6-33. Radiation Transmission versus Thickness for Various Densities at 150 kVp.

6.7.3.6.1

For materials of approximately uniform thickness where the range of transmitted X-ray intensities is small, the technique producing high contrast will show all portions of the area of interest with an increased radiographic sensitivity. If, however, the part radiographed transmits a wide range of X-ray intensities, then a technique producing lower contrast will be necessary to record the detail in all portions of the radiograph, probably with some decrease in radiographic sensitivity. In cases where an extreme range of intensities is transmitted, high radiographic contrast may be obtained by loading the film holder with two high contrast films of different speeds. The kilovoltage and exposure are so chosen that the thick portions of the object be satisfactorily recorded on the faster film and the thin portions on the slower film.

6.7.3.7 Film Contrast.

Film contrast has been covered in Section III. In general, films of the no-screen type give higher contrast with or without lead screens than screen type films with or without lead screens. Screen type films with calcium tungstate screens, however, produce maximum contrast with sacrifice of detail due to the grain size of the screens. The contrast of a film can be seen from the slope of the characteristic curves.

6.7.3.8 Film Latitude.
The film characteristic that is the reverse of contrast or gamma is film latitude. The higher the contrast, the smaller the latitude and the lower the contrast, the greater the latitude. Latitude is, therefore, the range of radiation intensities that a film is capable of recording.

6.7.3.9 Screens.
The radiation reaching the film may be in part caused by the use of intensifying screens to reduce the exposure time. The intensification factor for lead or calcium tungstate screens depends on the energy converted to either electrons or light to which the screen is sensitive. This factor varies with kilovoltage and type of film. The film must be selected to achieve highest efficiency of energy conversion from the screens used. The use of screens is covered more thoroughly in Section III.

6.7.4 Technique Charts.
The characteristics of X-ray equipment must be known to properly operate the unit and obtain maximum results. The utilization of X-ray equipment with the least amount of lost time requires a set of technique charts which show the exposure times required for various thicknesses of material under stated conditions. These charts are generally available from the manufactures of X-ray machines. (See Figure 6-34). However, due to the differences between individual machines, it may be necessary or desirable to prepare additional technique charts for the specific purposes and conditions to which the machine will be applied. If published technique charts are available; these charts can be used as a guide in preparing the detailed charts.

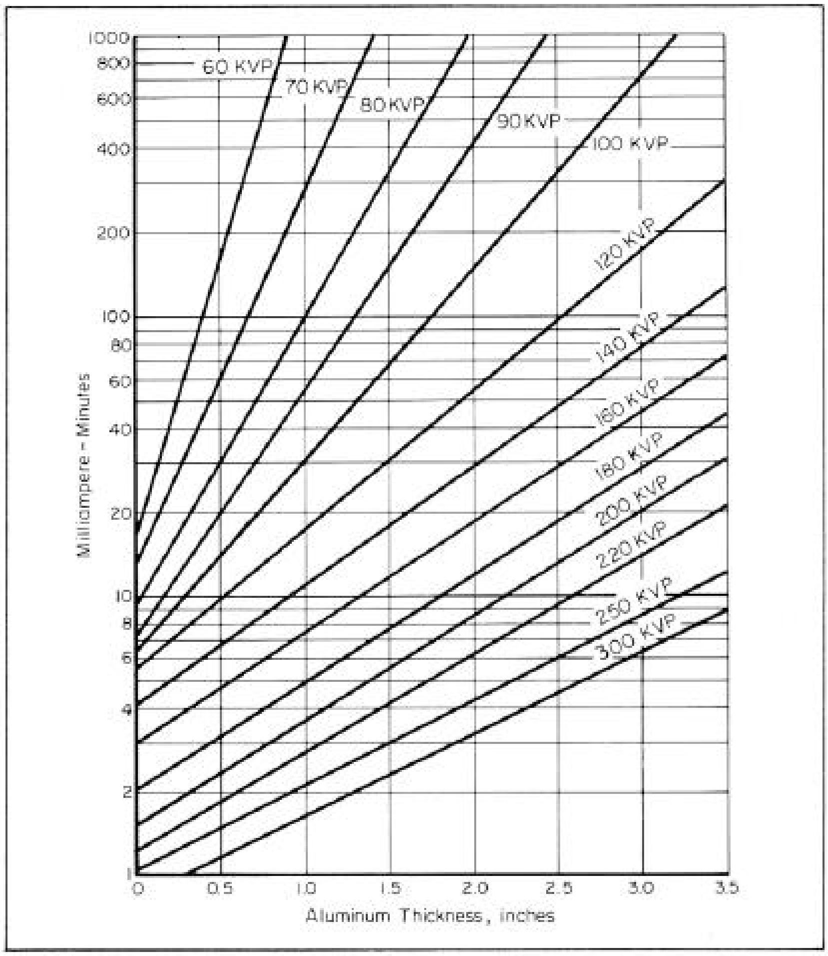


Figure 6-34. A Typical X-ray Exposure Technique Chart.

6.7.4.1
The following items must be recorded to adequately identify technique charts:

a. Type of unit.

b. Material (type and thickness).

c. Film type.

d. Quality Enhancers (screens).

e. Kilovoltage.

f. Current and exposure time.

g. Source-to-film distance.

h. Film processing factors (temperature, method, etc.).

i. Density of radiograph desired.

6.7.4.2 Step Wedge Radiographs.
A step wedge of the material is usually used as the object to be radiographed. (See Figure 6-35) The wedge may be a solid block or made up from plates of the material. A radiograph of the step wedge will give a symmetrical shadow picture of varying densities corresponding to the steps on the wedge. Make a series of radiographs of the step wedge at different exposures while keeping other radiographic factors constant (including subsequent processing). Preparation of the technique chart requires the following steps:

a. Select an estimated exposure for the thinnest section of the step wedge based on exposures for similar material in the middle of the voltage range or a trial exposure on this material. In planning the exposures pick out a series in an approximate geometrical progression. For example, a series of 120MAS, 220MAS, 320MAS and so on might be chosen.

b. Expose the step wedge under conditions previously selected at the times calculated for the mid-voltage point.

c. Process the radiographs using fresh solutions according to manufacturer’s directions.

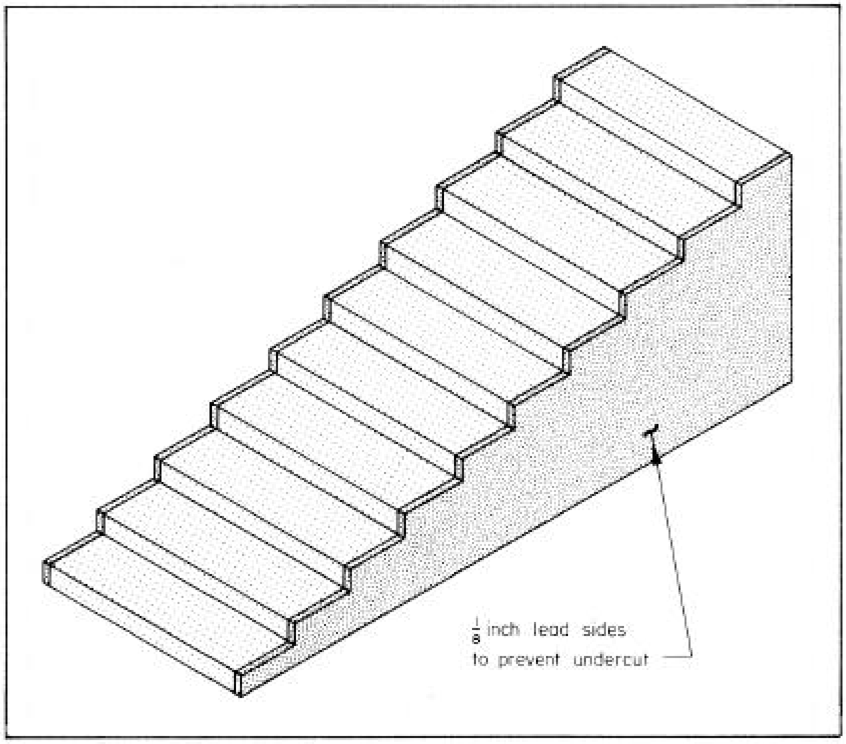


Figure 6-35. Sketch of Desirable Stepped Block for Radiation Measurements.

6.7.4.3 Plotting the Data.

NOTE

The Constant Exposure Chart is for a single kilovoltage setting. Additional curves for other kilovoltages can be made by repeating the procedure at any desired kilovoltage.

Make density measurements of each step of the radiographs with a densitometer and record this data in a table. The final table should show a density for each step thickness at each exposure. Now plot this data on semilogrithmic graph paper with density and object thickness as the coordinates. This will give a set of curves, one for each exposure. This is a Constant-exposure chart and is only one type of technique chart.

6.7.4.4 Constant Density Charts.

It is more common to plot technique charts in the form shown in Figure 6-36. This is a constant-density chart for three different kilovoltages. To prepare this type of technique chart, it is necessary only to plot points taken from the graph prepared in Paragraph 6.7.4.3. Record and plot the points for each thickness at the intersection of the selected density and exposure curves. This will result in a single curve on the constant density chart for one kilovoltage.

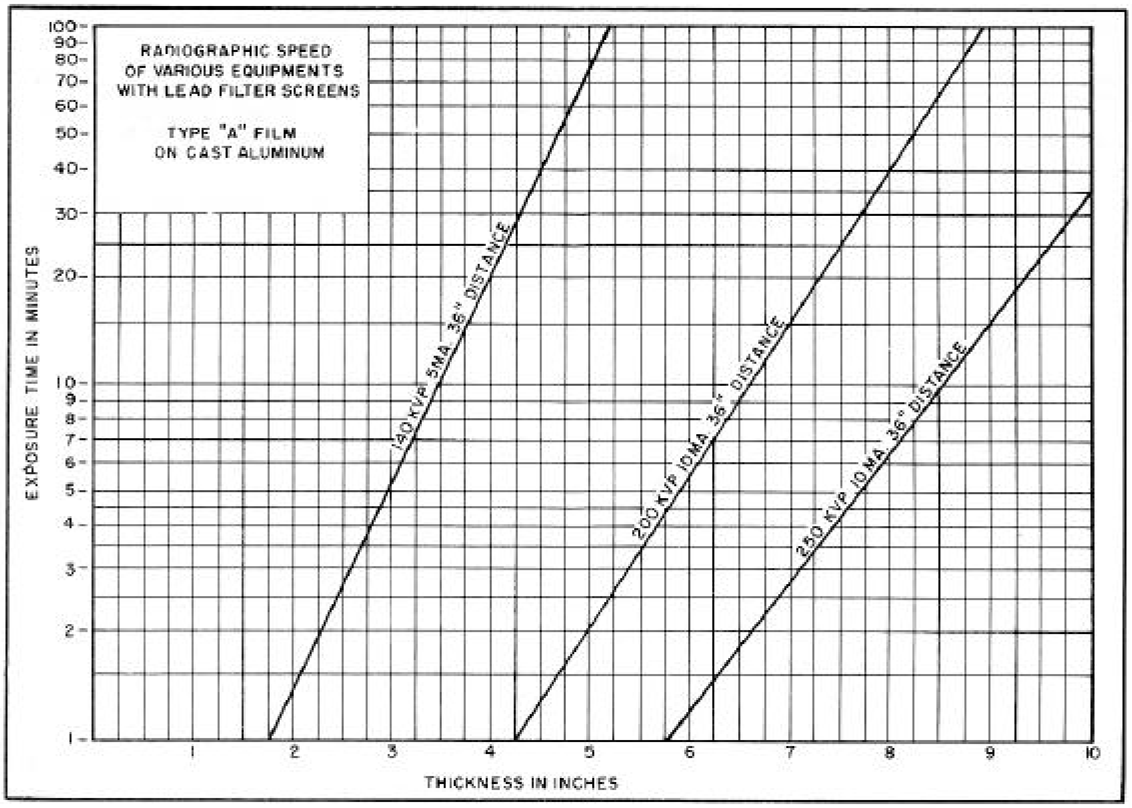


Figure 6-36. Typical Technique Constant-Density Chart.

6.7.4.4.1
Constant density charts may also be prepared directly from the radiographs if a set of constant exposure charts is not desired. To do this proceed as follows

a. Select the exposure and thickness of the step wedge that will produce the density desired.

b. Plot this exposure of time versus the thickness of material on a sheet of semilogrithmic graph paper and label this line with the kVp used for this series of exposures.

c. Repeat the above procedure for a series of voltages through the voltage range of the equipment.

6.7.4.5 Logarithms.

The use of logarithms was covered in Section III. This review explains the use of Figure 6-37, the "Scale for Determining Logarithms".

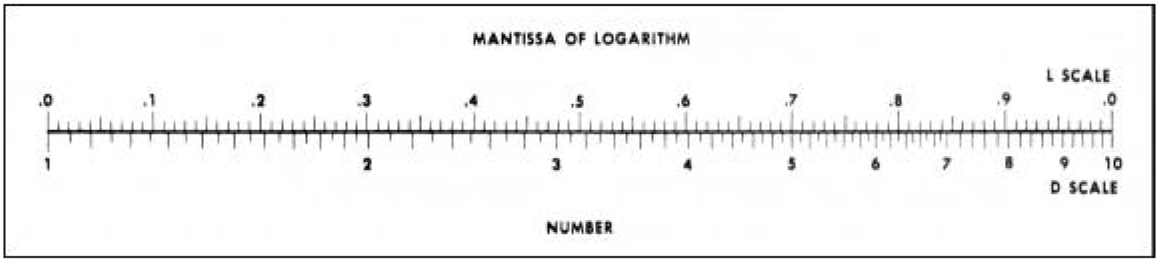


Figure 6-37. Scale for Determining Logarithms.

6.7.4.5.1

Since logarithms are used a great deal in the following section, a brief discussion of them is included here. A more detailed treatment will be found in Paragraph 6.4.1.5 and some handbooks and intermediate algebra texts. Before discussing logarithms, it will be necessary to define the term "power". The power of a number is the product obtained when it is multiplied by itself a given number of times. Thus 10^3 = 10 X 10 X 10 = 1000; 5^2 = 5 X 5 = 25. In the first example, 1,000 is said to be the third power of 10; in the second, 25 is the second power of 5, or 5 raised to the second power. The figure^2 is known as the exponent. Fractional exponents are used to denote roots.

6.7.4.5.1.1

For example: Negative exponents indicate reciprocals of powers. Thus: The common logarithm of a number is the exponent or the power to which ten must be raised to give the number in question. For example, the logarithm of l00 is 2. The logarithm of 3l6 = 2.50, or log 3l6 = 2.50; the logarithm of l000 is 3, or log l000 = 3. It is also said that 1000 is the antilogarithm of 3, or antilog 3 = 1000. Logarithms consist of two parts: a decimal that is always positive called the mantissa; and an integer which may be positive or negative, called the characteristic. In the case of log 316 = 2.50, .50 is the mantissa and 2 is the characteristic. The mantissa may be found by reference to a table of logarithms, by the use of a slide rule (D and L scales), or by reference to Figure 6-37. No matter what the location of the decimal point may be, the logarithms of all numbers having the same figures in the same order have the same mantissa. The characteristic of the logarithm is determined by the location of the decimal point in the number. If the number is greater than one, the characteristic is positive and its value is one less than the number of digits to the left of the decimal point. If the number is less than one (i.e., a decimal fraction), the characteristic is negative, and has a numerical value of one greater than the number of zeros between the decimal point and the first integer. A negative characteristic of, say, 3, is written 3 ... to indicate that only the characteristic is negative, or 7 . . . -10. From Figure 6-37 we see that the mantissa of the logarithm of 20 is 0.30. The characteristic is 1.

log 20 = 1.30
log 40 = 1.60
log 80 = 1.90
log 160 = 2.20
log 200 = 2.30
log 2000 = 3.30
log 20000 = 4.30
log 0.2 = 1.30 or 9.30 - 10
log 0.02 = 2.30 or 8.30 - 10

The tabulation above illustrates a very important property of logarithms. Note that when a series of numbers increases by a constant factor (e.g., the series 20, 40, 80, 160 or the series 20, 200, 2000, 20,000), their logarithms have a constant difference, in these cases, 0.30 and 1.00 respectively. In other words, a constant increase in the logarithm of a number means a constant percentage increase in the number itself.

6.7.5 Industrial Radiographic Film Characteristics.

6.7.5.1 Background.
Historically, when faced with the necessity for film substitution, the radiographer would examine manufacturer's literature and then perform trial exposures with a new film. Using the first radiograph as a basis, the radiographer would modify his exposure parameters and try again. Often this procedure would have to be repeated several times, depending on the experience of the radiographer and difficulty of subject, before an acceptable radiograph was produced. This iterative process involves considerable expenditure of time and the now significant cost of film. Available manufacturer's literature generally provides speed, contrast and processing data pertinent to only the films and chemicals they produce. Presentation of the data differs greatly between manufacturers, as do their methods for developing this data. Contact the engineering authority for your weapon system for current information on how each manufactures film works for your specific application.

6.7.6 Developing Theory.
The purpose of a developing solution or developer is threefold. First, it blackens those parts of the emulsion that have received exposure. When a crystal of the film's silver bromide emulsion has been exposed to X-ray radiation and is put into a developing solution, the developer takes the bromide away from the silver and leaves black metallic silver in the gelatin. Thus, where full exposure has occurred, a maximum number of crystals are affected and almost all of them are reduced by the developing solution to metallic silver.

6.7.6.1
The second purpose of a developer is to produce various shades of gray where the film has been only partially exposed. These grays are the result of partial removal of bromide. The concentration of black metallic silver per unit area of the film is dependent upon the amount of exposure received and determines the factor known as film density. The image of the object radiographed consists of varying densities spread over the film, corresponding to the varying amounts of exposure received by the film.

6.7.6.1.1
The third and equally important function of the developer is its effect on those parts of the film that have received no exposure. Since no crystals have been affected, the developer should leave these parts unchanged. Thus we see that a developing solution should remove bromide from the film emulsion where exposure has occurred, but should produce no effect on unexposed areas of the film.

6.7.6.1.1.1
A very limited number of chemicals possess the ability to distinguish between exposed and unexposed crystals and therefore only a few are suitable for use in developers. No chemical known will leave an unexposed area indefinitely unchanged. All will begin to develop unexposed parts after a period of time, producing a condition called chemical fog. All developing agents have a definite fogging time beyond which bromide will be freed in unexposed areas.

6.7.7 Developing Solutions.

NOTE

Follow manufactures data sheet for use of developers.

Three reducing agents commonly used in radiographic developers are metol, phenodone and hydroquinone. A combination of these ingredients produces all of the steps of grays and jet black, bringing out the best possible results. Developers are made up, by the manufacturer in standard powder and liquid forms. The temperature of the development chemicals has a direct effect on their activity and therefore, the time it takes for film to achieve a specific density. The higher the development solution temperature is above 68°F (20°C), the lower the sensitivity, resolution and contrast of the developed film will be. With the reduction of these preferred qualities, latitude and fog level will increase, decreasing the usefulness of inspection results. The radiographic film development process SHALL be performed as close as possible to 68'F (20°C); taking into consideration chemical manufacturer's instructions. See Table 6-16. Film SHALL not be left in the developer solution any longer than the prescribed time for its specific temperature. Uncontrolled time and temperature during film development causes under or over development, which reduces or eliminates useful information from being discernible on the radiograph. Developing/processing solutions past their useful life should be disposed of properly. Check state and local regulations to determine proper method of disposal.

Table 6-16. Developing Time versus Temperature.

Time (Minutes)		Temperature
Normal	Maximum	
3-1/4	6-1/4	80
3-3/4	6-3/4	76
4	7	72
4-1/2	7-1/2	70
5	8	68 (Recommended)
5-1/2	8-1/2	65
6	9	63

6.7.7.1

Metol or phenodone and hydroquinone will not develop when used alone. To produce any density on the film also requires an alkaline solution. The alkali in effect "opens the door" and permits the developing agents to enter the pores of the emulsion. The speed with which the "door opens" is determined by the amount and potency of the alkali. If too much alkali is present, the developer will tend to produce chemical fog. But if too little is used, developing will be retarded. Within these limits the stronger the alkali the more rapidly development will be completed. Some of the alkali’s used in developing solutions are sodium hydroxide, potassium hydroxide, sodium carbonate, potassium carbonate and borax.

6.7.7.1.1

Developing solutions containing only the develop agents and alkali would rapidly be exhausted by oxidation from the air. The life of all developing agents are limited by (1) the reduction of silver bromide to metallic silver, and (2) the amount of oxygen absorbed by the developing agents from the air. However, there is a chemical whose inclusion in developing solutions extends its useful life. This chemical, sodium sulfite, and oxygen have a natural attraction for each other. The affinity is so great that when added to a developing solution sodium sulfite actually prevents oxidation by air of the other components for limited periods of time. To assist in reducing oxidation of developing solutions the following SHALL apply:

a. A floating lid, that matches the general configuration of the container, SHALL be used for replenishment and, when not in use for development; manual processing developing solutions. The floating lid SHALL be manufactured from a material that will not react with the processing chemistry. It should also have a specific gravity less than the chemistry so it will float naturally. One material that has these characteristics is polypropylene. The floating lid SHALL be used in conjunction with the dust cover lid that fits over the top opening of the container.

b. Only the amount of replenisher that is consumed in a one-week period SHALL be mixed for use.

c. Developing solutions that are not mixed for use or replenishment SHALL be maintained in their closed, original manufacturer's containers.

d. Developing solutions SHALL not be used two years past the date of their manufacture.

6.7.7.1.1.1
As was pointed out earlier, all developing agents have a tendency to deposit silver in the unexposed parts of the film emulsion after a certain period of time. This tendency may be retarded or restrained if bromide is added to the solution. However, the addition of the restrainer also tends to slow up development. Therefore, the proportion of bromide in an X-ray developer should be just enough to prevent chemical fog without materially reducing the activity of the solution. It has already been seen that bromide is removed from the film emulsion during development. Therefore, since bromide is a restrainer it is also evident that as each film is developed, restrainer is being added to the solution. In addition, the developing agents gradually lose potency, and as each film is processed the developing time for the next film must be theoretically increased. The most important characteristic of any developing formula is its ability to produce and reproduce a certain degree of film blackening for a particular quantity of absorbed X-ray energy. A consistent end result can be secured only by maintaining constant developer activity. To achieve this stability, the developing solution SHALL be tested and replenished as per process control requirements and manufacturer's instructions. Whenever these two sources of information are in conflict, the process control requirements within this technical order SHALL take precedence.

6.7.8 Stop Bath Solution.

WARNING

Glacial acetic acid should be handled with adequate ventilation, and great care should be used to avoid injury to the skin or clothing. Always add glacial acetic acid to water slowly, with constant stirring. Never add water to the acid that may cause boiling and splatter strong acid on the hands or face, causing burns.

NOTE

It is most important that while developer solution is draining off of the radiograph, it SHALL not be allowed to drain back into the developer solution tank. The developer solution that is draining becomes oxidized and reduces the useful life of the working bath.

A stop bath solution is used to stop development in the shortest period of time and prevent uneven area of development and subsequent film streaking. The stop bath consists of a mild glacial acetic acid solution designed to neutralize the alkali of the developer. The stop bath also protects the fixing solution, which is slightly acid, from the alkalis of the developer, thereby extending its useful life. The stop bath will become contaminated with developer solution. Much of this contamination can be eliminated by allowing the radiograph to drain for one or two seconds prior to being placed in the stop bath. If sodium carbonate is used to formulate the stop bath it must be used between 65°F (18°C) and 70°F (21°C); otherwise, it will cause carbon dioxide blisters to form in the film's emulsion. Stop bath SHALL be used during hand developing radiographic film, when allowed by the operational environment.

6.7.9 Fixing Solution.
After development, the emulsion contains all of the unexposed and undeveloped grains of silver bromide. The undeveloped silver bromide must be removed from the emulsion if the image is to be permanent. To do this a fixing solution or fixer is used. There are only two chemicals in common use that will act as clearing agents by dissolving the undeveloped silver bromide in thin film emulsion. They are sodium thiosulfate (hypo) and ammonium thiosulfate.

Weight for weight, ammonium thiosulfate has approximately three times the fixing power of sodium thiosulfate. It is the clearing agent in liquid high-speed fixing concentrates, while hypo is used in regular-speed formulas.

6.7.9.1

It is essential that the fixing solution neutralize the alkaline developer adhering to the film. In other words, development must stop before fixing can begin. The neutralizer is an acid; the most suitable of which are acetic and sulfuric acid in weak concentration. If a fixing bath is to be used for a long period of time, a large quantity of acid is necessary to neutralize the alkalinity of the developer. Fixing is accomplished by means of the thiosulfate only. However, in transferring the film from one stage to another, materials from the developing solution may be transferred to the fixer bath. These may oxidize in the fixer causing stains on the film. To counteract this condition, sodium sulfate is employed as a preservative.

6.7.9.1.1

Because X-ray films are handled frequently and are subject to more abuse than photographic negatives, it is customary to use a hardening agent. This hardening agent or hardener tans and toughens the emulsion. Some of the common hardeners are alum and aluminum and chloride for high-speed fixers. One of the distinct advantages of the hardener used in a high-speed fixer is the production of a hardened film which will not melt in water as hot as 85°C (175°F) after the film is dried.

6.7.9.1.1.1

When a film is removed from the developing solution the undeveloped areas are swollen and yellow in appearance. Sometime after immersion in the fixer this yellow becomes transparent; this change may be observed and recorded. The time required for this change is known as the "clearing time." To adequately fix a film it SHALL be immersed in the fixer at least two times as long as it took to clear. This period SHALL not exceed fifteen minutes. For example, if the clearing time is two minutes then the fixing time is four minutes. The fixing solution will become deficient with use. This deficiency is insidious and may be overcome by adjusting the fixing time up to the maximum fifteen-minute time period. The cause of the fixer degradation may be one or more of the following:

a. Accumulation of soluble silver salts. This condition will gradually prevent the fixer from dissolving unexposed silver halide from the film emulsion. Therefore, making the fixer incapable of properly clearing the radiographic film.

b. Loss of chemical activity is evident when long periods of time are required to clear a radiograph. This situation will cause colored stains on the radiograph, swelling of the emulsion that inhibits hardening and results in long drying times, and reticulation or sloughing during drying.

c. Reduction of activity caused by dilution of the fixer solution when stop bath, rinse water, and developer solution are carried in by the film being processed. The effects of this dilution/contamination are reduced by allowing the radiograph to drain into the stop bath prior to being put in the fixer. Care should be used not to contaminate the developer.

6.7.10 Washing.

The purpose of washing films is to remove the chemicals present after fixing. Because hardeners are used in X-ray fixing solutions, it is difficult to remove small quantities of the fixer retained by the gelatin. The speed of washing is determined by the speed with which the clearing agent diffuses out of the film into the water. The quantity of clearing agent remaining in the gelatin is continually halved in the same period of time as washing continues. For example, if a film gives up one-half its clearing agent in 1 minute, then after 2 minutes one-quarter remains, after 3 minutes one-eighth, in 4 minutes one-sixteenth, and so on, providing the film is continually exposed to fresh water. It is obvious that washing will never remove the last traces of fixer. The object in washing is to remove enough fixer so the film may be kept without fading for a given period of time. For most practical purposes, X-ray films will be washed sufficiently in 30 minutes if the water changes at the rate of four to eight times per hour (see Table 6-16). The wash Water temperature should be between 65°F and 80°F. Regardless of the type of fixer used, if the film is allowed to fix twice the required time, three times a normal washing time is required.

Table 6-17. Manual Washing of Radiographic Film.

MANUAL Approximate Film-Washing Times at 68^0 F		
Class of Film	Rate of Water Change	Washing Time
I	4 times per hr.	35 minutes
I	8 times per hr.	20 minutes
II	4 times per hr.	35 minutes
II	8 times per hr.	20 minutes
III	8 times per hr.	35 minutes
IV	4 times per hr.	35 minutes
IV	8 times per hr.	20 minutes

6.7.10.1

If the temperature of the wash water falls below 50 degrees F, it is not possible to adequately remove the fixer from the emulsion in the above length of time. Washing takes three times as long when the temperature is between 50 to 60 degrees F as it does at 70 to 75 degrees F. Thus the rule for washing time for X-ray films is true only when the wash water is relatively warm. If the film has been over fixed and then washed at 50 degrees F, there is no practical way to remove enough fixer to prevent fading of the image. In addition, if the temperature difference between fixer and wash water exceeds 15 degrees F, there is a possibility of unequal swelling of the emulsion known as reticulation.

6.7.10.2 Wetting Agent.

The use of a wetting agent between the washing and drying operations is highly recommended. When the films are removed from the wash tank, small drops of water will cling to the emulsion. Areas under these drops will dry more slowly and cause distortion of the gelatin, changing the density of the silver. These are frequently visible and can be troublesome in film interpretation. Most water also contains large amounts of solid material in the form of calcium and other chemicals which will remain on the film as a white residue the water drops have, evaporated. Such "water spots" can be prevented by immersing the washed films in a wetting agent for one to two minutes before transfer into the drying cabinet. Various detergents or commercial wetting agents can be used.

6.7.11 Drying.

The final step in processing is the drying of the X-ray film. It consists simply of allowing the water on the film to evaporate slowly. This is easily accomplished by hanging up the films in a dry rack where the film hangers can be suspended. Where a large number of films must be handled special equipment may be necessary. Drying by any method will be accelerated if the film is immersed in a solution of water and wetting agent following washing. In addition to speeding drying time, this technique also prevents the formation of watermarks or streaking on the emulsion.

6.7.12 Dark Room Equipment.

The size of the processing room depends upon the volume of work to be processed. If a darkroom is available which is used for other film processing, there is no reason why it cannot be used for processing radiographs unless the various activities interfere with each other. If new facilities are desirable, the floor space should be kept to a minimum considering the equipment that must be used in the dark room. For safelight and process control in the dark room see the process control section in chapter 1.

6.7.12.1 Cleanliness.

NOTE

If spilled chemicals evaporate, they may settle on films and cause spotting. Benches and any accessories must also be washed. It is advisable to sterilize developing tanks periodically with a 5 percent solution of sodium hypochlorite (bleach). Allow the sterilizing solution to remain in the tank overnight and then drain and rinse thoroughly.

Due to the sensitivity of X-ray film, cleanliness is very important. Film hangers, funnels, stirring rods, thermometer and all mixing containers must be washed thoroughly after use. Processing tanks must be scrubbed clean before filling with fresh solutions. If any solution is spilled, wipe it up immediately.

6.7.12.2 Mixing Solutions.

CAUTION

Keep exposed film away from the direct light of the safelight; exposed films are more sensitive to illumination from safelights than are unexposed films. Screen-type films are more sensitive to fogging than non-screen films. In addition, emulsions are less sensitive when wet so they can be exposed to safelights for longer periods after immersion in the developing solution.

All mixing vessels SHALL be enamelware, stainless steel, glass, hard rubber or glazed earthenware. Metal containers such as aluminum, iron and zinc will contaminate the solutions and result in fog on the developed radiograph and therefore, SHALL not be used. In accordance with the manufacturer's instructions, all chemicals must be mixed thoroughly.

6.7.12.3 Film Handling.

CAUTION

Always handle the film at the extreme edges to avoid fingerprints.

NOTE

The punched number must beat the bottom of the hanger to prevent streaking due to developer flow through the holes when processing.

This procedure must be performed in the dark room.

a. To remove the film from the cassette or film holder, open up the cassette or film holder completely. Turn the film over at the edge with the reverse or bottom side up. Do not slide the film out.

b. If the film must be punched for identification, punch the number in the upper right-hand corner.

c. To place the film on the film hanger, grasp one upper corner between the thumb and index finger and fasten it to the hanger with one of the bottom hanger clips.

d. Fasten the other bottom clip and finally the two top clips.

e. The film should be flat and taut with the punched number (if any) at the bottom of the hanger. If it is not, repeat the procedure.

6.7.12.4 Manual Processing.

Suggested arrangement of manual processing tanks is shown in Figure 6-38. The chemicals should be arranged as shown in the sketch in sequential steps of the process and traversing from left to right. This arrangement is used with the assumption that most people are right-handed.

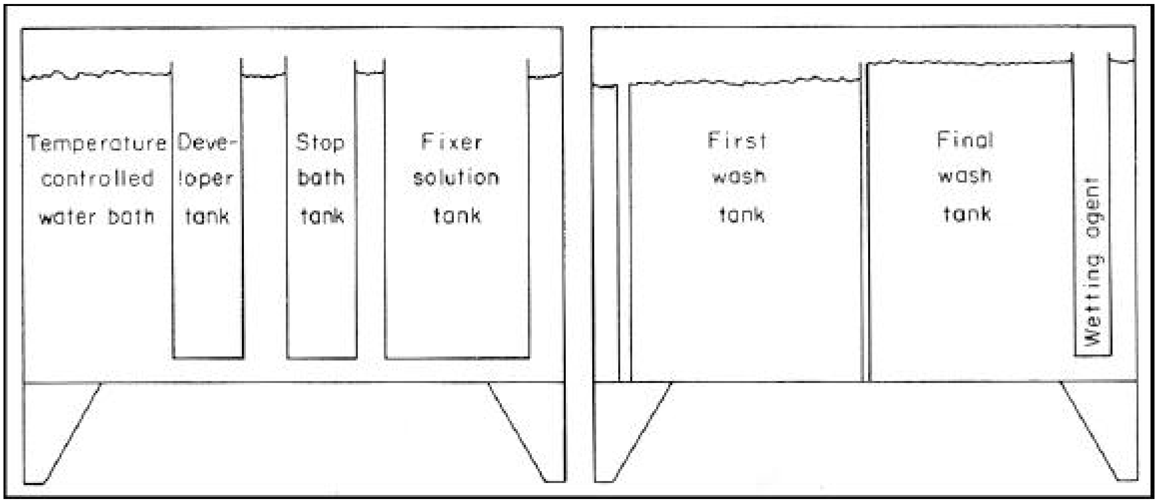


Figure 6-38. Suggested Arrangement of Manual Film Processing Tank.

6.7.13 Preliminary checks.

a. Be sure all films are placed on hangers properly.

b. Check the temperature of all processing solutions using a bimetallic thermometer. Refer to Table 6-16.

c. Agitate the developing chemicals and make sure they are at the proper level; replenish if necessary.

d. Be sure wash water flow is adequate. Refer to Table 6-17.

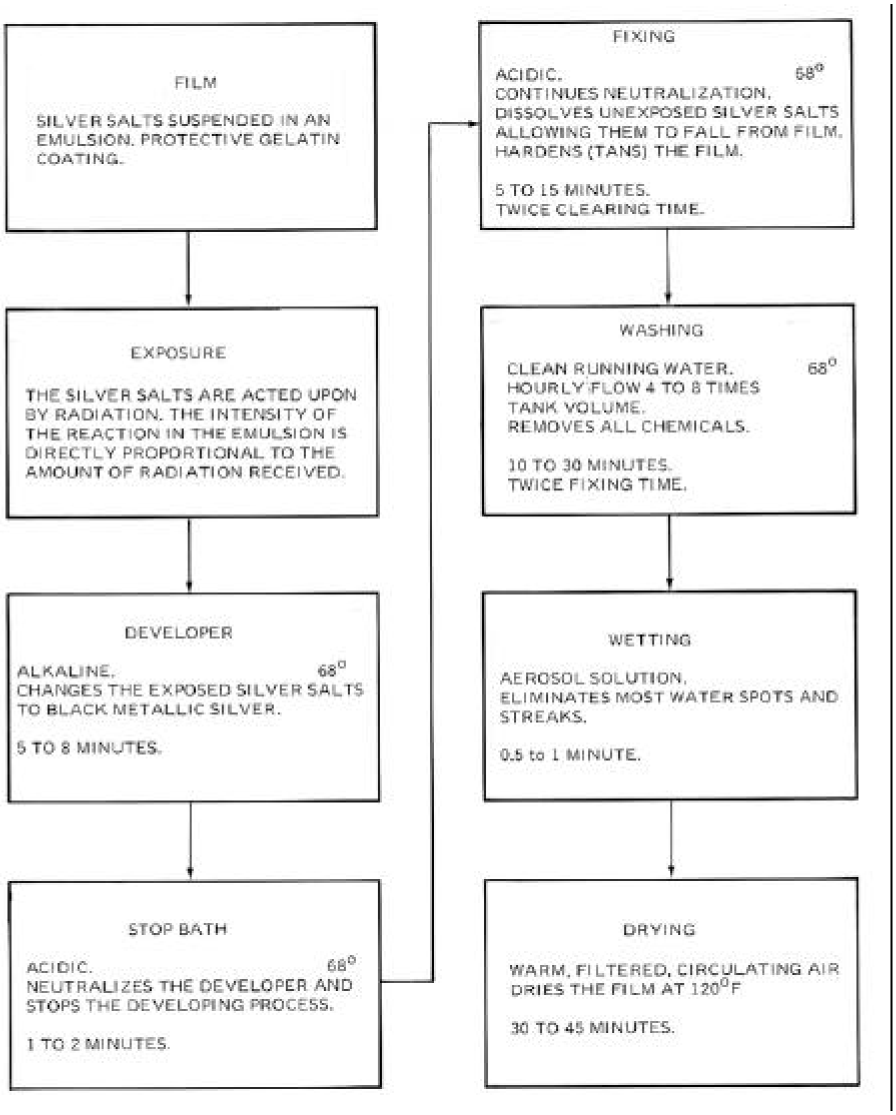
6.7.14 Developing Procedure. (See Figure 6-39)

CAUTION

Do not allow films to remain out of solutions for extended periods of time since this will cause uneven development.

NOTE

Drain the films and hangers for several seconds between operations to prevent carryover of chemicals from one tank to another.



FILM

SILVER SALTS SUSPENDED IN AN EMULSION. PROTECTIVE GELATIN COATING.

EXPOSURE

THE SILVER SALTS ARE ACTED UPON BY RADIATION. THE INTENSITY OF THE REACTION IN THE EMULSION IS DIRECTLY PROPORTIONAL TO THE AMOUNT OF RADIATION RECEIVED.

DEVELOPER

ALKALINE. 68°
CHANGES THE EXPOSED SILVER SALTS TO BLACK METALLIC SILVER.

5 TO 8 MINUTES.

STOP BATH

ACIDIC. 68°
NEUTRALIZES THE DEVELOPER AND STOPS THE DEVELOPING PROCESS.

1 TO 2 MINUTES.

FIXING

ACIDIC. 68°
CONTINUES NEUTRALIZATION.
DISSOLVES UNEXPOSED SILVER SALTS ALLOWING THEM TO FALL FROM FILM.
HARDENS (TANS) THE FILM.

5 TO 15 MINUTES.
TWICE CLEARING TIME.

WASHING

CLEAN RUNNING WATER. 68°
HOURLY FLOW 4 TO 8 TIMES TANK VOLUME.
REMOVES ALL CHEMICALS.

10 TO 30 MINUTES.
TWICE FIXING TIME.

WETTING

AEROSOL SOLUTION.
ELIMINATES MOST WATER SPOTS AND STREAKS.

0.5 to 1 MINUTE.

DRYING

WARM, FILTERED, CIRCULATING AIR DRIES THE FILM AT 120°F

30 TO 45 MINUTES.

Figure 6-39. Manual Film Processing.

a. Immerse the films (and hanger) in the developing solution. Agitate the hangers by hand at 30-second intervals. This must be done during the entire developing time.

b. Remove the films from the developer and immerse in stop bath for approximately 1 minute.

c. Remove the films from the stop bath solution and immerse in the fixing solution. The total "clearing time" SHALL be determined according to Paragraph 6.7.9.

d. Remove the films from the fixing bath and immerse in the wash water for the recommended period.

e. Dry the films.

f. Remove the films from the film hangers.

6.7.14.1 Agitation.
If films are allowed to develop without any movement, there is a tendency for each area of the film to affect the development of the areas immediately below it. This is because the products of development have a higher specific gravity than the developer. As these products diffuse out of the emulsion layer, they flow downward over the film surface and retard the development of the areas over which they pass. The greater the film density from which the reaction products flow, the greater is the restraining action upon the development of lower portions of the film. Thus, large lateral variations in film density will cause uneven development in the areas below, and this may show up in the form of streaks.

6.7.14.2 Developer Aging.

NOTE

It is recommended that radiographic inspection facilities use the replenishment method while performing the manual film development process.

As films are developed without replenishment, the developing solution becomes exhausted chemically until no developing action can take place. For a given quality of developer, without considering the effects of oxidation, levels of bromide and hardener, and contamination; the development time must be increased for successive films to fully develop them. It is estimated that a five-gallon tank of developer will develop 140 films, size 14 x 17, satisfactorily without excessive increase in development time. It is convenient to divide the total number of films that can be developed by 5 gallons of developer into seven groups of 20 films each. As each group of 20 films, 14 x 17, or equivalent film area is developed, the development time must be increased 1/4 minute, assuming a normal time of 5 minutes at 20°C (68°F). Even when drained, each film carries about 1-1 /2 ounces of developer with it, so developer must be added to keep the tank at the 5-gallon level. When the specified number of films have been developed, discard the solution. This method is known is the exhaustion method of developing.

6.7.14.2.1
Another method of processing is the replenisher method. By adding replenisher solution periodically, the activity of the developer is kept at the same level. In this method films must be removed from the tank quickly without allowing the excess developer to drain off the film back into the tank. Approximately 1 gallon of replenisher should be added for every 40 films, 14x 17, or equivalent film area (based on 5 gallons of developer). If this amount of developer cannot be added at the specified time, too much developer is draining back into the tank. In this case enough developer must be drained from the tank so the replenisher can be added. The developer solution shall be discarded when the replenisher used equals four times the original quantity of developer solution, when it fails the process control requirements or at each two month period, whichever occurs first. For dense radiographs it may be necessary to increase the quality of replenisher added. In this case, it is also desirable to add replenisher at shorter intervals to keep the level of developer activity more nearly constant.

6.7.14.2.1.1
Fresh developer is "wild" and will often result in excessive contrast on the first few films. This is apparently due to the lack of equilibrium between the developer and the reaction products. It is sometimes recommended that a small quantity of old developer be mixed with the fresh developer to temper the solution.

6.7.15 Testing Developer Activity.
The success of this method of compensating for the gradual decrease of developer activity will depend upon the use of an adequate system for testing this activity. Since there is no simple direct physical or chemical test of developer activity, the easiest way of making the test is to process, at frequent intervals, film strips exposed in some standard manner, and to compare the densities obtained with a identical strip that had been processed in the fresh solution. The standard strips are cut from a sheet film, 8 by 10 inches or larger, which has been exposed to direct x-rays through a test object. The most suitable form of test object is a stepped wedge made up of a number of sheets of any convenient metal. The wedge should have about 15 steps and be large enough to cover completely the largest cassette or film holder used. When given the proper exposure this should produces series of densities extending over the density range used in practice. It is essential that all strips used in testing a batch of developer receive identical exposures. For this

reason, no screens of any kind are used and all the sheets of film that will be required should be exposed simultaneously in the same cassette. For instance, at 80 kilovolts, using an aluminum step tablet, three sheets may be exposed in the same cassette without introducing significant differences in the densities of the top and bottom films. At l80 kilovolts, using a steel tablet, five sheets may be exposed at once. At 1000 kilovolts, a steel tablet having steps l/4-to l/2-inch high can be used, and five sheets of film exposed at once. When this penetrating radiation is used, two extra films are included, and the top and bottom films are discarded after exposure. The exposed films should be stored in as cool and dry a place as possible (ideally, at 70°F and 50 percent relative humidity, or below). Any exposed films not used at the end of two to three weeks should be discarded. In processing test strips, they should be developed dark end down on regular film-processing hangers in the center of the tank and be given the same development time and agitation that will be used in practice. When a new batch of developer is put into use, one or more strips are processed and preserved as the standard for comparison throughout the useful life of the developer. Thereafter, a strip should be processed, say, after every 50, 14 by 17-inch films, or equivalent, processed per 5 gallons of developer. If the densities of the test strip are less than those of the strip processed in the fresh solution, the rate of addition of replenisher should be increased. On the other hand, if the densities of the test strips are too high, the rate of addition of replenisher should be decreased. The stepped wedge method of testing developer activity is also useful in cases where the temperature of the processing solutions cannot be exactly controlled. Strips are developed for a series of times, and the development time that a strip matching the one developed at 68°F in the fresh solution is used for routine work.

6.7.15.1 Stop Bath Acidity.

The stop bath acidity is not as critical as developer activity, but a check can be made with litmus paper to assure the bath is acidic and capable of neutralizing the alkaline developer.

6.7.15.2 Fixer Bath Activity.

The diminished activity of the fixer solution with use in manual processing can be readily noted by the extended time required for clearing of the film emulsion. Fixer time can be increased to compensate for deterioration of the chemicals or chemicals may be replenished by addition of the chemical constituents of the fixer.

6.7.16 Automatic Film Processing.

The advantages of automatic processors are speed and control of the development process. Automatic processing is particularly advantageous when large volumes of film need to be processed. Automatic processing also provides for greater uniformity of development, thus providing more consistent results. The quality level of these results is determined by chemical and equipment condition, and conscientiousness of the operator. However, because the cycle is faster and the chemical temperatures are higher in automatic processing than they are with manual processing, the use of automatic processing will produce a more narrow (high) latitude radiograph and has a noticeable effect on the radiograph technique. Therefore, apparent film characteristics will be significantly altered by the use of automatic processing. As a result, film quality, when automatic processing is used, is generally lower than that which is obtainable with manual processing. However, the advantage of speed of processing, lower manpower requirements, and consistency of development generally are felt to be more important in the decision to use automatic processing. The general arrangement of a darkroom, where an automatic processor is used, is illustrated in Figure 6-40. The loading end of the processor is located in the dry area of the darkroom and is under safelight illumination. The output end of the processor is generally located on the outside of the darkroom wall under ambient illumination. In processing film in the automatic processor, the film is unloaded from the cassette film holder as in manual processing. However, it is then immediately fed into the loading end of the processor. After processing is completed, the film exits the other end of the processor. At this point, the film is ready for interpretation and filing as required. Cleanliness in automatic processing is essential. Lint and other contaminants, if they are allowed to enter the processor, can cause many spots as they collect on rollers and affect subsequent films.

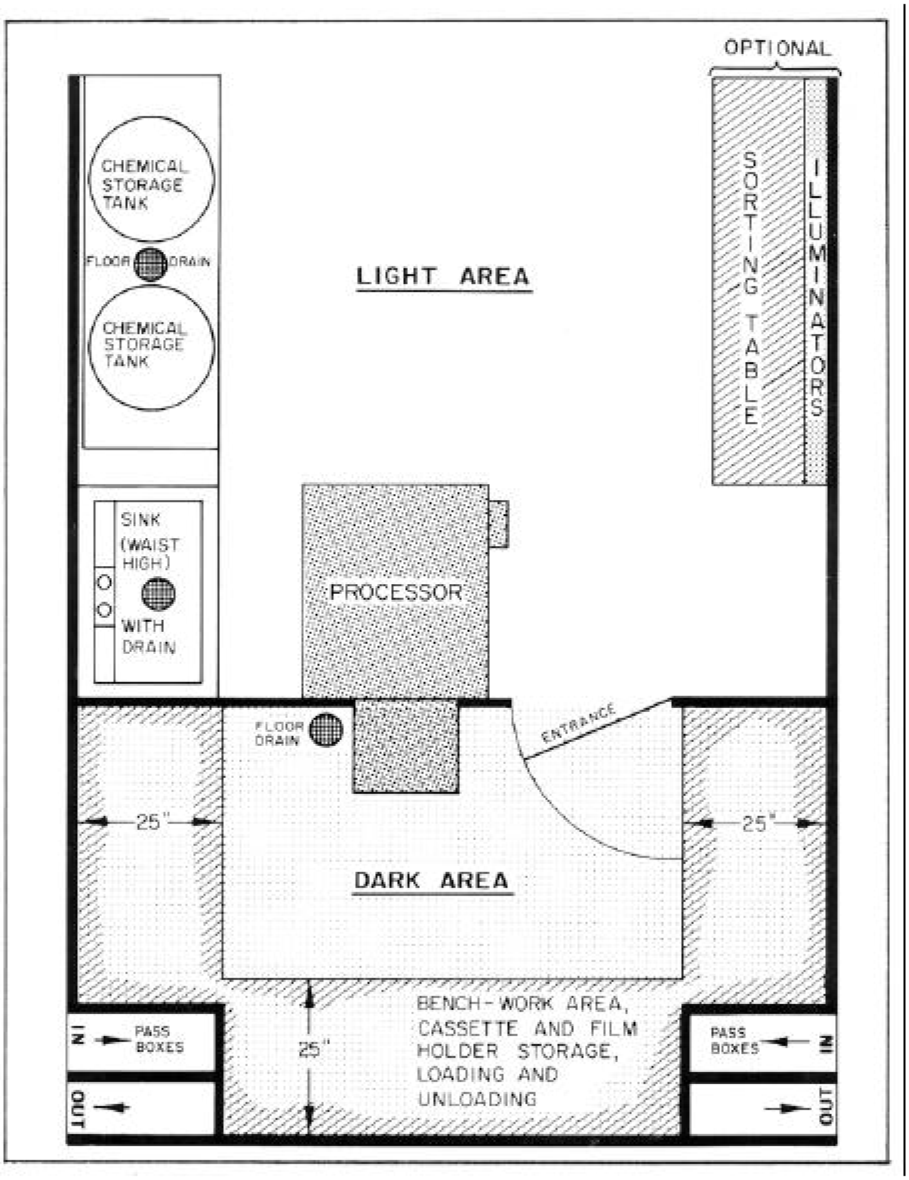


Figure 6-40. Typical Arrangement of Through-the-Wall Automatic Processing Darkroom.

6.7.16.1 Chemicals.

The development chemicals that are used in automatic industrial radiographic process differ in formulation from those that are used during the industrial manual process and medical automatic processing. For instance, the developing solution contains a hardener in addition to its constituents to inhibit excessive softening of the emulsion. Softening of the emulsion interferes with the transport of the film through the processor. These chemicals are specially designed for use at high temperatures. Medical automatic processing chemicals are formulated to function at high temperatures, but are not capable of producing acceptable industrial radiographic results. Only development chemicals formulated to be used to develop industrial radiographic film SHALL be used in industrial radiographic film processors.

6.7.16.2 Maintenance.

Periodic inspection, maintenance and lubrication of radiographic film processing equipment is required by the technical manual governing its operation. It is imperative that the prescribed daily, bi-weekly and monthly requirements be strictly followed to insure proper operation of equipment, and to support quality radiographic inspection results. With appropriate maintenance, automatic processors should give reliable and repeatable service for long periods of time.

6.7.17 Silver Recovery.

The unexposed and undeveloped silver bromide grains in the film emulsion are removed by the fixer solution. Therefore, the exhausted fixer becomes rich in silver content. The value and scarcity of silver makes recovery economically feasible. Approximately 80 percent of the silver in the film emulsion is transferred to the fixer solution; the remaining 20 percent forms the radiographic image. There are three basic methods of silver recovery from the fixer solution. These are by electrolysis, metallic replacement, and chemical precipitation.

6.7.17.1 Electrolysis Recovery Method.

When electric current is passed between two electrodes immersed in the silver-bearing fixer, the silver is electronically deposited upon the cathode. This silver can be stripped from the cathode and refined. This method permits re-use of the fixer.

6.7.17.2 Metallic Replacement.

This method consists of replacing the metallic silver with a less valuable base metal such as iron, zinc, or copper. As an example, if steel wool is inserted into the exhausted fixer solution, the silver in solution is replaced by the iron, and the silver accumulates on the bottom of the container in the form of sludge. The sludge is removed and refined to reclaim the silver. The fixer must be discarded after silver recovery by this method.

6.7.17.3 Chemical Precipitation.

Silver can be reclaimed from fixer by the addition of certain chemicals to the exhausted fixer. The silver is precipitated out of the solution in the form of a sludge that can be recovered and refined. The chemical reaction generates obnoxious fumes and odors, and separate facilities are recommended for this method of silver recovery. The fixer must be discarded.

6.7.17.4 Silver Recovery from Films.

There are two methods used to recover silver from obsolete films. One method is to strip the silver bearing emulsion from the film base by using chemical or mechanical means. The emulsion is then refined to reclaim the silver. The second method is by burning the film in an incinerator that controls the burning process and the fly ash. The residual ashes are then processed to obtain the silver content. It is usually more economical to simply market used or obsolete film than to attempt silver reclamation from film on a small scale. Detailed information on silver recovery is provided in Air Force Regulation (AFR) 400-14, "Reclamation and Use of Silver."

6.7.18 Film Reproduction Technique.

Often duplicate radiographs are required. If it is known in advance that duplicate films are required, it is more economical and quicker to expose two films simultaneously in the original exposure. If lead screen techniques are being used, slight increases in exposure will be required.

6.7.18.1

If multiple copies of an existing radiograph are required, they can be reproduced by contact printing techniques. The duplicate radiograph can be made on a direct-positive film that produces a duplicate-tone facsimile of the original. The film gradient of the duplicating film is -1.0, which means that density differences in the original image are faithfully reproduced in the duplicate image. Duplicating film cannot reproduce radiographic density ranges equivalent to originals. But by varying exposure, the density differences can be recorded accurately.

6.7.18.1.1

If duplicating film is not available, it is possible to use medical film that is designed for use with fluorescent screens. These duplicates are also produced by the direct printing method. However, these films have a special property. While not a positive film, they do undergo reversal with large exposures. That is, they increase in density up to a saturation point after which time they decrease in density with exposure, and thus reverse. It is necessary to expose these films such that reversals occur, and the original image is duplicated. If the original radiograph has a high density, exposures of as much as two minutes to a photoflood lamp may be required. These exposure requirements must be generated for each specific situation; generalization here is not practical.

6.7.19 Film Artifacts.

An artifact is the product of human error and, in the case of film, is usually due to mishandling of the film in some step in the radiographic process.

6.7.19.1 Processing Artifacts.

Chemical spots can occur if any chemicals are splashed, contacted, or transferred by wet fingers to the undeveloped film. Dark spots indicate either water or developer on the film before processing. Light or undeveloped spots indicate that the stop bath or fixer has been allowed to contact the film before processing. Stains caused by chemical reactions, over development or underdevelopment, are processing artifacts. Streaks from contaminated hangers are quite common as well as streaks from lack of agitation during the development period.

6.7.19.2 Handling Artifacts.

Many artifacts are introduced by film handling. Crow-foot static marks can be caused by sliding the film over surfaces, creating an electrical discharge of static electricity, particularly under very dry atmospheric conditions. Half-moon-shaped marks (either dark or light) can be caused by crimping the film, particularly with the thumb. These are often referred to as thumb crimps, handle X-ray film as if it were a piece of wet paper. Scratching of the emulsion when the film is wet and the emulsion is soft is a common artifact.

6.7.19.3 Exposure Artifacts.

The most common exposure artifacts are caused by excessive pressure applied to the film before, during, or after exposure. Either heavy parts or excessive bending of the film can apply sufficient pressures to the film emulsion as to render it insensitive to exposure. These artifacts usually appear as unexposed areas on the film.

6.7.19.4 Manufacturing Artifacts.

Artifacts due to the manufacturing process are comparatively rare. On occasion exposed spots or other manufacturing artifacts, such as roller marks or foreign material may occur on the emulsion surface. Table 6-18 lists artifacts which are commonly encountered, their cause, and any remedial action which may be taken.

Table 6-18. Description of Film Artifacts

Condition	Cause	Remedy
1. Pressure Marks	White or dark areas as result of pressure on emulsion.	Handle film carefully, avoid bending when placing in cassette. Do not place heavy objects on exposure holder.
2. Exposure to light	Usually dark areas on film of shadow pattern.	Light leaks in corners of exposure holders. Test film by developing without exposure to X-rays.
3. Static pattern	Black, sharp chicken-track type pattern. The result of rapid removal of film from paper cover of film box.	Handle film properly.
4. Paper pattern	Mottled effect over complete area on film.	Remove paper from film when exposing with screens.
5. Moisture on screen	Spots on radiograph.	Do not allow film to remain in lead screen exposure holders overnight in humid atmosphere.
6. Mottle pattern	Processing streaks.	Use adequate short-stop and agitate film during processing.
7. Film reversal	X-ray image reversed; light areas dark, dark areas light.	Extremely excessive exposure to radiation. Reduce exposure.
8. Films stuck together during processing	Can be either dark or light depending on where in process this occurred.	Agitate film during processing to assure solution penetrates emulsion.
9. Water spots	Result of splashing water on films after they are dried.	Handle film in dry area of darkroom. Completely remove from processing section. Do not remove film from hangers until dry under clips.
10. Developer scum	Surface on developer clings to surface of films in developer.	Mix solutions thoroughly before processing films.
11. Lead screen patterns	Streaking on film due to alloy segregation of lead.	Examine lead screens visually before use.

Table 6-18. Description of Film Artifacts - Continued

Condition	Cause	Remedy
12. Lead screen scratches	Normally appear as dark sharp lines on radiograph.	Discard all lead screens having scratches.
13. Unclean screens	White dots on film.	Clean lead screens with steel wool and soap periodically.
14. Fuzzy image	Can be lack screen contact with film.	Clamp exposure holder or cassette together securely. Avoid using film holder in vertical direction because of screen and film sag.
15. Grainy image	Can be grain pattern of some high-temperature alloys.	Certain high temperatures are associated with grain pattern at voltage range of 150 to 250 kVp. This condition is eliminated at higher voltages.
16. Dichroic fog	Surface of film is discolored when viewed by reflected light.	Change developer and short-stop since this condition is usually the result of exhausted solutions.
17. Film scratches	Emulsion scratched by mishandling.	Handle films on smooth surfaces at all times.
18. Illuminator dirt	Spots on illuminator appear as dark areas on radiograph.	Wipe illuminators periodically with damp cloth.
19. Surface conditions	Can appear as internal discontinuities.	Examine castings or welds for visible surface conditions before reading.
20. Non-uniform light pattern from illuminator	Can appear as shadowed area on film.	Change lamps to correct filament pattern and select fluorescent lamps to match in light response.
21. Unexplained pattern of hinges	Back scatter pattern of cassettes.	Back up cassette with lead blocking to prevent scatter from cassette or other surfaces.
22. Foggy films	Use of film beyond expiration or inadvertent exposure to radiation.	Protect films from radiation by lead-lined film chest. Use film before expiration. If questionable, check film by processing before exposure.

Table 6-18. Description of Film Artifacts - Continued

Condition	Cause	Remedy
23. Puckered or net-like linkages	Reticulation. Film processed through extreme temperature changes.	Maintain all processing solutions and wash water at approximately same temperature, 68°F.
24. Blisters	Reaction between alkaline developed and acid-fixing bath.	Maintain correct solutions by following manufacturer's directions.
25. Water on screens	White blotches on film.	Dry screens. Do not use for 24 hours.
26. Dark areas on film	Exposure to light.	Light leaks in corners of exposure holders. Test film by developing without exposure to X-rays.
27. Spots on radiograph	Moisture on screen.	Do not allow film to remain in lead screen exposure holders overnight in humid atmosphere.
28. Either dark or light areas on film, depending where in the process this occurs.	Films stuck together during processing.	Agitate film during processing to assure solution penetrates emulsion.
29. White dots on film	Unclean screens.	Clean lead screens with steel wool and soap periodically.
30. Surface of film is discolored when viewed by reflected light	Dichroic (chemical) fog.	Change developer and short-stop since this condition is usually the result of exhausted solutions.
31. Unexplained shadowed area on film	Non-uniform light pattern from illuminator.	Change lamps to correct filament pattern and select fluorescent lamps to match in light response.

Table 6-19. Deleted

6.7.20 Care of Radiographs.

The final radiograph represents a considerable investment of time and money, and great care should be taken to preserve the final image.

6.7.20.1 Handling of Radiographs.

The radiographs should not be handled with bare hands. Soft white cotton gloves should be used to handle all radiographs between the time they are processed and the time they are disposed of. The film should not be crimped or sharply bent. Foreign substances such as water, coffee, or other materials should not be allowed to contact the emulsion surfaces. The films should always be picked up carefully, never sliding them across surfaces that may be dirty or have

some gritty substances that can introduce scratches on the emulsion surfaces. In attempting to interpret high-density film areas with high-intensity illuminators, care should be used to prevent overheating of the radiograph. White cotton gloves can be ordered through the supply system.

6.7.20.2 Storage of Radiographs.

The final radiographs should be placed in film filing envelopes for final storage. These envelopes are constructed of heavy paper to protect the films. The envelope should be identified as to the radiographs it may contain and filed in a systematic manner to facilitate retrieval if and when necessary. Envelopes should be marked prior to insertion of the film to prevent pressure marks. Films should not be stored in high humidity areas. Film filing cabinets are available for film storage. Ordinary filing cabinets are not sufficiently strong to withstand the heavy loads of filed film. X-ray films present no greater fire hazard in storage than an equal quantity of paper records. There is no necessity for expensive vaults, equipped with elaborate fire protection devices. The storage area must be kept clean.

6.7.20.2.1

The length of time that inspection radiographs are maintained SHALL be according to AFI 37-138/9 and specific inspection instructions. Specific inspection instructions and TO 00-20-1 SHALL be consulted to determine which inspection radiographs SHALL become part of official aircraft/support equipment records. All radiographs SHALL be disposed of according to AFMAN 23-110.

SECTION VIII
RADIOGRAPHIC INTERPETATION

6.8 RADIOGRAPHIC INTERPRETATION.

6.8.1 General.

The recording of an X-ray image pattern on a film is called radiography. This film, when processed, is called a radiograph. Its interpretation is called radiographic inspection. To obtain the greatest value from this procedure, characteristics of the radiograph must be understood and properly applied. It is possible to make erroneous deductions based on radiography that could result in improper disposition of the material. It is the duty of the radiographer to continually guard against this possibility. The interpretation and correlation of this information is affected by a number of characteristics in the process that ultimately are reflected in the radiograph. The characteristics of the radiograph are reviewed and discussed in the following paragraphs.

6.8.2 Radiographic Image Quality.

Radiographic interpretation cannot be performed without knowledge of the image quality. Knowledge of the image quality tells the film reader the minimum size of discontinuities he can expect to visualize.

6.8.3 Sensitivity.

Radiographic sensitivity is defined as the differential in thickness in terms of percentage of total thickness that can be recorded by radiography. This sensitivity is a result of X-ray image contrast, film contrast, image sharpness, image distortion and image density obtained in the radiograph. In a normal radiographic practice no attempt is made to record the ultimate radiographic sensitivity in each radiograph. However, it is required that a certain quality of radiography be attained to assure satisfactory inspection. To assure this quality of inspection by radiography, penetrameters (image quality indicators) are used. The application of penetrameters is discussed in an earlier section.

6.8.3.1

Examination of the penetrameter image on the radiograph will indicate the sensitivity. Correct radiographic procedure will show the image details of the penetrameter sharply defined. However, the penetrameter sensitivity is a gauge of a certain standard of sensitivity. It cannot actually measure the sensitivity in percent. This idea of penetrameter sensitivity has several limitations that should be kept in mind:

a. The eye is limited in resolution.

b. Discontinuities are detectable only in the direction of primary radiation.

c. Variations in material density are not considered.

d. Definition or sharpness of transition between densities is not considered.

e. Actual defects are usually irregular in shape while penetrameters have a definite size and shape.

6.8.4 Definition or Detail.

Definition or detail in radiography is the sharpness of the image outline reproduced on the film. The size of the focal spot, the physical condition of exposure and the film resolution determine the definition. If a screen is used, then the screen resolution will also affect the definition. In addition to the focal spot size, the object-to-film distance is an important factor in the sharpness of shadow picture (see Figure 6-41). The resolution of the film is a function of grain size. Refer to Section III for detail discussion of film and related items.

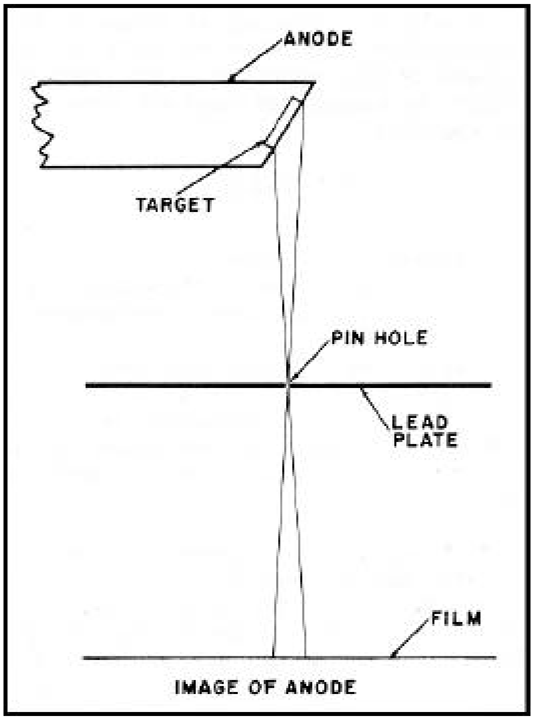


Figure 6-41. Pinhole Picture of Focal Spot.

6.8.4.1

Since the radiograph is a shadow picture, the geometric interrelationship between the elements of the radiographic system is important. Ideal X-ray focal spots and radioisotope sources should be pinpoints. With such sources, we would obtain sharp images under all conditions. All our radiation sources have finite size since X-ray tube focal spots must be large enough to withstand the energy dissipated as heat to prevent melting and target destruction. The radioactive activity of an isotope is proportional to the source strength in curies, so the smaller the size, the lower the intensity.

6.8.4.1.1

To better understand geometrical relationship, refer to Figure 6-42 which illustrates various conditions true to X-ray and light shadow formations. Diagram A in Figure 6-42 shows that the size of the shadow is to the size of the object as the distance of the light to the card is to the distance of the light to object. This image is a true projection. If the source has finite size, the shadows cast will not be perfect projections, but will have surrounding areas that will be out of register, producing a gray cast of unsharpness, which is, called penumbra. Diagrams B through D in Figure 6-42 show the effect of changing source size, altering the relative position of source, object and recording surface. From these examples, it will be seen that the following conditions are desirable to produce sharp shadow images:

a. The X-ray source should be as small as possible.

b. The X-ray source should be as far from the object as possible.

c. The recording surface should be as close to the object as possible.

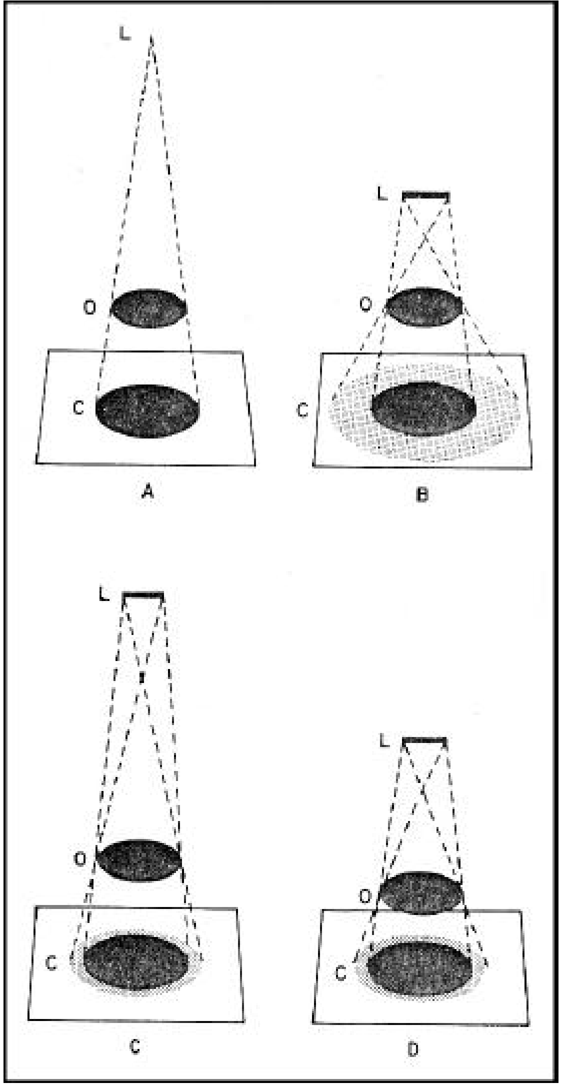


Figure 6-42. Geometrical Factors

6.8.4.1.1.1
There are other factors affecting detail. They include motion, screens, film and scatter. If the source, object, or film move independently of each other or are not in phase, blurring will result. Rigid supports for all three elements must be used to prevent this blurring. Since characteristics and conditions of film, screens, and scatter are also related to film contrast and density, they will be discussed later in subsequent paragraphs.

6.8.5 Density.

Radiographic density is the blackening or darkening produced on the radiograph resulting from the metallic silver deposits remaining on the film after exposure and processing. Density is measured in terms of visible light transmission. The accepted scale of density measurement is the logarithm of the ratio of incident light to transmitted light as given by the following equation:

$$D = \log \frac{I_o}{I_E}$$

Where:

D = density

Io = intensity of incident light

It = intensity of transmitted light

6.8.5.1

Measurement of radiographic density SHALL be done with electronic direct-reading type densitometers. The electronic direct-reading type densitometer is more accurate than the visual type. This densitometer SHALL be capable of measuring the light transmitted through a radiograph with a film density up to 4.0 with a density unit resolution of 0.02. When film densities greater than 4.0 are required to perform a radiographic inspection a densitometer applicable to film densities up to maximum density is necessary. A photographic or radiographic-calibrated reference density strip, traceable to the National Institute of Standards and Technology (NIST), SHALL be used to calibrate the densitometer prior to determining the density of a radiograph. These calibrated density strips shall be replaced whenever they are physically damaged (i.e., scratched, crimped, or become wet by any fluid) to such an extent that it may influence their effectiveness. The carbon, dot printed, etc. density strips SHALL NOT be used even though they may be NIST traceable. These strips are not able to correlate the densitometer directly to Air Force radiographic needs. Each type of calibrated reference density strip will calibrate the densitometer to a different standard level. The restrictive use of only the photographic or radiographic calibration reference density strip will better enable the standardization of all densitometers to a single calibration value establishing a common (H and D units) density for a given radiographic inspection. The aperture of the densitometer SHALL be black in color. If it is not, it may be darkened with a black magic marker or other indelible ink.

6.8.5.1.1

While performing the densitometer calibration procedure, the following SHALL apply:

a. Follow manufacturer's instructions, substituting the calibration strip supplied with the instrument with the NIST traceable radiographic calibration reference density strip.

b. The calibration reference density strip SHALL be removed from its protective cover during the calibration procedure and maintained in its protective cover when not in use.

c. The calibration reference density strip SHALL NOT be pulled or slid when it is between the aperture and stage diffuser. The aperture SHALL be raised so that it is not in contact with the density strip when the strip is being repositioned or removed from the densitometer.

d. Calibrated reference density strip measurements SHALL be determined from the center of the steps that are used for the calibration procedure.

e. While reading the density of a radiograph, DO NOT pull or slide it between the aperture and stage diffuser. When repositioning or removing the radiograph from the densitometer the aperture SHALL be raised.

6.8.5.1.1.1

The density of a radiograph is important. Densities less than 0.5 show very little of the object due to three factors: (1) the density of the emulsion base, (2) the basic "fog" of the film and (3) the lack of uniform response of the film at low radiation exposures. Special illuminators are required to view radiographs with a density of 3 to 4. Radiographs with a density over 4 are extremely difficult to "read." A density of 2 to 3 is recommended for all radiographs.

6.8.6 Contrast.

Maximum contrast is achieved in radiography when the maximum X-ray image contrast is coupled with the maximum available film contrast. High density radiographs viewed with high intensity illuminators provide the best radiographic contrast. As one of the factors that affect sensitivity, contrast should be high. Some of the general rules regarding contrast are as follows:

(1) Contrast increases as kVp decreases.

(2) Contrast increases as film development increases.

(3) Contrast increases as film speed decreases.

(4) Contrast decreases as kVp increases.

(5) Contrast decreases as film development decreases.

(6) Contrast decreases as film speed increases.

6.8.7 Fog.

Fog is the darkening of radiographic emulsion caused by humidity, heat, cosmic radiation, certain chemicals, out of control development chemicals, scatter radiation and bad development practices. It is defined as the darkening of the film emulsion by an inadvertent cause. The fog level of film brings no useful information to the film and merely creates a high background that reduces contrast and image visibility. The faster the speed of the film is, the more susceptible it will be to fogging.

6.8.8 Distortion and Magnification.

Some of the factors that cause distortion and magnification are discussed in other areas of this manual. However, distortion can also be caused by improper alignment of the X-ray machine and/or film in relation to the object. If distortion is excessive so that areas are obscured, it may be necessary to radiograph the object at a different angle. The total distortion or magnification that can be tolerated on a radiograph will depend upon the desired sensitivity and the geometry of the object itself.

6.8.9 Kilovoltage and Processing.

Any attempt to evaluate a radiograph must take into consideration the conditions under which the radiograph was made. The effects of different kilovoltages and processing techniques cause a variation in contrast and latitude.

6.8.10 Viewing and Reading.

GENERAL. Viewing and reading of the radiograph is the final step in the radiographic inspection procedure. The radiographer must be aware of the various factors that can influence his decision. Some factors are density of the film, artifacts on films as a result of handling and processing, level of illumination for viewing radiographs, response of human eye to differences in light intensity and the acuity of vision.

6.8.11 Viewing Conditions.

Reading large numbers of radiographs is a strain on the eyes and fatiguing to the film interpreter. The environment of a film reading area should be pleasant and SHALL be free of objectionable background light that may cause reflection on the radiographic film. Two and one-half (2.5) foot-candles of ambient light measured at the viewer is optimum for viewing. This light level will aid the film interpreter by accommodating the eye so they are more sensitive to light. When attempting film interpretation, the radiographer should wait at least three (3) minutes before reading film, when coming into the viewing room from ordinary artificial room light. When coming from full sunlight, the interpreter should allow five (5) minutes for dark adaptation before viewing. If the eyes are subject to the full brightness of the illuminator during changes of the radiographs, at least thirty (30) seconds re-adaptation is necessary (see Figure 6-43).

The film reading illuminator or illuminators should transmit at least two (2) foot-candles of light through the film at the viewing surface of the film. This quantity of light is sufficient to view radiographs with a density of three (3) H and D units. There should also be a high intensity illuminator with a variable light intensity capable of transmitting the required light through densities in the order of four (4) to four and a half (4.5) H and D units for interpreting these high densities. All film viewers SHALL be of the type that provides a uniform level of illumination over the entire viewing surface.

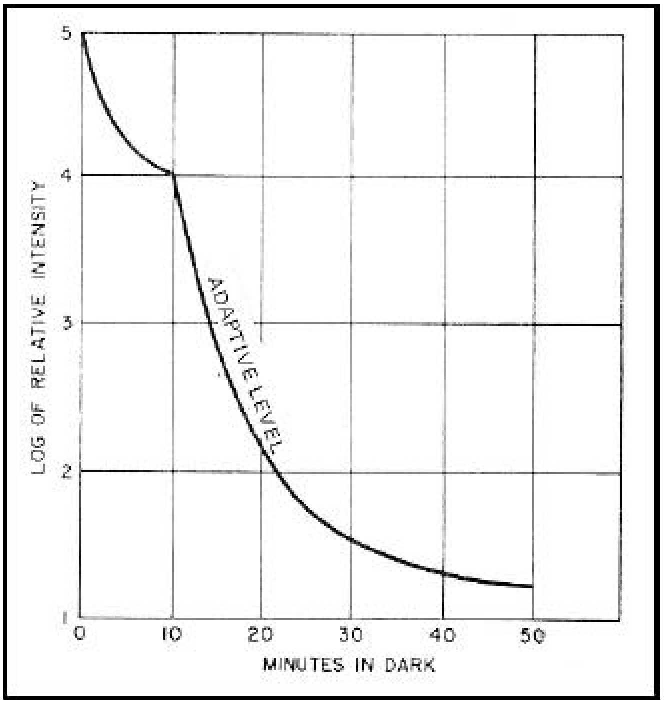


Figure 6-43. Dark Adaptation Diagram.

6.8.11.1 <u>Limitations of Eye</u>.

The eye is the evaluation medium in radiography. Visual accuracy varies considerably from one individual to another. Oddly enough, a perfect eye does not necessarily mean a perfect visual system. Certain "defects" can be present. Vision must not only record shapes and sizes, but also the variation of light intensities. In this area the eye is especially unreliable. The relative brightness of two light sources, for example, can be gauged only approximately. And even such approximate evaluation is possible only when the light sources are close to the same order of brightness. For example, a bright object or area appears brighter when viewed against a dark field. Conversely, the object will appear darker than it really is when the surrounding area is comparatively brighter.

6.8.11.2 <u>Visual Size</u>.

In any task requiring critical examination, we are usually more conscious of size than anything else. The minimum size of an object that can be seen under a given set of conditions is called the threshold size. This varies greatly depending on brightness-contrast between the immediate background and the detail being examined. It also varies with the level of brightness. The physical size of an object can easily be measured, but it is difficult for most individuals to interpret physical size into visual size. The type in which this is printed has a definite physical size measured in points, a point being about 1/72 of an inch. The visual size, however, depends on the distance from the page to the eye. The visual size of the letters at two feet is only one-half that obtained for a page-to-eye distance of one foot. The visual size is the angle subtended at the eye by an object at a distance. The threshold size of a critical detail (such as this black print on a white background) is about one minute (l/60 of one degree) for persons of normal vision. An individual with sub-normal vision will be able to pick up an object of just about twice the visual size required for normal vision. The relation of a visual size of one minute of a degree to physical size for different viewing distances is given in Table 6-20.

Table 6-20. Visual Size versus Physical Size.

Viewing Distance (inches)	Physical Size (inches)
10	0.0029
12	0.0035
15	0.0044
20	0.0058
24	0.0070

6.8.11.2.1

For a given viewing distance the visual size is maximum when the line of sight is perpendicular to the plane in which the object lies. Referring again to this printed page, this means a line from the eye perpendicular to the page. As the page is inclined (to decrease the angle between the line of sight and the page), the visual size of the print is decreased until at 45 degrees the type size is only 70 percent of what it was at 90 degrees. For a 45-degree angle, assuming an object of fixed physical size and fixed viewing distance, visibility equal to that at 90 degrees can be had only by increasing the illumination level by 2-1/2times. An aid in reading radiographic film is the pocket comparator with graduated reticules having linear and circular scales. They are able to measure the size of discontinuities and/or defects depicted on this film:

6.8.11.3 Visual Contrast.

A certain level of contrast is desirable between small detail and its immediate surroundings. However, a high degree of contrast between those immediate surroundings and any large area outside the field in which the detail lies is unfavorable. The contrast between this print and the page is favorable. But a high contrast between the page and the desk on which it lies is detrimental to good vision. For each contrast there is a threshold size, and, conversely, for each threshold size there is a minimum contrast if the object is to be just visible. As the brightness level decreases, the difference in brightness levels must be greater and greater if the eye is to detect a difference. It is evident from this figure that the eye must have considerable time to adjust to low levels of light intensity.

6.8.11.4 Speed Of Sight.

Sight is not instantaneous. It takes time to see. We do not see when the eyes are in motion. In reading this line the eyes focus on a point called the point of fixation. This point of fixation is then moved along the line in a series of jumps. The eyes come to a dead stop several times, about three times usually in reading a line of this print. What we do is read a portion of the line during each fixation period. The time of one of the fixation periods varies between 0.07 and 0.3 second. Hence, these times become the limiting periods in seeing. As a visual task increases in difficulty, these fixation periods become longer. Involved, too, is the problem of reaction time, that is, the time that elapses between seeing and acting. Any task involving sight becomes a series of complex time intervals. The time for seeing is naturally greatly influenced by experience, mental reaction time, brightness level, contrast-brightness, and visual size. The rapidity with which any visual examination can be carried out is a relation between these factors and the necessary accuracy or exactness of the examination.

6.8.11.5 Illuminators.

The illuminator must provide sufficient light to transmit adequate light for the observer to distinguish areas easily. Since the human eye has greater visual acuity and contrast visualization at given levels of light, then the illuminator must provide control of light levels to adjust for optimum visual response of observer. The accepted differential of density detectable by the average individual is 0.02. Thus, a 2 percent change in thickness must result in density change of 0.02 or more. The contrast sensitivity of the human eye is greatest when light reaching the eye comes from one source. Therefore radiographs should be read in areas of subdued light to avoid reflection and glare. The eye responds best if all the light reaching it is of approximately the same brightness (see Figure 6-44). The ASTM standard on illuminators is cited in Ref. 15.

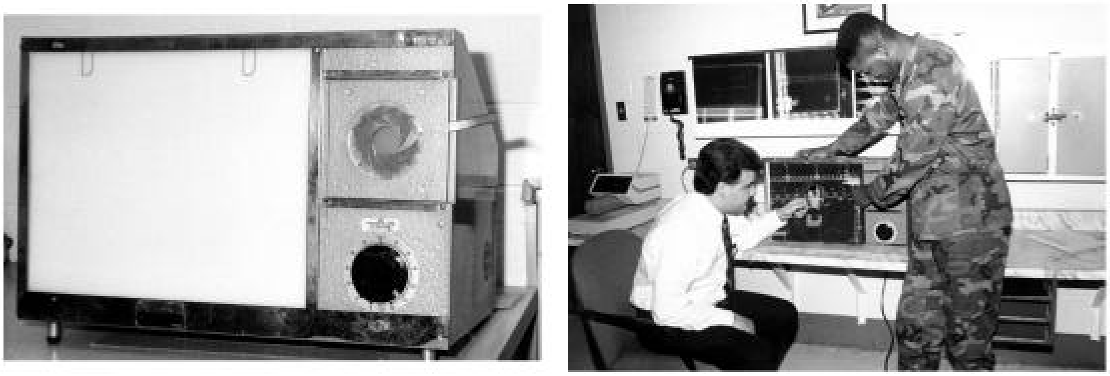


Figure 6-44. Typical High Intensity Viewer.

6.8.11.5.1

Opaque masks to suit the size of radiographs to be viewed and to isolate areas of interest SHALL be used to avoid brightness around edges of film, excess light from low density areas of no interest and reduce light intensity from the illuminator when changing radiographs. This prevents the eye from continually adjusting itself to the changing light levels that cause fatigue. At normal light levels the eye can see the differences in light brightness of two percent. As light reaching the eye decreases, the percentage increases radiographs having great ranges of density and complicated image patterns should be viewed on high intensity, 14 x 17 illuminators having adjustable diaphragms and variable light intensity to assure best eye response.

6.8.12 Reading Radiographs.

Interpretation of radiographic images cannot be translated into mathematical formulas or routine procedures. The wide variety of test objects and the various fabrication processes by which they have been made makes radiographic interpretation a complex subject. Radiographic inspection is conducted to assure that a material or part has the required integrity to reliably perform the function for which it was designed. This does not mean perfection. All parts, materials, and processes are imperfect. Therefore, the purpose of radiography is to determine the degree of imperfection. The effects of discontinuities or manufacturing deviations must be correlated with the function of the part. Specifications are usually used to spell out the discontinuities that may be considered detrimental to the function of the part and the acceptable magnitudes of the discontinuities. It is the duty of the film interpreter to recognize the various discontinuities, their magnitudes, and be capable of relating them to the particular specification required. The responsibility and capability of the radiographic interpreter cannot be over emphasized. Often many human lives and investments of millions of dollars are depending on the judgment of the radiographic interpreter. Any information that can be of assistance in making a judgment of discontinuities should be fully utilized. Interpretation of the shadow images visible in the radiograph is an acquired skill and there is no substitute for experience. Experience aids the film reader in recognizing discontinuities and in identifying where they can be expected to occur in a particular part or structure. The mistakes in radiographic interpretation most often are a result of misreading film artifacts. There are a number of density patterns that resemble welding and casting defects that are often unjustified causes for rejects. Processing and handling errors that affect radiographs and can be misinterpreted are listed in Table 6-21. A good check is to look at the surface of the film by reflected light to observe any unusual patterns.

Table 6-21 Deleted

6.8.12.1

The inspector reading radiographs should be acquainted with the exposure technique used, material radiographed, conditions of processing, and the geometry of the exposure setup. In this way he can judge more accurately the radiographs produced and interpret the discontinuities more accurately. To determine if the part is rejectable or acceptable he will generally consult with the structural or design engineer unless standards have been established. To properly apply information obtained through radiography, the material inspected must also be accurately identified with respect to the object radiographed. Lead letters or numbers are radiographed with the object to provide identification. This identification must be recorded and keyed to the object.

6.8.13 Typical Radiographic Discontinuities.

The radiographic inspection process is comparatively expensive and should be used for evaluation of internal discontinuities that cannot be evaluated by more economical methods. Therefore surface discontinuities of a magnitude to be considered detrimental to the function of the part should be evaluated by visual inspection or other NDI methods that are more economical than radiography. The major use of radiography is to reveal internal discontinuities.

6.8.14 Castings.

The process of forming various shapes of metal by pouring molten metals into molds accounts for a considerable share of the critical components of an aircraft. These castings are made by melting ferrous and nonferrous alloys. The majority of the castings encountered requiring X-ray inspection are made of light alloys; that is, aluminum and magnesium alloys. There are a number of inherent difficulties in this manufacturing technique which plague the foundry. Since the molten metal occupies a larger space than the same material after it freezes or cools, precautions must be taken to prevent the metal from shrinking too rapidly and forming voids which are called shrinkage or from rupturing the metal to cause hot cracks. The molten metal also traps considerable gases from the air. These may result in tiny regular shaped bubbles in the solid metal casting. Some metals such as aluminum accumulate gas on the surface of the molten metal. This may be trapped in the casting if adequate precautions are not taken to prevent pouring the gas into the mold. In addition, sand may wash from the walls of the mold into the casting forming inclusions that reduce the strength of the castings.

6.8.14.1

It is necessary to control the quality of the casting process to assure reliability of the castings. Radiographic inspection is a satisfactory quality control since the conditions likely to make the casting unacceptable are readily detected by this inspection. For the purpose of inspection, airframe castings may be divided into classes based on their function and on their margins of safety for design loading conditions. These classes are defined in specification MIL-C-6021 F "Castings, Classification and Inspection of" and are basically as follows:

a. Class 1. A casting, the single failure of which would cause significant danger to operating personnel or would result in a significant operational penalty. In the case of missiles, aircraft, and other vehicles, this includes loss of major components, loss of control, unintentional release or inability to release armament stores, or failure of weapon installation components. Class 1 castings shall be further classified under Class 1A and Class 1B below.

    (1) Class 1A. A Class 1 casting, the single failure of which would result in the loss of a missile, aircraft, or other vehicle. These castings receive 100 percent radiographic inspection.

    (2) Class 1 B. Class 1 castings not included in Class 1A. Radiographic inspection in accordance with sampling Table 1 of Spec. MIL-C-6021F.

b. Class 2. All castings not classified, as Class 1. Class 2 castings shall be further classified under Class 2A and Class 2B below.

    (1) Class 2A. Castings have a margin of safety of 200 percent or less. Radiographic inspection in accordance with Table 11 of Spec. MIL-C-6021F.

    (2) Class 2B. Castings have a margin of safety greater than 200 percent, or for which no stress analysis is required. All target drone castings and aerospace ground support equipment fall in this category, except for such critical parts, the failure of which would make the equipment unsatisfactory and cause the vehicles which they are intended to support to be inoperable. Radiographic inspection is not required.

6.8.14.2

Radiographic examination is ideally suited to the inspection of castings because the most common casting discontinuities are three dimensional and are, therefore, almost independent of angle of inspection. Exceptions in some cases include fine cracks, cold shuts, unfused chills and chaplets. To reveal these, the radiation must be at or near the same parallel plane as the discontinuity. Hairline surface cracks, such as those produced by grinding are seldom, if ever, revealed by radiography.

6.8.14.2.1

It is possible in most cases to identify the radiographic images of the common types of discontinuities that are inherent in the casting process. This information is valuable to the foundry in procedure development work that may be necessary to meet a standard of quality. Although the discontinuities commonly encountered in aluminum and magnesium castings are similar to those in ferrous metals, a group of irregularities called "dispersed defects" may frequently be present. These "defects," prevalent in light alloy castings, consist of tiny voids scattered throughout part or all of a casting. Gas porosity and shrinkage porosity in aluminum alloys are examples of dispersed defects. On radiographs of sections more than one-half inch thick it is difficult to distinguish images corresponding to the individual voids. Instead, dispersed defects may appear on film deceptively as mottling, dark streaks or other irregularities.

6.8.14.3

Radiographic studies of new casting produced by the foundry reveal the type and location of internal discontinuities. This aids the foundry to change the casting technique by altering the gating, relocating chills, changing the pouring temperatures, repositioning, increasing or decreasing the risers or altering the size, correcting a faulty sand condition, or increasing the venting in the mold. After developing an acceptable casting procedure the casting can be duplicated with assurance of a quality part.

6.8.14.4

In general, castings are irregular in shape and may vary considerably in cross section thickness from area to area. It is, therefore, important to utilize equipment of adequate capacity to penetrate the section thickness and kind of material under consideration with a technique giving inherent wide latitude with adequate sensitivity. In some instances even when radiographing light alloys castings, lead filter screens may be employed.

6.8.14.4.1

Correct radiographic procedure requires the selection of the lowest voltage that will do the job in a reasonable exposure time. Where many castings are examined, a convenient technique is to establish a reasonable exposure time and select the voltage required for the thickness of the particular section being radiographed. Good practice normally requires that exposures be longer than 1 minute. When castings with great difference in thickness must be radiographed in one exposure, an increase in voltage will provide wider latitude, as well as shorter exposure time. However, contrast is reduced. If other factors remain constant, the most desirable combinations of voltage and exposure time for a specific part being examined may be governed largely by the acceptable radiographic sensitivity.

6.8.15 Casting Defects.

6.8.15.1 Microshrinkage.

Microshrinkage appears as a dark feathery streak or dark irregular patches, corresponding to a grain boundary shrinkage condition. This condition may be suspected in a magnesium base alloy.

6.8.15.2 Shrinkage Porosity.

Shrinkage porosity or sponge appears as a local honeycombed or mottled pattern; it may be the result of pouring temperature or alloy composition.

6.8.15.3 Gas Porosity.

Gas porosity appears as round or elongated smooth, dark spots occurring individually or in clusters, or distributed throughout the casting. This condition can be caused by gas forming during solidification, by the evaporation of moisture or volatile material from the mold surface. Insufficient core baking, venting and entrapment of air in the cope surface of the casting before complete solidification are other likely causes.

6.8.15.4 Inclusions.

Inclusions of tramped material in the molten flow may be poured into the mold. This appears as light areas in a radiograph since the inclusions are denser than the alloyed casting. Sand inclusions appear as gray or light spots of uneven granular texture within distinct outline and tend to concentrate near the drag (bottom) side of the casting. Inclusions which are lighter than the casting appear as isolated, irregular or elongated variations of film blackening not corresponding to variations in thickness of material or to cavities. They may be due to sand slag or oxides.

6.8.15.5 Hot Cracks.

Hot cracks appear as ragged dark lines of variable width and numerous branches with no definite line of continuity. They may exist in groups and start at the surface or they may be internal. This condition is usually a result of the normal contraction of the casting, being restricted by the mold and/or core during or immediately after solidification.

6.8.15.6 Cold Cracks.

Cold cracks appear generally as a single, straight, sharp dark line usually continuous throughout its length. Cracks of this nature may be produced by cooling from elevated temperature during flame burning, grinding or quenching operations and internal stresses that are set up by thermal gradients.

6.8.15.7 Cold shuts.

Cold shuts appear as a distinct darkened line of variable length and definite smooth, (Heavier than Casting) outline. Cold shuts are formed when two bodies of molten metal flowing from different directions fail to unite and form homogeneous metal. Cold shuts may be produced by interrupted pouring, slow pouring or pouring the metal at too low temperature.

6.8.15.8 Misruns.

Misruns appear as prominent darkened areas of variable dimensions with a definite smooth outline. Misruns are produced by failure of the molten metal to completely fill a section of a casting, leaving the region void. This condition may be produced by lack of fluidity or pouring at too low temperature.

6.8.15.9 Dendritics.

Dendritics appear as a series of irregular sharp lines usually in a parallel pattern.

6.8.15.10 Unfused Chaplets.

Unfused chaplets may appear as a dark smooth line conforming to the shape of the chaplet and casting. In light alloy castings unfused chaplets may also appear as light lines. This condition is caused by cold or coated chaplets or by pouring the metal at too low temperature to fuse properly with the chaplet.

6.8.15.11 Core shift.

Core shift may be detected when it is possible to angle the radiation or rotate the piece in a manner that would make it possible to measure the deviation of a specified wall thickness. Core shifts may be caused by jarring the mold, insecure anchorage or omission of chaplets.

6.8.15.12 Surface Irregularities.

Surface irregularities may cause an image corresponding to any irregularity visible on the surface. These irregularities frequently show on a radiograph and may resemble or are confused with a flaw in the metal. It is, therefore, good practice to have the casting conveniently at hand when making an accurate interpretation of a radiograph.

6.8.16 Welds.

Metal may be joined together by welding to form many shapes and structures required in an aircraft. This fabrication procedure, when carefully controlled, will provide a joint that is equal in strength to the parent materials. There must be just enough heat to produce fusion and adequate penetration, but not too much, which would cause porosity, cracks or undercutting. Most weld discontinuities can be readily detected by radiographic inspection since they consist of a change in material homogeneity. Cracks in welds are often detectable since they will usually occur in the direction of the thickness of the plate and will be parallel to the X-ray beam. Stresses created in the metal by welding and not accompanied by a physical separation of material will not be detected by radiography and cracks not properly oriented may also be missed. Oxides created by the molten metal may be trapped in the weld. This condition results in reduced strength and is subject to review to determine possible implication as a result of the service the weld is expected to yield.

In tungsten inert gas (TIG) welding, tungsten electrode inclusions can occur. These appear as nearly clear specks in a radiograph due to the very high absorption of the radiation by tungsten. These inclusions usually appear in clusters of 2 or more. A single tungsten inclusion is unusual. Foreign material whose density is approximately the same as the weld metal may not be detected. In the inspection of weldments, radiography is an indispensable tool for the location of internal discontinuities. It is the oldest and best known nondestructive means for this purpose. It is used to establish welding procedures, to qualify welders, to inspect welded fabrications in process, and for quality control of welded parts. For routine inspection, test welds made periodically on production welding may be inspected by X-ray to supplement destructive tests where results are in doubt. When quality has been established, an occasional X-ray exposure can be made on routine work. All X-ray shadow images are geometric projections of the actual size of conditions in or on the weld. There may be some slight distortion depending on angle of X-ray beam and distance of the weld from the film. Density, in general, is some indication of the depth magnitude of the weld discontinuity.

6.8.17 Welding Defects and Conditions.

6.8.17.1 Coverbead.
The face of the weld is a comparatively wide band, which is the actual width of the bead covering the entire area to be examined. The cover bead area should have enough density to distinctly show surface ripples. But it should not be so dark as to obscure subsurface regions.

6.8.17.2 Undercutting.
This appears on the radiograph as a dark line of some width at the junction of the weld and the plate. A fine line in this darker area may indicate a crack at the fusion line and should be further investigated.

6.8.17.3 Excessively High Cover.
Where radiation exposure is satisfactory, a cover bead of this kind will appear as a very transparent area, obscuring all but major subsurface defects. When such an excessively high cover bead extends for a considerable distance, the bead should be ground and re-examined so that cracks or other hard-to-find defects may not be overlooked.

6.8.17.4 Splatter.
Either on the bead or plate next to the weld, this will appear on the radiograph as a light spot. Although not a defect in itself, splatter may cover some more serious defects.

6.8.17.5 Arc Tracks and Burns.
These result from carelessness on the part of a welder in striking an arc at the side of the welding groove. Such tracks are readily recognized on the radiograph. A burned spot may show a small "star" or lines radiating from the center which are actually cracks in the plate. In the cover bead these are frequently heavy, leaving an almost blank area on the film and obscuring subsurface defects. These are points that frequently harbor inclusions and cracks.

6.8.17.6 Surface Cracks.
These will appear in the weld as rather fine lines, either parallel to or transverse to the weld. Such surface cracks are frequently found near or at the edge of the weld, or follow a ripple across the weld.

6.8.17.7 Narrow Cover Bead.
This may indicate either of two conditions. The bead may actually be of less width than the subsurface weld, in which case a differential in density will be noted between the edge of the weld, or the plate material may be mismatched.

6.8.17.8 Offset Cover Bead.
Where the cover bead is not placed directly over the remainder of the weld, the radiograph will show the relative positions of the cover and root beads. In severe cases these two beads may be side by side instead of superimposed; such a condition may definitely weaken the weld structure.

6.8.17.9 Porosity.
Gas pockets are usually spherical and are readily recognizable as dark spots the intensity of which varies directly with their diameter. Gas pockets are not peculiar to any one spot in the weld and may be fairly well scattered.

6.8.17.10 Slag and Wagon Tracks.
Isolated slag deposits usually form an irregular body and are most frequently found at the edge or fusion line of the particular bead. The most frequent type of slag deposits are found between the first or root pass and the second pass. Such slag deposits may be quite long and appear as lines of some width. Where such lines are found on both sides of the root bead they are commonly referred to as "wagontracks." These frequently have considerable length but seldom are of excessive width. Isolated slag pockets on the other hand frequently have decided width as well as length. Generally, the density of a slag inclusion is rather uniform throughout.

6.8.17.11 Cracks.
In the path of radiation these are readily distinguished as fine lines of considerable length but without great width. Generally, they do not follow a straight course. At an angle to the source of radiation, cracks are difficult to recognize

until considerable experience has been gained. Such cracks appear as a blur with one side of heavy density fading out toward the other edge. Since cracks frequently do not extend to the surface, they may not be found by visual inspection of outside areas. Cracks normal or nearly normal to the line of radiation cannot be seen.

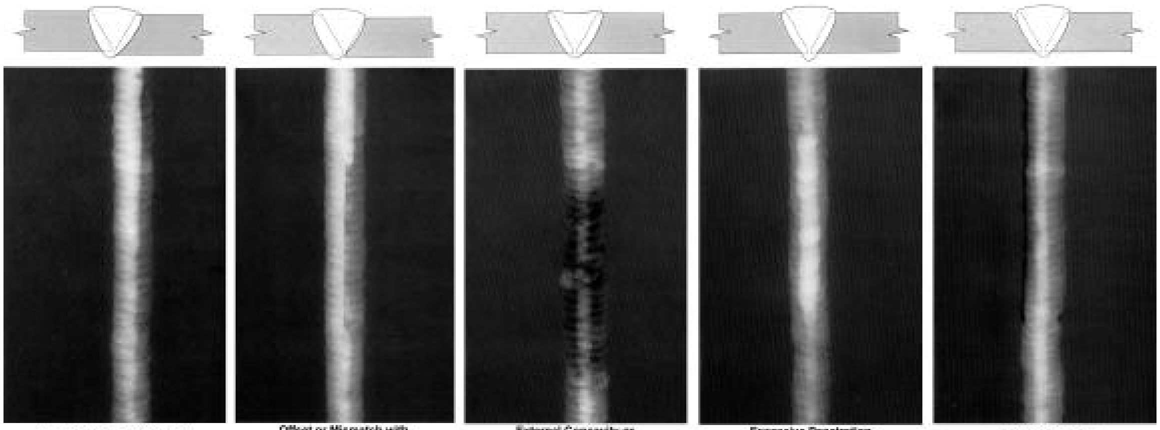
6.8.17.12 Lack Of Root Penetration.
This will appear on the radiograph as a straight wide line through the center of the weld.

6.8.17.13 Lack Of Root Bead.
Frequently penetration will barely have been completed or will be lacking very slightly of complete penetration and no root bead will have been formed. In such instances the radiograph will show total absence of the root bead as indicated by the superimposed band, but will not reveal the line mentioned above for lack of penetration.

6.8.17.14 Lack Of Fusion.
Lack of fusion will appear as a blur similar to the angular crack but will have considerably more definition. Frequently this condition will exist in connection with lack of penetration. In such instances the line mentioned above will have a blurred edge on one or both sides. The extent of this blur will indicate the depth of the unfused area. Since this blur is a horizontal projection of an angular plane, the depth of the unfused area will be several times as great as the width of the blur.

6.8.17.15 Incomplete Penetration.
Incomplete penetration may occur in a fillet weld. This will show on a radiograph as dark lines along one side of weld image.

6.8.17.16 Burn Through.
This will appear on the radiographs a relatively large round or oblong area in the root area. Where such an area is indicated merely by a circle with possibly a light area in the center the second pass has filled the original defect. When this appears as a dark area, the radiographer can be sure that a void of some magnitude exists. Frequently an area will appear only slightly darker than the weld density, but will contain a very black line in the center. This indicates that the second pass filled the original hole in the root pass but that a shrinkage crack has developed at this point. Such shrinkage cracks may extend entirely through the second pass. These are potential stress points. The following Figure 6-45 shows radiographic examples of welds.



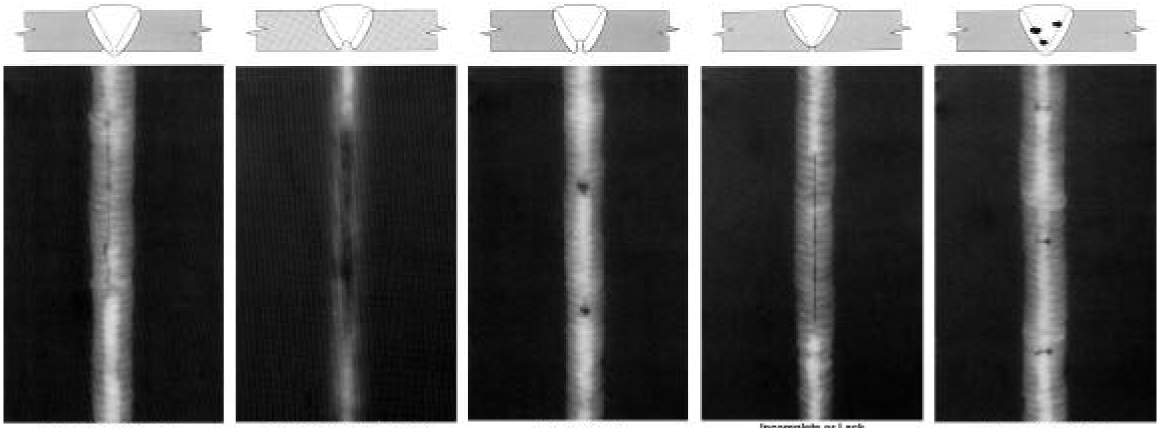
Offset or Mismatch (Hi-Lo)

Offset or Mismatch with Lack of Penetrant (LOP)

External Concavity or Insufficient Fills

Excessive Penetration (Icicles, Drop-thru)

External Undercut



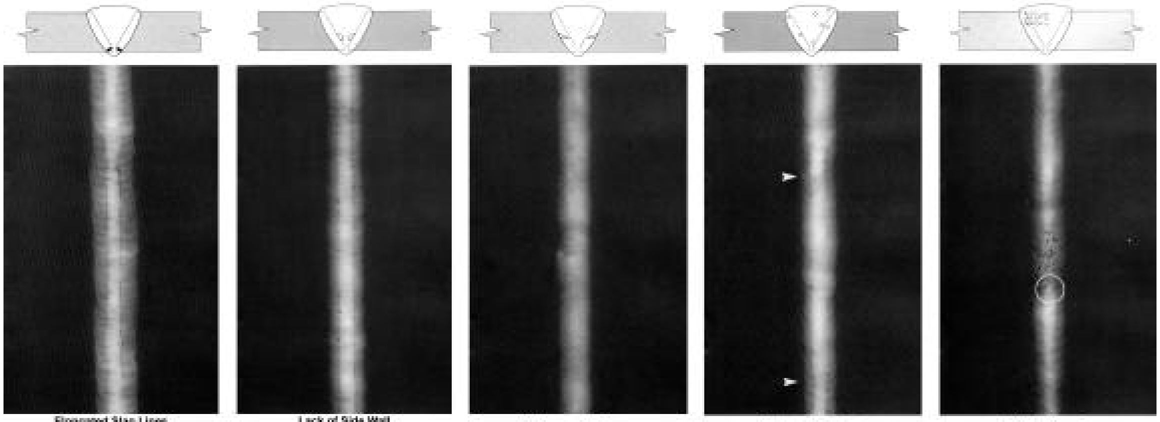
Internal (Root) Undercut

Internal Concavity (Suck Back)

Burn Through

Incomplete or Lack of Penetration (LOP)

Interpass Slag Inclusions



Elongated Slag Lines (Wagon Tracks)

Lack of Side Wall Fusion (LOF)

Interpass Cold Lap

Scattered Porosity

Cluster Porosity

Figure 6-45. Radiographic Examples of Welds (Sheet 1 of 2)

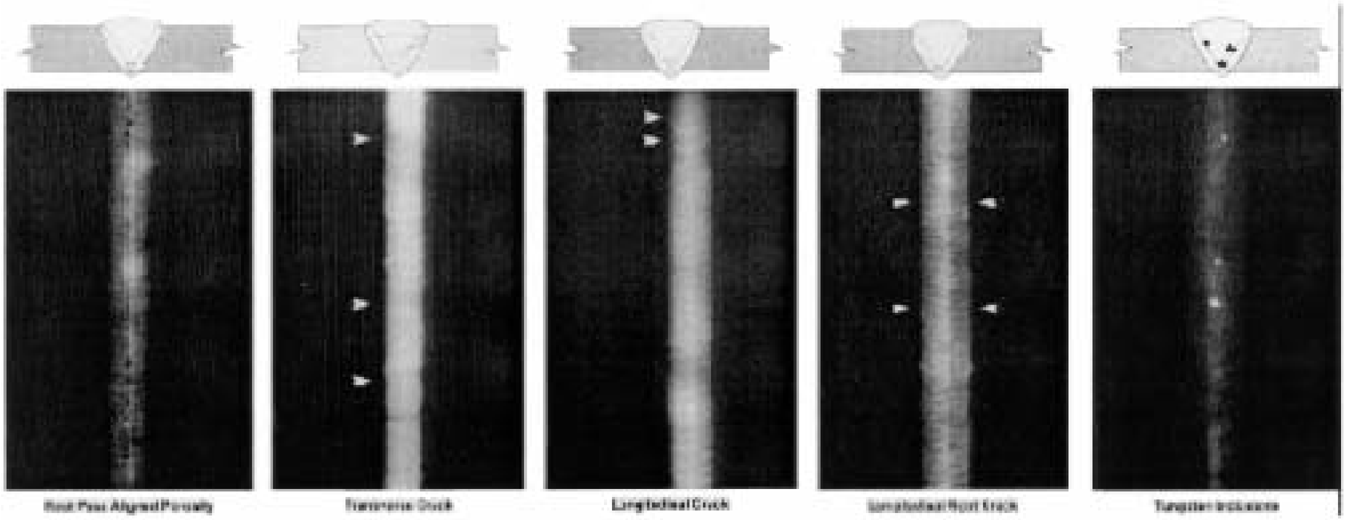


Figure 6-45. Radiographic Examples of Welds (Sheet 2 of 2)

6.8.17.17 Aluminum and Magnesium Welds.

Radiographic technique and equipment for examining welds in aluminum and magnesium alloys are no different than methods used for steel welds. The discontinuities produced by fusion welding of aluminum and revealed on film by radiography include:

a. Entrapped gas, ranging from fine gas porosity to large gas holes. The porosity may be in line or at random.

b. Inclusions of tungsten particles, foreign materials, flux and oxide. Since the density of oxide films is nearly the same as that of aluminum, they will not produce a detailed indication on a radiograph unless present in large quantities.

c. Inadequate penetration.

d. Incomplete fusion.

e. Cracks.

f. Surface irregularities.

6.8.18 Spot Welds.

A special exposure technique is necessary for the inspection of spot welds. The welded areas are X-rayed with a low-voltage, high-intensity, beryllium-window X-ray tube on extremely fine grained films. Spot welds and seam welds produce X-ray images of aluminum and its alloys that are entirely different from those of any other welding technique. Because of the rather large percentage of radiographically dense alloying constituents that produce informative patterns, some of the high strength aluminum alloys are well suited for spot weld radiography. The images show positive indications of the following:

a. Variations in weld nugget shape (oversize, undersize, absence, misshapen, doughnut and crescent shaped).

b. Extrusion and expulsion of metal from nugget.

c. Cracks.

d. Foreign materials (for example, tip pickup).

e. Porosity.

f. Segregation of the alloying elements.

g. Electrode impressions.

6.8.18.1

Flash welding, which produces heat by creating an arc between the pieces to be joined, and pressure welding, done by applying pressure to suitably prepared surfaces at temperatures lower than the melting point of the parts, are seldom radiographically inspected. When performed, the inspection is usually made to detect cracks produced in welding procedure.

6.8.18.2

Incomplete fusion at the interfaces between weld and parent metal has certain factors in common with a crack. But the plane of incomplete fusion is rarely normal to the plate surface and for this reason is not always revealed. Where such a discontinuity is suspected, additional exposures at various angles may reveal the lack of bonding.

6.8.19 Service Inspection.

6.8.19.1 General.

When materials are utilized fully as required in the design of modern aircraft, there is occasional failure due to fatigue. These failures are results of over-stress of the material due to unusual operating conditions or deterioration of the material. This type of material change is most difficult to detect due to the very nature of the changes and the inaccessibility of the areas in which these changes are most likely to occur in an aircraft. These service type changes in an aircraft are usually due to wear, corrosion, fractures or shear of material. Radiography has been used to detect these conditions when they occur in inaccessible areas and are not available for visual inspection.

6.8.19.2 Wear.

Rivets and bolts may wear the skin, spar and frame holes so that there is not a correct fit in the holes for adequate strength in joints or attachments of a wing section. This can occur due to continued flexing of components from use or because of severe stress due to unusual operating conditions in turbulent weather or an adverse landing. This condition may also result in radial cracks from boltholes. This type of failure is extremely difficult to detect by radiography. Any angle of exposure results in superimposition of bolt or nut over crack. Loose bolts and rivets have been detected satisfactorily when occurring in position to be located. Elongation of rivet holes caused by bearing failure or sheared rivets should not be confused with elongation of holes from drilling. If fatigue is suspected in a riveted joint, the half moon indications should all be on the same side of the rivet and the rivets in the joint should show similar indications of failure. Intermittent indications would normally be considered fabrication tolerance.

6.8.19.3 Corrosion.

Corrosion may occur in aircraft materials, which reduces its strength and expedites the possible failure. This deterioration of the metal may be due to electrolytic action, moisture, chemicals or gases which attack the metals, intergranular action due to improper heat treatment at the time of manufacture, or other factors. This condition usually occurs on internal surfaces of such components as tubular supports or housings. Since corrosion represents a change of material and occurs in all directions it is easily detected by a proper radiographic exposure. If corrosion has proceeded to this point, the support is appreciably reduced in strength and may experience failure.

6.8.19.4 Cracks and Crack-Like Discontinuities.

Cracks and other crack-like discontinuities are found in numerous parts and/or structures and are very dangerous discontinuities. This is particularly true where structures are subjected to vibration or fatigue loading, due to propagation of these crack-like discontinuities. Crack-like discontinuities will appear in a radiograph as very straight and sharply outlined dark or black lines. Cracks may also appear as diffused jagged lines. In some cases they have a tree-like pattern. Scatter radiation from the sides of a crack can act as an amplifier of the crack image in a radiograph. This is the most difficult service type failure to detect by radiography since these crack separations are usually not associated with other detectable conditions that give clue to their presence. A crack-like discontinuity oriented at any angle other than 90 degrees to the X-ray film and not parallel with the X-ray beam offers very little difference to the radiation transmission and may not be visible in the radiographic image. Radiography can only be depended on to reveal crack-like discontinuities that are aligned within approximately 7 degrees of the X-ray beam. This depends on the thickness and width of the crack. Normally cracks that are easily detectable by X-ray are visible to the naked eye. Radiography may be used to determine extent of cracks or other conditions detected visually or by magnetic particle or penetrant methods of inspection. In castings, crack-like discontinuities can be due to shrinkage, hot tears, cold shuts, or other sources typical of the casting process. In weldments, longitudinal or transverse cracks may be found. Lack of weld penetration produces a crack-like discontinuity. The forging process can introduce cracks, laps, and seams that appear crack-like in radiographic images.

6.8.19.5 Water In Honeycomb.

A typical condition that occurs in honeycomb structures is the formation of water in the cores. This entrapped water freezes and expands at high altitudes. The expansion distorts the cells and can break the bonds between core and facing sheets. When this condition exists, vibration of the face sheet can occur causing failure of adjacent bonds and propagation of bond failure. Entrapped water causes corrosion of both face sheet and core material. Radiographic inspection is conducted to evaluate core damage and water content as a maintenance inspection. Entrapped water in honeycomb cells usually appears as a smooth, consistent, light density area that does not have a grainy or porous appearance. The lightest area (more dense substance) indicates greater amounts of water.

a. Epoxy in honeycomb cells appears grainy, non-homogeneous. If the cell is not spotty and completely filled, the epoxy will be located around the periphery of each cell.

b. Radiographic inspection for moisture detection can be made with the honeycomb core cell walls in either the vertical or horizontal plane. The preferred method is with the core cell walls in the horizontal plane because core cells which are partially filled with moisture are more readily identifiable (less easily confused with solid adhesive).

c. If practical, confirmation of partially filled cells with water can be made by repeating the radiographic procedure with the honeycomb cell walls in the opposite plane.

d. Radiographic exposures indicating filled core cells are not always conclusive for moisture detection and should be confirmed by other means if possible.

6.8.19.6 Location of Foreign Objects.

Radiography is an excellent method to locate and evaluate foreign objects. Foreign objects may be free rivets, bolts, or other objects that could be detrimental to the function of the part or assembly.

6.8.19.7 Assemblies.

Radiography has found wide use in the revaluation of various assemblies to determine status or condition. If the use of the assemblies produces changes in it which are recordable by an X-ray beam, then radiography may be useful in supplying confirming evidence of the suspected condition. Radiographic inspection of oil coolers has resulted in an inspection method that can detect foreign material in the cooler.

6.8.19.7.1 Workmanship

Radiographic inspections, after completion of repair, assure quality of workmanship. On occasion components are mis-assembled. In some areas it is not possible to check dimension by physical or visual means. Radiography may be used if precautions are taken to assure proper geometrical relation to determine dimension of internal spacing.

6.8.20 Radiographic Standards.

6.8.20.1 General.

It is inherent to good practice in many cases that castings or weldments are thicker in cross section than required for the necessary strength of the part. For this reason some flaws in the casting can be tolerated with no detrimental effect to the aircraft. In order to determine what castings or weldments are acceptable for use in an aircraft, standards of acceptability are prepared as a guide to the radiographer. There are two general types of standards prepared the specific standard applicable to only one particular part and the general standard.

6.8.20.2
A specific standard for a part is prepared by x-raying the part, then destructively testing the part by applying force of the same type and direction as would be expected in actual service. If the yielding force is greater than the design load, the X-ray film of the part may be used as a standard. These types of standards are normally used by foundries and copies of these standards are limited in supply since the part is destroyed by testing and additional retakes cannot be made.

6.8.20.3
General standards are prepared by an engineering society, company, or government agency as a guide in determining if the casting and weldments are sound. These standards are based on experience and engineering judgment to provide a casting and weldment that is generally acceptable for normal use. Radiographic standards prepared by the American Society for Testing and Materials, 1916 Race Street, Philadelphia 3, Pennsylvania, are approved for use. ASTM standards dealing with radioscopic and radiographic inspection of castings and weldments are cited in Reference 16.

6.8.20.4
Paints, sealants and adhesives used in fabricating structures often build up to thicknesses that are readily observed on radiographs. Radiographic indications of these materials can result in obliterating the area of concern and/or cause misinterpretation of the radiograph. The method of application and the built up thickness causes a very rough surface of widely varying thicknesses. The radiographic indication often appears similar to a radiograph of a weld bead. The materials in the liquid or gel state can entrap foreign particles such as metal chips or gas bubbles. These cause radiographic indications similar to inclusions or porosity. During curing, drying, or service, the organic material can form crack patterns. Radiographic indications of the cracks can appear as dry mud cracks, dendrites (tree branches), or one or two very wide cracks. It is difficult and requires experience to interpret these indications. Cracks in coating materials are normally recognized by the crack pattern and the fact the crack will exceed normal or usual metal crack width. The best method of confirming the indications is to remove the paint, sealant, or adhesive and to re-X-ray. Unfortunately, limited access does not always permit coating removal. Triangulation can be used to define the location of the indication as being on top of the structure.

SECTION IX
RADIATION PROTECTION

6.9 SCOPE AND PURPOSE.

a. This section is intended to serve as a guide toward the safe use of X-ray and sealed gamma-ray sources for industrial radiographic purposes. It provides guidance to persons who use these sources and to others who may have a responsibility for their use. It recommends operational procedures, personnel controls and radiation protection practices to eliminate needless exposure of personnel to ionizing radiation. In addition, it provides criteria for the guidance of qualified personnel for the design or modification of industrial radiographic X-ray and sealed gamma-ray installations.

b. The word “shall” identifies requirements that are necessary to meet the standards of protection of this section. The word “should” indicates advisory recommendations that are to be applied when practicable.

c. The provisions of this section incorporate provisions of Title 10, Code of Federal Regulations, Parts 19-21, and 34, for the Air Force, AFI 48-125 and miscellaneous policy statements, and for the Army, AR 40-5, AR 40-14, and AR 385-11. Although the provisions incorporated herein are correct at the time of issuance, users should review these federal, Air Force and Army regulations periodically to assure compliance with current regulations. This section is based in part on recommendations contained in National Institute of Standards and Technology (NIST) (formerly National Bureau of Standards) Handbook 114, General safety Standard for Installations Using Non-Medical X-ray and Sealed Gamma Source, Energies up to 10 MeV, and in National Council on Radiation Protection and Measurement (NCRP) Report No. 116, Limitation of Exposure to Ionizing Radiation, and Report No. 51, Radiation Protection Design Guidelines for 0.1-100 MeV Particle Accelerator Facilities. Exposure limits specified herein and in AR 40-14 are derived from those specified in federal regulations, particularly Title 10, Code of Federal Regulations, (10 CFR) Part 20. In the event of conflict, the more restrictive limits apply; thus, as used herein, limits/standards specified in AR 40-14 should be interpreted to read “standards specified in AR 40-14 or applicable federal regulations”.

6.9.1 Responsibilities (Air Force/Navy).

6.9.1.1 Base Radiation Safety Officer.

a. The Base Radiation Safety Officer (RSO) is responsible for initiation, supervision and execution of the base radiation protection program. This program provides for routine health physics surveillance of all operations involving the use of ionizing radiation to insure safe practices. Consultant services of qualified individuals are available at the following locations to assist the Base RSO with the radiation protection program:

(1) CONUS: AFIERA/SDRH
2402 E. Drive
Brooks AFB, TX 78235-5114
DSN 240-3486
Commercial (210) 536-3486

(2) USAFE: 601 Med Sq/SGB
Unit 4095, Box 25
APO AE 09136-9525 (Sembach AB, Germany)

(3) PACAF: Det 3 AL (AFMC)
Unit 5213
APO AP 96368-5213 (Kadena AB, Japan)

b. Assist to develop and annually review operating instructions for radiation safety during NDI operations.

c. Provide ALARA training in accordance with 10CFR19 and 29CFR1910.

d. Annually assess exposures in controlled and uncontrolled areas (ref. 6.9.8).

e. Assist in any investigations of overexposures, abnormal exposures or incidents involving radiation exposures resulting from NDI operations.

f. Assure contract radiography services are conducted in accordance applicable state and federal regulations, and the requirement of this technical order (ref. 6.9.4.1).

g. Establish appropriate action levels for personnel dosimetry results, such that if this level is exceeded an investigation will result to assess the cause and minimize future occurrences.

6.9.1.2 Maintenance Supervisor.

The Maintenance Supervisor is responsible for the Nondestructive Inspection Laboratory, Industrial Radiography Section, and its radiation protection program. He will insure that the requirements of this publication are fulfilled.

6.9.1.3 NDI Laboratory Supervisor.

The NDI Laboratory Supervisor will normally be delegated the responsibility for administering all industrial radiography operations and insuring compliance with all aspects of the radiation protection program. He will:

a. Maintain control of all industrial radiographic equipment.

b. Develop and maintain current radiological safety operating and emergency procedures approved by the base Radiation Safety Officer (RSO). Emergency procedures SHALL specify but not be limited to the following.

   (1) Individuals to contact in the event of a suspected overexposure: as a minimum, the NDI supervisor, Base RSO (Bioenvironmental Engineer) and Unit Safety Officer/NCO.

   (2) Forms to be completed (e.g., AF Form 190, AFTO 125).

   (3) Where to take the individual for treatment/observation.

   (4) How to approximate the degree of exposure.

   (5) What to do with personnel/pocket dosimeters.

c. Maintain a copy of the radiological safety operating and emergency procedures with the radiation producing equipment during all radiographic operations.

d. Establish and maintain a personnel-monitoring program in conjunction with the base Radiation Safety Officer, unless exempted by the base RSO.

e. Procure and maintain adequate radiation survey instruments and establish a survey instrument calibration program.

f. Maintain exposure devices, radiography facilities and associated equipment.

g. Maintain, as a minimum, two bound utilization logs; one for shielded areas and the other for unshielded areas. The unshielded log shall be subdivided to clearly identify each unshielded area and include its own set of utilization forms (AFTO Form 115 and AFTO Form 125).

h. Assume control and institute corrective actions in emergency situations.

i. Investigate the cause of accidents and determine necessary preventive action.

j. Determine the competency of industrial radiographers.

k. Assure compliance with the requirements of 10CFR34 when conducting radiography operations using sealed sources.

6.9.2 Responsibilities (Army).

6.9.2.1 Commander.

The Commander of each organization/installation using radiation sources or X-ray machines for industrial radiography shall:

a. Establish, in writing, a formal radiation safety program consistent with Federal and Army regulations and with Status of Forces Agreements and assure adequate resources (personnel, materiel and funding) are provided to implement and maintain an effective program (paragraph 1-20, AR 385-11). This program will include a comprehensive standing operating procedure to provide personnel with clear and specific requirements and actions to assure that no person, to include members of the public, receives a dose equivalent in excess of the radiation exposure standards specified in AR 40-14 and that radiation exposures are maintained "As Low As Reasonably Achievable" (ALARA). Special consideration must be given to the potential impact on adjacent operations including those operations conducted near boundaries of military control or in leased facilities.

b. Implement and enforce compliance with the provisions incorporated herein (paragraph 9-9a(2)(a), AR 40-5).

c. Appoint a qualified Radiation Safety Officer (RSO) and Alternate to perform those functions specified in AR 40-5, AR 40-14, and AR 385 11, and 10 CFR (paragraph 9-4b, AR 40-5). The authority of the RSO to immediately halt unsafe operations and his direct access to the Commander shall be clearly stated. The training and experience of the Radiation Safety Officer will be commensurate with the hazards and will include a basic understanding of radiation protection principles and practices. As a minimum, the formal training of the Radiation Safety Officer will be successful completion of the Radiological Safety Course presented by the US Army Chemical School or its equivalent. (Training required for a RSO to serve as the Radiation Safety Officer for radiography sources licensed by the NRC may be much more comprehensive). (Equivalency will be determined by ATCOM, ATTN: AMSAT-R-X, 4300 Goodfellow Blvd., St. Louis, MO 63120-1798 pursuant to paragraph 1-5a(1), AR 385-11 or by the MAJCOM Radiation Control Officer). Organizationally, the RSO must be in a position to effectively advise the commander and radiography personnel on matters of radiation protection. Generally it is not desirable that the RSO be an operator, supervisor of operators, or under the supervision of such individuals. To provide continuity of operation, an alternate Radiation Safety officer shall also be appointed. Minimum training of Alternate RSOs shall be the same as for the RSO. (Personnel from other services or MAJCOMs such as Health Physicists, Health Physics Technicians, USAF Bioenvironmental Engineers or 4B071's (SEI 492), can, pursuant to Memorandums of Understanding or Interservice Support Agreements, be authorized to provide radiation safety support for Army units).

d. Implement a radiation dosimetry program in accordance with AR 40-14. As an integral part of the dosimetry program an individual must be designated, in writing, to serve as the done record custodian to be responsible for preparing and maintaining the records of occupational exposure to ionizing radiation.

e. Appoint a Radiation Control Committee (RCC) and institute administrative procedures for its operations. (Pursuant to AR 40-14, an RCC is required for all operations such as portable X-rays for which radiation exposures are sufficiently high so as to mandate the dosimetry use).

f. Assure review and approval of plans and specifications for construction of new X-ray facilities or modification of existing X-ray facilities by a qualified expert prior to construction/modification. (NRC licensees must also assure prior NRC approval of all construction and modification activities) Upon completion of construction/modification assure that a comprehensive radiation safety survey is accomplished by a qualified expert prior to operation of the facility (paragraph 9-9b(10) and (11), AR 40-5 and paragraph 1-20e, AR 385-11).

g. Assure that procedures to be followed when an accident or incident occurs are defined, that individuals are designated (in writing) to receive notice in the event of emergencies and that radiation accidents and incidents are reported as specified by AR 385-40 and 10 CFR.

h. Assure that only qualified individuals operate radiography equipment. A qualified individual is one who has completed training to qualify for Additional Skill Identifier "N2" and has demonstrated competence to use radiography and related equipment to include radiation survey instruments. Further, assure that operators perform "daily preoperational, operational and postoperational checks or surveys to ensure proper radiation safety" (paragraph 9, AR 40-5).

i. Assure that health and safety instrumentation is calibrated in accordance with AR 750-43, TB 43-180, TB 750-25 and TB 9-6665-285, and 10 CFR. (X-ray survey instruments are only calibrated by US Army TMDE Activity, ATTN: AMXTM-SR, Redstone Arsenal, AL 35898-5400, DSN: 746-7666) (Paragraph 9-8, AR 40-5).

j. Perform, and document in writing, an annual quality assurance audit/self-assessment of the organization's Radiation Protection Program. (Quality audit checklist is available upon request from Commander, ATCOM, ATTN: AMSAT-R-X, 4300 Goodfellow Blvd., St. Louis, MO 63120-1798.)

k. Designate in writing, a qualified radiographer, generally the OIC or NCOIC, to serve as "Radiography Supervisor" supervising overall industrial radiography operations and assuring compliance with all aspects of the radiation protection program.

l. Assure that radiography operations are not conducted on non-Army property without verification that such operation is properly licensed by and in full compliance with applicable state and local regulations and laws.

m. Consultant services of qualified individuals are available from the respective MAJCOM Headquarters and from the following to assist with the Radiation Protection Program:

(1) US Army Aviation and Troop Command
ATTN: AMSAT-R-X
4300 Goodfellow Blvd.
St. Louis, MO 63120-1798
Commercial (314) 263-2196; DSN 693-2196

(2) US Army Center for Health Promotion and Preventive Medicine
ATTN: MCHB-MR-HI
Aberdeen Proving Ground, MD 21010
Commercial (910) 671 3502; DSN 584-3502

6.9.2.2 Radiation Control Committee (RCC).

The Radiation Control Committee shall perform functions outlined in AR 40-5, AR 40-14, AR 385-11, and any applicable NRC license.

6.9.2.3 Radiation Safety Officer (RSO).

The Radiation Safety Officer shall establish and manage the radiation protection program. Specific duties of the RSO, as defined in AR 405, AR 40-14 and AR 385-11, include (but are not limited to):

a. Provide advice and assistance to the Commander in formulating policies, programs and procedures pertaining to radiation protection that complies with applicable regulations and directives. Advise the Commander in writing of any unsafe practices, defects, or noncompliance’s under 10 CFR 21.

b. Evaluate and document hazards. "Radiation protection surveys will be performed periodically by the RSO to determine the exposure or exposure rate in the environment during operation of the equipment" as necessary to evaluate and control the potential radiation hazard. This evaluation includes physical measurements or calculations of radiation levels present a prediction of potential hazards resulting from changes in materials or operations and proposed corrective actions. (Surveys must be accomplished by a health physicist or Nuclear Medicine Science Officer before placing equipment in routine operation for all new or modified industrial radiographic operations.) Consistent with NRC quality audit criteria, surveys shall be accomplished at least annually by the local RSO in conjunction with audit of the local radiation safety program. Care must be taken to assure that radiation levels are adequately controlled in areas such as roofs, and in rooms and outdoor areas adjacent to the X-ray operations.

c. Develop emergency procedures and assure that all actual or alleged overexposures to ionizing radiation are investigated and reported in accordance with AR 385-40 and 10 CFR 20.

d. Calculate the collective exposure to ionizing radiation of all persons for which a DD Form 1141 (or equivalent) is maintained and report quarterly to the radiation control committee and commander, as applicable, on the collective, average, and highest exposure.

e. Instruct personnel in safe working practices, emergency procedures, harmful effects of radiation overexposures, and other topics as mandated by 10 CFR 19 and 29 CFR 1910. Records of these instructions will be maintained by the RSO and will include a brief outline of the instructions and a list of persons who received these instructions.

f. Establish and maintain a personnel dosimetry program in accordance with AR 40-14 to include obtaining personnel exposure histories and providing personnel with reports of radiation exposures as required.

g. Assign administrative radiation doses.

h. Manage DA Radiation Permit program (AR 385-11; 32 CFR 655).

6.9.2.4 Radiography Supervisor.

This individual shall supervise overall industrial radiography operations and assure compliance with all aspects of the radiation protection program. He shall:

a. Control and maintain all industrial radiographic equipment to include assuring that the X-ray tube head, cables, and consoles and gamma radiography shielding and shutters (and the associated safety equipment for each) are checked for obvious defects prior to the first use at the beginning of each shift.

b. Develop and maintain current radiological safety operating and emergency procedures approved by the Radiation Safety Officer and Commander. Safety procedures will specifically address checklists for periodic inspection and reliability testing of safety systems to include interlocks, audible and visual warning devices, use of radiation monitoring equipment and "daily pre-operational, operational and post-operational checks or surveys to ensure proper radiation safety" (paragraph 9-9, AR 40-5). Emergency procedures must include but are not limited to the following:

   (1) Individuals to contact in the event overexposure. Include name, office symbol, telephone number (duty and nonduty hours), duty title.

   (2) Notifications required by 10 CFR and/or AR 385-40 and accident incident forma to be completed pursuant to AR 385-40, as supplemented.

   (3) Where to take the individual for treatment.

   (4) How to approximate the degree of exposure.

   (5) What to do with dosimetry devices.

   (6) A copy of the radiation safety operating and emergency procedures must be maintained with radiation producing equipment during all radiographic operations. These procedures must assure that required warning signs and notices are properly posted and that warning signals (beacon lights and audible alarms) and safety switches are functioning properly (paragraph 9-9a(2)(d), AR 40-5).

c. Establish and maintain personnel monitoring program in conjunction with the Radiation Safety Officer and assure proper use and storage of personnel monitoring devices.

d. Assure the availability, calibration, and proper maintenance of radiation survey instrumental.

e. Maintain utilization logs. Assure that detailed procedures are implemented for maintaining an operational log for each piece of equipment that will identify when interlocks and other control or warning devices are bypassed or overridden (paragraph 9-9(b) 5, AR 40-5).

f. Assume control and institute corrective actions in emergency.

g. Investigate, in coordination with the Radiation Safety Officer, the cause of accidental and incidents to include suspected overexposures and unnecessary radiation exposures and determine necessary action to prevent recurrence of accidents and incidents and maintain all radiation exposures "As Low As Reasonably Achievable" (AR 385-40 and AR 40-14).

h. Verify the competency of industrial radiographers to include assuring that only qualified 68D personnel with ASI "N2" perform X-ray operation or use X-ray equipment and that only individuals authorized by the applicable NRC license use gamma radiography sources.

i. Assure that all radiation workers are subjected to medical surveillance in accordance with AR 40-14.

6.9.3 Qualifications of Industrial Radiographers.

MIL-STD-410, *Nondestructive Testing Personnel Qualification and Certification*, as amended, defines minimum qualifications for radiography personnel (including recertification requirements).

6.9.3.1 X-Ray Sources.

All industrial radiographers must complete the approved course of instruction in the use of industrial X-ray equipment, including radiation hazards control, and demonstrate an understanding of acceptable practice.

6.9.3.1.1 Initial Training.

As a minimum, each radiographer must be instructed in those portions of the following subjects that apply to X radiation and shall demonstrate understanding thereof.

A. Fundamentals of radiation safety
    1. Characteristics of X and gamma radiation
        a) Electromagnetic spectrum
        b) Properties of X and gamma rays
    2. Interaction of radiation with matter
        a) Ionization
        b) Photoelectric effect
        c) Compton effect
        d) Pair production
    3. Attenuation of radiation
        a) Exponential function
        b) Half-value layer (HVL) and tenth-value layer (TVL)
        c) Filtration
        d) Shielding
    4. Inverse square law
    5. Radiation scattering
        a) Secondary
        b) Sky shine
    6. Units of radiation measurement
        a) Roentgen

      - b) rad, rem, RBE
      - c) Gray (Gy), 1 Gy = 100 rad; Sievert (Sv), 1 Sv = 100 rem
      - d) Exposure rate and dose rate
   - 7. Quantity of radiation
      - a) Curie, Becquerel; 1 curie (Ci) = 3.7 x 10^{10} Becquerel (Bq)
- B. Hazard of exposure to radiation
   - 1. Naturally occurring radiation
   - 2. Biological effects
      - a) Mechanism of tissue damage
      - b) Variables influencing radiation doses
      - c) Somatic and genetic effects
      - d) Occupational dose limits
      - e) Non-occupational/public exposure limits
- C. Records of radiation exposure
   - 1. Prior exposure history
   - 2. Reports of radiation exposures
- D. Radiation measurement
   - 1. Principles of radiation measurement
      - a) Energy dependence
      - b) Response time
      - c) Ionization chamber instruments
      - d) Geiger-Mueller instruments
   - 2. Personnel dosimetry
      - a) Use of TLD (or film) badges
      - b) Pocket dosimeters
      - c) Alarm devices/rate meters
   - 3. Area survey meters
      - a) Differences between types of meters
      - b) Operation, calibration
      - c) Capabilities and limitations
      - d) Survey techniques
- E. Radiation Protection
   - 1. Control of radiation dose
      - a) Dose rate factors (X-ray and/or gamma ray)
      - b) Exposure time
      - c) Exposure distance
      - d) Shielding
   - 2. Safety equipment for unshielded operations
   - 3. Safety equipment for shielded operations
- F. Practical application requirements
   - 1. Radiographic equipment to be used
   - 2. Radiation exposure in shielded operations
      - a) Accidental exposure
      - b) Beam orientation
      - c) Location of operating controls
      - d) Checkout of safety devices
   - 3. Radiation exposure in unshielded operations
      - a) High (and very high) radiation areas
      - b) Placement of barriers
      - c) Measurement of exposure rates
- G. Inspection and maintenance performed by radiographers
   - 1. Interlocks
   - 2. Warning devices
   - 3. Radiography equipment/facilities

H. Emergency procedures
I. Case histories of radiography accidents
J. Regulations
    1. Applicable military service
    2. Federal
    3. State
    4. Local

6.9.3.1.1.1 Air Force.

Qualifications may be through the USAF Nondestructive Inspection Course conducted by the Air Education and Training Command at NAS Pensacola, FL, or through equivalent training courses conducted by industry or civilian institutions. For this training to be, considered equivalent to that provided by the Air Training Command NDI Course, approval by the Air Force NDI Office (AFRL/MLS-OL, 4750 Staff Dr., Tinker AFB, OK 73145-3317; DSN 339-4931) is required. The use of any radiation producing equipment is prohibited until written approval of equivalency is received by requester.

6.9.3.1.1.2 Army.

Qualifications may be through the USAF Nondestructive Inspection Course conducted by the Air Education and Training Command at NAS Pensacola, FL, the U.S. Navy Radiographic Operator Course (A-701-0032) or through equivalent training courses conducted by industry or civilian institutions. To be considered equivalent to training mandated for American Society of Nondestructive Testing for the Industrial Radiography Radiation Safety Personnel (IRRSP) Certification Program, the initial training shall include 40 hours of training in radiation safety topics which includes those topics listed in Appendix A of 10 CFR 34. Equivalency must be reviewed and approved by TRADOC or the Army NDI Program Manager (Weapon System Manager for Aviation Ground Support Equipment) ATTN: AMSAT-I-WAG, 4300 Goodfellow Blvd., St. Louis, MO 63120-1798. The use of any radiation producing equipment is prohibited until written approval of equivalency is received by requester.

6.9.3.1.2 Retraining (Army).

Each radiographer must also receive retraining each time there is a change in equipment, operating procedures or regulations and annual retraining. Annual retraining of at least eight hours duration (FR Vol. 56, No. 53, page 11505) shall be conducted or arranged by the RSO or his designated representative and documented. This training must include the following:

a. Topics specified in 10 CFR 19.12 (including proper storage, transfer and use of radiation sources; public health problems associated with use of the radiation sources; precautions or procedures to minimize radiation exposure and the purposes and functions of protective devices employed; the responsibility to promptly report any condition which may lead to unnecessary radiation exposure; actions to take in the event of malfunction of protective devices or other emergency conditions; and exposure reports which workers may request).

b. Deficiencies identified during periodic quality audits of the radiation protection program and unit training inspections.

c. Review of accidents and unusual events.

d. Review of dosimetry results (emphasizing dose reduction and ALARA).

e. Review of basic radiation safety principles, operations, emergency procedures, new safety regulations, license requirements and other pertinent information.

6.9.3.1.3 Documentation.

6.9.3.1.3.1 Air Force.
Job qualification/proficiency shall be documented per command policy and filed in the individual's AF Form 623, On-the-job Training Record Folder.

6.9.3.1.3.2 Army.
MOS qualification shall be documented in accordance with Army Regulations.

6.9.3.2 Sealed Gamma Ray Sources.
Sealed sources used in radiography usually contain multi-curie quantities of gamma emitting radioactive material and are extremely hazardous if not used properly. Therefore, each radiographer and radiographer's assistant must meet minimum training and experience requirements. A thorough understanding of the hazards and proper procedures for safe handling and use of radiography sources is a fundamental requirement for any individual who is to assume the duties and responsibilities of a radiographer.

6.9.3.2.1
Title 10, Code of Federal Regulations, Part 34 (10 CFR 34) limits assignment of the duties of radiographer or radiographer's assistant to individuals who meet the requirements for those positions set forth in paragraph 34.31. Records of training, including copies of written tests dates of oral tests and field examinations, which are used to qualify individuals to act as a radiographer or radiographer's assistant shall be maintained for a minimum period of three years (by the licensee).

6.9.3.2.2
Specific training is mandated in 10 CFR 19 for personnel who are occupationally exposed to radiation. Additional training requirements are mandated by 10 CFR 34.31 for radiographers. Licensees shall NOT permit any person to act as a radiographer until such individual:

a. Is adequately trained in radiation safety. Each industrial radiographer will be encouraged to obtain certification in radiation safety through the Certification Program for Industrial Radiography Radiation Safety Personnel of the American Society for Nondestructive Testing, Inc. prior to commencing duties as radiographers (10 CFR 34.11(b)(5)). As a minimum, each radiographer must have been instructed in the subjects outlined in Appendix A, 10 CFR 34 and shall have demonstrated understanding thereof.

b. Has received copies of and instructions specified in 1) NRC regulations contained in 10 CFR 34 and in the applicable portions of 10 CFR 19 and 20, 2) NRC license(s) under which the radiographer will perform radiography, and 3) the licensee’s operating and emergency procedures.

c. Has demonstrated competence to use the licensee's radiographic exposure devices, sealed sources, related handling tools, and survey instruments.

d. Has demonstrated understanding of the instructions contained herein by successful completion of a written test and a field examination on the subjects covered.

e. Has completed periodic training mandated by 10 CFR 34.11(b)(2) and (3) and 34.

6.9.3.2.3
Radiographers' assistants are individuals who, under the personal supervision of a radiographer, use radiographic exposure devices, sealed sources or related handling tools, or radiation survey instruments in radiography (10 CFR 34.2). Within the Army, radiographer's assistants will generally be limited to personnel undergoing training through a TRADOC approved course of instruction. In accordance with 10 CFR 34.11(b)(6), licensees shall NOT permit any person to act as a radiographer's assistant until such individual:

a. Has received copies of and instructions in the licensee's operating and field emergency procedures, and shall have demonstrated understanding thereof.

b. Has demonstrated competence to use, under the personal supervision of the radiographer, the radiographic exposure devices, sealed sources, related handling tools and radiation survey instrument which will be employed in his assignment.

c. Has demonstrated understanding of the instructions contained herein by successfully completing a written or oral test and a field examination on the subjects covered.

d. Has demonstrated his understanding of and ability to comply with the operating and emergency procedures by successful completion of appropriate test (s) and a field examination on the subjects covered.

6.9.3.2.4
Each unit must maintain an internal training inspection program. In accordance with 10 CFR 34 this program must:

a. Include observation of the performance of each radiographer and radiographer's assistant during an actual radiographic operation at intervals not to exceed three months.

b. Provide that, if a radiographer or a radiographer's assistant has not participated in a radiographic operation for more than three months since the last training inspection, that individual's performance must be observed and recorded the next time the individual participates in a radiographic operation.

c. Retaining for three years the training inspection records of the performance of radiographers and radiographers' assistants (for inspection by the U.S. Nuclear Regulatory Commission).

6.9.4 Possession and Use of Gamma Ray Sources.

6.9.4.1 Air Force.

a. Air Force activities SHALL NOT obtain, possess, or use radioactive material sources until they have received a USAF Radioactive Material Permit in accordance with AFI 40-201, Managing Radioactive Materials in the USAF. Application should be made through the base RSO channels to HQ AFMOA/ SGOR, Brooks AFB, TX 78235-5217.

b. Approval by the Base Radiation Safety Officer is required for contractor personnel to use radioactive materials on any Air Force installation. The base Radiation Safety Officer SHALL be consulted for current procedures for obtaining that approval. Additionally, in cases where contractor requests assistance in performing gamma radiation inspections under his license, the NDI lab chief, or assistant in his/her absence, SHALL contact the base Radiation Safety Officer to insure proper authorization has been granted and proper procedures are followed.

6.9.4.2 Army.

a. Army activities shall NOT procure or use gamma sources (by-product material) until formally licensed to do so by the U.S. Nuclear Regulatory Commission (NRC). Application for NRC licenses is made by the Radiation Safety Officer in accordance with AR 385-11 through Command channels.

b. In cases where a contractor requests approval to perform X-ray inspections or gamma radiography (under the contractor's NRC or agreement state license) on federal property, the local RSO will verify the validity of applicable licenses and initiate action pursuant to AR 385-11 and 32 CFR 655.10 to obtain and/or issue a DA Radiation Permit. (RSOs should assure also that reciprocity notification has been provided to the applicable NRC Regional Office if the contractor is an agreement state licensee.)

Although responsibility for safe use of sealed sources remains with the contractor pursuant to the contractor's license, RSOs must review operating procedures to verify compliance with applicable regulations and to assure that Army personnel and property are protected.

6.9.5 Radiation Safety Monitors.

Radiation safety monitors are qualified radiographers who work under the direct supervision of the radiographer in charge.

6.9.5.1 Training.

Radiation safety monitors for both X-ray and gamma-ray sources will receive training in the subject areas listed in 10 CFR 19 as well as training commensurate with their assigned duties to include applicable elements specified in paragraph 9-10d(1) therein.

6.9.5.2 Duties.

a. Operate radiation survey meters.

b. Establish location of radiation barriers.

c. Set up personnel barriers.

d. Prevent unauthorized personnel from entering a radiation area.

e. Record radiation intensity reading at barriers.

f. Record personnel pocket dosimeter reading.

g. Utilize dosimetry devices as specified by the Radiation Safety Officer.

h. Perform other duties as directed by the radiographer in charge.

6.9.6 Radiation Safety Monitor Assistants.

Radiation Safety Monitor Assistants are those persons who assist the radiographer and/or the Radiation Safety Monitor in preventing unauthorized access into radiographic inspection areas. Safety assistants are not authorized inside the radiation area during irradiation. Assistants will be stationed outside the radiation area but in such a location as to be able to monitor the barrier and to prevent barrier penetration. Assistants will at all times be in direct vision or contact with the safety monitor or radiographers to effect radiation termination if required. If this is not possible, adequate means of communication SHALL be specified by the local RSO during a survey of the radiographic inspection area and operation. Adequate means of communication may include, but need not be limited to, two-way radios, whistles, electronic/propellant activated noise alarms or ultrasonic/infrared intrusion barriers. Assistants will receive their instructions directly from the radiographer in charge or the Radiation Safety Monitor, but not from another assistant.

6.9.6.1 Training.

As mandated by 10 CFR 19, assistants shall receive, as a minimum, radiation safety training covering the following items: properties of X and gamma rays, hazards of excessive exposure to radiation, methods of measuring radiation, radiation protection, and operation of specific measurement devices that will be used. This training must be conducted by a qualified radiographer, Bioenvironmental Engineer or Radiation Safety Officer and documented in the individual's training record or the Maintenance Management Information Control System (MMICS). Refresher training SHALL be conducted annually.

6.9.6.2 Duties.

a. Operate radiation survey meters.

b. Assist with setting up personnel barriers.

c. Prevent unauthorized personnel from entering a radiation area.

d. Wear a TLD or film badge only if specified by the Radiation Safety Officer.

6.9.7 Radiation Protection Surveys.

6.9.7.1 Definition.
As used in this section, radiation protection survey means an evaluation of potential radiation hazards associated with the use of industrial X-ray and gamma-ray equipment under specified conditions when used in shielded and/or unshielded for Air Force installations, or protective, enclosed and/or unshielded location for the Army. When appropriate, such evaluation includes inspection of equipment, examination of its location with reference to controlled and uncontrolled areas in the immediate environment, and measurements of exposure levels.

6.9.7.2 Shielded Installations.
A radiation protection survey of all new shielded X-ray installations, or new equipment in existing installations, shall be made by a fully qualified health physicist, Bioenvironmental Engineer, Nuclear Medicine Science Officer or qualified radiological health technician before the installation is placed into routine operation. The installation SHALL be inspected to verify adequacy of shielding, radiation protective devices and operational procedures.

6.9.7.2.1
Consultant services of qualified health physicists can be obtained through command channels: Air Force – from those organizations listed in paragraph 6.9.1.1a; Army -- from MAJCOM Headquarters or from those organizations listed in paragraph 6.9.2.1m. All such requests must contain the following radiological design criteria of the facility to be surveyed.

a. Projected workload in milliampere minutes (mA-min) per week.

b. Maximum X-ray tube potential (kVp).

c. Minimal distance from tube head to exterior wall(s), ceilings and floors.

d. Type of facility (shielded or unshielded).

e. The use factors for each wall, floor and ceiling as appropriate. This is the fraction of the workload during which the useful beam is pointed in the direction under consideration.

f. A diagram, showing the functions of all adjacent areas to the x-ray operation location.

6.9.7.2.2
An assessment of shielded installations shall be made by or under the direction of the local Radiation Safety Officer annually or before changes are made in shielding, operation, workload, equipment ratings or occupancy of adjacent areas when these changes, in the opinion of the RSO, can adversely affect radiation protection. If supplementary shielding is installed as a result of the radiation protection survey or re-evaluation, another survey shall be made to confirm the adequacy of the shielding after the modification.

6.9.7.2.3
When surveying shielded installations, the radiation exposure measurements SHALL be made in all adjacent areas accessible to personnel. The measurements SHALL be made under facility design conditions of operation that will result in the greatest exposure at the point of interest. X-ray apparatus shall be operated at the maximum kilovoltage specified in the design criteria for the facility and at its maximum milliamperage for continuous operation at that voltage. High energy equipment (such as linear accelerators, betatrons, etc.) should be operated at maximum (roentgen) output.

6.9.7.2.4

In evaluating the results of the survey, consideration shall be given to actual operating conditions, including workload, use factor, occupancy factor and attenuation of the useful beam provided by objects permanently in the path of the useful beam.

NOTE

> Use of engineering design controls such as addition of shielding will take precedence over operational (administrative) controls.

6.9.7.2.5

Whenever, in the opinion of the RSO or the radiographer, there is a reasonable probability that a person in an uncontrolled area adjacent to any type of radiation installation may receive more than 2 mrem (20 µSv) in any one hour or 100 mrem (1 mSv) in any calendar year, then one or more of the following courses of action (whichever may be appropriate) shall he taken to ensure that no person will receive exposure in excess of the basic radiation protection standard:

a. Use personnel or area monitoring devices to estimate the exposure received by occupants of the area, applying appropriate occupancy factors for each assessed location (Air Force personnel must coordinate with AL/OEBD, Brooks AFB TX, 78235-5114, DSN 240-3486)

b. Add supplementary shielding to the protective barriers to insure conformity with protective barrier recommendations contained in this publication.

c. Restrict use of the equipment (workload (on-time), kVp or use factor).

d. Restrict occupancy of the area.

6.9.7.2.6

Radiation hazards found in the course of a survey of any type installation shall be eliminated before the installation is used routinely. If the design and/or approved use of a shielded installation depend upon restrictions on the use factor of any primary barrier, it must be verified that these restrictions are actually observed.

6.9.7.2.7

All interlocks, “ON-OFF” beam control mechanisms, safety and warning devices, remote monitoring systems, etc. shall be inspected for proper operation prior to initial operation on each shift when x-ray equipment will be used and subjected to detailed testing to assure proper operation at intervals not to exceed six months. A log initialed by the person making the inspection shall be maintained. Any malfunctioning devices shall be appropriately serviced prior to use and reinspected to verify proper operation.

6.9.7.3 Unshielded Installations.

A detailed radiation protection survey of all unshielded installations upon initial use or use with new equipment shall be made by a fully qualified health physicist, Bioenvironmental Engineer, Nuclear Medicine Science Officer or qualified radiological health technician. Unshielded installations shall be surveyed by radiographers during each subsequent operation. In addition, a radiation assessment shall be made by the RSO as an integral part of the annual quality assurance audit of the Radiation Protection Program. Assessments shall verify the adequacy of operating procedures, the presence and proper use of radiation warning signs and signals and other necessary equipment. Initial surveys must include radiation exposure measurements to establish or verify safe operating conditions as established by the applicable standard operating procedures.

6.9.7.4 Portable Equipment Set-Ups.

The radiographer shall assure that a comprehensive radiation protection survey is performed each time portable equipment is used in an unshielded area to insure that exposures are adequately controlled. He shall also survey radiation levels prior to re-entry into the radiation area to assure that the radiation source has ceased to function or has returned to its shielded position, as applicable.

6.9.7.5 Report of Radiation Protection Survey.

No existing installation shall be assumed to conform to the provisions of this publication unless a valid radiation protection survey has been made by a qualified expert and a report has been placed on file at the installation.

6.9.8 Distribution and Retention.

6.9.8.1 Army.

The written survey report of new or modified fixed radiography facilities shall be forwarded by the individual conducting the survey through command channels to the owning organization with an information copy to the Commander, ATCOM, ATTN: AMSAT-R-X, 4300 Goodfellow Blvd., St. Louis, MO 631201798. A statement of corrective action(s) taken by the owning organization, if required, should be submitted to the MAJCOM Safety Office with information copy to Commander, ATCOM, ATTN: AMSAT-R-X, 4300 Goodfellow Blvd., St. Louis, MO 63120-1798. Survey reports shall include recommendations for any corrective measures and should indicate if a further survey is necessary after corrections have been made.

6.9.8.1.1

Survey reports for fixed radiography facilities shall be retained by the Radiation Safety Officer and the organization performing industrial radiography (together with a record of corrective actions taken to address deficiencies) until such reports are superseded or radiography operations are permanently discontinued. All records of surveys performed (including those performed by radiographers and RSOs) shall be maintained for a minimum period of three years (10 CFR 34. 32(b)).

6.9.8.1.2 Air Force.

The written survey report (with attachments) SHALL be forwarded by the individual conducting the survey to the organization surveyed with an information copy to the Air Force NDI Office, AFRL/MLS-OL, 4750 Staff Dr., Tinker AFB, OK 73145-3317; DSN 339-4931. Should the survey be performed by an organization other than the AL/OEBZ, 2402 E. Drive, Brooks AFB TX 78235-5114, a copy of the survey report shall be submitted to them for review. A statement of corrective action(s) taken, if required, should be submitted by the NDI function to the organization that performed the survey with information copies to the MAJCOM, Base Bioenvironmental Engineer(s) and AL/OEBZ. The report shall include recommendations for any corrective measures and should indicate if a further survey is necessary after corrections have been made.

6.9.8.1.2.1

Reports of all radiation protection surveys shall be retained by the local Bioenvironmental Engineering Services and the NDI function together with a record of the actions taken with respect to the recommendations the survey contains.

6.9.8.2 Contents.

a. Identification of the radiation source(s), and location of each by suitable means, e.g., serial number, room number, or building number or name.

b. The radiation output of the radiographic device (The radiation output of the device will be the level specified by the manufacturer or obtained from remote survey readings. Unnecessary radiation exposure will not be incurred to obtain such information.):

   (1) X-ray source -- in roentgens per minute (R/min) at one meter at maximum kVp and mA (under shielding conditions indicative of normal operation). The potential and current at which the X-ray tube was operated during the test will be specified if less than the system operating limits.

   (2) Gamma-ray source -- in roentgens per hour (R/hr) at one meter or specific activity remaining (curies or Becquerel) and calibration date.

c. Identification of the radiation survey instruments used including its serial number and the date calibrated.

d. The location of the source and the orientation of the useful beam with relation to each exposure measurement.

e. Exposure rates in all adjacent areas accessible to personnel. The location of exposure rate measurements shall be in accordance with applicable criteria and shall be suitably identified by drawings when appropriate.

f. An assessment of whether the measured exposure rates will result in uncontrolled areas have a total exposure of greater than 2 mR in any one hour, or greater than 100 mR in a year, using the expected workloads, use factors and occupancy factors for the facility.

g. A description of the existing mechanical and electrical limiting devices and safety devices that restrict the orientation of the useful beam and position of the source or otherwise support radiation protection efforts.

h. A statement indicating the appropriate classification of the installation (shielded or unshielded) and the radiological design criteria for which it was designed, if available.

i. A statement of what controls are required if exposures are estimated to exceed >100 mR/year or 2 mR in any one hour in uncontrolled areas. Engineering controls (e.g. additional shielding, physical barriers, etc.) should always take precedence over administrative controls (e.g. restrictions on workload).

j. Identification of the individual conducting the survey to include parent organization (plus the MOS or GS series for Army), and the date the survey was accomplished.

k. A statement of facility compliance/non-compliance with the following directives.

    (1) If an installation is found not to comply with this publication, it SHALL be stated what action must be taken to insure compliance.

    (2) If a resurvey will be required, it SHALL be so stated. The time frame as to when the resurvey is required and whether or not operations shall be permitted prior to the resurvey shall be included.

6.9.9 Exposure to Radiation.

6.9.9.1 Keeping Exposures "As Low As Reasonably Achievable" (ALARA).
Exposure to radiation, even at very low dose rates, is permissible only when the benefit derived from such exposure exceeds the risk incurred. Each individual shall strive at all times to maintain all radiation exposures "As Low As Reasonably Achievable". No individual shall ever knowingly expose himself or cause others to be unnecessarily exposed to radiation.

6.9.9.2 Occupational Dose Limits.

6.9.9.2.1 Dose Limits for Occupationally Exposed Adults.
The annual peacetime ionizing radiation dose received by occupationally exposed adults shall not exceed the following limits:

a. An annual limit, which is the more limiting of –

    (1) The total effective dose equivalent (TEDE) of 5 rems (50 millisieverts (mSv)); or

(2) The sum of the deep dose equivalent from external sources and the committed dose equivalent to any individual organ or tissue, other than the lens of the eye, of 50 rems (500 mSv).

b. The annual limits to the lens of the eye, to the skin, and to the extremities, which are –

(1) An eye-lens dose equivalent of 15 rems (150 mSv); and

(2) A shallow-dose equivalent to the skin or to any extremity of 50 rems (500 mSv).

6.9.9.2.2 Dose Limit for Minors.
The annual occupational dose limits for minors (less than 18 years of age) are 10 percent of the annual occupational dose limits specified for adults.

6.9.9.2.3 Embryo/Fetus Dose Limits.

6.9.9.2.4 Air Force:
The radiation dose to the embryo/fetus of an occupationally exposed pregnant female shall not exceed 0.5 rem (5 mSv) for the entire pregnancy. Additionally, efforts should be made to maintain the exposures ALARA and relatively uniform that is, free of substantial dose rate variations above monthly exposure rates. See AFI 48-125 for details.

6.9.9.2.5 Army:
The radiation dose to the embryo/fetus of and occupationally exposed pregnant female shall not exceed 0.5 rem (5 mSv) for the entire pregnancy. Additionally, efforts should be made to maintain the exposures ALARA and relatively uniform that is, free of substantial dose rate variations above monthly exposure rates. (Note: A formal declaration of pregnancy is the prerogative of each pregnant female. A female occupationally-exposed to radiation does not fall under the lower dose limit until she formally declares her pregnancy in a written statement, "I hereby make notification that I am occupationally exposed to radiation in the course of my normal job duties, and that I am now pregnant. My estimated date of conception is _______. I understand that by declaring my pregnancy, my occupational exposure to ionizing radiation will be controlled as prescribed by DA Pam 40-18." The declaration shall be made on a SF 600 (Health Record--Chronological Record of Medical Care), signed and dated by the woman and placed in the woman's health record. A copy shall also be provided to the RSO. (Note: If the dose to the embryo/fetus exceeds 0.5 rem (5 mSv) or is within 0.05 rems (0.5 mSv) of this dose at the time the woman declares the pregnancy to the RSO, the organization shall be considered in compliance with the limit prescribed above provided that any additional dose to the embryo/fetus does not exceed 0.05 rems (0.5 mSv) during the remainder of pregnancy.

6.9.9.3 Dose Limits for Individual Members of the Public.
The total effective dose equivalent to members of the public shall not exceed 100 mrem (1 mSv) in a year from all radiation sources under control of the installation activity commander. Additionally, the dose in any unrestricted area from external radiation sources such as industrial X-rays shall not exceed 2 mrem (20 microsieverts (µSv)) in any one hour.

6.9.9.4 Multiple Sources of Radiation.
When any individual is likely to be exposed to radiation from more than one source simultaneously, or at different times, the protection associated with each source shall be increased so that the total dose received by any one person from all sources shall NOT exceed applicable exposure limits. Additionally, total effective dose equivalent (TEDE) limits the sum of external and internal radiation exposure thus special consideration must be given to assure that the combination of internal and external exposure does not exceed limits.

6.9.9.5 Medical, Dental and The Raputic Radiation, And Naturally Occurring Sources of Radiation.
Radiation exposures resulting from necessary medical and dental diagnostic or therapeutic X-ray procedures shall NOT be included in the determination of the radiation exposure status of the individual concerned. Similarly, exposures resulting from naturally occurring sources or from sources in consumer products, shall NOT be included in determining

an individuals dose. Occupationally exposed personnel shall NOT wear their dosimetry devices while undergoing medical or dental X-ray procedures.

6.9.10 Measuring Exposures Rates: Ionization Chamber Type Survey Instruments.

6.9.10.1 Basic Operating Principle.

Radiation exposure is most accurately measured with ionization chamber type survey instruments. These detectors use an air filled chamber across which an electric field is applied. When X-ray or gamma radiation interacts with the air in the chamber, it creates positive and negative ions that drift apart under the influence of the electric field. As the ions are collected on the electrodes within the chamber, a small current is generated which is measured by the instrument and related directly to the radiation exposure rate in air.

6.9.10.2 Characteristics.

Radiation exposure measurement instrumentation must have a range suitable for the conditions of use. Accordingly, all survey instruments used for industrial radiography "shall have a range such that two milliroentgens per hour through one roentgen per hour can be measured" (10 CFR 34.24).

6.9.10.2.1

Portable survey instruments are affected by such factors as ambient temperature, configuration of radiation source (i.e., round, square, rectangular, etc.), isotope source, atmospheric pressure and relative humidity, direction of radiation beam, radiation quality (effective energy or radiation spectra), and instrument susceptibility to radio frequency (RF) radiation. Instrument response variations due to temperature and pressure usually do not exceed ±5% for survey instruments. Instrument directional dependence is negligible when the instrument's sensitive volume is pointed in the direction of the radiation origin. Instrument susceptibility to radiofrequency radiation (RFR) may significantly affect ionizing radiation measurements in the presence of RF radiation. If RF interference is suspected, it can often be confirmed by placing a piece of leaded (Pb) rubber or similar shielding material over the ionization chamber of the instrument to filter out the gamma or X-radiation, while observing the instrument reading. If no change is noticed in the reading when the lead is placed over the chamber, the reading obtained previously was due primarily to RF interference.

6.9.10.2.2

An X-ray machine operating at a given tube potential (kVp) produces a spectrum of X-ray energies. Since industrial X-ray machines do not contain primary beam filtration (except the X-ray tube window), the X-ray spectrum contains a relatively large portion of low energy X-rays (below 50 keV) regardless of the tube potential (kVp) setting employed. Therefore, it is important that the survey instrument used in determining the exposure rate produced by such X-ray machines be energy independent or, in other words, is capable of accurately measuring the exposure rate over a wide range of X-ray energies.

6.9.10.3 Recommended Instruments for Exposure Measurements.

CAUTION

Under no circumstances shall Geiger-Mueller (GM) tube type instruments such as the AN/PDR-27, AN/PDR-77, and ADM-300, and AN/VDR-2 be used during X-ray operations or X-ray radiation protection surveys. The response of GM-type instruments to the relatively low effective energies typical of X-ray operations is extremely variable. This extreme variability together with lack of adequate response to low X-ray energies could lead to serious personnel overexposures. For example, at 32 keV the AN/PDR-27 measures only 1% of the true exposure rate.

Table 6-22 lists several instruments that are suitable for measuring exposure rates resulting from NDI operations. The table differentiates between older instruments that have been used historically for this purpose, as well as newer instruments that make suitable replacements. Included with the table is the relative response of each instrument as a function of the x-ray or gamma ray energy being detected. The relative response is defined as the indicated exposure rate divided by the true exposure rate. A brief description of each type of instrument follows the Table 6-22.

Table 6-22. RECOMMENDED INSTRUMENTS FOR SURVEYS AND THEIR RELATIVE ENERGY RESPONSE.

	Relative Response					
Effective Energy (keV) →	22	32	70	120	170	663(a)
Older Instruments (no longer available)						
Victoreen Model 440 NSN 6665-00-938-6806	0.94	1.04	11.6	1.18	1.16	1.0
Heat Pipe Corp. Model VR-10 Cap Off NSN 6665-00-581-0220	1.06	1.16	1.03	1.0	1.03	0.82
Nuclear Research Corp. Model SM400 Cap Off NSN 6665-01-157-3780	1.00	1.05	1.08	1.08	1.07	0.96
External Probe Cap On	--	0.34	1.35	1.94	1.34	1.0
Internal Probe	--	0.01	2.22	2.1	2.0	1.0
New Instruments (currently available)						
Victoreen Model 450B Bottom Off Bottom Cap Off	0.93 0.58	0.98 0.80	1.06 1.12	1.08 1.12	1.05 1.06	- 0.93
Victoreen Model 450P Bottom oriented field	0.55	0.88	1.06	1.04	1.03	1.03
Victoreen Model RPO-50 Bottom Cap Off Bottom Cap On						
Instrument Suitable in RF Fields						
Victoreen 440 RF/D						

(a) **Note** that the 663 keV response was obtained from Cs-137, which is commonly used for calibration.

6.9.10.4 Descriptions and Operating Characteristics of Specific Instruments.

6.9.10.4.1 Common Instruments: Models 440, SM400 And VR-10 Survey Meters.

CAUTION

The VR-l0 survey meter may reflect a false reading when near an RF environment. reading is stray RF energy being generated by the X-ray control panel components and is not hazardous radiation. Caution should be exercised using this meter at this location; however, the aforementioned does not preclude its use.

The Victoreen Model 440, Nuclear Research Corporation SM400 and the Heat Pipe Model VR-10 survey meters have been standard instruments authorized for use in the Air Force in TA-455 for industrial radiography. These instruments are no longer available from the manufacturer. Suitable replacement instruments are listed in the above table and described briefly in the following section. When monitoring radiation fields with these instruments, their front caps SHALL be removed. The thin mylar cover at the end of the ionization chamber is easily punctured. If it is punctured, the instrument is inoperative and must be repaired.

a. The 440 (Table 6-22), SM-400 and the VR-10 are similar in size, appearance and specifications. All are authorized for use during NDI radiographic operations.

b. The dial of the meter is calibrated in mR/hr and measures X or gamma radiation up to 300 mR/hr. The instrument has 5 range selections: 0-3 mR/hr, 0-10 mR/hr, 0-30 mR/hr, 0-100 mR/hr, and 0-300 mR/hr.

c. The instruments are, for practical purposes, energy independent from 15 keV to 1.2 MeV with their front caps removed.

d. The batteries for the 440 and VR-10 consist of our "D" flashlight cells. Each instrument weighs approximately 5-1/2 pounds and its overall dimensions are 10″ long, 4″ wide and 7″ high. The SM 400 uses two "D" flashlight cells and weighs approximately 5 pounds. Its overall dimensions are 10″ long, 4.5″ wide and 7″ high.

e. When the selector switch is OFF, the batteries are disconnected and the meter is short-circuited, making the instrument inoperative. With the switch in the battery position the batteries are connected, permitting the operator to check the battery condition. Although instruments such as the 440 can accurately measure low levels of X-ray emissions and scattering, care must be exercised to assure that the upper limit is not exceeded.

f. The SM-400 end cap contains a lever-operated alpha/beta check source to verify instrument operation each time it is used.

6.9.10.4.2 Recommended New Instruments:

6.9.10.4.2.1 Victoreen Model 450P Survey Meter.

The Model 450P is a lightweight portable survey meter designed to measure X radiation above 25 keV. It has a five decade operating range from 0-500 µR/hr (0-5 µSv/hr) on the lowest scale to 0-5 R/hr (0-50 mSv/hr) on the highest scale and has a programmable "flash alarm" which causes the display to pulsate at a rate of once per second when the measured dose rate exceeds a preset limit. The detector is a 300-cc ionization chamber pressurized to 6 atmospheres. The Model 450P measures exposure, exposure rate, and can be used to "freeze" the maximum exposure rate encountered and displays results on an illuminated analog/digital display. For maximum sensitivity, the Model 450P survey meter should be perpendicular to the ground plane when making measurements rather than being parallel to the ground.

6.9.10.4.2.2 Victoreen Model 450B and 450-CHP Survey Meters.

The Model 450B and 450-CHP Survey Meters are similar instruments that detect gamma and X-ray radiation above 7 keV. Both have a five decade operating range measuring from 0-5mR/hr (0-50 µSv/hr) to 0-50 R/hr (0-0.5 Sv/hr). The detector for both instruments is a 349-cc air ionization chamber that has a 200-mg/cm^2 bakelight wall and a 1.7 mg/cm^2 mylar window. They operate continuously for about 200 hours on a set of two new 9-volt batteries. The Models 450B and 450 CHP should always be used with the cap off when measuring X-ray and gamma radiation with energies below 200 keV due to energy response variation.

6.9.10.4.2.3 Victoreen Model RPO-50 Survey Meter.

The Model RPO-50 Survey Meter is an excellent replacement for the older instruments listed in the above table. It has similar controls compared to the SM-400, and Victoreen 440, but has significantly improved performance characteristics. It detects gamma and x-ray radiation above 7 keV. The Model RPO-50 has four operating ranges, measuring from 0-5mR/hr (0-50 µSv/hr) to 0-5 R/hr (0-. 05 Sv/hr). The detector is a 349-cc air ionization chamber that has a 493-mg/cm^2 bakelight wall and a 3.5 mg/cm^2 window. It operates continuously for about 3000 hours on a set of four new 9-volt batteries. It is environmentally sealed and has limited RF shielding, permitting its use in demanding environments. The Model RPO-50 should always be used with the cap off when measuring X and gamma radiation with energies below 200 keV due to energy response variations.

6.9.10.4.3 Recommended Instruments for Use in RF Fields.

6.9.10.4.3.1 Victoreen Model 440RF-D Survey Meter.

The Model 440 RF/D Survey Meter is specially designed to be used in strong radiofrequency radiation fields up to 20 mW/cm^2. It detects gamma and X-ray radiation above 12 keV. The Model 440 RF/D has 5 operating ranges, measuring from 0-1 mR/hr (0-50 μSv/hr) to 0-100 mR/hr (0-5000 μSv/hr). The detector is a cylindrical 3.56-cm diameter, 10-cm2 cross-section air ionization chamber that has a 1.5 mg/cm^2 mylar window and a 13-mg/cm^2 magnesium window. It operates continuously for about 200 hours on a set of five new 9-volt batteries. The model 440 RF/D includes an internal check source to verify correct system operation. The instrument does have a significant variation in energy response, requiring the instrument reading to be corrected dependent on the kVp of the x-ray system being surveyed.

6.9.11 Calibration and Use of Radiation Survey Instruments.

6.9.11.1 Calibration.

Radiation survey meters used for X-radiography shall be calibrated as follows:

a. Air Force radiation survey meters shall be calibrated in accordance with T.O. 33K-1-100-2.

b. Army radiation survey meters shall be calibrated in accordance with T.B. 43-180.

c. Navy radiation survey meters shall be calibrated “not to exceed six months.”

Radiation survey meters used for source radiography shall be calibrated at intervals not to exceed three months. In addition, all meters shall be calibrated after each instrument servicing. A record shall be maintained of the results of each instrument for three years after the date of calibration (10 CFR 34.24).

6.9.11.1.1

The calibration of all radiation survey instruments shall be checked by the user with a radiation check source prior to the first monitoring operation of the day and at two-week intervals for instruments not in daily use as per its operational manual.

6.9.11.1.2 Additional Information.

a. Army. Consult AR 750-43 (Army Test Measurement and Diagnostic Equipment Program), TB 750-25 (TMDE Calibration and Repair Support Program) and TB 43-180 (Calibration and Repair Requirements for the Maintenance of Army Materiel) for detailed information on the calibration and repair programs. X-ray survey instrumentation can only be calibrated by the US Army TMDE Activity, ATTN: AMXTM-SR, Redstone Arsenal, AL 35898-5400, DSN: 746-7666. (To preclude unnecessary delays, instruments should be shipped direct without regard to local TMDE activities.)

b. Air Force: Reference T.O.’s 11H4-7-15-1 and 33K-1-100 for record keeping information.

6.9.11.2 Guidelines for Use.

Whenever radiographic operations are performed, at least one calibrated and operable radiation survey instrument shall be available at shielded installations and at least two operable radiation survey instruments shall be available at unshielded installations. The instrument(s) SHALL be turned ON and available for immediate use by the radiographer during all radiographic operations. The instrument(s) used SHALL have an adequate instrument response for the range of radiation energies encountered.

6.9.11.2.1

Survey meters are delicate instruments. It is essential that reasonable care be taken in their use to assure reliability. Most survey instruments are not waterproof. If it should rain when you are working outdoors a clear plastic bag will have no appreciable effect on the radiation and it will not hamper the operating of the control switches. If the components of the survey meter become wet, the instrument may have to be serviced and recalibrated. When survey meters are transported in vehicles they should be placed in the driver’s compartment with adequate support and restraint to prevent damage during transit.

6.9.11.2.2
Survey meters should be allowed to stabilize after first turning on for several minutes prior to first use. Further, survey meters do not instantly indicate the maximum exposure rate because of the response time of electrical components. Typically survey meters have a response time ranging from 2 to 15 seconds with longer response times being required for lower dose rates. (For the Victoreen Models 450B, and 450P the response time required to reach 90% of final value ranges from 2 to 8 seconds and from 1.8 to 5 seconds respectively.) Thus when using the survey meter the operator must hold the meter in a set position for a period of time longer than the specified response time in order to accurately measure the actual dose rate present. Survey meter response times are published in the instrument instruction manual.

6.9.11.2.3
If a battery indicator is located on the survey meter it shall be checked each time the instrument is turned on. Some survey meters do not have a battery indicator. However, if the instrument can be zeroed with a zero control, sufficient battery power is available. Note that the zero will constantly shift on some survey meters, so personnel using these meters should continually recheck the zero control and adjust the meter as necessary.

6.9.12 Personnel Monitoring Devices.

6.9.12.1 General.

Personnel who may be exposed to ionizing radiation during the normal course of their duties or occupation SHALL wear personnel monitoring devices, if directed by the base RSO. Personnel monitoring devices are designed to measure the total accumulated dose to which an individual is exposed. The devices of most general importance are the thermoluminescent dosimeter (TLD), the electronic personal dosimeters (EPD), the personal alarming dosimeter (PAD) or Digital Alarming Dosimeter (DAD) (commonly called a "Chirper"), and the direct reading pocket dosimeter. TLDs are the primary dosimetry device and have generally replaced film badges as the legal record of radiation exposure in the Army and Air Force.

6.9.12.2 Thermoluminescent Dosimeter (TLD).

6.9.12.2.1 Theory of Operation.

TLDs are well suited for personnel and environmental monitoring of X-ray and gamma radiation. TLDs are special materials which, when exposed to ionizing radiation, results in raising the electrons of the detector material to temporary higher energy states. When these materials are later heated, the electrons fall back to their normal energy states and in the process emit light. The amount of light emitted is directly related to the amount of radiation dose the TLD received. By measuring this light, the dose received by the individual wearing the dosimeter can be assessed. Although a number of materials can be used as TLDs, lithium fluoride, lithium borate and calcium sulfate are the most common material used for personnel dosimetry.

6.9.12.2.2 Control TLD (Or Film Badge).

To accurately measure personnel dose, each radiography area will have at least one device designated as a "Control TLD/Badge ". It is used to measure radiation exposure received by personnel monitoring devices (primarily from naturally occurring background radiation) while badges are in storage and transit.

a. The control device will be stored in the same area as the personnel TLD badges away from sources of radiation in a temperature and humidity controlled area.

b. It SHALL NEVER be worn by any individual.

6.9.12.2.3 Refer to Personnel Monitoring, paragraph 6.9.13. for personnel monitoring requirements.

6.9.12.3 Dosimetry (TLD) Service.

6.9.12.3.1 Air Force.
Dosimetry service for Air Force installations is provided by Armstrong Laboratory, AL/OEBD, 2402 E Drive, Brooks AFB, TX 78235-5114, through the base RSO, in accordance with the provisions of AFI 48-125, *USAF Personnel Dosimetry Program*.

6.9.12.3.1.1
The Air Force Bioenvironmental Engineering Service is responsible for the dosimeter program at base level. This organization will receive all routine reports issued by the Armstrong Laboratory. The Base Radiation Safety Officer is also responsible for investigating all dose reports which exceed predetermined action levels and for insuring that all records of radiation dosage are property maintained for each individual on the program.

6.9.12.3.2 Army.
DA (and DLA) activities, to include reserve forces, are required to use the Army dosimetry service provided by the US Army Ionizing Radiation Dosimetry Center (AIRDC), TMDE Activity, ATTN: AMXTM-SRD, Redstone Arsenal, AL 35898-5400. Organizations initiating industrial radiography operations should contact AIRDC in advance to assure receipt of dosimeters prior to the date on which such operations are scheduled to commence prior.

6.9.12.4 9-63A. Electronic Personnel Dosimeter (EPD).
Although approved by NVLAP (ANSI-N13.11) as a dosimeter of record in lieu of a TLD, the EPD is currently used within DoD for instant readout of dose and dose rate. It measures gamma and X radiation over the range of 20 keV to 6 MeV and beta radiation from 250 keV to 1.5 MeV, and it provides a readout of both skin (7 mg/cm^2) and deep dose equivalent (1000 mg/cm2). The readout provides a dose equivalent range of 0.1 to 1000 rem. The radiation is detected by three silicon diode detectors which save data to secure memory every few minutes and provide visible and audible alarms if either the accumulated dose or dose rates exceed specified levels. Doses are checked periodically throughout the day when performing radiography and are recorded in the dosimetry log at the end of each day of operation for comparison with TLD results. EPDs are submitted for calibration on an annual basis at which time long-term dose memory is reset to zero. They are used in the same manner as TLDs.

6.9.12.5 Digital/Personal Alarm Dosimeter (DAD/PAD).
The DAD/PAD is a pocket dosimeter designed to replace the direct-reading pocket dosimeter. It is used in conjunction with, but never in lieu of the TLD. The DAD/PAD is approximately the size and shape of a typical telephone paging unit. It provides both a visual and audible indication in direct proportion to radiation-intensity/dose-rate. The term "chirper" is also used as a common name for this type of dosimeter because of the audible sound emitted when operated in the presence of radiation. The DAD/PAD SHALL be worn between the neck and waist on an outer garment. It may also be worn on a belt provided the DAD/PAD's securing clip is designed for attachment to a belt.

6.9.12.5.1

CAUTION

Geiger Mueller tubes will saturate at high dose rates (R/hr). They are never to be used in areas where dose rates can reach these levels.

The DAD/PAD is a solid state dosimeter that uses a halogen-quenched, filtered Geiger-Mueller (GM) tube for detecting and measuring radioactivity. The GM tube converts the radiation detected into pulses which are fed to an amplifier and then to a pulse-division circuit which produces an output to the digital display counter whenever pulses equivalent to one dose increment have been accrued. At the same time, the division circuit output actuates the audible system and emits a “chirp” for each dose increment. The radiation is recorded normally in dose increments of 0.25 mR to 1 mR units.

6.9.12.5.2
Some units of this type are equipped with a chirp rate switch allowing the user to select a low or high chirp rate. In the low position, each dose increment produces one chirp; in the high position, each increment produces about 40 chirps, giving a more immediate audible warning at relatively low exposure rates. For example, at an exposure rate of 10 mR/hr, the unit will chirp about every 6 minutes in low position and about every 10 seconds in the high position.

6.9.12.5.3
The alarm dosimeter has a case usually constructed from aluminum or high impact plastic. The DAD/PAD is lightweight (8 ounces or less), has a corrosion-resistant surface coating and operates on a 9-volt alkaline battery for up to 6 months of normal use.

6.9.12.5.4
Operation is very simple: turn the unit on. Some units reset the display each time the unit is turned on; others require resetting the display with a reset switch or button. A memory is available on some models, which allows the unit to be turned off without losing the stored dose. This feature permits a single daily recording of the wearer’s exposure dose because the dosimeter will continue to monitor exposure to the radiation without having to record each exposure dose if operations are stopped and resumed several times in a day’s operation. Dosimeter reading for each individual shall be entered on the utilization log at the end of the workday.

6.9.12.5.5
Any time a DAD/PAD is used by a different radiographer, it SHALL be reset to zero prior to use. Each radiographer SHALL wear a single DAD/PAD, which has been reset to zero prior to the start of each day’s operation and calibrated in accordance with specific equipment technical data. A reading may be obtained at any time while working in a radiation area by simply pushing a read button to view the accumulated dose on the readout display. An emergency situation should be considered to exist whenever a daily accumulated dose of 100 mrem or more is registered on the display of the dosimeter.

6.9.12.5.6
The Victoreen Model 885 PAD is one example of the alarm dosimeter. It detects gamma and X-rays over a range of 0-999 mR (0-10 mSv) by integrating radiation exposures. It provides both a visual and audible indication and “chirps” in direct proportion to radiation intensity/dose rate with “chirps” at the rate of one chirp per 0.025 mR. Using one 9V alkaline battery, the PAD will operate for 30 days continuously or for 120 days at 8 hours per day. (Low battery indicator notes when battery life drops below 100 hours.) The Model 885 PAD must be worn under outer garments when conducting operations during cold weather as it is designed to function properly only when the lower operating temperature is above zero degrees Celsius (32 degrees Fahrenheit).

6.9.12.5.7 Each personal alarming dosimeter/alarm rate-meter must:

NOTE

> Calibration of both pocket dosimeters and personnel alarm dosimeters must be scheduled so that sufficient quantities remain on hand to support continuing radiography operations. Additionally, except in cases of emergency, TLD badges should not be submitted until replacement badges have been received.

a. Be checked to ensure that the alarm functions (sounds) use at the start of each shift.

b. Be set to give alarm signals a preset dose rate of not more that 500 mR/hr (5 mSv/hr).

c. Require special means to change the preset alarm function.

6.9.13 Personnel Monitoring Requirements.

6.9.13.1 Criteria.

NOTE

> A monthly wearing period shall be implemented for thermoluminescent dosimeters issued to minors and to pregnant women.

Criteria requiring individual dosimetry are defined in Title 10, Code of Federal Regulation, Parts 20 and 34, for the Air Force in AFI 48-125, and for the Army in AR 40-14 and the supporting DA Pam. Use of personnel monitoring devices is mandatory for each individual who may be exposed to ionizing radiation during the normal course of their duties or occupation according to the following criteria:

a. Occupationally exposed adults who may reasonably be expected to receive an annual dose in excess of 500 mrem (5 mSv).

b. Occupationally exposed adults entering any high or very high radiation area (regardless of the anticipated magnitude of exposure).

c. Radiographers and Radiographer's Assistants, at all times during radiographic operations, shall wear a minimum of one pocket dosimeter and/or one personal alarming dosimeter, and one TLD badge except that for permanent radiography facilities where other appropriate alarming or warning devices are in routine use, the wearing of an alarming rate-meter is not required (10 CFR 34.33). As used here radiographer includes radiographers' assistant but specifically excludes occasionally exposed personnel with ancillary duties outside of radiation restricted areas. Notwithstanding the above, pocket dosimeters and personal alarming dosimeters shall not be required for X-radiation operations conducted solely within shielded installations.

d. Declared pregnant women who may be expected to receive a radiation dose exceeding 50 mrem (500 μSv) to the whole body/fetus for the entire period of pregnancy.

e. All minors who may reasonably be expected to receive an annual radiation dose in excess of 50 mrem (500 μSv) total effective dose equivalent (TEDE) to the whole body.

f. Other individuals as necessary for the effective management of the ALARA program, such as radiation safety monitors supporting unshielded radiography operations who do not otherwise require dosimetry devices, will be provided with dosimetry devices to include TLDs if their radiation dose would reasonably be expected to exceed the general public exposure limit of 100 mrem (1 mSV) TEDE per year.

g. Individuals not meeting any of the criteria contained herein should not be enrolled in or be needlessly continued in the dosimetry program except on a case by case basis. If in doubt RSOs should enroll individuals in the dosimetry program for a limited duration and base continued use of dosimetry on actual exposures received.

6.9.13.2 Wear Of Whole-Body Dosimeters.

Thermoluminescent dosimeter (TLD) badge used to provide a permanent record of the cumulative exposure to the whole body must be worn on the trunk (below the shoulders and above the hips) outside of clothing on the portion or area of the body nearest the radiation source. The dosimeter window must face out from the body.

6.9.13.3 Wearing Additional Dosimeters.

If exposure to the eyes, extremities, or skin is likely to be significantly different from whole body exposure, additional TLDs (collar, wrist, ring etc.) must be worn to document the actual exposure received by these areas. (Note: If eye protection providing at least 700 milligram per square centimeter thickness is used, the RSO must annotate this fact on the dosimetry issue listing beside the individual's name so that the correct eye exposure can be noted.)

6.9.13.4 Storage of Monitoring Devices.

TLD badges and pocket dosimeters shall be stored in racks located in a low background radiation area, in an environment free from excessive temperature and humidity. The TLD badges and pocket dosimeters shall be returned to the rack at the end of each work period.

6.9.13.5 Recording Of Pocket Dosimeter Readings.

Pocket dosimeters SHALL be read and doses recorded daily in the utilization log. (For industrial radiography operations conducted pursuant to 10 CFR 34, "each record of these exposures shall be maintained for three years after the record is made.") If an individual's pocket dosimeter is discharged beyond its range or a DAD/ PAD reads 100 mrem or above during a daily radiographic operation, his/her TLD (or film badge) shall be immediately serviced.

6.9.14 Dose Reporting and Recording Procedures.

6.9.14.1 Dose Record Custodian.

Commanders must designate in writing an individual to serve as the dose record custodian to be responsible for preparing and maintaining the records of occupational exposure to ionizing radiation. This individual may be the medical/health records custodian, RSO, or another individual who prepares the dosimetry report and controls dosimeter issuance and recovery.

6.9.14.2 Automated Dosimetry Record (ADR), Army Only.

Completed forms will be maintained on file for a minimum of one year from the date of last entry. It provides a complete occupational dose history for each occupationally exposed individual (upon written request from the RSO), calendar year-to-date updates of radiation exposures (on a quarterly basis), and includes dose records of whole-body and skin of the whole-body, head and neck, hands and forearms, feet and ankles, and lens of the eye, as applicable. The RSO verifies that all ADR related information is contained in the ADR, takes action to correct errors, signs and dates the ADR to certify the information as the occupationally-exposed individual's official dose record. He also reviews and certifies each of the AIRDC updates and adds them to each individual's dosimetry record. (Updates for previous quarters during that calendar year need not be retained.)

6.9.14.3 Personnel Termination, Army Only.

Period and employment termination dose reports will be provided to occupationally exposed individuals in accordance with AR 40-14.

6.9.14.4 Utilization Log.

Completion of the Industrial Radiography Utilization Log, AFTO Form 125 (see Figure 6-46) or equivalent, is mandatory only when a suspected overexposure to any individual has taken place or when radiographic inspections take place in an unshielded area. The following information shall be recorded:

a. kVp (For gamma radiography, identify the source and its activity rather than the kVp and mA)

b. mA

c. Exposure time

d. A sketch of the radiographic setup containing the following identified:

  (1) Primary beam direction

  (2) X-ray tube or source position

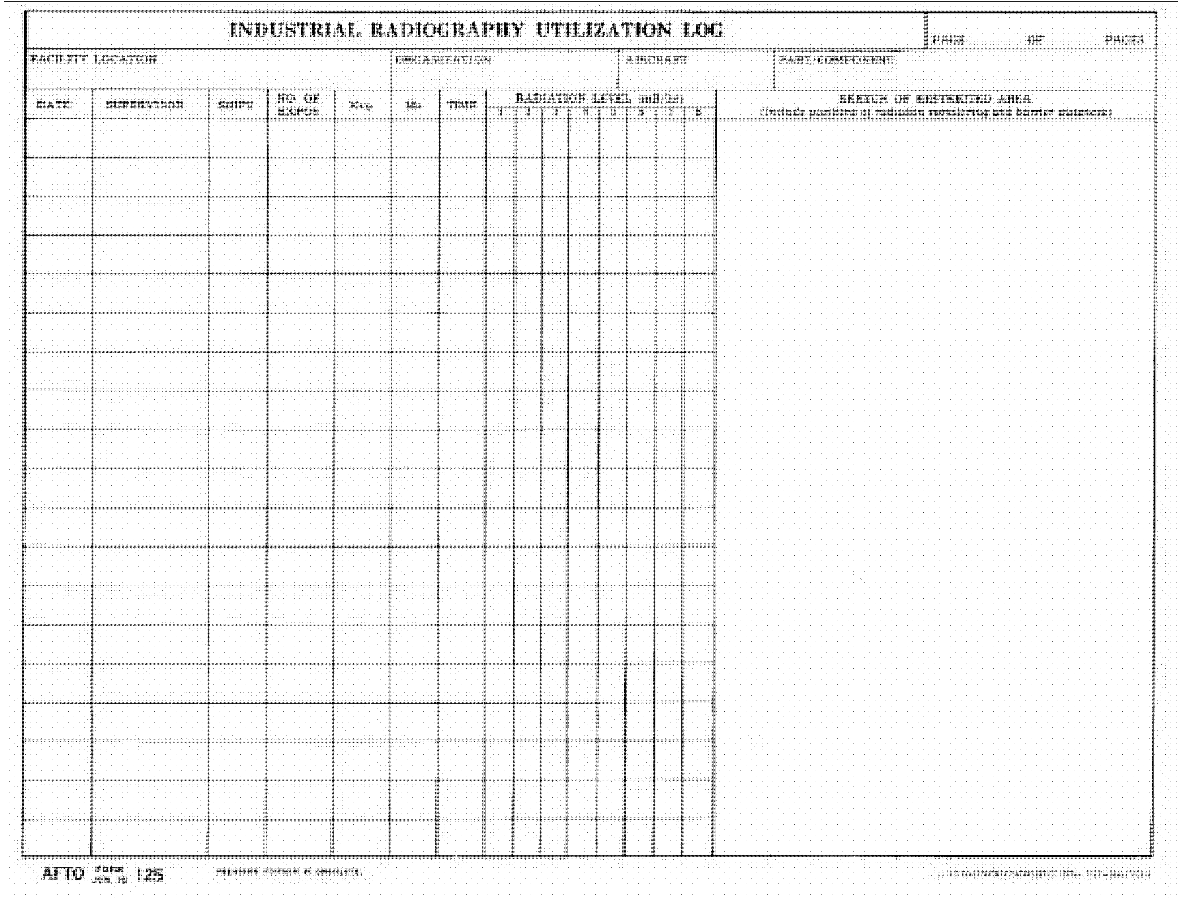
  (3) Control console position

(4) Film and part position

(5) Barrier position

(6) Exposure rates (mR/hr) at the barrier

(7) The approximate location(s) of the individual during the exposure



INDUSTRIAL RADIOGRAPHY UTILIZATION LOG

PAGE OF PAGES

FACILITY LOCATION

ORGANIZATION

AIRCRAFT

PART/COMPONENT

DATE	SUPERVISOR	SHIFT	NO. OF EXPOS	Kvp	Ma	TIME	RADIATION LEVEL (mR/hr)								SKETCH OF RESTRICTED AREA (Include positions of radiation monitoring and barrier distances)
							1	2	3	4	5	6	7	8	

AFTO FORM JUN 76 125 PREVIOUS EDITION IS OBSOLETE.

Figure 6-46. AFTO Form 125

6.9.14.4.2

The completed form will be permanently maintained on file. If a suspected overexposure occurs, any other documents generated during the subsequent investigation shall be filed with the respective utilization log.

6.9.14.4.3

When a log is completed, the radiography supervisor will sign the log.

6.9.15 Suspected Overexposure of Ionizing Radiation.

6.9.15.1 Operational Definition.

NOTE

> Pocket dosimeters determined to go off-scale or drift prior to the first actual X-ray production of the day or shift shall be considered defective and shall not be treated as off-scale pocket dosimeters. They shall be withdrawn from use and turned in to the servicing TMDE or PMEL calibration facility for evaluation.

a. Air Force: Whenever both of an individuals' direct reading pocket dosimeters read off scale or the digital alarm dosimeter registers 100 mR or more.

b. Army: Whenever a pocket dosimeter or personnel alarm dosimeter indicates an exposure which exceeds defined exposure action limits specified in AR 40-14 or local ALARA exposure guidelines.

c. Any time the radiography supervisor, regardless of dosimeter readings, believes that an overexposure has occurred either to another radiographer or to any person(s) not directly involved in the radiographic operation.

6.9.15.2 Suspected-Overexposure Actions (Pending Processing of TLDs).

ARMY NOTE

> If the Radiation Safety Officer cannot be notified, contact the MAJCOM Radiation Control Officer and the US Army Ionizing Radiation Dosimetry Center (AIRDC) immediately by telephone, and promptly send the TLD badge(s) of all affected individuals, together with the appropriate control badge, by the most expeditious means to the AIRDC, ATTN: AMXTM-SRD, Redstone Arsenal, AL 35898-5400. (TLDs suspected of having received a potential overexposure must be annotated as such, in writing, when they are shipped to the AIRDC for processing.)

AIR FORCE NOTE

> In those instances where the base Bioenvironmental Engineering services cannot be notified or is not locally available, the control TLD and the TLD of the suspected overexposed individual should be sent via "AIR MAIL" from overseas or "FIRST CLASS" from CONUS to:
>
> AL/OEBZ
> 2402 E Drive
> Brooks AFB TX 78235-5114
> DSN 240-3486

If an overexposure is suspected, an emergency situation SHALL be considered to exist. The following actions shall be taken (Army: Consult 10 CFR 20, AR 385-40, AR 40-14 and applicable supplements):

a. Immediately cease all radiography operations and report the incident to the unit commander (Army) or the immediate supervisor (Air Force).

b. Obtain the name, social security number and organization of all personnel suspected of overexposure.

c. Notify the Radiation Safety Officer or Bioenvironmental Engineering Services of the suspected overexposure. Prepare to turn in the affected individual's TLD badge and the control badge for immediate processing, as directed. The occupational health physician in consultation with the RSO will determine the need for medical treatment.

d. Read and record pocket dosimeter readings.

e. Determine and record exact position and duration of exposure.

f. Update the Industrial Utilization Log as needed. Make sure the detailed sketch of the area includes the positions of personnel suspected of being overexposed. Record all other pertinent data about the incident.

g. Obtain a signed statement from the exposed individual(s) of actions resulting in (or contributing to) the exposure.

h. After completion of the above phase of the investigation and in the case of non-monitored personnel being exposed, the following procedure can be used by the RSO or radiographers to quantify personnel exposure. Re-establish the exact positions of all objects at the time of the accident. Place suitable dosimetry devices at the position of the exposed individuals. Do not use survey meters, unless they have an integrate mode or remote cameras are available to observe the instruments, since personnel using them will be unnecessarily exposed to radiation. Expose the dosimeters, operating the gamma-ray or X-ray apparatus at the same technique as occurred during the accident, with the time of the exposure equal to the time personnel indicated they were present in the area or enclosure. If personnel were moving within the enclosure during the accident exposure, the dosimeters shall be placed at the position closest to the X-ray apparatus and at various points of his travel.

i. Air Force: A complete report of the incident shall be prepared by the Chief of the Nondestructive Testing Laboratory with signed statements from all operators and personnel exposed indicating their concurrence with the report. A copy of this report shall be provided to the Base Radiation Safety Officer for review and filing in the industrial workplace case file, additionally, copies will be forwarded to Air Force NDI Office, AFRL/MLS-OL, 4750 Staff Dr., Tinker AFB, OK 73145-3317; DSN 339-4931, and to AL/OEBD, 2402 E Drive, Brooks AFB TX 78235-5114.

j. Army: Upon return receipt of TLD results confirming personnel overexposures (or after validation of exposure dose to non-monitored personnel) the RSO shall complete accident investigations as specified in paragraph below and report the accident pursuant to 10 CFR 20, AR 385-40 and AR 40-14, as applicable.

k. Assure that a new control badge is obtained and designated as a replacement for the control badge that was submitted for analysis.

6.9.15.3 (Army) External Potential Overexposure Criteria and Investigations.

Upon the detection of a potential overexposure, the following investigations shall be made (AR 40-10, paragraph 4-10).

6.9.15.3.1

The US Army Ionizing Radiation Dosimetry Center (AIRDC) promptly report to the RSO any dosimeter that exceeds the applicable Level II values found in Table 6-23. AIRDC also reports the results from dosimeters which indicate exposure exceeding criteria found in Table 6-24 to the RSO, to the Office of the Surgeon General, and to Headquarters, Army Materiel Command.

Table 6-23. Investigation Levels(Extract of Table 2-l, DA PAM 40-18*)

	Quarterly monitoring (mrem)	
	Level I	Level II
Whole body	125	375
Lens of the eye	375	1125
Other	1250	3750

*DA Pam 40-18 is the companion DA Pamphlet to AR 40-14

Table 6-24. Dosimeter Results That Require Notification of OTSG (Extract of Table 4-l, DA Pam 40-18)

	Quarterly Monitoring (mrem)	Monthly Monitoring (mrem)
Whole body	1250	400
Lens of the eye	3750	1250
Other*	12500	4150

*As used above, “other” includes dose to the skin or to any extremity or to any individual organ or tissue other than lens of the eye

6.9.15.3.2
For dosimeters used for industrial X-ray operations which were potentially overexposed at a rate exceeding limits in Table 6-24, the RSO shall:

a. Conduct an investigation.

b. Determine the cause, time frame, and circumstances surrounding the apparent potential overexposure.

c. Take or recommend to the commander corrective actions to prevent recurrence of the situation.

d. Determine whether or not the dosimeter was actually worn by the occupationally exposed individuals during the dosimeter wear period.

e. Report the overexposure in accordance with l0 CFR 20 and AR 385-40 (as applicable) if it was determined that the badge was actually worn.

f. Fully document the investigation and maintain investigation records as a permanent file per AR 25-400-2. Copies of the final investigation report including any to the individual also are provided to the individual concerned and to the individual's medical records custodian for inclusion in the individual's health or medical records. The written investigation report shall contain:

    (1) A copy of the affected occupationally exposed individual’s ADR covering the previous 12 months, if available.

    (2) Result of any bio. essays and medical examinations.

    (3) Statements from supervisors or other knowledgeable personnel.

    (4) A statement from the affected occupationally-exposed individual stating, "To the best of my knowledge and belief I (did) (did not) receive this dose because____.”

    (5) Procedures describing corrective actions.

g. Review the ALARA program to reduce the likelihood of recurrence and minimize future radiation doses.

h. Remove overexposed individuals from duties that could lead to additional radiation exposures pending completion of the overdose investigation.

i. Refer any occupationally exposed individual who sustains an actual overexposure to the supporting occupational health physician. (The occupational health physician in consultation with the RSO will determine the appropriate medical examinations (if any) and plan appropriate medical care.)

6.9.15.4 (Army) Administrative Assessment of Dose.

If a dosimeter is lost or damaged or if the occupationally-exposed individual's TEDE or CEDE cannot otherwise be determined, the RSO shall determine and assign an administrative dose pursuant to paragraph 4-13 of AR 40-14, and report the assigned dose to the US Army Ionizing Radiation Dosimetry Center for inclusion in the individual's permanent dosimetry file.

6.9.16 Standard Department Of Defense Industrial X-Ray Radiographic Equipment.

6.9.16.1 Lorad Model LPX-160A Portable Industrial X-Ray Unit.

The LPX-160A is an air or water-cooled X-ray unit with an operating potential of up to 160 kV and a tube current of up to 5 milliamperes (mA). The tube head is insulated with sulfur hexafluoride gas, pressurized to 50 psig @ 70°F, is end grounded and has a 0.063-inch thick beryllium window (for beam filtration) located approximately 2 inches from the end of the tube. At 0.5 meter from the window, the dose rate in the beam is about 240 R/min (2.4 Sv/min) and 14 R/min (140 mSv), unfiltered and filtered respectively through 0.5 inches of aluminum. The unit has a radiation cone of 40 degrees. Leakage radiation as measured one meter from the tube head, with the main beam being absorbed by 25 half-value layers of lead, ranged from 12.7 mR/hr (127 µSv/hr) to 385 mR/hr (3.85 mSv/hr). The measured half-value layer (HVL) of 0.41 inches corresponds to an average X-ray energy of about 83 keV.

6.9.16.2 Magnaflux Model GXR7.6B/GXR7.6C 150-KVP X-Ray Unit.

Unit output is approximately 49 R/min (0.49 Sv/min) at one meter from the tube target with the tube operating at 150 kVp and 7 mA. The tube head assembly contains an end-anode ceramic-enveloped X-ray tube with a 0.03-inch (0.75-mm) beryllium window for beam filtration. The unit has a radiation cone of 40 degrees. Maximum leakage radiation is approximately 1.3 R/hr (13 mSv/hr) at 1 meter with the tube h-ad placed in a hori20ntal position and with the beam port down and blocked by a ¼-inch lead sheet.

6.9.16.3 Sperry Model SPX 160-KVP X-Ray Unit.

The output of this unit is approximately 60 R/min (0.6 Sv/min.) at one meter from the tube target with the tube operating at 160 kVp and 5 mA. The only filtration in the primary X-ray beam is that provided by the 0.092 inch (2.3 mm) beryllium window. The nominal cone of radiation is 40 degrees and the duty cycle is continuous with external cooling. The end-anode type of X-ray tube is shielded with a 1/8-inch lead collar with a circular aperture for the primary beam. Typical tube housing leakage radiation exposure rates range from 300 to 600 mR/hr (3 to 6 mSv/hr) at one meter from the tube target. However, a cone of leakage radiation, ranging from 1 to 4 R/hr (10 to 40 mSv/hr) at one meter and emanating from the high-voltage-input end of the tube housing at an angle of approximately 10-18 degrees with the major axis, may be detected with some units.

6.9.16.4 Sperry 275-KVP Unit.

WARNING

When surveying the cone of radiation leakage in the rear of the tube head of Sperry units the survey instrument should be scanned from the floor toward the ceiling. This will prevent the instrument operator from unknowingly entering the high radiation area produced in this cone. Perimeters shall be established on the basis of the highest reading obtainable at a given point.

The maximum output in the beam of a typical 275-kVp X-ray unit is 150 R/min (1.5 Sv/min) at one meter from the tube target with the tube operating at 275 kVp and 10 mA. The beryllium window provides an inherent filtration approximately equivalent to 0.1-mm aluminum. The nominal cone of radiation is 35 degrees and the duty cycle is continuous with external cooling. The end-anode type of X-ray tube is shielded with a 1-inch lead collar with a circular aperture for the primary beam. Typical tube housing leakage radiation exposure rates range from 500 to 1000 mR/hr (5 to 10 mSv/hr) at one meter from the tube target. The 1000 mR/hr (10 mSv/hr) exposure rates generally occur at 90 degrees to the major tube axis at the high-voltage-input end of the tube housing.

6.9.16.5 Sperry 300-KVP Unit.

The maximum output of the 300-kVp unit is about 117 R/min (1.17 Sv/min) in the beam at 1 meter from the tube target with the tube operating at 300 kVp and 10 mA. Filtration of the primary X-ray beam is 2.36 mm beryllium for the 35-degree tube heads and 0.5 mm nickel for the 360-degree tube heads.

6.9.17 Classification and Selection of Radiographic Installations.

6.9.17.1 Summary.

Basically any installation which so constructed and operated as to meet the basic radiation protection standards is acceptable. However, if this were the only requisite, the assumptions as to the use of the equipment and degree of occupancy might be subject to widely divergent interpretations.

6.9.17.1.1 Air Force: The Air Force defines two types of NDI installations.

a. Shielded Installation. A facility designed with sufficient shielding so that exposure limit requirements are met.

b. Unshielded Installation. Applies where fixed shielding cannot be used (i.e. flight line, open hangers, make-shift buildings, etc.)

ARMY: In order to ensure certain minimum standards of protection without needless expenditures, it has been found advisable to divide installations into three different classes.

a. Protective Installation. Provides the highest level of inherent safety; exposure limit requirements are met

b. Enclosed Installation. Provides fixed shielding for low use and low radiation levels (“Protective" radiographic facilities generally will be used within the Army rather than "Enclosed" facilities.)

c. Unshielded Installation. Applies where fixed shielding cannot be used (i.e. flight line, open hangers, make-shift buildings, etc.)

6.9.17.1.2 New Facilities.

New radiation facilities shall be constructed to meet the requirements of one of these classes of installations. The classes differ in the relative dependence on inherent shielding, operating restrictions and supervision necessary to secure the required degree of protection. In addition, each class has certain advantages and limitations. The above referenced paragraphs contain details of the respective installation classes.

6.9.17.2 High Radiation Areas.

Each of the types of installations specified herein involves the creation of "High Radiation Areas". Access to all high radiation areas created by radiographic operations with sealed sources shall be controlled in accordance with 10 CFR 20.1601. To insure high levels of safety, these rules will also be applied to radiographic operations performed with x-ray sources. Requirements include:

a. Control devices that, upon entry into the area, cause the level of radiation to be reduced (below that level at which an individual might receive a deep-dose equivalent of 100 mrem (1 mSv) in 1 hour at 30 centimeters from the source (or from any surface that the radiation penetrates).

b. Control devices that energize a conspicuous visible or audible alarm so that the individual entering the area and the supervisor of the activity are made aware of the entry.

c. Entryways that are locked, except during periods when access to the areas is required, with positive control over each entry.

d. Continuous direct or electronic surveillance that is capable of preventing unauthorized entry.

6.9.17.3 Very High Radiation Areas.

Additional measures shall be instituted to ensure that an individual is not able to gain unauthorized or inadvertent entry into a "Very High Radiation Area." (A "Very High Radiation Area" is an area in which radiation levels could be encountered at 500 rads (5 gray) per hour at one meter from a radiation source or from any surface that the radiation penetrates) (10 CFR 20.1602). The requirements of 10 CFR 20.1603 shall be implemented for all radiation sources, including X-ray machines, which create very high radiation areas.

6.9.18 Protective Installations or Shielded Installations.

6.9.18.1 Features.

a. PROTECTIVE INSTALLATIONS: This class provides the highest degree of inherent safety because the protection does not depend on compliance with any operating limitations. This type also has the advantage of not requiring restriction in occupancy outside the enclosure; the built-in shielding is generally sufficient to meet the maximum permissible dose requirements for the environs.

b. The allowable usage exposure level limits exposures to the lesser of 0.5mR (5 μSv) in any one hour or 2 mR (20 μSv) per week (when corrected for workload, utilization, and type of occupancy) for this class of installation necessitates a higher degree of inherent shielding. For radiation sources of lower energies, and for smaller enclosures such as cabinets, the initial extra cost of the increased shielding is usually insignificant compared with the operational advantage.

c. At higher energies, as in the megavolt region with high workloads, the required additional shielding will usually make the use of this class extremely expensive compared with the enclosed installation.

d. SHIELDED INSTALLATIONS: The Air Force describes a shielded installation as any enclosed radiographic facility designed to limit exposures on the outside of the facility to less than 2 mR in any one hour and less than 100 mrem per year. The shielding design incorporates the energy of the x-ray or gamma ray source to be used, as well as the expected workload, use factors and occupancy factors of installation.

6.9.18.1.1 Requirements.

An installation shall be classified as "protective" or "shielded" when it conforms to all of the following mandatory requirements.

a. The source and all objects exposed thereto are within a permanent enclosure, within which no person is permitted to remain during irradiation.

b. Each entrance that is used for personnel access to the enclosure/high-radiation area shall have both visible and audible warning signals as described in paragraph 6.9.18.1.1c(1). At a minimum, a signal interlock system shall be placed on each door to interrupt power to the control box/tube head, stopping the irradiation process, when unauthorized access is attempted.

c. Each of the following shall be provided (except where specifically noted) without regard to the size and/or configuration of the enclosure:

NOTE

A time delay/interlock may be locally fabricated in order to meet this requirement. Note that the wiring harnesses are similar to the harnesses used with X-ray Interlock Assembly, NSN 6635-00-292-7637. All time delay interlock systems installed shall be compatible with all X-ray units commonly available.

(1) Pre-exposure audible alarm and rotating or flashing strobe-type (blinking, low intensity, warning lights shall not be used) red visible warning signals within the enclosure which must be actuated at least 20 seconds before irradiation can be started. Audible alarms will cease when radiation is started, but visible warning signal will remain actuated during irradiation. The audible signal shall be of a frequency or capable of producing a sound pressure level such that it can be heard over background noise that may be present. Audible alarms are NOT required if the enclosure is as small that it cannot be entered by an individual. An example of such an enclosure is a cabinet X-ray system that has a small opening into which the part to be radiographed is placed but into which an individual could not walk or even crawl without difficulty.

(2) Suitable means of exit, so that any person who accidentally may be shut in can leave the enclosure without delay.

(3) Emergency shut-off switch(es) shall be provided within the facility labeled by a sign "EMERGENCY SHUTOFF" in red letters on a white background Sufficient number of signs and switches shall be placed where they are visible and readily activated from any portion of the interior of the protective installation. An emergency shut-off switch is NOT required if the enclosure is so small that it cannot be entered by an individual. An example of such an enclosure is a cabinet X-ray system.

(4) Rotating or flashing strobe-type (blinking, low intensity, warning lights shall not be used) warning lights, inside the enclosure and outside all entrances to the enclosure. These lights should be located such that they are visible to an individual entering or already inside of the facility and will be operational when X-rays are being produced. An adequate sign should be displayed near the lights to explain their function. Rotating/flashing strobe-type (blinking, low intensity, warning lights shall not be used) red warning lights will be located inside the enclosure and red or yellow outside all entrances to the enclosure.

(5) A pre-start switch, located inside the enclosure, so that if irradiation is interrupted by the opening of a safety interlock, resumption of operation can only be accomplished after the prestart switch has been reactivated. A pre-start switch is NOT required provided that:

(a) The tube head is de-energized (or gamma shutter is closed) when an interlock is tripped.

(b) The X-ray tube (or gamma shutter) can NOT be re-energized by merely closing the interlock. To re-energize the X-ray tube, the entire time delay interlock system must be reinitiated at the X-ray machine control panel.

d. Exposure Limits:

(1) Protective Installations: The exposure at any accessible region 2 inches (5 cm) from the outside surface of the enclosure cannot exceed 0.1 mR (1 µSv) in any one hour. (The distance of 2 inches is chosen as being the minimum practical distance from the barrier at which the exposure may be measured.) The limit of 0.1 mR (1 µSv) in one hour assures with reasonable probability

that under practical conditions of occupancy and use, the dose received by individuals outside the enclosure will not exceed the annual limit of 100 mrem (1 mSv) per year for members of the general public

(2) Shielded Installations: The exposure rate at any accessible location 2 inches (5 cm) from the outside surface of the enclosure cannot exceed 2 mR in any one hour, and 100 mR per year at the exterior surface of the facility.

e. All installations must display suitable warning signs as follows:

(1) The interior of the exposure room shall be posted with sufficient "Caution, High Radiation Area" (or "Danger, High Radiation Area" or "Danger, Very High Radiation Area") signs so as to be visible from any location. The interior of a cabinet installation must be posted with an identical sign that must be visible with the access door open.

(2) The entrance to the exposure room, or cabinet of cabinet type installations, housing X-ray equipment shall be coated with radiation marking signs, either "Caution, Radiation Area", "Warning, High Radiation Area" or "Warning, Very High Radiation Area", as applicable. In addition, gamma radiography sources and cabinet type installations containing a radioactive source shall have a "Caution, Radioactive Materials" sign attached to the outside and a label or sign "Caution, Produces X-rays when energized" (or equivalent) shall be affixed to the X-ray tube head.

f. No person, either within the controlled area or in the environs of "Protective" (“Shielded”) installations shall receive radiation exposures exceeding the total effective dose equivalent limits for members of the public.

6.9.18.1.2 Operating Procedures.
The following are mandatory operating procedures that must be adhered to in a “protective” and “shielded” installations:

a. Protective Installations: No restrictions shall be imposed on the mode of operation (kVp, mA, workload, or adjacent operations) for protective installations.

b. Shielded Installations: Facilities for shielded operations are designed to limit the exposure at the exterior surface of facilities to 2 mR in an one hour and 100 mrem per year. Since such designs incorporate expected workloads, use factors and occupancy factors, these “design” parameters serve as administrative limits for the operations of shielded installations. When the operating conditions have changed so that there is a probability that the exposure of any person may be increased, a radiation protection resurvey or evaluation shall be conducted. In case of doubt, a health physicist or nuclear medicine science officer shall be consulted

c. Personnel access to areas in which radiography is in progress is prohibited except as an exception to policy that shall require MAJCOM Headquarters approval.

d. A thorough search for personnel working within the enclosure shall be conducted prior to activating the source.

e. The installation shall be inspected by the radiographers each day the facility is to be used to verify the proper operation of audible red visible warning signals, interlock, delay switches, and other exercises that have a bearing on radiation protection. Interlocks shall be subject to detailed testing at intervals not to exceed six months to assure that they function as designed. A bound log, initialed by the individual making the inspection shall be maintained.

f. A qualified radiographer shall be present at the control panel during all radiographic exposures and will be the only person authorized to operate radiographic equipment. An operational, calibrated, survey instrument shall be available for immediate use by the radiographer during all radiographic operations.

g. Except when making daily verification of safety interlock operation and in emergencies, door interlocks will not be used to terminate the exposure. The exposure shall be terminated at the control panel.

h. When radiographic exposures have been competed, the safety-switch key shall be removed from the control panel. The radiation-producing equipment and power safety-switch key shall be placed in secure areas separate from one another. Only radiographers specifically authorized by the Commander shall have access to the storage areas.

6.9.18.2 Enclosed Installations (Air Force: N/A).

6.9.18.2.1 Features

a. This class usually offers the greatest advantage for fixed installations with low use and low occupancy factors. This is particularly true for high-energy sources where the reduction in shielding may result in significant savings.

b. The shielding requirements are considerably lower than for the protective installations, as much as 4.3 half-value layers (HVL) less; yet, the inherent protection is such that the possibility of significant overexposure is remote.

c. With proper supervision, this class of installation offers a degree of protection similar to the protective installation.

6.9.18.2.2 Requirements.

An installation shall be classified as "enclosed" when it conforms to all of the following mandatory requirements:

a. The source of radiation and all objects exposed thereto are within a permanent enclosure, within which no person is permitted to remain during irradiation.

b. Each entrance that is used for personnel access to the enclosure/high-radiation area shall have both visible and audible warning signals to warn of the presence of radiation. The visible signal shall be actuated by radiation whenever the source is exposed/in operation. The audible signal shall be actuated when an attempt is made to enter" the enclosure while radiation is being produced (10 CFR 34.29(b)). In addition, reliable dual independent interlocks are desirable on each door to prevent access to the enclosure during irradiation. A single interlock system on each door to prevent access to the enclosure during irradiation is a mandatory requirement.

c. Each of the following shall be provided (except where specifically noted) without regard to the size and/or configuration of the enclosure.

NOTE

A time delay interlock may be locally fabricated in order to meet this requirement. The suggested design is optional and not mandatory since numerous design approaches can be used. Note that the wiring harnesses are similar to the harnesses used with X-ray Interlock Assembly, NSN 6635-00-292-7637. All time delay interlock systems installed shall be compatible with all X-ray units commonly available.

(1) Pre-exposure audible alarms and rotating red visible warning signals within the enclosure that must be actuated at least 20 seconds before irradiation can be started. A sign shall be displayed near these devices to explain their function. Audible alarms will cease when radiation is started, but visible warning signal will continue throughout exposure.

(2) Suitable means of exit, so that any person who accidentally may be shut in can leave the enclosure without delay.

(3) An emergency shut-off switch shall be provided within the facility labeled by a sign "EMERGENCY SHUT-OFF" in red letters on a white background. Sufficient number of signs and switches shall be placed such that they are visible and readily activated from any portion of the interior of the enclosed installation. If only one emergency shut-off switch is provided, it should NOT be adjacent to personnel exit door since the door itself can act as an emergency shut-off device. The switch should be located as far from the door as is practical.

(4) Rotating or flashing strobe-type (blinking, low intensity, warning lights shall not be used) warning lights, red inside the enclosure and red or yellow outside all entrances to the enclosure. These lights should be located at approximately eye level and shall be operational. An adequate sign shall be displayed near the lights to explain their function. If a) the shielding provided by the roof is less than that provided by the walls, or b) there is direct access from the roof into the exposure room, then one of the following shall be provided: a) a rotating flashing strobe type (blinking, low intensity, warning lights shall not be used) red or yellow light on the roof with an explanatory sign adjacent to it, or b) a sign indicating "Restricted Area, Contact (Name, Ext.) Before Entering" on all permanent accesses to the roof and on the roof itself so that it will be visible to anyone attempting to climb onto the roof.

(5) A pre-start switch, located inside the enclosure, such that if irradiation is interrupted by the opening of a safety interlock, resumption of operation can only be accomplished after the pre-start switch has been reactivated. A pre-start switch is not required provided that:

(a) The tube head is de-energized (or gamma shutter is closed) when an interlock is tripped.

(b) The X-ray tube CANNOT be re-energized by merely closing the interlock. To re-energize the X-ray tube, the entire time delay interlock system must be re-initiated at the X-ray machine control panel. (Comparably, the gamma shutter cannot be opened without proceeding through the standard system setup/initiation procedures.)

d. The exposure at any accessible and <u>occupied</u> area one foot (30 cm) from the outside surface of the enclosure does not exceed 2 mrem (20 µSv) in any one hour and the exposure at any accessible and normally unoccupied area one foot (30 c) from the outside surface of the enclosure does not exceed 20 mR (200 µSv) in any one hour. (Access to normally unoccupied areas in which doses could exceed 2 mrem (20 µSv) in any one hour or result in exposures to members of the public exceeding 100 mrem (1 mSv) per year must be secured or continuously monitored to preclude personnel entry.)

(1) For X-ray installations, these exposure limitations shall be met for any X-ray tube to be used in the enclosure and operating at any specified mA and kVp rating within the manufacturer's published recommendations.

(2) No beam limiting device or filter shall be used during these tests unless such devices and filters are permanently attached to the X-ray tube or gamma exposure device and the unit cannot be operated without their use.

The radiation source and beam direction shall be positioned and oriented so that the highest dose rate will be encountered in the area under test provided that such positioning and orientation will serve a practical purpose in normal usage.

e. All installations must display suitable Warning signs as given below:

  (1) The interior of the exposure room shall be posted with sufficient "Danger, High Radiation Area" or "Danger, Very High Radiation Area" signs as applicable, so as to be visible from any location. The interior of a cabinet installation must be posted with an identical sign which must be visible with the access door open.

  (2) The entrance to the exposure room and cabinet of cabinet type installations housing X-ray equipment shall be posted with radiation marking signs, either "Caution, Radiation Area", "Warning, High Radiation Area" or "Warning, Very High Radiation Area", as applicable. In addition, gamma radiography sources and cabinet type installations containing a radioactive source shall; have a "Caution, Radioactive materials" sign attached to the outside and a label or sign "Caution, Produces X-rays when energized" (or equivalent) shall be affixed to the X-ray tube head.

  (3) The area accessible to personnel in which radiation doses could exceed 5 mrem (50 μSv) in any one hour shall be posted with a "Caution, Radiation Area" sign.

f. No person, either within the controlled area or in the environs of the installation, is exposed to more than the radiation protection standard applicable to members of the public unless exposure is approved in writing, in advance, by the Radiation Safety Officer.

6.9.18.2.3 <u>Operating Instructions.</u>

The following are mandatory operating instructions that must be adhered to in "enclosed installations":

a. Since the safe operation of an "enclosed" installation is based on the normal operating conditions specified in the applicable radiation protection survey report, the equipment shall be operated only within the indicated limits. A copy of the survey report shall be readily available during radiographic exposures.

b. When the operating conditions have changed so that there is a probability that the exposure of any person may be increased, a radiation protection resurvey or evaluation shall be conducted. In case of doubt, a health physicist or nuclear medicine science officer shall be consulted.

c. Personnel access to areas where radiography is in progress shall be limited to that which is absolutely required. All entries into the enclosure must be monitored.

d. A thorough search for personnel working within the enclosure shall be conducted prior to activating the source.

e. The tube head or gamma radiography source, as applicable, should be placed as close as possible to the center of the room. Whenever possible the beam should be directed toward the floor, and a piece of 1/8-inch thick lead plate should be placed on the floor so as to interrupt the entire primary beam in order to reduce scatter radiation.

f. The installation shall be inspected by the radiographers each day the facility is to be used to verify the proper operation of audible alarms, red visible warning signals, interlocks, delay switches, and other devices that have a bearing on radiation protection. Interlocks shall be tested by verifying that they do indeed de-energize the tube head when tripped. Interlocks will be subjected to detailed testing at a frequency not to exceed six months. A log, initialed by the individual making the inspection, shall be maintained.

g. A qualified radiographer shall be present at the console panel during all radiographic exposures and will be the only person authorized to operate radiography equipment. A calibrated survey instrument shall be available for immediate use by the radiographer during all radiographic operations.

h. Except when conducting daily verification of safety interlock operation and in emergencies, door interlocks will not be used to terminate the exposure. The exposure shall be terminated at the control panel.

i. When radiographic exposures have been completed, the power safety-switch key shall be removed from the control panel. The radiation-producing equipment and power safety-switch key shall be placed in secure areas separate from one another. Only radiographers authorized by the Unit Commander shall have access to the storage area.

6.9.18.3 Unshielded (Open) Installations.

6.9.18.3.1 Features.

a. This class shall be selected only if operational requirements prevent the use of either of the other classes. For radiography its use should be limited mainly to mobile and portable equipment where fixed shielding cannot be used. Fluoroscopy shall be done only by remote observation, such as by closed circuit television.

b. The operational requirements of other types of installations may necessitate use of this class.

c. The protection of personnel and public depends almost entirely on strict adherence to safe operating procedures. With this adherence, unshielded installations may provide a degree of protection similar to the other classes.

d. The lack of inherent shielding necessarily increases the importance of an effective ALARA program. Additionally, lack of interlock and engineered access to high radiation areas increases the importance of unauthorized use of devices.

6.9.18.3.2 Requirements.

NOTE

> High Radiation Area boundaries shall be calculated only. Verification surveys shall not be performed unless such surveys can be accomplished (using devices such as those, which integrate dose) without additional, unnecessary exposure to personnel.

An installation shall be classified as “unshielded” if due to operational requirements it cannot be provided with the inherent degree of protection specified for either Army “protective” or “enclosed” and Air Force shielded installations. Such installations include fenced or “roped-off” areas located either in the open or inside buildings such as hanger bays. An installation so classified shall conform to all of the following mandatory requirements:

a. The source and all objects exposed thereto shall be within a conspicuously posted perimeter that limits the area in which the exposure can exceed 100 mR (1 mSv) in any 1 hour. This area will be conspicuously coated with “Danger, High Radiation Area” or “Caution, High Radiation Area” signs. No person shall have access to the “High Radiation Area” within this perimeter nor may remain in the area during irradiation.

b. A second perimeter delineating a “Radiation Area” shall be calculated, posted with sufficient “Caution, Radiation Area” signs so as to be conspicuous from any direction of approach, and radiation levels verified by radiation surveys. Such radiation surveys shall be documented in operating logs and shall include a minimum of two readings for each side of the radiation boundary. (A “Radiation Area” is defined as any area accessible to individuals in which ionizing radiation dose rate levels could result in an individual receiving a dose in excess of 5 mrem (50 μSv) one hour at 30 centimeters (one foot) from the radiation source or from any source that the radiation penetrates.)

c. Compliance with radiation dose limits applicable to the general public and to occasionally exposed individuals requires that access to areas in which radiation doses could exceed 2 mrem (20 μSv) in any one hour or 100 mrem (1 mSv) in a year must be restricted. “Radiation Area” postings shall be extended out from the X-ray tube such as to encompass such areas, or alternative arrangements made to restrict access to this area.

d. If the beam orientation or technique factors change between exposures, the radiation and high radiation area boundaries must be reestablished and the boundaries of radiation areas re-verified.

e. Rotating/flashing strobe-type (blinking, low intensity, warning lights shall not be used) red warning lights should be used on the perimeter. A rotating/flashing strobe-type (blinking, low intensity, warning lights shall not be used) red warning light shall be positioned at the source and shall be rotating/flashing only when the source is energized.

f. An X-ray interlock (NSN 6635-00-292-7637 or equivalent) or gamma shutter, as applicable, shall be installed between the control unit and the rotating/flashing strobe-type X-ray (or gamma) “on” light. The interlock assembly enables electrical power to the “X-ray on” power circuits only after the rotating/flashing strobe type “X-ray on” warning light is attached. X-ray/gamma radiography interlocks shall be inspected by radiographers each day that the X-ray equipment is used to verify their proper operation. They shall be tested every six months by verifying that they do indeed de-energize the X-ray tube head when tripped.

g. If the perimeter is of such a size or is so arranged that the operator cannot readily determine whether the radiation area is unoccupied, a sufficient number of radiographers and/or radiation safety monitors shall be strategically located to provide adequate visual surveillance over the entire area. These personnel shall have in their possession an adequate and properly calibrated, operable survey meter. This requirement for additional monitors may not be necessary if the radiographic procedures are to be accomplished in a fenced-in or locked area to which access is controlled by the radiographer and not less than one radiation safety monitor. (X-ray and gamma-ray controls should be placed so that all monitors of the entire perimeter of the barrier can be seen and heard by the radiographer. If this is not possible, a hand held battery powered communication device of intrinsically safe design shall be utilized.)

h. The radiation source and equipment essential to the use of the source shall be inaccessible to unauthorized use, tampering or removal when not in use. This shall be accomplished by such means as a locked enclosure.

i. At least two qualified radiographers and as many radiation safety monitor assistants shall be used. If two qualified radiographers are not available, at least one qualified radiographer and as many radiation safety monitor assistants (see page 6-119, paragraph 6.9.6) as required to prevent radiation barrier penetration. Training for radiation safety monitor assistants shall be conducted IAW page 6-119, paragraph 6.9.6.1. This applies to standard industrial X-ray systems only. No radioactive material (RAM) used as the source.

j. If the unshielded installation is in remote area and if entry into the enclosed area can be absolutely prevented during irradiation, the source and all objects exposed thereto may be within a conspicuously posted perimeter that limits the area in which the exposure can exceed 100 mR (1 mSv) in an hour provided:

   (1) The perimeter is posted with a sufficient number of “Caution, (or ′Danger′) High Radiation Area” signs so as to be conspicuous from any direction of approach.

   (2) The boundary of the restricted area can be determined where applicable.

   (3) The requirements of paragraph 6.9.18.3.2 can be met.

k. No person, either within a controlled area or in the environs of the installations, is exposed to more than appropriate basic radiation protection standards prescribed 6.9.10 of this TO.

l. When entering the area after inactivation of the radiation source, radiographers shall use a suitable calibrated survey meter to assure that the source has returned to its “off” position or that X-rays are no longer being produced.

6.9.18.3.3 Operating Procedures.

The following are minimum mandatory requirements that must be adhered to when performing radiographic inspection operations in “unshielded” areas:

6.9.18.3.3.1 General.

Industrial X-ray or sealed gamma-ray sources will be used in unshielded areas by only qualified radiographers and with written approval of the Radiation Safety Officer. (Devices generating “Very High Radiation” areas shall not be used in unshielded areas without prior written approval from the applicable MAJCOM Headquarters.)

6.9.18.3.3.2 Equipment.

In addition to the radiation producing equipment the following equipment must be readily available for use at the site selected for radiographic purposes.

a. At least two serviceable, properly calibrated, radiation survey meters authorized for use with X-ray or gamma radiography operations. One instrument shall be placed by the operator’s console and other utilized for surveys of the perimeter as appropriate. Each radiation survey meter shall be checked for acceptable response to radiation using the provided check source prior to the first operation of the day or shift, and after suspected damage such as would occur if dropped.

b. A minimum of one pocket dosimeter and/or one personal alarming dosimeter, and one TLD badge for each radiographer involved in the radiography operations.

c. An interlock assembly designed to prevent irradiation unless a properly functioning warning light is connected in the circuit.

d. At least two 250-foot coils of rope with sufficient supporting stands (recommended).

e. Radiation warning signs: sufficient quantity of each required type, i.e., “Caution, Radiation Area” and Caution, or “Danger” “High Radiation Area” and “Danger, Very High Radiation Area.”

f. For X-ray equipment, at least 75 feet of power cable and coolant hose; or as recommended by the equipment manufacturer.

g. A rotating/flashing strobe-type (blinking, low intensity, warning lights shall not be used) red light and a radiation warning sign stating “X-ray ON” (or “SHUTTER OPEN” for gamma radiography), when the light is lit. The sign shall be as close to the radiation source as possible and still be visible from all angles of approach, and shall be connected to the control circuit in such a manner that the sign is ON when the radiation source is activated.

h. For night radiographic operations, sufficient lighting equipment to illuminate the area.

i. A minimum of 500 feet (150 meters) of commercially available barrier material which states “CAUTION RADIATION AREA” (bright yellow background with magenta letters and radiation symbol) and self supporting stands may be used to cordon off the affected area.

6.9.18.3.3.3 Restricted Area.

Radiographic operations in unshielded facilities require an initial evaluation of the exposure area to determine the bounds of the area to be restricted during exposure.

a. A restricted area means any area to which access is controlled by the individual in charge of radiation protection for the purpose of protection of individuals from exposure to radiation and radioactive materials. This implies that a restricted area is one that requires control of access, occupancy and working conditions for radiation protection purposes.

b. The dose limit in any unrestricted area from external radiation sources shall not exceed 2 mrem (0.02 mSv) in any one hour. In addition operations shall be conducted such that radiation exposure to individual members of the public shall not exceed 100 mrem (1 mSv) in a year. It shall be noted that the definition does not limit the radiation exposure to a particular rate (such as 2.5 mR/hr), but permits higher exposure rates PROVIDING that the total quantity of radiation in any unrestricted area during any one hour does not exceed 2 mrem (20 μSv) and during any calendar year does not exceed 100 mrem (1 mSv) to any single individual.

c. Special consideration must be given to assure that restricted areas are of sufficient size as to preclude adverse impact on adjacent operations. Assure that qualified experts are consulted prior to initiation of operations if in doubt.

d. Table 6-25 provides summary data comparing the measured exposure rate with the maximum allowable on time (in minutes per hour) of the radiation source so that the total dose in any one hour does not exceed 2 mrem.

Table 6-25. Maximum Permissible Dose Rate Versus Hourly Duty Cycle

Measured Exposure Rate (mrem/hr)	Total Time X-ray Machine (or Gamma-ray Source) Is Operated During a One-Hour Period (minutes)
60	2
40	3
30	4
24	5
20	6
17	7
15	8
13	9
12	10
8	15
6	20
5	24
4	30

6.9.18.3.3.4 Operations.

a. Once the restricted area is identified, it shall be adequately posted to assure against inadvertent entry. In some buildings it may be feasible to lock appropriate doors or limit access to very large work areas as a simple means of radiation area control. In other locations it may be necessary to establish boundaries by roping off or barricading passageways at appropriate locations. In any event, sufficient control in the form of posting, use of safety monitors and use of access limiting devices shall be in place to guarantee that no individual can enter the area inadvertently.

b. In general, when radiographic operations are conducted without benefit of shielding it is necessary to erect a rope barrier around X-ray tube head at a distance of 70 meters (230 feet) or more for vertical beam orientation. For exposures requiring near horizontal or horizontal beams, the barrier may have to be extended in the direction of the beam for several hundred meters to achieve exposure rates at the barrier that are less than or equal to the maximum limits. (Fixed or portable shielding should be used whenever practicable to reduce the size of area which must be controlled.) Obvious1y, if the exposures can be made in an area completely isolated, and unauthorized entry into the radiation area can be absolutely guaranteed, these barriers can be relaxed. However, all entrances into the isolated area shall be secured and posted, and any uncontrolled area must not contain exposure rates that would allow personnel to receive in excess of 2 mrem (20 μSv) in any one hour. All positions around the barrier must be in view of one of the radiographers or radiation monitors during exposures.

c. Place radiation warning signs along the barrier so that at least one can be seen from any direction of approach.

d. Extend the power cable from the tube head to the controls so that the operator is located as far as possible from the radiation source, usually at least 75 feet (23 meters). Place the controls so that all monitors or the entire perimeter of the barrier can be seen by the radiographer. If this is not possible, adequate means of communication shall be specified by either a consultant health physicist or Nuclear Medicine Science Officer or other qualified individual during a survey of the unshielded operation. Adequate means of communications may includes two-way radios, whistles, electronic/propellant-activated noise alarms or ultrasonic infrared intrusion barriers but need not be limited to these methods.

e. Place the sign “X-RAY ON”, when lit, near the X-ray tube and connect to the X-ray interlock circuit.

f. Illuminate the area for night operation.

g. Insure that no one is INSIDE the object being radiographed.

h. Prior to making an exposure, the area shall be surveyed by the radiographers to establish pattern of any radiation fields that may be present and to determine the adequacy of rope barrier placement.

i. Upon completion of the survey and modification of the barrier, if needed, put the film in place and proceed with the radiographic exposure.

j. If the barrier is penetrated by anyone during the exposure, the radiation source shall be turned off immediately and the incident reported to the radiography supervisor.

k. The radiographic apparatus shall NOT be left unattended when operating nor shall it be operated by unauthorized personnel. This equipment shall always be stored in secure area. A key lock shall be installed on all radiographic unit consoles. While in storage or unattended by an authorized radiographer, the power safety-switch key shall be removed from the console and securely maintained separate from the apparatus. Only radiographers authorized by the Unit Commander shall have access to the industrial radiographic unit power safety-switch key storage areas.

l. In the case of multiple exposures in an open area in which the beam direction, intensity (kVp, mA) or attenuating materials are significantly altered, the barrier perimeter shall be re-established as necessary.

m. All information required on the bound utilization log shall be recorded by the radiographer. (Army only, if a suspected overexposure has occurred). This will include the radiation levels detected at the barrier.

6.9.19 Design or Modification of Installations.

6.9.19.1 Responsibility for Determining Shielding Requirements.

The structural shielding requirements of any new installation or of an existing one in which changes are contemplated, may be decided by a health physicist, radiological physicist, or a Nuclear Medicine Science Officer provided it is approved by the appropriate MAJCOM Headquarters.

6.9.19.2 Data required For Determining Shielding Requirements.

To adequately determine shielding requirements, the following data concerning the source of radiation must be provided:

a. Type of radiation source (e.g., X-ray or gamma-ray)

b. Maximum and average tube potential (kilovoltage) or the energy of the radiation.

c. Maximum and average tube current (milliamperage) or the source output in roentgens per hour at one meter (Rhm) from the source.

d. The expected workload in hours per week.

e. The use factors for each wall, floor and ceiling as appropriate. This is the fraction of the workload during which the useful beam is pointed in the direction under consideration (see Table 6-26).

f. The type of occupancy of all areas which might be affected by the installation (see Table 6-27).

g. The structural details of the building. This will include a dimensioned drawing of the facility, with notation of the typical distances from the x-ray source to each barrier of the facility, as well as the expected construction materials for the facility.

Table 6-26. Use Factors (U)*

		Enclosed	
Installation Use	Exempt All Uses	Collimated Sources	Open Sources
Floors	1	1	1
Walls	1	¼	1
Ceilings	1	1/16	1

* For use as a guide in planning shielding when complete data are not available

Table 6-27. Occupancy Factors (T).

Full Occupancy (T = 1) X-Ray control space and waiting space, darkrooms, film reading areas, workrooms, shops, offices and corridors large enough to hold desks, living quarters, children's play areas, occupied space in adjoining buildings.
Partial Worker Occupancy (X = ¼) Worker restrooms, occupational use corridors too narrow for desks.
Partial Occupancy (X = 1/8) Public corridors too narrow for desks, utility rooms, employee lounge.
Occasional Public Occupancy (T = 1/20) Rest rooms or bathrooms, storage rooms, vending areas, outdoor areas with seating
Rare Occupancy (T=1/40)Outside areas used only for pedestrians or vehicular traffic, unattended parking lots, attics or crawl spaces, stairways, unattended elevators, janitors closets.

* For use as a guide in planning shielding where adequate occupancy data are not available.

6.9.19.3 Direction of Useful Beam.

a. The cost of shielding may be reduced significantly by arranging the installation so that the useful beam is directed toward occupied areas as little as possible. (There is, of course, no objection to directing the useful beam at occupied areas provided there is adequate protection.)

b. Devices that permanently restrict the direction and cross section of the useful beam may reduce the area requiring primary barriers.

6.9.19.4 Radiation Energy, Output and Workload.

The shielding for each occupied area shall be determined on the basis of the expected maximum kilovoltage or energy, mA or Rhm, workload, use factor and occupancy factor affecting it. Consideration should be given to the possibility that the values of these parameters may increase in the future. It may be more economical to provide a higher degree of protection initially than to add to it later.

6.9.20 Structural Details of Protective Barriers.

Shielding for radiographic installations is normally provided by installation of sheet lead, or concrete. Facilities where high workloads and gamma-ray sources are used may use a combination of these materials, or use concrete loaded with a high iron content aggregate to improve shielding efficiency. The half-value layers of lead and concrete (the thickness of each material necessary to reduce the exposure intensity by a factor of two) for various energy x-rays and gamma rays is shown in Table 6-28.

Table 6-28. Peak Voltage (kVp)

TABLE. HALF-VALUE AND TENTH-VALUE LAYERS						
|Approximate values obtained at high attenuation for the indicated peak voltage at, Peak Voltage (kVp)						
Attenuation Material						
Peak Voltage (kVp)	Lead (mm)		Concrete (in)		Steel (in)	
	HVL	TVL	HVL	TVL	HVL	TVL
50	0.05	0.16	0.17	0.6		
70	0.15	0.5	0.33	1.1		
100	0.24	0.8	0.6	2.0		
125	0.27	0.9	0.8	2.6		
150	0.29	0.95	0.88	2.9		
200	0.48	1.6	1.0	3.3		
250	0.9	3.0	1.1	3.7		
300	1.4	4.6	123	4.1		
400	2.2	7.3	1.3	4.3		
500	3.6	11.9	1.4	4.6		
1000	7.9	26	1.75	5.8		
2000	12.7	42	2.5	8.3		
3000	14.7	48.5	2.9	9.5		
4000	16.5	54.8	3.6	12.0	1.08	3.6
6000	17.0	56.6	4.1	13.7	1.2	4.0
10000	16.5	55.0	4.6	15.3		
Cesium-137	6.5	21.6		6.2	.064	2.1
Cobalt-60	12	40		8.1	0.82	2.7
Radium	16.6	55	2.7	9.2	0.88	2.9

6.9.20.1 Quality of Protective Material.
All shielding materials shall be of assured quality, uniformity and permanency

6.9.20.2 Lead Barriers.

a. Lead barriers shall be mounted in such a manner that they will not cold-flow because of their own weight and shall be protected against mechanical damage.

b. Lead sheets at joints should be in contact with a lap of at least one-half inch, or twice the thickness of the sheet, whichever is the greater.

c. Welded or burned lead seams are permissible provided the lead equivalent of the seams is not less than the minimum requirement.

6.9.20.3 Joints Between Different Materials or Structures.

a. Joints between different kinds of protective materials shall be constructed so that the overall protection of the barrier is not impaired.

b. Joints at the floor and ceiling shall be constructed so that the overall protection is not impaired.

6.9.20.4 Shielding Of Openings in Protective Barriers.

In the planning of an installation, careful consideration should be given to reducing the number and size of all perforations of protective barriers and openings into the protected areas. Protection for all such openings shall be provided by means of suitable protective baffles.

a. Perforations. Provision should be made to ensure that nails, rivets, or screws which perforate lead barriers shall be covered to give protection equivalent to that of the unperforated barrier.

b. Openings for Pipes, Ducts, Conduits, Louvers, etc. Holes in barriers for pipes, ducts, conduits, louvers, etc. shall be provided with baffles to insure that the overall protection afforded by the barrier is not impaired. These holes should be located outside the range of possible orientations of the useful beam.

c. Doors and Observation Windows. The lead equivalent of doors and observation windows of exposure rooms, cubicles, and cabinets shall not be less than that required for the walls or barrier in which they are located.

6.9.20.5 General Requirements for Doors into Protected Areas.

a. Location of Doors. Where practical, doors into exposure rooms should be so located, that the operator has control of access to the room.

b. Interlock Switches for Doors. All door(s) and panel(s) opening into an X-ray exposure room or cabinet (except those that can be opened or removed only with tools) shall be provided with single interlocking switches preventing irradiation unless the door or panel is closed. Double doors shall have interlock switches that operate independently of each other.

c. Resumption of Operation. If the operation of any radiation source has been interrupted by the opening of a door or panel to a Shielded, Protective or Enclosed Installation, it shall not be possible to resume operation by merely closing the door or panel in question. To resume operation, it must be necessary to re-energize the source at the console, and this procedure shall cause the time delay interlock system to be reinitiated. It shall NOT be possible to resume operation by merely re-engaging the interlock.

d. Escape, or Interruption of Irradiation, from Inside Exposure Room. The exposure room shall include at least one means of exit that may be rapidly opened from the inside. Suitable means shall be provided to quickly interrupt irradiation from inside the room. The means of accomplishing this shall be explained to all personnel and a sign explaining its use shall be conspicuously posted inside the exposure room. Preferably, the beam should not be directed toward the door or interrupting device.

e. Threshold Baffle for Door Sill. A door baffle or threshold will generally be required for radiography sources and for installations operating above 125 kVp, if the discontinuity can he struck by the useful beam.

f. Lap of Door Jamb. The protective lead covering of any door leading to an exposure room or cabinet shall overlap that of the door jamb and lintel so as to reduce the radiation passing through clearance spaces to the allowable limit for the door itself.

SECTION X

6.10 RT REFERENCES.

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GLOSSARY

A

ABSOLUTE (ET): Refers to measurements made without a direct reference in contrast to differential measurements. Absolute measurements are affected by any change in electromagnetic properties; differential measurements are affected only by differences between the test area and a comparative standard.

ABSOLUTE PROBE: A probe containing a coil that responds to all electromagnetic properties of the test part.

ABSOLUTE SIGNAL: The value of the amplitude of a signal without consideration of its relative phase, frequency or waveform.

ABSORBED DOSE: The energy imparted by ionizing radiation per unit mass of irradiated material. The units of absorbed dose are the rad and the gray (Gy).

ABSORPTION: The process whereby the particles or quanta (see PHOTON) in a beam of radiation are reduced in number or energy as they pass through some medium. The particles lose energy by interaction with either the nucleus (core) or electrons (shell) of the atoms of the medium.

ABSORPTION COEFFICIENT (RT): A fraction expressing the decrease in the intensity of a beam of radiation per unit thickness (linear absorption coefficient), or per atom (atomic absorption coefficient of the medium through which the radiation is passing).

ABSORPTION COEFFICIENT, LINEAR (UT): The fractional decrease in transmitted intensity per unit of absorber material thickness. It is designated by the symbol (µ) and is expressed in units of cm-1.

ABSORPTION (PT): The process of one material (liquid, solid, or gas) merging with a second material by penetration into the particles of the second material ... as opposed to adsorption where the material coats and is retained on the surface of the particles of the second material.

ABSORPTION (RT): The process whereby the particles or quanta (see PHOTON) in a beam of radiation are reduced in number or energy as they are passed through some medium. The particles lose energy by interaction with either the nucleus (core) or electron (shell) of the atoms of the medium.

ADSORPTION (PT): The process of one material (liquid, solid, or gas) merging with a second material by coating and being retained on the surface of the particles (and interstices) of the second material ... as opposed to absorption where the material penetrates into the particles of the second material.

AC (ALTERNATING CURRENT): Electric current that reverses its direction of flow at regular intervals.

ACCELERATOR: A device that accelerates charged atomic particles to high energies. An X-ray machine or a betatron is an accelerator.

ACCEPTANCE NUMBER: The term used to designate the allowable number of defects in a statistical quality control sample.

ACID EMBRITTLEMENT: A form of hydrogen embrittlement that may be induced in some metals by acid treatment.

ACOUSTIC IMPEDANCE (UT): A material property, which determines the product of the velocity of sound in a material and the density of the material used in determining the reflection characteristics of interfaces.

ACTIVATION: The process by which neutrons bombard stable atoms to make them radioactive.

ACTIVITY: A measure of how radioactive a particular radioisotope is. Activity is calculated by the number of atoms disintegrating per unit of time. Its unit of measurement is the curie. See SPECIFIC ACTIVITY.

ACUTE RADIATION SYNDROME (RT): The immediate effects of a short-term whole-body over exposure of a person to ionizing radiation. These effects include nausea and vomiting, malaise increased temperature, and blood changes.

ADDED FILTER: Filter added to the inherent filtration.

ADDITIVE, ABSORPTIVE (RT): See CONTRAST AGENT.

ADHERENCE: The extent to which a coating bonds to a substrate.

ADHERENCE INDEX: The measure of the adherence of porcelain enamel and ceramic coatings to sheet metal (ASTMC-313).

ADHESION: The adhering or sticking together of substances in contact with each other.

AERIAL IMAGE (RT): The representation (in relief) of the distribution of the intensity of the radiation in the plane of the radiograph (plane of the film).

AFTERGLOW (RT): The persistence of light emission from an intensifying screen or fluorescent screen after an exposure. It is a form of phosphorescent radiation.

AGE HARDENING: Increasing the hardness and possible strength of an alloy by a relatively low-temperature heat treatment that causes precipitation of components or phases of the alloy from the supersaturated solid solution. Also known as precipitation hardening.

AGGLOMERATION (PT) (MT): An indiscriminately formed mass. A cluster of disparate elements.

AGING: A metallurgical change in a metal alloy resulting in an increase in mechanical properties. This change can occur in some instances at room temperatures. More often its effects are increased by holding for specified lengths of time at elevated temperatures. Also known as precipitation hardening.

AIR-COOLED TUBE (RT): An X-ray tube for which the principal method of cooling is dissipation of heat into surrounding air.

AIRCRAFT QUALITY STEEL: Steel produced in such a way as to be as nearly free of discontinuities as possible.

AIR GAP (MT): When a magnetic circuit contains a small gap that the magnetic flux must cross, the space is referred to as an air gap. Cracks produce small air gaps on the surface of a magnetized part.

AIR HOLE: A hole in a casting caused by air or gas trapped in the metal during solidification; also, Gas Hole

AIR SCATTER (RT): Ionizing radiation that, because of a scattering interaction with air, arrives at a point by way of an indirect route instead of arriving directly from the source.

ALARA: (acronym for “as low as is reasonably achievable") means making every reasonable effort to maintain exposures to radiation as far below dose limits as is practical consistent with the purposes for which the radiation exposure is received, taking into account the state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of radiation in the public interest.

ALCLAD ALUMINUM: A term applied to aluminum alloy sheet and wire products to which a thin coating of high purity aluminum or aluminum alloy of different composition has been bonded for corrosion protection.

ALLOY: A metal composed of two or more chemical elements at least one of which is a metal.

ALLOY STEEL: Steel that has had sufficient quantities of alloying elements added to produce desired changes in the mechanical or physical properties.

ALLOY SYSTEM: A complete series of compositions produced by mixing in all proportions any group of two or more components, at least one of which is a metal.

ALLOYING ELEMENT: An element added to a metal to create a desired change in its properties.

ALPHA PARTICLE (RT): A positively charged particle emitted by certain radioactive materials. It is made up of two neutrons and two protons; hence it is identical with the nucleus of a helium atom.

ALPHA “RAY” (RT): A stream of fast moving helium nuclei. This is a strongly ionizing radiation with very weak penetration.

ALPHA ROCKWELL HARDNESS: The index of the resistance of a plastic to surface penetration by a specified indentor under a specified load applied with a tester. Higher values indicate higher resistance to indentation (ASTMD-785).

ALTERNATING CURRENT (AC): Alternating current is current that reverses its direction of flow at regular intervals. Such current is frequently referred to as AC

ALUMINUM EQUIVALENT (RT, UT): The thickness of aluminum having a specified purity, affording the same attenuation, under specified conditions, as the material in question.

AMPERAGE: The strength of a current of electricity measured in amperes.

AMPERE: This is the unit of electrical current. One ampere is the current that flows through a conductor having a resistance of one ohm, at a potential of one volt.

AMPERE TURNS (MT): This term refers to the product of the number of turns in a coil and the number of amperes of current flowing through it. This is a measure of the magnetizing or demagnetizing strength of the coil. For example: 800 amperes in a 6 turn coil = 800 x 6 = 4800 ampere turns.

AMPLIFIERS: Circuit components that increase the magnitude of an electronic signal.

AMPLITUDE: The extent of vibratory movement measured from the mean position to an extreme; the maximum departure of alternating voltage or current from the average value; indicated by vertical height on an A-scan presentation.

AMPLITUDE ECHO (UT): The total vertical or pulse height of the received signal indicated by “A” scan presentation.

AMPLITUDE RESPONSE: That property of the test system whereby the amplitude of the detected signal is measured without regard to phase.

AMU: Atomic mass unit.

ANGLE BEAM (UT): A sound beam traveling at some angle other than normal to me surface of the test object. Measured from normal incidence.

ANGLE OF INCIDENCE (UT): The angle defined by the direction of propagation of refracted wave and the normal to the interface at the point of incidence.

ANGLE OF REFLECTION (UT): The angle defined by the direction of propagation of refracted wave and the normal to the interface at the point of incidence.

ANGLE TRANSDUCER (UT): A transducer used in angled testing in which the sound beam is set to some predetermined angle to achieve a special effect, e.g., setting up shear or surface waves in the tested piece.

ANGSTROM (A): Unit of length usually reserved for the expression of wavelength. One Angstrom equals 10-8 cm. Under the standard system of units, the Angstrom will be replaced by the nanometer (1.0 A = 0.10 nm). This is the standard unit for measuring wavelengths of light.

ANNEAL: Heating metal to above its critical temperature range, then slowly cooling to remove stresses, induce softness, remove gases, alter ductility, induce toughness, or modify electrical, magnetic or other physical properties.

ANODE (TARGET) (RT): The positive terminal of an X-ray tube. It is a high atomic number, high melting point element, and receives the electron bombardment from the cathode or negative terminal.

ANODE CORROSION: The dissolution of a metal acting as an anode.

ANODE CURRENT (RT): See tube current.

ANODE STEM (RT): The metallic rod on which the target is mounted, and which is sealed to the envelope of the X-ray tube.

ANODIZING: Forming a coating on a metal surface by anodic oxidation; most frequently on aluminum.

ANTINODE: Point in a standing wave where some characteristics of the wave field has a maximum amplitude.

ANTI-SCATTER GRID (RT): An array of X-ray opaque and transparent sections of materials placed between the specimen and the film to minimize the effect of scattered radiation on the radiographic image, e.g., a Potter-Bucky diaphragm.

APPLICATION TIME (PT): The period of time wherein parts are immersed in a bath of liquid penetrant, plus the time the liquid penetrant remains on the surface of the part, i.e., soak time and dwell time.

ARC STRIKE: A burned area where the weld or adjacent surface is marred by the slight addition or loss of metal usually caused by inadvertent contact with the welding electrode.

AREA MONITORING (RT): The continued measurement of ionizing radiation exposure or dose levels in an area for the purpose of radiation protection.

AREA OF INTEREST (RT): The specific portion of the specimen image on the radiograph that is to be evaluated.

ARTIFACT (RT): Film blemishes produced during the manufacture, packaging, handling, or processing of film which are not associated with the actual condition of the material tested. They appear as white or black crescents, fogging, staining, etc.

A-SCAN (UT): A data presentation method by which intelligence signals from a signal object located are displayed. As generally applied to pulse echo ultrasonics, the horizontal and vertical sweeps are proportional to time or distance and amplitude or magnitude respectively. Thus the location and magnitude of acoustical interface are indicated as to depth below the transducer.

ASTM: Abbreviation for American Society for Testing and Materials.

ASTM BLOCK: Specific type of reference standard, cylindrically shaped and having a specified size FBH at a specified metal travel distance from the top of the block. See ASTM.

ASTM HARDNESS NUMBER: The depth (in thousandths of an inch) of penetration of an indentor into a rubber specimen under loads and conditions specified in ASTMD-314. While suited for most common grades of rubber, ASTM hardness number is not applicable to extremely hard or soft rubbers.

ATOM: The smallest particle of an element that can enter into a chemical combination. All chemical compounds are formed of atoms, the difference between compounds being attributable to the nature, number and arrangement of their constituent atoms.

ATOMIC MASS UNIT (AMU): 1.66 x 10-24 grams. Arbitrarily defined as 1/12th of a carbon-12 atom. An AMU is approximately the mass of a proton (1.0073 AMU) or a neutron (1.0087 AMU).

ATOMIC NUMBER: An integer that expresses the positive charge of the nucleus in multiples of the fundamental electronic charge. In present theory, it is the number of protons in the nucleus.

ATOMIC WEIGHT: The relative weight of the atom of an element, referred to some element taken as a standard. An atomic weight of 16 for oxygen is the one usually adopted as a basis for reference.

ATTENUATION (RT): Reduction in the intensity of a beam of ionizing radiation due to passage through matter.

ATTENUATION (UT): Loss of energy caused by scattering of the sound beam within a material or at an interface or an electronic device in or attached to the instrument.

ATTENUATION COEFFICIENT (RT): Average rate that a beam of radiation changes as it passes through a body.

ATTENUATOR: A device that causes a known loss in energy of a beam that is passed through it. It may be calibrated in decibels.

AUGER ELECTRON (RT): An orbital electron emitted by an atom, instead of a photon of characteristic radiation, when a vacancy in an inner electron shell is filled.

AUSTENITIC STEELS: Steels whose constituents remain in solution with each other at room temperature and are, therefore, non-magnetic and corrosion resistant.

AUTORADIOGRAPH (RT): The image of an object obtained on a photographic emulsion by means of radiation emitted by the object itself.

AUTORADIOGRAPHY (RT): A test in which the object being inspected is radioactive, or made radioactive, and the inherent radiation so produced is used to produce the image on a film.

AUTOTRANSFORMER (RT): A special type of transformer in which the output voltage can be easily varied. The autotransformer is thus employed to adjust the primary voltage applied to the step-up transformer that produces the high voltage applied to the X-ray tube.

AVERAGE GRADIENT (RT): (of a film) The steepness of the characteristic curve of a film. Usually measured as average gradient between two levels of density; e.g., the average gradient between a density of 0.25 and a density of 2.0 is the slope of a straight line connecting these points. Most x-ray films have a gradient of 2.5 to 4.0, and any film with a gradient over 1.0 amplifies the subject contrast.

AVERAGE LIFE (MEAN LIFE) (RT): The arithmetic mean value of the lives of the atoms of a radioactive nuclide. It is the reciprocal of the decay constant.

B

BACKGROUND (PT, MT): The surface of the test part upon which the indication is viewed. It may be the natural surface of the test part, or it may be the developer coating on the surface. This background may contain traces of unremoved penetrant, fluorescent or visible, which if present, can interfere with the visibility of the indication.

BACKGROUND FLUORESCENCE (PT): Fluorescent residues observed over the general surface of the part during fluorescent penetrant inspection. It is usually due to poor emulsification or rinsing of the fluorescent penetrant, or due to excessive roughness of the surface causing entrapment of the fluorescent penetrant.

BACKGROUND NOISE (UT): Extraneous signals caused by signal sources within the ultrasonic testing system, including the material in test.

BACKGROUND RADIATION (RT): Radiation coming from sources other than the radioactive material or X-ray machines used in making an exposure. Such radiation is primarily due to cosmic radiation from outside the earth's atmosphere and leakage from nearby sources.

BACK REFLECTION (UT): Signal from the far boundary of the test part.

BACKSCATTER (RT): Secondary radiation that is deflected at angles greater than 90 degrees with respect to the original direction of motion. Such radiation should be filtered from the film, as they bring no information to the film and cause a reduction in contrast due to an increase in noise.

BAND PASS FILTER: An electronic circuit which allows flow of signals of a specific frequency range but suppresses signals of both greater and smaller rates of response.

BANDED STRUCTURE: A segregated structure of nearly parallel bands aligned in the direction of working.

BACKING RING: A metal ring placed inside pipe for butt welding, to assure complete weld penetration and a smooth internal surface.

BANDWIDTH: The range of a band of different frequencies; the number of hertz between the maximum frequency of the range and the minimum frequency of the range, usually measured between points of equal and stated amplitude levels.

BANKING CONCEPT (RT): An idea or model used to facilitate the explanation of radiation exposure permitted in a lifetime.

BARIUM CLAY (RT): A molding clay blocking material containing barium used to eliminate or reduce the amount of scattered or secondary radiation reaching the film.

BARIUM CONCRETE (RT): Concrete containing a high portion of barium compounds, used for radiation protection purposes.

BARIUM PLASTER (RT): Plaster containing a high proportion of barium compounds, used for radiation protection purposes.

BARIUM TITANATE TRANSDUCER (UT): (Polycrystalline Barium Titanate BaTiO3). A ceramic material composed of many individual crystals fired together, and polarized by the application of a D.C. field for use as a transducer.

BARK: The decarburized layer just beneath the scale that results from heating steel in an oxidizing atmosphere.

BARN (RT): A very small unit of area used in measuring the cross sections of atoms, nuclei, electrons, and other particles. One barn is equal to 10-24 square centimeter. The term is a measure of the probability that a given nuclear reaction will occur.

BARRIER (PROTECTIVE) (RT): Barrier of attenuating materials used to reduce radiation exposure.

BASE DENSITY (RT): The slight density that is due only to the film base and the blue dye in it. It is measured with the emulsion layer removed, or on a film which has been fixed without prior development.

BASE PLUS FOG (RT): The density of a film’s base material plus the darkening of its emulsion caused by fog. The base plus fog level brings no useful information to the film and merely creates a high background that reduces contrast and image visibility.

BASELINE (UT): The horizontal trace across the A-scan CRT display for a no signal condition.

BATH (colloquial) (PI, MT):

(1) The liquid penetrant inspection materials (penetrant, emulsifier, developer) into which parts are immersed during the inspection process.

(2) Penetrant materials retained in bulk in immersion tanks intended for re-use.

(3) Term used to designate a suspension of ferromagnetic particles with oil or water.

BEAM: A directed flow of energy into space or matter.

BEAM ANGLE (RT): The smallest angle between the central axis of the radiation beam and the plane of the radiographic film.

BEAM DIVERGENCE (RT): The solid angle of the beam of radiation as it emerges from the X-ray tube or gamma-ray exposure device.

BEAM QUALITY (RT): An expression used to describe the penetrating power (energy spectrum) of a beam of radiation. The quality of an X-ray beam is usually expressed in terms of the half-value layer of some reference material, such as aluminum or copper.

BEAM SPREAD (UT): Divergence of a sound beam as it travels through material.

BERNOULLI EFFECT (PT): A law of hydrodynamics: a liquid will flow through a conduit at a constant velocity governed by the pressure. When a section of the conduit is decreased in size, the velocity of the liquid flow in the reduced section is increased. If a small opening is placed in the reduced section, a vacuum or suction will be created at the opening.

BETA PARTICLE (RT): An electron or positron emitted from a nucleus during decay. The term “beta particle” is reserved for electrons and positrons.

BETA “RAY” (RT): A stream of high speed electrons that is of nuclear origin. This radiation is more penetrating than alpha radiation, but it ionizes less strongly.

BETATRON (RT): A circular electron accelerator that is a source of either high energy electrons or X-rays. The electrons are injected by periodic bursts into a region of an alternating magnetic field. After acceleration, the electrons are brought out directly or directed against a target to produce X-rays.

BLACK LIGHT (PT, MT): The term given to electromagnetic radiation having wavelengths from 320-400 nm. Typical units used in penetrant inspection provide an intensity of 100 to 150 foot-candles at 15 inches from the lace of the filter and are used to excite fluorescent materials in a range visible to the eye.

BLACK LIGHT INTENSITY (PT, MT): The amount of properly filtered black light measured at the surface of the part being inspected.

BLACK LIGHT FILTER (PT, MT): A filter that transmits ultraviolet light (320-400-nm wavelength) while suppressing the transmission of visible light of the longer wavelengths.

BLEED OUT (PT): The action by which the penetrant exudes out of the discontinuities onto the surface of a component, due primarily to “capillary action” and to “blotting” or “soaking up” effect of the developer.

BLISTER: A defect in metal on or near the surface, resulting from the expansion of gas in a subsurface zone. Very small blisters are called “pinheads” or “pepper blisters.”

BLOCKING: See MASKING.

BLOCKING MEDIUM (RT): Material of appropriate radiation opacity for applying to an object, either around the edges or as a filling for holes, to reduce the effect of scattered radiation and to shield portions of the film which would otherwise be overexposed (e.g., radiographic putty).

BLOTTING (PT): The action of the developer in soaking up the penetrant from the surface of the discontinuity, so as to cause maximum bleed out of the dye penetrant for increased contrast and sensitivity.

BLOWHOLE: A hole in a casting or a weld caused by gas entrapped during solidification. See POROSITY.

BLUR (RT): See unsharpness; penumbra.

BODY (PT): The term used to describe the ability of a penetrant vehicle to maintain an adequate suspension of visible or fluorescent dye material.

BODY BURDEN: The amount of radioactive material present in the body of man or animals.

BOLTHOLE PROBE (ET): A probe coil(s) assembly used for electromagnetically inspecting the walls of fastener holes or other small holes of limited length.

BOLTHOLE SCANNER (ET): An eddy current device designed to provide automatic, uniform inspection of walls of fastener holes.

BOTTOM ECHO (UT): See BACK REFLECTION.

BOUNDARY ECHO (UT): A reflection of an ultrasonic wave from an interface.

BOUNDARY WAVELENGTH (QUANTUM LIMIT) (RT): The shortest wavelength present in a continuous X-ray spectrum. It is inversely proportional to the peak voltage applied to the X-ray tube.

BRAZING: Joining of metals and alloys by fusion of nonferrous alloys that have melting points above 800°F, but lower than melting points of materials being joined.

BREMSTRAHLUNG (RT): Electromagnetic radiation emitted by charged particles when they are slowed down by electric fields in their passage through matter. Literally, “braking radiation” in German.

BRIDGE CIRCUIT (ET): An electrical circuit designed to pass only the changes in voltage or current flow through a system while eliminating the larger steady state component. Such circuits in eddy current inspection reflect the changes in the electromagnetic variables while eliminating the larger current from the readout.

BRIGHTNESS AMPLIFIER (RT): See image intensifier.

BRINELL HARDNESS: A measure of the hardness of a metal, as determined by pressing a hard steel ball into the smooth surface under standard conditions. For aluminum, the steel ball is 10 millimeters in diameter and total load is 500 kilograms. Results are calculated as the ratio of applied load to total surface area of indentation and are referred to in terms of Brinell Hardness Number or BHN.

BRITTLE CRACK PROPAGATION: A very sudden propagation of a crack with the absorption of no energy except that stored elastically in the body. Microscopic examination may reveal some deformation even though it is not noticeable to the unaided eye.

BRITTLE FRACTURE: Fracture with little or no plastic deformation.

BRITTLENESS: The quality of a material that leads to crack propagation without appreciable plastic deformation.

BROAD-BANDED (UT): Having a relatively large bandwidth; used to describe instruments having an initial pulse with a relatively wide bandwidth and an amplifier with response to a relatively wide range of frequencies; opposite of narrow-banded or tuned.

BROAD BEAM (RT): An uncollimated beam containing scattered radiation as well as the primary beam.

BROAD-BEAM ABSORPTION (RT): Absorption measured under conditions in which scattered radiation is not excluded from the measuring apparatus.

B-SCAN (UT): A data presentation method generally, applied to pulse echo techniques which yields a two dimensional view of a cross-sectional plane through the test piece. The horizontal sweep is proportional to the test piece, with the vertical sweep proportional to distance, showing the front and back surfaces and discontinuities between.

BUBBLER (UT): See WATER DELAY COLUMN.

BUILD-UP (RT): An increase in radiation transmitted through material because of forward scatter.

BUILD-UP FACTOR (RT): In the passage of radiation through a medium, the ratio of the total value of a specified radiation quantity at any point to the contribution to that value from radiation reaching the point without having undergone a collision.

BUNSEN-ROSCOE RECIPROCITY LAW (RT): States that the end result of a photochemical reaction is dependent only on the product of the radiation intensity (1) and the duration of the exposure (t), and is independent of absolute values of either quantity. This implies that the resultant density of a film would depend only on the products of the radiation intensity reaching the film and the exposure time.

BURNING: Extreme overheating makes grains excessively large and causes the more fusible constituents of steel to melt and run into the grain boundaries, or it may leave voids between the grains.

BURST: Fissures or ruptures caused by rolling or forging improperly or at improper temperatures.

BY-PRODUCT MATERIAL (RT): In atomic energy law, any radioactive material (except source or fissionable material) obtained in the process of producing or using source or fissionable material. Includes fission products and many other radioisotopes produced in nuclear reactors.

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CALCIUM TUNGSTATE (RT): A fluorescent chemical compound which emits visible blue-violet light when activated by either X- or gamma radiation.

CALIBRATION: The standardization of the instrument, prior to test, to a known reference value.

CALIBRATION STANDARD: See REFERENCE STANDARD.

CANNON TUBE SHIELD (RT): A tube shield in the form of a long cylinder generally supported in cantilever fashion. The X-ray beam emerges through an aperture in the lead-lined wall of the cylinder, at right angles to its axis.

CAPILLARY ACTION (PT): The tendency of certain liquids to travel or climb when exposed to small openings, cracks, fissure, etc., due to factors such as surface tension, cohesion, adhesion and viscosity.

CARBON STEEL: Steel that does not contain significant amounts of alloying elements other than carbon. Also known as straight carbon, ordinary steel or plain carbon steel contains carbon up to 2%, also termed plain carbon steel or ordinary steel.

CARBURIZE: To produce surface hardness on low carbon steels by heating above the critical range while in contact with a suitable material containing carbon.

CARRIER FLUID (MT): A term used colloquially to designate the liquid used to carry the magnetic substance for the wet process.

CASCADE TUBE (RT): A high voltage X-ray tube of cylindrical form divided into sections, the potential difference across each of which is a fraction of the voltage applied to the whole tube. The electron stream is accelerated to its maximum energy in stages.

CASE: In a ferrous alloy, the outer portion that has been made harder than the inner portion, or core, by CASE HARDENING.

CASE HARDENING: Hardening a ferrous alloy so that the outer portion, or case, is made substantially harder than the inner portion, or core. Typical processes used for case hardening are carburizing, cyaniding, carbonitriding, nitriding, induction hardening and flame hardening.

CASSETTE (RT): A lightproof container used for holding the radiographic films in position during the radiographic exposure. These holders may or may not contain intensifying and/or filter screens.

CASTING:

(1) An object at or near finished shape obtained by solidification of a substance in a mold.

(2) Pouring molten metal into a mold to produce an object of desired shape.

CASTING SHRINKAGE:

(1) “Liquid shrinkage” - the reduction in volume of liquid metal as it cools to the liquidus.

(2) “Solidification shrinkage” the reduction in volume of metal from the beginning to ending of solidification.

(3) “Solid shrinkage” - the reduction in volume of metal from the solidus to room temperature.

(4) “Total shrinkage” - the sum of the shrinkage in parts (1), (2) and (3).

CASTING STRAINS: Strains in a casting caused by casting stresses that develop as the casting cools.

CASTING STRESSES: Stressed set up in a casting because of geometry and casting shrinkage.

CAST-WELD ASSEMBLY: An assembly formed by welding one casting to another.

CATHODE (RT): The negatively biased electrode of an X-ray tube from which the electrons are emitted to be accelerated to the anode.

CATHODE RAY (UT, RT): A stream of electrons emitted by a heated filament and projected in a more or less confined beam under the influence of a magnetic and/or electric field.

CATHODE RAY TUBE (UT): A vacuum tube, containing a screen, upon which signals are displayed; basic display device for an A-scan. Abbreviation is CRT.

CENTISTOKE: A unit of kinematic viscosity. Water has a viscosity of about one centistoke.

CENTRAL CONDUCTOR (MT): A conductor made of copper, aluminum, steel or flexible cable that is passed into or through an opening in a cylindrically-shaped part or other shapes when applicable for the purpose of establishing a circular field on the inside diameter.

CENTRIFUGAL CASTING: A casting made in a mold (sand, plaster, or permanent mold) which rotates while the metal solidifies under the pressure developed by centrifugal force.

CERMET (PT): A strong alloy of a heat-resistant compound and a metal.

CERTIFIED DENSITY (RT): See STEP-WEDGE CALIBRATION FILM.

CESIUM-137: A radioactive isotope of the element cesium having a half-life of 80 years, plus or minus three years.

CESIUM-137 (RT): A radioactive nuclide of the element cesium having a half-life of 30 years, and photon energy of 882 KeV (which is 0.862 MeV).

CHAIN REACTION: A reaction that stimulates its own repetition. In a fission chain reaction, a fission nucleus absorbs a neutron and fissions, releasing more than one additional neutron. These in turn can be absorbed by other fissionable nuclei, releasing more neutrons. A fission chain reaction is self-sustaining when the number of neutrons released in a given time interval equals or exceeds the number of neutrons absorbed.

CHALK TEST: The forerunner of modern penetrant methods. A method of locating cracks by applying oil to a part and then removing the excess from the surface, which is then coated with whiting or chalk. After a short period of time the oil seeps out of the cracks into the whiting, or chalk, causing an appreciable difference in whiteness. This method has been replaced with more advanced penetrant methods for most applications.

CHARACTERISTIC CURVE (RT): A curve which expresses film density as a function of log relative exposure. These curves are useful in determining exposure correction factors and to define the gamma characteristics of the film.

CHARACTERISTIC RADIATION (RT): X-radiation consisting of discrete wavelengths which are characteristic of the emitting material.

CHARPY: The name of an impact-testing machine that tests a specimen by striking it with a swinging hammer. The specimen is placed against anvil supports that are 40 millimeters apart.

CHATTER: In machining or grinding,

(1) A vibration of the tool, wheel or workpiece producing a wavy surface on the work.

(2) The finish produced by such vibration.

CHECKS (CHECK MARKS): Numerous, very small cracks in metal or other material caused in processing.

CHEMICAL FOG (AERIAL FOG) (RT): Fog caused by unwanted chemical reactions during processing of film.

CHILL:

(1) A metal insert imbedded in the surface of a sand mold or core or placed in a mold cavity to increase the cooling rate at that point.

(2) White iron occurring on a gray iron casting, such as the “chill” in the wedge test.

(3) (Unfused chaplets) A uniform line or band outlining the object and indicating the lack of fusion between the metal and the casting.

CHLORINATION: The process of passing dry chlorine gas through molten aluminum alloys to remove trapped oxides and dissolved gases.

CINE-FLUOROGRAPHY (RT): Cine-radiography of images produced on a fluorescent screen.

CINE-RADIOGRAPHY (RT): The production of a series of radiographs that can be viewed rapidly in sequence, thus creating an illusion of continuity.

CIRCULAR MAGNETISM (MT): When an electric current is passed through a solid magnetic conductor, a circular magnetic field is developed not only around the conductor, but also within the conductor.

CLADDING: A process wherein a metallic coating is applied to a base metal by simultaneously rolling the base metal and the cladding material.

CLEAN: Free of solid or liquid contamination from the surface or in the voids of the flaw that may interfere with the penetration of the dye penetrant into the flaws, or with the occurrence of the inspection process.

CLEARANCE:

(1) The gap or space between two mating parts.

(2) Space provided between the relief of a cutting tool and the surface cut.

CLEARING TIME (RT): The time required for the first stage of fixing during which the whiteness (opaqueness) of the film disappears.

CLEAVAGE: The splitting (fracture) of a crystal on a crystallographic plane of low index.

CLEAVAGE FRACTURE: A fracture, usually of a polycrystalline metal, in which most of the grains have failed by cleavage, resulting in bright reflecting facets. It is one type of crystalline fracture. Contrast with SHEAR FRACTURE.

COALESCENSE (PT): The merging of two or more particles of a liquid, gas, or solid into a single larger particle: The uniting by growth in one body.

COBALT-60: A radioisotope of the element cobalt.

COBALT-60 (RT): A radionuclide of the element cobalt, emitting gamma rays with energies of 1.33 and 1.17 MeV, with a half-life of 5.3 years.

COEFFICIENT OF THERMAL EXPANSION: The linear expansion or contraction per unit length per degree Fahrenheit between specified lower and upper Fahrenheit temperatures. If aluminum is involved, such values are multiplied by one million for easier reading.

COERCIVE FORCE (MT): The value of the reversing magnetizing force necessary to bring the flux density back to near zero.

COHERENT SCATTER: The result of Compton scattering in which the electron receives none of the energy from the primary radiation. The resultant scattered radiation is of the same energy as the incident beam.

COHESION: Molecular attraction by which the particles of a solid are held together.

COIL (ET, MT): One or more turns of conductor wound to produce a magnetic field when current passes through the conductor.

COIL IMPEDANCE (ET): The total opposition to current flow through a coil and is represented by the ratio of the coil voltage to the coil current. This impedance is affected by the material within the magnetic field generated by the coil and is sometimes used to measure eddy current response.

COIL SHOT (MT): A term used colloquially to indicate a shot of magnetizing current passed through a solenoid or coil surrounding a part, for the purpose of establishing a longitudinal field.

COIL SIZE (ET, MT): The geometry or dimension of a coil; for example, length or diameter.

COIL SPACING: The axial distance between two encircling coils in a different system.

COLD CRACKS: Appear as a straight line, usually continuous throughout its length and generally exist singly. These cracks start at the surface.

COLD SHORT: A condition of brittleness existing in some metals at temperatures below the recrystallization temperature.

COLD SHUT:

(1) A discontinuity that appears on the surface of cast metal as a result of two streams of liquid meeting and failing to unite.

(2) A portion of the surface of a forging that is separated, in part, from the main body of metal by oxide.

COLD WORKS: Permanent strain produced by an external force in a metal below its recrystallization temperature.

COLD WORKING: Deforming metal plastically at a temperature lower than the recrystallization temperature.

COLLIMATOR (RT): A device used to limit the size, shape, and direction of the primary radiation beam.

COLLIMATOR (UT): A lens assembly attachment designed to reduce the ultrasonic beam spread.

COLLIMATION: The process by which a divergent beam of energy or particles is converted into a parallel beam.

COLLOIDAL (MT): A liquid suspension of solid particles in which the particles will not settle on standing.

COLLOIDAL SUSPENSION (MT, PT): An intimate mixture of two substances, one of which, called the dispersed phase (or colloidal), is uniformly distributed in a finely divided state through the second substance, called the dispersion medium (or dispersing medium); the dispersion medium or dispersed phase may be gas, liquid, or solid. Also known as colloidal dispersion; colloidal system.

COLOR-CONTRAST DYE (PT): A dye which can be used in a penetrant to impart sufficient color intensity to give good color contrast in indications against the background of the surface being tested, when viewed under white light.

COLOR-CONTRAST PENETRANT: A penetrant incorporating a dye - usually nonfluorescent - sufficiently intense to give good visibility to flaw indications under white light.

COLUMNAR STRUCTURE: A coarse structure of parallel columns of grains, having the long axis perpendicular to the casting surface.

COMBINATION DIE (DIE-CASTING): A die having two or more different cavities for different castings.

COMBINATION SCREENS (RT): A pair of intensifying screens in which the front screen (to be placed on the tube side of the film) is usually thinner than the back screen.

COMBINED STRESSES: Any state of stress that cannot be represented by a single component of stress; that is, one that is more complicated than simple tension, compression or shear.

COMMERCIAL SOLVENTS: A liquid containing no emulsifiers and having chemical properties similar to those exhibited by solvents conforming to Government Specifications TT-N-97 and A-A-2904.

COMPARATIVE TEST BLOCK (see REFERENCE STANDARD): An intentionally cracked metal block having two separate but adjacent areas for the application of different penetrants so that a direct comparison of their relative effectiveness can be obtained. Can also be used to evaluate penetrant test techniques or test conditions, or both.

COMPENSATOR: An electrical matching network to compensate for circuit impedance differences.

COMPLETE FUSION: Fusion that has occurred over the entire base-metal surfaces exposed for welding.

COMPOSITE FILTER (RT): A filter of two or more materials chosen so that the longer wavelengths of a beam are readily absorbed, and within this range undesirable radiation transmission is avoided. The materials are usually arranged so that the second material filters secondary radiation produced in the first material and so on. A particular example is the “Thoraeus Filter” which consists of 0.44 mm of tin, 0.25 mm of copper and I mm of aluminum in this order in the beam of radiation.

COMPOSITE PLATE: An electrodeposit consisting of layers of at least two different compositions.

COMPOUND: A chemical combination of elements.

COMPRESSIONAL WAVE (UT): Waves in which the particle motion or vibration is in the same direction as the propagated wave. Same as longitudinal wave. See LONGITUDINAL WAVES.

COMPRESSIVE STRENGTH: The maximum stress developed in a material when located in compression. For practical purposes, the compressive yield strength is considered as the maximum compressive strength, particularly in the case of wrought metals.

COMPTON ABSORPTION (COMPTON EFFECT) (RT): The reduction of the energy of an incident photon by its interaction with an electron. Part of the photon energy is transferred to the electron (Compton electron or recoil electron) and part is redirected as a photon of reduced energy.

COMPTON EFFECT (RT): The glancing collision of an X-ray or gamma ray with an electron resulting in a gain of energy for the electron.

COMPTON SCATTERING (RT): A process in which a photon transfers a portion of its energy to an orbital electron in matter and a lower energy photon is scattered at an angle to the original photon path.

COMPUTED TOMOGRAPHY (RT): A method by which a radiograph of a predetermined interior plane of a thick material is obtained through the use of a computer. The images resulting from a series of exposures at different angles are stored and reconstructed into a single image by the computer.

CONCAVE: Curved or rounded and hollow as the outer boundary of a spherical or circular form viewed from within; opposite of convex.

CONCENTRATE (MT): A term used colloquially to designate the dry magnetic materials used to prepare a suspension. Also called Dry Concentrate.

CONCENTRATION TEST (MT): The method used to determine the quantity of magnetic material in the suspension at any given time. Also known as settling test.

CONDENSER IONIZATION CHAMBER (RT): An ionization chamber which, having been charged to a certain potential, can be irradiated and subsequently attached to an electrometer to measure the residual charge, whereby the exposure is determined.

CONDUCTIVITY: This is the inverse of resistance, and refers to the ability of a conductor to carry current.

CONDUCTIVITY REFERENCE STANDARD (ET): Sections of metallic materials with accurately measured electrical conductivity values in percent IACS. These standards are used to calibrate conductivity measuring eddy current instruments.

CONE (RT): A lead diaphragm or cone placed on the tube head to limit the X-ray beam to a volume defined by a cone.

CONSTANT-POTENTIAL CIRCUIT: A circuit, which is so, arranged to apply and maintain a substantially constant potential across an X-ray tube.

CONSTANT VOLTAGE (CONSTANT POTENTIAL) (RT): A unidirectional voltage of essentially constant magnitude.

CONSTRAINT: Any restriction that occurs to the transverse contraction normally associated with a longitudinal tension, and that hence causes a secondary tension in the transverse direction.

CONTACT HEAD (MT): Electrode assembly used to clamp and support a part to facilitate passage of electrical current through the part for circular magnetization.

CONTACT METHOD (UT): The inspection method in which the search unit face makes direct contact with the test part and ultrasonic energy is transmitted through a thin film of couplant.

CONTACT PADS (MT): Replaceable metal pads, usually copper braid, placed on the contact heads to give good electrical contact, thereby reducing the possibility of damage to the part by arcing or burning.

CONTACT TESTING (UT): Testing with transducer assembly in direct contact with material through a thin layer of couplant.

CONTACT TRANSDUCER: A transducer that is coupled to a test surface either directly or through a thin film of couplant.

CONTAINER, GAMMA-RAY SOURCE (RT): A device for housing radionuclides and giving a required degree of protection against radiation. (This may take the form of an exposure device or a storage container.)

CONTAMINATION (PT, MT): Any material in the wet suspension other than the liquid vehicle and the magnetic material being used. This could be shop dust, lint, soil from improperly cleaned parts, oil, etc.

CONTAMINATION (RT): The presence of unwanted radioactive matter, or the “Soiling” of object or materials with “Radioactive Dirt.”

CONTINUOUS METHOD (MT): The method in which the inspection medium is applied while the magnetizing current is on.

CONTINUOUS SPECTRUM (RT): The characteristic radiation pattern that exhibits energies for an unbroken series of frequencies over a wide range.

CONTINUOUS WAVE (UT): Steady generation of ultrasonic energy; opposite of pulsed.

CONTINUOUS WEDGE (RT): A wedge, the thickness of which varies continuously.

CONTRACTED SWEEP (UT): A contraction of the horizontal sweep line or time axis on the viewing screen of the ultrasonic instrument. A contraction of this sweep permits viewing defect or back reflection occurring over a greater length of time.

CONTRAST AGENT (RT): Any suitable substance, solid, liquid, or gas, applied to a material being radiographed, to enhance its contrast in total or in part.

CONTRAST RATIO (PT, MT): The relative amount of light emitted or reflected as between an indication and its background.

CONTRAST RATIO (RT): The relative amount of light emitted or reflected as between an indication and its background.

CONTRAST (MT, PT, RT): The difference in visibility between an indication and the surrounding surface.

CONTRAST, FILM (RT): Change in density that results from a given change in incident radiation. Determined from the slope of the characteristic curve. See FILM GAMMA.

CONTRAST, RADIOGRAPHIC (RT): The difference in density between an image and its immediate surroundings on a radiograph.

CONTRAST, SUBJECT (RT): The ratio (or logarithm of the ratio) of the radiation intensities transmitted by selected portions of the specimen.

CONTROL ECHO (UT): Reference signal from constant reflecting surface, such as the back reflection from a smooth, regular back surface.

CONTROL PANEL (RT): A console or unit that contains the controls necessary to operate a radiation source and any ancillary equipment used for radiography.

CONTROLLED AREA (RT): A defined area in which the occupational exposure of personnel to radiation or to radioactive material is under the supervision of an individual in charge of radiation protection. (This implies that a controlled area is one that requires control of access, occupancy, and working conditions for radiation protection purposes.)

CONVEX: Curved or rounded as the exterior of a spherical or circular form viewed from without; opposite of concave.

COOLIDGE TUBE (RT): An X-ray tube in which the source of the bombarding electrons is a heated filament in the cathode.

COOLING CRACK: See CRACKS, COOLING.

COOLING STRESSES: Residual stresses resulting from non-uniform distribution of temperature during cooling.

CORE (MT): In reference to an electromagnetic inspection, it is a laminated steel conductor located within the electrical winding of a hand-held yoke or probe. Also, laminated steel conductor used in conjunction with a magnetizing coil to produce a stronger collapsing field in induced current magnetization of ring-shaped parts.

CORNER EFFECT (UT): The strong reflection obtained when an angle beam is directed normal to the intersection of two perpendicular reflectors.

CORONA: In spot welding, an area sometimes surrounding the nugget at the faying surfaces, contributing slightly to overall and strength.

CORROSION: The deterioration of a metal by chemical or electrochemical reaction with its environment or other material.

CORROSION EMBRITTLEMENT: The severe loss of ductility of a metal, resulting from corrosive attack, usually intergranular and often not visually apparent.

CORROSION FATIGUE: Effect of the application of repeated or fluctuating stresses in a corrosive environment characterized by shorter life than would be encountered as a result of either the repeated or fluctuating stresses alone or the corrosive environment alone.

COULOMB: A unit of electric charge in the “practical” system of units. It contains 3 x 109 electrostatic units (see ESU) of charge.

COUPLANT (UT): A substance (usually liquid) used between the search unit and test part to permit or improve transmission of ultrasonic energy into the test part.

COUPLING (ET): An interaction between systems or between properties of a system.

CRACK: A discontinuity that has a relatively large cross-section in one direction and a small or negligible cross-section when viewed in a direction perpendicular to the first.

CRACKS COLD: A crack, which occurs in a casting after solidification, due to excessive strain generally resulting from non-uniform cooling.

CRACK CONTAMINANT: Material which fills a crack and which may prevent penetrants from entering.

CRACKS COOLING: In bars of alloy or tool steels, are the result of uneven cooling after rolling and usually are deep in a longitudinal direction, but are not straight.

CRACKS, FATIGUE: Progressive cracks which develop in the surface caused by the repeated loading and unloading of the part, or by what is called reverse bending.

CRACKS, FORGING: Cracks developed in the forging operation due to forging at too low a temperature, resulting in rupturing of the steel.

CRACKS, GRINDING: Thermal cracks due to local over-heating of the surface being ground, generally caused by lack of coolant, improper coolant, dull wheel, too rapid a feed, or too heavy a cut.

CRACKS, HEAT TREATING: See CRACKS, QUENCHING.

CRACKS, HOT: Same as CRACKS, COLD, but developing before the casting has completely cooled.

CRACKS, MACHINING: A surface defect generally called machining tear and caused by too heavy a cut, a dull tool, chatter, or dragging the tool over the metal when not cutting cleanly.

CRACKS, NOT OPEN: Indications which are difficult to discern or prove upon the use of contrast penetrant inspection techniques.

CRACKS, OPEN: Those flaws which can be detected by contrast penetrant inspection techniques.

CRACKS, PICKLING: Cracks caused by the release of internal stresses due to metal removal by immersion in acid or chemical solutions.

CRACKS, PLATING: A crack developed by the plating process, usually occurring in parts having high internal stresses.

CRACKS, QUENCHING: Ruptures produced in the tempering of metal, due to uneven cooling and contracting of one portion of a part.

CRACKS, SERVICE: Ruptures that occur on a part after all fabrication has been completed and the part placed in-service. Failure may be due to fatigue, corrosion, overstressing, or undetected processing discontinuities.

CRATER:

(1) In machining, a depression in a cutting tool face eroded by chip contact.

(2) In arc welding, depressions at the termination of a bead or in the weld pool beneath the electrode.

CREEP: Time-dependent strain occurring under stress. The creep strain occurring at a diminishing rate is called primary creep; that occurring at a minimum and almost constant rate, secondary creep; that occurring at an accelerating rate, tertiary creep.

CREEP STRENGTH:

(1) The constant nominal stress that will cause a specified quantity of creep in a given time at constant temperature.

(2) The constant nominal stress that will cause a specified creep rate at constant temperature.

CREVICE CORROSION: A type of concentration cell corrosion; corrosion of a metal that is caused by the concentration of dissolved salts, metal ions, oxygen or other gases, and such, in crevices or pockets remote from the principal fluid stream, with a resultant building up of differential cells that ultimately cause deep pitting.

CRITICAL ANGLE (UT): The angle of the incident sound beam with respect to the normal to an interface, beyond which a given mode of refracted beam will not exist.

CRITICAL SIZE: The established flaw size deemed to be detrimental to the serviceability of the product criteria. The acceptance/rejection levels established by design engineering required limits to meet design performance.

CROSS TALK (UT): The signal leakage (acoustical or electrical) across an intended barrier, such as signal leakage between the transmitting and receiving transducer elements of a dual search unit.

CRT: Abbreviation for cathode ray tube.

CRYSTAL (UT): See TRANSDUCER ELEMENT.

CRYSTAL MOSAICS (UT): Two or more crystals mounted in the same plane in one holder and connected so as to cause all crystals to vibrate as one unit.

CRYSTALS (X-CUT) (UT): Section cut so that its thickness is parallel to the X-axis of the crystal. A thickness-extensional mode of vibration occurs when excited.

CRYSTALS (Y-CUT) (UT): Section cut so that its thickness is parallel to the Y-axis of the crystal. A thickness- shear mode of vibration occurs when excited.

CRYSTALS (Z-CUT) (UT): Section cut 50 that its thickness is parallel to the Z-axis of the crystal. Piezoelectric effect is restricted to the X and Y-axis; therefore mode of vibration is width-extensional.

C-SCAN (UT): A data presentation method generally applied to pulse echo techniques yielding a two dimensional plan view of the scanned surfaces of the part. Through gating, only echoes arising from the interior of the test object are indicated. In the C-scan no indication is given of the echo depth.

CUMULATIVE DOSE (RADIATION) (RT): The total dose resulting from repeated exposure to radiation of the same region or of the whole body.

CUPOLA: A cylindrical vertical furnace for melting metal, especially gray iron, by having the charge come in contact with the hot fuel, usually metallurgical coke.

CURIE (RT): A unit of measure to express the rate at which a radioactive material decays. It is defined as that quantity of any radioactive material in which 3.7 x 1010 disintegrations per second are occurring. Under the new International System (SI) of Units, the curie will be replaced by disintegrations per second (1 Curie = 3.70 x 1010 disintegrations per second).

CURIE POINT (MT): The temperature at which ferromagnetic materials become nonmagnetic and can no longer be magnetized by outside sources. The range of temperatures is 1200°F-1600°F.

CURRENT: The flow of electrons through a conductor. It is measured in amperes, milliamperes or microamperes.

CURRENT FLOW METHOD (MT): See CIRCULAR MAGNETIZATION.

CURRENT INDUCTION METHOD (MT): See INDUCED CURRENT MAGNETIZATION.

CUTIE-PIE (RT): A colloquial term applied to a portable instrument equipped with a direct reading meter used to determine the level of radiation in an area.

CYANIDING: Introducing carbon and nitrogen into a solid ferrous alloy by holding above Acl in contact with molten cyanide of suitable composition. The cyanided alloy is usually quench hardened.

CYCLOTRON: A particle accelerator in which the atomic particles are whirled around in a spiral between the ends of a huge magnet gaining speed with each rotation. The cyclotron is normally used for nuclear research but the particles can be made to collide with a target to produce X-rays.

D

D: Symbol for diameter.

d: Symbol for distance.

d/t RATIO: The working distance for the X-ray tube in relation to the film distance. The working distance, d, and the specimen thickness, t, are both measured with reference to the source side of the specimen.

DAC: Abbreviation for distance amplitude correction; also used to denote electronic distance amplitude correction on some instruments.

DAMPING: Hindering or decreasing the time of vibrations or oscillations in the motion of a body or in an electrical system subjected to influences which are capable of causing vibration or oscillation. Compare with attenuation.

DAMPING (UT): Limiting the duration of and/or decreasing the amplitude of vibrations, as in damping of a transducer element; also designates a bond inspection method in which good bonds are verified by damping ultrasonic energy transmitted to the back surface.

DAMPING CAPACITY: The ability of a metal to absorb vibration (cyclical stresses) by internal friction converting the mechanical energy into heat.

DAMPING MATERIAL (UT): Material contained within a search unit in back of the transducer element and used for damping.

DARK ADAPTION: The ability of the eye to adjust so that objects, lights, or colors can be seen in darkened areas. This is important when performing a fluorescent penetrant, fluorescent magnetic particle inspections or when interpreting radiographic film.

dB: Abbreviation for decibel.

DC (DIRECT CURRENT): An electrical current that flows continually in one direction through a conductor.

DEAD ZONE: Zone in the test part directly underneath the sound entry surface where discontinuities cannot be detected; caused by the finite length of the initial pulse, ringing time of the transducer element, and/or electronic characteristics of the instrument.

DECALESCENCE: A phenomenon, associated with the transformation of alpha iron to gamma iron on the heating (superheating) of iron or steel, revealed by the darkening of the metal surface owing to the sudden decrease in temperature caused by the fast absorption of the latent heat or transformation.

DECARBURIZATION: The loss of carbon from the surface of a ferrous alloy as a result of heating in a medium that reacts with the carbon at the surface.

DECAY (MT): The falling off to zero of the current in an electrical circuit. Magnetic fields can also decay in a similar manner. This is important in demagnetization.

DECAY (RT): Spontaneous change of a nucleus with emission of a particle or a photon. For a definite quality of a nuclide, the rate of decay is usually expressed in terms of half-life.

DECAY CURVE (RT): A graph showing radioactive strength in curies as a function of time for an isotope. Such curves are used in radiography to determine the compensation or correction for exposure time in selecting exposure conditions.

DECIBEL: Logarithmic expression of a ratio of two amplitudes; abbreviation is dB. dB -20 log10 (A2/Al), where Al and A2 are amplitudes.

DECONTAMINATION (RT): The removal of radioactive contaminants from surfaces by cleaning and washing with chemicals.

DECONTAMINATION FACTOR (RT): The ratio of the amount of radioactive contaminant initially present to the amount remaining after a suitable processing step has been completed. A factor referring to the reduction of the gross measurable radioactivity.

DEEP-DOSE EQUIVALENT: Applies to whole-body exposure, is the dose equivalent at a tissue depth of 1 cm (1000 mg/cm^2)

DEEP ETCHING: Severe etching of a metallic surface for examination at a magnification of ten diameters or less to reveal gross features such as segregation, cracks, porosity or grain flow.

DEFECT: A discontinuity that interferes with the usefulness of a part. A fault in any material or part detrimental to its serviceability. Note that all cracks, seams, laps, etc. are not necessarily defects as they may not affect serviceability of the part in which they exist.

DEFECT DETECTION SENSITIVITY (RT): See sensitivity, defect.

DEFECT ORIENTATION (PT, MT): The position of the defect in relation to the inspection surface and the magnetic or penetrant indication.

DEFECT REFLECTION (UT): The oscilloscope presentation of the energy returned by a rejectable flaw in the material.

DEFECT RESOLUTION: A property of a test system which enables the separation of signals due to defects in the test specimen that are located in close proximity to each other.

DEFINITION, RADIOGRAPHIC (RT): Measure of sharpness in outline in the radiographic image of an object. Radiographic definition is a function of the types of screens, exposure geometry, radiation energy, and the film characteristics.

DEFINITION (RT): A general and qualitative term that refers to the degree of distinctness of image details in a radiograph, photographic reproduction, or viewing-screen image.

DEGREASING FLUID: Solvents or cleaners employed to remove oil and grease from the surface of components before the penetrant liquid is applied.

DELAY (UT): See SWEEP DELAY.

DELAY COLUMN (UT): See WATER DELAY COLUMN.

DELAY LINE (UT): Material (liquid or solid) placed in front of the search unit to cause a time delay between the initial pulse and front surface signal.

DELAYED SWEEP (UT): An A-scan or B-scan presentation in which an initial part of the time scale is not displayed.

DELTA EFFECT: Acoustic energy re-radiated by a discontinuity.

DEMAGNETIZATION (MT): The reduction in the degree of residual magnetism in ferromagnetic materials to an acceptable level.

DENDRITE: A crystal that has a tree-like branching pattern being most evident in cast metals slowly cooled through the solidification range.

DENSITOMETER: Instrument utilizing the photoelectric principle to determine the degree of darkening of developed photographic film. Measures optical density of films.

DENSITOMETRY (RT): The measurement of the degree of darkening of a developed photographic/radiographic film, providing one measure of the quality of the film. Measuring the optical density of films.

DENSITY COMPARISON STRIP (RT): Alternative term for step-wedge comparison film.

DENSITY, FILM (RT): The degree of blackening of a film is density. Film blackening or density is usually expressed in terms of the H & D curve (Hurter & Driffield) which is defined a the logarithm of the reciprocal of the transparency of the film. D Log2Io where D density, Io = Light incident on the film, and I = Light intensity transmitted.

DENSITY GRADIENT: The change in density of a radiographic film at a particular film density per unit change in the logarithm of the exposure received by the film. The maximum density gradient of a film is usually called gamma.

DEOXIDIZER: A substance that can be added to molten metal to remove either free or combined oxygen.

DEOXIDIZING:

(1) The removal of oxygen from molten metals by use of suitable deoxidizers.

(2) Sometimes refers to the removal of undesirable elements other than oxygen by the introduction of elements or compounds that readily react with them.

(3) In metal finishing, the removal of oxide films from metal surfaces by chemical or electrochemical reaction.

DEPTH OF FUSION: The depth to which the base metal melted during welding.

DEPTH OF PENETRATION (MT, EC): The depth at which the magnetic field or induced eddy currents has decreased to a specified percentage of its surface value or has reached the limit of its effectiveness. The depth of penetration is an exponential function of the frequency of the signal and the conductivity and permeability of the material.

DESCALING: Removing the thick layer of oxides formed on some metals at elevated temperatures.

DESENSITIZATION (RT): An effect on the emulsion of a radiographic film caused by pressure of any type exerted on the emulsion prior to exposure. A desensitized area on a film is characterized by low density in the affected area.

DETAIL: See DEFINITION, RADIOGRAPHIC

DETAIL SENSITIVITY (RT): The radiographic definition or sharpness of detail as indicated by the drilled holes in a penetrameter. It is expressed by a number x-yT, where x is the thickness of the penetrameter expressed as a percentage of the nominal subject thickness, and y is the diameter of the hole expressed as a multiple of the penetrameter thickness T.

DETECTOR (RT): A device that determines the presence of ionizing radiation.

DETERGENT REMOVER (PT): A penetrant remover that is a solution of a detergent in water.

DEUTERIUM: The isotope of hydrogen having one proton, one neutron, one electron, and an AMU of two.

DEVELOPER DRY (PT): A light fluffy dry absorbent powder, applied to the part being penetrant inspected after the excess surface penetrant has been removed and the part has been dried. The “Dry” developer adheres primarily to the flaw openings wetted by the penetrant liquid, to obtain increased bleed out of the penetrant and provide sharp flaw delineations.

DEVELOPER (PT): Material, wet or dry, which will draw or absorb penetrant from a surface crack or defect to the extent the defect will be visible under natural, artificial, or black light, as applicable. Developers also control the background of the high contrast penetrant color system.

DEVELOPER (RT): A chemical solution that reduces exposed silver halide crystals to metallic silver.

DEVELOPER, NON.AQUEOUS (PT): Absorbent powdered materials suspended in a non-aqueous liquid, used to provide a white background for maximum color contrast, and to enhance the bleed out of the penetrant from the flaw cavity to obtain increased accuracy of penetrant inspection.

DEVELOPER, SOLUBLE (PT): A developer completely soluble in its carrier, not a suspension of powder in a liquid, which dries to an absorptive coating.

DEVELOPER, SOLVENT: A developer consisting of fine particles suspended in a volatile solvent. The volatile solvent helps dissolve the penetrant out of the discontinuity and bring it to the surface.

DEVELOPER, WET (PT): An absorbent powder supplied in the dry form to be mixed and suspended in water for application to the part being penetrant inspected, after the excess surface penetrant has been removed. The “Wet” developer, on drying, provides an absorbent white background to the part for maximum color contrast, and enhances the bleed out of the penetrant from the flaw cavity to obtain increased inspection accuracy.

DEVELOPING AGENT (RT): The constituent of a developer that reduces sufficiently exposed silver halide grains to metallic silver at a greater rate than unexposed or insufficiently exposed grains.

DEVELOPING TIME (PT): The elapsed time necessary for the applied developer to bring out indications from penetrant entrapments. Usually one-half the penetrant dwell time.

DEVELOPMENT (RT): The conversion of a latent image into a visible image by treatment of the film emulsion with a suitable chemical solution (developer).

DEZINCIFICATION: Corrosion of some copper-zinc alloys involving loss of zinc and formation of a spongy porous copper.

DIAMAGNETIC: A material that has less magnetic permeability than a vacuum. Although diamagnetic materials have relative magnetic permeabilities slightly less than 1, the amount of difference is insignificant in eddy current testing and diamagnetic material are classified as nonmagnetic with a relative permeability of 1.

DICHROIC FOG (RT): Fog caused by the deposition of a very thin layer of finely divided silver on an emulsion, which when examined in white light, appears in two colors, red by transmission and green by reflection.

DIE: Various tools used to impart shape to material primarily because of the shape of the tool itself. Examples are blanking dies, cutting dies, drawing dies, forging dies, punching dies, and threading dies.

DIE CASTING:

(1) A casting made in a die.

(2) A casting process where molten metal is forced under high pressure into the cavity of a metal mold.

DIE FORGING: A forging whose shape is determined by impressions in specially prepared dies.

DIE LINES: Lines or markings on formed, drawn or extruded metal parts caused by imperfections in the surface of the die.

DIFFERENTIAL COILS (ET): Two or more coils electrically connected in series opposition such that any electromagnetic condition which is not common to the areas of the specimen being tested or the test specimen and the standard will produce an unbalance in the system and thereby be detected.

DIFFERENTIAL MOTTLING (RT): Minor irregularities in the distribution of density over the whole of the radiograph.

DIFFERENTIAL SENSING: A method of measuring eddy current response in which two coils are used to determine relative variations between two sections of material. These two sections may be two separate pieces of material (one a standard, the other the test material).

DIFFRACTION (RT): The scattering of incident radiation from the regularly spaced atoms in crystals or complex molecules such that interference between the scattered waves results in a pattern of maxima and minima in the intensity of the scattered radiation.

DIFFRACTION (UT): The deflection of a wave front when passing the edges of an obstacle.

DIFFRACTION MOTTLE (RT): A superimposed mottle or pattern on an image due to diffraction of certain wavelengths in the incident beam, caused by tile size and orientation of the crystals of the material through which they have passed.

DIFFRACTION MOTTLING: A diffuse diffraction pattern on a radiograph resulting from X-raying thin sections of crystalline material.

DIFFUSE INDICATIONS (MT): Indications of some sub-surface indications that are broad, fuzzy, feathery and are not clearly defined.

DIFFUSE REFLECTION (UT): Rough surface or associate interface reflection of ultrasonic waves from irregularities of the same order of magnitude or greater than the wavelength.

DIFFUSION:

(1) Spreading of a constituent in a gas, liquid or solid, tending to make the composition of all parts uniform.

(2) The spontaneous movement of atoms or molecules to new sites within a material.

DIGGING: A sudden erratic increase in cutting depth or in the load of a cutting tool caused by unstable conditions in the machine setup. Usually, the machine is stalled or either the tool or the workpiece is destroyed.

DIMENSIONAL STABILITY: Refers to the ability of an alloy to remain unchanged in size or shape after aging,

DIMPLING:

(1) Stretching a relatively small, shallow indentation into sheet metal.

(2) In aircraft, stretching metal into a conical flange for the use of a countersunk head rivet.

DIP RINSE (PT): A means of removing excess penetrant in which the test parts are dipped into an agitated tank of water or remover.

DIRECT CURRENT: Electric current flowing continuously in one direction through a conductor. Such current is frequently referred to as DC.

DIRECT FILM (RT): See non-screen film.

DIRECTIONAL PROPERTIES: Properties whose magnitude varies depending on the relation of the test axis to the specific direction within the metal. The variation results from preferred orientation or from fibering of constituents or inclusions.

DISCERNABLE IMAGE: Image capable of being recognized by sight without the aid of magnification; corrected vision excepted.

DISCONTINUITY: An interruption in the normal physical structure or configuration of a part such as cracks, laps, seams, inclusions, porosity. A discontinuity may or may not affect the usefulness of a part. See DEFECT.

DISINTEGRATION, NUCLEAR: A spontaneous nuclear transformation (radioactivity) characterized by the emission of energy and/or mass from the nucleus.

DISLOCATION: A linear defect in a crystal or lattice of a material. The two basic types are edge and screw.

DISPERSANT (PT): A substance for promoting the formation and stabilization of dispersed particles of one substance in another.

DISPERSION, SOUND: Scattering of rays of an ultrasonic beam as a result of reflection from a highly irregular incident surface above that normally associated with a particular transducer.

DISTANCE AMPLITUDE CORRECTION (UT): Compensation for variance in amplitude from equal reflectors at different sound travel distances. The abbreviation is DAC. Also used to denote electronic change of amplification to provide equal amplitude from equal reflectors at different sound travel distances. Other designations for this electronic change of amplification are Swept Gain (SG), Time Corrected Gain (TCG), Time Variable Gain (TVG) and Sensitivity Time Control (STC).

DISTORTED FIELD (MT): The direction of a magnetic field in a symmetrical object will be substantially uniform if produced by a uniformly applied magnetizing force, as in the case of a bar magnetized in a solenoid. But if the piece being magnetized is irregular in shape, the field is distorted and does not follow a straight path or have a uniform distribution.

DOSE OR RADIATION DOSE: A generic term that means absorbed dose, dose equivalent, etc. And represents the total amount of radiation received during the applicable period of exposure.

DOSE EQUIVALENT: The product of the absorbed dose in tissue, quality factor, and all other necessary modifying factors at the location of interest. The units of dose equivalent are the rem and Sievert (Sv).

DROSS: The scum that forms on the surface of molten metals largely because of oxidation but sometimes because of the rising of impurities to the surface.

DRY DEVELOPER (PT): A developer powder that is applied as a dust without a liquid carrier.

DRYING OVEN (PT): An oven used for drying rinse water from test pieces.

DRYING TIME (PT): The time during which a washed or wet-developed part is in the hot air drying oven.

DRY METHOD (MT): Magnetic particle inspection in which the particles are applied in a dry powder form.

DRY POWDER (MT): Finely divided ferromagnetic particles suitably selected and prepared for magnetic particle inspection. Colors employed are usually red, gray, yellow or black.

DUAL SEARCH UNIT (UT): A single search unit containing two transducer elements; one used as a transmitter of ultrasonic energy, the other used as a receiver of ultrasonic energy.

DUCTILE CRACK PROPAGATION: Slow crack propagation that is accompanied by noticeable plastic deformation and requires energy to be supplied from outside the body.

DUCTILITY: The ability of a material to deform plastically without fracturing, being measured by elongation or reduction of area in a tensile test, by height of cupping in an Erichsen test or by other means.

DUPLITIZED FILM (RT): Radiographic film that consists of a coating of photosensitivity emulsion on both sides of the tinted polyester base.

DWELL TIME (PT): The period of time wherein the liquid penetrant remains on the surface of the part. For the immersion techniques, the period subsequent to soak and prior to wash, i.e., draining process is considered dwell time.

DYE: The chemical component added to a penetrant vehicle to provide a characteristic color to the penetrant.

DYE PENETRANT: Penetrant with dye added that makes it readily visible in light.

DYE STUFFS (MT, PT): A natural or synthetic coloring matter whether soluble or insoluble that is used to color materials usually from a solution or fine dispersion and sometimes with the aid of a chemical (mordant) that serves to fix a dye in or on a substance.

DYNAMIC CREEP: Creep that occurs under conditions of fluctuating load or fluctuating temperature.

DYNAMIC RANGE (UT): The ratio of maximum to minimum reflective areas that can be distinguished on the cathode ray tube at a constant gain setting.

E

ECHO: Signal of reflected ultrasonic energy.

EDDY CURRENTS: Currents caused to flow in an electrical conductor by the time and/or space variation of an applied magnetic field.

EDDY CURRENT INSPECTION OR TESTING: A nondestructive inspection method in which eddy current flow is induced in the test object. Changes in the flow caused by the variations in the specimen are reflected into a nearby coil or coils for subsequent analysis by suitable instrumentation and techniques.

EDDY-SONIC (UT, ET): Describes a process in which sonic or ultra-sonic energy is produced in a test part by coil on or near the surface of the test part. The coil is used to produce eddy currents in the test part. Vibrations in the test part result from the interaction of the magnetic field from the eddy currents in the test part with the magnetic field of the coil.

EDGE EFFECT (ET): The effect on the magnetic field caused by the geometric boundaries of the test specimen. The effect is large in magnitude and similar in phase to a large crack. Also called END EFFECT.

EFFECTIVE DEPTH OF PENETRATION: The depth within a material, under test, where the transmitted or induced energy is sufficient to detect discontinuities (determine condition of interest). EDP is approximately equal to three time's standard DOP.

EFFECTIVE FOCAL SPOT (RT): An elongated, rectangular electron focus so angled that the focal spot size, as viewed along the X-ray beam axis, is smaller and approximately square, thereby permitting increased total area loading of the target for a given focal spot size.

ELASTIC AFTER-EFFECT: A lagging elastic recovery, of minor proportions, following a decrease in or removal of the load.

ELASTIC CONSTANTS: Modulus of elasticity, either in tension, compression or shear, and Poisson's ratio.

ELASTIC DEFORMATION: Change of dimensions accompanying stress in the elastic range, original dimensions being restored upon release of stress.

ELASTIC LIMIT: The maximum stress to which a material may be subjected without any permanent strain remaining upon complete release of stress.

ELASTICITY: That property of a material by virtue of which it tends to recover its original size and shape after deformation.

ELECTRICAL NOISE: Extraneous signals caused by externally radiated electrical signals or from electrical interferences within the ultrasonic instrumentation.

ELECTROCHEMICAL CORROSION: Corrosion that occurs when current flows between cathodic and anodic area on metallic surfaces.

ELECTRODE SKID: In spot, seam or projection welding, the sliding of an electrode along the surface of the work.

ELECTROGALVANIZING: The process of electroplating zinc on iron or steel.

ELECTROMAGNET: A soft iron core surrounded by a coil of wire. The iron core becomes magnetic when an electric current flows through the wire.

ELECTROMAGNETIC INSPECTION OR TESTING (ET): A nondestructive test method for engineering materials including magnetic materials, which use electromagnetic energy having frequencies less than those of visible light to yield information regarding the quality of test material. This term includes both eddy current testing and magneto-inductive testing.

ELECTROMAGNETIC RADIATION (RT): Radiation consisting of electric and magnetic waves that travel at the speed of light. Examples: light, radio waves, gamma rays, X-rays. All can be transmitted through a vacuum.

ELECTROMAGNETIC SPECTRUM: The wavelength range of the various forms of electromagnetic radiation.

ELECTROMOTIVE FORCE (EMF): The work or energy that causes the flow of an electric current. Expressed as volts. It should be noted that the term "force" is a misnomer. However, the term is so well established that its use continues in spite of its being incorrect.

ELECTRON: One of the fundamental constituents of atoms. The electron is a very small negatively charged particle with a rest mass of approximately 1/1836 that of the hydrogen atom, or 9.107 x 10-28 gm. It has an electric charge of 4.802 x 10-10 statcoulomb (the electrostatic unit of charge). Electrons appear to be uniform in mass and charge.

ELECTRON CAPTURE (RT): A mode of radioactive decay in which a bound electron is captured by the nucleus of the same atom, producing a vacancy in an inner emission of characteristic X-rays or auger electrons.

ELECTRON FOCUS (RT): The surface of the intersection of the electron beam and the anode of the X-ray tube.

ELECTRON GUN (RT): A device in which electrons (usually liberated from a hot filament) are focused and accelerated, and from which they are emitted as a narrow beam.

ELECTRON PAIR (RT): An electron and a positron resulting from pair production.

ELECTRON RADIOGRAPHY (RT): The process whereby a photographic image of an object is produced by electron radiation that has penetrated through the object.

ELECTRON VOLT: A unit of energy commonly used to express the energy of X-rays. One electron volt is the energy gained by an electron when it is accelerated by a potential difference of 1 volt (1 eV = 1.60210 x 10-19 joule - SI).

ELECTROPLATING: Electrodepositing metal in an adherent method upon a metal object serving as a cathode. Examples would be nickel chromium and cadmium deposits. Thicknesses under 0.005 do not interfere with magnetic particle inspection.

ELECTROSTATIC SPRAYING (PT): A technique of spraying wherein the material being sprayed is given a high electrical charge, while the test piece is grounded.

ELEMENT: One of the 103 known chemical substances that cannot be divided into simpler substances by chemical means. Examples: hydrogen, lead, and uranium.

ELEMENTARY PARTICLE: Originally a term applied to any particle that could not be further subdivided; now applied only to protons, electrons, neutrons, antiparticles, and strange particles, but not to alpha particles and deuterons.

ELONGATION: In tensile testing, the increase in the gage length, measured after fracture of the specimen within the gage length, usually expressed as a percentage of the original gage length.

EMBRITTLEMENT: Reduction in the normal ductility of a metal due to a physical or chemical change.

EMBRYO/FETUS: The developing human organism, from conception until the time of birth.

EMISSIVITY: The energy emission rate usually expressed as r/c/hr @ 1 ft or mR/mc/hr @ 1 ft.

EMULSIFICATION (PT): The process of dispersing one liquid in a second immiscible liquid; the largest group of emulsifying agents are soaps, detergents, and other compounds, whose basic structure is a paraffin chain terminating in a polar group.

EMULSIFICATION TIME (PT): The time allowed for the emulsifier to act on the penetrant before the part is washed, after emulsifier is applied as a separate step.

EMULSIFIER (PT): A liquid agent that must be applied to the non-water washable penetrant after the proper dwell time has elapsed to permit water rinsing. This requires an additional step and a period of time must be allowed for the combining to occur. A suspension of one liquid phase in another.

EMULSIFIER-REMOVER (PT): A type of solvent that can be rinsed off with water after it is applied or used as a solvent wipe remover.

EMULSIFICATION TIME (PT): Time required for the emulsifying agent to combine with the penetrant. This is critical as insufficient time will result in failure to remove the penetrant and lead to false indications, and too long a time may remove the penetrant from the flaws. Emulsification time usually ranges from 30 seconds to 5 minutes.

EMULSION (RT): The gelatinous substance in which fine grains of silver halides are dispersed. The emulsion is coated on a base, usually polyester, and contains the image forming substance of a radiographic film.

EMULSION FOG (RT): The slight density in an unexposed area of the film due to a small number of silver bromide crystals developing spontaneously. Film speed and improper processing or storage will affect emulsion fog. Safelight, white light, or radiation fog is not considered part of emulsion fog.

ENCAPSULATION: The process of sealing radioactive materials to prevent contamination.

ENCIRCLING COIL (MT, ET): Coil(s) or coil assembly which surrounds) the part to be tested. Coils of this type are also referred to as annular, circumferential, or feed-through coils.

END EFFECT (ET, MT): The effect on the magnetic field caused by the geometric boundaries of the test specimen that makes it impractical to apply electromagnetic test methods to the associated regions of the test specimen; also called EDGE EFFECT.

ENDURANCE LIMIT: A value used to measure the load-carrying ability of a metal subjected to infinitely repeated loading. It is determined from the S-N curve as the stress at which the curve becomes parallel to the N axis, i.e.; it projects to an infinite number of cycles of stress without failure.

ENDURANCE RATIO: Same as FATIGUE RATIO.

ENERGY, RADIOGRAPHIC (RT): The energy of X-radiation is generally expressed in multiples of the electron volt (1,000,000 eV = 1,000 KeV = 1 MeV).

EQUIAXED GRAIN STRUCTURE: A structure in which the grains have approximately the same dimensions in all directions.

EQUI-OPAQUE SUBSTANCE (RT): A material having radiation absorption similar to that of the specimen, applied along its edges or in its cavities in order to obtain homogeneous absorption and thereby avoid local overexposure of the film.

EQUIVALENT PENETRAMETER SENSITIVITY (RT): The thickness of penetrameter, expressed as a percentage of the part thickness, in which the 2T hole would be visible under the same radiographic conditions.

EROSION: Destruction of metals or other materials by the abrasive action of moving fluids usually accelerated by the presence of solid particles or matter in suspension. When corrosion occurs simultaneously, the term erosion-corrosion is often used.

ET: Symbol for eddy current method of nondestructive testing/inspection.

ETCH CRACKS: Shallow cracks in hardened steel, containing high residual surface stresses, produced on etching in an embrittling acid.

ETCHING: Subjecting the surface of a metal to preferential chemical or electrolytic attack in order to reveal structural details.

EUTECTIC ALLOY: The composition in a binary alloy system that melts at the lowest temperature. More than one eutectic composition may occur in a given alloy system consisting of more than two metals.

EUTECTIC MELTING: Melting of localized micro areas whose composition corresponds to that of the eutectic in the system.

EVALUATION: The process of deciding as to the severity of the condition after the indication has been interpreted. Evaluation leads to the decision as to whether the part must be rejected, salvaged or may be accepted for use.

EXFOLIATION: A type of corrosion that progresses approximately parallel to the outer surface of the metal, causing layers of the metal to be elevated by the formation of corrosion product.

EXPANDED SWEEP (UT): An expansion of the horizontal sweep line or time axis on the viewing screen of the ultrasonic instrument. This permits, when used in conjunction with the sweep delay, to more closely scrutinize any portion of the pattern.

EXPOSURE (RT): The product of the X-ray intensity as measured by filament current in milliamperes and time in seconds or minutes for X-rays, or the product of source strength in curies and time in seconds or minutes for gamma rays. The exposure factor determines the degree of film blackening as long as the reciprocity law is valid. See RECIPROCITY LAW and RECIPROCITY LAW FAILURE.

EXPOSURE CHART (RT): A graph showing the relation between material thickness, kilovoltage, and exposure. It is only adequate for determining exposure time for a uniform thickness of material.

EXPOSURE DEVICE (RT): A shield in the form of a package designed to contain and allow the controlled use of one or more sealed sources for the purpose of making radiographic exposures.

EXPOSURE FACTOR (RT): A quantity that combines milliamperage or source strength, time, and distance. Numerically, the exposure factor is the product of milliamperage and time divided by distance squared for X-rays and the product of curies and time divided by distance squared for gamma rays.

EXPOSURE FOG (RT): Fog caused by any unwanted exposure of a film to ionizing radiation or light, at any time between manufacture and final fixing.

EXPOSURE LATITUDE (RT): The range of thickness of a specified material that corresponds to the range of useful film densities.

EXPOSURE METER (RT): An instrument for measuring exposure (radiation quantity).

EXPOSURE RATE (RADIATION QUANTITY) (RT): The exposure unit time. Special unit: roentgens per second.

EXPOSURE RATE METER (RT): An instrument for measuring exposure rate (radiation quantity).

EXPOSURE TABLE (RT): A table giving the radiographic exposures suitable for the different thicknesses of a specified material.

EXTERNAL DISCONTINUITIES: Surface irregularities that cause density variations on a radiograph. These are observable with the naked eye.

EXTERNAL DOSE: The portion of the dose equivalent received from radiation sources outside the body.

EXTREMITY: means hand, elbow, and arm below the elbow; foot, knee, and leg below the knee.

EXTRUSION: Conversion of a billet into lengths of uniform cross section by forcing the plastic metal through a die orifice of the desired cross-sectional outline.

EXTRUSION DEFECT: A defect of flow in extruded products caused by the oxidized outer surface of the billet flowing into the center of the extrusion. It normally occurs in the last 10 to 20% of the extruded bar. Also called “pipe” or “core.”

EXUDED (PT): To ooze out slowly in small drops through openings; to flow slowly out.

EYE DOSE EQUIVALENT: applies to the external exposure of the lens of the eye and is taken as the dose equivalent at a tissue depth of 0.3 centimeters (300-mg/ cm^2).

F

f: Symbol for frequency.

FALSE INDICATIONS: See NON-RELEVANT INDICATIONS.

FALSE INDICATIONS (MT): An indication of magnetic particles on the part held by gravity or surface roughness. It is neither caused nor held in place by leakage field.

FAMILY CONCEPT (PT): See SYSTEM CONCEPT. The term “Family Concept” has been changed to “System Concept” to comply with DOD standardization requirements. The two terms have the same meaning.

FAMILY (PT): A family of materials refers to the entire series of materials supplied by one manufacturer, necessary to perform a specific type or process of inspection.

FAR FIELD (UT): Sound beam zone in which equal reflectors give signals of exponentially decreasing amplitude with increasing distance; zone beyond the near field; also known as the FRAUNHOFER ZONE.

FAST FILM: Radiographic film that has inherent graininess characteristics of a coarse nature intended to increase the relative film speed.

FATIGUE: The progressive fracture of a material that begins at a defect and increases under repeated cycles of stress. Fatigue fractures are progressive, beginning as minute cracks that grow under the action of the fluctuating stress.

FATIGUE CRACKS: See CRACKS, FATIGUE.

FATIGUE LIFE: The number of cycles of stress than can be sustained prior to failure for a stated test condition.

FATIGUE LIMIT: The maximum stress below which a material can presumably endure an infinite number of stress cycles. If the stress is not completely reversed, the value of the mean stress, the minimum stress or the stress ratio should be stated.

FATIGUE RATIO: The ratio of the fatigue limit for cycles of reversed flexural stress to the tensile strength.

FATIGUE STRENGTH: Maximum stress that a metal will withstand without failure for a specified number of cycles of stress.

FATIGUE STRENGTH REDUCTION FACTOR (Kf): The ratio of the fatigue strength of a member or specimen with no stress concentration to the fatigue strength with stress concentration. Kf has no meaning unless the geometry, size and material of the member or specimen and stress range are stated.

FAYING SURFACE: The surface of a piece of metal (or a member) in contact with another to which it is or is to be joined.

FBH: Abbreviation for flat bottom hole.

FERRITE BANDING: Parallel bands of free ferrite aligned in the direction of working. Sometimes referred to as ferrite streaks.

FERROMAGNETIC MATERIAL: Materials that are strongly attracted by a magnetic field. Iron, steel, nickel, and cobalt are included in this category. Permeability is much greater than one, and is effected by the applied magnetic field. Such materials exhibit hysteresis behavior.

FERROUS METALS: Containing iron, such as steel, stainless steel and cast iron.

FFD (RT): Film focal distance; distance between film and tube target.

FIBER (FIBRE):

(1) The characteristic of wrought metal that indicates Directional Properties and is revealed by the etching of a longitudinal section or is manifested by the fibrous or woody appearance of a fracture. It is caused chiefly by the extension of the constituents of the metal, both metallic and nonmetallic, in the direction of working.

(2) The pattern of preferred orientation of metal crystals after a given deformation process, usually wire-drawing.

FIBROUS FRACTURE: A fracture where the surface is characterized by a dull gray or silky appearance. Contrast with crystalline fracture.

FIBROUS STRUCTURE:

(1) In forgings, a structure revealed as laminations, not necessarily detrimental, on an etched section or as a ropy appearance on a fracture. It is not to be confused with the “silky” or “ductile” fracture of a clean metal.

(2) In wrought iron, a structure consisting of slag fibers embedded in ferrite.

(3) In rolled steel plate stock, a uniform, fine-grained structure on a fractured surface, free of laminations or shale-type discontinuities. As contrasted with part (1) above, it is virtually synonymous with “silky” or “ductile” fracture.

FIELD, BIPOLAR (MT): A longitudinal field within a part having two poles.

FIELD, CIRCULAR (MT): The magnetic field surrounding any magnetic conductor or part resulting from the current being passed through a central conductor or the part.

FIELD COIL (ET): The coil generating the magnetic field that produces eddy currents in the part being tested.

FIELD INDICATOR (MT): A device for indicating the amount of magnetism in a part.

FIELD, LEAKAGE (MT): The field that leaves or enters the surface of a part at a discontinuity or change in section configuration.

FIELD, LONGITUDINAL (MT): A field created by a coil shot or cable wrap and in which the flux lines traverse the part essentially parallel with its longitudinal axis. A localized field, on the surface of a part, traversing from one leg of a yoke or probe to the other.

FIELD, MAGNETIC (MT): The space within and surrounding a magnetized part or a conductor carrying current in which magnetic lines of force exists.

FIELD, RESIDUAL (MT): The magnetism that remains in a piece of magnetizable material after the magnetizing force has been removed.

FIELD, RESULTANT (MT): The magnetic field resulting when two or more magnetizing forces, operating in different directions, are applied to ferromagnetic materials.

FILAMENT (RT): The source of electrons in a hot-cathode tube. It is usually a heated wire.

FILAMENT TRANSFORMER (RT): A transformer supplying power to heat the filament of a hot-cathode. The primary and secondary windings must be sufficiently insulated to withstand the peak potential difference between the cathode and earth.

FILLED CRACK: A crack-like discontinuity, open to the surface, but filled with some foreign material - oxide, grease, etc. - which tends to prevent penetrants from entering.

FILLET: Radius imparted to the inside of two meeting surfaces.

FILL FACTOR (MT): The square of the ratio of the diameter of a part to the diameter of one encircling coil(s). The square of the ratio of the internal coil diameter to the bore diameter for internal probes. The fill factor is a measure of coupling between the encircling or internal coil and the test object.

FILM BADGE (RT): A piece of masked radiographic film worn in the form of a badge that is used to measure exposure. The amount of exposure is determined from the degree of film blackening.

FILM BASE (RT): A flexible, transparent, or translucent material that is coated with a photosensitive emulsion.

FILM CLEARING TIME (RT): See CLEARING TIME. FILM CONTRAST (RT): See CONTRAST, FILM. FILM DENSITY (RT): See DENSITY, FILM.

FILM GAMMA (RT): Term used to describe the amplification factor of a radiographic film, equal to the absolute slope of the characteristic curve.

FILM GRAININESS (DIRECT X-RAY EXPOSURES) (RT): The visual impression of irregularity of density, in areas where exposure is macroscopically uniform, due to the random spatial distribution of X-ray quanta absorbed in the film. In general, fast films exhibit greater graininess than slow films.

FILM HOLDER (RT): A light-tight carrier for films and screens.

FILM ILLUMINATOR (RT): A device incorporating a suitable source of illumination for viewing radiographs or other transparencies.

FILM LATITUDE (RT): Latitude refers to the exposure range within which a satisfactory radiograph is produced. Films which have the widest latitude are those which have the lowest film gradient and therefore the lowest film contrast.

FILM PROCESSING (RT): See PROCESSING, FILM.

FILM, RADIOGRAPHIC (RT): A photographic film that is usually coated on both sides with an emulsion designed for use with X-rays and gamma rays.

FILM RING (RT): A film badge worn as a ring to measure the exposure of the fingers to ionizing radiation.

FILM SPEED (RT): A measure of the rate at which a film responds to a given amount of radiation. Slower films require a longer period of time to reach the same film density than a fast film under the same exposure conditions.

FILM UNSHARPNESS (RT): See UNSHARPNESS.

FILM VIEWER (RT): See FILM ILLUMINATOR.

FILTER (RT): A layer of absorptive material which is placed in the beam of radiation for the purpose of absorbing rays of long wavelengths to control the quality of the radiograph.

FILTERS (UT, ET): Filters are electrical circuits designed to eliminate various frequencies from a circuit output or input. Filter may be low pass (high frequencies suppressed), high pass (low frequencies suppressed) or band pass (frequencies outside a specified range suppressed).

FILTRATION: See INHERENT FILTRATION.

FILTRATION (RT): The use of a filter to alter the characteristics of a radiation beam.

FINE CRACK: A discontinuity in a solid material with a very fine opening to the surface, but possessing length and depth greater than the width of this opening; usually depth is many times the width.

FINISH:

(1) Surface condition, quality or appearance of a metal.

(2) Stock on a forging to be removed when finish machined.

FIRE SCALE: Oxide subscale formed just under the surface of certain alloys when they are annealed in air.

FISH EYES: Areas on a fractured steel surface having a characteristic white crystalline appearance.

FISSION: The splitting of a heavy nucleus into two roughly equal parts (which are nuclei of lighter elements) accompanied by the release of a relatively large amount of energy and frequently one or more neutrons. Fission can occur spontaneously, but usually it is caused by the absorption of gamma rays, neutrons, or other particles.

FISSION PRODUCTS: Nuclei formed by the fission of heavy elements. They are of medium atomic weight, and almost all are radioactive. Examples: strontium-90, cesium-137.

FISSIONABLE MATERIAL: Any material readily fissioned by slow neutrons, for example, uranium-235 and plutonium-239.

FIT: The amount of clearance or interference between mating parts.

FIXER (RT): A chemical solution that removes unexposed silver halide crystals from film emulsion.

FIXING (RT): The procedure used in film processing that removes all of the undeveloped silver salts of the emulsion from the surface of the film, thus leaving only the developed latent image.

FLAME HARDENING: A method of hardening where the surface layer is heated by a high temperature torch and then quenched.

FLAKES: Short discontinuous internal fissures in ferrous metals attributed to stresses produced by localized transformation and decreased solubility of hydrogen during cooling after hot working. In a fractured surface, flakes appear as bright silvery areas; on an etched surface they appear as short, discontinuous cracks. Also called “shatter cracks and snowflakes.”

FLANGE: The projecting annular rim around a cylinder that is used for strengthening, fastening, or positioning.

FLANGE RADIUS: The radius formed at the junction of a flange and the wall of a casting.

FLASH:

(1) In forging, the excess metal forced between the upper and lower dies.

(2) In die casting, the fin of metal that results from leakage between the mating die surfaces.

(3) In resistance butt welding, a fin formed perpendicular to the direction of applied pressure.

FLASH LINE: The line of location of flash formed around a forging.

FLASH MAGNETIZATION (MT): Magnetization by a current flow of very brief duration.

FLASH POINT: The lowest temperature at which a substance will decompose to a flammable gaseous mixture. The temperature at which the vapor air mixture first ignites is the flash point. This temperature can be determined by raising the temperature of the liquid in accordance with the pre-determined schedule, and periodically introducing a flame or other ignition means immediately above the surface.

FLASH TUBE (RT): An X-ray tube designed for use in flash radiography.

FLASH X-RAY: Term used to describe the technique in which a tube capable of producing very short (10 to 100 nanoseconds) high intensity pulses of radiation are used for special radiographic investigations.

FLAT BOTTOM HOLE (UT): A type of reflector commonly used in reference standards. Abbreviation is FBH.

FLAW: An imperfection in an item or material that may or may not be harmful. See DISCONTINUITY.

FLAW SENSITIVITY (RT): See SENSITIVITY, DEFECT.

FLOW LINES: A fiber pattern frequently observed in wrought metals, which indicates the manner in which the metal flows during deformation. The pattern is made more visible by acid etching.

FLOW STRESS: The uniaxial true stress required to cause plastic deformation at a particular value of strain.

FLUORESCENT (RT): The emission of electromagnetic radiation by a substance as the result of the absorption of electromagnetic or corpuscular radiation having greater unit energy than that of the fluorescent radiation. Fluorescence is characterized by the fact that it occurs only so long as the stimulus responsible for it is maintained. The characteristic X-radiation emitted, as a result of absorption of X-rays of higher frequency is a typical example of fluorescence. Property of emitting visible light as the result of and only during, the absorption of radiant energy from some other source (i.e., black light).

FLUORESCENT DYE PENETRANT (PT): A highly penetrating liquid which fluoresces when subjected to ultra-violet or black light, used to produce luminous indications of surface flaws or discontinuities.

FLUORESCENT MAGNETIC PARTICLE INSPECTION (MT): The inspection process employing magnetic materials which have been coated with a material that fluoresces when activated by light of suitable wavelength.

FLUORESCENT SCREEN (Salt Screen) (RT): Intensifying screens composed of fluorescent all, such as calcium tungstate, which emit a visible blue-violet electromagnetic radiation when activated by the absorption of the primary rays, thereby reducing the exposure time.

FLUORESCENT SCREENS (RT): Intensifying screens composed of fluorescent salts which emit a visible blue-violet electromagnetic radiation when activated by the absorption of the primary rays, thereby reducing the exposure time.

FLUOROGRAPHY (RT): The use of photography to record fluoroscopic images on film.

FLUOROMETALLIC SCREEN (RT): A screen consisting of a metal foil (usually lead) coated with a material that fluoresces when exposed to ionizing radiation. It combines the properties of the fluorescent and metal screen.

FLUOROSCOPY (RT): The visual observation on a fluorescent screen of the image of an object that has been exposed to penetrating, ionizing radiation.

FLUX: A fusible salt mixture or gas used to purify molten metal by removing suspended oxides or dissolved gas.

FLUX (NEUTRON): The intensity of neutron radiation. It is expressed as the number of neutrons passing through I square centimeter in 1 second.

FLUX DENSITY (MT): The number of magnetic flux lines per unit of area taken at right angles to the direction of magnetic field flow. This is a measure of field strength.

FLUX LINES (MT): Also called lines of force, magnetism or induction. Imaginary lines used as means of explaining the distribution and potential of magnetic fields.

FLUX, MAGNETIC LEAKAGE: See FIELD, LEAKAGE.

FLUX PENETRATION (MT): The depth to which magnetic flux is effective in a part.

FOCAL-FILM DISTANCE (FFD) (RT): The distance in inches between the focal spot of the X-ray tube, or gamma source, and the film.

FOCAL SPOT (RT): The area on the target that receives the bombardment of electrons and emits the primary radiation necessary to produce an image of the object on a radiographic film. The spot at which the sound beam from a focused search unit converges to maximum intensity.

FOCUSED BEAM (UT): Sound beam that converges to a focal spot.

FOCUSED TRANSDUCER (UT): A transducer with a concave face which converges the acoustic beam to a focal point or line at a definite distance from the face. Also known as a focused search unit.

FOCUSING: Concentration or convergence of energy into a small beam.

FOCUSING (RT): Concentration or convergence of energy into a narrow beam. FOD (RT): Film object distance; distance from film to object being radiographed.

FOG (RT): A general term used to denote any increase in the optical density of a processed film caused by anything other than the direct action of image-forming radiation.

FOG DENSITY (RT): See FOG.

FOG THRESHOLD (RT): The minimum uniform density inherent in a processed emulsion without prior exposure.

FOIL: Metal in sheet from less than 0.006 inches in thickness.

FOLD: See LAP.

FOREIGN MATERIALS: They may appear as isolated, irregular, or elongated variations of film density not corresponding to variations in thickness of material or to cavities. May be sand, slag, oxide or dross, or metal of different density, included in the material being examined.

FORGING: Working metal into a desired shape by hammer, upsetting, or pressing, either hot or cold, or by a combination of these processes.

FORGING CRACKS: See CRACKS, FORGING.

FORGING RANGE: Temperature range in which a metal can be forged successfully.

FORGING STRAIN: Internal strains in the metal set up by the forging operation.

FORGE WELD: Uniting metal by heat and pressure during forging.

FORMABILITY: The relative ease with which a metal can be shaped through plastic deformation.

FORMING: Making a change, with the exception of shearing or blanking, in the shape or contour of a metal part without intentionally altering the thickness.

FORWARD SCATTER: Radiation scattered in approximately the same direction of the primary beam.

FOUNDRY: A commercial establishment or building where metal castings are produced.

FRACTOGRAPHY: Descriptive treatment of fracture, especially in metals, with specific reference to photographs of the fracture surface. Macrofractography involves photographs at low magnification; microfractography, at high magnification.

FRACTURE: A break, rupture, or crack large enough to cause a full or partial partition of a casting.

FRACTURE STRESS:

(1) The maximum principal true stress at fracture. Usually refers to unnotched tensile specimens.

(2) The (hypothetical) true stress which will cause fracture without further deformation at any given strain.

FRACTURE TEST: Breaking a specimen and examining the fractured surface with the unaided eye or with a low-power microscope to determine such things as composition, grain size, case depth, soundness, or presence of defects.

FRAGMENTATION: The subdivision of a grain into small discrete crystallites outlined by a heavily deformed network or intersecting slip as a result of cold working. These small crystals or fragments differ from one another in orientation and tend to rotate to a stable orientation determined by the slip systems.

FRAUNHOFER ZONE (UT): See FAR FIELD.

FREE CARBON: The part of the total carbon in steel or cast iron that is present in the elemental form as graphite or temper carbon.

FREQUENCY: Frequency in uniform circular motion or in any periodic motion is the number of revolutions or cycles completed in unit time. The International Systems of Units expresses frequency in Hertz (1 Hz = 1 cycle per second).

FREQUENCY (FUNDAMENTAL) (UT): In resonance testing, the frequency at which the wavelength is twice the thickness of the examined material.

FREQUENCY (INSPECTION) (UT): Effective peak ultra-sonic wave frequency used to inspect the test part.

FREQUENCY (PULSE REPETITION) (UT): The number of pulses per second.

FRESNEL ZONE (UT): See NEAR FIELD.

FRETTING (FRETTING CORROSION): Action that results in surface damage, especially in a corrosive environment, when there is relative motion between solid surfaces in contact under pressure.

FRILLING (RT): See SLOUGHING.

FULL-WAVE RECTIFIED SINGLE-PHASE AC: This is rectified alternating current for which the rectifier is so connected that the reverse half of the cycle is “turned around,” and fed into the circuit flowing in the same direction as the first half of the cycle. This produces pulsating D.C., but with no interval between the pulses. Such current is also referred to as single-phase full-wave D.C. It is also known as unidirectional current, single phase.

FULL-WAVE RECTIFIED THREE-PHASE AC: When three-phase alternating current is rectified the full-wave rectification system is used. The result is D.C. with very little pulsation - in fact only a ripple of varying voltage distinguishes it from straight D.C. It is also known as unidirectional current, three phase.

FURRING (MT): Buildup or bristling of magnetic particles due to excessive magnetization of the component under examination resulting in a furry appearance.

FUSION: The process by which two light nuclei combine to form a heavier nucleus.

G

GADOLINIUM-153: A radioisotope of the element gadolinium.

GAIN: See SENSITIVITY.

GALVANIC CORROSION: Corrosion consisting of two dissimilar conductors in an electrolyte, or two similar conductors in dissimilar electrolytes.

GAMMA, FILM (RT): See GRADIENT.

GAMMA INFINITY (RT): The maximum gamma that can be achieved by prolonged development of a photographic film.

GAMMA RADIOGRAPHY (RT): The process whereby a photographic image of an object is produced by gamma radiation that has penetrated through the object.

GAMMA RADIOGRAPHY SYSTEM (RT): All components necessary to make radiographic exposures with gamma radiation, including the exposure device, source assembly, control, and other components associated with positioning the source such as source guide tubes, exposure head, and collimators, if used.

GAMMA-RAY SOURCE (RT): A quantity of a radionuclide that emits gamma radiation suitable for radiography.

GAMMA-RAY SOURCE CONTAINER (RT): See CONTAINER, GAMMA-RAY SOURCE

GAMMA RAYS: The electromagnetic radiation of high frequency or short wavelength emitted by the nucleus of an atom during a nuclear reaction. Gamma rays are undeflected by electric or magnetic fields. They are identified in nature and properties to X-rays of the same wavelength, and differ only in their manner of production.

GAS HOLES: Blow holes, channels, or porosity produced by gas evolution, usually during solidification.

GAS HOLES (RT) (ON RADIOGRAPH): Appear as round or elongated, smooth-edged dark spots, occurring individually, in clusters, or distributed throughout the casting.

GAS POROSITY: Refers to porous sections in metal that appear as round or elongated dark spots corresponding to minute voids usually distributed through the entire casting.

GAS POROSITY (RT) (ON RADIOGRAPH): Represented by round or elongated dark spots corresponding to minute voids usually distributed through the entire casting.

GATE (UT): Electronic device to monitor signals in a selected segment of the distance trace on an A-scan display.

GAUSS: This is the unit of flux density or induction. The strength of field induced in a ferromagnetic body is described as being so many Gausses. It is usually designated by the letter “B.” Numerically, one Gauss is one line of flux per square centimeter of area.

GEIGER COUNTER: A radiation detection and measuring instrument. It contains a gas-filled tube that discharges electrically when ionizing radiation passes through it. Discharges are counted to measure the radiation’s intensity.

GENETIC EFFECTS OF RADIATION: Effects that produce changes in those cells of organisms which give rise to egg or sperm cells and therefore affect offspring of the exposed individuals.

GEOMETRIC FACTORS (RT): General term used to describe the factors in radiographic exposures that account for distortion and/or enlargement. Some of the more common geometric factors include focal spot size, specimen thickness, and source-to-film distance.

GEOMETRIC UNSHARPNESS (RT): See UNSHARPNESS.

GHOST (UT): An indication that has no direct relation to reflected pulses from discontinuities in the materials being tested.

GRADIENT (RT): The slope of a characteristic curve at a specified density. Symbol: G. Note: The term “gamma” is used for the slope of the approximately straight portion of the curve.

GRAININESS (RT): A film characteristic which consists of the grouping or clumping together of the countless small silver grains into relative large masses visible to the naked eye or with slight magnification.

GRAIN BOUNDARY: An interface separating two grains when the orientation of the lattices changes from that of one grain to that of another. When the orientation change is very small, the boundary is sometimes referred to as sub-boundary.

GRAIN FLOW: See FLOW LINES.

GRAINS: Individual alloy crystals that form the structure of the metal.

GRAIN SIZE: Size of the crystals in metal when compared with a standard. Usually referred to as being fine, medium or coarse.

GRAIN SIZE (RT): The average size of the silver halide particles in a photographic emulsion.

GRAPHITIZATION: Formation of graphite in iron or steel. Where graphite is formed during solidification, the phenomenon is called “primary graphitization”; where formed later by heat treatment, “secondary graphitization.”

GRAY (Gy): The SI unit of absorbed dose. One gray is equal to an absorbed dose of 1 Joule/kilogram (or 100 rads).

GRID (RT): An assembly of strips of metal, opaque to X-rays, assembled edgewise and interleaved with material of low absorption, to be placed between the object and the screen or film, in order to reduce the effects of scattered radiation from the object.

GRID RATIO (RT): The ratio of the depth of the opaque strips of a grid, measured in the direction of the primary beam, to the spacing between them.

GRINDING CRACKS: See CRACKS, GRINDING.

GRINDING STRESS: Residual stress, generated by grinding, in the surface layer of work. It may be tensile, compressive, or both.

GRIT BLAST: See SANDBLAST.

GROSS POROSITY: In weld metal or in a casting, pores, gas holes or globular voids that are larger and in greater number than obtained in good practice.

H

H AND D CURVE (RT): See CHARACTERISTIC CURVE.

HAIRLINE SEAM: See SEAM.

HALATION (RT): The fogging of a film emulsion due to reflection and dispersion of the radiation within the emulsion. This is generally apparent at locations of heavy exposure.

HALF-LIFE (RT): The time in which half the atoms in a radioactive substance disintegrate. Half-lives vary from millionths of a second to billions of years.

HALF-LIFE (BIOLOGICAL): The time required for a biological system, such as a man or an animal, to eliminate, by natural processes, half the amount of a substance that has entered it.

HALF-VALUE LAYER (RT): The thickness of a material that transmits 50 percent of the radiation incident upon it. In exponential attenuation, the half-value layer is related to the linear attenuation coefficient and the mean free path.

HALF-VALUE PERIOD (RT): See HALF-LIFE.

HALF-WAVE RECTIFIED AC (MT): Alternating current which passes through a rectifier in such a manner that the reversing half of the cycle (negative) is blocked out completely. It is pulsating unidirectional current. It differs from full-wave.

HALL DEVICE (MT): An element composed generally of a semiconductor material which exhibits a relatively large output voltage across the edges of the element in a directional mutually perpendicular to current flowing through the material and a magnetic field at right angles to the current flow.

HALL EFFECT (MT): The phenomenon wherein a voltage is generated across the opposite edges of an electrical conductor carrying current and placed in a magnetic field. The generated voltage differential is mutually perpendicular to the direction of current flow and the applied magnetic field.

HAMMER FORGING: Forging in which the work is deformed by repeated blows. Compare with press forging.

HARDENABILITY: In a ferrous alloy, the property that determines the depth and distribution of hardness induced by quenching.

HARDENER (RT): An agent incorporated into the fixer solution to harden the emulsion during the fixing process. The acid hardener prevents the swelling of the emulsion and facilitates the drying process.

HARDENING: Heating metal to within its critical range as in annealing, followed by rapid cooling as in quenching.

HARD FACING: Depositing filler metal on a surface by welding, spraying or braze welding, for the purpose of resisting abrasion, erosion, wear, galling and impact.

HARDNESS: Resistance of metal to plastic deformation, usually by indentation. However, the term may also refer to stiffness or temper or to resistance to scratching, abrasion or cutting.

HARDNESS TESTING: By means of instruments such as Brinnel, Rockwell, Scleroscope, Vickers, etc.

HARD RADIATION (RT): A term used to describe qualitatively the more penetrating types of radiation.

HARDWARE FINISH: Refers to an especially smooth, as cast, surface which requires a minimum of preparation for plating.

“HARD” X-RAYS: A term used to express the quality or penetrating power of X radiation. Hard X-rays are very penetrating.

HARMONICS (UT): Those vibrations that are integral multiples of the fundamental frequency; used in resonance testing.

HASH: Numerous, small indications appearing on the viewing screen of the ultrasonic instrument indicative of many small inhomogeneities in the material and/or background noise; also known as grass.

HEADING: Upsetting wire, rod or bar stock in dies to form parts having some of the cross-sectional area larger than the original. Examples are bolts, rivets, and screws.

HEADS: The clamping contacts on a stationary magnetizing unit.

H & D CURVE (HURTER AND DRIFFIELD) (RT): See CHARACTERISTIC CURVE.

HEADSHOT (MT): A term used colloquially to designate the magnetizing current passing through a part or a central conductor while clamped between the head contacts of a stationary magnetizing unit for the purpose of circular magnetization.

HEALTH PHYSICS: A term in common use for that branch of radiological science dealing with the protection of personnel from harmful effects of ionizing radiation.

HEAT (MELT) OF METAL: A quantity of metal manufactured from one melt.

HEAT-AFFECTED ZONE: That portion of the base metal which was not melted during brazing, cutting or welding, but whose microstructure and physical properties were altered by the heat.

HEAT CHECK: A pattern of parallel surface cracks that are formed by alternate rapid heating and cooling of the extreme surface metal, sometimes found on forging dies and piercing punches. There may be two sets of parallel cracks, one set perpendicular to the other.

HEAT CHECKING: The crazing of a die surface, especially when the die is subjected to alternate heating and cooling by molten metal; the resulting fine cracks produce corresponding veins on castings.

HEAT TINTING: Coloration of a metal surface through oxidation by heating to reveal details of the microstructure.

HEAT TREAT: Heating and cooling of a metal or alloy in the solid state for the purpose of obtaining certain desirable conditions or properties.

HEAT TREAT CRACKS: See CRACKS, QUENCHING.

HEAT TREATMENT: Exposure of a metal to predetermined temperatures beyond the range of normal atmospheric conditions for a specific time to obtain a specific range of mechanical properties.

HERTZ: One cycle per second; a unit for frequency. Abbreviation is Hz.

HETEROGENEOUS RADIATION (RT): Radiation consisting of particles or photons that have a broad spectrum of energies.

HIGH-CONDUCTIVITY COPPER: Copper that, in the annealed condition, has a minimum electrical conductivity of 100% IACS as determined in accordance with ASTM methods of test.

HIGH RADIATION AREA: Means an area, accessible to individuals, in which radiation levels could result in an individual receiving a dose equivalent in excess of 0.1 rem (1 mSv) in 1 hour at 30 centimeters from the radiation source or from any surface that the radiation penetrates.

HOMOGENIZING: Holding at high temperature to eliminate or decrease chemical segregation by diffusion.

HOMOGENIZING TREATMENT: A heat treatment of an alloy intended to make it uniform in composition by eliminating coring and concentration gradients.

HOODED ANODE (RT): A type of anode, in medium or high voltage X-ray tubes, in which the target is recessed in a metal hood that intercepts electrons. The hood may also incorporate a filter to absorb unwanted radiation.

HORIZONTAL LINEARITY (UT): Constant relationship between the incremental horizontal displacement of vertical indications on an A-scan presentation and the incremental time required for reflected waves to pass through a known length in a uniform transmission medium.

HORSESHOE MAGNET: A bar magnet, bent into the shape of a horseshoe so that the two poles are adjacent. Usually the term applies to a permanent magnet.

HOT-CATHODE TUBE (RT): An X-ray tube in which the cathode is electrically heated to provide electrons.

HOT CELL: A heavily shielded enclosure in which radioactive materials can be handled remotely through the use of manipulators and viewed through shielded windows so that there is no danger to personnel.

HOT CRACKS: See CRACKS, HOT.

HOT FORMING: Working operations, such as bending, drawing, forging, piercing, pressing and heading performed above the recrystallization temperature of the metal.

HOT SHORTNESS: Brittleness in metal in the hot forming range.

HOT SPOT: The point of retarded solidification caused by an increased mass of metal at the juncture of two sections. It frequently results in shrinkage and inferior mechanical properties at this location.

HOT TEAR: A fracture formed in a metal during solidification because of hindered contraction. Usually on the surface of the part.

HOT WORKING: Deforming metal plastically at such a temperature and rate that strain hardening does not occur. The low limit of temperature is the recrystallization temperature.

HYDROGEN EMBRITTLEMENT: A condition of low ductility in metals resulting from the absorption of hydrogen.

HYDROMETER: An instrument used to determine specific gravity and hence the strength. It consists of a sealed, graduated tube, weighted at one end, that sinks in a fluid to a depth used as a measure of the fluid's specific gravity.

HYDROPHILIC (PT): Having an affinity for, attracting, adsorbing, or absorbing water. A substance soluble in water.

HYDROPHILIC REMOVER (PT): A water compatible remover used with standard penetrants. Provides for improved control of the emulsification step process. It requires different processing steps than the standard Lipophilic emulsifiers.

HYSTERESIS (MT): A retardation or lagging of the magnetic effect when the magnetizing forces acting upon a ferromagnetic body are changed.

Hz: Abbreviation for hertz.

I

IACS (ET): International Annealed Copper Standard is an international standard of electrical conductivity. It is based on a high purity grade of copper designated as 100 percent.

ICICLES (BURN THROUGH): A coalescence of metal beyond the root of the weld. IIW: Abbreviation for International Institute of Welding.

IIW BLOCK: Specific type of reference standard used for angle beam, straight beam, and surface wave methods. See IIW.

IMAGE AMPLIFIER (RT): A device that enhances a radiographic image for the purpose of decreasing interpretation time or increasing image detail.

IMAGE CONTRAST (RT): See CONTRAST, FILM.

IMAGE DEFINITION (RT): See DEFINITION, RADIOGRAPHIC.

IMAGE INTENSIFIER (RT): A device used in fluoroscopy to produce an image brighter than that, which would be produced by the unaided action of the X-ray beam on a fluorescent screen.

IMAGE QUALITY INDICATOR (IQI) (PENETRAMETER) (RT): A device used to determine from the appearance of its image in a radiograph, the overall quality of that radiograph. It is not intended for use in judging size nor establishing acceptance limits for discontinuities.

IMAGE QUALITY LEVEL (RT): See RADIOGRAPHIC QUALITY LEVEL.

IMMERSION METHOD (UT): The inspection method in which the search unit and the test part are submerged in a fluid, usually water, which acts as the coupling medium.

IMMISCIBLE (PT): Pertaining to liquids that will not mix with each other.

IMPACT ENERGY (IMPACT VALUE): The amount of energy required to fracture a material, usually measured by means of an Izod or Charpy test.

IMPACT STRENGTH: The ability to resist shock, as measured by an impact testing machine.

IMPACT TEST: A test to determine the behavior of materials when subjected to high rates of loading, usually in bending, tension or torsion. The quantity measured in the energy absorbed in breaking the specimen by a single blow, as in the Charpy or Izod tests.

IMPEDANCE: This term is used to refer to the total opposition to the flow of current represented by the combined effect of resistance, inductance and capacitance of a circuit.

IMPEDANCE (ACOUSTIC): Resistance to flow of ultrasonic energy in a medium. Impedance is a product of particle velocity and material density.

IMPEDANCE PLANE DIAGRAM: A graphical representation of the locus of points indicating the variations in the impedance of a test coil as a function of basic test parameters such as electrical conductivity, magnetic permeability, test frequency, thickness and magnetic coupling.

IMPEDANCE TESTING: A term generally applied to eddy current testing which measures the overall change in impedance caused by variations in electromagnetic properties as differentiated from phase analysis testing which measures changes in phase.

IMPURITIES: Elements or compounds whose presence in a material is undesired.

INCLUSION: Particles of impurities, usually oxides, sulphides, silicates, and such, which are retained in the metal during solidification or which are formed by subsequent reaction of the solid metal.

INCOMPLETE FUSION: Fusion that is less than complete. Failure of weld metal to fuse completely with the base metal or proceeding bead.

INCOMPLETE JOINT PENETRATION (LACK OF FUSION): Appears as elongated darkened lines of varying length and width that may occur in any part of the welding groove.

INCOMPLETE PENETRATION: Root penetration that is less than complete or failure of a root pass and a backing pass to fuse with each other.

INDENTATION: In a spot, seam or projection weld, the depression on the exterior surface of the base metal.

INDENTATION HARDNESS: The resistance of a material to indentation. This is the usual type of hardness test, in which a pointed or rounded indenter is pressed into a surface under a substantially static load.

INDICATION: In nondestructive inspection, a response or evidence of a response, that requires interpretation to determine its significance.

INDICATION (MT): This term refers to any magnetically held magnetic particle pattern on the surface of a part being tested.

INDICATION (PT): The visible evidence of penetrant which has come out of a discontinuity, indicating to the inspector that some sort of surface opening is present.

INDICATION (UT): The signal displayed on the ultrasonic equipment.

INDIVIDUAL MONITORING DEVICES: Devices designed to be worn by a single individual for assessment of dose equivalents. Although they may include film badges, thermoluminescent dosimeters (TLDs), pocket ionization chambers and personal air sampling devices, their use within the Army is usually limited to TLDs.

INDUCED CURRENT MAGNETIZATION (MT): A special technique used to establish a circular field for the detection of circumferential discontinuities in ring-shaped parts without making direct contact with the surface of the part. Sometimes referenced as Induced Field.

INDUCED RADIOACTIVITY: Radioactivity that is created by bombarding a substance with neutrons in a reactor or with charged particles produced by particle accelerators.

INDUCED RADIOACTIVITY (RT): Radioactivity resulting from irradiation of matter.

INDUCTANCE: A property of a circuit that opposes any change in the existing current. Inductance is present only when the current is changing. A coil is a source of inductance.

INDUCTION: Magnetic induction is the magnetism induced in a ferromagnetic body by some outside magnetizing force.

INDUCTION HARDENING: Quench hardening in which the heat is generated by electrical induction.

INDUCTIVE REACTANCE: This is the opposition, independent of resistance, of a coil to the flow of an alternating current.

INDUSTRIAL RADIOLOGY (RT): That branch of radiology covering industrial applications of ionizing radiation.

INGATE: Same as GATE.

INGOT: A casting suitable for working or remelting.

INHERENT DEFECTS: Defects introduced into steel at the time it originally solidifies from the molten state.

INHERENT FILTRATION (RT): The filtration exhibited by the walls and other materials of a radiation source through which the radiation must pass before it is utilized. Inherent filtration affects the spectral distribution of the radiation, and thus, the quality of the final radiograph.

INHERENT UNSHARPNESS (RT): See UNSHARPNESS.

INHIBITOR: A substance that retards some specific chemical reaction such as rusting.

INITIAL PULSE (UT): Electrical pulse generated by the ultrasonic instrument; used to excite a search unit in order to produce ultrasonic energy. Sometimes called the main bang.

IN-MOTION RADIOGRAPHY: A method in which either the object being radiographed or the source of radiation is in motion during the exposure.

IRRELEVANT INDICATION: See GHOST.

INSPECTION: Process of examining for possible defects or for deviation from established standards.

INSPECTION (MT): Visually observing, or looking at the surface of a part after it has been magnetized and magnetic particles applied to assure that the part is free of discontinuities.

INTENSIFYING SCREEN (RT): A layer of material that, when placed in contact with a photographic film, improves the efficiency of the photographic action of ionizing radiation on the film emulsion. The increased rate of absorption of radiation energy by the emulsion enables reduction of exposure time.

INTENSITY, RADIATION (RT): The amount of energy passing per unit time per unit area at a point in a beam of radiation, the area being perpendicular to the direction of propagation.

INTERACTION (RT): Any process in which all or part of the energy of incident radiation is transferred to the electrons or nuclei of the atoms that constitute matter, or in which only the direction of the incident particle is altered.

INTERFACE: The physical boundary between two adjacent surfaces.

INTERGRANULAR CORROSION: Corrosion occurring preferentially at grain boundaries.

INTERLOCK (RT): A device for precluding access to an area of radiation hazard either by preventing entry or by automatically removing the hazard.

INTERMEDIATE LAYER METHOD (ET): A method of liftoff compensation where the same eddy current indication is obtained from bare metal and at a predetermined distance from the bare metal using a nonconductive shim (intermediate layer).

INTERNAL COIL (ET): A coil wound upon a bobbin and having a cross-sectional configuration close to that of the internal bore or passage of the test object.

INTERNAL CONVERSION (RT): The transfer of nuclear energy directly to a bound electron in the same atom, which causes the electron to be ejected from the atom. Subsequent filling of the vacancy thus created results in the emission of characteristic X-rays or auger electrons.

INTERNAL STRESSES: Unseen forces existing within a part. These are forces that exist without the part being subjected to a working load.

INTERPRETATION (Evaluation): The determination of the cause of an indication or the evaluation of the significance of discontinuities from the standpoint of whether they are detrimental defects or superficial blemishes.

INTERPRETATION (MT): The determination of what condition in the part has caused the magnetic particle pattern.

INTERSTITIAL SOLID SOLUTION: An alloy in which small atoms of alloying elements including carbon, nitrogen or hydrogen assume positions between the lattice sites normally occupied by the base metal.

INVERSE SQUARE LAW (RT): At constant kilovoltage or source strength, the intensity of the radiation reaching the object is governed by the distance between the focal spot or radioactive source and the object, varying inversely with the square of the distance.

INVERSE VOLTAGE (RT): A voltage that may appear across an X-ray tube or rectifier during one half-cycle of an alternating current and that reverses the polarity of the electrodes relative to the previous half-cycle.

INVESTMENT CASTING:

(1) Casting metal into a mold produced by surrounding (investing) in expendable pattern with a refractory slurry that sets at room temperature after which the wax, plastic or frozen mercury pattern is removed through the use of heat. Also called precision casting or lost-wax process.

(2) A casting made by the process.

ION (RT): An ion is an atom or group of atoms that is not electrically neutral but instead carries a positive or negative electric charge. Positive ions are formed when neutral atoms or molecules lose valance electrons; negative ions are those which have gained electrons.

ION PAIR (RT): A positive ion and a negative ion or electron having charges of the same magnitude, and formed simultaneously from a neutral atom or molecule with energy supplied by radiation or any other suitable source.

ION PAIRS: A positive ion and a negative ion or electron having charges of the same magnitude, and formed from a neutral atom or molecule by the action of radiation or by any other agency that supplies energy.

ION SOURCE (ION GUN) (RT): A device by which gaseous ions are produced, focused, and accelerated, and are emitted as a narrow beam.

IONIC (RT, PT): Relating to, existing in the form of, or characterized by ions.

IONIZATION: The process of adding electrons to, or knocking electrons from, atoms or molecules, thereby creating ions. High temperatures, electrical discharges, and nuclear radiation can cause ionization.

IONIZATION CHAMBER: An instrument that detects and measures ionizing radiation by observing the electrical current created when radiation ionizes gas in the chamber, making it a conductor of electricity.

IONIZING RADIATION: Any radiation that directly or indirectly displaces electrons from the outer domains of atoms. Examples: alpha, beta, and gamma radiation.

IQI SENSITIVITY (RT): The sensitivity (quality level) of a radiographic process, as determined by the use of an image quality indicator (IQI). Properly called radiographic sensitivity.

IRIDIUM-192: A radioactive isotope of the element Iridium that has a half life of 75 days. It is used extensively as a source of gamma radiation.

IRRADIATION: Exposure to radiation, as in a nuclear reactor.

ISOMER: One or two or more nuclides having the same atomic number, but existing for measurable time intervals in different quantum states, with different energies and radioactive properties.

ISOMER (RT): One of two or more nuclides that are both isotopes (same atomic number) and isobars (same mass number) of each other, but which have some measurably different physical property, such as half life.

ISOMERIC TRANSITION (RT): The transition of an isomer to a lower energy state. It is accompanied by the emission of gamma radiation that may be internally converted.

ISOTOPE (RT): One of several nuclides having the same number of protons in their nuclei, and hence belonging to the same element, but differing in the number of neutrons, and therefore in mass number. Small quantitative differences in chemical properties exist between elements and isotopes. Isotopes may or may not be unstable. Unstable isotopes undergo transitions to other isotopes or elements with a loss of energy. Such energy is usually given off in the form of electromagnetic or particle radiation. Isotopes are used as source of radiation for radiography.

ISOTROPY: Quality of having identical properties in all directions.

ITEMS: An item is one of the compounds necessary to make up a family of penetrant materials. For example: penetrant, emulsifier, remover, or developer.

IZOD TEST: A pendulum-type of single-blow impact test in which the specimen, usually notched is fixed at one end and broken by a falling pendulum. The energy absorbed, as measured by the subsequent rise of the pendulum, is a measure of impact strength or notch toughness.

J

JIG: A fixture or template employed to insure exact location of one part in relation to another.

JOINT EFFICIENCY: The strength of a welded joint expressed as a percentage of the strength of the unwelded base metal.

JOINT PENETRATION: The distance weld metal and fusion extend into a joint.

K

K-ELECTRON CAPTURE: Electron captured by a nucleus of an electron from the “K” or innermost shell of electrons surrounding it. Also loosely used to designate any orbital electron captured.

KEY SWITCH (RT): A device that requires a Key for making and breaking electrical connections.

KHz: Abbreviation for kilohertz.

KILLED STEEL: Steel deoxidized with a strong deoxidizing agent such as silicon or aluminum in order to reduce the oxygen content to such a level that no reaction occurs between carbon and oxygen during solidification.

KILOHERTZ: 1,000 Hz. Abbreviation is kHz.

KILOVOLT: Unit of electromotive force or potential equal to 1,000 volts.

KILOVOLT PEAK: The crest value of electromotive force or potential, in kilovolts, of a pulsating source of electric potential.

L

LO: Symbol for near field length.

LACK OF FUSION: Two-dimensional defect due to lack of union between weld metal and parent metal,

LAMB WAVE (UT): A complex type of ultrasonic wave propagated in metal sheets up to a few wavelengths thick. Their propagation characteristics are dependent upon the properties of the material and its thickness, along with the frequency of the incident wave. These vibrations occur throughout the thickness of the material and consist of two basic types, symmetrical and asymmetrical. Each of these types may have an infinite number of modes, which are determined, by the wave’s incident angle. They can be very effective for detecting laminar discontinuities, but, because of their complexity, practical application can be difficult.

LAMBDA (k): Symbol for wavelength; the eleventh letter of the Greek alphabet.

LAMINATE:

(1) A composite metal, usually in the form of sheet or bar, composed of two or more metal layers so bonded that the composite metal forms a structural member.

(2) To form a metallic product of two or more bonded layers.

LAMINATIONS: Discontinuities in plate, sheet or strip caused by pipe, inclusions, or blowholes in the original ingot; after rolling they are usually flat and parallel to the outside surface.

LAMINOGRAPHY: A special form of tomography which is used for limiting an inspection to a single plane in the material; images of the condition along the plane of interest are brought into sharp focus while other images are smeared or blurred.

LAP: A surface defect, appearing as a seam, caused by folding over hot metal, fins or sharp corners and then rolling or forging them into the surface, but not welding them.

LATENT IMAGE (RT): The metallic silver image of the material radiographed brought out by the developing process.

LATITUDE (RT): Latitude, most closely aligned with contrast, is the range of thickness that can be transferred or recorded on a radiograph within the useful reading range of film density. A high contrast has little latitude whereas a low contrast film will have great latitude.

LATTICE: The repetitive three-dimensional arrangement of atoms in a solid.

LAW: Liquid Active Waste.

LAW OF RECIPROCITY, PHOTOGRAPHIC (RT): See RECIPROCITY LAW.

LD (RT): See MEDIAN LETHAL DOSE.

LEAD EQUIVALENT (RT): The thickness of lead affording the same attenuation of radiation under specified conditions, as the material in question.

LEAD GLASS (RT): Glass containing a high proportion of lead compounds, used as a transparent shielding material.

LEAD RUBBER (RT): Rubber containing a high proportion of lead compounds. It is used as a flexible shielding material.

LEAD-RUBBER GLOVES (PROTECTIVE GLOVES) (RT): Gloves incorporating lead rubber as a shielding material.

LEAD SCREENS: See SCREENS, LEAD.

LEAK: A hole or void in the wall of an enclosure, capable of passing liquid or gas from one side to the other under action of a pressure or concentration difference existing across the wall.

LEAKAGE (RT): The undesired release of radioactive material from a sealed source.

LEAKAGE FIELD: See FIELD, LEAKAGE.

LEAKAGE RADIATION (RT): Radiation other than the useful beam emitted from an X-ray tube assembly or source housing.

LEAKAGE RATE: The quantity of gas per unit time at a given temperature and pressure, that flows through a leak or leaks; normally expressed in standard cubic centimeters per second (STD. cm3/s).

LEAK TEST (RT): A method capable of detecting the leakage of radioactive material from a sealed source.

LEAK TESTING (PT): Method of applying penetrant to one surface and developer to the opposite side of a structure to detect flaws that extend entirely through the structure.

LEAKER-PENETRANT: The type of penetrant especially designed for leak detection.

LENGTH/DIAMETER RATIO (MT): A ratio of the length and diameter of a part for the purpose of calculating the amperes required for longitudinal magnetization.

LICENSED MATERIAL: Source material, special nuclear material, or by-product material received, possessed, used, or transferred under a general or special license issued by the Atomic Energy Commission.

LICENSED MATERIAL (RT): Source material, special nuclear material, or byproduct material received, possessed, used, or transferred under a general or special license issued by the Nuclear Regulatory Commission or an Agreement State.

LIFT-OFF (ET): A measure of the gap between the face of a surface probe and the surface being inspected. It is a measure of the coupling between the probe and the material being inspected.

LIFT-OFF COMPENSATION (LIFT-OFF ADJUSTMENT) (ET): Procedures for instrument adjustments whereby impedance variations caused by a variable gap between an eddy current surface and the test part are suppressed. This adjustment is designed to provide a better signal-to-noise ratio for eddy current inspection.

LIFT-OFF EFFECT (ET): The effect observed in the test system output due to a change in magnetic coupling between a test specimen and a probe coil whenever the distance of separation between them is varied.

LIGHT METAL: One of the low-density metals such as aluminum, magnesium, titanium, beryllium or their alloys.

LIGHT METER (MT, PT): A device used to measure the light intensity of a black light in foot candles or micro-watts per square centimeter, whichever is appropriate.

LIMIT FREQUENCY: A mathematically derived frequency value used to establish impedance diagrams.

LINDEMANN GLASS (RT): Glass of low X-ray absorption containing lithium, boron and beryllium.

LINEAR ABSORPTION COEFFICIENT: See ABSORPTION COEFFICIENT, LINEAR.

LINEAR ACCELERATOR: An apparatus used to accelerate electrons to high velocities by means of a high frequency electrical wave traveling along a tube in the linear direction of the electron beam.

LINEAR DISCONTINUITIES: Ragged lines of variable width. May appear as a single jagged line or exist in groups. They may or may not have a definite line of continuity.

LINEAR ENERGY TRANSFER (LET) (RT): The energy lost by a charged particle per unit distance of material traversed. It can be expressed as electron volts per meter, or some convenient multiple or submultiple, such as KeV per millimeter.

LINEAR INDICATIONS: An indication having length three or more times its width.

LINEARITY: See VERTICAL LINEARITY and HORIZONTAL LINEARITY.

LINE FOCUS (RT): See EFFECTIVE FOCAL SPOT.

LINE FOCUS PRINCIPLE (RT): The process of making the angle between the anode face and the central ray such that the effective focal spot is small in relation to the actual spot size.

LINE-FOCUS TUBE (RT): An X-ray tube in which the electron focus is approximately a rectangle and the foal spot size is approximately a square.

LINES OF FORCE (MT): Imaginary lines used to visualize the magnetic field.

LIMITS (dose limits): The permissible upper bounds of radiation doses.

LIPOPHILIC (PT): An oil based liquid used in penetrant inspection to make penetrant oil water-washable.

LIQUID VEHICLE (MT): The liquid in which the magnetic particles are suspended to facilitate their application.

LOCALIZING CONE (COLLIMATING CONE) (RT): A cone that limits the divergence of a beam of radiation.

LONGITUDINAL MAGNETIZATION (MT): Magnetization of a material in such a way that the magnetic lines of force are essentially parallel to the test parts longitudinal axis.

LONGITUDINAL WAVE (UT): A type of wave in which the particle motion of the material is essentially in the same direction as the wave propagation.

LOSS OF BACK REFLECTION (UT): Absence of an indication of the far surface of the article being inspected.

LUDERS' LINES: Lines that are produced on the surface of low carbon steel by deforming the metal just past the yield point.

LUMEN (PT, MT): A measure of the brightness of light. A unit of luminous flux equal to the light emitted in a unit solid angle by uniform point source of one candle.

LUMINESCENCE (RT): A phenomenon in which the absorption of radiation by a substance gives rise to the emission of light characteristic of the substance.

M

MACMNEABILITY: Refers to the ease and speed with which a metal may be cut (with free chip removal) to produce a reasonably smooth surface.

MACHINED SURFACE: The metal surface left by the cutting tool.

MACHINING: Removing material, in the form of chips, from work, usually through the use of a machine.

MACHINING STRESS: Residual stress caused by machining.

MACRO-ETCH: Etching of a metal surface for accentuation of gross structural details and defects for observation by the unaided eye or at magnifications not exceeding ten diameters.

MACROGRAPH: A graphic reproduction of the surface of a prepared specimen at a magnification not exceeding ten diameters. When photographed, the reproduction is known as a photomacrograph.

MACRO INSPECTION: Utilizes deep etch and examination under low magnification up to 10 diameters. It reveals flow lines, etc.

MACROPOROSITY (PT): Voids or gas pockets in metals that are large enough to be seen at magnification of less than 10 diameters.

MACROSCOPIC: Visible at magnifications from one to ten diameters.

MACROSCOPIC STRESSES: Residual stresses which vary from tension to compression in a distance (presumably many times the grain size) which is comparable to the gage length in ordinary strain measurements, hence, detectable by X-ray or dissection methods.

MACROSTRUCTURES: The structure of metals, as revealed by the eye or at a magnification of less than 10 diameters.

MAGNET: Materials that show the power to attract iron and other substances to themselves, and that exhibit polarity, are called magnets.

MAGNET, PERMANENT: A highly retentive metal that has been strongly magnetized; for example, the alloy Alnico.

MAGNETIC COUPLING (MT): A term designating the interaction of a magnetic field with an adjoining test part.

MAGNETIC DISCONTINUITY (MT): This refers to a break in the magnetic uniformity of the part - a sudden change in permeability. A magnetic discontinuity may not be related to any actual physical break in the metal, but it may produce a magnetic particle indication.

MAGNETIC FIELD (MT): The space around a source of magnetic flux in which the effects of magnetism can be determined.

MAGNETIC FIELD STRENGTH (MT): The intensity of the magnetic field surrounding the magnetized part measured in GAUSS.

MAGNETIC FLUX: The total number of magnetic lines existing in a magnetic circuit is called “magnetic flux.”

MAGNETIC FORCE: In magnetic particle inspection the magnetizing force is considered to be the total force tending to set up a flux in a magnetic circuit. It is usually designated by letter “H.”

MAGNETIC HYSTERESIS: See HYSTERESIS.

MAGNETIC LOOP: If a conductor carrying an electric current is bent in a loop, the magnetic lines of force enter on one side of the loop and leave at the other, and the space within the loop is found to contain a magnetic field which has very definite directional properties. Polarity is created within the coil with one end being a north pole and the opposite end a south pole. The space enclosed by the loop is longitudinally magnetized.

MAGNETIC MATERIALS: Materials are affected by magnets in two general ways. Some of them are attracted by a magnetic force, while others exert a repellent force. The first is called “paramagnetic” and the latter “diamagnetic.” In magnetic particle inspection we are not ordinarily concerned with either of the two classes, but with what may be termed a subdivision of the first class called “ferromagnetic materials.”

MAGNETIC PARTICLE INSPECTION (MT): A method for detecting discontinuities on or near the surface in suitably magnetized materials, which employ finely divided magnetic particles that tend to congregate in regions of the magnetic non-uniformity, i.e., along cracks, over inclusions, voids, etc.

MAGNETIC PERMEABILITY (MT): A term indicating the ease with which a magnetic field can be established in a material. It is determined by the ratio of the strength of the resultant magnetic force to the applied magnetic force.

MAGNETIC POLES: The ability of a magnet to attract or repel is not uniform over its surface, but is concentrated at local areas called “poles.” Each magnet has at least two poles, one of which is attracted by the earth’s North Pole and is called the north pole of the magnet, and the other which is attracted by the earth's South Pole and is called the south pole of the magnet. Magnetic leakage occurs at poles.

MAGNETICALLY HARD ALLOY: A ferromagnetic alloy capable of being magnetized permanently because of its ability to retain induced magnetization and magnetic poles after removal of externally applied fields; an alloy with high coercive force. The name is based on the fact that the quality of the early permanent magnets was related to their hardness.

MAGNETICALLY SOFT ALLOY: A ferromagnetic alloy that becomes magnetized readily upon application of a field and that returns to practically a nonmagnetic condition when the field is removed; an alloy with the properties of high magnetic permeability, low coercive force and low magnetic hysteresis loss.

MAGNETIC RUBBER INSPECTION (MT): An inspection process involving the use of a formulation of magnetic particles dispersed in a room temperature curing rubber. An extension of the magnetic particle method used for detection of flaws in problem areas such as bolt holes, tubes, etc.

MAGNETIC SATURATION (MT): The degree of magnetization when increasing the magnetizing force upon a part no longer increases the magnetic flux density (permeability) in the part.

MAGNETIC WRITING (MT): A form of nonrelevant indications, sometimes caused when the surface of a magnetized part comes into contact with another piece of ferromagnetic material.

MAGNETISM (MT): The ability of matter to attract other matter to itself and exhibit polarity.

MAGNETIZING CURRENT (MT). The flow of either alternating, rectified AC or direct current used to induce magnetism into the part.

MAGNETIZING FORCE: For the purpose of this discussion, magnetizing force is considered to be the total force tending to set up a magnetic flux in a magnetic circuit. It is usually designated by the letter "H" and the unit is the "Oersted."

MAGNETOGRAPH: A magnetograph is a picture of a magnetic field made by the use of iron powder under conditions that allow it to arrange itself into the pattern of the field.

MAGNETROSTRICTIVE (MT): The property of changing dimension with changing magnetic field.

MAIN BANG (UT): See INITIAL PULSE.

MAINTENANCE INSPECTION: Inspecting any tooling, machines, or equipment periodically, or during rebuilding to prevent future in-service failure.

MALLEABILITY: That property which allows a material to be permanently deformed, by compression, without rupture.

MALLEABLE CAST IRON: A cast iron made by a prolonged anneal of white cast iron in which decarburization or graphitization, or both, take place to eliminate some or all of the cementite. The graphite is in the form of temper carbon.

MANIPULATOR (UT): A device used for orientation of the transducer assembly. As generally applied to immersion techniques provides either angular or normal sound wave path.

MAP: Locating the boundaries of a discontinuity.

MARKERS: A series of square waves, or other beam deflections displayed on the cathode-ray tube screen of the ultrasonic equipment used to determine the distance from the test surface of the article being inspected to a subsequent discontinuity or boundary.

MAS: Milliampere seconds, utilized to standardize radiographic exposures. Example: 5 MA X 60 seconds = 300 MAS.

MASKING (RT): Surrounding specimens or covering thin sections with absorptive material to eliminate scatter and halation on the film image.

MASS ABSORPTION COEFFICIENT (RT): A numerical expression of the absorption characteristics of a given material. The mass absorption coefficient is different for different materials, and is dependent on kilovoltage. It is equal to the Linear Absorption Coefficient divided by the mass density.

MASS ATTENUATION COEFFICIENT (RT): The fraction of uncharged ionizing particles that experience interactions in traversing a unit distance in a material of density.

MASS NUMBER: The sum of the neutrons and protons in a nucleus. The mass number of uranium-235 is 235. It is the nearest whole number to the atom’s actual atomic weight.

MATERIAL NOISE: Extraneous signals caused by the structure of the material being tested.

MAXIMUM PERMISSIBLE DOSE (MPD): That dose of ionizing radiation which competent authorities have established as the maximum that can be absorbed without undue risk to human health.

MEAN FREE PATH: Average distance a particle travels between collisions.

MEAN LIFE: The average time during which an atom or other system exists in a particular form.

MEAN STRESS:

(1) In fatigue testing, the algebraic mean of the maximum and minimum stress in one cycle. Also called the steady stress component.

(2) In any multiaxial stress system, the algebraic mean of three Principal Stresses; more correctly called mean normal stress.

MECHANICAL PROPERTIES: The properties of a material that reveal its elastic and in-elastic behavior where force is applied, thereby indicating its suitability for mechanical applications; for example, modulus of elasticity, tensile strength, elongation, hardness, and fatigue limit.

MEDIAN LETHAL DOSE (RT): The whole-body dose, resulting from a single short exposure (minutes or hours), that will cause the death, within a specified period of time, of 50 percent of the individuals irradiated. The dose sufficient to cause death to 50 percent of the individuals within 30 days is indicated as LD and is on the order of 300 rads.

MEGACYCLE: One million cycles; often used to express one million cycles per second. Abbreviation is mc.

MEGAHERTZ: One million hertz. Abbreviation is MHz.

METAL SCREEN (RT): A screen consisting of a foil of dense metal (usually lead) that emits secondary electrons when exposed to X- or gamma radiation. It also reduces the undesirable effects of scattered radiation.

METALLOGRAPH: An optical instrument designed for both visual observation and photomicrography of prepared surfaces of opaque materials at magnifications ranging from about 25 to about 1500 diameters.

METALLOGRAPHY: The science dealing with the constitution and structure of metals and alloys as revealed by the unaided eye or by such tools as low-powered magnification, optical microscope, electron microscope and diffraction or X-ray techniques.

METALLURGY: The science and technology of metals.

MeV: One million electron volts.

MHz: Abbreviation for megahertz.

MICRO: A prefix that divides a basic unit by one million.

MICROFISSURE: A crack of microscopic proportions.

MICROGRAPH: A graphic reproduction of the surface of a prepared specimen, usually etched, at a magnification greater than ten diameters. If produced by photographic means it is called a photomicrograph (not a microphotograph).

MICROHARDNESS: The hardness of microscopic areas or of the individual microconstituents in a metal, as measured by such means as Tukon, Knoop or scratch methods.

MICRO-INSPECTION: Utilizes a mild etch and high magnification (up to 1000 diameters) for examination of specifically prepared polished samples.

MICRO-SHRINKAGE: Irregular feathery cavities occurring in the grain boundaries. (Occurs predominantly in magnesium alloys.)

MICROPOROSITY: Porosity visible only with the aid of a microscope.

MICROSCOPIC STRESSES: Residual stresses which vary from tension to compression in a distance (presumably approximating the grain size) which is small compared to the gage length in ordinary strain measurements. Hence not detectable by dissection methods, they can sometimes be measured by X-ray line shift.

MICROSECOND: Unit of the time equivalent to 10-6 second or 0.000001 second.

MICRORADIOGRAPHY: A technique used to examine very small objects or minute detail through the use of low voltage X-rays and an ultrafine grain film emulsion which is examined with the aid of optical enlargement.

MICROSHRINKAGE (ON RADIOGRAPH): Cracks that appear as dark feathery streaks, or irregular patches that indicate cavities in the grain boundaries.

MICROSTRUCTURE: The structure of polished and etched metals as revealed by a microscope at a magnification greater than ten diameters.

MILLI: A prefix that divides a basic unit by one thousand.

MILLIAMPERAGE (RT): Milliamperage is a measure of the current flowing between the cathode and the anode in an X-ray tube, and is a measure of the intensity of the emitted radiation.

MILLIAMPERE (RT): A unit of electrical current equal to one thousandth of an ampere.

MILLIAMPERE-SECONDS (RT): A term used to quantify radiographic exposures made with X-rays. It is the product of tube current in milliamperes and exposure time in seconds. Abbreviation: mAs.

MILLICURIE-HOUR (RT): A term used to quantify radiographic exposures made with a gamma-ray source. It is the product of the activity of the source in millicuries and the exposure time in hours.

MILLIROENTGEN (mR): One-thousandth of a roentgen.

MINIATURE ANGLE BEAM BLOCK (UT): Specific type of reference standard primarily used for the angle beam method, but also used for the straight beam and surface wave methods.

MINIATURE-FILM RADIOGRAPHY (MASS MINIATURE RADIOGRAPHY) (RT): Fluorography using miniature photographic film.

MISCIBLE (PT): The tendency of capacity of two or more liquids to form a uniform blend, that is, to dissolve in each other; degrees are total miscibility, partial miscibility, and immiscibility.

MISRUN: A casting not fully formed, resulting from the metal solidifying before the mold is filled.

MISRUNS (RADIOGRAPHIC): Appears as prominent darkened areas of variable dimensions with a definite smooth outlines

MOBILITY (MT): The ease with which magnetic particles move over the surface of a magnetized part and accumulate at a discontinuity exhibiting polarity.

MODE: The manner in which acoustic energy is propagated through a material as characterized by the particle motion of the wave.

MODE CONVERSION (UT): Changing from one mode of vibration to another; caused by retraction at an interface.

MODE OF VIBRATION (UT): Type of wave motion; e.g., longitudinal, transverse, etc. Three common modes of vibration used in ultrasonic inspection are longitudinal, transverse, and surface wave modes.

MODULATION ANALYSIS (ET): An instrumentation method used in eddy current testing which separates responses based on their frequency or rate of response. For instance, slow responses from gradual dimension changes can be separated from rapid responses from a crack.

MODULUS OF ELASTICITY: The ration of stress to the corresponding strain within the limit of elasticity.

MODULUS OF RUPTURE: Nominal stress at fracture in a bend test or torsion test.

MOLD: A form or cavity into which molten metal is poured to produce a desired shape. Molds may be made of sand, plaster or metal and frequently require the use of cores and inserts for special applications.

MOLECULE: The smallest unit quantity of matter that can exist by itself and retain all the properties of the original substance. Molecules are formed by the chemical combination of atoms.

MONITORING (RT): Periodic or continuous determination of the amount of ionizing radiation or radioactive contamination present in an occupied region.

MONOCHROMATIC: (Homogeneous) of the same wavelength.

MOTTLING (RT): Large graininess effect on a radiograph that may be due to diffraction by large grain structures in materials, or can be caused by the use of fluorescent screens. Mottling is readily distinguishable from film graininess because of its coarse appearance and lack of definition.

MOVEMENT UNSHARPNESS (RT): See UNSHARPNESS.

MT: Symbol for the magnetic particle method of nondestructive testing/inspection.

MULTIAXIAL STRESSES: Any stress state in which two or three principal stresses are not zero.

MULTI-DIRECTIONAL MAGNETIZATION: Two separate fields, having different directions, cannot exist in a part at the same time. But two or more fields in different directions can be imposed upon a part sequentially in rapid succession. When this is done magnetic particle indications are formed when discontinuities are located favorably with respect to the directions of each of the fields, and will persist as long as the rapid alternations of field direction continue. This, in effect, does constitute two or more fields in different directions at the same time, and enables the detection of defect oriented in any direction in one operation.

MULTIPLE REFLECTIONS (UT): Successive echoes of ultrasonic energy between two surfaces.

N

NANOMETER (PT): A unit of length equal to one billionth of a meter, or 10-9 meter. The Nanometer has replaced the angstrom unit as a measurement of short wave length, electromagnetic radiation where 1 nm = 10 angstroms.

NANOSECOND: (10-9) one billionth of a second.

NARROW-BANDED (UT): Having a relatively narrow bandwidth; opposite of broad-banded; see TUNED.

NEAR FIELD (UT): The region of the ultrasonic beam adjacent to the search unit, having complex beam profiles; also known as the Fresnel zone. The length of the near field extends from the face of the search unit to the point at which the far field begins and is given by the equation: L0 = D2f /4v

where:

L0 = near field length - inches.

D = the major dimensions of the search unit element - inches.

For circles, D = the diameter. For rectangles or squares, D = diagonal.

f = ultrasonic frequency - hertz.

v = ultrasonic velocity - inches per second.

NEIGHBORHOOD EFFECT (RT): The name given to various effects arising from the diffusion of developer which has become locally exhausted or loaded with oxidation products by its action on a heavily exposed region of an emulsion. Typical examples are developer streaks and abnormal density variations near the edges of regions of high density.

NET DENSITY (RT): Total film density less the base plus fog density.

NETWORK STRUCTURE: A structure in which one constituent occurs primarily at the grain boundaries, thus partially or completely enveloping the grains of the other constituents.

NEUTRON: An uncharged elementary particle with a mass nearly equal to that of the proton. The isolated neutron is unstable and decays with a half-life of about 13 minutes into an electron, proton, and neutrino. Neutrons sustain the fission chain reaction in a nuclear reactor. Neutron radiograph is a technique in which neutrons are used as a penetrating radiation to produce a radiograph.

NEUTRON RADIOGRAPHY (RT): The process whereby a photographic image of an object is produced by neutron radiation that has penetrated through the object.

NITRIDING: Introducing nitrogen into a solid ferrous alloy by holding at a suitable temperature (below Acl for ferritic steels) in contact with a nitrogenous material, usually ammonia or molten cyanide of appropriate composition. Quenching is not required to produce a hard case.

NOBLE METAL: A metal whose potential is highly positive relative to hydrogen electrode. A metal with a marked resistance to chemical reaction.

NODE: A point in a standing wave where some characteristic of the wave field has essentially zero amplitude.

NODULAR CAST IRON: A cast iron that has been treated while molten with a master alloy containing an element such as magnesium or cerium to give primary graphite in the spherultic form.

NOISE (UT, ET): Any undesired signal that tends to interfere with normal reception or processing of the desired signal. Origin may be electrical or from small reflectors in a material.

NONAQUEOUS DEVELOPER: See SOLVENT DEVELOPER.

NONDESTRUCTIVE INSPECTION: A method used to check the soundness of a material or a part without impairing or destroying the serviceability of the part.

NONFERROMAGNETIC MATERIAL (NONMAGNETIC): A material that is not magnetizable and hence, essentially not affected by magnetic fields. This would include paramagnetic materials having a magnetic permeability slightly greater than that of a vacuum and approximately independent of the magnetizing force and diamagnetic materials having permeability less than a vacuum. Some metals free from iron are zinc, tin, aluminum, brass, copper and pot metal.

NON-METALLIC INCLUSION: Inclusions (or stringers) are impurities in the metal as a mechanical mixture. They may be stretched out and broken up during rolling or forging and are at various depths from the surface.

NON-RELEVANT INDICATIONS: An indication due to misapplied or improper inspection. Also, an indication caused by an actual discontinuity in the material that does not affect the usefulness of the part (such as a change of section).

NONRELEVANT INDICATION (MAGNETIC PARTICLE INSPECTION): A magnetic particle indication due to a weak leakage field caused by some condition other than a discontinuity but does not affect the usefulness of the part; such as a keyway, dissimilar parts, etc.

NON-SCREEN FILM (RT): X-ray film designed for use with or without metal screens, but not intended for use with salt screens. It may be of relatively high speed and coarse grain (ordinary non-screen film) or of lower speed and finer grain (fine grain non-screen film).

NON-STOCHASTIC EFFECT: Means health effects, the severity of which varies with the dose and for which a threshold is believed to exist (below which there are no effects). Radiation-induced cataract formation is an example of a non-stochastic effect.

NORMALIZE: Heating steel to above its critical range, as in annealing, and then cooling it in still air at ordinary room temperature.

NOTCH BRITTLENESS: Susceptibility of a material to brittle fracture at points of stress concentration.

NOTCH SENSITIVITY: A measure of the reduction in strength of a metal caused by the presence of stress concentration. Values can be obtained from static, impact or fatigue tests.

NOZZLE: The outlet end of a gooseneck, or the fitting that joins the gooseneck to the sprue hole of the die.

NUCLEAR REACTION: A reaction involving an atom's nucleus, such as fission, neutron capture, radioactive decay, or fusion, as distinct from a chemical reaction, which is limited to changes in the electron structure surrounding the nucleus.

NUCLEAR REACTOR: A device by means of which a fission chain reaction can be initiated, maintained, and controlled. Its essential component is a core with fissionable fuel. It usually has a moderator, a reflector, shielding, and control mechanisms.

NUCLEAR TRANSITION (RT): A change in the energy state or level of an atomic nucleus which may, or may not, result in the emission of radiation.

NUCLEUS: The heavy central part of an atom in which most of the mass and the total positive electric charge is concentrated. With the exception of the nucleus of hydrogen, nuclei are composed of protons and neutrons. The charge of the nucleus, an integral multiple of the charge of the electron, is the essential factor that distinguishes one element from another chemically.

NUCLIDE: Any species of atom that exists for a measurable length of time. A nuclide can be distinguished by its atomic weight, atomic number, and energy state. The term is used synonymously with isotope. A radionuclide is a radioactive nuclide.

NUCLIDE (RT): A species of atom characterized by its mass number, atomic number, and nuclear energy state, and that has a measurable mean life.

O

OBJECT-TO-FILM DISTANCE (RT): The distance from the tube or source side of the irradiated specimen to the film surface, i.e., inclusive of specimen thickness. Abbreviation: ofd.

OCCUPANCY FACTOR (RT): The factor by which the workload should be multiplied to correct for the degree or type of occupancy of the area in question. Symbol: T.

OCCUPATIONAL DOSE: The dose received by an individual in a restricted area or in the course of employment in which the individual's assigned duties involve exposure to radiation. Occupational dose does not include dose received from background radiation, as a patient from medical practices, from voluntary participation in medical research programs, or a member of the general public.

OERSTED (MT): A unit of field strength that produces magnetic induction designated by the letter "H." The Oersted is numerically equal in air or in a vacuum. Oersted (H) refers to the magnetizing force tending to magnetize an unmagnetized body, and Gauss refers to the field (B) so induced in the body.

OHM: The ohm is the unit of electrical resistance. It is the value of a resistance that will pass one ampere of current at a potential of one volt.

OIL-COOLED TUBE (RT): An X-ray tube in which the heat produced is dissipated, directly or indirectly, by means of oil.

OIL-IMMERSED TUBE (RT): An X-ray tube designed for operation in oil.

OPERATING STRESS: The stress to which a structural unit is subjected in service.

OPTICAL DENSITY (RT): See DENSITY.

OPTICAL PYROMETER: A temperature measuring optical device used to compare the incandescence of a heated object with that of an electrically heated filament whose brightness can be regulated.

OPTIMUM FREQUENCY (ET, UT): That frequency, which provides the highest signal-to-noise ratio obtainable for the detection of an individual property such as conductivity, crack, or inclusion of the test specimen. Each type of defect in a given material may have its own optimum frequency.

ORANGE-PEEL EFFECT: A surface roughening in the form of a grain pattern where a metal of unusually coarse grain is stressed beyond its elastic limit. Also called pebbles and alligator skin.

ORBITAL ELECTRON (SHELL ELECTRON) (RT): An electron in the extra-nuclear structure of an atom.

ORIENTATION: Position of a discontinuity or part or surface in relation to the test surface of the article or ultrasonic beam.

ORIENTATION (CRYSTAL): Arrangement in space of the axes of a crystal with respect to a chosen reference or coordinate system.

OSCILLATOR (ET): A component of an electrical circuit that provides a source of current that varies in magnitude and direction with time. In eddy current testing, the oscillator provides a source of alternating current to establish a varying magnetic field.

OSCILLOGRAM (UT): Common term for photograph of data displayed on CRT.

OVER-DEVELOPMENT (RT): Development that is greater than that required to produce the optimum results in a particular radiograph. It may arise from development for too long a time, or at too high a temperature, and may give rise to excessive graininess and lack of contrast.

OVERHEATED: Steel subjected to such high temperatures that coarse grains are produced without destroying the stock as in burning. This may be corrected by suitable heat treat.

OVERLAP: Protrusion of weld metal beyond the bond at the toe of the weld.

OVERLOAD INTERLOCK, X-RAY UNIT (RT): An X-ray machine in which the presetting of voltage, current, and time are interlinked in such a way that if their product (i.e., the energy to be applied) exceeds the permissible loading of the X-ray tube, the latter cannot be energized.

OVERSTRESSING: In fatigue testing, cycling at a stress level higher than that used at the end of the test.

OXIDATION: The reaction of an element to oxygen or an oxygen containing compound.

OXIDATION FOG (RT): Fog caused by exposure of a film to air during development.

P

PAIR PRODUCTION (RT): The conversion of very high-energy photons, when absorbed in matter, by a process wherein the photon is converted in the electrical field of a nucleus into an electron (negative charge) and a positron (equal but opposite positive charge).

PARALLEL MAGNETIZATION: A magnetic field induced in a piece of magnetizable material that is placed parallel to a conductor carrying an electric current.

PARAMAGNETIC (MT): Materials in which the magnetic permeability is slightly greater than one. These materials are classified as nonmagnetic with a permeability of one for purposes of eddy current inspection. A material which can be slightly magnetized, but not sufficiently to permit magnetic particle inspection.

PART: A term used to refer to a manufactured article that is being inspected.

PARTICLE: A minute constituent of matter with a measurable mass, such as a neutron, proton, or meson.

PARTICLE MOTION (UT): Movement of particles in an article brought about by the action of a transducer.

PARTICLE (RT): A minute constituent of matter with a measurable mass, such as an electron, neutron, proton, or meson.

PARTICULATE RADIATION (RT): Radiation consisting of charged or uncharged atomic particles.

PARTING LINE: The line along which a pattern is divided for molding or along which the sections of a mold separate.

PASTE (MAGNETIC): Finely divided, ferromagnetic particles in paste form used in preparing wet suspensions magnetic particle inspection.

PEAK VOLTAGE (RT): The maximum value achieved by a varying voltage.

PENETRABILITY (PT): The property of a penetrant that causes it to find its way into very fine openings, such as cracks.

PENETRAMETER (RT): A device employed to obtain evidence on a radiograph that the technique used was satisfactory. It is not intended for use in judging the size of discontinuities nor for establishing acceptance limits for materials or products.

PENETRAMETER SENSITIVITY (RT): See SENSITIVITY, RADIOGRAPHIC.

PENETRANT (PT): A liquid of high surface tension and high capillary action which is a vehicle for a colored or a fluorescent dye, used to penetrate into the defect and detect surface discontinuities.

PENETRANT INDICATION: Readings that mark or denote the presence of material defects.

PENETRANT, POST EMULSIFIABLE (PT): A penetrant that requires the application of a separate emulsifier to render the surface penetrant water-washable.

PENETRANT REMOVER (PT): A penetrant remover is a solvent-type liquid used to clean penetrants from the surface of a material.

PENETRANT SENSITIVITY (PT): Penetrant sensitivity is the ability of the penetrant, processing technique, and developer to detect surface-connected discontinuities and provide an indication visible to the unaided eye.

PENETRANT, VISIBLE (PT): A penetrant that is characterized by an intense visible color, usually red, that allows it to give contrasting indications on a white developer background.

PENETRANT, WATER-WASHABLE (IT): See WATER-WASHABLE.

PENETRATION: The maximum depth from which indications can be measured in a material.

PENETRATION (RT): A qualitative term used to describe the degree to which radiation is capable of penetrating a given object. Penetration is usually a function of the applied tube voltage in X-rays or equivalent voltage in isotope radiography.

PENETRATION TIME (PT): The time allowed for the penetrant to enter into surface discontinuities, i.e., the length of time elapsing between the application of the penetrant to the part and removal of penetrant.

PENUMBRA (RT): The shadow cast when the incident radiation is partly, but not wholly, cut off by an intervening body; the space of partial illumination between the umbra, or perfect shadow, on all sides and the full light. A marginal region of borderland of partial obscurity.

PERSONNEL MONITORING EQUIPMENT (RT): Devices designed to be worn or carried by an individual for the purpose of measuring the dose received (e.g., film badges, pocket chambers, pocket dosimeters, film rings, etc.)

PERIODIC TABLE: A tabular arrangement of elements according to their properties.

PERMEABILITY (MT): The ease with which a material can become magnetized. It is the relationship between field strength and the magnetizing force.

PERMEABILITY (MT): The ease with which a magnetic field or flux can be set up in a magnetic circuit. It is not a constant value for a given material, but is a ratio. At any given value of magnetizing force, permeability is B/H the ratio of flux density, B, to magnetizing force H.

PERMANENT MAGNETS: A body that possesses the ability to retain or hold a large amount of the applied magnet field after the active power of the field is removed.

PERMANENT MOLD: A metal mold (other than an ingot mold) of two or more parts that is used repeatedly for the production of many castings of the same form. Liquid metal is poured in by gravity.

PERMANENT SET: Plastic deformation that remains upon releasing the stress that produces the deformation.

PHASE: In periodic changes of any magnitude varying according to a simple harmonic law (as ultrasonic vibrations, alternating electric currents, etc.), the point or stage in the period to which the variation has advanced, considered in its relation to a standard position; can be expressed in degrees.

PHASE ANALYSIS: An instrumentation technique which discriminates between variables in the test part by the different phase angle changes which these conditions produce in the test signal.

PHASE ANGLE: The angular equivalent of the time displacement between corresponding points on two sine waves of the same frequency.

PHASE SHIFT: A change in the phase relationship between two alternating quantities of the same frequency.

PHI (0): Symbol for the sound beam angle as measured from the normal to a sound entry or sound reflecting surface; the Greek letter Phi.

PHOTOELECTRIC ABSORPTION (RT): A process by which electromagnetic radiation imparts energy to matter.

PHOTOGRAPHIC EMULSION (RT): See EMULSION.

PHOTOGRAPHIC FOG (RT): Fog caused solely by the properties of an emulsion and the processing conditions, i.e., the total effect of inherent fog and chemical fog.

PHOTOGRAPHIC INTENSIFICATION (RT): Chemical treatment of a processed emulsion, usually with an oxidizing agent, to lessen the density. There may be a change of contrast, depending on the process used.

PHOTOGRAPHIC TRANSMISSION DENSITY (RT): See DENSITY.

PHOTON (RT): An electromagnetic packet of radiation. It has a dual character, acting sometimes like a particle and at other times like a wave. Photons all have equal velocity (the speed of light), have no electric charge, and have no mass.

PHOTO-SENSITIVITY (RT): A property of a photographic emulsion by virtue of which electromagnetic or particulate radiation may produce chemical or physical changes in the emulsion.

PHOTOTHERMOGRAPHIC FILM (RT): A blue/green sensitive “dry silver” film used in conjunction with special fluorescent screens in vacuum cassettes which can serve as an alternative to X-ray film for noncritical applications. The principle advantage of this film is that it is processed thermally, eliminating the need for wet chemicals.

PHYSICAL PROPERTIES: The properties, other than mechanical properties, that pertain to the physics of a material; for example, density, electrical conductivity, heat conductivity, thermal expansion.

PHYSICAL TESTING: Determination of Physical Properties.

PICKLE: Using acid or other chemicals with suitable inhibitors to remove scale or smeared metal without affecting the sound metal.

PICKLE PATCH: A tightly adhering oxide or scale coating not properly removed during the pickling process.

PICKLE STAIN: Discoloration of metal due to chemical cleaning without adequate washing and drying.

PICKLING CRACKS: Cracks caused by internal stresses being released as the pickling acid eats away the surface of the material.

PIEZOELECTRIC (UT): That ability of a material to convert electrical energy into mechanical energy and vice versa.

PIG: A cast slab of primary metal that must be remelted before use.

PINHOLES: Very small holes; sometimes found as a type of porosity in a casting because of microshrinkage or of gas evolution during solidification.

PINHOLE (RT): A through hole of small diameter in a sheet of material opaque to radiation.

PINHOLE POROSITY: Porosity, in either castings or metal formed by electrodeposition, resulting from numerous small holes distributed throughout the metal.

PIPE:

(1) The central cavity formed by contraction in metal, especially ingots, during solidification.

(2) The defect in wrought or cast products resulting from such a cavity.

(3) An Extrusion Defect due to the oxidized surface of the billet flowing toward the center of the rod at the back end.

(4) A tubular metal product, cast or wrought.

PITCHBLENDE: An ore that contains uranium.

PITCH-CATCH (UT): Used to describe an inspection method in which the ultrasonic energy is emitted by one transducer element and received by another on the same or adjacent surface.

PITTING: Forming small sharp cavities in a metal surface by nonuniform electrodeposition or by corrosion.

PLANCK’S CONSTANT (RT): A fundamental physical constant; the ratio of the energy of a photon to its frequency.

PLASTIC DEFORMATION: Working of a material beyond its elastic limit to produce a permanent change in dimensions.

PLASTIC FLOW: Same as PLASTIC DEFORMATION.

PLASTICITY: The ability of a metal to deform nonelastically without rupture.

PLATE PENETRAMETER (STRIP PENETRAMETER) (RT): A plate of material similar to the specimen under examination, having a thickness of 1 or 2 percent of the specimen thickness, and having holes of different diameters.

PLATED CRYSTAL: Crystal on which metallic surfaces are deposited for protection and/or to give surfaces on which the electrical potential can be impressed.

PLATEN: That part of a casting machine against which die sections are fastened, or presses against which trim dies are fastened.

PLATING: Forming an adherent layer of metal upon an object.

PLATING CRACK: See CRACK, PLATING.

PLATE WAVE: See LAMB WAVE.

POINT OF INCIDENCE (UT): Designates the point at which the center of the sound beam leaves the wedge from an angle beam search unit.

POLARITY: The quality of having two opposite magnetic poles, one north and one south.

POLE (MT): The area on a magnetized part from which the magnetic field leaves or enters the part.

POROSITY: Random pits or holes in the object.

POSITRON: A fundamental particle of nature having a mass equal to that of the electron and possessing a positive charge equal to the negative charge of the electron. The mass of the positron is therefore 9.107 x 10-28 gm; the electrical charge carried by the positron is equal to 4.802 x 10-10 statcoulomb (electrostatic unit of charge).

POST-CLEANING (PT): The removal of residual penetrant and/or developer from the item after the inspection operation.

POST-EMULSIFICATION (PT): The technique wherein a separate emulsifying step is required to facilitate water rinse removal of the surface penetrant.

POTTER-BUCKY DIAPHRAGM (RT): A device incorporating an anti-scatter grid that is kept in motion during the time of a radiographic exposure so as to avoid grid images on the radiograph.

POTTER-BUCKY GRID (RT): See POTTER-BUCKY DIAPHRAGM.

POWDER, DRY (MT): Finely divided ferromagnetic particles suitably selected and prepared for magnetic particle inspection.

PRECIPITATE (MT): The separating of the magnetic particles from the liquid vehicle. Used primarily for checking concentration of magnetic particles in the vehicle.

PRECIPITATION HARDENING: The process by which a metal is hardened by the formation of small particles of secondary composition from a solid solution. This process is usually performed at an elevated temperature considerably below the temperature of solution heat treating.

PRECIPITATION HEAT TREATMENT: Artificial aging in which a constituent precipitates from a supersaturated solid solution.

PRE-CLEANING: The cleaning of a part before testing so that it is free from all foreign material (paint, grease, oil, rust, scale, layout dye, wax crayon markings, etc.) which may cover a surface discontinuity and thereby inhibit the entrance of the penetrant liquid, or absorb the penetrant and render an “irrelevant indication.”

PRESENTATION: The method used to show ultrasonic wave information. May include A, B, or C scans displayed either on various types of recorders or cathode ray instrumentation’s.

PRESERVATIVE, DEVELOPER (RT): A constituent (e.g., sodium sulfate) that minimizes the exhaustion of a developer caused by aerial oxidation, and serves to remove oxidation products which might retard development or produce stain.

PRESSURE MARK (RT): An effect produced by pressure on a film which after developing results in areas of either increased or decreased density. The crescent-shaped pressure mark due to severe local bending of a film is often called a crimp mark.

PRIMARY MAGNETIC FIELD (ET): In eddy current inspection, the field produced by the test coil or coils as differentiated from the magnetic field produced by the eddy current or the resultant field.

PRIMARY RADIATION (RT): Radiation coming directly from the source of radiation that has undergone no physical process changing its character.

PROBE (ET, MT, UT): An assembly containing a small coil or coils designed for eddy current inspection of small areas immediately adjacent to the coil and an electromagnet producing magnetic fields for magnetic inspection. The unit has two jointed laminated pole pieces permitting adjustment to varying surfaces configuration. Also the device contains a microphone used with an ultrasonic leak detector to receive ultrasonic energy resulting from leakage. See SEARCH UNIT.

PROBE WOBBLE (ET): The change in angular orientation between a surface probe and the inspection surface. Probe wobble results in lift-off variations.

PROCESS ANNEALING: In the sheet and wire industries, heating a ferrous alloy to a temperature close to, but below, the lower limit of the transformation range and then cooling, in order to soften the alloy for further cold working.

PROCESS ATTAINMENT (ABILITY): The ultimate ability of a process to find a defect of minute size at the current state-of-the-art, usually defined as the ability to detect defects as small ... See SENSITIVITY.

PROCESS CAPABILITY: The ability of a process to repeatedly find a defect under the influence of normal day-to-day variations of process, people, materials, environment and other influences normally tied to a confidence level.

PROCESS CONTROL: Is a general term used to encompass the actions and documentation, as required by official directives or logic, that are necessary for a NDI method to be effective in detecting conditions of interest (e.g., cracks, foreign objects, corrosion, alignment of parts, thickness of parts/coating and pressure/vacuum leaks).

PROCESSING DEFECTS: Defects occurring in the material during any of the processing stages from molten metal to the finished product.

PROCESSING, FILM (RT): A series of operations, such as developing, fixing, and washing, associated with the conversion of a latent image into a stable visible image.

PROCESSING UNIT (RT): A series of tanks forming a single unit for holding chemical solutions used during processing.

PROCESS INSPECTION: To establish correct manufacturing procedure by inspection methods, and then by periodic inspection to insure that the process continues to operate correctly.

PRODS (MT): Hand held electrodes attached to cables to transmit the magnetizing current from the source to the part being inspected.

PROGRESSIVE AGING: Aging by increasing the temperature in steps or continuously during the aging cycle.

PROGRESSIVE FORMING: Sequential forming at consecutive stations either with a single die or with separate dies.

PROJECTOR (RT): See exposure device.

PROOF LOAD: A predetermined load, generally some multiple of the service load, to which a specimen or structure is submitted before acceptance for use.

PROOF STRESS:

(1) The stress that will cause a specified small permanent set in a material.

(2) A specified stress to be applied to a member or structure to indicate its ability to withstand service loads.

PROPAGATION: Advancement of a wave through a medium.

PROPORTIONAL LIMIT: The maximum stress at which strain remains directly proportional to stress.

PROTECTIVE APRON (RT): Apron made of attenuating materials, used to reduce radiation exposure.

PROTECTIVE MATERIAL (RT): Shielding material used for the purpose of radiation protection.

PROTON: An elementary particle with a single positive electrical charge and a mass approximately 1847 times that of the electron. The atomic number of an atom is equal to the number of protons in its nucleus.

PSIGG: Pounds per square inch; gauged air pressure gauged by a regulator.

PT: Symbol for the liquid penetrant method of nondestructive testing/inspection.

PUBLIC DOSE: The dose received by a member of the public from exposure to radiation.

PULL CRACKS: In a casting, cracks that are caused by residual stresses produced during cooling, and that result from the shape of the object.

PULSE (UT): A series of vibrations or oscillations having a brief duration.

PULSE-ECHO METHOD (UT): An inspection method in which the presence and position of a discontinuity is indicated by the echo amplitude and time position; also designates a method of inspecting bonded honeycomb structures by monitoring the echoes from the far side of the core.

PULSE LENGTH (UT): A measure of the duration of a pulse, expressed in time or number of cycles.

PULSE REPETITION RATE (UT): See FREQUENCY, PULSE REPETITION.

PULSE TUNING (UT): Control, on some instruments, used to optimize the response of the search unit and cable.

PYROMETER: Any device used for determining temperatures over a wide range, including extremely high temperatures.

Q

QUALITY CONTROL INDICATOR (RT): See PENETRAMETER.

QUALITY FACTOR (RT): The linear-energy-transfer-dependent factor by which absorbed doses are to be multiplied to obtain, for radiation protection purposes, a quantity (i.e., dose equivalent) that expresses on a common scale for all ionizing radiation the irradiation incurred by exposed persons. The quality factor weights the absorbed dose for the biological effectiveness of the particular type of radiation producing the absorbed dose. Symbol: Q.

QUALITY LEVEL (RT): See RADIOGRAPHIC QUALITY LEVEL.

QUALITY OF RADIATION (RT): The quality of a radiation determines its degree of penetration, and is related to the energy of the radiation.

QUANTUM: If the magnitude of a quantity is always an integral multiple of a definite unit, then that unit is called the quantum of the quantity. The photon is a quantum of the electromagnetic field and the meson is considered to be the quantum of the nuclear field.

QUANTUM (RT): A discrete amount of radiation energy. The quantum energy is $E=h\upsilon$, where υ is the frequency of the radiation and h is Plank’s constant.

QUENCH AGING: Aging induced by rapid cooling after Solution Heat Treatment.

QUENCH ANNEALING: Annealing an austenitic ferrous alloy by Solution Heat Treatment.

QUENCH CRACKS: See CRACKS, QUENCHING.

QUENCH HARDENING: Hardening a ferrous alloy by austenitizing and then cooling rapidly enough so that some or all of the austenite transforms to martensite. The austenitizing temperature for hypoeutectoid steels is usually above Ac3 and for hypereutectoid steels usually between Acl and Accm.

QUENCHING: Rapid cooling. When applicable, the following more specific terms should be used: direct quenching, fog quenching, hot quenching, interrupted quenching, selective quenching, spray quenching, and time quenching.

QUICK-BREAK: Sometimes called “FAST BREAK.” The sudden breaking of a direct current causes a transient current to be induced in the part by the rapid collapse of the magnetic field. In magnetic particle testing, fast breaking of the magnetizing current is used to generate a transient current in a part which is favorable for finding transverse defects at the ends of longitudinally magnetized bars. Such defects are often concealed by the strong polarity at the bar ends. At such locations the lines of force of the longitudinal field are leaving the bar in a direction normal to the surface, which prevents them from intercepting transverse defects in those areas. The field induced by the transient current does intercept such discontinuities.

QUENCHING OF FLUORESCENCE (MT, PT): The extinction of fluorescence by causes other than removal of the black light (the exciting radiation).

R

RAD: The special unit of absorbed dose. One rad is equal to an absorbed dose of 100 ergs/gram or 0.01 Joule/kilogram (0.01 gray).

RADIATION (RT): The propagation of energy through matter or space in the form of waves. In atomic physics the term has been extended to include fast-moving particles (alpha and beta rays, free neutrons, etc.). Gamma rays and X-rays, of particular interest in atomic physics, are electromagnetic radiation in which energy is propagated in packets called photons.

RADIATION AREA: An area, accessible to individuals, in which radiation levels could result in an individual receiving a dose equivalent in excess of 5 mrem (0.05 mSv) in any one hour at 30 centimeters from the radiation source or from any surface that the radiation penetrates.

RADIATION BURN (RT): A burn caused by overexposure to radiant energy.

RADIATION DAMAGE (RT): A general term for the alteration of properties of a material arising from radiation exposure to X-rays, gamma rays, neutrons, heavy-particle radiation or fission fragments in nuclear fuel material.

RADIATION DETECTOR (RT): See DETECTOR.

RADIATION HAZARD (RT): A situation or condition that represents potential danger to health as the result of exposure to ionizing radiation.

RADIATION MAZE (RT): An indirect route of access to a room that contains a radiation source. It is designed to allow easy access when the source is turned off or is fully shielded, and to reduce radiation intensity outside the room to acceptable levels when the source is turned on or exposed. Reduction of radiation intensity is achieved through multiple scattering from walls and application of the inverse square law.

RADIATION METER (RT): An instrument consisting of one or more radiation detectors, associated electronics, and an indicator of the magnitude of the measured radiation quantity.

RADIATION MONITOR (RT): A radiation meter that is designed and used to keep track of radiation levels in a specific area, and to record those levels, or to provide an audible or visual signal when a predetermined level is exceeded.

RADIATION PROTECTION GUIDE: The total amounts of ionizing radiation dose over certain periods of time which may safely be permitted to exposed industrial groups. These standards, established by the Federal Radiation Council, are equivalent to what was formerly called the “maximum permissible exposure.”

RADIATION PROTECTION (RT): A branch of the physical, biological, and chemical sciences applying to the prevention of the risks presented by exposure of persons to ionizing radiation.

RADIATION PROTECTION SURVEY (RT): Evaluation of the radiation hazards in and around an area where a radiation source is used or stored. It customarily includes an examination of the arrangement and use of the source and related equipment, and measurements of exposure rates under expected operating conditions.

RADIATION QUALITY (RT): See BEAM QUALITY.

RADIATION SAFETY INTERLOCK (RT): A device for precluding access to an area of radiation hazard either by preventing entry or by automatically removing the hazard.

RADIATION SAFETY OFFICER: An individual engaged in the practices of providing radiation protection. He is the representative appointed by the licensee for liaison with the Atomic Energy Commission.

RADIATION SICKNESS (RT): See ACUTE RADIATION SYNDROME.

RADIATION SOURCE (RT): A machine or a material emitting, or capable of emitting, ionizing radiation.

RADIATION SURVEY (RT): See RADIATION PROTECTION SURVEY. RADIATION TRAP (RT): See RADIATION MAZE.

RADIOACTIVE: Atoms that are energetically unstable and decay to a stable condition by emitting radiation are said to be radioactive.

RADIOACTIVE CONTAMINATION: Deposition of any radioactive material in any place where it is not desired, particularly where it may be harmful.

RADIOACTIVE DECAY (RT): The spontaneous nuclear disintegration of a material. It occurs on an atomic scale by the loss of subatomic particles (i.e., protons, neutrons, electrons, etc.). See HALF-LIFE.

RADIOACTIVE MATERIAL: Includes any such material whether or not subject to licensing control by the Commission.

RADIOACTIVE SERIES (RT): A sequence of radionuclides formed by successive nuclear transitions until a stable (non-radioactive) nuclide, the end product, is reached.

RADIOACTIVE SOURCE (RT): A radiation source consisting of radioactive material.

RADIOACTIVE WASTE: Equipment and materials (from nuclear operations) which are radioactive and for which there is no further use.

RADIOACTIVITY: Spontaneous nuclear disintegration with emission of corpuscular or electromagnetic radiation. The principal types of radioactivity are alpha disintegration, beta decay (electron emission, positron emission, and electron capture) and isomeric transition.

RADIOACTIVITY CONCENTRATION GUIDE: The concentration of radioactivity in an environment which results in doses equal to those in the radiation protection guide. This Federal Radiation Council term replaces the former “maximum permissible concentration.”

RADIOBIOLOGY: The study of the scientific principles, mechanisms, and effects of the interaction of ionizing radiation with living matter.

RADIOGRAPH (RT): A permanent visible image on a recording medium produced by penetrating radiation passing through the material being tested.

RADIOGRAPHER: Any individual who performs or who, in attendance at the site where the sealed source or sources are being used, personally supervises radiographic operations and who is responsible to the licensee for assuring compliance with the requirements of these regulations and the conditions of the licenses.

RADIOGRAPHER'S ASSISTANT: Any individual who under the personal supervision of a radiographer, uses radiographer exposure devices, sealed sources or related handling tools, or survey instruments in radiography.

RADIOGRAPHER'S EXPOSURE DEVICE: Any instrument containing a sealed source fastened or contained therein, in which the sealed source or shielding thereof may be moved, or otherwise changed, from a shielded to unshielded position for purposes of making a radiographic exposure.

RADIOGRAPHIC CODE: A code for specifying minimum standards related to radiographic practices.

RADIOGRAPHIC EXPOSURE DEVICE (RT): See EXPOSURE DEVICE.

RADIOGRAPHIC FILM (RT): See FILM, RADIOGRAPHIC.

RADIOGRAPHIC PAPER (RT): White paper coated on one side with emulsion, suitable for some purposes as an alternative to X-ray film.

RADIOGRAPHIC PROJECTION METHOD (RT): A method whereby image magnification is achieved by projection.

RADIOGRAPHIC QUALIFICATION TEST: A procedure for determining the optimum value of the d/t ratio, or the proper working distance of an X-ray tube or a radioactive source.

RADIOGRAPHIC QUALITY LEVEL (RT): An expression of the quality (sensitivity) of a radiograph in terms of an image quality indicator (penetrameter). When a standard hole-type penetrameter is used, quality level is stated as a-bT, where a is the penetrameter thickness, expressed as a percentage of the maximum thickness of the specimen, and b is the diameter of the smallest discernible hole, expressed as a multiple of penetrameter thickness, T. For example, the 3-2T quality level means that the penetrameter thickness equals 3 percent of maximum specimen thickness, and the smallest discernible penetrameter hole has a diameter equal to twice the penetrameter thickness.

RADIOGRAPHIC RANGE (RT): See EXPOSURE LATITUDE.

RADIOGRAPHIC SCREEN (RT): See INTENSIFYING SCREEN.

RADIOGRAPHIC SCREENS: Metallic or fluorescent sheets used to intensify the radiation effect on films.

RADIOGRAPHIC SENSITIVITY (RT): See SENSITIVITY, RADIOGRAPHIC.

RADIOGRAPHICALLY SIMILAR MATERIAL (RT): A material or alloy that has approximately the same radiation absorption as the material being radiographed.

RADIOGRAPHIC CONTRAST (RT): See CONTRAST, RADIOGRAPHIC. RADIOGRAPHIC DEFINITION (RT): See DEFINITION, RADIOGRAPHIC. RADIOGRAPHIC ENERGY (RT): See ENERGY, RADIOGRAPHIC.

RADIOGRAPHIC EQUIVALENCE FACTOR (RT): The factor by which the thickness of a material must be multiplied in order to determine what thickness of a standard material (often steel) will have the same absorption.

RADIOGRAPHIC INSPECTION (RT): The use of X-rays or nuclear radiation or both to detect discontinuities in material, and to present their images on a recording medium.

RADIOGRAPHIC INTERPRETATION (RT): The identification of subsurface discontinuities indicated on the radiograph. The evaluation as to the acceptability or rejectability of the material is based upon the judicious application of the radiographic specifications and standards governing the material.

RADIOGRAPHIC TECHNIQUE (RT): The selection of those radiographic factors such as kilovoltage, milliamperage, type of film and screen, distance, and exposure time as to render the best possible radiographic sensitivity.

RADIOGRAPHY (RT): A nondestructive testing method wherein a source of X-rays or gamma rays, is utilized to indicate the subsurface condition of opaque materials. A permanent record of the soundness characteristics is generally made on a specially prepared film called the radiograph.

RADIOISOTOPE: An unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation. More than 1300 natural and artificial radioisotopes have been identified.

RADIOLOGY: That branch of medicine that uses ionizing radiation for diagnosis and therapy.

RADIONUCLIDE (RT): A nuclide that is radioactive.

RADIUM: A radioactive element with the atomic number 88 and an atomic weight of 226. In nature, radium is found associated with uranium, which decays to radium, by a series of alpha and beta emissions. Radium is used as a radiation source.

RANGE (UT): The maximum ultrasonic path length that can be displayed; see SWEEP.

RANGE MARKERS: See MARKERS.

RAREFACTION: The thinning out, or moving apart of the particles in a material as an ultrasonic wave is propagated. Opposite in its effect to compression. The sound wave is composed of alternate compressions and rarefactions of the material.

RATE METER (RT): A device designed to measure radiation per unit time, as in milliroentgens per hour. It is used for detecting radiation fields and measuring the exposure rate.

RAY: A beam of energy of small cross section.

RAYLEIGH WAVE (UT): See SURFACE WAVE.

RBE DOSE: RBE stands for relative biological effectiveness. An RBE dose is the dose measured in rems. (This is discussed in the report of the International Commission on Radiological Units and Measurements, 1956, NBS Handbook 62, p. 7).

READOUT (ET): The method by which eddy current information is presented or displayed. Readout includes meters, recorders and CRTs (cathode ray tubes).

REAL-TIME RADIOGRAPHY (RT): A type of radiography in which an image is not produced photographically, but is instead produced on a fluorescent screen viewed by a video camera. The image may be intensified or enhanced before display on a television monitor. This enables radiographic interpretation concurrent with irradiation of a specimen, and lends itself to remote rapid inspection of items on an assembly line. A video recorder may be used to record the image.

RECARBURIZE:

(1) To increase the carbon content of molten cast iron or steel by adding carbonaceous material, high-carbon pig iron or a high-carbon alloy. (2) To carburize a metal part to return surface carbon lost in processing.

RECEIVER (UT): Search unit or transducer element, used to receive ultrasonic energy from a test part.

RECESS: A groove or depression in a surface.

RECIPROCITY LAW (RT): Law that states that the film blackening is determined by the product of the milliamperage or source strength and the time of exposure. See RECIPROCITY LAW FAILURE.

RECIPROCITY LAW FAILURE (RT): A term used to describe situations in which the reciprocity law is not applicable. For very short or very long exposures, problems with film response time can cause the reciprocity law to fail.

RECORDING MEDIUM (RT): A photographic film or other material that converts radiation energy into a permanent visible image.

RECOVERY TIME: The time required for a test system to return to its original state after it has received a signal.

RECRYSTALLIZATION:

(1) The change from one crystal structure to another, as occurs on heating or cooling through a critical temperature.

(2) The formation of a new, strain-free grain structure from that existing in cold worked metal, usually accomplished by heating.

RECTIFICATION: Any method by which a unidirectional voltage can be obtained from an alternating supply.

RECTIFIED ALTERNATING CURRENT: By means of a device called a rectifier, which permits current to flow in one direction only, alternating current can be converted to direct or unidirectional current. This differs from direct current in that the current value varies from a steady level. This variation may be extreme, as in the case of half-wave rectified single-phase AC or slight, as in the case of three-phase rectified AC

RECTIFIER: A tube or circuit capable of converting the high voltage alternating waveform into a usable unidirectional voltage waveform.

REDUCTION:

(1) In cupping and deep drawing, a measure of the percentage decrease from blank diameter to cup diameter or of diameter reduction in redraws.

(2) In forging, rolling and drawing, either the ratio of the original to final cross-sectional area or the percentage decrease in cross-sectional area.

REDUCTION FACTOR: Dose rate without a shield divided by the dose rate with a shield interposed between a source and a point at which radiation is measured.

REDUCTION OF AREA:

(1) Commonly, the difference expressed as a percentage of original area, between the original cross-sectional area of a tensile test specimen and the minimum cross-sectional area measured after complete separation. (2) The difference expressed as a percentage of original area, between original cross-sectional area and that after straining the specimen.

REFERENCE BLOCKS: A block or series of blocks of material containing artificial or actual discontinuities of one or more reflecting areas at one or more distances from the test surface, which are used for reference in defining the size and distance of defective areas in materials.

REFERENCE NUMBER: A mathematical value established to summarize the combined effects of conductivity, magnetic permeability, test frequency, coil radius and thickness for use in impedance diagrams.

REFERENCE RADIOGRAPHS: A group of radiographs containing images of discontinuities. These can be used as comparison “standards” for acceptability of materials.

REFERENCE STANDARD: A piece of material, part, or piece from a part, containing an artificial discontinuity of known size; provides a means of producing a reflection of known characteristics; used to establish a measurement scale. Also, a known size discontinuity used to produce a reflection of known characteristics. References are constructed for thickness measurement, conductivity measurement or flaw detection.

REFLECTION (UT): An indication that has arisen as a result of an incident sound beam being reflected at the boundary of two materials of dissimilar acoustic impedance.

REFLECTION DENSITY (RT): The common logarithm of the ratio of the brightness of a non-absorbing perfect diffuser to that of the sample, both being illuminated at an angle of 45 degrees to the surface, the direction of measurement being normal to the surface.

REFLECTOGRAM: A picture of recording of the indications presented on the cathode ray tube of the ultrasonic instrument.

REFLECTOGRAPH: A recording or chart made of either the signals transmitted through a part or reflected back from defects within a part, or both.

REFLECTOR (UT): An interface at which an ultrasonic beam reflects.

REFRACTED BEAM (UT): The beam that occurs in the second medium when an ultrasonic beam passes obliquely from one medium to another when each medium has different sound velocities.

REFRACTION (UT): Change in direction of an ultrasonic beam as it passes obliquely through the interface between two materials with different acoustic velocity; see SNELL’S LAW.

REFRACTIVE INDEX (UT): The ratio of the velocity of a wave in one medium to the velocity of the wave in a second medium is the refractive index of the second medium with respect to the first. It is a measure of the amount a wave will be refracted when it enters the second medium after leaving the first.

REFRACTORY:

(1) A material of very high melting point with properties that make it suitable for such uses as furnace linings and kiln construction.

(2) The quality of resisting heat.

REFRACTORY ALLOY:

(1) A heat-resistant alloy.

(2) An alloy having an extremely high melting point. See REFRACTORY METAL.

(3) An alloy difficult to work at elevated temperatures.

REFRACTORY METAL: A metal having an extremely high melting point. In the broad sense, it refers to metals having melting points above the range of iron, cobalt and nickel.

REINFORCEMENT OF WELD:

(1) In a butt joint, weld metal on the face of the weld that extends out beyond a surface plane common to the members being welded.

(2) In a fillet weld, weld metal that contributes to convexity.

(3) In a flash, upset or gas pressure weld, the original diameter or thickness.

REJECT (SUPPRESSION) (UT): A control used for minimizing or eliminating low amplitude signals (electrical or material “noise”) so that larger signals are emphasized. Use of this control can reduce the vertical linearity of the amplifier.

REJECTION LEVEL (UT): The setting of the signal level above or below which all parts are rejectable as, in an automatic system, at which objectionable parts will actuate the reject mechanism of the system.

RELATIVE BIOLOGICAL EFFECTIVENESS (RBE): The relative effectiveness of a given kind of ionizing radiation in producing a biological response as compared with 250,000 electron volt gamma rays.

RELATIVE EXPOSURE: Exposure expressed relative to a standard exposure that is arbitrarily assigned the value of 1.0.

RELATIVE SPEED (RT): The exposure time of any radiographic film relative to one particular type of film whose speed is arbitrarily assigned the value of 100.

RELEVANT DISCONTINUITY: Discontinuity that is detrimental to the intended use of a part or material.

RELUCTANCE: The degree of difficulty with which the magnetic flux is produced within a material. Material of high permeability has low reluctance.

REM: The special unit of any of the quantities expressed as dose equivalent. The dose equivalent in rems is equal to absorbed dose in rads multiplied by the quality factor (1 rem = 0.01 sievert).

REMNANT MAGNETISM: This is the term applied to the magnetism remaining in a magnetic circuit after the magnetizing force is removed.

REMOVER (PT): See PENETRANT REMOVER.

REP: Roentgen equivalent physical. An obsolete unit of radiation dosage now superseded by the rad.

REPETITION RATE (UT): The rate at which the individual pulses of acoustic energy are generated; also PULSE RATE.

REPLENISHER (RT): A modified form of the original developer which, when added to partially exhausted developer, restores its efficiency.

RESIDUAL ELEMENTS: Elements present in an alloy in small quantities, but not added intentionally.

RESIDUAL FIELD (MT): See FIELD, RESIDUAL.

RESIDUAL MAGNETISM (MT): The magnetic field remaining in a part after the current has been removed.

RESIDUAL METHOD (MT): Bath is applied after current has been shut off; that is, the indicating particles are on the part when residual (remaining) magnetic field is present.

RESIDUAL STRESS: Stress present in a body that is free of external forces or thermal gradients.

RESILIENCE:

(1) The amount of energy per unit volume released upon unloading.

(2) The capacity of a metal, by virtue of high yield strength and low elastic modulus, to exhibit considerable elastic recovery upon release of load.

RESISTANCE: Resistance is the opposition to the flow of an electrical current through a conductor. Its unit is the ohm.

RESOLUTION (RT): The smallest distance between adjacent distinguishable images on a radiograph or viewing screen. It may be expressed as the number of lines (or line parts) per millimeter that can be seen as discrete images.

RESOLVING POWER (UT): The measure of the capability of an ultrasonic system to separate in time two discontinuities at slightly different distances or to separate the multiple reflections from the back surface of flat plates.

RESONANCE (UT): The condition in which the frequency of the forced vibration (ultrasonic wave) is the same as the natural frequency of the body (test piece) which results in abnormally large amplitudes of vibration.

RESONANCE METHOD: A technique in which continuous ultrasonic waves are varied in frequency to identify resonant characteristics in order to discriminate some property of a part as thickness, stiffness, or bond integrity.

RESONANT FREQUENCY: The frequency at which a body will vibrate freely after being set in motion by some outside force.

RESTRAINER (RT): The constituent (e.g., potassium bromide) that reduces the activity of the developing agent but enhances its preferential action by reducing the rate of development of unexposed grains to a greater extent than it does that of exposed grains. It thus tends to reduce chemical fog.

RESTRICTED AREA: Any area access to which is controlled by the licensee.

RESTRIKING:

(1) Striking a trimmed but slightly misaligned or otherwise faulty forging one or more blows to improve alignment, improve surface, maintain close tolerance, increase hardness or to effect other improvements.

(2) A sizing operation in which coining or stretching are utilized to correct or alter profiles and to counteract distortion.

RESULTANT (VECTOR FIELD) (MT): When two or more magnetizing forces operating in different directions are simultaneously applied to a ferromagnetic material, a resultant field is produced, having a direction which is determined by the relative strengths and directions of the applied magnetizing forces. Such a field is also referred to as a vector field. If either or both of the applied magnetizing forces are themselves varying in direction or amount, the resultant field is moving or swinging in direction and strength. Such a moving resultant field is sometimes referred to as a “swinging field”.

RESIDUAL METHOD (MT): The method in which magnetic particles are applied to the material after the magnetizing current has been discontinued.

RESIDUAL STRESS: Internal stress remaining in a piece of metal following some processing operation, such as hardening, cold working, etc.

RESISTANCE: The opposition to the flow of an electrical current through a conductor or circuit that does not include inductive or capacitive elements. It can be expressed as the ratio of the applied voltage to the current.

RESOLUTION, DEFECT: A property of a test system that enables the separation of indication due to defects in a test specimen that are located in close proximity to each other.

RESONANCE METHOD: A method that varies the frequency of continuous ultrasonic waves to excite standing waves in a body generally used for thickness measurement.

RETENTIVITY (MT): The ability of a material to retain magnetism after the current has been removed.

RETICULATION (RT): The swelling of film emulsion because of sudden change of temperature, in excess of 15’F during processing.

REVERSAL (RT): The production of a positive instead of a negative image in an emulsion or vice versa.

RF DISPLAY (UT): A CRT signal display that is not rectified. Displayed signals are both above and below the sweep or base line.

RHM (RT): See ROENTGENS PER HOUR AT ONE METER. rhr: Abbreviation for roughness height rating.

RIGGING: The engineering design, layout, and fabrication of pattern equipment for producing castings; including a study of the casting solidification program, feeding and gating, risering, skimmers, and fitting flasks.

RIMMED STEEL: A low-carbon steel containing sufficient iron oxide to give a continuous evolution of carbon monoxide while the ingot is solidifying, resulting in a case or rim of metal virtually free of voids. Sheet and strip products made from the ingot have very good surface quality.

RINGING METHOD (UT): A bonded structure inspection method in which unbonds are indicated by increased amplitude ringing signals.

RINGING SIGNALS (UT): Closely spaced multiple signals can be caused by multiple reflections in a thin material or continued vibration of a transducer element.

RINGING TIME (UT): The time that the mechanical vibrations of a transducer element continue after the electrical pulse has stopped.

RIPPLE (RT): The periodic variation in the potential differences between the cathode and anode of an X-ray tube, resulting from rectification of an alternating current. As the ripple is decreased by the use of filtering circuits, a constant potential is more nearly approached.

RINSE (PT): In penetrant inspection, the operation by which the excess surface penetrant is removed from the part. Sometimes also referred to as the WASH.

RISER: A reservoir of molten metal connected to the casting to provide additional metal to the casting, required as the result of shrinkage before and during solidification.

R-METER: An ionization-type instrument designed to measure radiation dose.

ROCKWELL HARDNESS TEST: A test for determining the hardness of a material based upon the depth of penetration of a specified penetrator into the specimen under certain arbitrarily fixed conditions of test.

ROD-ANODE TUBE (RT): A special type of X-ray tube in which the target is situated at the outer end of a long tubular anode. It usually produces panoramic radiation.

ROENTGEN ® (RT): The international unit of the quantity of X or gamma radiation which cause the emission of ions carrying 1 electrostatic unit quantity of charge per 0.001293 grams of air. It is usually employed to express the radiation output of a given source in terms of roentgens per hour at one meter (Rhm). Under the International System of Units this will be expressed in coulombs/kilogram (1 r = 2.579560 x 10-4 C/ kg).

ROENTGENS PER HOUR AT ONE METER (RT): A specification of the output of a source of X- or gamma radiation in terms of the exposure rate, in roentgens per hour, measured in air at a distance of one meter from the source. Abbreviation: Rhm.

ROLL BENDING: Curving sheets, bars and sections by means of rolls.

ROLL FLATTENING: Flattening of sheets, that have been rolled in packs, by passing them separately through a two-high cold mill, there being virtually no deformation. Not to be confused with roller leveling.

ROLL FORGING: Forging with rotating dies that are not full round, the desired shape, either straight or tapered, being produced by a groove in the dies.

ROLL FORMING: Metal forming by the use of power-driven rolls whose contour determines the shape of the product. Sometimes used to denote power spinning.

ROLL STRAIGHTENING: Straightening of metal stock of various shapes by passing it through a series of staggered rolls, the rolls usually being in horizontal and vertical planes.

ROLLING: Reducing the cross-sectional area of metal stock, or otherwise shaping metal products, through the use of rotating rolls.

ROOT CRACK: A crack in either the weld or heat-affected zone at the root of a weld.

ROOT OF JOINT: The location of closest approach between parts of a joint to be welded.

ROOT PENETRATION: The depth to which weld metal extends into the root of a joint.

ROTATING-ANODE TUBE (RT): An X-ray tube in which the anode can rotate. The axis of rotation is offset from the axis of the electron beam, so that the focus lies on a circle on the rotating surface.

ROUGHNESS: Relatively finely spaced surface irregularities, the height, width and direction of which establish the predominant surface pattern.

ROUGHNESS HEIGHT RATING: Quantitative expression of the roughness of a surface; arithmetical average, normally expressed in microinches, of the absolute values of surface height deviation from the mean surface height. Abbreviation is rhr.

RT: Symbol for the radiographic method of nondestructive testing/inspection.

RUPTURED METAL: See BURSTS.

RUST: A corrosion product consisting of hydrated oxides of iron. Applied only to ferrous alloys.

S

SAFELIGHT (RT): A special lamp used in the darkroom to provide working visibility without affecting the photosensitive emulsion of the radiographic film.

SALT SCREEN (RT): See intensifying screen.

SALVAGE INSPECTION: Inspection for salvage parts that can be repaired.

SAMARIUM-145: A radioisotope of the element samarium.

SAMPLING INSPECTION: Inspecting a random sample from a lot of parts to determine the lot quality, the sample size having been chosen in accordance with statistical methods.

SAND: A granular material resulting from the disintegration of rock. Foundry sands are mainly silica. “Bank sands” are found in sedimentary deposits and contain less than 5% clay. “Dune” sand occurs in wind blown deposits near large bodies of water and is very high in silica content. “Moulding sand” contains more than 5% clay; usually between 10 and 20%. “Silica sand” is a granular material containing at least 95% silica and often more than 99%. “Sand core” is nearly pure silica. “Miscellaneous sand” includes zircon, olivine, calcium carbonate, lava, and titanium minerals.

SAND BLAST: (Grit Blast) The use of sand or grit at high velocity through air pressure to clean surfaces.

SAPONIFICATION (PT): The process of converting chemicals into soap; involves the alkaline hydrolysis of a fat or oil, or the neutralization of a fatty acid.

SATURATION (MT): The point in the magnetization of a magnetizable object at which an increase in the magnetizing force produced no increase in the magnetic field within the part. See VERTICAL SATURATION (SCOPE) (UT): A term used to describe an indication of such a size as to reach full scope amplitude (100%). Beyond this point there is no visual display to estimate the actual real height of the response signal unless the equipment is provided with dB readout.

SCAB: A defect consisting of a flat volume of metal joined to a casting through a small area. It is usually set in a depression, a flat side being separated from the metal of the casting proper by a thin layer of sand.

SCALE: Oxide formed on metal by chemical action of the surface metal with oxygen from the air.

SCALE PIT: Shallow surface depression in metal, caused by scale.

SCALING:

(1) Forming a thick layer of oxidation products on metals at high temperatures.

(2) Depositing water-insoluble constituents on a metal surface, as in cooling tubes and water boilers.

SCANNING (ET, UT): Relative movement of the search unit over a test part.

SCARFING: Cutting surface areas of metal objects, ordinarily by using a gas torch. The operation permits surface defects to be cut from ingots, billets or the edges of plate that is to be beveled for butt welding.

SCATTER (RT): One of the causes of haziness or fog. Some of the incident radiation is scattered by atomic electrons of the object being radiographed much as light is dispersed by fog. Any material, whether specimen, cassette, tabletop walls, floors, etc., receiving direct radiation, is a source of scattered radiation.

SCATTER UNSHARPNESS (RT): See UNSHARPNESS.

SCATTERED ENERGY (UT): Energy that is reflected in a random fashion by small discontinuities in the path of a sound beam.

SCATTERED RADIATION (RT): Radiation that, as the result of interaction with matter, has had its direction changed and, for some interactions, its energy decreased.

SCATTERING (RT): A change of direction, and possibly reduction of energy, of an incident particle or photon as the result of interaction with an atom, nucleus, or other particle.

SCATTERING ANGLE (RT): The angle between the directions of propagation of the incident and scattered radiation.

SCHLIEREN SYSTEM (UT): An optical system used to visually display an ultrasonic beam passing through a transparent medium.

SCHWARZCHILD EXPONENT (RT): A mathematical index that may be applied to one of the variables in order to correct for the failure of the reciprocity law over a limited range.

SCINTILLATION (RT): A localized flash of light caused by a particle or photon of ionizing radiation incident on a fluorescent material.

SCINTILLATION COUNTER: A device for counting atomic particles by means of tiny flashes of light (scintillations) which the particles produce when they strike certain crystals.

SCINTILLATOR (RT): A substance that emits a localized flash of light when excited by an incident particle or photon of ionizing radiation.

SCLEROSCOPE TEST: A hardness test where the loss in kinetic energy of a falling metal “tup,” absorbed by indentation upon impact of the tup on the metal being tested, is indicated by the height of rebound.

SCORING:

(1) Marring or scratching of any formed part by metal pickup on the punch or die.

(2) Reducing the thickness of a material along a line to weaken it purposely along that line.

SCOTCH TAPE TRANSFER (MT): The use of colorless tape to lift a magnetic particle indication from a part.

SCRATCH: A shallow mark or injury produced by abrasion.

SCRATCH HARDNESS: The hardness of a metal determined by the width of a scratch made by a cutting point drawn across the surface under a given pressure.

SCREEN (RT): Alternative term for intensifying screen.

SCREENS, FLUORESCENT (RT): See FLUORESCENT SCREENS.

SCREENS, INTENSIFYING (RT): See INTENSIFYING SCREENS.

SCREENS, LEAD (RT): Layers of lead foil, used in intimate contact with the film during exposure. They act to improve radiographic quality or to decrease exposure time, or both.

SCREEN MOTTLE (RT): (Fluorescent Screen Exposures) The visual impression of irregularity of density, in areas where the exposure is macroscopically uniform, due to the random spatial distribution of X-ray quanta absorbed in the screens. Screen mottle is much larger in scale and “softer” in outline than film graininess. See FILM GRAININESS.

SCREEN-TYPE FILM (RT): A radiographic film produced specially to be used with fluorescent screens. This type of film has high sensitivity to the fluorescent light emitted by such screens under the effect of ionizing radiation. (Improperly called screen film.)

SCREEN UNSHARPNESS (RT): See UNSHARPNESS.

SEALED SOURCE: Any by-product material that is encased in a capsule designed to prevent leakage or escape of the by-product material.

SEALING:

(1) Closing pores in anodic coatings to render them less absorbent.

(2) Plugging leaks in a casting by introducing thermosetting plastics into porous areas and subsequently setting the plastic with heat.

SEAM: A discontinuity caused by a void or crack in rolled material parallel to the axis of the material which although closed is not welded. A line of junction; a line, groove, ridge, or interstice formed by or between two contracting edges.

SEARCH UNIT (UT): A device for generating and/or receiving ultrasonic energy; may contain one or more transducer elements or, in the case of the Harmonic Bond Tester, a microphone and coil.

SEASON CRACKING: Cracking resulting from the combined effects of corrosion and internal stress. A term usually applied to stress-corrosion cracking of brass.

SECONDARY MAGNETIC FIELD (ET): In eddy current testing, the magnetic field produced by the eddy currents in the test material. The secondary field opposes the primary field.

SECONDARY RADIATION (RT): Radiation other than primary radiation emerging from irradiated matter.

SEEABILITY (PT, MT): The characteristic of an indication that enables an observer to see it against the conditions of background, outside light, etc.

SEGREGATION: Where a metallic constituent which cools last, forms a final brittle film between crystals. It may also be a concentration of non-metallic impurities. Segregations may occur at the center or be grouped in some regular form about the center.

SELF-ABSORPTION: Gamma ray emission from large sources wherein the gamma radiation emitted from the center of the source will be appreciably absorbed by the outer layers of the source material.

SELF-EMULSIFIABLE (PT): (Water-Washable) Self-emulsifiable material is an oil base material containing an emulsifying agent that forms an emulsion when rinsed with water.

SELF-RECTIFYING TUBE (RT): Any hot-cathode X-ray tube that permits current to flow only from the cathode to the anode, when the anode is kept cool.

SEMI-KILLED STEEL: Steel that is incompletely deoxidized and contains sufficient dissolved oxygen to react with the carbon to form carbon monoxide to offset solidification shrinkage.

SEMIPERMANENT MOLD: A permanent mold in which sand or plastic cores are used.

SENSITIVITY (MT, ET, RT, PT, UT): The capacity or degree of responsiveness to magnetic particle inspection. The ability of an ultrasonic system to detect a very small discontinuity. The ability of a penetrant to detect surface defects. Higher sensitivity indicates finer cracks can be detected.

SENSITIVITY, DEFECT (RT): The minimum dimension of a discontinuity, considered to be a defect, that can be detected in a radiograph under specified conditions.

SENSITIVITY, IQI (RT): See IQI SENSITIVITY.

SENSITIVITY (PERCENTAGE): A ratio of the smallest detectable thickness difference divided by the thickness of material being examined.

SENSITIVITY, RADIOGRAPHIC: The ratio of the smallest difference in thickness that is detectable on the radiograph to the thickness of the specimen. It may be expressed as a percentage, and is an indication of ability to detect a small discontinuity. In practice, it is determined by the use of an image quality indicator (penetrameter).

SENSITIVITY, SPECTRAL (RT): The variation in radiographic exposure, as a function of X-ray energy, required to produce a given film density.

SENSITOMETRIC CURVE (RT): See CHARACTERISTIC CURVE.

SENSITOMETRY (RT): A quantitative measurement of the response of a film to exposure and development.

SEPARATION ANGLE: The angle on the impedance plane between the thickness change curve and the lift-off curve for a specific material.

SETTLING TEST (MT): See CONCENTRATION TEST.

SG: See DISTANCE AMPLITUDE CORRECTION.

SHADOW (UT): A region in a body, which cannot be reached by ultrasonic energy, traveling in a given direction; caused by the geometry of the body or a discontinuity in it.

SHALLOW DISCONTINUITY: A discontinuity open to the surface of a solid object which possesses little depth in proportion to the width of this opening. A scratch or nick may be a “shallow discontinuity” in this sense.

SHALLOW-DOSE EQUIVALENT: As it applies to external exposure of the skin or an extremity, is taken as the dose equivalent at a tissue depth of 0.007 centimeters (7 mg/cm^2) averaged over an area of 1 square centimeter.

SHARPNESS (RT): See definition RADIOGRAPHIC (RT).

SHEAR: That type of force which causes or tends to cause two contiguous parts of the same body to slide relative to each other in a direction parallel to their plane of contact.

SHEAR FRACTURE: A fracture in which a crystal (or a polycrystalline mass) has separated by sliding or tearing under the action of shear stresses.

SHEAR LIP: A narrow, slanting (hence “shear”) ridge along the edge of a fracture surface. The term sometimes also denotes a narrow, often crescent-shaped, fibrous region at the edge of an otherwise cleavage fracture, even though this fibrous region is in the same plane as the rest of the fracture surface.

SHEAR STRENGTH: The stress required to produce fracture in the plane of cross-section, the conditions of loading being such that the directions of force and of resistance are parallel and opposite although their paths are offset a specified minimum amount.

SHEAR WAVE (UT): A type of wave in which the particle motion is perpendicular to the direction of propagation.

SHEET: A flat-rolled metal product of some maximum thickness and minimum width arbitrarily dependent on the type of metal. It is thinner than plate.

SHEET SEPARATION: In spot, seam or projection welding, the gap which exists between faying surfaces surrounding the weld, after the joint has been welded.

SHIELD: A layer or mass of material used to reduce the passage of ionizing radiation.

SHOCK-PROOF (RT): A term applied to those components of the high-voltage circuit of X-ray equipment which are entirely surrounded by grounded metal enclosures, e.g., shock-proof tube, shock-proof cable.

SHOCK-PROOF TUBE (RT): An X-ray tube surrounded by a grounded conducting enclosure.

SHOE (UT): Device used to adapt a straight beam search unit for use in a specific type of inspection such as inspection of a curved surface, angle beam or surface wave inspection, inspection around a fastener hole, etc. Also, see WEDGE.

SHORTNESS: A form of brittleness in metal. It is designated as “cold,” “hot,” and “red,” to indicate the temperature range in which the brittleness occurs.

SHOT PEENING: Cold working the surface of a metal by metal-shot impingement.

SHRINK MARK: A surface depression on a casting that sometimes occurs next to a thick section that cools more slowly than adjacent sections.

SHRINKAGE CAVITIES: Cavities in castings caused by lack of sufficient molten metal as the casting cools.

SHRINKAGE CAVITY (ON RADIOGRAPH): A small bubble in metal that appears as a dendritic, filamentary, or jagged darkened area on a radiograph film.

SHRINKAGE CRACKS: Hot tears associated with shrinkage cavities.

SHRINKAGE POROSITY OR SPONGE (NONFERROUS ALLOYS,

RADIOGRAPHIC): A localized lacy, or honeycombed, darkened area on a film that indicates porous metal.

SHUTTER (RT): A device that incorporates a movable shield used to block the useful beam emitted from an X-ray tube assembly or source housing.

SIDE LOBE ENERGY (UT): Ultrasonic energy emitted from a search unit to the sides of the main sound beam.

SIEVERT (Sv): The SI unit of any of the quantities expressed as dose equivalent. The dose equivalent in sieverts is equal to the absorbed dose in grays multiplied by the quality factor (1 Sv = 100 rems).

SIGNAL (UT): Vertical deflection from the base line on an A-scan.

SIGNAL-TO-NOISE RATIO (UT): The ratio of the signal from the variable of interest (flaw, thickness change or conductivity change) to signals from variables which are of no interest (lift-off, geometry and finish changes and electronic components).

SILKY FRACTURE: A metal fracture in which the broken metal surface has a fine texture usually dull in appearance. Characteristic of tough and strong metals.

SILVER HALIDE (RT): A compound of silver with one of the halogen elements, e.g., silver bromide.

SINGLE-PHASE ALTERNATING CURRENT: This term refers to a simple current, alternating in direction. Commercial single-phase current follows a sine wave. Such a current requires only two conductors for its circuit. Most common commercial frequencies are 25,50 and 60 cycles per second.

SKIN EFFECT (MT, EC): The phenomenon that causes current to flow along the surface of a conductor. As frequency increase, skin depth decreases.

SKIP DISTANCE (UT): In angle beam testing, the distance from the sound entry point to the first reflection point on the same test surface; also sometimes called V-Path.

SKY SHINE (RT): Scatter radiation caused by interaction of the X-ray photons with the atoms in the air molecules, or structures in the vicinity, and radiates back toward the earth. Skyshine can be detected at considerable distance from the source, therefore, it should be considered when establishing barriers, etc.

SLAG: A non-metallic residue that forms on molten metal as a result of the combining of impurities.

SLAG INCLUSIONS: Nonmetallic solid material entrapped in weld metal or between weld metal and base metal.

SLAG LINES: Elongated cavities containing slag or other foreign matter.

SLIP LINES: (Slip Bands) Traces of slip planes observed at low magnifications on the polished surface of a crystal which has been deformed after polishing.

SLIP PLANES: In a given metal, slip occurs most easily along certain croplatographic planes. Hence, these planes are termed slip planes.

SLOUGHING (RT): The loosening of an emulsion from its base, commencing at the edges. It is usually caused by prolonged immersion in a liquid at too high a temperature or of unsuitable chemical composition.

SLUGGING (STUBBING): The addition of a separate piece or pieces of material in a joint before or during welding.

S-N DIAGRAM: A plot showing the relationship of stress, S, and the number of cycles, N, before failure in fatigue testing.

SNELL'S LAW (UT): Law that defines the angle of incidence and angle of refraction or mode conversion; expressed as:

sinØl divided by sinØ2 = V1 divided by V2

where:

Ø1 = angle (measured from the normal to the interface surface) of the incident sound beam.

Ø2 = angle (measured from the normal to the interface surface) of the refracted or mode converted beam.

V1 = velocity of incident sound beam.

V2 = velocity of refracted or mode converted sound beam.

SOAKING: Prolonged holding at a selected temperature.

SOAK TIME (PT): The period of time wherein parts are immersed in a bath of liquid penetrant.

SOD (RT): Source to object distance. The distance between x-ray tube or radioisotope and the object being radiographed.

SOFT RADIATION (RT): A qualitative term used to describe the relatively less penetrating types of ionizing radiation.

SOFT X-RAYS: A term used to express the quality or penetrating power of X radiation; their penetrating power is relatively light.

SOLARIZATION (RT): The instances decreased (photographic) density produced by exposure additional to that required to give maximum density. This may result in reversal.

SOLDER EMBRITTLEMENT: Reduction in mechanical properties of a metal as a result of local penetration of solder along grain boundaries.

SOLDERING: Sticking or adhering of metal to portions of the die.

SOLENOID: A solenoid is a coil consisting of a number of loops of wire or cable to carry electric current. It may be used for both magnetizing and demagnetizing purposes.

SOLIDIFICATION SHRINKAGE: The decrease in volume of a metal during solidification.

SOLUBLE (PT): The amount of a substance that will dissolve in a given amount of another substance and is typically expressed as the number of parts by weight dissolved by 100 parts of solvent at a specified temperature and pressure or as a percent by weight or by volume.

SOLUTION HEAT TREATMENT: A heat treatment in which an alloy is heated to a sufficiently high temperature to permit many or all of the alloying elements to become randomly dispersed throughout the metal.

SOLVENT ACTION: The dissolution of a fluid or solid by another material.

SOLVENT CLEANING (PT): The process of removing the excess penetrant from the surface of a part by washing or wiping with a solvent for the penetrant.

SOLVENT DEVELOPER (PT): A developer in which the developing powder is applied as a suspension in a quick-drying solvent.

SOURCE (RT): The origin of radiation; an X-ray tube or radioisotope.

SOURCE ASSEMBLY (RT): A component of a gamma radiography exposure device to which the sealed source is affixed or in which the sealed source is contained. The source assembly includes the sealed source.

SOURCE CAPSULE (RT): The immediate container that, along with the contained radioactive material, constitutes a sealed source of ionizing radiation.

SOURCE-FILM DISTANCE (SFD) (RT): The distance between the focal spot of an X-ray tube or radiation source and the film generally expressed in inches.

SOURCE GUIDE TUBE (CONDUIT) (RT): A flexible or rigid tube for guiding the sealed source from the exposure device to the exposure head.

SOURCE HOUSING (RT): An enclosure for a sealed source that provides attenuation for the radiation emitted by the source. The enclosure may have an aperture through which the useful beam is emitted or through which the source is extracted.

SOURCE MATERIAL: In atomic energy law, any material, except special nuclear material, which contains 0.05% or more of uranium, thorium, or any combination of the two.

SOURCE MATERIAL (RT): Any material, except special nuclear material, which contains 0.05 percent or more of uranium, thorium, or any combination of the two.

SOURCE-SHIFT RADIOGRAPHY (RT): See TRIANGULATION.

SOURCE SIZE, EFFECTIVE: The apparent dimensions, as viewed along the beam axis, of that portion of the source from which ionizing radiation are emitted. For the purpose of calculating geometric unsharpness, the effective dimensions must always be used.

SPALL: Cracking off, or flaking off of small particles of metal, usually in thin layers, from the surface.

SPECIFIC ACTIVITY (RT): Specific activity is a measure of the activity per unit weight generally measured in curies per gram (SI) dis/sec-dm (See CURIE).

SPECIAL NUCLEAR MATERIAL: In atomic energy law, includes plutonium, uranium-233, uranium containing more than the natural abundance of uranium235, or any material artificially enriched by any of these substances.

SPECIFIC ACOUSTIC IMPEDENCE (UT): A factor that determines the amount of reflection that occurs at an interface and represents the product of the density of the medium in which the wave is propagating and the wave velocity.

SPECIFIC ACTIVITY (RT): Total radioactivity of a given isotope per gram of element.

SPECIFIC HEAT: The number of British thermal units required to raise the temperature of 1 pound of metal 1ºF.

SPECIFIC IONIZATION: Number of ion pairs per unit length of path of the ionizing particle in a medium, e.g., per cm of air per micron of tissue.

SPECTRAL SENSITIVITY (RT): The areas of the EMR spectrum to which a film is sensitive. Silver bromide films are all sensitive to ultraviolet and blue light as well as X-rays. Screen-type medical X-ray films are designed to be particularly sensitive to blue light and ultraviolet radiation from fluorescent screens, but some X-ray films are designed to be used without screens and are particularly sensitive to direct exposure from X-rays.

SPECTRUM: An orderly array of the components of a beam of electromagnetic waves according to their frequency, wavelength, or energies.

SPEED EFFECT (ET): The phenomenon in electromagnetic testing of which the evidence is a change in the signal voltage resulting from EMFs produced by the relative motion between a specimen and test coil assembly. These EMFs cause eddy currents that result in a space redistribution of the magnetic field.

SPEED, FILM (RT): See FILM SPEED.

SPHEROIDLZING: Heating and cooling to produce a spheroidal or globular form of carbide in steel.

SPILL: The accidental release of radioactive liquids.

SPINNING: Shaping of seamless hollow cylindrical sheet- metal parts by the combined forces of rotation and pressure.

SPLIT GATE: A gate having the sprue axis in the die parting.

SPOT EXAMINATION: Local examination of welds or castings

SPRINGBACK:

(1) The elastic recovery of metal after stressing.

(2) The degree to which metal tends to return to its original shape or contour after undergoing a forming operation.

STABILIZER (RT): A device that automatically compensates for variation of main voltage and/or frequency in an electric circuit. An example is the stabilization of filament heating current, and therefore the anode current, in an X-ray tube.

STABILIZING TREATMENT: Any treatment intended to stabilize the structure of an alloy or the dimensions of apart.

STABLE ISOTOPE: A nuclide that does not undergo radioactive decay.

STABLE ISOTOPE (RT): A non-radioactive nuclide of a particular element.

STACKED CRYSTAL: Several crystals cemented together with the faces of the same polarity in the same direction.

STAMPING: A general term covering almost all press operation. It includes blanking, shearing, hot or cold forming, drawing, bending, coining.

STANDARD:

(1) A reference used as a basis for comparison or calibration.

(2) A concept that has been established by authority, custom, or agreement to serve as a model or rule in the measurement of quantity or the establishment of a practice or procedure.

STANDARD CUBIC CENTIMETER PER SECOND: Unit of leakage rate equivalent to one cubic centimeter at atmospheric pressure (14.7 pounds per square inch) and standard temperature (77ºF) leaking each second. Abbreviation is STD.cm3 /s.

STANDARD DEPTH OF PENETRATION (ET): The depth at which the eddy current field has fallen to I/ e, or 37 percent, of its strength at the surface. In practice, it is generally used to define the sensing limit of the eddy current field.

STANDING WAVES (UT): Waves that exist in a body when the thickness of the body is equal to an integral number of ½ wave lengths (thickness equal to ½, 1, 1 ½, 2, or 2 ½, etc., wave lengths); used with the resonance method.

STATIONARY GRID (RT): A grid in which the opaque strips are so thin and so close together that it can remain stationary during exposure without causing images of the strips that would interfere with interpretation of the radiograph (e.g., Lysholm grid).

STATISTICAL INSPECTION: The inspection of a proportion of the number of parts (such as 5 to 10%) as predetermined by probability analysis. This method does not provide complete assurance of the lot quality.

STC: See DISTANCE AMPLITUDE CORRECTION.

STD. cm3/s: Abbreviation for standard cubic centimeters per second.

STEP-WEDGE CALIBRATION FILM (RT): A step-wedge comparison film, the densities of which are traceable to a nationally recognized standardizing body. It is used for reference when determining the density or densities of a radiograph.

STEP-WEDGE COMPARISON FILM (RT): A strip of processed film carrying a stepwise array of increasing photographic density.

STEP-WEDGE PENETRAMETER (STEP PENETRAMETER): A penetrameter of similar material to the specimen under examination, having steps ranging usually from 1 to 5 percent of the specimen thickness. Each step may contain one or more drilled holes for the assessment of definition.

STEPPED WEDGE (RT): A device that is used, with appropriate penetrameters on each step, for the inspection of parts having great variations in thickness or a complex geometry. The stepped wedge must be made of material radiographically similar to that being radiographed.

STEREOFLUOROSCOPY (RT): The production of a pair of radiographs suitable for stereoscopic viewing.

STEREORADIOGRAPHY (RT): The process of finding the position and dimensions of details within a specimen by measurements made on radiographs taken from different directions.

STEREOSCOPIC (RT): A type of viewing that employs an optical instrument (stereoscope) to combine the images of two radiographs taken from slightly different angles, thus achieving a three-dimensional effect.

STEREOSCOPY (RT): The three-dimensional visual effect resulting from binocular vision.

STIFFNESS: The ability of a metal or shape to resist elastic deflection. For identical shapes, the stiffness is proportional to the modulus of elasticity.

STOCHASTIC EFFECTS: The health effects that occur randomly and for which the probability of the effect occurring, rather than its severity, is assumed to be a linear function of dose without threshold. Hereditary effects and cancer incidence are examples of stochastic effects.

STOP BATH (RT): A chemical solution (or clean running water) used for arresting the activity of the developer remaining in the film emulsion.

STORAGE FOG (RT): Fog caused by storing film in a high humidity/temperature environment.

STRAIGHT BEAM (UT): A vibrating pulse wave train traveling normal to the test surface.

STRAIN: The change per unit of length in a linear dimension of a stressed body. It may be thought of as the deformation caused by an applied load and is measured in inches of change per inch of stressed length, or in percentage of dimensional change of a specified stressed length.

STRAIN AGING: Aging induced by cold working.

STRAIN ENERGY:

(1) The work done in deforming a body.

(2) The work done in deforming a body within the elastic limit of the material. It is more properly elastic strain energy and can be recovered as work rather than heat.

STRAIN HARDENING: An increase in hardness and strength caused by plastic deformation at temperatures lower than the recrystallization range.

STRAY RADIATION (RT): Radiation other than the useful beam. It includes leakage, secondary, and scattered radiation.

STRESS: Force per unit area, often thought of as force acting through a small area within a plane.

STRESS CONCENTRATION FACTOR (Kt): The ratio of the greatest stress, in the region of a notch or other stress raiser as determined by advanced theory, photo-elasticity or direct measurement of elastic strain, to the corresponding nominal stress.

STRESS-CORROSION CRACKING: Failure by cracking under combined action of corrosion and stress, either external (applied) or internal (residual). Cracking may be either intergranular or transgranular, depending on metal and corrosive medium.

STRESS RAISERS: Changes in contour of discontinuities in structure that cause local increases in stress.

STRESS RELIEVING: Heating to a suitable temperature, holding long enough to reduce residual stresses and then cooling slowly enough to minimize the development of new residual stresses. See TEMPER.

STRESS RUPTURE TEST: A tension test performed at constant load and constant temperature, the load being held at such a level as to cause rupture. Also known as “creep-rupture test.”

STRETCH FORMING: Shaping of a sheet or part, usually of uniform cross-section, by first applying suitable tension or stretch and then wrapping it around a die of the desired shape.

STRETCHER LEVELING: Leveling where a piece of metal is gripped at each end and subjected to a stress higher than its yield strength to remove warp and distortion. Sometimes called “patent leveling.”

STRETCHER STRAIGHTENING: A process for straightening rod, tubing and shapes by the application of tension at the ends of the stock. The products are elongated a definite amount to remove warpage.

STRETCHER STRAINS: Elongated markings that appear on the surface of some materials when deformed just past the yield point. These markings lie approximately parallel to the direction of maximum shear stress and are the result of localized yielding. Same as Luders Lines.

STRIKING: Electrodepositing, under special conditions, a very thin film of metal which will facilitate further plating with another metal or with the same metal under different conditions.

STRINGER: In wrought materials, an elongated configuration of microconstituents or foreign material aligned in the direction of working. Commonly, the term is associated with elongated oxide or sulfide inclusions in steel.

STRIPPING EMULSION (RT): A photographic emulsion, for use in autoradiography, which can be removed from its base and placed in contact with a specimen containing radioactive material.

SUBJECT CONTRAST: See CONTRAST, SUBJECT.

SUBJECT CONTRAST (RT): The ratio (or the logarithm of the ratio) of the radiation intensities transmitted by selected portions of the specimen.

SUBJECT RANGE (RT): The range of thickness or radiation opacity of material in a specimen.

SUBJECTIVE CONTRAST (RT): A qualitative estimate of the contrast in a radiograph or fluorescent screen reproduction.

SUBSTITUTIONAL SOLID SOLUTION: An alloy composed of two or more chemical elements in which both metals are randomly distributed at equivalent lattice positions throughout the metal.

SUBSTRATE: Layer of metal underlying a coating, regardless of whether the layer is basis metal.

SUBSURFACE CORROSION: Formation of isolated particles of corrosion products beneath the metal surface. This results from the preferential reaction of certain alloy constituents by inward diffusion of oxygen, nitrogen and sulfur.

SUB-SURFACE DEFECT: Any defect which does not break the surface of the part in which it exists.

SUBSURFACE INDICATION: Any indication that does not open onto the surface of the part in which it exists.

SUPERFICIAL ROCKWELL HARDNESS TEST: Form of Rockwell Hardness Test using relatively light loads, which produce minimum penetration. Used for determining surface hardness or hardness of thin sections or small parts, or where large hardness impression might be harmful.

SUPPRESSION (UT): See REJECT.

SURFACE FINISH:

(1) Condition of a surface as a result of a final treatment.

(2) Measured surface profile characteristics, the preferred term being Roughness.

SURFACE INDICATION: Any indication that is open onto the surface of the part in which it exists.

SURFACE IRREGULARITY: An image on a radiograph film that corresponds to an irregularity visible on the surface of an object being tested.

SURFACE IRREGULARITY (RT): An image on a radiograph that corresponds to an irregularity visible on the surface of a specimen.

SURFACE IRREGULARITIES: Any change in material surface that renders the specimen unserviceable.

SURFACE TENSION (PT): That property due to molecular forces, by which the surface of all liquids tends to bring the contained volume into a form having the least superficial area.

SURFACE WAVE (UT): A type of wave which travels along a surface; characterized by elliptical particle motion having effective penetration less than one wave length.

SURFACTANT (PT): (Surface active agent) A soluble compound that reduces the surface tension of liquids, or reduces interfacial tension between two liquids or a liquid and a solid.

SURGE METHOD (MT): Inspection by first employing a high surge of magnetizing force, followed by a reduced magnetic field during application of a finely divided ferromagnetic inspection medium.

SURGE SUPPRESSOR: A device that automatically reduces abnormally high voltage or current transients to acceptable levels.

SURVEY: An evaluation of the radiological conditions and potential hazards incident to the presence of radiation. When appropriate, such an evaluation includes a physical survey of the location and measurements or calculations of the levels of radiation.

SURVEY METER (RT): A portable instrument that measures dose rate of exposure or radiation intensity.

SUSPENSION (MT): The correct term applied to the liquid bath in which is suspended the ferromagnetic particles used in the wet magnetic particle inspection method.

SWAGING: Forming a taper or a reduction on metal products such as rod and tubing by forging, squeezing or hammering.

SWEEP (UT): The uniform and repeated movement of an electron beam across the CRT.

SWEEP DELAY (UT): See DELAYED SWEEP. A delay in time, after the initial pulse, of starting the sweep presentation; also used to denote the control used for adjusting the time of starting the sweep presentation.

SWEEP LENGTH (UT): Length of time or distance represented by the horizontal base line on an A-scan.

SYSTEM CONCEPT (PT): A combination of penetrant and emulsifier supplied by one manufacturer and intended to perform a specific type or process of inspection. The term “Family Concept” has been changed to “System Concept” to comply with DOD standardization requirements.

T

TARGET (RT): The area on the anode of an X-ray tube on which the electron stream impinges and from which the primary beam of X-rays is emitted.

TARNISH: Surface discoloration of a metal caused by formation of a thin film of corrosion product.

TCG: See DISTANCE AMPLITUDE CORRECTION.

TEAR, HOT: Same as CRACK, HOT; but developing before the casting has completely solidified.

TEAR, MACHINING: See CRACKS, MACHINING.

TECHNIQUE CHART (RT): See EXPOSURE CHART.

TEMPER:

(1) In heat treatment, reheating hardened steel or hardened cast iron to some temperature below the eutectoid temperature for the purpose of decreasing the hardness and increasing the toughness. The process also is sometimes applied to normalized steel.

(2) In tool steels, “temper” is sometimes used, but inadvisedly, to denote the carbon content.

(3) In nonferrous alloys and in some ferrous alloys (steels that cannot be hardened by heat treatment), the hardness and strength produced by mechanical or thermal treatment, or both, and characterized by a certain structure, mechanical properties, or reduction in area during cold working.

TEMPER BRITTLENESS: Brittleness that results when certain steels are held within, or are cooled slowly through, a certain range of temperature below the transformation range. The brittleness is revealed by notched- bar impact tests at or below room temperature.

TEMPERATURE ENVELOPE (PT): The temperature range over which a particular penetrant inspection test will operate.

TEMPERING: Reheating a quench-hardened or normalized ferrous alloy to a temperature below the transformation range and then cooling at any rate desired.

TEMPLATE: A guide, gage or pattern for checking dimensions or locations.

TEMPORARY MAGNETS: A body of normally soft steel or piece iron which is readily magnetized but retains only a very small field after the active power of the external magnetic field is removed.

TENSILE STRENGTH: The maximum stress that a material is capable of withstanding without breaking under a gradually and uniformity applied load. Other terms commonly used to express the same thing are ultimate tensile strength and, less accurately, breaking strength.

TENTH-VALUE LAYER (TVL) (RT): The thickness of the layer of a specified substance which, when introduced into the path of a given narrow beam of radiation, reduces the intensity of this radiation to one-tenth the original value.

TEST BLOCK: See REFERENCE STANDARD.

TEST FREQUENCY: The number of complete input cycles per unit time of a periodic quantity such as alternating current employed for a specified inspection. The test frequency is always considered to be the fundamental whenever harmonics are generated in the process of testing certain materials such as ferromagnetic materials.

TEST PART: A part, material, or assembly being inspected.

TEST SURFACE: The test part surface through which the ultrasonic energy used for inspection initially enters the test part.

THERMAL ANALYSIS: A method for determining transformations in a metal by noting the temperatures at which thermal arrests occur. These arrests are manifested by changes in slope of the plotted or mechanically traced heating and cooling curves. When such data are secured under nearly equilibrium conditions of heating and cooling, the method is commonly used for determining certain critical temperatures required for the construction of equilibrium diagrams.

THERMAL CAPACITY: A measure of the amount of heat that can be obtained in a given mass of material.

THERMAL FATIGUE: Fracture resulting from the presence of temperature gradients which vary with time in such a manner as to produce cyclic stresses in a structure.

THERMAL FOCUS (RT): That part of the anode of an X-ray tube submitted to direct heating by the electron beam.

THERMAL SHOCK: The development of a steep temperature gradient and accompanying high stresses within a structure.

THERMAL STRESSES: Stresses in metal, resulting from non-uniform temperature distribution.

THERMIONIC EMISSION (RT): The emission of electrons from the surface of a heated material by virtue of their thermal energy.

THERMOLUMINESCENCE (RT): The property possessed by certain crystals, of emitting light when heated after having been exposed to ionizing radiation.

THERMOLUMINESCENCE DOSIMETER (TLD) (RT): A dosimeter, commonly used as a personnel monitor that uses thermoluminescent material. The total amount of light emitted upon heating of the material is proportional to the amount of radiation energy absorbed.

THETA (0): Symbol for the half angle of beam spread; the Greek letter Theta.

THORIATED TUNGSTEN FILAMENT (RT): A vacuum-tube filament consisting of tungsten mixed with thorium oxide to give improved electron emission. Also known as thoriated emitter.

THORIUM: A heavy malleable, radioactive metal used in the manufacture of thoriated tungsten target material in the X-ray tube head.

THREE-PHASE ALTERNATING CURRENT: Commercial, electricity is commonly transmitted as three single phase currents, that is, three separate currents following separate sine curves, each at 60 cycles (or other frequency) per second, but with the peaks of their individual curves one-third of a cycle apart. At least three (sometimes four) conductors are required for three-phase alternating current.

THRESHOLD: In reference to currents or magnetic fields, the minimum strength necessary to create a looked-for effect is called the threshold value. For example, the minimum current necessary to produce a readable indication at a given defect, is the threshold value of current for that purpose.

THRESHOLD DOSE (RT): The minimum absorbed dose or dose equivalent that will produce a specified effect.

THROUGH TRANSMISSION METHOD (UT): An inspection method in which ultrasonic energy is generated by one search unit and received by another at the opposite surface of the test part.

3-2T RADIOGRAPHY: Quality level of radiography in which the finished radiograph displays a discernible image or a penetrameter hole that has a diameter equal to twice the penetrameter thickness. The penetrameter thickness equals 3 percent of the material thickness.

THYLIUM-170: A radioisotope of the element thulium.

TIME DELAY (UT): See SWEEP DELAY.

TLD (RT): See THERMOLUMINESENCE DOSIMETER.

TOE CRACK: A base-metal crack at the Toe of Weld.

TOE OF WELD: The junction between the face of a weld and the base metal.

TOLERANCE: The specified permissible deviation from a specified nominal dimension, or the permissible variation in size of a part.

TOMOGRAPH (RT): A radiograph of a specified plane of a deep structure.

TOMOGRAPHY (RT): The radiography of a predetermined interior plane of a thick material. In one method the X-ray tube and the film are moved simultaneously in opposite directions about a pivotal point in the plane of the layer.

TORSION: A twisting action resulting in shear stresses and strains.

TOUGHNESS: Ability of a metal to absorb energy and deform plastically before fracturing. It is usually measured by the energy absorbed in a notch impact test, but the area under the stress-strain curve in tensile testing is also a measure of toughness.

TOXIC: The quality of certain materials being proportionally poisonous, as indicated by jeopardy to life, health or comfort.

TRACER: An element or compound that has been made radioactive so that it can be easily followed (traced) in biological and industrial processes. Radiation emitted by the radioisotope pinpoints its location.

TRANSDUCER: Any device that is capable of converting energy from one form to another.

TRANSDUCER (UT): An electroacoustical device for converting electrical energy into acoustical energy and vice versa.

TRANSDUCER ELEMENT (UT): A piezoelectric element in a search unit.

TRANSFER: Compensation for differences in signal amplitude from equivalent reflectors in a test part and the reference standard used in an inspection.

TRANSIENT CURRENTS: These currents are of short duration, generated by sudden changes in the electrical or magnetic conditions existing in an electrical or magnetic circuit.

TRANSMISSION ANGLE (UT): The incident angle of the transmitted ultrasonic beam. It is zero degrees when the ultrasonic beam is perpendicular to the test surface.

TRANSMISSION CHARACTERISTICS (UT): Test part characteristics that influence the transmitting and receiving of ultrasonic energy in an inspection; includes surface effects and internal effects.

TRANSMISSION TARGET (RT): A relatively thin target so arranged that the X-ray beam emerges from the surface opposite that on which the electron stream is incident.

TRANSMITTER (UT): Search unit or transducer element, used to generate ultrasonic energy to be transmitted into a test part.

TRANSVERSE: Literally, “across,” usually signifying a direction or plane perpendicular to the direction of working.

TRANSVERSE WAVE (UT): See SHEAR WAVE.

TREES: Visible projections of electrodeposited metal formed at sites of high current density.

TREPANNING: A type of boring where an annular cut is made into a solid material with the coincidental formation of a plug or solid cylinder.

TRITIUM: A radioactive isotope of hydrogen with two neutrons and one proton in the nucleus. It is heavier than deuterium (heavy hydrogen). Tritium is used in industrial thickness gages, as a label in tracer experiments, and in controlled fusion experiments.

TUBE CURRENT (RT): The current flowing between the cathode and anode during the generation of radiation by an X-ray tube.

TUBE DIAPHRAGM (RT): An adjustable device, normally attached to a tube housing, that limits the cross section of the emergent X-ray beam.

TUBE FILTER (RT): A filter that can be attached to the X-ray tube housing.

TUBE HOUSING (RT): An enclosure that contains an X-ray tube and has a port through which the useful beam is emitted. The tube housing may also contain transformers and other appropriate components.

TUBE RATING (RT): The maximum electrical power (in watts) that can be safely applied to an X-ray tube for a specified period.

TUBE SHIELD (RT): The housing of an X-ray tube that normally provides protection against electric shock and affords a degree of protection against radiation.

TUBE-SHIFT RADIOGRAPHY (RT): See TRIANGULATION.

TUBE SHUTTER (RT): A device attached to a tube housing, generally of lead and usually remotely operated, used to permit or to prevent the emergence of the X-ray beam.

TUBE STAND (RT): A support, often in the form of one or more vertical pillars with adjustable attachments, for holding an X-ray tube in position for use.

TUBE WINDOW (RT): The relatively thin section of the X-ray tube through which the useful beam emerges. (Materials have different absorption properties, and thus some “Windows” are designated by their material, e.g., “Beryllium Window”.)

TUNED: Having a relatively narrow bandwidth; used to describe instruments having an initial pulse with a relatively narrow bandwidth and/or an amplifier with response to a relatively narrow range of frequencies.

TUNGSTEN ALLOY (HEAVY ALLOY) (RT): A shielding material containing tungsten, copper, and nickel, and having a density about 50 percent greater than that of lead.

TUNGSTEN INCLUSIONS: Inclusions in welds resulting from particles or splinters of tungsten welding electrodes.

TURBIDITY (PT, MT): The state of being turbid, characterized by being cloudy, muddy, dully, impure or polluted.

TVG: See DISTANCE AMPLITUDE CORRECTION.

TWO-CRYSTAL METHOD (UT): Use of two transducers for sending and receiving. May be send-receive or through-transmission method.

TWO-FILM TECHNIQUE (RT): A procedure wherein two films of different relative speeds are used simultaneously to radiograph both the thick and the thin sections of an item.

2-2T RADIOGRAPHY: Quality level of radiography in which the finished radiograph displays a discernible image of a penetrameter hole that has a diameter equal to twice the penetrameter thickness. The penetrameter thickness equals 2 percent of the material thickness.

TYPE A PACKAGING (RT): The name given, in the regulations concerning the transport of radioactive materials, to packaging capable of preventing any loss or dispersion of the radioactive contents and of maintaining its function of shielding against radiation in normal transport conditions.

TYPE B PACKAGING (RT): The name given, in the regulations concerning the transport of radioactive materials, to packaging capable of resisting not only normal transport conditions like type A packaging but also a serious accident.

U

UMBRA (RT): A region behind an object in a beam of radiation such that a straight line drawn from any point in this region to any point in the source passes through the object. The umbra is sometimes referred to as the region of total shadow.

ULTIMATE COMPRESSIVE STRENGTH: The maximum compressive stress that a material can withstand under a gradually and uniformly applied load.

ULTIMATE STRENGTH: The maximum conventional stress, tensile, compressive or shear, that a material can withstand.

ULTRA-BLUE LIGHT (PT): Monochromatic blue light of approximately 4300 AU wavelength used to cause certain dye penetrants to fluoresce.

ULTRASONIC (UT): Pertaining to mechanical vibrations having a frequency greater than approximately 20,000 hertz.

ULTRASONIC ABSORPTION: A dampening of ultrasonic vibrations that occurs when the wave transverses a medium.

ULTRASONIC SPECTRUM; The frequency span associated with elastic waves greater than the highest audible frequency, generally regarded as being higher than 2.0 x 104 cycles per second, to approximately 109 cps.

ULTRASONIC TESTING: A nondestructive method of testing materials by transmitting high frequency sound waves through them.

UNDERBEAD CRACK: A subsurface crack in the base metal near the weld.

UNDERCUT (RT): A depression or groove adjoining the toe of a weld in a metal object. Appears on a radiograph as a dark area.

UNDERCUT (RT): Undercut is a term that is used to describe the excessive radiation intensity that may be found at the edge of an object. Such undercutting is usually associated with scattered radiation.

UNDER-DEVELOPMENT (RT): Development that is less than that required to produce the optimum results in a particular radiograph. It may arise from development for too short a time, or at too low a temperature, or from the use of exhausted developer.

UNDERFILL: Storage of metal so that the true shape is not completely filled.

UNIAXIAL STRESS: A state of stress in which two of the three principal stresses are zero.

UNIDIRECTIONAL: Having one direction only.

UNIDIRECTIONAL VOLTAGE: A voltage of which the polarity, but not necessarily the magnitude is constant.

UNIFORM STRAIN: The strain occurring prior to the beginning of localization of strain (necking); the strain to maximum load in the tension test.

UNRESTRICTED AREA (RT): Any area to which access is not controlled for purposes of radiation protection.

UNSHARPNESS (RT): Unsharpness is a term used to describe the lack of definition of an edge due to geometric factors related to the source size and the source-to-film distance.

UPSETTING: Working metal so that the cross-sectional area of a portion or all of the stock is increased.

USE FACTOR (RT): The fraction of the workload during which the useful beam is pointed in the direction under consideration when designing shielding. Symbol: U.

USEFUL BEAM (RT): All radiation that emerges from a source housing or an X-ray tube assembly through a port, diaphragm, or cone.

USEFUL DENSITY RANGE (RT): The range of density over which the gradient is adequate for the recognition of image details. The upper density limit is determined mainly by the brightness available in the film illuminator, and the lower density limit by the sensitivity required.

UT: Symbol for the ultrasonic method of nondestructive testing/inspection.

V

v: Symbol for velocity.

V-PATH: See SKIP DISTANCE.

VACUUM DEPOSITION: Condensation of thin metal coatings on the cool surface of work in a vacuum.

VACUUM MELTING: Melting in a vacuum to prevent contamination from air, as well as to remove gases already dissolved in the metal; the solidification may also be carried out in a vacuum or at low pressure.

VAN DE GRAAF GENERATOR: An electrostatic type X-ray generator in the million and multi-million volt category.

VECTOR FIELD (MT): See FIELD, RESULTANT.

VELOCITY (UT): The distance an ultrasonic wave travels in unit time.

VERTICAL LIMIT (UT): The maximum readable level of vertical indications, determined either by an electrical or a physical limit of an A-scan presentation.

VERTICAL LINEARITY (UT): Constant relationship between the amplitude of the indications on an A-scan display and the corresponding magnitudes of the reflected ultrasonic waves from reflectors of known size.

VERY HIGH RADIATION AREA: An area, accessible to individuals, in which radiation levels could result in an individual receiving an absorbed dose in excess of 500 rads (5 grays) in 1 hour 1 meter from a radiation source or from any surface that the radiation penetrates.

NOTES

At very high doses received at high dose rates, unit of absorbed dose (e.g., rads and grays) are appropriate, rather than units of dose equivalent (e.g., rems and sieverts).

The maximum dose rate 1 meter from the aperture of the Lorad LPX-160A Industrial X-ray Unit is 2.4 grays (240 RDAs) per minute at 0.5 meters thus the maximum dose received in one hour would equate to about 0.6 grays (60 RDAs) per minute. As such, "Very High Radiation" areas can exist for this and comparable radiation sources.

VIBRATION MODE (UT): See MODE OF VIBRATION.

VICKERS HARDNESS TEST: Same as diamond pyramid hardness test.

VIDEO PRESENTATION (UT): A CRT presentation in which rectified signals are displayed.

VIEWING MASK (RT): A device for limiting the field of examination of the radiograph.

VISCOSITY: Quality, state or degree of being viscous. That property of a body by virtue of which, when flow occurs inside it, forces arise in such a direction as to opposite the flow.

VISCOSITY: A measurement of a liquids resistance to change of shape or flow. Also referred to as flow resistance.

VISIBLE: Capable of being discerned by the eye.

VISIBLE DYE PENETRANT (PT): An intensely colored (usually red) highly penetrating liquid which will provide maximum contrast with the white developer when used for detection of surface discontinuities under normal light.

VISIBILITY (MT): The ability of magnetic particles to be seen against a contrasting background.

VOID: Discontinuities in which there is a physical separation between opposite walls.

VOLTAGE: The unit of electromotive force that tends to cause an electric current to flow through a conductor.

VOLTAGE REGULATOR: A device that automatically compensates for variations in line-power voltage, thus maintaining nearly constant voltage on the electrical circuit.

W

WATER-BREAK (MT): A method of testing the water suspension for the proper amount of wetting agent. The inability of the rinse water to cover the entire surface in an unbroken film.

WATER-COOLED TUBE (RT): An X-ray tube for which the principal method of cooling is dissipation of heat, directly or indirectly, by means of water.

WATER DELAY COLUMN (UT): A hollow column filled with water and attached to a search unit; causes a time delay between the initial pulse and front surface signal.

WATER PATH (UT): In immersion inspection or inspection using a water column delay, the distance from the search unit face to the test part front surface.

WATER TOLERANCE (IT): The amount of water that a penetrant or emulsifier can absorb before its effectiveness is impaired.

WATER TRAVEL (UT): In immersion testing the distance from the face of the search unit to the entry surface of the material under test.

WATER WASHABLE (PT): A water-washable penetrant is an oil-like material containing an emulsifying agent that makes it washable by water rinsing.

WATER-WASHABILITY (PT): The property of a penetrant that permits it to be cleaned from the surface of a part by washing with water.

WAVE FRONT (UT): In a wave disturbance, a continuous surface drawn through the most forward points which have the same phase.

WAVE INTERFERENCE (UT): The production of a series of maxima and minima of sound pressure, as a consequence of the superimposition of waves having different phases.

WAVELENGTH: The distance between two points having the same phase in two consecutive cycles of a periodic wave, along a line in the direction of propagation.

WAVELENGTH (UT): The distance between two corresponding points of the periodic pattern of particle motion that is a characteristic of ultrasonic energy propagation.

WAVE TRAIN (UT): Succession of ultrasonic waves arising from the same source, having the same characteristics, and propagating along the same path.

WEAR FACE (UT): A device attached to the face of a search unit to prevent wear of the transducer element.

WEDGE (RT): See STEP WEDGE.

WEDGE (UT): A device used to direct ultrasonic energy into a test part at an angle; also, see SHOE.

WEDGE FILTER (RT): A filter so constructed that its thickness varies continuously or in steps from one edge to the other. Wedge filters may be used to increase the uniformity of radiation in certain types of exposures.

WELD BEAD: A deposit of filler metal from a single welding pass.

WELD CRACK: A crack in weld metal.

WELDING STRESS: Residual stress caused by localized heating and cooling during welding.

WELD LINE: The junction of the weld metal and the base metal, or the junction of the base-metal parts when filler metal is not used.

WELD METAL: That portion of a weld which has been melted during welding.

WELD NUGGET: The weld metal in spot, seam or projection welding.

WELD STRUCTURES: The micro-structures of a weld deposit and heat affected base metal.

WET CONTINUOUS PROCESS (MT): The method of applying the wet suspension to the inspection surfaces just prior to applying the magnetizing current.

WET DEVELOPER (IT): A developer in which the developing powder is applied as a suspension or solution in a liquid, usually water.

WET METHOD (MT): The magnetic particle inspection method employing ferromagnetic particles suspended in a liquid bath.

WETTING ACTION (MT): The ability of a solution to adhere to the surface of an object.

WETTING AGENT (RT, MT): In film processing, a chemical additive to the final water rinse to promote complete wetting of the film, thus assuring adequate washing away and neutralization of the prior processing solutions and prevention of water spots during the drying cycle. In magnetic particle inspection a material added to liquid that enables it to wet and cover surfaces that the liquid itself would ordinarily not wet.

WHEEL SEARCH UNIT (UT): Ultrasonic device which couples ultrasonic energy to a test part through the rolling contact area of a wheel containing a liquid and one or more transducer elements.

WHITE CAST IRON: Cast iron that gives a white fracture because the carbon is in a combined form.

WHOLE BODY: Means, for purposes of external exposure, head, trunk (including male gonads), arms above the elbow or legs above the knee.

WIRE PENETRAMETER (RT): An image quality indicator incorporating a series of wires that are graded in diameter and usually of similar material to the specimen under examination.

WOBBULATION (ET): An effect which produces variations in an output signal of a test system and arises from variations in coil spacing due to lateral motion of the test specimen in passing through an encircling coil.

WORK HARDENING: Same as STRAIN HARDENING.

WORKLOAD (RT): The output of a radiation machine or a radioactive source integrated over a suitable time and expressed in appropriate units.

WROUGHT IRON: A commercial iron consisting of slag (iron silicate) fibers entrained in a ferrite matrix.

X

X-RADIATION (RT): See X-RAYS.

X-RADIOGRAPHY (RT): The process of producing radiographs using X-rays.

X-RAYS (RT): A form of radiant energy resulting from the bombardment of a suitable target by electrons produced in a vacuum by the application of high voltages. X-rays have wavelengths between 10-11 cm and 10-6 cm.

X-RAY FILM (RT): A film base that is coated (usually on both sides) with an emulsion designed for use with X-rays.

X-RAY PAPER (RT): White paper coated on one side with emulsion for use with or without an intensifying screen. It is suitable for use with X-rays.

X-RAY SPECTROMETER (RT): An instrument used to determine the wavelengths of X-rays and the relative intensities of different wavelengths in an X-ray beam.

X-RAY SPECTROSCOPY (RT): The study of X-ray spectrums and their interpretation.

X-RAY TUBE: A glass vacuum tube that decelerates the high velocity electrons, and produces X-rays.

X-RAY TUBE (RT): A vacuum tube intended for the production of X-rays by bombarding the anode with a beam of electrons accelerated under a difference of potential between anode and cathode.

X-RAY TUBE ASSEMBLY (RT): A tube housing with the tube installed. It may include high voltage and filament transformers and other appropriate elements when they are contained within the tube housing.

XERO-RADIOGRAPHY (RT): A process using the photoconductive property of amorphous selenium to produce a radiological image, instead of photographic film.

Y

YIELD POINT: The load (in psig) at which a marked increase in deformation occurs without an increase in load.

YIELD STRENGTH: The stress at which a material exhibits a specified deviation from proportionality of stress and strain. An offset of 0.2% is used for many metals.

YOKE (MT): A “C” shaped piece of soft magnetic material either solid or laminated, around which is wound a coil carrying the magnetizing current.

YOKE MAGNETIZATION (MT): A longitudinal magnetic field induced in a part, or in an area of a part, by means of an external electromagnet shaped like a yoke.

Z

Z: Symbol for acoustic impedance.

ZIRCON SAND: A highly absorptive material used as a blocking or masking medium for drilled holes, slots and highly irregular geometric parts to reduce or eliminate scattered radiation.

ZONE MELTING: Highly localized melting, usually by induction heating, of a small volume of an otherwise solid piece. By moving the induction coil along the rod, the melted zone can be transferred from one end to the other. In a binary mixture where there is a large difference in composition on the liquidus and solidus lines, high purity can be attained by concentrating one of the constituents in the liquid as it moves along the rod.

By Order of the Secretary of the Army:

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General, United States Army
Chief of Staff

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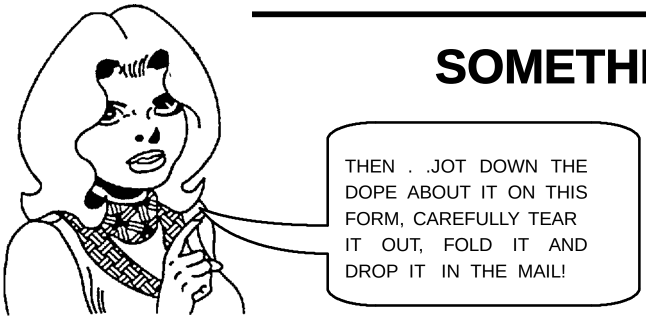

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81		4-3		Callout 16 on figure 4–3 is pointed at a <u>bolt.</u> In key to figure 4–3, item 16 is calle a <u>shim</u>—Please correct one or the other

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