DEPARTMENT OF THE AIR FORCE
Headquarters US Air Force
Washington DC 20330

AF MANUAL 85-5

9 February 1982

Civil Engineering—General

MAINTENANCE AND OPERATION OF CATHODIC PROTECTION SYSTEMS

This manual provides the guidance necessary to maintain and operate cathodic protection systems (CPS) at Air Force installations. Appointed base corrosion control engineers are required by AFR 91-27, Corrosion Control, to develop and maintain a base corrosion control program (BCCP). Required surveys and testing, chapter 9, and required records and reports, chapter 8 of this publication, are mandatory components of every BCCP. The actual field testing and operation and maintenance work is assigned to technicians in the base electrical shop. This publication contains information about the testing of existing facilities to determine the extent of active corrosion. The design and installation of CPSs are described in AFM 88-45, Cathodic Protection Design. The use of a name of any specific manufacturer, commercial product, commodity, or service in this publication does not imply endorsement by the Air Force.

Chapter 1—Introduction to Maintenance and Operation of Cathodic Protection Systems

Chapter 2—Cathodic Protection Systems

Chapter 3—Test Equipment and Field Measurements

Chapter 4—Operation and Maintenance of Galvanic Anode Systems

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Supersedes AFM 85-5, 1 November 1965. (See signature page for summary of changes.)
No. of Printed Pages: 82
OPR: HQ AFESC/DEMM (Mr. T. F. Lewicki)
Approved by: HQ AFESC (Col. John L. Perry)
Writer-Editor: Novella S. Hill
Distribution: F

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Chapter 1

INTRODUCTION TO MAINTENANCE AND OPERATION OF CATHODIC PROTECTION SYSTEMS

1-1. Civil Engineering Responsibilities. The management and authority for the overall cathodic protection program rest with the base corrosion engineer. Basic responsibilities for actual operation, maintenance, and testing of CPSs are assigned to the chief of operations and accomplished by the cathodic protection technician. Effective corrosion control programs with adequately maintained CPSs require that all civil engineering personnel understand the importance of this work and the function of each shop in the program. It is, therefore, necessary that a civil engineering operating instruction be issued describing the responsibilities and duties of all concerned.

1-2. Safety Procedures. Specific instructions for safe operating procedures are contained in Occupational Safety and Health Administration Standards, Air Force Occupational Safety and Health Standards, and AFP 85-1, Electrical Facilities Safe Practices Handbook. The director of ground safety at each installation can provide further assistance and direction. For fundamentals of corrosion and cathodic protection, see AFM 88-45, Cathodic Protection Design (to be published).

Chapter 2

CATHODIC PROTECTION SYSTEMS

2-1. Impressed Current Systems. This method of cathodic protection is a deliberately established electrolytic corrosion cell. The protection feature is obtained by setting the direction of current flow so that the protected structure is the cathode of the cell and some other material is the anode. Figure 2-1 shows the similarity between an electrolytic cell and an impressed current CPS.

a. **Rectifier Assembly.** Present day impressed current systems use "rectifiers" as the external source of current in the electrolytic cell. The "rectifier" is an assembly including a multi-tap alternating current (AC) step-down transformer, an arrangement of metallic rectifiers, a protective circuit breaker or fuse, and meters for monitoring both voltage and current output. Figure 2-2 shows the complete circuit diagram for the most commonly used commercial rectifiers.

b. **Transformer Assembly.** Each rectifier assembly will contain a transformer to furnish the proper voltage for rectification and output to the system. As each impressed current system is planned, the designer determines the amount of current necessary to furnish protection and the size of transformer needed. As circuit conditions change, it is sometimes necessary for the engineer to request a transformer or rectifier change in order to get sufficient current output.

(1) Rectifier units are manufactured in various sizes having specific input and output ratings. A transformer-rectifier assembly chosen for one specific system may not function satisfactorily on another system. To compensate for uncertainties in design and changes in electrolyte resistance and to allow standardization of equipment, each transformer is provided with a series of taps. By changing taps, voltage can be varied to provide the proper current output under actual field conditions.

(2) Additionally, the transformer electrically isolates the CPS from the power distribution system. Rectifier units without transformers may generate stray currents that may enter and affect the AC power distribution system. Therefore, rectifier units without transformers must not be used.

c. **Metallic Rectifiers (Semiconductors).** There are two types of metallic rectifiers commonly used in cathodic protection — selenium and silicon:

(1) Selenium Rectifiers. Most rectifiers in CPSs are of selenium oxide. The basic unit is made up of a layer of selenium oxide on an iron or aluminum plate and covered with a layer of conductive alloy. This combination presents little resistance to the flow of electric current in one direction and a high resistance to current flow in the other direction. Each selenium plate is limited in the voltage which it can effectively block or rectify. This limiting voltage is called the "peak inverse voltage" or PIV. In order to rectify at higher voltages, it is necessary to connect a number of selenium plates in series forming a "stack." Since the current carrying capacity of a selenium plate is dependent on its area because of heat lost, a stack with large plates will handle more current than a stack with small plates. Sometimes, to increase current capacity, the selenium plates are connected in parallel and interleaved. Although open air-cooled stacks are the cheapest and most common, the exposed plates may corrode and become fouled with dust and dirt. The fouled plates cannot radiate heat effectively and the stacks may overheat and fail prematurely. Oil immersed rectifier stocks are available for use where high temperature, corrosive atmosphere, or dirty operating locations are a problem. Forced air cooling is sometimes used where the atmosphere will not damage the plates.

(a) Ordinary selenium plates employ an artificial barrier layer, usually some form of lacquer, between the selenium itself and the counter electrode or contact surface of the cell. This barrier impairs efficiency and life expectancy in two ways. First, it increases the forward voltage drop of the cell, thereby generating more heat per square inch for a given current density. Second, the barrier deteriorates with continued usage. Such deterioration, called aging, produces additional heat which eventually necessitates replacement of the cell. The higher the temperature, the shorter the life of the plate. An ordinary selenium plate will cause a voltage drop of 1.25 volts when new. The voltage may increase to 2.5 volts or more per plate due to aging. Ordinary selenium plates are usually rated to operate at a current density of 160 MA/square inch or less.

(b) Non-aging selenium plates are produced by eliminating the artificial barrier and creating a basic barrier by a diffusion process. These plates are basically of high current density, rated to operate at 385 MA/square inch or less. The stacks widely used today are the non-aging type.

(c) Voltage surges accelerate the rate of aging by increasing the operating temperature. Severe surges will completely burn out a rectifier plate, causing stack failure. In a bridge-type rectifier, the unit will continue to operate as a half-wave rectifier even though one stack has failed. However, the operating stacks will be overloaded and will age more rapidly than normal.

(2) Silicon Rectifiers. These use a crystal of silicon as the semiconductor element. These rectifiers can be operated at higher temperatures and current densities than selenium rectifiers. These rectifiers have the advantages of increased efficiency at high direct current (DC) voltages, small size for high current capacity, and lack of deterioration due to aging. However, silicon units will break down under voltage surges and, therefore, require elaborate surge and overload protection. Selenium should be used when rectifiers are designed to operate below 70 volts DC and silicon should be used when operating above 70 volts DC.

d. **Anode Material.** The anodes of an impressed current system provide the means for the protective current to enter the electrolyte. Since the anodes form the corrod-

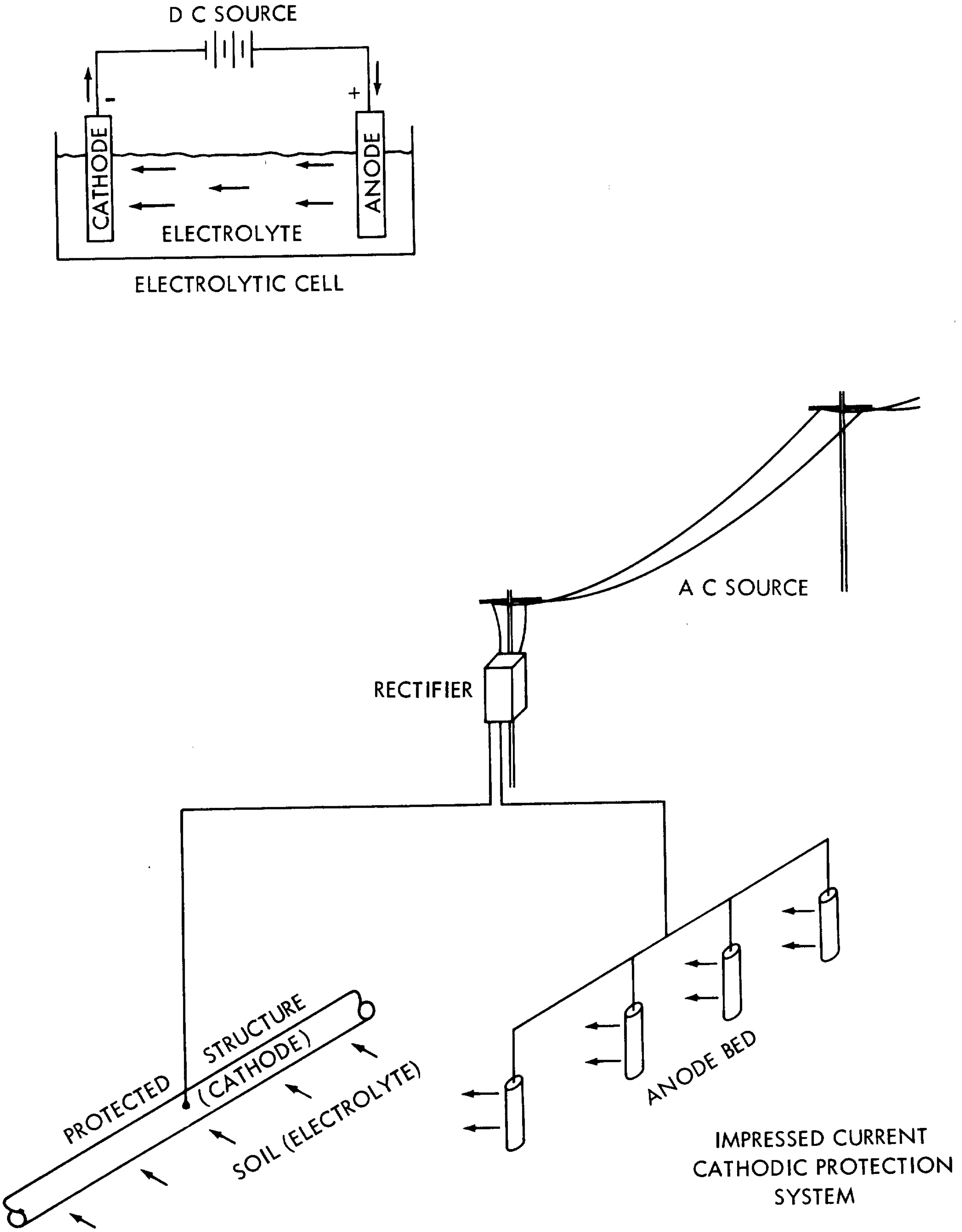


Figure 2-1. Impressed Current Cathodic Protection System.

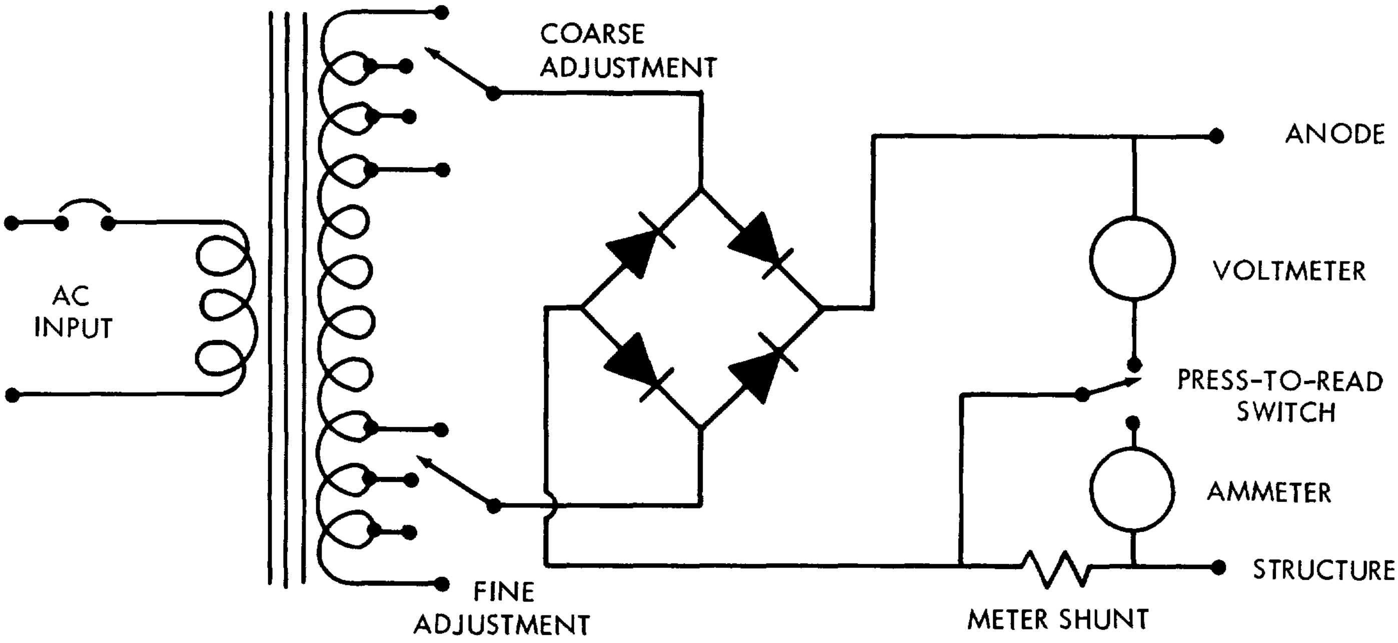


Figure 2-2. Typical Single Phase, Full-Wave Bridge Type Rectifier Circuit.

ing part of the system, the best material is one which has a low rate of weight loss per ampere-year (see table 2-1). The most commonly used materials for impressed current anodes are graphite and high-silicon cast iron. Aluminum is sometimes used in water storage tanks where it is convenient to install, has a low, first cost, and ice damage is likely. In areas where heavy icing is not a problem, high-silicon cast iron anodes should be used instead of aluminum for lower long-term cost. Platinum coated titanium or niobium anodes are becoming more prevalent as impressed current anode material. Impressed current anodes are also available packaged in metal stove-pipe-like cans, but are not recommended for Air Force use except in swampy or hard to install areas because of the higher cost and the lead-to-anode connection. Also, the anode itself cannot be inspected for breaks.

Table 2-1. Electrochemical Equivalents of Common Structural Metals.

Metal	Weight Loss Pounds Per Ampere-Year
Carbon (Graphite)	2.2
Iron	20.1
Aluminum	6.5
Lead	74.5
Copper	22.8
Zinc	23.6
Magnesium	8.8
Nickel	21.1
Silver	77.6
Tin	42.0

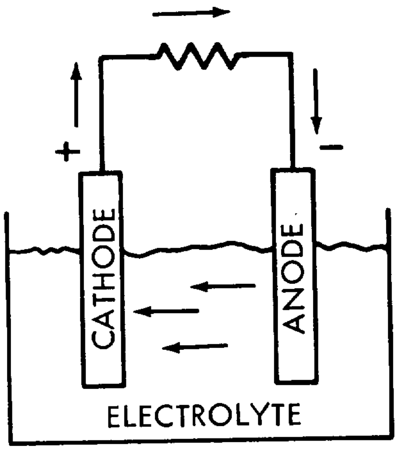
(1) Graphite anodes are produced by fusing a mixture of crushed petroleum coke and coal-tar pitch at a temperature of 2800 degrees Centrigrade (C) and then impregnating the fused rod with linseed oil to prevent absorption of water when the anode is in service. These graphite anodes corrode away at a rate averaging 2.2 pounds per ampere-year.

(2) High-silicon cast iron anodes are made of cast iron containing at least 14 percent silicon along with small amounts of carbon, manganese, chromium, and sometimes molybdenum. This compares with ordinary gray cast iron which contains less than 2.75 percent silicon. The corrosion rate of these anodes depends on the electrolyte and on the density of current flow, (amperes per square foot of anode surface), but generally is under 0.5 pound per ampere-year in soil or freshwater and under 1 pound per ampere-year in seawater.

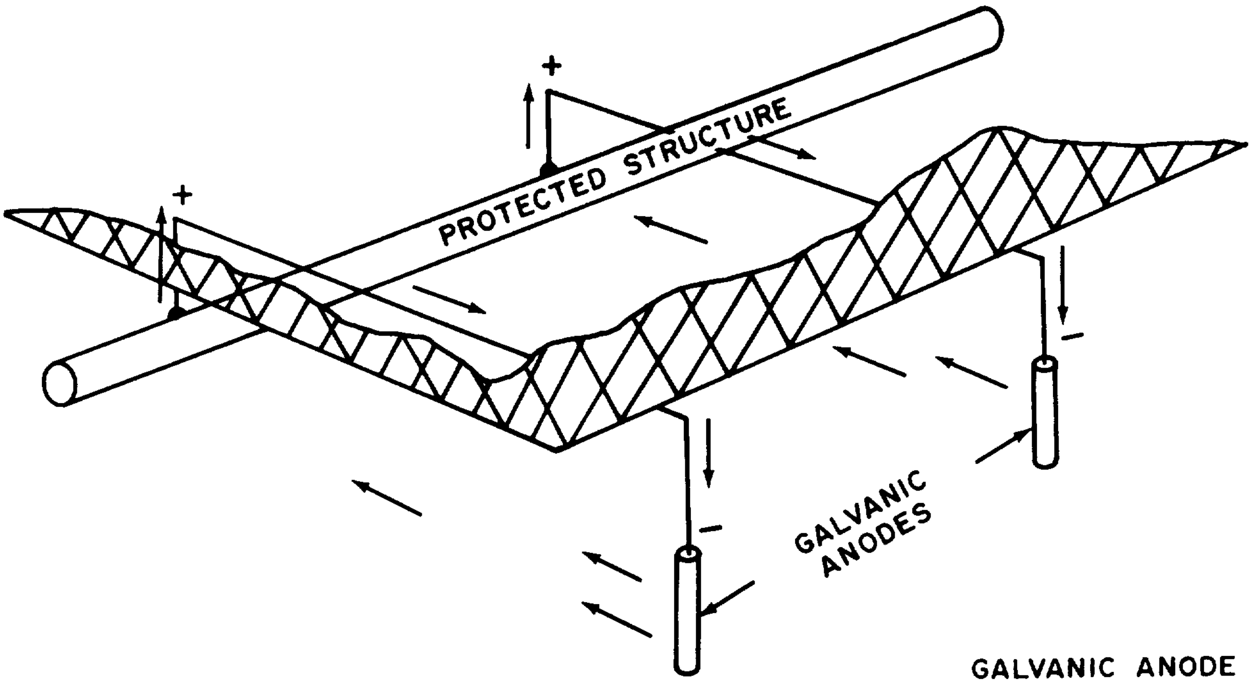
(3) Aluminum anodes are consumed at the average rate of 6.5 pounds per ampere-year. However, because of its low density, the volume of material corroded away is considerable. These anodes must be routinely replaced each year.

2-2. Galvanic Anode Systems:

a. A galvanic anode system for cathodic protection is a deliberately established corrosion cell using the protected structure as one electrode (the cathode) and a metal near to the active end of the galvanic series as the anode. Because the anode is specifically chosen to corrode away in place of the protected structure, these systems are also known as sacrificial anode systems. Figure 2-3 shows the similarity between a galvanic corrosion cell and a galvanic anode system. As in any electro-chemical cell, the electrodes must be immersed in an electrolyte (in this case, soil) and must be connected electrically through a metallic conductor. Occasionally, specific circumstances require the limiting of current flow to the protected structure as in the case of aluminum. Where this occurs, resistance should be placed inside a test station between



GALVANIC CORROSION CELL



GALVANIC ANODE
CATHODE PROTECTION
SYSTEM

Figure 2-3. Comparison Between a Galvanic Cell and a Galvanic Anode System.

the anode lead and the structure lead. Also, resistance may be used to limit current for extending the life of the anodes while achieving adequate protection. This resistance is usually a piece of nichrome wire cut to the required length.

b. Types of Anodes. Anodes for galvanic systems may be either zinc, magnesium, or aluminum alloy.

(1) Magnesium anodes are used for protecting buried pipelines and tanks, heat exchangers and chillers, large gate valves, evaporative condensers, hot water tanks, etc. They are available in many shapes and sizes as well as either bare metal or prepackaged with chemical backfill. Prepackaged anodes will be used in all underground installations where possible.

(a) Although the average corrosion rate of magnesium is 8.8 pounds per ampere-year, the actual rate of corrosion depends on various factors, such as metal composition, electrolyte variation and current output, and may be greater than 8.8 pounds per ampere-year.

(b) Magnesium anodes may be obtained in either the standard alloy or a special high-manganese alloy. Although the rates of metal loss are similar for both materials, the standard alloy anode will produce a driving voltage of about 0.70 volts with a buried iron or steel cathode while the high-manganese alloy anode will produce a voltage of about 0.90 volts with the same cathode.

(c) Replacing a standard anode with a high-manganese anode will raise the galvanic cell potential by about 28 percent and, according to Ohm's law, the current flow rate will change in the same proportion. Since the rate of metal loss varies directly with the current flow, the anode life will be reduced by 28 percent.

(d) The same rules apply when replacing a high-manganese anode with a standard anode. Because the voltage is lower by 28 percent, the life of the anode will be increased by 28 percent. However, in this case, the amount of electrical protection is reduced because (according to Ohm's law) the lower voltage reduces the current proportionately.

(2) Zinc anodes were the earliest galvanic anodes used in CPSs and they are still in widespread use today, primarily in low-resistivity areas. These anodes are available in various shapes and sizes and in two alloys: One for soil electrolytes and one for seawater electrolyte. The average corrosion rate of zinc is about 28 pounds per ampere-year. The advantage of using zinc as an anode material rather than magnesium is that zinc is more efficient (90 percent efficiency as compared to 50 percent efficiency for magnesium). In low-resistivity electrolyte (less than 2,000 ohm-cm) where high driving potential is not required, zinc anodes may be economical.

2-3. Chemical Backfill:

a. Special chemical backfill material is used to provide a uniform environment for anodes installed in earth. This backfill has the following advantages:

(1) Allows uniform deterioration of the anode material.

(2) Provides a low resistance path to earth.

(3) Allows greater current flow.

b. Several materials are used for backfill, depending on the particular situation:

(1) Galvanic Anodes. Backfill for sacrificial zinc or magnesium anodes is usually a 75 percent gypsum, 20 percent bentonite, and 5 percent sodium sulfate mixture. Sacrificial anode backfill must be installed dry and be well tamped.

(2) Impressed Current Anodes. Coke breeze, derived from coal or petroleum, is the standard material used to surround graphite or high-silicon cast iron anodes installed underground. Figure 5-2 and 5-3 show impressed current anode-coke breeze backfill installations. Material made from petroleum has a high electrical resistance and must be calcined before it can be used and is, as a result, more costly.

Chapter 3

TEST EQUIPMENT AND FIELD MEASUREMENTS

3-1. General Information. The proper operation and maintenance of any CPS requires that certain electrical measurements be made in the field. These measurements serve two purposes:

a. They tell whether the system is functioning as it was designed to function and whether it is providing adequate protection.

b. They disclose both sudden and long-term changes in electrical flow through the system in order to furnish clues to the physical state of anodes, operating condition of rectifiers, and changes in the electrical characteristics of the protected and nearby structures.

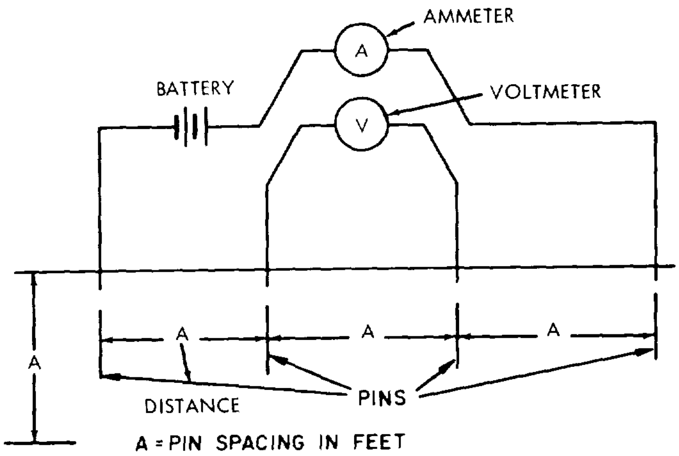
3-2. Types of Measurements. The basic types of electrical measurements made are measurements of potential voltage (volts), current (amps), resistance (ohms, and resistivity (ohm-cm).

a. **Potential Measurements.** Measurements of potential are made to determine the effectiveness of the CPS. Three types of measurements are made: Direct measurement of applied voltage (across the output terminals of a rectifier), structure-to-electrolyte, and structure-to-structure potential measurements. Direct measurement of applied voltage and structure-to-structure potential measurements are familiar procedures and require no background discussion in this manual. Structure-to-electrolyte potentials, however, are generally unknown to operating personnel. Therefore, an understanding of the electrical principles involved is necessary to make sure that the measurements are accurate and furnish a true picture of conditions as they actually exist. Structure-to-soil potential of a buried pipeline is determined by measuring the voltage with a standard copper-copper sulfate half cell. The measured potential is said to be "referred to a copper-copper sulfate half cell." Other types of half cells are available, however, in actual practice, they are almost never used.

b. **Current Measurements.** The measurement of current output is used to determine the operating condition of anodes and rectifiers and to make sure that sufficient current is being applied to the protected structure.

c. **Resistance and Resistivity Measurements.** The ability of soil or water to conduct electricity is closely related to the rate at which buried or immersed structures will corrode. The lower the resistance to current flow the higher the rate of corrosion. The practical measure of the ability of a material to resist the flow of electricity is known as resistivity. Resistivity is defined as the resistance in ohms between opposite faces of a 1-centimeter cube of material.

(1) Soil resistivity is found by measuring the current flow through a specified section of earth, determining the voltage drop across all or part of the earth under test and using these measured values to calculate the resistivity by formula. Figure 3-1 shows the basic circuit used for this determination.



CIRCUIT MEASURES THE AVERAGE SOIL RESISTIVITY TO A DEPTH OF 'A' FEET IN OHM CENTIMETERS AFTER CALCULATION

Figure 3-1. Basic Soil Resistivity Circuit.

The resistivity (P) is calculated from the formula:

$$P = \frac{191.5\ AE}{I}$$

Where: P = Resistivity in ohm-centimeters.
A = Pin spacing in feet.
E = Voltage drop between pins in volts.
I = Current flow in amperes.

This calculation will give the average soil resistivity down to a depth about equal to the pin spacing. By changing the pin spacing, the resistivity to other depths can be determined.

(2) Polarization and galvanic effects between the electrodes may cause errors in the calculated resistivity when only one DC measurement is made. These effects may be eliminated by reversing the DC leads and averaging the results, or by using AC measuring equipment. Commercial earth resistivity meters use AC for this reason.

(3) Water resistivity is usually determined by calculation from its inverse characteristic, conductivity. Conductivity is the ability of a material to conduct electricity and is numerically equal to the reciprocal of the resistivity. The basic unit of conductivity is mhos per centimeter, but most water analyses report conductivity in millionths of mhos (or micromhos) per centimeter. The conductivity of every domestic water supply used by the Air Force is reported as part of the water analysis done by the Occupational and Environmental Health Laboratory, Brooks AFB TX. This analysis is done annually for surface supplies and every three years for ground supplies. The bioenvironmental engineer assigned to the base hospital keeps the reports for 10 years.

(4) The calculation of resistivity from a known value of conductivity is a simple one. For example:

Assume a water with a reported conductivity of 200 micromhos/cm (.000200 mho/cm).

R_w = Resistivity (ohm-cm)
C = Conductivity (mho-cm)

$$Rw = \frac{1}{C}$$

or

$$Rw \quad \frac{1}{0.000200} \quad =$$

R = 5000 ohm-cm.

3-3. Potential Surveys and Leak Detection. One of the many benefits from determining structure potentials is that of pinpointing possible leak locations, such as those on a gas pipeline system. While many leaks are found and repaired, there are a significant number of leaks that are not located without extensive excavation and pipe damage. Measuring the structure-to-electrolyte (soil) potentials, tests are conducted over the structure at equally spaced intervals, such as 25 or 50 feet. This information will indicate, by variation in potential readings, where the structure is most likely to corrode. On an unprotected (non cathodic protection) structure, this would be where the greatest negative values with respect to a copper-copper sulfate half-cell electrode are located. Upon selecting these areas, a resurvey of the structure is made at closer intervals to pinpoint the most corrosive area. While this method is not always 100 percent successful, it is a valuable tool under most circumstances.

3-4. Instruments and Equipment:

a. The electrical measuring instruments used in cathodic protection testing are usually just variations of commonly used devices. CPSs are characterized by relatively low voltages and high current flows which means that the system, as a whole, has a low resistance. Under those conditions, the insertion of an electrical instrument into the system can alter it enough to change the electrical measurement itself. For example, assume a sacrificial anode has a potential, with respect to the protected structure, of 1.5 volts and a total cell resistance of 2 ohms. Ohm's law indicates:

$$I = \frac{E}{R} \qquad \frac{1.5}{2} = 0.75 \text{ ampere}$$

If an ammeter having a resistance of even 1 ohm is inserted into the system, the resistance seen by the cell is increased a full 50 percent to 3 ohms. Again, applying Ohm's law:

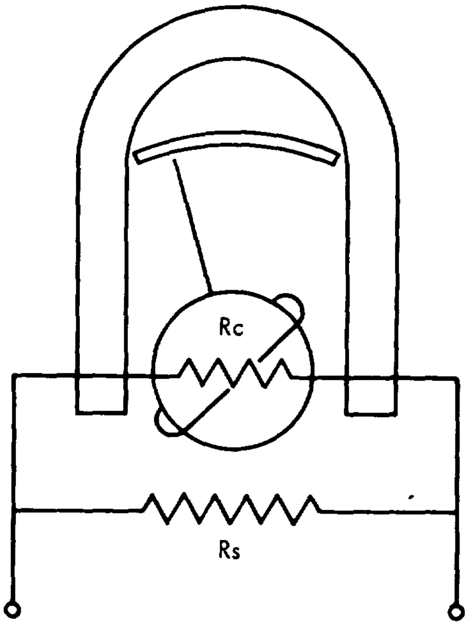
$$I = \frac{E}{R} \qquad \frac{1.5}{3} = 0.50 \text{ ampere}$$

Therefore, while the actual current flow from the structure to the anode is 0.75 ampere, simply placing the meter in the circuit has changed the circuit and reduced the flow enough to make the meter read only two-thirds of the actual flow. It is apparent then, that an ideal ammeter would have no resistance. Conversely, the nature of voltmeters and voltage measurements is such that the ideal voltmeter would have an infinite resistance.

b. In practice, low-resistance ammeters and high-resistance voltmeters are used for many measurements with satisfactory results. However, two instruments are available which have no electrical effect on the circuit being tested. The potentiometer-voltmeter draws no current from the circuit under test and the zero-resistance ammeter, in effect, introduces no resistance into the circuit under test.

3-5. Ammeters. The term "ammeter" includes all current measuring meters used in cathodic protection, including microammeters and milliammeters. The ammeter, as used in the field, is a voltmeter with a calibrated resistor, known as a shunt, assembled in one unit. Electrically, the unit is as shown in figure 3-2 where Rc is the internal resistance of the meter movement and Rs is the resistance of the shunt. When measuring a current that is greater than the capacity of an ammeter, an external shunt and a high-resistance voltmeter should be used. The voltmeter leads should be connected to the shunt to measure the voltage drop caused by current flow through the shunt.

3-6. Voltmeters. A voltmeter consists of a galvanometer connected in series with a resistor as shown in figure 3-3. The galvanometer measures the current flowing through the meter circuit. As long as the resistance of the meter circuit (Rc + Rs) is known and the current is determined by the meter, the voltage across the meter terminals can be calculated using Ohm's law (E = IR).



Rc = INTERNAL RESISTANCE OF THE MOVEMENT

Rs =RESISTANCE OF THE SHUNT

Figure 3-2. Ammeter Circuit.

Since the resistance of the meter unit remains constant and the circuit is exactly proportional to the applied voltage, the usual practice is to calibrate the meter scale directly in volts.

a. Sensitivity is a measure of the current used by a voltmeter in reaching full-scale deflection. Since the current required is proportional to the resistance of the meter unit, sensitivity is expressed in ohms per volt of full-scale deflection. A meter with a total resistance of 200 ohms and calibrated to read 2 volts, has a sensitivity of 100 ohms per volt. A meter reading 150 volts at full scale and having a total resistance of 3 megohms (3,000,000 ohms) has a sensitivity of 20,000 ohms/volt. Generally, instruments with sensitivities of 10,000 ohms per volt or more are classified as high-sensitivity instruments, and those with sensitivities below 10,000 ohms per volt as low-sensitivity instruments.

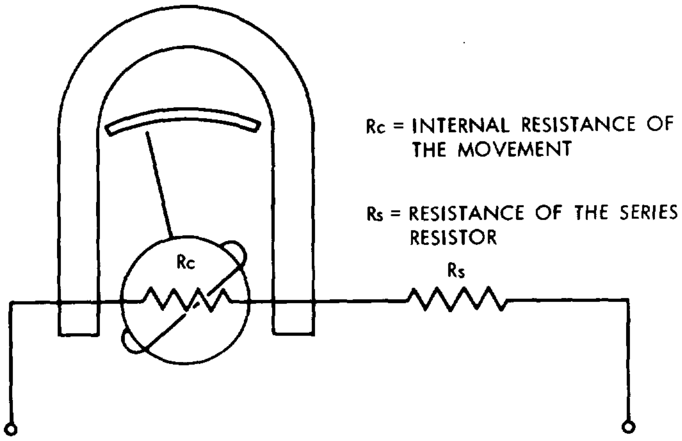


Figure 3-3. Voltmeter Circuit.

b. Generally, low-sensitivity voltmeters are not suitable for cathodic protection work because they draw too much current, affect the electrical characteristics of the circuit, and give erroneous readings. Very-high-sensitivity instruments have very high resistance and thus little or no significant effect on the circuit being measured. This is important in cathodic protection testing.

3-7. Specialized Instruments. Because of the unusual electrical characteristics of CPSs and underground corrosion, certain specialized instruments have been developed and adopted for use.

a. **Potentiometer-Voltmeter.** The potentiometer-voltmeter is a device for measuring voltage without drawing any current from the circuit being tested. In this device, an internal (battery) source of voltage is balanced against the external voltage being measured using a galvanometer to determine the point of exact balance (zero current) and a voltmeter to measure the balancing voltage. The circuit diagram is shown in figure 3-4. The potentiometer-voltmeter actually uses its internal current source to drive the voltmeter and uses the galvanometer as a sensitive means of determining the zero-current point or "null". The standard potentiometer-voltmeter used by the Air Force is a portion of the Miller Model M-3-M "multi-combination meter" shown in figure 3-5. This instrument includes a potentiometer-voltmeter, a high-resistance voltmeter, a low-resistance voltmeter, and an ammeter.

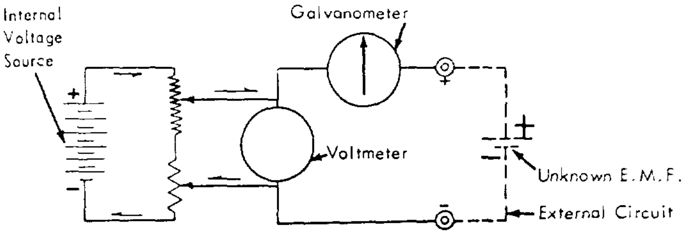


Figure 3-4. Potentiometer-Voltmeter Circuit.

b. Earth Resistivity Meter. The earth resistivity meter is a device for determining soil resistivity directly without complicated calculations. The instrument uses the rule discussed in paragraph 3-2c and reads either in ohms or in a fraction (one-tenth, one-hundredth, etc.) of the actual value.

(1) The standard Air Force-supplied earth resistivity meter is the Vibroground instrument. A schematic diagram of this instrument is shown in figure 3-6. This is an AC instrument using a vibrator and transformer to convert battery supplied DC to AC. This instrument passes an AC from terminals C1 and C2 through the earth.

(2) The potential or IR (current times resistance) drop is measured between terminals P1 and P2. The potentiometer is calibrated to read directly in ohms, and use of a simple factor dependent on the pin spacing will give the soil resistivity in ohm-centimeters.

c. **Half Cells.** The standard reference electrode for cathodic protection work is the copper-copper sulfate half cell.

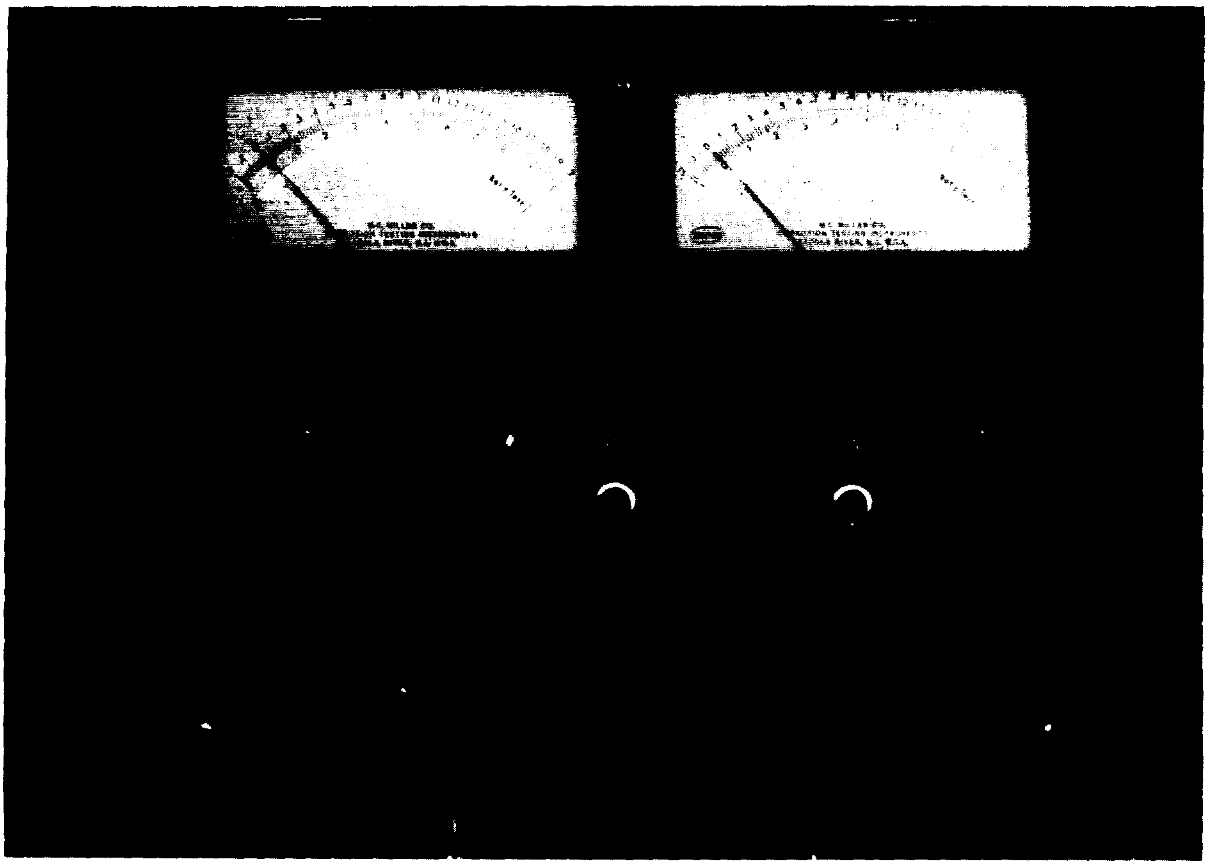
(1) There are several types of copper-copper sulfate half cells in use, differing in construction details only. The most common type is shown in figure 3-7. The copper electrode is immersed in the copper sulfate electrolyte and the electrical connection is made by clipping onto the threaded portion of the copper rod.

(2) To reduce evaporation of the electrolyte solution, the porous plug of the cell is covered with a removable rubber cap or crutch tip when the cell is not in use.

d. **Pipe Locators.** Pipe locators are electronic instruments which can locate buried iron or steel structures. Two systems are used, inductive and conductive, both of which use a transmitter and receiver combination.

(1) In the inductive system, the operator moves both the transmitter and receiver over the surface of the ground. The transmitter radiates energy (similar to a radio transmitter) into the ground, and the receiver detects disturbances in the pattern of energy caused by iron structures in the ground.

(2) In the conductive system, the transmitter is connected to the structure being traced, and the receiver alone is moved over the ground surface. In this situation, the receiver picks up the signal being transmitted through the structure itself.



HIGH-RESISTANCE VOLTMETER	0.2 to 20 VOLTS
POTENTIOMETER-TYPE VOLTMETER	0.2 to 3 VOLTS
LOW RESISTANCE VOLTMETER	2 MV to 100 VOLTS
MILLIAMMETER/AMMETER	2 MA to 10 AMPERES

Figure 3–5. Multi-Combination Meter.

(3) Inductive operation is used where only one structure is being traced or where no part of the structure is available for electrical connection to the transmitter. Conductive operation is used where several structures are buried and it is necessary to trace the location of one specific structure. For example, if it is necessary to locate a water main crossing an isolated airfield clear zone, and no other buried structures are near, inductive operation should be used. If it is necessary to trace the location of a gas main in an area where water lines, communication cables, and even petroleum, oils, and lubricants (POL) lines are also located, it is better to use conductive operation to avoid picking up the wrong pipe where lines cross or run close together.

(4) If the systems are electrically connected, either deliberately as a cathodic protection measure or accidently where they cross, or are connected to the same appliance, even conductive operation will not allow one system to be distinguished from the other.

3–8. Field Measurements. Field measurements of potential, current, and resistivity provide the information needed to determine the actual operating condition of a CPS or to determine if cathodic protection is needed on an unprotected system. Measurement of the rectifier output (both voltage and current) is a familiar procedure. However, the actual techniques of measuring structure-to-electrolyte and anode-to-electrolyte potentials and anode-to-structure currents, using test stations and soil resistivities are not so familiar. Attachment 13 contains procedures for testing pipeline casings.

3–9. Structure-To-Electrolyte Potentials. The structure-to-electrolyte potential is one of the most important measurements made in cathodic protection. The basic arrangement of components is shown in figure 3–8. The negative terminal of a voltmeter is connected to the structure and the positive terminal to the electrode of a copper-copper sulfate half cell. The potential is indicated

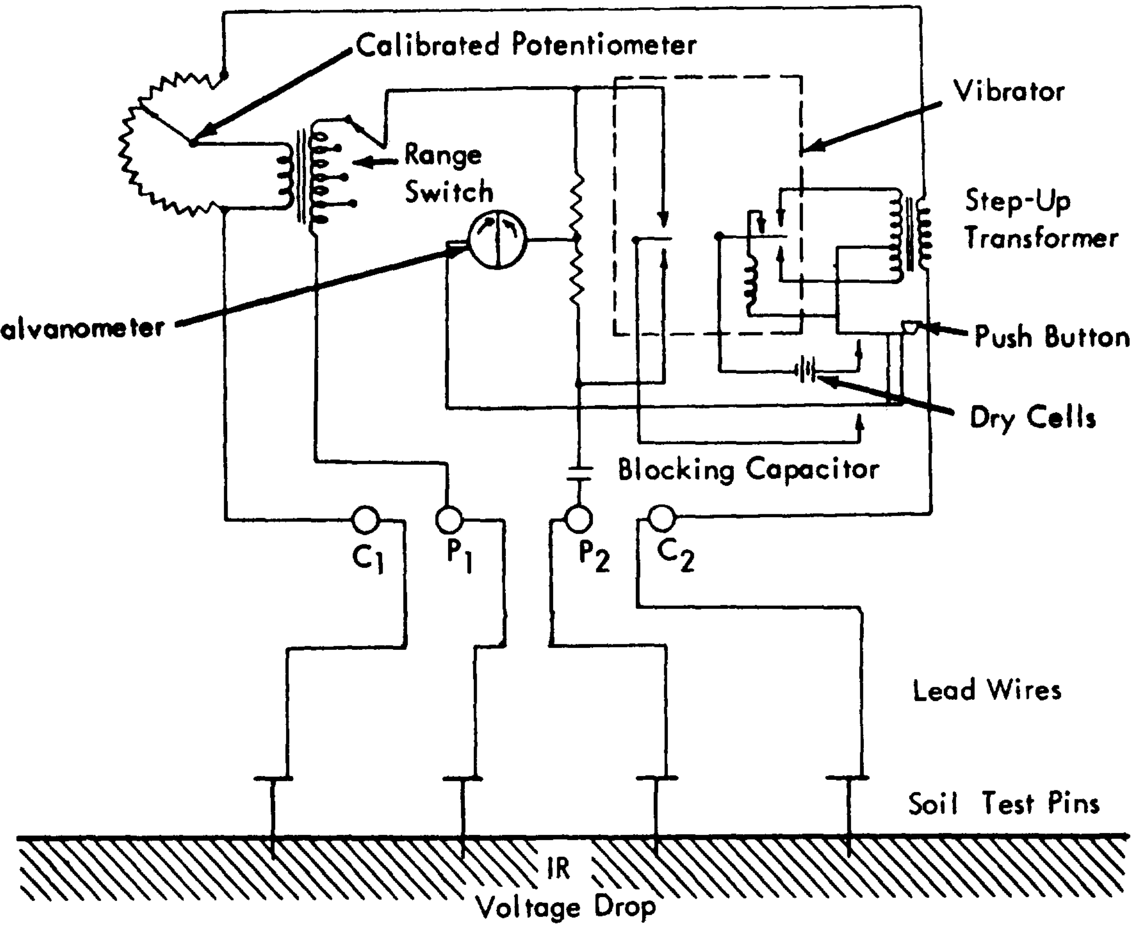


Figure 3-6. Schematic Wiring Diagram of a Vibrator Type Soil Resistivity Meter.

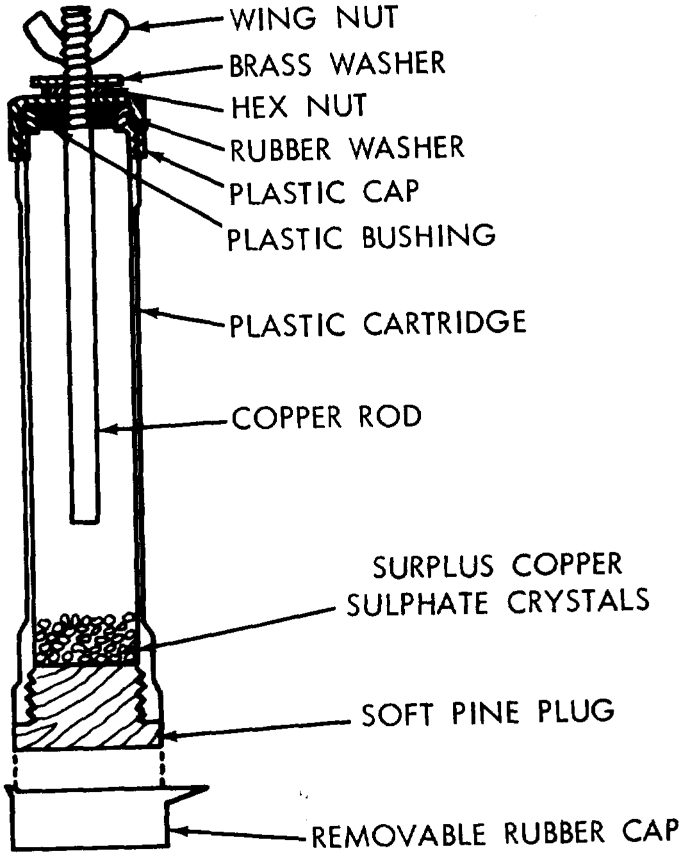


Figure 3-7. Copper-Copper Sulfate Reference Electrode.

by the voltmeter. This potential value will tell the operator whether the structure is adequately protected at the point of test. (Iron and steel structures are adequately protected at a potential of − 0.85 volts or more negative.) Any sudden changes in potential indicate either some outside influence (such as stray current) or a change or failure in the CPS.

a. It is important to make sure that good contact is obtained between the components of the circuit. Any high-resistance connection will cause erroneous readings to be taken. The operator must be certain that the porous plug of the reference half cell is in contact with moist earth (or water in a tank), and that a solid metal-to-metal contact is made between the structure and the test lead to the voltmeter. With soil electrolytes, it may be necessary to scrape down to moist earth or even to dampen the soil with water. Test prods or clips should be wiggled on the metal surface to penetrate any dirt or oxide coatings. In survey work, it is desirable that structure-to-soil readings be taken with the reference half cell directly over the structure to be tested.

b. Connection to buried structures being tested is sometimes difficult. A list of possible points of electrical contact are:

(1) Cathodic protection test stations.
(2) Water or fuel hydrants.
(3) Exposed service entrances.
(4) Meter installations.
(5) Valve bonnets.

c. It is also important to be sure that the electrical contact is properly made to the structure. Two common causes of trouble are making contact to the pipeline on the wrong side of an insulated bushing or union and to a valve stem which is insulated from the valve body by packing or seating materials.

d. Sometimes it is necessary to make contact with a buried structure at a point where there is no exposed place of connection. If it can be absolutely determined that the structure is bare, contact may be made by probing down with a steel bar. Under no circumstances should coating be damaged by steel bar probing. Electrical contact with exposed structures such as tanks, sheet piling, or exposed pipelines poses no difficulties, but good metal-to-metal contact must be assured.

e. Where two structure wires are available, always use the wire that is not carrying current.

3-10. Anode-To-Electrolyte Potentials. The anode-to-electrolyte potential provides an indication of which lead wire is attached to the anode. Also, by moving the half cell reference electrode, the location of the buried anode may be pinpointed. An abnormally low potential of anode-to-electrolyte may indicate a severed lead wire or a dispersed anode.

a. The measurement of anode-to-electrolyte potential is usually possible only at cathodic protection test stations. This measurement is not necessary where the anode can be physically inspected, as in a water tank or along a wharf.

b. This measurement is made with exactly the same electrical connections as for measuring structure-to-soil potential. The positive terminal of the voltmeter is connected to the reference half cell electrode and the negative terminal to the anode under test. When measuring at a test station, connect the negative meter lead to the appropriate terminal to measure either structure or anode potential.

3-11. Anode-To-Structure Current. The ability of a CPS to do its job is directly related to the amount of current which passes from the anode to the structure. If the current decreases or stops, the amount of protection decreases or stops in direct proportion. A record of anode-to-structure current gives an indication of the level of protection provided to the system by the anodes under test.

a. This measurement is made by inserting an ammeter into the conductor between the anode and the protected structure. In a sacrificial anode system, this requires physically breaking into the anode-to-structure connecting lead. In an impressed current system, the electrical connections are similar, except that the meter shunt is usually permanently connected into the circuit and it is only necessary to connect a millivoltmeter across the shunt.

b. As in all DC measurements, it is necessary to observe the correct polarity and start at the highest range of the instrument in order to prevent overloading and damage to the meter.

3-12. Test Stations. Cathodic protection test stations are simply leads which are brought to the surface of the ground or to some other easily accessible place so that

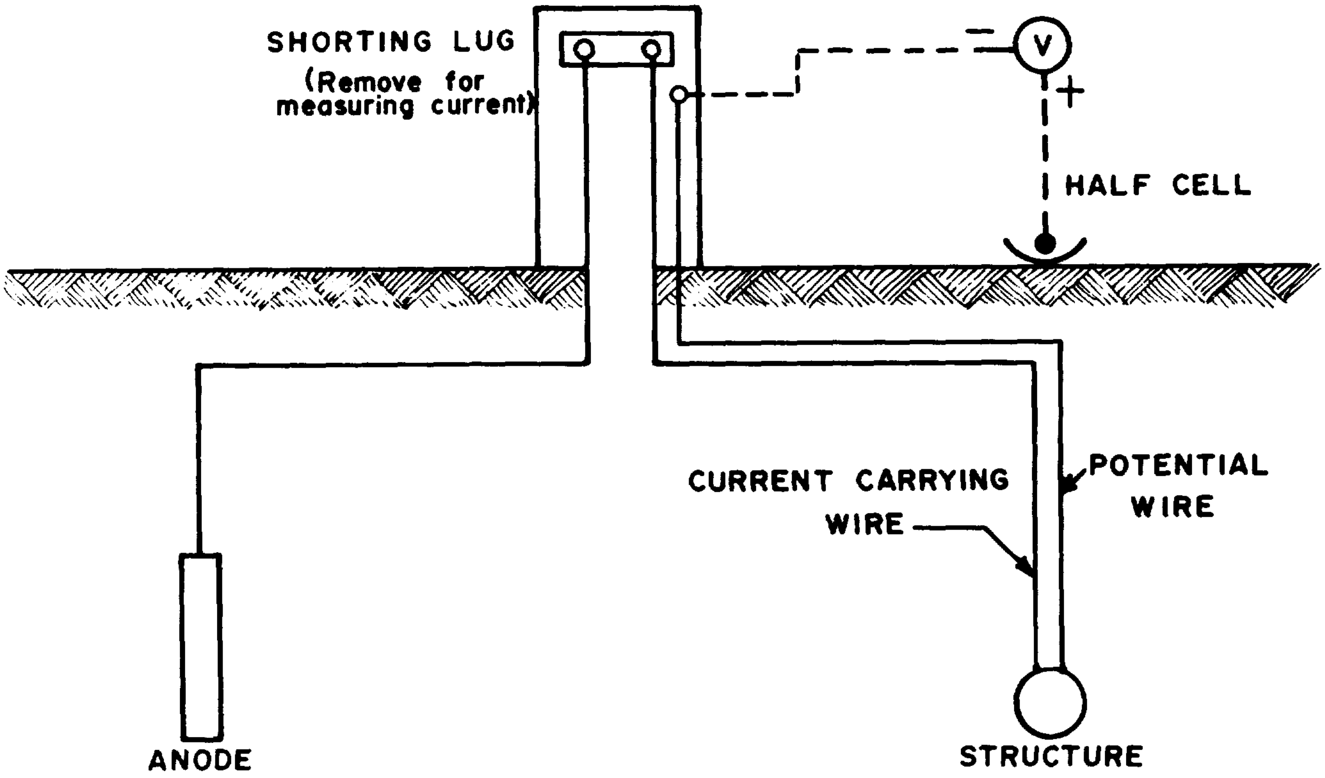
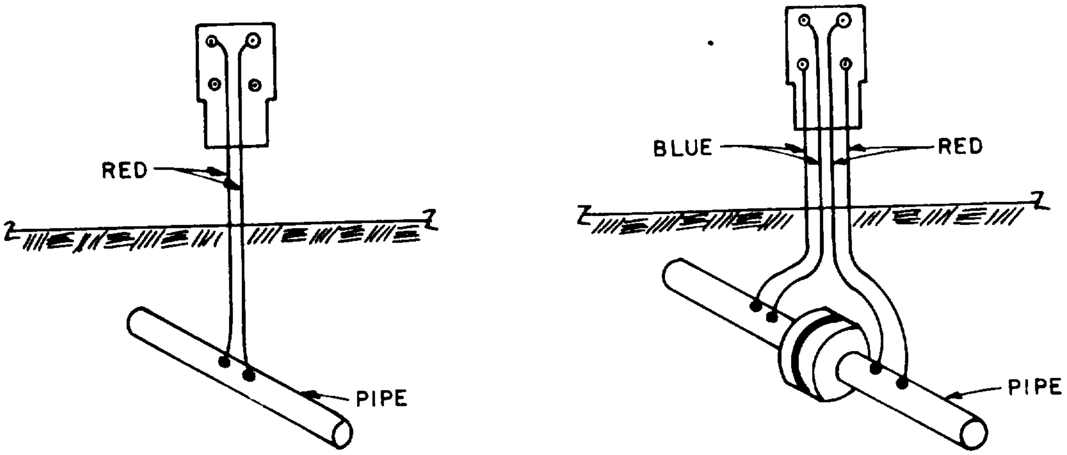


Figure 3-8. Surface Type Potential-Current Station.

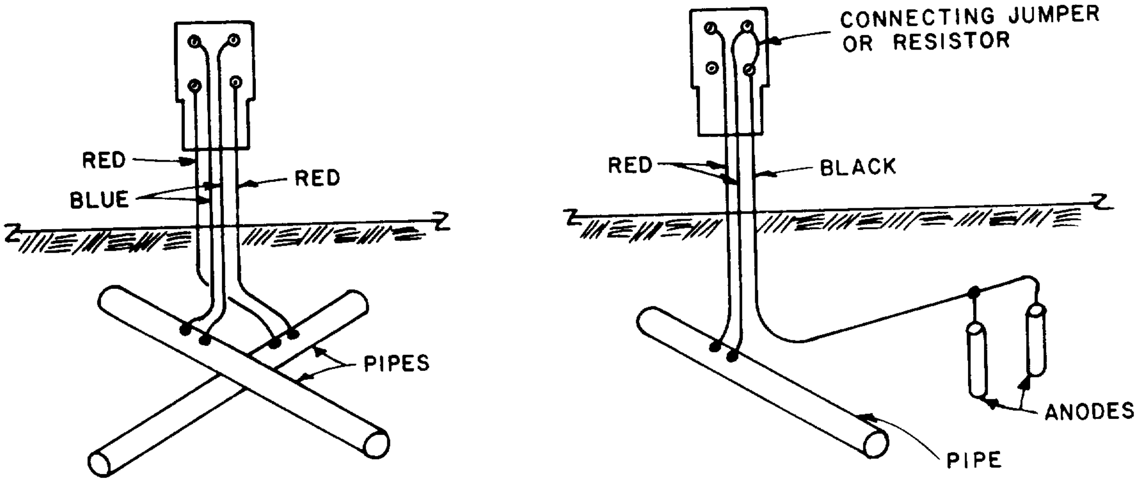


POTENTIAL TEST STATION

A

INSULATING JOINT TEST STATION

B



LINE CROSSING TEST STATION

C

GALVANIC ANODE TEST STATION

D

NOTE: All leads must be No. 10 AWG, Type TW, THW, RHW, THWN, XHHW, or USE insulated.

Figure 3–9. Test Station Connections.

electrical measurements may be made conveniently. There are two basic types of stations, subsurface and surface. Since the use of the test stations usually requires making a physical disconnection between the anode and the structure, it is extremely important to make sure that the connection is properly restored at the completion of the testing. Where shorting lugs are used, be sure that the nuts or screws holding the lugs in place are firmly snugged down and that a good metal-to-metal contact is made. Where sacrificial anodes are involved, test leads should be terminated on terminals. Various test stations encountered are shown in figures 3-9 through 3-15.

3-13. Soil Resistivity. The basic circuit for the measurement of soil resistivity is shown in figure 3-1. While resistivity measurements can be made using a voltmeter and ammeter as shown, most resistivity measurements are made using the Vibroground instrument described in paragraph 3-7b, and diagrammed in figure 3-6. Figure 3-16 shows how the instrument is connected in the field to soil probes or pins. The Vibroground instrument reads directly in ohms. The soil resistivity is calculated from the formula:

$$P = \frac{191.5\,AE}{I} \text{ (see paragraph 3-2c(1)).}$$

$$\text{Or } P = 191.5\,AR.$$

Where A = pin spacing in feet.

R = instrument reading in ohms.

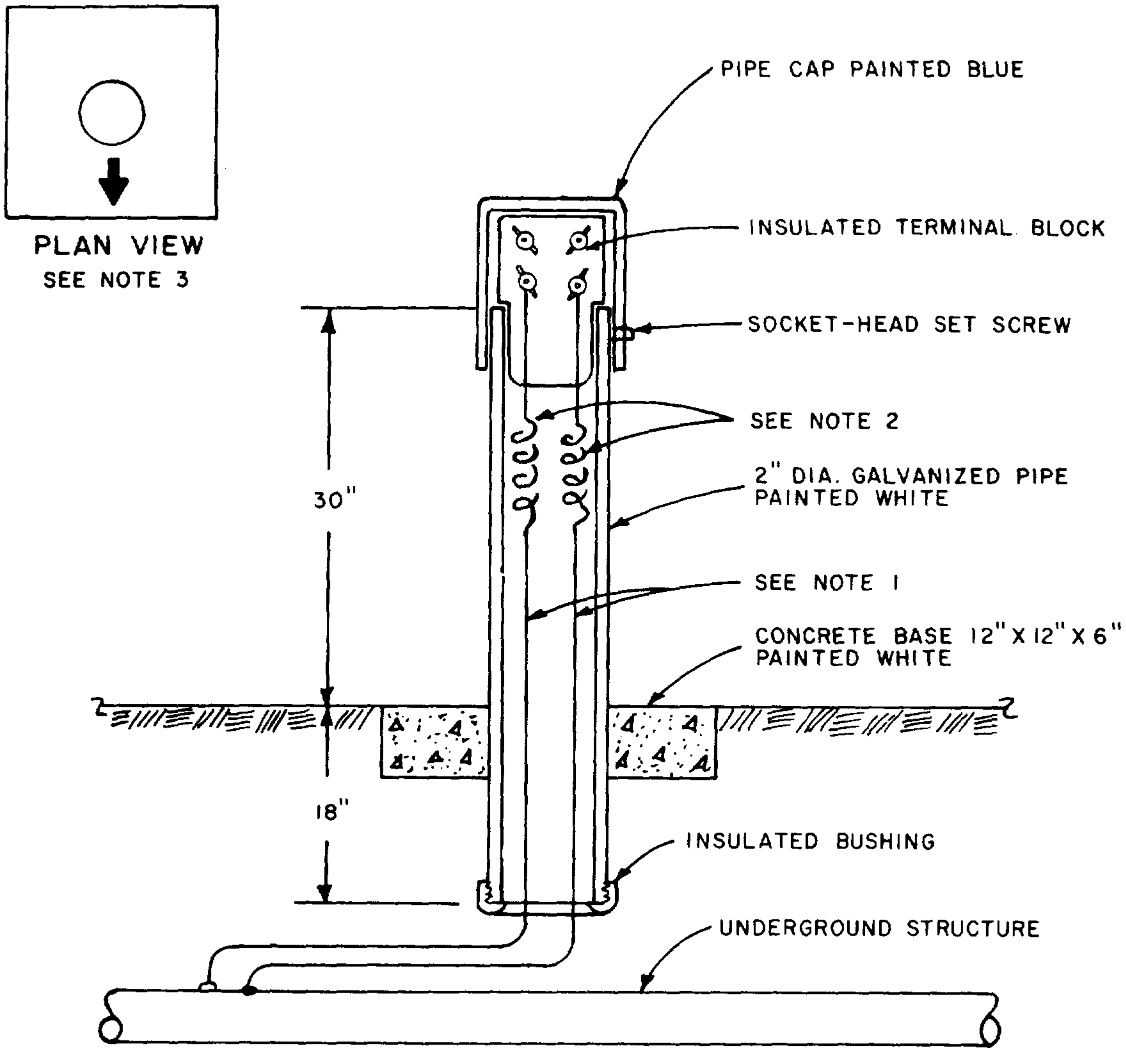
The formula may be further simplified to:

$$P = KR.$$

Where K = 191.5A

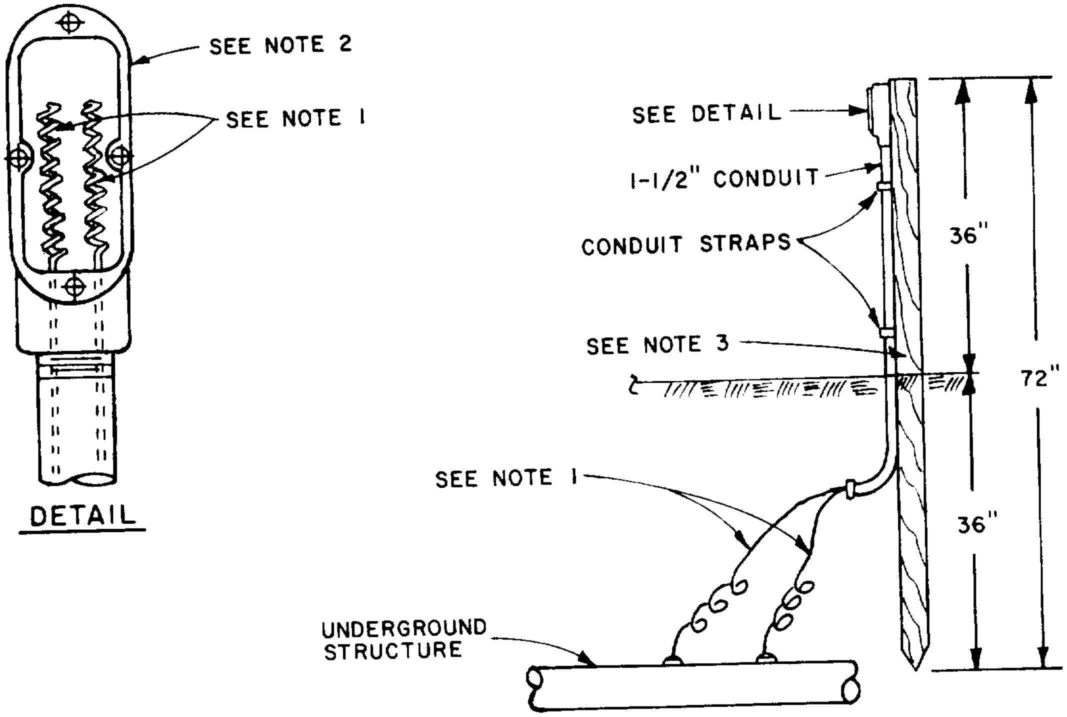
A table of K values follows:

K Factors for Measuring Soil
Resistivity
P = KR



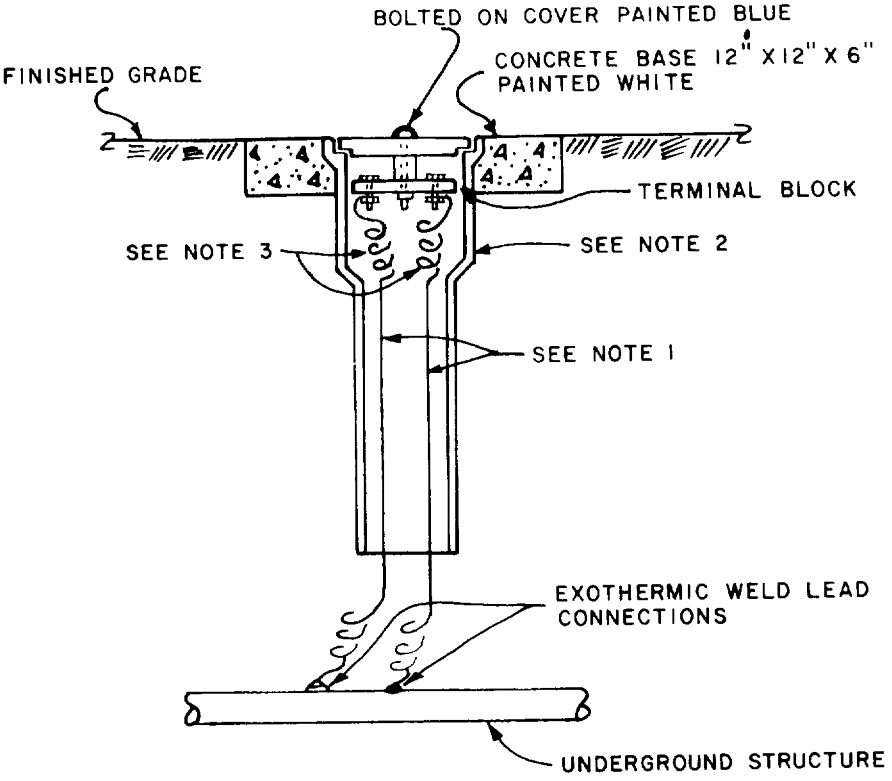
NOTES:
1. Provide two test leads unless otherwise indicated.
2. Leave sufficient slack in leads to allow removal of the terminal block.
3. Inscribe an arrow in concrete base pointing in the direction of buried structure.

Figure 3-10. Test Station—Aboveground for Potential Measurements.



NOTES:
1. Provide two test leads, color coded red.
2. Test station box must be complete with gasket and cover.
3. Wood post must be 4" x 4" x 6' long, treated.

Figure 3-11. Test Station—Aboveground for Potential Measurements.



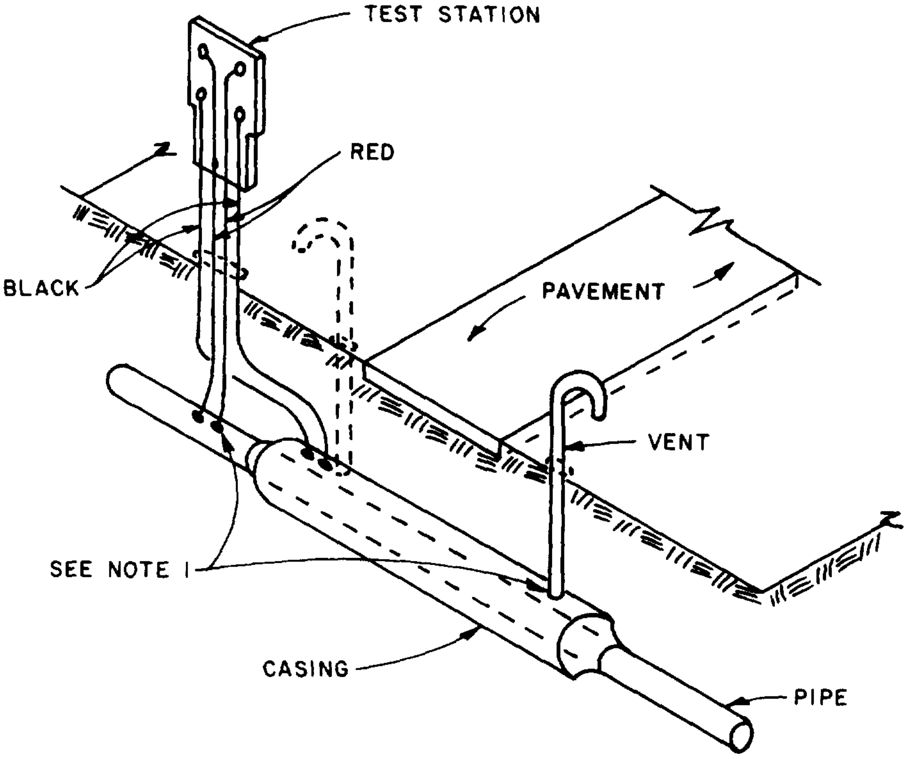
NOTES:
1. Provide two test leads, color coded red.
2. Curb box must be a standard product and may be made of cast iron or plastic. The box must be complete with two or more contact terminal strips bolted to cover and ready to receive the test leads.
3. Leave sufficient slack in leads to allow removal of the cover for testing.

Figure 3-12. Test Station—Flush Mounted for Potential Measurements.

Normal Pin Spacing	*Actual Pin Spacing*	*K Values*
2'6"	2'7"	500
5'0"	5'3"	1000
7'6"	7'10"	1500
10'0"	10'6"	2000
15'0"	15'9"	3000

Resistivity is simply calculated by multiplying the instrument reading by K from the table. A commonly used pin spacing is 5 feet 0 inches so that K = 1,000.

3-14. Potential Measurements of Facilities Under Pavement. It has been discovered that past methods of measuring structure-to-electrolyte potentials of metallic facilities (pipelines, tanks, metallic sheath cables, etc.) under pavement, using a reference electrode in contact with the pavement, will result in appreciable error. The most efficient way of getting accurate measurements is to install a permanent pavement insert with a removable plug that will allow insertion of a reference electrode. These inserts should be installed in the pavement at points where metallic facilities cross and at least every 100 feet along the route of metallic pipelines or cables. Figure 3-17 shows a typical installation of a 1⅝-inch plastic insert with a three-fourths of an inch removable cadmium-plated plug. A copper-copper sulfate reference electrode that will easily fit through the hole in the pavement insert is commercially available. The hole beneath the pavement insert should be filled with sand to within 4 inches of the top of the pavement insert to allow the 5¾-inch long and three-eighths of an inch diameter reference electrode to make contact with the sand. If measurements must be taken immediately after adding sand, a small amount of water should be poured into the hole before taking potential measurements with the proper voltmeter. For future measurements, the sand will absorb enough moisture from the surrounding media so that accurate measurements can be made without adding water if a potentiometer-voltmeter circuit or a voltmeter having at least 10 megohm internal impedance is used.



NOTES:
1. If the casing has two vents aboveground, the casing leads may be omitted. If only one vent is provided, both leads must be provided and connected to the unvented end. If no vents are provided, connect the black casing leads to the far end of casing. In any case, red leads must be installed on the carrier pipe.
2. All leads must be No. 12 AWG, type TW, THW, RHW, THWN, XHHW, or USE insulated.

Figure 3-13. Cased Roadway Crossing.

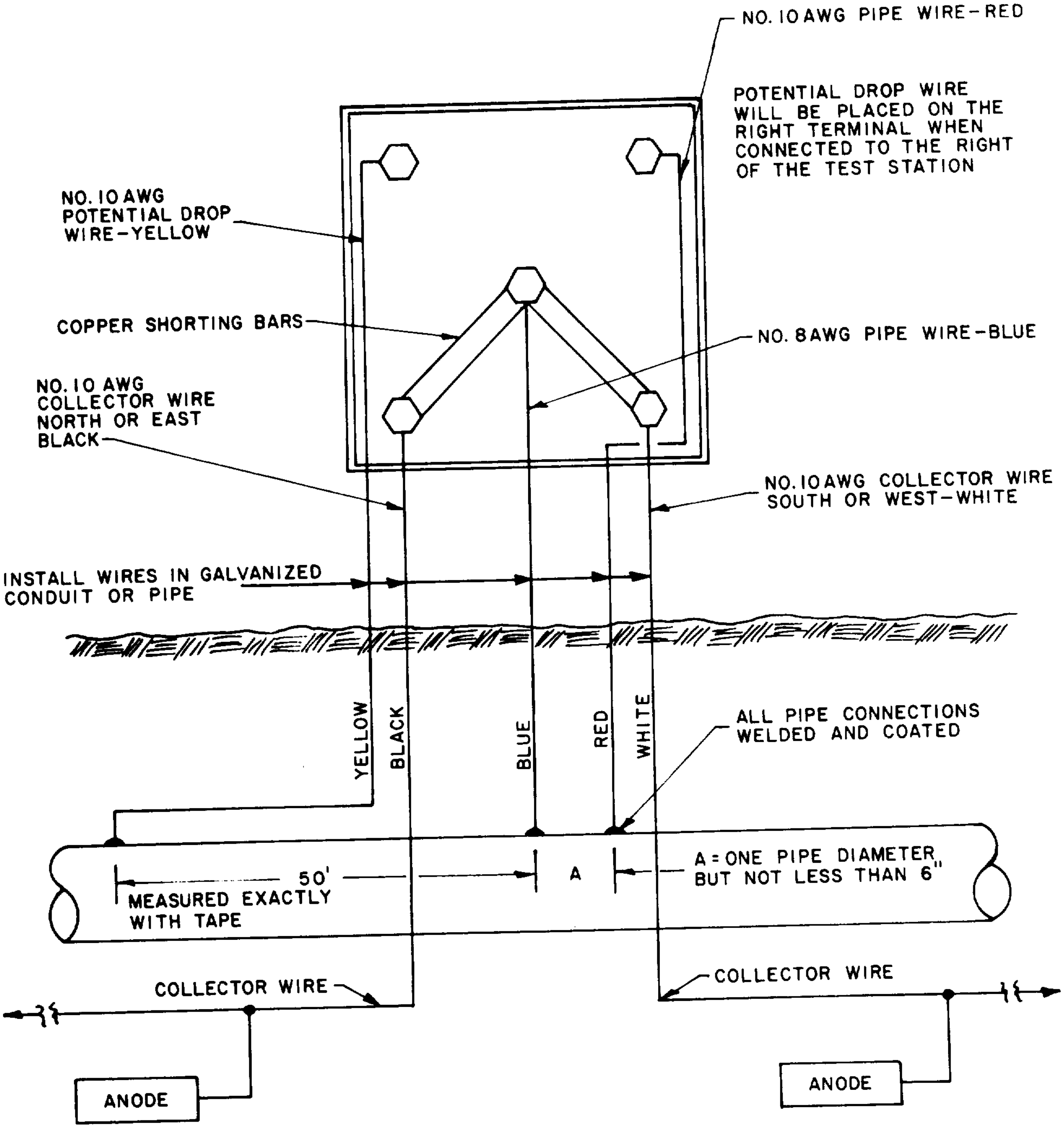


Figure 3-14. Test Station for Continuous Collector Wire.

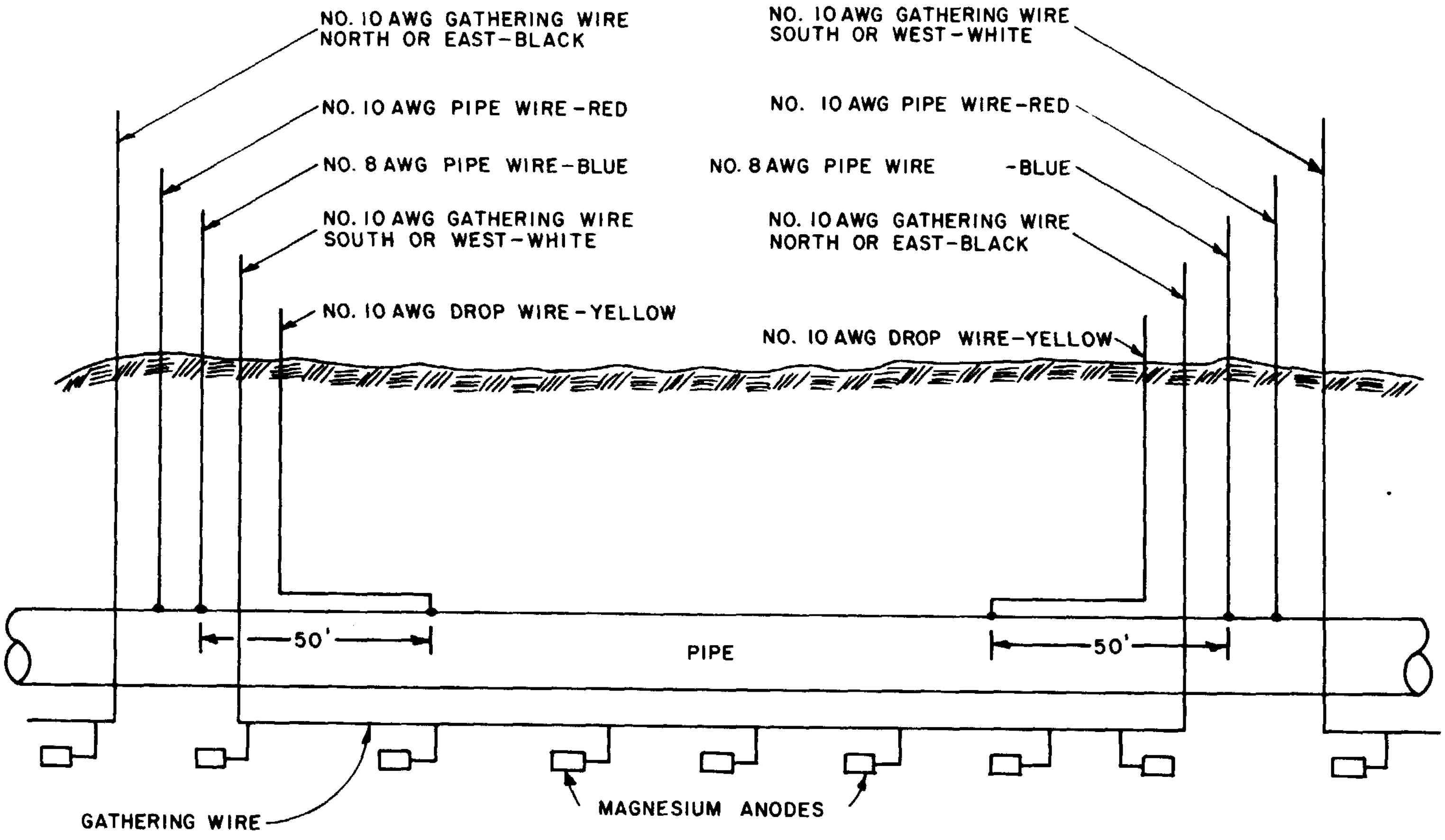
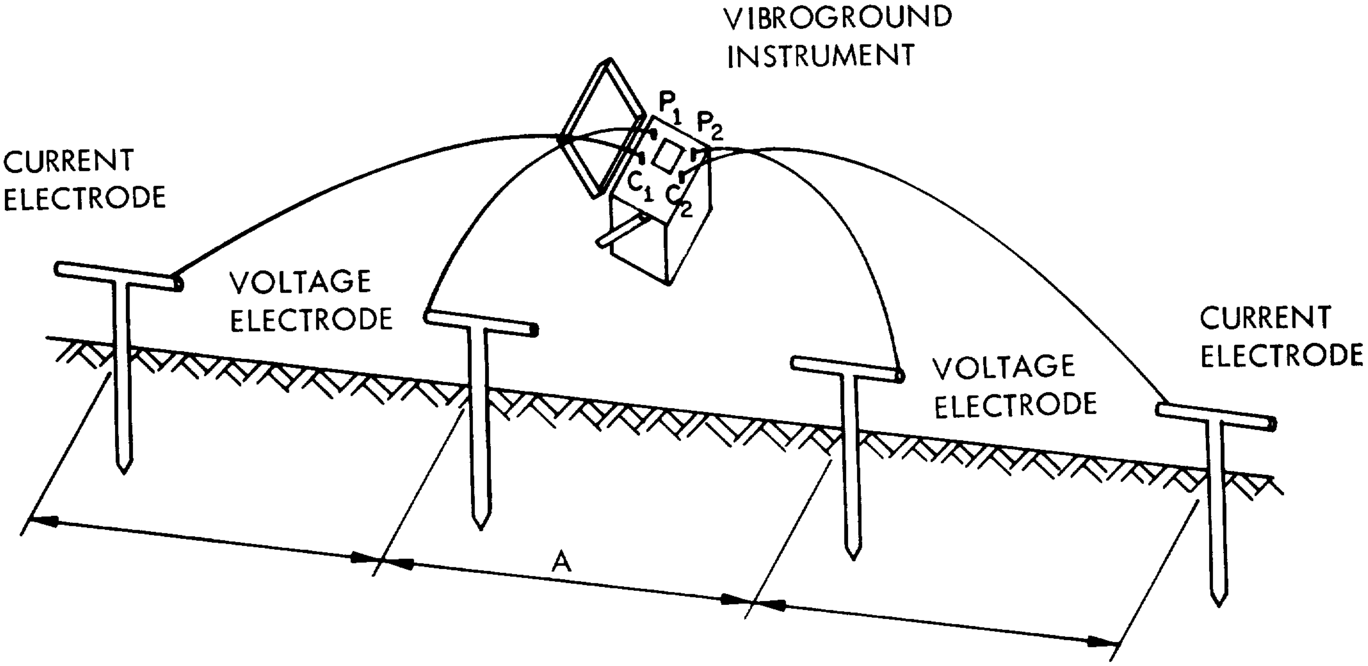
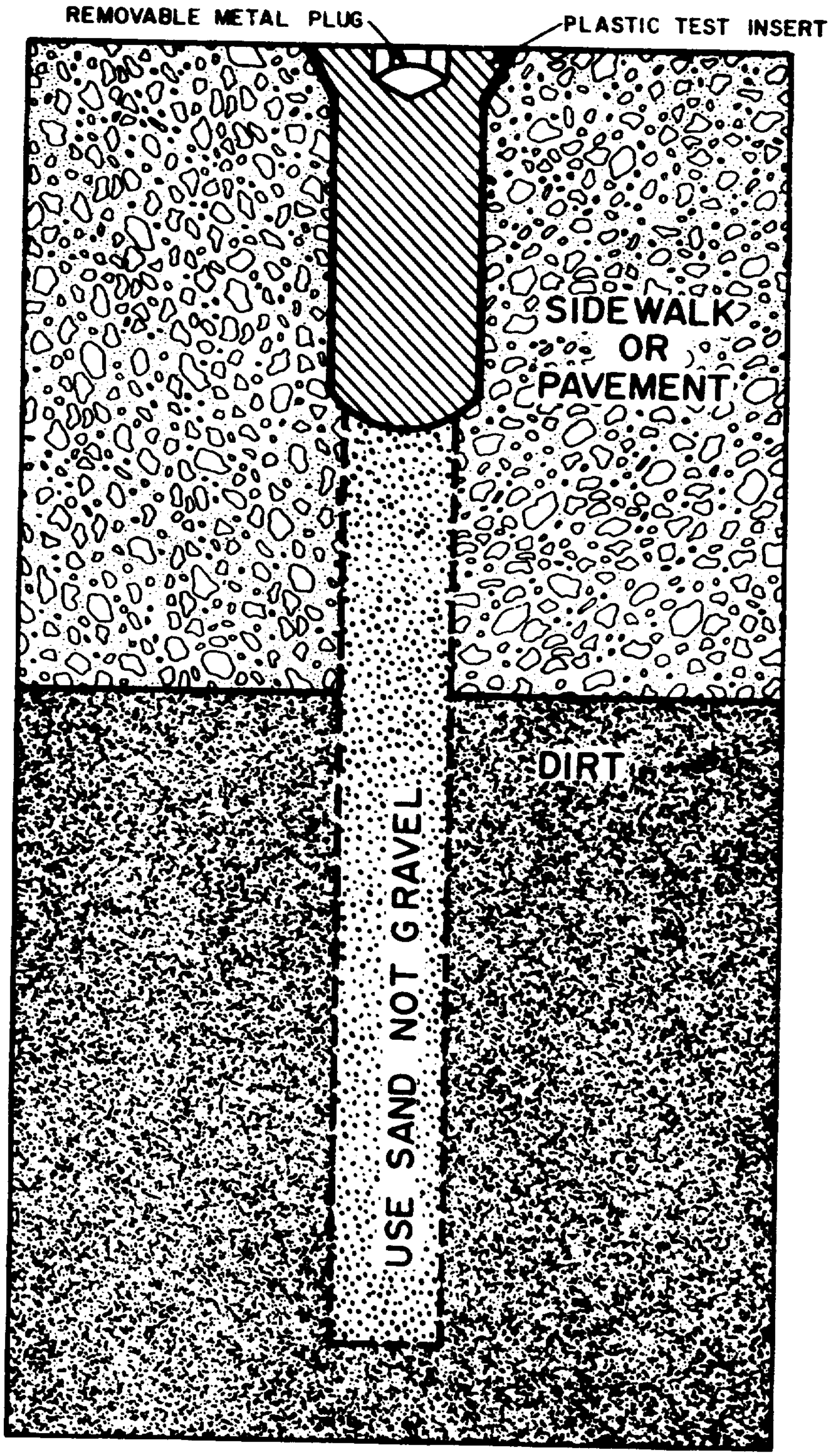


Figure 3-15. Test Station Connections for Continuous Gathering Wire.



NOTE: A= Electrode spacing in feet, equivalent to the depth to which an average resistivity can be taken.

Figure 3-16. Field Measurement of Soil Resistivity.



Drill a hole 1-5/8 inches in diameter. Just hammer unit in until flush with paving. Sealing should not be necessary.

Figure 3–17. Plastic Test Insert.

Chapter 4

OPERATION AND MAINTENANCE OF GALVANIC ANODE SYSTEMS

4-1. General Information. The operation and maintenance of galvanic anode CPSs include visual inspections whenever possible, the measurement of current and potential for buried systems and water storage tanks, and the replacement of anodes and adjustment of anode output.

4-2. Visual Inspections. Visual inspection may be made of both the protected structures and the galvanic anodes. Inspection of the protected structure tells if corrosion is occurring, and by inference, if corrosion control methods are effective. Inspection of galvanic anodes tells whether the anodes are, in fact, sacrificing themselves to protect the structure and if the anodes need to be replaced.

a. **Structures.** Usually, only protected structures such as the interiors of water storage tanks, hot water tanks, chillers, and heat exchangers may be visually inspected for corrosion. Inspection should be done periodically as required by AFM 85-13, Maintenance and Operation of Water Plants and Systems, and AFM 85-31, Industrial Water Treatment. The base corrosion engineer must keep a permanent file of the inspection report. Buried pipelines and tanks must be inspected by the corrosion engineer when excavations are made for repairs, extension, or the installation of other facilities. Excavations for the specific purpose of examining buried structures are seldom justified. When inspecting structures, one should look at both the type and extent of corrosion and the condition of any coating which may be present. The surface of the uncoated structure should be cleaned down to bare metal by using a wire brush, scraper, or chipping tool on selected spots. The appearance of the clean metal should be reported, as well as the depth and extent of any pits or grooves which may be noted. If it is necessary to remove the applied coating of wrapped pipe for inspection purposes, the coating should be properly repaired before the backfill is replaced.

b. **Anodes.** Galvanic anodes used in hot water tanks, water storage tanks, and mechanical equipment such as water chillers, heat exchangers, and evaporative condensers should be visually inspected whenever the equipment is down for repairs or inspection. If necessary, replacement of galvanic anodes should be made during the down period. A record of the inspection report should be kept in the corrosion engineer's file.

4-3. Criteria for Effective Protection:

a. Maximum pipe-to-soil potentials must be measured directly over the pipe at locations where the piping is nearest the anode ground bed. All piping and underground metallic structures in the vicinity of each ground bed should be checked to determine the potential of each. Maximum allowable pipe-to-soil potentials must not exceed the following values:

Material	**Maximum Potential**
Coated steel	– 2.5 volts (see paragraph 7-5c)
Lead	– 1.1 volts
Aluminum	– 1.2 volts
Coated water tanks	– 1.5 volts

NOTE: The above criteria also apply to POL facilities.

b. When the maximum pipe-to-soil potentials are reached and all the piping served by the anodes cannot be protected, additional anodes must be considered. The installed anodes should be adjusted using resistance (nichrome wire) to produce a maximum permissible design potential when making tests to determine the requirements for the additional anodes.

c. The following criteria are published as section six of the National Association of Corrosion Engineers (NACE), Standard RP-01-69.

(1) Introduction. The purpose of this section is to list criteria for cathodic protection which, when complied with either separately or collectively, will indicate the adequate cathodic protection of a metallic system in its electrolyte has been achieved.

(2) General:

(a) The objective of using cathodic protection is to control the corrosion of metallic surfaces in contact with electrolytes.

(b) The selection of a particular criterion for achieving the objective in (a) above, depends, in part, upon past experience with similar structures and environments where the criterion has been used successfully.

(c) The criteria in (3) have been developed through laboratory experiment or empirically determined by evaluating data obtained from successfully operated CPSs. It is not intended that the base corrosion engineer be limited to these criteria if it can be demonstrated that the control of corrosion has been otherwise achieved.

(3) Criteria:

(a) Steel and Cast Iron Structures:

1. A negative (cathodic) voltage of at least – 0.85 volt as measured between the structure surface and a saturated copper-copper sulfate half cell contacting the electrolyte. Determination of this voltage is to be made with the protective current applied. The corrosion engineer must consider voltage (IR) drops other than those across the structure-to-electrolyte boundary for valid interpretation of the voltage measurement.

2. A negative (cathodic) voltage shift of at least 300 mv (millivolt) as measured between the structure surface and a saturated copper-copper sulfate half cell contacting the electrolyte. Determination of this voltage shift is to be made with the protective current applied. This criterion of voltage shift applies to structures not in contact with dissimilar metals. The corrosion engineer must consider voltage (IR) drops other than those across the structure-to-electrolyte boundary for valid interpretation of the voltage measurements.

3. A minimum negative (cathodic) polarization voltage shift of 100 millivolts measured between the structure surface and a saturated copper-copper sulfate half cell contacting the electrolyte. This polarization voltage shift is to be decided by interrupting the protective current and measuring the polarization decay. When the current is initially interrupted, an immediate voltage shift will occur. The voltage reading, after the immediate shift, must be used as the base reading from which to measure polarization decay.

4. A voltage at least as negative (cathodic) as that originally established at the beginning of the Tafel segment of the E-log-I curve. This voltage must be measured between the structure surface and a saturated copper-copper sulfate half cell contacting the electrolyte.

5. A net protective current from the electrolyte into the structure surface as measured by an earth current technique applied at predetermined current discharge (anodic) points of the structure.

(b) Aluminum Structures:

1. A minimum negative (cathodic) voltage shift of 150 millivolts, produced by the application of protective current. The voltage shift is measured between the structure surface and a saturated copper-copper sulfate half cell contacting the electrolyte. The corrosion engineer must consider voltage (IR) drops other than those across the structure-to-electrolyte boundary for valid interpretation of the voltage measurements. See precautionary notes in *3* and *4*, below.

2. A minimum negative (cathodic) polarization voltage shift of 100 millivolts measured between the structure surface and a saturated copper-copper sulfate half cell contacting the electrolyte. This polarization voltage shift is to be decided by interrupting the protective current and measuring polarization decay. When the current is initially interrupted, an immediate voltage shift will occur. The voltage reading, after the immediate shift, must be used as the base reading from which to measure polarization decay. See precautionary notes in *3* and *4*, below.

3. Precautionary Note—Excessive Voltages. In spite of the alternative minimum criteria in *1* and *2* above, aluminum, if cathodically protected at voltages in excess of 1.20 volts, measured between the structure surface and a saturated copper-copper sulfate half cell contacting the electrolyte and compensated for the voltage (IR) drops other than those across the structure-to-electrolyte boundary, may suffer corrosion resulting from the build-up of alkali on the metal surface. A voltage in excess of 1.20 volts should not be used unless previous test results indicate that no appreciable corrosion will occur in the particular environment.

4. Precautionary Note—Alkaline Soil Conditions. Since aluminum may suffer from corrosion under high pH conditions and since application of cathodic protection tends to increase the pH at the metal surface, careful investigation or testing should be made before applying cathodic protection to stop pitting attack on aluminum structures in environments with a natural pH in excess of 8.0.

(c) Copper Structures. A minimum negative (cathodic) polarization voltage shift of 100 millivolts measured between the structure surface and a saturated copper-copper sulfate half cell in the electrolyte. This polarization voltage shift is to be determined by interrupting the protective current and measuring the polarization decay. When the current is initially interrupted, an immediate voltage shift will occur. The voltage reading, after the immediate shift, must be used as the base reading from which to measure polarization decay.

(d) Dissimilar Metal Structures. A negative (cathodic) voltage, between all structure surfaces and a saturated copper-copper sulfate half cell contacting the electrolyte, equal to that needed for the most anodic metal, should be maintained. If amphoteric structures are involved that could be damaged by high alkalinity (see precautionary notes in (3)(b)*3* and (3)(b)*4*, above), they should be electrically isolated with insulating flanges, or the equivalent.

(4) Alternate Reference Half Cells:

(a) Other standard reference half cells may be substituted for the saturated copper-copper sulfate half cells. Two commonly used reference half cells are listed below, along with their voltage equivalent to −0.85 volt referred to a saturated copper-copper sulfate half cell:

1. Saturated KC1 calomel half cell: −0.78 volt.

2. Silver-silver chloride half cell used in seawater: −0.80 volt.

(b) In addition to these standard reference half cells, an alternate metallic material or structure may be used in place of the saturated copper-copper sulfate half cell if the stability of its electrode potential is assured and if its voltage equivalent referred to a saturated copper-copper sulfate half cell is established.

(5) Special Considerations:

(a) Voltage measurements on pipelines are to be made with the half cell located on the electrolyte surface as close as possible to the pipeline. Such measurements on all other structures are to be made with the half cell positioned as close as possible to the structure surface being investigated. The corrosion engineer must consider voltage (IR) drops other than those across the structure electrolyte boundary and the influence of other structures for valid interpretation of the voltage measurements.

(b) No one criterion for evaluating the effectiveness of cathodic protection has proven to be satisfactory for all conditions. Often a combination of criteria is needed for a single structure.

(c) Special cases may exist which require the use of criteria different from those listed above. Measurements of current loss and gain on the structure and current tracing in the electrolyte have been useful in such cases.

(d) In addition to the NACE criteria quoted in (3) above, lead structures should be cathodically protected to a minimum negative (cathodic) polarization voltage shift of 100 millivolts, measured as described above.

4-4. Electrical Measurements. Since the components of buried galvanic anode systems cannot be visually inspected on a routine basis, the operator and engineer must rely on electrical measurements to indicate the condition of the system. Chapter 3, paragraph 3-8, describes taking field measurements. The routine measurements to be made are: structure-to-soil (electrolyte) potential, anode-to-soil potential, and structure-to-anode current. Attachment 10 describes troubleshooting procedures.

4-5. Frequency of Measurements. It is desirable to make a series of electrical measurements on a newly installed buried galvanic anode CPS to determine the initial level of cathodic protection. After the initial series, measurements should be made quarterly for the first year. This will enable the corrosion engineer to identify deficiencies (from settlement) and program corrective action. After the first year of operation, measurements will be made biannually unless the major command (MAJCOM) requires more frequent testing. Data must be recorded on Air Force forms as outlined in chapter 8.

4-6. Structure-To-Soil Potential. The primary measurement to be made is that of structure-to-soil potential since this determines the adequacy of protection. Figure 3-8 shows the basic arrangement for making the measurement. The following spacing of potential measurements must be made initially and annually. In congested areas, structure-to-soil potentials must be measured at service risers and at points over the main farthest from the anodes. Potential measurements over long pipelines must be made over the main at points farthest from the anodes, but in no case farther than 1,000 feet. The measuring and recording of structure-to-soil potentials can be used to determine the level of protection and the trend of changes in protection. Gradual changes in potential are indicative of anode corrosion, changes in soil resistivity, or distant interference. Sudden changes indicate broken leads, interference, shorted insulation, or changes in piping. Attachments 10 and 11 show the causes of the different conditions and levels of protection together with methods of troubleshooting and remedies to be applied.

4-7. Anode-To-Soil Potential. The measurement of anode-to-soil potential serves as a check of lead continuity, anode condition, and location (peak potential occurs directly over anode). Where test stations are provided, the measurement should be made at the same time as that of structure-to-soil potential.

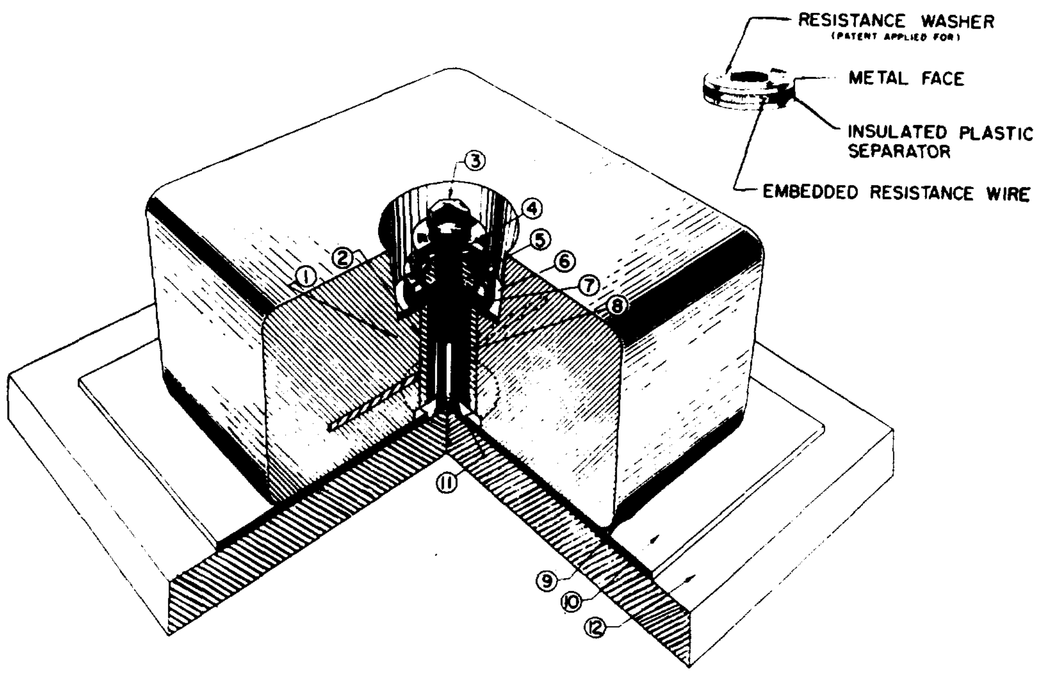
4-8. Structure-To-Anode Current. The rate of anode metal loss is directly dependent on the rate of current flow between the structure and the anode. This current flow is measured to give an indication of proper anode operation and to allow calculation of anode life. Where test stations are provided, the measurement should be made at the same time as that of structure-to-soil potential.

4-9. Galvanic Anode Replacement. It may be cheaper and easier to install new anodes than to troubleshoot and repair damage. Breaks in long gathering wires may be located with cable and pipe locators. When structure-to-earth potentials are too low because of depleted anodes, new anodes should be added to provide continuous protection of the structure.

4-10. Waterside Installations for Tanks and Equipment. Galvanic anodes are routinely used for protection of the waterside of mechanical equipment such as condensers, hot water tanks, evaporative condenser plants, fire truck tanks, or other water carrying equipment. Although anodes are available in many shapes and sizes, generally they can be grouped as blocks, rods, or ribbons. The general pattern of metal loss is such that rod-shaped anodes may "neck down" near the point of attachment or suspension and a large part of the anode may fall off. For this reason, long slender anodes usually have an iron core which, being itself protected by the anode material, does not corrode, and holds the pieces of anode together, both physically and electrically, until all of the anode material is sacrificed. Block-type anodes, on the other hand, can be bolted in place. Figure 4-1 shows a typical block-type anode installation for protecting a condenser head. Note that the stud is insulated from the anode and electrical connection is made through a resistance washer. Washers are available in ¼, ½, and 1 ohm resistances. When replacing those anodes, use a washer with the same resistance as originally installed. Figure 4-2 shows a horizontal method of installing sacrificial anodes in hot water tanks. Domestic hot water tanks usually use vertical rods or sectionalized anodes. The sectionalized anodes are made of magnesium sections on flexible wire. The wire can be bent to allow installation of long anodes where headroom is low. Generally, equipment type anodes should be replaced with similar items. Do not change anode material or anode shape without getting the corrosion engineer's approval. Different anode materials establish different cell potentials and levels of protection. Changes in anode shape change the physical area protected.

4-11. Soil Anodes. Installing anodes in soil includes excavation, placing and backfilling, restoring the electrical connection to the test station or structure, and testing and adjusting the output.

a. **Anode Installation.** Anodes are normally installed in holes augered near to the structure to be protected. Since current output is largely determined by soil resistivity, it is desirable to make each hole as deep as possible in an attempt to reach permanent moisture. Whenever possible, anodes should be installed at a lower elevation than the protected structure so that, should the ground water level go down, the anode will remain in conductive moist soil even though the soil around the structure has dried out (see figures 4-3 and 4-5). In case rock is met, the anode may be placed horizontally above the rock (see



1 & 2. 15-POUND MAGNESIUM ANODE, approximately 8 by 8 by 4 inches, having two 1 29/32 by 3/4-inch pipe core cast in center with a 1/8-inch diameter cross bar welded to core and embedded in anode.

3. PLASTIC STUD PROTECTOR, 1/2-inch, 13 threads per inch.

4. 1/2-INCH STAINLESS STEEL STUD, extending 3 5/8 inches above surface.

5. 1/2-INCH, 13 THREAD FLEX-LOCK NUT.

6. RUBBER GASKET for plastic stud protector.

7. RESISTANCE WASHER.

8. RUBBER TUBING, 2-inches long, 1/2-inch I.D., 1/16-inch wall thickness.

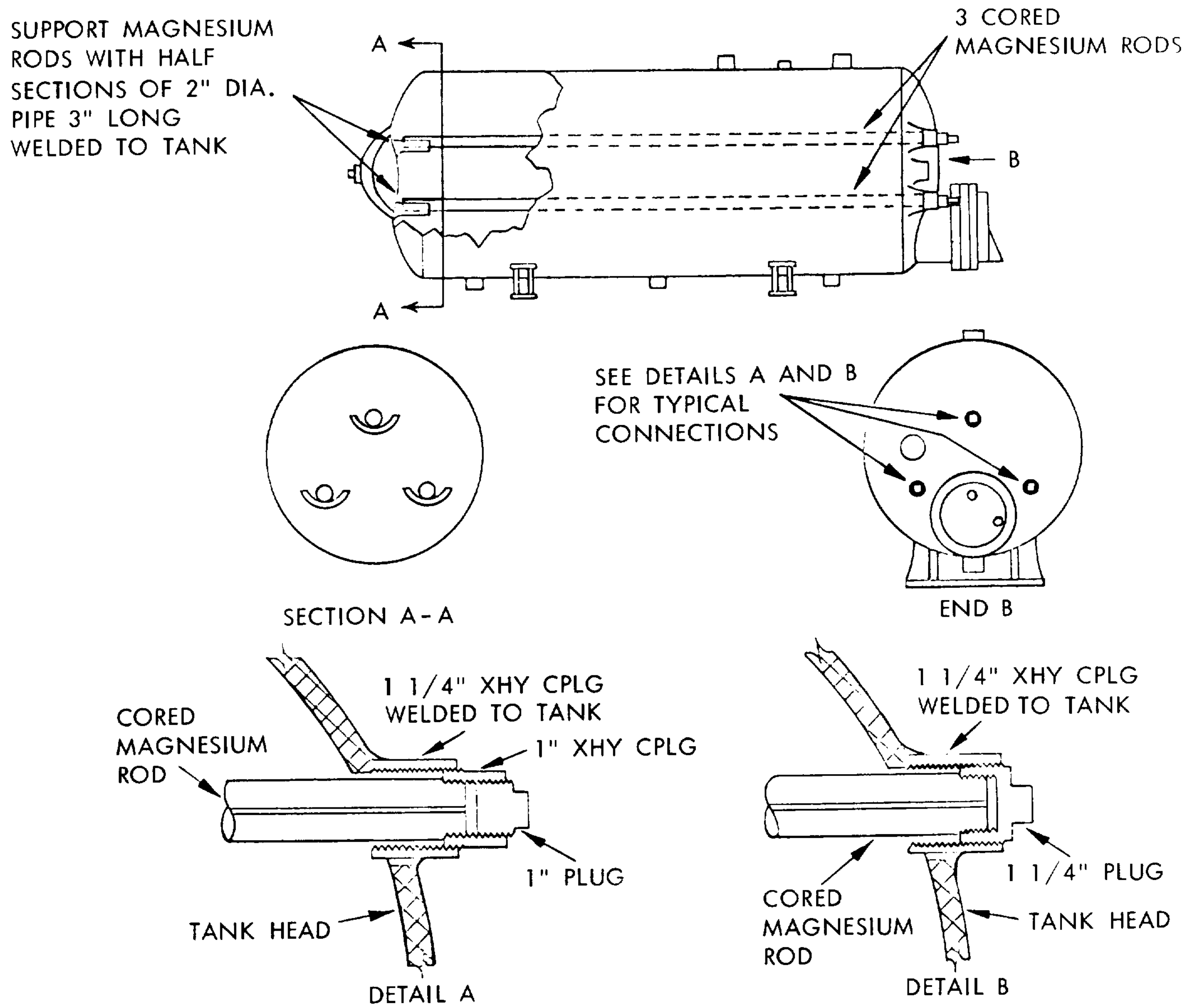
9. GASKET SEALER COMPOUND.

10. 1/16-inch SHEET RUBBER, 10 by 10-inches with 1/2-inch hole at center.

11. TYPE 304 STAINLESS STEEL STUD ATTACHMENT, To Steel-Fillet weld using type 310 stainless steel electrode at 70-105 amp.
To Cast Iron-Drill and tap in cast iron surface.
(Note: Extra stud length required for tapping.)

12. PROTECTED SURFACE.

Figure 4–1. Condenser Head Installation of 15 Pound Magnesium Anode.



NOTE:
PIPE FITTINGS DETAILS A AND B FOR 1.315" ROD. PIPE FITTINGS FOR OTHER SIZE RODS SHOWN IN TABLE.

ALL THREADS TO BE TAPERED PIPE THREADS. THE CORED MAGNESIUM ROD SHOULD EXTEND TO WITHIN 1" OF END OF TANK.

TABLE
PIPE FITTINGS FOR VARIOUS SIZES OF MAGNESIUM ROD

	MAGNESIUM ROD		
DETAIL-A			
DESCRIPTION	0.840 DIA.	1.050 DIA.	1.313 DIA.
OUTSIDE COUPLING WELDED	3/4" XHY	1" XHY	1-1/4" XHY
COUPLING	1/2" XHY	3/4" XHY	1" XHY
PLUG	1/2"	3/4"	1"
DETAIL-B			
DESCRIPTION	0.840 DIA.	1.050 DIA.	1.315 DIA.
OUTSIDE COUPLING WELDED	3/4" XHY	1" XHY	1-1/4" XHY
PLUG	3/4"	1"	1-1/4"

Figure 4-2. Details of Magnesium Rod Installation in Water Tanks.

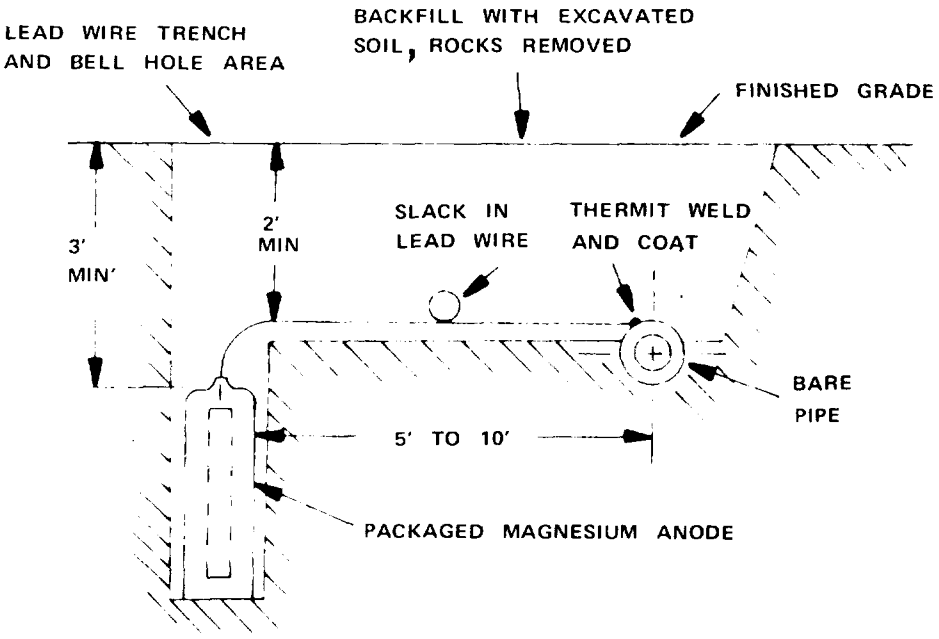


Figure 4–3. Vertical Magnesium Anode Installation.

figure 4-4). The anode should be installed at least as deep as the bottom of the structure and a sufficient distance away to give current throwing power (the distance along the pipe that protection is achieved). Anodes attached to *coated pipe* should be installed at least 2 feet away from the pipe. Anodes installed on a bare structure should be installed at least 5 feet away.

(1) To simplify installation and reduce costs, prepackaged anode units have been developed. The anodes are prepackaged in standard anode backfill and must always be used for galvanic systems installed in soil. The backfill serves as a good conductor to allow electricity to flow between the anode and the soil. Bases using galvanic anodes should maintain adequate bench stock of the most appropriate size for the soil resistivity of the particular base. Anode installation requires placement of the prepackaged unit in the hole. An additional advantage of the prepackaged unit is that the anode may be installed horizontally and will still be properly centered in the chemical backfill. Horizontal installation may be needed over rock or where only a thin layer of low-resistivity soil is available. Magnesium anodes must be carried as a standby level item where bench stock will not be maintained because of the consumption rate.

(2) Prepackaged anodes are normally shipped in an outer plastic-lined paper bag containing one or more an-

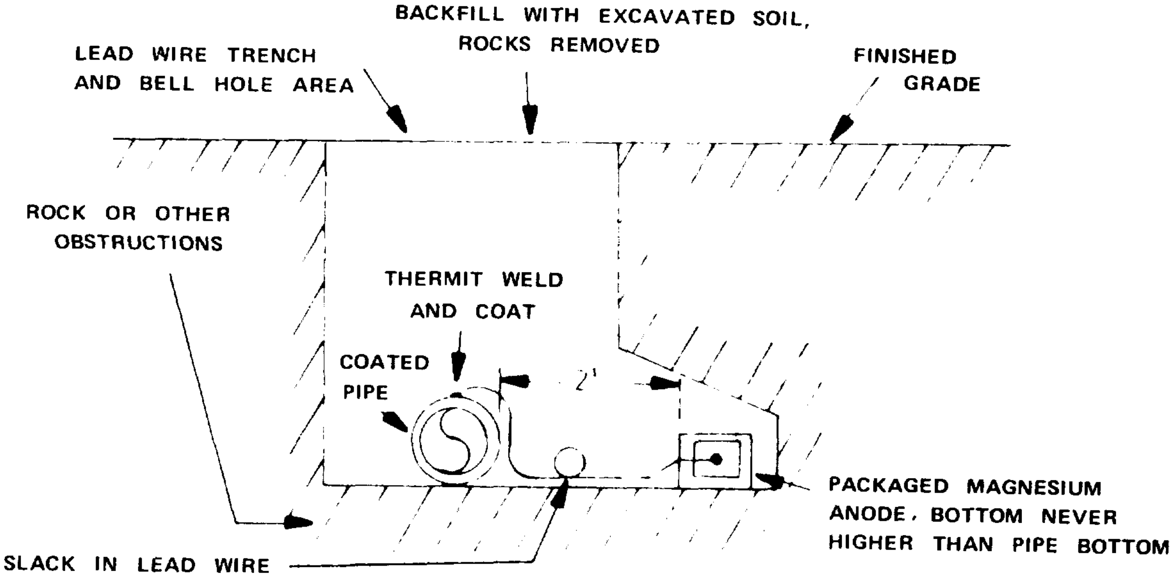


Figure 4–4. Horizontal Magnesium Anode Installation Where Bottom of Ditch Is Rock.

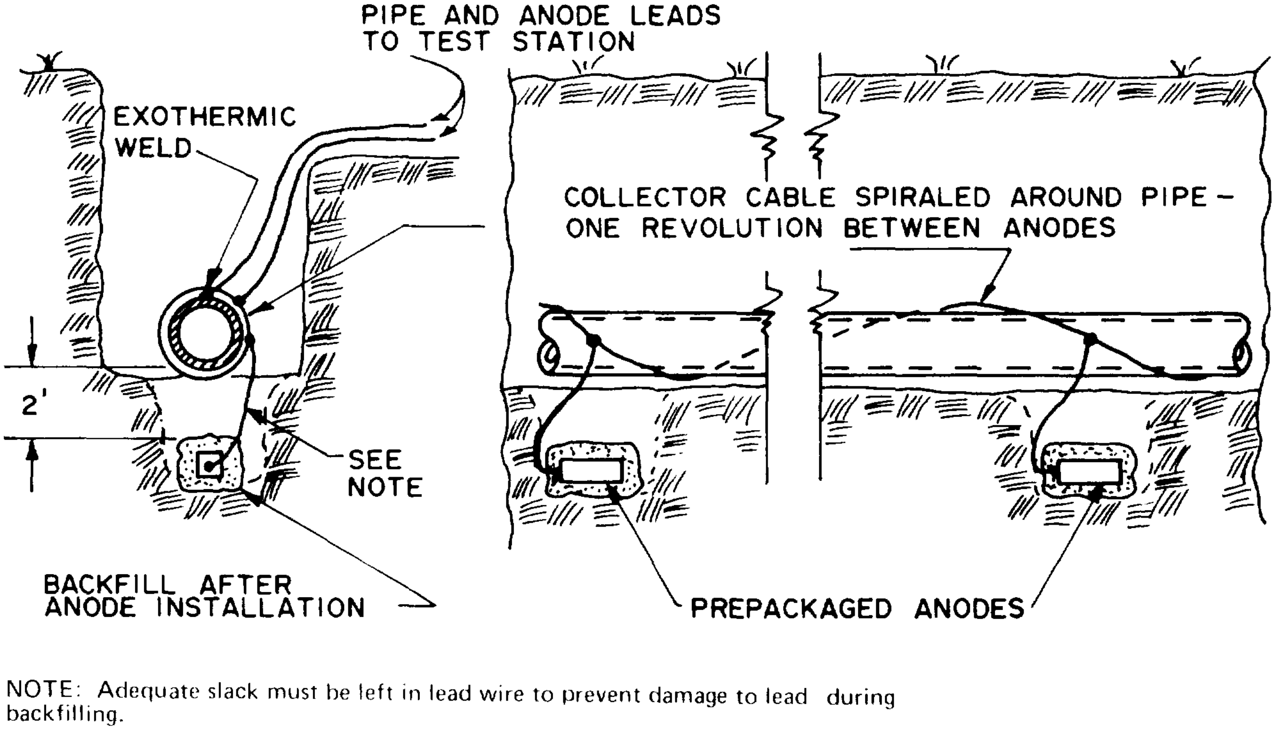
odes depending on weight. The outer plastic-lined paper bag must be completely removed and discarded before installation of the anode. Only one anode should be installed in an augered hole. The anode should be lowered into the augered hole by grasping the neck of the cloth bag or by using a fabric or rope sling. The anode lead wire must never be used to lower the anode into the hole. The hole must be backfilled in 6-inch layers and each layer must be well tamped around the anode. Care must be exercised not to strike the anode or lead with the tamper. If immediate testing is desired, water may be added only after backfilling and tamping has been completed to a point 6 inches above the anode. Approximately 2 gallons of water may be poured into the hole. After the water has dissipated, backfilling and tamping may be completed to the top of the hole.

(3) It is good corrosion control practice to install a magnesium anode in the open hole that has been excavated for repair of a leak if potentials show the level of cathodic protection is below recommended criteria. Installation should be at the maximum distance from the pipe that the hole will allow.

b. **Adjusting Anode Output.** When magnesium anodes are installed in a low resistivity electrolyte, the current output may be too high. This excess current may adversely affect metals such as aluminum, zinc, or lead and will cause the anodes to be used up too quickly. If it is necessary to limit the anode current output, a resistor must be installed in the lead between the anode and the structure to prevent the excess current. The actual current needed should be determined by the base corrosion engineer. The best way to adjust anode current is by trial, using a piece of nichrome wire as the resistor. Using a movable clip, determine the exact length of nichrome wire needed to properly limit the current, and permanently install that much nichrome wire in the anode-structure circuit between the anode lead and the pipe lead. The nichrome wire may be carefully coiled on a pencil and the coil placed inside the test station after removing the pencil. If bare nichrome wire is used, care must be taken not to short the turns of the coils to each other or to the test station.

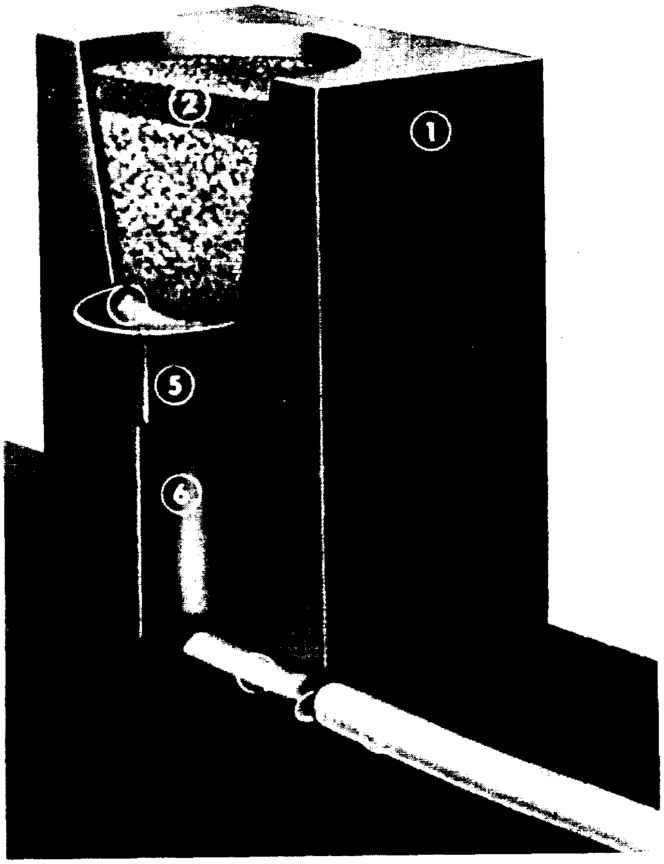
4-12. Installing Test Stations. Test stations are necessary for measuring CPS performance. It is desirable to install all of the anodes on a collector wire through a test station. If this is not possible, one of every ten anodes must be connected to the pipe through a test station. Figures 3-9 through 3-15 show details of typical test stations and anode installations. The overall plan of test stations should be determined by the corrosion engineer. The two types of test stations used are discussed in paragraph 3-12.

a. Surface stations may be made from a pipe or a weatherproof terminal box and a short piece of electrical conduit fastened to an upright steel or wood post as shown in figures 3-10 and 3-11. The post should extend into the ground 2 to 3 feet or more to give adequate protection against damage from moving equipment. It may also be desirable to extend the post above the box and paint it a conspicuous color so that it is visible at all times. A white bottom and blue top has been selected as



NOTE: Adequate slack must be left in lead wire to prevent damage to lead during backfilling.

Figure 4-5. Bottom of Ditch Anode Installation—New Construction.



(1.) Cutaway of Thermit TH Welder.

(2.) Starting Powder.

(3.) Powdered copper oxide and aluminum.

(4.) Metal disc.

(5.) Tap hole.

(6.) Weld cavity.

(7.) Copper sleeve on bare conductor (when required).

(8.) Insulated wire.

Figure 4-6. Thermit^{TM} Welder.

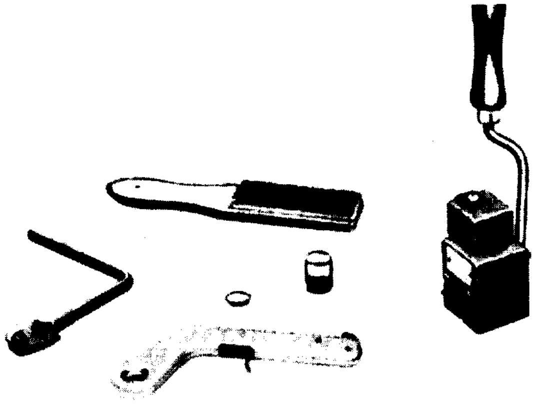
standard Air Force colors for all cathodic protection test stations and rectifiers (Federal Standard 595, Colors; Blue 15045, White 17778).

b. Subsurface stations may use test boxes as shown in figure 3-12.

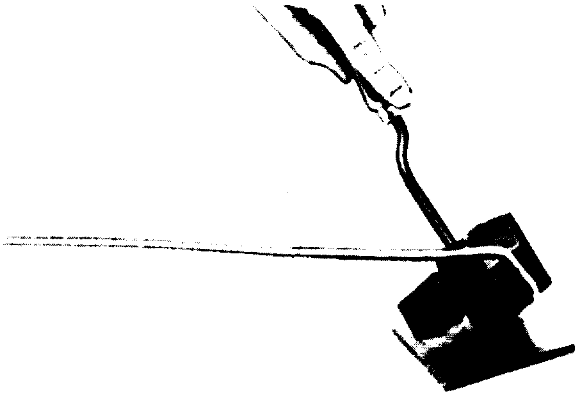
4-13. Protection of Anode Lead Wires:

a. The AF Form 103, "Base Civil Engineering Work Clearance Request," must be coordinated and signed by the corrosion engineer in column 1 (other). The corrosion engineer will accurately locate all underground cathodic protection cables when excavations are needed.

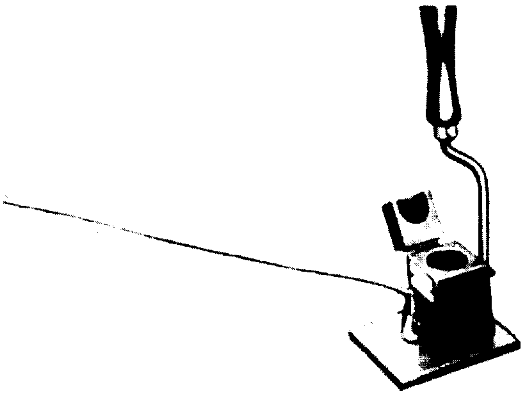
b. Plastic warning tape must be installed in the ditch above the anode lead wires. The warning tape should be located 6 to 8 inches below the surface. The warning tape replaces the wooden board as a protective warning for direct buried lead wires.



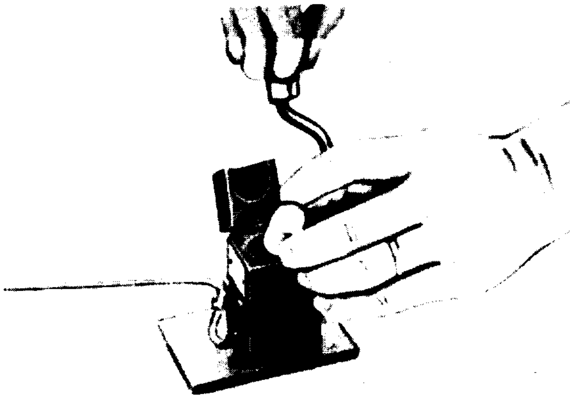
1 Thermitwelding equipment — Thermitwelder, cartridge, disc, flint gun, cleaning tool.



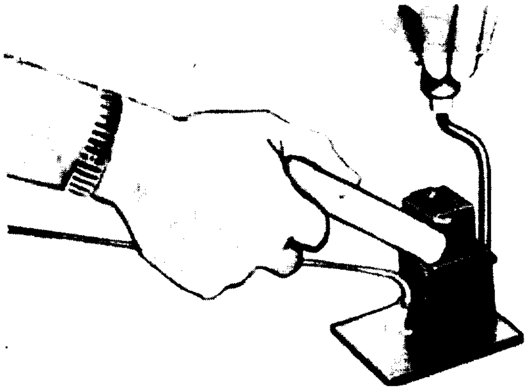
2 Strip conductor insulation and apply sleeve when necessary. File surface to be welded — remove paint and mill scale. Cable and Thermitwelder must be clean and dry to avoid porous welds.



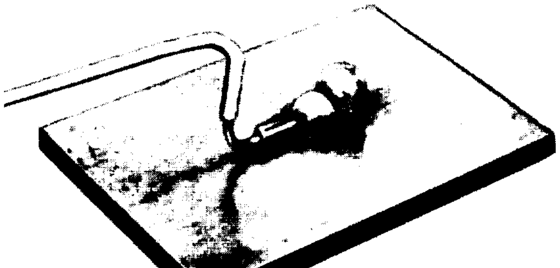
3 Insert conductor in Thermitwelder — do not push end of conductor past center of the tap hole. Note: Cable clip helps maintain position of cable in Thermitwelder. Drop metal disc over tap hole.



4 Remove cap from cartridge and dump contents into Thermitwelder. Remove all starting powder from cartridge by tapping the inverted cartridge on lip of the Thermitwelder.



5 Close cover, hold Thermitwelder steady, ignite starting powder with flint gun as shown. When powder fires; remove gun immediately. Hold Thermitwelder steady for 10 seconds. Remove slag with cleaning tool and strike completed weld with light hammer to insure sound connection.



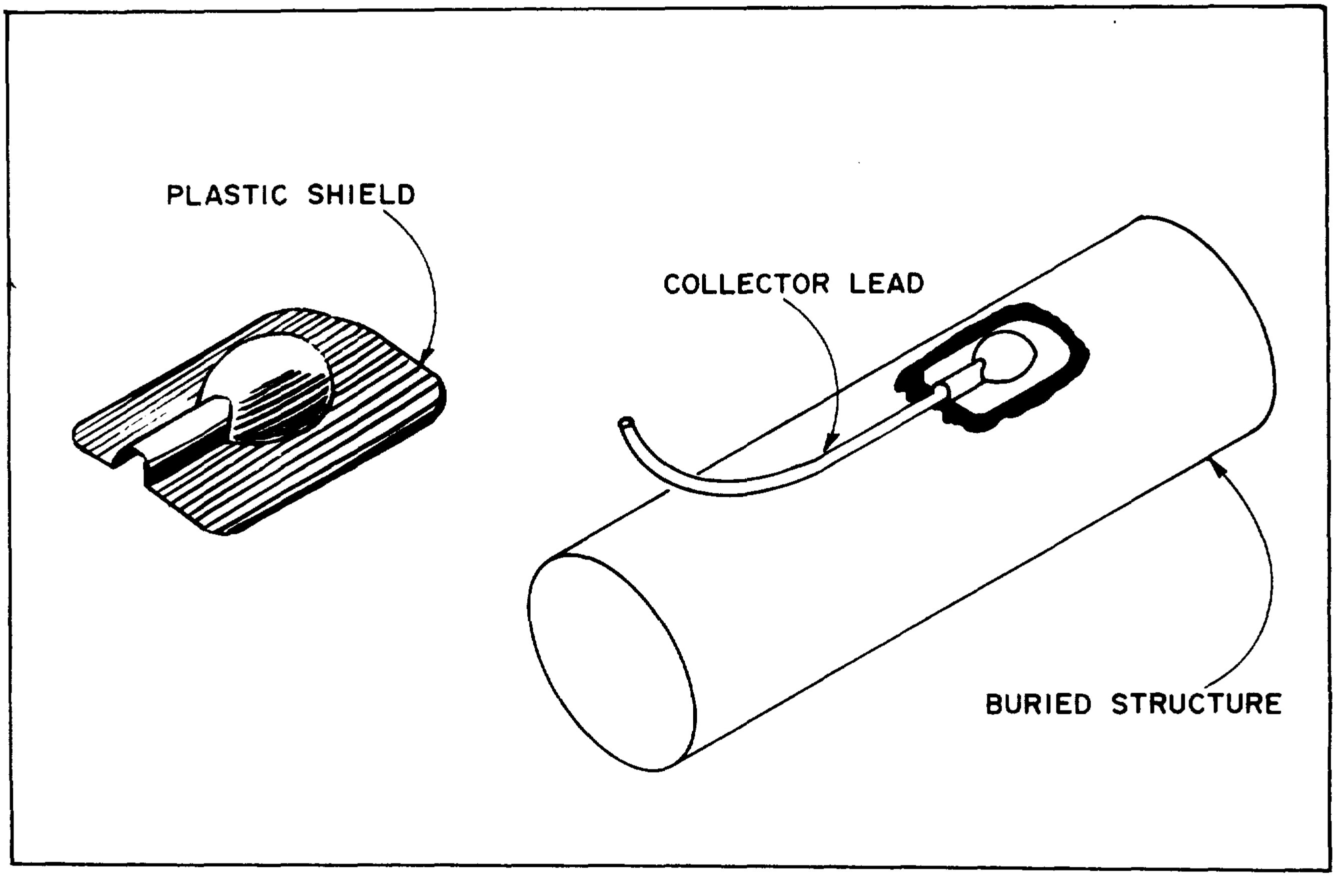
6 Finished Thermitweld.

Figure 4-7. Thermit^{TM} Weld Process.

4-14. Welding and Splicing Electric Conductors. Since CPSs are electrical, it is important that the current be allowed to flow where it is needed without unnecessary loss or restriction. The two usual causes of loss and restriction are high-resistance connections and poorly insulated connections. Connections to the structure will be exothermic welded or brazed and then insulated from the electrolyte. Conductor splicing should be avoided where possible. Permanent conductor splices will be accomplished by exothermic welding or crimped pressure connection with proper ratchet tools.

a. The simplest and best method of attaching leads to structures and getting a good electrical connection is the exothermic welding process such as Thermit™ welding. Exothermic welding is a means of permanently fastening copper conductors to steel or iron structures or to another copper conductor. Powdered copper oxide and aluminum are burned to provide heat and molten copper. The molten copper flows over the conductor and the structure, permanently welding them together. The equipment is light and portable, and no outside source of heat or power is needed. The exothermic weld furnace must be of the proper size for the pipe and wire size encountered. Figure 4-6 shows a sectionalized view of an exothermic welding apparatus. Figure 4-7 shows the steps in welding a conductor to a structure. Underground splices usually can be adequately insulated by three wraps of insulating electrical tape.

b. The completed exothermic weld and exposed copper wire must be coated with an exothermic weld cap filled with mastic (see figure 4-8). The cap must not be installed until after the weld has cooled sufficiently to prevent mastic from melting or burning.



NOTE: Shield must be completely filled with mastic sealant and pressed in contact with the pipe over the connection until mastic is squeezed out at edges of the shield.

Figure 4-8. Exothermic Weld Cap.

Chapter 5

OPERATION AND MAINTENANCE OF IMPRESSED CURRENT SYSTEMS

5-1. General Information. The operation and maintenance of impressed current systems of cathodic protection includes placing the system in service initially and then performing routine inspections including visual checks, rectifier inspection, electrical measurements, and correcting deficiencies found during inspection. These duties will be performed by the corrosion control engineer (CCE) and the cathodic protection technician (CPT).

5-2. Placing the System in Service. In order to get the best performance from an impressed current system, it should be checked and adjusted in the following manner at the time it is first placed in service:

a. Determine structure-to-soil potentials at all service line risers, all perimeter points, at locations closest to ground bed and at points every 1,000 feet where risers do not exist. Determine structure-to-soil potentials on all metallic piping systems that are not included in the protected system and are within 500 feet of the ground bed. Record the locations and the test data for future reference.

b. Set the rectifier voltage to the lowest taps, visually check to assure that the anode conductor is connected to the positive terminal and that the structure conductor is connected to the negative terminal, and then energize the rectifier.

c. Increase current output by changing the rectifier taps one step at a time to reach design current. WARNING! After each increase, measure structure-to-earth potential over the structure closest to the ground bed to assure that the potential increases in the negative direction, and that the potential does not exceed the maximum limit (see paragraph 4-3a).

d. Repeat structure-to-soil potentials at points designated in paragraph a.

e. Adjust the rectifier output to obtain a minimum recommended protected potential at perimeter points of the system to assure adequate protection (not to exceed criteria limits at any point on the system).

f. Repeat structure-to-soil potentials at all points designated in paragraph a after the rectifier has operated for 30 days. Polarization will have occurred during the 30-day operating period. The rectifier will be readjusted if needed to get complete protection of the structure.

g. Conduct cathodic interference tests and install required interference bonds as described in chapter 6. Interference bonds will reduce the effective protection of the structure. To assure adequate protection, tests at perimeter points will be repeated after interference bonds are installed. Any necessary rectifier adjustments should be made.

h. Record all data for future reference.

i. Identify all areas that are not receiving adequate protection. The corrosion engineer will submit the data and a plan of required corrective action to the command CCE for approval and guidance.

5-3. Rectifier Inspections. Montly inspection of cathodic protection rectifiers must be made by the CPT to make sure that all components are in proper operating condition and that the unit is producing adequate DC to provide complete protection. The inspection includes measurements of current and voltage output, maximum and minimum potentials, and a check of components for deficiencies. Oil-immersed rectifiers require additional inspection as listed in attachment 12.

5-4. Output Measurements. The first step in conducting a rectifier inspection is to measure both current and voltage output and record the readings in the "as found" columns, AF Form 491, Cathodic Protection Operating Log for Impressed Current System. Most rectifier assemblies include both a voltmeter and an ammeter for measuring applied potentials and impressed currents. Some meters are permanently connected into the circuit which allows the voltage and current to be continuously read. Other meters are normally disconnected from the circuit and are energized by pressing a switch or button as shown in figure 5-1. When using a "press to read" switch, press and release the switch slowly three or four times before recording the readings. Because these switches are idle for long periods between use, the contacts sometimes do not seat properly and may make a high-resistance connection. Actuating the mechanism carefully several times allows the movement to "free up" and the contacts to meet properly. Compare the rectifier output readings with those of the previous inspection. Adjust the voltage, if necessary, to maintain the required current output. Any significant change indicates a component failure in the rectifier or a change in the system or system environment.

5-5. Component Inspections. Inspection of the individual rectifier components is made to ensure that all parts are operating properly to maintain protection of the structure.

a. **Stack Temperature.** After turning the unit off, immediately feel the rectifier stacks to determine if they are operating properly. Operating stacks should be warm. Cold stacks indicate they are not operating. In either a full-wave or full-wave bridge rectifier circuit failure, one rectifier stack will cause the unit to operate as a half-wave rectifier. This situation can be determined because half of the stacks will be warm and half will be cold.

b. **Contact Temperatures.** Any mechanical connection in a rectifier assembly can become loosened and cause a high-resistance joint. A high-resistance joint heats up, causes oxidation which results in more heating and more oxidation, and so on, until failure. After the unit is turned off, feel the electrical connections for warm or hot joints which are an indication of high resistance.

c. **Filter Inspection.** Some rectifiers include DC filters to smooth out the rectified current. These filters in-

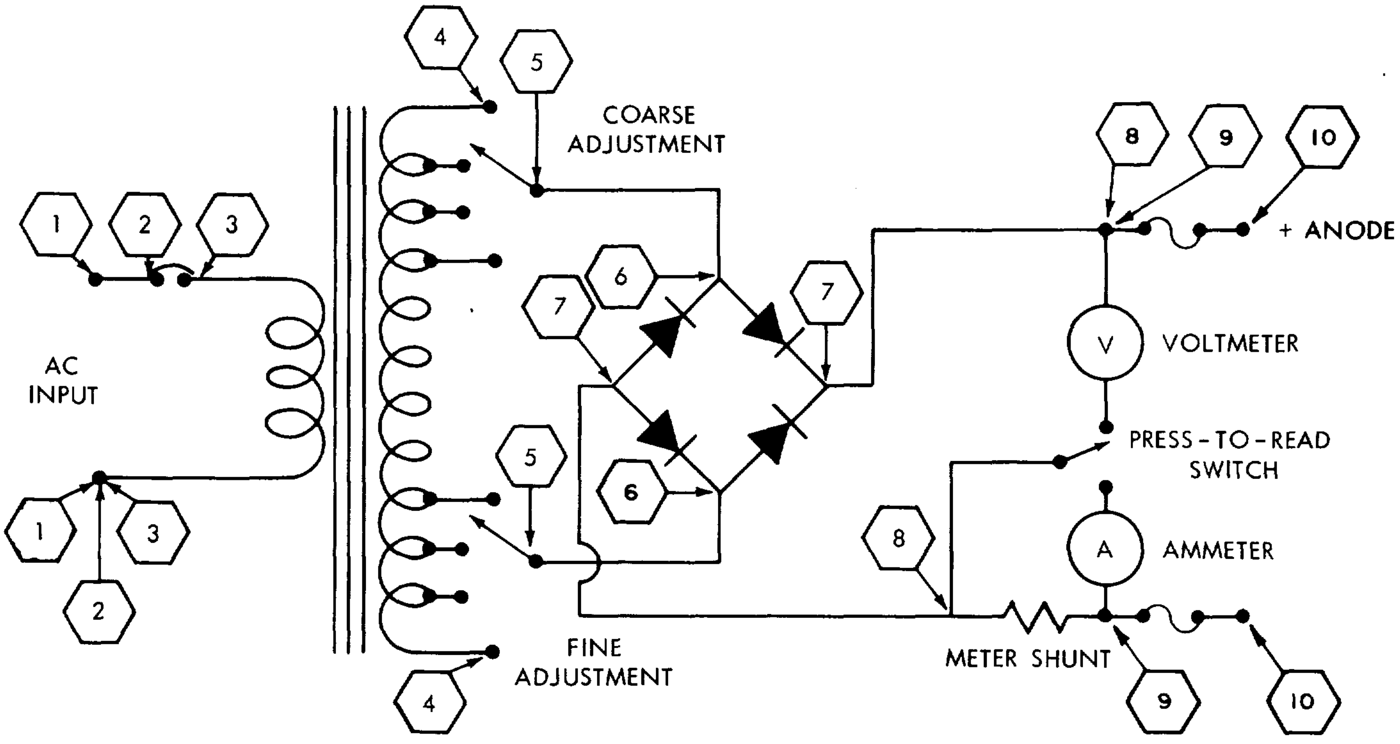


Figure 5-1. Voltage Test Sequence for Rectifier Troubleshooting. (See table 5-1 for sequence.)

clude a choke and generally two capacitors. Visually inspect these items and then check for overheating. The capacitors are likely to be fused, which means the fuses should be checked.

d. **Arc Paths.** Look over the components for the burn mark or arc path caused by an electric arc jumping from one conductor to another. These arcs may be caused by lightning surges, water entering the unit, or insulation breakdown from age or physical damage.

e. **Cleanliness of Stacks.** The life of a rectifier stack is dependent mostly on the temperature at which it is operated. Proper cooling is essential to achieve satisfactory stack life. Accumulations of dust, dirt, insects, bird nests, and the like in the unit interfere with stack cooling and thus cause premature stack failure. Most units are ventilated through screens with fairly small openings (about one eighth of an inch). Accumulations which interfere with the stacks, or with the passage of air through the screens, should be removed. If it is necessary to clean the stacks, use a soft brush or cloth. Be extremely careful not to scratch or bend the rectifier plates.

5-6. Potential Measurements. The point of maximum potential and three points of minimum potential for each rectifier system must be selected each year from the annual performance survey. The location of these points must be recorded in section 9 of AF Form 491. Also, the current required to provide complete protection, as determined during the initial start up or the annual performance survey described in attachment 17, must be recorded in section 8 of AF Form 491. The four potential measurements must be made after assuring that the required current output is provided. The data obtained must be reviewed by the corrosion engineer who will provide guidance if any changes in current output are needed.

5-7. Annual Meter Tests. Meters in each rectifier unit must be checked for accuracy each year. A portable instrument of known accuracy is used to check the unit meters by measuring the voltage across the output terminals and comparing the reading with that of the unit meter, and by inserting the test ammeter in the output circuit and comparing its reading to that of the unit ammeter. The test voltmeter should be at least as sensitive (in ohms per volt) as the unit voltmeter being checked. The test ammeter should offer less resistance to the circuit than does the unit ammeter.

a. The difference in voltages (or currents) as read by the two meters should not exceed the accuracy limits of the two meters together. For example:

Using a 50 volt voltmeter accurate to 1 percent of full scale to check a 30 volt voltmeter rated as accurate to 2 percent of full scale, the allowable error is:

1 percent of 50 volts = 0.5 volts
2 percent of 30 volts = 0.6 volts
Total = 1.1 volts (allowable error)

If the difference in readings exceeds 1.1 volts (and the test meter is known to be within its rated accuracy) the unit meter should be replaced.

The above method of calculation of allowable accuracy is also used to determine allowable error in ammeters.

b. Because meter accuracies are measured in terms of full-scale readings, always try to use a meter range which will give readings in the upper third or half of the scale. To illustrate, assume a 100 volt voltmeter accurate to 1 percent of full scale (within 1 volt):

	Full Scale	½ Scale	⅒ Scale
Actual voltage	100 volt	50 volt	10 volt
Measured voltage	99 volt	49 volt	9 volt
Error	1 percent	2 percent	10 percent

In each instance above, the meter is performing within its rated limits of accuracy. However, at the lower end of the scale, it is reading 10 percent off actual voltage. All rectifiers should have a shunt mounted on the front panel to check the accuracy of the current output. The shunt will be marked as to the amps or millivolt rating which should be used in calculating the current.

5-8. Troubleshooting. If inspection reveals that a unit has failed (or is near failure) the troubleshooting procedure should be followed to locate faulty components and restore the rectifier unit to operation. The simplest means of troubleshooting is to follow the flow of electricity through the rectifier unit, component by component. Figure 5-1 shows the sequence of checking through a rectifier with a voltmeter using nine tests. This same procedure can be used on any rectifier circuit from a single-phase, half-wave unit to a three-phase bridge. Be sure to use AC meters on the AC side of the stacks and DC meters on the DC side of the stacks. Table 5-1 also shows the voltage test sequence for troubleshooting a rectifier.

a. Before troubleshooting a unit, study the circuit diagram furnished with the manufacturer's instructions that are mounted in the rectifier cabinet. If no circuit diagram is available, it is usually worthwhile to trace out the circuit and develop a diagram. A copy of the circuit diagram should be filed with other record drawings.

b. Voltage test points are not limited to those shown in figure 5-1. Intermediate points can and should be checked in a search for loose connections and broken conductors.

c. Precautions. Turn off rectifier by throwing the AC circuit breaker and the outside disconnect switch before touching parts to check for heat buildup on loose connections. Be sure the test meters are properly connected and the range selected is high enough to prevent meter damage. Observe the same safety practices as when inspecting other electrical equipment. The cause of rectifier failure may have left hazardous conditions not usually met in electrical equipment.

Table 5-1. Voltage Sequence for Rectifier Troubleshooting (see figure 5-1).

Probe Points	*Measurement Indicates*
1-1.	AC voltage from the disconnect switch.
*2-2.	AC voltage to the circuit breaker or fuse.
*3-3.	AC voltage to the transformer primary winding.
4-4.	AC voltage through the transformer.
5-5.	AC voltage through top adjustment connections.
*6-6.	AC voltage to the rectifier.
*7-7	DC voltage from the rectifier.
*8-8.	DC voltage to the metering terminals.
9-9	DC voltage to the protective fuse terminals.
10-10	DC rectifier voltage output.

*[illegible]ually, these [illegible] made without removing the panel [illegible]

5-9. Troubleshooting Procedures. The following are the troubleshooting procedures to be used for locating the cause of reduced or interrupted rectifier output:

a. If no output voltage is indicated on the rectifier meter, make the following checks and repair as necessary:

(1) Check AC circuit breaker, DC fuses, and AC disconnect switch and fuses. If circuit breaker or fuses are blown, check the reason for the interruption and make necessary repairs.

(2) Check for evidence of lightning damage or excessive heating in the rectifier cabinet. Also, strange colors indicate heat damage.

(3) Check the DC output voltage with the multimeter connected across the rectifier output terminals. If no voltage is indicated, repair the meter or wiring.

(4) Check the DC fuses, fuse holders, and connections.

(5) Check the disconnect switch for supply voltage, blown fuses, or loose connections using an AC meter. If no disconnect switch has been installed, have one installed.

(6) Request the appropriate electric shop to repair power source trouble if AC voltage is not available to the disconnect switch.

(7) When voltage is available from the disconnect switch but not to the rectifier stacks, open the disconnect switch and check for continuity through the AC circuit breaker. Trouble may be in the switch, wiring, or terminal connections.

(8) Check the AC power supply through the transformer to the rectifier stacks by testing AC voltage across the fixed center terminals of the coarse and fine adjustments. (Caution: Do not make this check in an oil-cooled rectifier when terminals are submerged.)

(9) Check the rectifier stack for DC output voltage. If there is input voltage but no output voltage and all terminal connections are tight, the stacks may be defective and should be checked for opens or shorts.

b. If the DC voltage is normal at the rectifier output terminals, but no current flow is indicated on the ammeter, make the following checks:

(1) Check for current output with the multimeter. The ammeter may be defective, the current may be too small to register on the meter, or connections and wiring may be defective.

(2) If no current is flowing, there is an opening in one of the external DC leads. Look for recent excavations between the rectifier, and both the anode bed and the structure.

(3) If the open circuit is in the buried cable to the anode bed, it may be found using a pipeline locator or by making an over-the-cable potential survey with the rectifier set for minimum potential. The negative terminal of the high resistance voltmeter must be connected to the *negative* (to structure) DC output of the rectifier while

the copper-copper sulfate electrode is moved over the route of the buried cable.

(4) In water storage tanks, the open circuit may be at the negative lead connection to the tank (bolted instead of exothermic welded) or in the conductor to the anodes. Also, the anodes may be consumed, the conductor may be broken with the anodes lying at the bottom of the tank, or the anodes may be above the low water level. Generally, a visual check will reveal these conditions.

c. If the output voltage is normal and the amperage is noticeably lower, check to determine if some of the anode bed has been lost through excavation or deteriorated connections. Check as in b(3) above.

d. If the output voltage is normal and the amperage decreases slowly over a long period of time, the anode bed resistance has increased due to gas blockage, dry soil, or the exhausted anodes may need replacing. Dry soil may be suspected during the dry season if the anode installation is relatively new. Soak the anodes by flooding the area to restore the electrolyte. If the low amperage persists, carefully uncover the tops of the anodes (do not damage anode leads or header cable) and backfill with pea gravel from the top of the coke breeze to within 6 inches of the grade level to allow gas dissipation. If the anodes are approaching their design life, the first in the string may be excavated for inspection to determine if the anodes need replacing.

e. If the output voltage is very low, the amperage is very high, and the structure is not protected, the DC circuit is shorted. Check the circuit in the rectifier and at the output terminals.

f. Some rectifier circuits include capacitors, fusing, lightning arresters, current control rheostats, and noise interference filters. If this equipment fails, it may be necessary to remove it from the circuit until replacement can be made. Capacity of the component must be considered in replacement, particularly where evidence of heating is found.

g. The most frequent impressed current system troubles are blown fuses, loose terminals, lightning damage, faulty meters, and open circuit breakers.

h. Attachment 11 contains additional troubleshooting information.

5-10. Impressed Current Anode Replacement. Anodes for impressed current systems are usually of either graphite, high-silicon cast iron, aluminum, or platinum. Sometimes scrap iron is used, although it deteriorates rapidly and has a short useful life as an anode material. Abandoned water well casings and abandoned pipelines, if properly located, can be used as anode beds.

a. Impressed current anodes are discussed in chapter 2, paragraph 2-1d. The replacement of impressed current anodes in soil is similar to the replacement of sacrificial anodes described in chapter 4, paragraph 4-9, except that prepackaged units are not recommended and that adjustment of current output is made at the rectifier rather than at the anode. Impressed current anodes are usually installed in "ground beds" rather than individually. The chemical backfill used is coke breeze rather than gypsum and bentonite. See figures 5-2 and 5-3 for examples of proper impressed current anode installation.

b. The lead wire-to-anode connection is the most critical portion of the anode assembly. The anode tends to deteriorate faster on the ends than in the center. If the deterioration exposes the anode lead, an open circuit will result at the lead connection. To prevent that from happening, epoxy encapsulation of the lead connection should be specified when ordering impressed current anodes. Underground electrical splices in the positive header wire are also critical. These splices must be insulated with an epoxy splice kit (see figure 5-4). To reduce premature failure of lead wire or lead wire-to-anode connections, several improvements in materials have been made and have recently become commercially available. One is a new insulation for impressed current anode lead wire that is more resistant to chlorine gas generated by the electrochemical reaction at the anode. This new insulation is a fluoro-copolymer called Halar™. Since Halar™ is

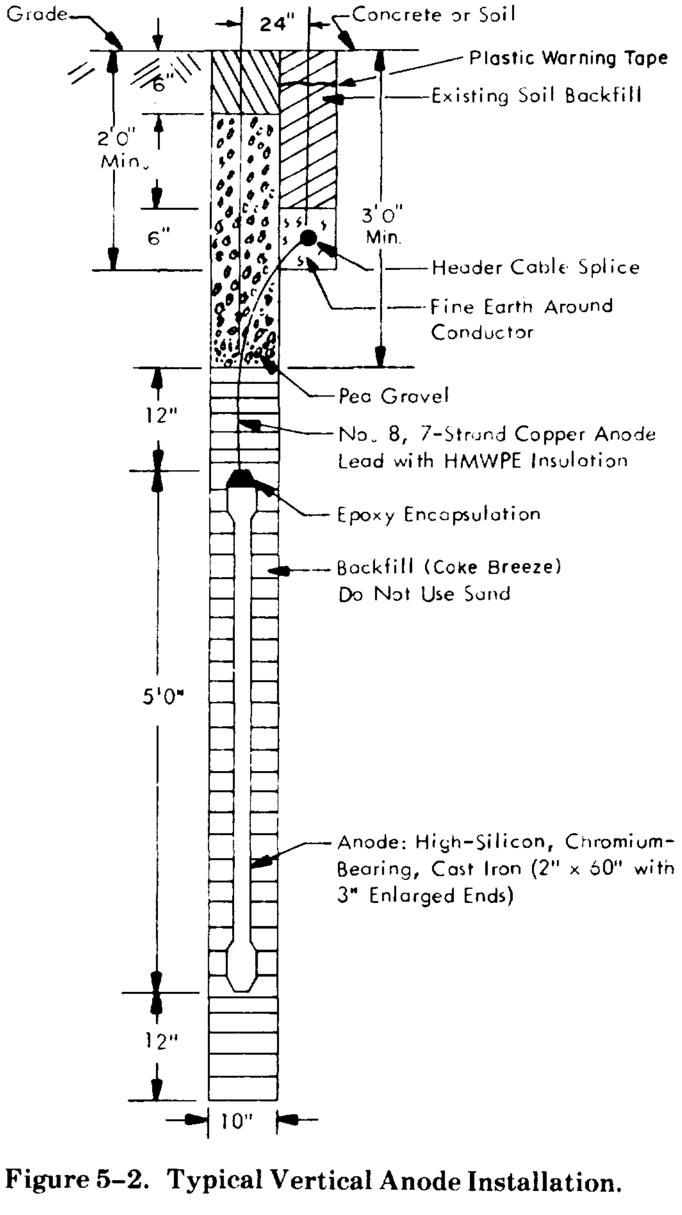


Figure 5-2. Typical Vertical Anode Installation.

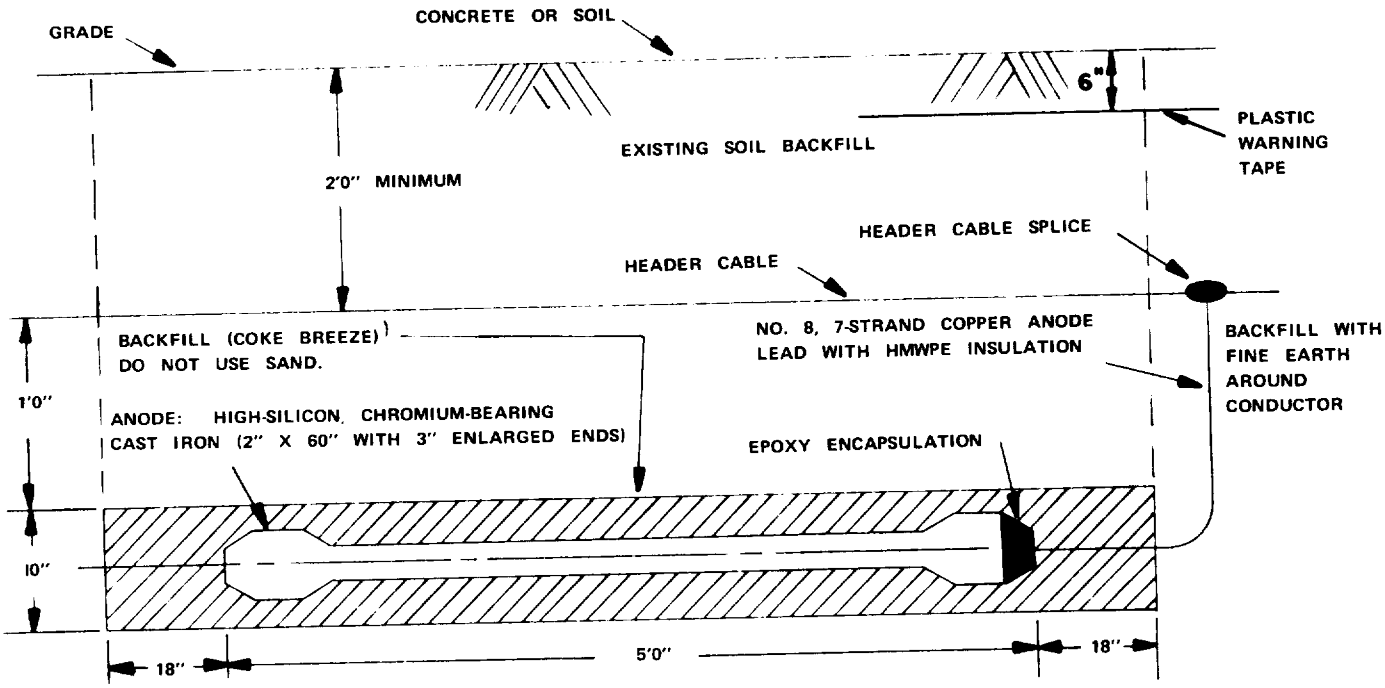


Figure 5-3. Typical Horizontal Anode Installation.

expensive and not very resistant to mechanical damage, it is manufactured with an outer layer of high molecular weight polyethlyene (HMWPE). This combination is known as Duralar™ and consists of 20 mils of Halar™ over seven-strand, tin-coated copper conductor with an outer jacket of 80 mils of HMWPE. Another improvement is the manufacture of cast iron anodes with the wire-to-anode connection made in the center of the anode from the interior.

5-11. Aluminum Anode Replacement. Aluminum anodes used in water storage tanks are normally designed for a 1-year life, and must be replaced routinely. Aluminum anodes are recommended only in the colder climates where ice cakes move up and down with changes in water level. These ice cakes will actually tear the tank anodes from their mountings. It is advisable to remove the tank anodes before the ice cake forms in early winter and reinstall the anodes in the spring when the danger of ice formation has past. Long life, high-silicon cast iron anodes should be used where ice is not a problem. Where mild icing occurs, polypropylene rope may be used to give added support to the high-silicon cast iron anodes, figure 5-5.

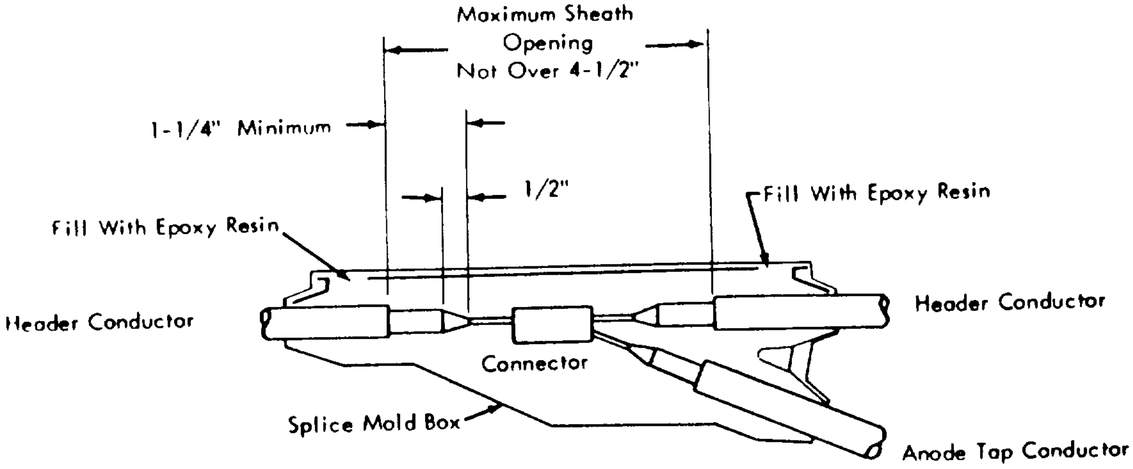
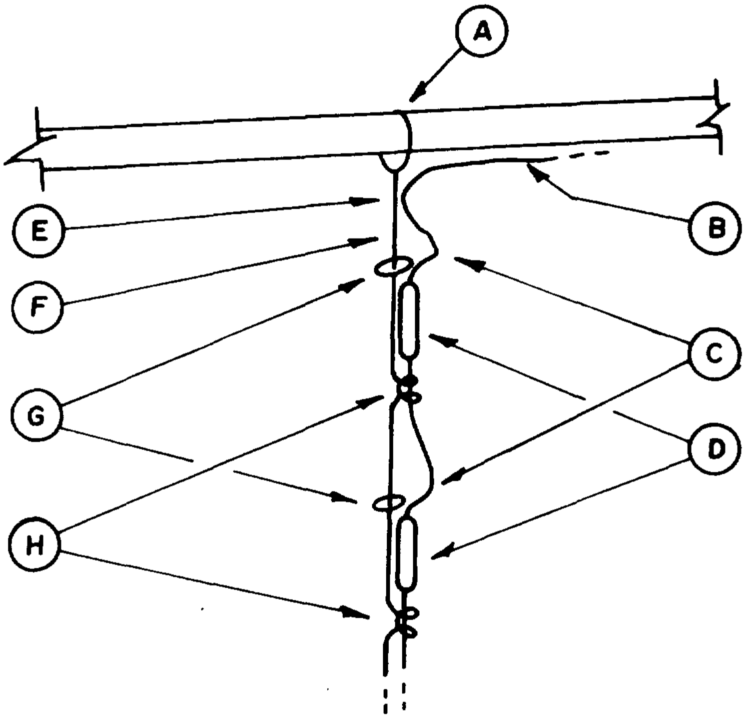


Figure 5-4. Underground Electrical Splice for Impressed Current Anode.

POLYPROPYLENE ROPE SUSPENSION SYSTEM FOR ANODE STRING IN WATER STORAGE TANKS



Ⓐ Fasten polypropylene rope to hangar attached to dome plate (if plate is capable of supporting the weight of ice in the tank) or to structural support member.

Ⓑ Anode stringer wire.

Ⓒ For each foot of rope between fastening points, allow 3 inches of slack in anode stringer to accommodate stretch due to weight of ice.

Ⓓ Anodes (such as Durco high-silicon cast iron anodes, type FW).

Ⓔ Fasten anode stringer to rope or structural support member.

Ⓕ Polypropylene rope, ¼” diameter.

Ⓖ Rings, slipped over rope, fastened to anode stringer wire just above anodes.

Ⓗ Using non-slip knot, fasten rope to anode stringer wire just beneath all anodes from high water level to just below low water level.

Figure 5-5. Anode Suspension System.

Chapter 6

INTERFERENCE TESTING AND CONTROL

6-1. General Theory. Cathodic protection interference occurs when buried or submerged metallic structures pickup or collect current from a CPS without being electrically connected to the structure that is cathodically protected, or to the CPS itself. The metallic structure which is not electrically connected to the CPS is usually called the foreign structure. The foreign structure may, or may not, have its own CPS. Usually, the foreign structure must be physically located near (0-2,000 feet) the ground bed of the CPS causing the interference, and either cross or come close to the protected structure. However, the exact point of interference may be located several miles away. The chain of events which occur in interference problems is as follows:

a. Direct current from the ground bed is collected on the foreign structure in the area where it is closest to the ground bed. The magnitude of the length over which the foreign structure will collect the current can vary from several lineal feet to several miles.

b. The area of the foreign structure that is collecting the current is actually under cathodic protection. The structure-to-soil potential measurements will reflect a protected structure.

c. The current that is collected will travel along the foreign structure until it reaches the path of least resistance. The location of the path of least resistance could be only several feet away from the point of collection or it could be several miles away (see figures 6-1 and 6-2). When the current reaches the path of least resistance it will leave the foreign structure, travel through the electrolyte (ground), and be collected by the protected structure and returned to the source—the rectifier.

d. The area where the current leaves the foreign structure will corrode rapidly. This is the actual point of interference. The structure-to-soil potential measurements at that point will be more positive when the rectifier is operating than it is when the rectifier is not operating. If the foreign structure is not cathodically protected, the potential measurement will be less (more positive) than −.85 volts. If the foreign structure is cathodically protected, the structure-to-soil potential may be above (more negative than) −.85 volts except where the current leaves the structure because of interference. Where the current leaves the structure to enter the electrolyte, the potential will be less than its original potential (with no cathodic protection). There is always a chance that interference will be caused by impressed current systems. The larger the current output the more likely that interference will occur. All metallic structures near the ground bed should be checked for current collection. This can be performed by connecting a current interrupter to the rectifier and performing potential measurements on all underground structures. Interference can be expected whenever the potential measurements change as the rectifier cycles on and off. Listed below are several underground structures that are often ignored when installing cathodic protection. It is recommended that each of the facilities be checked to determine if interference exists:

(1) Lead covered communications cables.
(2) Lead covered electrical cables.
(3) Fences.
(4) Cast iron piping systems.
(5) POL pipelines.
(6) Pneumatic tube systems.
(7) Nongovernment owned pipelines.

6-2. Interference Bonds. An electrical connection is needed between the foreign structure and the protected structure to alleviate cathodic interference. This electrical connection is called a bond. There are two types of bonds: A 100 percent bond and a resistance bond. The 100 percent bond allows all of the current that can collect on the foreign line to flow back to the rectifier. The resistance bond only allows a portion of the current to flow through the bond. The purpose of the resistance bond is to limit the amount of current collected on the foreign structure. There are two reasons for limiting the current flow:

a. The current flow should be limited if the potential exceeds the maximum allowable for the metal of which the foreign structure is composed. If the resistance needed to alleviate cathodic interference is not enough to restrict the current collection so that the maximum potential of the foreign structure is not exceeded, the current output of the rectifier causing the interference should be reduced. An alternate method for control of interference could be accomplished by moving the ground bed.

b. The current flow should be limited if the foreign structure is not owned by the government or does not require cathodic protection. The purpose of this limitation is to conserve power consumption and reduce operating costs.

6-3. Structure-To-Earth Potential Survey Profile. In the course of conducting a structure potential survey of a long pipeline, it is particularly helpful to plot the survey results in a graph form. A fictitious form is shown in figure 6-3. As illustrated, the potential measurements, with respect to a copper sulfate electrode, were taken over the route of pipeline T-4 at approximately 50-foot intervals. The plot of potential measurements when coupled with a plan view of the pipeline, sometimes clearly indicates reasons for high or low potentials and possible corrosion areas—"possible" in that other factors such as soil resistivity are involved.

a. Following the lower solid graph line (pipeline with no cathodic protection) the potential rises toward −.85 volts near station 3+50 and dips to −.4 volts at a pipeline side connection. From the plan view, note that an insulated flange is present. The lower potential at that point may indicate shorted insulation or an area of bare

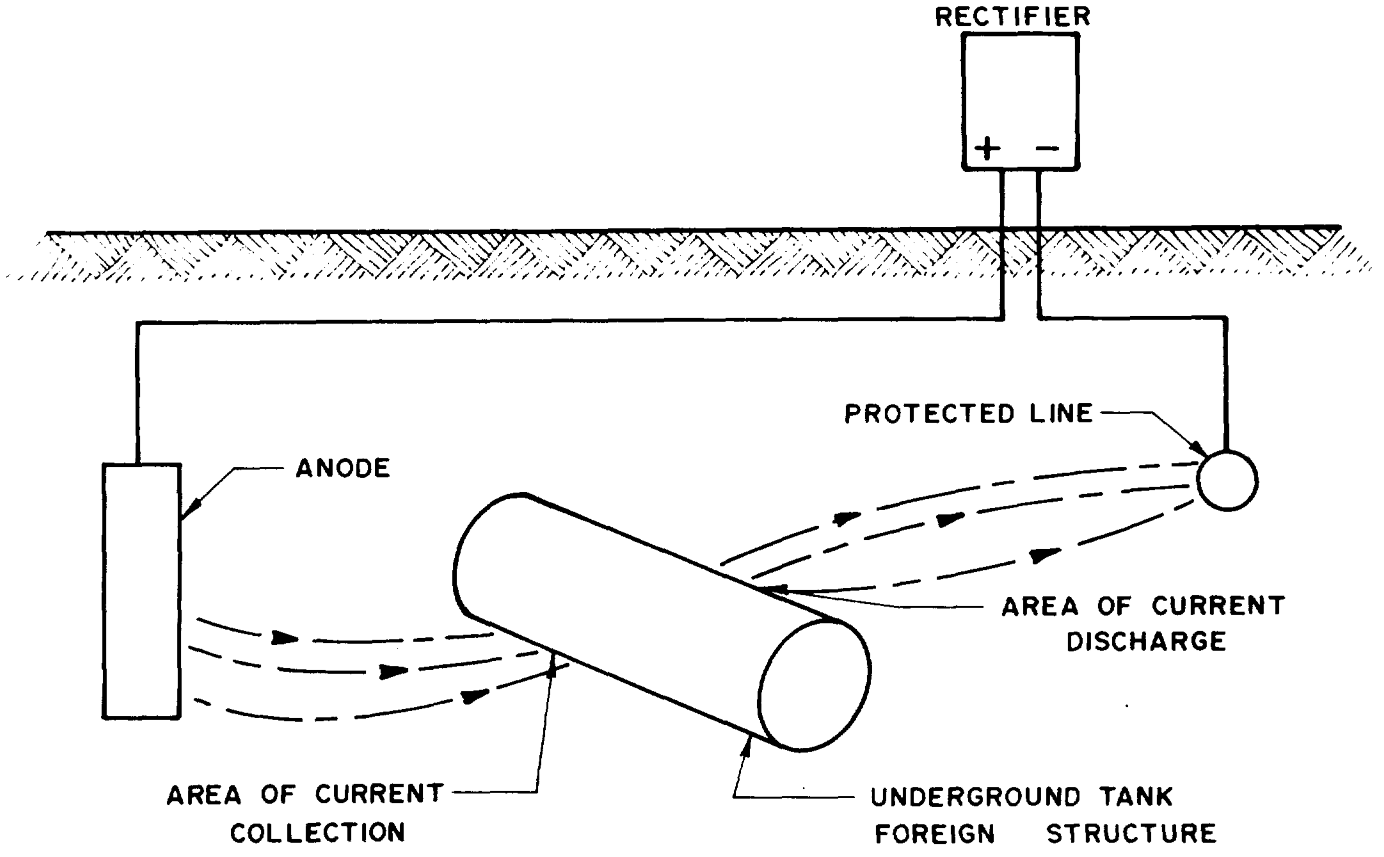


Figure 6-1. Small Area of Current Collection.

piping. The potential again rises and begins to increase sharply becoming cathodically protected from the nearby rectifier as it approaches the "foreign" pipeline (W. Trans Company). Pipeline T-4 is in a "pick-up" area. At the pipeline crossing, the potential drops sharply indicating a cathodic interference discharge point. Corrosion could be severe at that point without an interference bond. On the other side of the crossing the potential rises again into another "pick-up" area.

b. Following the higher broken graph line (pipeline with cathodic protection) the potential is raised above that of the unprotected line; however, at the side connection, a low point (−.80 V) is observed. Again, the insulated flange may be shorted and require replacement or additional cathodic protection may be needed. Following the graph, the potential in the interference "discharge" area is below −.85V; that is, −.75V. Note also, that "discharge" or corrosion could still be occurring at that point.

c. From the above explanation, much can be learned from plotting such a potential survey profile. Use of the method is highly desirable and, at times, mandatory for understanding potential survey results.

d. Another useful tool in analyzing and pinpointing corrosion interference problems is the measurement of IR (voltage) drop. By measuring the voltage drop between two test points or connections on a pipeline, it is possible to calculate the quantity of current flowing on the structure and its direction of movement. Attachments 15 and 16 describe the caluculation method and provide necessary data.

6-4. Locating the Interference Point. Structure-to-soil potential measurements should be made with the rectifier on to locate the point of most positive potential. Measurements should be made every 50 feet on pipelines to find the area of interference. Measurements should be made every foot in the area to pinpoint the location where the current is leaving the foreign pipeline (point of most positive potential). That point should be marked as the location where the reference electrode should be placed when making further tests.

6-5. Lead Wires. Two test lead wires should be bonded to the foreign structure and two wires bonded to the protected structure. One lead from each line will be used as the bond and the other as a test lead. The location of the test station should be near the point where the two pipelines cross or the point where the two structures are nearest to each other.

NOTE: If the foreign structure does not belong to the government, permission for the bonding of the test leads should be scheduled with the owner so that the corrosion engineers from that organization can be present during the test. Each engineer should have a copy of the test data and should sign the data sheet as a witness.

6-6. Structure-To-Soil Potential Measurements. With the rectifier from the protected line (the one causing the interference) turned on, measure and record the structure-to-soil potential using one of the test leads from the foreign structure and placing the reference electrode

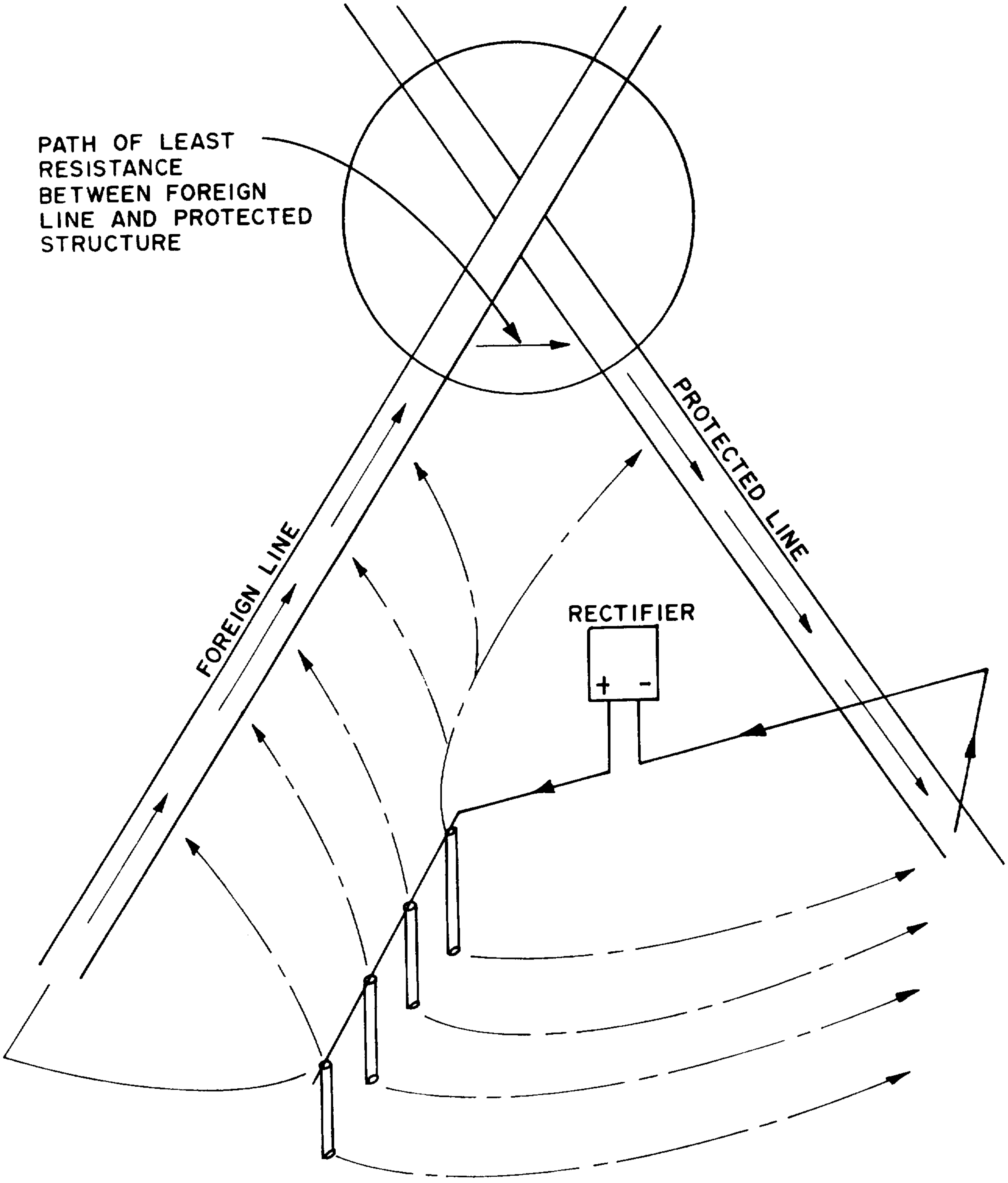


Figure 6–2. Large Area of Current Collection.

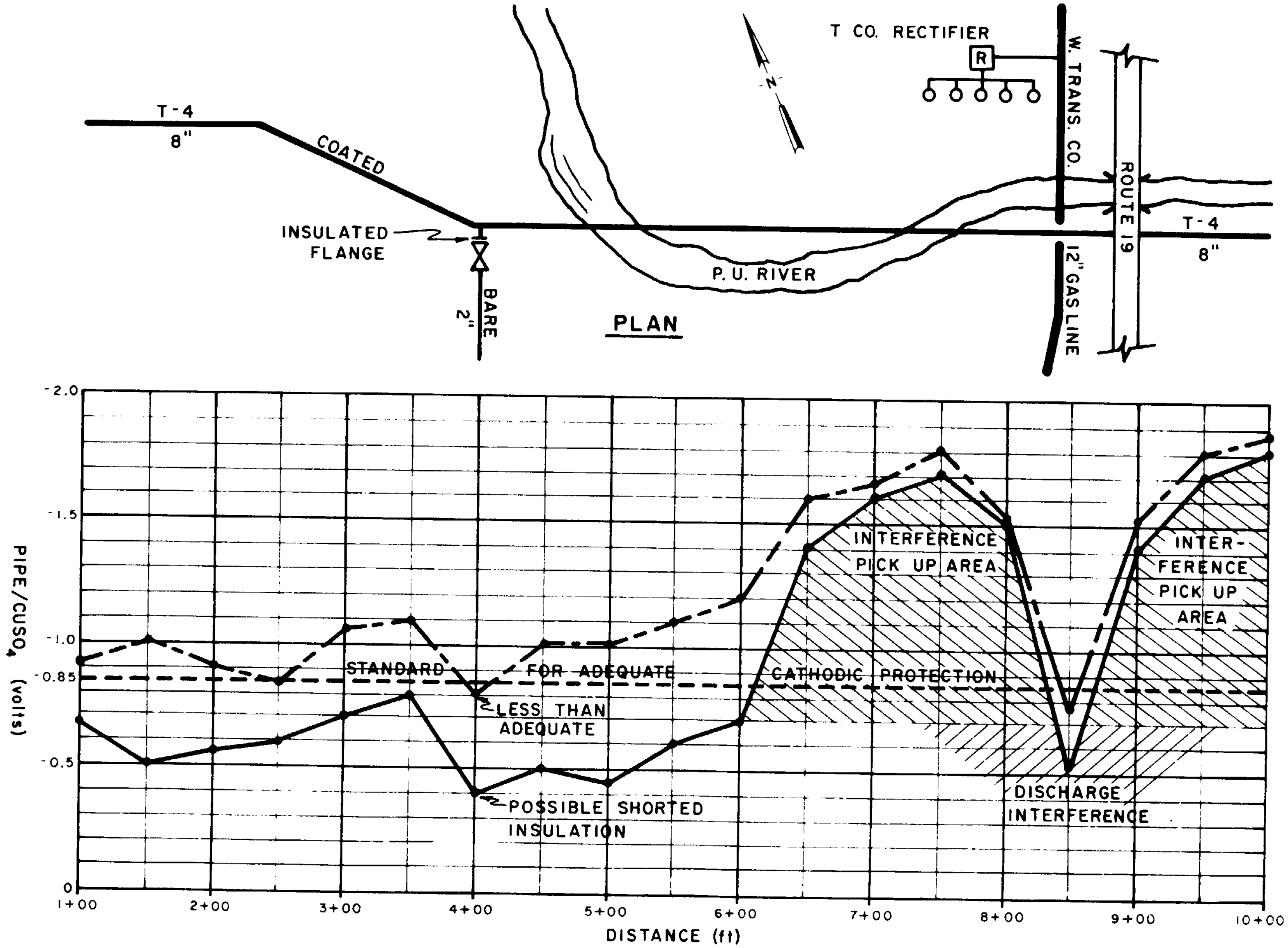


Figure 6–3. Structure Potential Survey Profile.

directly above the point of interference found in paragraph 6-4. The Miller M-3-M multimeter should be used to get the best accuracy. Turn off the rectifier connected to the protected line, then measure and record the structure-to-soil potential at the same point. If the foreign pipeline is protected by impressed current, turn the nearest rectifier(s) on the foreign line off, then measure and record the potentials as described above. These tests indicate how the interfering rectifier on the protected line affects the foreign line's native state potential (no cathodic protection). Interference is corrected when the interfering rectifier does not cause the potential of the foreign line to go more positive than its native state potential.

6-7. Sizing the Resistance Bond. The potential at the interference point should become more negative when the rectifier from the protected structure is turned off (see table 6-1):

a. Connect one of the test leads from the foreign pipeline to one of the test leads from the protected pipeline. Repeat the measurements outlined in 6-6 above. The potential of the foreign pipeline should be approximately the same as the potential of the protected pipeline. Disconnect the test leads. This tests the 100 percent bond.

Table 6-1. Interference Test.

Rectifier on the Protected Line
No Rectifier on the Foreign Line or
Foreign Line Rectifier Turned Off

Without Bond			
Foreign Line		Protected Line	
On	Off	On	Off
−.76	−.79*	−.92	−.75
Indicates Interference		Indicates Protection	
With 100 percent Bond			
Foreign Line		Protected Line	
On	Off	On	Off
−.90	−.77	−.90	−.77
With Resistance Bond			
Foreign Line		Protected Line	
On	Off	On	Off
−.79**	−.76	−.91	−.76

Resistance: 37 ohms
Current: 100 milliamperes

Rectifier Protected Line On:	Current Flow from Foreign Line to Protected Line.
Rectifier Protected Line Off:	Current Flow from Protected Line to Foreign Line.

NOTE: On and off refers to interrupting the rectifier and not the bond.

*The foreign line's native state potential.

**Goal is to adjust this value with the resistance bond to equal the native state potential. Achieve −.80 (slightly more negative than native state potential) if the foreign line is cathodically protected.

b. Connect either a piece of nichrome wire or a slide wire resistor between the two test lead wires to create a resistance bond. Vary the resistance between the two pipelines until the structure-to-soil potential of the foreign line with the interfering rectifier on is equal to the foreign line's native state potential (no bond and all rectifiers off). If the foreign line is under cathodic protection, the bond should be adjusted until the structure-to-soil potential of the foreign line is slightly more negative with the projected line rectifier on than the foreign line's native state potential. Hopefully, when the foreign line's rectifier(s) is turned on the structure-to-soil potential of the foreign line will be −.85 volts or more negative so that both systems are protected, (see table 6-1). Also, adjusting the rectifiers on the protected and foreign lines may eliminate the interference altogether, making the resistance bond unnecessary.

c. Measure and record the value of resistance needed to solve the interference problem. Also measure and record the amount of current flow through the resistor. The polarity of the meter should be noted so the direction of current flow can be determined.

6-8. Alternate Method of Controlling Cathodic Interference. Under some conditions, bonds to solve interference problems do not work satisfactorily or are too costly to install. An alternate method to control cathodic interference is to install a sacrificial anode or anodes at the point of interference. The sacrificial anodes will serve as a better ground where the collected current can leave the foreign structure and return to the protected structure. The sacrificial anodes should be conected to the foreign structure and installed on the side of the foreign structure nearest to the protected structure. The sacrificial anodes should be located 15 to 25 feet away from the foreign structure if conditions permit. Probably more than one sacrificial anode will be required to provide a design life of 20 years. A combination of soil resistivity and current drain should be used to determine the number and size of sacrificial anodes needed.

6-9. Corrosion Coordinating Committees. To better accomplish interference and stray current testing, corrosion personnel in various areas of the country have formed organizations known as regional corrosion coordinating committees. The committees are generally composed of utility companies, industrial, and government representatives. These committees serve the purpose of coordinating all the testing activities, providing rectifier installations information to members, and maintaining records of installations. In keeping with this corrosion control practice, corrosion personnel are encouraged to participate in such organizations if they exist in their area.

Chapter 7

PROTECTIVE COATINGS

7-1. General Information. Installation of a good protective coating is essential to economically achieve cathodic protection on utility systems. Whereas coatings constitute a corrosion control measure, they are not by themselves the perfect answer to corrosion control. Coatings plus cathodic protection provide the most effective means of limiting corrosion. In principle, coatings prevent corrosion by physically separating a metal structure from the electrolyte or corrosive environment. In that respect, coatings directly influence the need for and the effectiveness of CPSs. Ideally, if a structure could be completely covered with an electrically insulating coating, and remain that way, there would be no current flow and no need for cathodic protection; however, in practice, that does not occur and coatings must be complemented with cathodic protection wherever possible.

7-2. Bare or Damaged Spots (Holidays). While it is obvious that a good continuous unbroken coating will reduce corrosion, it is not so apparent that corrosion may be accelerated at the bare or damaged spots (holidays). While the rate of corrosion depends upon the current density at the surface of the metal, a small electric current leaving the very small area of bare metal at a holiday will create a high current density. This will cause deep pitting and premature structural failure.

7-3. Types of Coatings. The number, composition, and types of coatings are great and beyond the scope of this publication; however, broad classification is made according to two general kinds of structures:

a. Buried structures such as pipelines, fuel oil storage tanks etc., are usually covered with built-up coatings or more recently, "thin-film" polymeric coatings. Common examples of these coatings are hot coal tar reinforced with pipe wrapping impregnated with bituminous binder and recently, epoxy and extruded polyethylene coatings. These coatings are resistant to moisture, electrical, and physical damage.

b. Immersed structures such as elevated water storage tank interiors, condenser pans, condensate receiver tanks, etc., are usually painted with coatings having bituminous, rubber, epoxy, or vinyl bases. These types of coatings are also resistant to moisture, electrical, and physical damage.

7-4. Handling, Storage, and Construction of Coated Facilities. The effectiveness of any coating may be impaired through physical damage. Proper storage and handling must be accomplished as follows:

a. **Handling.** Coated materials will be handled with equipment designed for that purpose at all times. Equipment such as wide canvas or nylon slings, end hooks, padded clamps, and wide padded skids will be used to prevent coating damage (figure 7-1). Bare cables, chains, metal bars, narrow skids, or unpadded forks should not be permitted to come into contact with any coating.

b. **Storage.** Any location where coated structures are stored, should be free of rocks, sticks, and other sharp objects that could damage coatings (figure 7-2). Storage locations should be in an atmospheric environment that would not create coating deterioration or damage. Where possible, coated materials such as pipe should be stored undercover and away from direct sunlight. Proper stacking of stored coated items such as pipe is essential to prevent coating damage.

c. **Construction.** During construction, coated pipe requires particular handling. Pipe should not be dragged or shifted into position for welding or fitting purposes. Belt slings or padded clamps must be used to move pipe. Prying, wedging, or hammering of coating is not recommended. Ditch bottoms and sides should be clean and free of sharp objects. Under no circumstances should skids or other supporting materials be placed in the ditch to remain after construction. Backfill material should be clean, uniform, and nondetrimental to coatings or structures.

7-5. Coating Damage. In addition to the coating damage described above, damage may occur in other ways, that is, by careless or improper use of corrosion control and cathodic protection techniques.

a. **Mechanical Damage.** Probe bars for corrosion testing must not be driven into the soil to make contact with coated pipe. Damage that results from excavation of adjacent facilities must be repaired. Installation of test leads, bonding conductors, or anode leads will require coating removal. After leads have been attached, coating must be repaired.

b. **Electrical Damage.** Electrical damage to a coating may be caused by excessive voltage from a holiday detector or by excessive structure-to-earth potential applied by an impressed current system. The following empirical formula defines the voltage to be applied by the holiday detector:

$V = K\sqrt{T}$

Where V = peak voltage output (kilovolts).

T = thickness of coating in mils (do not include wrappers).

K = constant depending on type of coating (1.0 for somastic, 1.25 for coat tar, 1.5 for epoxy or plastic).

The voltage will pinpoint the holidays, but will not further damage the coating. Measuring the holiday detector voltage in the field requires a special high-voltage-pulse voltmeter. The formula will determine the output voltage capacity of the holiday detector needed. To adjust the detector to the proper voltage in the field, the procedure outlined in the manufacturer's instructions should be used.

c. **Cathodic Protection Damage.** It is possible to

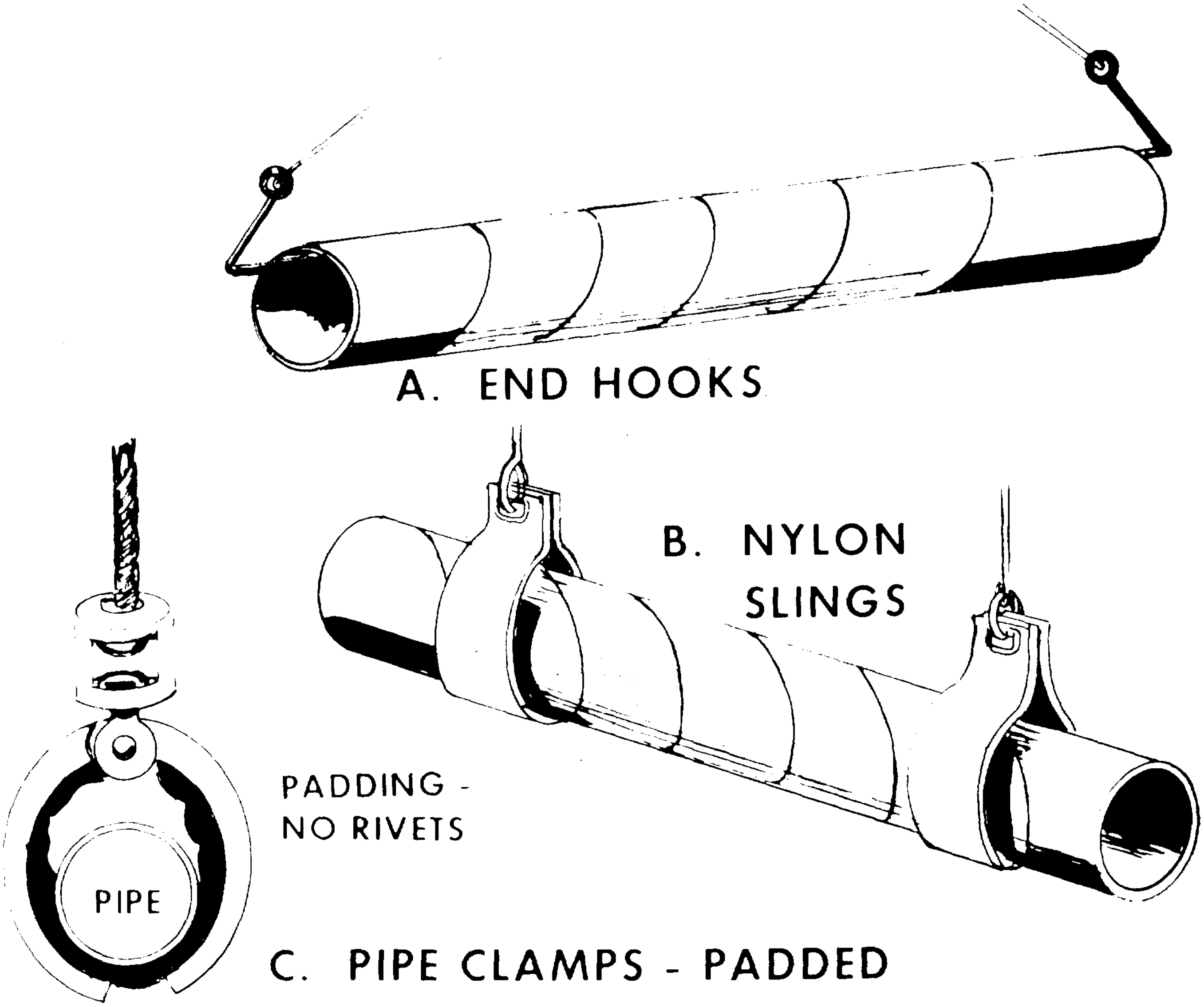


Figure 7-1. Proper Coating Handling.

cause extensive coating damage through improper rectifier operation. This results from maintaining excessive structure-to-electrolyte potential. For this reason, it is imperative that the cathodic protection criteria be followed. The following empirical formula specifies the maximum ferrous structure-to-earth potential at all points on a structure which will not cause coating damage:

$$E = (125P^{0.3} + 600)$$

Where E = potential in millivolts.
P = resistivity in ohm-cm.

This will limit the ferrous structure-to-earth potential in the vicinity of the rectifier connection. The table below lists the safe maximum potential limits for specific resistivities as calculated, using the above formula:

P (ohm-cm)		E (volts negative)
2,000	-	1.8
3,000	-	2.0
5,000	-	2.2
10,000	-	2.6
15,000	-	2.7
20,000	-	3.0
30,000	-	3.3
40,000	-	3.6

Potentials listed are too high for coated aluminum and lead structures and will result in chemical deterioration of the metal. See paragraph 4-3 for maximum limits on aluminum and lead. Water storage tank potentials should be limited to −1.5V maximum to prevent coating damage.

d. Miscellaneous Coating Damage. Damage or defects in coatings may also be caused by:

(1) Damage to coating by subsequent construction (probe bars for pole installation, etc.).

(2) Cracks from excessive thermal or mechanical stresses.

(3) Action of chemicals in the earth surrounding a pipeline.

(4) Action of bacteria in the soil surrounding a pipeline.

(5) Flaws in the coating material as applied.

(6) Failure to properly field-coat joints when exten-

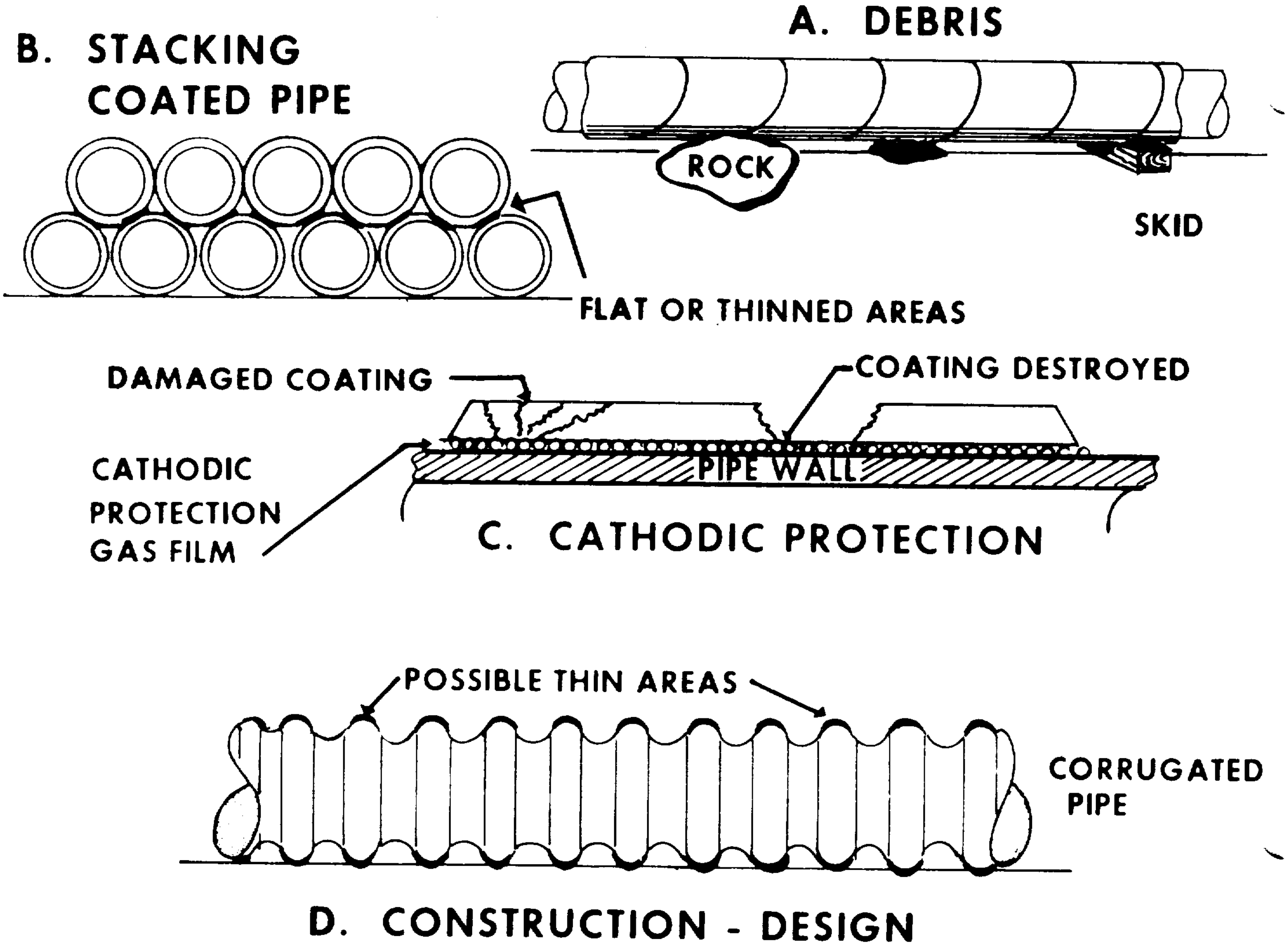


Figure 7-2. Examples of Coating Damage.

sions or modifications are made to a coated pipeline.

e. **Coating Aging.** As coatings age, they become less effective as electrical insulators. As the coating loses its insulating properties, it allows current to flow out of the surface of the structure and corrosion to take place under the coating film. For this reason, the amount of current needed to give adequate protection becomes greater. It is important that any breaks in a coating be carefully repaired before the structure is placed in service. During the life of the structure, any breaks found in protective coatings must be repaired.

7-6. Coating Repair. During the inspection of any coated structure, damaged or missing coating will be repaired immediately with coatings equal to or better than the original coating. In all cases, coatings will be compatible for use on buried or submerged structures and should follow coating specifications and standards covered in NACE RP-01-69, Control of External Corrosion on Underground or Submerged Metallic Piping Systems. Large scale repairs of coatings will be brought to the attention of the operations superintendents for programming action.

7-7. Materials and Methods of Application:

a. **Materials.** Many products are available in tape and liquid form for coating repair. The design of any coating system must be based on specific use and operation of the structure. Manufacturer's recommendations for application of their coatings and primers should be followed. Coatings for repair work should be kept in stock (standby) for use as needed.

b. **Methods of Application:**

(1) Underground Piping. As illustrated in figure 7-3, coating repairs are usually made in one of three ways; spiral wrapping with overlap, cigarette wrap, and dripping or ragging. Tape is generally preferred because of ease and safety during application. Spiral wrapping the tape is preferred because of greater strength. Ragging with hot wax or coal tar is useful in coating objects with very irregular surfaces, for example, valves, couplings, etc.

(2) Miscellaneous Equipment—Interior Coatings. Repair of paint-type coatings, such as epoxies, urethanes, vinyls, etc., is accomplished in the manner directed by each manufacturer; however, any repair of coating re-

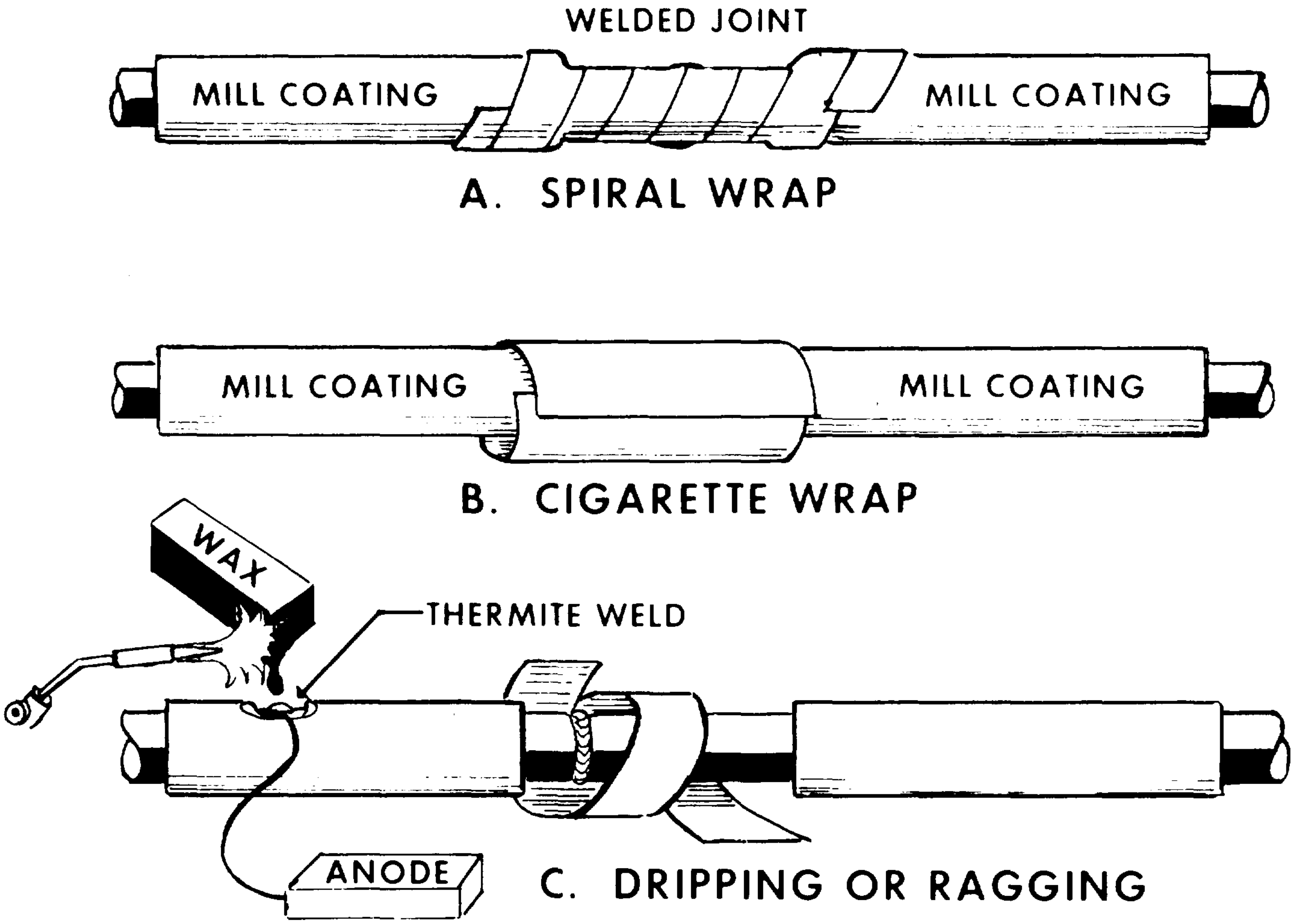


Figure 7-3. Coating of Field Joints.

quires surface preparation such as wire brushing or sand blasting before coating.

c. **Inspection.** Coating must be electrically inspected with a holiday detector set to proper voltage when extent of repair involves coated pipe greater than 100 feet in length. See paragraph 7-5b for proper voltage settings.

Chapter 8

INITIATION AND MAINTENANCE OF RECORDS

8-1. General Information. The success and effectiveness of a cathodic protection program depends on periodic servicing of installed systems. Corrosion control by cathodic protection can be very effective *when maintained adequately*. The operation of CPSs requires that certain records be kept and reports made. These records, when taken together, provide a history of the CPS telling what, when, where it was installed, what care has been given the system, and whether the system is doing its job.

8-2. Terms Explained:

a. **Annual Cathodic Protection Performance Survey.** Bases that have cathodic protection installed must check all protected facilities each year to determine if each system is receiving adequate protection. Facilities that have dielectric insulation installed to separate dissimilar metals must also be checked to determine adequacy of electrical isolation.

b. **Initial Base-Wide Survey.** The initial cathodic protection survey is performed by an Air Force team or architect-engineer (A-E) to determine the requirements for installing cathodic protection. Some bases will need protection on 100 percent of their systems, while others might not need any cathodic protection.

8-3. Equipment Maintenance Program Records. Maintenance action sheets must be developed as explained in AFR 85-1, Resources and Work Force Management, to allow time to perform the testing required by AF Forms 491, Cathodic Protection Operating Log for Impressed Current System; 1686, Cathodic Protection Operating Log for Sacrificial Anode System; 1688, Annual Cathodic Protection Performance Survey; and 1689, Water Tank Calibration, for all installed CPSs.

a. Keep the various cathodic protection forms in the facility jacket folder for the CPS, category code 890-269. Keep equipment maintenance records and maintenance action sheets according to AFR 85-1. Establish a separate collection work order number (cost account code 53070 for base and X7500 for housing) for the time expended by the CPT to include the following:

(1) Annual performance survey.

(2) Monthly rectifier checks.

(3) Biannual sacrificial anode checks.

(4) Maintenance of rectifiers.

(5) Maintenance of ground beds.

(6) Maintenance of sacrificial anodes.

(7) Maintenance of dielectric fittings.

(8) Maintenance of cathodic protection for water heaters.

(9) Inspection of leaks.

b. Establish a separate collection work order number (cost account code 13000) for the time expended by the base corrosion engineer.

8-4. Comprehensive Master Plan. TAB G-8 of the master plan, CPS, must show all installed rectifiers, ground beds, and magnesium anodes. Reflect all changes in system design on TAB G-8. The corrosion engineer is responsible for updating the master plan as needed.

8-5. Cathodic Protection Records. The corrosion engineer must keep a cathodic protection program record. The record must be in a tabulated form as shown in attachment 9 and must include the installed and proposed installation of CPSs. List an accurate description of all facilities protected under each project. If only a portion of a particular system is protected, list the percentage that applies. The "utility system protected" description must be in detail including rectifier size and number of anodes.

8-6. Technical Records. The corrosion engineer at each installation must keep a file of technical records on each installed CPS. These technical records must include, but not be limited to, items such as:

a. Cathodic Protection Annual Performance Booklet. This booklet must be updated each year and sent to the MAJCOM for evaluation. The booklet must be prepared according to attachment 17 and must be sent to command headquarters by 1 February of the following year.

b. Manufacturer's data on installed equipment.

c. Operating instructions.

d. Lists of repair parts.

e. Names and addresses of sources of parts and service.

f. Current price lists.

g. Repair and maintenance instructions.

h. Construction specifications.

i. Shop drawings.

j. As-built drawings showing the location and extent of each CPS, any modification made during the life of the system, and the exact location of each rectifier, anode bed, and test station.

k. All underground utilities must be shown on a base layout map (such as in TAB G-8 of the comprehensive master plan) and installed in the office of the corrosion engineer to describe systems receiving cathodic protection. Mount the map or maps over a fibrous board or boards. Place a colored head pin at each point where a leak or failure is attributed to corrosion. Leave the pins in place for at least 5 years and use a different colored pin for each calendar year:

(1) If several leaks occur on the same system during a year in the same location, use the same color pin; however, note on the map the dates that the leaks occurred.

(2) At the end of 5 years, it will be necessary to review and update those base maps. Always keep a file of old maps.

(3) Transfer the old map data to the new map so that a continuous history can be maintained. Delete the markings that are over 5 years old if the map is crowded.

l. In addition to the base layout map pinpointing leaks, the cathodic protection technician (CPT) or the corrosion engineer must inspect all leaks in underground utilities and complete AF Form 1687, Leak/Failure Data Record. At all leak sites, it is imperative that the cause of the failure be found and remedial actions taken to prevent recurrence.

m. File the following technical records in the program development section of the cathodic protection facility jacket folder. The requirements specified in this publication are in addition to those of AFR 85-1. The corrosion engineer must validate the contents of these files:

(1) AF Form 491, attachment 3.
(2) AF Form 1686, attachment 5.
(3) AF Form 1687, attachment 6.
(4) AF Form 1688, attachment 7.

n. Before utility leaks are repaired, the operations production work control supervisor must notify the corrosion engineer or the CPT of the leak and the approximate time the excavation will be complete and ready for inspection.

8-7. Air Force Forms:

a. **AF Form 491, Cathodic Protection Operating Log for Impressed Current System:**

(1) This log must be kept on a monthly basis. The CPT must make entries in column 10A through M every calendar month, and verify that information recorded in blocks 1 through 9 is correct. Each month, submit the log to the corrosion engineer for evaluation.

(2) This monthly log includes the readings of four check or test points, the location of which must be given on AF Form 491. Those test points must be selected each year from the annual performance survey. Some of the test points will remain the same from year-to-year, while others may change each year.

(3) For monthly readings on water storage tanks, see paragraph 9-14 of this publication.

(4) Complete AF Form 491 in duplicate and keep one copy in the cathodic protection facility jacket folder and the other copy in the cathodic protection annual performance booklet. Attachment 2 contains instructions for completing AF Form 491.

b. **AF Form 1686, Cathodic Protection Operating Log for Sacrificial Anode System.** This log is kept on a biannual basis and entries in the log are made by the CPT in columns 7A through H, making sure that all the basic information in blocks 1 through 6 is correct. Submit this log to the corrosion engineer for evaluation. Approximately 10 percent of all sacrificial anodes in a system must have test stations. Monitor each of the test stations using a separate log. Complete the log in duplicate, keeping one copy in the cathodic protection facility jacket folder and the other copy in the cathodic protection annual performance booklet. Attachment 4 contains instructions for completing AF Form 1686.

c. **AF Form 1687, Leak/Failure Data Records:**

(1) The corrosion engineer or CPT must inspect all leaks or failures and complete the form as required. The corrosion engineer is primarily responsible for performing inspections and records maintenance. In the absence of the corrosion engineer, the CPT must accomplish the tasks and submit all copies of the form to the corrosion engineer for review and further dissemination. One copy must be placed in the facility jacket folder, one copy in the cathodic protection annual performance booklet, and one copy sent to the MAJCOM. When a leak is found to be caused by corrosion, make an entry on the base layout map according to paragraph 8-6k.

NOTE: The completed copy submitted to the MAJCOM should be sent immediately.

(2) Before the excavation is backfilled, the corrosion engineer must decide whether to install sacrificial anode(s). If the piping system is protected by an impressed current type CPS, the corrosion engineer must decide whether the rectifier current output is adequate or what adjustments are needed. Perform the planning, programming, and scheduling according to the provisions of AFR 85-1.

(3) During the repair of corrosion leaks, it is desirable to make color photographs of the failed structure. Color slides in sharp focus will be acceptable if color photographs cannot be made. Keep one slide of each leak at the base with the leak record and send one to the MAJCOM.

d. **AF Form 1688, Annual Cathodic Protection Performance Survey.** AF Form 1688 is a survey worksheet to be used for the annual survey conducted by the base CPT and engineer. The purpose of the survey is to check the total system and to show the degree to which the system is performing and meeting its intended purpose. Structure-to-soil potential measurements should be made at each building service line and at various other points along each distribution line that is protected by CPSs. The corrosion engineer must evaluate the data to determine the performance of the system. Using AFR 85-1 and the annual work plan, the corrosion engineer must initiate changes, improvements, or readjustments wherever there are indications that parts of the system are not properly protected. Complete the form in duplicate. Keep one copy in the cathodic protection facility jacket folder and the other copy in the cathodic protection annual performance booklet. The MAJCOM corrosion engineer will review the survey data to determine if necessary or appropriate action has been taken by the base and to evaluate the base's cathodic protection program.

8-8. Disposition of Documentation. The documentation created by this regulation will be kept and disposed of according to AFM 12-50, Disposition of Air Force Documentation.

Chapter 9

REQUIRED SURVEYS AND TESTING

9-1. Annual Cathodic Protection Performance Survey. An annual cathodic protection performance survey is required to make sure that complete protection is given to all structures needing cathodic protection. Perform the planning, programming,˙ and scheduling as outlined in AFR 85-1. The first survey should be made within 6 months after installing the CPS. This survey will indicate the adequacy of the newly installed system. Note all deficiencies and initiate corrective actions immediately. The annual performance survey is concerned only with structures with installed CPSs or structures which are insulated or isolated electrically from another structure to prevent electrolysis due to dissimilar metals.

9-2. Potential Measurements Survey. Ample potential measurements must be taken to make sure that all facilities and structures are protected. Time required to make the survey will vary according to the size of the base and existing cathodic protection. Normally, it is expected that approximately 6 to 8 weeks with two people will be needed at larger bases. It is important to make the potential measurements at the same locations each time. The correct location of the reference electrode is directly over the structure tested. When testing a sacrificial anode system, the reference electrode should be located as described in paragraph 4-6.

9-3. Measurement Comparisons. Make comparisons between recent measurements and those taken at the last annual survey to determine where changes have occurred and to plan the necessary corrections. Determine the required DC output of each impressed current system by the trial-and-error method. First, make sure that the low potential points are at a protective level and then that the higher potential points do not exceed the maximum allowed in paragraph 4-3. The current output determined in this manner should be kept throughout the following year by adjusting the DC voltage of the rectifier as needed.

9-4. Magnesium Anodes. Magnesium anodes must be carried as a standby level supply item where consumption does not justify a demand level. They should be installed as needed to maintain a protective potential.

9-5. Underground Piping Systems. Underground piping systems or structures that are not cathodically protected but have dielectric insulation installed to prevent electrolysis must be checked annually to ensure the effectiveness of electrical isolation. Record the results of these tests on AF Form 1688. Change the heading of the "ON" and the "OFF" columns to read "STREET SIDE" and "HOUSE SIDE" and perform a potential test on each side of the insulation.

9-6. Reduction of Rectifier Current. Frequently, polarization may allow reduction of rectifier current output while maintaining complete protection on the structure. Decreased outputs will extend the life of the ground beds and reduce operating costs.

9-7. Rectifier Adjustments:

a. After rectifier adjustments are made, resurvey the areas in question to determine that all affected areas are protected. All survey results and rectifier settings must be verified by the corrosion engineer and kept in the cathodic protection facility jacket folder and the cathodic protection annual performance booklet.

b. After it is determined that a system is inoperative, needs maintenance, or repair, notify the appropriate operations superintendent. The operations superintendent, with the assistance of the work authorization specialist, will take care of the problem.

9-8. Cathodic Protection Interference. Cathodic interference may cause corrosion to unprotected metallic piping or structures. Chapter 6 gives guidance for testing and correcting interference problems.

9-9. Cathodic Protection Communications. One of the most important items in connection with foreign line (non-Air Force) crossings is the matter of communications with the representatives of the foreign line companies involved, so that information relative to changes in corrosion control systems on existing foreign lines will be available. It is equally important to be aware of plans for new foreign pipeline construction in the vicinity of the Air Force base. Plans for cooperative interference tests and corrective bond design can be taken when there is danger of interference damage to either party. Perform the planning, programming, and scheduling according to the provisions of AFR 85-1.

9-10. Stray Current Electrolysis. It is also important that the corrosion engineer be alert for any information pertinent to stray current electrolysis in the area. Any change in the use of direct current on railway, transit lines, or in mining operations, for example, will enable the engineer to make corrosion control required modifications when these changes take place. If resistance bonds have been installed between pipelines for foreign line interference corrections, they require testing during the annual cathodic protection performance survey.

9-11. Rectifier Area of Influence. Use the map or maps in TAB G-8 of the comprehensive master plan to show graphically the limits of protection provided by each rectifier. Show the areas protected by two rectifiers by crosshatching. The following are procedures to determine limits for each rectifier area:

a. Install a current interrupter in the rectifier circuit at the most appropriate point. The interrupter should be set to provide unequal "on" and "off" periods so they may be easily recognized while measuring potentials. All other rectifiers should be on and adjusted to optimum operation.

NOTE: The rectifier should be turned off only a short period of time while attaching the current interrupter so that the structure will not depolarize. The maximum difference between "on" and "off" measurements of the pipe-to-soil potential occurs near the ground bed. As potential measurements are made along the line away from the ground bed, the change in potential provided by the rectifier will become smaller. When a point is reached where the "on" potential is no longer above −0.85 volts the "limit of adequate protection" has been established for that particular rectifier. The area of influence of the rectifier extends beyond that limit to a perimeter where a change in potential is no longer measured.

b. Using AF Form 1688, record the potential measurements of all facilities, for both the "off" and "on" readings, throughout the system being tested.

c. Plot the points of "limit of adequate protection" (−0.85 volts) determined in paragraph a for each rectifier system on a map similar to that used in TAB G-8 of the comprehensive master plan. Join all points by a line so that the rectifier is completely encircled. Use contrasting colors for adjoining rectifier systems.

d. Continue the above process for each rectifier installed. The areas which are covered by two or more circles receive protective current from two or more rectifiers. When increasing the potential of a point in those areas, each of the rectifiers supplying current to that area must be adjusted. If the low potential point is closer to one limit line than the other, the amount of adjustment should be made accordingly.

9-12. Ground Bed Maintenance. Ground bed maintenance must consist of visual inspections to make sure that there has been no disturbance of the earth above the anode bed and along the line of the header cable.

a. If construction work is to occur in the vicinity of the ground bed, stake the location of each anode and the route of the header cable.

b. If routine tests show a marked increase in resistance, make measurements to locate the break or anode that is not working.

c. Failed anodes may be located as described in paragraph 5-9b.

9-13. Deep Anode Beds. It would be advantageous for the current output of all anodes to be maintained equally. This will ensure the useful life of each anode to be the same. Perform the planning, programming, and scheduling as outlined in AFR 85-1, Resources and Work Force Management.

a. Measure the current output of each anode annually and record on AF Form 1688. Make all measurements with the current on continuously. Record the first set of measurements in the column marked "on."

b. If the current from any one anode exceeds the maximum limit of 1 ampere per square foot of anode surface, a resistor should be placed in series with that anode and adjusted to limit the flow.

c. After resistor adjustments have been made, the voltage of the rectifier should be adjusted until the total current output reads the required amount to obtain adequate protection indicated by structure-to-earth potential. Record the new rectifier setting at the top of the worksheet.

d. Retest the current output of all anodes and record in the "off" column. Change the off column to read "as left." Record all discrepancies or irregularities in detail on the reverse side of the form.

9-14. Water Storage Tanks. Physically inspect anodes in water storage tanks annually. Also, make water-to-structure potential measurements annually and adjust rectifier current to provide complete protection. A properly cleaned rubber raft may be used to get readings. Readings may also be taken through hand holes in the roof, if properly located. The amount of current needed to give complete protection will be determined from the annual survey and should be maintained throughout the following year by monthly adjustments, if required. Perform the planning, programming, and scheduling as outlined in AFR 85-1.

a. Location of the anodes in water tanks is not uniform in all installations and depends upon design, size, and other criteria. At least four test points on the tank wall must be set up at locations farthest from the anodes. Also, four points on the tank bottom farthest from the anodes must be established. Take readings between anode sections along the standpipe wall if the opening is not covered by a screen. Care must be exercised not to lower the electrode more than 6 to 8 feet to avoid entanglement with the anode string.

b. Testing of the water tanks should be done by recording potentials within 6 inches of the tank surfaces. In the riser pipe, the test should be made half-way between each anode and within 6 inches of the wall. The porous plug at the bottom of the electrode must not come in contact with the tank, otherwise, erroneous readings will result. To avoid contact, a plastic cap with the bottom cut out and slots cut in the sides can be fitted over the electrode's porous plug. An extended cap about 1 inch longer than the porous plug will prevent contact between the plug and the tank and the lots will allow any trapped air against the plug to escape. On new anode systems, readings should be made with the current off. After circuits have been on for 12 hours, the readings should be repeated.

c. For the annual inspection and potential measurements inside the water storage tanks, use AF Form 1689, Water Tank Calibration, (attachment 8) to record the tank-to-water potential at each electrode location. Tank-to-water potential readings with the rectifier off should be made on initial start up of new rectifier systems or if anodes have been replaced. During annual checks of operating systems, the "off" readings need not be taken.

9-15. Federal Safety Standards. Design and maintenance of facilities for natural gas, POL, and other hazardous pipeline facilities will comply with the minimum federal safety standards. Rules and regulations of the standards are outlined in the Federal Register, volume 35, number 161, Department of Transportation, Hazardous Materials Regulation Board, Transportation of Natural and Other Gas by Pipeline, Minimum Safety Standards.

9-16. Amendments to Standards. Amendments to the standards are available for clarification and updating of the standards. They can be obtained from the Department of Transportation, Office of Pipeline Safety, Wash., DC 20596.

9-17. Bonding Joints for Electrical Continuity. The following paragraph should be included in all maintenance, repair, or construction contracts and must be adhered to when work is done by the civil engineering forces:

> "All underground metallic pipe joints other than screwed or welded must be bonded using a No. 4 AWG polyethylene sheath copper conductor. The conductor must be attached to the pipe by thermit welding process. The area of the weld must be coated with the same material as used to protect the pipe or a heavy overall coating of coal tar enamel or epoxy resin mixture suitable for this use."

Properly coating the area where the wire is attached to the pipe is a "must" to prevent corrosion caused by the dissimilar metals of the wire and the pipe.

9-18. Underground and Aboveground Tank Potentials. Structure-to-soil potential measurements should be made at three locations for each buried tank. The multimeter can be attached to any aboveground piping that is continuous and has electrical continuity with the tank. The reference electrode should be placed directly over the centerline of the tank as described below:

a. **Tanks Covered by Earth.** One measurement should be made directly over the center of the tank and at each end of the tank (see figure 9-1). The reference electrode should be located approximately the same distance beyond the end of the tank as the depth from grade level to the bottom of the tank. The reference electrode should not be placed near where metallic piping or objects extend from the tank to the surface. Electrodes should be located a distance away from such objects equal to the depth from grade level to the top of the tank.

b. **Tanks Covered by Earth and a Building.** The above procedure should be followed with the exception of the end under the building. For that measurement, the electrode should be placed a distance away from the building equal to the depth from grade to the top of the tank (see figure 9-2).

c. **Aboveground Tanks.** Potential measurements should be made in each quadrant of the tank, as shown in figure 9-3. The measurement closest to the tank should have the reference electrode approximately 5 feet from the side. The reference electrode for the outer measurements should be located a distance equal to one-half of the tank diameter from the tank.

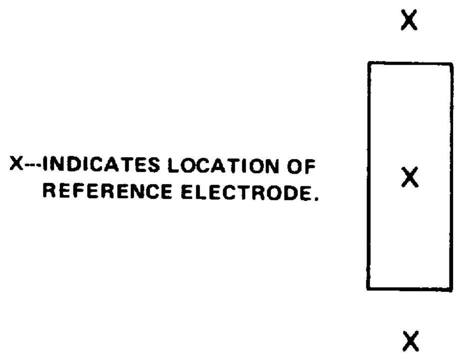


Figure 9-1. Tank Covered by Earth.

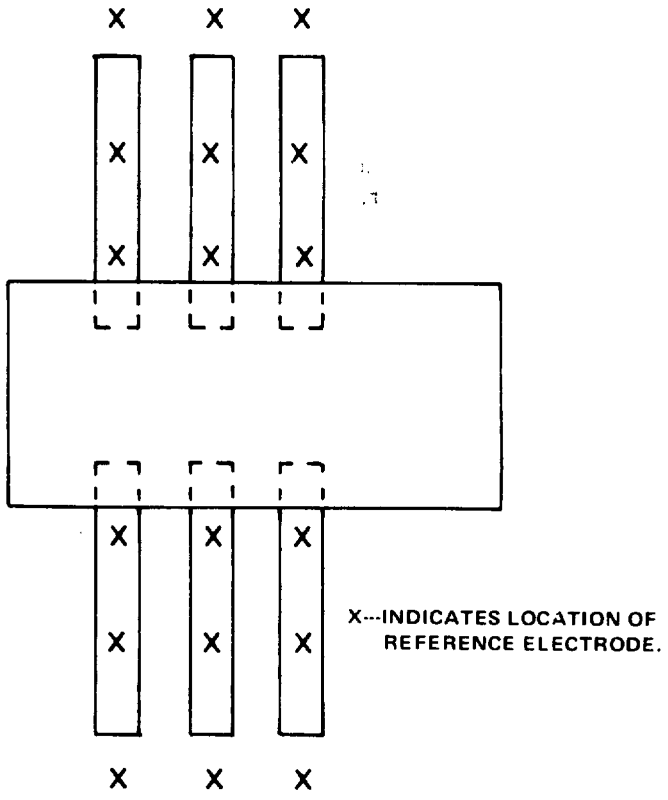


Figure 9-2. Tanks Covered by Earth and a Building.

9-19. Cased Crossing Maintenance. Where one metal pipe of a larger size is used as a casing to mechanically protect a metallic carrier pipeline, it is very important to insulate the carrier pipeline from the casing. Should a short circuit occur, the casing will divert the cathodic protection current from the carrier pipeline to the casing. This will leave the carrier pipeline without cathodic protection allowing corrosion to occur. Where casings exist, test station wires must be installed on both the carrier pipe and the casing to allow testing.

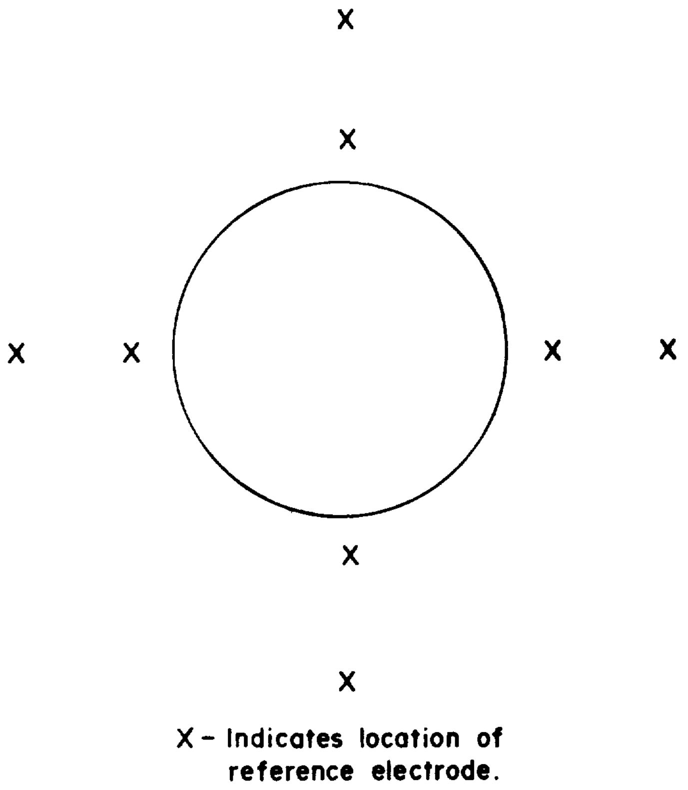


Figure 9–3. Aboveground Tank.

9–20. Test Point Maintenance. Test points are very important parts of the CPS, since they are the main locations at which measurements can be made. It is, therefore, essential that they be kept in good order. Perform the planning, programming, and scheduling as outlined in AFR 85-1.

a. Broken wires at test points present a problem if the break is not at the surface receptacle. If the test point is located close to the pipe connections, the effort required to locate and repair the trouble is a simple excavating job. Damaged conductors may be located using a pipeline locator. However, it may be necessary to make an over-the-line potential survey as outlined in paragraph 5-9b. In this event, a current interrupter and a 67 ½-volt radio "B" battery will probably be needed to supply a high enough voltage to locate the break in the test lead.

b. In many instances of shorted leads and some instances of open leads, it is more economical to install new leads than to locate and repair the fault.

BY ORDER OF THE SECRETARY OF THE AIR FORCE

OFFICIAL

LEW ALLEN, JR., General, USAF
Chief of Staff

JAMES L. WYATT, JR., Colonel, USAF
Director of Administration

SUMMARY OF CHANGES

This is a complete revision. AF Forms 1686, 1687, 1688, 1689 have been added and are shown as attachments 5 through 8.

GLOSSARY

Active Metal—Metal that is in a condition in which it tends to corrode.

Anaerobic—Absence of air or uncombined oxygen.

Anion—An ion that carries a negative charge. The cloride ion in seawater is an anion.

Anode—The less noble electrode of an electrolytic cell at which corrosion occurs.

Anode Cap—An electrical insulating cover or coating placed over the lead wire connection of an anode.

Bell Hole—An excavation to expose a buried structure.

Cathodic Protection—A technique to prevent the corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

Continuity Bond—A metallic connection that provides electrical continuity.

Corrosion—The deterioration of a material, usually a metal, because of a reaction with its environment.

Corrosion Cell—Consists of an anode and a cathode immersed in an electrolyte and electrically bonded together. The anode and cathode may be separate metals or dissimilar areas on the same metal.

Corrosion Rate—The speed at which a metal or alloy corrodes. This may be expressed in terms of loss in weight or loss of thickness in a given period of time. The common units are:

a. Inches penetration per year (Ipy.).

b. Mils penetration per year (Mpy.) for loss in thickness.

c. Milligrams per square decimeter per day (Mdd.) for loss in weight.

Corrosion rates in terms of thickness change refer to the loss of metal from one side only. Hence, for sheet metal that is exposed to corrosion on both sides, its total corrosion rate would be double the Ipy.

Couple—Two or more dissimilar metals or alloys in electrical contact with each other so that they can act as the electrodes of a cell if they are immersed in an electrolyte.

Current Density—The current per unit area.

Depolarization—Anything that reduces or prevents polarization and thereby acts to maintain the current of a corrosion cell at its initial value. Anodic and cathodic polarization reduce corrosion. Oxygen in seawater is a cathodic depolarizer and thereby accelerates corrosion of steel. High velocity can decrease anodic polarization by removing corrosion products and thus can accelerate corrosion of copper.

Dezincification—Corrosion of an alloy containing zinc in which the zinc is corroded away leaving copper.

Electrical Isolation—The condition of being electrically separated from other metallic structures or the environment.

Electrode—A metal or alloy that is in contact with an electrolyte and serves as the site where the electricity passes in either direction between the electrolyte and metal. The current in the electrode itself is a flow of electrons whereas, in the electrolyte, ions carry electric charges and their orderly movement in solution constitutes a flow of current in the electrolyte.

Electrode Potential—The potential of an electrode as measured against a reference electrode. The electrode potential does not include any loss of potential in the solution due to current passing to or from the electrodes, that is, it represents the reversible work required to move a unit charge from the electrode surface through the solution to the reference electrode.

Electrolyte—A chemical substance or mixture, usually liquid, containing ions that migrate in an electrical field. For the purpose of this manual, electrolyte refers to the soil or liquid adjacent to and in contact with a buried or submerged metallic structure, including the moisture and other chemicals contained in this publication.

Electromotive Force Series (EMF Series)—A list of elements arranged according to their standard electrode potentials. A hydrogen electrode is the standard reference and is placed equal to zero. All potentials are positive or negative with respect to the hydrogen electrode.

Electro-Osmotic Effect—Passage of a charged particle through a membrane under the influence of a voltage. Soil may act as the membrane.

Erosion—Sometimes called impingement corrosion. Destruction of a metal by the combined action of corrosion and abrasion or attrition by a liquid or gas with or without suspended matter.

Film—A thin layer of material that may or may not be visible.

Foreign Structure—Any structure that is not intended as a part of the system of interest.

Galvanic Anode—A metal which, because of its relative position in the electromotive series, provides sacrificial protection to metal or metals that are lower in the series, when coupled in an electrolyte. These anodes are the current source in one type of cathodic protection.

Galvanic Cell—A cell consisting of two or more dissimilar metals or alloys in contact with the same electrolyte.

Galvanic Series—A list of metals and alloys arranged in order of their relative potentials in a given environment. The order of their arrangement in this list may be different in other environments.

Graphitization (Graphitic Corrosion)—Corrosion of gray cast iron in which metallic iron is converted into corrosion products, leaving a residue of intact graphite mixed with iron corrosion products and other insoluble constituents of cast iron and having approximately the original dimensions and appearance of the casting.

Half Cell Reference Electrode—See Reference Electrode.

Holiday—A discontinuity of coating that exposes the metal surface to the environment.

Impressed Current—Direct current supplied by a device employing a power source external to the anode system.

Inhibitor (As Applied To Corrosion)—A chemical substance or mixture which when added in small amounts to a solution markedly decreases corrosion.

Insulating Coating System—All components comprising the protective coating, the sum of which provides effective electrical isolation of the coated structure.

Interference Bond—A metallic connection designed to control electrical current interchange between metallic systems.

Ion—An electrically charged atom or group of atoms.

Isolation—See Electrical Isolation.

Line Current—The direct current flowing on a pipeline.

Local Action—Corrosion caused by the flow of galvanic current between points on a metal surface.

Local Cell—A cell in which the driving force is due to the difference in potential between areas on a metal or alloy surface immersed in an electrolyte.

Microampere—1/1,000,000 of an ampere.

Milliampere—1/1,000 of an ampere.

Millivolt—1/1,000 of a volt.

Noble Metal—A metal that is so inert that it is usually found as uncombined metal in nature. It always exhibits a relatively large electropositive potential that is not dependent upon the existence of chemical films on its surface. Platinum, gold, and silver are noble metals.

Open-Circuit Potential—The difference in voltage between a structure and a reference electrode under a condition of no current flow.

Oxygen Concentration Cell—A cell existing on a metal surface due to the difference in oxygen concentration in the solution at one point as compared to another. Usually the area in contact with the solution with lower oxygen content, as in crevices, is the more active or anodic area.

Packaged Anode—An anode that is supplied completely surrounded by a selected conductive material. (Prepackaged).

Passive—A relatively inactive state wherein a metal displays a more noble behavior than normally anticipated.

pH—The pH of an electrolyte is a term used to express the effective hydrogen ion concentration. It ranges from pH = 1 to pH = 14. pH = 7 indicates a neutral solution. Values lower than 7 indicate an acid condition.

Pitting—Localized corrosion taking the form of cavities in the surface.

Polarization—A shift in potential, due to a flow of current. It is a complex reaction due to resistance effects (formation of gas film), alteration of the solution at the metal surface, and other factors.

Potential—The difference in voltage between two points.

Potentiometer—An electrical instrument used to measure voltage or potential without draining current from the surfaces being investigated.

Protective Current Density—The amount of current per unit area required to achieve cathodic protection.

Protective Potential—A term used in cathodic protection to describe the potential as measured against an appropriate half cell at which all anodic corrosion reactions can be assumed to be eliminated and protection achieved.

Reference Electrode—A device whose open-circuit potential is constant under similar conditions of measurement.

Reverse-Current Switch—A device that prevents the reversal of direct current through a metallic conductor.

Sacrificial Protection (Galvanic Protection)—Reduction or prevention of corrosion of a metal in an electrolyte by galvanically coupling it to a more anodic metal.

Stray Current—Current flowing through paths other than the intended circuit.

Stray Current Corrosion—Corrosion resulting from direct current flow through paths other than the intended circuit.

Structure-To-Soil Potential (Pipe-To-Soil Potential)—The potential difference between a buried metallic structure and the soil surface which is measured with a half cell reference electrode in contact with the soil.

Structure-To-Structure Potential—The difference in potential between metallic structures in a common electrolyte.

Voltage—An electromotive force or a difference in electrode potentials expressed in volts.

INSTRUCTIONS FOR COMPLETING AF FORM 491

1. Entries on AF Form 491 must be made on a monthly basis.
2. No readings of the structure-to-soil potentials are to be taken where the electrode is in contact with frozen ground.
3. Readings are to be made with the authorized meters only (see note under item 10 of instructions).

Item 1. **Installation.** Enter the official name and location of the installation as: HAMILTON AFB, CA. Do not abbreviate or use unit designations.

Item 2. **Year.** Enter the calendar year.

Item 3. **Protected Structure.** Enter the name of the protected structure and its number as shown on USAF Real Property Report (RCS: HAF-PRE(SA)7115) as "Water Tank 902" or "Gas piping system family housing."

Item 4. **Rectifier Number.** Enter the number of the rectifier as assigned by the corrosion engineer. Numbers are consecutive starting with number 1 and are conspicuously shown on the enclosure of the rectifier.

Item 5. **Rectifier Data** (from nameplate).
A. **Manufacturer:** Enter full name and address of manufacturer.
B. **Model Number:** Enter model number as shown on nameplate.
C. **Serial Number:** Enter serial number as shown on nameplate.
D. **AC Rated Capacity:** Enter AC voltage and phase.
E. **DC Rated Capacity:** Enter DC voltage and amperage.
F. **Date Installed:** Enter date installed. This information is to be obtained from the base corrosion engineer. Where no detailed information is available, estimate and enter approximate date.

Item 6. **Ground Bed Data:**
A. **Anode Material.** Enter the name of the material and alloy designation, if known, as "graphite," "aluminum 3003," or "high-silicon cast iron."
B. **Size of Anode.** Enter the dimensions or the standard size designation as 1½" x 60" or 3" x 60".
C. **Number of Anodes.** Enter number of anodes.
D. **Type of Backfill.** Enter the type of backfill used around the anodes as "coke breeze" or "natural soil."
E. **Date Installed.** Enter the date when the anode bed was installed.

Item 7. **Location Reference Drawing Number.** Location of rectifier and test stations as recorded on drawings. Enter number of drawing and sheet number for easy reference.

Item 8. **Current Required:** Enter the amount of current needed to give complete protection and the date such determination was made.

Item 9. **Location Description:** Enter a brief description of the location of the rectifier and test points so that they can be found easily, as "west leg of tower," "pole 468-1," "300 feet east of side entrance to Building 1450." The test points indicated here and in items 10H through 10K for recording values are the same test points.

Item 10. **Operating Record:**
Column A. The month tests are performed.
Column B. Enter the date of the month.
Columns C through G are readings of direct current only and must be taken with authorized instruments that are recently calibrated.
Columns C and E: Enter the DC voltage as found and before any adjustments are made in column C. At the same time, read the amperage as found and enter it in column E.
Columns D and F: Adjust voltage until the required DC level is reached (item 8). Enter the voltage obtained in column D and amperage value obtained in column F.
Column G. The corrosion engineer must compute the circuit resistance using ohms law.

$$\text{Resistance} = \frac{\text{voltage as adjusted}}{\text{amperage as adjusted}}$$

and enter that value in column G.

Column H. Test point 1 (referred to as "maximum potential area") must be determined using data obtained from the annual performance survey. This point is located closest to the ground bed and is to be taken over the structure in that area. Enter this value in column H. Care must be taken to read the correct polarity.

Columns I through K. Test points 2, 3, and 4 are the lowest potential points of the protected structure being protected by the rectifier. These test points must be determined using data obtained from the annual performance survey. They are subject to change as directed by the corrosion engineer. Enter values found for the appropriate points.

Column L. State whether soil is wet, moist, dry, or powdery. NOTE: For the testing of structure-to-soil potentials, only authorized multimeters and potentiometers will be used. For structure-to-electrolyte potential readings, the potentiometer circuit must be used. If the ground is frozen, do not take readings and state so in column L by entering "GF".

Abbreviate or use unit designations.

Item 2. **Year.** Enter the calendar year.

Item 3. **Protected Structure.** Enter the name of the protected structure and its number as shown on USAF Real Property Report (RCS: HAF-PRE(SA)7115) as "Water Tank 902" or "Gas piping system family housing."

Item 4. **Rectifier Number.** Enter the number of the rectifier as assigned by the corrosion engineer. Numbers are consecutive starting with number 1 and are conspicuously shown on the enclosure of the rectifier.

Item 5. **Rectifier Data** (from nameplate).

A. **Manufacturer:** Enter full name and address of manufacturer.
B. **Model Number:** Enter model number as shown on nameplate.
C. **Serial Number:** Enter serial number as shown on nameplate.
D. **AC Rated Capacity:** Enter AC voltage and phase.
E. **DC Rated Capacity:** Enter DC voltage and amperage.
F. **Date Installed:** Enter date installed. This information is to be obtained from the base corrosion engineer. Where no detailed information is available, estimate and enter approximate date.

Item 6. **Ground Bed Data:**

A. **Anode Material.** Enter the name of the material and alloy designation, if known, as "graphite," "aluminum 3003," or "high-silicon cast iron."
B. **Size of Anode.** Enter the dimensions or the standard size designation as 1½" x 60" or 3" x 60".
C. **Number of Anodes.** Enter number of anodes.
D. **Type of Backfill.** Enter the type of backfill used around the anodes as "coke breeze" or "natural soil."
E. **Date Installed.** Enter the date when the anode bed was installed.

Item 7. **Location Reference Drawing Number.** Location of rectifier and test stations as recorded on drawings. Enter number of drawing and sheet number for easy reference.

Item 8. **Current Required:** Enter the amount of current needed to give complete protection and the date such determination was made.

Item 9. **Location Description:** Enter a brief description of the location of the rectifier and test points so that they can be found easily, as "west leg of tower," "pole 468-1," "300 feet east of side entrance to Building 1450." The test points indicated here and in items 10H through 10K for recording values are the same test points.

Item 10. **Operating Record:**

Column A. The month tests are performed.

Column B. Enter the date of the month.

Columns C through G are readings of direct current only and must be taken with authorized instruments that are recently calibrated.

Columns C and E: Enter the DC voltage as found and before any adjustments are made in column C. At the same time, read the amperage as found and enter it in column E.

Columns D and F: Adjust voltage until the required DC level is reached (item 8). Enter the voltage obtained in column D and amperage value obtained in column F.

Column G. The corrosion engineer must compute the circuit resistance using ohms law.

$$\text{Resistance} = \frac{\text{voltage as adjusted}}{\text{amperage as adjusted}}$$

and enter that value in column G.

Column H. Test point 1 (referred to as "maximum potential area") must be determined using data obtained from the annual performance survey. This point is located closest to the ground bed and is to be taken over the structure in that area. Enter this value in column H. Care must be taken to read the correct polarity.

CATHODIC PROTECTION OPERATING LOG FOR IMPRESSED CURRENT SYSTEM

1. INSTALLATION: Dyess AFB Texas

2. YEAR: 1971

3. PROTECTED STRUCTURE: Housing Gas System

4. RECTIFIER NUMBER: 7

5. RECTIFIER DATA *(From Nameplate)*

A. MANUFACTURER: Good-All Ogallala, Nebr.

B. MODEL NUMBER:

C. SERIAL NUMBER:

D. AC RATED CAPACITY: VOLTS 120 PHASE 1

E. DC RATED CAPACITY: VOLTS 60 AMPS 40

F. DATE INSTALLED: JAN 1963

6. GROUND BED DATA

A. ANODE MATERIAL: CAST IRON

B. SIZE OF ANODE: 1½" x 60"

C. NUMBER OF ANODES: 16

D. TYPE OF BACKFILL: COKE BREEZE

E. DATE INSTALLED: JAN 1963

7. LOCATION REFERENCE DRAWING NO: 473 SHEET 3

8. CURRENT REQUIRED

DATE	ADJUSTED CURRENT *(AMPS)*
3 OCT 68	32
15 OCT 71	36

9. LOCATION DESCRIPTION

RECTIFIER: SOUTH SIDE BLDG. 1476 "C" STREET

TEST POINT 1: GAS LINE BLDG 1476 "C" STREET

TEST POINT 2: GAS LINE BLDG 7063 "F" STREET

TEST POINT 3: GAS LINE BLDG 4634 "G" STREET

TEST POINT 4: GAS LINE BLDG 43 FRONT STREET

10. OPERATING RECORD

		RECTIFIER					TEST POTENTIAL					
		VOLTS		AMPS			TEST POINTS *(Volts)*					
MO A	DAY B	AS FOUND C	AS ADJUSTED D	AS FOUND E	AS ADJUSTED F	CIRCUIT RESISTANCE G	1 H	2 I	3 J	4 K	SOIL CONDITION L	INITIALS OF TECHNICIAN M
JAN	3	29.0	34.5	26.3	31.3	1.1	-2.1	-.84	-.86	-.90	MOIST	DRE
FEB	7	34.5	41.1	34.5	31.6	1.3	-2.1	-.85	-.87	-.90	"	DRE
MAR	4	41.1	48.3	33.0	32.2	1.5	-2.2	-.86	-.87	-.91	"	DRE
APR	6	48.3	48.0	27.6	32.0	1.5	-2.2	-.88	-.86	-.92	"	DRE
MAY	17	48.0	44.0	28.2	31.4	1.4	-2.1	-.85	-.88	-.89	"	DRE
JUN	6	44.0	51.1	29.0	31.9	1.6	-2.2	-.85	-.86	-.90	DRY	DRE
JUL	3	51.1	32.1	34.3	32.1	1.0	-2.2	-.84	-.85	-.89	MOIST	DRE
AUG	9	32.1	38.1	35.2	31.7	1.2	-2.1	-.83	-.85	-.86	"	DRE
SEP	12	38.1	52.2	28.1	32.6	1.6	-2.0	-.79	-.80	-.83	DRY	DRE
OCT	15	52.2	54.0	32.0	36.0	1.5	-2.4	-.90	-.89	-.92	MOIST	DRE
NOV	3	54.0	54.0	32.0	36.0	1.5	-2.4	-.90	-.89	-.92	MOIST	DRE
DEC	7	54.0	66.5	30.0	37.0	1.8	-2.4	-.91	-.90	-.93	DRY	DRE

DATE: 20 DEC 71

SIGNATURE OF CATHODIC PROT. TECH.: Douglas R Evans

DATE: 22 DEC 71

SIGNATURE OF BASE CORROSION ENGINEER:

AF FORM JAN 81 491 PREVIOUS EDITION IS OBSOLETE.

REMARKS *(Date and Initials)*	CORRECTIVE ACTION *(Date and Initials)*
Oct. 15, 1971 Increased current output to provide a protective potential O.J.K.	
Dec. 7, 1971 Circuit resistance too high - Voltage output higher than rated capacity O.J.K.	Dec. 10, 1971 Tested Anodes & found one not Working. Lead wire had burned in ~~[illegible]~~. TWO Repaired wire which reduced circuit resistance to 1.4 ohms. O.J.K.

DATE	SIGNATURE OF CORROSION ENGINEER
20 Dec. 1971	Homer L. Bearce, PE

INSTRUCTIONS FOR COMPLETING AF FORM 1686

1. Entries on AF Form 1686 will be made biannually, or more often if required by the parent command.
2. No readings of the structure-to-soil potentials are to be taken where the ground is frozen.
3. Readings are to be made with the authorized meters only.

Item 1. **Installation.** Enter the official name and location of the installation as: MARCH AFB, CA. Do not abbreviate or use unit designations.

Item 2. **Year.** Enter the calendar year.

Item 3. **Protected Structure.** Enter the name of the protected structure and its number as shown on USAF Real Property Report (RCS: HAF-PRE(SA)7115) such as "Underground Gas Pipeline Capehart Hsg Nr 220".

Item 4. **Test Station Number.** Enter the number of the test station where the reading of the potential is to be taken. Test stations should be numbered consecutively starting with number 1 for the entire base.

Item 5. **Systems Data:**

A. **Number of Anodes.** From records, find the number of existing anodes on this system and enter it on the form. Also, note under remarks on back of form if any new anodes were installed during the last year and how many.

B. **Number of Test Stations.** Enter here the total number of test stations for this piping system. List the test stations by number.

Item 6. **Anode Data:**

A. **Type.** Enter the name of the anode, trade name, its manufacturer, and the name of the material, as "magnesium H-1" or "zinc."

B. **Size.** Enter the dimensions or the standard size designations as "2″ by 5′ long" or "17 lb," or "32 lb."

C. **Type of Backfill.** Enter the type of backfill used around the anodes as "prepackaged," or "bentonite," or "none."

D. **Location Description.** Enter a brief description of the location of the anode so that it can be located easily, as "gas line 50′ W to 10′ N of Building 2263."

E. **Date Installed:** Enter date of installation. This date will be supplied by the corrosion engineer. Where no detailed information is available, estimate and enter approximate date.

Item 7. **Operating Record:**

Column A. The month tests are performed.

Column B. Enter the date of the month of the survey.

Column C. Structure-To-Soil Potential At Test Station (Volts). This reading will usually be taken at the test station(s) of the system. Where no test stations are installed, readings must be taken at points as directed by the corrosion engineer. Enter the value found in column C.

Column D. Structure-To-Soil Potential Between Anodes (Volts). This is the potential-to-ground of the structure halfway between two anodes (or the most remote point of a structure from the anode protecting it). It is important to know how far the protection of an anode extends. Enter the value in column D.

Column E. Anode-To-Soil (Volts). This reading represents the open-circuit voltage of the anode with the structure (load) disconnected. Enter reading in column E.

Column F. Anode-To-Structure (Milliamps). Connect the milliamp meter between the structure and anode at the test station and enter the value in column F.

Column G. Soil Conditions. State whether soil is wet, moist, dry, or powdery. The condition of soil is approximately 1 foot below surface. If the ground is frozen, do not take readings and so state by entering "GF".

Column H. Initials of Technician: The initials of the CPT must be shown in this column.

Signatures: Each log must be signed by the CPT and the base corrosion engineer before submission to higher headquarters.

CATHODIC PROTECTION OPERATING LOG FOR SACRIFICIAL ANODE SYSTEM

1. INSTALLATION: GRAND FORKS AFB ND

2. YEAR: 1981

3. PROTECTED STRUCTURE: GASLINE TO WATER WELL NO. 3

4. TEST STATION NUMBER: 47

5. SYSTEMS DATA	6. ANODE DATA
A. NUMBER OF ANODES 117	A. TYPE MAGNESIUM
B. NUMBER OF TEST STATIONS 11	B. SIZE 17 lb
47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57	C. TYPE OF BACKFILL PREPACKAGED
	D. LOCATION DESCRIPTION 1 ANODE EVERY 200' STARTING AT WELL HOUSE
	E. DATE INSTALLED JANUARY 1981

7. OPERATING RECORD *(Complete on three month intervals)*

MONTH A	DAY B	STRUCTURE TO SOIL/WATER *(Volts)* C	REMOTE STRUCTURE TO SOIL/WATER *(Volts)* D	ANODE TO SOIL/WATER *(Volts)* E	ANODE TO STRUCTURE *(Milliamps)* F	SOIL CONDITION G	INITIALS OF TECHNICIAN H
JAN	6	-1.1	-.90	1.5	40	MOIST	JJK
FEB							
MAR							
APR	20	-1.0	-.88	1.4	35	MOIST	JJK
MAY							
JUN							
JUL	16	-.85	-.75	1.5	15	MOIST	JJK
AUG							
SEP							
OCT	7	-1.2	-.94	1.6	50	MOIST	JJK
NOV							
DEC							

DATE	SIGNATURE OF CATHODIC PROT. TECH.	DATE	SIGNATURE OF BASE CORROSION ENGINEER
DEC 15, 1981	Joel J. Keith, P.E.	DEC 16, 1981	Edw. Morrisette, Jr.

AF FORM JAN 81 1686

REMARKS *(Date and Initials)*	CORRECTIVE ACTION *(Date and Initials)*
15 OCT 81 Increased current output to provide a protective potential. JLB	
7 DEC 81 Circuit resistance is too high — voltage output higher than rated capacity. JLB	10 DEC 81 Tested anodes and found one not working. Lead wire had burned off. Repaired wire which reduced circuit resistance to 1.4 ohms. JLB

DATE	SIGNATURE OF CORROSION ENGINEER
Dec 18, 1981	David E. Sherr

LEAK/FAILURE DATA RECORD
(See INSTRUCTIONS on reverse side)

DISTRIBUTION *(Check appropriate box on individual form at time of distribution)*
(ORIGINAL) ☐ RETAINED BY ORIGINATOR ☐ TO CORROSION ENGINEER
☐ TO CORROSION ENGINEER FOR CATHODIC PROTECTION ANNUAL PERFORMANCE BOOKLET ☒ TO MAJCOM/DEEE

1. INSTALLATION: FAIRCHILD AFB,
2. DATE: JUNE 30, 197
3. FACILITY AND NUMBER: GAS LINE 1376
4. AREA: GAS LINE TO WATER WELL
5. DRAWING NO: 1736
6. AVERAGE TEMP: 50°F

7. FLUID TRANSPORTED OR STORED ☐ WATER ☒ GAS ☐ AVIATION GAS ☐ JP-4 ☐ STEAM ☐ CONDENSATE ☐ HI TEMP HOT WATER ☐ OTHER *(Specify)*

8. SIZE — DIAMETER: 6" — HEIGHT *(ft)*:
9. LINE DEPTH *(inches)*: 24
10. AGE *(years)*: 8
11. OPERATING PRESSURE *(lbs/sq in)*:
12. EXACT LOCATION OF LEAK:
13. TYPE OF FACILITY ☐ TANK ☒ PIPE ☐ CONDUIT ☐ OTHER *(Specify)*
14. TYPE OF COATING ☒ COAL TAR ☐ PLASTIC WRAP ☐ CONCRETE ☐ ASPHALT ☐ ENAMEL ☐ NONE ☐ OTHER *(Specify)*
15. STRUCTURE-TO-SOIL POTENTIAL — AS FOUND: −.63 — AS LEFT: −.87
16. SOIL (p^H): 6.4
17. CONDITION OF COATING ☒ GOOD ☐ DAMAGED ☐ POOR ☐ OTHER *(Specify)*
18. TYPE OF CATHODIC PROTECTION ☒ GALVANIC ANODE ☐ IMPRESSED CURRENT ☐ NONE
19. HISTORY OF REPAIR — DATE LEAK DISCOVERED: JUNE 14, 1972 — DATE LEAK REPAIRED: JUNE 15, 1972
20. SOIL RESISTIVITY *(Ohm/Cm³)* — 2½ FT DEPTH: — 5 FT DEPTH: 1200 — 10 FT DEPTH:
21. MATERIAL ☐ CAST IRON ☐ STEEL GALVANIZED ☐ COPPER ☐ WROUGHT IRON ☒ STEEL, BLACK ☐ PLASTIC ☐ OTHER *(Specify)*

22. TYPE OF JOINT ☐ BELL SPIGOT ☐ MECHANICAL ☐ FLANGE ☐ COMPRESSION ☒ WELDED ☐ THREADED ☐ OTHER *(Specify)*
23. CONDITION OF JOINT ☒ GOOD ☐ POOR ☐ CORRODED BOLTS ☐ POOR GASKET ☐ POOR CAULK ☐ CORRODED METAL ☐ OTHER *(Specify)*
24. SOIL ☐ ASHES ☐ GRAVEL ☐ SAND ☒ CLAY ☐ LOAM ☐ ROCK ☐ SWAMP ☐ CINDER ☐ OTHER *(Specify)*
25. PAVING ☐ CONCRETE ☒ DIRT ☐ BLACKTOP ☐ OTHER *(Specify)*
26. LEAK LOCATION ☐ MAIN ☐ VALVE ☐ SERVICE ☐ TOP ☐ CORNER ☐ BOTTOM ☒ SIDE ☐ CREVICE ☐ OTHER *(Specify)*
27. CAUSE OF LEAK ☐ FREEZE ☐ SETTLEMENT ☐ STRAIN ☒ CORROSION ☐ DRYING ☐ IMPROPER INSTALLATION *(Explain)* ☐ OTHER *(Specify)*
28. TYPE OF LEAK ☐ JOINT ☒ CORROSION ☐ BREAK ☐ OTHER *(Specify)*
29. METHOD OF REPAIR ☐ CONTRACT ☒ IN-HOUSE — CONTRACT NO/W.O. NO: W.O. 4736

30. COST OF REPAIR

MILITARY MANHOURS EXPENDED 17	COST $ 34.
CIVILIAN MANHOURS EXPENDED 11	COST $ 33.
TOTAL LABOR COST $ 67.00	EQUIPMENT CO $ 12.
MATERIAL COST $ 7.00	TOTAL JOB CO $ 86

REMARKS *(Continue on reverse)*

REPLACE 2' SECTION OF PIPE.
INSTALLED ONE 17 Lb. MAGNESIUM ANODE.

31. LEAK DISCOVERED BY: S Bara
32. SHOP FOREMAN: Joe Golar
33. CATHODIC PROT. TECH.: DK Evans
34. BASE CORROSION ENGINEER: R. L. Banks
DATE: Ju

AF FORM JAN 81 1687

INSTRUCTIONS

Check appropriate boxes. If insufficient space or unusual happenings, delays, or events occur for any item to furnish a required specific answer, key to remarks by item number and complete answer. All items are self-explanatory with the following exceptions.

Item 1. INSTALLATION: Enter official name and location of the installation such as, "VANDENBERG AFB, CA. . DO NOT USE UNIT DESIGNATIONS OR ABBREVIATIONS SUCH AS, "VAFB".

Item 2. DATE: Enter the day, month, and year.

Item 3. FACILITY AND NUMBER: Enter the name of the building or facility and its number as shown on the USAF Real Property Report, such as, "WATER TANK 902".

Item 4. AREA: Enter the general area so that it can be located on the drawing such as, "NORTH SIDE OF BLDG 11234", or "BETWEEN BLDGS 11234 and 11235".

Item 5. DRAWING NUMBER: Show drawing number of the map upon which this leak is located for the purpose of recording installation leak history.

Item 6. AVERAGE TEMP OF FLUID: Enter approx average temp of fluid. If facility does not carry fluid, enter N/A.

Item 11. OPERATING PRESSURE: If this is a high pressure line, enter pressure. If item does not apply enter N/A.

Item 16. SOIL (p^H): p^H should be taken at pipe depth of undisturbed soil with an antimony electrode or a p^H meter.

Item 20. SOIL RESISTIVITY: Obtain soil resistivity at all appropriate depths using Vibraground, Model 263A.

Item 29. METHOD OF REPAIR: Check appropriate block and enter contract/work order number. Enter in Remarks how the leak was repaired, such as, "Replaced section", or "Welded pit".

REMARKS *(Continued)*

ANNUAL CATHODIC PROTECTION PERFORMANCE SURVEY

DATE 29 Sep 81

☒ IMPRESSED CURRENT SYSTEMS
☐ SACRIFICIAL ANODE SYSTEM

INSPECTOR CHARLES WEST

RECTIFIER NO. 5

ANODE TEST STATION N/A

LOCATION BLDG. 705

STRUCTURE PROTECTED POL System

RECTIFIER SETTING

DC VOLTS 30

DC AMPS 10

NO.	TEST STATIONS LOCATION	ON[1&2]	OFF[1]	REMARKS
1	Hydrant Outlet A-1	0.86	0.55	
2	Hydrant Outlet A-2	0.56	0.56	Check for Isolation
3	Hydrant Outlet A-3	0.88	0.57	
4	Hydrant Outlet A-4	0.89	0.57	
5	Hydrant Outlet A-5	0.87	0.56	
6	Inlet Piping, Pit A	0.89	0.58	
7	Outlet Piping, Pit A	0.90	0.58	
8	Pump House No. 1, Inlet Pipe	0.86	0.55	
9	Pump House No. 1, Outlet Pipe	0.88	0.56	
10	Pump House No 1, Tank 1	0.86	0.50	See [3]
11	Pump House No 1, Tank 1	0.14	0.47	3; Anodes required between tanks
12	Pump House No 1, Tank 1	0.73	0.46	3; Anodes required between tanks
13	Pump House No. 1, Tank 2	0.87	0.47	See [3]
14	Pump House No. 1, Tank 2	0.15	0.46	3; Anodes required between tanks
15	Pump House No. 1, Tank 2	0.72	0.45	3; Anodes required between tanks
16	Pump House No. 1, Tank 3	0.88	0.50	See [3]
17	Pump House No. 1, Tank 3	0.75	0.48	3; Anodes required between tanks
18	Pump House No. 1, Tank 3	0.74	0.47	3; Anodes required between tanks
19	Pump House No. 1, Tank 4	0.86	0.49	See [3]
20	Pump House No. 1, Tank 4	0.75	0.47	3; Anodes required between tanks
21	Pump House No. 1, Tank 4	0.74	0.46	3; Anodes required between tanks
22	Pump House No 1, Tank 5	0.86	0.47	See [3]
23	Pump House No 1, Tank 5	0.74	0.45	3; Anodes required between tanks
24	Pump House No. 1, Tank 5	0.75	0.46	3; Anodes required between tanks

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[1] Structure to electrolyte potentials in volts to a copper-copper sulfate reference electrode.

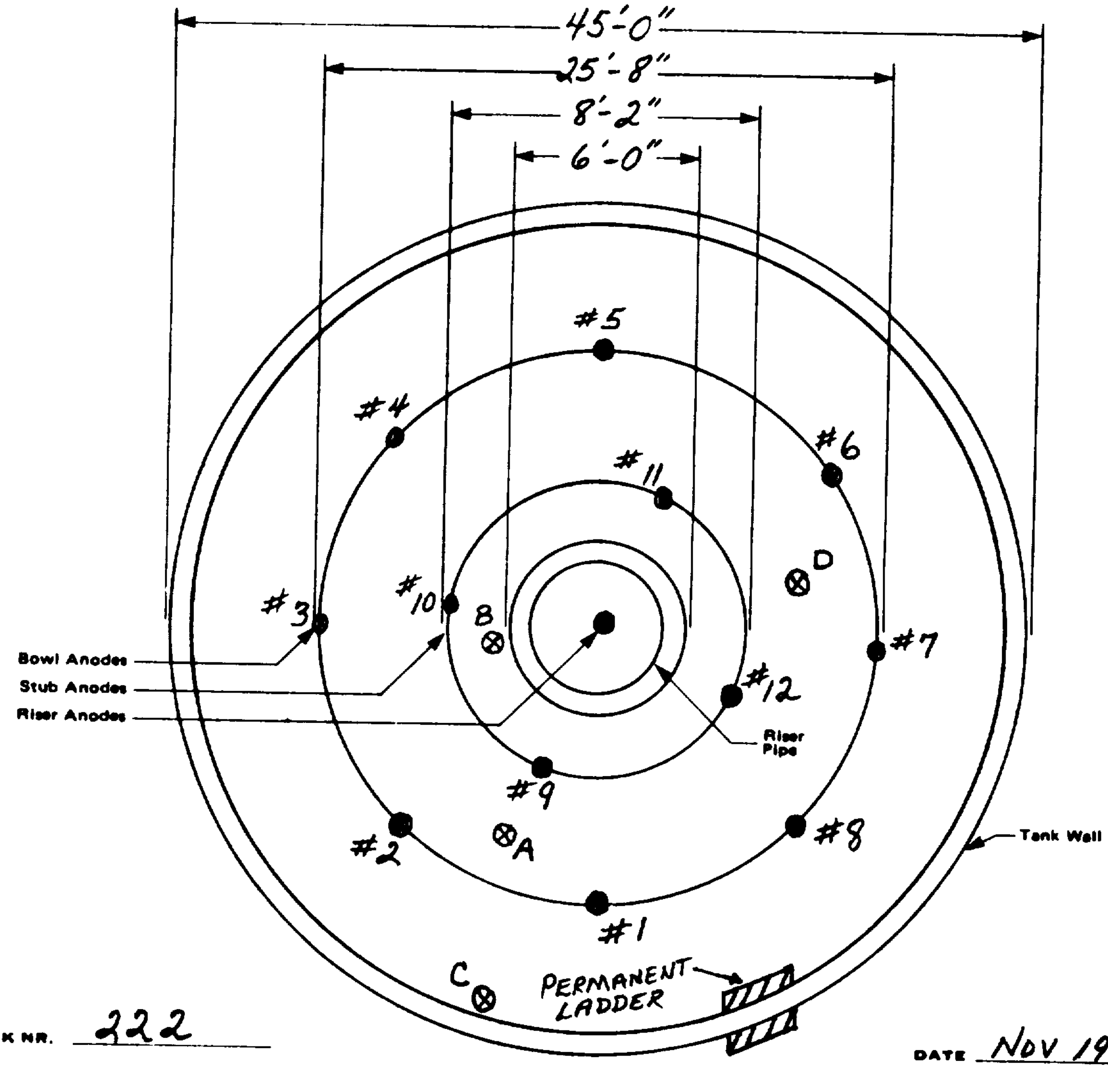
[2] For sacrificial anode system enter reading here.

[3] See figure No. 4. pump house No. 1 for electrode location.

AF FORM JAN 81 1688

WATER TANK CALIBRATION

(Draw in individual tank features)



TANK NR. 222

GALLONS 500,000

DATE NOV 1968

LOCATION ZD AIR BASE

REFERENCE ELECTRODE LOCATION	TANK-TO-WATER POTENTIAL
A- MIDWAY BETWEEN ANODES #1-2-9, 2" OFF BOTTOM	1.2
B- MIDWAY BETWEEN ANODES #9-10, Edge OF STAND PIPE 4, 2" OFF BOTTOM	.89
C- MIDWAY BETWEEN ANODES #1-2, ADJACENT TO OUTER WALL AND 5' UNDER SURFACE OF WATER	.98
D- MIDWAY BETWEEN ANODES #6-7-11-12, 2" OFF BOTTOM	1.1

AF FORM JAN 81 1689

SAMPLE CATHODIC PROTECTION PROGRAM RECORD

BASE NAME AFB

No. Utility Systems Protected	Project No.	Project Date	Estimated (Est. Cost)	Contract Award	Contract Complete	Project Cost
1. 200,000 gallon elevated water tank 402. Surveyed: In-house. Design: Harco. Construction: Cathodic Protection Service. Rectifier (50A-20V) and Duriron anodes (1).	Unknown	1953	Unknown	June 1953	1953	$5,000
2. POL tank farm and hydrant fueling system (copper laterals not protected). Surveyed: Hinchman Company. Design: Hinchman Company Construction: Corrosion Services Inc. Two rectifiers on hydrant system, 32 lb anodes (25) on tank farm. a. Pump house A-20A-30V - Duriron anodes (10). b. Pump house B-30A-30V - Duriron anodes (15).	35-4	1957	$13,300	Unknown	July 1958	$16,000
3. Capehart gas mains and service lines and water service lines (water mains transite). Survey: Unknown. Design: Unknown. Construction: In-house. 17 lb. magnesium anodes (1,360).	544-6	1960	$26,000	Unknown	Sept. 1960	$28,900
4. Additional anodes added to system No. 3. Survey: In-house 1970. Design: In-house 1970. Construction: 17 lb. magnesium anodes (540).	72-4	Jan. 1971	$18,900	Est. Dec 71	Est. March 71	
5. Base gas and water system, 15 miscellaneous oil tanks, water filtration plant and 2 sewage lift stations. Survey: Negotiating with Harco Corp. Design: Est. Dec. 1975. Construction: Est. Nov. 1977.	72-8	Jan. 1976	$120,000 Type A services $12,000 Type B services, $5,000			

SACRIFICIAL ANODE TROUBLESHOOTING

CONDITION	CAUSES	METHOD TROUBLESHOOTING	REMEDY
1. Structure-to-soil potential is − 0.85 or slightly higher (complete protection).	System O.K.	None	
2. Structure-to-soil potential is lower than − 0.85 and higher than original or unprotected structure-to-soil condition.	a. Lead wire between anode and structure broken.	a. Check potential between anode and copper sulfate electrode. Potential should be − 1.50 volts or higher. Also, make continuity tests on structure leads and measure anode current output.	a. Replace the broken lead wire.
	b. Coating damaged or deteriorated.	b. Conduct coating conductance tests and Pearson-type over-the-ground holiday detector tests.	b. Excavate line and patch coating or install additional anodes.
	c. New section of structure added without added cathodic protection.	c. Check as-built or construction records.	c. Install additional cathodic protection.
	d. Insulators shorted—bare structure shorted to protected structure.	d. Test all insulated fittings.	d. Replace shorted insulated fittings.
	e. Improper design—not enough anodes installed.	e. Measure current output of anodes and conduct current requirement tests.	e. Install additional cathodic protection.

IMPRESSED CURRENT TROUBLESHOOTING

CONDITION	CAUSES	METHOD OF TROUBLESHOOTING	REMEDY
1. Rectifier output same as previous test. Potential reading – 0.85 minimum for steel.	System O.K.	None needed.	None needed.
2. Rectifier output changed slightly from previous test. Potential readings slightly lower or higher than design limits.	Polarization. Electrolyte resistance change. Extension or retirement of small percentage of structure under protection.	Potential survey to determine extent of over or under protection.	Adjust rectifier taps to obtain desired protection.
3. Zero DC voltage output.	a. Faulty rectifier voltmeter or wiring.	a. Check output with multimeter. Check for loose connections or broken wiring.	a. Replace meter and repair wiring.
	b. Circuit breaker off (AC).	b. Check for shorts or overload which may have caused breaker to open.	b. Repair damage and close breakers.
	c. Disconnect switch off or fuses blown (AC).	c. Same as above.	c. Repair damage, replace fuses and close connect.
	d. AC supply interrupted (AC).	d. Notify responsible electric shop of the interruption.	d. Shop will repair.
	e. Transformer circuit trouble (AC).	e. Check output at fixed center terminals of course and fine tap adjustments.	e. Replace damaged transformer or tighten tap connections.
	f. Rectifier stack damage.	f. Check rectifier input voltage (AC) and rectifier output voltage (DC). Visually check for dirt, heat indications, and loose connections.	f. Tighten loose connections and clean or replace damaged stocks.

CHECKS ON OIL IMMERSED RECTIFIERS

1. Make an annual check on a clear, dry day.

2. Shut off the rectifier.

3. Open the drain cock located at the bottom of the oil reservoir and slowly drain oil into a clean glass vessel. If water is visible in the vessel, continue to slowly drain the liquid until the water is extracted from the reservoir.

4. Check the level of the oil inside the rectifier case. If oil must be added to maintain the proper level, use only clean transformer oil taken from a sealed container.

5. Check gaskets on rectifier case once a month in addition to the monthly operating tests of impressed current systems. Replace gaskets promptly to avoid contamination of oil with dust or moisture.

CASED CROSSING MAINTENANCE PROCEDURE

1. The status of insulation at cased crossings should be measured during each annual survey. If a short circuit is found, immediately schedule it for repair. Also, pinpoint the short as closely as possible by observation and electrical measurements. See figure 3-13 for test station outline.

2. First, check the test point at the cased crossing. Often the short circuit is not in the casing but is the result of contact between the casing vent and test point wires.

3. If it is established that the short is between the pipe and the casing, the next check is to uncover one end of the casing, remove the end seal, and check for a short by visual inspection. If the short is present, jack the carrier pipe and casing apart and insert a new centering cradle. Replace the casing and seal before backfilling. Similarly, if the short is not on the end of the casing initially checked, it will be necessary to check the opposite end of the casing.

4. Where the tests indicate that the point of contact is well back from the end of the casing, it probably cannot be cleared economically. In that event, the proper procedure is to safeguard the carrier pipe by filling the annular space between pipe and casing with a material that will inhibit any corrosion tendency. Casing filler should be heated and pumped into the low-end vent pipe until it emerges from the high-end vent.

SAMPLE BASE CATHODIC PROTECTION OPERATING INSTRUCTIONS

DEPARTMENT OF THE AIR FORCE
Headquarters,
AFB

BCE OI X-X

BASE CATHODIC PROTECTION OPERATION AND MAINTENANCE PROCEDURES

1. Purpose. The purpose of this instruction is to set up a uniform method of handling all phases of maintenance and operation of CPSs including the maintenance of required records and the making of periodic inspections and tests as set forth in:

AFR 91-27, Corrosion Control.
AFM 85-5, Maintenance and Operation of Cathodic Protection Systems.
AFM 88-9, Chapter 4, Corrosion Control.

2. Responsibility. The engineering and environmental planning branch chief is assigned primary responsibility for implementing the Base Corrosion Control Program. Normally, the corrosion engineer will serve as the approving authority and will manage the functions necessary to assure adequate protection. To this end, the chiefs of operations, and resources and requirements, must support and perform those tasks necessary for success.

a. The chief of resources and requirements must assure that all work identified and approved by the corrosion engineer is supported by material control, planning, and production control.

b. The chief of operations must assure that the corrosion engineer is informed of all utility and POL systems leaks, that the corrosion engineer is notified when excavation work is complete and the damage ready for inspection, and that the CPT works closely with the corrosion engineer.

c. The corrosion engineer is responsible to the engineering and environmental planning branch chief for the following:

(1) Prescribing the technical servicing actions that are required on AF Form 1841, Maintenance Action Sheet.
(2) Reviewing of cathodic protection logs.
(3) Giving technical instructions to the CPT and establishing the desired operating level for each CPS.
(4) Maintaining a file of technical records on each installed CPS.
(5) Inspecting and recording all leaks in the underground utility systems due to corrosion.
(6) Preparing the annual CPS survey and performance booklet.

d. The CPT must:

(1) Perform cathodic protection checks on all installed systems as outlined in applicable directives.
(2) Identify and submit maintenance requirements to installed systems following the procedures of AFR 85-1.
(3) Install sacrificial anodes at points where leaks occur if a CPS is not planned for the near future.
(4) Repair breaks in coating on underground structures where excavations are made.
(5) Coordinate all phases of work with production control and the corrosion engineer.
(6) Refer to the corrosion engineer for systems management and technical advice.
(7) Retain custody of cathodic protection test equipment.

3. Procedures:

a. The procedures for the equipment maintenance program, AFR 85-1, chapter 10, will be used to authorize and schedule cathodic protection program actions at required intervals.

(1) When the BEAMS Recurring Preventive Maintenance (RPM) schedule is issued, the CPT must contact the corrosion engineer and discuss the required work.

(a) At that time, the corrosion engineer must give technical instructions and establish the desired operating level for each CPS.

(2) Upon completion of the servicing required by RPM schedule and corresponding AF Form 1841, the CPT must hand-carry the completed forms to the corrosion engineer for review and filing in the new cathodic protection facility jacket folder. From that review and discussion, the need for further correction action will be determined.

(3) The CPT must annotate the proper forms and return them to the corrosion engineer when all corrective actions have been accomplished.

b. Report leaks in gas, water, sewer, and liquid fuels facilities to the corrosion engineer, together with the estimated time that the piping will be exposed for inspection. If the leak is to be repaired by a clamp, it is imperative that the inspection be made before installation of the clamp. The person in charge of the repair crew during other than normal duty hours must make the inspection and describe the findings to the corrosion engineer.

PIPE LINE CURRENT FLOW DATA

IR-DROP TABLES

Pipe Size	Ohms/1000 Ft.	CURRENT FLOW FOR 1 MV DROP In 1 Ft.	In 25 Ft.	In 50 Ft.	In 100 Ft.
¾″	.191	5.24	.210	.105	.052
1″	.129	7.75	.310	.155	.078
1¼″	.095	10.5	.420	.210	.105
1½″	.079	12.7	.508	.254	.127
2″	.057	16.9	.676	.338	.169
2½″	.0373	26.8	1.07	.536	.268
3″	.0285	35.1	1.40	.702	.351
4″	.0200	50.0	2.00	1.00	.500
5″	.0148	67.6	2.70	1.37	.676
6″	.0114	87.7	3.51	1.76	.877
8″	.0076	132.	5.26	2.63	1.32

Pipe Size	Ohms/1000 Ft.	CURRENT FLOW FOR 1 MV DROP In 1 Ft.	In 25 Ft.	In 50 Ft.	In 100 Ft.
10″	.0053	189.	7.55	3.77	1.89
12″	.00436	229.	9.16	4.58	2.29
14″	.00396	253.	10.1	5.06	2.53
15″	.00369	271.	10.8	5.42	2.71
16″	.00344	291.	11.6	5.82	2.91
18″	.00306	327.	13.1	6.54	3.27
20″	.00275	364.	14.6	7.28	3.64
24″	.00173	578.	23.2	11.6	5.78
26″	.00159	631.	25.2	12.6	6.31
30″	.00138	725.	29.1	14.5	7.25
36″	.00114	877.	35.0	17.5	8.77

DENSITY OF STEEL 489 lbs./ft.^{3} RESISTIVITY OF STEEL 13.44×10^{-6} ohm/cm^3 or $.441\times10^{-6}$ ohm/ft.^{3}

RESISTANCE OF PIPE (ohms/L. F.) $\frac{216\times10^{-6}}{\text{lbs./ft.}}$

EXAMPLE: 12″ Standard 49.6 lb./ft. pipe

Resistance of Pipe $= \frac{216\times10^{-6}}{49.6} = \underline{\underline{4.36\times10^{-6}\text{ ohm/L. F.}}}$

Current Flow/1 mv drop in 100 ft. $= \frac{.001\text{ volt}}{4.36\times10^{-6}\,(100)} = \underline{\underline{2.29\text{ amps.}}}$

PIPE DATA

	STANDARD PIPE					EXTRA STRONG		
Pipe Size	External Diameter	Lbs./Ft.	Wall Thickness	Surface Area sq. ft./ft.	Micro-Ohms/Ft.	Lbs./Ft.	Wall Thickness	Micro-Ohms/Ft.
¾″	1.05″	1.13	.113″	.275	191	1.47	.154	147
1″	1.31	1.68	.133	.344	129	2.17	.179	100
1¼″	1.66	2.27	.140	.434	95	3.00	.191	72
1½″	1.90	2.72	.145	.497	79	3.63	.200	60
2″	2.37	3.65	.154	.622	59	5.02	.218	43
2½″	2.87	5.79	.203	.753	37.3	7.66	.276	28.2
3″	3.50	7.57	.216	.916	28.5	10.25	.300	21.1
4″	4.50	10.8	.237	1.18	20.0	15.0	.337	14.4
5″	5.56	14.6	.258	1.45	14.8	20.8	.375	10.4
6″	6.62	19.0	.280	1.73	11.4	28.6	.432	7.6
8″	8.62	28.6	.322	2.26	7.6	43.4	.500	4.98
10″	10.75	40.5	.365	2.81	5.3	54.7	.500	3.94
12″	12.75	49.6	.375	3.34	4.36	65.4	.500	3.30
14″	14.00	54.6	.375	3.67	3.96	72.0	.500	3.00
15″	15.00	58.6	.375	3.92	3.69	77.4	.500	2.79
16″	16.00	62.6	.375	4.19	3.44	82.6	.500	2.61
18″	18.00	70.59	.375	4.71	3.06	93.4	.500	2.32
20″	20.00	78.60	.375	5.24	2.75			
24″	24.00	125.0	.500	6.28	1.73			
26″	26.00	136.17	.500	6.80	1.59			
30″	30.00	157.0	.500	7.85	1.38			
36″	36.00	189.0	.500	9.43	1.14			

90,000	5.3	6.8	8.6	11.0	13.7	17.2	27.5	44.2	67.5
80,000	4.7	6.1	7.7	9.7	12.2	15.3	24.4	38.6	60.0
70,000	4.2	5.3	6.8	8.5	10.6	13.4	21.4	33.8	52.5
60,000	3.5	4.6	5.8	7.3	9.1	11.5	18.3	29.0	45.0
50,000	3.0	3.7	4.8	6.0	7.6	9.6	15.3	24.0	38.0
40,000	2.4	3.0	3.8	4.8	6.1	7.7	12.2	19.3	30.0
30,000	1.8	2.2	3.0	3.6	4.5	5.7	9.2	14.5	28.0
20,000	1.2	1.5	1.9	2.4	3.0	3.8	6.1	9.7	20.0
10,000	0.6	0.7	1.0	1.2	1.5	1.9	3.1	4.8	7.5
9,000	0.6	0.7	0.9	1.0	1.4	1.7	2.7	4.4	6.8
8,000	0.5	0.6	0.8	0.9	1.2	1.5	2.4	3.9	6.0
7,000	0.5	0.6	0.7	0.8	1.1	1.4	2.1	3.4	5.3
6,000	0.4	0.5	0.6	0.7	0.9	1.2	1.8	2.9	4.5
5,000	0.3	0.4	0.5	0.6	0.8	1.0	1.5	2.4	3.8
4,000	0.2	0.3	0.4	0.5	0.6	0.8	1.2	1.9	3.0
3,000	0.2	0.2	0.3	0.4	0.5	0.6	0.9	1.5	2.3
2,000	0.1	0.2	0.2	0.2	0.3	0.4	0.6	1.0	1.5
1,000	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.5	0.8

ALUMINUM

500,000	47.9	60.0	75.2	95.5	120.0	151.5	241.5	382.0	647.5
400,000	38.4	48.0	60.4	76.4	96.0	121.0	193.0	307.0	478.0
300,000	28.8	36.0	45.3	57.3	72.0	91.0	145.0	230.0	359.0
200,000	19.2	24.0	30.2	38.2	48.0	60.6	96.6	153.0	239.0
100,000	9.6	12.0	15.1	19.1	24.0	30.3	48.3	76.7	120.0
90,000	8.8	10.8	13.6	17.2	21.6	27.1	43.4	69.1	107.6
80,000	7.7	9.6	12.1	15.3	19.2	24.1	38.6	61.4	95.6
70,000	6.8	8.4	10.6	13.4	16.8	21.2	33.8	53.7	83.7
60,000	5.7	7.2	9.1	11.5	14.4	18.2	29.0	46.0	71.7
50,000	4.8	6.0	7.5	9.5	12.0	15.1	24.1	38.4	59.8
40,000	3.8	4.8	6.0	7.6	9.6	12.1	19.3	30.7	47.8
30,000	2.9	3.6	4.5	5.7	7.2	9.1	14.5	23.0	36.0
20,000	1.9	2.4	3.0	3.8	4.8	6.1	9.7	15.3	23.9
10,000	1.0	1.2	1.5	1.9	2.4	3.0	4.8	7.7	12.0
9,000	0.9	1.1	1.4	1.7	2.1	2.7	4.4	6.9	10.8
8,000	0.8	1.0	1.2	1.5	1.9	2.4	3.9	6.1	9.6
7,000	0.7	0.8	1.1	1.4	1.6	2.1	3.4	5.4	8.4
6,000	0.6	0.7	0.9	1.2	1.4	1.8	2.9	4.6	7.2
5,000	0.5	0.6	0.8	1.0	1.2	1.5	2.4	3.9	6.0
4,000	0.4	0.5	0.6	0.8	1.0	1.2	1.9	3.1	4.8
3,000	0.3	0.4	0.5	0.6	0.7	0.9	1.5	2.3	3.6
2,000	0.2	0.2	0.3	0.4	0.5	0.6	1.0	1.5	2.4
1,000	0.1	0.1	0.2	0.2	0.2	0.3	0.5	0.8	1.2

* 8 solid conductor, (all others stranded).

GUIDELINES FOR PREPARING THE CATHODIC PROTECTION ANNUAL PERFORMANCE BOOKLET

1. The annual survey must be submitted in a hard cover, three-ring binder. The binder will contain basic information and the annual survey data placed in the following order:

Tab A: Title Page. List the base, type of survey, date survey was completed, and the names of the corrosion engineer and the CPT.

Tab B: Index.

Tab C: General Description. Describe in detail and in numerical order what the CPSs on the base consist of; whether impressed current or sacrificial anode system; how many systems installed and for which utilities or structures, such as: Water distribution systems, gas distribution systems, POL, heating, storage tanks, etc. Add information on type of metal used in mains and service lines, types of coatings, when installed, and by whom.

Tab D: Summary of Survey Analysis and Actions Required. Describe in detail reasons or probable reasons for either high- or low-potential measurements. Describe actions needed to provide protective potentials, estimated costs, and completion dates.

Tab E: Base Cathodic Protection Operation and Maintenance Procedures. Provide a copy of the cathodic protection operations and maintenance procedures prepared according to paragraph 1-1 of this publication.

Tab F: Cathodic Protection Program Record. Provide a copy of the cathodic protection program record prepared according to attachment 9 of this publication. This record must be updated yearly, as necessary.

Tab G: Maintenance Action Sheet. The maintenance action sheet must be prepared as outlined in AFM 85-1, chapter 10.

Tab H: Leak/Failure Data Records. Complete and provide one copy of AF Form 1687 as outlined in attachment 6, this publication, for each failure which was caused by corrosion during the preceding year. This record must be kept on all systems without regard to the application of cathodic protection.

Tab I: Master Plan Tab G-8. A copy of Tab G-8 of the master plan must be included.

Tab J: Cathodic Protection Operating Logs. The operating logs from the preceding year must be included for each system, see attachments 3 and 5.

Tab K: This tab should be used to list all cathodic protection equipment on hand and the condition of equipment.

Tab L: Annual Performance Survey Data. All survey data must be provided including areas which are resurveyed after rectifier adjustments are made. Each system as listed in the program record (Tab F) must have its individual data sheets, showing location of test points by building number or other landmarks. Maximum and minimum test points as required by AF Form 491 must be identified, such as 7h, 7i, 7j, 7k, for rectifier number 7.

Tab M: Sketches and Drawings. A sketch must be provided for each underground tank system indicating location of tank and where readings were taken. Include any additional drawings which will assist in the evaluation of the survey data.

Tab N: Personnel Roster. Provide a list of the name and grade of the corrosion engineer and the CPT and a description of their training in cathodic protection along with the date received.

2. Only one copy of the cathodic protection annual performance booklet should be prepared. The booklet must be submitted by 1 February following the year of survey to the MAJCOM which will review and return it along with comments and recommendations.

OPERATIONS AND MAINTENANCE CHECKLIST

	Monthly	Biannually	Annually
1. System Area:			
a. Keep entire area near rectifiers free from all safety, fire, and explosive hazards.	X		
b. Keep grass and weeds cut.	X		
2. Rectifiers:			
a. Adjust voltage to maintain the needed current output. Record "as found" and "as left" readings on AF Form 491.	X		
b. Look, feel, and smell to determine if rectifier is operating properly.	X		
c. Measure structure-to-soil potentials at each of the four test points and record on AF Form 491.	X		
d. Revise current output (AF Form 491, column 8) as required to provide complete protection at the three minimum test points.	X		
e. Test voltmeters and ammeters—replace as needed.			X
f. Check rectifier housing for corrosion. Paint as needed.			X
g. Analyze rectifier size with regard to the requirement. Replace as needed.			X
3. Sacrificial Anodes:			
a. Check structure-to-soil potential, current output, and anode-to-soil potential, and record on AF Form 1686.		X	
b. Check "structure-to-soil between anodes" potential.		X	
NOTE: The reference electrode should be located directly over the structure and mid-point between two sacrificial anode installations for these readings.			
c. Add additional sacrificial anodes as needed to give complete protection.		X	
4. Annual Performance Survey:			
a. Structure-to-soil potential measurements must be made on all pipelines, building gas service risers, isolating insulations, hydrant outlets in the POL system, underground tanks, and aboveground tanks.			X
b. Submit annual performance survey booklet to MAJCOM for review.			X
c. Locate new test points to be used the following year when making the monthly measurements. Record on AF Form 491.			X
d. Determine current output needed for each rectifier. Record on AF Form 491.			X
e. Determine actions needed to provide complete protection.			X
f. Update cathodic protection program record.			X
g. Review maintenance action sheets to assure that adequate time is allowed for complete testing and performing the needed maintenance.			X
h. Keep up-to-date, as-built drawings of each anode installation and each rectifier ground bed installation.			X

AUTHORIZED AND REQUIRED CATHODIC PROTECTION EQUIPMENT

Base Required Equipment:

a. The following cathodic protection equipment is authorized for each base and must be kept in good working condition:

TA No.	Item	NSN
486	Multimeter, PN M3M.	6625-00-051-2786
486	Vibroground, Model 293 with accessories and carrying case.	6625-00-083-5979
486	Insulated Joint Flange Tester.	6625-01-097-0053
486	Thermit™ Welding Kit, PN M880R.	3439-00-018-4928
486	Copper/Copper Sulfate Electrode.	5935-01-012-9823
486	Pipe Locator, Pipe Horn.	6695-01-032-5228
486	Current Interrupter (If applicable).	6625-00-943-2888
(Requested) Expendable	Reel, Wire, 400 Feet No. 22 AWG, Single Conductor Nylon Core Wire.	6150-NL
486	Tester-Corrosion, Electronic Voltmeter.	6625-01-065-2049YB
Expendable	Submersible Adapter, w/50′ Lead, for water proofing copper sulfate electrode.	5935-01-012-9824

b. The following cathodic protection equipment is available on a loan basis from most MAJCOMs or the Air Force Engineering and Services Center:

(1) Recording millivolt/volt meter consisting of one low-resistance recorder, 5,000 ohms/volt and one high-resistance recorder 150,000 ohms/volt.

(2) Current interrupter.

(3) Soil box.

(4) Soil test kit.

(5) One ammeter shunt rated 75 ampere capacity.

c. Other equipment used frequently in cathodic protection work consists of the following items.

2 - Ammeter shunts (one each MCM 75A external shunt and MCM dual range shunt).
1 - Pit depth gage.
1 - Holiday detector.
1 - Separate millivolt meter (in airfield lighting kit).
1 - Carbon pile rheostat.
2 - Two-way radios (walkie-talkies).
4 - Probing bars (for current flow tests).
6 - Ground rods (for temporary ground beds).
1 - 6 volt automobile starter solenoid.
1 - Cable test detecting set (located in airfield lighting instrument trunk).
1 - Antimony electrode (for soil pH testing).

REFERENCE MANUALS, REGULATIONS, AND TEXTBOOKS

1. **Air Force Regulations:**

a. 85-1, Resources and Work Force Management.
b. 85-19, Maintenance and Operation of Electric Power Generating Plants.
c. 91-7, Heating.
d. 91-10, Operation Maintenance of Air Force Waterworks Facilities.
e. 91-20, Gas Supply and Distribution.
f. 91-28, Permanently Installed Storage and Dispensing Systems for Petroleum and Unconventional Fuels (see paragraph on cathodic protection).

2. **Air Force Manuals:**

a. 85-3, Paints and Protective Coatings.
b. 85-12, Operation and Maintenance of Central Heating Plants and Distribution Systems.
c. 85-13, Maintenance and Operation of Water Plants and Systems.
d. 85-14, Maintenance and Operation of Sewage and Industrial Waste Plants and Systems.
e. 85-15, Coal Handling.
f. 85-16, Maintenance of Permanently Installed Storage and Dispensing Systems for Petroleum and Unconventional Fuels.
g. 85-18. Maintenance and Operation of Refrigeration, Air Conditioning, Evaporative Cooling, and Mechanical Ventilating Systems.
h. 85-20, Plumbing.
i. 85-31, Industrial Water Treatment.
j. 88-9, Electrical, all chapters.
k. 88-10, Water Supply and Water Treatment, all chapters.
l. 88-11, Sewage and Industrial Waste, all chapters.
m. 88-12, Fuels, all chapters.
n. 88-15, Air Force Design Manual—Criteria and Standards of Air Force Construction.
o. 91-3, Facilities Engineering, Electrical Exterior Facilities.
p. 91-6, Maintenance and Operation of Gas Systems.

3. **Textbooks:**

a. Corrosion Handbook (H. H. Uhlig, Editor; Publisher—John Wiley & Sons, New York, 1948).
b. Control of Pipeline Corrosion (A. W. Peabody; Publisher—National Association of Corrosion Engineers; P.O. Box 986, Katy, TX 77450).
c. Recommended Practice-Control of External Corrosion on Underground or Submerged Metallic Piping Systems (RP-01-69). Same publisher as b above.
d. Pipeline Corrosion and Cathodic Protection (Marshall E. Parker; Publisher—Gulf Publishing Company, Houston, TX).
e. National Association of Corrosion Engineers (NACE) Basic Corrosion Course.

4. **Technical Reports:**

a. AFCEC TR 74-6, volume I.
b. AFCEC TR 74-6, volume II.
c. AFCEC TR 74-6, volume III.

SUBJECT INDEX

(Paragraph numbers are shown in parentheses)

U.S. GOVERNMENT PRINTING OFFICE: 1982-360-972:142