TECHNICAL MANUAL

UNIT, INTERMEDIATE DIRECT SUPPORT AND

INTERMEDIATE GENERAL SUPPORT MAINTENANCE MANUAL

FOR

MAIN ENGINE

MODEL NUMBER 645E6

P/N 16-645E6

This technical manual is an authentication of the manufacturers commercial literature and does not conform with the format and content requirements normally associated with Army technical manuals. This technical manual does, however, contain all essential information required to operate and maintain the equip, meet.

HEADQUARTERS, DEPARTMENT OF THE ARMY
21 OCTOBER 1987

CHANGE

NO. 1

HEADQUARTERS
DEPARTMENT OF THE ARMY
WASHINGTON, D.C., 30 December 1993

Unit, Intermediate Direct Support and
Intermediate General Support Maintenance Manual
for
MAIN ENGINE
MODEL NUMBER 645E6
P/N 16-645E6

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Remove pages	Insert pages
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WARNING PAGE

WARNING

To avoid injuries to skin or eyes and to prevent damage to clothes or equipment, follow supplier's recommended protective measures when using cleaning fluids and solvents.

WARNING

Failure to comply with packaging procedures when returning cylinder power assemblies can result in injury to personnel or costly damage to components.

WARNING

Following an engine shutdown due to activation of the crankcase pressure detector or hot oil, DO NOT open any handhole or top deck covers to make an inspection until the engine has been stopped and allowed to cool off for at least two hours. DO NOT attempt-to restart the engine until the cause of the trip has been determined and corrected.

The action of the pressure detector indicates the possibility of a condition within the engine, such as an overheated bearing, that may ignite the hot oil vapors with explosive force if air is allowed to enter.

If crankcase pressure detector cannot be reset, DO NOT operate the engine until the detector has been replaced, since the diaphragm backup plates may be damaged.

WARNING

Failure to follow prescribed procedures for the disassembly and reassembly of the special air starting motor could result in injury to personnel.

WARNING

A fuel system pressure of greater than 60 psi might fracture the fuel sight glass. Beware of possible fire hazards due to fuel spillage.

WARNING

When troubleshooting the tank vent valve on pressure cooling system, do not get hands or face close to the water bucket. A defective valve could release hot air or coolant inhibitor.

First aid procedures are available in FM 21-11, First Aid for Soldiers.

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SUPPLEMENTARY INTRODUCTDRY MATERIAL

1-1. Maintenance Forma and Records.

"Department of the Army forma and procedures used for equipment maintenance will be those described by DA Pam 738-750, The Army Maintenance Management System."

1-2. Reporting Errors and Recommending Improvements.

(A) "You can help improve this manual. If you find any mistakes or if you know of a way to improve the procedures, please let us know. Mail your letters, DA From 2028 (Recommended Changes to Publications and Blank Forms), or DA Form 2028-2 direct to: Commander, U.S. Army Troop Support Command, Attn: AMSTR-MCTS, 4300 Goodfellow Blvd., St. Louis, MO 63120-1798. A reply will be furnished to you."

1-3. Preparation for Storage and Shipment.

"Refer to paragraph _____ for maintenance instructions."

1-4. Destruction of Army Material to Prevent Enemy Use.

"Refer to TM 750-244-2 and TM ?50-244-3 for instructions covering the destruction of Army Material to prevent enemy use."

645E6

Marine Engine/Systems

4th Edition

ELECTRO-MOTIVE

55E1086

FOREWORD

This manual contains maintenance information for the 8, 12, and 16-cylinder Model 645E6 diesel engines. The material describes the basic engine and common extra equipment. However, the coverage of any particular system or component does not imply that the equipment is part of any specific order.

The illustrations generally depict the 16-cylinder model as representative of the location, size, and relative shape of various components and accessories.

Units of measurement appearing in this manual are shown in metric units and U.S. standard units. A conversion table is provided to convert U.S. standard to metric units.

Special tools, referred to in the text and shown in many of the illustrations, are not supplied with the engine, but are available on order.

File numbers contained in this manual represent detailed drawings for the construction of fabricated tooling. These drawings are available from ElectroMotive Service Department.

References, specifications, and a list of service equipment are presented as Service Data at the end of most sections.

Clearance and dimensional limits listed in Service Data are defined as follows:

1. New limits are those to which new parts are manufactured. (Drawing tolerances.)

2. Minimum, maximum, and tolerance measurements are provided as service limits. At time of rebuild or any time unscheduled maintenance is performed, the service limits should not be exceeded. Engine components within these limits may be reused with the assurance that they will perform satisfactorily until the next scheduled overhaul.

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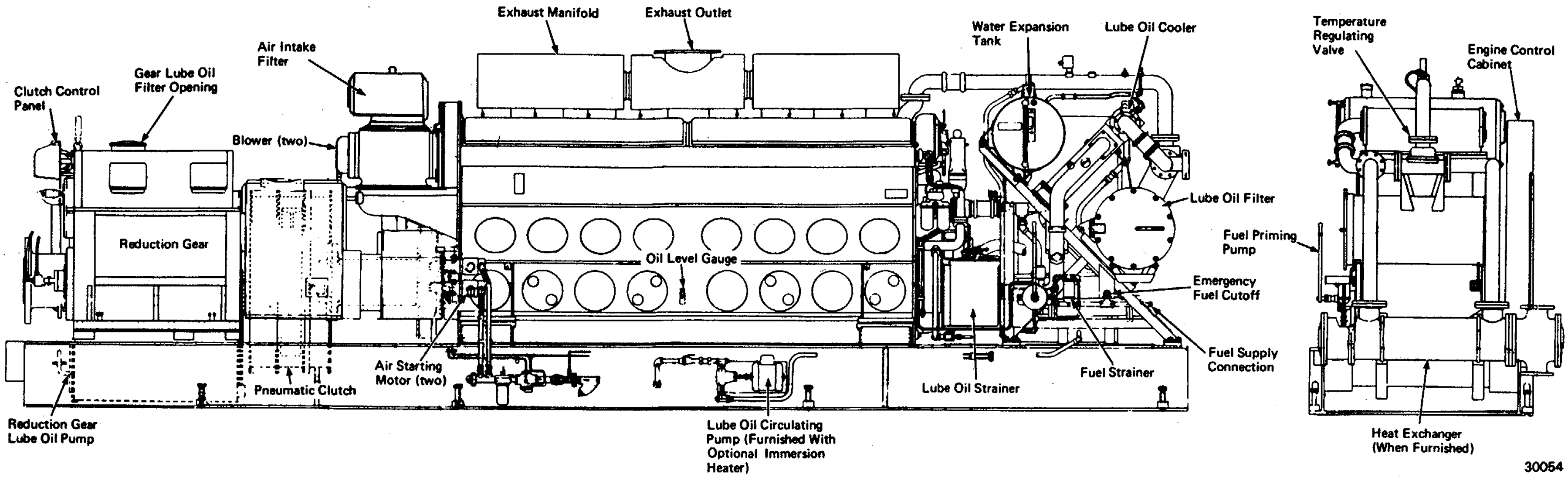
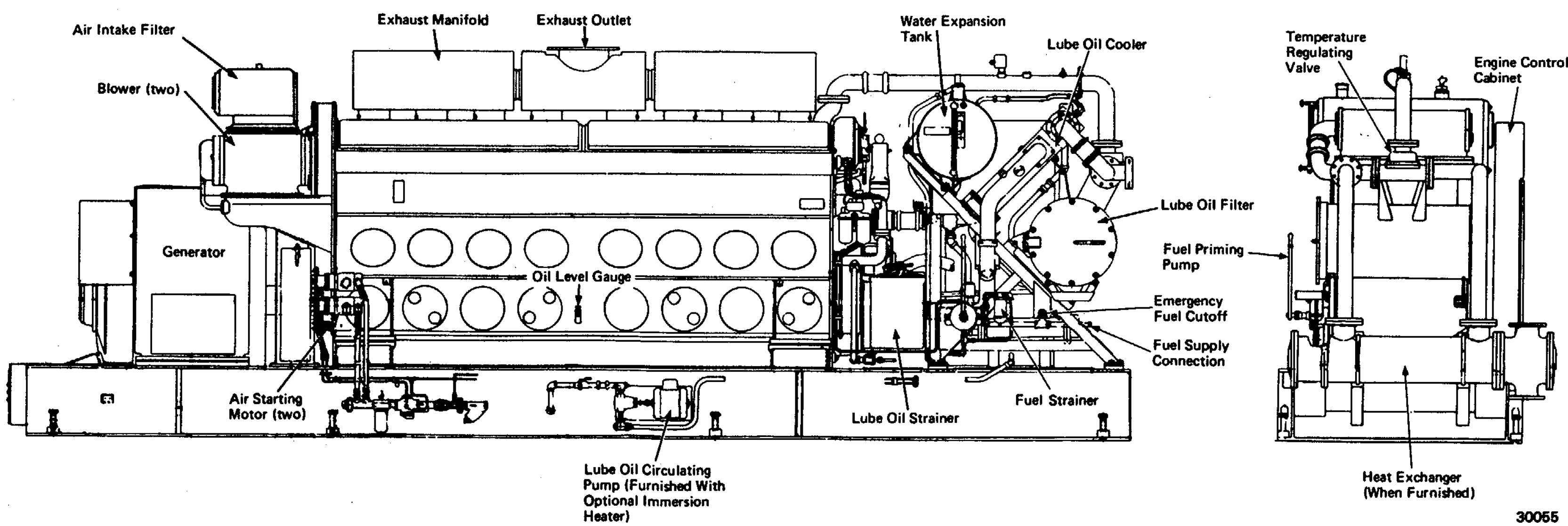


Typical Model GMB8E6, GMB1 2E6, And GMB1 6E6 General Arrangement



Typical Model MGB8E6, MBG12E6, And MGB16E6 General Arrangement

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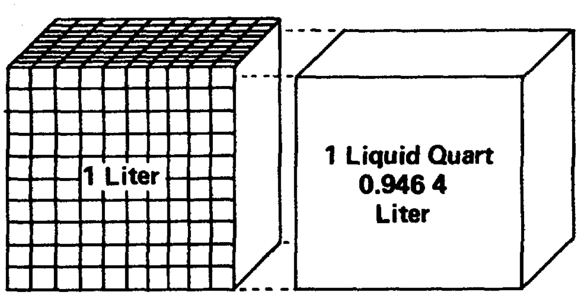
ELECTRO-MOTIVE

METRIC CONVERSION

TABLE OF FREQUENTLY USED UNITS

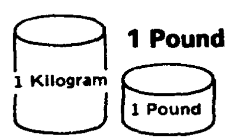
Multiply	by	to get equivalent number of:
LENGTH		
Microinch	.025 4	micron (μ)
Inch	25.4	millimeters (mm)
Foot	0.304 8	meters (m)
Yard	0.914 4	meters
Mile	1.609	kilometers (km)
AREA		
Inch^2	645.2	millimeters^2 (mm^2)
	6.45	centimeters^2 (cm^2)
Foot^2	0.092 9	meters^2 (m^2)
Yard^2	0.836 1	meters^2
VOLUME		
Ounce	29.574	centimeter^3 (cm^3)
Inch^3	16 387.	mm^3
	16.387	cm^3
	0.016 4	liters (l)
Ft^3	0.028 3	meter^3 (m^3)
Quart	0.946 4	liters
Gallon	3.785 4	liters
Yard^3	0.764 6	meters^3 (m^3)
MASS		
Ounce	28.350	grams (g)
Pound	0.453 6	kilograms (kg)
Ton	907.18	kilogram
Ton	0.907	tonne (t)
FORCE		
Kilogram	9.807	newtons (N)
Ounce	0.278	newtons
Pound	4.448	newtons
TEMPERATURE (THERMOMETER READING)		
Degree Fahrenheit	(t° F-32)÷1.8	degree Celsius (C)
TEMPERATURE RISE		
Degree Celsius	1.8	Degrees Fahrenheit

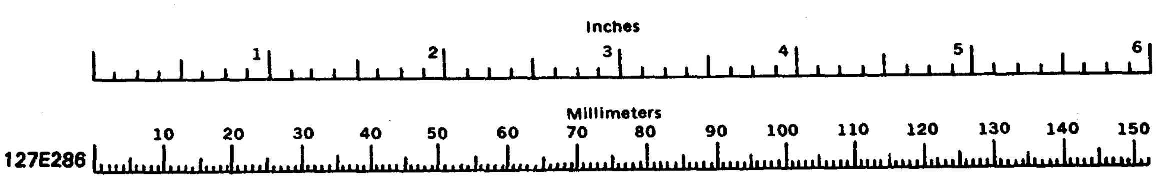
Multiply	by	to get equivalent number of:
ACCELERATION		
Foot/sec^2	0.304 8	meter/sec^2 (m/s^2)
Inch/sec^2	0.025 4	meter/sec^2
TORQUE		
Ounce-force-inch	0.007 06	newton-meter
	0.069 2	*kilogram-meter*
Pound-inch	0.112 98	newton-meters (N·m)
	0.011 52	kilogram-meters
Pound-foot	1.355 8	newton-meters
	0.138 25	*kilogram-meters*
POWER		
Horsepower	0.746	kilowatts (kW)
PRESSURE OR STRESS		
Inches of water	0.249 1	kilopascals (kPa)
Inches of mercury	3.376 85	kilopascals
Kilopascal	0.296 13	Inches of mercury
Pounds/sq.in.	6.895	kilopascals
ENERGY OR WORK		
BTU	1 055.	joules (J)
Foot-pound	1.355 8	joules
Kilowatt-hour	3 600 000 *or 3.6 x 10^6*	joules (J = one W·s)
LIGHT		
Footcandle	10.764	lumens/meter^2 (lm/m^2)
FUEL PERFORMANCE		
Miles/gal.	0.425 1	kilometers/liter (km/l)
Gal/mile	2.352 7	liters/kilometer (l/km)
VELOCITY		
Miles/hour	1.609 3	kilometers/hr. (km/h)



The comparative dimensions of an inch and a millimeter, a liter and a quart, and a kilogram and a pound are shown.

1 Pound = 0.453 6 kg





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ELECTRO-MOTIVE

SECTION A
645E6
Marine Engine/Systems

INTRODUCTION

A General Motors marine propulsion unit (GM unit) consists of an EMD Model 645E6 diesel engine with accessories, a reverse-reduction gear with pneumatic clutch, and includes pilothouse and engine room controls.

A General Motors marine generating unit (MG unit) consists of an EMD Model 645E6 diesel engine with accessories, synchronous AC generator with exciter.

Model 645E6 8, 12, and 16 cylinder engines are used as the power source for GM and MG units.

The engine associated accessory components are either interconnected on a rack and mounted on a supporting subbase or are supplied as loose items to be located and interconnected by the shipbuilder.

Section A

MODEL DESIGNATIONS

Associated with each model designation, such as 16-645E6, there is a basic equipment configuration and an option pertaining to engine rotation and accessory rack construction. Engine rotation can be left or right hand with left-hand rotation as standard and the accessory rack can be made as either left or right-hand construction. Accessory rack construction indicates on which side of the engine the operating controls and alarm cabinet are located.

NOTE

All engines are now manufactured as left-hand construction with respect to the placement of starting motors, water pumps, and fuel filters. Refer to Fig. D-2.

Many combinations of diesel engine and accessories are available to make up a specific GM unit or MG unit. In order to identify the arrangement, a code system is used. The code system with definitions follows:

CODE

GM Marine diesel reverse-reduction gear propulsion unit.

MG Marine diesel generating unit.

B Added after the "GM" or "MG" designation indicates inclusion of a base. The base may include the reverse-reduction gear or generator, diesel engine, and accessory rack or may include just the reverse reduction gear or generator and the diesel engine with the accessory rack separate or the accessory components shipped loose.

8, 12, 16 Number of engine cylinders.

E6 Model 645E6 blower-type engine.

NOTE

When referring to the engine, the complete model designation includes a prefix indicating the number of cylinders, such as, 1-645E6.

An additional letter is used after the "E6" to designate accessory configuration:

A Indicates accessory components shipped loose for shipbuilder installation.

L Indicates left-hand construction of accessory rack (rack constructed to be operated from the left side).

R Indicates right-hand construction of accessory rack (rack constructed to be operated from the right side).

SAMPLE MODEL DESIGNATIONS

GM16E6L or R	Reverse-reduction gear, 16-cylinder 645E6 blower-type engine, and accessory rack. No base is supplied. The L or R indicates either a left-hand or right-hand construction of the accessory rack.
MG16E6L or R	Generator and exciter, 16-cylinder 645E6 blower-type engine, and accessory rack. No base is supplied. The L or R indicates either a left-hand or right-hand construction of the accessory rack.
GM16E6A	Reverse-reduction gear, 16-cylinder 645E6 blower-type engine, loose accessory-components. No base is supplied.
MG16E6A	Generator and exciter, 16-cylinder 645E6 blower-type engine, loose accessory components. No base is supplied.
GMB16E6L or R	Reverse-reduction gear, 16-cylinder 645E6 blower-type engine, and accessory rack, all mounted on a common base. The L or R indicates either a left-hand or right-hand construction of the accessory rack.
MGB16E6L or R	Generator and exciter, 16-cylinder 645E6 blower-type engine, and accessory rack, all mounted on a common base. The L or R indicates either a left-hand or right-hand construction of the accessory rack.
GMB16E6A	Reverse-reduction gear, 16-cylinder 645E6 blower-type engine, loose accessory components. A base is supplied for the reduction gear and the engine.
MGB16E6A	Generator and exciter, 16-cylinder 645E6 blower-type engine, loose accessory components. A base is supplied for the reduction gear and the engine.

SECTION B

PRESTART PROCEDURE

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TURNING ENGINE MANUALLY

Some of the following prestart checks and procedures require a manual turning of the engine. There are several methods to do this. Crankover tool 9561844 with electric drive unit, Fig. B-1, or with optional air drive kit 9560333, Fig. B-2, can be used as jacking gear to rotate the engine.

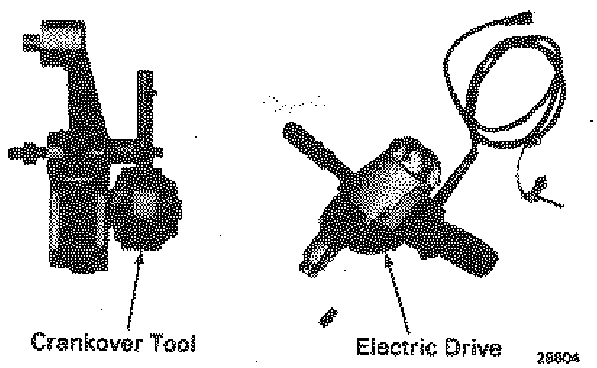


Fig. B-1 - Crankover Tool 9561844 And Electric Drive Unit 9543867

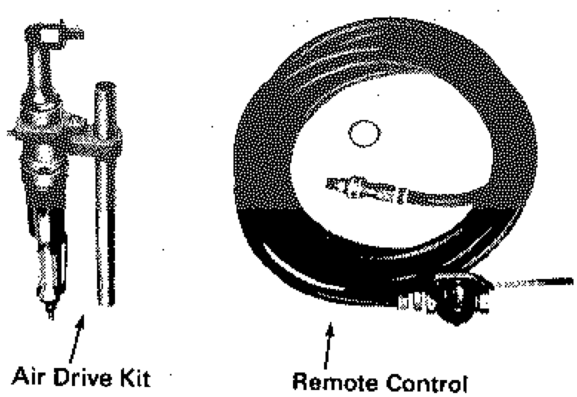


Fig. B-2 - Air Drive Kit 9560333 And Remote Control 9560338

Another method of turning the engine manually is to utilize the air starting motors as follows:

1. Close the shutoff valve in the main air line of the starting system, Fig. B-3.

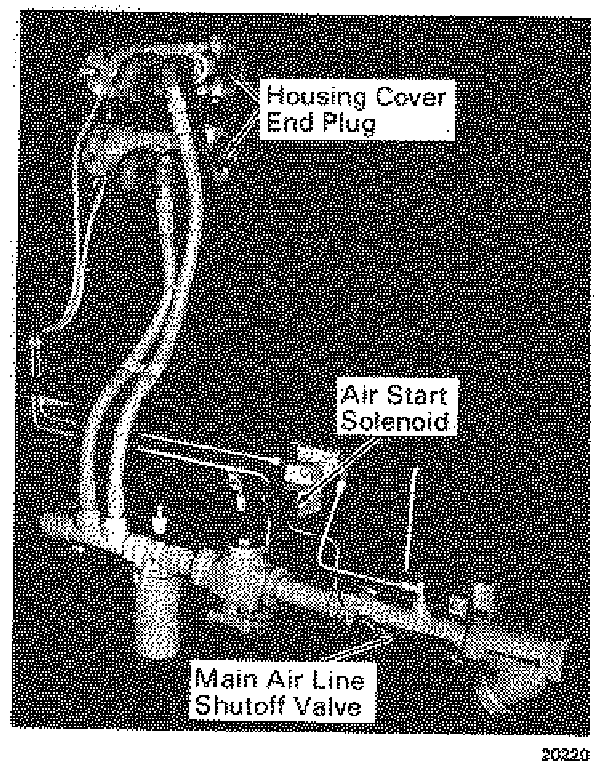


Fig. B-3 - Air Starting System

2. Engage the pinion gears with the engine ring gear by one of the following methods:

   a. Attach a jumper wire at the rear of the Engine Start switch to bypass the switch. This will energize the air start solenoid allowing air to move the pinion gears forward.

   b. Open the manual "T" handle override valve, Fig. B4, on the air start solenoid valve to move pinion gears forward.

CAUTION

Ensure the override valve is closed when the turning operation is completed or the engine will crank when the main air line shutoff is opened.

3. Remove the housing cover end plug from the rear of either of the starting motors, Fig. B-3. Insert a 5/16" allen wrench into housing cover

end plug opening (barring hole). The alien wrench can either be rotated by hand or a 1/2" ratchet wrench can be used. Rotate the alien wrench slowly which will rotate the engine.

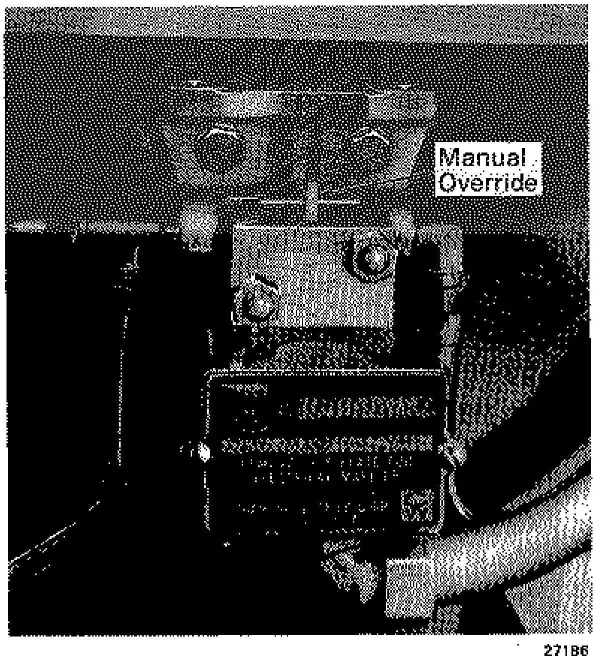


Fig. B-4 - Solenoid Valve Override

ENGINE ADJUSTMENTS AFTER EXTENDED SHUTDOWN

Before starting an engine that has been overhauled, or an engine that has been inoperative for a long period of time, refer to the applicable sections of this manual for procedures of the following checks and adjustments.

1. Check the injector racks for sticking and the injector governor linkage for binding.

NOTE

The need for the following checks and adjustments will depend upon the engine condition and performance prior to shutdown.

2. Check injector timing.

3. Set injector racks.

4. Adjust hydraulic lash adjusters.

PRELUBRICATION OF ENGINE

Prelubrication of a new engine, an engine that has been overhauled, or an engine which has been inoperative for more than 48 hours is a necessary practice. Prelubrication protects unlubricated engine parts during the interval when the lube oil pump is filling the passages with oil.

PRELUBRICATION PROCEDURE FOR UNIT WITH ACCESSORY RACK (E6 Models)

1. Remove the pipe plug at the main lube oil pump discharge elbow, Fig. B-5, and connect an external source of clean, warm oil at the discharge elbow. Prelubricate engine at a minimum of 69 kPa (10 psi) for a period of not less than 3 and not more than 5 minutes (approximately 57 1pm [15 gpm] using a 1.1 to 1.5 kW [1-1/2 to 2 hp] motor).

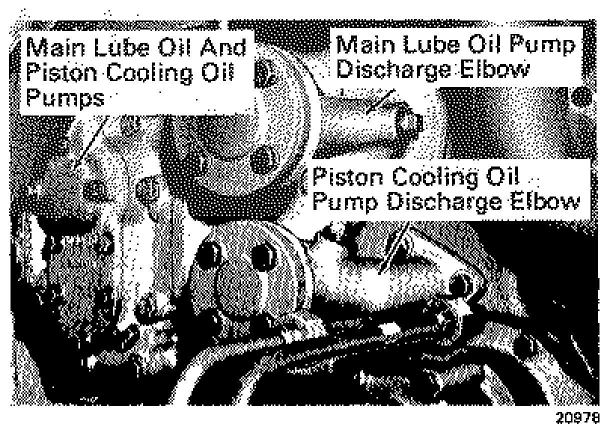


Fig. B-5 - Main Lube Oil and Piston Cooling Oil Pump Discharge Elbows

NOTE

Openings are provided on the main lube oil pump and piston cooling pump discharge elbows for a customer connection of a priming pump. Refer to Fig. B-6 for a typical priming pump connection. Typical hand priming pump capacity is 571pm (15 gpm) 50 double strokes per minute.

2. While oil pressure is being applied, open the cylinder test valves, Fig. B-7, and turn the engine manually one complete revolution. Check all bearings at the crankshaft, camshafts, rocker arms, and at the rear gear train for oil flow. Also check for restrictions or excessive oil

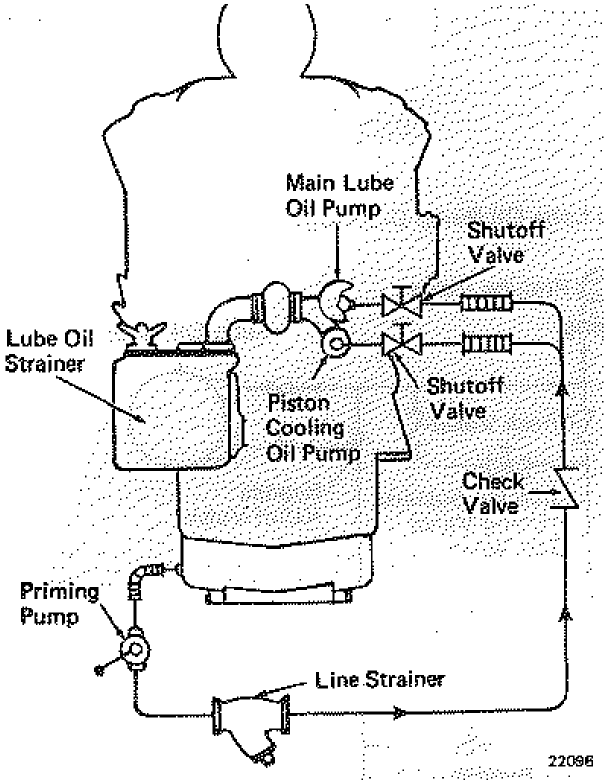


Fig. B-6 - Typical Priming Pump Connection

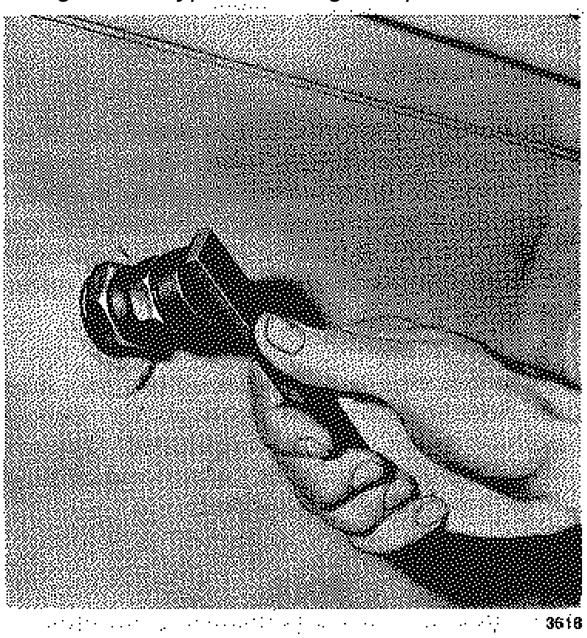


Fig. B-7 - Test Valve Wrench

flow. Check for fluid discharge at the cylinder test valves. If there is any sign of water or oil being ejected at the test valves, or any indication of obstruction while rotating the engine, determine the cause before attempting to start the engine.

3. On new or overhauled engines remove the pipe plug at the piston cooling oil pump discharge elbow, Fig. B-5, and connect an external source of clean, warm oil at the discharge elbow. Check for unrestricted flow of oil at each piston cooling tube.

4. Disconnect external oil source and replace the pipe plugs at the pump discharge elbows. Close the cylinder test valves.

5. Pour a liberal quantity of oil over the cylinder mechanism of each bank.

6. Check oil level in strainer housing and, if required, add oil to strainer housing until it overflows into the oil pan.

7. Replace and securely close all handhole covers and engine top deck covers.

NOTE'

When an engine is replaced due to mechanical breakdown, it is important that the entire oil system, such as oil coolers, filters, and strainers, be thoroughly cleaned before a replacement engine or the reconditioned engine is put in service.

In some cases engines have been removed from service and stored in the "as is" condition by draining the oil and applying anti-rust compound. When these engines are returned to service, care must be taken to see that any loose deposits are flushed out before adding a new oil charge. The entire engine should be sprayed with fuel to break up any sludge deposits and then drained, being careful that the drains are not plugged. Fuel should not be sprayed directly on the valve mechanism or bearings, as lubrication will be removed or dirt forced into these areas. The surfaces should then be wiped dry before new oil is added to the engine.

PRELUBRICATION PROCEDURE FOR UNIT WITHOUT ACCESSORY RACK (E6A Models)

NOTE

A unit without an accessory rack and with customer supplied system piping must have a priming pump in the system. Refer to applicable Engine Lube System drawing for piping arrangement. Refer to Fig. B-8 for a typical arrangement.

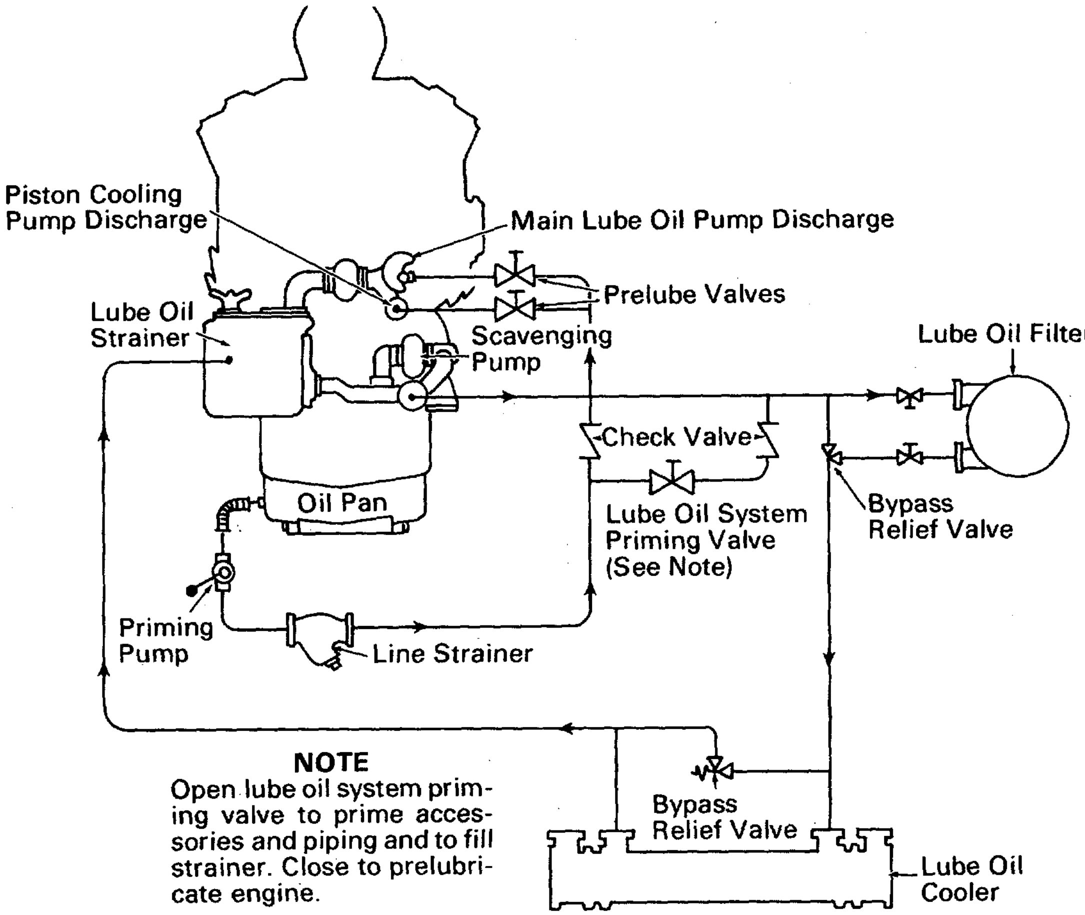


Fig. B-8 - Typical Model E6A Lube Oil System Piping

1. Open lube oil system priming valve and operate priming pump to fill lube oil system until strainer housing is filled by oil draining from the lube oil cooler. Strainer housing should be filled until oil overflows into oil pan.

2. Close lube oil system priming valve. Ensure main lube oil prelube valve is open and piston cooling prelube valve is closed, if unit so equipped. Operate priming pump. Prelubricate engine at a minimum of 69 kPa (10 psi) for a period of not less than three and not more than five minutes (approximately 57 1pm [15 gpm] using a 1.1 to 1.5 kW [1-1/2 to 2 hp] motor. Typical hand priming pump capacity is 57 1pm [15 gpm] at 50 double strokes per minute).

NOTE

If unit does not have a permanent connection to the main lube oil pump discharge elbow, remove pipe plug from the elbow and connect an external oil source at that opening.

3. While pressure is being applied, open cylinder test valves and turn engine manually one complete revolution. Check all bearings at the crankshaft, camshafts, rocker arms, and at the rear gear train for oil flow. Check for fluid discharge at the cylinder test valves. If there is any sign of water or oil being ejected at the test valves, or any indication of obstruction while rotating the engine, determine the cause before attempting to start the engine.

4. On new or overhauled engines, close main lube oil prelube valve and open piston cooling prelube valve, if unit so equipped. Operate priming pump. Check for unrestricted oil flow at each piston cooling oil pipe.

NOTE

If unit does not have a permanent connection to piston cooling pump discharge, remove pipe plug from piston cooling pump discharge elbow and connect an external source of oil.

5. Close cylinder test valves.

6. Pour a liberal quantity of oil over the cylinder mechanism of each bank.

7. Check oil level in strainer housing and, if required, add oil to strainer housing until it overflows into the oil pan.

8. Replace and securely close all handhole covers and engine top deck covers.

NOTE

When an engine is replaced due to mechanical breakdown, it is important that the entire oil system, such as oil coolers, filters, and strainers, be thoroughly cleaned before a replacement engine or the reconditioned engine is put in service. A recurrence of trouble may be experienced in the clean engine if other system components have been neglected.

In some cases engines have been removed from service and stored in the "as is" condition by draining the oil and applying anti-rust compound. When these engines are returned to service, care must be taken to see that any loose deposits are flushed out before adding a new oil charge. The entire engine should be sprayed with fuel to break up any sludge deposits and then drained, being careful that the drains are not plugged. Fuel should not be sprayed directly on the valve mechanism or bearings, as lubrication will be removed or dirt forced into these areas. The surfaces should then be wiped dry before new oil is added to the engine.

PREPARATION FOR STARTING ENGINE

1. Ensure exhaust stack is open.

2. Check engine coolant and fill if required. Refer to Cooling System Service Data for system capacity.

CAUTION

Do not continue to operate an engine requiring periodic addition of coolant. Locate and repair leak.

3. Check starting air pressure. Should be a minimum of 1 034 kPa (150 psi) for 8-cylinder engines and 1 379 kPa (200 psi) for all other engines.

4. Check control air pressure. Should be between 862 and 965 kPa (125 and 140 psi).

5. Check lubricating oil level, Fig. B-9, and add oil if required. Refer to Lubricating Oil System Service Data for system capacity. Recheck lube oil after engine is at operating temperature. Lube oil level should be on full mark on dipstick with engine at idle speed and oil hot.

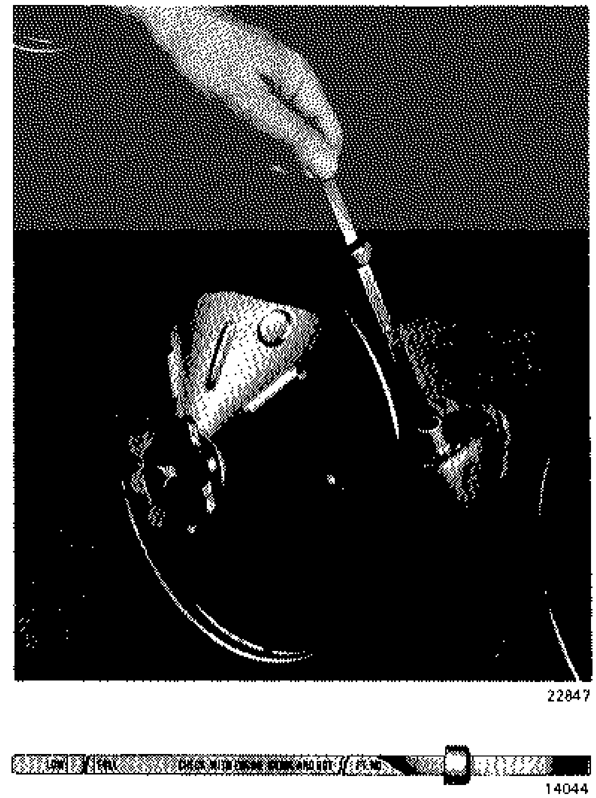


Fig. B-9 - Oil Level Gauge

6. Ensure oil in the governor is at correct level in the sight glass, Fig. B-10.

NOTE

Governor oil level will rise after engine is started and the oil temperature increases.

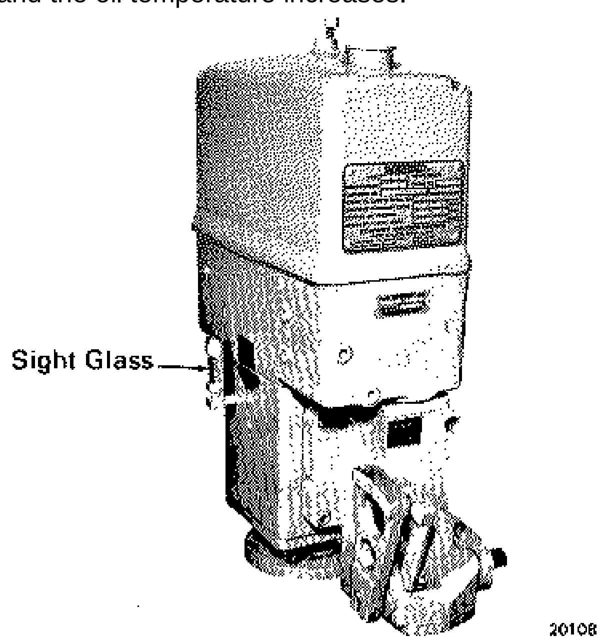


Fig. B-10 - PGA Governor, 3/4 Front View

7. Ensure overspeed trip lever, Fig. B-11, is in running (latched) position.

8. Ensure governor manual speed adjusting knob, Fig. B-12, is set in the idle speed position.

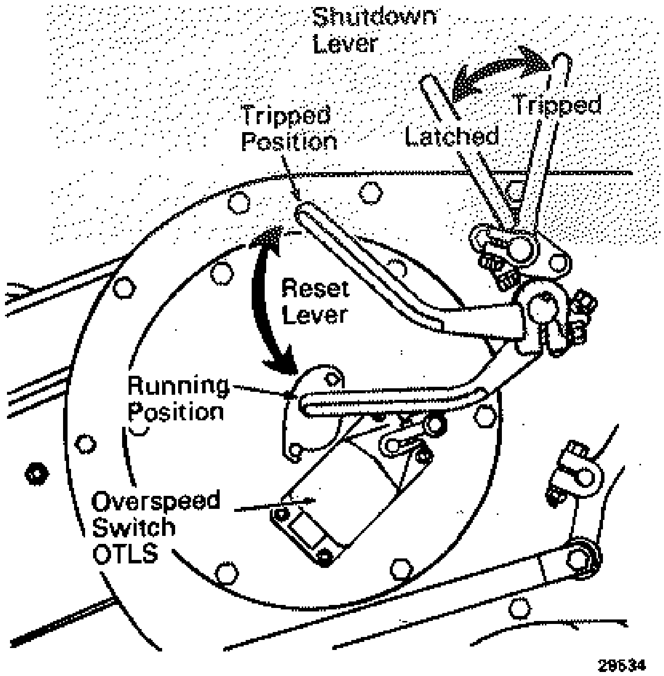


Fig. B-11 - Reset And shutdown Lever Positions

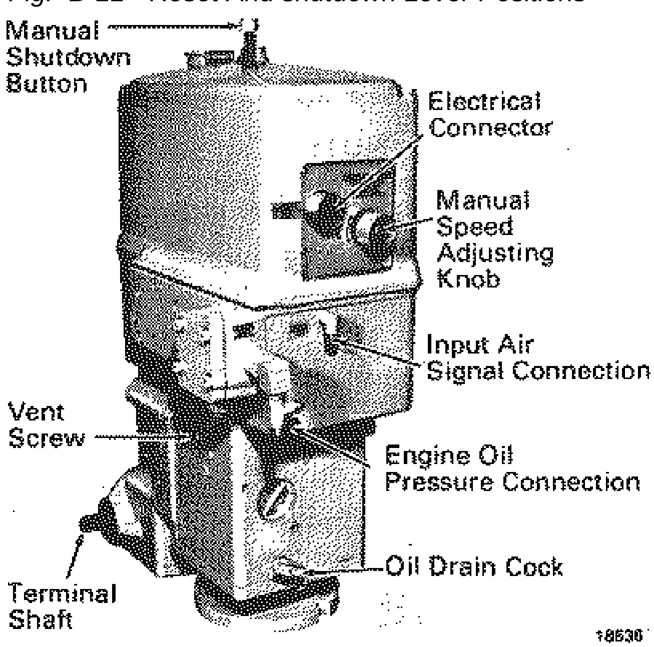


Fig. B-12 - PGA Governor 3/4 Rear View

9. Check engine fuel supply. Ensure strainers and filters are clean.

10. Operate hand fuel priming pump until pressure is shown on the engine control cabinet FUEL OIL pressure gauge.

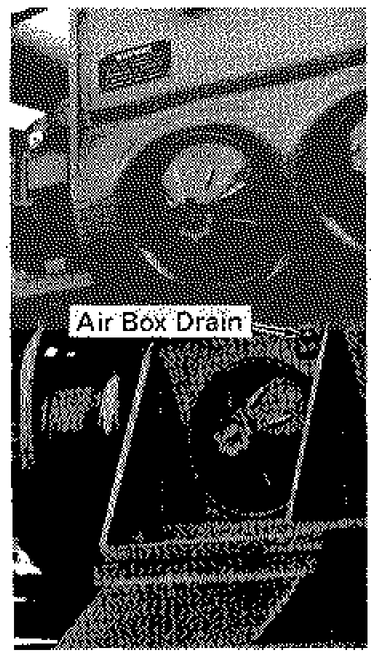
NOTE

If unit is equipped with a motor driven fuel priming pump, operate motor to prime the engine.

11. Check air box drains, Fig. B-13, for proper operation.

NOTE

Air box draining should be done periodically, as indicated in the Scheduled Maintenance Program, if air box drains are kept closed.



NOTE

Air box drains are located at front and rear of engine on both sides.

Fig. B-13 - Air Box Drain

12. Check oil level in reduction gear using dipstick.

NOTE

A new engine, engine that has been overhauled, or an engine that has been inoperative for more than 48 hours will require prelubrication. Refer to Prelubrication Of Engine portion of this section. If engine requires prelubrication, recheck oil level, as an appreciable quantity of oil may have been transferred to the external system (cooler, filter, strainer). Add oil if required.

13. In the engineroom control station, place the engine speed and clutch control air valve in the NEUTRAL position and the control air transfer valve in the LOCAL position.

NOTE

Engineroom speed and clutch control air valve and control air transfer valve are furnished as individual components for installation in the engineroom by the customer.

14. If engine has been shut down for at least 12 hours, but has not been prelubricated and manually rotated, open the cylinder test valves and turn the engine manually one complete revolution. Check for fluid discharge at the cylinder test valves. If there is any sign of water or oil being ejected at the test valves, or any indication of obstruction while rotating the engine, determine the cause before attempting to start the engine.

15. Replace and securely close all handhole covers and engine top deck covers.

CAUTION

Do not inch engine with starting motors. Ensure the strainer housing is full before starting the engine. If strainer housing is empty, serious engine damage can occur.

SECTION C

OPERATION

CONTENTS PAGE

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OPERATION

This section contains recommended procedures for operation of the unit with basic accessories supplied with the engine. As these accessories can be installed by the user and can vary in accord with a specific application, the operation procedures must be considered "typical."

STARTING THE ENGINE

Before starting the engine, refer to Prestart Procedures Section.

1. Position the injector control lever, Fig.C-1, toward the center of the engine at about one-third rack (idle position).

2. Press and hold ENGINE START pushbutton on the engine control cabinet until engine starts. The engine should start within 10 seconds. Release ENGINE START pushbutton when engine starts.

3. Control speed of the engine with the injector control lever until governor assumes control, then release lever. Do not operate the injector control to increase engine speed until oil pressure is confirmed.

4. Check lubricating oil pressure. If pressure is not indicated on the gauge within 30 seconds, stop the engine and determine cause.

5. Check fresh and raw water pressures to make sure water is being circulated. Check water level in expansion tank.

6. Check governor oil for proper level on gauge.

RUNNING THE ENGINE

CAUTION

Do not increase engine speed beyond idle until fresh water temperature is 49° C (120° F).

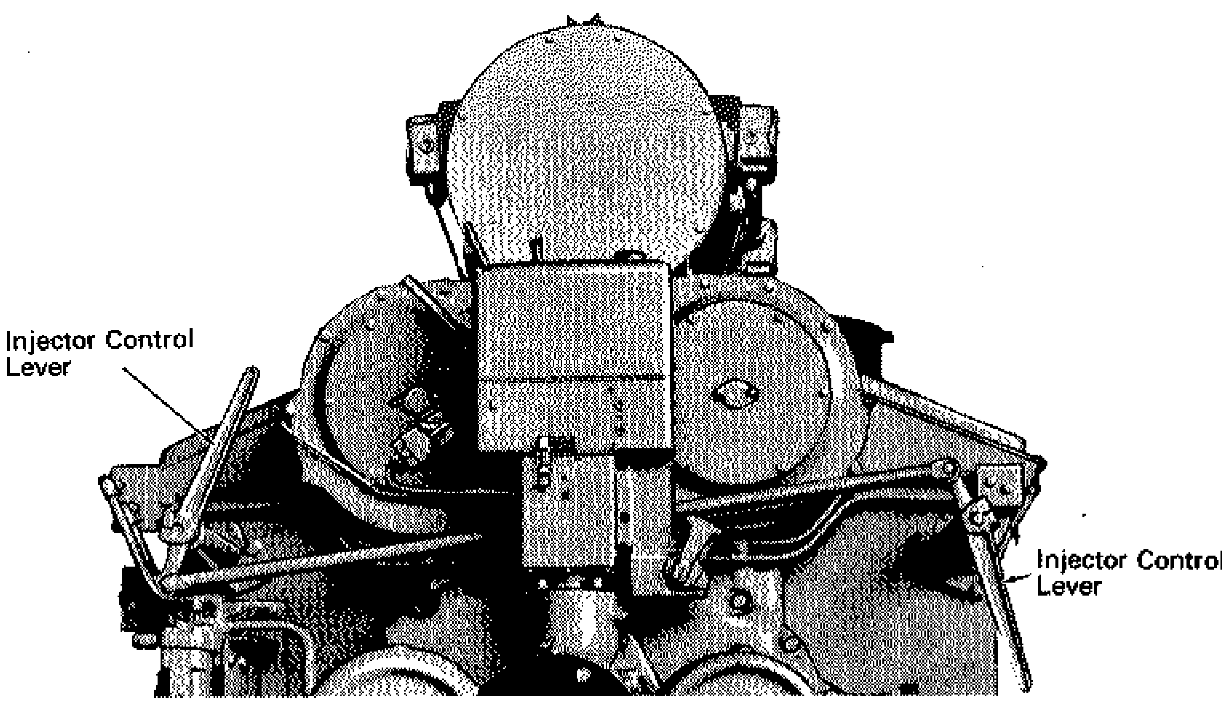

Fig. C-1 - Injector Control Lever

1. Increase the engine speed slowly to full speed by means of the governor manual speed adjusting knob or the remote speed control.

NOTE

If engine has been repaired or overhauled, it is good practice to run the engine slowly with frequent inspections to ensure that the renewed parts are satisfactory. Check pressures and temperatures carefully during this run.

2. Check oil flow sight gauge at top-rear of the reduction gear to ensure oil is flowing when the gear clutch is engaged.

3. At rated load and speed, ensure the temperatures and pressures are within the limits specified in the Service Data.

4. Refer to Fig. C-2 for engine brake and propeller horsepower data in relation to engine RPM. Refer to Fig. C-3 for engine brake horsepower data in relation to governor rack position at a specific RPM.

STOPPING THE ENGINE

1. Remove load from engine.

2. Let engine run for at least 2 minutes to allow cooling water to remove excess heat.

3. Stop engine by pulling injector control lever at the front of the engine, away from the engine and hold injector control lever until engine stops. On engine equipped with a remote stop button, engine may be stopped by pressing button.

4. In an emergency, the engine may be stopped by tripping the overspeed trip mechanism.

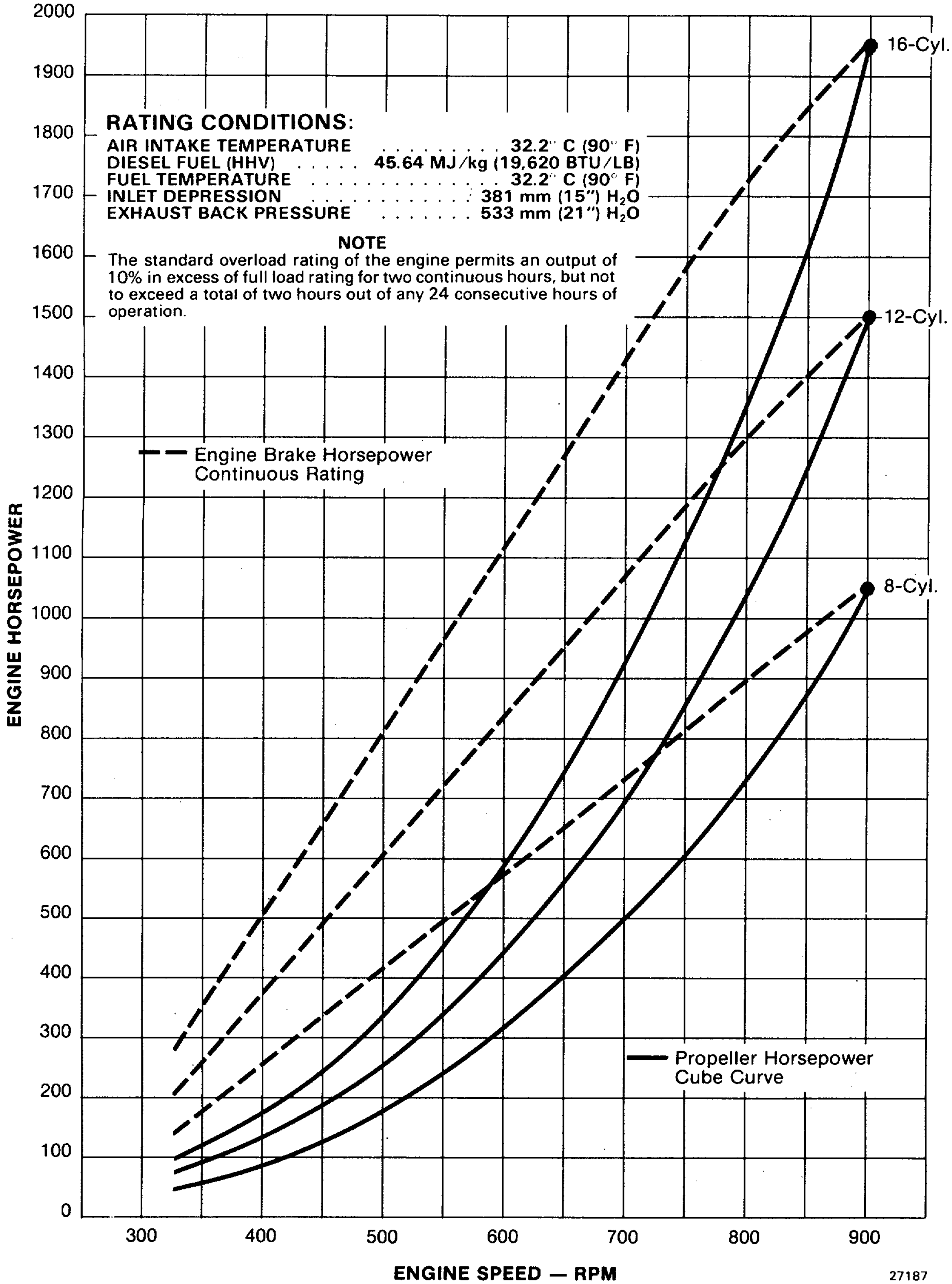

Fig. C-2 - 645E6 Engine HP/RPM Curves

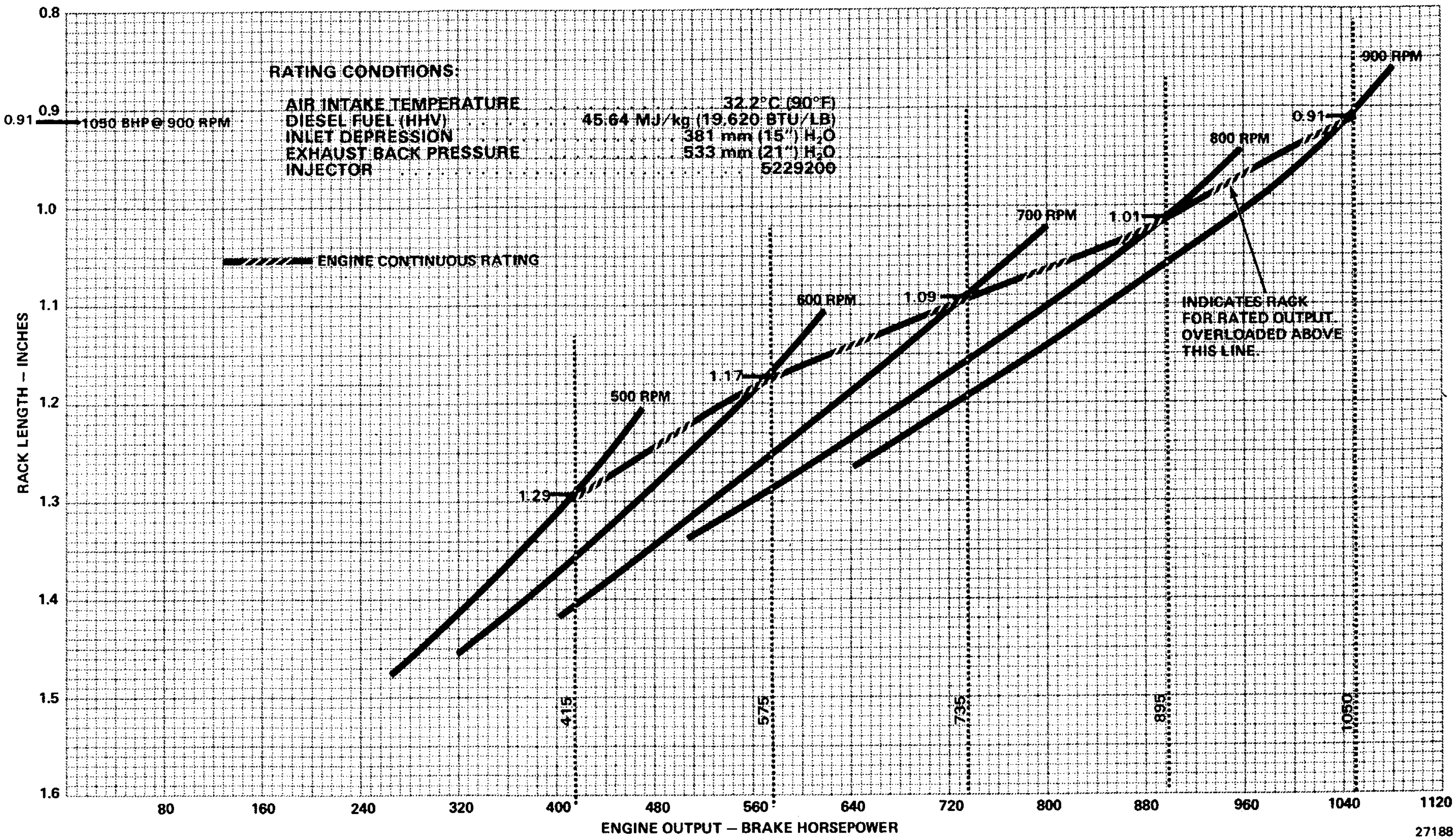

Fig. C-3 - 8-645E6 Injector Rack Position/Brake HP At Various Engine Speeds

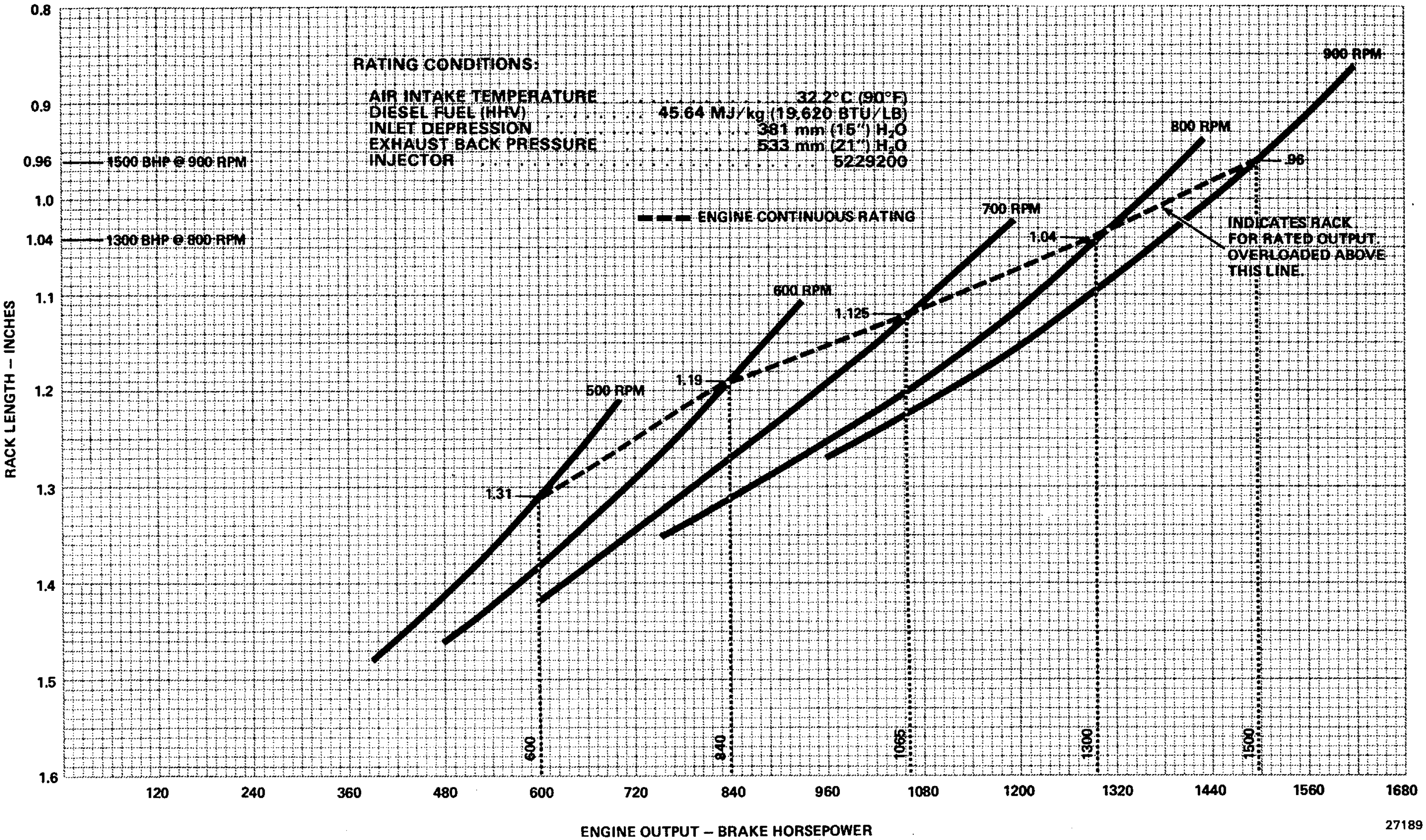

Fig. C-4 - 12-645E6 Injector Rack Position/Brake HP At Various Engine Speeds

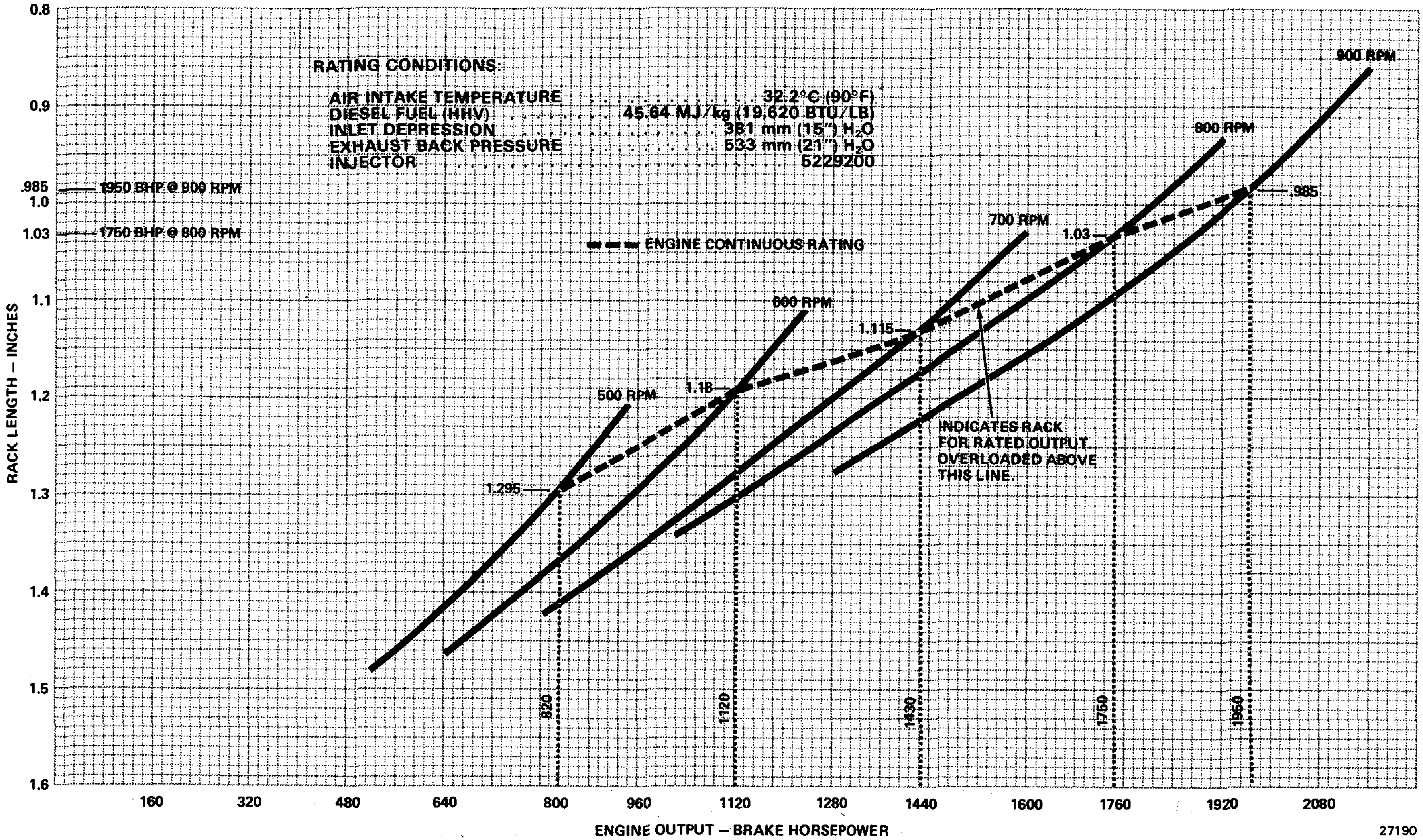

Fig. C-5 - 16-645E6 Injector Rack Position/Brake HP At Various Engine Speeds

SERVICE DATA
OPERATION

SYSTEM PRESSURES AND TEMPERATURES
(at rated load and speed)

LUBRICATING OIL SYSTEM

Pressure At Normal Operating Temperature
At Governor Connection (nominal) .... 276-483 kPa (40-70 psi)
Temperature
To Engine (from cooler) .... 74-93° C (165-200° F)
From Engine (to cooler) .... 85-104° C (185-220° F)
Temperature Differential .... 11-14° C (20-25° F)
Alarm Settings
LOS, Lube Oil Switch
Rated Speed .... 117-145 kPa (17-21 psi)
Idle Speed .... 34-62 kPa (5-9 psi)
HOS, High Oil Temperature Switch (into engine) .... 104° C (220° F)

FRESH WATER SYSTEM

Pressure Rise Across Fresh Water Pump At 900 RPM
8-Cyl .... 200 ± 34.4 kPa (29 ± 5 psi)
12-Cyl .... 269 ± 28 kPa (39 ± 4 psi)
16-Cyl. .... 262 ± 28 kPa (38 ± 4 psi)
Temperature
To Engine .... 68-77° C (155-170° F)
From Engine .... 74-82° C (165-180° F)
Temperature Differential .... 4.4-5.5° C (8-10° F)
From Fresh Water Cooler To Lube Oil Cooler .... 66-74° C (150-165° F)
Alarm Setting
ETS, Engine Water Temperature (from engine)
With Accessory Rack .... 98° C (208° F)
Without Accessory Rack .... 88° C (190° F)

RAW WATER SYSTEM

Pressure Rise Across Raw Water Pump At 900 RPM
(maximum suction 27.6 kPa [4 psi] at pump inlet)
With Gear Cooler
8-Cyl .... 245-255 kPa (35.5-37.0 psi)
12-Cyl .... 186 ± 14 kPa (27 ± 2 psi)
16-Cyl. .... 186 ± 14 kPa (27 ± 2 psi)
Without Gear Cooler
8-Cyl. .... 248-259 kPa (36.0-37.5 psi)
12-Cyl .... 207 ± 14 kPa (30 ± 2 psi)
16-Cyl .... 207 ± 14 kPa (30 ± 2 psi)
Design Temperature
To Fresh Water Cooler (max.) .... 29° C (85° F)
Raw Water Temperature Rise Across Fresh Water Cooler
8-Cyl .... 5.0-7.2°C (9-13° F)
12-Cyl .... 3.9-5.6° C (7-10° F)
16-Cyl .... 5.6-7.2° C (10-13° F)

FUEL SYSTEM

At Filter Inlet (from pump) .... 276-345 kPa (40-50 psi)

COMPRESSED AIR SYSTEM

Clutch Air Pressure
To Clutch (at reservoir) ....862-965 kPa (125-140 psi)

SECTION D

ENGINE INFORMATION

<u>**CONTENTS**</u> PAGE

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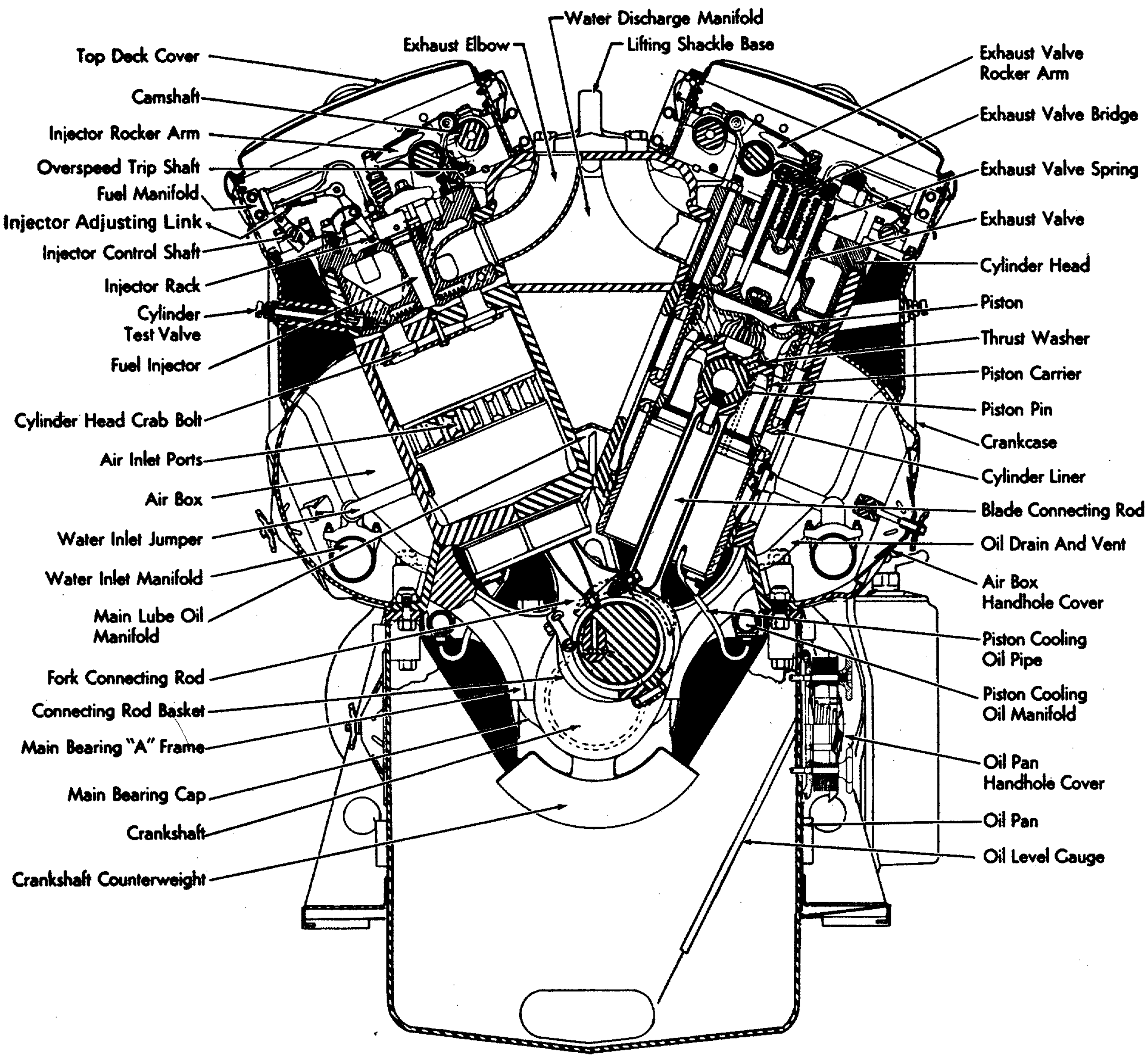

645 SERIES DIESEL ENGINE
ELECTRO-MOTIVE DIVISION
GENERAL MOTORS CORPORATION
LA GRANGE, ILLINOIS, U.S.A.

56E476

ENGINE INFORMATION

DESCRIPTION

Model 645 marine diesel engines are "V" type high compression, two cycle engines with the advantages of solid unit injection, a positive scavenging air intake system, and low weight per horsepower.

OPERATION

In a two-cycle engine each cylinder completes a power cycle in one revolution of the crankshaft. The piston does not function as an air pump during one crankshaft revolution as is the case in a four-cycle engine which requires two revolutions of the crankshaft to complete one power stroke in each cylinder. A separate means is provided in a two-cycle engine to supply the needed air and to purge. the combustion gases from the cylinder.

The engine is equipped with blowers shown schematically in Fig. D-1, to efficiently provide the air needed for combustion and scavenging.

Referring to Fig.D-1, and assuming that the piston is at the bottom of its stroke and just starting up, the air intake ports and the exhaust valves will be open. Air under pressure enters the cylinder through the liner ports, pushes the exhaust gases remaining from the previous power stroke out through the exhaust valves and fills the cylinder with a fresh supply of air. When the piston is 45° after bottom dead center, the air intake ports will be closed by the piston as indicated on the timing diagram. Shortly after the air intake ports are closed, the exhaust valves will also be closed, and the fresh air will be trapped in the cylinder. Closing the exhaust valves after the intake air ports provides for the greatest efficiency in cylinder scavenging of combustion gases.

As the piston continues upward, it compresses the trapped air into a very small volume. Just before the piston reaches top dead center, the fuel injector sprays fuel into the cylinder. Ignition of the fuel is practically instantaneous, due to the temperature of the compressed air trapped in the top of the cylinder. The fuel burns rapidly as the piston is forced down on the power stroke of the piston. As shown in the timing diagram, the piston continues

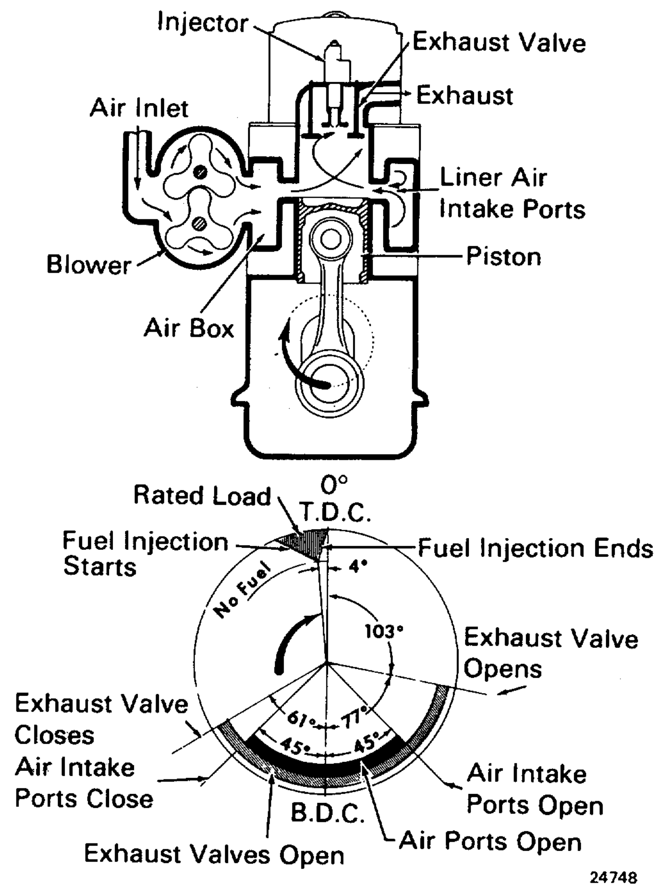

Fig. D-1 - Schematic Illustration Of Engine Operation

downward in the power stroke until the exhaust valves open.

The exhaust valves are opened ahead of the air intake ports to permit most of the combustion gases to escape and reduce the pressure in the cylinder. When the air intake ports are uncovered by the piston at 45° B.B.D.C. as it continues downward, air from the air box under pressure can immediately enter the cylinder, scavenging the remaining combustion gases from the cylinder and providing fresh air for combustion. The piston is again at the original starting point of the description and the cycle of events is repeated.

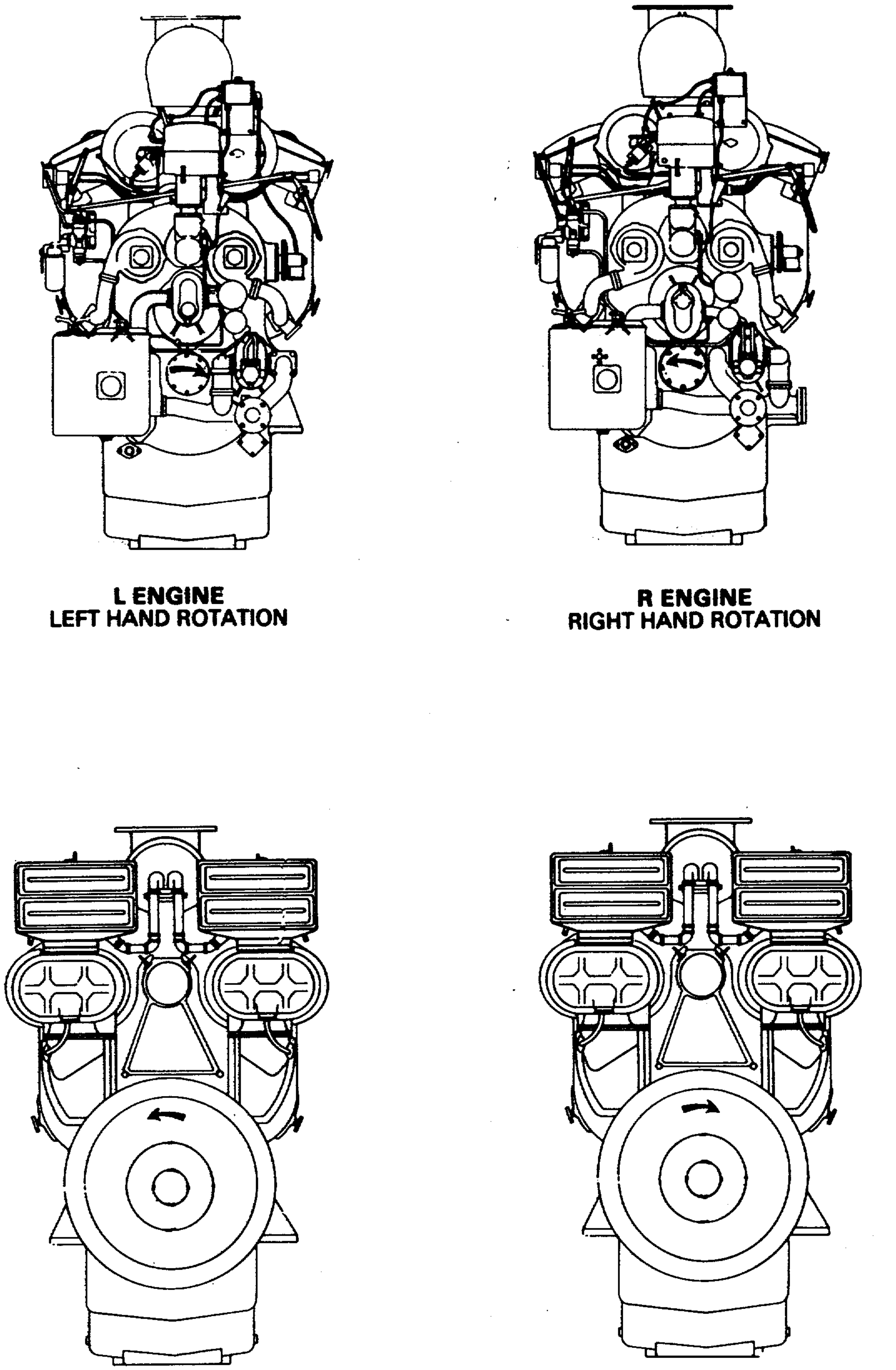

Fig. D-2 - Engine Configurations

ARRANGEMENT

Cylinder location and the designation of the ends and banks of the engine, as referred to throughout the manual, are shown in Fig. D-3. The governor, water pumps, and lube oil pumps are mounted on the "front" of the engine. The blowers and flywheel are located at the coupling end or "rear" of the engine. Left and right will be in respect to looking toward the "front" of the engine when standing at the "rear".

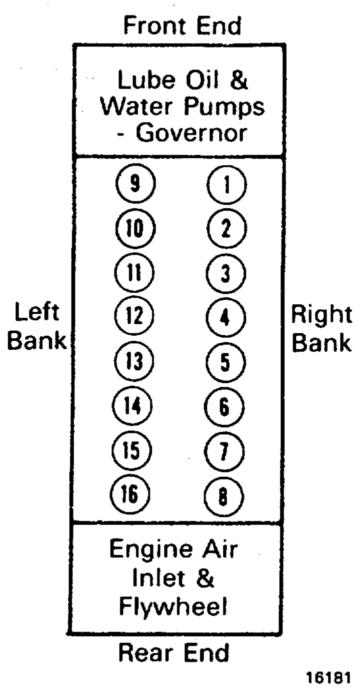

Fig. D-3 - Engine Arrangement

For identification and location of internal engine components refer to engine cross-section preceding this section.

SERIAL NUMBERS

Major components of the engine are identified by serial numbers for historical record. When reference is made regarding a part having a serial number, the serial number should be included in the information as well as other identification used concerning the part. Following are major engine items identified with a serial number, and its location on the part.

ENGINE - serial number is shown on the engine nameplate located at the right bank of the engine, and stamped on the left bank of the engine at the accessory end below the cover frame base. Section D

CRANKCASE - serial number is on the right side of the main bearing caps, right side of each end "A" frame, and at the top of the left bank at the rear end.

OIL PAN - serial number is located on the left side of the oil pan below the top rail at the rear end.

CRANKSHAFT - serial numbers are located on the web of either the first or last throws (8 & 12-cyl.) and on the web of both the first and last throws (16-cyl.).

CYLINDER HEAD - serial number is located at the front center section of the top face.

CYLINDER LINER - serial number is located below the water inlet connection.

PISTON - serial number is located at the bottom inside diameter below the oil control ring.

PISTON CARRIER - serial number is located below the thrust washer platform on the outside diameter.

PISTON PIN - serial number is located at end of pin on same end as small identification hole.

FORK CONNECTING ROD - serial numbers are located in three different locations as the fork rod assembly consists of two basket halves and the rod. On basket half with dowel, number is located above basket-to-rod bolt hole. On other half, it is located below basket-to-basket bolt holes. On the rod, number is located to the left of center above serrations on the dowel side of rod.

BLADE ROD - serial number is located at end of slipper opposite the long toe.

CAMSHAFT ASSEMBLY - serial number of the assembly is located at the end of the accessory end stubshaft.

ENGINE GEARS - serial number is located on the rim of the gear.

GOVERNOR - serial numbers are provided on the governor nameplate.

WATER PUMP - serial number is located on the housing flange rim and is preceded by an "R" or "L" to show pump installation, at the right or left bank.

LUBRICATING OIL PUMP - serial number is located at the front end cover and is preceded by the letter "L" it identify it as a lubricating pump.

SCAVENGING OIL PUMP - serial number is located at end cover and is preceded by the letter "S" to identify it is the scavenging pump.

FUEL INJECTORS - serial number is located on the same side as the injector rack, and is provided by injector manufacturer.

PAINTING

If an engine is to be removed from service and completely overhauled and the interior repainted, the parts to be painted must be cleaned in a vat of caustic solution to remove old paint, grease, and oil from the pores of the metal. The caustic solution must be thoroughly removed by washing the parts in clean hot water, and drying with an air hose. (Aluminum parts must not be washed in the caustic solution.) If caustic cleaning is not done before painting, the paint will peel off the interior of the engine and contaminate the lube oil lines. Mask off parts not being painted.

Use zinc-free crankcase primer sealer on the following: interior of crankcase, oil pan, air duct, top deck, cylinder head cover frames (except on seal surface), accessory and camshaft drive housings. Do not paint machined surfaces, liners, heads or seal surfaces.

To refinish the engine exterior, remove grease and oil with alkaline cleaner. Mask off water, fuel and oil fittings. If required, apply coat of primer. Then apply finish coat.

SERVICE DATA

ENGINE INFORMATION

SPECIFICATIONS

Bore	230.19 mm (9-1/16”)
Stroke	254.0 mm (10")
Angle between banks	45°
Compression ratio	16:1
Displacement per cyl.	10 570 cm3 (645 cu. in.)
Firing Order	
Left-hand rotation -	
8-Cyl.	1, 5, 3, 7, 4, 8, 2, 6
12-Cyl.	1, 12, 7, 4, 3, 10, 9, 5, 2, 11, 8, 6
16-Cyl.	1, 8, 9, 16, 3, 6, 11, 14, 4, 5, 12, 13, 2, 7, 10, 15
Right-hand rotation -	
8-Cyl	1, 6, 2, 8, 4, 7, 3, 5
12-Cyl.	1, 6, 8, 11, 2, 5, 9, 10, 3, 4, 7, 12
16-Cyl.	1, 15, 10, 7, 2, 13, 12, 5, 4, 14, 11, 6, 3, 16, 9, 8
Exhaust valves (per cyl.)	4
Main bearings -	
8-Cyl.	5
12-Cyl	7
16-Cyl.	10
Governor (Woodward)	PGA, EGB, or UG8
Scavenging	Uniflow
Type of scavenging blower	Helical Lobe
Cooling system	Pressurized
Fresh water pumps	Centrifugal
Raw Water Pump	Centrifugal
Lubricating oil system	Full pressure
Oil Pumps -	
Main oil pump and piston cooling pump	Two pumps in one housing siamesed inlet, double discharge
Scavenging oil pump	Helical gear type
Fuel injection	Unit injector with needle valve
Fuel pump	Positive displacement
Engine starting -	
8-Cyl	Single air motor
12, 16-Cyl.	Dual air motors
Starting air pressure	1034-1379 kPa (150-200 psi)
Air starting control solenoid	120 volt AC/DC
Idle speed - UGB actuator or UG8 governor	325 RPM
PGA governor	350 RPM
Full speed	900 RPM

CAPACITIES

Oil Pumps
Main lube oil -

	750 RPM LPM	750 RPM GPM	900 RPM LPM	900 RPM GPM
8-Cyl	223	59	269	71
12-Cyl	333	88	397	105
16-Cyl.	496	131	594	157
Piston cooling -				
8-Cyl.	114	30	136	36
12-Cyl.	155	41	182	48
16-Cyl.	208	55	250	66
Scavenging -				
8-Cyl	439	116	530	140
12-Cyl.	647	171	776	205
16-Cyl.	882	233	1056	279
Fuel Pump				
8 & 12-Cyl	5.7	1.5	6.8	1.8
16-Cyl	12.5	3.3	15.1	4.0
Fresh Water Pump				
8-Cyl.	776	205	871	230
12-Cyl. (2)	1211	320	1741	460
16-Cyl. (2)	1211	320	1741	460

WEIGHTS

The weights as listed below are approximate maximum weights for the numbered cylinder engine shown. The weights are provided as an aid in determining the handling procedure to be used. Weights represent kilogram/ pounds per unit, as described.

DESCRIPTION	8-Cyl. kg	8-Cyl. Lb	12-Cyl. kg	12-Cyl. Lb	16-Cyl. kg	16-Cyl. Lb
Engine assembly (w/o accessory rack)	9158	20,190	12,064	26,596	16,634	36,670
Crankcase (includes bearings & caps)	2626	5790	3561	7851	5319	11,727
Oil pan	765	1687	879	1937	1099	2422
Crankshaft	776	1710	944	2080	1442	3180
Crankshaft damper (gear type)	170	375	170	375	170	375
Accessory drive gear	42	92	42	92	44	98
Crankshaft gear	51	112	51	112	51	112
Ring gear	132	290	132	290	132	290
Coupling disc	147	325	147	325	147	325
Cylinder power pack assembly w/fork rod.	185	408	185	408	185	408
w/blade rod	165	363	165	363	165	363
Cylinder head assembly	66	145	66	145	66	145
Cylinder liner	58	127	58	127	58	127
Piston	19	42	19	42	19	42
Connecting rod (fork)	23	50	23	50	23	50

SERVICE DATA (CONT'D)

DESCRIPTION	8-Cyl.		12-Cyl.		16-Cyl.	
	kg	Lb	kg	Lb	kg	Lb
Connecting rod (blade)	11	25	11	25	11	25
Camshaft w/stubshaft assembly	55	122	79	172	100	220
Camshaft drive gear	40	89	40	89	40	89
Camshaft drive housing	154	340	154	340	154	340
Idler gear stubshaft assembly	43	94	43	94	43	94
Blower drive gear	14	30	14	30	14	30
Lower idler gear (No. 1)	28	62	28	62	28	62
Upper idler gear (No. 2)	37	81	37	81	37	81
Accessory drive cover assembly	60	132	60	132	60	132
Overspeed trip housing assembly	19	42	19	42	19	42
Governor (PGA, EGB)	50	110	50	110	50	110
Governor (UG-8)	23	50	23	50	23	50
Governor drive gear assembly	24	53	24	53	24	53
Governor drive housing assembly	18	40	18	40	18	40
Fresh water pump	49	109	49	109	49	109
Water manifold assembly	16	35	20	45	31	68
Main lube & piston cooling oil pump assembly	62	136	66	146	89	197
Scavenging oil pump assembly	77	170	78	172	88	194
Lube oil strainer assembly	92	203	92	203	92	203
Fuel oil filter assembly	22	49	22	49	22	49
Blower assembly	188	415	188	415	188	415
Oil separator assembly	18	39	18	39	18	39
Exhaust manifold chamber	86	190	86	190	86	190
Expansion joint	14	32	14	32	14	32
Starting motor	20	45	20	45	20	45
Starting motor mounting bracket	26	58	26	58	26	58

SERVICE DATA (CONT'D)

TORQUE VALUES

NOTE

When torque values are listed as "initial" and "final", torquing procedures in the manual text MUST be followed.

TOP DECK

	N·m	FT-LBS
Camshaft stubshaft bearing bracket bolts -		
5/8" hex head	190	140
1/2" socket head	102	75
Cylinder head crab nuts (studs and nuts lubricated)*		
Initial	542	400
Final	2440	1800
Injector crab nuts (lubricated)*	68	50
Cylinder head-to-liner nuts (lubricated)*		
Initial	95	70
Final	325	240
Top deck head frame bolts (300M bolts with hardened washers)	54	40
Overspeed trip assembly	32	24
Injector fuel lines	54	40
Camshaft bearing blocks	43	32
Rocker arm shaft nuts (lubricated)*		
Initial	203	150
Final	407	300
Rocker arm oil line bolts	9.5	7
Fuel manifold blocks	54	40
Cylinder test valve packing nut	88	65
Water outlet elbow-to-head bolts	41	30
Exhaust manifold-to-crankcase (lubricated)**		
Initial	68	50
Final	176	130

ACCESSORY END

	N·m	FT-LBS
Accessory drive housing-to-crankcase and oil pan (w/sealing compound)t	88	65
Overspeed trip housing-to-crankcase	88	65
Fresh water pump mounting bolts	88	65
Fresh water pump elbows	88	65
Scavenging oil pump mounting bolts	88	65
Scavenging oil pump elbows	88	65
Lube oil pump mounting bolts	88	65
Lube oil pump elbows	88	65
Oil strainer housing mounting bolts	88	65
Governor drive housing mounting bolts	88	65
Governor-to-drive housing	88	65
Overspeed trip cover-to-overspeed trip housing	41	30
Fuel manifolds-to-filter	47	35
Oil strainer elbows-to-strainer housing	54	40
Accessory drive oil seal cover	54	40
Oil seal retainer to accessory drive oil seal cover	41	30

	N·m	FT-LBS
Accessory drive coupling retaining bolt		
Initial	136	100
Final	678	500
Accessory drive flange locking spring bolt	88	65
Governor drive gear assembly		
Stubshaft-to-crankcase	102	75
Stubshaft dowel bolts	23	17
Oil jumper-to-stubshaft	47	35
Retainer plate-to-stubshaft	47	35
Governor drive flange-to-drive gear	47	35
Counterweight-to-camshaft stubshaft		
1/2"	122	90
5/16" (dowel bolts)	23	17

BLOWER END

Piston cooling manifold flange-to-crankcase	37	27
Idler gear stubshaft bracket-to-crankcase -		
1/2"	122	90
3/8"	37	27
5/16'"	23	17
No. 1 idler gear thrust plate-to-crankcase -		
1/2"	102	75
5/8"	251	185
Blower rotor shaft nut	678	500
Blower timing gear cover nuts	47	35
Blower end plate-to-housing nuts	88	65
Blower support-to-crankcase	88	65
Blower-to-support	88	65
Blower drain lines	88	65
Auxiliary drive housing-to-crankcase	238	175
Camshaft drive housing-to-crankcase	88	65
Camshaft drive gear cover-to-housing (w/sealing compound)†	88	65
Oil slinger-to-crankshaft gear	23	17
Oil retainer-to-camshaft drive housing	41	30

CRANKCASE AND OIL PAN

Main bearing nuts (lubricated)*		
Initial	475-542	350-400
Final	1017	750
Crankcase-to-oil pan		
Initial	136	100
Final	610	450
Connecting rod-to-piston pin (lubricated)*	610	450
Basket-to-connecting rod (lubricated)*		
Initial	14	10
Final	258	190
Connecting rod basket	102	75
Piston cooling oil pipe bolts	27	20
Water jumper-to-liner	41	30
Water jumper saddle strap nuts	20	15
Torsional damper-to-crankshaft (lubricated)*	678	500
Bolt-on crankshaft stubshaft (lubricated)*(where applicable)	678	500
Bolt-on crankshaft stubshaft retention bolts	81	60
Accessory drive gear to crankshaft (lubricated)*	407	300
Accessory drive gear oil slinger	33	24

	N·m	FT-LBS
Coupling disc-to-crankshaft (lubricated)*	440	1800
Coupling disc rim bolts	400	295
Handhole cover bolts	27-41	20-30
Engine mounting bolts	617	455

* Lubricate with Texaco Threadtex No. 2303
** Lubricate with Fel-Pro C5A or equivalent
† Apply Loctite Sealing Compound No. 242

EQUIPMENT LIST

Crankcase primer-sealer (3.79 liters [1 U.S. gal.])	8187781
(18.93 liters [5 U.S. gal.])D	8187782
Suede gray enamel (3.79 liters [1 U.S gal.])	8122047
(18.93 liters [5 U.S. gal.])	8133054
(0.95 liters [1 U.S. qt.])	8078289
Enamel thinner (3.79 liters [1 U.S. gal.])D	8079447
Buff primer (3.79 liters [1 U.S. gal.])	8228726

SECTION 1

CRANKCASE AND OIL PAN

CRANKCASE AND OIL PAN

CRANKCASE

DESCRIPTION

The crankcase, Fig. 1-1, is the main structural part of the engine. It is a steel fabrication forming a rigid self-supporting assembly to accommodate the cylinder power assemblies, crankshaft, and engine mounted accessories.

Handholes in the side panels, provided with gasketed covers, Fig. 1-2, allow inspection of liners and pistons, cleaning of air box, and access to water manifold and oil pan mounting bolts.

MAINTENANCE

CLEANING

The crankcase should be cleaned to remove foreign material, after any work has been done on the interior of the engine, or if damage has occurred in the engine. This can be done by using a spray gun and solvent. The equipment near the engine should be protected against the spray. After spraying the top deck, wipe with towels saturated with solvent. Wipe all solvent trapped in corners and pockets. Use only lintless, bound-edge towels.

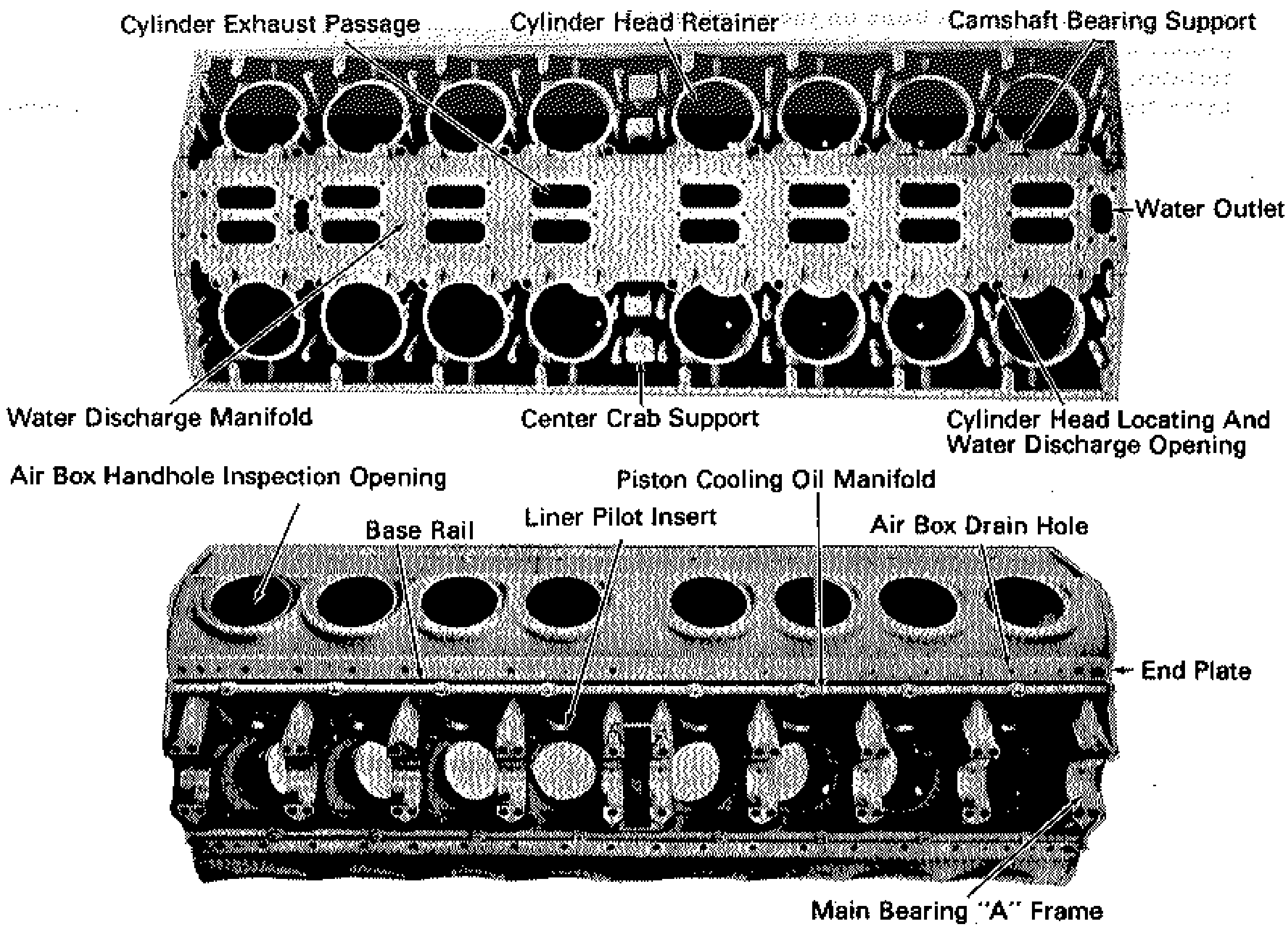

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Fig. 1-1 - Crankcase, 16-cylinder

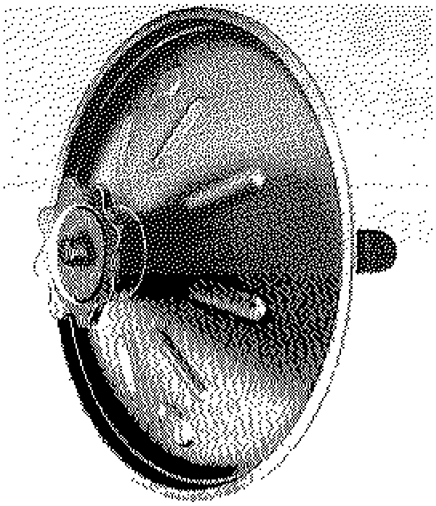


Fig. 1-2 - Crankcase Handhole Cover

Cleaning of the air box with a spray gun while liners are in place is not recommended practice, due to possibility of dirt entering liners at the ports.

At any time cleaning is done on the crankcase, protection should be given to oil passages, bearing surfaces, and gears, to prevent gritty material from being trapped. Cleaning procedures should be in accord with accepted practice or as recommended by the supplier of cleaning material.

INSPECTION

Periodic inspection of the crankcase should be performed to detect minor discrepancies which, if not corrected, could result in major crankcase failure. Early detection and repair of the crankcase is essential since major repairs usually cannot be performed in the field. In instances where extensive welding is required, the crankcase must be stress relieved and remachined where necessary. Therefore, it is recommended that a crankcase requiring rebuild or reconditioning be returned to the manufacturer for repair.

LOWER LINER BORE INSERT

DESCRIPTION

A replaceable cast iron insert, Fig. 1-3, is used in each lower liner bore of the crankcase to provide a wear surface at the lower liner pilot. Seals held in grooves in the lower liner pilot, prevent air passage between the insert and the liner.

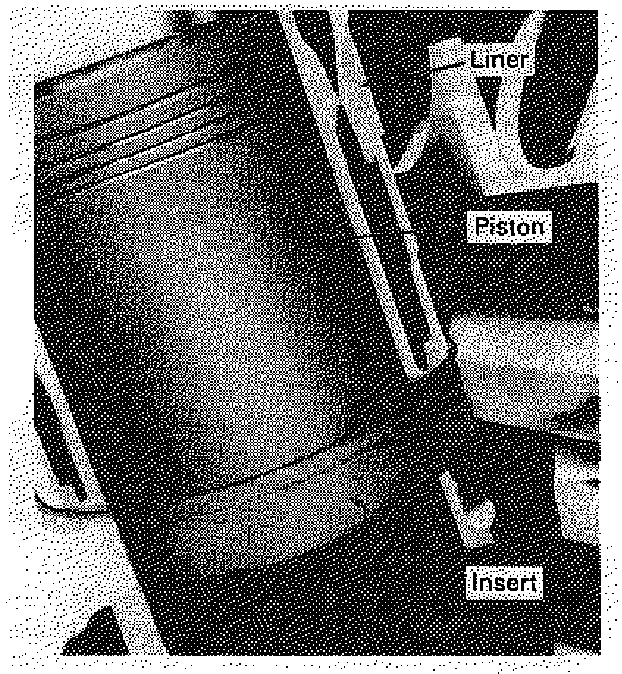


Fig. 1-3 - Lower Liner Bore Insert

MAINTENANCE

When the inside diameter of the insert, installed in the crankcase, reaches the maximum limit, the insert should be removed and a new one installed.

Replacement of the insert in the lower liner bore of the crankcase requires the use of a sturdily constructed tool to apply and remove the insert safely and efficiently. The lower liner insert application and removal tool, Fig. 14, is specifically designed to do this work. This tool consists of a press and puller assembly and a 10 ton hydraulic jack. The hydraulic jack consists of a 10 ton hydraulic ram, a high pressure hose, and a high pressure hydraulic pump.

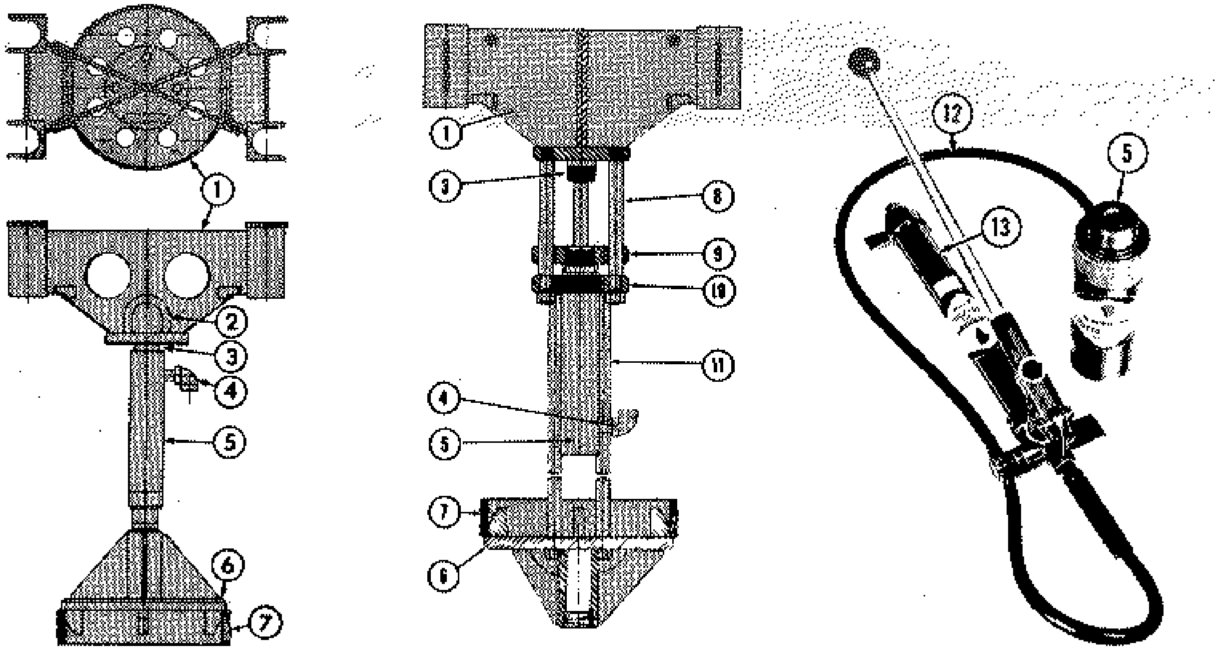
INSERT APPLICATION

The arrangement of the tool for insert application is shown in Figs. 1-4a and 1-4c. The insert is installed as follows:

1. Coat the contact area of the outside diameter of the insert with mounting compound.

2. Manually place the insert (7) in place in the lower bore, and position it for the pressing operation by starting it uniformly in the bore.

3. Assemble the tool as shown in Fig. 1-4a, with the ram screwed into the screw plug, and into



a. Insert Application b. Insert Removal c. Hydraulic Jack

1. Crab Stud Holding Assembly
2. Hoisting Ring
3. Screw Plug
4. High Pressure Hose Connection
5. 10-Ton Ram
6. Insert Plate
7. Insert
8. Holding Studs
9. Upper Plate
10. Ram Plate
11. Pulling Studs
12. High Pressure Hose
13. Hydraulic Pump

Fig.1-4 Liner Bore Insert Application And Removal Tool

the boss of the insert plate (6). The ram plunger should be in the retracted position. Disconnect the high pressure hose (12) if it is attached to the ram.

4. Lift the tool at the hoisting ring (2), and place the tool into the cylinder bore resting upon the cylinder retainer. The tool should be positioned so the hose connection is accessible from the stress plate inspection opening. Secure the tool using four crab nuts at the crab stud holding bosses.

5. Attach the high pressure hose (12) to the ram (5) at the ram connection (4), and using the hydraulic pump, extend the plunger to contact and press the bore until the shoulder is seated.

INSERT REMOVAL

The arrangement of the tool for insert removal is shown in Fig. 1-4b. The insert is removed as follows:

1. Assemble the tool for removal as shown and remove the four nuts holding the insert plate (6) and remove the plate. Also, remove the high pressure hose (12) from the ram (5) if it is connected.

2. Lift the tool using the hoisting ring and place in the cylinder, resting upon the retainer. Position the tool so that the hose fitting may be reached at the outboard side to permit hose application. Apply four crab nuts to secure the tool.

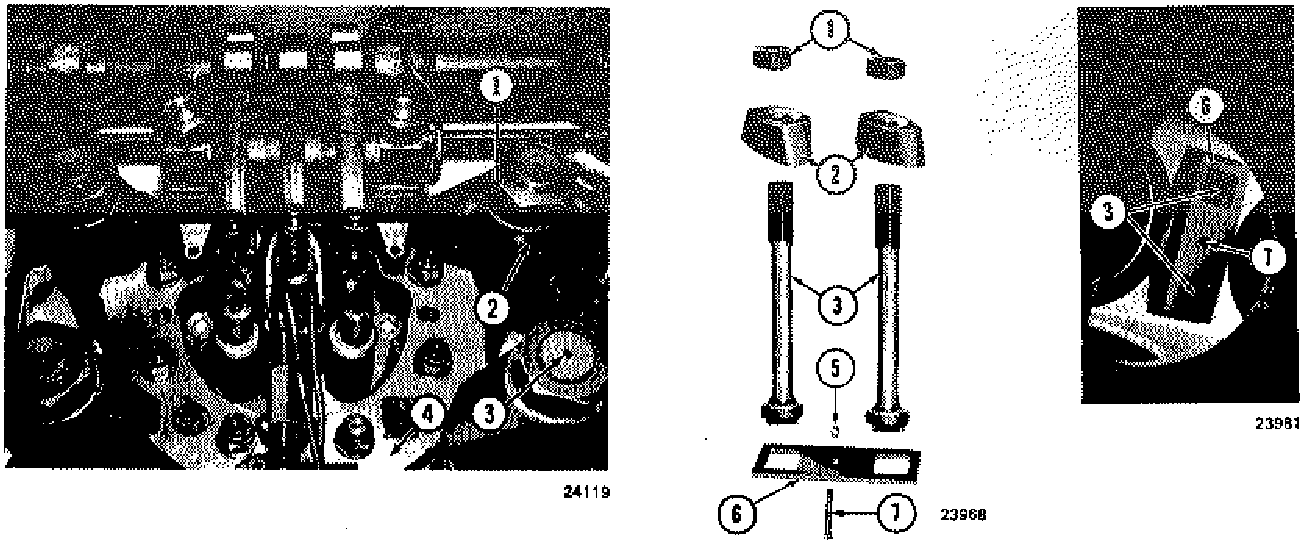
3. Place the ram plunger so that the insert plate bolts extend below the insert to permit insert plate application, as shown in Fig. 1-4b. Apply the insert plate and its holding bolts.

4. Connect the high pressure hose (12) to its fitting (4) on the ram (5) and using the pump (13) remove the insert (7) from the crankcase bore.

In the event that the insert application and removal tool is not available, the insert may be applied and removed using a mallet and a phenolic or wooden block.

CRAB BOLTS
DESCRIPTION

The cylinder head and liner are bolted together and this assembly is held in the cylinder head retainer by crab bolts, head crabs, and nuts, Fig. 1-5. The crab



1. Crab Nut
2. Crab
3. Crab Bolt
4. Cylinder head
5. Retainer Bolt Nut
6. Retainer Plate
7. Retainer Bolt

Figure 1-5 - Crab Bolt Installation

bolts extend up through the cylinder bank upper deck plate adjacent to each cylinder retainer. The bolt heads have a spherical seating surface which seats in a like surface, the bolts being held in position by a separate plate and bolt for each pair of bolts. The square bolt heads fit corresponding holes in the plate which prevents their turning when being torqued.

MAINTENANCE

The 1-3/4"-12-UNR crab bolts can be removed through the air box by removing the crab bolt retainer plate bolt and retainer plate. The retainer plate and bolt are easily accessible only after liner has been removed. Minor damage to crab bolt threads may be cleaned up using thread file. Crab nut threads may be cleaned up using a 1-3/4"-12 tap. Whenever crab bolt threads are exposed, they should be covered with thread protectors.

CAUTION

To prevent damage to crab bolts having UNR (rolled threads), only the proper thread file should be used, as listed in the Service Data.

If one of the two crab bolts located at either end of either bank, or one of the center crab bolts (16-cyl.) was broken, the other three bolts holding the cylinder head should be changed. If a broken crab bolt was in any other location, the remaining five crab bolts holding the heads held by the broken crab bolt should be changed.

MAIN BEARING STUD BOLTS AND CAPS

DESCRIPTION

The main bearing stud bolts are shown in Fig. 1-6. Each "A" frame has four 1-1/4" UNR coated main bearing studs except the center "A" frames (16-cyl.), which have two each. They pass through the "A" frame and main bearing caps, Fig. 1-6. A transverse hole at the upper end of each stud accommodates a bolt which passes through the stud and slots in the upper nut. Semicircular or D-shaped nuts are used at the upper end of the stud.

The upper nuts have a spherical seating surface to match a similar surface in the "A" frame. Since the center "A" frames (16-cyl.) are separated from each other, a retainer assembly is used to prevent the upper nuts from turning. The retainer assembly is held in place over the nuts by bolts which pass through the nuts and studs.

MAINTENANCE

A thread file can be used to clean up minor damage to the stud bolts, while a tap can be used on the slotted stud nuts. To aid in obtaining correct torque values, the threads should be cleaned before parts application.

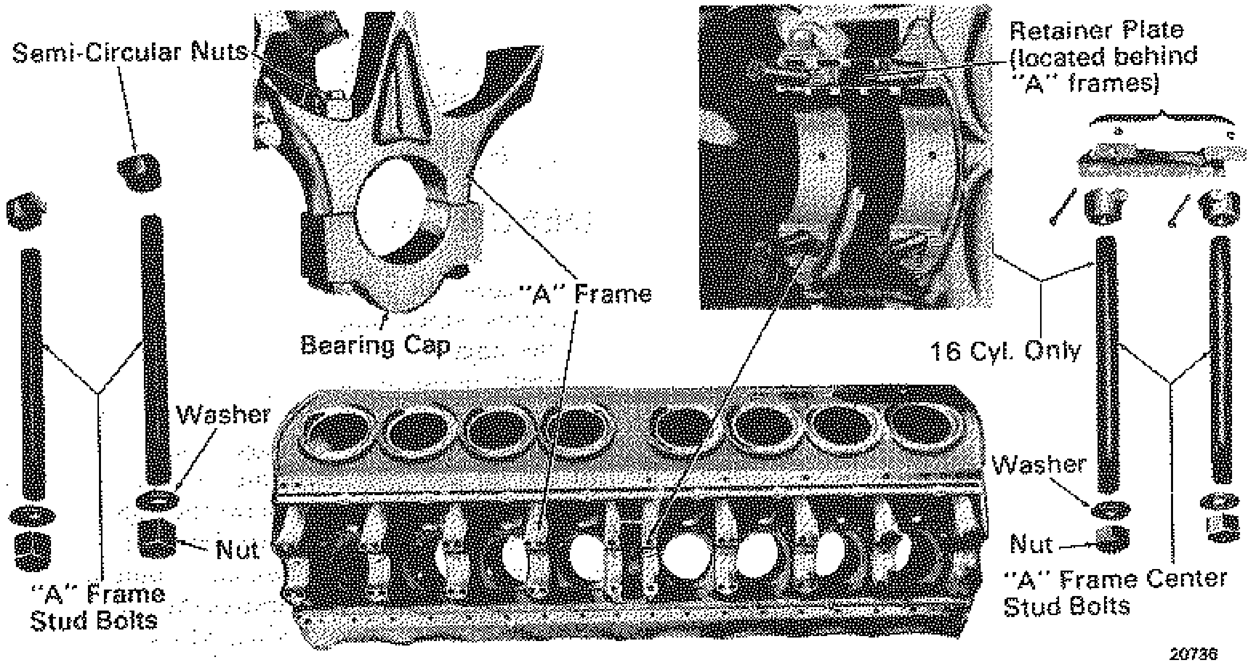


Figure 1-6 - Main Bearing Stud Bolts

Upon application, each stud is inserted into its place in the "A" frame and run into its nut until the hole in the top of stud lines up with the bolt slot of the nut. The lower end of the stud should be 178 mm (7") from the serrations on the "A" frame when the stud is brought out with the spherical surface of the upper nut contacting the mating surface in the "A" frame. This is to ensure that the lower stud nuts can be properly tightened when the bearing cap is applied. The bolt and self-locking nut may then be applied except the center "A" frames (16-cyl.). The upper nut flats contact each other when in place on all "A" frames except the center "A" frames (16- cyl.), which are separated from each other. A retainer plate is used on the center "A" frame upper nuts to prevent them from turning. After the stud has been run into the nuts the proper amount, the retainer, which is like a channel, is placed over the nuts. The bolts are then applied through the retainer and stud and across the nut slots. The bolt slots in the retainer are of different widths, one slot being larger to secure the bolt head and prevent it from turning when being tightened. The retainers are cut away on one side to provide clearance for a stiffener plate between the center "A" frames (16-cyl.).

Main bearing caps are originally applied to the "A" frame and then are line bored; therefore, they are not interchangeable or available for replacement. They must be reapplied on the same "A" frame in the same position as removed. Each cap and "A" frame is stamped on the right side with their bearing number, and in addition, all caps and the end "A" frame are stamped with crankcase serial number.

Before cap application, check serrations in cap and "A" frame and remove any burrs or foreign material that would prevent a good mating fit.

CHECKING MAIN BEARING STEEL BORE DIMENSIONS

At time of crankcase overhaul, or whenever a crankshaft is removed from an engine, it is necessary to determine whether main bearing steel bore dimensions are within tolerance.

1. Place the crankcase on its side.

2. Be sure that the crankcase "A" frame bores and serrations are clean.

3. Lubricate the studs, nut seats, and hardened washers with Texaco Threadtex No. 2303.

CAUTION

Use of the hardened washer under the main bearing cap nut is mandatory to ensure proper bolt stretch and to retain nut torque. Damaged nut seat areas on the caps must be cleaned by spot-facing or by taking a cut (1.59 mm [1/16"] maximum depth) parallel to the serration surface.

4. Apply the main bearing caps, and torque the nuts in two passes. On the first pass, torque the nuts to 475-542 N•m (350-400 ft-lbs). On the second pass, final torque the nuts to 1 017 N•m (750 ft-lbs).

NOTE

No one nut on any one cap should be torqued to 1 017 N•m (750 ft-lbs) until all the nuts on that cap have been torqued to 475-542 N•m (350-400 ft-lbs).

5. Check that the main bearing bore dimensions are within the minimum and maximum limits given in the Service Data. Take two sets of measurements at each bore, one set 12.7 mm (1/ 2") in from the accessory end of the bore and one set 12.7 mm (1/2") in from the opposite end of the bore at points shown in Fig. 1-7.

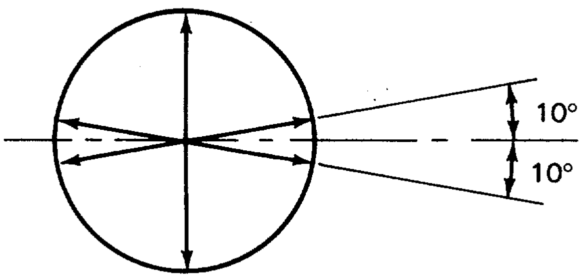


Fig. 1-7 - Main Bearing Bore Measurement

6. If any one diameter is out of tolerance -
a. The crankcase may be shipped to EMD for remanufacture.
b. If the engine owner has facilities for crankcase machining and wishes to do his own remanufacture, contact the EMD service representative for information concerning control of main bearing steel bores during remanufacture.

NOTE

A procedure using stud stretch measurements as the criteria for monitoring torques when the engine is disassembled is available from your EMD service representative.

If an overheated bearing makes it necessary to check an "A" frame for "close-in" with the crankshaft in the engine, it may be checked using a new upper main bearing. The bearing must fit into the "A" frame bore. Also check the clearance at each side between the bearing shell and the crankshaft at the split line above the serrations. Reference bearing inspection procedures in Section 6 for additional information.

A main bearing nut power wrench set may be obtained for use on the engine. This wrench, in use, is supported in the oil pan inspection opening. Also, an offset ratchet wrench set is available for running up and loosening main bearing nuts.

OIL PAN
DESCRIPTION

The engine oil pan, Fig. 1-8, is a fabricated steel assembly which supports the crankcase and serves as the engine base. The engine oil sump located centrally in the oil pan, is provided with oil drains.

A bayonet type oil level gauge extends from the side of the oil pan into the sump. A provision is also made in the side of the pan for the application of a float switch-type low oil level indicator. A scavenging oil pump suction line is built into the oil pan extending from the sump to the front end plate. Openings in each end plate allow oil from the camshaft and accessory end housings to drain into the oil pan.

Handholes at each cylinder location, provided with gasketed covers, allow access to enclosed engine parts. The covers on the control side of the engine oil pan are the same as those used on the crankcase, but some of the covers on the opposite side are flame arresting safety type, Fig. 1-9. The safety covers are spring loaded to permit their release when the crankcase pressures reach a certain predetermined limit. Excessive loads are relieved by the covers preventing a possible damaging explosion.

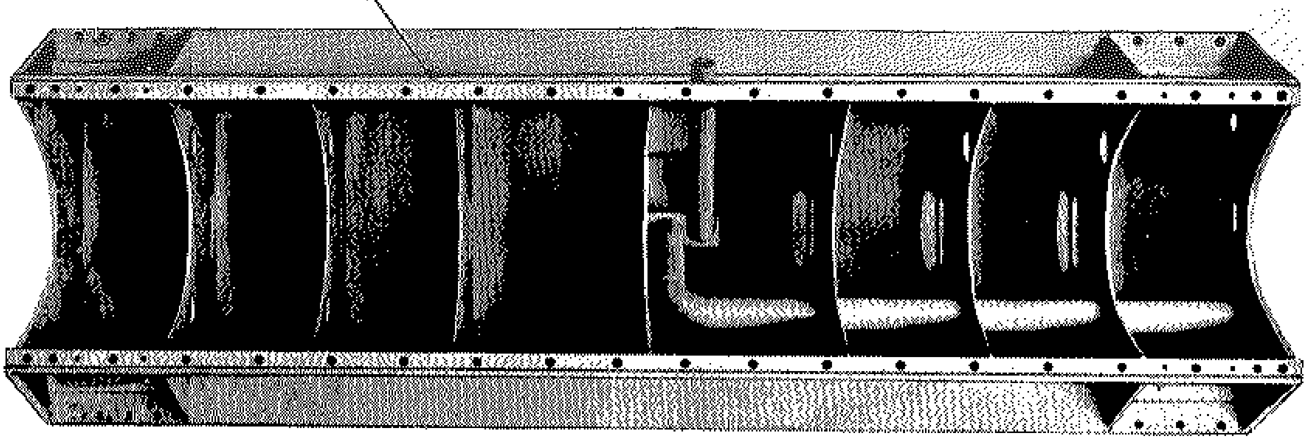
MAINTENANCE

CLEANING

The oil pan should be thoroughly cleaned at the time of an oil change or any time the engine is damaged. Particular attention should be given to the oil drain pipes to make certain there is no accumulation of foreign material. Wipe out accumulation from corners and pockets of pan and remove any loose or flaking paint from the pan interior.

INSPECTION

Inspect oil pan rails for nicks, burrs, or foreign material of any kind in seal grooves, and remove to provide a clean smooth surface. Any indentation in the seal grooves or base rails that would allow oil seepage must be filled with solder and finished flush with surrounding area. Also inspect air box drain pipes, end plates, and handhole cover gasket surface for any nicks or roughness.



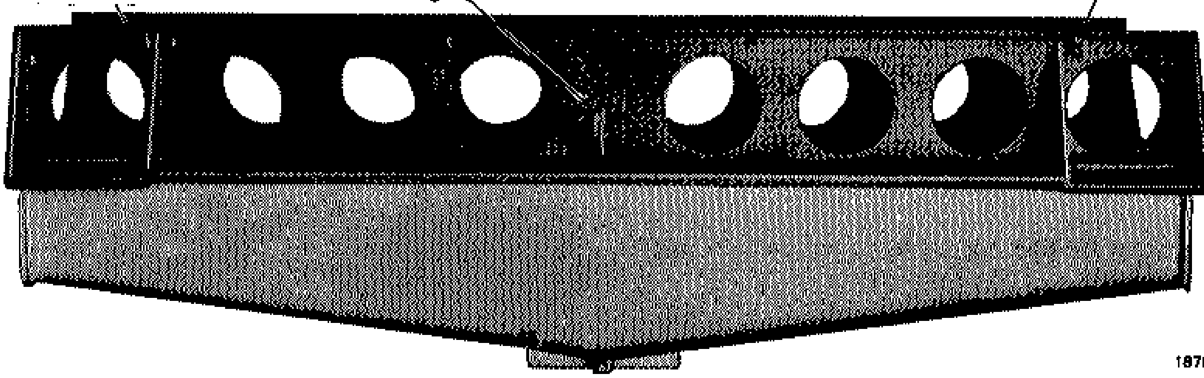


Fig. 1-8 - Typical Oil Pan (16-Cyl.)

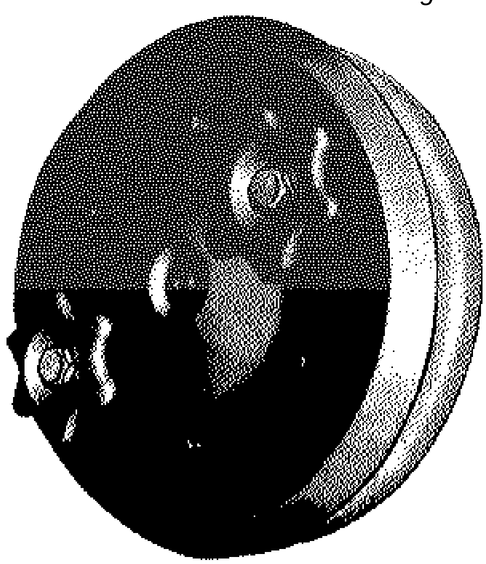


Fig. 1-9 - Oil Pan Safety Type Handhole Cover

AIR BOX DRAINS
DESCRIPTION

Accumulation of liquids from the engine air box is removed through drain holes in the base rails of the crankcase, which are connected to a pipe fitting, Fig. 1-8, or aligned with pipes located on each side of the oil pan at the front of the engine, Fig. 1-10. Both pipes connect to a common flange mounted on the oil pan end plate at the left-hand front of the engine.

Off-engine piping connects to the flange and provides a constant draining feature for the air box.

MAINTENANCE

Check operation of air box drains and clean, if necessary, as specified in the Scheduled Maintenance Program.

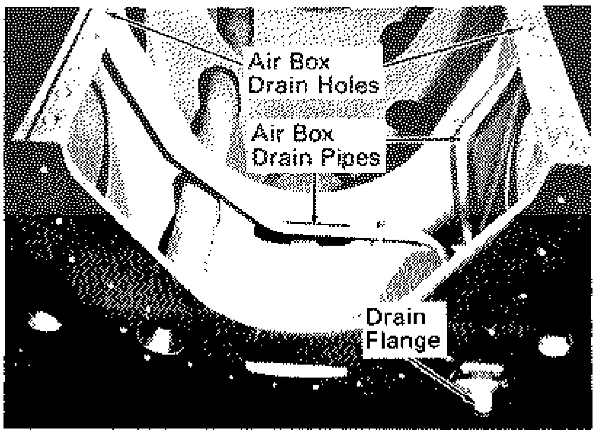


Fig. 1-1 - Typical Air Box Drain Installation

1. Disconnect external piping connected to the drain flange.

2. Remove the drain flange from the oil pan, and clean with brush and solvent.

3. Remove air box handhole covers nearest the drain holes.

4. Feed cleaning tool into the drain hole in the base rail, turning it and using a "rodding" motion to loosen carbon and sludge from inside of drain pipes.

   The cleaning tool can be fabricated from an ordinary plumber's 1/4" music wire snake as follows:

   Cut off the auger head, Fig. 1-11, and form new head by heating the first 25.4 mm (1") of the snake with a torch and stretching the tip area to form a loosely wound spiral.

5. Once both drains have been completely cleared, flush piping with fuel oil or similar solvent to remove loose material and dissolve additional residue.

6. Mount drain flange to oil pan, reconnect external piping, and reinstall air box handhole covers.

CRANKCASE TO OIL PAN SEAL
DESCRIPTION

A round silicone seal cord placed in a groove, Fig. 1-12, in the oil pan mounting rail effectively prevents any leakage at the junction of the crankcase and oil pan.

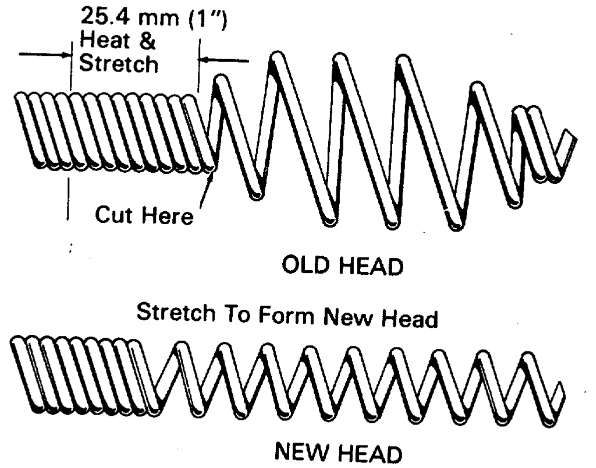


Fig. 1-11 - Snake Modification

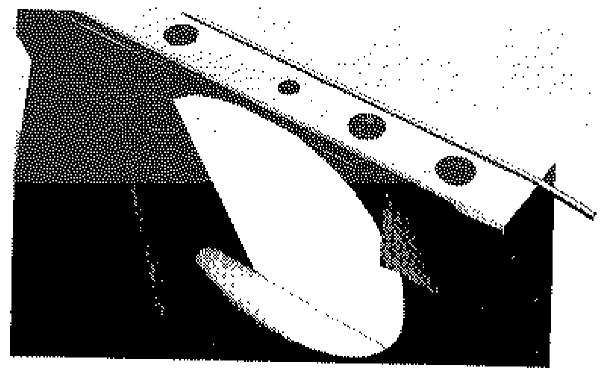


Fig. 1-12 - Crankcase To Oil Pan Seal

MAINTENANCE

Install seals in the grooves without twisting or stretching, and without lubricant. The individual seals for each model engine are longer than required, but do not cut off seal ends at this time.

Place crankcase over oil pan, and using lineup pin guides in the four corner holes, lower crankcase on oil pan. Apply taper dowel bolts and tighten. Check crankcase to oil pan alignment, using care not to damage seal cord.

CAUTION

Do not pull or stretch the ends of seal cord.

Assemble all crankcase to oil pan bolts with washers and snug four corner bolts to about 136 N•m (100 ft-lbs) torque. Starting with the center bolt and alternating between the bolts to the left and right of center, tighten bolts to a torque of 136 N•m (100 ft-lbs). After tightening bolts on both sides of engine to 136 N•m (100 ft-lbs) repeat tightening sequence bringing bolts to a final torque of 610 N•m (450 ft-lbs).

After all bolts have been tightened to 610 N•m (450 ft-lbs), cut seal cord ends to provide a seal protrusion from face of end plates of 2.38 ± 0.40 mm (3/32" ± 1/64"). This seal protrusion will seal the three way joint of oil pan, crankcase, and end housing.

TOP DECK HEAD FRAME AND COVER DESCRIPTION

Top deck cylinder head frames are mounted on the crankcase to protect and enclose the fuel lines and linkage, camshaft assemblies and rocker arm assemblies. The fabricated frames provide a flat seal surface for the top deck covers. The covers are held in place by easily released latches, making the top deck operating mechanism readily accessible. Support arms are provided to hold the cover open in any one of several positions. Special hinges provide easy removal of the cover for top deck maintenance.

A gasket between the bottom of the frame and crankcase and a rubber seal on the lower surface of the cover provide an air and oil tight seal.

When replacement of either the gasket or seal is necessary, see EMD parts catalog for the correct part numbers.

MAINTENANCE

Replace top deck cover seals at intervals stated in the applicable Scheduled Maintenance Program, or earlier if the seals are damaged or deteriorated.

When applying new seals to the cover, coat seals liberally with EMD High Temperature resistant grease No. 4. This will facilitate ease of application and prevent the seal from sticking to the head frame, and being pulled loose or damaged, when the cover is raised.

1. Begin application of seal at a point approximately 25.4 mm (1") from upper left hand corner of cover, as shown in Fig. 1-13, and make second joint (if required) at a similar point in the upper right hand corner.

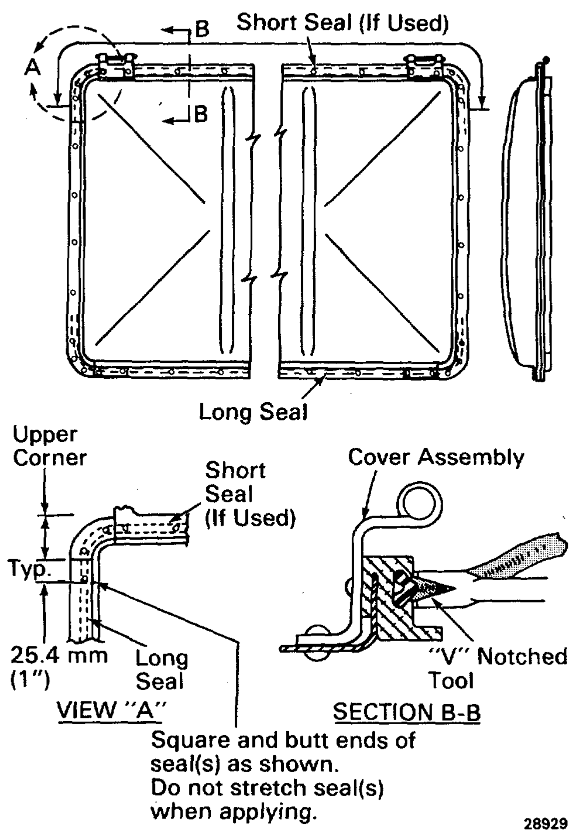


Fig.1-13 - Cover Seal Application

2. Insert first one edge of the "V" shaped seal into cover groove, then push the other edge into the groove with a flat tool, such as a screwdriver blade. Proceed to apply seal in this manner or use "V" notched tool which will compress the seal "V" together as it is drawn along the length of the seal around the cover groove.

NOTE

It is important to keep the seal compressed so that the total length fits into the groove without stretching.

3. Square off and butt ends of seal lengths tightly together.

New gaskets should be installed between the frame and crankcase whenever the frames are removed from the crankcase, or sooner if the gaskets show signs of leaking.

HEAD FRAME TO CRANKCASE APPLICATION

1. Check sealing surfaces of head frame, crankcase, and end housings for burrs and wipe free of dust and dirt.

2. Apply bead of silicone rubber sealing compound on head frame to crankcase joint. Apply head frame gasket sections to crankcase being sure gasket ends are properly joined and sealed.

NOTE

When applying end housing gaskets, coat all sealing surfaces with a generous amount of gasket sealing compound to ensure an oil tight seal.

3. Apply head frame to crankcase and install all bolts finger tight. If old bolts are being reused, apply a light coat of oil to the threads. New bolts may be installed without additional lubricant.

NOTE

Use of special 1/8" thick hardened washers under head frame bolts required for proper torque retention.

4. Torque all head frame mounting bolts to specified value in the following order.

- End bolts to camshaft drive housing;
- Inboard bolts in a row beginning at cam-shaft drive end;
- Outboard bolts in a row from camshaft drive end;
- End bolts to overspeed trip housing.

SERVICE DATA
CRANKCASE AND OIL PAN

REFERENCES

Crankcase Main Bearing Steel Bore Alignment Qualification .... M.I. 100
Crankcase Lower Deck Repair.................... M.I. 315

Resurfacing Of Cylinder Head Retainers -
567C, D, And All 645 Engines.................... M.I. 316

SPECIFICATIONS

Clearance and dimensional limits listed below are defined as follows:

1. *New limits are those to which new parts are manufactured. (Drawing tolerances.)*

2. *Minimum, maximum, and tolerance measurements are provided as service limits. At time of rebuild or any time unscheduled maintenance is performed, the service limits should not be exceeded. Engine components within these limits may be reused with the assurance that they will perform satisfactorily until the next scheduled overhaul.*

Upper liner pilot bore -
New.................... 307.19-307.26 mm (12.094"-12.097")
Max. .... 307.44 mm (12.104")

Lower liner pilot insert bore (installed in crankcase) -
Min. .... 263.58 mm (10.377")
Max. .... 263.80 mm (10.386")

Lower liner pilot bore in crankcase -
New .... 281.00-281.10 mm (11.063"-11.067")
Max. .... 281.13 mm (11.068")

Main bearing bore with all caps applied and torqued to 1 017 N•m (750 ft-lbs). Take two sets of main bearing bore measurements at each bore, one set 12.7 mm (1/2") in from the accessory end of the bore and one set 12.7 mm (1/2") in from the generator end of the bore. Ref. Fig. 1-6.

Diameter of bore -
Max .... 209.652 mm (8.2540")
Min. .... 209.474 mm (8.2470')
Bearing shell to crankshaft clearance
(Each side above serrations at split line)
Min. .... 0.038 mm (.0015")

EQUIPMENT LIST

Part No.

Crab stud thread protectors.................... 8034600
Crab nut tap 1-3/4"-12.................... 8050688
Main bearing nut tap 1-1/4"-12.................... 8060387
Hydraulic jack (9 012 kg [10 ton]).................... 8078281
Gasket sealing compound (.47 liter [1 pt.]).................... 8178639
Main bearing nut offset ratchet wrench 8191591
Spray gun (for engine cleaning).................... 8193041

EQUIPMENT LIST (Cont'd)

	Part No.
Lower inset application and removal tool	8275379
Press and puller assembly	8275380
Thread Lubricant, Texaco Threadtex No. 2303 (approx. 18.93 liter [5 gal.])	8307731
Silicone rubber sealing compound (340 grams [12 oz.] cartridge)	8366747
Torque indicator	8377322
High temperature resistant grease No. 4 (4.54 kg [10 lbs])	8425725
Main bearing power wrench set	8474807
Main bearing cap application and removal tool	8487487
Stud thread file	9549346
Crab nut wrench set (manual)	9551713

SECTION 2

CYLINDER HEAD AND ACCESSORIES

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CYLINDER HEAD AND ACCESSORIES

CYLINDER HEAD DESCRIPTION

The cylinder head, Fig. 2-1, is made of cast iron alloy with cast passages for water and exhaust gases. Drilled water holes at the bottom of the cylinder head match the water discharge holes in the liner. Cooling water is circulated through the head and is discharged through an elbow mounted on the side of the head mounting flange. Exhaust passages in the cylinder head line up with elbows in the crankcase, which conduct the exhaust gases through the water discharge manifold to the exhaust manifold.

A well is located in the center of the cylinder head for application of the unit fuel injector. To ensure correct positioning of the injector, a mating hole for the injector locating dowel is located in the head.

Fig. 2-2 shows the rocker arms, exhaust valves, valve bridges with springs, valve guides, overspeed trip pawl, fuel injector, and other related items making up a complete cylinder head assembly.

MAINTENANCE

NOTE

Procedures for disassembly, assembly, and qualification of cylinder head components are contained in this section. Procedures for removal and installation of a cylinder head or of a complete cylinder power assembly are contained in Section 5.

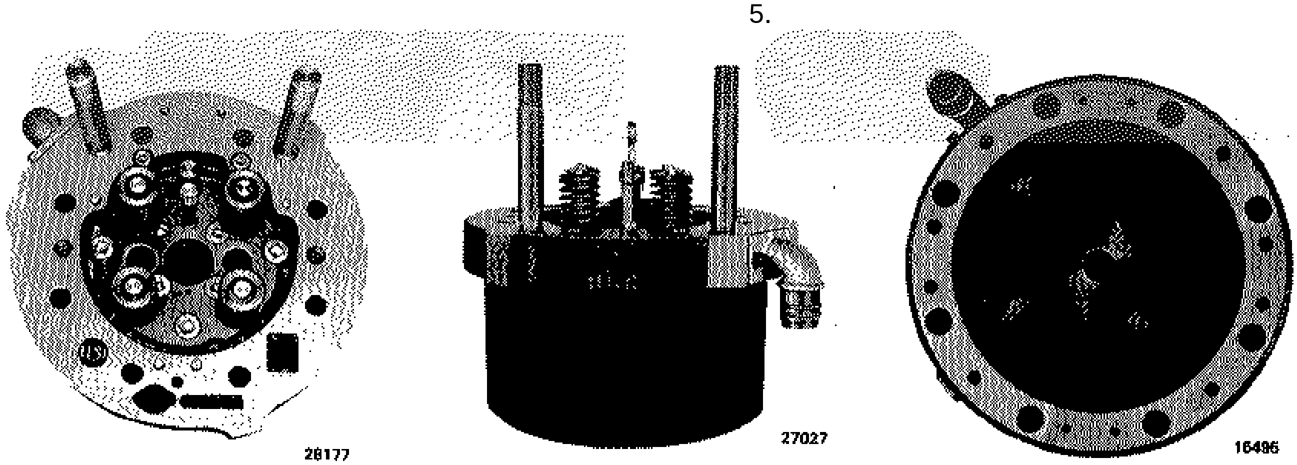


Fig. 2-1 - Cylinder Head With Valves

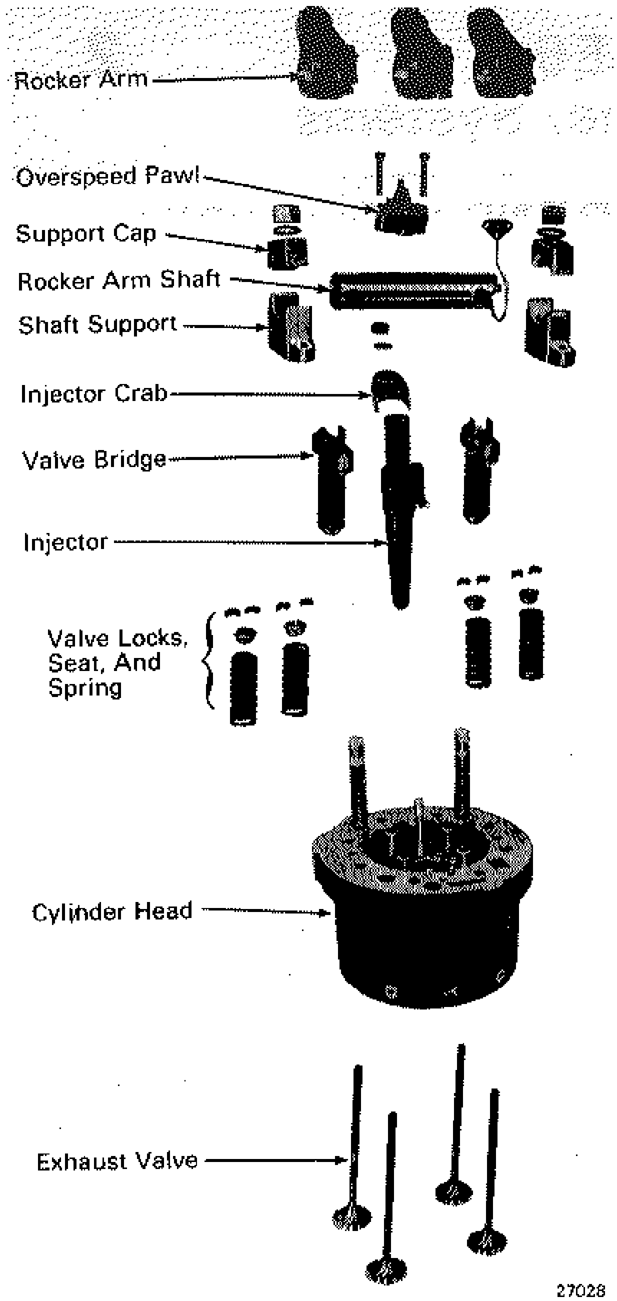
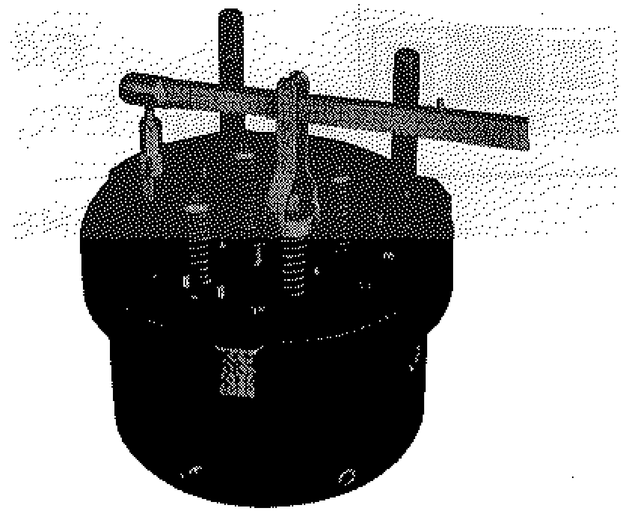


Fig.2-2 - Complete Cylinder Head Assembly, Exploded View



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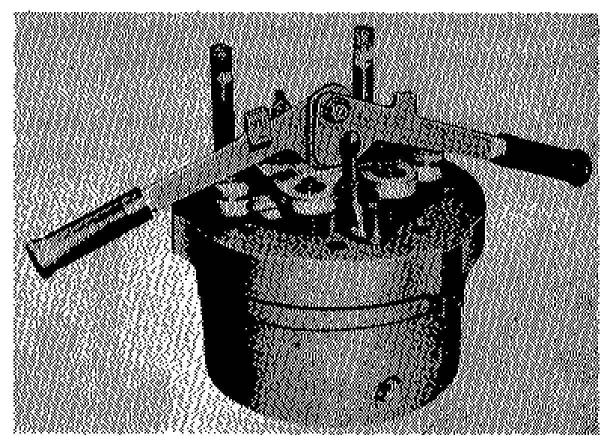
SINGLE



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MULTIPLE

Fig.2-3 - Compressing Valve Springs

EXHAUST VALVE AND SPRING REMOVAL

1. Remove exhaust valve springs using single valve compressor and adapter screwed into the head or the multiple valve spring compressor, Fig. 2-3.
2. Compress the springs sufficiently to remove the valve locks and spring seats, and then remove the springs.
3. After spring removal, the exhaust valves can be removed from the bottom of the head.

NOTE

Valve springs can be removed and replaced without removing the cylinder head from the engine. If this is done, the piston must be at top center to prevent the valves from falling into the cylinder when the valve locks are removed.

VALVE GUIDES

Cast iron valve guides are press fit in the cylinder head and can be pressed in or out without damage by using a valve guide installing or removing tool. Although the valve guides generally do not require reaming after assembly, it is recommended that a plug gauge be inserted after guide installation to ensure minimum diameter.

CLEANING CYLINDER HEAD

1. Clean cylinder head in a suitable solvent to remove surface oil and loosen baked-on carbon. Cleaning should be in accordance with accepted practice or as recommended by supplier of the cleaning material.

CAUTION

Do not use any form of blast cleaning (glass, sand, or shot) on the fireface of the head as blasting tends to remove sharp edges of the phonograph grooves of the gasket surface, reducing its sealing effectiveness.

2. Remove loose material from stud holes using stud hole cleaner and 115 volt drill, Fig. 2-4.

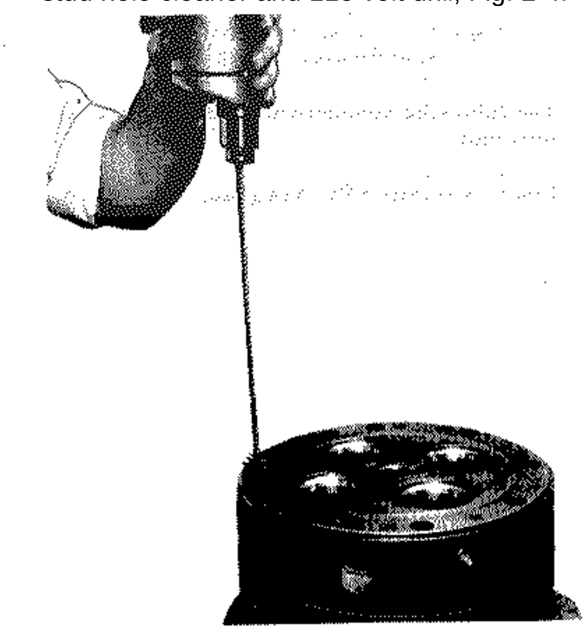


Fig.2-4 - Cleaning Stud Holes

3. Clean the cylinder test valve threads using standard 1/2" pipe thread tap.

4. Using valve guide cleaner and a 115 volt drill, clean guide as shown in Fig. 2-5. Any evidence of galling inside of guide must be entirely removed by reaming, or the guide should be replaced. The I.D. of the guide should not exceed the limit when measured at the bottom and 12.7 mm (1/2") from top and bottom.

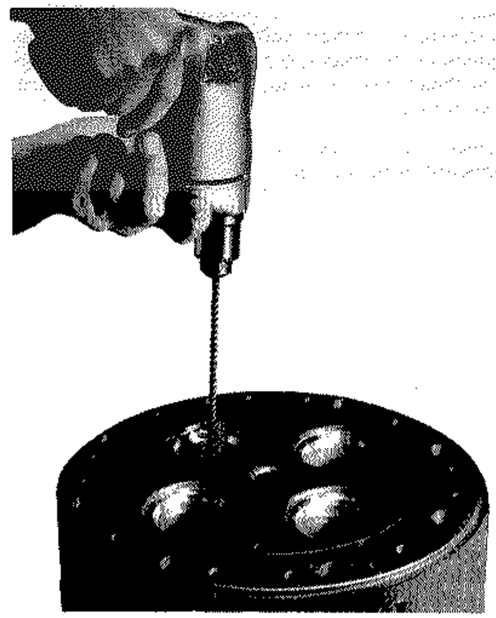


Fig.2-5 - Cleaning Valve Guides

5. Clean phonograph finish of fireface using wire brush in a circular motion to remove dirt and carbon from phonograph grooves.

CYLINDER HEAD LEAK TEST

Seal all water passages in the head and apply 586 to 655 kPa (85 to 95 psi) air pressure to the passages. Immerse the head in water maintained at 71° C (160° F) for two minutes. Using this method, the leaks are easily detected and minor leaks are opened-up by the hot water for easy detection.

NOTE

When performing the cylinder head leak test, a scrap injector should be installed using an injector crab, spherical washer and nut. Torque nut to 81 ± 14 N•m (60 ± 10 ft-lbs) before immersion into the hot water.

Core plug leaks can usually be repaired by replacing the plug. Leaks caused by cracks, porosity, or dirt inclusion are cause for rejection.

INSPECTION

Inspect cylinder head for cracks using magnaflux procedures. Small magnaflux indications in the blend between the injector hole and the fireface may be removed by machining or grinding.

Scratches or nicks in the sealing areas for the head gasket or the grommet sealing areas require fireface refinishing. Small scratches or nicks in the phonograph finish area outside the sealing areas for the head gasket or grommets do not require refinishing.

Small scratches and nicks are permissible in the area inboard of the combustion gasket sealing area on the fireface of the head. If such small defects exist, there is no need to refinish the face.

Inspect valve seats for pits and burned areas and perform dimensional checks. Seats not meeting visual or dimensional criteria must be resurfaced.

NOTE

Any head removed from an engine that has been overheated enough to "cook out" the head-to-liner grommets should be scrapped due to irreparable damage to the head.

CYLINDER HEAD REBUILD

A cylinder head with damaged valve seats, flange seating surface, fireface surface, or injector hole should be reworked in accordance with the following procedures.

INJECTOR HOLE REWORK

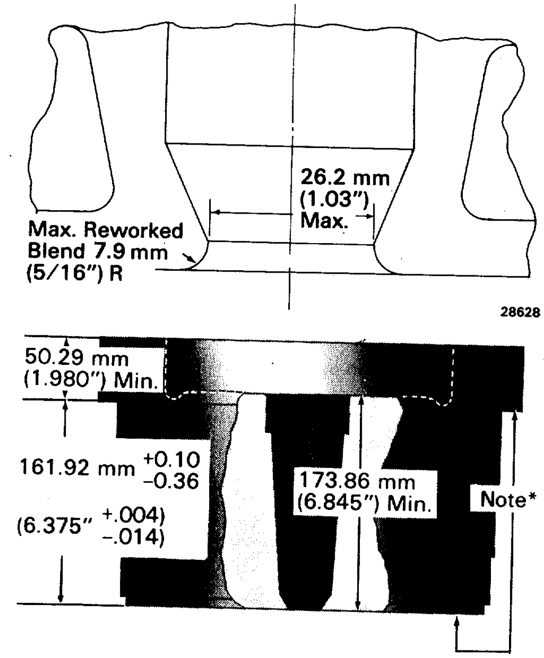
1. Blend chatter marks and gouges smooth at injector hole to fireface surface, leaving no sharp corners on injector seat side or fireface side of the blend.

2. Do not exceed maximum injector hole diameter or maximum allowable blend radius, Fig. 2-6.

FIREFACE AND FLANGE SEATING SURFACE REFINISHING

Refinishing of the cylinder head fireface and flange requires special tooling and procedures.
The following paragraphs contain recommendations for tooling and procedures to meet the required rework limits, Fig. 2-6.

1. A vertical lathe is recommended because of ease of loading and unloading; although any machine capable of chucking and turning a head will do.



*Mounting face to be flat and parallel to firing face within 0.05 mm (.002").

Fig.2-6 - Injector Hole Rework And Rework Limits

2. The following commercial tools are listed for reference:

   Insert-Valenite SPC-424 grade VC28 1/ 16" nose radius.

   Insert Holder-Valenite NVS-DN-12-C.

3. The depth of cut should be held to a minimum to extend the reconditioning life of the head. A cut of 0.152-0.203 mm (.006-.008") on the gasket surface and 0.254-0.406 mm (.010-.016") on the milled surface should be sufficient to clean up the fireface.

NOTE

To minimize the depth of cut, care should be taken to set up off the fireface rather than locating off the top of the flange.

4. Set feed at 0.61 mm (.024") per revolution and the RPM varied to maintain 76.2 smpm (250 sfpm). To achieve this constant cutting speed, the spindle speed will have to be increased as the tool approaches the center of the head to avoid tearing the surface of the head around the injector hole.

5. The distance between the underside of the flange and the gasket surface of the fireface must be maintained, Fig. 2-6. To hold this dimension within specification, it will generally be necessary to machine the fireface and underside of the flange simultaneously because of the tight requirement of parallelism between the underside of the flange and the fireface, Fig. 2-7. However, the cut on the underside of the flange should be a minimum within the allowable range of the fireface to flange dimension.
6. Sharp edges in the chamfer blend from the injector hole to the fireface must be blended smooth by hand using emery cloth. Deep scratches or gouges should be reworked in accordance with "INJECTOR HOLE REWORK."
7. When the fireface and flange underside are remachined. the fillets between the flange underside and the barrel section must be re-rolled to provide a necessary compressive preload. The fillets are rolled using a 0.085" radius roll at an angle of 280 to the heavy flanges. Sufficient force must be applied to the roll to displace the fillets to a depth of 0.05 mm (0.002') to 0.08 mm (0.003") in two equal length-arcs centered at the 3 o'clock and 9 o'clock positions, as shown in Fig. 2-8.

NOTE

If necessary, fillet may be rerolled a full 360° around head with heavier displacement allowed outside areas prescribed for arcs centered at the 3 o'clock and 9 o'clock positions, provided these two arcs meet the proper displacement specifications.

VALVE SEAT GRINDING

To ensure uniform seat width and proper location of the seating area relative to the seat on the exhaust valve, while holding the specified concentricity to the valve guide bore, the valve seat I.D., O.D., and seating surface must be ground relative to the centerline of the valve guide bore.

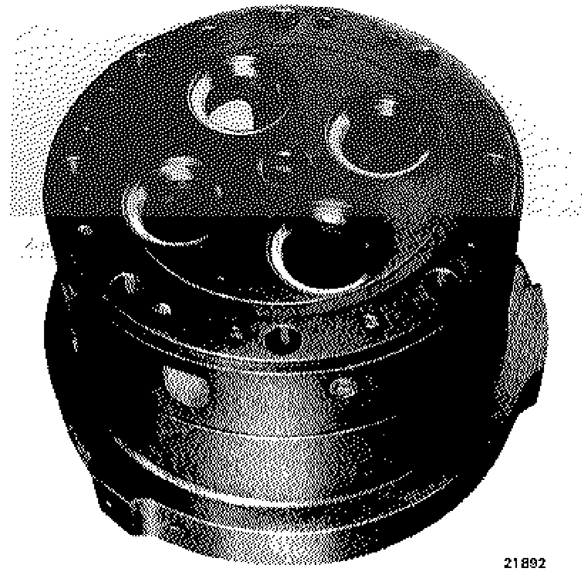
Using any one of the valve seat reconditioning tool sets listed in Service Data, perform the following procedures.

1. Mount each of the three grinding wheels on its own holder and dress the 45° wheel to 65°, the 30° wheel to 20°, and the 30° finishing wheel to 30°. Fig. 2-9.

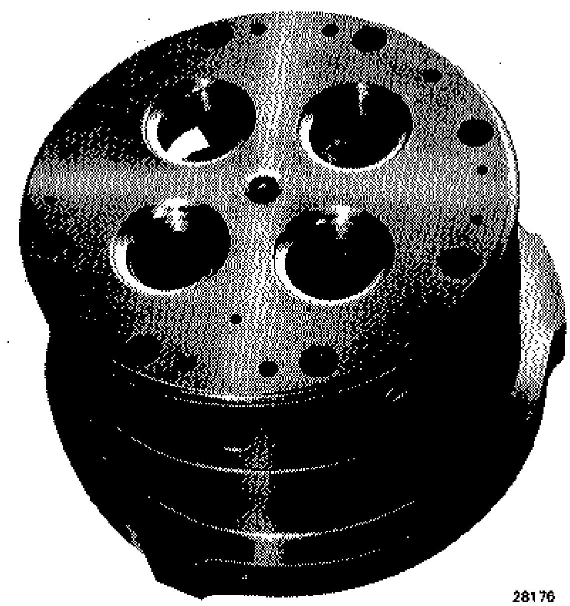
NOTE

Use separate dressing tool for each wheel to maintain seat angle accuracy.

a. Lubricate dressing tool pilot with light film of oil.



Original Finish



Reworked Finish

Fig.2-7-Fireface And Flange Refinishing

b. Mount grinding wheel and holder on dressing tool pilot, Fig. 2-10.
c. Check that dressing tool is adjusted to proper angle for tool being dressed.
d. Apply driver to wheel holder and rotate wheel and holder at high speed, holding driver as straight as possible.
e. Move diamond steadily across wheel, taking light cuts until wheel face is smooth and at the proper angle.

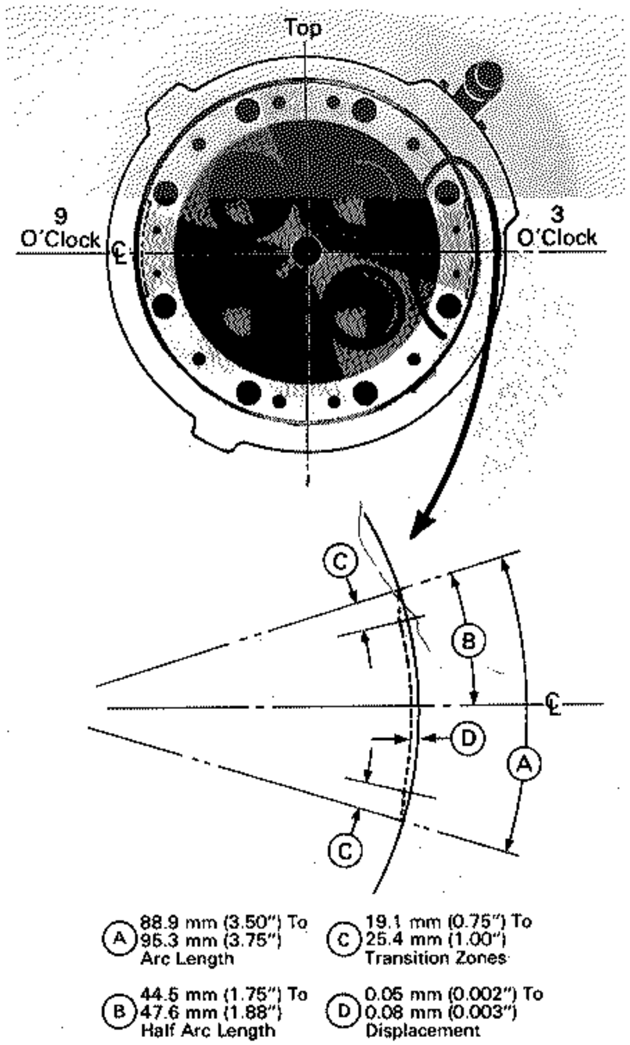


Fig.2-8-Fillet Rolling

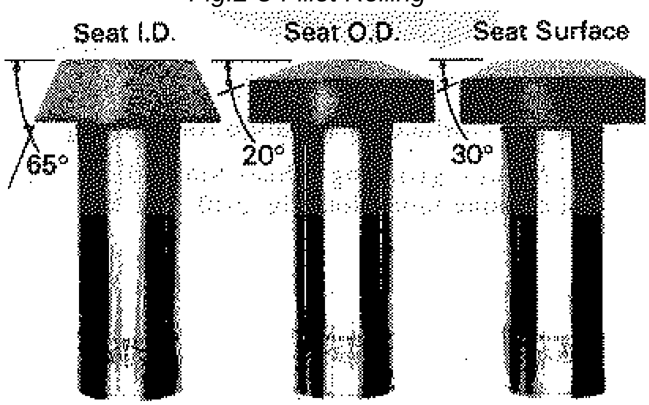


Fig.2-9-Valve Seat Grinding Wheels and Holders

Fig.2-10-Dressing Valve Seat Grinding Wheel

2. Select a tapered pilot which will bring the shoulder on the pilot above the valve guide. Press pilot firmly into guide, using pin, Fig. 2-11. Wipe pilot with an oily cloth.

   A fixture, Fig. 2-12, is available for checking tapered pilots. To ensure satisfactory results, pilot runout should not exceed 0.013 mm (.0005").

3. Install lifter spring over tapered pilot, Fig. 2-13, and place 30° grinding wheel and holder over the pilot and spring.

4. Apply driver to wheel holder and grind the 30° seat angle until the width of the seat is at least 2.36 mm (.093") all the way around. The driving motor should be held as straight as possible, Fig. 2-14, and operated at top speed while grinding. Raise grinding motor off seat before stopping motor.
5. Remove 30°grinding wheel and apply 65° grinding wheel and holder over pilot and lifting spring.

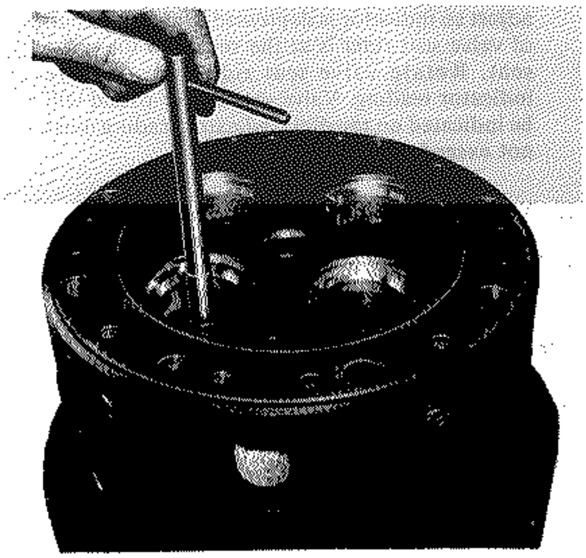


Fig. 2-11-Tapered Pilot Installation

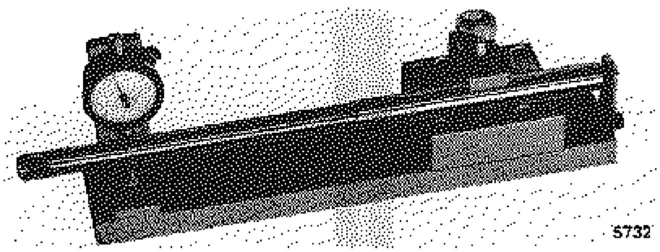


Fig.2-12-Tapered Pilot Checking Fixture

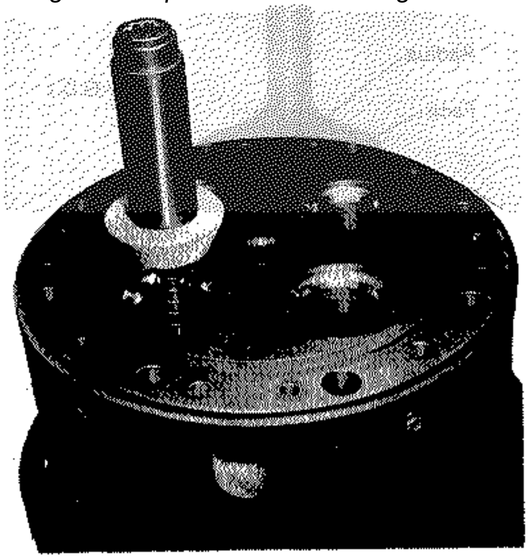


Fig.2-13-Lifting Spring Application

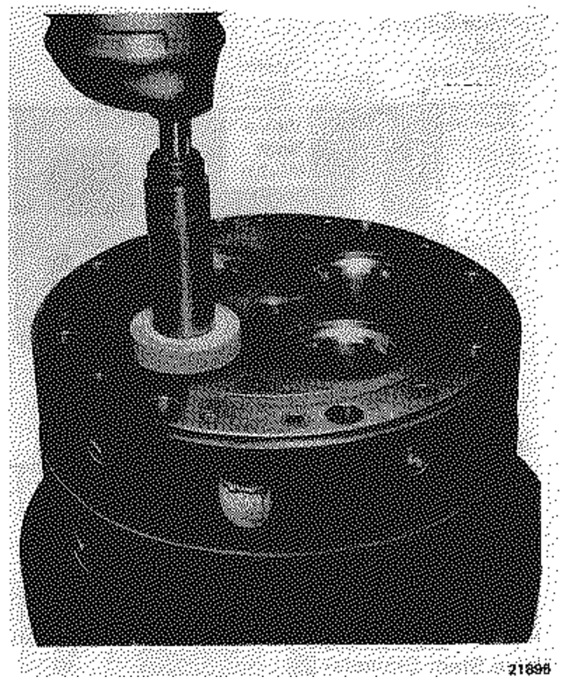


Fig. 2-14-Grinding Valve Seat

6. Grind 65° angle until the area adjacent to the 30° seat is smooth and clean.

NOTE

Grind away as little material as possible to maximize the wear life of the seats

7. Remove 650 grinding wheel and apply 20° grinding wheel and holder over pilot and lifting spring.

8. Grind 200 angle until the area adjacent to the 30° seat is clean and smooth. Continue grinding until seat width is within the specified tolerance.

9. Check valve seat for proper dimensions, Fig.2-15. If seat O.D. is too small, regrind seat with 30° grinder until O.D. is proper dimension. Then grind seat I.D. with 65° grinder until proper seat width is obtained.

   If seat O.D. is too large, regrind O.D. with 20° grinder until proper O.D. dimension is obtained. If seat width is too small, grind seat with 300 grinder and O.D. with 20° grinder alternately until proper seat O.D. and seat width are obtained.

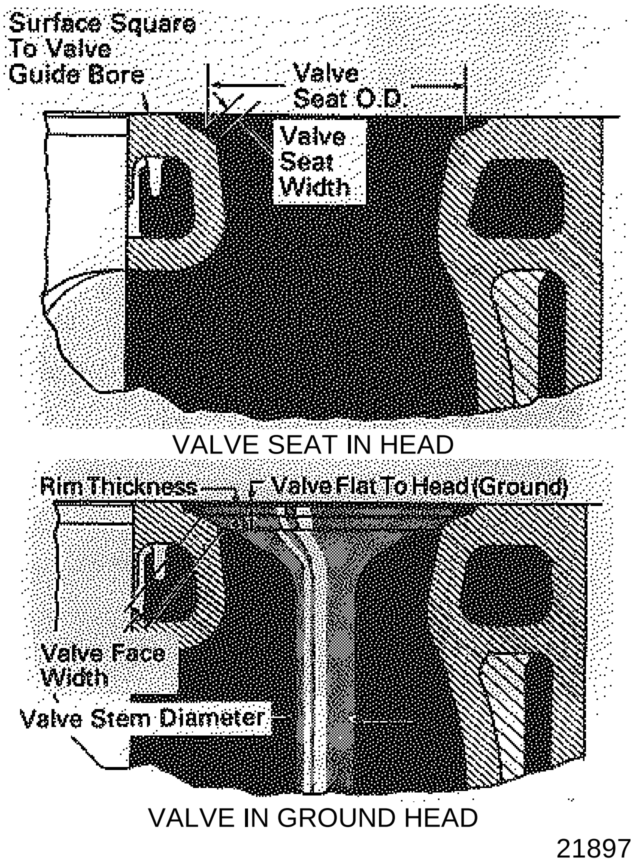


Fig.2-15-Valve Measurement Points

10. Reapply 30° wheel and grind seat lightly to remove burrs and improve the surface finish.

11. Use dial indicator included in the valve seat reconditioning set to measure trueness of valve seat. Place indicator over pilot, Fig.2-16, and adjust so indicator is depressed slightly and ball of valve seat rider is at the center of the valve seat. Rotate valve seat rider and observe indicator reading. Valve seat out-of-round will be indicated on the dial. Indicator reading must not exceed the limit.

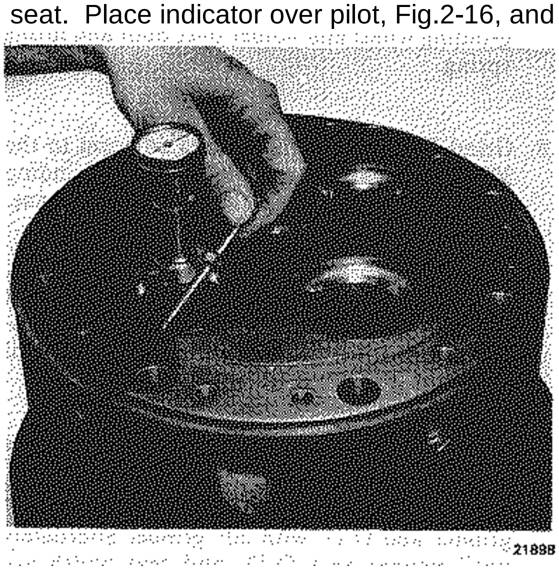


Fig.2-16-Checking Valve Seat Roundness

12. With the head positioned fireface up, install new valve in each position and measure the vertical distance from the fireface of the head to the rim of the exhaust valve, Fig. 2-15.

EXHAUST VALVES

DESCRIPTION

The long stem exhaust valves, Fig. 2-17, are fabricated from a forged nickel-chromium alloy steel head and a tip hardened steel stem by means of friction welding. Single bead valve locks hold the valve in a tapered spring seat. Precision valve guides ensure proper valve seating.

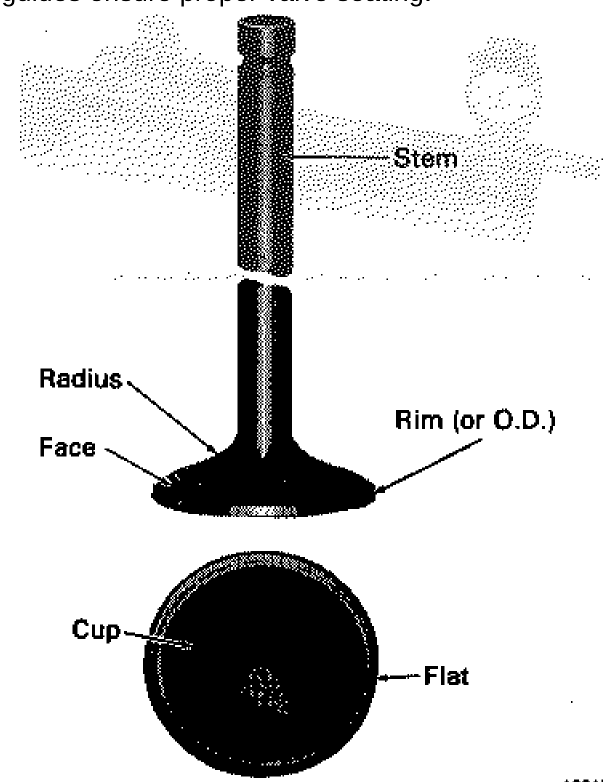


Fig.2-17-Exhaust Valve

MAINTENANCE

Handle valves carefully to avoid nicks and scuffs that might make the valve unfit for use. Piling valves on top of each other may cause nicks on the outside diameter of throat radius which can lead to valve failure. Before the valves can be reused, they must be reconditioned within the dimensional limits listed in the Service Data at the end of this section.

CLEANING

Thoroughly clean the exhaust valves using a suitable solvent to remove surface oil and loose carbon. If necessary, use glass bead and vapor blasting to remove hard carbon deposits from the valves. Grit for vapor blast must be maintained at a small enough size so the surface finish of the valve stems is not roughened beyond 0.635µm (25 µin.). If glass bead blasting is not available, wire brushing may be used as an alternative.

INSPECTION

Exhaust valves must be qualified by visual and Zyglo inspection prior to reconditioning. Accept- able conditions which allow valve reuse, and rejectable conditions which are cause for scrapping the valve are listed below. The valve surfaces referenced are identified in Fig. 2-17.

Acceptable Conditions:

1. Light pitting on the valve face that can be cleaned up within the maximum allowable valve face limit.

2. Protruding nicks and gouges in the valve stem must be removed before the valve face is ground in order to avoid scuffing of the valve guide and to ensure proper valve face runout. Belt sanding or buffing may be used to polish off protrusions, provided that the surface finish of the stem is maintained at or below 0.635 µm (25 µin.) with a circumferential lay.

Rejectable Conditions:

1. Indications found in the cup area, Fig. 2-18, are defects which require rejection of a valve.
2. Any cracks found on the outside diameter of rim section of the valve, Fig. 2-19, are cause for rejection.

   Since rim cracks usually extend some distance into the valve face, they usually lead to failure.

   The face area, Fig. 2-19, is the critical area of the valve. Grinding cracks, channeling, and thermal cracks are cause for valve rejection.

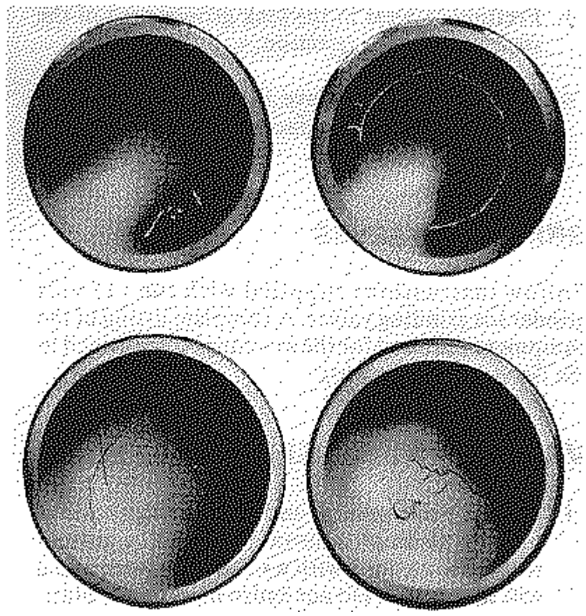


Fig.2-18-Cup Defects

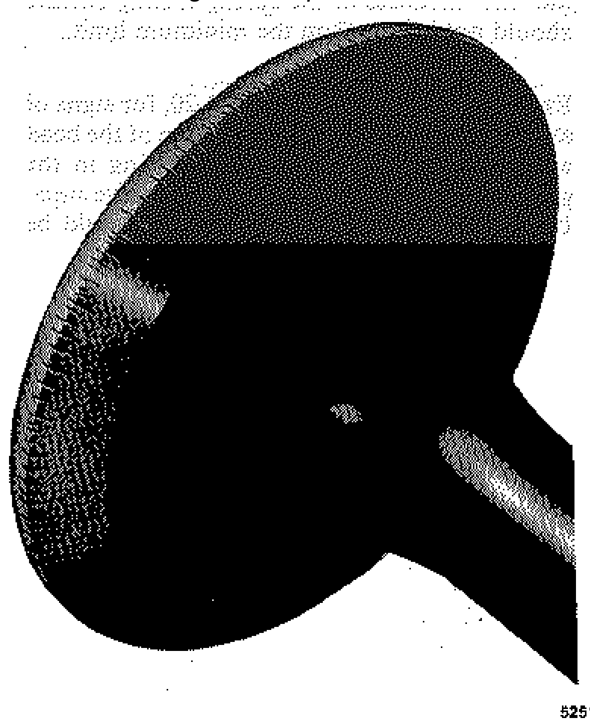


Fig.2-19-Face And Rim Defects

3. Fretting or wear in the lock groove area of the stem is cause for rejection.
4. Reject valves that have been damaged to the extent that critical surfaces have been nicked or scuffed.

GRINDING VALVES

Follow instructions supplied with the 115 volt grinder for grinding valves. A complete listing of the equipment required for the machines is contained in the Service Tool Catalog.

VALVE SPRING, SEAT, AND LOCK

1. Inspect valve springs and valve bridge springs for any nicks or unusual wear. Valve springs should be cleaned with a suitable solvent and a soft wire brush. Do not hydro blast or grit blast. Valve springs should be protected to prevent rusting.
2. Perform dimensional and pressure checks to qualify valve springs.

3. Valve spring seats should be clean and smooth and the thickness of the spring seating surface should not be less than the minimum limit.

4. Examine the valve locks, Fig. 2-20, for signs of excessive wear on the upper portion of the: bead and for evidence of excessive fretting in the ground diameter which engages the valve stem. If these conditions exist, the locks should be replaced.

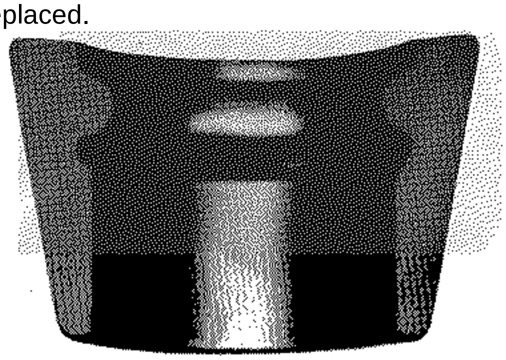


Fig.2-20-Valve Spring Seat Lock

EXHAUST VALVE INSTALLATION

After the exhaust valves have been reconditioned, they are applied to the reconditioned cylinder head.

Position the head properly and complete the assembly of valve springs, spring seats, and valve locks.

VALVE STEM HEIGHT CHECK

1. Clean bottom of tram feet, and that portion of the head on which the feet rest.

2. Apply tram firmly on cylinder head, Fig. 2-21.

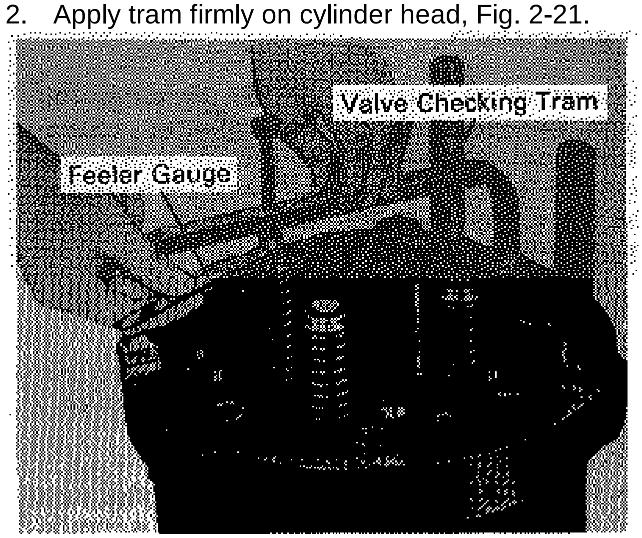


Fig.2-21-Checking Height Of Valve Stems

3. Using feeler gauge and tram adjusting screw, determine difference in valve stem heights. The difference between valve stems under the same bridge should not vary more than 1.59 mm (1/16"). If the difference varies more than 1.59 mm (1/16"), the high valve should be replaced or the low valve ground in, provided this does not exceed the limit. End of valve stem should not be ground off, as the tip is hardened.

VALVE SEAT SEAL TEST

1. Place head in an angular position, resting on the rocker arm studs with valve seats in the up position.

2. Wipe bottom of head to remove dirt and dust.

3. Apply a light film of oil to the concave surface of the tester vacuum cup and attach tester to cylinder head with handle in six o'clock position, and covering one valve, Fig. 2-22.

   Ensure that tester cup is firmly seated on fireface and not on the head of the valve.

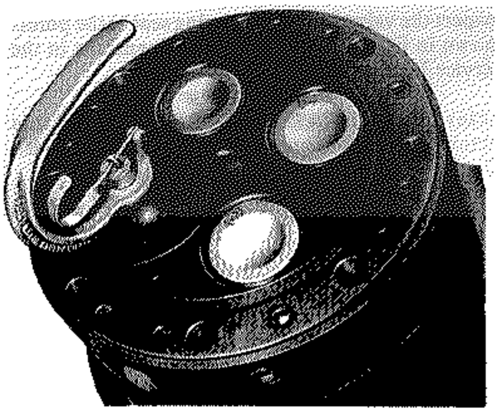


Fig.2-22-Testing Valve Seat Seal

4. If tester suction to fireface is depleted in less than two minutes, the valve seating is defective and the head seat and/or valve face must be reworked.

5. Open trigger valve to remove tester from head surface.

6. Check valve seat seal tester by applying it to a vertical piece of glass, as the release valve or rubber cup may be defective.

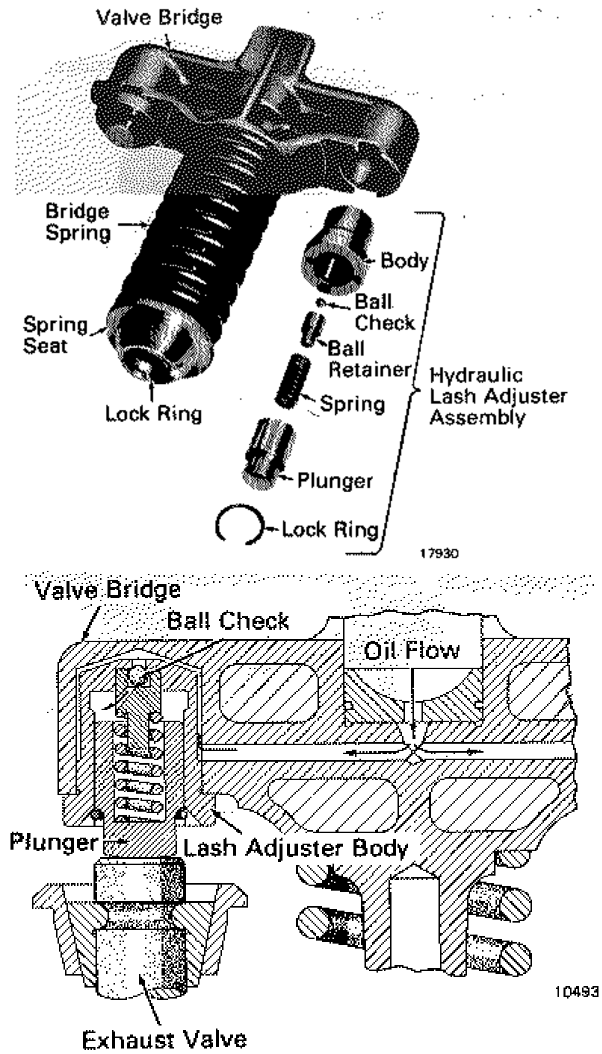


Fig.2-23-Valve Bridge Assembly

**EXHAUST VALVE
BRIDGE ASSEMBLY**

DESCRIPTION

The valve bridge, Fig. 2-23, operates two exhaust valves from one rocker arm. A spring and spring seat are held on the valve bridge stem by a lock ring. The spring seat rests in a socket in the cylinder head and the spring applies pressure to maintain contact between the valve bridge and the rocker arm.

The hydraulic lash adjuster maintains zero lash between the end of the valve stem and the valve bridge. Lube oil flows from the rocker arm through a drilled passage in the valve bridge to the top of the lash adjuster, past the ball check, and into the body. When the rocker arm depresses the valve bridge, a slight movement of the plunger in the lash adjuster seats the ball check, trapping the oil. Since the oil is practically incompressible, further movement of the rocker arm causes the lash adjuster plunger to force open the exhaust valve.

CLEANING

Prior to disassembly of the valve bridge, clean assembly with solvent. Do not use a caustic type cleaner, as the brass spring seat will be damaged.

DISASSEMBLY

1. Remove lash adjuster assembly from bridge, using adjuster puller, Fig. 2-24.

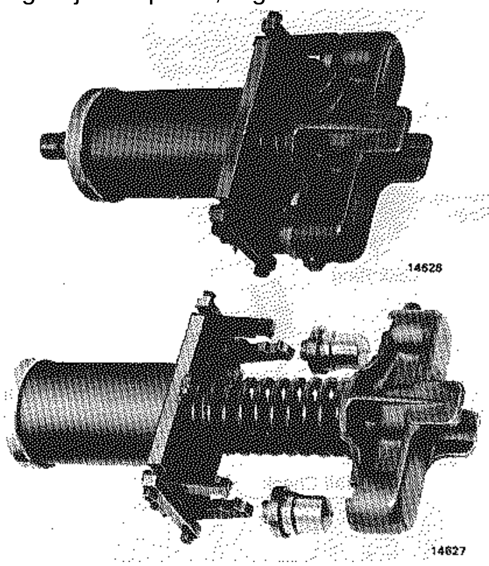


Fig.2-24-Removing Hydraulic Lash Adjuster

2. Mount valve bridge spring compressor in vise, Fig. 2-25. Install valve bridge in compressor, compress spring, remove lock ring, and remove spring seat and spring.

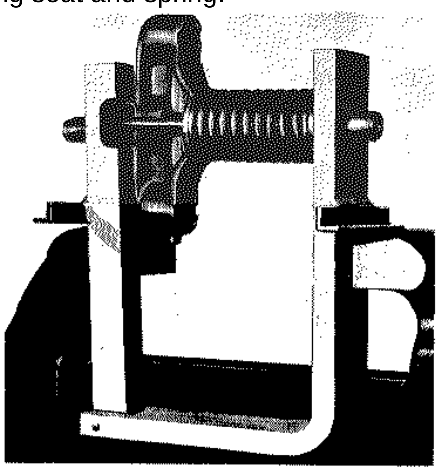


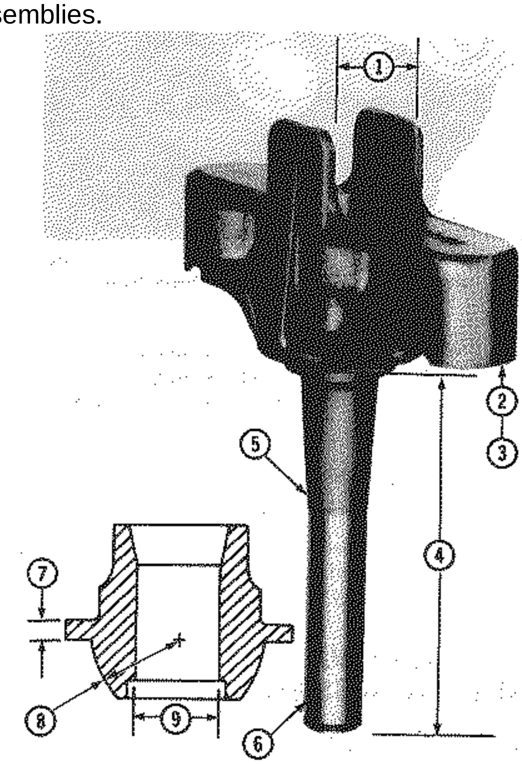
Fig.2-25-Compressing Valve Bridge Spring

INSPECTION

Visually inspect valve bridge parts and replace those that are damaged beyond repair. Check the pin in the end of the valve bridge for a bent shank. If the shank is slightly bent, it may be straightened and re-used.

Inspect the valve bridge and spring seat at the points shown in Fig. 2-26, and refer to dimensions in the Service Data at the end of this section.

Refer to "LASH ADJUSTER" portion of this section for maintenance and qualification of lash adjuster assemblies.



Refer to Service Data for applicable dimensions.

1. Distance between rocker arm guide ears.
2. Lash adjuster socket diameter (in bridge).
3. Lash adjuster body diameter.
4. Valve bridge shank length.
5. Shank diameter from shank end to 63.5 mm (2.50") above shank end.
6. Shank diameter from 9.53 mm (3/8") to 25.4 mm (1") above shank end.
7. Spring seat rim thickness.
8. Spring seat spherical radius.
9. Spring seat bore diameter.

28830

Fig.2-26-Valve Bridge Measurement Points

LASH ADJUSTER DISASSEMBLY

1. Depress lash adjuster plunger and remove locking ring, Fig. 2-23.

2. Carefully disassemble lash adjuster to avoid damaging the machined surfaces on the inside diameter of the body or the outside diameter of the plunger.

3. Replace spring and ball check with new parts prior to assembly of lash adjuster.

CLEANING

1. Lash adjuster parts may be cleaned using fuel oil. Varnish deposits can be removed with alcohol, lacquer thinner, or any suitable solvent. Completely remove any dirt, varnish, or metal particles.
2. Do not buff the outside or inside diameter of the body, the outside diameter of the plunger, or-the spherical radius on the tip of the plunger.

INSPECTION

1. Inspect the body for scores, scratches, or galled areas on the machined outside diameter, and replace if any are found.

2. Inspect the plunger for scores, scratches, or galling on the outside diameter, and replace if evidenced. Also, inspect the plunger tip, and if the contact point is worn flat more than 6.35 mm (.250") in diameter, the plunger should be replaced.

3. Inspect the ball retainer 4.22 mm (.166") diameter counterbore depth at the center of the ball depression. Replace the ball retainer if the depth is greater than 3.63 mm (.143").

ASSEMBLY

Assemble lash adjuster in an area free of dirt, lint, and metal particles.

QUALIFYING LASH ADJUSTER

It is recommended that lash adjuster test stand, Fig. 2-27, be used to qualify the lash adjusters for use in the engine. This test stand automatically measures the time required for the lash adjuster plunger to

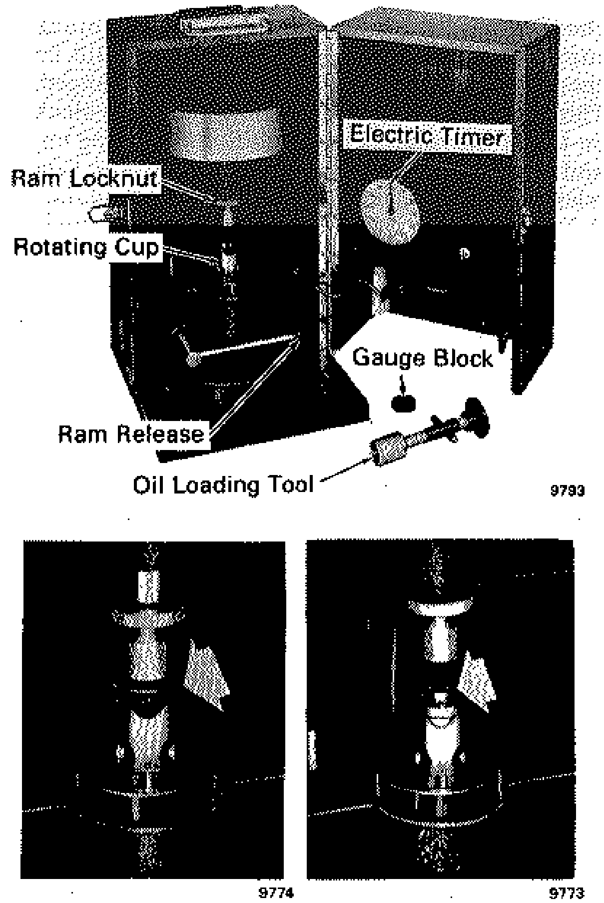


Fig.2-27-Lash Adjuster Test Stand

travel through 1.52 mm (.060") while it is subjected to the 13.6 kg (30 lbs) ram load, and rotated about 10 RPM relative to the lash adjuster body.

A gauge block and oil loading tool, Fig. 2-27, are supplied with the stand. The gauge block is used to check and adjust the tripping point of switches, if necessary, to ensure that the leak down time is measured over exactly 1.52 mm (.060') travel of the lash adjuster plunger. The oil loading tool is used to charge the lash adjuster with oil and bleed off any air which might cause incorrect leak down time intervals. It is essential that only Electro-Motive hydraulic lash adjuster test oil be used in conjunction' with this test stand since the operation of the test and limits governing the lash adjuster are based on the use of this oil.

TEST STAND OPERATION

The 1.52 mm (.060') travel of the ram starts when the tip of the ram is 9.52 mm (.375") from the top of the rotating cup. This starting point should be checked with the 9.52 mm (.375") gauge block supplied with the test stand, and it should be checked often enough to be sure it has not changed. This check is to be made by placing the gauge block on top of the rotating cup with the step facing up, and then lowering the ram by turning the ram release. The time clock on the test stand should start the very moment the ram load contacts the gauge block. If the timer does not start, or starts too soon, the ram should be readjusted. This is done by loosening the ram locknut, turning the ram tip up or down to the proper adjustment, and retightening the locknut. The time clock start and stop switches are permanently set so that the time for the 1.52 mm (.060") travel is automatically recorded on the time clock. If a switch has to be replaced, the 1.52 mm (.060") between the switch positions should be set by inverting the gauge block which has a 1.52 mm (.060") step on it.

TEST PROCEDURE

1. Place the lash adjuster assembly in oil loading tool and immerse it into a container of lash adjuster test oil that is deep enough for the hole in the lash adjuster to be well below the oil level.

2. Completely depress the lash adjuster plunger at least 10 times to ensure that any air trapped inside is pumped out.

3. Retract the spring-loaded plunger in the oil loading tool and allow the ball check to seat in the lash adjuster. Try to depress the lash adjuster plunger two or three more times to ensure that the ball check is seating. The assembly should feel firm, without any "give" to it.

4. Take the lash adjuster out of the test oil and remove the oil loading tool being careful that the spring-loaded plunger does not unseat the ball check. Wipe the excess oil off the lash adjuster and place it in the rotating cup on the test stand.

5. Turn the switch on to rotate the cup. Lower the ram until it rests on the lash adjuster plunger and release handle so that the plunger carries the full 13.6 kg (30 lbs) load.

NOTE

Be sure the lash adjuster body is rotating around the plunger.

6. Time for 1.52 mm (.060") travel (leak down time) will be automatically recorded on the time clock. The "leak down time" should be within limits of 20 seconds minimum and 60 seconds maximum, based on a normal temperature of 24° C (75° F) for the oil and lash adjuster. If the temperature of the oil and lash adjuster is other than 24° C (75° F), the limits should be determined by the following:

Oil And Lash Adjusters Temp. °C	°F	Min. Leak Down Time Seconds	Max. Leak Down Time Seconds
16	60	32.3	97.0
18	65	27.4	82.2
21	70	23.3	70.0
24	75 (Base)	20.0	60.0
27	80	17.3	51.9
29	85	15.1	45.3
32	90	13.3	40.0
35	95	11.8	35.5
38	100	10.5	31.5

The temperature of the test oil and lash adjuster should be allowed to become stable before leak down checks are made. If a lash adjuster fails to pass the minimum "leak down time," it should be refilled and retested to be sure that the failure was not due to air trapped in the lash adjuster.

ASSEMBLY OF VALVE BRIDGE

1. Using the valve bridge spring compressor, Fig. 2-25, assemble a qualified spring, spring seat and lock ring to the valve bridge.
2. Install the lash adjuster assembly in the valve bridge, using the installer tool, Fig. 2-28.

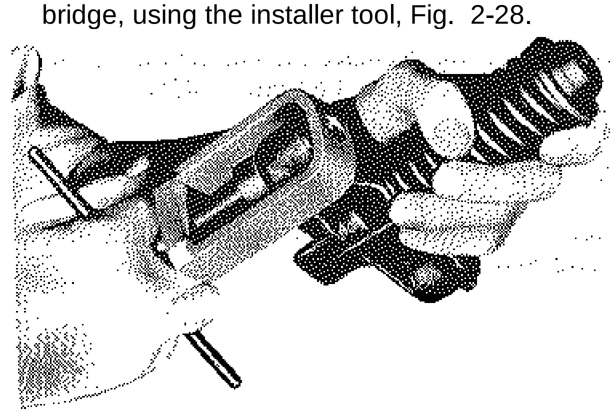


Fig.2.28-Installing Lash Adjuster

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ROCKER ARM ASSEMBLY

DESCRIPTION

Three rocker arms, Fig. 2-29, are mounted on the cylinder head. Two rocker arms actuate the four exhaust valves, the third operates the injector. The rocker arms are operated directly by the camshaft through a cam follower roller mounted at the fork end of each rocker arm. The opposite end of each rocker arm has an adjusting screw and locknut for setting the injector timing and adjusting the hydraulic lash adjusters. The injector rocker arm, although similar in appearance to the exhaust rocker arm, is stronger than the exhaust rocker arm, and can be identified by the yoke at the cam follower end which is square-shaped on the injector rocker arm, but V-shaped on the exhaust rocker arm. Also, only the injector rocker arm has the machined notch for the overspeed trip. Injector and exhaust rocker arms are not interchangeable.

Lubricating oil is supplied to the cam follower assembly and the adjusting screw end through drilled passages in the rocker arm.

MAINTENANCE

Remove adjusting screw and cam follower races, bushings, and pin and thoroughly clean all parts in fuel oil or similar solvent. Do not clean inner and outer races and bushings in a caustic solution. Handle parts with care to avoid nicking the bearing surfaces.

1. Inspect the rocker arm bushings, cam follower rollers, inner race, Fig. 2-30, and rocker arm shaft for evidence of heat discoloration, excessive wear, shelling or scuffing due to lack of lubrication and for fatigue cracks. Check machined notch (recess) on injector rocker arms for excessive wear step from trip pawl engagement.

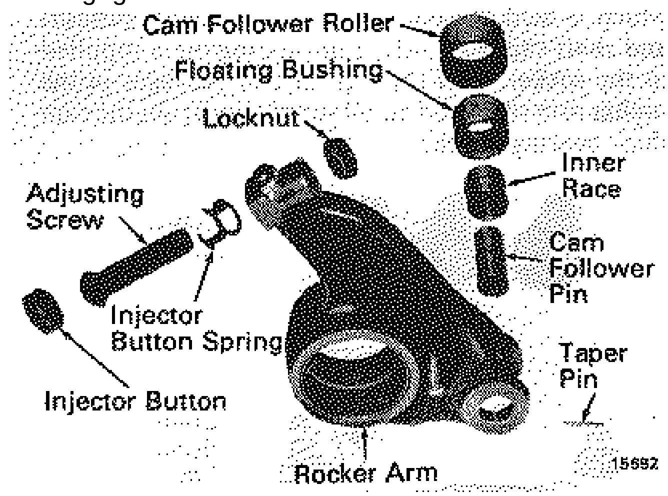

Fig.2-30-Injector Rocker Arm, Exploded View

NOTE

Injector rocker arms with excessive wear steps should be replaced with a new part. No attempt should be made to rework or salvage arms with excessive wear steps.

2. Check that all oil holes and passages are clean.
3. All adjusting screws should be checked for hand-free operation and any galling on the ball end.
4. All adjusting screw buttons should be visually checked for galling or cracking.

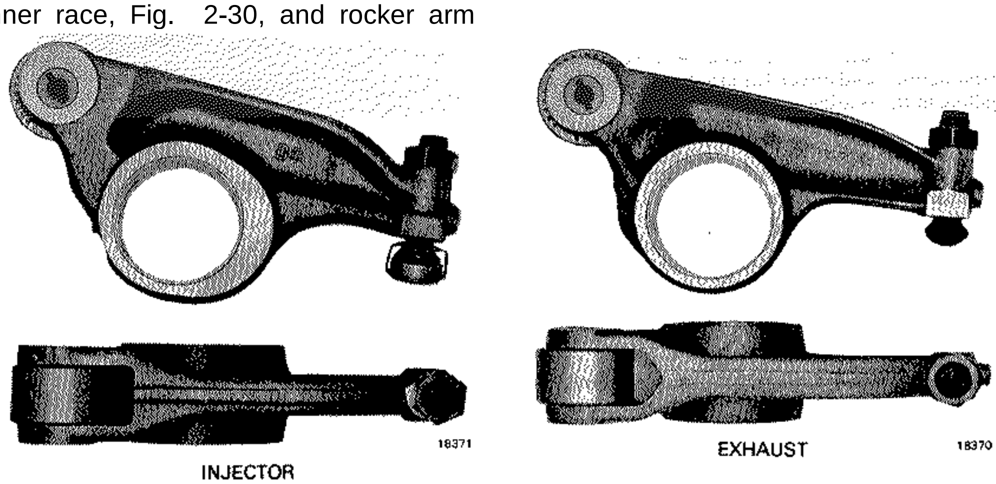

Fig.2-29-Rocker Arms

ROCKER ARM SUPPORT ASSEMBLY

DESCRIPTION

The rocker arms are mounted on rocker arm shaft which is held at each end between a shaft support and shaft cap, Fig. 2-31. Lubricating oil is supplied to the rocker arms through drilled passages in the rocker arm shaft and an oil supply line, from the cam shaft bearing bracket.

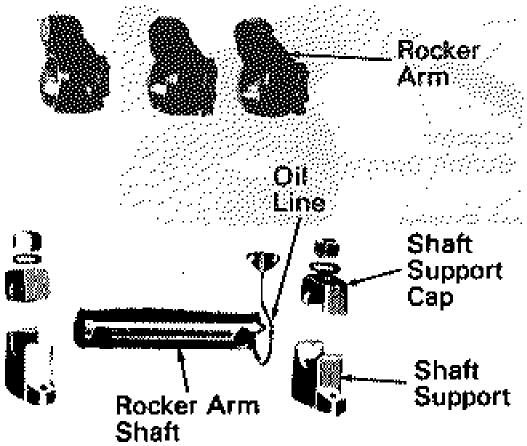

Fig.2-31-Rocker Arm Support Assembly

MAINTENANCE

Thoroughly clean shaft, support caps, and support in suitable solvent. Check that oil passages in shaft and oil line are clean and free from obstructions.

Check shaft diameter at wear step for proper dimensions, and check for cracks, scratches, or galling in the bearing areas.

Check the shaft support for the correct height dimension between the base and bottom of the bore. Holding this dimension with the limits will ensure that the height mismatch between supports for any one cylinder will be 0.15 mm (.006") or less. Mismatch greater than 0.15 mm (.006") can lead to camshaft lobe distress and broken rocker arm studs.

A flat and true nut seating surface must be provided on the support cap or broken washers and studs can result. If a seating surface is damaged, it may be remachined until a minimum dimension of 12.7 mm (1/2") is obtained between the seating surface and top of bore.

The surface must be machined square with the stud hole and parallel with the centerline of the rocker arm shaft within 0.25 mm (.010") total indicator reading. Cracks in the cap or shaft support are cause for rejection.

CYLINDER TEST VALVE

DESCRIPTION

Cylinder test valves, Fig. 2-32, are provided on the engine at each cylinder. Any time maintenance or inspection is performed, the valves are opened to relieve compression, reducing the effort required to rotate the crankshaft. With the test valves open, fuel and coolant leaks can be detected by fluid discharge at the valves while the engine is being barred over. The cylinder test valve is inserted in a housing within the crankcase and screwed into the cylinder head. A cylinder test valve wrench, Fig. 2-33, is used to open and close the valves.

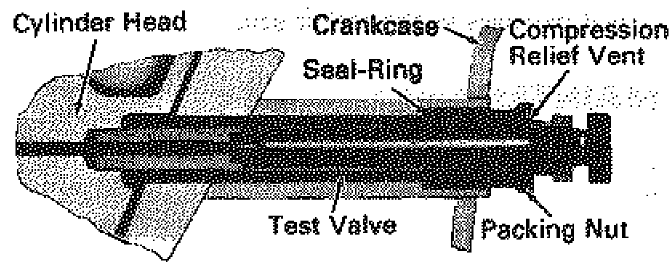

Fig.2-32-Cylinder Test Valve

Fig.2-33-Test Valve Wrench

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MAINTENANCE

1. If a cylinder test valve is leaking, check that packing nut, Fig. 2-32, has been torqued to the specified value. If nut has been overtightened, change seal-ring, Fig. 2-32, and correctly torque packing nut. Should valve continue to leak, remove the valve from the engine and ream the valve seat as shown in Fig. 2-34.

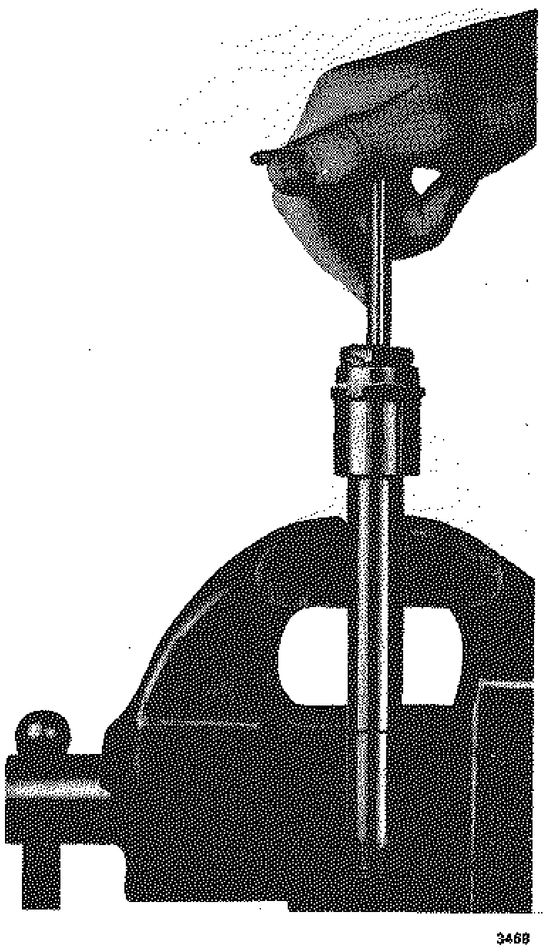

Fig.2-34-Reaming Test Valve Seat

NOTE

When replacing seal, use new non-asbestos seal-ring inserted with metal backing ring side in first.

2. If reaming will not correct the leaking due to a scored or damaged valve stem face, it should be reconditioned within the limits shown in Fig. 2-35. Reharden the tip to a depth of 0.13-0.25 mm (.005"-.010").

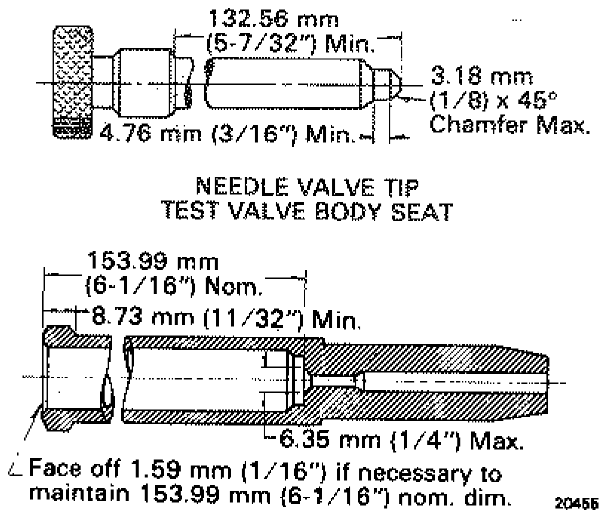

Fig.2-35-Test Valve Reconditioning Limits

3. The cylinder test valve body may be reworked to the dimensions shown in Fig. 2-35. Use reamer to recondition the valve seat. If necessary to exceed the 6.35 mm (1/4") maximum diameter of valve seat, Fig. 2-35, recut bottom of 12.7 mm (1/2") diameter counterbore and reface hexagon end to hold the 153.99 mm (6-1/16") nominal dimension.

4. After reconditioning, air test the valve assembly at 620 kPa (90 psi) air pressure.

CYLINDER HEAD SEAT RING

DESCRIPTION

The cylinder head seat ring is an aluminum bronze ring used between the crankcase head seat and the cylinder head to provide a seating surface for the cylinder head and to maintain proper piston to head clearance.

NOTE

Head seat rings may be provided which have a Viton or Silicon seal ring molded to the outer diameter.

MAINTENANCE

Inspect head seat ring for proper dimensions. If ring does not meet required specifications, it should be replaced with a new ring.

On head seat rings with seal rings molded to outer diameter, inspect seal portion for signs of tearing or abrasions that would render seal ineffective for oil retention. If seal is damaged, seat ring should be replaced.

SERVICE DATA
CYLINDER HEAD AND ACCESSORIES

SPECIFICATIONS

Clearance and dimensional limits listed below are defined as follows:

1. *New limits are those to which new parts are manufactured. (Drawing tolerances.)*

2. *Minimum, maximum, and tolerance measurements are provided as service limits. A t time of rebuild or any time unscheduled maintenance is performed, the service limits should not be exceeded. Engine components within these limits may be reused with the assurance that they will perform 'satisfactorily) until the next scheduled overhaul.*

Cylinder Head

Valve seat angle....................30° 00'-30° 15'
Valve seat width....................2.36-3.18 mm (.093"- .125")
Variation of seat width on a given seat-Max....................0.38 mm (.015")
Diameter at top of valve seat (ground)
Max....................61.90 mm (2.437")
Min....................60.33 mm (2.375")
Valve seat runout max (measured at center of seat)....................0.10 mm (.004")
Valve flat to head
New....................0.00-0.76 mm (.000"-.030")
Max....................2.36 mm (.093")
Valve lift....................17.48 mm (.688")
Fireface surface (refinished-circumferential lay)....................2 µm-3 µm (80 µin-120 µin)

Exhaust Valves

Stem diameter (measured within 127 mm (1/2") of weld and 127 mm (1/2") below P/N stencil on stem)
New....................15.786-15.812 mm (.6215"-.6225")
Min....................15.761 mm (.6205")
Diameter of head....................63.50 mm (2.500")
Valve face angle....................30°00'-29° 45'
Valve seat runout-Max....................0.05 mm (.002")
Valve rim thickness-Min (measured at O.D.)....................2.77 mm (.109")
Valve face width-Max....................8.71 mm (.343")

Valve Springs
Free length (approximately)
New....................104.78 mm (4.125")
Min....................100.79 mm (3.968")
Length-valve open....................68.28 mm (2.688")
Length-valve closed....................85.72 mm (3.375")
Pressure to compress spring to 6825 mm (2687") length
New....................96.6-102.1 kg (213-225 lbs)
Min....................79.4 kg (175 lbs)
Valve bridges spring-same as valve spring. Spring must not show any set after being compressed with coils touching:
Valve spring seat thickness-Min....................3.68 mm (.145")

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Rocker Arm

Rocker arm shaft diameter-Min .... 57.05 mm (2.246")
Rocker arm bushing inside diameter-Max .... 57.25 mm (2.254")
Press bushing to rocker arm .... 0.05-0.10 mm (.002"-.004")
Inner race outside diameter-Min .... 26.62 mm (1.048")
Floating bushing inside diameter-Max .... 26.80 mm (1.055")
Floating bushing outside diameter-Min .... 36.665 mm (1.4435")
Cam follower roller inside diameter-Max .... 36.843 mm (1.4505")
Injector rocker arm recess wear step-Max .... 0.794 mm (.0313")

Rocker Arm Shaft Assembly

Shaft support-support base to bottom of bore .... 55.47-55.63 mm (2.184"-2.190")
Shaft support cap-nut seating surface to top of bore-Min .... 12.70 mm (.500")
Shaft diameter-Min (measured at wear step) .... 57.05 mm (2.246")

Valve Guide

Inside diameter (not installed)-New .... 15.938-16.015 mm (.6275"-.6305")
(Installed in head)-Min .... 15.900 mm (.6260")
Max limit-127 mm (1/2") from bottom and top .... 16.08 mm (.633")
Valve stem to guide clearance-Max .... 0.25 mm (.010')
Press fit in head .... 0.013-0.051 mm (.0005"-.0020")

Cylinder Head Seat Ring

Thickness standard-New .... 4.83-4.93 mm (.190"-.194")
Minimum thickness .... 4.67 mm (.184")
Uniform thickness within .... 0.06 mm (.0025")
Maximum wear step .... 0.08 mm (.003")

Valve Bridge

Refer to Fig 2-26-circled numbers coincide with callouts on illustration

① Distance between rocker arm guide ears-
- Min .... 23.75 mm (.935")
- Max .... 23.88 mm (.940")

② Lash adjuster socket diameter (measured within 635 [1/4" into socket) -
- New .... 22.195-22.220 mm (.8738"-.8748")
- Max .... 22.225 mm (.8750")

③ Lash adjuster body diameter -
- Min .... 22.225 mm (.8750")
- Max .... 22.238 mm (.8755")

④ Valve bridge shank length-
- Min .... 103.18 mm (.4062")
- Max .... 103.96 mm (.4093")

⑤ Shank diameter from shank end to 635 mm (250') above the shank end -
- Min .... 15.799 mm (.6220")
- Max .... 15.837 mm (.6235")

⑥ Shank diameter from 953 mm (3/8) to 254 mm (1") above shank end -
- Min .... 15.781 mm (.6213")
- Max .... 15.837 mm (.6235")

⑦ Spring seat rim thickness-
- Min .... 2.36 mm (.093")
- Max .... 3.18 mm (.125")

⑧ Spring seat spherical radius -
- New .... 15.82 mm (.623")
- Max wear step on radius .... 0.79 mm (.031")

⑨ Spring seat bore diameter-
- New .... 15.862-15.900 mm (.6245"-.6260")
- Max .... 15.938 mm (.6275")

SERVICE DATA (CONT'D)

EQUIPMENT LIST

	Part No
Test valve wrench	8032587
Valve spring compressor (single)	8033783
Adapter (use with 8033783)	8034054
Crab stud protector tubes	8034600
Valve seat reconditioning tool set (115 volt)	8035775
Valve seat reconditioning tool set (220 volt)	8041445
Valve checking tram	8042773
Electric drill, 1/4" (115 volt)	8045450
Cylinder test valve seat reamer	8064804
Valve bridge spring compressor	8070883
Valve bridge lock ring guide	8070903
Lash adjuster installer	8072927
Lock ring remover-lash adjuster	8080632
Valve guide cleaner	8141439
Tapered pilot checking fixture	8173996
Cylinder head stud hole cleaner	8211907
Valve seat seal tester	8213518
Vacuum cup (spare for 8213518)	8213519
Valve spring compressor (multi-crank type)	8215081
Valve guide installer-remover	8224241
Lash adjuster test stand (110 V 60 Hz)	8267432
Lash adjuster test oil (1893 liters [5 gal])	8276528
Lash adjuster test stand (220 V 60 Hz)	8299249
Valve seat reconditioning tool set (air motor)	8332668
Lash adjuster puller	8394719
Lash adjusting pulling arm	8395481
Grinder-valve and tool-230 volts 60 Hz single phase	9310355
Grinder-valve and tool-230 volts 60 Hz three phase	9310356
Grinder-valve and tool-1 15 volts 50 Hz single phase	9310357
Grinder-valve and tool-230 volts 50 Hz single phase	9310358
Grinder-valve and tool-230 volts 50 Hz three phase	9310359
Grinder-valve and tool-1 15 volts 60 Hz single phase	9310360
Drive belt for valve grinders	9310380
Valve face grinding wheel with hub	9310382
Valve spring compressor (multiple)	9546582

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SECTION 3

PISTON ASSEMBLY AND CONNECTING RODS

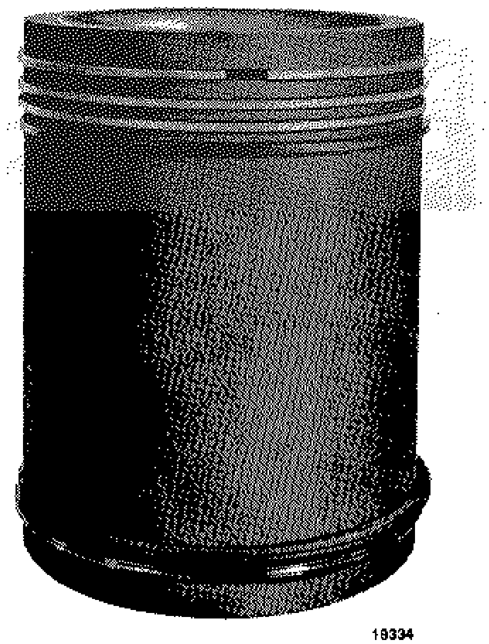
CONTENTS	PAGE

PISTON ASSEMBLY AND CONNECTING RODS

PISTON ASSEMBLY

DESCRIPTION

The piston assembly, Fig. 3-1, consists of a cast iron alloy piston, four compression rings, and two oil control rings. A "trunnion" type piston carrier, Fig. 3-2, is used with the piston assembly to allow the piston to rotate or "float" during engine operation. The carrier supports the piston at the internal piston platform. A thrust washer, Fig. 3-2, is used between the platform and the carrier. The carrier is held in position in the piston by a snap ring inside the piston. Oil taken up by the two oil control rings passes through the oil holes at the bottom of the piston.



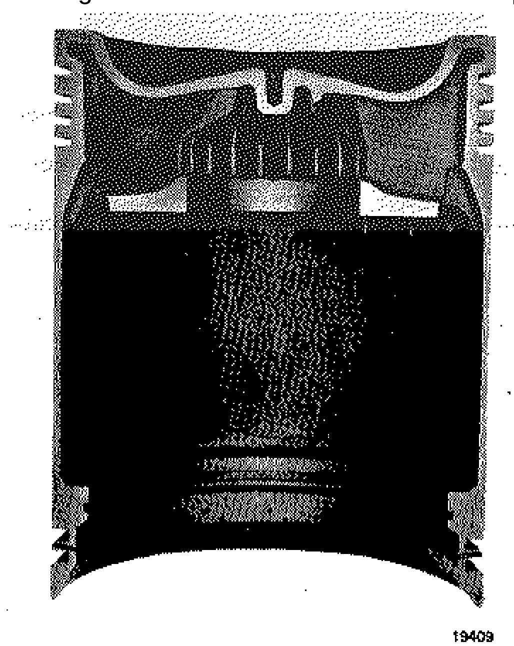


Fig.3-1-Piston Assembly

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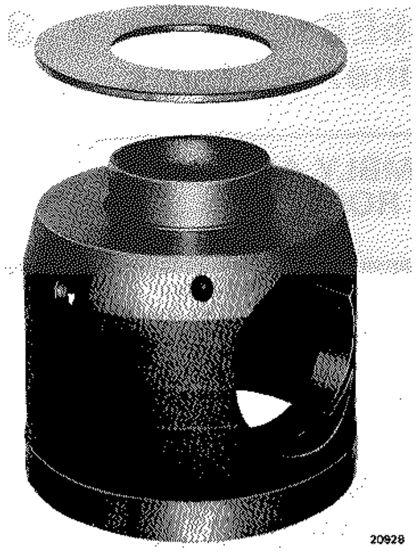

Fig.3-2-Piston Carrier And Thrust Washer

An insert bearing, Fig. 3-3, is applied in a broached slot in the carrier. Tangs at each end of the insert bearing are bent into a counterbore on the carrier to prevent endwise movement. The highly polished piston pin, Fig. 3-3, is applied in the carrier in contact with the insert bearing, and the assembly is bolted to the upper end of the connecting rod.

Internal parts of the piston are lubricated and cooled by the piston cooling oil. Cooling oil is directed through a drilled passage in the piston carrier, circulates about the underside of the piston crown area, and then drains through two holes in the carrier located at the taper as shown in Fig. 3-3.

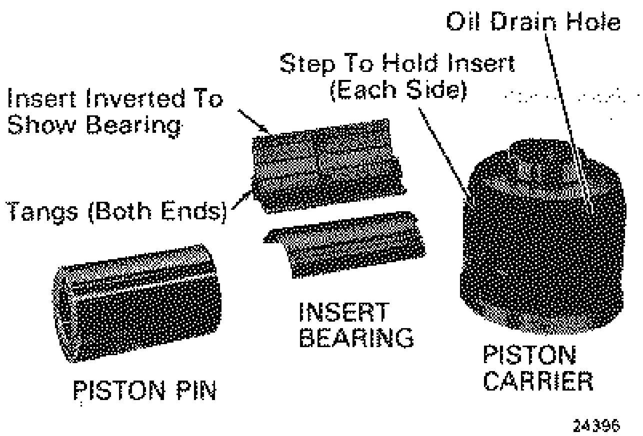

Fig.3-3-Piston Pin, Insert Bearing, And Carrier

MAINTENANCE
PISTON AND ROD INSPECTION (IN ENGINE)

Piston and connecting rod assemblies, Fig. 3-4, can be inspected while installed in an engine provided the engine is shut down and the air box and oil pan inspection covers are removed.

Precautions should be taken, before proceeding, to prevent the engine from being started.

Open all cylinder test valves to facilitate rotation of the crankshaft, using the turning jack.

1. Rotate crankshaft until piston of cylinder being inspected is at bottom center.

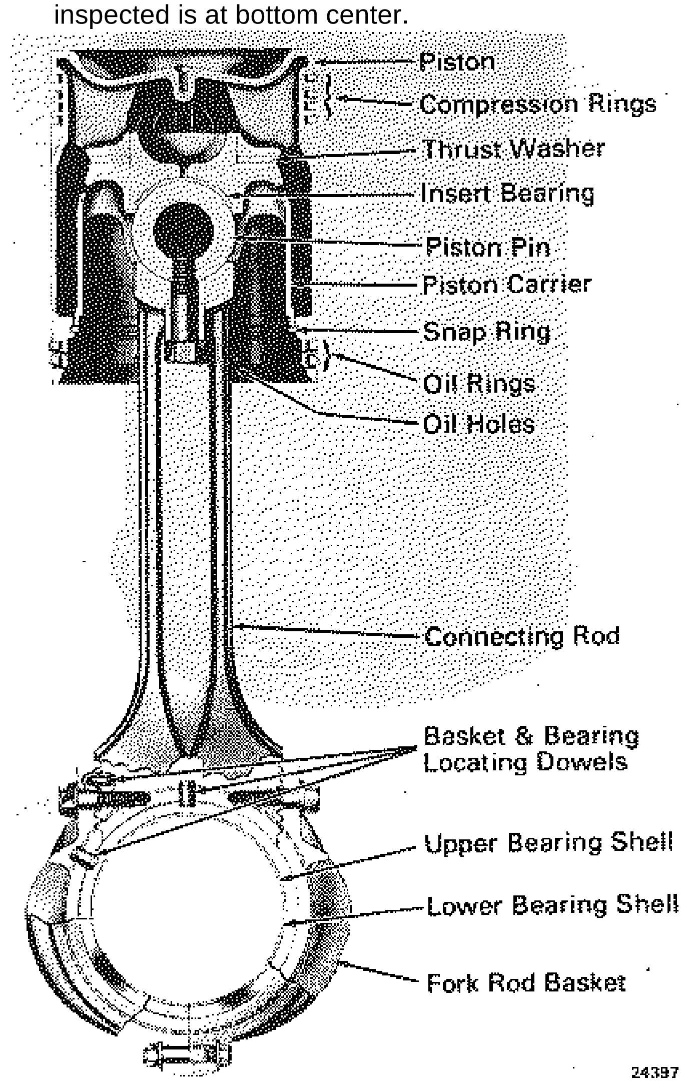

Fig.3-4-Piston And Connecting Rod Assembly, Cross-Section

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2. Inspect cylinder wall and top of piston. A wet piston crown would indicate a leaky injector. Check cylinder walls to make sure there is no scoring and inspect for water leaks.

3. Rotate crankshaft to move piston toward TDC until compression rings are visible through liner ports.

4. Visually inspect for the following ring conditions at the liner ports.
   a. Measure side clearance of the No.1 compression ring between the top of the ring and the ring groove using a feeler gauge.

   b. A ring in good condition will be bright and free in its groove.

   c. Broken ring. The ring face will normally be black if broken opposite the gap. Milling may also be evident above and below the liner ports.

   d. Worn ring. Renew or replace power assembly when plating is worn through on chrome first ring. The chrome ring wear classifications shown in Fig. 3-5, used in conjunction with, the description of each ring wear "type," will serve, as a guide during ring inspection.

      Barrel faced first rings used on power assemblies with chrome plated liner bores have twelve evenly spaced scallops around face of ring. This ring is normally side wear limited and is usually monitored by feeler gauge check of ring to land clearance. The scallops form an interrupted witness groove, providing a method of face wear assessment to guard against situations where rapid face wear occurs without corresponding side wear. Such a condition could allow contact between chrome sides of ring and chrome of liner bore causing wear-stepping of liner.

   e. Ring blow-by. Vertical brown streaks on the face of the ring indicate blow-by. Renew or replace power assembly when this condition becomes severe.

5. Inspect piston skirt for scoring or scuffing.

6. Inspect air box for foreign material and any signs of water or oil leakage.

OIL PAN INSPECTION

1. Inspect back of upper connecting rod bearing for cutting or signs of overheating.

2. To check for thrust washer, piston pin bearing, and connecting rod bearing wear, take a lead reading of piston to cylinder head clearance. Any significant increase since previous lead reading should be investigated as a possible component failure.

NOTE

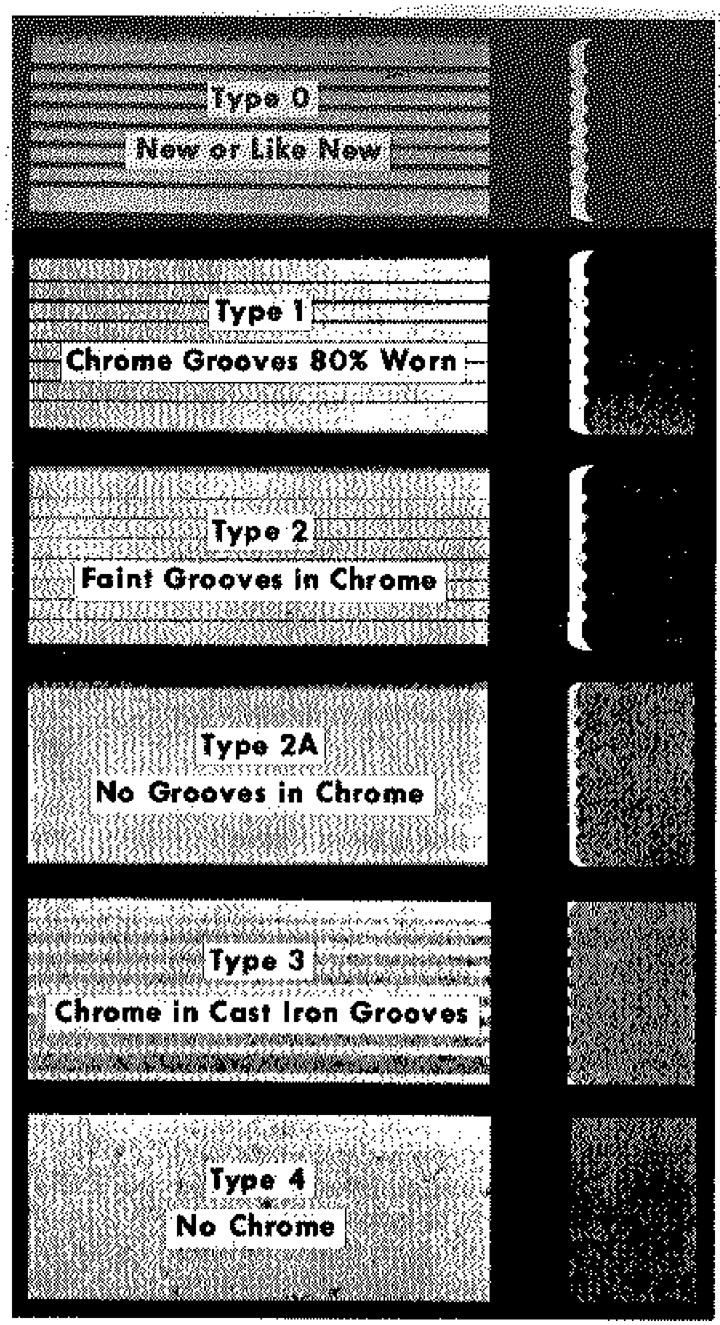
Due to carbon buildup on both the fire face of the cylinder head and the crown of the piston during service life, lead wire readings should not be used as a basis for power assembly renewal or replacement due to wear. The proper wear factors considered for power assembly removal should be side clearance of the No. 1 compression ring and piston ring face wear.

3. With piston at top center, inspect lower liner walls for scoring.
4. Inspect oil pan for foreign matter.

PISTON AND ROD DISASSEMBLY

NOTE

Procedures for disassembly and qualification of piston and connecting rod assembly components are contained in this section. Procedures for removal, assembly, and installation of the piston and connecting rod assembly, and of a complete cylinder power assembly are contained in Section 5.



A new or like new ring. This classification will only be evidenced during the first phase of top ring life.

On a shallow groove ring, these classifications will be evident on the top ring for a relatively short time. On a deep groove ring, these classifications will be evident for the major portion of ring life.

Chrome grooves are completely worn away, showing only a smooth chrome face. This will exist for the major portion of shallow groove ring life. It will be evident for a short time on only a small percentage of deep groove rings.

Rings are starting to wear into the cast iron, except for the grooves, which still contain chrome.

CAUTION

To prevent liner scoring, power assemblies with stainless steel rings should be renewed at this time.

Chrome is completely worn off and wear is concentrated on the cast iron. Rings in this classification are to be considered worn out.

NOTE

When classifying chrome plated stainless steel rings, substitute references to "cast iron" with "stainless steel". In addition, stainless steel rings have five grooves instead of seven.

Fig.3-5-Chrome Ring Wear Classification

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1. Place piston and rod assembly on a wooden topped work bench and remove piston snap ring, Fig. 3-6, using snap ring remover. Care should be taken in handling piston assembly to avoid nicking or scraping the piston skirt.

Fig.3-6-Removing Piston Snap Ring

2. Place rod and carrier in holding fixture, Fig. 3-7, and remove piston pin bolts. This fixture has mandrel(s) which fits in the piston pin bore to hold the pin while the rod bolts are removed. It must be securely mounted on a work surface. If fixture is unavailable, a vise having copper protected jaws may be used to hold the connecting rod. Clamp rod horizontally with pin close to vise so pin bolts may be removed without twisting rod.

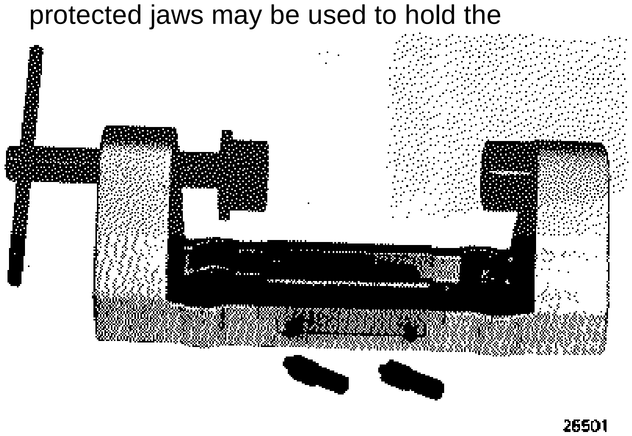


Fig.3-7-Typical Carrier Holding Fixture

3. Remove pin from carrier.

4. At the time of piston and rod disassembly, check that the thickness of the thrust washer exceeds the minimum dimension listed in the Service Data.

CLEANING

Cleaning procedures should be in accord with accepted practice or as recommended by the supplier of cleaning material.

PISTONS

1. Remove the piston rings using ring expander as shown in Fig. 3-8, and discard the old rings.

2. Immerse the piston in an alkaline solvent solution and allow to remain until the carbon deposits are loosened.

3. Wash the piston using steam or hot water and blow dry using compressed air.

4. Remove any carbon deposits from the compression ring grooves. Light grit blasting or a piece of compression ring can be used for this purpose.

5. Using 3/32" and 5/32" drills in the respective holes, clean the oil passages in the oil ring grooves.

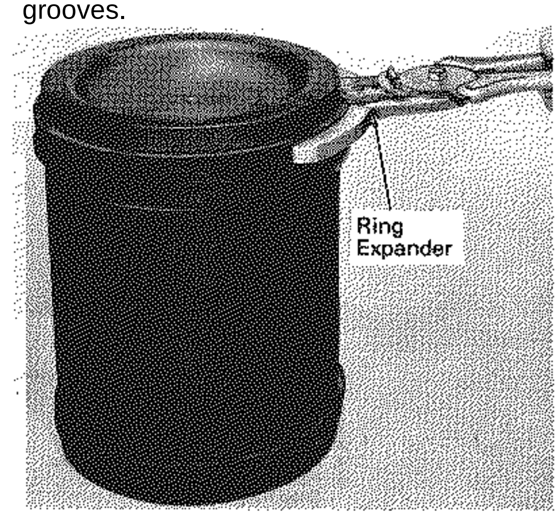


Fig.3-8-Removing Pistons Rings

PISTON PIN AND CARRIER

CAUTION

Abrasive material, including steel wool, should not be used to clean piston pins or insert bearings.

1. It is recommended that the piston pin and carrier assemblies be cleaned using a high flash point petroleum solvent, such as Stoddards solvent (60° C [140°F] flash point) or equal. These parts should never be washed in an alkaline or caustic solution.
2. Clean the carbon from the oil grooves in the insert with a suitably pointed wooden stick. Embedded particles do no harm if they do not project above the bearing surface; no attempt should be made to remove them. Parts of the assembly should be adequately protected against rust and corrosion at all times.

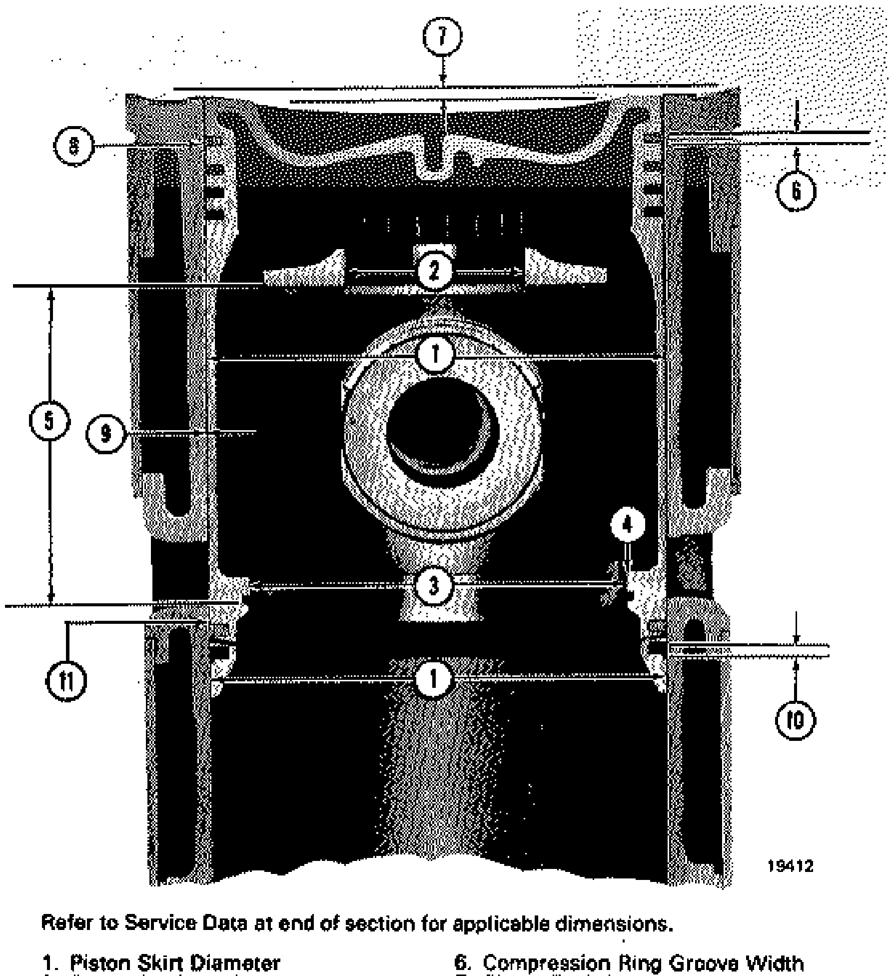
INSPECTION

PISTON

1. The phosphate treated surface of the piston skirt should be inspected for satisfactory condition. If the coating is worn through and bare metal in excess of approximately three square inches is exposed, the piston should be re-coated.

2. Inspect the piston surface for excessive scoring or other mutilation which would reject the piston.

3. Check all points of measurement as shown in Fig. 3-9. Discard any pistons that exceed the limits in the Service Data.



Refer to Service Data at end of section for applicable dimensions.

1. Piston Skirt Diameter
2. Piston Platform Bore
3. Piston Inside Diameter
4. Piston To Carrier Pilot Clearance
5. Piston Platform To Bottom Of Snap Ring Groove
6. Compression Ring Groove Width
7. Piston To Cylinder Head Clearance
8. Compression Ring To Land Clearance
9. Piston To Liner Clearance
10. Oil Ring Groove Width
11. Oil Ring To Land Clearance

Fig.3-9-Piston Measurement Points

4. Check piston ring groove wear step. Check wear step in top ring groove, Fig. 3-10. Top ring breakage can be caused by excessive wear step.

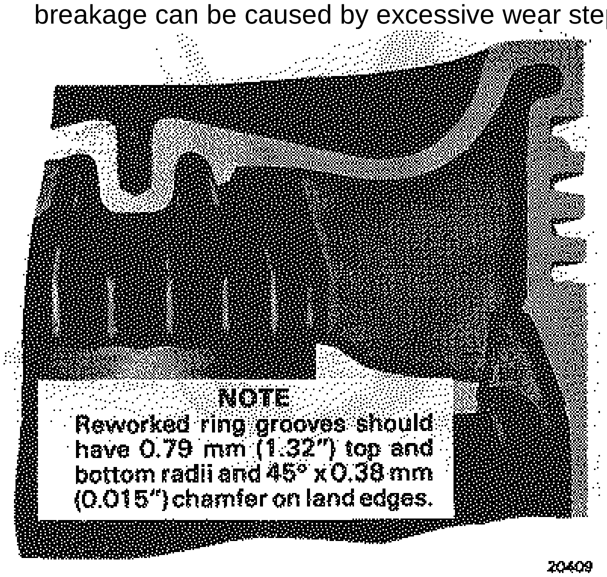


Fig.3-10-Typical Piston Ring Groove Wear Step

A piston ring groove gauge, Fig. 3-11, is available to make the wear step measurement. Gauges also are available for measuring wear step in oversize ring grooves. Each gauge consists of a number of separate width indicators precise to 0.001". Standard ring groove gauge has indicators from 0.194" through 0.203". See Service Data for available standard and oversize groove gauge part numbers with indicator size ranges.

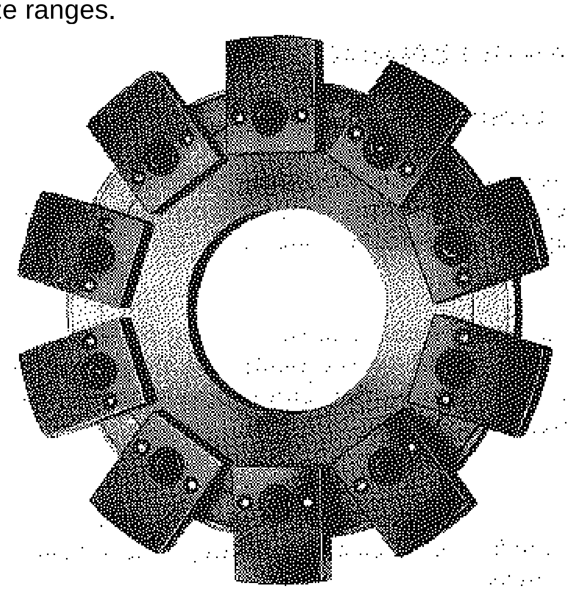


Fig.3-11-Piston Ring Groove Gauge

To measure wear step, it is first necessary to determine the original ring groove width, because it may vary from 4.93 to 5.00 mm (.194" to .197"). Insert gauge blocks in ring groove, and by trial, determine the largest one which enters its full depth. This will indicate the original width of the ring groove being measured. Then insert the largest block that will enter the groove up to the wear step. The size of the wear step is determined by subtracting the small block dimension from the large block dimension.

When a wear step, in excess of maximum allowable, is found in the top compression ring groove, the groove may be recut to remove the wear step, provided the finished width does not exceed 5.10 mm (.201") for use with a standard ring.

If the ring groove is worn beyond a width of 5.10 mm (.201"), it is possible to machine the top ring groove to use oversize ring. See Service Data for limits.

When performing either of the preceding operations, care must be taken to keep the ring groove faces parallel to each other and at right angles to the centerline of the piston. The surface finish must be smooth to avoid excessive wear.

5. Inspect the piston for cracks using magnaflux procedure.

6. Remove undercrown deposits. Pistons that have been found dimensionally and structurally satisfactory for reuse, should also have the heat dam area thoroughly cleaned of undercrown deposits. Undercrown cleaning should be accomplished using a sand or grit blast cleaning in conjunction with liquid cleaning.

CARRIER

In this assembly, Fig. 3-3, a broached slot or recess in the carrier receives a precision insert bearing. A hardened polished pin runs against the insert bearing.

Normal bearing wear does not affect the carrier. Maximum permissible wear on the insert piston pin, and carrier pilots are listed in Service Data. Used parts in good condition should not be interchanged. A new insert bearing should be used when a new piston pin is used. The piston pin should always be applied in the same relative position to the insert bearing.

The small hole in the piston pin should be matched with the piston cooling oil inlet hole in the carrier as a convenient means of keeping the pin and insert in the same relative position for maximum performance.

Except in extraordinary cases of pilot wear, carriers may be expected to have an indefinitely long life. Also, the insert bearing need not be removed unless its appearance is questionable and/or the wear on the piston pin is well advanced.

Measure the carrier to determine that the dimensions do not exceed the limits shown in the Service Data.

PISTON PIN

1. Inspect the pin. The bearing surface should be free of any roughness and have a mirror finish.
2. Fretting on the pin, only where it contacts the connecting rod, may be removed using a fine stone.
3. Check the 7/8"-14 bolt threads in the pin by retapping. If the threads are damaged, replace the pin.
4. Check piston pin wear step at oil groove location.

CONNECTING ROD ASSEMBLY

DESCRIPTION
The "trunnion type" connecting rods, Fig. 3-12, are interlocking, blade and fork construction. The blade rod moves back and forth on the back of the upper crankpin bearing and is held in place by a counterbore in the fork rod.

One end of the blade rod slipper foot is longer than the other and is known as the "long toe." The blade rods are installed in the right bank of left-hand rotation engines and in the left bank of right-hand rotation engines with the long toe toward the center of the engine.

The fork rods are installed in the left bank of left-hand rotation engines and in the right bank of right-hand rotation engines. Serrations on the sides of the

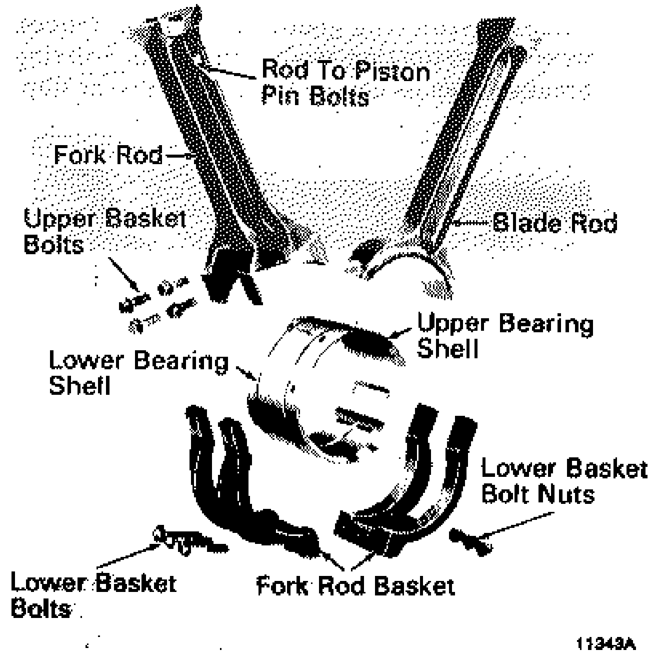


Fig.3-12-Connecting Rods, Bearing Shells, And Basket

rod at the bottom match similar serrations on the fork rod basket, Fig. 3-12. The rod basket consists of two halves, held together at the bottom by three bolts and self-locking nuts. The fork rod and basket are bolted together at the serrations. Fork rods and baskets are not interchangeable since they are line bored as an assembly. Both the fork rod and basket are stamped with an identical assembly serial number for matching and identification purposes.

MAINTENANCE

CLEANING
Cleaning procedures should be in accord with accepted practice or as recommended by the supplier of cleaning material.

The glazed finish and the bearing pattern oil stain usually found on the blade rod slipper surface is considered normal, and removal should not be attempted.

CAUTION
Abrasive material, including steel wool, should not be used to clean connecting rods or bearing shells.

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INSPECTION

FORK ROD

1. After all parts are clean, check the tapped holes in the fork rod. If threads are worn, the bolts holding the basket may loosen during operation and damage the engine.

   Plug gauge, Fig. 3-13, is available to check the fork rod bolt threads. One end of the gauge is marked "GO" and the opposite end "HI". The gauge should be used according to the following procedure.

   a. Thread the "GO" portion of the gauge into each of the holes, Fig. 3-13, and check for binding, which may indicate damaged threads. Normally, this gauge should enter the holes freely and a slight shake or wobble is permissible.

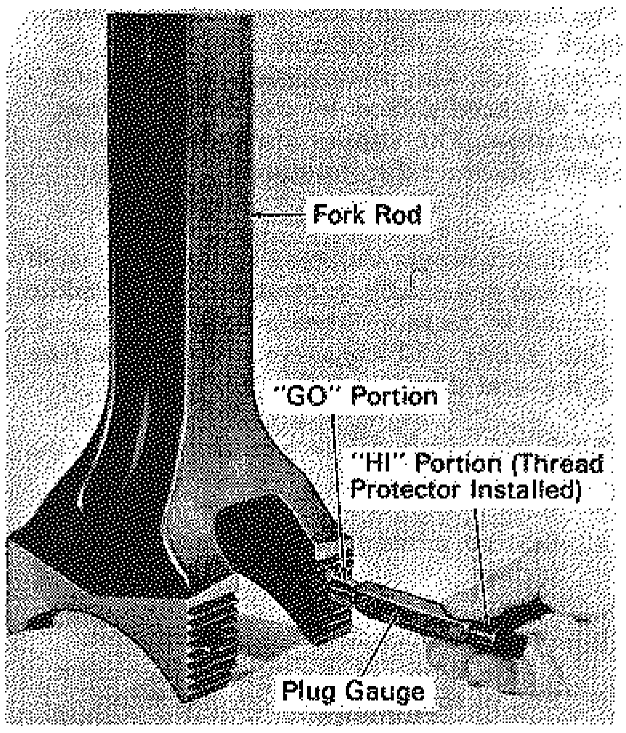

Fig.3-13-Checking Fork Rod Bolt Threads

   b. An attempt should then be made to screw the "HI" portion of the gauge into each of the holes. This is not a "no go" gauge, therefore, rods may be entirely satisfactory even though the gauge may be screwed in, the threads, even to the extent of bottoming.

   Normally, in rods having little wear, this gauge will be difficult to thread into the holes more than a couple of turns. In many cases, however, the gauge can be threaded into the rod but will be snug and tight. While threaded in, check for shake or wobble, taking care that the gauge is not bottomed in the hole, which would cause binding and a false reading.

   The fork should be scrapped if shake or wobble is experienced with the "HI" gauge. To further ensure proper torque values, it is recommended that new bolts be used. However, old bolts may be used if they are qualified by careful inspection. Discard any that may be bent or have threads showing signs of galling, wear, nicks or other imperfections.

2. Fork rod serrations should be checked for nicks, burrs, and cleanliness. Check tightness of upper bearing locating dowels. Step dowels are available in the event oversize dowels are required. Inspect for cracks in serrations and rod visually and by magnaflux.

3. To ensure proper clamping between the piston pin and rod saddle, protrusions in the saddle caused by nicks or fretting must be removed. Use grade 150 abrasive paper or a fine cylindrical stone.

4. Check fork rod bore by fastening basket halves securely in place using 238 N•m (175 ft-lbs) torque on upper basket bolts, Fig. 3-12. (Normal upper basket bolt torque is 258 N•m [190 ft-lbs] on assembly.) Torque lower basket (split line) bolts to specified value. Check to be certain inner counterbores in rod and baskets are in alignment. If not, loosen basket to rod bolts and use a brass hammer to tap baskets into alignment, then retorque bolts. Measure bore at points 600 apart as indicated in Fig. 3-14. Take one set of measurements at generator end of bore and one set at accessory end of bore. The average of each set of dimensions must not exceed the specified maximum. If bore is beyond this dimension, the rod and basket should be reworked.

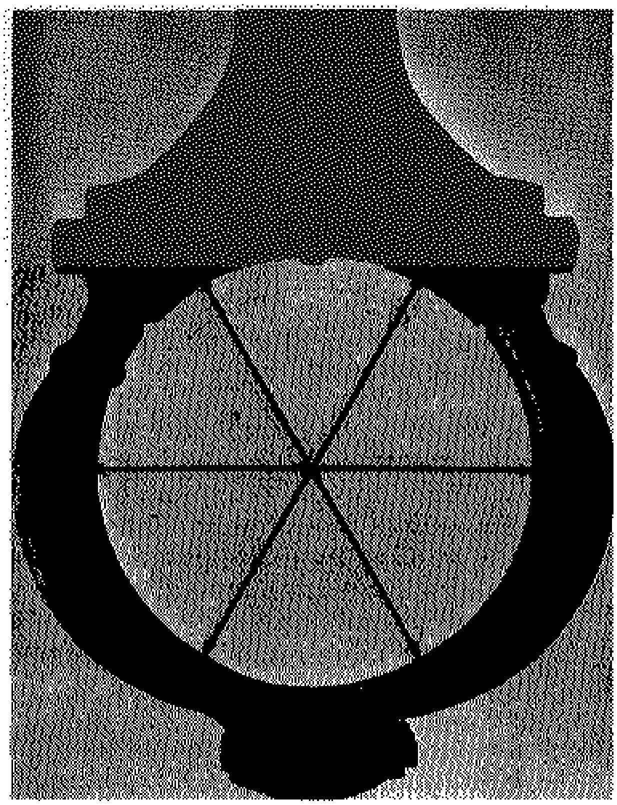

Fig.3-14-Checking Fork Rod Bore

5. Fork rod rework will be required for any of the following conditions:

   a. Average of three 60° measurements across fork rod and basket bore exceeds specified maximum.
   b. Nicks, burrs, or fretting on fork and basket serrations.
   c. Damaged threads in bolt holes (see Step 1), or loose dowels.
   d. Damaged or distorted basket.
   e. Out-of-parallel in excess of limit in length of saddle.
   f. Length of rod between bore centers is less than the minimum shown in Service Data.
   g. Fork .counter bore exceeds maximum depth.

6. Fork rod assembly should be scrapped if any one or more of the following conditions exist:

   a. Fatigue cracks through basket serrations and rejectable magnaflux indications.
   b. Heat discoloration in basket or fork.
   c. Rod twisted, bent, out-of-parallel, or damaged beyond repair.
   d. Length of rod between bore centers is less than minimum rework limit shown in Service Data.

BLADE ROD

1. The blade rod is checked in a 7.692" diameter mandrel to observe slipper surface for "open" or "closed" ends. Blade surface should be smooth. Rod should be scrapped if this surface shows heat discoloration.

NOTE

The flame hardening process produces a blue black color on the top side of the blade rod slipper foot. This discoloration is normal and has not been caused by overheating during operation. The slipper surface, however, should show no discoloration.

2. To ensure proper clamping between the piston pin and rod saddle, protrusions in the saddle caused by nicks or fretting must be removed. Use grade 150 abrasive paper or a fine cylindrical stone.

3. Blade rod rework will be required for any of the following conditions.

   a. Scarred, pitted or deeply rust-etched slipper surface.

   b. End of slipper closed in beyond limit.

   c. End of slipper opened beyond limit.

   d. Out-of-parallel exceeds limit along saddle length.
   e. Length of rod between bore centers is less than minimum shown in Service Data.

4. Blade rod should be scrapped if any one or more of the following conditions exist.
   a. Reject magnaflux indications.

b. Heat discoloration on slipper surface.

c. Less than minimum flange thickness on slipper shoulder.

d. Rod twisted, bent, out-of-parallel, or damaged beyond repair.

e. Length of rod between bore centers is less than minimum rework limit shown in Service Data.

CHECKING ROD LENGTH, TWIST, AND BORE PARALLELISM

A connecting rod checking fixture, Fig. 3-15, is available for accurate inspection of the connecting rod length, twist, and parallelism of piston pin saddle to bearing bore. Refer to Service Data for tool part number.

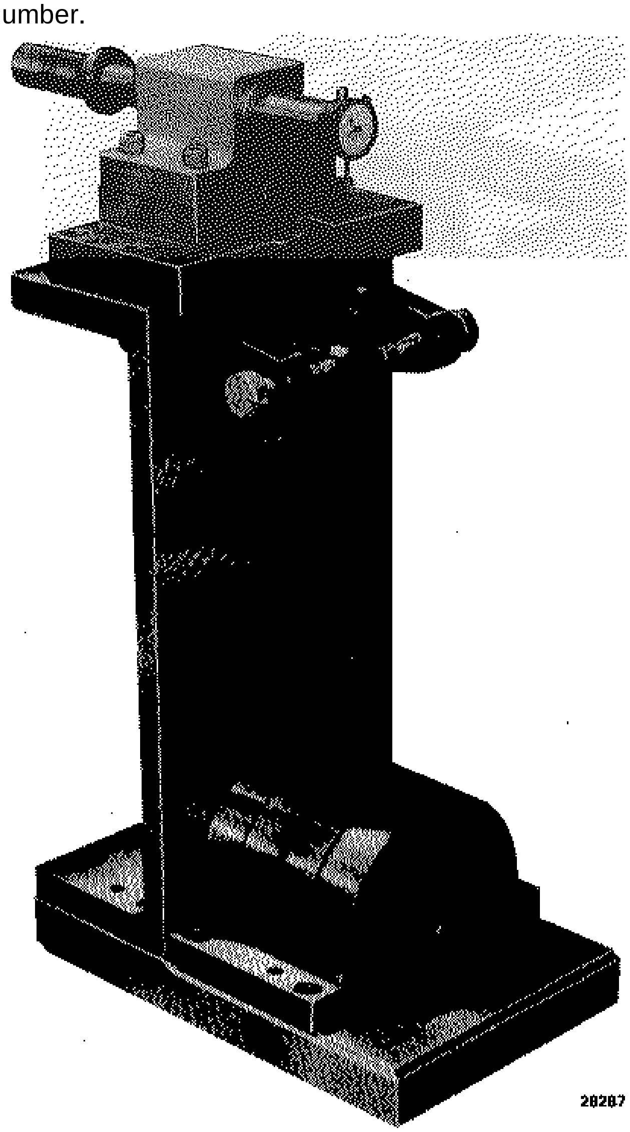

Fig.3-15-Rod Checking Fixture

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The following steps provide a general guideline for checking connecting rods, using the tool shown above.

1. Set dial indicator reading to "0" using gauge block provided with checking fixture.

2. Place connecting rod on checking fixture, being sure that checking fixture mandrel and rod art clean.

3. Using the dial indicator reading at each top edge of piston pin saddle contour, center rod on mandrel by adjusting the vertical centering thumb screws.

4. Check slipper surface on blade rods for open ends by trying a .003' feeler gauge between slipper surface and mandrel, at each end. Blade rods with open ends may be used providing a .003" feeler gauge cannot be inserted more than 51 mm (2") at either end.

   A closed-in slipper surface is evidenced by the ends having no clearance and the middle surface being open. Rods with closed-in bearing surface may be used, provided a clearance less than the limit is obtained when measured any place between ends of slipper surface and the mandrel.

5. Set dial indicator point at top inside edge of saddle. Sweep indicator along length of saddle. Indicator deflection shows rod twist in the length of the saddle which should not exceed limit shown in the Service Data.

6. Place indicator point at one end of bottom of saddle and note indicator reading. Check along length of saddle bottom, circumventing bolt holes, to check out-of-parallel. Indicator must not show more than maximum deflection along length of saddle.

7. To determine rod length, place dial indicator point on gauge plate and check "0" setting. Slide indicator button off block to bottom of saddle and note reading. Minimum reuseable and minimum rework rod dimensions are shown in the Service Data.

CONNECTING ROD BEARINGS

DESCRIPTION

Connecting rod bearings consist of upper and lower shells, Fig. 3-12. They are semicircular in shape and have a steel back with a layer of lead bronze bearing material covered by a lead tin coating on the inside diameter. The upper bearing has, in addition, a bearing surface in the center of the outer diameter consisting of a layer of bronze bearing material with a pure lead-flash overlay. This provides a bearing surface for the slipper of the blade connecting rod. Dowels in the fork rod and basket hold the bearing shells in proper position. Two dowels in the fork rod locate the upper shell and one dowel in the basket locates the lower shell.

There is no provision for connecting rod bearing adjustment. When bearing clearance exceeds the limit given in Service Data, they should be replaced. After bearing shells are once used on a crankpin and have accumulated numerous dirt scratches, they must not be used on any other crankpin.

MAINTENANCE

CHECKING CONNECTING ROD BEARINGS

The connecting rod bearings should be checked whenever the piston and rod assembly is removed from the engine. To make this check, apply bearings to fork rod and basket in which they are to be used. Torque upper basket bolts and lower basket (split line) bolts to specified values. Measure bearing bore at three points 60° apart. This is similar to the procedure used when checking fork rod basket bore, Fig. 3-14. The average of these three readings must not be less than is necessary to ensure a clearance between crankpin journal and bearing within the specified limits. After operation, rod bearings may give indication of being tight across the split line when loose on the crankpin. However, rod bearings intended for use should be mounted in the fork rod and then checked.

NOTE

After bearings have once been used, they should not be used on any other journal.

Check upper bearing step thickness as shown in Fig. 3-16. This will indicate blade rod bearing surface wear. Step thickness should not be less than minimum limit.

Bearing shells will usually be dirt scratched to some degree, but unless condition is severe, the bearings can be reused.

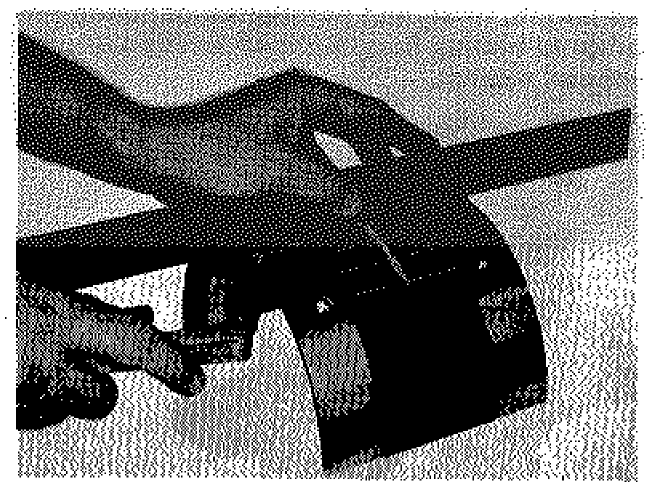

Fig.3-16-Checking Rod Upper Bearing Shell

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SERVICE DATA
PISTON ASSEMBLY AND CONNECTING RODS

REFERENCE

Piston Phosphate Treatment .... M.I. 1758
Removal Of Undercrown Deposits From Engine Pistons .... M.I. 1759

SPECIFICATIONS

Clearance and dimensional limits listed below are defined as follows:

1. *New limits are those to which new parts are manufactured (Drawing tolerances)*

2. *Minimum, maximum, and tolerance measurements are provided as service limits At time of rebuild or any time unscheduled maintenance is performed, the service limits should not be exceeded. Engine components within these limits may be reused with the assurance that they will perform satisfactorily until the next scheduled overhaul*

Connecting Rod
Connecting rod basket bore (see text)--
New .... 193.62-193.68 mm (7.623"-7.625")
Max. .... 193.70 mm (7.626")
Max. difference of any two readings at each end of bore (out of round) .... 0.23 mm (.009")

Blade rod bearing seat diameter (See text)-New .... 195.38-195.40 mm (7.692"-7.693")

Clearance between shoulder on blade rod and counterbore in fork rod-
New .... 0.20-0.33 mm (.008"-.013")
Max .... 0.64 mm (.025")
(This clearance measured by placing feeler gauge between blade rod and top of upper bearing)

Depth of counterbore in fork rod for slipper on blade rod -
*Max .... 10.16 mm (.400")
(*Provided the preceding maximum 064 mm (025") clearance is held)

Blade rod shoulder thickness -
*Min .... 8.51 mm (.335")
(*Provided the preceding maximum 064 mm (025") clearance is held)

Connecting rod length-New .... 584.15-584.25 mm (22.998"-23.002")
(Generated bore centerline dimension) -
Min .... 583.95 mm (22.990")
Min rework .... 583.69 mm (22.980")
Saddle end for piston pin
Twist in length of saddle-Max .... 0.15 mm (.006")
Parallelism in length of saddle-Max .... 0.10 mm (.004")

Blade rod slipper surface
"Closed in"-Max .... 0.18 mm (.007")
"Opened out"-Max .... 0.08 mm (.003")

Connecting Rod Bearings
Bearing inside diameter (Average of three 60° measurements)-
New .... 165.268-165.354 mm (6.5066"-6.5100")
Bearing to crankpin clearance-
New .... 0.18-0.28 mm (.007"-.011")
Max.. .0.38 mm (.015")
Upper connecting rod step thickness-Min.. 0.69 mm (.027")
Piston
Refer to Fig. 3-9-circled numbers coincide with callouts on illustration.
①Piston skirt diameter -
New .... 229.84-229.90 mm (9.049"-9.051")
Min.. 229.77 mm (9.046")
Out-of-round-Max.. 0.13 mm (.005")
(Check diameter below the oil ring grooves and at 63.5 mm to 69.8 mm [2.50" to 2.75"] below the compression ring grooves. Take two readings 90° to each other, at each location.)
② Piston platform bore (upper carrier pilot) -
New .... 90.55-90.60 mm (3.565"-3.567")
Max.. 90.68 mm (3.570")
(Check at two places 90° to each other.) Piston platform should be square to piston O.D. within 0.08 mm
(.003") total indicator reading.

③Piston inside diameter (lower carrier pilot) -
New .... 190.17-190.25 mm (7.487"-7.490")
Max.. 190.35 mm (7.494)

④Piston to carrier pilot clearance-
New .... 0.08-0.18 mm (.003"-.007")
Max.. 0.28 mm (.011")

⑤Piston platform to bottom of snap ring groove-
Min.. 161.95 mm (6.376")
Max.. 162.46 mm (6.396")
⑥No. 1 compression ring groove width w/standard ring -
New .... 4.93-5.00 mm (.194"-.197")
Wear-Max.. 5.10 mm (.201")

W/0.40 mm (1/64") O.S. ring
Remachined .... 5.31-5.38 mm (.209"-.212")
Wear-Max.. 5.49 mm (.216')
W/0.79 mm (1/32") O.S. ring
Remachined .... 5.72-5.79 mm (.225"-.228")
Wear-Max.. 5.89 mm (.232")

Wear step-Max .... 0.08 mm (.003")

⑦Piston to cylinder head clearance -
New Min.. 0.51 mm (.020")
New Max.. 1.73 mm (.068")
Differential reading between ends of lead wire .... 0.13 mm (.005")
Any sudden increase in compression clearance should be investigated immediately.

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SERVICE DATA (CONT'D)

⑧Compression ring to land clearance-
No. 1 groove chrome sided ring (chrome face & barrel face) -
New: .... 0.102-0.216 mm (.0040"-.0085")
Max. limit for ring installation .... 0.30 mm (.012")
No. 2 and 3 groove (chrome face & filled face)-
New .... 0.190-0.305 mm (.0075"-.0120")
Max. .... 0.38 mm (.015")
No. 4 groove, tapered ferrox ring -
New .... 0.190-0.292 mm (.0075"-.01 15")
Max. .... 0.38 mm (.015")

⑨Piston to liner clearance
Measured 152.40 mm (6") below liner gasket face -
New .... 0.216- 0.330 mm (.0085"-.0130)
Max. .... 0.56 mm (.022")

NOTE

Maximum piston to liner clearance of 0.56 mm (.022") determines the maximum wear limit of a liner at the 152.40 mm (6") dimension. If pistons are selectively fitted to liners, a liner at 230.45 mm (9.073") could be used with a 229.90 mm (9.051") piston. If pistons and liners are not selectively fitted, then the maximum wear limit of the liner at the 152.40 mm (6") dimension would be 230.340 mm (9.0685") as the minimum wear limit of a used piston is 229.77 mm (9.046").

⑩Oil ring groove width-
New .... 6.38-6.45 mm (.251"-.254")

⑪Oil ring to land clearance -
New .... 0.05-0.15 mm (.002"-.006")
Piston rings
Top compression ring gap (new ring in
9.062" gauge)-Chrome face .... 1.02-1.52 mm (.040"-.060")
Top compression ring gap (new ring in
9.062' gauge)-Barrel face .... 0.89-1.27 mm (.035"-.050")
Second and third compression ring gap .... 0.89-1.27 mm (.035"-.050")
Fourth compression ring gap .... 0.89-1.27 mm (.035"-.050")

NOTE

Piston ring end gap (clearance) should be measured with ring in a ring gauge and not in a cylinder liner. Cylinder liners are not perfectly round and ring cannot be placed perpendicular to the bore to measure gap accurately.

Carrier
Carrier height (top of platform to bottom of carrier)
Max .... 152.37 mm (5.999")
Min .... 151.99 mm (5.984")

Carrier top pilot diameter -
New .... 90.42-90.47 mm (3.560"-3.562")
Min .... 90.35 mm (3.557")
Carrier bottom pilot diameter -
New ....190.04-190.09 mm (7.482"-7.484")
Min .... 189.99 mm (7.480')
Carrier bearing insert thickness
New .... 3.81-3.83 mm (.150"-.151")
Min .... 3.78 mm (.149")
Piston Pin
Diameter -
New .... 93.54-93.60 mm (3.683"-3.685")
Wear step-Max .... 0.05 mm (.002')

Piston thrust washer
Thickness
New .... 4.704.78 mm (.185"-.188")
Min .... 4.44 mm (.175")
Thickness variation
Max .... 0.08 mm (.003")

EQUIPMENT LIST

	Part No.
Feeler gauge set	8067337
Piston cooling pipe cleaning tool	8087086
Torque wrench, (19.05 mm [3/4"] drive 0-407 N•m [0-300 ft-lbs])	8157121
Snap ring remover	8171633
Torque wrench extension (used with torque wrench 8157121)	8210136
Wire holder (has contour of piston crown to hold small lengths of lead wire for piston to head clearance)	8243220
Wire (lead, 3.18 mm [1/8"] dia., used with holder 8243220 or alone, 2.27 kg [5 lb] spool)	8243661
Connecting rod checking fixture	8257730
Fork connecting rod basket thread gauge	8265955
Piston ring groove gauge	
Standard 4.93-5.16 mm (.194"-.203")	8275503
.40 mm (1/64") O.S. 5.33-5.56 mm (.210"-.219")	8331113
.79 mm (1.32") O.S. 5.72-5.94 mm (.225"-.234")	8331043
Piston ring expander	8349892
Piston carrier holding fixture (2 mandrels)	9534635
Piston carrier holding fixture (single mandrel)	9542253

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SECTION 4

CYLINDER LINER

78E779

CYLINDER LINER

DESCRIPTION

The cylinder liner, Fig. 4-1, consists of casting having two separate water jackets applied and brazed to the casting. A row of air inlet ports completely encircles the liner. A flange on the outboard side of the liner below the ports, provides a connection for the liner water supply line. A water deflector, Fig. 4-2, prevents the inlet water from impinging directly on the inner liner wall.

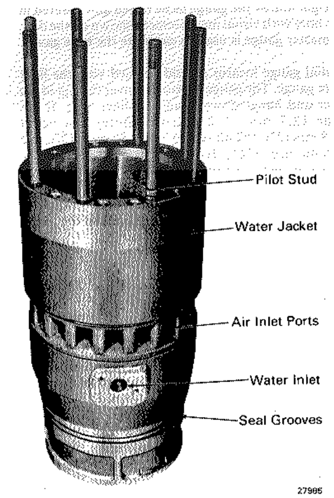

Fig.4-1-Cylinder Liner

The inlet water circulates around the bottom of the liner, progressing upward to discharge into the cylinder head through twelve drilled holes. A counterbore around each drilled hole accommodates a teflon heat dam and silicone water seal, Fig. 4-3, which seals the water passage when the cylinder head is installed. A copper clad steel gasket provides a combustion seal between the cylinder head and the liner.

MAINTENANCE
INSPECTION IN ENGINE

The air box handhole covers provide access to the cylinder liner upper bores while the oil pan handhole covers provide access to the lower bores.

1. Open the cylinder test valves and bar engine over to position the piston either below the ports for upper bore inspection or near top dead center for lower bore inspection.

2. Check the liner walls for scuffing or scoring above the ports.

3. Inspect externally for evidence of water leaks at liner to cylinder head gasket and water inlet line.

NOTE

Procedures for qualification of the liner are contained in this Section. Procedures for removal and installation of the liner, and of a complete cylinder power assembly are contained in Section 5.

CLEANING

General liner cleaning procedures should be in accord with accepted practice or as recommended by the supplier of cleaning material.

All water scale deposits and other foreign materials, which are detrimental to water seal life, should be removed from the seal counterbores. A File

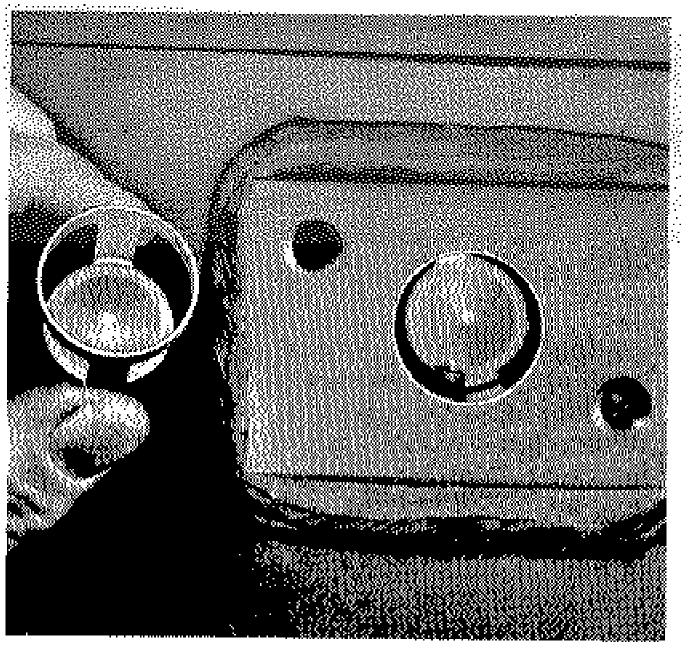

Fig.4-2-Water Inlet Deflector

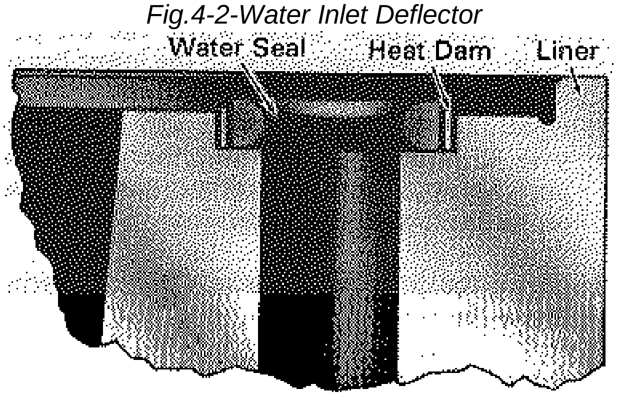

Fig.4-3-Water Seal

Drawing outlining details for construction of a waterseal counterbore cleaning tool is available upon request; see Service Data.

With the liner removed from the engine, the tool should be used prior to washing the liner so that all the loosened deposits will be removed in the wash. Only the grade of abrasive as specified on the File Drawing should be used to clean the counterbores without damaging the seating surfaces. Insert the tool in an electric or air powered drill which turns around 2000 RPM. Place a few drops of fuel or lubricating oil in the counterbore and, exerting a very light pressure on the tool, rock tool back and forth slightly for approximately five seconds per counterbore.

When the cylinder head is removed, but the liner remains installed in the engine, use the T-handle with the tool and manually clean counterbores so deposits will not enter cylinder.

MEASURING LINERS FOR WEAR

The cylinder liner should be measured in planes parallel and at right angles to the crankshaft.

Wipe the interior of liner clean before measuring bore, and check for physical defects that would require rework on the liner. A liner bore gauge, Fig. 4-4, or standard inside micrometers may be used to measure liner bore diameter. The gauge is of a special design for liner bore measurement, and will provide accurate measurement when used carefully. It has a three-pronged centering and measuring end that fits the liner bore. A dial indicator, mounted on an upright that extends down to the measuring prongs, gives instant reading of bore diameter. The upright allows the gauge to be raised and lowered in the bore with visual measurement shown on the dial. A master gauge is used to calibrate the bore gauge. A dial gauge locator should be used with the liner bore gauge. The gauge locator fits over the top of the liner and hangs down inside the liner bore. It has four 12.7 mm (1/2") drilled holes spaced at 50.8 mm (2"), 152.40 mm (6"), 304.80 mm (12"), and 406.40 mm (16") from the top to locate the measurement position.

A special box to protect the liner bore gauge also provides a place for the master gauge and the gauge locator.

NOTE

Refer to dimensional wear limits in Service Data at the end of the section.

New cylinder liners have a bore diameter which falls between a low and a high limit. The bore diameter at the port relief zone has different dimensional limits.

Accumulated liner and piston wear will increase piston to liner clearance and this clearance is a limiting factor at time of reapplication. No liner should be matched with a new or used piston where the diameters result in a piston to liner clearance exceeding the maximum limit, at a point 152.40 mm (6") below the gasket face of the liner.

The liner bore should be checked for out-of-round at two points 50.8 mm (2") and 152.40 mm (6") below top of liner, Fig. 4-5, using the dial gauge

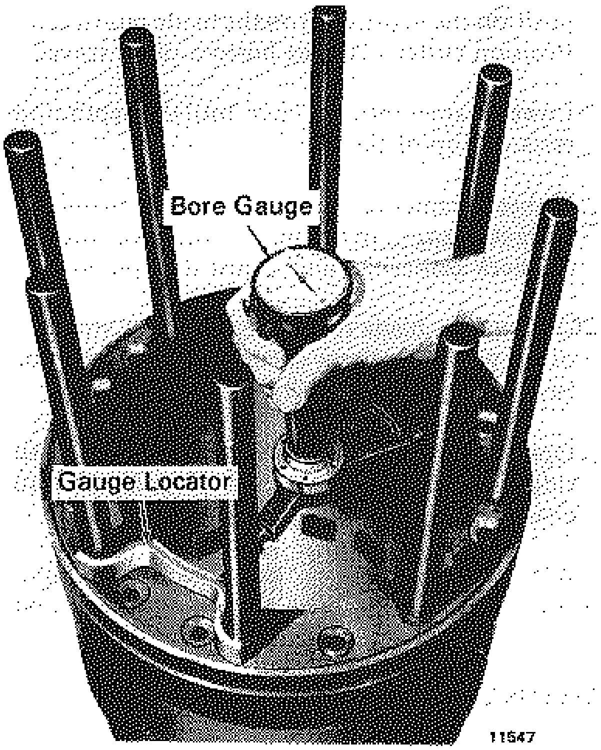

Fig. 4-4 - Liner Bore Gauge

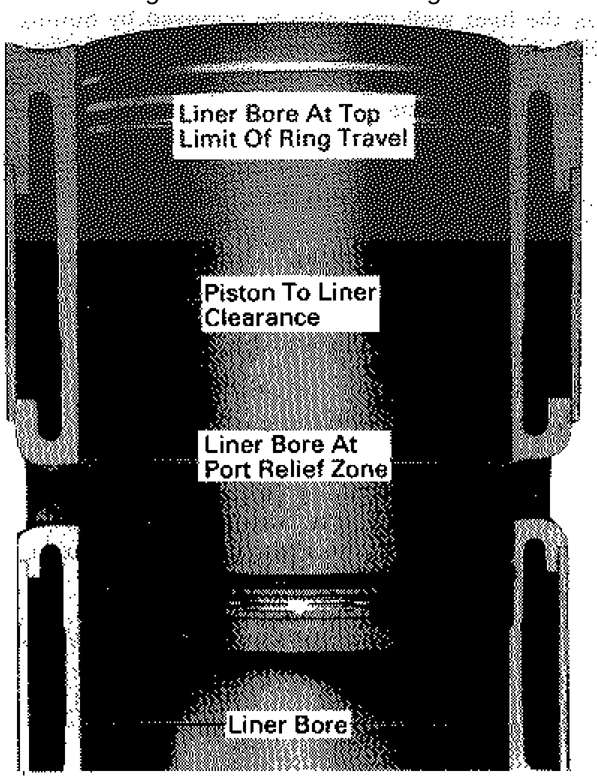

Fig. 4-5 - Liner Measurement Points

locator as a guide. Take two readings 90° apart to determine wear and out-of-round. Should the out-of-round exceed the limit, the liner must be rebored to the next oversize, regardless of other wear measurements which still may be within limits.

Using the maximum piston to liner clearance as a guide, worn liners may be used again, providing they are not over out-of-round limit, and are matched with pistons having a diameter which will not exceed the limit on piston to liner clearance. Maximum piston and liner usage is obtained by selective assembly within the clearance limit.

Liners will wear tapered, with maximum wear normally occurring approximately 152.40 mm (6") below the liner gasket face. Check that wear, taking two readings 900 apart, is within specified limit. A liner worn to this dimension will leave some stock to allow for cleaning up the bore to the first oversize. If this limit is exceeded, it may not be possible to rebore liner to the first oversize. It would then have to be rebored to the next oversize, losing a great amount of its wear life. Consequently, it is suggested that no liner be reinstalled if the bore diameter at point of maximum wear exceeds the allowable limit.

OVERSIZE LINERS

Liners can be rebored to 0.76 mm (.030") or 1.52 mm (.060") oversize. Oversize liner dimensions can be determined by increasing the standard liner figures in Service Data by 0.76 mm (.030") or 1.52 mm (.060") as the case may be. Standard or 0.76 mm (.030") oversize liners worn beyond their limits may be returned to Electro-Motive for refinishing to the next oversize. (Corresponding oversize piston assemblies must be used with oversize liners.)

REMOVING LINER RIDGE

After a long period of use, a wear ridge, caused by piston ring action, will appear near the top of the liner bore. After the liner is removed from the engine, the wear ridge must be entirely removed before honing the liner. Unless complete removal of the wear ridge is accomplished, it is not possible to properly hone the critical area of the liner at the top of the ring travel. In addition, removal of the wear ridge precludes any possibility of interference with new piston rings.

The cylinder liner ridge reamer, Fig. 4-6, is used to remove the ridge at the top inside bore of the liner.

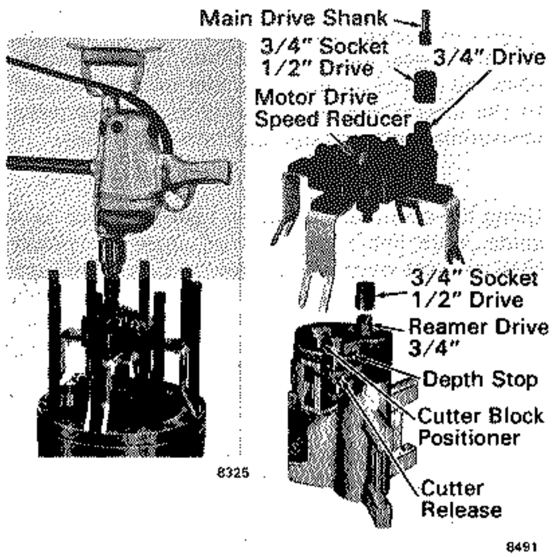

Fig. 4-6 - Application Of Liner Ridge Reamer And Speed Reducer

The reamer can also be used for the oversize liners. Reamers may either be manually or motor operated. If the reamer is motor operated, a speed reducer must be used, which is mounted on the reamer. The operating motor used with the speed reducer can be an ordinary heavy-duty electric drill having a no load speed of approximately 500 RPM.

Extra cutting blades may be obtained for reamers. Refer to Service Data at the end of this section.

Reamer cutting blades also may be resharpened. To resharpen a dull cutter, it is necessary only to lightly grind the leading angle which does the cutting using a grinding wheel suitable for grinding tungsten carbide tools. The clearance angle is 8° and must not be exceeded when grinding. It is better to provide "less" than more clearance, as these cutters will not stand up if given greater clearance.

In addition, a cutter should not be used if the guide portion has been reduced to a length of 16.67 mm (21 / 32") by resharpening, because the guide will not extend far enough past the pin hole to prevent undercutting. For resharpening service on the cutters, refer to the reamer manufacturer.

LINER RIDGE REMOVAL PROCEDURE

1. Oil liner wall just under the ridge, and see that felt pad in back of cutter is full of oil.

2. Retract cutting blade so it will be away from the liner wall when the reamer is installed, and position the depth stop on the blade retard cam. Position cutter blade at bottom of its travel.

3. Lower reamer into the liner until the depth stop rests on top of the liner.

4. Tighten reamer centering nut to hold reamer in correct position in the liner. Rotate the reamer to check centering, and adjust if required.

5. Operate the blade retard cam to swing stop out of the way and release cutter so it can move out to contact the liner wall.

6. Operate reamer manually or by motor until ridge is entirely removed, carrying the cut into chamfer at liner top if necessary.

7. After completing ridge removal, remove reamer, and clean liner by wiping off oil and cuttings

HONING LINERS

After removing the cylinder liner ridge, the liner must- be honed for the final finish. The purpose of honing is 'to remove glaze and to provide a proper seating surface for new piston rings. Light scuffing on the liner wall may also be removed by honing. However, if this condition is too advanced, the liner should be scrapped or rebored oversize, depending upon its condition.

Equipment required to perform the honing operation includes the honing kit, electric drill, stone cleaning brush, and cylinder honing fixture. As the operation is "wet" honing, a suitable container is required for the honing liquid and the honing fixture. See the Service Data at the rear of this section for description and part numbers of the equipment required.

HONING PROCEDURE

1. Ensure that honing kit is assembled per manufacturer's instructions and contains a matched set of stones and guides (identified by W47-J43 stamped on stones and guides).

2. Inspect stone cutting surfaces for cleanliness and clean with wire brush, if required.

3. Install the liner properly in the honing fixture.

4. Chuck the hone shank in the drill motor, and insert the hone into the liner, Fig. 4-7. Stones should not protrude more than 12.7 mm (1/2") out of liner bore.

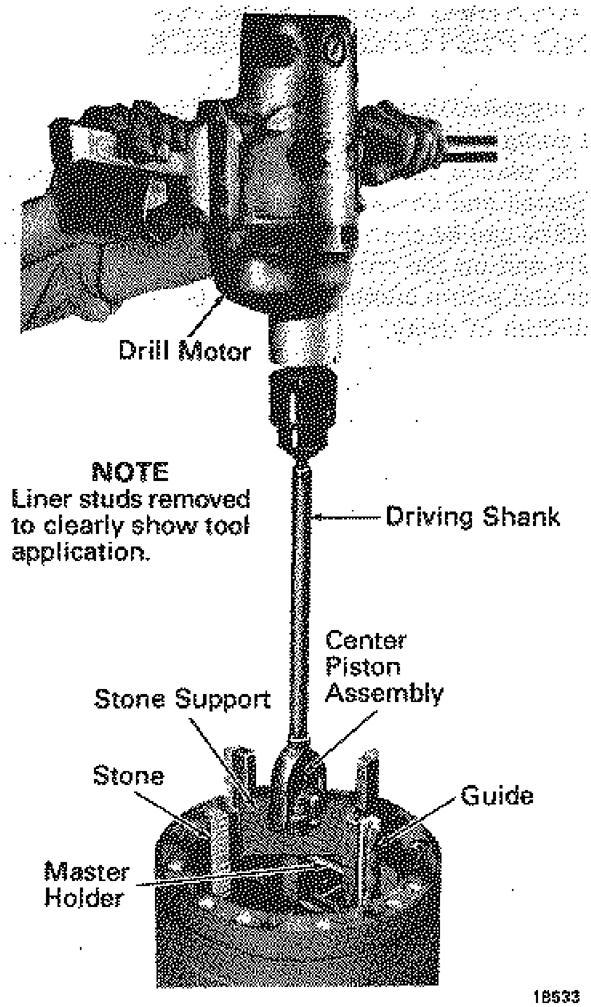

Fig. 4-7 - Honing Cylinder Liner

5. Raise the center pinion assembly about 6.35 mm (1/4") and turn it counterclockwise to set the stones roughly against the bore diameter. Lower the pinion assembly until it engages with the gear in the hone body.

6. Expand the stones firmly against the liner wall by turning the wing-wrench portion of the pinion assembly in a clockwise direction.

7. Always maintain firm stone pressure against the liner wall to ensure fast stock removal and accurate work. It may be necessary to increase the pressure after several strokes. If pressure is correct, the stones will emit a steady grinding noise.

8. A continuous flooding of the liner surface must be maintained with kerosene or honing oil, during the honing operation.

9. If the liner is not scuffed, merely break the glazed surface by stroking at a rate of approximately 30 complete cycles per minute to produce the cross-hatched pattern shown in Fig. 4-8.

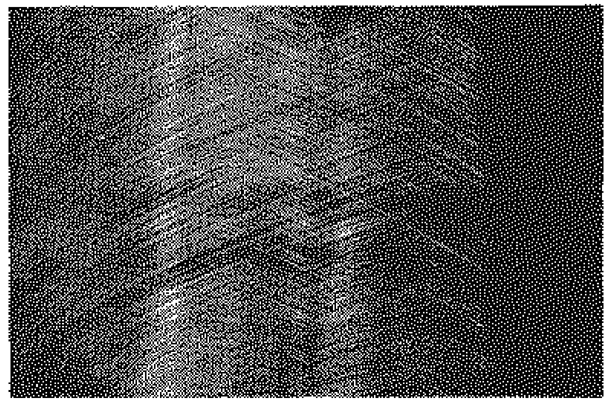

Fig. 4-8 - Honing Cross-Hatch Pattern

10. If the liner is scuffed, remove material build-up, or scuffing. Do not attempt to remove-any isolated dirt scratches as they do not significantly affect operation. Honing out these scratches needlessly reduces liner life. After the surface has been "cleaned up," the hone should be removed and the stones wire-brushed to remove any loading of the stones. The liner should then be honed with the clean stones, using heavy pressure to obtain a good cross-hatched pattern, Fig. 4-8. Do not remove any more metal than is necessary to obtain desired finish.

CLEANING

The liners must be thoroughly cleaned of abrasive and iron dust after honing. If the liners are not properly cleaned after honing, tiny particles left by the honing operation will attack the liners, rings, and pistons causing excessive wear in a short period of time. The liner is cleaned as follows:

1. Wash liner with detergent and hot water using a stiff fiberbrush.

2. Rinse liner thoroughly with clean water and wipe dry.

3. Swab liner with clean rag dipped in SAE No. 10 oil. It is important to use oil to pull the abrasive materials from the pores of the liner.

4. Wipe liner with a clean dry cloth.

5. Repeat Steps 3 and 4 until there is no evidence of contaminants on the liner surface.

NOTE

If liner is to be stored, repeat Steps 3 through 5 prior to assembly.

MEASURING LINERS

After honing, the liners should be measured in planes parallel and at right angles to the crankshaft. Dimensional limits are listed in Service Data.

MARKING USED LINERS AND PISTONS IN STOCK

It is suggested that used pistons and liners, which are not going back into an engine immediately, but are to be placed in stock, be thoroughly cleaned, inspected and checked for size. The dimensions as checked can be chalk marked on the outside of the liners and on the crown of pistons. This will allow liner and piston combinations to be selected with a minimum of delay.

SERVICE DATA

CYLINDER LINER

SPECIFICATIONS

Clearance and dimensional limits listed below are defined as follows:

1. *New limits are those to which new parts are manufactured. (Drawing tolerances.)*

2. *Minimum, maximum, and tolerance measurements are provided as service limits. At time of rebuild or any time unscheduled maintenance is performed, the service limits should not be exceeded. Engine components within these limits may be reused with the assurance that they will perform satisfactorily until the next scheduled overhaul.*

Cylinder liner bore (except through port relief zone) -
New...230.111-230.175 mm (9.0595"-9.0620")

Cylinder liner bore (port relief zone only) -
New...230.454-230.543 mm (9.0730"-9.0765")

Cylinder liner bore (measured 152.40 mm [6] below top of liner) -
Max. ....230.340 mm (9.0685")

Piston-to-liner clearance (152.40 mm [61 below top of liner) -
New..0.216-0.330 mm (.0085-.0130")
Max. ....0.56 mm (.022")

NOTE

Maximum piston to liner clearance of 0.56 mm (.022”) determines the maximum wear limit of a liner at the 152.40 mm (6") dimension. If pistons are selectively fitted to liners, a liner at 230.45 mm (9.073") could be used with a 229.90 mm (9.051") piston. If pistons and liners are not selectively fitted, then the maximum wear limit of the liner at the 152.40 mm (6") dimension would be 230.340 mm (9.0685") as the minimum wear limit of a used piston is 229.77 mm (9.046").

Cylinder liner bore out-of-round (measure at two points 50.8 mm [2] & 152.40 mm [6"] below top of liner -90° apart) -

Max. ....0.13 mm (.005")

Cylinder liner bore (top limit of piston ring travel) -
Max. .... 230.63 mm (9.080")

Length of studs above top of liner... 241.30 mm (9-1/2")

Crankcase upper pilot bore -
New..307.19-307.26 mm (12.094"-12.097")
Max. .... 307.44 mm (12.104")

Cylinder liner O.D. (at upper pilot) -
New..306.96-307.09 mm (12.085"-12.090")
Min .... 306.93 mm (12.084")

Cylinder liner O.D. (bottom of liner) -
New.. 263.462-263.538 mm (10.3725"-10.3755")
Min. .... 263.42 mm (10.371")

Insert bore (installed in crankcase) -
Min. .... 263.58 mm (10.377")
Max. .... 263.80 mm (10.386")

Crankcase lower insert bore -
New..281.00-281.10 mm (11.063"-11.067")
Max. .... 281.13 mm (11.068")

Cylinder liner stud torque -
Min. ....67.79 N•m (50 ft-lbs)

EQUIPMENT LIST

	Part No.
Wire brush (honing stones)	8078883
Stone and guide block set (W47-J43)	8084163
Drill (1/2" - 345-500 RPM, 115 volt [AC or DC])	8104770
Drill (1/2" - 345-500 RPM, 230 volt [AC or DC])	8104771
Cylinder liner lifter	8116358
Reamer speed reducer (used with 8374969)	8228304
Liner bore gauge	8275258
Gauge locator	8278541
Cylinder liner ridge reamer	8374969
Master gauge (used with 8275258)	8374970
Cutter blade (reamer)	8379037
Hone kit (less motor)	8431585
Honing fixture (facility drawing)	File 543
Cleaning tool (water seal counterbore)	File 686

SECTION 5

CYLINDER POWER ASSEMBLY

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75E480

ELECTRO-MOTIVE

645E6
ELECTRO-MOTIVE Marine Engine/Systems

CYLINDER POWER ASSEMBLY

DESCRIPTION

Sections 2, 3, and 4 contain information on the cylinder head, piston and connecting rod, and the cylinder liner respectively. Procedures are provided in these sections for disassembly and assembly of the power assembly components beyond what is done during removal from and installation into the engine. Also, the information concerning cleaning, inspection, and the qualification of components is detailed in these sections.

The following procedures are for the removal and installation of a cylinder power assembly, component by component, and the removal and installation of the power assembly as a unit.

COMPONENT BY COMPONENT REMOVAL

1. After draining the cooling system, remove the top deck cover over the affected cylinder. It is advisable to remove the front latches first, then the rear latches.

2. Remove the air box and oil pan handhole covers for the cylinder being removed and the opposing cylinder on the other side of the engine.

3. Remove the piston cooling oil pipe.

4. Remove the bolts holding the water inlet tube to the cylinder liner and remove the saddle strap nuts holding the tube to the water manifold.

5. Remove the gasket from the water manifold.

6. Open all cylinder test valves using the test valve wrench. This will facilitate manual barring of the engine.

7. When removing a fork rod assembly, bar the engine over until the piston is 1200 after top dead center. This will allow removal of the basket halves and the connecting rod bearing shells at one crankpin position.

8. Loosen the cylinder test valve packing nut and remove the cylinder test valve and seal. The entire test valve assembly must be removed before removal of the head, or damage to the head and/or the test valve will occur.

9. Disconnect the rocker arm oil line at the camshaft bearing block, Fig. 5-1. Also disconnect the line on the opposite cylinder, opposite bank. Remove the gaskets between the oil lines and the blocks.

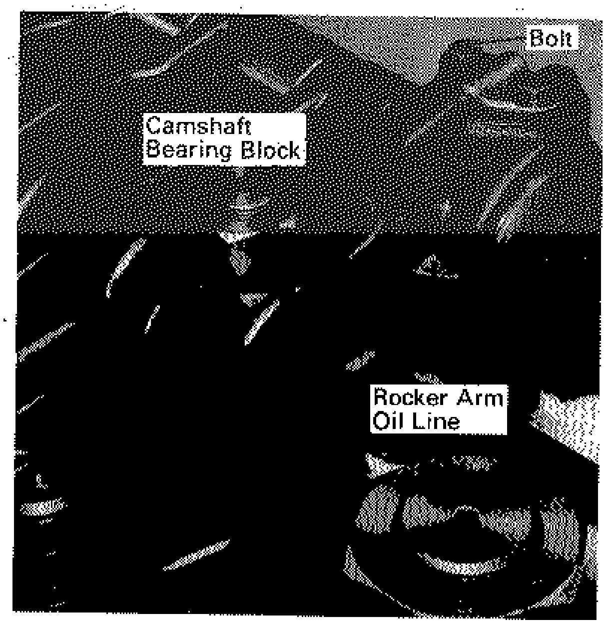

Fig. 5-1 - Rocker Arm Oil Line Removal

10. Loosen the locknuts on the exhaust valve rocker arms and the injector rocker arm. Back off the adjusting screws about two complete turns on the three rocker arms.

11. Remove the rocker arm shaft nuts, washers, and the rocker arm shaft caps, Fig. 5-2.

12. Take off the rocker arm shaft assembly with rocker arms, taking care not to drop the rocker arms.

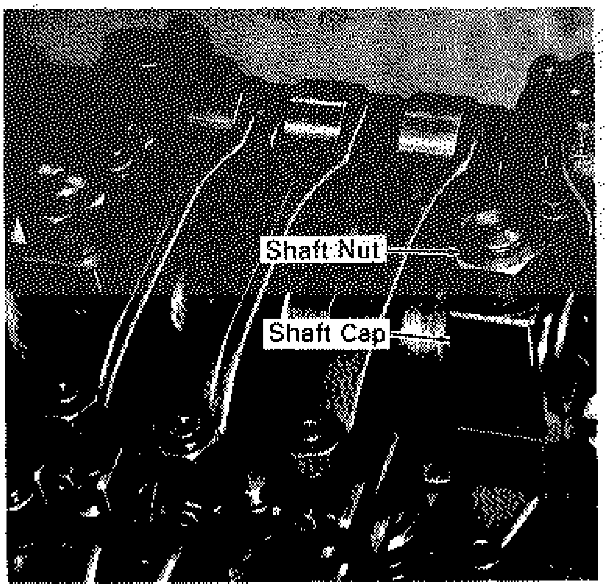

Fig. 5-2 - Rocker Arm Assembly Removal

13. Remove rocker arm shaft supports and valve bridge assemblies.

NOTE

For further breakdown of the valve bridge assemblies, refer to "Exhaust Valve Bridge Assembly" in Section 2.

14. Remove the fuel line assembly, Fig. 5-3. Also remove the fuel line from the opposite cylinder on the opposite bank of the engine. Care should be taken that the spherical seats on fuel line are not scratched or nicked as this could cause leakage.

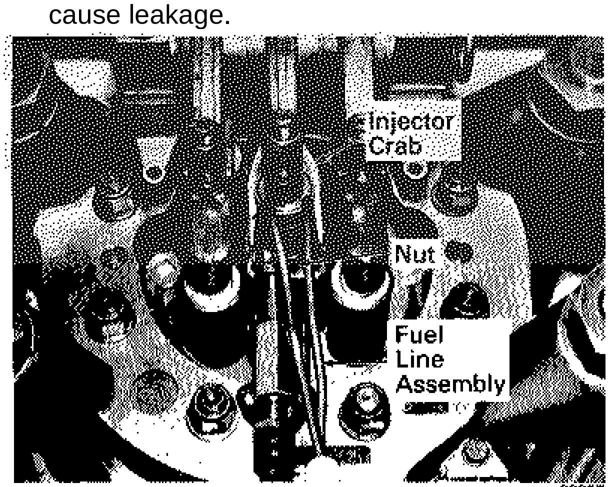

Fig. 5-3 - Fuel Line Assembly Removal

15. Remove the injector adjusting link assembly by removing the two spring retainers and the two clevis pins.

16. Remove the injector crab stud nut, spherical washer, and the injector crab.

17. Using the injector pry bar, Fig. 5-4, remove the injector from the tapered well in the cylinder head. Protect the injector from dirt and damage by using an injector holding rack.

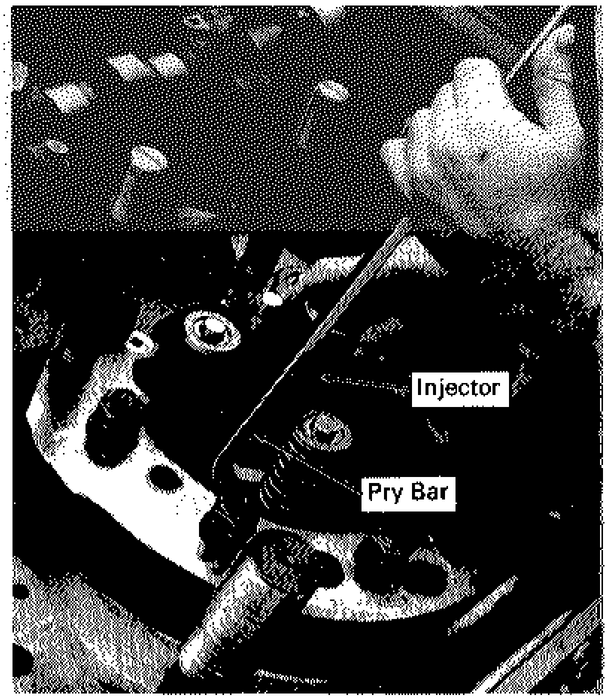

Fig. 5-4 - Removing Injector With Pry Bar

18. Remove the cylinder head overspeed trip assembly as it usually interferes with removal of the head.

19. The rocker arm shaft assembly with rocker arms and the injector on the opposite cylinder, opposite bank of the engine should also be removed. It is not necessary to remove the overspeed trip assembly from this cylinder.

20. Place a piston holding tool, Fig. 5-5, in the injector well on the opposite cylinder, opposite bank of the engine and thread the rod into the piston pulling eyebolt hole in the crown of the piston.

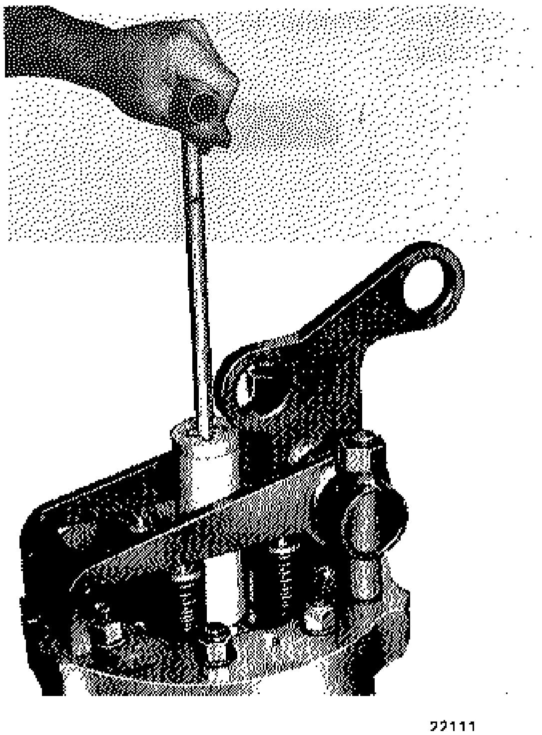

Fig. 5-5 - Piston Holding Tool

21. Remove the cylinder head-to-liner stud nuts and washers of the cylinder being removed.

22. Remove the crab nuts from the crab bolts using an air torque multiplier set or equivalent. Place the drive socket on the crab nut to be removed and the anchor on the crab nut above or below the crab nut to be removed. Position the multiplier so that the output is over the drive socket.

23. Install the air motor and set the pressure between 310-345 kPa (45-50 psi). Squeeze the air valve and the crab nut should break loose. If the wrench stalls out, increase the air pressure until the crab nut breaks loose.

24. After removing all nuts, and crabs, place thread protectors over crab bolts.

25. Be sure that the head puller holes, located at the 3 o'clock and 9 o'clock positions on the head, are free of dirt and oil and install the cylinder head removing fixture, Fig. 5-6. Make sure that the bolts are bottomed to support the weight of the head.

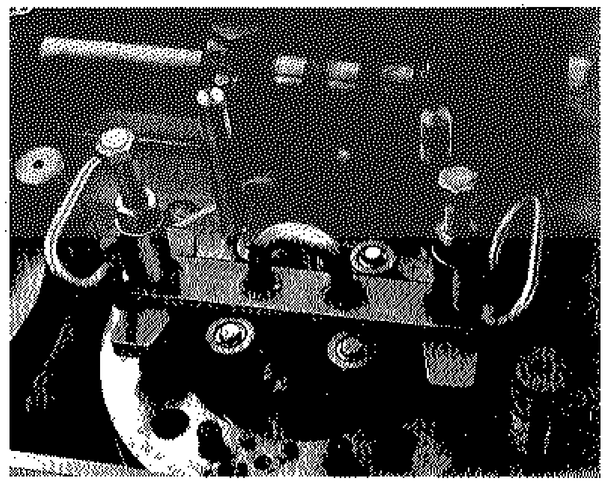

Fig. 5-6 - Cylinder Head Removing Fixture

26. Break the cylinder head free of the liner by turning the jacking screws, working first on one side and then the other until the head has broken free from the liner.

27. Using a suitable lifting device, remove the head.

28. Place the head in a cylinder head carrying basket having a soft wooden disc in the bottom to protect the machined fireface from being nicked or scratched.

NOTE

For further breakdown of the cylinder head, refer to "Exhaust Valve And Spring Removal" in Section 2.

29. Remove the lifting device and head removing fixture.

30. Remove the cylinder head seat ring.

31. Remove and discard the cylinder head to liner water seals and the head to liner gasket.

32. Install the piston pulling eyebolt in the threaded hole in the crown of the piston and hand tighten. Excessive pressure in the threaded hole may cause damage to the crown area.

If a power assembly containing a blade rod is to be changed out, the following Steps apply:

33. The opposing fork rod will have to be held out of the way so that the blade rod can be removed.

34. Remove the lower basket bolts and nuts using the spring-loaded basket bolt wrench, Fig. 5-7, with a ratchet and extension.

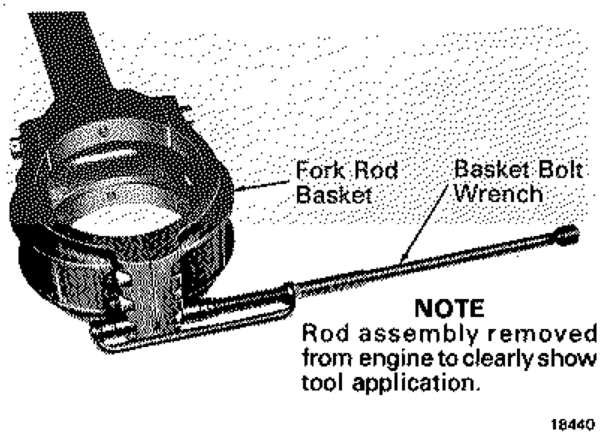

Fig. 5-7 - Basket Bolt Wrench Application

35. Remove the upper bolts from the inboard basket half.

36. Remove the bolts from the other basket half while holding the basket and lower connecting rod bearing shell.

37. Remove the bolts, basket, and bearing while maintaining the same relative upright position to prevent dropping the bearing shell or the basket into the oil pan.

38. Install the connecting rod positioning clamp on the blade rod, Fig. 5-8. The clamp should fit up far enough on the blade rod so that when the rod is lifted it will not strike the cylinder liner.

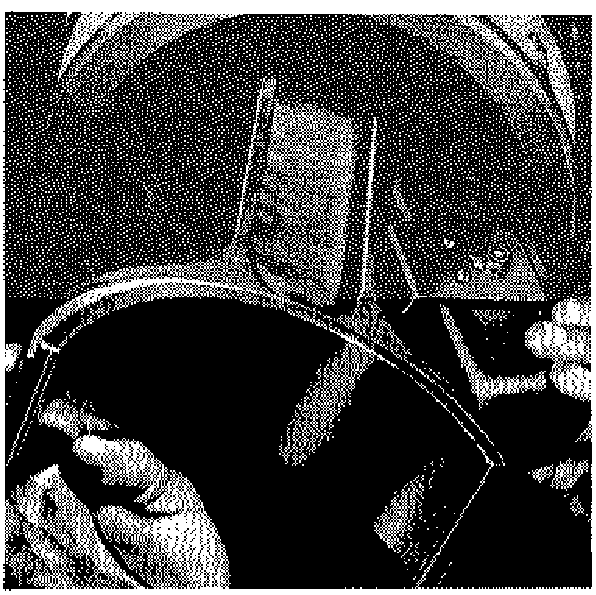

Fig. 5-8 - Connecting Rod Positioning Clamp Application

39. Using a suitable lifting device, raise the piston and fork rod assembly and apply fork rod support, Fig. 5-9, to the outboard side of the fork rod using two basket bolts. Rotate crankshaft in normal direction so that support will rest in oil pan. Protect upper bearing and continue rotation to position blade rod for removal.

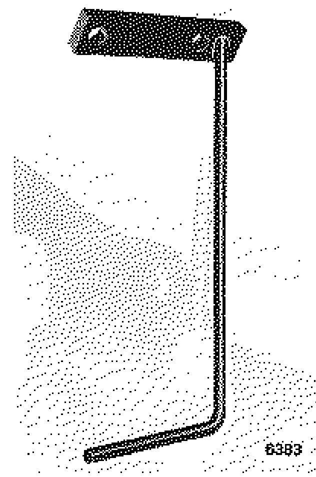

Fig. 5-9 - Fork Rod Support

40. Lift the piston and blade rod assembly until the protective boot can be applied.

41. Remove the upper connecting rod bearing shell.

42. Guide the blade rod assembly and remove it from the engine.

NOTE

For further disassembly of the connecting rod assembly, refer to Section 3.

If a power assembly containing a fork rod is to be changed out, the following Steps apply in addition to Steps 1 through 38.

43. Using a suitable lifting device, raise the piston and fork rod assembly enough so that the dowels in the fork rod clear the dowel holes in the upper connecting rod bearing and the inboard ends of the forks contact the bearing. As the fork rod is lifted, the upper connecting rod bearing should be held in place from the opposite side of the engine.

44. Lift the piston and blade rod assembly so that the piston holding tool, Fig. 5-5, can be positioned to hold the piston and rod at the top of the liner. The upper bearing shell should be removed as the piston and blade rod assembly is being raised.

45. Install the positioning clamp on the fork rod, and apply the protective boot.

46. Guide the fork rod assembly and remove it from the engine.

NOTE

For further disassembly of the connecting rod assembly, refer to Section 3.

47. Place the cylinder liner lifter over the liner studs and secure it with the stud nuts.

48. Attach the lifting device and remove the liner from the engine.

UNIT REMOVAL

A complete cylinder power assembly consists of the head, valves, liner, piston and rings, piston pin, insert bearing, carrier, thrust washer, snap ring, connecting rod, and the basket on fork rod assemblies.

1. After draining the cooling system, remove the top deck cover over the affected cylinder. It is advisable to remove the front latches first, then the rear latches.

2. Remove the air box and oil pan handhole covers for the cylinder being removed and the opposing cylinder on the other side of engine.

3. Remove the piston cooling oil pipe.

4. Remove the bolts holding the water inlet tube to the cylinder liner and remove the saddle strap nuts holding the tube to the water manifold.

5. Remove the gasket from the water manifold.

6. Open all cylinder test valves using the test valve wrench. This will facilitate manual barring of the engine.

7. When removing an assembly with a fork rod, bar the engine over until the piston is 120° after top dead center in the cylinder being removed. This will allow removal of the basket halves and the connecting rod bearing shells at one crankpin position.

8. Loosen the cylinder test valve packing nut and remove the cylinder test valve and seal. The entire test valve assembly must be removed before removal of the cylinder or damage to the head and/or the test valve will occur.

9. Disconnect the rocker arm oil line, Fig. 5-1, at the camshaft bearing block. Also disconnect the line on the opposite cylinder, opposite bank. Remove the gaskets between the oil lines and the blocks.

10. Loosen the locknuts on the exhaust valve rocker arms and the injector rocker arm. After this has been accomplished, back off the adjusting screws on the three rocker arms.

11. Remove the rocker arm shaft nuts, washers, and the rocker arm shaft caps, Fig. 5-2.

12. Take off the rocker arm shaft assembly with rocker arms, taking care not to drop the rocker arms.

13. Remove rocker arm shaft supports and valve bridge assemblies.

14. Remove the fuel line assembly, Fig. 5-3. Also remove the fuel line from the opposite cylinder on the opposite bank of the engine. Care should be taken that the spherical seats on the fuel line are not scratched or nicked as this could cause leakage.

15. Remove the injector adjusting link assembly by removing the two spring retainers and the two clevis pins.

16. Remove the injector crab stud nut, spherical washer, and the injector crab.

17. Using the injector pry bar, Fig. 5-4, remove the injector from the tapered well in the cylinder head. Protect the injector from dirt and damage by using an injector holding rack.

18. Remove the cylinder head overspeed trip assembly as it usually interferes with cylinder removal.

19. The rocker arm shaft assembly with rocker arms and the injector on the opposite cylinder, opposite bank of the engine should also be removed. It is not necessary to remove the overspeed trip assembly from this cylinder.

20. Remove the lower basket bolts and nuts using the spring-loaded basket bolt wrench, Fig. 5-7, with a ratchet and extension.

21. Remove the upper bolts from the inboard basket half.

22. Remove the bolts from the other basket half while holding the basket and lower connecting rod bearing shell.

23. Remove the bolts, basket, and bearing while maintaining the same relative upright position to prevent dropping the bearing shell or the basket into the oil pan.

24. Install the connecting rod positioning clamp on the rod up far enough so that when the rod is lifted it will not strike the cylinder liner.

If a power assembly containing a blade rod is to be removed, the following Steps apply:

25. Screw the piston holding tool, Fig. 5-5, into the threaded hole in the crown of the piston and fork rod assembly.

26. Using a suitable lifting device, raise the fork rod assembly and apply the fork rod support, Fig. 5-9, while holding the upper bearing shell in place.

27. Rotate the crankshaft in normal direction so support will rest in oil pan. Protect the upper bearing and continue rotation to position blade rod for removal.

28. Remove the crab nuts from the crab bolts using an air torque multiplier set or equivalent. Place the drive socket on the crab nut to be removed and the anchor on the crab nut above or below the crab nut to be removed. Position the multiplier so that the output is over the drive socket.

29. Install the air motor and set the pressure between 310-345 kPa (45-50 psi). Squeeze the air valve and the crab nut should break loose. If the wrench stalls out, increase the air pressure until the crab nut breaks loose.

30. After removing all nuts and crabs, place thread protectors over crab bolts.

31. Apply and attach lifting clamp, Fig. 5-10, to cylinder being removed, and screw in the piston holding tool, Fig. 5-11.

32. Lift the piston holding tool and remove upper bearing shell. Continue raising the piston and blade rod assembly until the piston holding tool can be secured to hold the assembly at the top of the liner.

33. Attach an overhead chain hoist to the lifting clamp or attach a hoist set. While guiding the power assembly, remove it from the engine.

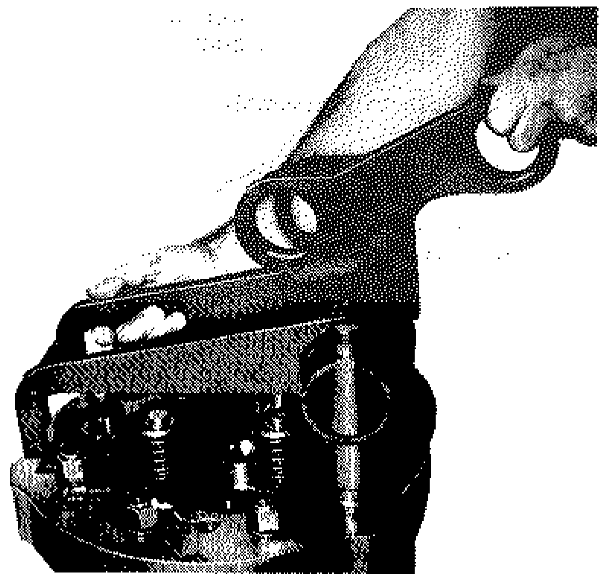

Fig. 5-10 - Lifting Clamp Application

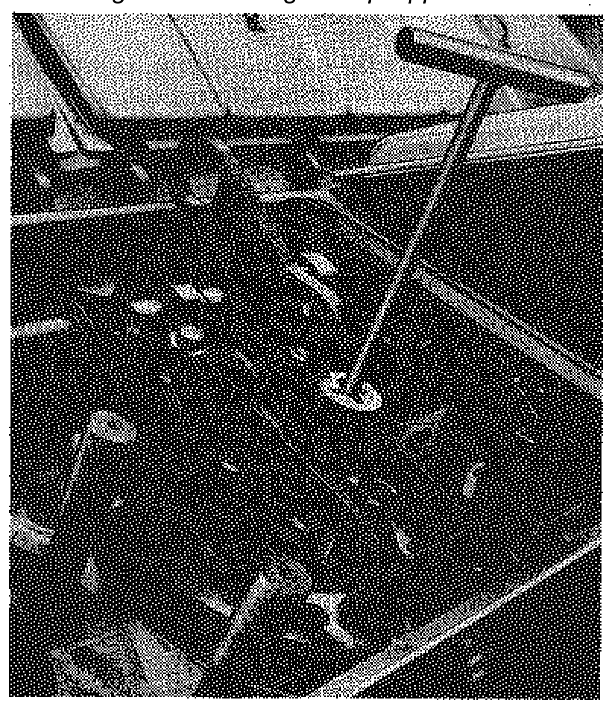

Fig. 5-11 - Piston Holding Tool Application

If a power assembly containing a fork rod is to be removed, the following Steps apply in addition to Steps I through 24.

34. Screw the piston holding tool into the threaded hole in the crown of the piston and blade rod assembly.

35. Remove the crab nuts from the crab bolts using an air torque multiplier set or equivalent. Place the drive socket on the crab nut to be removed and the anchor on the crab nut above or below the crab nut to be removed. Position the multiplier so that the output is over the drive socket.

36. Install the air motor and set the pressure between 310-345 kPa (45-50 psi). Squeeze the air valve and the crab nut should break loose. If the wrench stalls out, increase the air pressure until the crab nut breaks loose.

37. After removing all nuts and crabs, place thread protectors over crab bolts.

38. Attach the lifting clamp to the cylinder being removed, and screw in the piston holding tool.

39. Lift the piston holding tool while holding the upper bearing shell. Continue raising until the piston holding tool can be secured to hold the assembly at the top of the liner.

40. Install the connecting rod positioning clamp on the fork rod.

41. Lift the blade rod assembly and remove the upper bearing shell.

42. Attach an overhead chain hoist to the lifting clamp, Fig. 5-12. While guiding the power assembly, remove it from the engine.

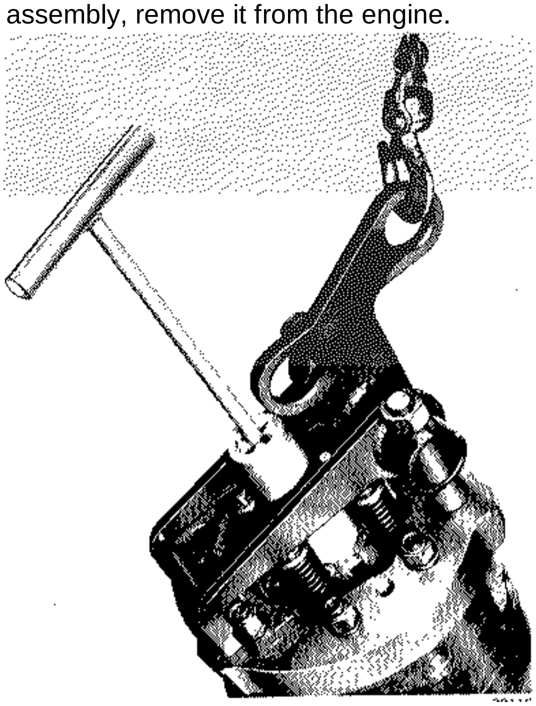

Fig. 5-12 - Power Assembly Removal With Lifting Clamp And Hoist

COMPONENT BY COMPONENT INSTALLATION

The power assembly components to be installed should be either new, remanufactured, or otherwise qualified parts. Prior to component installation, the crankcase upper and lower pilot bore should be checked and the dimensions should be within the tolerances shown in the Service Data pages of Section 4. In the case of the lower bore, the dimension is taken with the lower liner bore insert installed; if a rebuilt or remanufactured liner and/ or piston is used, the piston to liner clearance will have to be measured as described in the Service Data pages of Section 3.

1. Place a cleaned and inspected piston on a clean work bench.

2. Apply the spring-loaded oil control ring in the bottom groove.

3. Apply the spring to the groove first then, using the piston ring expander, apply the ring so that the spring will fit into the groove in the ring. The ends of the spring must be 1800 from the ring gap. Rings that are marked "TOP" on one side of the ring are placed in the groove with this marking facing the crown of the piston.

CAUTION

Be sure the spring is fully seated in its groove in the back of the ring. Attempting to install the piston and ring assembly into the liner with the spring not fully seated, or with a loop of spring protruding between the ring groove and ring, will result in a badly kinked spring or broken ring.

4. Using the ring expander, apply the double hook scraper oil control ring in the next groove up.

5. Apply the compression rings to the piston beginning with the bottom compression ring and ending with the No. I compression ring, Fig. 5-13. A ring marked "TOP GROOVE ONLY" must be installed in the No. I compression groove only.

6. The compression rings must be staggered so that the gaps of the first and second rings are 180° to each other; the third, 90° to the second ring, and the fourth ring 180° to the third. The oil control ring gaps should be 180° to each other.

7. If a new piston pin is to be used, a new insert bearing must be installed.

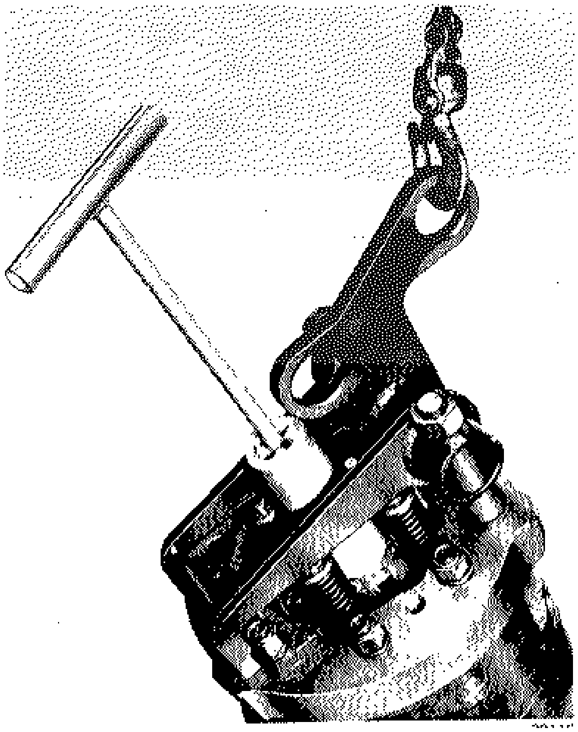

Fig. 5-13 - Installation Of Top Compression Ring

8. Carefully wipe out the insert slot in the carrier and examine the insert bearing to make sure that it is clean.

9. Apply the insert bearing in one end of the carrier slot and slide along the carrier bore. If a new insert bearing is not to be used, the old insert bearing must be applied in the same relative position from which it was removed.

10. Center the insert bearing so that the tangs, when bent, will be adjacent to the counterbores of the carrier to prevent endwise movement.

11. Using an indenter tool, Fig. 5-14, strike the center of the tangs to bend them into the carrier counter bore.

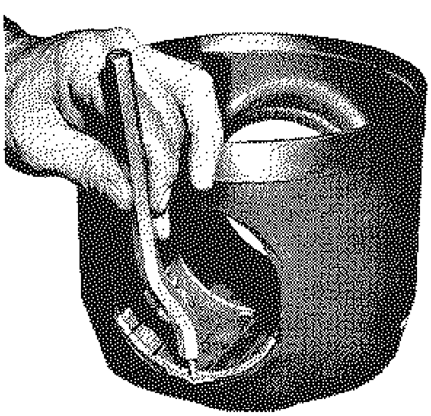

Fig. 5-14 - Piston Pin Bearing Insert Installation

12. Examine all mating surfaces of the carrier, piston pin, insert bearing, and connecting rod to be sure they are clean and smooth.

13. Manually coat the carrier bearing insert and the piston pin with clean oil, and insert the pin into the carrier.

14. Rotate the pin, while moving it slowly across the insert bearing, to check freedom of movement.

15. Install the piston pin so that the small identification hole in the end of the pin is at the same end as the piston cooling inlet hole in the carrier. When resusing these components, they must be kept in their same relative position.

16. Place the carrier assembly in a carrier holding fixture, Fig. 5-15, and secure it with the T-handle.

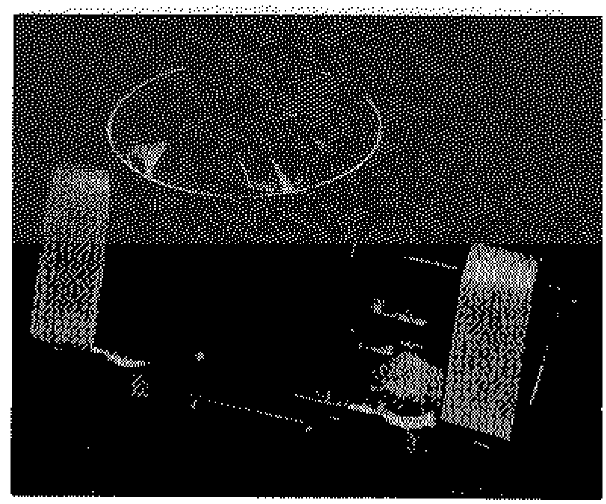

Fig. 5-15 - Carrier In Typical Holding Fixture

17. Apply Texaco Threadtex No. 2303 to the rod-to-piston pin bolts and thrust faces of rod and spacer. Place the connecting rod on the piston pin and apply the rod-to-pin bolt assemblies. Tighten bolts snugly (approximately 14 N•m [10 ft-lbs]) and perform a "finger tightness check." If a spacer can be rotated when a twisting effort is applied with a finger grip, the bolt assembly should be removed and inspected for the cause of not clamping.

18. When assembling the rod and carrier assembly, the piston cooling oil hole in the carrier must be on the same side as the dowel pin in the serrations of the fork rod and, on a blade rod, on the side opposite the long toe. This will ensure proper position of the hole when the assembly is installed in the engine.

19. Using a 300 ft-lb capacity torque wrench and extension, torque the piston pin bolts. To torque the bolts to the desired 610 N•m (450 ft-lbs), a torque reading of 300 ft-lbs is required when using the extension, the spacer should again be given a "finger tightness check" after the bolts are tight.

20. Place the piston and ring assembly on work bench with the open end up.

21. Check that the interior is clean and that the platform is free of any foreign material.

22. Apply some clean oil to the platform.

23. Place the thrust washer on the platform and apply clean oil to the thrust washer.

24. Carefully place the carrier and rod assembly into the piston and check the assembly for free rotation in the piston.

25. Using the snap ring tool, position the piston snap ring in the piston, Fig. 5-16.

Fig. 5-16 - Installing Piston Snap Ring

26. Check that the snap ring to carrier clearance does not exceed 1.07 mm (.042).

27. Perform a pre-installation inspection of the cylinder liner. Inspect liner water seal counterbores for nicks which may cut the water seals. Make sure that the counterbores and liner bore are clean. Check that the water inlet tube deflector is the correct type and is properly fitted in position in the cylinder liner.

28. Wipe the inside of the liner with a clean, oily cloth.

29. Apply the liner lifter, Fig. 5-17, over the liner studs and secure with the stud nuts.

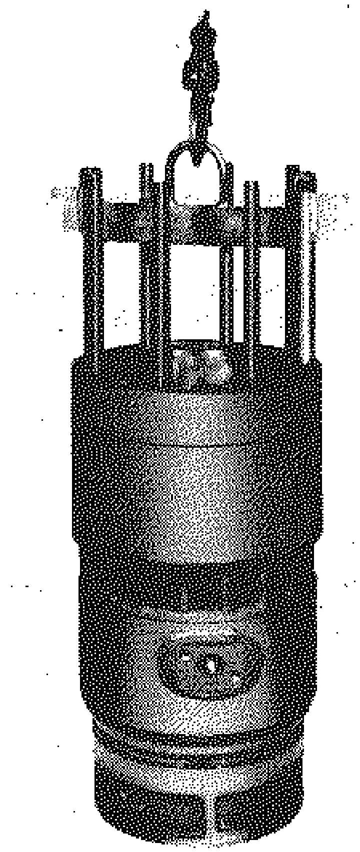

Fig. 5-17 - Liner Installation Using Liner Lifter

30. Attach a suitable lifting device to the liner lifter, raise slightly, and install lower liner seal (marked EMD PA) in upper groove. Install lower liner seal (marked EMD VIT and with red paint) in lower groove. Coat seals with an approved lubrication.

31. Lower the cylinder liner into place in the crankcase bore. Preliminary alignment can be obtained by positioning the pilot stud of the liner at the 5 o'clock position.

32. Place the piston ring compressor and guide over the studs on the cylinder liner.

33. Oil the ring compressor.

34. Place a protective boot over the end of the connecting rod.

35. Position the piston and rod assembly over the bore, and manually spread a film of oil on the outside of the piston.

36. Check that the ring gap positions have not changed.

37. Lower the piston and rod assembly into the liner.

38. Make sure that the serial number on the rod is facing outboard.

39. Lower the assembly until the piston crown is parallel to the top of the liner.

40. Oil the inside and outside surfaces of the connecting rod bearing shells and place the upper bearing in position on the connecting rod journal.

41. Hold the bearing shell in place while lowering the blade rod to rest on the upper bearing surface. If applicable, remove the piston holding tool.

NOTE

The blade or fork rod opposite to the rod being installed was positioned out of the way during "Component By Component Removal" by use of a piston holding tool for a blade rod or a fork rod support, Fig. 5-9.

42. If applicable, remove fork rod support and lower the fork rod until the rod makes contact with the bearing surface. The fork rod dowels should enter the bearing dowel holes without binding.

43. Be sure that the serial number on the basket matches the serial number on the connecting rod, Fig. 5-18.

44. Apply the lower connecting rod bearing to the dowel basket half, oil the bearing surface, and 5 place the basket half on the fork rod. When applying fork rod baskets be sure that the serial number on the prong of the dowel half is on the dowel side of the rod.

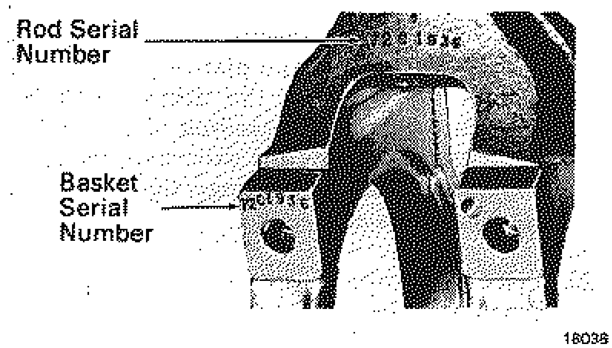

Fig. 5-18 - Rod And Basket Identification

45. Lubricate all upper basket bolts with Texaco Threadtex No. 2303 and tighten the upper basket fork rod bolts just enough to mate the serrations and to hold the bearing in place.

46. Apply the other basket half to the fork rod, tightening the rod bolts enough to mate the serrations.

47. Apply the lower basket bolts, washers, and locknuts.

48. Snug the four top basket bolts to approximately 14 N•m (10 ft-lbs) to firmly mesh the serrations. Give each washer a "finger tightness check." If a washer can be rotated by grasping with the fingers, the bolt assembly should be removed and inspected for the cause of not clamping.

49. Using the spring-loaded basket bolt wrench, Fig. 5-7, torque the lower basket bolts to specified value.

50. Torque the upper basket bolts to 258 N•m (190 ft-lbs).

51. Remove the connecting rod positioning clamp and piston holding tool from the blade rod assembly on the opposite bank of the engine.

52. Disconnect the lifting device from the eyebolt.

53. Remove the piston ring compressor and guide from the engine. Remove the piston pulling eyebolt.

54. Install the liner to head water seals and heat dam insulators.

55. Install the head-to-liner gasket, Fig. 5-19, making sure that the proper gasket is used and that the gasket is placed over the liner studs with the part number and "TOP" stamp facing up, and the notched ear of the gasket is placed over the pilot stud of the liner.

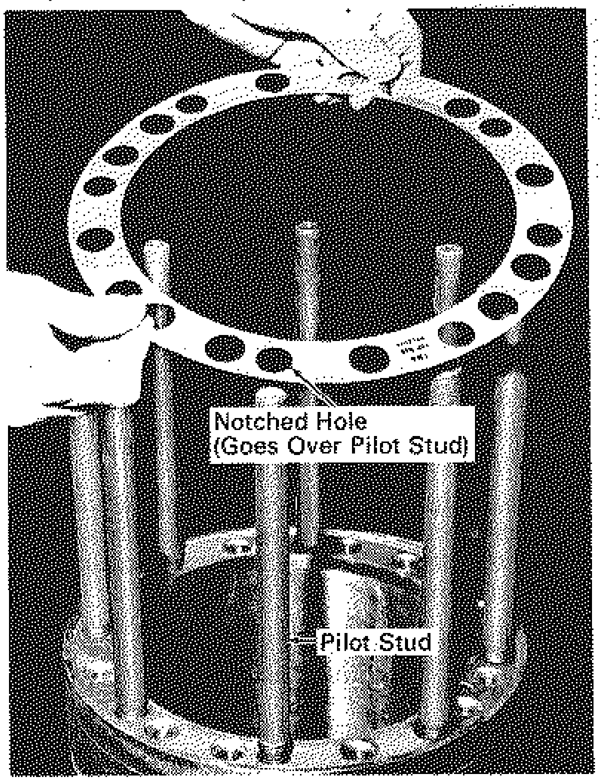

Fig. 5-19 - Head-To-Liner Gasket

56. Attach the head fixture and lifting device to the head, and partially raise head. Check that the injector well is covered.

NOTE

At time of head installation, the exhaust valves have already been applied to the head. For this installation, refer to "Exhaust Valve Installation" in Section 2.

57. Apply a light coat of Dow 4 silicone grease to water outlet (discharge) elbow seals and install two black seals to the grooves entering the crankcase and a red seal to the groove between the elbow and the cylinder head. Bolt elbow to cylinder head and torque to specified value.

58. Check that the bottom surface of the head is clean and place the seat ring, Fig. 5-20, on the head, making sure that the chamfered side is facing up.

On head seat rings with seal rings molded to outer diameter, word "TOP" stamped on chamfered side should be facing up. No other positioning reference is used.

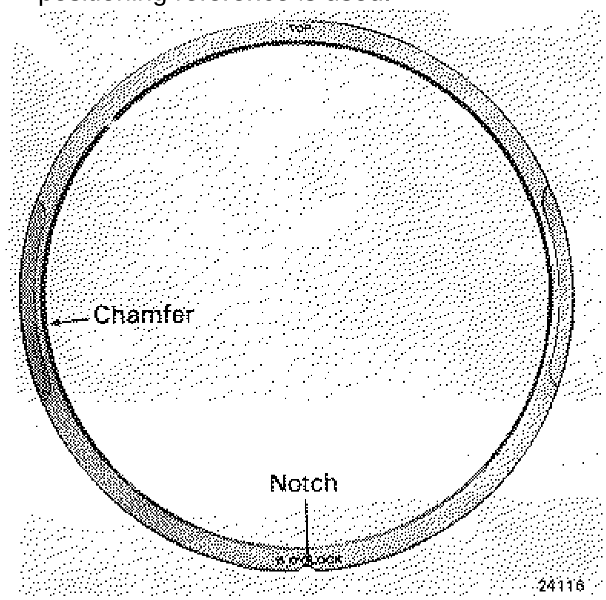

Fig. 5-20 - Cylinder Head Seat Ring

59. Lower the head slowly into position making sure that the notch in the seat ring is at the 6 o'clock position.

60. Line up the water discharge elbow with the mating hole in the crankcase, Fig. 5-21. Be careful that the seals are not damaged or twisted in the grooves while the head is lowered into position. Before the head contacts the liner, recheck the position of the seat ring notch and finish lowering the head. Remove the head fixture and lifting device.

61. Apply Texaco Threadtex No. 2303 to cylinder liner studs and stud nuts.

62. Apply the liner washers and stud nuts, and snug them down.

63. Following the sequence as shown in Fig. 5-22, torque the head-to-liner nuts to 95 N•m (70 ft-lbs), then final torque to 325 N•m (240 ft-lbs).

64. Remove thread protectors, and make sure that crab bolts, crab seats, and crab nuts are free from burrs, and are lubricated with Texaco Threadtex No. 2303.

65. Apply crabs and crab nuts. Center the crab bolts by manually seating the nuts while moving the crab bolts back and forth.

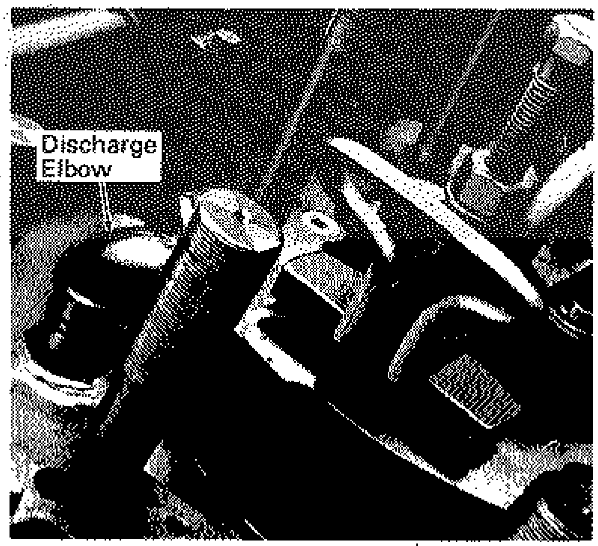

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Fig. 5-21 - Water Discharge Elbow Alignment

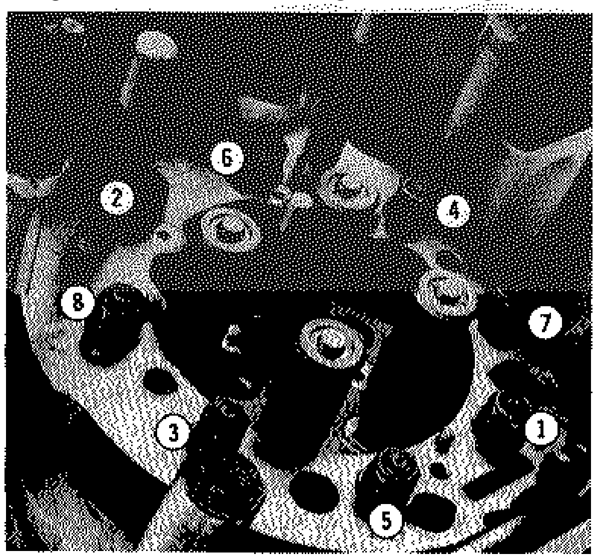

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Fig. 5-22 - Head-To-Liner Nut Tightening Sequence

66. Check that the crabs are positioned so that a wrench can be applied to the head-to-liner stud nuts.

CAUTION

Intermediate inboard crabs, those bearing on two cylinder heads in the row closest to the camshaft and identified by three raised ribs, are designed for application at these locations only. Do not interchange these crabs with intermediate outboard crabs (without identification ribs) as this will unfavorably alter stress loads which may result in cylinder head cracking.

67. After seating the crab nuts, torque them to approximately 542 N•m (400 ft-lbs).

68. Using an air motor and torque multiplier with a power ratio of-38:1, or any mechanical advantage wrench, final torque the crab nuts to 2 440 N•m (1800 ft-lbs). If a 12:1 power wrench is used with a 300 ft-lb capacity hand torque wrench, the pointer should indicate 150 ft-lbs for the final pass.

69. Install the overspeed trip assembly on the cylinder head, and torque the bolts to specified value.

70. Uncover the injector well and install the injector into the cylinder head. Check that the locating dowel is properly seated.

71. Lubricate the threads on the injector stud and nut. Place the injector crab over the crab stud. Place the spherical side of the washer into the spherical seat of the crab. Apply and snug down the nut.

72. Be sure that the injector crab is not cocked at an angle so that it would prevent the entry of the injector timing tool, and torque the crab nut to specified value.

73. Install the injector adjusting link assembly using the two clevis pins and spring retainers.

74. Attach the fuel manifold to the top deck cover frame. Connect the fuel lines from the manifold to the injector. Care must be taken not to damage the spherical seats of the fuel lines as fuel leakage could occur.

75. Position the valve bridges in the cylinder head (with protruding boss toward camshaft for uniform assembly).

NOTE

At time of installation, valve bridges are an assembly, For buildup, refer to "Valve Bridge And Hydraulic Lash Adjuster" in Section 2.

76. Lubricate the shaft studs with Texaco Threadtex No. 2303 and install the rocker arm shaft assembly, Fig. 5-23. Apply the shaft caps with the short toe facing out.

77. Make sure that the hardened washer is used between the rocker arm shaft nuts and the shaft caps and that all contact surfaces are clean and free from burrs. Apply the washers and nuts to the shaft studs.

78. Alternately torque the shaft nuts to 203 N•m (150 ft-lbs) on the first pass, and to a final torque of 407 N•m (300 ft-lbs).

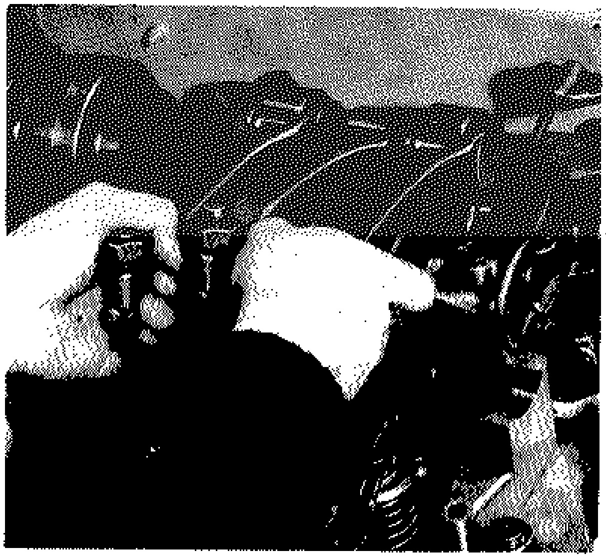

Fig. 5-23 - Rocker Arm Shaft Installation

79. Use a new gasket and attach the rocker arm oil line to the camshaft bearing bracket. Torque bolts to specified value. Refer to the procedures in this section for injector timing and adjustment of the hydraulic lash adjusters.

80. Coat a new seal with Dow 4 silicone grease and place in the groove at the liner end of the water inlet tube, Fig. 5-24.

Fig. 5-24 - Applying Seal To Water Inlet Tube

81. Position saddle straps around the water manifold and then through the inlet tube flange.

82. After the strap nuts have been applied and tightened finger tight, check that the seal is seated in the groove, position the tube on the liner, and finger tighten the bolts.

83. Take a new gasket and shape it to fit around the water manifold. Insert the gasket between the tube flange and manifold making sure the sides of the gasket are flush with the sides of the flange, and that the ends of the gasket are within the clamping radius of the flange.

84. Torque the strap nuts to specified value.

85. Prior to torquing the tube to liner bolts, remove the bolts and washers from the flange. If the tube moves, it must be repositioned on the water manifold; if no movement is detected, the tube to liner bolts and washers may be reapplied and torqued to specified value.

86. Using a new gasket, place the piston cooling oil pipe against the piston cooling oil manifold.

87. Place the nozzle end of the pipe into the liner bore so that the dowels on the pipe align with the dowel holes in the liner.

88. If the bolt holes in either of the flanges do not line up, replace the pipe. No attempt should be made to fit the pipe by bending it. This would place a stress on the pipe which could result in subsequent failure.

89. Install the fine thread bolts into the manifold, and the coarse thread bolts into the liner. Torque bolts to specified value.

90. Check proper alignment of the piston cooling oil pipe by placing the alignment gauge into the nozzle of the pipe, Fig. 5-25. Bar over the engine to bottom dead center of the cylinder being checked. At the same time, rotate the gauge to make sure it does not bind in the carrier hole.

91. If the gauge indicates misalignment, replace the pipe. Do not use the gauge to align the pipe.

92. It is important, after installing a power assembly, to determine the head to piston clearance. This will provide the information necessary to evaluate the amount of subsequent wear, or a change in head to piston relationship. The procedure for applying the lead wire in wire holder is as follows:

   a. Place a length of 1/8" diameter lead wire in each end of the wire holder and position the holder on top of a piston of the same size as the one being checked in the engine. Each end of the wire should be at least 3.18 mm (1/8") from the outside diameter of the piston.

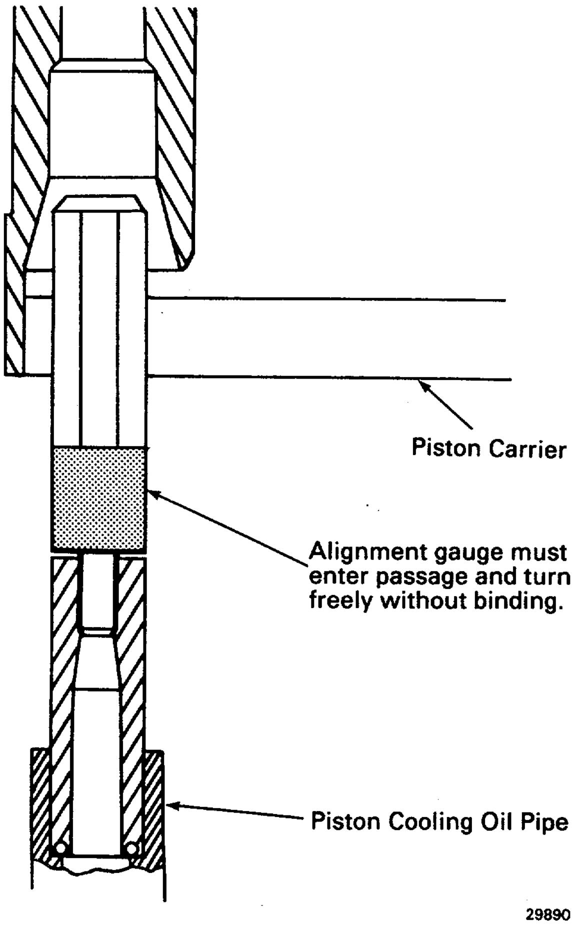

Fig. 5-25 - Piston Cooling Oil Pipe Alignment

b. Bar the engine over until the piston being checked is at bottom dead center.

c. Apply the lead wire and holder through a liner port and position it on top of the piston so that it is parallel with the crankshaft.

d. Bar the engine over one complete revolution to compress the lead wire. Remove the wire from the engine and measure the inboard portion of both compressed ends of the wire, Fig. 5-26.

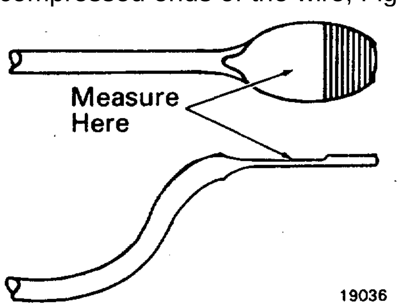

Fig. 5-26 - Lead Wire Measurement

NOTE

It is important that the thinner of the two compressed areas be measured to provide the minimum piston to head clearance.

e. Within the maximum clearance and minimum clearance, the difference in micrometer readings between the two compressed ends should not exceed 0.13 mm (0.005"). If it does, repeat the process as the wire may have changed position.

93. Place a new packing seal in the cylinder test valve bore and apply high temperature thread lubricant to valve body threads. Install the valve body and packing nut.

94. Tighten the valve body into the cylinder head and snug down the packing nut.

95. Torque the packing nut to specified value and install the needle valve.

96. Refill the cooling system and check for water leaks.

97. Install the top deck and handhole covers.

98. Bar the engine over one complete revolution and close all the cylinder test valves.

99. Start the engine and raise the water temperature to 77° C (170° F). After running the engine, shut it down and re-check the torque on the crab and liner stud nuts. Also re-check for oil and water leaks.

UNIT INSTALLATION

Left and right banks of the engine are determined by looking toward the "front" (governor end) of the engine when standing at the "rear" (coupling end) of the engine. In a left-hand rotating engine (basic), power assemblies with blade rods are installed in the right bank with the "long toe" of the slipper foot facing the center of the engine. The power assemblies with fork rods are installed in the left bank.

In a right-hand rotating engine (standard extra), power assemblies with blade rods are installed in the left bank with the "long toe" of the slipper foot facing the center of the engine. The power assemblies with fork rods are installed in the right bank.

1. The complete power assembly is packaged in either a storage type metal reinforced container, Fig. 5-27, or expendable cardboard and wood container. The metal cover on the storage type container is removed by using a wrench and

turning the hex head fasteners on the side of the container. The cover forms the top and three sides of the container.

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Fig. 5-27 - Power Assembly And Container

2. Remove the card containing the applicable seals and gaskets and, if a power assembly with a fork rod, the small box containing the basket bolts.

3. Remove the two nuts and bolts holding the top mounting block to the rocker arm studs, and take off the block.

4. Remove the piston holding bolt and block.

5. Insert a clean rag into the injector well and remove the tape from around the liner ports.

6. If the power assembly has a fork rod, remove the connecting rod basket from the metal bracket at the front of the container, Fig. 5-27.

7. The assembly has been coated with an anti-rust compound which does not have to be removed and is totally compatible with lube oil.

8. Install the rocker arm shaft supports, if required, making sure that the locating dowel holes are properly positioned.

9. Install the lifting clamp, Fig. 5-28, and secure it with the rocker arm shaft nuts.

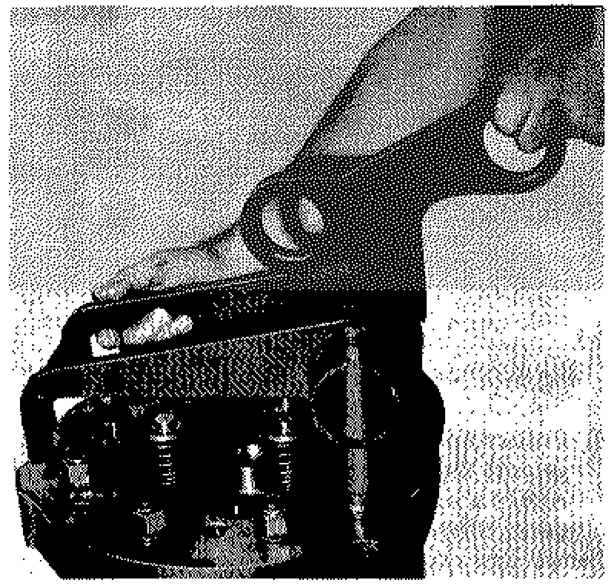

Fig. 5-28 - Lifting Clamp Application

10. Remove the rag from the injector well and apply the piston holding tool, Fig. 5-29.

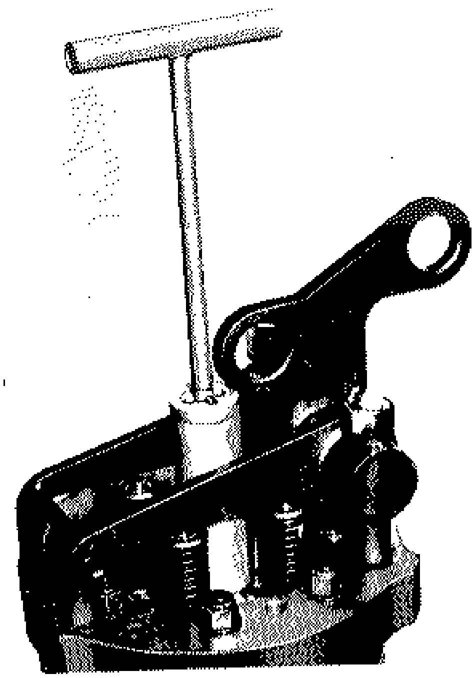

Fig. 5-29 - Piston Holding Tool Application

11. Attach a chain hoist to the eye at the center of the lifting clamp and remove the power assembly from the container.

12. Support the assembly on a suitable stand and attach the connecting rod positioning clamp.

13. Be sure and check, if a fork rod, that the rod and basket serial numbers match, Fig. 5-30.

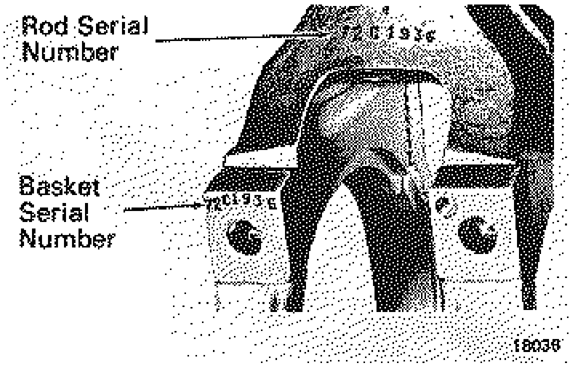

Fig. 5-30 - Rod And Basket Identification

14. Before applying the water discharge elbow, inspect the internal and external seal grooves. Apply a light coat of silicone grease to water outlet elbow seals and install two black seals to the grooves entering the crankcase and a red seal to the groove between the elbow and the cylinder head. Bolt elbow to cylinder head, and torque to specified value.

15. Change the hoist to the end hole of the lifting clamp, Fig. 5-31, to position it at the proper angle for installation in the engine.

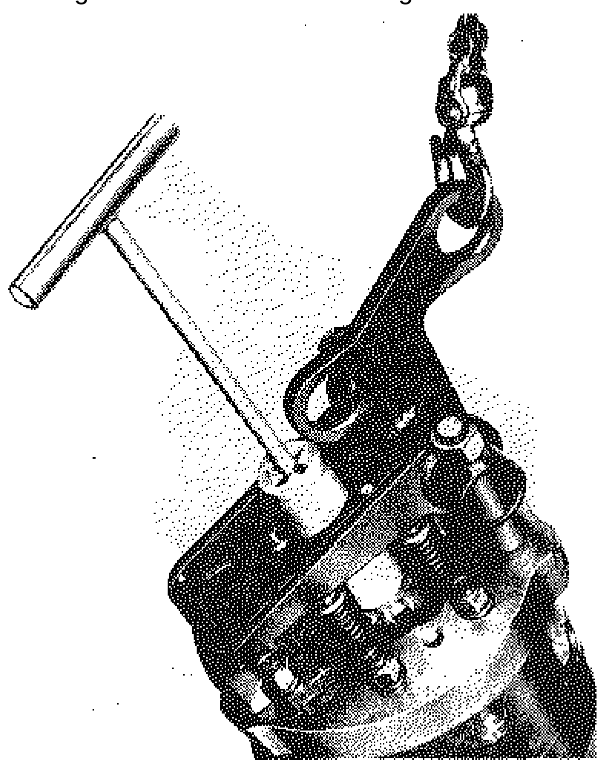

Fig. 5-31 - Power Assembly Installation With Lifting Clamp And Hoist

16. Raise assembly and install lower liner seal (marked EMD PA) in upper groove. Install lower liner seal (marked EMD VIT and with red paint) in lower groove. Coat seals with an approved lubricant.

17. Place the seat ring on the assembly, Fig. 5-32, making sure that the chamfered side is facing up, and the notch (if used) is at the 6 o'clock position. Place thread protectors on cylinder head crab bolts.

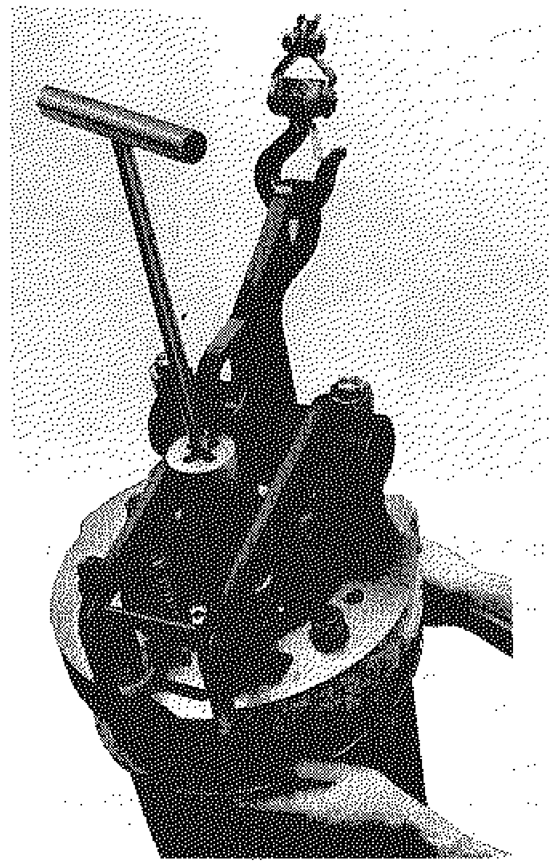

Fig. 5-32 - Seat Ring Installation

18. Lower the assembly slowly into the crankcase bore, lining up the water discharge elbow with the mating hole in the crankcase, Fig. 5-33. Be careful that the seals are not damaged or twisted in the grooves while the head is lowered into position.

19. Before the head contacts the crankcase, recheck the position of the seat ring notch and lower the assembly into final position.

20. Remove the chain hoist from the lifting clamp and attach it to the piston holding tool in the power assembly being installed.

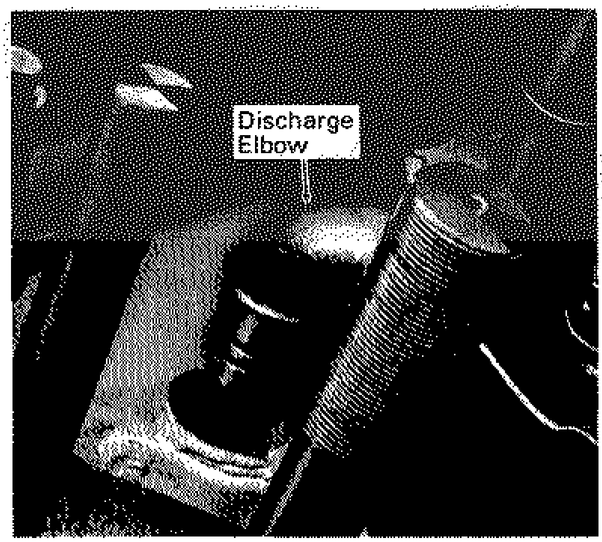

Fig. 5-33 - Water Discharge Elbow Alignment

NOTE

The blade or fork rod opposite to the rod in the power assembly being installed was positioned out of the way during "Unit Removal" by use of a piston holding tool.

21. Oil the inside and outside surfaces of the connecting rod bearing shells and place the upper bearing in position on the connecting rod journal.

22. Hold the bearing shell in place while lowering the blade rod to rest on the upper bearing surface.

23. Lower the fork rod until the rod makes contact with the bearing surface. The fork rod dowels should enter the bearing dowel holes without binding.

24. Remove the piston holding tool and the lifting clamp and place a clean rag in the injector well.

25. Remove the connecting rod positioning clamp from each connecting rod. Also remove the piston holding tool from the opposite cylinder.

26. Apply the lower connecting rod bearing to the dowel basket half, oil the bearing surface, and place the basket half on the fork rod. When applying fork rod baskets be sure that the serial number on the prong of the dowel half is on the dowel side of the rod.

27. Lubricate all upper basket bolts with Texaco Threadtex No. 2303 and, tighten the upper basket fork rod bolts just enough to mate the serrations and to hold the bearing in place.

28. Apply the other basket half to the fork rod, tightening the rod bolts enough to mate the serrations.

29. Apply the lower basket bolts, washers, and locknuts.

30. Snug the four top basket bolts to approximately 14 N•m (10 ft-lbs) to firmly mesh the serrations. Give each washer a "finger tightness check". If a washer can be rotated by grasping with the fingers, the bolt assembly should be removed and inspected for the cause of not clamping.

31. Using the spring-loaded basket bolt wrench, Fig. 5-34, torque the lower basket bolts to specified value.

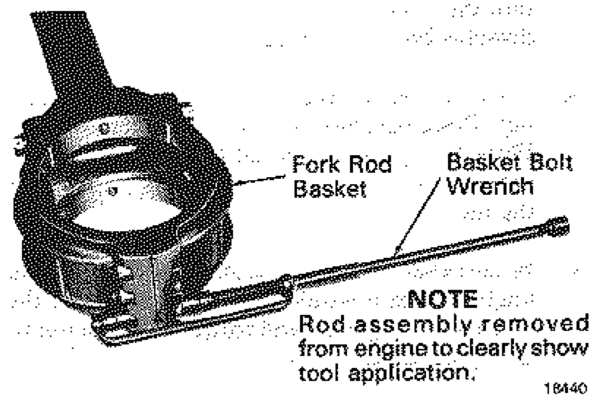

Fig. 5-34 - Basket Bolt Wrench Application

32. Torque the upper basket bolts to 258 N•m (190 ft-lbs).

33. Check the head to liner stud nuts for specified torque, starting with the pilot stud and using the tightening sequence as shown in Fig. 5-22.

34. Remove thread protectors and make sure that crab bolts, crab seats, and crab nuts are free from burrs, and are lubricated with Texaco Threadtex No. 2303.

35. Apply crabs and nuts. Center the crab bolts by manually seating the nuts while moving the crab bolts back and forth. Check that the crabs are positioned so that the wrench can be applied to the head-to-liner stud nuts.

CAUTION

Intermediate inboard crabs, those bearing on two cylinder heads in the row closest to the camshaft and identified by three raised ribs are designed for application at these locations only. Do not interchange these crabs with intermediate out-board crabs (without identification ribs) as this will unfavorably alter stress loads which may result in cylinder head cranking.

36. After seating the crab nuts, torque them to approximately 542 N•m (400 ft-lbs).

37. Using an air motor and torque multiplier with a power ratio of 38: 1, or any mechanical advantage wrench, final torque the crab nuts to 2 440 N•m (1800 ft-lbs). If a 12:1 power wrench is used with a 300 ft-lb capacity hand torque wrench, the pointer should indicate 150 ft-lbs for the final pass.

38. Install the overspeed trip assembly on the cylinder head and torque the bolts to specified value.

39. Uncover the injector well and install the injector into the cylinder head. Check that the locating dowel is properly seated.

40. Lubricate the threads on the injector stud and nut. Place the injector crab over the crab stud. Place the spherical side of the washer into the spherical seat of the crab. Apply and snug down the nut.

41. Be sure that the injector crab is not cocked at an angle so that it would prevent the entry of the injector timing tool, and torque the crab nut to specified value.

42. Install the injector adjusting link assembly using the two clevis pins and spring retainers.

43. Connect the fuel lines from the manifold to the injector. Care must be taken not to damage the spherical seats of the fuel lines as fuel leakage could occur.

44. Position the valve bridges in the cylinder head (with protruding boss toward camshaft for uniform assembly).

NOTE

At time of installation, valve bridges are an assembly. For buildup, refer to "Valve Bridge And Hydraulic Lash Adjuster" in Section 2.

45. Lubricate the shaft studs with Texaco Threadtex No. 2303 and install the rocker arm shaft assembly, Fig. 5-23. Apply the shaft caps with the short toe facing out.

46. Make sure that the hardened washer is used between the rocker arm shaft nuts and the shaft caps and that all contact surfaces are clean and free from burrs. Apply the washers and nuts to the shaft studs.

47. Alternately torque the shaft nuts to 203 N•m (150 ft-lbs) on the first pass, and to a lineal torque of 407 N•m (300 ft-lbs).

48. Use a new gasket and attach the rocker arm oil line to the camshaft bearing bracket. Refer to the procedures in this section for injector timing and adjustment of the hydraulic lash adjusters.

49. Coat a new seal with Dow 4 silicone grease and place in the groove at the liner end of the water inlet tube, Fig. 5-24.

50. Position saddle straps around the water manifold and then through the inlet tube flange.

51. After the strap nuts have been applied and tightened finger tight, check that the seal is seated in the groove, position the tube on the liner, and finger tighten the bolts.

52. Take a new gasket and shape it to fit around the water manifold. Insert the gasket between the tube flange and manifold making sure the sides of the gasket are flush with the sides of the flange, and that the ends of the gasket are within the clamping radius of the flange.

53. Torque the strap nuts to specified value.

54. Prior to torquing the tube to liner bolts, remove the bolts and washers from the flange. If the tube moves, it must be repositioned on the water manifold; if no movement is detected the tube to liner bolts and washers may be reapplied and torqued to specified value.

55. Using a new gasket, place the piston cooling oil pipe against the piston cooling oil manifold.

56. Place the nozzle end of the pipe into the liner bore so that the dowels on the pipe align with the dowel holes in the liner.

57. If the bolt holes in either of the flanges do not line up, replace the pipe. No attempt should be made to fit the pipe by bending it. This would place a stress on the pipe which could result in subsequent failure.

58. Install the fine thread bolts into the manifold, and the coarse thread bolts into the liner. Torque bolts to specified value.

59. Check proper alignment of the piston cooling oil pipe by placing the alignment gauge into the nozzle of the pipe, Fig. 5-25. Bar over the engine to bottom dead center of the cylinder being checked. At the same time, rotate the gauge to make sure it does not bind in the carrier hole.

60. If the gauge indicates misalignment, replace the pipe. Do not use the gauge to align the pipe.

61. It is important, after installing a power assembly, to determine the head to piston clearance. This will provide the information necessary to evaluate the amount of subsequent wear, or a change in head to piston relationship. The procedure for applying the lead wire in wire holder is as follows:

a. Using a piston of the same size as the one being checked in the engine, place a length of 1/ 8" diameter lead wire in each end of the wire holder. When positioned on top of the piston, each end of the wire should be at least 3.18 mm (1/8") from the outside diameter of the piston.

b. Bar the engine over until the piston being checked is at bottom dead center.

c. Apply the lead wire through a liner port and position it on top of the piston so that it is parallel with the crankshaft.

d. Bar the engine over one complete revolution to compress the lead wire. Remove the wire from the engine and measure the inboard portion of both compressed ends of the wire, Fig. 5-35.

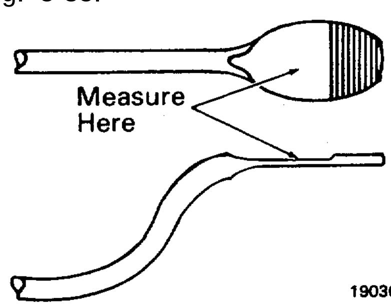

Fig. 5-35 - Leader Wire Measurement

NOTE

It is important that the thinner of the two compressed areas be measured to provide the minimum piston to head clearance.

e. Within the maximum clearance and minimum clearance, the difference in micrometer readings should not exceed 0.13 mm (0.005"). If it does, repeat the process as the wire may have changed position.

62. Place a new packing seal in the cylinder test valve bore and apply high temperature thread lubricant to valve body threads. Install the valve body and packing nut.

63. Tighten the valve body into the cylinder head and snug down the packing nut.

64. Torque the packing nut to specified value and install the needle valve.

65. Refill the cooling system and check for water leaks.

66. Install the top deck and handhole covers.

67. Bar the engine over one complete revolution and close all the cylinder test valves.

68. Start the engine and raise the water temperature to 77° C (170° F). After running the engine, shut it down and re-check the torque on the crab and liner stud nuts. Also re-check for oil and water leaks.

POWER ASSEMBLY PACKAGING

WARNING

Failure to comply with the proper packaging procedures, when returning power assemblies, can result in injury to personnel or costly damage to components.

The container, in which the power assembly is shipped, has been specially constructed to prevent damage to components. To properly package the assembly being returned, the following procedure should be used:

1. Before attempting to move the assembly, place the piston holding block over the injector hole and over the injector crab stud and secure with the bolt threaded into the threaded lifting eye hole in the crown of the piston.

2. Attach the lifting clamp assembly and hoist.

3. Position assembly in shipping container so that liner is firmly seated and connecting rod straddles support in bottom of container.

4. Remove hoist and lifting clamp assembly.

5. Place top mounting block over rocker arm shaft studs and secure with washers and nuts. Make sure that the block attaching bolts holding the block to the container are secure.

6. On fork rod assemblies, make sure each half of the basket is properly positioned and secured to the main body of the container.

7. Place container cover in position and secure.

ADJUSTING HYDRAULIC LASH ADJUSTERS

Application of properly operating lash adjusters, correct setting, and subsequent inspection at regular maintenance intervals is very important to valve operation. Improperly set or defective lash adjusters cause the exhaust valves to be subjected to increased stress which leads to ultimate failure and probable damage to the engine.

After complete cylinder head assembly or power assembly has been installed, the lash adjusters must be set.

1. Open cylinder test valves and rotate crankshaft so that piston is at or near top dead center of the cylinder being set.

2. Loosen rocker arm adjusting screw locknuts.

3. Turn rocker arm adjusting screw down until the last valve just touches the hydraulic lash adjuster plunger, or use a 0.001" shim between valve tip and adjuster plunger, and then turn it down 1-1/2 turns.

4. Check valve bridge spherical seat to be sure that it is spring-loaded against the cylinder head spherical seat. If the bridge spring spherical seat is not spring-loaded against the cylinder head spherical seat, turn down the rocker arm adjusting screw until no movement is felt, and then turn it another 1/4 turn.

5. Tighten rocker arm adjusting screw locknut to a torque of 108 ±: 7 N•m (80 ± 5 ft-lbs).

6. After running the engine until lube oil reaches operating temperature, check the clearance between lash adjuster bodies and the end of the valve stems with the piston near top center. If the clearance is less than minimum, the cylinder head should be removed for reconditioning or rejection. Use minimum clearance gauge, Fig. 5-36, to gauge clearance between lash adjuster and exhaust valve. This gauge is 1/16" thick and should fit between lash adjuster body and valve stem top, to ensure the minimum clearance.

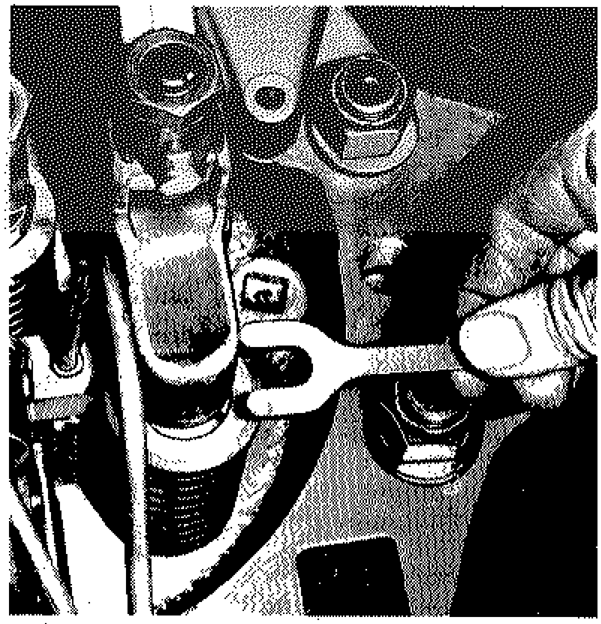

Fig. 5-36 - Checking Lash Adjuster To Valve Clearance

TIMING THE INJECTOR

With the injector installed, make timing adjustment as follows:

1. Bar engine over in the normal direction of rotation until flywheel pointer indicates the correct crankshaft position in degrees relative to top dead center of the cylinder being timed. Refer to setting instructions on Injector Timing Plate (located on right rear side of engine crankcase) and see Table 1 in Section 7 for top dead center settings.

2. Insert injector timing gauge into the hole provided for it in the injector body, Fig. 5-37.

3. Loosen locknut and turn the rocker arm adjusting screw until the shoulder of the gauge just passes over the injector follower guide.

NOTE

Injectors cannot be timed if the overspeed has been tripped. It must first be reset and the engine crankshaft barred over at least one revolution.

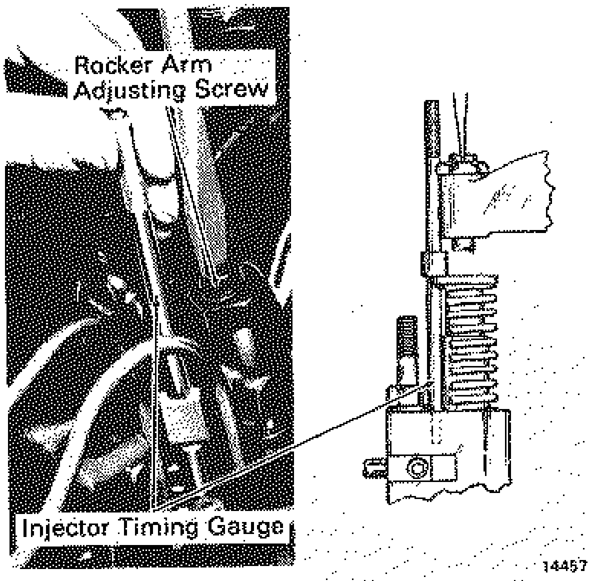

Fig. 5-37 - Timing Injector

4. Tighten adjusting screw locknut while holding adjusting screw in position with a screwdriver.

5. Recheck setting.

CRAB NUT TIGHTNESS CHECK AND RETORQUING

All new or replaced power assemblies should have the crab nuts checked for tightness at interval specified in Scheduled Maintenance Program. Using a torque wrench, tighten to 2 440 N•m (1800 ft-lbs) any nut that turns at a lower value. If the nut does not turn at 2 440 N•m (1800 ft-lbs), do NOT tighten further.

Retorque crab nuts at intervals specified in Scheduled Maintenance Program. When retorquing crab nuts, loosen all nuts one flat (approximately 1356 N•m [1000 ft-lbs]) and retorque to 2 440 N•m (1800 ft-lbs).

SERVICE DATA

CYLINDER POWER ASSEMBLY

SPECIFICATIONS

Clearance and dimensional limits listed below are defined as follows:

1. *New limits are those to which new parts are manufactured. (Drawing tolerances.)*

2. *Minimum, maximum, and tolerance measurements are provided as service limits. At time of rebuild or any time unscheduled maintenance is performed, the service limits should not be exceeded. Engine components within these limits may be reused with the assurance that they will perform satisfactorily until the next scheduled overhaul.*

Carrier to piston snap ring clearance -
Min. .... 0.05 mm (.002")
Max. .... 1.07 mm (.042")

Piston to cylinder head clearance -
New Min. .... 0.51 mm (.020")
New Max. .... 1.73 mm (.068")
Differential reading between ends of lead wire .... 0.13 mm (.005")
Any sudden increase in compression clearance should be investigated immediately.

EQUIPMENT LIST

	Part No.
Test valve wrench	8302587
Crab stud protector tubes	8034600
Injector timing gauge	8034638
Piston pulling eyebolt	8040413
Injector prybar	8041183
Fork rod support	8052958
Cylinder head carrying basket	8060247
Blade rod protector boot	8062033
Fork rod protector boot	8062034
Piston cooling pipe alignment gauge	8071720
Cylinder head removing fixture	8075894
Piston cooling pipe cleaning tool	8087086
Lash adjuster minimum clearance gauge	8107788
Cylinder liner lifter	8116358
Torque wrench 19.05 mm (3/4") drive (0-407 N•m [0-300 ft lb])	8157121
Snap ring remover	8171633
Torque wrench extension (use w/torque wrench 8157121)	8210136
Basket bolt wrench	8236718
Wire holder (has contour of piston crown to hold lengths of lead wire for piston to head clearance check)	8243220
Wire (lead 3.18 mm [1/8"] dia. use with holder 8243220) 2.27 kg (5 lb) spool	8243661
Thread lubricant, high temperature (.946 liter [1 qt.])	8278929
Thread lubricant, Texaco Threadtex No. 2303 (approx. 18.93 liter [5 gal])	8307731
Bearing insert to carrier indenter tool	8311268
Piston ring expander	8349892

EQUIPMENT LIST (Cont'd)

Item	Part No.
Lifting clamp assembly	8417858
Piston holding tool	8417859
Connecting rod positioning clamp assembly	8417881
Silicone grease (150 g [5.3 oz.] tube)	8425724
Injector holding rack	8431626
Piston ring compressor and guide (standard size)	9333846
Piston carrier holding fixture (2 mandrels)	9534635
Piston carrier holding fixture (single mandrel)	9542253
Crab nut wrench set (manual)	9551713

SECTION 6

CRANKSHAFT ASSEMBLY AND ACCESSORY DRIVE GEAR TRAIN

CONTENTS	PAGE

CRANKSHAFT ASSEMBLY AND ACCESSORY DRIVE GEAR TRAIN

GENERAL

The crankshaft assembly is made up of the crankshaft, main bearings and caps, thrust collar, torsional damper, and the accessory drive gear. Although the accessory drive gear is part of the crankshaft assembly, it will be described as part of the accessory drive gear train.

The accessory drive gear train provides power from the crankshaft to drive the oil pumps, water pumps and the governor.

CRANKSHAFT

DESCRIPTION

The crankshaft, Fig. 6-1, is a drop forging of carbon steel material with induction hardened main and crankpin journals. On 8 and 12-cylinder engines, the crankshaft is a one piece forging. On 16-cylinder engines, the crankshaft is made up of two sections whose flanges are bolted together. Counterweights are provided to give stable operation and all crankshafts are dynamically balanced.

Drilled oil passages provide for lubrication of the main bearings as shown in Fig. 6-2.

Crankshafts with bolt-on accessory drive stubshafts are available for 12 and 16-cylinder engines.

Refer to "Accessory Drive Gear" for removal and installation of stubshaft.

MAINTENANCE

INSPECTION

Whenever the main or connecting rod bearings are removed, the crankshaft journals should be inspected. Check for scoring and cracks, and signs of distress, as will generally be evidenced first in the bearings. When the crankshaft is removed from the engine; it should be visually and dimensionally inspected, and magnaflux inspected if possible.

The journals of the crankshaft are induction hardened. Excessive heat resulting from lack of lubrication, insufficient bearing clearance, or other causes will usually produce, thermal cracks on the

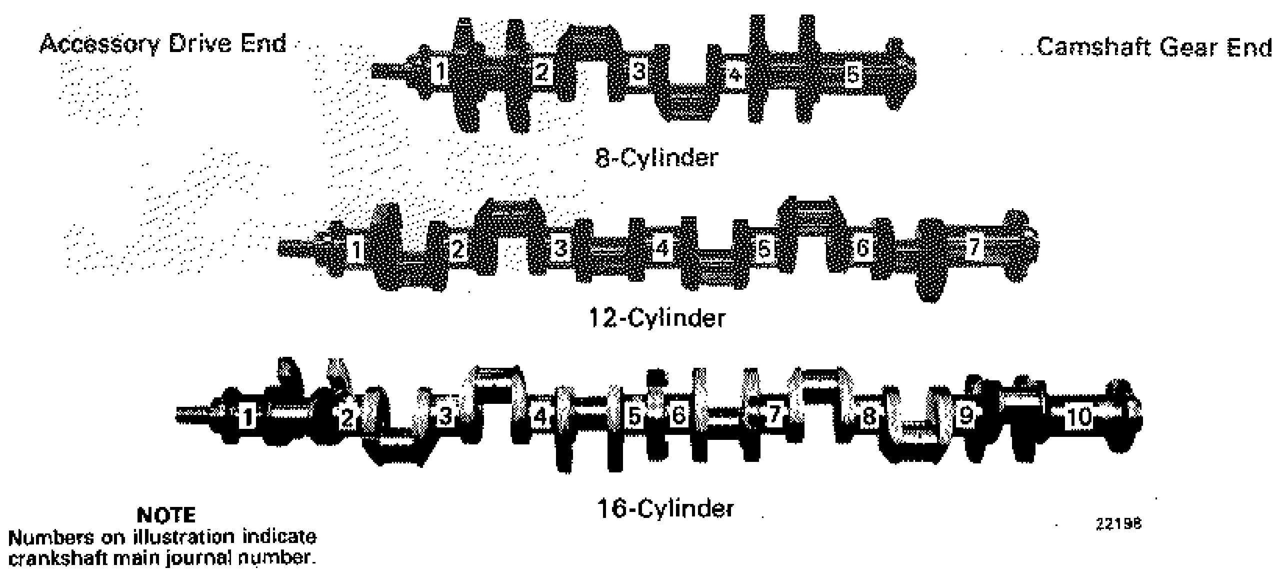

Fig. 6-1 - Engine Crankshafts

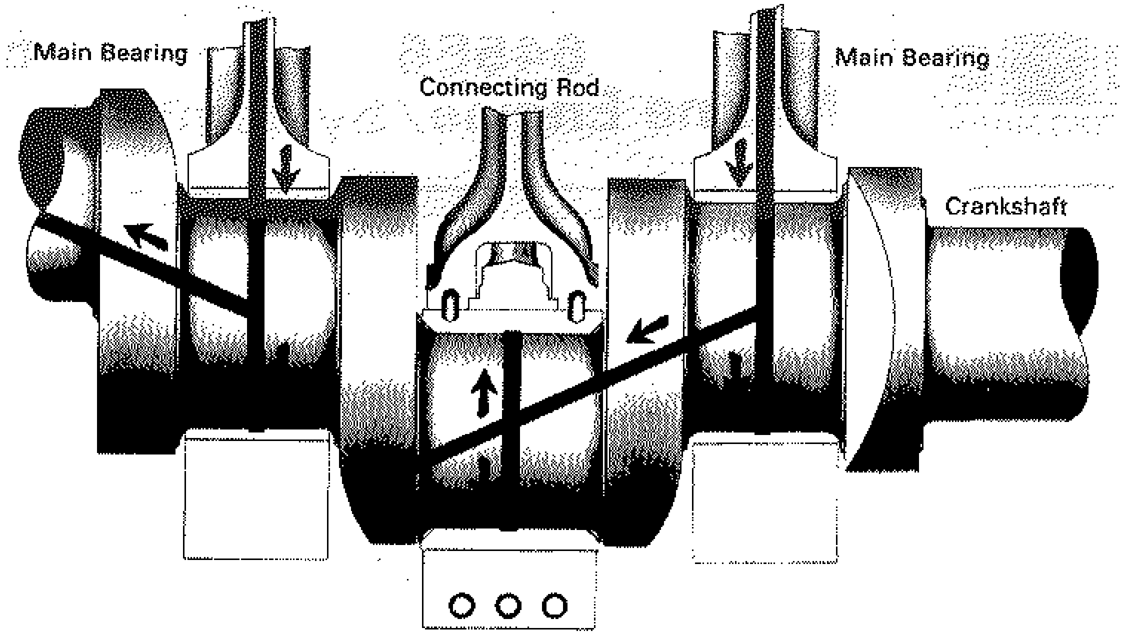

Fig. 6-2 - Crankshaft Oil Passages

journal. Damaged crankshafts can usually be reconditioned at EMD to reestablish journal size and condition to use standard size bearings. In some instances, crankshafts may have to be reground requiring the use of undersize bearings.

Attempts to grind crankshafts in the field have proven unsuccessful, as during the regrinding process, the depth of the induction hardened zone must be checked, and when necessary, rehardened. This requires special induction hardening equipment. It is therefore recommended that the crankshaft be returned for grinding. To aid identification, reground crankshafts with undersize journals or oversize thrust bearings will have this information stamped on the same cheek as the serial number.

INSTALLATION

1. Apply the main bearings to the "A" frame bores and to the bearing caps, lining up the bearing tangs.

NOTE

See "Main Bearings" for qualification of bearings.

2. Inspect the crankshaft and be sure it is clean. Oil the crankshaft journals and main bearing shells, using clean oil.

3. Place the thrust collars in their respective "A" frame counterbores, as shown in Fig. 6-3.

NOTE

Thrust collars are applied in the center "A" frame counterbores only. None are used in the corresponding main bearing caps.

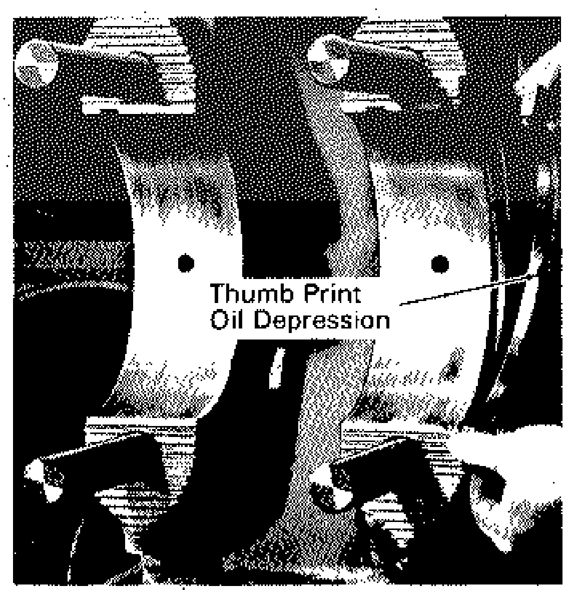

Fig. 6-3 - Applying Thrust Collar (16 & 20-Cyl.)

4. Place the crankshaft in the "A" frame bearing shells and apply the two end and two center (16 & 20-cyl.) bearing caps to hold the crankshaft in place. Apply bearing caps to "A" frames with stamped cap number facing right side of engine. The cap number must match the number stamped on the "A" frame. Check that the

studs, nut seats, and washers are lubricated with Texaco Threadtex No. 2303 and secure the caps. Tighten the nuts until they contact the bearing caps.

5. Remove the hoist or crane hooks.

6. Apply the remaining bearing shells and caps. Manually tighten the nuts until hardened washers are seated on bearing cap.

7. Using a power wrench, all nuts are torqued to 475-542 N•m (350-400 ft-lbs). After all nuts have been tightened to this torque, final torque nuts to 1 017 N•m (750 ft-lbs). Do NOT over torque.

NOTE

No one nut on any one cap should be torqued to 1 017 N•m (750 ft-lbs) until all nuts on that cap have been torqued to 475-542 N•m (350400 ft-lbs).

MAIN BEARINGS

DESCRIPTION

The main bearing shells, Fig. 64, are precision type steel-backed lead-bronze, with a thin layer of lead tin. Tangs in the bearings locate them in the proper axial position and prevent bearing turning. Upper and lower bearing shell halves are not interchangeable.

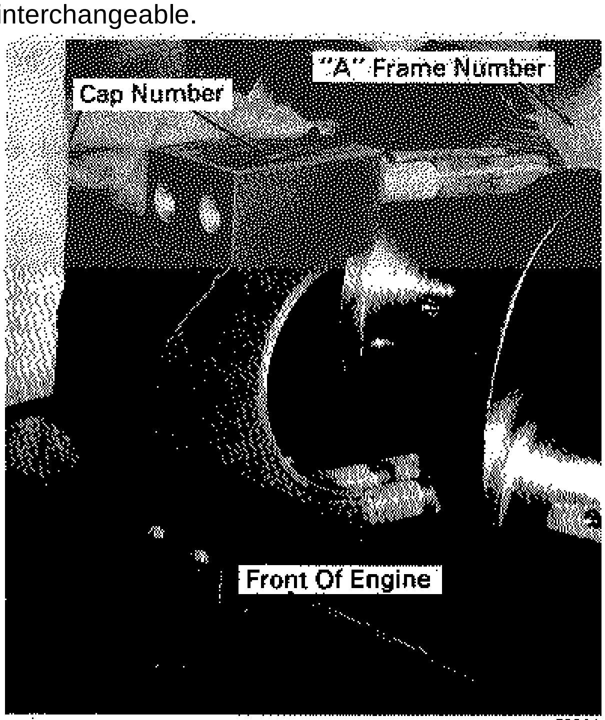

Fig. 6-4 - Main Bearing Shell And Cap

Lower main bearing shells have two tangs on each side which fit into the main bearing cap. Upper main bearing shells have one tang which fits into a groove on the right side of the "A" frame bore. Upper shells can be rotated out, in a direction opposite to normal crankshaft rotation, when the lower bearing and cap are removed on left hand rotating engines or in the normal direction of crankshaft rotation on right hand rotating engines.

MAINTENANCE

SCHEDULED RENEWAL

Lower main bearings should be renewed at the intervals specified in the Scheduled Maintenance Program.

Upper main bearings need not be removed when lower main bearings are renewed unless the lower bearings show definite signs of distress. Upper main bearings may be changed out individually as required, not in sets.

INSPECTION

UPPER MAIN BEARINGS

Inspection of upper main bearings is not recommended; however once the upper main bearings are removed, they should not be reinstalled.

LOWER MAIN BEARINGS

Lower main bearing inspection should be performed only when necessary as an element of risk is involved whenever main bearings are disturbed.

1. The lower main bearings should be inspected when abnormal conditions are observed in the engine, such as contamination of lube oil due to dilution with fuel or water, or the presence of foreign material in the lube oil filters, screens, or engine oil pan.

2. Lower main bearings need not be inspected in routine service, but should be renewed at the intervals specified in the Scheduled Maintenance Program.

INSPECTION SAMPLE

Unless evidence is present calling for other action, inspection of main bearings should be limited to the following "selected" lower bearings, which experience has shown to be the most critical. See Fig. 6-1 for main bearing numbering location.

Number Of Cylinders	Bearing Number To Be Inspected
8	2,4
12	2,6
16	2,6,9

DISQUALIFICATION CRITERIA

All lower main bearings are to be renewed if any one lower main bearing is disqualified at any one of the "selected" bearing locations indicated above, or at any additional locations inspected for other reasons.

The following numbered paragraphs give examples of conditions requiring renewal of all lower main bearings.

1. Any one bearing shows evidence of overheat. An overheat condition results in flowing of the overlay, and discoloration of exposed bronze. (An upper main bearing is to be renewed when the corresponding lower bearing shows evidence of overheat.)

2. Any one bearing shows a milky white color on the overlay. (This is evidence of an extremely thin overlay and indicates water contamination.)

3. Any one bearing has an area of wear-exposed bronze 3.18 mm (1/8") or more wide running along either edge, or if two or more bearings have any exposed bronze.

NOTE

The lead-tin overlay on the bearings must be present to provide an adequate safety margin against temporary marginal lubrication or corrosive conditions. Exposed bronze in healed dirt cuts does not affect bearing operation, but exposed bronze due to wear does cause a bearing to lose its protection against temporary marginal lubrication conditions.

4. Exposed bronze due to isolated abnormal wear or overlay flaking.

5. Severe fretting along the mating edge of the upper and lower bearing. (The corresponding upper bearing should be renewed at any location exhibiting severe fretting, and bearing cap serrations inspected for possible damage.)

6. Severe dirt scratches or dirt impregnation resulting in an abrasive surface.

CAUTION

Dirt impregnation or scratches are evidence that bearing oil is not properly filtered. The filtration system should be checked, and scheduled pressure monitoring of lube oil filter condition established.

INSPECTION PROCEDURE

A visual inspection is made by dropping the main bearing cap, with the bearing in it, low enough to make the inspection without removing the cap from the studs or the bearing from the cap. Removal of a reusable main bearing from the cap may result in improper reseating. Bearing removal also allows the possibility of replacing the bearing in a reversed position or at the wrong journal location. Either condition can lead to early failure. In addition, removal of the cap from the studs involves the risk of damage by dropping and the risk of replacing the cap backwards.

If a reusable bearing is inadvertently removed from the cap during inspection, perform the following:

1. Determine the previous bearing position by matching the wear patterns on the cap bore and the back of the bearing. If this cannot be done, a new bearing should be installed. This is the only case where a lower main bearing may be renewed independently.

2. When previous position is determined, mark a mud pocket to identify right or left bank side.

3. Thoroughly clean the bearing back and cap bore. Remove any raised material in fretted areas. High spots may distort the bearing and cause premature failure.

4. Thoroughly clean the cap and "A" frame serrations before assembly.

REMOVAL AND APPLICATION

Lower main bearings are to be removed with the bearing caps, and new bearings installed in the caps before the caps are reapplied. It is recommended practice to install new bearings with the part numbers towards the accessory end of the engine. A main bearing cap application and removal tool is available for removal and application of main bearing caps.

All upper main bearings, except No. 5 on 8-cylinder engines, No. 7 on 12-cylinder engines, Nos. 5 and 6 on 16-cylinder engines, Fig. 6-1, are removed by inserting the upper main bearing shell remover into the journal oil passage and rotating the crankshaft opposite to the normal direction of rotation on left- had rotating engines. Right-hand rotating engines must be turned in the same direction as normal crankshaft rotation to remove the upper main bearings. Upper main bearings on journals without oil holes or which are fretted (or welded) to the "A" frame bore can be removed by using upper bearing removal tool.

New upper main bearings are to be fitted by hand between the crankshaft and steel bore. If the bearings can not be hand fitted, the reason must be found and corrected. The engine may have to be removed and the crankcase remanufactured.

To apply the main bearings, see the instructions for installation of crankshaft.

SPECIAL PROCEDURES FOR

OVERHEATED BEARINGS

If an overheat condition is detected, all lower main bearings are to be renewed. Upper main bearings are to be renewed only at the overheat locations. In addition to routine cleanup of main bearing caps and "A" frame serrations, perform the following:

1. Measure main bearing cap serration spacing, using serration gauge. If the gap is closed in more than 0.51 mm (.020") from nominal (dial indicator on gauge set to zero with master bar), the engine should be removed and the crankcase remanufactured.

2. If new upper main bearings can not be hand fitted between the crankshaft and the steel bore, the reason must be found and corrected. The engine may have to be removed and the crankcase remanufactured.

3. If crankcase inspections proved satisfactory and new bearings are installed, perform a "feel over" check after the break-in run. The main bearing caps should be lowered on the studs at the locations where the overheat was detected, and a bearing inspection made.

4. Bearing inspection should be repeated at the overheat locations at the end of one month of operation, and at the end of three months of operation.

THRUST COLLAR

DESCRIPTION

The thrust collars (two), Fig. 6-5, are solid bronze and are semicircular in shape. One face of each collar has "thumb print" oil depressions to ensure adequate lubrication. They are placed in the counterbore of each center bearing "A" frame and are held in position by the bearing caps. Their purpose is to limit the longitudinal movement of the crankshaft.

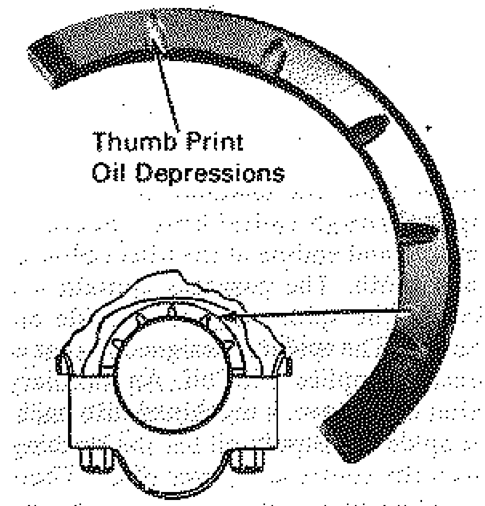

Fig. 6-5 - Crankshaft Thrust Collars (Two Collars For Each Engine)

The thrust surfaces are lubricated by main bearing leak-off oil and are installed with their "thumb print" oil depressions away from the "A" frame in which they are placed.

MAINTENANCE

Thrust collars which exceed clearance limit should be replaced.

GEAR TYPE TORSIONAL DAMPER

DESCRIPTION

The gear type damper, Fig. 6-6, is a hydraulic paddle wheel device which absorbs torsional vibrations of the crankshaft by forcing engine lubrication oil through narrow passages in the damper. The damper consists of a spider, with external spur teeth, an intermediate ring, with internal spur teeth, and two outer side plates secured with bolts and nuts. A continuous circulation of oil is provided to the damper through an oil passage in the crankshaft.

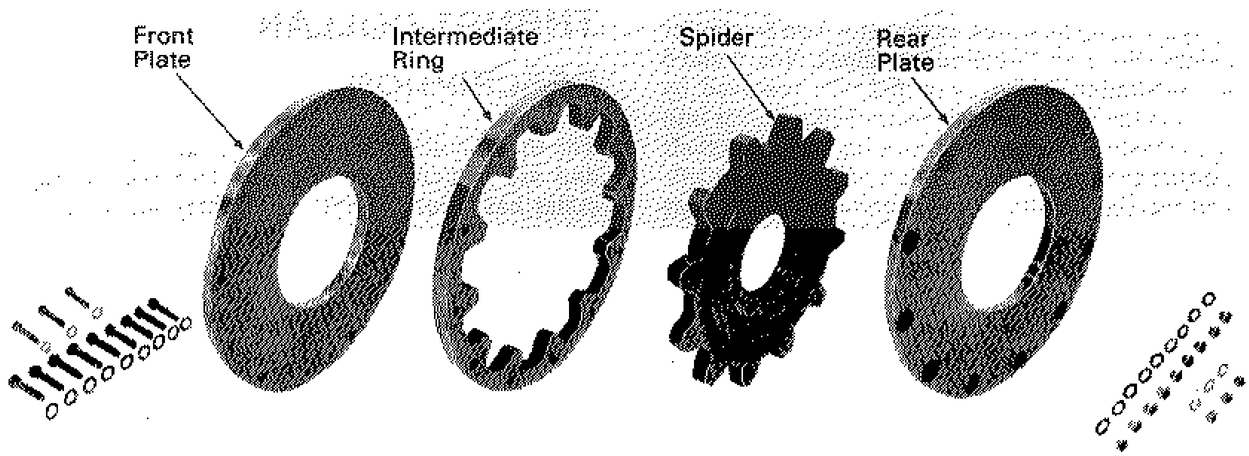

Fig. 6-6 - Gear Type Damper, Exploded View

Oil flows from the chamber in the center of the damper through radial holes, beginning in the spider hub and ending at the fillet radius at the base of each tooth. The passages contain a narrowed section at the spider hub to provide an oil flow restriction. The spider is designed so that each tooth is directly supplied with oil. An auxiliary circumferential oil groove is machined into each side face of the spider to supply oil for the rubbing surfaces between the spider and outer plate. These grooves are supplied by means of passages connecting the grooves to the radial holes.

The intermediate ring is ground on both sides to a uniform thickness, slightly thicker than the spider. This difference in thickness provides the axial clearance necessary for proper oil passage. In addition, clearance between the intermediate ring and the spider is provided to allow the ring to "float" on the oil film generated at the tips of the spider teeth.

Four vent holes are drilled through the rim of the intermediate ring to relieve oil pressure and readjust the ring to a central position when it becomes displaced. The holes, which are equally spaced around the ring, are normally covered by the tips of the spider teeth. However, oil is permitted to vent when the intermediate ring becomes displaced and the spider teeth no longer cover the holes; thereby reducing pressure. The higher pressure on the opposite side of each tooth then prevails and restores the intermediate ring to its correct position. This design is used to prevent sudden bumping of the teeth.

Two identical outer side plates are secured to the intermediate ring by means of through bolts. The inner faces of the plates (adjacent to the spider) are covered with oil which flows through the clearance between the spider and the outer plates and drains to the crankcase.

MAINTENANCE

The damper requires no maintenance other than inspection at the time of normal overhaul. However, the damper should be checked for free movement as specified in the applicable Scheduled Maintenance Program. This check can be performed by removing the front handhole covers and rotating the damper about 100 in each direction. If the damper cannot be moved, it should be removed and disassembled.

DISASSEMBLY

1. Scribe a line across the outer plate, intermediate ring, and outer plate. Also mark the relationship of the spider to the outer plate. These marks will be used during reassembly of the unit.

2. Using 1-1 / 8"thinwall sockets, remove nine 3/4" bolts, washers and nuts from damper.

3. Using 15/16" thinwall sockets, remove three 5/8" bolts, washers and nuts from damper.

4. Remove front plate, intermediate ring, and spider from rear plate.

INSPECTION

1. Inspect vent holes and gear tooth pockets of intermediate ring for sludge or other obstructions. Remove debris from vent holes using a wire or thin metal rod. Clean deposits from tooth pockets with a suitably pointed wooden stick.

2. Inspect axial oil feed holes and I.D. circumferential oil groove in the spider. Clean oil holes

using a wire or thin metal rod. Clean circumferential oil groove with a pointed wooden stick.

3. Clean all components with fuel oil and examine all surfaces for excessive scratching or scoring.

4. High points due to minor galling or scoring may be cleaned up by filing and stoning.

ASSEMBLY

1. Place front plate with stamped serial number and part number facing down.

2. Apply a liberal coating of engine oil to all contact surfaces between the spider and the intermediate ring, and the inner and outer plates.

3. Place spider on front plate with stamped "FRONT" facing down, and align scribe mark on spider to line on front plate.

4. Place intermediate ring on front plate so internal teeth mesh with teeth of spider and scribe mark on ring aligned with mark on front plate.

5. Position rear plate on intermediate ring and align scribe marks.

6. Apply Texaco Threadtex No. 2303 to threads of three 5/8" body bolts and install bolts and washers in 5/ 8" holes of rear plates, intermediate ring, and front plate.

CAUTION

Apply Texaco Threadtex No. 2303 to bolt threads only. Excessive use of this material may cause it to accumulate in gear tooth pockets and restrict spider movement. Do not use this material as a lubricant coating for contact surfaces.

7. Install 5/8" washers and nuts and torque to 203 N-m (150 ft-lbs).

8. Apply Texaco Threadtex No. 2303 to threads of nine 3/4" bolts and install bolts and washers in remaining holes of rear plate and secure with washers and nuts torqued to 325 N•m (240 ft-lbs).

INSTALLATION

Install damper on crankshaft with side of spider stamped "FRONT" facing away from engine. An "O" stamped above one of the mounting holes is to be applied in line with the number one crank pin. Apply Texaco Threadtex No. 2303 to mounting bolt threads and all thrust faces and install eight mounting bolts and hardened washers. Torque to specified value.

NOTE

When applying Texaco Threadtex No. 2303 to spider hub thrust faces, use care to prevent material from accumulating in I.D. circumferential oil groove.

ACCESSORY DRIVE GEAR TRAIN

DESCRIPTION

The accessory drive gear train, Fig. 6-7, is located at the front of the engine, and provides power from the crankshaft to drive the oil pumps, water pumps, and the governor.

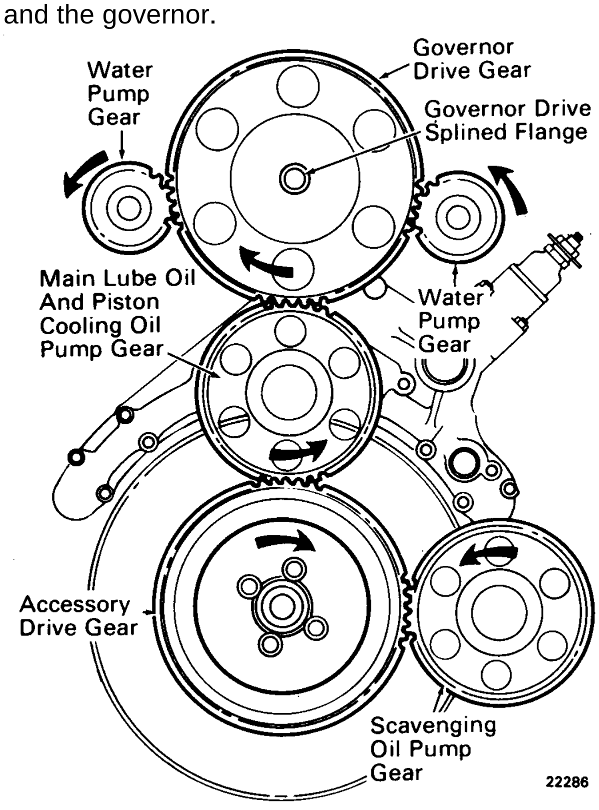

Fig. 6-7 - Accessory Drive Gear Train

The gear train consists of the accessory drive gear, scavenging oil pump gear, main lube oil pump gear, right and left hand water pump gears, and the governor drive gear.

The accessory drive gear, governor drive gear and the accessory drive housing are aligned and mounted directly on the engine. The oil pumps, water pumps, and governor drive housing are mounted on the accessory drive housing.

MAINTENANCE

Unless a complete engine disassembly is being undertaken it is unlikely that the entire gear train would be removed from the engine at one time.

The water pumps, oil pumps, and governor drive assembly can be removed from the gear train as individual units. Removal of the accessory drive gear or the governor drive gear requires removal and realignment of the accessory drive housing.

ACCESSORY DRIVE GEAR

DESCRIPTION

The coil spring design accessory drive gear, Fig. 6-8, damps the transmission of crankshaft torsional vibrations to the accessory gear train. The accessory drive gear meshes directly with and provides the drive for the lube oil scavenging pump and the main lube oil and piston cooling oil pump.

MAINTENANCE

The accessory drive gear should be removed and inspected at the time of a complete engine overhaul. The accessory drive gear requires very little maintenance. At inspection intervals, it should be disassembled for inspection of parts.

Parts which show obvious damage should be replaced.

REMOVAL

The following removal procedures apply to gears mounted on standard crankshafts and to gears mounted on bolt-on stubshafts.

STANDARD CRANKSHAFT

1. Remove four accessory drive gear mounting bolts and hardened washers securing gear to crankshaft.

2. Remove oil slinger.

3. Remove gear from crankshaft.

BOLT-ON STUBSHAFT

The stubshaft is mounted to the crankshaft with eight 7/8"-14 Hex head bolts which allows removal and application of the accessory drive gear without removing the stubshaft from the crankshaft.

1. Remove eight spline head accessory drive gear mounting bolts and hardened washers securing gear to stubshaft.

2. Remove oil slinger.

3. Remove gear from stubshaft.

GEAR

The gear should be inspected for rough or scored surfaces on the gear teeth, and magnaflux inspected.

If wear in excess of maximum limit occurs on the drive side of holes, the gear should be reversed. The serial number side of the gear is placed adjacent to

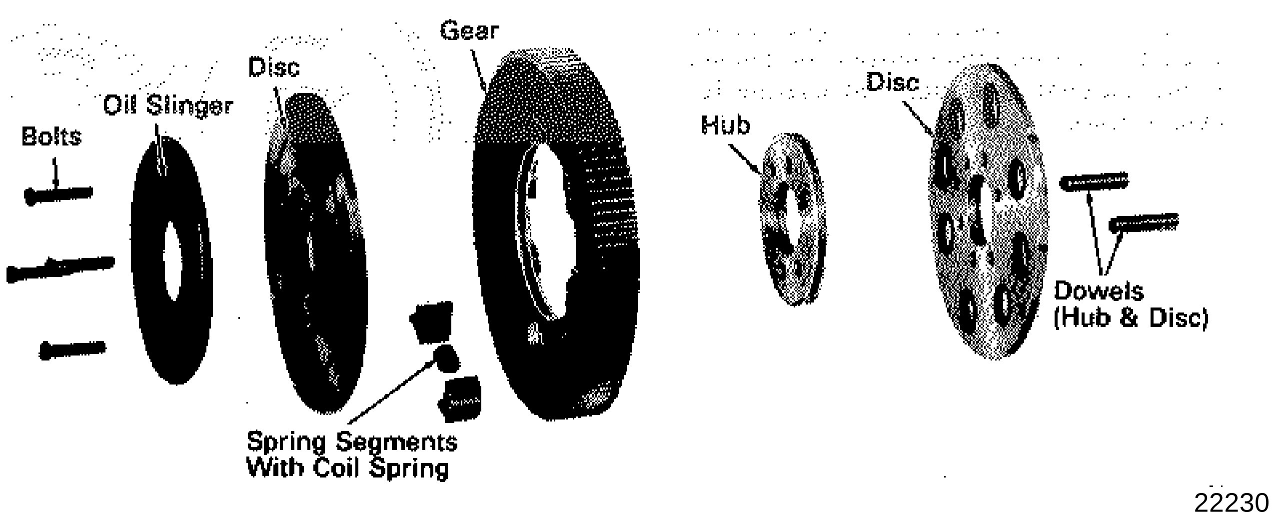

Fig. 6-8 - Accessory Drive Gear, Exploded View the oil slinger at original installation. To identify the drive side when gear is reversed, the original serial number should be ground off and restamped on the opposite side.

The maximum bore diameter is permissible, provided that the hub to gear clearance does not exceed the maximum limit. (This bore may be chrome plated and reground to new dimension.)

HUB

A hub having a 190.436 mm (7.4975") diameter may be used if the maximum hub to gear clearance is not exceeded.

DISC

The disc may be re-used providing the spring segment bores do not exceed maximum diameter and are otherwise in good condition.

SPRING SEGMENTS

Spring segments should be marked, prior to disassembly, as to their relative position in the gear.

Wear should be checked on the right-hand segment half (viewed at 12 o'clock position) where the segment contacts the gear bore when driving the gear. If wear at this point exceeds maximum limit, the segment half should be replaced.

When reassembling spring segments, re-locate the segment, originally on the driven side, to the drive side, and place the replacement segment at the driven side of the gear.

SPRINGS

Springs may be re-used providing a pre-load exists at assembly of the spring and segments in the gear.

PHOSPHATE TREATMENT

It is recommended that the gear, hub, discs, and segments be phosphate treated before reassembly.

ASSEMBLY

Before reassembling the drive gear, be sure all parts are clean and well lubricated. Place the slotted disc on the bench with the slots facing down, and apply the gear over the disc. Align the holes in the gear and disc. Place a coil spring between two segments, and with the tabs down, and the assembly pressed together, start it into the gear. Drive the assembly all the way down, using a rawhide mallet, until the tabs enter the slot in the disc. Repeat this operation for the remaining spring assemblies. After they are in place, install the hub in the gear bore, and the remaining spring assemblies. After they are in place, install the hub in the gear bore, and apply the top disc. Line up the dowel holes in both discs and hub, and apply the dowels. A snug dowel fit should be maintained by reaming, and if necessary, applying oversize dowels. A bolt and nut should be used to clamp the assembly together until it is applied to a crankshaft.

INSTALLATION

The following procedures apply to crankshaft mounted gears and to bolt-on stubshaft mounted gears.

CRANKSHAFT MOUNTED

1. Install accessory drive gear on crankshaft and align mounting holes with holes in crankshaft.

2. Install oil slinger and align mounting holes with holes in gear.

3. Lubricate four mounting bolts with Texaco Threadtex No. 2303. Install bolts and hardened washers and torque to specified value.

BOLT-ON STUBSHAFT MOUNTED

1. If stubshaft has not been installed, align stubshaft retention mounting bolt holes with holes in crankshaft and secure stubshaft to crankshaft with eight 7/8"-14 hex head bolts torqued to specified value.

2. Install accessory drive gear on crankshaft stubshaft and align mounting holes with holes in stubshaft.

3. Install oil slinger and align mounting holes with holes in gear.

4. Lubricate eight spline head mounting bolts with Texaco Threadtex No. 2303. Install bolts and hardened washers and torque to specified value.

GOVERNOR DRIVE GEAR AND STUBSHAFT

DESCRIPTION

The governor drive gear is mounted on the governor drive stubshaft, Fig. 6-9, and is driven by the main lube oil and piston cooling pump gear. The

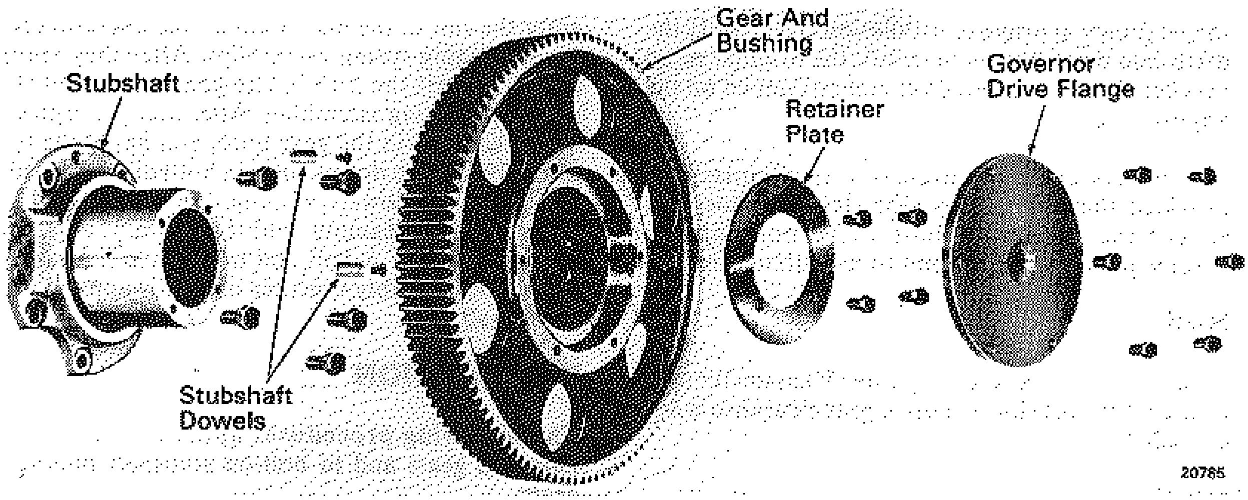

Fig. 6-9 - Governor Drive Gear and Stubshaft

governor drive gear is used to drive the water pump and the governor drive assembly.

MAINTENANCE

The governor drive gear and stubshaft require no maintenance other than inspection at the time of normal overhaul.

Inspect gear teeth for fatigue indications, cracks, pits or other evidence of failure. If possible, a magnaflux inspection should be performed. Inspect the gear bushings and stubshaft for gouges or other damage and ensure that stubshaft oil passage is not plugged.

INSTALLATION

1. Position stubshaft on crankcase with oil inlet on left side.

2. Secure stubshaft to crankcase using four 1/2"-20 hex head drilled bolts. Do not torque bolts at this time.

3. Apply governor drive gear assembly to stubshaft.

4. Place "dummy" main lube oil pump gear on top of accessory drive gear with teeth meshed with accessory drive gear and governor drive gear.

NOTE

Drive gear from main lube oil pump can be removed from pump for use as "dummy" gear if suitable spare gear is not available.

5. Raise or lower governor drive gear stubshaft until backlash' between governor drive and 6 main lube oil pump gear is 0.41-0.81 mm (0.016"-0.032").

NOTE

Since the "dummy" oil pump gear is resting on the accessory drive gear with zero backlash, the backlash between the "dummy" gear and the governor drive gear is twice the normal requirement of 0.20-0.41 mm (0.008"-0.016").

6. Remove "dummy" gear and governor drive gear.

7. Tighten governor drive stubshaft bolts to specified value.

8. Ream the two dowel holes in the governor drive stubshaft with a 0.494" tapered reamer and a 0.4998" ± 0.0002" bottoming reamer, being sure to use cutting oil.

NOTE

If the dowel holes in governor drive stubshaft do not align with holes in crankcase, drill and ream for oversize dowels as required to produce full circumference fit. See parts catalog for listing of oversize dowels.

9. Use an air hose to blow chips and oil out of the dowel holes, and insert 1/4"-28 bolts approximately 6.35 mm (1/4") into the dowel pins.

10. Place dowels in dowel holes in the stubshaft and drive into the crankcase end plate.

11. Torque the dowel bolts to specified value and lockwire stubshaft mounting bolts and dowel bolts in groups of three or less.

12. Apply gasket between oil jumper and oil passage on stubshaft. Secure oil line to stubshaft using two 3/8"-24 hex head drilled bolts and torque to specified value. Lockwire mounting bolts.

13. Apply governor drive gear to stubshaft.

14. Install retainer plate and secure to stubshaft using four 3/8"-24 hex head bolts torqued to specified value.

15. Lockwire retainer plate mounting bolts.

16. Apply governor drive flange to governor drive gear and secure with six 3/8"-24 hex head drilled bolts torqued to specified value.

17. Lockwire flange bolts to two groups of three bolts each.

ACCESSORY DRIVE HOUSING APPLICATION AND ALIGNMENT

The following procedure is provided to properly align the accessory drive housing to the accessory drive and governor drive assemblies for subsequent application of the water and lube oil pumps.

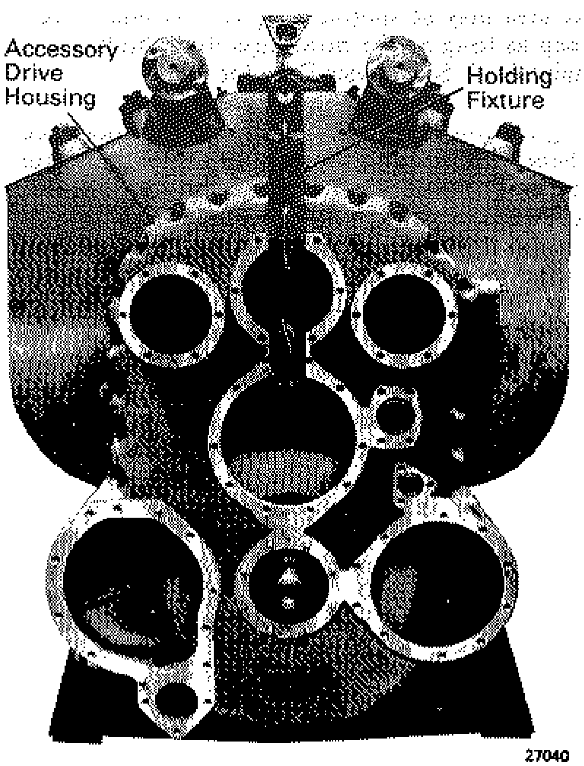

Fig. 6-10 - Accessory Drive Housing Positioning

1. Apply gasket sealing compound to accessory drive housing mounting flange, and apply gasket.

2. Place mounting bolts and washers in housing mounting holes.

3. Using holding fixture (File 758) and a suitable lifting device, position housing on crankcase, Fig. 6-10, and secure with one mounting bolt on each side of housing.

4. Remove holding fixture from housing.

5. Hand-tighten all mounting bolts.

6. Apply left-hand water pump alignment gauge (File 761) to left pump opening (right bank) in housing so that gauge gear teeth mesh with governor drive gear, Fig. 6-11.

7. Apply right-hand water pump alignment gauge (File 762) to right pump opening (left bank) in housing so that gauge gear teeth mesh with governor drive gear.

8. Apply oil pump alignment gauge (File 763) to the main lube oil pump opening in housing so that gauge gear teeth mesh with accessory drive gear. This same gauge is used to align the housing to the governor drive gear.

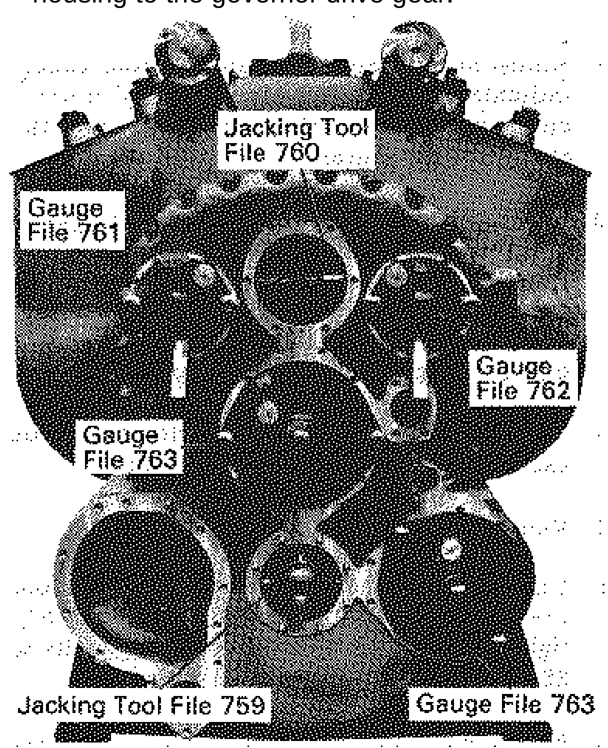

Fig. 6-11 - Accessory Drive Housing Alignment

9. Apply another oil pump alignment gauge (File 763) to scavenging oil pump opening in housing so that gauge gear teeth mesh with accessory drive gear.

10. Position jacking tool (File 759) over the end of the accessory drive shaft until the adjusting nuts are in line with the accessory drive opening, Fig. 6-1 1.

Movement of the vertical adjusting nuts will affect the gauge readings of the governor drive gear and the accessory drive gear that are taken by the alignment gauge applied to the main lube oil pump opening.

Movement of the horizontal adjusting nuts will affect the gauge reading of the accessory drive gear which is taken by the alignment gauge applied to the scavenging oil pump opening.

11. Insert spline end of jacking tool (File 760) into splines of the governor drive gear drive flange until the adjusting nuts are in line with the governor drive opening. Adjusting nuts should be in a horizontal position, Fig. 6-11.

Movement of the adjusting nuts affects the gauge readings of the governor drive gear which are taken by the alignment gauges mounted at the water pump openings.

12. Adjust both jacking tools until all four gauges indicate within 0.20-0.41 mm (0.008"-0.016") clearance between the gauge gears and the engine mounted gears.

13. Disengage the gear of the alignment gauge mounted in the main lube oil pump opening from the accessory drive gear and rotate approximately 1800 to mesh with the governor drive gear. Recheck all gauge indications of 0.20-0.41 mm (0.008"-0.016") clearance.

14. Tighten four mounting bolts, preferably one on each side, and one at top and bottom.

15. Remove both jacking tools from housing.

16. Check all alignment gauges. If all indications are within 0.20-0.41 mm (0.008"-0.016"), tighten remaining housing mounting bolts to 88 N-m (65 ft-lbs).

17. Replace oil seal cover on accessory drive housing crankshaft opening using gasket sealing compound on gasket surfaces. Apply 1/2" aircraft washers and self locking nuts on mounting studs. Tighten nuts to specified value.

RING GEAR AND COUPLING DISC (FLYWHEEL)

DESCRIPTION

The ring gear, Fig. 6-12, is used on engines equipped with starting motors. Engaging the teeth on the ring gear rotates the crankshaft for engine starting or selects a crankshaft position when using an engine turning gear device. The ring gear pilots on the engine side of the coupling disc and is bolted to the coupling disc.

The coupling disc serves as the coupling between the engine crankshaft and the driven shaft. Degree and top dead center markings are stamped on the outer rim of the coupling disc. Holes are also provided around the circumference of the rim for insertion of a turning bar to manually rotate the crankshaft.

MAINTENANCE

Inspect the engine coupling disc for cracks or damaged surfaces. Also inspect the coupling disc to crankshaft bolt holes for elongation or fretting at the bolt head mating surface. If the surface is fretted i the area may be spotfaced up to 1.59 mm (1/16") deep as long as the minimum disc thickness is maintained. See Service Data for limits.

Engine coupling discs should be re-qualified whenever the engine, the gearbox, or the generator assembly is removed. Maximum trouble free performance of the engine coupling can best be ensured by careful magnetic particle inspection of both discs prior to their reuse. This inspection is particularly important if it is known that the coupling has been subjected to unusual stress.

Engine coupling discs of the same type are interchangeable, providing top dead center pointer location on the engines is the same. The serrated coupling is assembled without using body bound bolts and for this reason has no reamed holes. All rim bolts are the same size. The coupling disc should be applied to the crankshaft with the small "O" marks on the coupling disc and the crankshaft coinciding. This will position the coupling with the point at the 0° mark on the rim when the No. 1 piston is at TDC.

Apply Texaco Threadtex No. 2303 to engine coupling bolts and install indicator brackets (if used) with the first having the tapped hole lined up

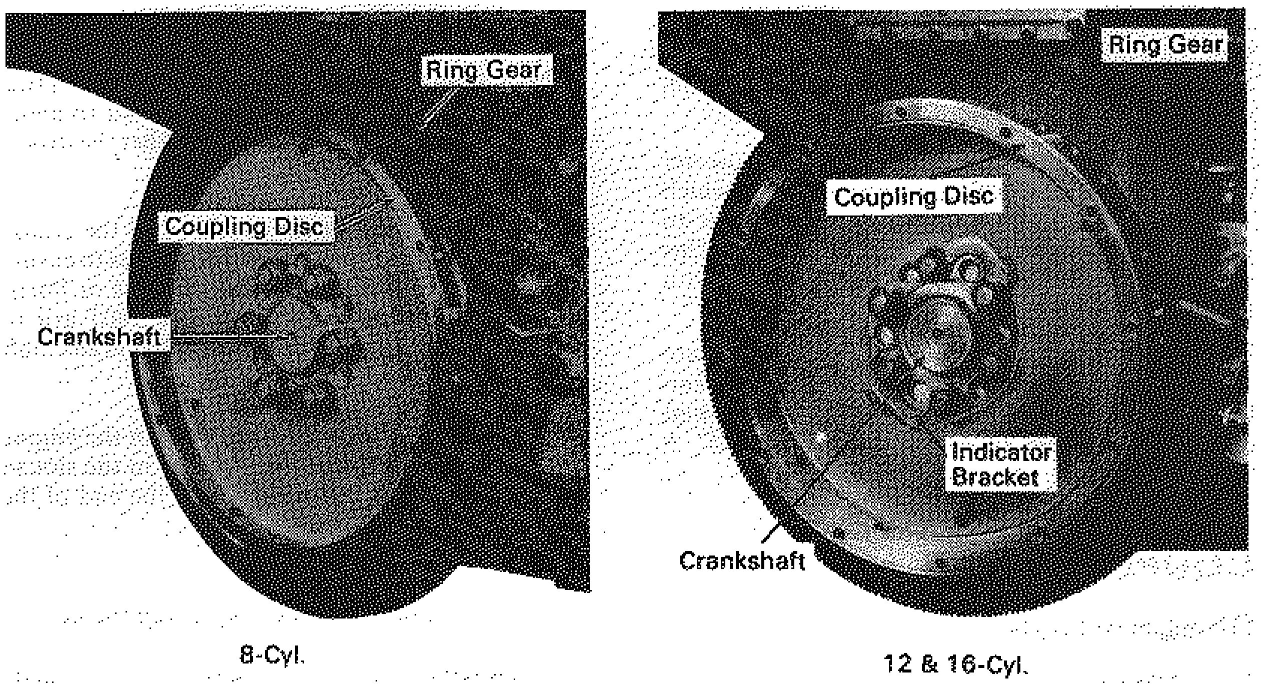

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Fig. 6-12 - Typical Ring Gear And Coupling Disc Installations

with the engine barring hole nearest the TDC mark and the second bracket 180° apart from the first. Tighten coupling bolts to specified value. Tighten the rim bolts uniformly (to avoid cocking the coupling on the serrations) to specified value. The gap between the coupling halves at the rim bolts should not be less than minimum after the rim bolts have been properly torqued.

CAUTION

The coupling bolts must be applied with the chamfered side of the head placed adjacent to the crankshaft fillet.

Face runout and rim eccentricity should be checked after installation of coupling disc to crankshaft, and with crankshaft positioned to avoid thrust interference. Eccentricity of rim outside diameter and runout on rim face should not exceed maximum indicator reading listed in Service Data.

MAGNETIC SPEED PICKUP(S)

Units furnished basic with EGB-P governor (actuator) utilize a magnetic pickup mounted on the starter bracket at the engine flywheel, Fig. 6-13. Ring gear teeth passing by the pickup produce magnetic pulses which are used to generate an electrical signal voltage proportional to engine speed. The signal voltage is compared to the speed setting voltage by an electrical control unit to

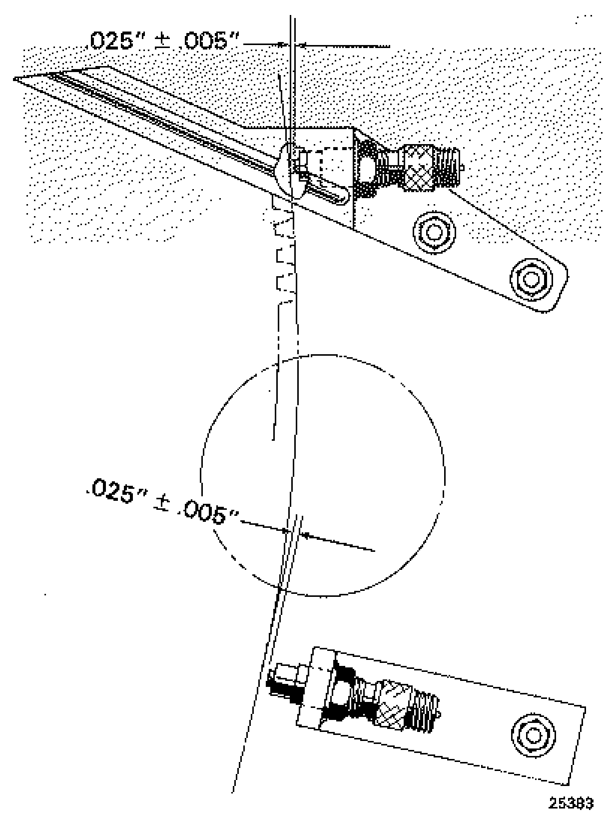

Fig. 6-13 - Mounting Of Magnetic Speed Pickup(s) position the actuator for an increase or decrease of fuel. This magnetic pickup is mounted by means of an "L" bracket at a left bank or right bank location, depending on application.

Units provided with an electronic digital tachometer also use a magnetic pickup to create pulses which are counted and processed by the tachometer to produce a numerical display of engine RPM. This magnetic pickup is usually mounted integrally with the flywheel pointer, as shown.

If the magnetic pickup is removed to facilitate engine service or rebuild, clearance between flywheel ring gear and pickup must be checked during replacement to ensure a gap of 0.025" f 0.005", as shown.

ACCESSORY DRIVE COUPLING

DESCRIPTION

The accessory drive coupling assembly, Fig. 6-14, is bolted and keyed to the tapered front end of the crankshaft to provide a power takeoff connection for components driven from the front of the engine. In some applications, the coupling is bolted to a tapered stubshaft.

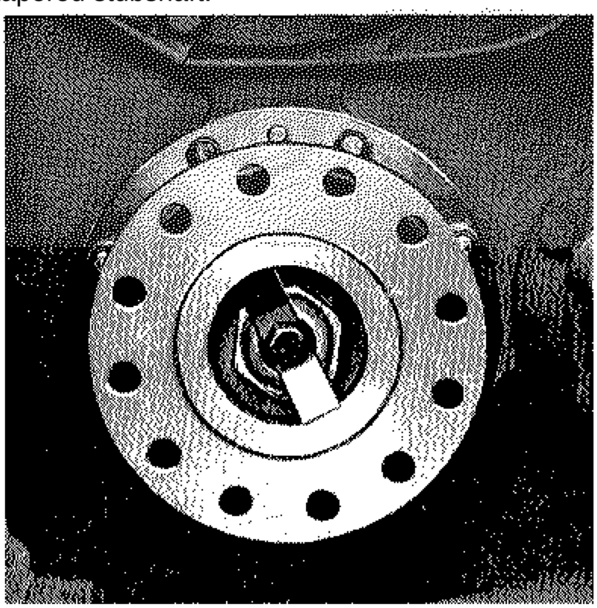

Fig. 6-14 - Accessory Drive Coupling

MAINTENANCE

The accessory drive coupling does not require any routine maintenance.

COUPLING APPLICATION

If the coupling has been removed, it is essential that the proper application procedure is used to avoid severe damage to the crankshaft of either the driven unit or the engine.

1. Prior to mounting the coupling on the crankshaft, inspect the two tapered surfaces to ensure the mating surfaces are free of nicks or burrs. Use aluminum oxide cloth of a 180J grit to clean the tapered surfaces and the crankshaft key slot.

2. Hand fit 2-1/2" key so it is tight in the engine crankshaft key slot. Tap the key in the slot so the end of the key is flush with the end of the crankshaft.

NOTE
If the key slides in the keyway, scrap the key.

3. Slide felt oil seal and oil seal retainer over barrel end of coupling flange, then fit coupling onto the shaft. Make certain that the key 'remains flush with the end of the shaft.

4. Lubricate the threads on the retaining bolt and both sides of the washer with Texaco Threadtex No. 2303. Torque the retaining bolt to 136 N•m (100 ft-lbs).

5. Attach a dial indicator to the coupling with the button of the indicator on the accessory housing or on one of the studs at the coupling seal. Zero the indicator.

6. Torque the retaining bolt to 678 N•m (500 ft-lbs) and record the advance,. measured to the nearest thousandth. Failure to obtain a reading within the limits given in the Service Data is usually caused by imperfections found on one of the tapered surfaces or within the keyway. These surfaces should be free of all nicks or burrs.

7. Install the lock spring, lockwasher, and 1/ 2"-20 bolt in the head of the retaining bolt and torque to specified value.

8. With a dial indicator button resting on the outside diameter of the coupling flange, record the T.I.R. of the rim to be sure it does not exceed the limits given in the Service Data.

9. Carefully insert oil seal into groove of seal cover and apply seal retainer with 3/8"-16 hex head bolts torqued to specified value.

SERVICE DATA
CRANKSHAFT ASSEMBLY AND
ACCESSORY DRIVE GEAR TRAIN

REFERENCES

Alignment Of Rotating Equipment..M.I. 1765

SPECIFICATIONS

Clearance and dimensional limits listed below are defined as follows:

1. New limits are those to which new parts are manufactured. (Drawing tolerances.)

2. Minimum, maximum, and tolerance measurements are provided as service limits. At time of rebuild or any time unscheduled maintenance is performed, the service limits should not be exceeded. Engine components within these limits may be reused with the assurance that they will perform satisfactorily until the next scheduled overhaul.

Crankshaft
Diameter, main journal -
New.. 90.45-190.50 mm (7.498"-7.500")
Max ....190.411 mm (7.4965")
Diameter, crankpin journal -
New...165.05-165.10 mm (6.498"-6.500")
Max. ....165.011 mm (6.4965")

Clearance (diametric main bearings to crankshaft) -
New .... 0.190-0.368 mm (.0075"-.0145")
Max . ... 0.521 mm (.0205")
Thrust Bearing Clearance -
(8 & 12-Cyl.) -
New.. 0.20-0.38 mm (.008"-.015")
Max. .... 0.76 mm (.030")
(16-Cyl.) -
New .... 0.20-0.46 mm (.008"-.018")
Max. .... 0.76 mm (0.30")

Thrust Bearing Collar Thickness -
8 &16-Cyl.. 9.35-9.37 mm (.368"-.369")
12-Cyl .... 22.07-22.10 mm (.869"-.870")
Accessory End Gear Train
Backlash (all drive gears) -
New .... 0.20-0.41 mm (.008"-.016")
Max. .... 0.64 mm (.025")

Accessory Drive Gear
Hub to gear clearance -
New .... 0.038-0.080 mm (.0015"-.0030")
Max. .... 0.089 mm (.0035")
Diameter of gear spring segment holes - New .... 50.95-51.05 mm (2.006"-2.010")
Wear on drive side of gear - Max.. 0.02 mm (.001")

Gear bore diameter -
New ....190.50-190.53 mm (7.500"-7.501")
Max. .... 190.55 mm (7.502")
(If hub to gear maximum clearance is not exceeded)

Hub outside diameter - Min ....190.436 mm (7.4975")
(If hub to gear maximum clearance is not exceeded)

Disc spring segment bore - Max.. 51.08 mm (2.011") I)
Spring segment wear (right half as viewed
from 12 o'clock position) - Max .... .0.02 mm (.001")

Governor Drive Gear
Governor drive gear to stubshaft clearance
New .... 0.08-0.15 mm (.003"-.006")
Max . ... 0.20 mm (.008")

Thrust clearance
New .... 0.15-0.36 mm (.006"-.014")
Max. .... 0.51 mm (.020")

Flexible Coupling
Crankshaft pilot diameter - Max. ....203.264 mm (8.0025")
Mounting bolt hole diameter - Max. .... 45.212 mm (1.780")
Thickness at mounting bolt holes - Min. .... 17.462 mm (.6875')

Clearance between coupling discs at
rim bolts, after bolts are torqued - Min. ....0.038 mm (.0015'")

Coupling face runout (taken at machined groove) - Max.. 0.25 mm (.010') T.I.R.

Coupling rim eccentricity - Max .... 0.13 mm (.005") T.I.R.

Accessory Drive Coupling
Coupling advance - coupling-to-crankshaft.. 0.51-1.52 mm (.020"-.060")
Coupling rim runout - Max .... .025 mm (.010') T.I.R.

EQUIPMENT LIST

	Part No.
Upper main bearing shell remover	8055837
Gasket sealing compound (0.47 liter [1 pt.])	8178639
Thread lubricant, Texaco Threadtex No. 2303 (approx. 18.93 liter [5 gal.])	8307731
Main bearing cap application and removal tool	8487487
Upper main bearing removal tool	8488833
Serration gauge	9081052
Accessory drive housing holding fixture	File 758
Accessory drive housing jacking fixture	File 759
Accessory drive housing jacking fixture	File 760
Accessory drive housing aligning gauge - L.H. water pump application	File 761
Accessory drive housing aligning gauge - R.H. water pump application	File 762
Accessory drive housing aligning gauge - Oil pump application	File 763

SECTION 7

CAMSHAFT GEAR TRAIN, AUXILIARY DRIVE, AND CAMSHAFT ASSEMBLIES

CONTENTS	PAGE

CAMSHAFT GEAR TRAIN, AUXILIARY DRIVE, AND CAMSHAFT ASSEMBLIES

CAMSHAFT GEAR TRAIN

DESCRIPTION

Power necessary to drive the camshafts, and the blowers is supplied through the gear train at the rear of the engine. Fig. 7-1 shows the gear train before the camshaft drive housing and blowers are installed, and Fig. 7-2 shows a cross-section of the gear train.

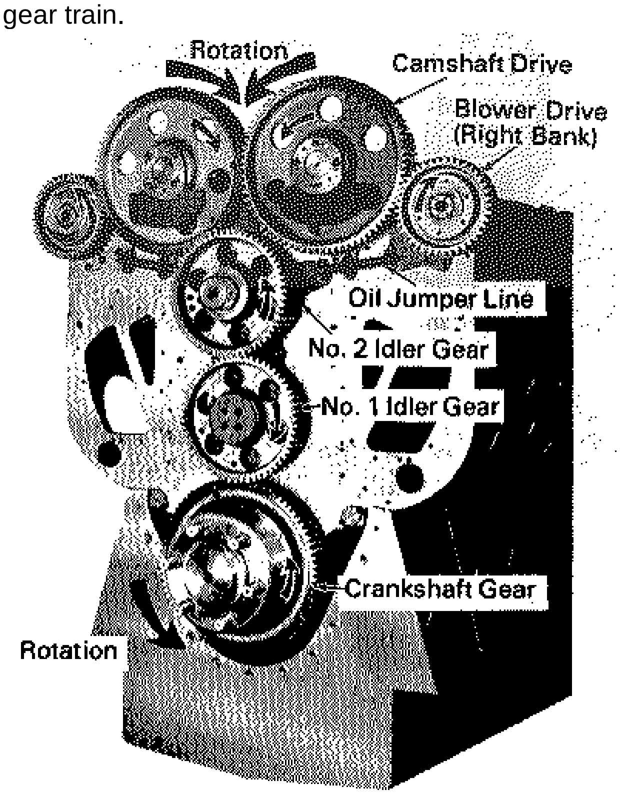

Fig. 7-1 - Camshaft Gear Train (Left-Hand Rotation Engine)

The gear train, Fig. 7-1, consists of a crankshaft gear, two idler gears, two camshaft drive gears, and the blower drive gears (one on 8-cyl. and two on 12 & 16-cyl.). The camshaft drive gears rotate inboard of the engine at the same speed as the crankshaft. The blower drive gears rotate outboard of the engine. On 12-cyl. engines, the blower drive gears are larger than those used on 8 and 16-cyl. engines and, therefore, rotate at a slower speed.

MAINTENANCE

Unless a complete engine disassembly is being undertaken, it is unlikely that the entire gear train would be removed from the engine at one time.

When any of the gears are removed from the gear train, they should be inspected for excessive backlash upon reassembly by inserting a feeler gauge the entire width of the gear face. Excessive backlash can cause improper valve operation and injection periods. Backlash clearance limits are given in the Service Data page at the end of this section. Clearances between gear stubshaft and bearings and thrust clearances must also be maintained within specified limits.

NOTE
Refer to "No. I Idler Gear" for a bearing clearance check without disassembly.

The blowers, blower supports, lube oil separator, auxiliary drive assembly, camshaft drive housing cover, and coupling disc must be removed from the engine to facilitate access to the camshaft gear train. If removal of the No. 1 idler gear or the crankshaft gear is required, the blower gears, camshaft gears, oil retainer, and camshaft drive housing must be removed.

NOTE
Engine timing will not be disturbed during idler gear removal as long as the camshafts and crankshaft are not moved when gears are removed.

If original idler gears are to be reapplied and it is desired to retain timing mark orientation for future work, mark the gears as they lie before removal.

The following paragraphs contain the removal, inspection, and installation procedures for each gear in the train.

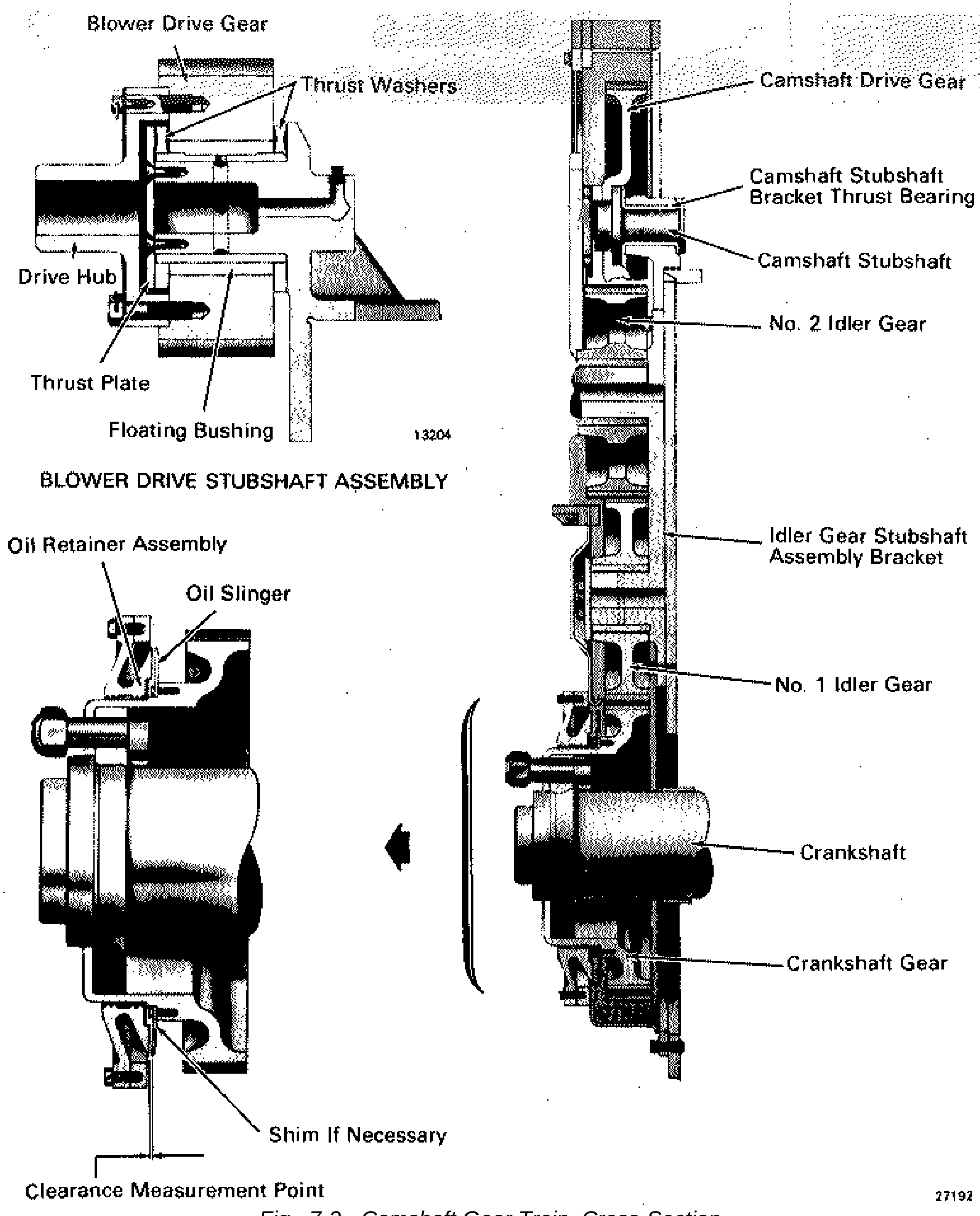

Fig. 7-2 - Camshaft Gear Train, Cross-Section

BLOWER DRIVE GEARS

REMOVAL

1. Remove the blower drive hub by removing the lockwire and the blower drive hub bolts.

2. Remove the thrust plate screws, thrust plate and outer thrust washer from the blower drive stubshaft assembly.

3. Pull the blower drive gear, inner thrust washer, and floating bushing from the stubshaft assembly.

INSPECTION

Inspect the gear teeth for fatigue indications, cracks, pits, or other evidence of failure. If possible a magnaflux inspection should be performed. Inspect the floating bushing to see that it is not gouged or damaged in any way.

INSTALLATION

1. Install the floating bushing on the stubshaft.

2. Slide the inner thrust washer over the floating bushing until it is flush against the stubshaft.

3. Install the blower drive gear and outer thrust washer on the floating bushing and secure with the thrust plate and thrust plate screws.

4. Install the drive hub, drive hub bolts, and drive hub dowels. Tighten the thrust plate bolts and apply lockwire.

CAMSHAFT DRIVE GEARS

REMOVAL

1. Remove the lockwire and the four bolts holding the counterweight and camshaft drive gear to the stubshaft.

2. Remove the dowel bolts and the retainer plate.

3. The counterweight and camshaft drive gear can now be removed from the stubshaft.

4. Remove the dowels from the counterweight and camshaft drive gear by driving them out from the back side of the gear.

INSPECTION

Inspect the gear teeth for fatigue indications, cracks, pits, or other evidence of failure. If possible a magnaflux inspection should be performed.

INSTALLATION

1. Install the camshaft drive gear on the stubshaft being sure to position it on the stubshaft so the position markings line up with the markings on the mating parts, as shown in Fig. 7-20.

2. Install counterweight on stubshaft with counterweight to stubshaft marks aligned.

3. Install dowels, dowel retainer plate, and counterweight to stubshaft bolts. Torque bolts to specified value.

4. Install dowel bolts and torque to specified value.

5. Lockwire mounting bolts and dowel bolts in groups of three (two mounting bolts and one dowel bolt).

6. If any gears in the camshaft gear train are replaced or the relationship of the crankshaft to the camshaft has been disturbed, refer to "Exhaust Valve Timing" at the end of this section for information on positioning and marking of gears.

NO. 2 IDLER GEAR ASSEMBLY

REMOVAL

The upper idler gear can be removed simply by pulling it off the stubshaft once the lube oil separator and camshaft drive housing cover have been removed.

INSPECTION

Inspect the gear teeth for fatigue indications, cracks, pits, or other evidence of failure. If possible a magnaflux inspection should be performed. Inspect the idler gear bearings to see that they are not gouged or damaged in any way.

INSTALLATION

1. Install the idler gear on the idler gear stubshaft, being sure the tooth position marks are aligned as shown in Fig. 7-20.

2. If a new gear is used, refer to "Timing Exhaust Valves" at the end of this section for information on positioning and marking of gears. Timing procedures are not required if camshaft and crankshaft positions have not been disturbed.

NO. 1 IDLER GEAR

BEARING CLEARANCE CHECK WITHOUT DISASSEMBLY

The No. I idler gear bearing clearance can be checked without any disassembly of the engine.

1. Remove the rear left bank oil pan handhole cover and insert the clearance checking rod assembly into the camshaft drive housing so the end with the flattened side is at the bottom.

2. Position the rod so the bracket mount straddles the crankcase endplate, and the top of the rod contacts the side of the No. 1 idler gear, Fig. 7-3. Hand tighten the bracket bolt.

3. Apply the light tension spring between the lower part of the rod and the edge of the handhole opening, Fig. 7-3, to maintain idler gar to rod contact.

4. Secure the support clamp of a dial indicator to the edge of the handhole opening. Position the indicator plunger so that it contacts the flattened side of the rod, Fig. 7-3.

5. With the cylinder test valves closed, use the engine turning bar, and manually rock the crankshaft as many times as necessary to remove the oil from the idler gear bearing. This will be evidenced on the dial indicator by no increase over previous reading taken for each direction of crankshaft travel.

6. Bar the crankshaft slightly in one direction until there is no further dial indicator movement, and set the indicator to zero. Bar the crankshaft in the opposite direction until there is no further dial indicator movement, and note reading.

Multiply the reading by 1.3 to obtain No. 1 idler gear bearing clearance. Refer to limits in Service Data.

NOTE

It may be necessary to lock the left bank camshaft in order to provide sufficient load on the No. I idler gear to obtain full movement. This should be done if clearance does not fall within the limits given in Service Data.

If idler gear is to be removed, refer to the following procedures.

REMOVAL

1. Remove the four bolts and washers holding the thrust plate and idler gear.

2. Remove the thrust plate and idler gear from the stubshaft.

INSPECTION

Inspect the gear teeth for fatigue indications, cracks, pits, or other evidence of failure. If possible a magnaflux inspection should be performed.

INSTALLATION

See "Camshaft Gear Train Assembly" for complete installation procedure.

NOTE
Photo at right was taken without the camshaft drive housing to illustrate the rod assembly-to-idler gear application.

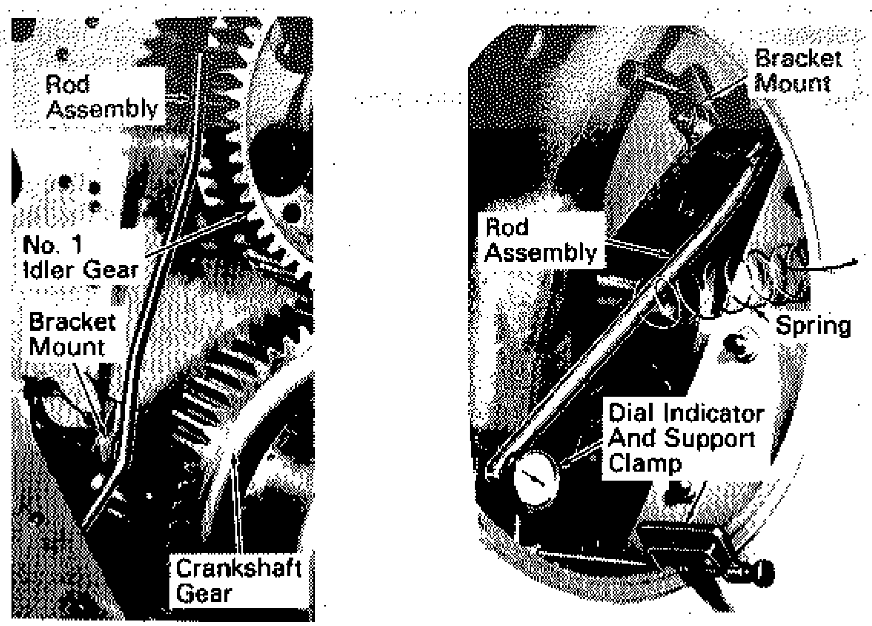

Fig. &-3 - Application Of Parts For Checking Bearing Clearance

IDLER GEAR STUBSHAFT ASSEMBLY

REMOVAL

1. After the idler gears and the attached oil lines have been removed, the stubshaft assembly can be taken off.

2. Remove the lockwire, dowel bolts, and the locating dowels.

3. Remove the mounting bolts and stubshaft assembly.

INSPECTION

1. Check that oil passages are not plugged.

2. Check alignment of oil holes in stubshaft bearings with holes or passages in stubshafts. Oil holes in upper stubshaft bearing must line up with holes in stubshaft within 0.8 mm (1/32"). Oil hole in lower stubshaft bearing must be directly opposite oil passage in stubshaft.

3. Inspect sleeves for nicks or gouges.

BEARING REPLACEMENT

1. To remove a press fit bearing from the idler stubshaft assembly, heat the bearing until it can be removed.

2. Install new bearing by heating bearing in oil to 149-163° C (300-325° F) and pressing on stubshaft. Make certain that oil holes in upper stubshaft bearing are aligned to within 0.8 mm (1/32') of oil holes in stubshaft. Oil hole in lower stubshaft bearing must be in the 12 o'clock position and in line with oil passage in stubshaft.

INSTALLATION

If a new stubshaft assembly is to be applied, see "Camshaft Gear Train Assembly" for installation procedure. If the stubshaft assembly that was removed from the engine is to be re-used, see the following installation procedure.

1. Attach the stubshaft assembly to the crankcase with the three vertically centered mounting bolts, and finger tighten.

2. Apply the lower idler gear to the stubshaft assembly to mesh with the crankshaft gear.

3. Place a feeler gauge between the lower idler and crankshaft gear teeth and check the backlash. Backlash limits are in the Service Data.

4. If necessary, reposition the stubshaft assembly until the allowable backlash is obtained.

5. Apply the remaining stubshaft assembly mounting bolts, and torque all bolts.

6. Install dowels and dowel bolts, and lockwire all bolts.

7. Apply the oil lines to the stubshaft bracket.

CRANKSHAFT GEAR

REMOVAL

1. Remove crankshaft gear from crankshaft.

2. The oil slinger can be removed from the crankshaft gear by removing the oil slinger to crankshaft gear bolts.

INSPECTION

Inspect the gear teeth for fatigue indications, cracks, pits, or other evidence of failure. If possible a magnaflux inspection should be performed. Inspect the oil slinger and oil seal retainer to see that they are not bent or damaged in any way.

INSTALLATION

See the "Camshaft Gear Train Assembly" information for complete installation procedure.

CAMSHAFT GEAR TRAIN ASSEMBLY

If the complete gear train has been disassembled (not including the camshaft stubshaft brackets), the following procedure should be used to install and align the various components.

STUBSHAFT BRACKET APPLICATION

1. Inspect the crankcase end plate for any burrs or damaged areas.

2. Clean any dirt or debris from the holes in the end plate or the end plate surface.

3. Wipe the crankshaft gear teeth clean, insert the coupling bolts in the gear from the back side and install it in its proper position on the crankshaft, as shown in Fig. 7-20. Secure the crankshaft gear with two nuts, moderately tightened.

If a new gear is used, refer to "Exhaust Valve Timing" at the end of this section for information on positioning and marking of gears. Timing procedures are not required if camshaft positions have not been disturbed.

4. Inspect the stubshaft bracket rear surface for burrs and wipe clean, making sure all oil passages are clean and free of dirt.

5. Install two temporary locating pins, Fig. 7-4, into the idler gear stubshaft mounting holes in the crankcase end plate. 20410

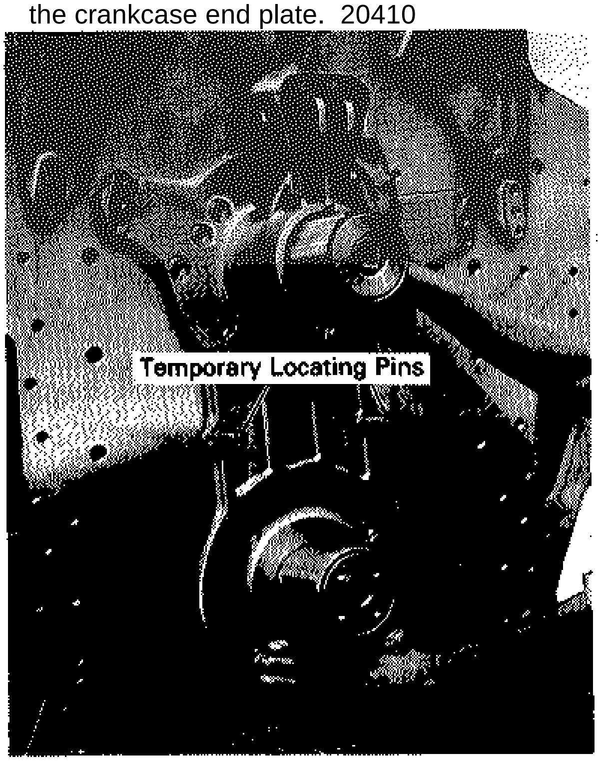

Fig. 7-4 Stubshaft Bracket Application

6. Install the stubshaft bracket in position and apply the three vertically centered 1/2"-20 mounting bolts with hardened washers. Finger tighten the mounting bolts.

7. Apply the idler gear gauge, File 768, to the No. 1 idler gear stubshaft, Fig. 7-5, and place a feeler gauge between the idler gear gauge teeth and the crankshaft gear teeth to check the gear backlash which is specified in the Service Data at the end of this section.

Fig. 7-5 Checking No. 1 Idler Gear To Crankshaft Gear Backlash

NOTE

The No. 1 idler gear may be used if a gauge is not available.

8. If the backlash is not within limits specified, gently tap the stubshaft bracket with a brass hammer until it is in position to obtain the proper backlash.

CAUTION

Do not tap on machined surfaces of the stubshaft bracket.

9. When the stubshaft bracket is properly aligned, tighten the bottom bolt to the proper torque and re-check the backlash.

10. Apply an idler gear stubshaft to camshaft stubshaft gauge (File 769) Fig. 7-6, and check

Fig. 7-6 - Aligning Idler Gear Stubshaft Bracket

the dimension between the No. 2 idler gear stubshaft and the left bank camshaft stubshaft making sure both stubshafts are wiped clean. Gauge must indicate less than 0.13 mm (0.005").

NOTE

The No. 2 idler gear and left bank camshaft drive gear may be applied and backlash reading taken between No. 2 idler gear and camshaft drive gear if gauge is not available. See Service Data for limits.

11. If the dimension is not within limits, gently tap the stubshaft bracket until it is properly positioned.

CAUTION

Do not tap on machined surfaces of the stubshaft bracket.

12. When the stubshaft bracket is properly positioned, tighten the top and center mounting bolts to the proper torque and recheck the backlash between the idler gear gauge and the crankshaft gear.

13. If the backlash is not within the proper limits, the three vertical mounting bolts must be loosened and Steps 7 thru 12 repeated.

14. Remove the idler gear gauge and apply the remaining stubshaft mounting bolts and washers.

NOTE

One 3/8"-24 bolt is used at the edge of the stubshaft bracket directly below the lube oil manifold connection to the stubshaft bracket.

15. Remove the two temporary locating pins and apply the two mounting bolts and washers. Then tighten all mounting bolts to the proper torque.

16. Ream the two dowel holes with a 0.494" tapered reamer and a 0.4998" + 0.0002" bottoming reamer while using cutting oil.

NOTE

If dowel holes in idler gear stubshaft bracket do not align with holes in crankcase, drill and ream for oversize dowels as required to produce full circumference fit. See parts catalog for listing of oversize dowels.

17. Use an air hose to blow chips and oil out of the dowel holes.

18. Insert 5/16"-24 bolts approximately 12.7 mm (1/2") into the dowel pins.

19. Place dowels in dowel holes of stubshaft bracket and drive into crankcase end plate.

20. Torque the dowel bolts to specified value and lockwire all mounting and dowel bolts in groups of three or less.

21. Using a No. 1 stubshaft to No. 2 stubshaft gauge (File 773) check parallelism between the No. 1 and No. 2 stubshafts, Fig. 7-7. Take one indicator reading with gauge as close to the stubshaft bracket as possible and the other reading with gauge near the end of the No. 1 stubshaft. Dial indicator readings must be within 0.10 mm (0.004").

NOTE

Parallelism may also be checked by applying both idler gears, then checking gear teeth mesh and taking backlash measurements. See Service Data for backlash limits.

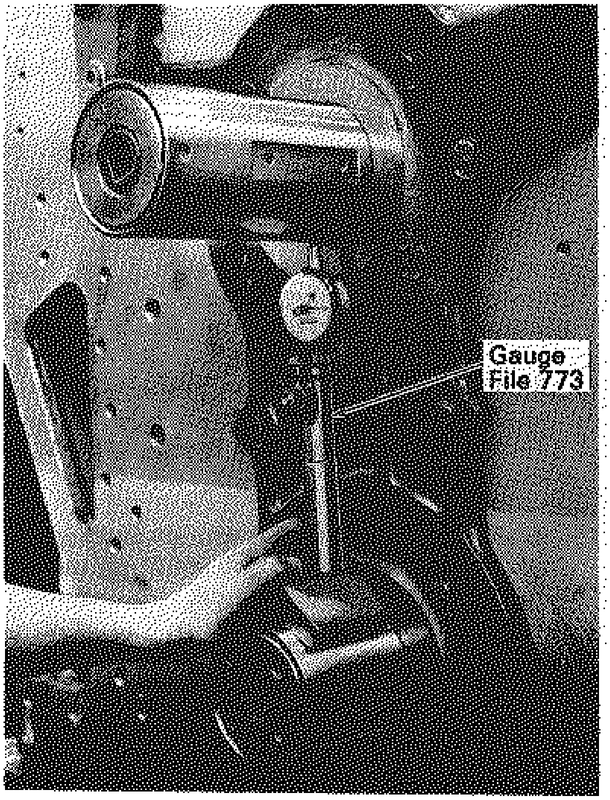

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Fig. 7-7 Checking Parallelism Of No. 1 And No. 2 Stubshafts

22. After a double idler stubshaft bracket has been applied to the crankcase rear end sheet, with all bolts torqued, the assembly should be checked for gaps in excess of 0.10 mm (0.004') which could cause a critical loss of oil pressure. To perform this check, run a 0.004" feeler gauge around the periphery of the bracket. If the feeler gauge can be inserted into an oil passage, the bracket must be removed and the cause eliminated.

23. Re-check the dimension between the No. 2 gauge idler stubshaft and the left bank camshaft stubshaft.

NO. 1 IDLER GEAR APPLICATION

1. Apply a light coat of lubricating oil to the No. 1 idler gear stubshaft and place the idler gear on the stubshaft so the tooth position marks are aligned as shown in Fig. 7-20.

   If a new gear is used, refer to "Exhaust Valve Timing" at the end of this section for information on positioning and marking of gears. Timing procedures are not required if camshaft and crankshaft positions have not been disturbed.

2. Install the No. I idler gear thrust plate, hardened washers, and bolts. (Hardened washers used with through-bolted brackets only.) Tighten bolts to the proper torque and lockwire in pairs using a crisscross pattern.

3. Use a feeler gauge to check that the No. I idler gear thrust clearance is within the limit specified in the Service Data.

4. Re-check the backlash between the crankshaft gear and the No. 1 idler gear as in Step 7 of "Stubshaft Bracket Application."

PISTON COOLING FLANGES, BLOWER DRIVE GEAR STUBSHAFTS, AND LUBE OIL MANIFOLD APPLICATION

1. If the flanges covering the piston cooling manifold openings on the crankcase end plate have been removed, install the flange gaskets, flanges, and 3/8"-24 bolts, Fig. 7-8. Torque the bolts to specified value and lockwire.

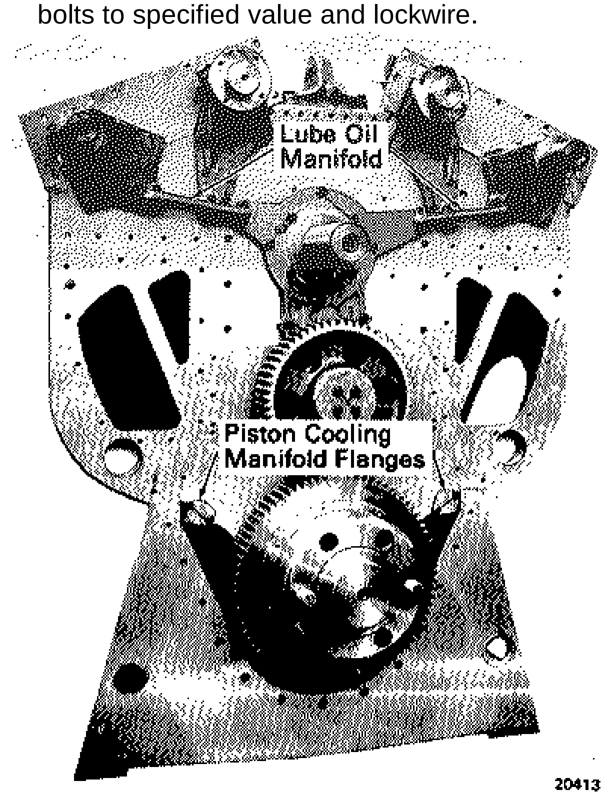

Fig. 7-8 Piston Cooling Flange And Lube Oil Manifold Application

2. Inspect the left and right bank blower drive gear stubshaft seating surfaces for burrs and wipe

clean. Apply the stubshaft brackets and snug down one bolt on top and one bolt on the face of the bracket to hold it in place during alignment.

3. Install the left and right bank lube oil manifold sections, Fig. 7-8, being sure to place gaskets between the manifold flanges and crankcase. Start the 3/8"-24 mounting bolts, but do not tighten them at this time.

4. Align each blower drive gear stubshaft to the camshaft stubshaft on the same side by using the blower drive gear alignment gauge, Fig. 7-9, (File 775 for 8 & 16-cylinder engines and File 776 for 12-cylinder engines) and a 0.008" feeler gauge.

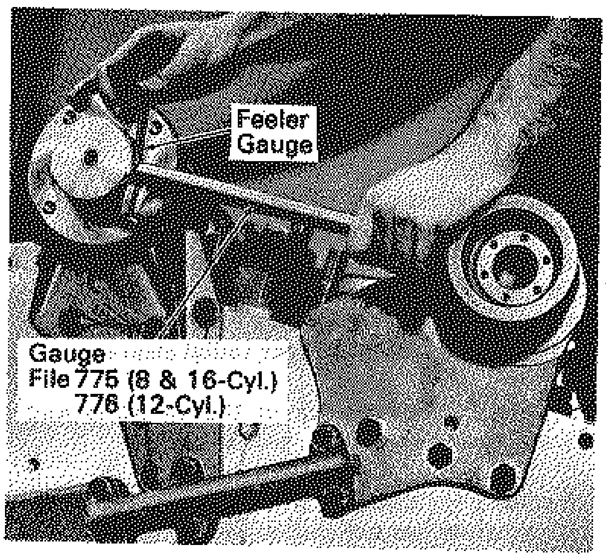

Fig. 7-9 Blower Stubshaft Alignment

5. Use a 0.002" feeler gauge to see that there is no gap between the stubshaft bracket and the crankcase end plate.

6. Remove alignment gauge and tighten 1/2"-20 bolts to specified torque value.

7. Ream the two dowel holes with a tapered reamer and a 0.4998" + 0.00 bottoming reamer while using cutting oil.

8. Use an air hose to blow chips and oil out of the dowel holes.

9. Insert 5/16"-24 bolts approximately 12.7 mm (1/2'") into the dowel pins.

10. Place dowels in dowel holes of stubshaft bracket and drive into crankcase end plate.

11. Torque the dowel pin bolts to specified value and lockwire the dowel pin bolt and the two inboard mounting bolts. The outboard mounting bolt will be lockwired to one of the camshaft housing bolts.

NOTE

If the stubshaft brackets do not have pipe plugs installed, coat the threads with high temperature thread lubricant and install.

12. Tighten the left and right bank lube oil manifold mounting bolts to specified value and lockwire.

NOTE

If the lube oil manifold sections do not have pipe plugs installed, coat the threads with high temperature thread lubricant and install in manifold.

CAMSHAFT DRIVE HOUSING APPLICATION

1. Check the camshaft drive housing seal surfaces for burrs and wipe free of dust and dirt.

2. Apply a coat of gasket sealing compound to the camshaft drive housing. Apply the gasket in sections to the camshaft drive housing being sure the gasket interlocks are joined properly.

3. Apply the camshaft drive housing to crankcase bolts to the housing and wipe the crankcase end plate clean.

4. Trim the rubber crankcase' to oil pan gasket extending from the joint at the crankcase end plate and apply gasket sealing compound to the joint area.

5. Locate the camshaft drive housing in its proper position and snug down several of the bolts to hold it in place.

6. Install two 12.7 mm (1/2") locating pins in the housing, Fig. 7-10, to act as positioning points for camshaft drive housing alignment gauge.

7. Install the camshaft drive housing alignment gauge (File 774) over the right bank blower stubshaft and the right bank locating pin.

8. If the gauge slides freely onto the stubshaft and locating pin without binding, repeat the process on the left bank.

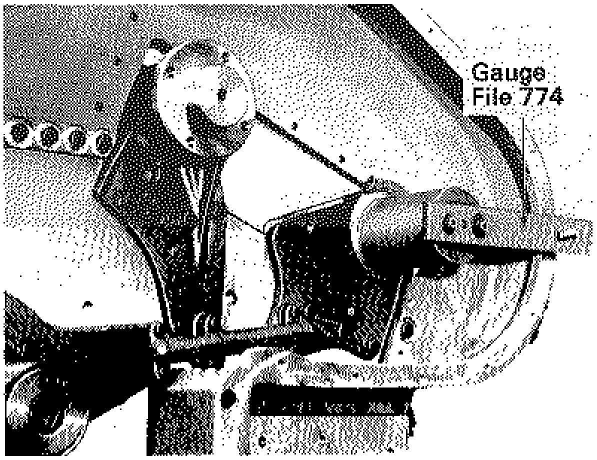

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Fig. 7-10 Camshaft Drive Housing Alignment

9. If the housing is not aligned properly, place a wedge (File 772) between the camshaft stubshaft bracket and the housing and drive the wedge in with a brass hammer.

10. When the camshaft drive housing is properly aligned, torque the mounting bolts to the proper torque as specified in the Service Data, then remove the wedge and recheck the alignment.

11. Ream the two dowel holes in the camshaft drive housing with a 0.494" tapered reamer and a 0.4998" ± 0.0002" bottoming reamer, being sure to use cutting oil.

NOTE

If dowel holes in camshaft drive housing do not align with holes in crankcase, drill and ream for oversize dowels as required to produce full circumference fit. See parts catalog for listing of oversize dowels.

12. Use an air hose to blow chips and oil out of the dowel holes, and insert 5/ 16"-24 bolts approximately 12.7 mm (1/2") into the dowel pins.

13. Place dowels in the dowel holes of the housing and drive into the crankcase end plate. Remove the dowel bolts.

14. Install the two remaining camshaft drive mounting bolts in the holes next to the dowel pins and torque to the specified torque.

15. Lockwire the camshaft drive housing upper bolts in three groups of three each, and the two remaining mounting bolts to the outboard bolts in the blower stubshaft brackets. 7

16. Install the oil slinger and the oil slinger-to crankshaft gear bolts. Torque bolts to specified value.

17. Prior to installation of the oil seal retainer, measure the distance from the inner face of the retainer mounting flange to the inner face of the retainer tapered flange, Fig. 7-2. Then measure the distance from the outer face of the camshaft drive housing to the face of the oil slinger with the crankshaft positioned toward the rear of the engine. The difference between the two measurements should equal the clearance specified in Service Data. If required, add or remove oil slinger shims to obtain proper clearance.

18. If oil retainer has dowels, remove the dowels.

19. Apply oil retainer gasket and oil retainer. Install four equally spaced bolts and washers finger tight.

20. Center the retainer by tapping the OD with a soft-faced hammer until the radial clearance between the retainer ID and the gear sealing surface OD is uniform around the circumference, as measured with a feeler gauge. Refer to Service Data for proper radial clearance.

21. Apply the remainder of the 24 bolts and washers and torque to specified value.

22. Recheck for uniform clearance to ensure that the retainer has not shifted.

23. Apply camshaft drive and blower gears.

AUXILIARY DRIVE ASSEMBLY

DESCRIPTION

The auxiliary drive assembly, (if used), Fig. 7-11, is mounted on the camshaft drive housing cover and is driven from the No. 2 idler gear.

MAINTENANCE

When new bearings are installed, they are pressed into the support housing and line reamed or bored to the dimension specified in Service Data.

After mounting the assembly on the camshaft drive housing cover, the backlash between the gears must be checked and adjusted, if necessary.

Check the backlash with a dial indicator, Fig. 7-11. Attach a small "C" clamp to the coupling flange so that clamp contacts the outer edge of the flange.

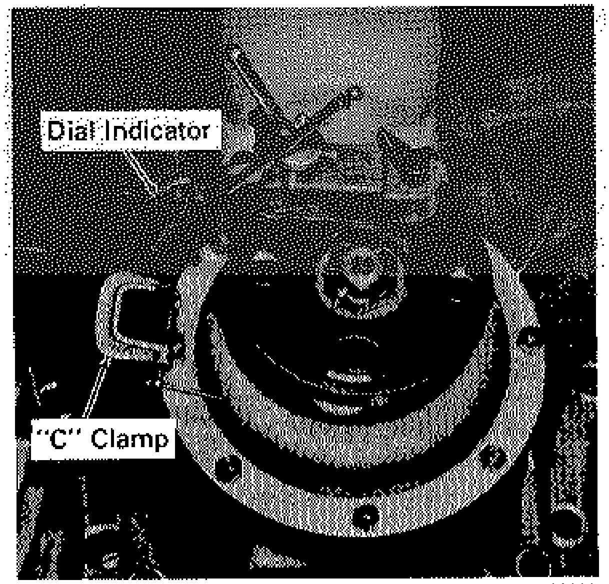


Fig. 7-1 1 Checking Auxiliary Drive Gear Backlash

Position the dial indicator with the contact point touching the "C" clamp. Remove play from gear teeth by turning the coupling flange. Set the dial indicator to zero and move flange in the opposite direction of the previous movement and note reading on dial indicator. Refer to Service Data for backlash limits. Backlash is adjusted by loosening the mounting bolts and repositioning the drive assembly on the camshaft drive housing cover.

After correct backlash is obtained, the mounting bolts are tightened, and the backlash checked to see that it has not changed.

CAMSHAFT ASSEMBLIES

DESCRIPTION

The camshaft assembly, Fig. 7-12, consists of flanged segments for front and rear stubshafts, and on 12 and 16-cylinder engines a spacer is used between the center segments. Segment flanges are marked as shown in Fig. 7-12 to aid in correct assembly. At each cylinder there are two exhaust valve cams, one injector cam, and two bearing journals. Two bearing blocks at each cylinder, equipped with steel-backed lead base-babbit lined inserts, support the camshaft.

MAINTENANCE

REMOVAL

The camshaft may be removed without disturbing the stubshafts by removing the dowel bolts connecting the segment and stubshaft flanges, removing oil lines from segment bearing blocks to rocker arms, and removing rocker arms. Remove segment bearing block caps to allow camshaft removal.

NOTE

Camshaft segment bearing blocks and caps are assembled new in mated pairs. This pairing must be maintained.

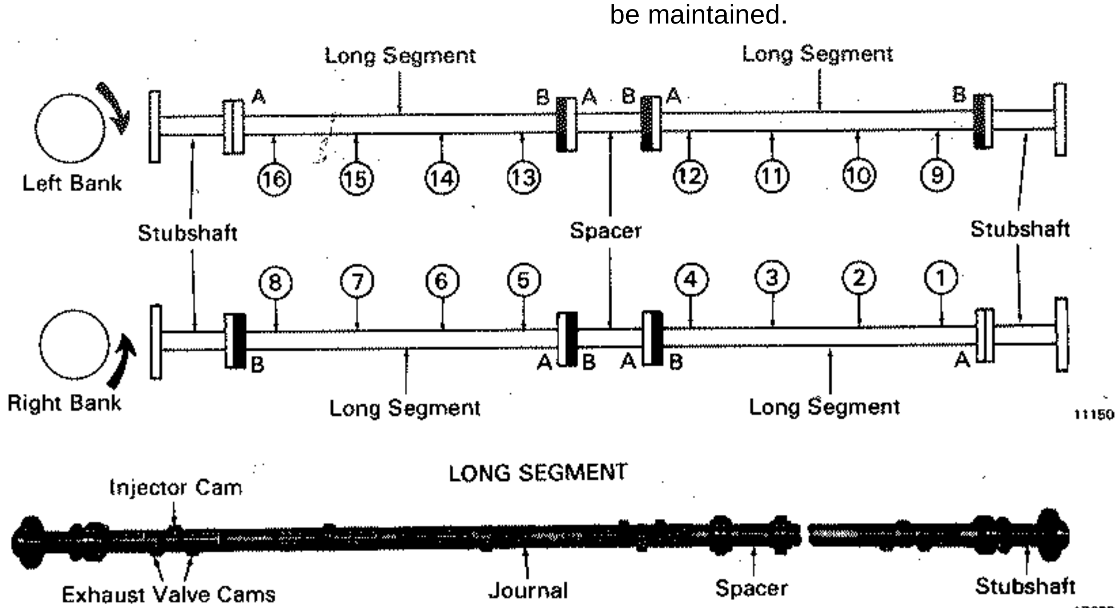


Fig. 7-12 - 16-Cyl. Camshaft Assembly (Left-Hand Rotating Engine)

If the camshaft is removed for reasons other than bearing replacement, an attempt should be made to retain relative position of the bearing shells on reinstallation of the camshaft. This may be accomplished by immediately replacing caps after camshaft removal, or if the entire block is removed, by inserting block bolts and wiring the free ends of the bolts. It is possible to remove a segment of the 16cylinder camshaft without removing the entire camshaft. However, the entire camshaft must be removed on a 12-cylinder engine to change a segment.

INSPECTION

After removal of camshaft, wash and remove all dirt from oil passages. Visually inspect stubshafts and segments paying particular attention to cam lobes and journals for pitting, chipping, excessive scoring, and heat discoloration. Journals and cams with light pit marks, minute 'flat spots, and light score marks may be reused after blending and removal of sharp edges by hand polishing. Check inside of dowel bolt holes for burrs, and remove.

Camshaft segments and stubshafts that show heat discoloration should be magnaflux inspected and hardness tested. Discoloration on the unfinished portion of the camshaft should be disregarded as it results from a production process and may be seen even on a new camshaft.

Check segment journal to bearing diametric clearances of all camshaft and stubshaft bearings against limits listed in the Service Data.

ASSEMBLY

The camshaft must be assembled as shown in Fig. 7-12. One dowel bolt hole in each segment flange is smaller than the others to ensure correct angular position.

After assembly of camshaft and stubshaft, check for concentricity between the stubshaft and camshaft journals and maximum runout over total length of the shaft. Support the camshaft on precision rollers at No. 2 and 7 (8-cyl.), 1,6, 7, and 12 (12-cyl.), and at 1, 7, 10, and 16 (16-cyl.) camshaft bearing journals. See Service Data for limits.

INSTALLATION

Camshaft assemblies installed on an engine must conform to segment sequence and position as indicated in Fig. 7-12. On right bank camshafts, the "A" marking on each flange is toward the front of the engine. On left bank camshafts, the "B" marking on the flange must be toward the front of the engine.

NOTE

Stubshafts connected to segment flanges with "A" markings are a different configuration than those connected to segment flanges with "B" markings.

1. If cam bearing blocks have been removed from the engine, check bearing block pads and keyways for foreign material, nicks, and burrs. Use a fine file to smooth nicks and remove burrs, then wipe area clean. Install all bearing blocks, putting oiler blocks to the R.H. side of each cylinder.

2. Wipe inside of camshaft bearings with a clean rag to remove any foreign material, then remove caps from bearing blocks and stubshaft brackets. Mark or otherwise arrange in order to maintain correct block to cap pairings.

3. Wipe bottom bearing shells clean once again and apply a liberal amount of engine oil to all lower bearings, including stubshaft bearings.

4. Install camshaft assembly on the engine in the proper orientation as previously described and shown in Fig. 7-12.

5. Apply a small amount of oil to each camshaft bearing journal, then rotate camshaft by hand to see if it turns freely and to distribute the oil evenly around the journals.

6. Apply all bearing caps to bearing blocks and stubshaft brackets. Snug down bolts on stubshaft bracket caps only to an initial torque not to exceed 13 N•m (10 ft-lbs).

7. Align bearing blocks to approximate center of bearing journals (if necessary) by tapping lightly with a copper or brass hammer.

8. Snug down all bolts on intermediate bearing block caps to an initial torque not to exceed 13 N•m (10 ft-lbs).

9. Final tighten all cap bolts to specified values.

10. Rotate camshaft by hand or by using a box wrench on a camshaft spacer nut to see if it turns freely. If camshaft binds, loosen bolts at one bearing block. If shaft still will not turn freely, continue loosening cap bolts one block at a time to determine which bearing is binding.

    Impact that bearing block cap with a lead or brass hammer to seat the bearing shell. Retighten and torque all cap bolts and check camshaft again for free rotation.

NOTE

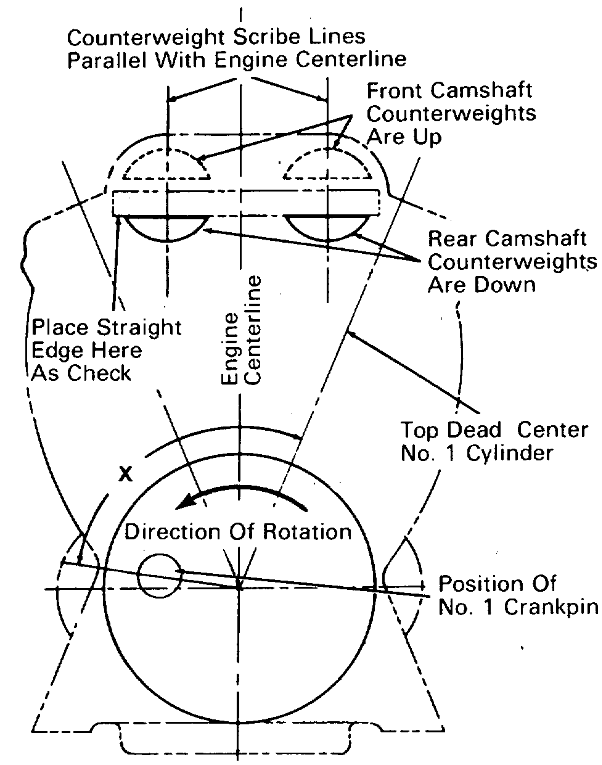
On occasion, it may be necessary to locate and impact more than one bearing and/or change out a bearing block and cap or stubshaft bracket in order to allow free camshaft rotation.

11. Check camshaft axial (thrust) clearance at rear stubshaft against limits listed in the Service Data.

12. If clearances are correct and no binding exists, apply flange dowel bolts and reassemble rocker arms and associated parts. Check valve timing of at least one cylinder to ensure that camshaft segment orientation is correct, then complete exhaust valve setting and injector timing adjustments.

CAMSHAFT COUNTERWEIGHT APPLICATION

Counterweight replacement usually is not necessary. However, when counterweights are installed, they should be applied in the position as shown in Fig. 7-13.



REAR END OF LEFT-HAND ROTATING ENGINE

X = Degrees after T.D.C. of No. 1 cylinder. To get the crankshaft in this position, turn the flywheel until this number is at the pointer.

Engine	L.H. Rotation	R.H. Rotation
8-Cyl.	X = 184°	X = 176°
12-Cyl.	X = 249-1/2°	X = 110-1/2°
16-Cyl.	X = 105°	X = 255°

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Fig. 7-13 - Camshaft Counterweight Timing

EXHAUST VALVE TIMING DESCRIPTION

Exhaust valve timing is very important as it ensures correct relationship of valve operation with the other events in the cylinder power cycle.

To check or adjust exhaust valve timing, it is necessary to know the top dead center of each cylinder as shown in Table 1.

Items which govern correct valve timing are given in the following procedures.

LEFT-HAND ROTATION ENGINE		RIGHT-HAND ROTATION ENGINE	
8-CYLINDER		8-CYLINDER	
FIRING ORDER	TOP DEAD CENTER	FIRING ORDER	TOP DEAD CENTER
1	0°	1	0°
5	45°	6	45°
3	90°	2	90°
7	135°	8	135°
4	180°	4	180°
8	225°	7	225°
2	270°	3	270°
6	315°	5	315°
12-CYLINDER		12-CYLINDER	
FIRING ORDER	TOP DEAD CENTER	FIRING ORDER	TOP DEAD CENTER
1	0°	1	0°
12	19°	6	26°
7	45°	8	75°
4	94°	11	101°
3	120°	2	120°
10	139°	5	146°
9	165°	9	195°
5	214°	10	221°
2	240°	3	240°
11	259°	4	266°
8	285°	7	315°
6	334°	12	341°
16-CYLINDER		16-CYLINDER	
FIRING ORDER	TOP DEAD CENTER	FIRING ORDER	TOP DEAD CENTER
1	0°	1	0°
8	22-1/2°	15	22-1/2°
9	45°	10	45°
16	67-1/2°	7	67-1/2°
3	90°	2	90°
6	112-1/2°	13	112-1/2°
11	135°	12	135°
14	157-1/2°	5	157-1/2°
4	180°	4	180°
5	202-1/2°	14	202-1/2°
12	225°	11	225°
13	247-1/2°	6	247-1/2°
2	270°	3	270°
7	292-1/2°	16	292-1/2°
10	315°	9	315°
15	337-1/2°	8	337-1/2°

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Table 1 - Firing Order And Top Dead Center

MAINTENANCE
LOCATING TOP DEAD CENTER

If it should become necessary to check the position of the flywheel or the flywheel pointer for top dead center, proceed as follows:

1. Remove an air box handhole cover at the No. 1 cylinder.

2. If necessary, bar the engine to position the No. 1 piston below the cylinder liner ports.

3. Insert a brass "stop-bar" (minimum 12.7 mm [1/2"] hexagonal or square preferred) of suitable length through the ports of the No. 1 cylinder so that the end of the bar passes through a port on the opposite side of the cylinder, Fig. 7-14.

NOTE

A bar of sufficient length to prevent reapplication of the handhole cover while the bar is in place is recommended. A flag on the end of the bar will caution against inadvertent rotation of the engine with the bar in place.

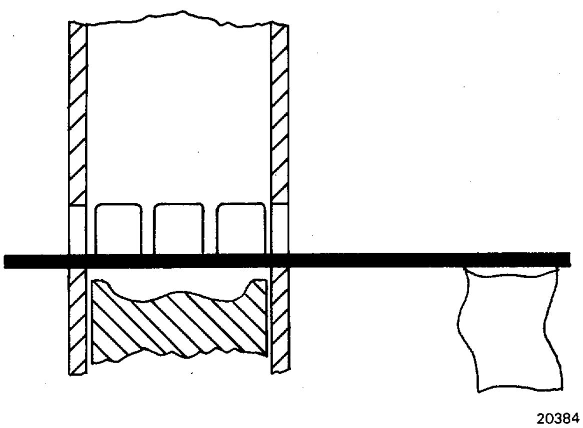

Fig. 7-14 - "Stop-Bar" Inserted Through Cylinder Ports

4. Manually bar the engine slowly in the normal direction of rotation until piston travel is stopped by the bar against the upper surfaces of the cylinder ports, Fig. 7-15.

CAUTION

Use extreme care to avoid excessive force.

5. Mark the position of the flywheel pointer on the flywheel, Fig. 7-16.

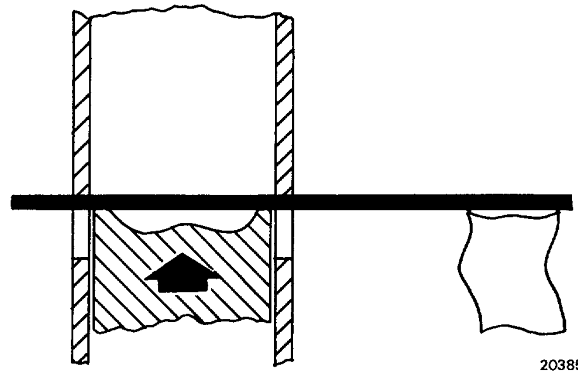

Fig. 7-15 - Piston Travel Limited By "Stop-Bar"

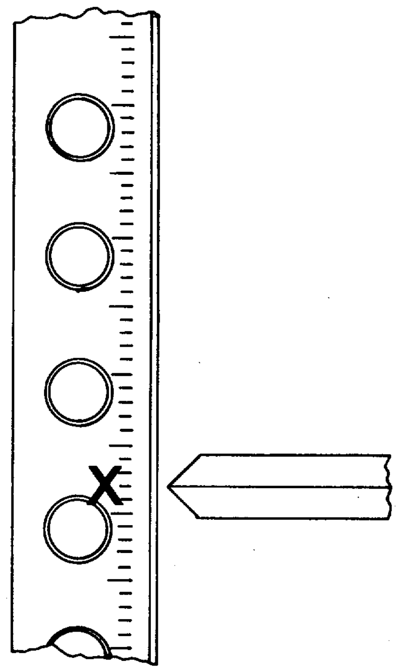

Fig. 7-16 - Limit Of Piston Travel Marked On Flywheel

6. Manually bar the engine slowly in the opposite direction from normal rotation until piston travel is again stopped by the bar against the upper surfaces of the cylinder ports, Fig. 7-15.

7. Mark the second position of the flywheel pointer on the flywheel, Fig. 7-17.

8. Determine the number of degrees between the two marks on the flywheel. Divide that number by 2. See Fig. 7-18 for a sample calculation.

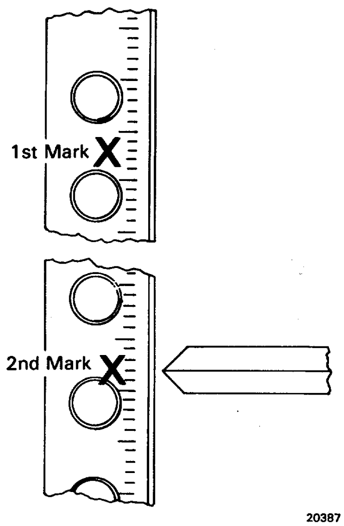

Fig. 7-17 - Second Limit Of Piston Travel Marked On Flywheel

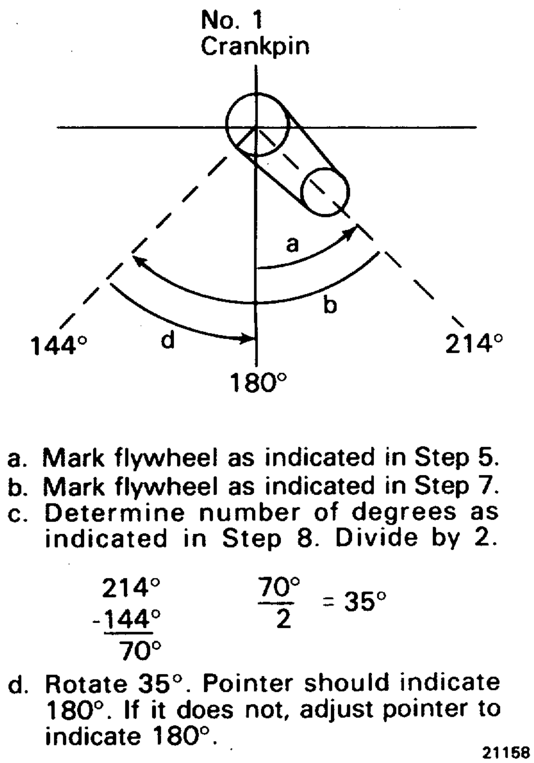

Fig. 7-18 - Sample Calculation

9. Rotate the crankshaft in the normal direction of rotation the exact number of degrees determined in Step 8 above. Remove the brass "stop-bar" from the engine.

10. The pointer should indicate 180° (bottom dead center). If it does not, position the pointer so that it does indicate 180°. The pointer will now indicate top dead center for the No. 1 crankpin when the engine is rotated so that the pointer is at zero degrees (0°).

CHECKING EXHAUST VALVE TIMING

To check timing, place a dial indicator on the rocker arm adjusting screw as shown in Fig. 7-19. Valve end of rocker arm must be in its highest position, so that the exhaust valves are closed. Press indicator down approximately 2.54 mm (.100") and set dial to zero.

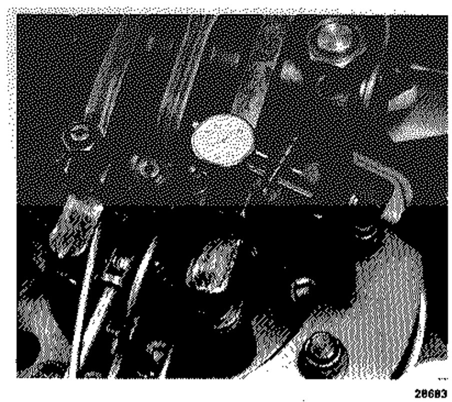

Fig. 7-19 - Timing Exhaust Valves

Turn crankshaft in normal direction of rotation until flywheel is at 106° A.T.D.C. of cylinder being checked.

If timing is correct, the valve bridge will have moved down 0.36 mm (.014"). Timing must not be later than 110° or earlier than 104° A.T.D.C. of cylinder being checked.

If timing is incorrect, check the following:

1. Proper installation of camshaft.
2. Camshaft gear train correctly timed.
3. Gears excessively worn.

TIMING EXHAUST VALVES

The exhaust valves should be timed when any gear or stubshaft of the camshaft gear train is replaced, with the exception of the No. 1 or No. 2 idler gears. To do this, the camshaft on each bank must be timed to the crankshaft, but only one cylinder of each bank needs to be timed.

CAUTION

To prevent possible valve damage, remove or loosen all rocker arm assemblies, except the one on the cylinder being timed. If rocker arm assemblies are removed, hydraulic lash adjusters should be checked for proper clearance to valve stems. See Section 5 for instructions.

1 Apply dial indicator to the rockerarm adjusting screw, Fig. 7-19, as done in "Checking Exhaust Valve Timing."
2. Remove lockwire from mounting bolts and dowel pin bolts securing rear camshaft counter-weight to the stubshaft. Remove bolts, washers, dowel retainer plate and two 1/2" dowel pins. Remove counterweight and gear.
3. Using a socket and wrench on stubshaft flange bolt nuts, rotate the camshaft in its normal direction of rotation until the valve bridge on which the dial indicator is resting moves down 0.36 mm (.014").
4. Bar engine crankshaft over in the normal direction of rotation until the flywheel pointer is at 105° after top dead center for the cylinder, being checked. Install camshaft gear and counterweight on stubshaft, secured in place with mounting bolts finger tight.
5. With flywheel at 105° A.T.D.C. of the cylinder being checked, the dowel holes in the camshaft drive gear, counterweight, and the camshaft stubshaft should be in line or approximately in line with each other. If by turning the crankshaft from 104° to 106° A.T.D.C., the dowel holes can be made to line up, then tighten the bolts to secure assembly for installation of dowel pins. 6. If the dowel holes do not line up within this tolerance, remove the camshaft counterweight and gear from the stubshaft. Rotate the gear 1800 and replace on stubshaft or move the gear one tooth and replace gear and counterweight on the stubshaft.
7. If dowel holes still do not line up but misalign-ment is less than 0.190 mm (.0075"), the holes may be reamed for installation of 0.005", 0.010", or 0.015" oversize dowels.

   If misalignment of dowel holes is greater than 0.190 mm (.0075") proceed to Step 17.

CAUTION

Before reaming (or drilling) dowel holes, be certain extra measures are taken to contain any metal shavings or chips to prevent their entering oil drains or contaminating the gear train.

8. Insert 5/16"-24 bolts approximately 12.7 mm (1/2") into dowel pins.
9. Place dowels in counterweight dowel holes and drive into stubshaft. Remove dowel bolts from pins.
10. Remove counterweight to stubshaft bolts.
11. Install dowel retainer plate, and counterweight to stubshaft bolts. Torque bolts to specified value.
12. Install dowel pin bolts and torque to specified value.
13. Lockwire mounting bolts and dowel pin bolts in groups of three. (Two mounting bolts and one dowel pin bolt.)
14. The crankshaft should now be rotated in its normal direction and the timing checked so that the valve bridge of the valve being checked has moved down 0.36 mm (.014") when the flywheel timing pointer is at 104°-106° A.T.D.C.
15. Repeat the operation on one cylinder on the opposite bank.
16. After timing has been completed, the relative position of the mating parts should be identified similar to the method used on new engines, shown in Fig. 7-20. The mating parts are marked with No. 1 piston at top dead center. This completes valve timing procedures.
17. Remove counterweight and gear from stubshaft.
18. Plug dowel holes in stubshaft as follows:

    a. Drill and tap the two dowel holes for 3/4"-16 NF thread with a minor diameter of 0.7031 " + 0.005" - 0.000" and pitch diameter of 0.7094" + 0.0016" - 0.0000".
    b. Countersink 1.6 mm (1/16") on gear mounting side.
    c. Drive threaded, hex head plugs into holes. See Service Data for plug part number.
    d. Cut plug head off and flare by peering into countersink.
    e. Grind plugs flush with flange face.
    f. Check 146.037 mm + 0.00 mm - 0.03 mm (5.7495" + 0.000" - 0.001") flange O.D. for high spots and grind to proper dimension.

CAUTION

If camshaft to crankshaft relationship has been disturbed, repeat Step 3.

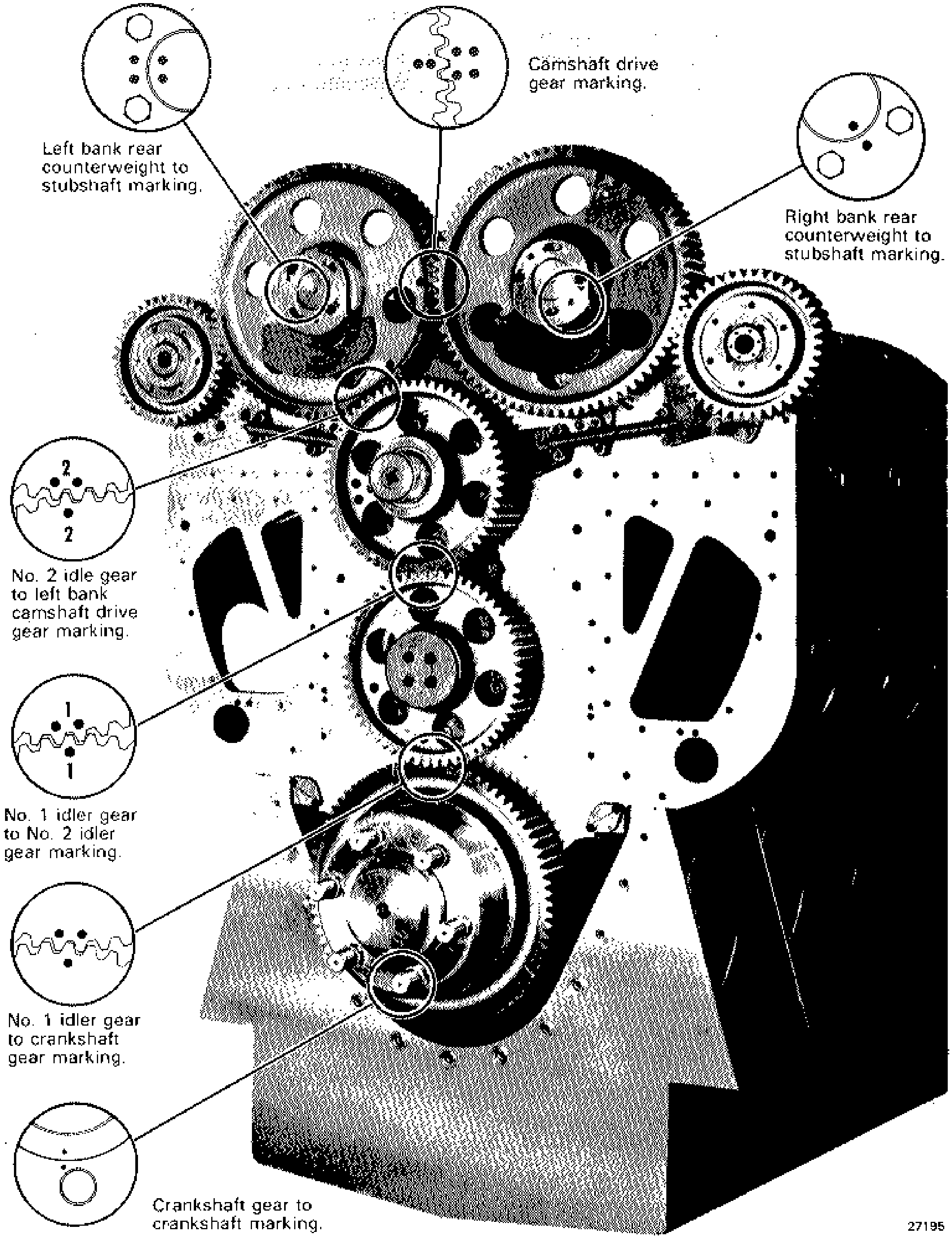

Figure 7-20 - Camshaft Gear Train Marking

19. Apply camshaft gear to stubshaft and secure with mounting bolts.

20. Rotate engine crankshaft to position indicated in Fig. 7-13.

21. Remove gear mounting bolts and position gear and counterweights on stubshaft with counterweight in down position and counterweight scribe line parallel with engine centerline. Ensure that gear and counterweight dowel holes are aligned.

22. Install mounting bolts and tighten to secure gear and counterweight to stubshaft.

23. Drill and ream stubshaft dowel holes to 12.662mm+0.13 mm-0.00mm(.4985"+.005"-.000").

24. Perform Steps 8 thru 16.

SERVICE DATA
CAMSHAFT GEAR TRAIN, AUXILIARY DRIVE, AND CAMSHAFT ASSEMBLIES

SPECIFICATIONS

Clearance and dimensional limits listed below, are defined as follows:

1. *New limits are those to which newt parts are manufactured. (Drawing tolerances.)*

2. *Minimum, maximum, and tolerance measurements are provided as service limits. At time of rebuild or anytime unscheduled maintenance is performed, the service limits should* ***not*** *be exceeded. Engine components within these limits may be reused with the assurance that they w ill perform satisfactory until the next scheduled overhaul.*

Crankshaft Gear

Oil slinger to oil retainer clearance .... 2.29-2.79 mm (.090"-.110")

Shims to obtain required clearance
8035526........ 0.25 mm (.010")
8035527........ 0.51 mm (.020")
8035528........ 0.76 mm (.030")
Oil retainer ID to crankshaft gear
sealing surface OD radial clearance........ 0.38-0.51 mm (.015"-.020")

Gear Backlash

Crankshaft gear to No. 1 idler - New........ 0.18-0.36 mm (.007"-.014")
No. 1 to No. 2 idler - New........ 0.18-0.36 mm (.007"-.014")
No. 2 idler to camshaft drive - New........ 0.18-0.41 mm (.007"-.016")
Camshaft drive to camshaft drive - New........ 0.18-0.56 mm (.007"-.022")
Camshaft drive to blower drive - New........ 0.18-0.41 mm (.007"-.016")
Auxiliary drive to No. 2 idler - New .... 0.18-0.41 mm (.007"-.016")
Max. (all gears above)........ 0.64 mm (.025")

Gear Train
(Idler gears and stubshafts include sleeve and bearings where applicable.)

No. 1 idler gear assembly (through bolted, fixed bearing stubshaft assembly)

Idler gear bore diameter -
New .... 117.48-117.50 mm (4.625"-4.626")
Max........ 117.58 mm (4.629")

Stubshaft diameter -
New .... 117.27-117.35 mm (4.617"-4.620")
Min........ 117.14 mm (4.612")

Idler gear to stubshaft clearance -
New .... 0.13-0.23 mm (.005"-.009")
Max........ 0.43 mm (.017")

Thrust clearance -
New........ 0.20-0.51 mm (.008"-.020")
Max. .... 0.71 mm (.028")

No. 2 idler gear assembly
Idler gear bore diameter -
New .... 117.48-117.50 mm (4.625"-4.626")
Max.. 117.58 mm (4.629")

Stubshaft diameter -
New .... 117.27-117.35 mm (4.617"-4.620")
Min.. 117.14 mm (4.612")

Idler gear to stubshaft clearance -
New .... 0.13-0.23 mm (.005"-.009")
Max.. 0.43 mm (.017")

Thrust clearance -
New .... 1.14-1.96 mm (.045"-.077")
Max.. 2.03 mm (.080")
Bushing minimum length .... 123.01 mm (4.843")

Blower drive (diametric clearance)
Bushing to stubshaft -
New .... 0.08-0.13 mm (.003"-.005")
Max.. 0.41 mm (.016")
Bushing to gear -
New .... 0.18-0.23 mm (.007"-.009")
Max.. 0.46 mm (.018")
Thrust clearance -
New .... 0.23-0.48 mm (.009"-.019")
Max.. 0.64 mm (.025")

Auxiliary Drive

Housing
Pilot diameter -
New .... 101.65-101.68 mm (4.002'-4.003")
Max.. 101.714 mm (4.0045")
Bearing diameter -
New .... 63.564-63.589 mm (2.5025"-2.5035")
Max.. 63.65 mm (2.506")
Thrust dimension -
New .... 255.643-255.526 mm (10.0647'-10.0601'")
Max.. 255.30 mm (10.051")
Drive shaft
Bearing diameter -
New .... 63.48-63.50 mm (2.499"-2.500")
Min.. 63.462 mm (2.4985")
Thrust dimension -
New .... 255.96-255.03 mm (10.007"-10.080")
Max.. 256.13 mm (10.084")
Clearance
Shaft to bushing -
New .... 0.064-0.114 mm (.0025"-.0045") --
Max.. 0.190 mm (.0075")
Thrust -
New .... 0.312-0.505 mm (.0123"-.0199")
Max.. 0.89 mm (.035")

SERVICE DATA (CONT'D)

Camshaft And Stubshaft

Camshaft journal diameter -
New .... 63.40-63.45 mm (2.496"-2.498")
Min. .... 63.37 mm (2.495")
Diametric clearance, segment journal to bearing -
New .... 0.05-0.15 mm (.002"-006")
Max. .... 0.25 mm (.010")
Taper in length of journal - Max .... 0.02 mm (.001")
Runout (journal) T.I.R. when supported
on adjacent journals - Max. .... 0.05 mm (.002")
Runout (base circle relative to journal) - Max. .... 0.05 mm (.002")
Mounting flange (not convex) flat within* - Max .... 0.013 mm (.0005")
Mounting flange square with longitudinal
centerline within T.I.R.* - Max .... 0.02 mm (.001")
*(Correct by grinding faces)

Concentricity between stubshaft and camshaft journals
and maximum runout over total length of shaft (T.I.R.) Max. .... 0.10 mm (.004")

Dowel bolt holes in flanges
One hole - Max .... 11.15 mm (.439")
Three holes - Max. .... 12.738 mm (.5015")
Stubshaft journal diameter -
New .... 63.40-63.45 mm (2.496"-2.498")
Min. .... 63.37 mm (2.495")
Diametric clearance, journal to bearing -
New .... 0.089-0.190 mm (.0035"-.0075")
Max. .... 0.25 mm (.010")
Stubshaft thrust clearance -
New .... 0.25-0.46 mm (.010"-.018")
Max. .... 0.64 mm (.025")
Dimension between thrust faces - Max. .... 106.55 mm (4.195")

Camshaft Timing
Ideal timing setting, valve open 0.36 mm (0.014") - A.T.D.C. .... 106°
Timing of new gear train not earlier than - Max. .... 2°
or
at 0.36 mm (0.014") valve opening - A.T.D.C .... 104°
Limit of lag - camshaft behind crankshaft due
to worn gears - Max. .... 4°
or
at 0.36 mm (0.014") valve opening - A.T.D.C. .... 110°
Flywheel pointer setting - T.D.C. of No. 1 cylinder .... 0°

EQUIPMENT LIST

	Part No.
Feeler gauge set	8067337
No. 1 idler gear clearance checking spring	8121868
Gasket sealing compound (0.47 liter [1 pt.])	8178639
Dial indicator	8255423
Thread lubricant, high temperature (0.946 liter [1 qt])	8278929
No. 1 idler gear clearance checking bar	8466308
Camshaft stubshaft plug	9082284
No. 1 idler gear to crankshaft gauge	File 768
Idler gear stubshaft to camshaft stubshaft gauge	File 769
Camshaft drive housing alignment wedge	File 772
No. 1 stubshaft to No. 2 stubshaft gauge	File 773
Camshaft drive housing alignment gauge	File 774
Blower drive gear stubshaft to camshaft stubshaft alignment gauge	
8 & 16-Cyl.	File 775
12-Cyl.	File 776

SECTION 8

AIR INTAKE AND EXHAUST SYSTEMS

CONTENTS PAGE

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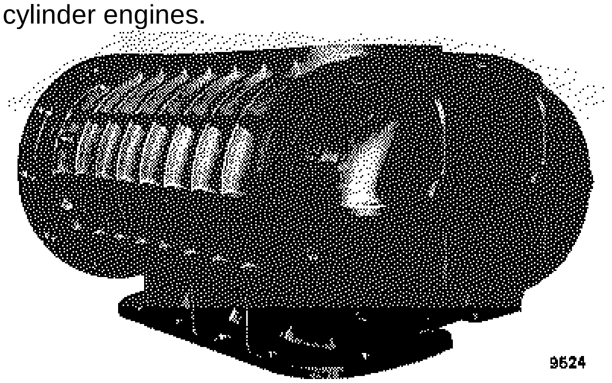
AIR INTAKE AND EXHAUST SYSTEMS

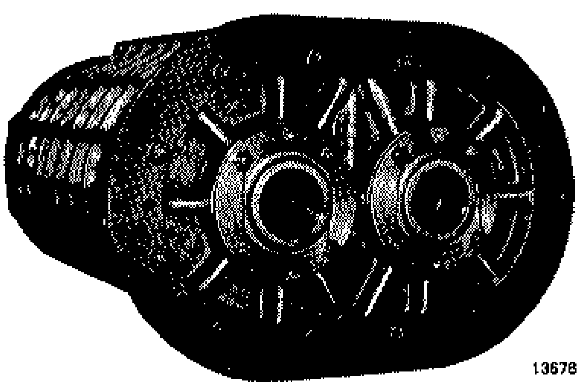
BLOWER

DESCRIPTION

The blower, Fig. 8-1, consists of a pair of helical three-lobed rotors, which revolve in a close fitting aluminum housing. This design, Fig. 8-2, ensures a large volume of air at low pressure, proportional to engine speed. A cross-section view of the blower is shown in Fig. 8-3. Two blowers are used on 12 and 16-cylinder engines and one on 8-cylinder engines.



FRONT VIEW



REAR VIEW

Fig. 8-1 - Blower Assembly

Each rotor is pressed on a tubular steel shaft. The engine end of these shafts are journals supported in the rear end plate bearings. The front, or gear ends of the shafts, are serrated. Flanged hubs having serrated bores are pressed onto the serrated tubular shaft ends and serve as bearing journals and drive flanges for a matched pair of helical rotor gears. Thrust bearings are included in the front end bearing blocks.

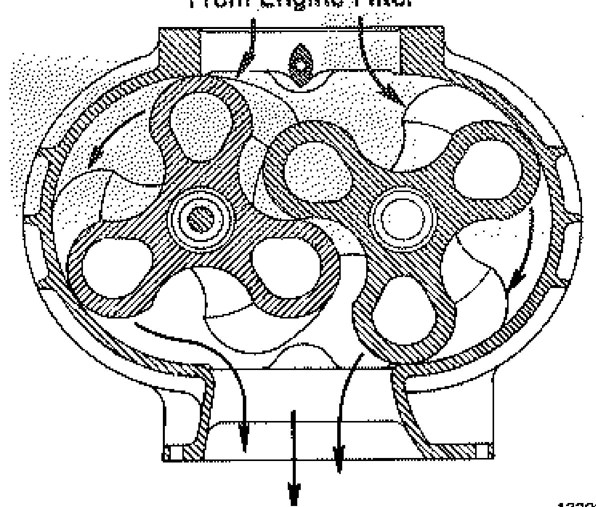


Fig. 8-2 - Blower Air Flow

Blower rotor bearings are pressure lubricated by engine oil supplied from the auxiliary drive housing. Oil is supplied to the bearings by drilled passages in the end plates; both end plates being connected by an oil passage in the top center of the housing. Rotor gears are splash lubricated. Oil seals are provided in each end plate around each rotor shaft to prevent oil leakage into the rotor housing.

Gaskets are not used between the end plates and blower housing. Instead a fine silk thread around the housing end, on each side of the stud line, together with a thin coating of gasket compound, provide an airtight seal.

Each blower is driven by a blower drive gear in the camshaft gear train. A flange with a serrated hub is bolted to the drive gear. A quill shaft having serrations on one end and a flange on the other end, is bolted to a rotor gear, and extends through the

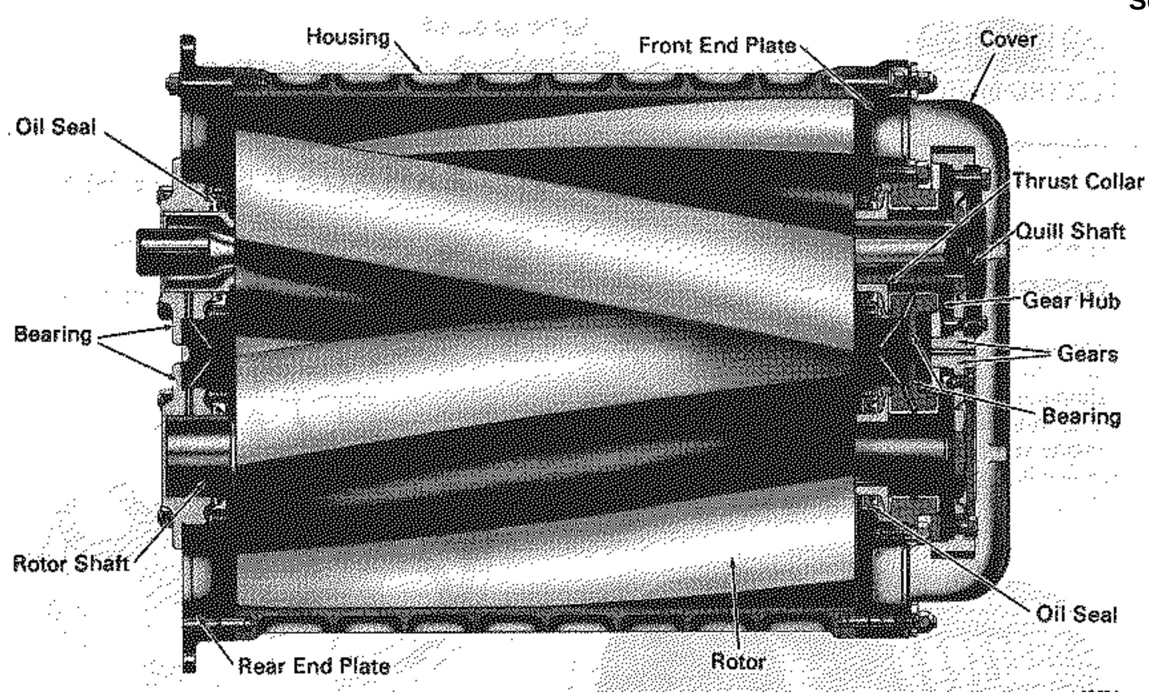


Fig. 8-3 - Blower, Cross-Section

outer rotor shaft. When the blower is in place, the serrated end of the quill shaft enters the serrated hub of the drive flange.

MAINTENANCE

SERVICING BLOWER

Blowers in need of rebuilding should be returned to the factory.

BLOWER INSPECTION

It is recommended that blowers be inspected at intervals specified in the Scheduled Maintenance Program.

If blower bearings become worn enough to cause rotor interference, aluminum dust will appear in the blower support housing and in the air box. A blower in this condition must be replaced at once.

A leak at the blower oil seals will result in an excessive amount of oil running down the blower support and into the air box, and excessive oil on rotors and end plates.

NOTE

Air pressure should not be used to test blower seals.

When inspecting blower rotors, a clean strip on the crown radius or high part of the lobes, running the entire length of the lobes, may be seen on some rotors. The strip appears to be flat, but actually is handworked to conform to the housing bore. The handworking operation is done to match pairs of rotors for close clearance, and the width of the strip will vary on different rotors.

The strips on the lobes come the closest to making rotor contact and therefore are usually cleaner than the other lobe areas. Scratches may appear on the strips due to dirt particles finding their way into the blower, but generally they are of no consequence. Accordingly, a clean strip or one with scratches on it should not be interpreted as an indication of rotor-to-rotor or rotor-to-housing contact.

BLOWER REMOVAL

General removal procedure as follows:

1. Remove the oil separator line to the blower.

2. Remove blower lube oil supply and drain lines. Apply blank flange or otherwise cover openings.

3. Remove air filter element, element housing, and blower adapter (if used).

4. Remove the bolts securing the blower to the support and to the camshaft drive housing.

5. Slide blower straight back from the engine until splined shaft clears spline drive on blower drive gear.

6. Apply blower lifting plate to the blower and then with the aid of a chain hoist or equally safe means, carefully raise and remove the blower from its support.

BLOWER INSTALLATION

The installation of a new or reconditioned blower may be made by following, in reverse, the "removal" procedure steps. The following additional steps will also be required.

1. Carefully remove the old gasket used between the blower housing and blower support. A scraper may be necessary for this operation. Thoroughly clean the blower support surface after the gasket is removed.

2. Apply gasket sealing compound to one side of the new gasket to be used between blower support and blower housing. Apply the gasket to the blower support.

3. Apply blower end plate to camshaft drive housing gasket, using gasket cement.

4. Apply grease or otherwise lubricate top of blower support gasket so blower can be moved on the gasket without tearing the gasket.

5. Mount blower on its support. Line up splined drive shaft with blower drive and slide the blower into correct position.

6. Apply the mounting bolts and washers to the blower support and camshaft drive cover. Care must be taken in the application of the camshaft drive cover bolts since they are of different lengths and if not applied in the correct locations, as shown in Fig. 8-4, may cause interference.

   Torque the blower mounting bolts to specified value.

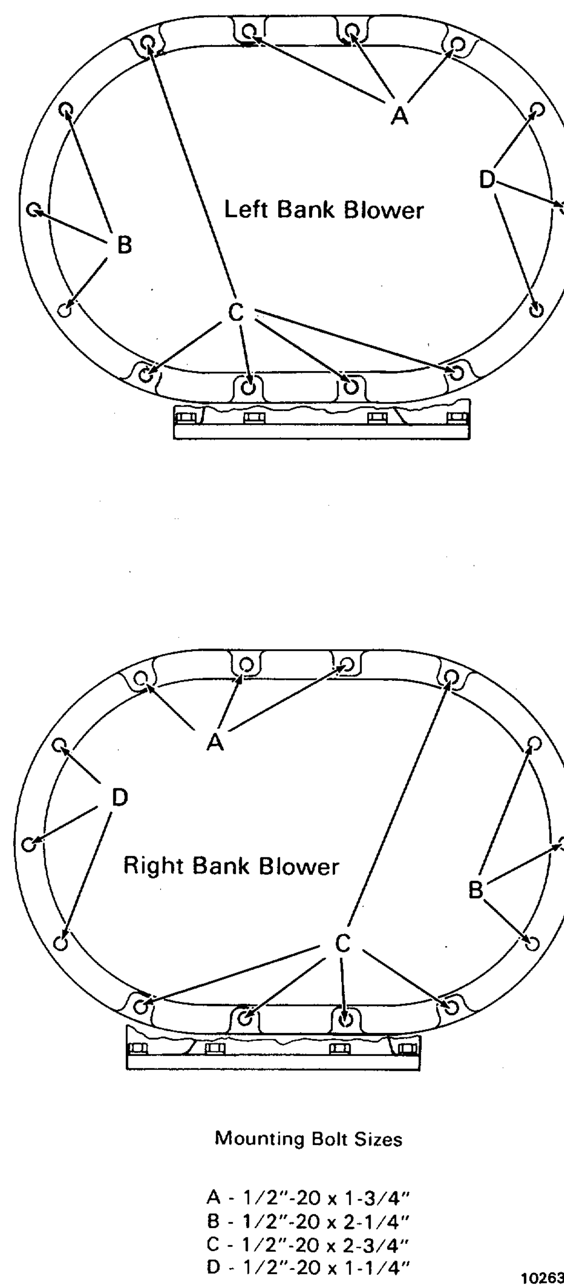


Fig. 8-4 - Location Of Blower To Camshaft Drive Cover Bolts

AIR INTAKE FILTERS

Air entering the engine must be thoroughly cleaned by passing through air intake filters to protect the power assemblies from abrasive material as well as to protect the lubricating oil from contaminants.

Although several types of filters are available, based on specific requirements, a couple of typical filter applications are described in the following paragraphs.

OIL BATH FILTER (BOWL TYPE)
DESCRIPTION

Each bowl type (circular) oil bath filter, Fig. 8-5, consists of a cover, element, and bowl. The bowl is filled with oil up to a level as determined by an oil sight glass or a fill pipe.

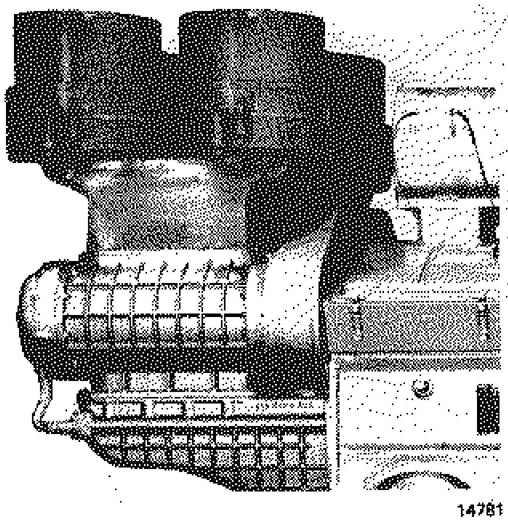


Fig. 8-5 - Bowl Type Oil Bath Filter

The air enters the filter between the bowl and the cover, Fig. 8-6. As the air reaches the oil, it breaks the oil seal. Upon breaking the oil seal it changes direction, causing the larger dirt particles to drop off into the oil. Increased air velocity at the oil seal results in a turbulent scrubbing of the air by the oil, which removes most of the remaining particles of dirt. The stream of air maintains a coating of oil on the outer and inner screens of the filter element. The particles of dirt impinged on the screens are washed into the oil bowl sump by returning oil, providing a self-cleaning feature. The filter element removes all oil from the air stream so that only clean, oil-free air enters the engine.

MAINTENANCE

The air intake filters should be serviced as specified in the Scheduled Maintenance Program.

OIL SUPPLY

To accurately check filter oil level and to add oil, the engine should be shut down for at least 15 minutes. This will allow sufficient time for the oil throughout the filter to drain into the bowl. The oil level should not be more than 12.7 mm (1/2") below the bead around the bowl. The proper oil level is at the center of the bead. The oil supply is in two chambers connected so that oil in the lower bowl replenishes oil in the upper bowl. The top fill and drain tee, Fig. 8-7, fills the upper chamber and the bottom fill and drain tee fills the lower chamber. When filling the filter, about one-quarter of the total amount required is added through the top tee and the balance through the bottom tee. It is important that the engine remain shut down when adding oil to prevent oil being drawn out of the bowl when the pipe plug in either tee is removed.

CHANGING OIL

The oil is drained at intervals as specified in the Scheduled Maintenance Program, or more frequently as indicated by filter operation. Drain the oil by removing the lower pipe plug from each of the two fill and drain tees. After the oil is drained, check the depth of the sludge remaining in the bowl through the inspection plug, Fig. 8-7. The sludge should not exceed 19 mm (3/4") in depth. If less than 19 mm (3/ 4) in depth, refill the filter to proper level. If more than 19 mm (3/4) in depth, disassemble and clean the filter as described below.

CLEANING FILTER

1. Loosen and remove cover hold down bolt. Remove the cover and element from the bowl.

2. Remove the sludge from the bowl.

3. If the element requires cleaning, it should be washed with kerosene, fuel oil, or mineral spirits. Do not immerse the element in hot caustic cleaner.

4. Whenever the filter is disassembled, new gaskets must be applied. Replace gaskets as follows:

    a. Remove old gaskets.

    b. Clean gasket surfaces with solvent to remove any old adhesive.

    c. Apply thin coat of an oilproof adhesive to the gasket surfaces and allow to set until tackiness is gone.

    d. Apply gasket in position using moderate pressure.

    e. If possible, allow one hour before subjecting gasket to oil.

5. Reassemble filter and tighten the cover hold down bolt securely.

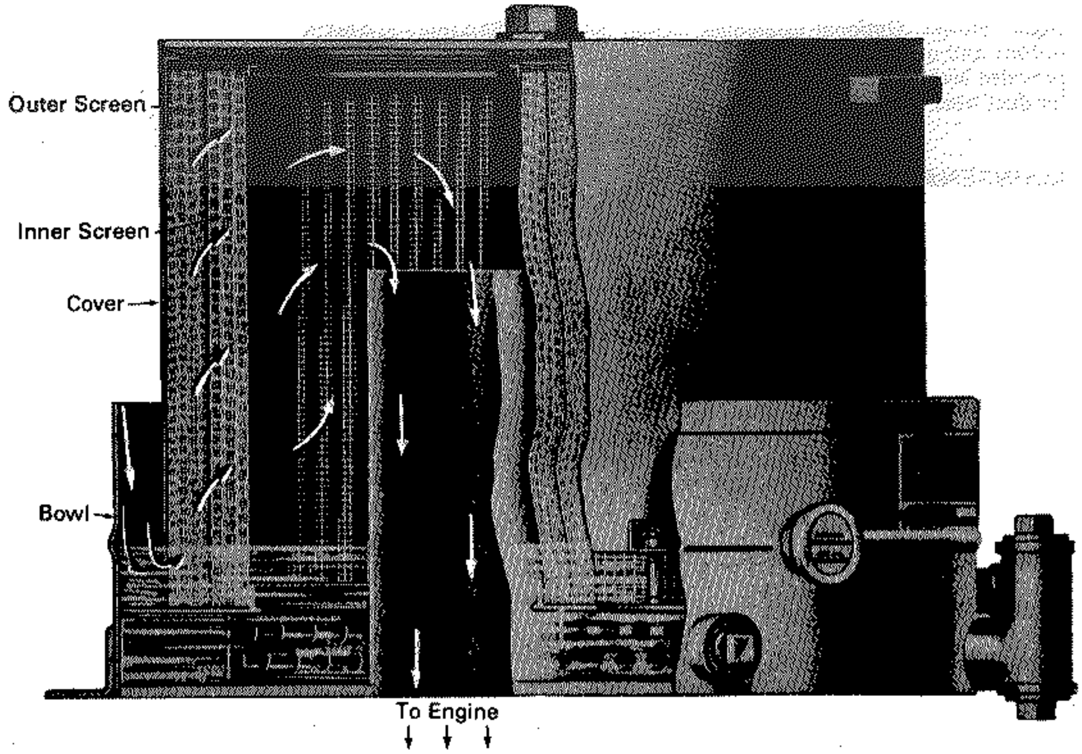


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Fig. 8-6 - Filter Air Flow

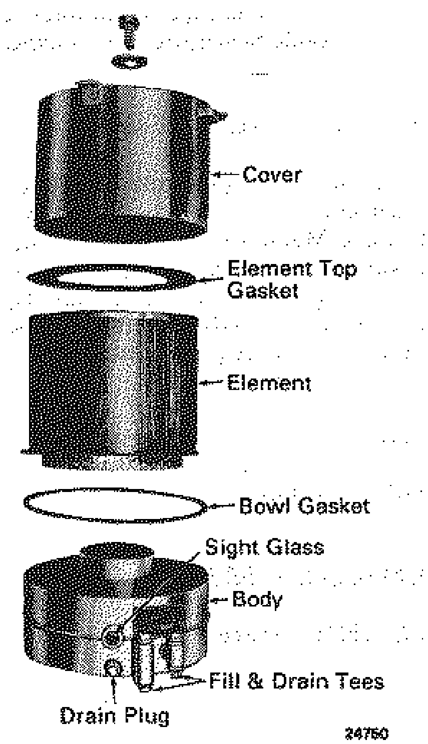

Fig. 8-7 - Bowl Type Filter, Partially Exploded

FIBERGLASS FILTER (DISPOSABLE TYPE)

DESCRIPTION

The fiberglass filter assembly, Fig. 8-8, consists of a welded steel housing containing two or more disposable cartridge-type elements. There is one filter assembly used on the 8-cylinder engine and two on the 12 and 16-cylinder engines. Each filter assembly is attached by an adapter to the top of the

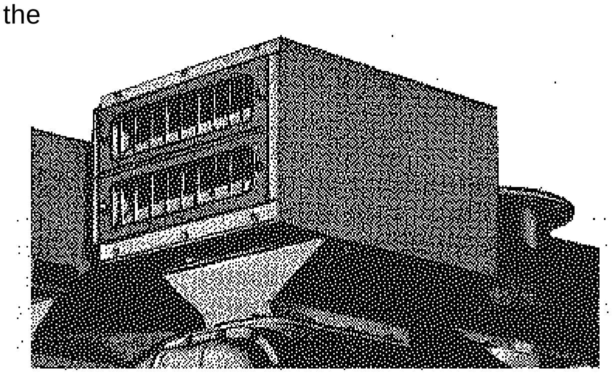

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Fig. 8-8 - Disposable Fiberglass Cartridge-Type Air Filter Assembly engine blower. Optional assemblies include both indoor and outdoor remote mounting versions provided with a transition duct or siamese adapter for duct work connection to the blowers.

MAINTENANCE

The fiberglass cartridge-type elements should be replaced as specified in the Scheduled Maintenance Program. However, operating conditions may warrant more frequent intervals which may be indicated by activation of an engine air filter alarm, if so equipped. To replace the cartridge-type filter elements, release sealing frame retainers, remove elements from the housing one at a time. Slide in new elements and replace sealing frames.

OIL BATH FILTER ASSEMBLY DESCRIPTION

The oil bath filter assembly, Fig. 8-9, is a fabricated rectangular housing designed for remote outdoor installation. The unit has a rain shield extending around the entire assembly above the air intake area. Oil fill and drain plugs are provided in removable clean-out plates at both ends of the oil bath reservoir. An oil level sight glass is also provided on the front face of the reservoir.

Air is drawn in under the rain shields on each side of the unit. The incoming air passes through a distribution plate which provides even dispersion of both air and oil over the filter surface areas. The oil is drawn up from the oil reservoir by pneumatic lift through a series of calibrated orifices in the distribution plate. The distribution plate is fitted with vari-flow valves (small discs over each orifice in the plate) which increase the pressure drop at low air volumes across the face of the plate to ensure oil circulation at all engine speeds.

Oil and dirt are carried upward in the air stream from the distribution plate into a set of self-cleaning filter pads where the dirt particles and oil are separated from the air. The air then passes through an additional set of oil eliminator pads to ensure that all oil and dirt has been completely removed from the air before it enters the engine. The collected dirt is washed out by the oil as it drains to the lower edges of the pads into channels and piping for return to the reservoir. Accumulated sludge settles to the bottom of the reservoir.

MAINTENANCE

Oil bath air intake filters should be serviced as specified in the Scheduled Maintenance Program.

OIL SUPPLY

To accurately check filter oil level and to add oil, the engine should be shut down for at least 20 minutes.

1. Remove the oil fill plug and add oil until the reservoir is full. The oil level should never be below the center of the sight glass.

2. After adding oil to correct level, the filter is ready for operation. Do not check oil level or add oil while the filter is in operation (engine running) as the operating oil level is lower than the non-operating oil level due to oil circulation in the filter.

INSPECTION

The level and condition of the oil and sludge in the unit should be inspected at regular intervals to determine when cleaning is required. Routine inspections should be made at the intervals specified in the applicable Scheduled Maintenance Program.

CLEANING FILTER ASSEMBLY

The oil should be changed and filter assembly cleaned at the intervals specified in the applicable Scheduled Maintenance Program. These intervals may vary depending on the operating schedule and amount of contaminants in the air. Operation in extremely dusty or dirty conditions will require cleaning at more frequent intervals.

Maintenance Instruction for complete servicing of this filter assembly is listed in the Service Data at the end of this section.

EXHAUST MANIFOLD DESCRIPTION

The exhaust gases from the engine cylinders are discharged from the cylinder heads into the exhaust elbows, which pass through the water discharge manifold and connect the cylinder head exhaust outlets to the exhaust manifold risers.

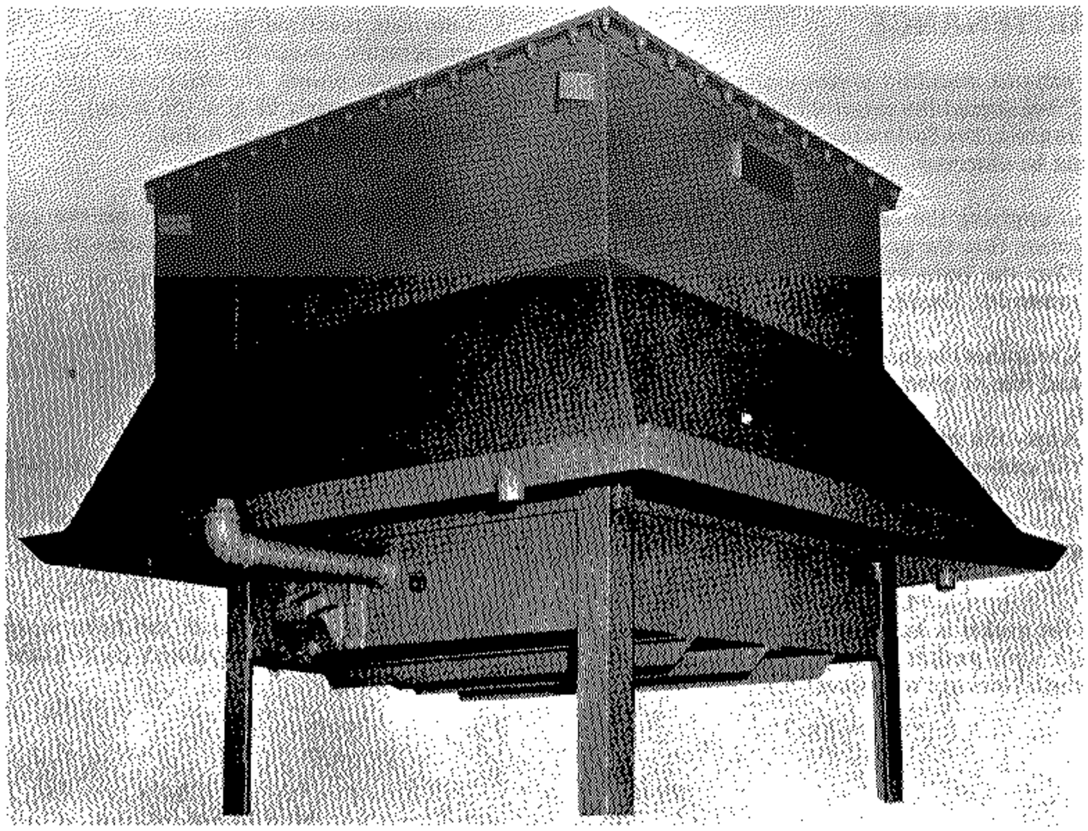

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Fig. 8-9 - Typical Oil Bath Filter Assembly

The exhaust manifold, Fig. 8-10, is made up of sections. Each section is insulated with thin layers of sheet metal, forming shields which completely surround the section. Air space between the shields and the manifold sections provides for additional insulation. The exhaust manifold sections are connected together with special band and clamp connector assemblies.

Junction boxes may be provided on the exhaust manifold for application of thermocouples provided with an exhaust pyrometer option. Pyrometer connection procedures are contained in the Maintenance Instruction on Marine Unit Installations listed in the Service Data at the end of this section.

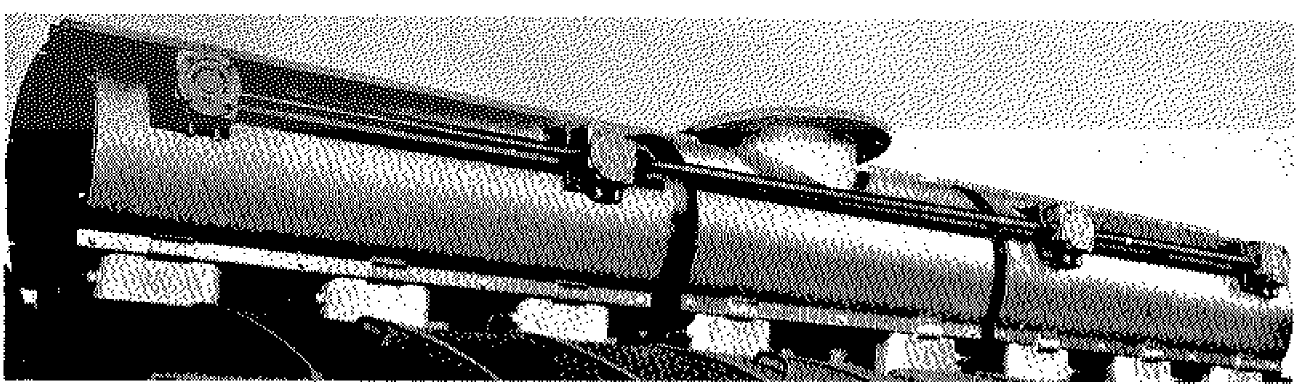

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Fig. 8-10 - Typical Exhaust Manifold

MAINTENANCE

The exhaust manifold is essentially "maintenance free," but should the manifold be disassembled for any reason, the following assembly provisions should be observed.

When applying the exhaust manifold gasket it is important that the gasket be positioned properly, and that the bolts be torqued and retorqued as recommended. Gasket should be applied as follows:

1. Check that the gasket area on the engine is clean and free of obstructions.

2. Apply the gasket making sure that the side of the gasket having the part number and the stamp "THIS SIDE UP" is in the *UP* position. This will ensure that the crimped side of the gasket is down.

CAUTION

If the gasket is incorrectly installed (crimped side up), gasket damage and subsequent exhaust leakage will occur.

3. Lubricate manifold mounting bolts with high temperature thread lubricant and torque the bolts in two passes. The first pass torque should be approximately 68 N•m (50 ft-lbs). The final torque is 176 N•m (130 ft-lbs).

To obtain maximum service life from the gasket application, ,retorquing instructions *MUST* be followed.

1. On new units, bolts *must* be retorqued at intervals stated in the Scheduled Maintenance Program.

2. If an engine has been overhauled or changed out, the bolts *must* be retorqued after load box test, in *addition* to the intervals stated in the Scheduled Maintenance Program.

3. If the engine is not tested, the bolts *must* be retorqued after approximately eight hours of service.

SERVICE DATA

AIR INTAKE AND EXHAUST SYSTEMS

REFERENCES

Marine Unit Installation .... M.I. 3600

SPECIFICATIONS

Clearance and dimensional limits listed below are defined as follows:

1. *New limits are those to which new parts are manufactured. (Drawing tolerances.)*

2. *Minimum, maximum, and tolerance measurements are provided as service limits. At time of rebuild or any time unscheduled maintenance is performed, the service limits should* <u>*not*</u> *be exceeded. Engine components within these limits may be reused with the assurance that they will perform satisfactorily until the next scheduled overhaul.*

	750 RPM	900 RPM
Blower speed - RPM		
8 & 16-Cyl	2040	2450
12-Cyl	1520	1825
Blower capacity - approximate cfm.		
8 & 16-Cyl.	2960	3550
12-Cyl.	2210	2650

Blower pressure - Inches of mercury (Based on engine speed of 900 RPM)... 7-9

Timing gear backlash -
- New.. 0.013 mm - 0.10 mm (.005"-.004")
- Max... 0.140 mm (.0055")

Blower base twist or warp - Max.. 0.15 mm (.006")

Front rotor bearing diametric clearance -
- New.. 0.08 mm - 0.140 mm (.003"-.0055")
- Max... 0.15 mm (.006")

Front rotor bearing thrust clearance -
- New.. 0.05 mm - 0.10 mm (.002"-.004")
- Max... 0.10 mm (.004")

Rear rotor bearing diametric clearance -
- New..0.063 mm - 0.063 mm - 0.100 mm (.0025"-.0040")
- Max... 0.114 mm (.0045')

Timing gear face runout - T.I.R. Max. .... 0.05 mm (.002")

Rotor-to-front end plate clearance -
- New.. 0.216 mm - 0.495 mm (.0085"-.0195")
- Max...0.56 mm (.022')

Rotor-to-rear end plate clearance -
- New.. 0.30 mm - 0.58 mm (.012"-.023")
- Max... 0.64 mm (.025")

Rotor-to-rotor clearance - Upright and Inverted -
- New.. 0.25 mm - 0.56 mm (.010"-.022")
- Max... 0.56 mm (.022")

Rotor-to-housing clearance - Upright -
- New.. 0.30 mm - 0.51 mm (.012"-.020")
- Max... 0.51 mm (.020")

Rotor-to-housing clearance - Inverted -
- New.. 0.38 mm - 0.53 mm (.015"-.021"')
- Max... 0.53 mm (.021")

Quill shaft runout (after assembly) - T.I.R. Max... 0.64 mm (.025")

Static or dynamic balance of rotor assembly - Max.. 0.007 N•m (1 ounce-inch)

EQUIPMENT LIST

	Part No.
Feeler gauges (1/2" x 36” - .010” - .020”)	8049131
Feeler gauges (1/2" x 12" - .008" - .020")	8049132
Feeler gauges (.0015" - .200" short)	8067337
Blower lifting plate	8072929
Blower nut ratchet wrench	8177166
Gasket sealing compound (0.47 liter [1 pt.])	8178639
Thread lubricant, high temperature (.946 liter [1 qt.])	8278929

SECTION 9

LUBRICATING OIL SYSTEM

CONTENTS PAGE

LUBRICATING OIL SYSTEM

DESCRIPTION

The complete engine lubricating oil system is a combination of three separate systems. These are the main lubricating system, the piston cooling system and the scavenging oil system. Each system has its own oil pump. The main lube oil pump and piston cooling oil pump, although individual pumps, are both contained in one housing and driven from a common drive shaft. The scavenging oil pump is a separate pump. All the pumps are driven from the accessory gear train at the front of the engine. Parts of the complete oil system and a schematic arrangement of oil circulation are shown in Fig. 9-1.

MAIN LUBRICATING SYSTEM

The main lubricating oil system supplies oil under pressure to most of the moving parts of the engine. The main lube oil pump takes oil from the strainer housing at the right front of the engine. Oil from the pump goes into the main oil manifold which is located above the crankshaft, and extends the length of the engine. Maximum oil pressure is limited by a relief valve in the passage between the pump and the main oil manifold.

Oil tubes at the center of each main bearing "A" frame conduct oil from the main manifold to the upper half of crankshaft bearings. Drilled passages

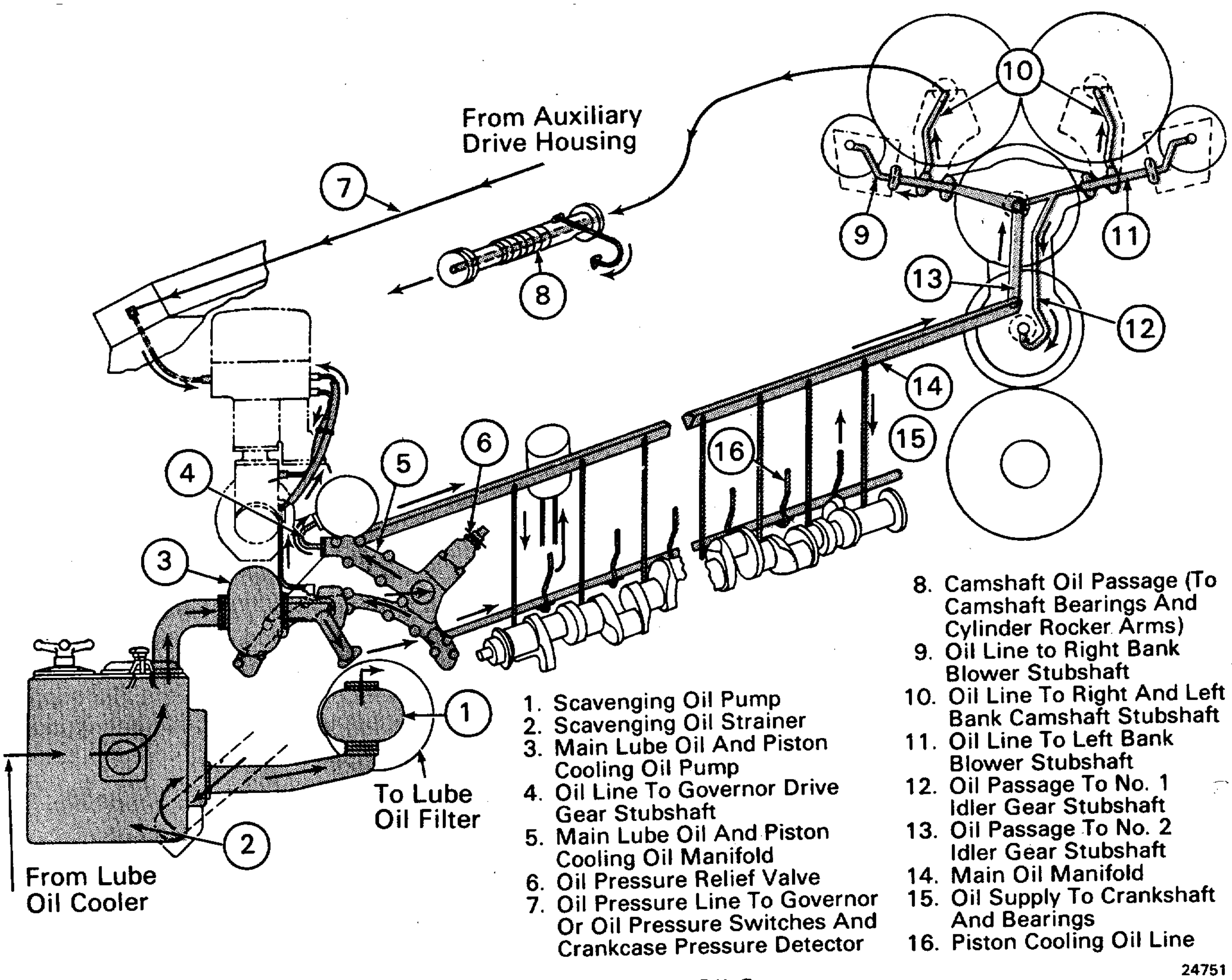


Fig. 9-1 - Lubricating Oil System

in the crankshaft supply oil to the connecting rod bearings, torsional damper, and accessory drive gear at the front of the crankshaft. Leak-off oil from the adjacent main bearings lubricates the crankshaft thrust bearings.

Oil from the main lube oil manifold enters the gear train at the rear of the engine, at the idler gear stubshaft bracket. Oil passages in the stubshaft bracket conduct the oil to the No. 2 idler gear stubshaft bearing and through connecting lines to the No. 1 idler gear stubshaft, camshaft drive gears, blower stubshafts and bearings. Oil enters the hollow bore camshafts from the camshaft drive stubshafts. Radial holes in the camshaft conduct oil to each camshaft bearing. An oil line from one camshaft bearing at each cylinder supplies oil to the rocker arm shaft, rocker arm cam follower assemblies, hydraulic lash adjusters, and the injector rocker arm button. Leak-off oil returns to the oil pan through passages between the top deck and the oil pan.

Oil from the upper idler gear stubshaft lubricates the auxiliary drive bushings and then through connecting lines to the blower bearings and blower gears. A drain line at the gear end of each blower returns the oil to the oil pan sump. An oil pressure line which carries oil to the auxiliary drive housing is also connected to a low oil pressure device in the governor or to an oil pressure switch and the crankcase pressure detector.

On unit without accessory rack, there is a manually operated priming valve located in the bypass line around the main lube oil and piston cooling oil pump. This provides the means for a priming pump to circulate oil through the main lube oil system.

PISTON COOLING OIL SYSTEM

The piston cooling oil system pump receives oil from a common suction with the main lube oil pump and delivers oil to the two piston cooling oil manifolds extending the length of the engine, one on each side. A piston cooling oil pipe at each cylinder directs a stream of oil through the carrier to cool the underside of the piston crown and the ring belt. Some of this oil enters the oil grooves in the piston pin bearing and the remainder drains out through holes in the carrier skirt to the sump.

SCAVENGING OIL SYSTEM

The scavenging oil system pump, Fig. 9-1, takes oil through the scavenging oil strainer from the oil pan sump or reservoir. The pump then forces the oil through the oil filters and oil cooler which are located near the engine. Oil then returns to the strainer housing to supply the main lube oil pump and piston cooling oil pump with cooled and filtered oil. Excess oil spills over a dam in the strainer housing and returns to the oil pan.

OIL GAUGE

An oil level gauge, Fig. 9-2, extends from the side of the oil pan into the oil pan sump. The oil level should be maintained between the low and full marks on the gauge, with the reading taken when the engine is at idle speed and the oil is hot.

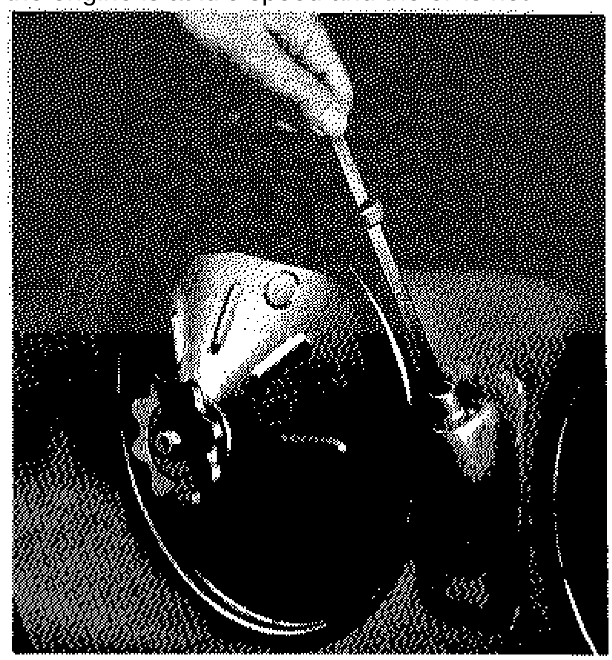


Fig. 9-2 - Oil Level Gauge

MAINTENANCE MAIN LUBRICATING OIL PRESSURE

Adequate lubricating oil pressure must be maintained at all times when the engine is running. Upon starting and idling the engine, it should be noted that the oil pressure builds up almost immediately. In the event of cold oil, the pressure may rise to the relief valve setting of approximately 414 kPa (60 psi).

Lubricating oil pressure is not adjustable. The operating pressure range is determined by such things as manufacturing tolerances, oil temperature, oil dilution, wear, and engine speed. The pipe plug can be removed from the opening in the pump discharge elbow and a gauge installed to determine the pressure.

The minimum oil pressure is approximately 28-41 kPa (4-6 psi) at idle and 103-131 kPa (15-19 psi) at full speed. In the event of insufficient oil pressure, a shutdown feature built into the governor or an oil pressure switch will automatically protect the engine by shutting it down. (In some applications where shutdown is not desirable, a warning bell will ring.) Maximum pressure is determined by the relief valve setting.

PISTON COOLING OIL PRESSURE

Pressure of the piston cooling oil will be governed by oil viscosity, speed of engine, temperature of oil, and wear of pump parts. The pipe plug can be removed from the opening in the pump discharge elbow and a gauge installed to determine the pressure.

MAIN LUBE OIL AND PISTON COOLING OIL MANIFOLD

DESCRIPTION

The main lube oil and piston cooling oil manifold, Fig. 9-3, is a one piece casting with cored passages. The manifold is mounted and doweled in the front end plate, under the accessory drive cover. Connecting tubes passing through the accessory drive cover, protected against leakage by seal rings, connect the manifold to the discharge side of the main lube oil and piston cooling oil pumps.

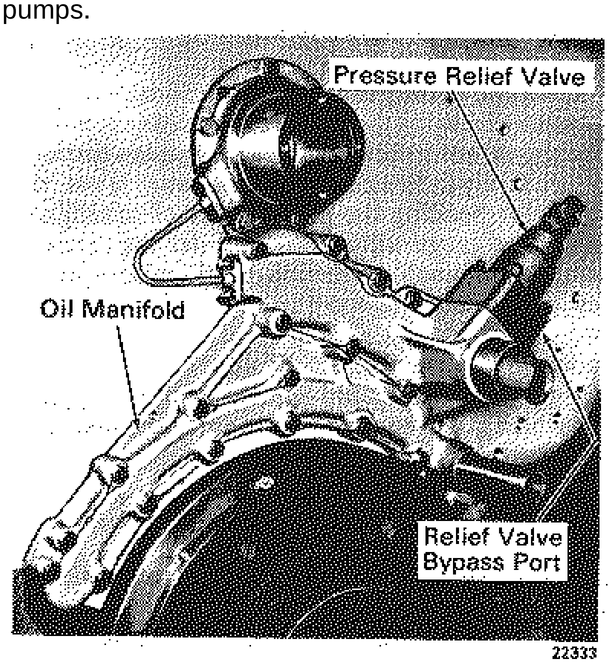


Fig. 9-3 - Main Lube Oil And Piston Cooling Oil Manifold

The purpose of the manifold is to transfer the oil supplied by the pumps to the main bearing oil header in the center of the engine. The manifold also transfers oil to the piston cooling oil header pipes on each side of the crankcase, just inside the oil pan mounting flange.

LUBE OIL PRESSURE RELIEF VALVE

DESCRIPTION

The lube oil pressure relief valve, Fig. 9-4, is installed on the lube oil manifold, inside the accessory gear train housing on the left side of the engine, Fig. 9-1. Access for valve inspection and adjustment is provided by removal of the engine protector.

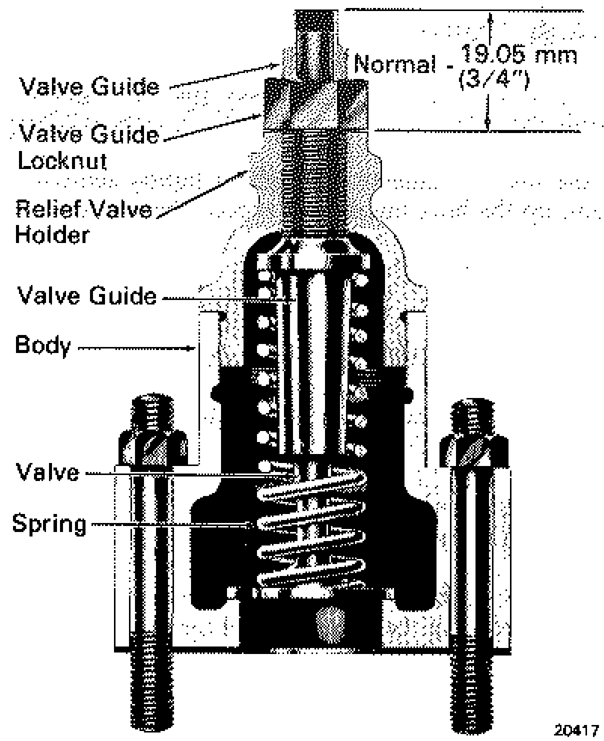


Fig.9-4 - Lube Oil Pressure Relief Valve

The purpose of the valve is to limit the maximum pressure of the lube oil entering the engine oil system. When the lube oil pump pressure exceeds the spring tension on the valve, the valve will be lifted off its seat and relieve the excess pressure. This oil drains into the accessory housing and then into the oil pan.

MAINTENANCE

The oil pressure relief valve should be removed and the parts inspected at intervals specified in the Scheduled Maintenance Program. Disassemble the valve and wash all the parts thoroughly. Back off on the valve guide all the way before removing the valve holder and spring. Inspect the parts as follows to determine their condition for reuse.

VALVE SPRING

Check the valve spring for any nicks which could cause subsequent spring failure.

Test the valve spring by applying a load of 91 kg (200 lbs). Under this load the spring length should not be less than 85.72 mm (3-3/8").

VALVE GUIDE

Using a telescoping gauge, check the valve guide inside diameter.

If the inside diameter is rough or lightly scuffed, clean up the bore but do not exceed the maximum diameter.

VALVE

Examine the valve stem for roughness and light scuffing. The stem may be handstoned and buffed to remove high spots. Replace the valve if the stem is badly galled.

Check that the outside diameter of the valve stem is not less than the minimum limit.

Also, check for a possible bent valve or distorted face by checking the squareness of the valve face to the stem, measuring from the outer edge of the valve face. Total indicator reading should be as specified.

INSTALLATION

When installing relief valve on engine, make sure that the bypass port is positioned in the downward direction, Fig. 9-3.

SETTING OIL PRESSURE RELIEF VALVE

The setting of the oil pressure relief valve connected to the lube oil manifold determines the maximum oil pressure at the main lube oil pump. It is not set by pressure gauges, but by a specific dimension from the top of the valve guide to the top of the valve holder.

To set the valve, loosen the locknut, Fig. 9-4, and position the valve guide so that it extends 19.05 mm (3/4") above the valve holder.

This setting will permit a maximum oil pressure of about 414 kPa (60 psi) under cold oil conditions, and allow an adequate pressure for normal operation and *hot* oil.

Lubricating oil manifold pressure or pressure at the valve can be determined by applying a pressure gauge at the main lube oil pump discharge elbow.

PISTON COOLING OIL PIPE

DESCRIPTION

The piston cooling oil pipe is bolted at one end to a flange on the piston cooling oil manifold, and at the other end to the bottom of the cylinder liner. A pipe is located at each cylinder to direct a stream of oil through the piston carrier to the undercrown of the piston. Alignment of the piston cooling oil pipe is very important.

MAINTENANCE

The alignment of the piston cooling oil pipe to the inlet hole in the piston carrier is checked with an alignment gauge as shown in Fig. 9-5.

The small end of the gauge fits into the nozzle of the pipe and by bringing the piston to bottom center the gauge should enter the inlet hole in the piston carrier and turn freely in this position. This gauge is not to be used for bending the pipe in case of misalignment. If the gauge will not freely enter the carrier hole, the pipe should be removed and replaced with a new or correctly aligned one.

In addition to the alignment check, the piston cooling pipe nozzle should be examined for ragged edges which might cause the oil to spray out instead of shoot out in a stream.

CHECKING OIL VISCOSITY

Oil viscosity should be checked on a routine basis to monitor the suitability of the oil for continued use. By comparing the viscosity at different intervals, taken at the same temperature, excessive fuel dilution may be detected by an unusual drop in viscosity. Excessive oxidation of the oil may be detected by an unusual rise in viscosity within the

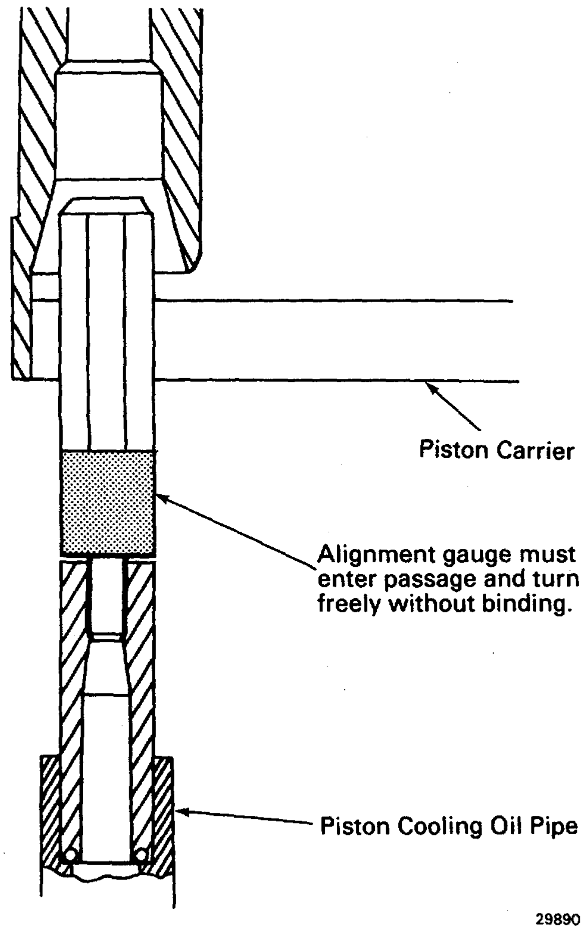


Fig. 9-5 - Piston Cooling Oil Pipe Alignment

recommended oil drain periods. The viscosity limits are directly related to the type of oil being used and the type of viscosity measurements being made. The oil suppliers will furnish these values, which should correspond to a maximum of 5% fuel dilution and a 35% viscosity rise.

Operating an engine with badly oxidized oil or poor oil filtration will result in oil cooler core plugging, carbon buildup on piston undercrowns, ring grooves, oil rings, and piston pin bearing grooves, and limitation of oil flow to the main and connecting rod bearings and subsequent engine damage.

To provide protection to the engine, the oil and system components should be carefully observed. for proper functioning and corrective measures taken where necessary. Oil and filter change periods should be followed closely since the oil is not only oxidizing, but contaminants are coming into the engine from fuel combustion, as well as the normal airborne contaminants which are not caught by the air filters. It is therefore beneficial to drain the oil and eliminate these contaminants.

CHANGING OIL

Engine lube oil should be drained periodically, filters replaced, and strainers and screens cleaned as outlined in the Scheduled Maintenance Program. Before the oil is drained, its viscosity should be checked for any indication of fuel dilution. If fuel leakage is indicated, the leak should be corrected before charging the engine with new oil.

GENERAL PROCEDURE

1. Shut down the engine.
2. Open drain valve in the oil strainer to drain oil into the engine sump.
3. Provide a container or oil runoff line for drained oil.
4. Remove pipe plug from oil drain valve and open valve to drain all the oil from the engine oil pan sump.
5. Remove pump strainers from strainer housing, and remove the oil filters from the filter housing.
6. Clean the strainers using a suitable cleaner, and rinse thoroughly.
7. Wash down top deck, oil pan, and filter housings using fuel oil or kerosene. Drain off cleaning fluid and wipe areas free of excess fluid, using bound edge absorbent towels.
8. Replace pipe plugs in drain lines, where required, and close valve. Where necessary, renew gaskets.
9. Install clean strainers and screens. Install new elements in filter containers. Prepare system to receive new oil.
10. Recharge engine with new lubricating oil qualified for use. Add oil through square filler opening in strainer housing.

CAUTION

Ensure that strainer housing internal drain valves are closed and oil strainer is filled to overflow before starting engine.

Sufficient oil will be retained in the housing to supply main lube and cooling oil pumps on starting. Engine oil level is shown on the oil gauge. Pour a liberal quantity of oil over cylinder heads and top deck components before starting.

11. Inspect engine prior to starting, then start engine. Check oil level with engine at idle speed. If oil level is not to "full" mark on gauge, add oil to bring level to "full" mark, with engine at idle speed and with *hot* oil.

NOTE

Under some conditions the oil level may be above the bottom of the oil pan handholes, so care must be taken when the oil pan handhole covers are removed.

OIL STRAINER HOUSING

DESCRIPTION

The oil strainer housing, Fig. 9-6, is a large box-shaped cast aluminum housing which is mounted on the right front side of the engine on the accessory drive cover. It contains independent strainers for the main oil pump supply and scavenging oil pump. There are two strainers for the main lube pump oil and one strainer screen for scavenging pump oil, with a separate oil inlet and discharge for each of the systems.

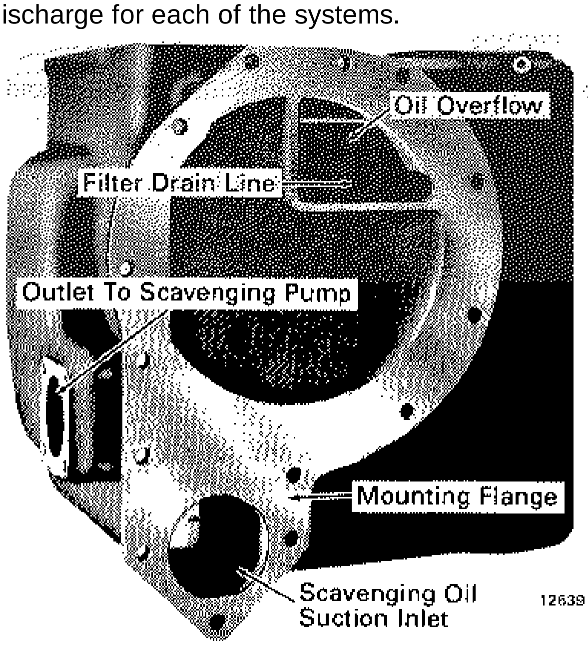


Fig. 9-6 - Oil Strainer Housing

The two main lube oil pump strainers, Fig. 9-7, each consists of a replaceable element of a pleated perforated metal core covered with mesh screening, and a metal cylinder which encloses the element. The cylinder prevents collapse of the element in the event of a high pressure drop. The element is attached to the cylinder by a through bolt in the cylinder which runs through the base of the element and is secured with a locknut. The unperforated

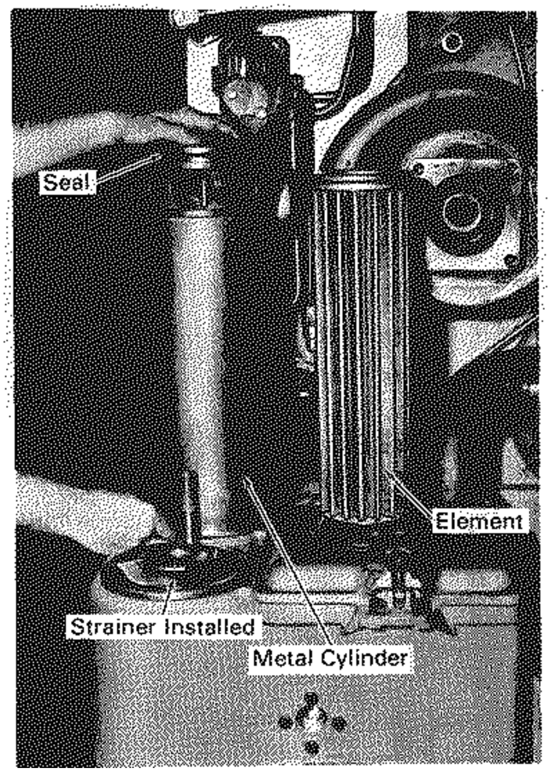


Fig. 9-7 - Main And Piston Cooling Oil Pump Strainers

outer cylinder provides a constant head of oil since suction is from the bottom only and not through the entire length of the screen. The flow of oil is from the bottom of the strainer between the cylinder and the mesh screen, through the mesh screen and the perforated metal core into the center of the element, then out the top of the strainer.

When in place, they are held by a crab and handwheel on the stud between the holes. Each strainer is sealed at the top by a seal ring. Also, oil under pump pressure is admitted to a groove around each strainer, just below the seal, to prevent air entry in event of a leaky seal. A partition adjacent to the strainers, open at the bottom, separates them from the oil inlet area of the housing. Oil enters the strainers at the partition bottom and is taken up by the pump through a cast passage in the housing.

The scavenging oil pump strainer, Fig. 9-8, has a rigid perforated metal screen which retains its shape and is easily cleaned. When the strainer is installed in the housing, it is held in position with three nuts. Two handwheels on swivel bolts secure a cover over the strainer and drain valves. The scavenging oil strainer inlet and outlet openings are shown in Fig. 9-6.

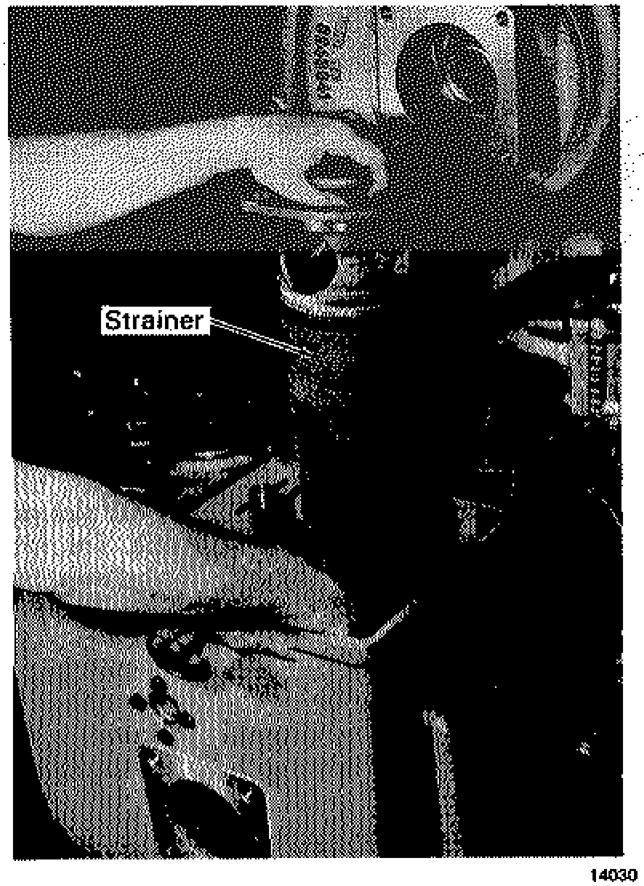


Fig. 9-8 - Scavenging Oil Pump Strainer

An oil level is maintained in the strainer housing up to the bottom of the overflow opening, Fig. 9-6. Excess oil returns to the oil pan sump. A spring-loaded valve, Fig. 9-9, is provided to drain the oil from the strainer housing into the oil pan sump, at the time of an oil change. An additional valve, Fig. 9-9, is used to drain the oil filter housing on units provided with internally manifolded Lube oil filter housing. Both valves are located under the filler cover and must be kept closed at all times except for the period of draining.

MAINTENANCE

Lube oil strainers should be removed at each oil change and strainers and housing thoroughly cleaned, using a petroleum solvent.

As previously described, the engine lube oil strainers have a seal of oil under pressure in addition to the seal rings. The oil under pressure will leak out under the strainer flanges if the seal rings are not seated properly or are damaged. When strainers are replaced, care should be taken to see that the sealing surfaces are free from nicks and scratches and seal rings are in good condition. Also, that the oil passages to the seals are open and clear.

The pressure oil seal may be checked, with the engine at idle speed, by loosening the large handwheel until the seal ring of the farthest strainer

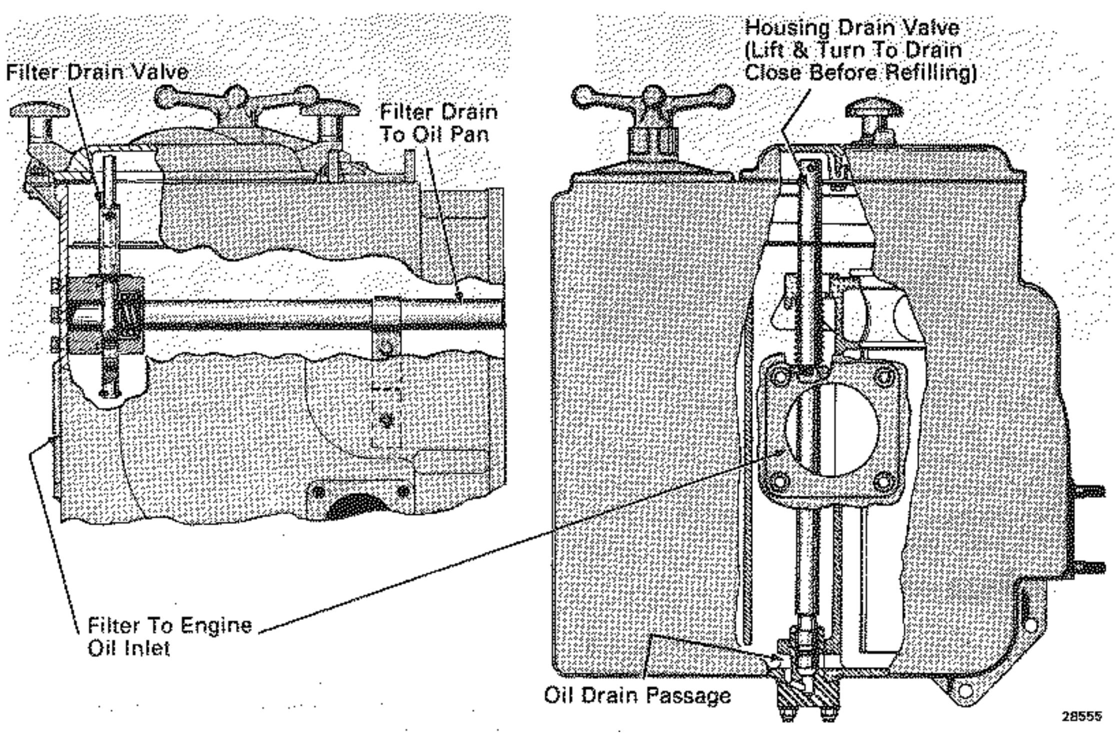


Fig. 9-9 - Strainer Housing Drain Valves from the engine is free of the housing. Oil should leak out around the strainer flange. If no oil appears, the engine should be shut down and the oil supply passages inspected and cleaned.

Any air which might enter system at this location will be discharged with the lubricating oil and may cause damage, even though normal oil pressure is indicated.

When replacing the scavenging strainer, be sure the strainer is seated properly or the scavenging pump will lose suction causing a loss of lube oil pressure.

LUBE OIL SEPARATOR

DESCRIPTION

The oil separator, Fig. 9-10, is a cylindrical housing containing a wire mesh screen element. It is mounted on the auxiliary drive housing.

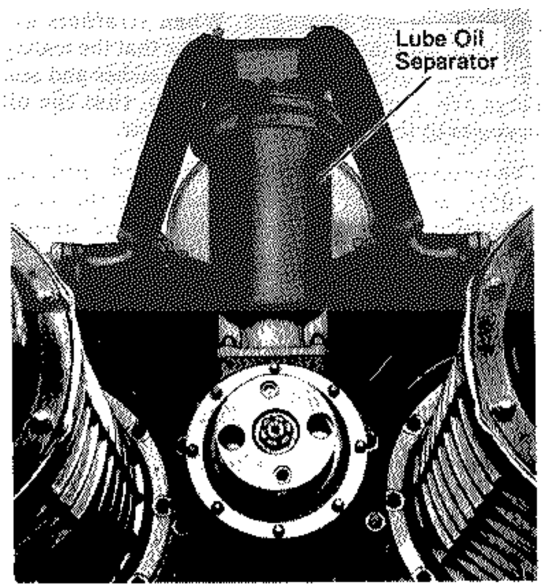


Fig. 9-10- Lube Oil Separator

Blower suction draws up engine oil vapors from the oil pan through the rear gear train housing into the separator element. The oil collects on the element and drains back into the engine.

MAINTENANCE

The screen should be removed from the oil separator and cleaned as specified in the Scheduled Maintenance Program.

1. Shut the engine down.
2. Disconnect the suction hoses from the cover and remove the housing cover.
3. Remove the screen element assembly and wash it in a petroleum solvent, then rinse the element with hot water and blow dry with air.
4. Replace the element and the cover and attach the hoses to the cover.

MAIN LUBE OIL AND PISTON COOLING OIL PUMPS

DESCRIPTION

The main lube oil and piston cooling oil pumps, Fig. 9-11, are contained in one housing. The two pumps are separated by a spacer plate between the sections of the pump body. Each has its individual oil inlet and discharge opening. The piston cooling pump gears at the end are narrower than the lube oil pump gears. The lube oil and piston cooling oil pump assembly is mounted in the center of the accessory drive housing and is driven by the accessory drive gear.

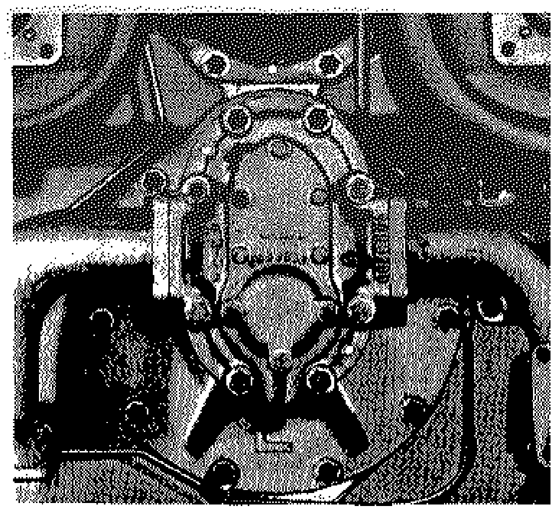


Fig. 9-11 - Main Lube Oil And Piston Cooling Oil Pumps

MAINTENANCE

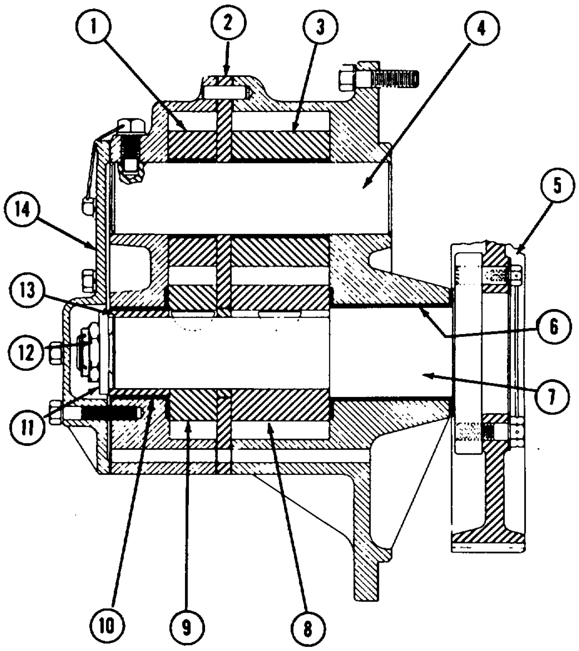
DISASSEMBLY

1. Clean the pump externally before disassembly.
2. Hold the pump in a suitable vise.

NOTE

As a safety precaution, provide an additional support at the center of the pump until the front body and bushing and piston cooling pump gears are removed.

3. Remove the long bolts, Fig. 9-12, holding the front body to the rear body.



1. Piston Cooling Driven Gear
2. Spacer Plate
3. Lube Oil Pump Driven Gear
4. Idler Shaft
5. Drive Gear
6. Inner Bushing
7. Drive Shaft
8. Lube Oil Pump Drive Gear
9. Piston Cooling Drive Gear
10. Front Bushing
11. Washer
12. Shaft Nut
13. Shaft Sleeve
14. Cover

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Fig. 9-12 - Main Lube Oil And Piston Cooling Oil Pumps, Cross-Section

4. Using a rawhide mallet, tap the front body at the inlet and outlet openings, to remove the front body, cover, idler shaft, and the outer driven gear as an assembly.
5. Remove the drive shaft nut, and washer.
6. Support pump on its flange, pump drive gear down, so that gear is free to move downward.
7. Apply pressure to shoulder of drive shaft and press the shaft down a maximum of 12.7 mm (1/2").

CAUTION

If shaft is pressed down too far, the piston cooling pump gear key will shear the collar in the spacer plate.

8. Manually raise pump drive gear and drive shaft until a 12.7 mm (1/2") clearance is obtained between the drive shaft sleeve and the piston cooling pump drive gear.
9. Attach a puller to the drive shaft sleeve and remove sleeve from the drive shaft.
10. Remove the piston cooling pump drive gear and its key.
11. Remove the spacer plate and collar.
12. Remove the lube oil pump inner driven gear, drive gear, and key.
13. The pump drive gear and shaft assembly is then removed.

NOTE

Pump drive gear and shaft assembly should not be separated unless gear is being replaced or is required for use as a "dummy" gear during backlash adjustment of governor drive gear.

14. Keep all parts of the one pump assembly together.

CLEANING

Clean all the individual parts of the pump using a petroleum solvent. After cleaning, dry the parts with compressed air.

INSPECTION

PUMP BODIES

1. Check the surface of the pump bodies for nicks, dents or scratches which may have protrusions above the normal surface. Smooth down any evidence of roughness.
2. Inspect the drive shaft bushings for imbedded dirt, metallic particles, flaking and pitting. Bushings with light scratches and small quantities of imbedded dirt may be reused after smoothing up, provided bore sizes are within the maximum limits.
3. Replace the bushings if any other adverse conditions exist. Details of construction and application of bushing installation and removal tools are shown in Fig. 9-13.
4. Using fine abrasive cloth on a smooth surfaced tool, clean off the gasket face of the pump bodies.

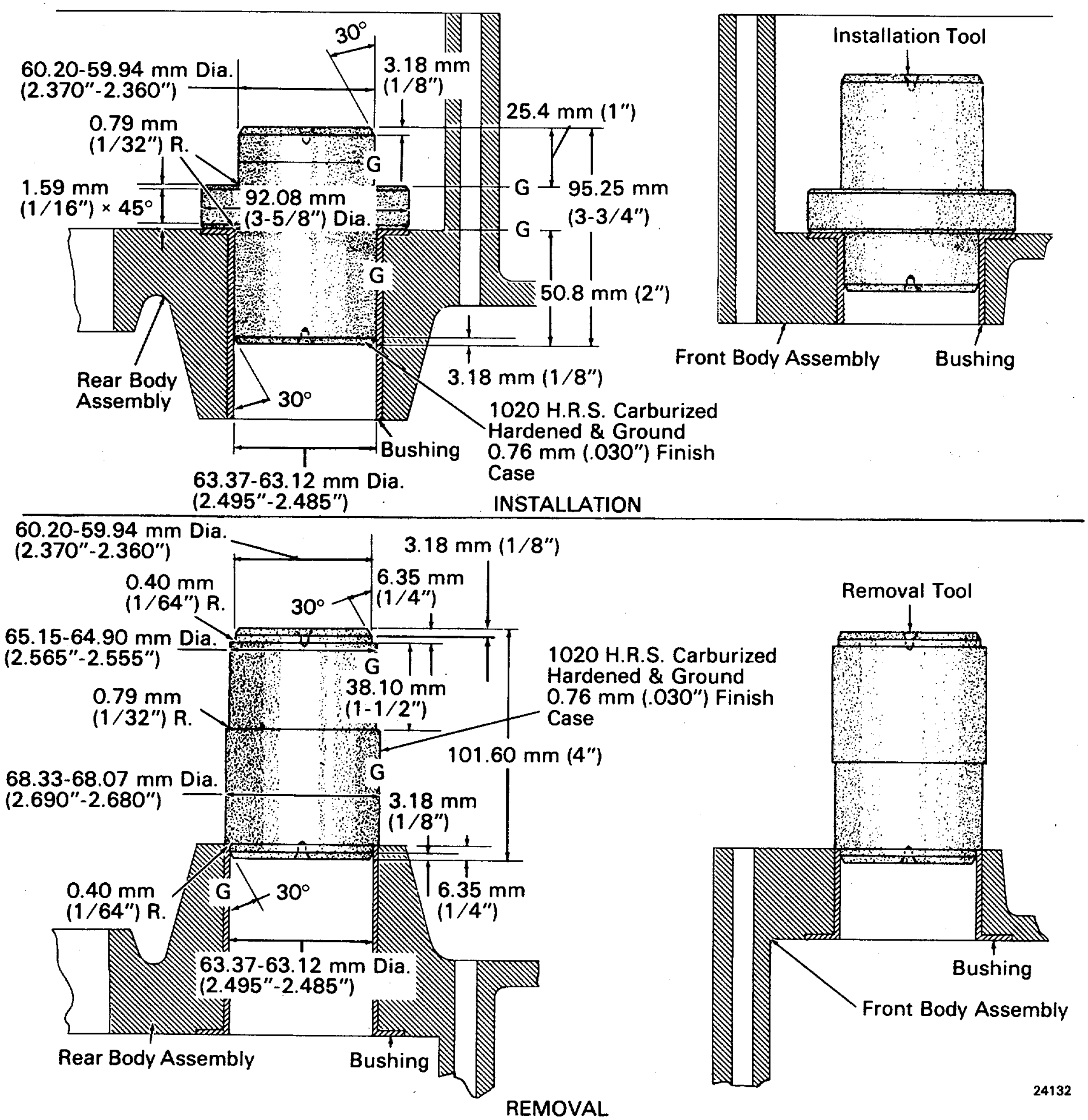


Fig. 9-13 - Oil Pump Body Bushing Tools

SPACER

Inspect the sides of the spacer for smoothness. If necessary, smooth the sides using fine abrasive cloth held flat on a flat surfaced tool.

GEARS

1. Inspect the gear teeth for nicks, pitting, and excessive wear. Light nicks are permissible provided they are blended by filing and stoning.
2. Gears having tooth faces pitted in excess of 30% of tooth contact area should not be reused.
3. Inspect the driven gear bushing inside diameter for wear and possible damage.
4. Driven gear bushing installation and removal tool construction and application is shown in Fig. 9-14

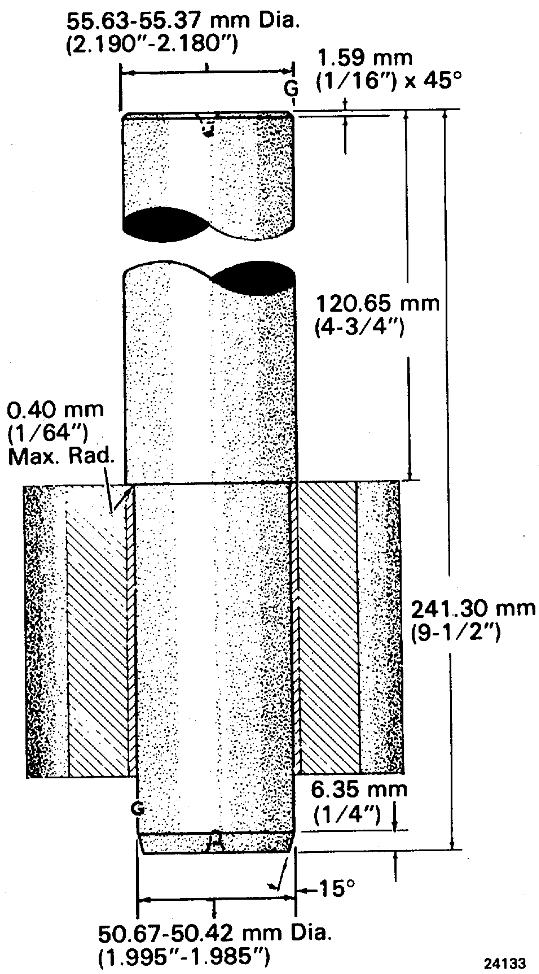


Fig. 9-14 - Oil Pump Driven Gear Bushing Tool

5. Inspect the keyways in the drive gears for any damage which would interfere with the key application.
6. The drive shaft gear may be magnaflux inspected.

DRIVE SHAFT, KEYS, AND IDLER SHAFT

1. Inspect the shafts for any roughness. Check the drive shaft keyways and key fit, making sure the keys fit snugly in the shaft.
2. Check the drive shaft diameter to determine whether the drive shaft to body bushing clearance is within maximum limits.
3. Also check the idler shaft to make certain that the shaft to bushing clearance is within maximum limits.

ASSEMBLY

1. Place the mounting flange of the cleaned and inspected rear body, Fig. 9-12, in the bench vise with the drive shaft bore facing up.

NOTE

If pump drive gear was removed from pump, reapply gear on drive shaft using four 1/2"-20 bolts. Apply thread lubricant to bolt threads and torque to 88 N-m (65 ft-lbs). Lock wire bolt heads together.

2. With the pump drive gear applied to the drive shaft, lightly oil the shaft journal and insert the shaft in the rear body bushing.
3. Place the inner drive gear key in the drive shaft and install the inner drive gear on the shaft.
4. After oiling the bushing, apply the mating driven gear, meshing it with the drive gear.
5. Oil the pump rear body gasket and apply it to the gasket face of the rear body, being careful to align the bolt and dowel holes.
6. Apply the spacer plate to the rear body and the collar to the drive shaft.
7. Install the piston cooling drive gear key in the drive shaft and apply the drive gear.
8. Apply the sleeve, heavy duty washer, and nut to the drive shaft. Tighten nut to 441-475 N-m (325-350 ft-lbs) torque.
9. Oil the spacer plate gasket and apply it to the spacer.
10. Completely coat the bushing in the front body with oil.
11. Apply the piston cooling pump driven gear to the idler shaft which was left assembled to the front pump body and cover, and apply this assembly to the pump. If the front body, cover, and idler shaft were disassembled, apply these parts individually, using new oiled gasket between the cover and the front body.
12. Complete assembly of the pump by installing the long bolts through the cover. Tighten securely.

ASSEMBLY INSPECTION

1. After pump assembly, rotate the pump drive gear to check for gear noise or tight assembly.
2. Check the thrust of the drive gears. This may be done by securing an indicator on the pump flange with the indicator button contacting the

rim of the pump drive gear, Fig. 9-15. Push the drive gear inward so that all clearance is located at one end, then set the indicator to zero. Pull the drive gear outward to determine the amount of thrust clearance.

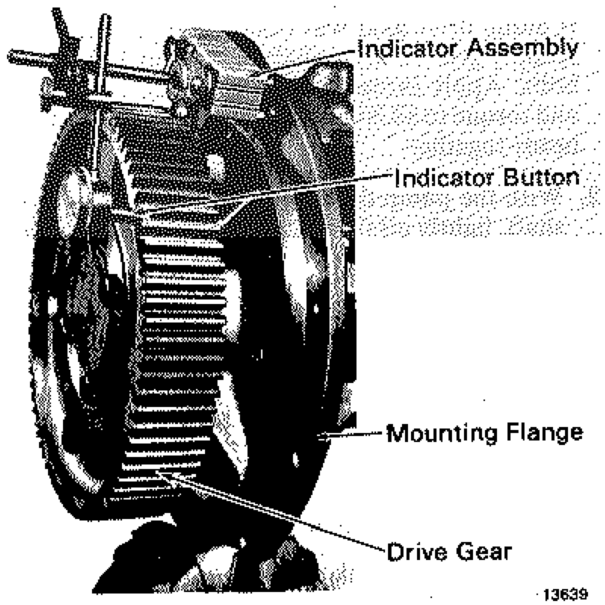


Fig. 9-15 - Checking Pump Drive Gear End Thrust

3. Leaving the indicator button on the outside pump drive gear rim, rotate the drive gear to check the gear runout. Drive gear runout should not exceed specified total indicator reading, with thrust in one direction.

4. Check the pump flange runout. Mount the indicator clamp on the drive gear and place the indicator button to contact the pump flange. Set the indicator to zero, and with the thrust held in one direction, rotate the drive gear. The runout of the pump flange face should not exceed specified total indicator reading.

5. Check the pump gears to body radial clearance. Clearance should be within the specified limits.

6. Additional clearances and limits are listed in the "Service Data" at the end of the section. Some clearances must be obtained by comparing the individual mating parts, or by assembly and disassembly using lead wire or other suitable means to obtain the part to part clearance.

7. After pump inspection, seal off the pump body openings, and provide protection for the teeth of drive gears.

SCAVENGING OIL PUMP

DESCRIPTION

The scavenging oil pump, Fig. 9-16, is a positive displacement, helical gear type pump. The pump body, split transversely for ease of maintenance, contains sets of mated pumping gears. The driving gears are retained on the pump drive gear shaft by keys. The idler shaft is held stationary in the housing by a set screw, and the driven pump gears rotate on this shaft on bushings pressed into the gear bores. The drive shaft turns in bushings pressed into the pump body. These bushings are made with thrust collars which protrude slightly above the pump body and absorb the thrust of the drive gears. The scavenging pump is mounted on the accessory housing in line with and to the left of the crankshaft, and is driven by the accessory drive gear.

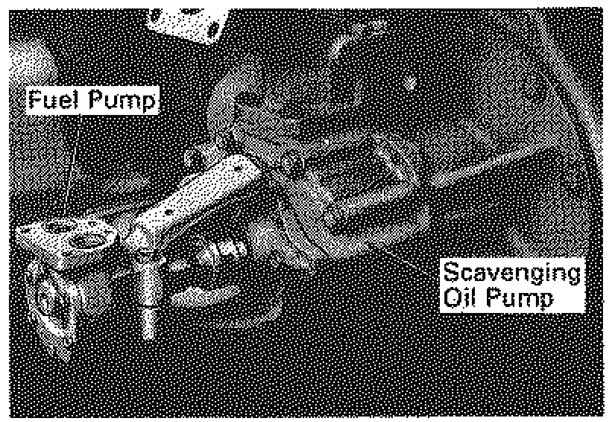


Fig. 9-16 - Scavenging Oil Pump

MAINTENANCE

Construction and maintenance of the scavenging oil pump is similar to the main lube oil and piston cooling oil pump, except for the use of the spacer in the main lube oil pump.

DISASSEMBLY

1. Clean the external surfaces of the pump before disassembly.

2. Hold the pump in a suitable vise. As a safety precaution, provide additional support until the rear body is removed.

3. Remove the nut and bolt holding the fuel pump in the bracket. Loosen the set screws in the fuel pump to drive shaft extension coupling, then remove the coupling.

4. Remove the long bolts, Fig. 9-17, holding the pump bodies together.

5. Using a rawhide mallet, tap the front body at the oil inlet and outlet openings to remove the front body, idler shaft, and the cover as an assembly.

6. Remove the drive shaft nut, washer, and sleeve from the drive shaft.

7. Remove the outer drive gear, key, and driven gear.

8. Remove the inner drive gear, key, and driven gear.

9. Remove the pump drive gear and shaft as an assembly from the rear pump body.

10. Keep all parts of the same pump together.

CLEANING

Clean all the individual parts of the pump using a petroleum solvent and rinse in hot water. Dry the parts, using compressed air.

INSPECTION

Refer to the corresponding procedures in the preceding "Main Lube Oil And Piston Cooling Oil Pumps" coverage. Also, refer to "Service Data" at the end of the section.

ASSEMBLY

1. Place the cleaned and inspected rear body, Fig. 9-17, in the vise with the drive shaft bore facing up.

2. Oil the drive shaft journal sparingly, and apply the pump drive gear and shaft as an assembly to the rear body.

3. Apply the drive gear key to the drive shaft and apply the inner drive gear. Apply the mating driven gear.

CAUTION

Refer to Service Data for diagram of helix angle position of abutting gears.

4. Oil the body gasket and apply it to the rear body.

5. Apply the outer drive gear key to the drive shaft and install the outer drive gear.

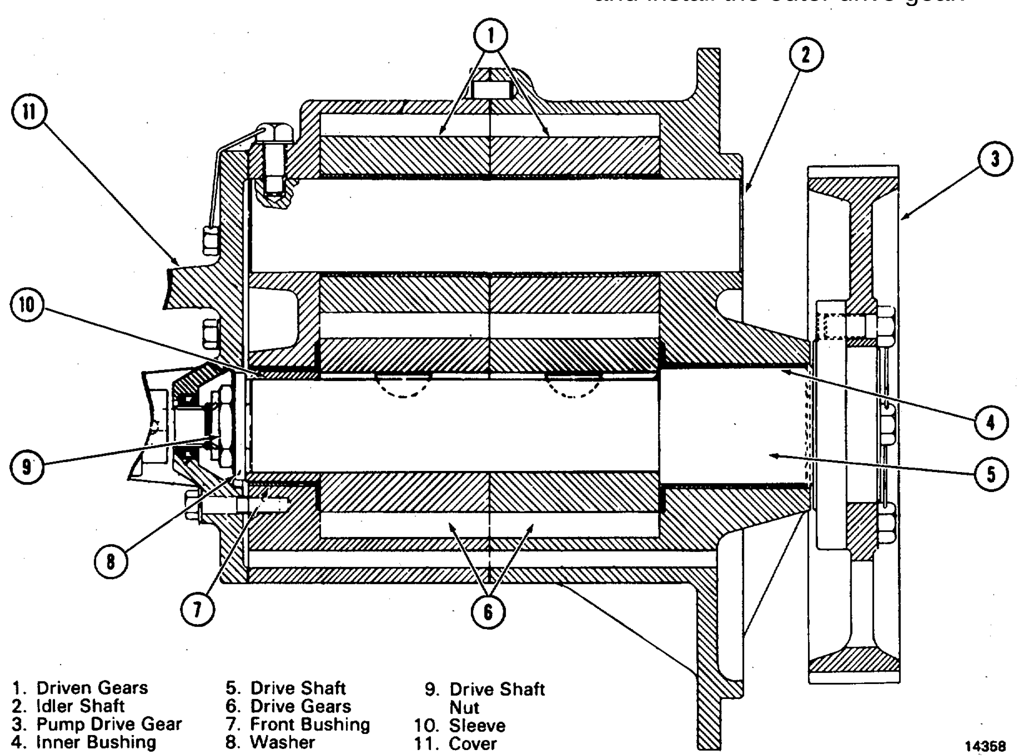


Fig. 9-17 - Scavenging Oil Pump, Cross-Section

6. Apply the sleeve, heavy duty washer, and nut to the drive shaft. Tighten nut to 441-475 Nm (325-350 ft-lbs) torque.
7. If the seal was removed form the fuel pump bracket, clean the seal bore and press in a new seal. Make sure the lip of the seal is toward the mounting side of the pump bracket.
8. Before applying the fuel pump bracket assembly, place the tapered sleeve oil seal installer tool on the pump shaft extension. This tool will aid in protecting the seal when applying the pump bracket.
9. Since the front body, idler shaft, and fuel pump bracket were left as an assembly, these parts may be applied to the pump together. Apply the outer driven gear to the idler shaft and apply this assembly to the pump. Remove the oil seal installer tool. A tapped hole is provided in the end of the seal installer for a 1/4"-20 bolt to aid in the removal of the tool.
10. Install the long bolts through the fuel pump bracket and tighten securely.
11. Apply the fuel pump and couplings.

ASSEMBLY INSPECTION

1. After pump assembly, rotate the pump drive gear to check for gear noise or tight assembly.
2. Check the thrust of the pump drive gears. This is done using the same indicator arrangement shown in Fig. 9-15 for the main lube oil pump. Attach the indicator holder to the pump flange with the indicator button contacting the rim of the pump drive gear. Push the drive gear inward to take up all thrust in one direction. Set the indicator button to zero and pull the drive gear outward to determine clearance. Thrust clearance using new parts should be within the specified limits.
3. With the indicator button on the outside of the pump drive gear rim, as when checking thrust clearance, rotate the gear with the thrust held in one direction to check drive gear runout. Drive gear runout should not exceed specified total indicator reading.
4. Check the pump flange runout. Mount the indicator clamp on the drive gear and place the indicator button to contact the pump flange. Set the indicator to zero, and with the thrust held in one direction, rotate the drive gear. The runout of the pump flange face should not exceed specified total indicator reading.
5. Check the pump gears to body radial clearance. Clearance should be within the specified limits.
6. Additional clearances and limits are listed in the "Service Data" at the end of the section. Some of the clearances must be obtained by comparing the individual mating parts, or by assembly and disassembly using lead wire or other suitable means to obtain the part to part clearance.
7. After pump inspection, seal off the pump body openings and provide protection for the drive gear teeth.

LUBE OIL CIRCULATING PUMP (OPTIONAL)

On power generating units equipped with an immersion heater, a lube oil circulating pump and motor are mounted on the side of the base assembly, Fig. 9-18.

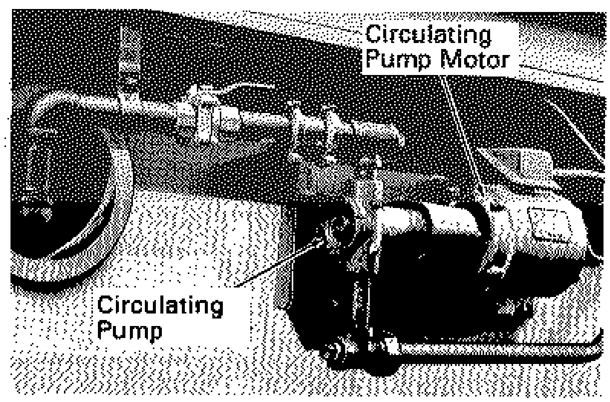


Fig. 9-18 Lube Oil Circulating Pump And Motor Installation

The lube oil circulating pump circulates oil through the lubricating oil system to keep a standby engine in a constant state of readiness for an immediate start. As the circulating oil passes through the oil cooler, it is warmed by water which flows from the immersion heater through the water passages of the oil cooler.

The lube oil circulating pump draws oil from the oil pan and pumps it through a 207 kPa (30 psi) check valve, the main lube oil filter, and the oil cooler and is then returned to the strainer housing. The pump control system operates continuously and is controlled by a manual ON-OFF switch.

ACCESSORY RACK COMPONENTS

The lube oil filter and lube oil cooler are mounted on the accessory rack, Fig. 9-19, adjacent to the front end of the engine. Since these components vary in accord with specific applications, the descriptive, maintenance, and illustrative data should be considered as "typical."

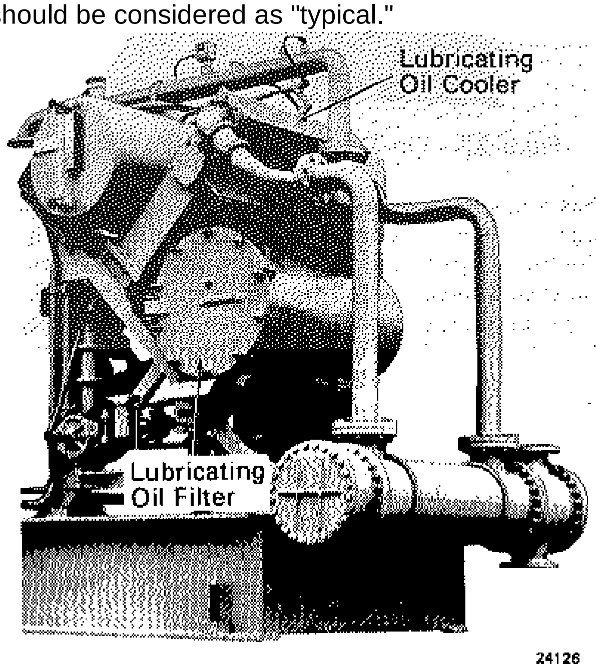


Fig. 9-19 - Accessory Rack Oil System Components

LUBRICATING OIL FILTER

DESCRIPTION

The lubricating oil filter, Fig. 9-20, is a full flow type and consists of a circular tank containing the filter elements which are mounted on standpipes. A hinged cover closes the open end of the tank and is held tightly by the cover holddown bolts. A gasket is used between the cover and the rim of the tank to prevent oil leakage during operation. Flanged openings are provided for the oil inlet and outlet connections and for filter housing drain lines. In some installations, a separate drain line extends from the filter to a valve in the engine mounted strainer housing. The valve is opened to provide quick draining of the filter during maintenance by permitting oil to return to the engine oil pan.

Internally, the filter is divided into two compartments by a false bottom or separator plate. The portion

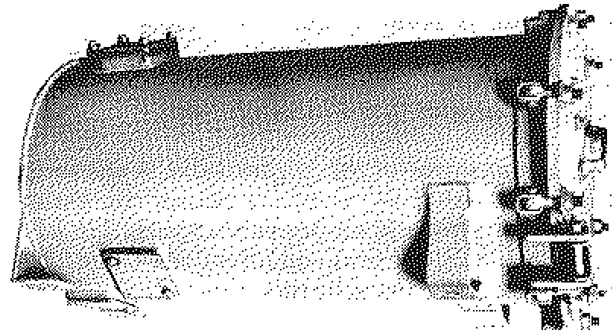


Fig. 9-20 - Lubricating Oil Filter

above the false bottom is the element compartment which receives the unfiltered oil. The lower portion is the discharge compartment which receives the oil after it has passed through the filter elements.

The filter elements are properly positioned within the housing by cradles, Fig. 9-21, which are located in a position to ensure correct application of the elements. The elements are placed over the standpipes and allowed to rest on the cradle.

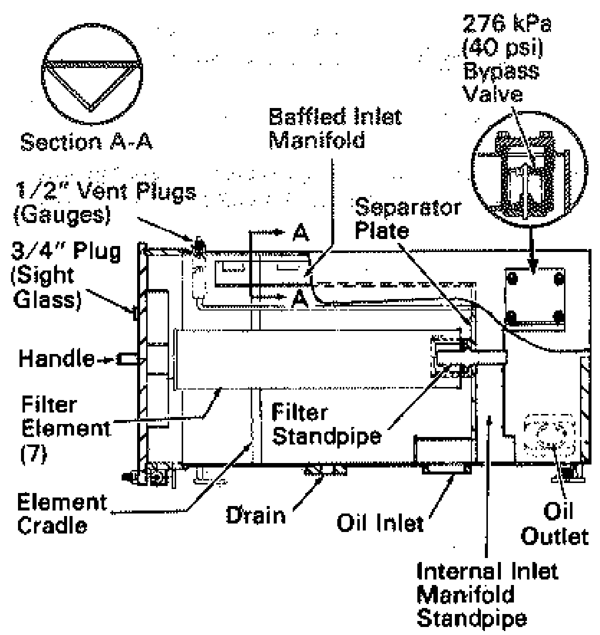


Fig. 9-21 - Lubricating Oil Filter, Cross-Section

The filtered oil flows through the center of the elements and out through the standpipes to the discharge compartment. All elements are sealed at the bottom so the dirty oil cannot pass directly into the discharge compartment. Baffles are provided at the oil inlet of the housing to prevent direct impingement of the incoming oil against the filter elements.

Provision is made in the filters to permit oil circulation in the event of cold oil or dirty filters. The oil begins to bypass the filter at differential pressures greater than 276 kPa (40 psi).

The arrangement of the bypass valve is shown in Fig. 9-21. The bypass valve has a passage connecting it to the oil inlet. If oil pressure exceeds 276 kPa (40 psi), the valve opens and oil is dumped into the filter discharge compartment.

MAINTENANCE

The lube oil filter elements should be changed as outlined in the Scheduled Maintenance Program. Each time the elements are changed, the element compartment should be cleaned of sludge. The filter elements cannot be cleaned and must be renewed each time.

CHANGING ELEMENTS

1. Open filter drain valve in lube oil strainer, if applicable.
2. Carefully open filter cover so any lube oil remaining in filter will drain into drain trough.
3. Remove elements from their cradles.
4. Clean elements compartment of sludge and install new elements. Check the center tube seats when installing the elements to determine that there is no foreign material on the surface which will prevent proper seating of the element.
5. Close filter cover being sure gasket is in place and is not damaged.
6. Tighten cover bolts.
7. Close filter drain valve in lube oil strainer, if applicable.

BYPASS VALVE ASSEMBLY

The lube oil filter bypass valve should be serviced at intervals specified in the Scheduled Maintenance Program. Maintenance Instructions for servicing this valve are referenced on the Service Data pages.

LUBE OIL COOLER

DESCRIPTION

The fin-tube core type lube oil cooler, Fig. 9-22, is made up of a core surrounded by a steel tank and

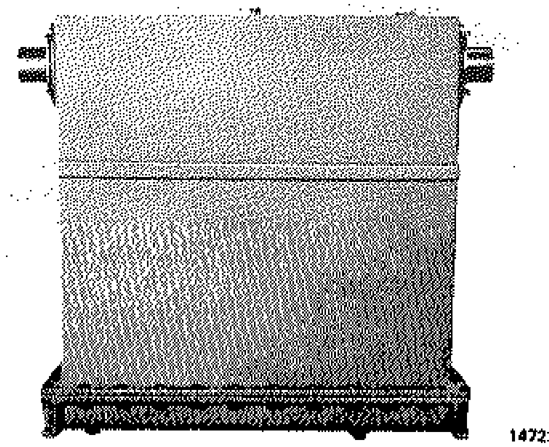


Fig. 9-22 - Fin-Tube Core Type Oil Cooler

has a header assembly at each end. The oil cooler core, Fig. 9-23, consists of tubes and fins. The cooling water flows through the tubes and the lube oil is circulated around the fins and the tubes. The water enters the cooler though each side of the upper header and is discharged through and outlet in the lower header. The lube oil enters the cooler through an outlet on the opposite side of the lower header.

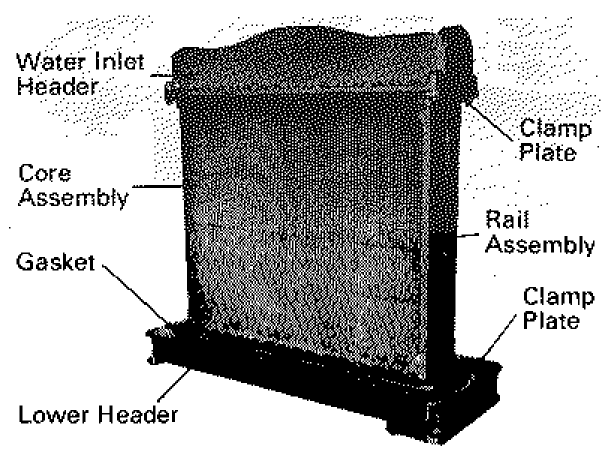


Fig. 9-23 - Cooler Core And Header Assembly

MAINTENANCE

The lube oil cooler should be serviced as specified in the Scheduled Maintenance Program. Maintenance Instructions for cleaning and repair of the lube oil cooler are referenced on the Service Data page.

UNATTACHED ACCESSORIES

On units which do not have an accessory rack, the lube oil filter and lube oil cooler may vary in size and configuration from rack mounted equipment.

As these components may also vary in accord with specific applications, the descriptive, maintenance, and illustrative data should be considered as "typical."

LUBRICATING OIL FILTER

DESCRIPTION

The lubricating oil filter, Fig. 9-24, is a full flow type and consists of a circular tank containing the filter elements which are mounted on standpipes.

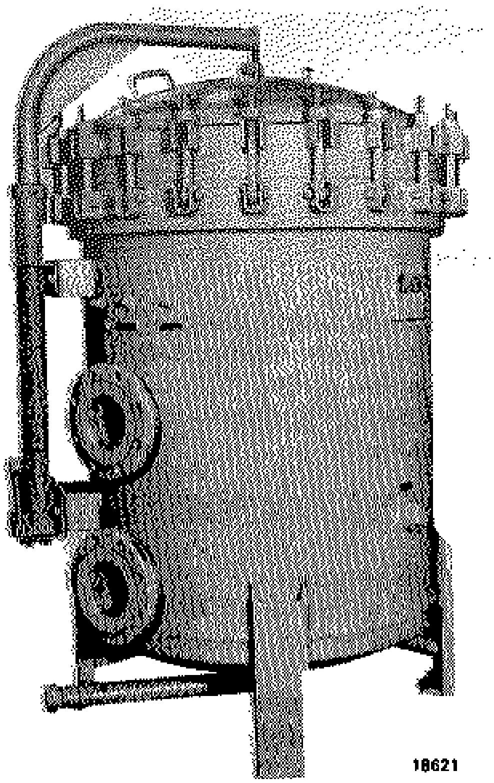


Fig. 9-24 - Lubricating Oil Filter

The oil passes through the filter elements into the perforated standpipes in the center of each element and then flows down to the filtered oil compartment, discharging into the system through the outlet connection. All of the oil flowing through the system passes through the filter unless the elements become so clogged with dirt that the pressure builds up and forces the oil through the bypass relief valve, set at 138 kPa (20 psi), in the bypass line around the filter.

MAINTENANCE

The lube oil filter elements should be changed as outlined in the Scheduled Maintenance Program. Each time the elements are changed, the element compartment should be cleaned of sludge. The filter elements cannot be cleaned and must be renewed each time.

CHANGING ELEMENTS

1. Close inlet valve and open sludge drain.
2. Open air bleed vent at top center of cover.
3. Remove cover bolts and cover.
4. Lift elements from standpipes.
5. Clean element compartment of sludge and install new elements.
6. Renew cover gasket if damaged and replace cover.
7. Tighten cover bolts and open inlet valve.

NOTE

Bleed air out of filter by opening vent cock when engine is started and inspect cover gasket for leaks.

LUBRICATING OIL COOLER

DESCRIPTION

The lubricating oil cooler, Fig. 9-25, is made up of a cylindrical shell, a bundle of straight tubes held in place by a tube sheet at each end, and headers which are separated from the shell space by the tube sheets. The tube sheet at one end is bolted between the header and the shell. The tube sheet at the other end floats in a sealed joint to allow the tube bundle to expand and contract in the shell.

The fresh water, used for cooling the lubricating oil, enters through a flanged connection in one header, flows through the tubes and is discharged through a flanged connection in the header at the opposite end of the cooler. The lubricating oil enters the shell through a flanged connection near one end of the cooler, flows transversely around the tubes and around the end of the baffles and leaves the shell through a flanged connection near the opposite end of the cooler. The fresh water and the oil flow through the cooler in opposite directions to produce the maximum cooling effect.

MAINTENANCE

The oil cooler should be cleaned as specified in the Scheduled Maintenance Program, or whenever the system indicates a restricted flow

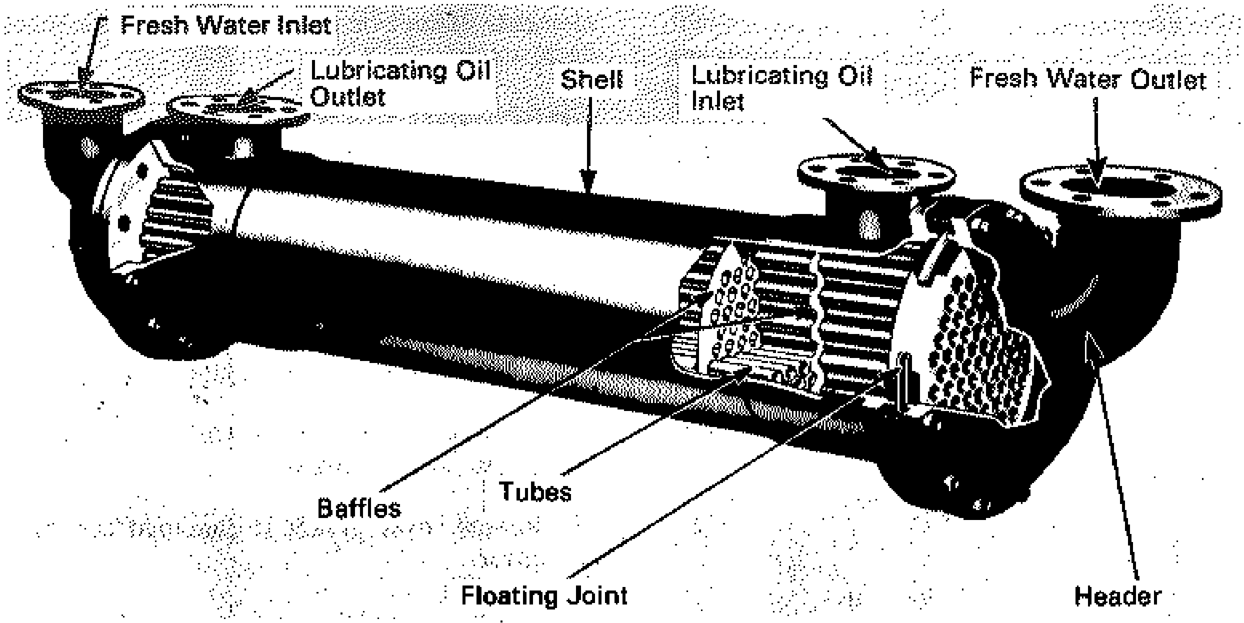


Fig. 9-25 - Lubricating Oil Cooler

through the cooler. Cleaning at regular intervals will ensure maximum operating efficiency.

Cleaning, testing, and repair procedures for the oil cooler are contained in the Maintenance Instruction listed in Service Data at the end of this section.

PRELUBRICATION OF ENGINES

Prelubrication of a new engine, an engine that has been overhauled, or an engine which has been inoperative for more than 48 hours, is a necessary and important practice. Prelubrication alleviates loading of unlubricated engine parts during the interval when the lube oil pump is filling the passages with oil. It also offers protection by giving visual evidence that oil distribution in the engine is satisfactory. Refer to "Prelubrication of Engines" in Operation-Section B.

OIL SYSTEM INFORMATION

Additional information on the oil system and components is given in the latest revisions of Maintenance Instruction bulletins. These instructions cover important items such as the Scheduled Maintenance Program, which outlines maintenance intervals, and flushing and cleaning information.

Engine lubricating oil should be qualified for use.

SERVICE DATA
LUBRICATING OIL SYSTEM

REFERENCES

SPECIFICATIONS

Clearance and dimensional limits listed below are defined as follows:

1. New limits are those to which new parts are manufactured. (Drawing tolerances.)

2. Minimum, maximum and tolerance measurements are provided as service limits. At time of rebuild or any time unscheduled maintenance is performed, the service limits should not be exceeded. Engine components within these limits may be reused with the assurance that they will perform satisfactorily until the next scheduled overhaul.

Lube Oil Pressure Relief Valve

Valve guide inside diameter - Max. .... 12.764 mm (.5025")
Valve stem outside diameter - Max. .... 12.484 mm (.4915')
Valve face to stem squareness
(outer edge of valve face) - T.I.R. Max. .... 0.05 mm (.002')

Oil Pumps
Drive shaft to rear housing bushing clearance -
New .... 0.038-0.114 mm (.0015"-.0045")
Max. .... 0.18 mm (.007')

Sleeve to bushing clearance -
New.. 0.038-0.127 mm (.0015"-.0050")
Max... 0.18 mm (.007")

Idler shaft to gear bushing clearance -
New .... 0.038-0.130 mm (.0015"-.0051'")
Max... 0.18 mm (.007")

Driven gears - total thrust clearance -
New..0.41-0.61 mm (.016"-.024")
Max...0.61 mm (.024")

Thrust face of bushing to body clearance (front and rear) -
New.. 0.02-0.18 mm (.001"-.007')
Min.. 0.000 mm (.000")

Drive and driven gear backlash -
New.. 0.30-0.41 mm (.012"-.016")
Max... 0.76 mm (.030")

Radial clearance of drive and driven gear to body -
Min.. 0.038 mm (.0015")
Max...0.25 mm (.010")

Drive shaft thrust clearance (scavenging pump assembled) .... 0.20-0.56 mm (.008"-.022')

Drive shaft thrust clearance
(main lube oil and piston cooling oil pumps assembled) ....0.13-0.56 mm (.005"-.022")

Pump drive gear face runout - T.I.R. Limit..0.08 mm (.003")

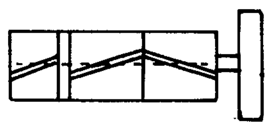
Pump flange face runout - T.I.R. Limit...0.13 mm (.005")

Pump flange pilot concentricity - T.I.R Limit. ....0.05 mm (.002")

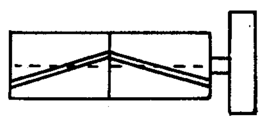
Pump drive gear to accessory drive gear backlash
New... 0.20-0.41 mm (.008"-.016")
Max... 0.64 mm (.025')

Pump/Motor Assembly
Parallel coupling alignment - Max. .... 0.38 mm (.015")
Axial clearance between jaw and spider - Min. .... 0.76 mm (.030")

HELIX ANGLE POSITION OF OIL PUMP GEARS



MAIN LUBE OIL AND PISTON COOLING PUMPS



SCAVENGING OIL PUMPS

24752

TYPICAL LUBE OIL SYSTEM CAPACITIES

NOTE
Actual capacities can vary due to differences in shipyard piping.

Model 645E6	Liters	Gallons
8-Cylinder		
Engine	416	110
Accessories	575	152
12-Cylinder		
Engine -		
(River Service)	606	160
(Ocean Service	549	145
Accessories	575	152
16-Cylinder		
Engine	700	185
Accessories	575	152

EQUIPMENT LIST

	Part No.
Gauge - piston cooling oil pipe alignment	8071720
Cleaner - piston cooling oil pipe	8087086
Spray gun	8193041
Loctite cleaner activator (0.17 kg [6 oz])	8352873
Loctite sealing compound (50 cc bottle)	9505663

SECTION 10
COOLING SYSTEM

55E1086

COOLING SYSTEM

GENERAL

The complete engine cooling system is made up of two systems, namely the raw water system and the fresh water system. Each of these systems is separately described in the following paragraphs.

RAW WATER SYSTEM

DESCRIPTION

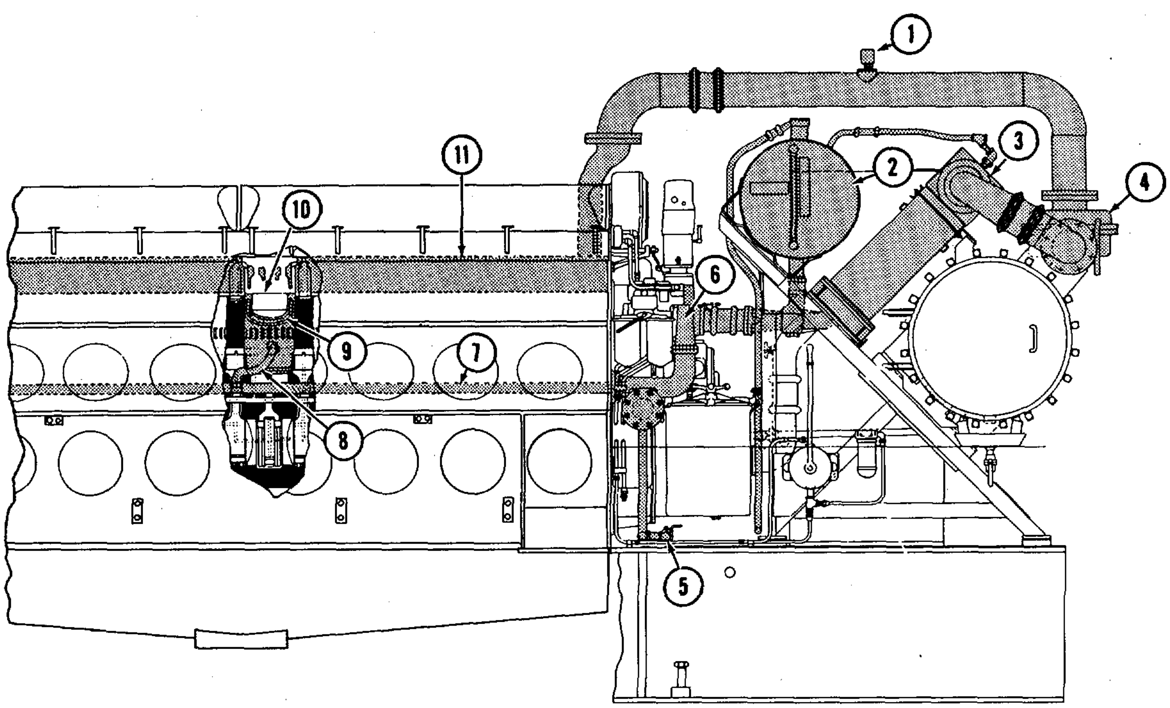
There are different types of raw water systems. Some applications require the use of an engine driven raw water pump. This pump circulates raw water through a cooler to cool the engine fresh water supply. The raw water pump is mounted at the front of the accessory rack.

The raw water pump and the fresh water cooler are described later in this section. Other components of the raw water system are off-engine shipboard items, which are not included in the coverage of this manual.

FRESH WATER SYSTEM

DESCRIPTION

The fresh water system consists of engine driven centrifugal water pumps, replaceable inlet water manifolds with an individual jumper line to each liner, cylinder head discharge elbows, and an outlet manifold through which cooling water is circulated. The two centrifugal water pumps are mounted on the accessory drive housing and are driven by the governor drive gear. A representative illustration of the engine cooling system is shown in Fig. 10-1.



1. High Temperature Alarm Contactor
2. Expansion Tank
3. Lube Oil Cooler
4. Thermostatic Valve
5. Drain Valve
6. Water Pump
7. Inlet Manifold
8. Inlet Tube
9. Liner Water Passage
10. Cylinder Head
11. Discharge Manifold

Fig. 10-1 - Cooling System Schematic

The engine discharge water flows through an external cooling system to dissipate the heat taken up in the engine. This system consists of a water tank, water level gauges, temperature gauges, cooler and connecting piping.

MAINTENANCE

ENGINE WATER TEMPERATURE

Temperature gauges are provided in the cooling system to visually check that the engine water temperature is within the recommended limits. Automatic temperature controls are set to maintain the water temperature within set limits.

CAUTION

It is desirable that engine coolant temperature be 49° C (120° F) or higher before full load is applied to the engine. After idling at low ambient temperature, increase to full load level should be made gradually.

This restriction does not apply to units equipped with immersion heater systems supplied by EMD.

A hot engine alarm indicates excessively high water discharge temperature. Hot engine water could result from faulty water cooling equipment or excessive loss of cooling water. In the event of a hot engine alarm, engine load should be reduced in an attempt to obtain normal temperature. Before resuming operation, the cause of the hot engine water should be found and the condition corrected.

ENGINE COOLANT SOLUTION

Coolant solutions are composed of water, corrosion inhibitor and, if necessary, antifreeze. The selection and maintenance of a proper coolant solution are necessary for efficient cooling system operation. Failure to recognize the importance of these factors can result in cooling system damage, increased maintenance costs, and unnecessary equipment down time.

Coolant samples should be taken from the cooling system for analysis to ensure that the specific concentration of corrosion inhibitor is maintained.

COOLING SYSTEM PIPING

DESCRIPTION

Refer to Fig. 10-2 for piping details. Pump outlet elbows conduct water from the pumps to the removable water inlet manifolds located in each air box. The rear end flange of the manifold is equipped with two seals, which prevent the leakage of air from the air box. A flange at the front end of the manifold contacts the outer face of the front end plate when the manifold is installed.

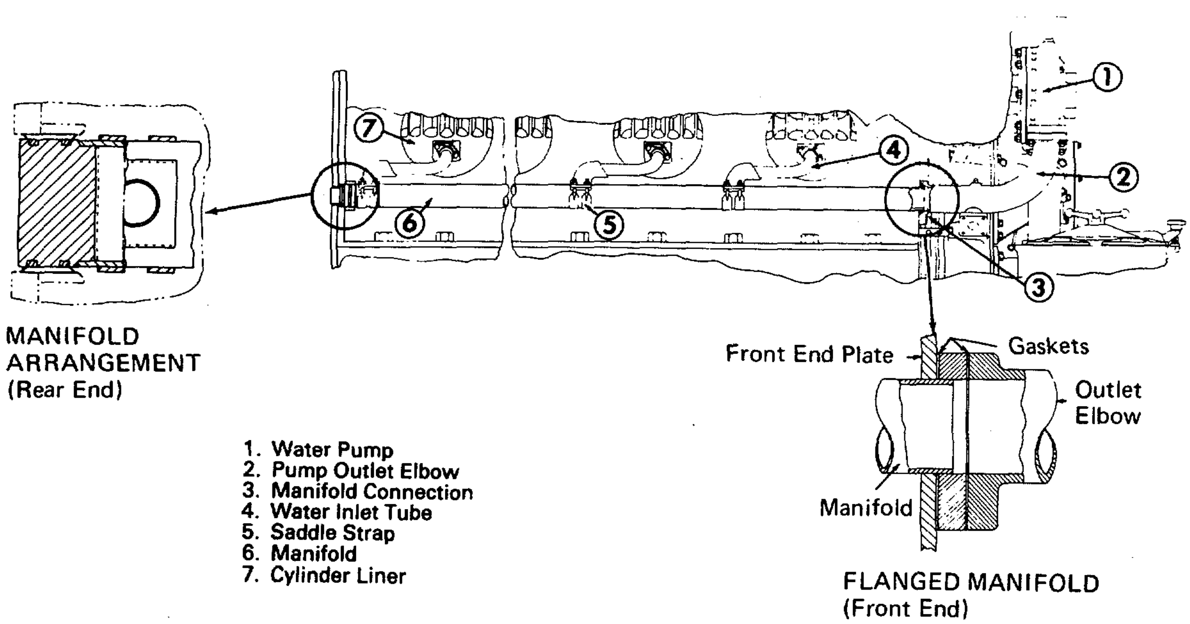


Fig. 10-2 - Cooling System Piping

Each liner is individually supplied with coolant from the water manifold through a water inlet tube assembly. A deflector is used at each liner water inlet to divert the water and prevent direct impingement on the inner liner wall. Water enters the cylinder head through 12 discharge holes at the top of the liner. A counterbore around each hole accommodates a heat dam and a water seal. A water discharge elbow is bolted to each cylinder head to provide a water passage to the water discharge manifold which extends along the top of the crankcase. The crankcase has two "built-in" siphon tubes inside the water discharge manifold. One is located at the second cylinder from the rear end on the right bank, and the other at the second cylinder from the front end on the left bank. When engine water is drained, this will provide for engine cooling water draining in the event the engine is not level.

MAINTENANCE

PIPING INSTALLATION

After the cylinder head and liner are properly installed in the engine, the water inlet manifold and liner water inlet tube may be applied.

1. Inspect the water manifold for any dirt or roughness in the area of the discharge holes and at the front end plate flange.
2. Place the manifold flange gasket over the manifold and insert the manifold into the air box.
3. Carefully guide the end of the water manifold into the rear end plate so that seals are not damaged. When positioned correctly, the manifold should be firmly supported at the end.
4. Apply and tighten the manifold flange to front end plate bolts. Temporary bolts may be used if the water pump discharge elbow is not ready to be applied.
5. Place the new seal in the groove at the liner end of the water inlet tube.
6. Position saddle straps around the water manifold, and through the inlet tube flange.
7. After the strap nuts have been applied and tightened finger tight, check that the seal is seated in the groove, position the tube on the liner, and finger tighten the bolts.
8. Take a new gasket and shape it to fit around the water manifold. Insert the gasket between the tube flange and manifold making sure the sides of the gasket are flush with the sides of the flange, and that the ends of the gasket are within the clamping radius of the flange.
9. Torque the strap nuts to specified value.
10. Prior to torquing the tube to liner bolts, remove the bolts and washers from the flange. If the tube moves, it must be repositioned on the water manifold; if no movement is detected, the tube to liner bolts and washers may be re-applied and torqued to specified value.
11. After all liner water inlet tubes are properly applied, the manifold will be securely held and the temporary bolts, if applied, should be removed and the water pump discharge elbow connected.

WATER LEAKS

If loss of water in the cooling system is noticed, check for leakage of piping, pump seals, jumper tube connections, cylinder head discharge elbow, junction of head to liner, and check for liner or cylinder head cracks.

Unless very obvious, the location of the crack in the cylinder head or liner is very difficult to find, and requires careful examination. Any indication of a water leak in the head or liner requires removal and thorough inspection. Inspect cylinder interior through liner ports.

Water may leak and enter the lube oil at the cylinder head discharge elbow seals. These seals can be replaced without disturbing the cylinder head, provided a crab nut and crab are removed and the water is drained. Water contamination of lubricating oil will necessitate draining the oil. Before the oil is renewed, the system should be flushed.

Lube oil contamination is best determined by laboratory analysis, but in the absence of such means, the following method of checking for water in the oil may be used.

Draw or dip a gallon of lube oil from the bottom of the engine lube oil sump. Let it stand for about 10 minutes, then spill about 3/4 of the oil from the container. Place the remaining 1/4 in a glass bottle and allow sample to stand another 10 minutes. If any water is indicated in the bottom of the bottle, it is recommended that the lube oil system be drained and flushed. Replace with new oil after source of contamination is eliminated.

FRESH WATER PUMPS

DESCRIPTION

The two engine cooling water pumps (one on 8-cyl. engines), Fig. 10-3, are self-draining centrifugal pumps, which rotate in the opposite direction of the engine crankshaft. The components of the water pump are identified in Fig. 104.

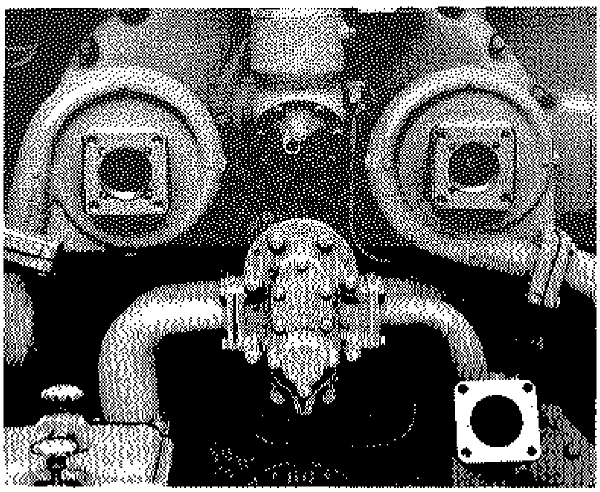


Fig. 10-3 - Water Pump Installation

The pumps are carried under two part numbers to identify the right and left bank pumps. The only difference between right and left bank pumps is the position of the impeller housing in relation to the pump shaft housing. The position of the impeller housing may be changed on either pump to permit use on the opposite bank.

The pump drive shaft is supported in the main pump housing by two ball bearings separated by a steel spacer. The bearings are grease lubricated and permanently sealed. The outer bearing adjoins a water slinger which bears against a shoulder on the shaft. The inner bearing is held in place by a retainer and snap ring to absorb any thrust in the shaft. The pump drive gear is keyed to the pump shaft abutting the inner bearing, and is held on the shaft by a washer and nut.

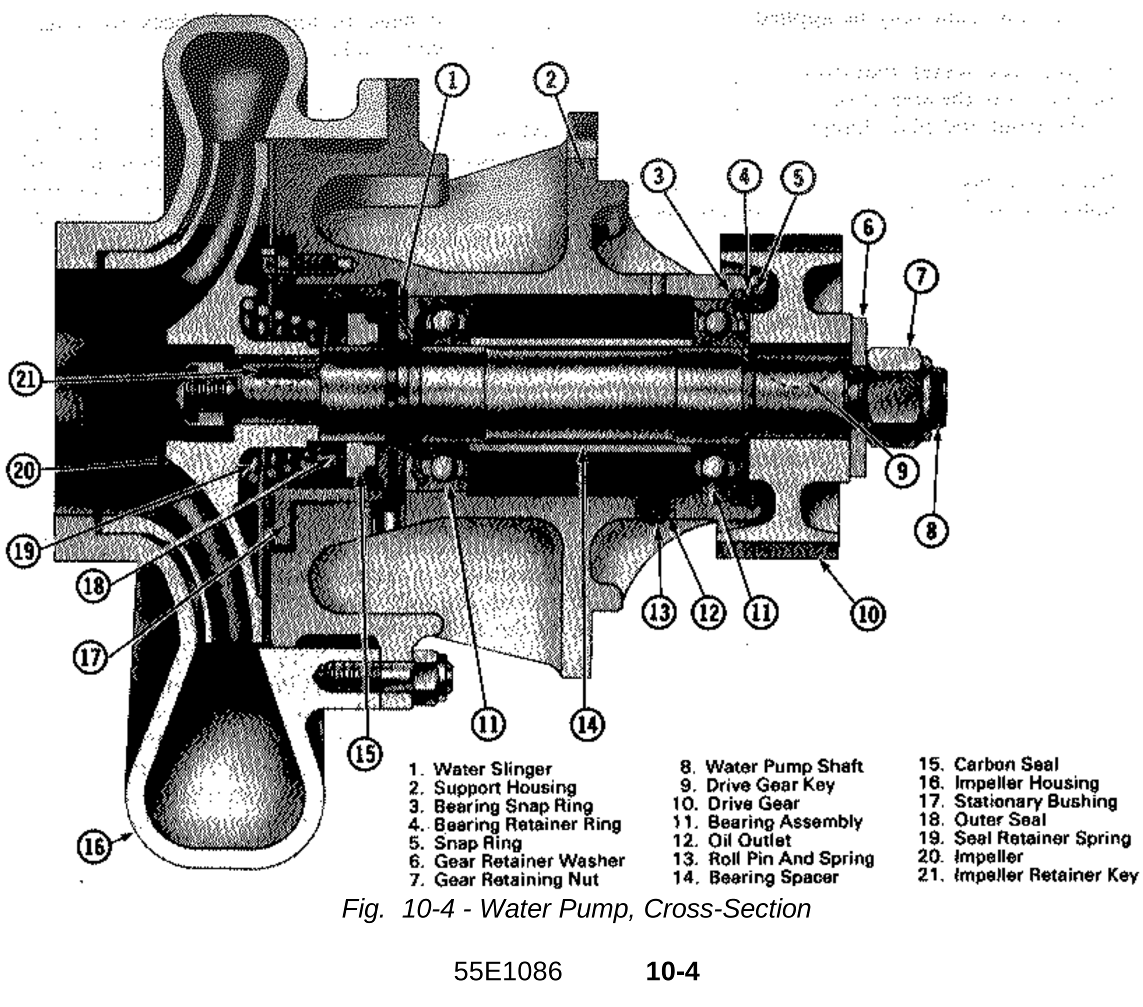


Fig. 10-4 - Water Pump, Cross-Section

The stationary bushing, Fig. 10-9, is applied to the drive shaft housing. The carbon of the seal assembly, Fig. 10-10, faces against the smooth inner surface and is held by a spring. Any water leakage past the seal is indicated at a tell-tale drain in the drive shaft housing which permits runoff, and prevents water from reaching the engine side of the pump.

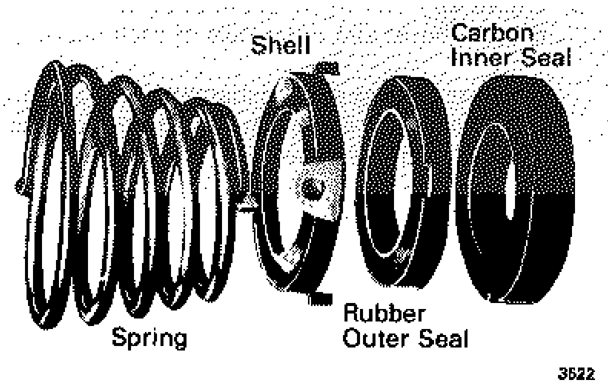


Fig. 10-5 - Spring And Seal Assembly

The impeller is keyed to the pump shaft and is secured to the shaft by a washer and nut. It is enclosed by the impeller housing, which is assembled to the main pump housing by eight studs and nuts.

MAINTENANCE

PUMP REMOVAL

1. Drain cooling system.

2. 'water pump inlet connection.

3. Disconnect pump discharge flange connection.

4. Remove mounting bolts and pump from engine.

PUMP DISASSEMBLY

1. Remove impeller end nut and washer.

2. Remove drive gear end nut and washer. Apply gear puller, Fig. 10-6, and remove pump drive gear and key.

3. Remove snap ring and bearing retainer ring, Fig. 10-4.

4. Loosen hex nuts securing impeller housing to pump support housing. Remove six of the eight nuts, leaving remaining two nuts on any pair of studs directly across from each other. This is necessary to prevent housings from separating completely before shaft and bearing assembly is free of impeller and support housing.

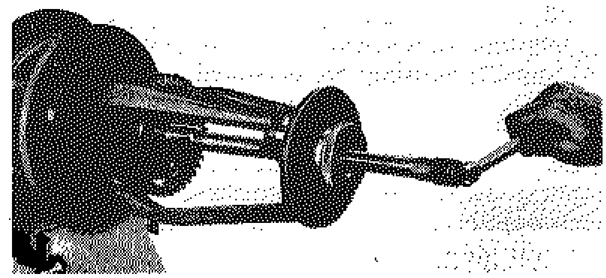


Fig. 10-6 - Drive Gear Removal

5. Insert adapter for pump disassembly tool over impeller shaft end, Fig. 10-7, then mount disassembly tool to impeller housing with two 1/2-13 x 1-1/2" hex head bolts across from each other.

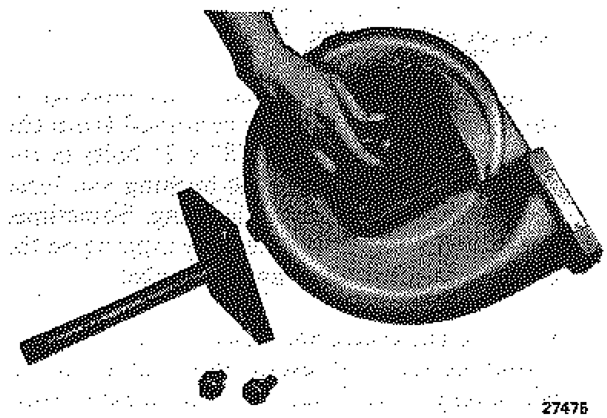


Fig. 10-7 - Disassembly Tool Application

6. Using a box end wrench or impact gun and socket, Fig. 10-8, run in drive screw of disassembly tool until shaft and bearing assembly is free.

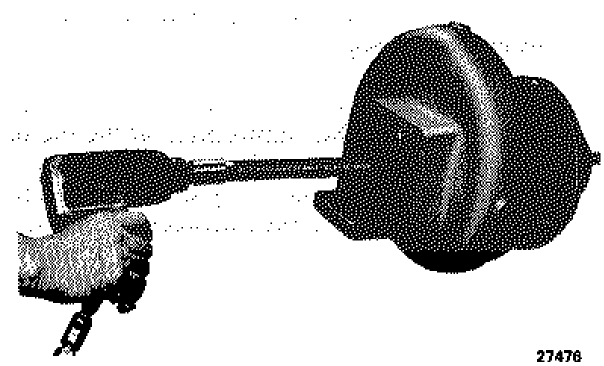


Fig. 10-8 - Removing Shaft Assembly

7. Remove remaining two housing nuts and continue to run in drive screw until support and impeller housings are separated.

NOTE

Drive screw should not be loosened during pump disassembly until housings have been completely separated. Relieving tension on screw may allow impeller to drop down, preventing further run in of screw.

8. Remove loose impeller from impeller housing and complete removal of shaft and bearing assembly from support housing - by hand, if possible. If not, some light tapping on shaft impeller end with a wood or brass block may be necessary to get outer (impeller end) shaft bearing clear of support housing.

9. Remove loose spring and seal assembly from support housing, Fig. 10-4.

10. Remove the bolts from stationary bushing. If the bushing is not easily removed from the support housing, insert 3/8" x 2" bolts in the puller holes provided in the bushing and force the bushing out from the housing. Sometimes the bushing may be loosened by tapping on the bushing flange with a rawhide mallet. Discard the stationary bushing as this item should be replaced, along with seal assembly, whenever pump is disassembled for maintenance.

11. Place the shaft and bearing assembly in an arbor press and remove both bearings.

PUMP ASSEMBLY

1. Clean the pump shaft and inspect the bearing journal areas for signs of damage (i.e., nicks or scoring). Journal diameter should not be less than minimum limit listed in the Service Data at the end of the section.

2. Measure bearing bore and ensure compliance with the Service Data limits given at the end of the section relative to shaft journal and bearing bore fit. Also check that pump shaft diameter to gear bore fit is within the tolerance given in the Service Data.

3. Assemble water slinger, outer bearing, bearing spacer, and inner bearing to the pump shaft, making certain that inner (gear end) bearing with snap ring is positioned correctly with the snap ring to the outside. These parts are assembled, Fig. 10-4, first with the slinger next to the shoulder on the shaft, concave side toward the impeller end, followed by the outer bearing (without snap ring), bearing spacer and inner bearing, abutting each other snugly.

4. Place the support housing in a vise with jaw protectors.

5. Clean any dirt or oil from support housing bearing bores and outer race of each bearing.

   Measure bearing outside diameters and housing bores to ensure compliance with Service Data limits at end of this section.

   Apply a thin coating of silicone rubber sealing compound to outer (impeller end) bearing bore in housing.

6. Insert the shaft and bearing assembly, slinger end first, from the drive gear end of the housing. Using a rawhide mallet, lightly tap the assembly until it aligns with and enters the first bearing bore and continue tapping the assembly until it is properly seated in the housing.

7. Insert bearing retainer ring into drive gear end of support housing with chamfered side in toward bearing. Apply snap ring.

8. Place key in shaft and assemble drive gear to shaft, using a rawhide mallet. Apply washer and a new gear nut. Torque nut to 359 Nm (265 ft-lbs).:

9. Turn pump in vise to allow assembly of impeller end.

10. Before applying the stationary bushing, be sure the bushing and mounting surfaces are clean. Foreign material can cause the bushing to cock and interfere with effective sealing. Also, be sure that the smooth flat seal surface of the bushing is clean and dry. Apply new stationary bushing gasket and bushing. Tighten the bolts evenly and torque to 11.3 Nm (100 in-lbs).

CAUTION

The sealing surface of the stationary bushing must be absolutely smooth and flat to prevent wear of the carbon washer.

After applying the stationary bushing, check runout of the carbon seal surface using an indicator mounted on the end of the pump shaft. See the Service Data limits at the end of this section for required stationary bushing seal seat squareness with drive shaft. If runout limit is exceeded, reposition bushing 1800 and/or scrape off mounting surface in area of high reading.

11. Install the new seal assembly, Fig. 10-4. Check carbon face for cleanliness. Apply carbon inner seal with the narrow end contacting the stationary bushing. Apply rubber outer seal to shell, and apply to carbon seal so ears of shell fit into the slots in the carbon seal. One end of the drive spring fits into the shell while the other end must be fitted into a slot at the bottom of the impeller when it is assembled.

12. Fig. 10-9 shows the impeller installer being used to assemble the impeller to the drive shaft housing. The threaded bushing is screwed on pump shaft threads and then by turning outer portion of installer tool, the impeller is pressed into position. Care must be taken to start the impeller straight on the shaft and to see that the key and keyway are aligned. Before the impeller is brought all the way down, check the underside to see that the seal spring is in the spring slot under the impeller and then finish the impeller application.

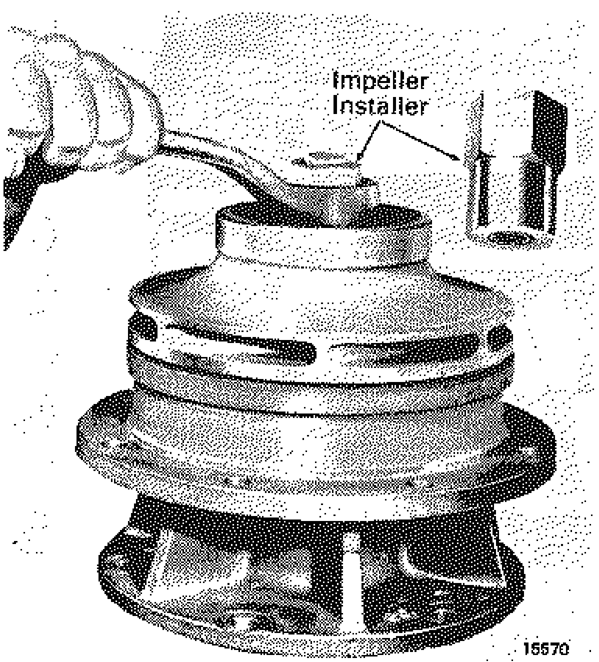


Fig. 10-9 - Installer Pump Impeller

13. Check the insert in the impeller shaft nut to see that it is free from tears and disintegration. Apply the impeller retaining washer and nut. Torque value of the impeller nut is 108 N-m (80 ft-lbs).

14. Check that drilled drain passage is free of obstruction.

15. Determine whether the pump is to be used on the right or left bank of the engine since the impeller housing is positioned differently in each case.

16. An arrow is cast at the bottom of the pump shaft housing and the impeller housing has a letter "R" and "L". For a right hand bank pump, assemble the impeller housing so that "R" is opposite the arrow on the shaft housing or for a left bank pump, the "L" is opposite the arrow, as shown in Fig. 10-10.

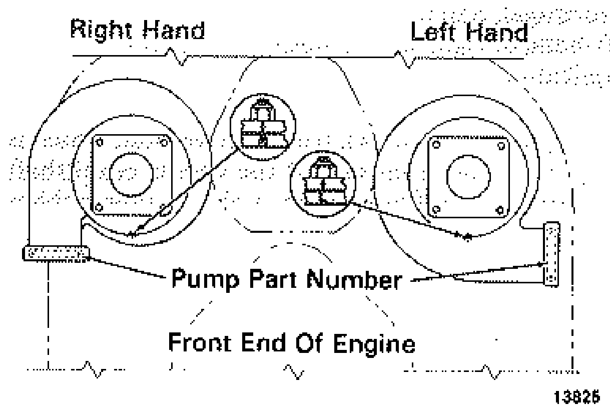


Fig. 10-10- Pump Housing Positioning

17. Install housing in the correct position, using new gasket between the impeller and shaft housing. Apply housing nuts to studs and tighten to 88 Nm (65 ft-lbs).

INSTALLING PUMP

1. The pumps are installed in the position shown in Fig. 10-10 for the right and left bank. Torque mounting bolts to specified value.
2. The part number of the pump is located on a plate attached to the pump discharge flange, as shown in Fig. 10-10. It should also be noted on pump installation, that the water inlet elbow is the proper one as listed in the parts book for the engine installation.
3. When installing a water pump, care should be taken with the application of the water inlet connection. This connection consists of a sleeve, synthetic rubber seals, seal retainers, and bolted clamps.

ACCESSORY RACK COMPONENTS

The raw water pump (if applicable), thermostatic valve, and fresh water expansion tank are cooling system components which are mounted on the accessory rack, Fig. 10-11. Since these components vary in accord with specific applications, the descriptive, maintenance, and illustrative data should be considered as "typical."

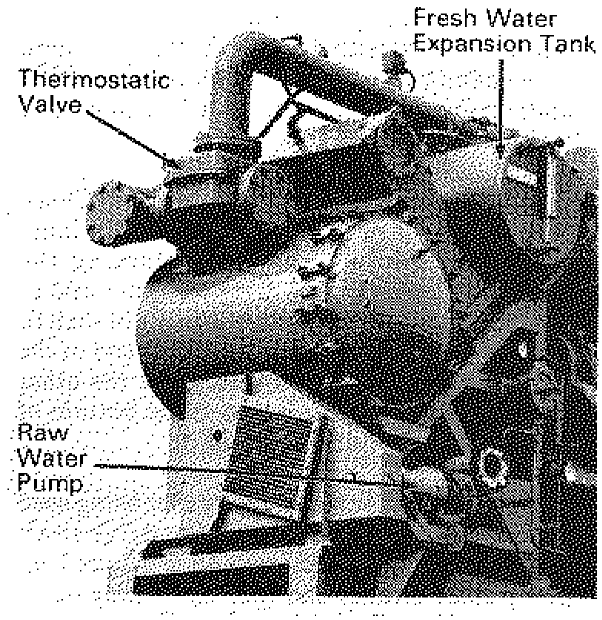


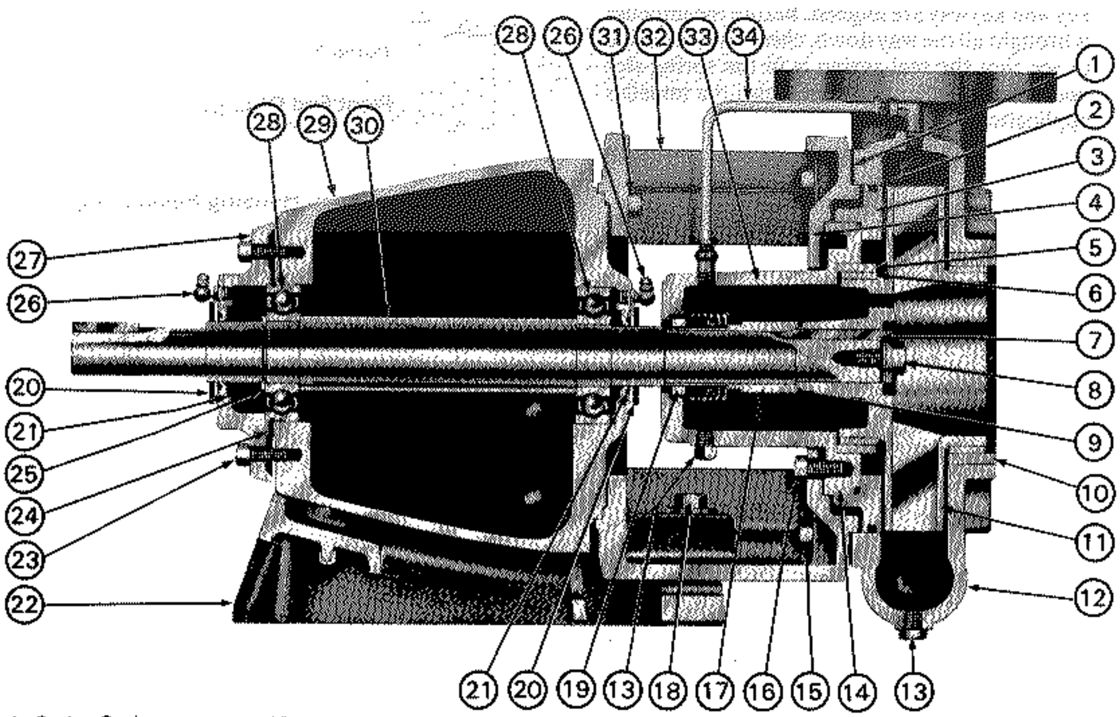
Fig. 10-11 - Typical Accessory Rack

RAW WATER PUMP

DESCRIPTION

The raw water pump, Fig. 10-12, is a horizontal, centrifugal, ball bearing type pump. It can be either left-hand or right-hand rotating depending upon the application.

The pump is belt driven from a drive shaft which is coupled to the front end of the engine crankshaft accessory drive flange with a sleeve type rubber



1. Casing Gasket
2. Adapter Gasket
3. Adapter
4. Bearing Insert Gasket
5. Bearing Insert Wear Ring
6. Impeller Wear Ring
7. Key
8. Impeller Bolt
9. Impeller Gasket
10. Casing Wear Ring
11. Impeller
12. Casing
13. Drain Plug
14. Bearing Insert To Adapter Gasket
15. Casing To Bracket Bolt
16. Insert To Bracket Bolt
17. Sleeve
18. Bracket To Support Bolt
19. Seal
20. Slinger
21. Bearing Seal
22. Support
23. Bearing Cap To Frame Bolt
24. Bearing To Gasket
25. Retaining Ring
26. Grease Fitting
27. Bearing Cap
28. Bearing
29. Frame
30. Shaft
31. Bracket To Frame Bolt
32. Bracket
33. Bearing Insert
34. Tubing

Fig. 10-12 - Typical Raw Water Pump Cross-Section coupling. The outer end of the drive shaft is carried in a pillow block pedestal bearing mounted to the accessory rack.

The pump impeller is a single suction enclosed type one piece casting. Wear rings are used on both sides of the impeller between the impeller and impeller casing.

MAINTENANCE

The pump drive belt should be inspected periodically for signs of slipping or chafing and adjusted for proper tensioning, when required.

No routine maintenance to the pump is required other than occasional inspection, cleaning, and lubrication of bearings at the fittings provided at each end of the power frame.

DRIVE BELT REPLACEMENT AND TENSIONING

Pump drive belt should be replaced whenever belt tension cannot be maintained or belt has become frayed or otherwise damaged. To replace drive belt, refer to steps 1 through 9 following. To adjust drive belt tension, remove access panel from belt guard assembly and refer to steps 6 through 9 of the following procedures.

1. Unbolt and remove belt guard assembly located around pump drive train.
2. Loosen, but do not remove, pump base mounting bolts and all tensioner assembly bolts, including the square head set screw on lower idler bracket.
3. Position pump and idler sheaves to provide sufficient clearance for drive belt removal and application.

NOTE

Do not force drive belt over sheaves while removing, if belt is to be reinstalled, or when applying new belt as this may cause ply breakage and cover damage which can decrease belt service life.

4. Place drive belt over pump drive sheaves and into the respective grooves in order from first belt hand. Spread idler sheaves to engage and hold belt in place.
5. Move pump back to original position and retighten base mounting bolts. Adjust both idler sheaves equally to tighten drive belt and snug up tensioner assembly bolts to secure adjustment.
6. To final adjust tension on drive belt, adjust square head set screw on lower idler bracket. Check tension by applying a perpendicular force at the center of the belt span between the pump and top idler sheaves, as shown in Fig. 10-13. Proper adjustment is achieved when belt is tensioned to a reading of 20 to 24 lbs at 7.94 mm (5/16") belt deflection using tension tester 8396624.

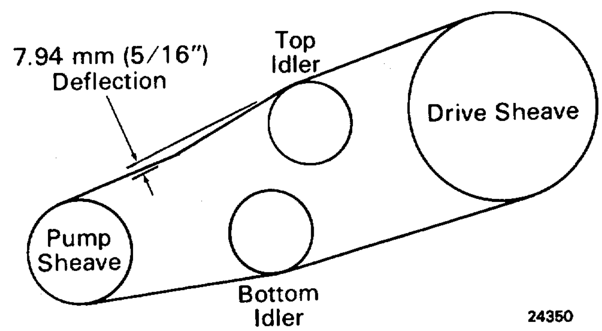


Fig. 10-13- Checking Drive Belt Tension

7. After belt tension is adjusted, final tighten tensioner assembly bolts. Recheck tension.
8. Check alignment of pump and idler sheaves which should be parallel to each other within 0.794 mm (1/32") and 2.03 mm ± 0.51 mm (0.080'±0.020") ahead of the drive sheave with engine crankshaft cold.

NOTE

Accessory drive shaft coupling is factory aligned and adjusted so that a certain amount of axial freedom exists in the pillow block bearing to allow for thermal expansion of the crankshaft.

9. If tension recheck is satisfactory and alignment is correct, reinstall belt guard assembly (or access panel).

NOTE

New belt should be checked for proper tension after a one hour run-in period and again after the first 24 hours, the first week and the first month of operation.

ACCESSORY DRIVE SHAFT ALIGNMENT

After replacement of an accessory drive component, it may be necessary to check alignment of the drive shaft to the pump drive train.

Before attempting to check alignment of the drive shaft, remove the drive belt from the drive sheaves as previously described for drive belt replacement.

1. Mount a dial indicator on coupling sleeve or accessory drive flange to read drive shaft angularity. Indicator must be positioned with the plunger resting on the shaft at a point 50.8 mm (2") from the outer face of the coupling sleeve. Zero the indicator.
2. Bar engine over one complete revolution and check indicator readings at each quarter turn (90°). Drive shaft is considered aligned if total indicator reading TIR is no more than 0.31 mm (0.012").
3. If total reading exceeds this limit, loosen pillow block bearing mounting bolts and reposition shaft end (sideways with slotted holes or up and down by addition or removal of shims) until satisfactory alignment can be attained.
4. Pull pillow block bearing out away from engine to remove all axial clearance, then retighten bearing mounting bolts. This allows for crankshaft thermal growth without putting thrust load on the bearing.
5. Recheck dial indicator readings to be certain they remain within the limits. If tolerances are satisfactory, replace drive belt, set tensioning and check sheave alignment as previously described for drive belt replacement.

PUMP DISASSEMBLY

1. Remove all external lines from pump.

2. Break suction and discharge piping and remove the two drain plugs from the casing, Fig. 10-12.

3. Remove bolts holding the casing to bracket and remove the casing and gasket.

4. Unscrew impeller nut being careful not to damage gasket.

5. Slide impeller and impeller key from the shaft, being careful not to damage gasket, behind impeller.

6. Casing wearing rings are pressed into place with an interference fit and must be removed with a puller.

7. Impeller wearing rings must be cut off if replacement is necessary. Be careful not to cut into impeller.

8. Slide sleeve and rotating parts of mechanical seal from the shaft.

9. Remove capscrews from bracket and slide insert with adapter, gaskets, and stationary parts of the mechanical seal from the shaft.

CAUTION

During removal of the seal, take extreme care not to drop or damage any part of the seal. Take particular care not to scratch the lapped faces on the washers or the sealing seat.

10. Press the seal flexible cup and stationary seat out of the insert and clean the cavity of all residue. Make sure the 1/32" radius in the seal seat cavity is not damaged during disassembly since a sharp edge can easily cut the flexible cup during reassembly.

PUMP ASSEMBLY

1. Press grease seals into frame.

2. Press bearings onto shaft and snap retainer ring in place.

3. Press shaft and bearing into frame and place bearing cap gasket in place.

4. Install bearing cap in position with capscrews. Then insert grease seals and place slinger on the shaft.

5. Mount bracket to frame being sure to tighten bolts evenly.

6. If bracket and frame were removed from support, bolt the assembly to the support using washers under bolt heads.

7. To replace adapter, first set gasket on insert, then press adapter onto the insert and place gasket in the slot around the adapter.

8. Coat the mating surfaces of the insert wearing ring and insert with Locktite and press them together.

9. Coat the surfaces of the casing wear rings with Locktite and insert them in the casing.

CAUTION

Do not hammer rings into place. Use a press, or clamp the parts in a bench vise, using wooden blocks to protect the rings. If the facilities are available, it is good practice to take a very light finish cut or to ream the inside diameter of the casing rings after pressing to restore roundness. When rings are pressed, they may get squeezed out of shape.

10. Make sure the gasket surface on the bracket is clean and free from nicks or abrasions. Put a small amount of grease on gasket and set it in position.

11. Inspect the seal cavity in the seal insert for burrs or nicks which could damage the seal seat. Apply a film of soapy water or light oil (not grease) to the seal seat and install in seal cavity evenly and squarely.

NOTE

When applying seal components refer to Fig. 10-14 for correct positioning.

THERMOSTATIC VALVE DESCRIPTION

The thermostatic valve, Fig. 10-15, is a diverting valve that is used to maintain a constant temperature at the engine water outlet. When an engine is started and cold, the valve causes all water to bypass the heat exchanger in the engine cooling system. After warm up, part of the heated water bypasses and part is directed to the heat exchanger. The bypassed water is then mixed with the cold water returning from the heat exchanger before re-entering the engine. Valve action and mixing of water maintains the desired engine water temperature. However, if water from engine reaches the nominal temperature for the particular valve, the valve will close the bypass side entirely, and all water will flow to the heat exchanger.

The valve is self-contained and self-powered. It contains thermostatic element assemblies that hold valve sleeves in the bypass position by spring tension when cold water from the engine outlet passes over the elements. As water temperature increases, a thermostatic material that is highly sensitive to temperature changes expands to develop pressure that overcomes the force of the return spring. The thermostatic material drives a molded synthetic rubber plug into a reduced diameter piston guide that, by extruding action, multiplies the travel of the plug. The plug drives a piston that forces the valve sleeves to open the valve outlet to the heat exchanger and at the same time constrict the bypass opening. This action is illustrated in Fig. 10-16.

MAINTENANCE

Disassembly and inspection of the thermostatic valve should be performed as prescribed in the applicable Scheduled Maintenance Program or at any time improper cooling of the engine is evident. Improper cooling may be due to the O-ring deterioration or malfunctioning thermostatic elements.

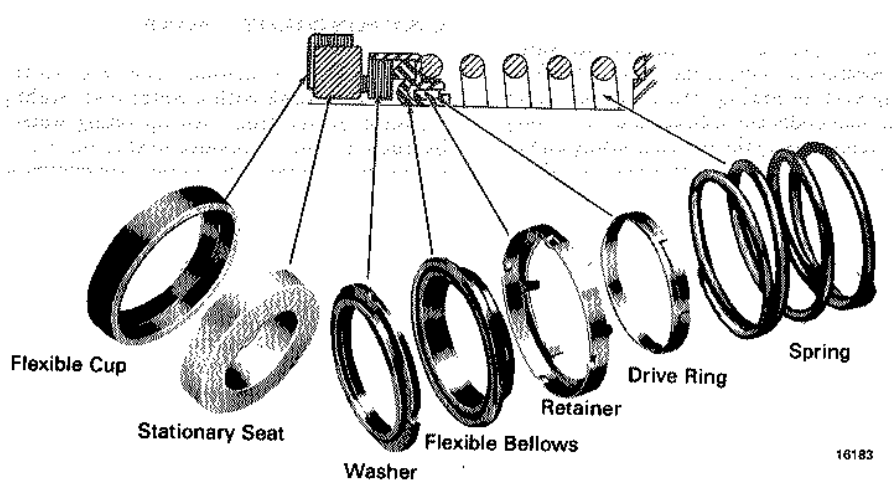


Fig. 10-14 - Raw Water Pump Seal

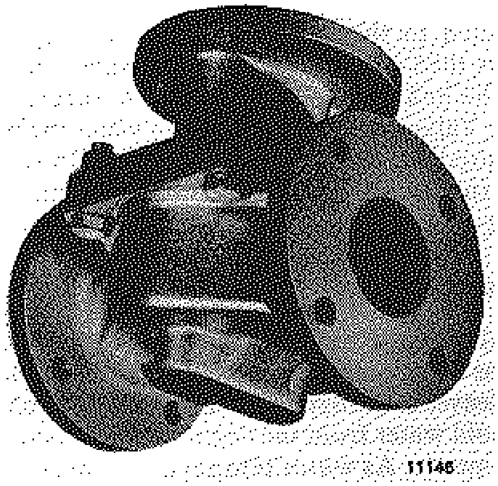


Fig. 10-15 - Thermostatic Valve

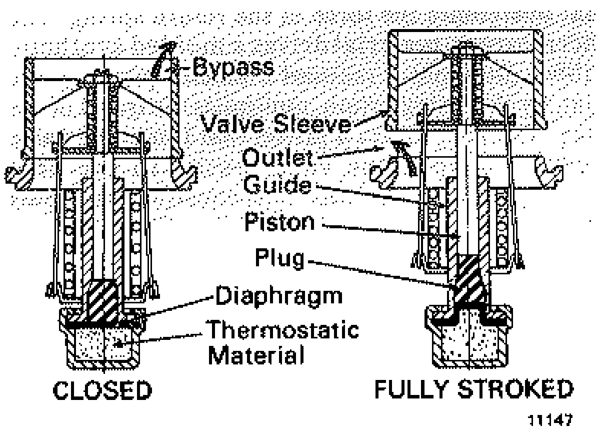


Fig. 10-16 - Thermostatic Element Application

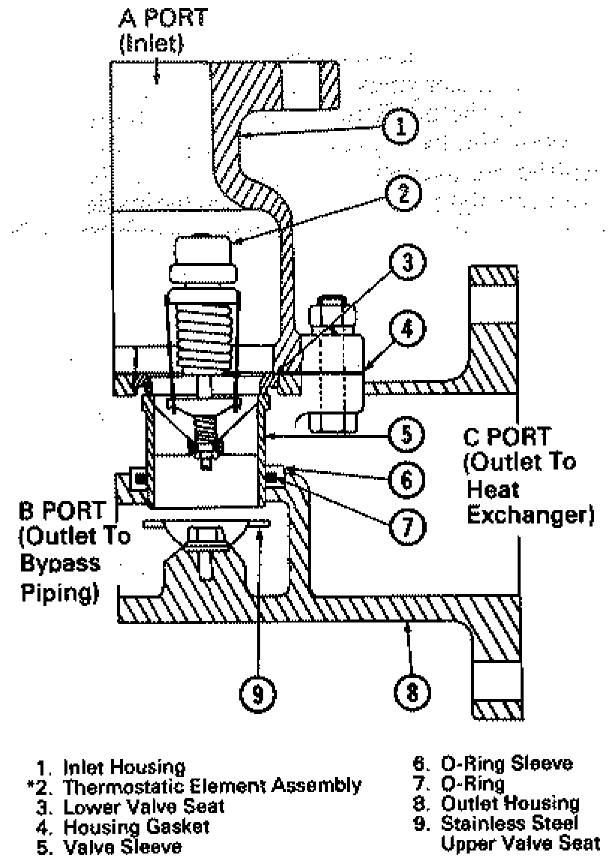


Fig. 10-17 - Thermostatic Valve Cutaway View

To perform an inspection on the thermostatic valve, it may be necessary to remove the entire valve from the cooling system piping. However, on some installations and under some circumstances, it may be easier to remove only the bolted housing and its attached piping from the valve. If the entire valve is to be removed, it is advisable to tag or otherwise mark the pipe flanges with the letter appearing at the adjacent valve flange. The letter "A" identifies the valve inlet flange. The letter appears on the bolted housing. The letter "B" identifies the outlet to the bypass piping. The letter "C" identifies the outlet to the heat exchanger.

Due to the different valve body housing designs, the location of some bolts and flanges are such that the assembly and disassembly sequence may be altered. Fig. 10-17 gives a general location arrangement.

FRESH WATER EXPANSION TANK

The fresh water expansion tank, Fig. 10-18, is a welded steel tank with a water level sight glass mounted on the front. An operating water level instruction plate is provided next to the water level sight glass. The instructions indicate minimum and maximum water level with the engine running or stopped. The water level mark should not be permitted to go below the applicable "low" water level mark.

The system is filled through a filler opening located at the top of the expansion tank. Water is added until it reaches the full mark on the upper instruction plate at the water sight glass.

An overfill drain pipe is provided to allow run-off in the event of overfilling or excessive water expansion during operation.

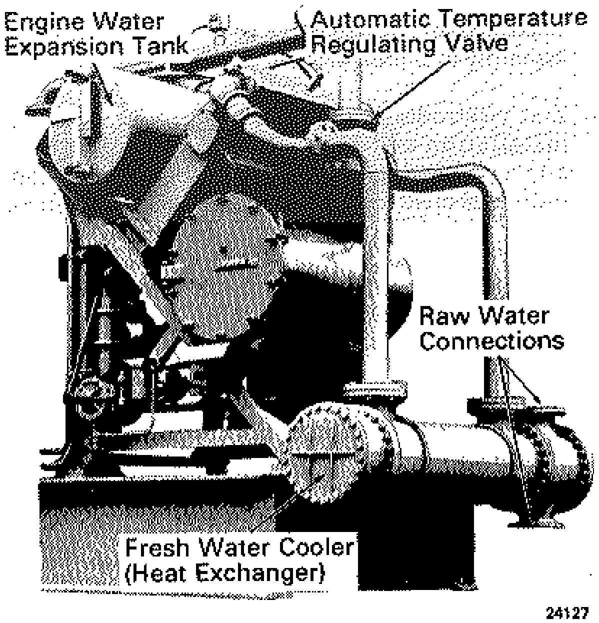


Fig. 10-18 - Accessory Rack Cooling System Components

A pressure cap on the expansion tank prevents loss of water due to evaporation during operation, and maintains pressure on the cooling system to provide better cooling for the engine. The cap is designed to open and relieve the system of excessive pressure during operation.

IMMERSION WATER HEATER (OPTIONAL)

DESCRIPTION

The electric immersion heater, Fig. 10-19, is used to keep the engine in a constant state of readiness for an immediate start.

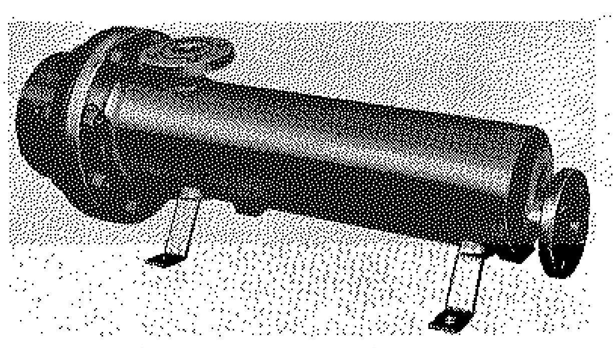


Fig. 10-19 - Immersion Heater

The heater is made up of a cylindrical shell containing a removable heating element and is mounted at the bottom of the accessory rack.

When an immersion heater is used on a marine propulsion system, the immersion heater heats the engine cooling water which is circulated through the engine by a water pump mounted near the heater.

When an immersion heater is used on a marine generating system, Fig. 10-20, the immersion heater heats the engine cooling water which circulates through the lube oil cooler by thermosyphon action. The heated water then warms the oil being circulated through the oil cooler by the oil circulating pump. A thermostat IHTS controls the immersion heater elements to keep the water in the cooler between 52° C (125° F) and 68° C (155° F).

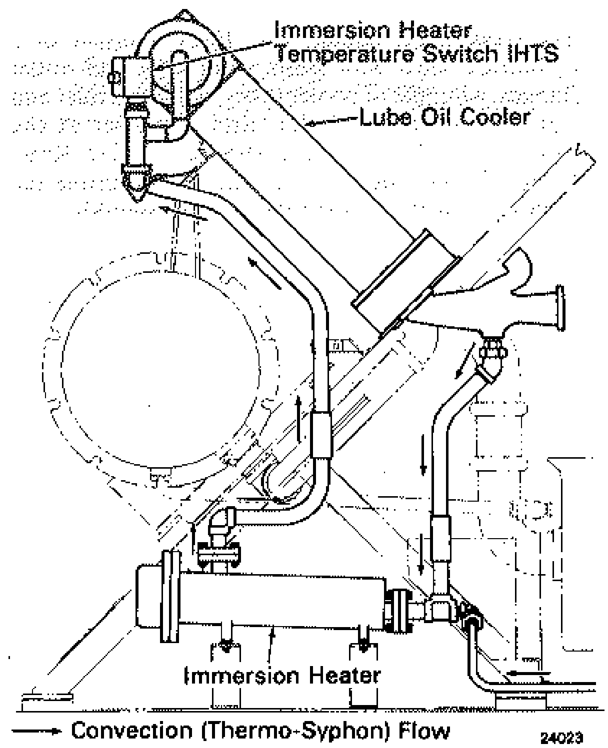


Fig. 10-20 - Immersion Heater System For Marine Generator Unit

MAINTENANCE

Disassembly and inspection of the immersion heater should be performed any time improper heating is evident. Improper heating may be caused by scale accumulation or damage to the heating element. Sludge deposits in the heater may be removed through the drain plug in the bottom of the heater.

WARNING

Be sure electrical power is disconnected before removing heating element from unit, or anytime the cooling system or heater is drained.

UNATTACHED ACCESSORIES

The fresh water cooler, although not attached to the engine proper, is considered to be a component of the basic marine engine. As the coolers vary in accord with specific applications, the descriptive maintenance, and illustrative data should be considered as "typical."

FRESH WATER COOLER

DESCRIPTION

The fresh water cooler, Fig. 10-21, consists of a cylindrical shell with fresh water inlet and outlet flanges, a bundle of cooler tubes, a flanged inlet and outlet raw water header, and a header at the opposite end to reverse the raw water flow. Combination tube supports and baffles inside the shell support the cooler tubes in the assembly.

Fresh water enters the cooler at one end of the shell, flows transversely around the tubes and baffles, and discharges at the opposite end of the cylindrical shell. The raw water used for cooling, enters the cooler at the fresh water inlet end and flows through one-half of the tubes. The water reverses at the opposite end of the cooler and flows back through the remaining half of the discharge flange. Zinc electrodes are located in the headers at the end of the assembly to inhibit electrolytic action on the tubes.

Zinc electrodes should be examined 30 days after installation and every 30 days thereafter. Any appreciable deterioration within these periods indicates electrolytic action, caused by external grounded electric currents. In that case, this condition must be corrected to avoid serious damage to the cooler. Internal electrolysis causes a gradual erosion of the electrodes, necessitating periodic renewal.

Inspection may show that the zinc electrodes are coated with insulating foreign materials. This coating must be removed by wire brushing and scraping before reinstalling electrodes. The electrodes should be renewed when 50% eroded.

MAINTENANCE

The fresh water cooler should be cleaned as frequently as found necessary to provide an unrestricted flow of water. This will vary, depending on operating conditions. In certain types of service deposits form more rapidly than others. Heavy deposits cause an objectionable increase in pressure drop through the cooler, and a decrease in the cooling effect. Cleaning at regular intervals will ensure maximum operating efficiency at all times.

The inside and outside of the cooler tubes may be cleaned with a pressure stream of water, and the inside of the tubes may be further cleaned by passing a round wire brush through them.

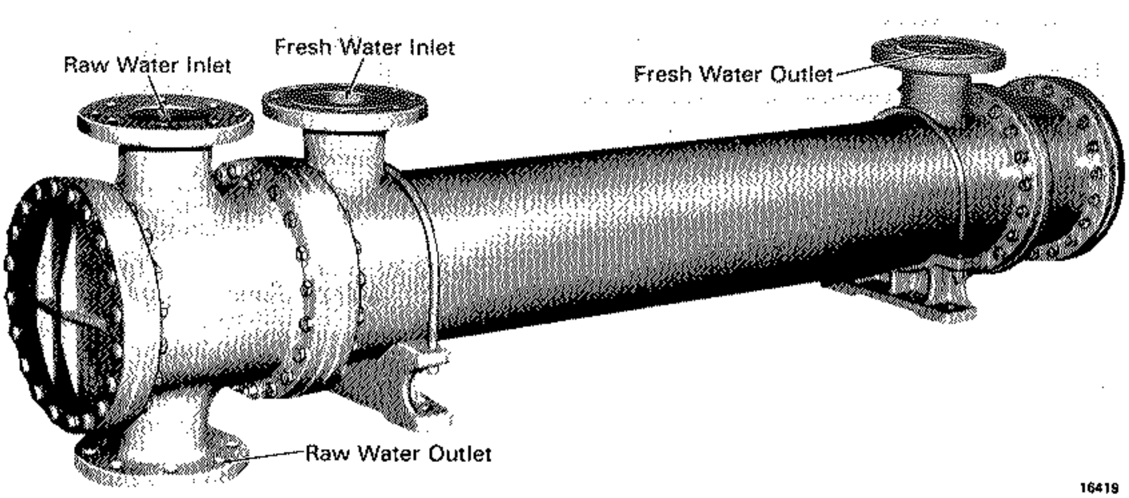


Fig. 10-21 - Typical Fresh Water Cooler

SERVICE DATA

COOLING SYSTEM

REFERENCES

Engine Coolant...M.I. 1748

SPECIFICATIONS

Clearance and dimensional limits listed below are defined as follows:

1. *New limits are those to which new parts are manufactured. (Drawing tolerances.)*

2. *Minimum, maximum, and tolerance measurements are provided as service limits. At time of rebuild or any time unscheduled maintenance is performed, the service limits should not be exceeded. Engine components within these limits may be reused with the assurance that they will perform satisfactorily until the next scheduled overhaul.*

Pump drive gear backlash -
New...0.20-0.41 mm (.008"-.016')
Max. ....0.76 mm (.030")

Bearing bores in support housing may be oversize or bearing outer diameter undersize. The limits governing the fit are:	Interference - Max. .... 0.002 mm (.0001") Clearance - Max. .... 0.051 mm (.0020")
Pump shaft bearing mounting diameters to bearing bores. No wear allowed. The limits governing the fit are: Clearance - Max.	Interference - Max. .... 0.023 mm (.0009") 0.002 mm (.0001")
Pump shaft drive gear mounting diameter to gear bore. The limits governing the fit are:	Interference - Max. .... 0.013 mm (.0005") Clearance - Max. ....0.02 mm (.001')
Pump shaft impeller mounting diameter to impeller bore. The limits governing the fit are:	Interference - Max. ....0.064 mm (.0025') Interference - Min. ....0.013 mm (.0005')

Stationary bushing seal seat squareness
with drive shaft - T.I.R. Max .... 0.051 mm (.0020")

TYPICAL COOLING SYSTEM CAPACITIES

NOTE
Actual capacities can very due to differences in shipyard piping.

Model 645E6 Engine

	Liters	Gallons
8-Cylinder		
Engine..	273	72
Accessories..................................	91	24
12-Cylinder		
Engine..	322	85
Accessories..................................	114	30
16-Cylinder		
Engine..	454	120
Accessories..................................	159	42

EQUIPMENT LIST

	Part No.
Impeller installer	8052959
Water pump impeller/ gear puller	8354367
Vee belt tension indicator	8396624
Silicone rubber sealing compound (0.14 kg [5 oz])	8453256
Water pump mounting bolt wrench	9519601
Water pump disassembly tool	9549072

SECTION 11

FUEL SYSTEM

CONTENTS **PAGE**

55E1086

FUEL SYSTEM

DESCRIPTION

The engine fuel system, Fig. 1 1-1, consists of the fuel injectors, fuel pump, the engine mounted fuel filter, and fuel supply and return manifolds.

Components external to the engine such as the fuel tank, fuel suction strainer, and connecting lines complete the fuel system.

In operation, fuel from the fuel tank is drawn up by the fuel pump through a suction strainer and is delivered to the engine mounted filter. It then passes through the filter elements to the fuel manifold supply line and injector inlet filter at each cylinder into the injector. A small portion of the fuel supplied to each injector is pumped into the cylinder, at a very high pressure, through the needle valve and spray tip of the injector.

The quantity of fuel injected depends upon the rotative position of the plunger as set by the injector rack and governor. The excess fuel not used by the injector, flows through the injector, serving to lubricate and cool the working parts.

The fuel leaves the injector through the return fuel filter. This filter protects the injector in the event of a backward flow of fuel into the injector from the return fuel line. From the return fuel filter in the injector, the excess fuel passes through the fuel return line in the manifold.

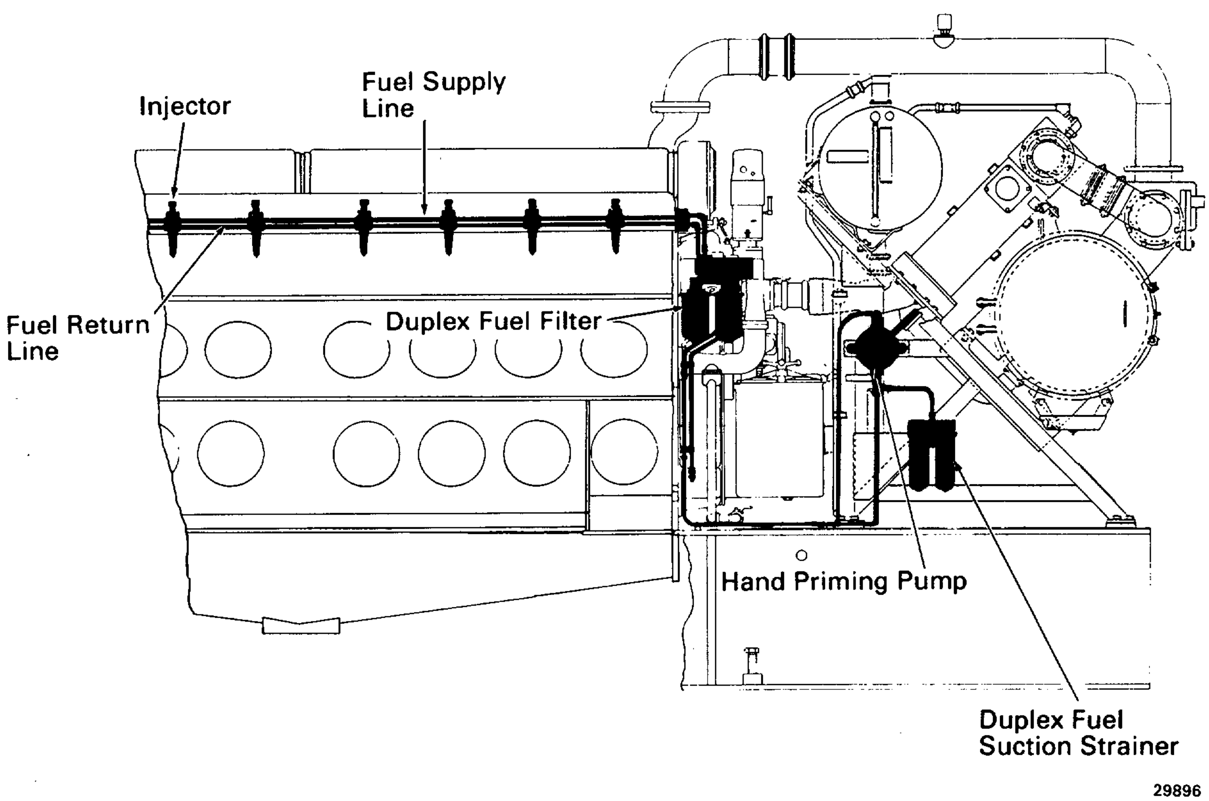


Fig.11-1 - Typical Fuel System

FUEL INJECTORS

DESCRIPTION

An injector, Fig. 11-2, is located and seated in a tapered hole in the center of each cylinder head, with the spray tip protruding slightly below the bottom of the head. It is positioned in the head by a dowel and held in place by an injector crab and nut.

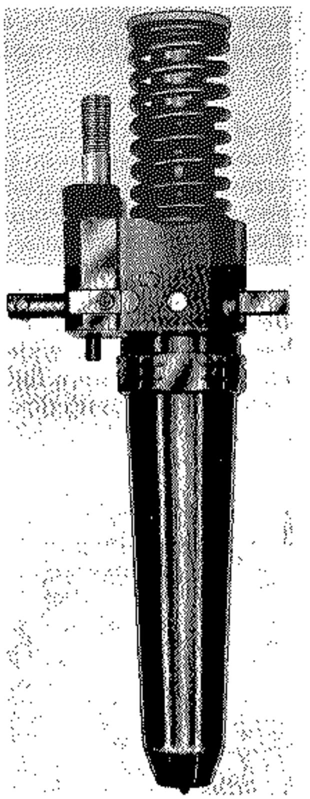


Fig. 11-2 Fuel Injector

The external working parts of the injector are lubricated by oil from the end of the injector rocker arm adjusting screw. The internal working parts are lubricated and cooled by the flow of fuel oil through the injector.

A cross-section of the unit injector and names of the various parts are shown in Fig. 11-3.

The plunger is given a constant stroke reciprocating motion by the injector cam acting through the rocker arm and plunger follower. The timing of the injection period during the plunger stroke is set by an adjusting screw at the end of the rocker arm. Fig. 11-4 shows flow of fuel through the injector during one downward stroke. Rotation of the plunger, by

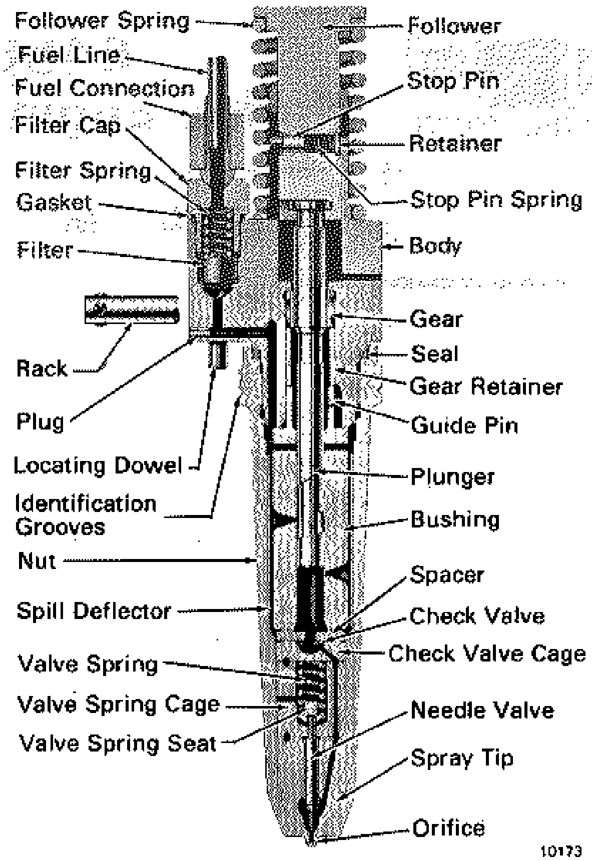


Fig. 11-3 Fuel Injector, Cross-Section

means of the rack and gear, controls the quantity of fuel injected into the cylinder during each stroke. Rack position is controlled by the governor through the injector control lever and linkage. The gear is keyed to and is a sliding fit on the plunger to allow plunger vertical movement.

The helices near the bottom of the plunger control the opening and closing of both fuel ports of the plunger bushing. Rotation of the plunger regulates the time that both ports are closed during the downward stroke, thus controlling the quantity of fuel injected into the cylinder, as shown in Fig. 11-5. As the plunger is rotated from idling position to full load position, the pumping part of the stroke is lengthened, injection is started earlier, and more fuel is injected.

Proper atomization of the fuel is accomplished by the high pressure created during the downward stroke of the plunger, which forces fuel past the needle valve and out through the spray holes in the tip of the injector.

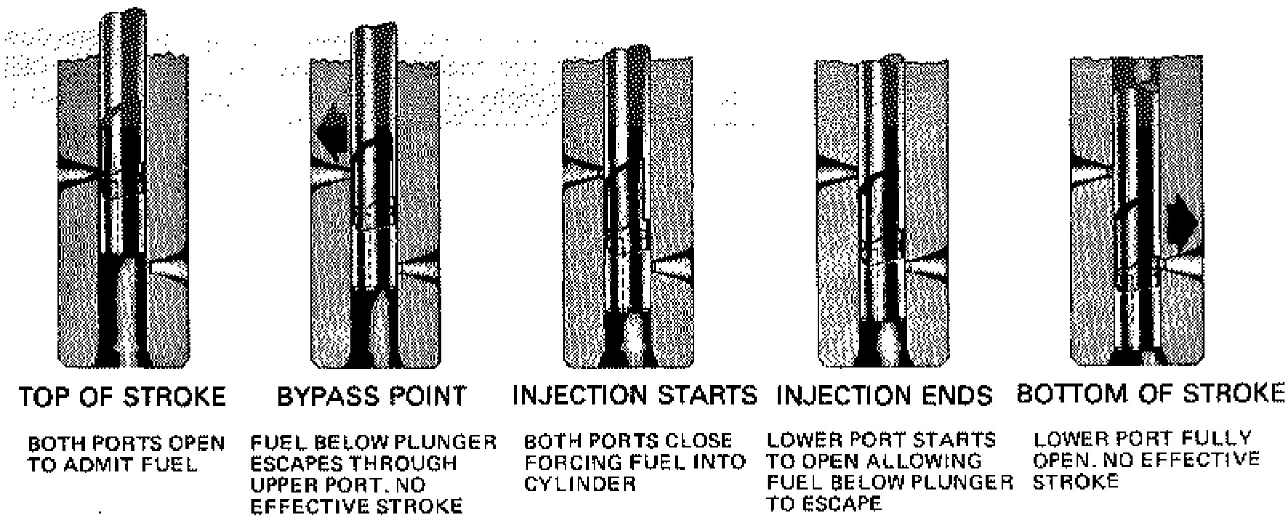


Fig. 11-4 - Injector Fuel Flow

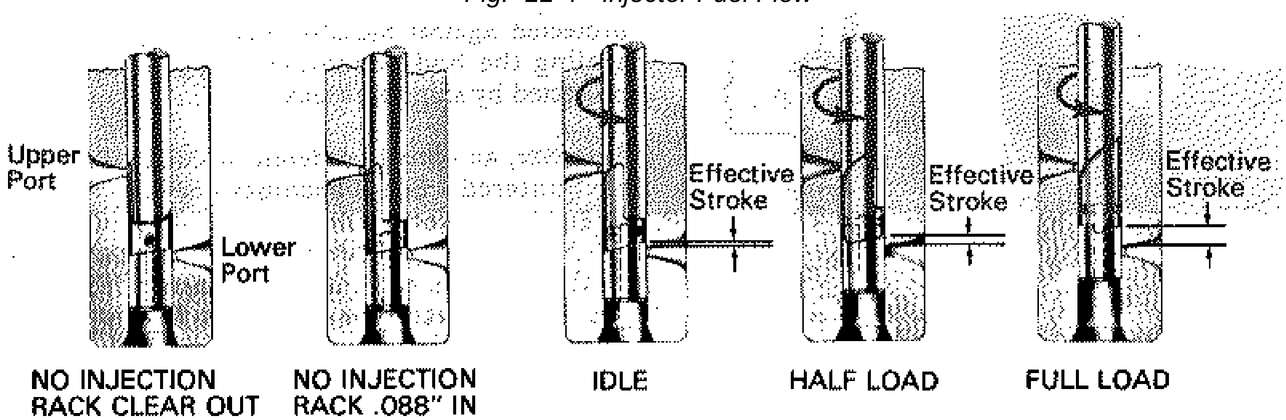


Fig. 11-5 - Plunger Fuel Control

The injectors have an adjustable calibrating slide mounted on the side of the injector body, adjacent to the rack. This slide is incorporated solely as a means of adjusting injector output on the calibrating stand.

Filters at the fuel inlet and outlet connections protect the working parts of the injector.

MAINTENANCE

INSTALLATION

1. When installing an injector in an engine, make sure it is the correct injector for the engine in which it is to be applied.

2. See that injector body and tapered hole in cylinder head are clean.

3. Install injector and apply injector crab, spherical washer, and nut. Torque nut to specified value.

4. Connect injector rack to lever assembly.

5. Install and tighten fuel supply and return lines to injector and engine fuel manifold.

6. Install rocker arm shaft and rocker arms. Loosen injector rocker arm locknut and back off on adjusting screw before tightening rocker arm shaft nuts. Injector is now ready for timing.

TIMING THE INJECTOR

With the injector installed, make timing adjustment as follows:

NOTE

Injector cannot be timed if the overspeed has been tripped. It must first be reset and the engine crankshaft barred over at least one revolution.

1. Bar engine over in the normal direction of rotation until flywheel pointer indicates the correct crankshaft position in degrees relative to top dead center of the cylinder being timed. Refer to setting instructions on Injector Timing Plate (located on right rear side of engine crankcase) and see Table 1 in Section 7 for top dead center settings.

2. Insert injector timing gauge into the hole provided for it in the injector body, Fig. 11-6.

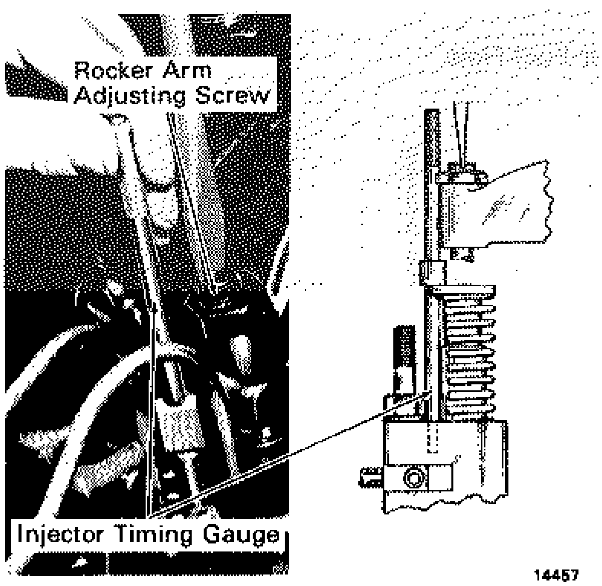


Fig. 11-6 - Timing Injector

3. Loosen locknut and turn the rocker arm adjusting screw until the shoulder of the gauge just passes over the injector follower guide.

4. Tighten adjusting screw locknut while holding adjusting screw in position with screwdriver.

5. Recheck setting.

STICKING INJECTORS

Engines may encounter sticking injectors due to fuel, lube oil, or filter maintenance conditions. Since these conditions very often are momentary, injector removal may be minimized by utilizing alcohol to free up injectors while installed. This is done by applying ordinary commercial methanol to the injectors through a hole opposite the timing tool hole, and "popping" the injectors or motoring the engine. This sticking condition usually occurs on injectors which are held with the plungers down when the engine is stopped. Should injector racks show signs of sticking, they should be checked for gum or varnish deposits. If present, the rack should be cleaned with alcohol and rechecked. If sticking persists, the injectors should be removed and replaced with operational injectors. In no case should injectors be "crutched out" or cut out and the engine operated. If injectors operating unsatisfactorily cannot be remedied or replaced, the engine should be shut down until corrective action has been taken.

SERVICING INJECTORS

When servicing injectors, clean working conditions must be maintained. Dust or dirt in any form is a frequent cause of injector failure. When an injector is in an engine it is protected against dirt, dust, and other foreign materials by the various filters employed. When the injector is in storage, it is protected against harmful material by the filters sealing the body openings, which are in turn protected by shipping blocks.

However, an entirely different set of conditions is encountered when it becomes necessary to disassemble an injector for repair or overhaul. These conditions necessitate special shops, equipment, and trained personnel. It is recommended that nonoperational injectors be returned to Electro-Motive for rebuild or unit exchange.

INJECTOR TESTER

In order to ensure efficient engine performance, injectors should be tested whenever removed from an engine, regardless of the reason for removal. It is advisable to test the complete engine set during each annual inspection. It is recommended that injectors be tested with the same oil used for protection against rust as given under "Storing Injectors".

It is important that the individual doing the testing understands the basic principles of injector operation and testing procedures in order to prevent acceptance of defective injectors and rejection of good ones. Instructions in the use of the injector tester and an outline of each separate test procedure along with a basic explanation of operation follows:

These injectors cover the testing of all needle valve injectors using the tester shown in Fig. 11-7. The procedures are not applicable to other types of testing equipment, since injector leakoff rates vary greatly in proportion to the volume of fuel contained in the high pressure portion of the tester.

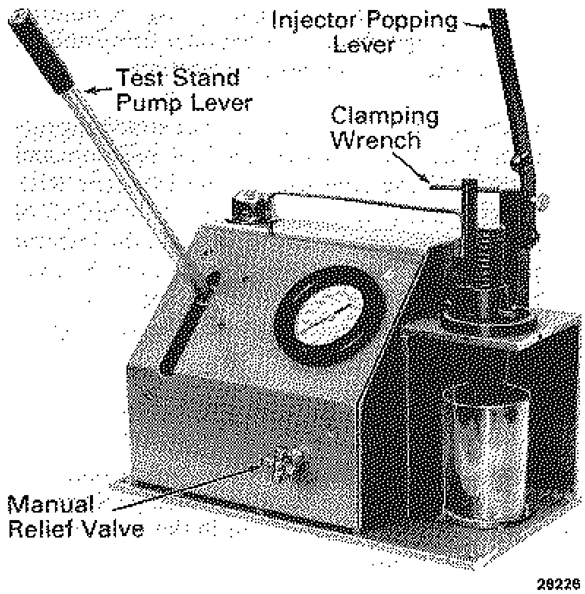


Fig. 11-7 - Injector Tester

SETTING UP TESTER

Basically, the tester consists of a fuel reservoir, filter, high pressure pump, pressure gauge, manual relief valve and necessary connecting lines and fittings to supply fuel to the injector under test. The tester should be set up as instructed by the manufacturer. Inspect carefully for dirt or foreign material in the tank and liners. Fill the tank with clean fuel and operate the pump to purge all free air from the system.

Investigation has shown that the viscosity of the fuel oil used in the tester has a marked effect on the test results obtained. Regular fuel oil may be used provided the viscosity is not less than 32 S.S.U. at 380 C (1000 F). Do not reuse fuel oil which has been pumped through the injectors into the plastic bowl.

CHECKING AND OPERATING TESTER

Install the test block in place or an injector in the tester and pump up pressure to 13 790 kPa (2000 psi), as indicated by the gauge. After five minutes, the pressure should not have dropped below 13 618 kPa (1975 psi). Release the block and recheck at 3 448 kPa (500 psi) and 6 895 kPa (1000 psi). These pressures should hold one minute with no apparent gauge drop. Make these tests with the pressure shutoff valve, Fig. 11-7, open all the way. If the tests are satisfactory, all injector tests may be made without using the shutoff valve. If the preceding tests indicate leakage, repeat the tests, closing the shutoff valve before timing the leakoff rates. If the tests are satisfactory with the shutoff valve closed, it will be necessary to use the shutoff valve when making the injector holding pressure test.

When placing a new tester in operation, or after removing and replacing the gauge, fuel tank, filter, or pump, for any reason, the test block should be installed and pressure raised to 17 238 kPa (2500 psi) and vented at least six more times before making an operational check.

The operator must consider the tester as an instrument, rather than a tool. Every effort should be made to make the manual operation of repeated tests the same. The following general information is provided to help in obtaining uniform operation.

GENERAL INFORMATION

1. When operating the pump, use a rate of 40 strokes per minute. This provides a fuel rate to operate the check valve smoothly and to circulate fuel within the injector.

2. When using the popping lever, do not use such force as to damage either the injector or the lever. Do not permit the lever to fly up freely.

3. In making holding tests, do not pump the stand above 17 238 kPa (2500 psi).

4. Testers regularly in use should be checked daily for leaks, using the test blocks.

5. Fuel oil used for testing should not be reused.

INJECTOR TESTS

PREPARATION

1. Install the injector in the tester.

2. Fill the injector with fuel oil, but do not connect the fuel line from pump to injector at this time.

3. Set the injector rack at maximum fuel output position (minimum rack length).

4. "Pop" the injector with the popping lever, Fig. 11-7, using approximately 40 smooth even strokes per minute. A finely atomized spray should show at each of the holes in the tip. Rapid closing of the needle valve should produce a sharp "chatter".

   If the valve opens without producing a finely atomized spray or the valve seats without producing a sharp "chatter", make several rapid strokes with the lever to dislodge any foreign material on the valve seat. If the needle valve still fails to function properly, a stuck needle, dirt on the valve seat, or a defective valve seat may be the cause.

HOLDING PRESSURE AND LEAK TEST

1. All injectors lose pressure due to leakage at any of several points, but this leakage must be controlled during injector manufacture to prevent engine lube oil dilution. The holding pressure test will qualify injectors having specified leakoff rates, providing this leakage is at the proper point and is satisfactorily controlled.

2. Manually hold the tester fuel line block on the injector. Pump until fuel is discharged from filter cap on opposite side, to remove air. Apply 12 411 kPa (1800 psi) to 13 790 kPa (2000 psi) pressure to the injector. No leakage is permitted at the nut to body seal, filter cap gasket, body plugs or between spray tip and injector nut.

3. Injectors should be qualified on the pressure test by timing the interval for a drop in pressure from 13 790 kPa (2000 psi) to 10 342 kPa (1500 psi). If this interval is less than 20 seconds (used) or 30 seconds (new or reconditioned), repeat the test, but close the pressure shutoff valve immediately after establishing the 13 790 kPa (2000 psi) pressure. This is to ensure that the leakdown time is not being affected by the possible leakage in the tester itself. If the timed interval for the pressure drop from 13 790 kPa (2000 psi) to 10 342 kPa (1500 psi) is still less than 20 seconds (used) or 30 seconds (new or reconditioned), the injector should be rejected. To relieve the pressure before removing the injector from the tester, wrap a cloth around the injector fuel line connections and back off on the clamping wrench, Fig. 11-7.

RACK FREENESS TEST

1. The rack engages with a small pinion on the injector plunger and serves to rotate the plunger with respect to two ports in the injector bushing, which regulates the amount of fuel injected with each stroke of the plunger. Binding of the rack is generally caused by damaged gear teeth, scored plunger and bushing, or galling of rack itself. A binding rack may cause sluggish or erratic speed changes and overspeed trip action.

2. To be considered satisfactory, the rack must fall in and out through full travel by its own weight when injector is held horizontally and rotated about its axis.

BINDING PLUNGER TEST

1. Failure of the injector plunger to move up and down freely indicates scoring of the plunger and bushing or weak or broken spring. A binding plunger will cause erratic cylinder firing and, in extreme cases, overspeed trip action.

2. Place injector in tester but do not attach the fuel line. Place rack in the full fuel position and pump all the fuel out of the injector with injector popping lever, Fig. 11-7. When all of the fuel has been removed, depress the injector plunger to full extent of its travel. Slowly release popping lever and simultaneously move injector rack repeatedly in and out through its full travel.

REPLACING INJECTOR FILTERS

Injector filters should not be disturbed or removed except during injector reconditioning (when all parts are completely washed), or in the event of fuel stoppage to the injector.

STORING INJECTORS

When injectors are not to be used for a considerable length of time, they should be protected against rust by using a stable, noncorrosive straight-run petroleum distillate in the kerosene volatility range. It is also recommended that injectors be tested using this oil. If this is done, treatment will be taken care of at time of injector test.

After treatment, the injectors should be stored in a protective container until needed. This container should accommodate an injector holding rack similar to that shown in Fig. 11-8.

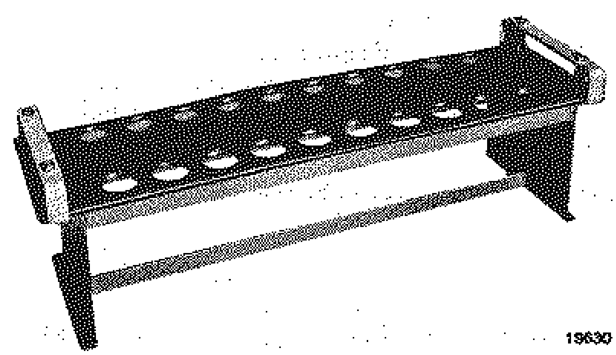


Fig. 11-8 - Injector Holding Rack

INJECTOR LINKAGE

DESCRIPTION

The injector linkage, Fig. 11-9, consists of the mechanical arrangement between the governor and the injector permitting all injector rack positions to be changed simultaneously when the governor terminal shaft is rotated. Two injector control rods connect the lever on the governor terminal shaft to

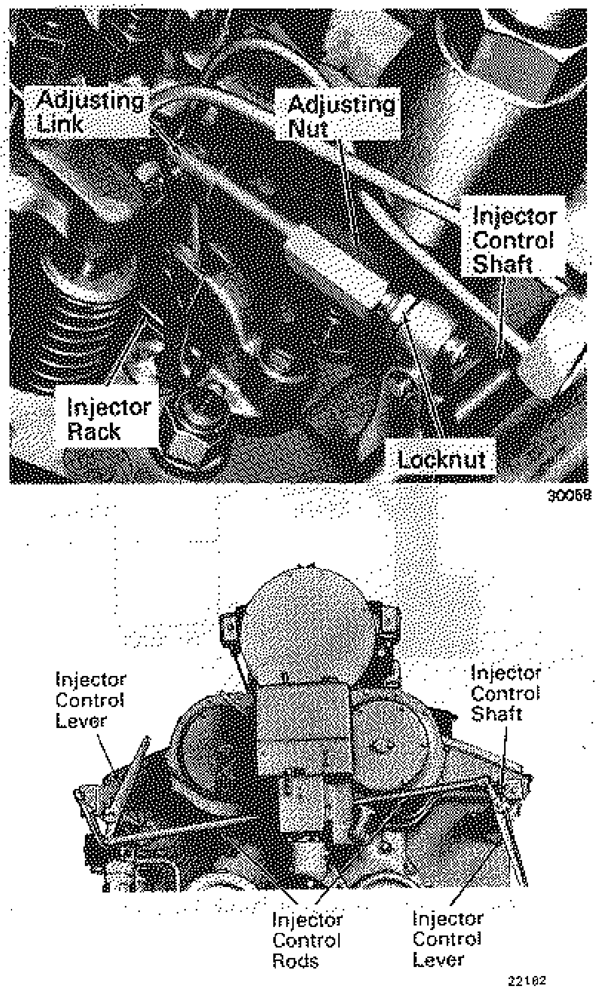


Fig. 11-9 - Injector Linkage

the injector control shafts. The injector control shafts, one for each bank, extend the length of the cylinder banks under the cylinder head cover frames. At each cylinder location, a lever is pinned to the control shaft. An adjusting link connects the control shaft lever to an injector control lever mounted on the cylinder head, one end of which straddles the ball at the end of the injector rack.

MAINTENANCE

Before attempting to set injector racks, all racks and linkage should be checked for binding, sticking, or wear which would affect operation.

SETTING INJECTOR RACKS

Injector racks should be set with the engine at operating temperature. If racks are set when engine is not at operating temperature, the settings should be rechecked when operating temperature is reached. As engine temperature increases, the right bank rack length shortens and the left bank rack length increases. The change on the left bank is insignificant, but the change on right bank may shorten the racks beyond the minus 0.40 mm (1/64") tolerance.

NOTE

Every time a governor is installed on an engine, the injector rack setting should be checked. Due to manufacturing tolerances in governor mounting bolt holes, the position of the governor in relation to the injector linkage can change the rack setting.

Set the injector rack on the engine as follows:

1. Install the applicable injector linkage setting jack, Fig. 11-10.

2. For engines equipped with PGA or EGB governors, adjust the setting jack until the pointer on the governor aligns with governor terminal shaft scale at the 1.00" mark.

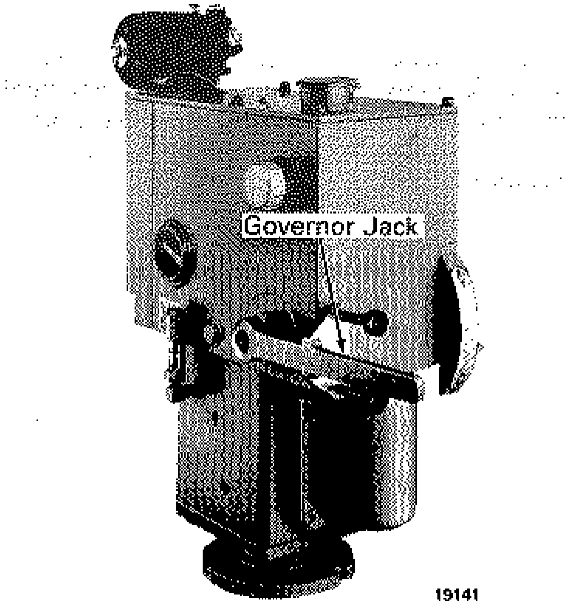
   For engines equipped with UG-8 governors, turn the LOAD LIMIT knob on the governor to the maximum load position. Adjust the setting jack until the terminal shaft is in full fuel position.

3. Use the rack gauge, without the adapter, Fig. 11-11, for setting the rack on engines having PGA or EGB type governors. Set the rack within the setting range marks on the gauge.

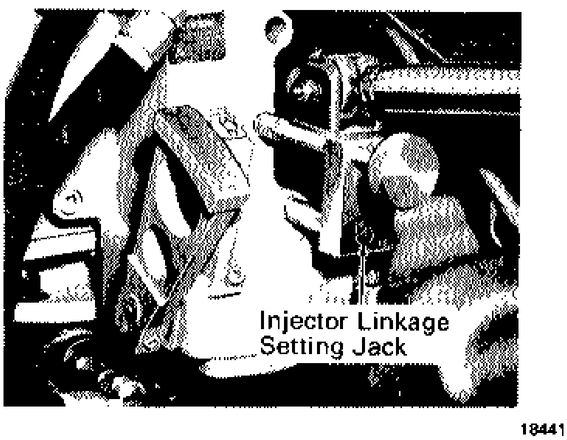
   Use the rack gauge with the adapter, Fig. 11 -1 1, for setting the racks on engines having UG-8 governors. Set the rack within the setting range marks on the gauge.

   The rack setting gauge is an 8 to 1 multiplying gauge which indicates the 0.40 mm (1/64") tolerance by marks 3.18 mm (1/8") each side of the center mark on the gauge scale.

   It is important that the proper rack gauge be used, as previous model-rack gauges still measure the rack length from the body of the injector instead of from the face of the calibrating slide. The correct gauge for setting injectors with calibrating slides can be readily identified by the single locating button on the front face of the gauge. This gauge can be used for all injectors.



EGB



PGA

UG-8

Fig. 11-10 - Injector Rack Positioning

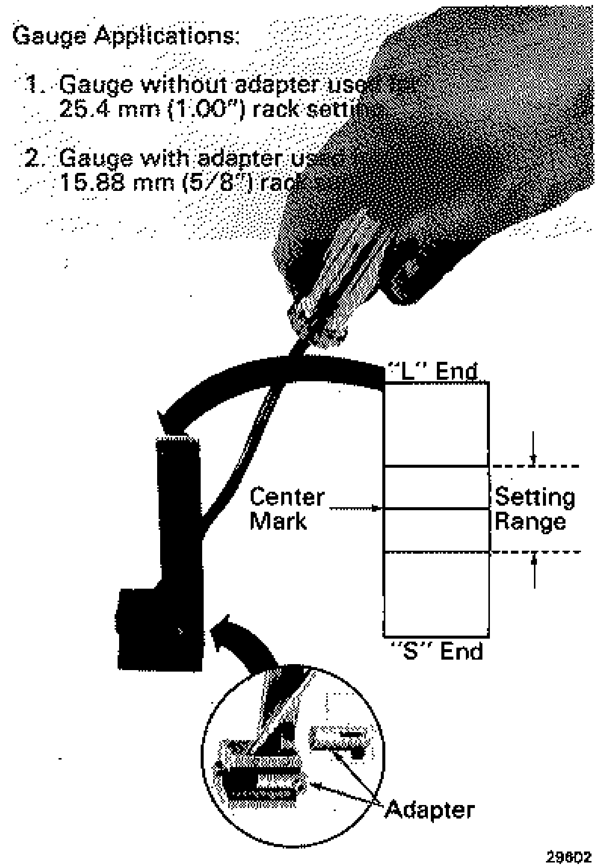


Fig. 11-11 - Injector Rack Gauge

4. Place the gauge over the injector rack and hold the gauge firmly against the face of the calibrating slide on the injector, Fig. 11-12, and check the gauge pointer. If the pointer is at the short ("S") end of gauge scale, outside of the setting range, the rack is not extending out far enough from the injector. Loosen the locknut on the adjusting link, Fig. 11-9, and turn adjusting nut on link until pointer is at the long ("L") end of the scale; then reverse pointer travel until it is within the scale setting range. Hold the adjusting nut and tighten locknut. The reason for exceeding the setting range when making adjustment is so that, in setting all of the racks, the backlash will be taken up in the same direction.

5. When pointer is at the long ("L') end of scale, set pointer within the setting range. The accuracy of the injector rack gauge can be checked by inserting the master block in the gauge body, Fig. 11-13. Pointer should align with center mark on scale.

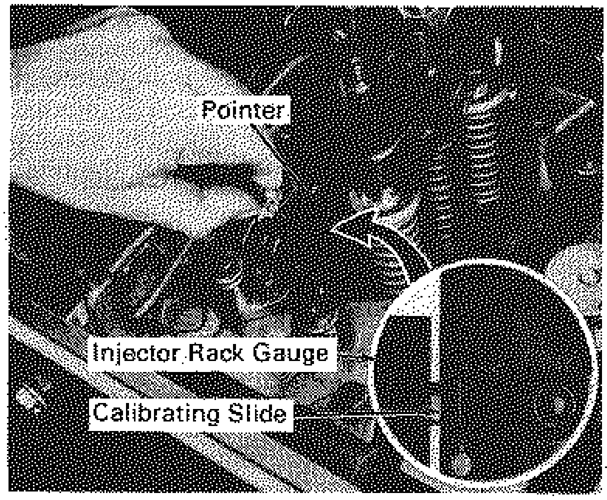


Fig. 11-12 - Injector Rack Gauge Application

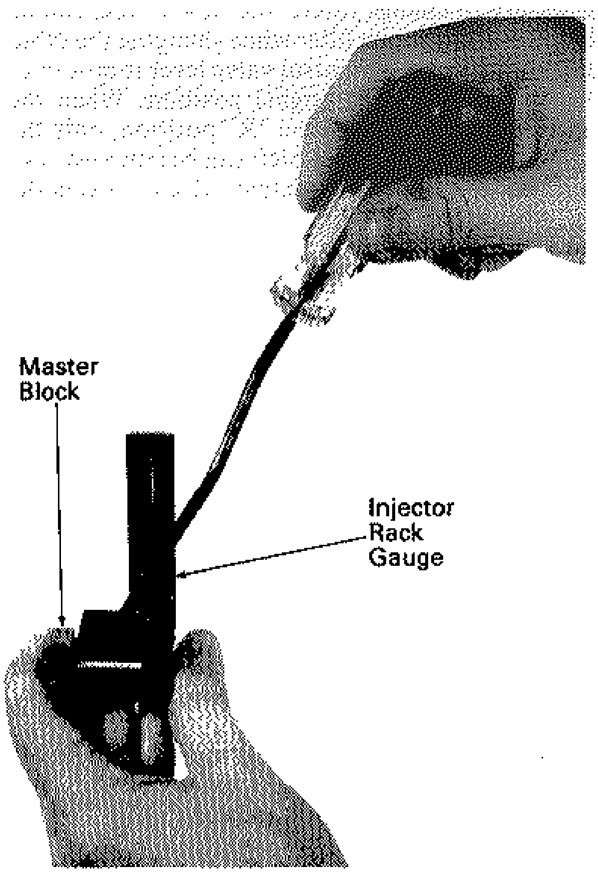


Fig. 11-13 - checking Injector Rack Gauge

FUEL PUMP

DESCRIPTION

The single unit fuel pump, Fig. 11-14, is mounted on and directly driven by the lubricating oil scavenging pump.

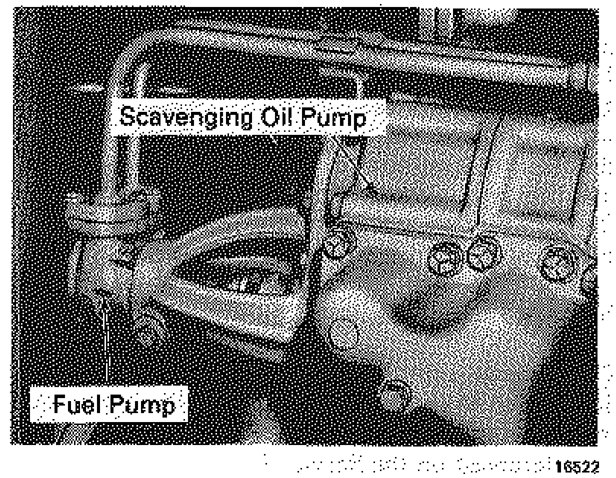


Fig. 11-14Fuel Pump Installation

NOTE

The fuel pump must be driven in the direction of the arrow stamped on the pump body. Some pumps have a passage from the suction part of the pump to the seal assembly so a partial vacuum is created in the seal which tends to hold the seal faces together. Should the pump rotation be reversed, there will be a pressure on the seal which will force the seal off its seat as the pump pressure increases.

The pump is an "internal" gear type, Fig. 11-15. Fuel is drawn into the inlet portion to fill a space created by the gear teeth coming out of mesh. The fuel is then trapped in the space between the gear teeth and carried to the outlet side of the pump. There the gears mesh, which forces the fuel from between the gear teeth to flow through the outlet.

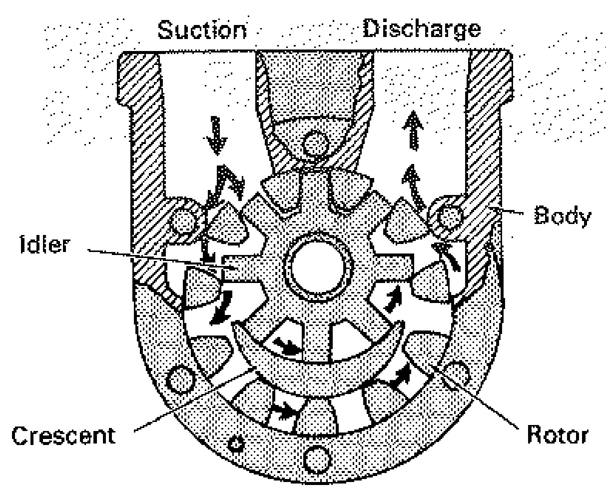


Fig. 11-15 - Fuel Pump Operation

The seal is a device to prevent leakage between the stationary pump body and the rotating drive shaft. This is done by providing a perfectly smooth surface on the pump body against which a perfectly smooth surface on the shaft can turn with such small clearance that resistance to fuel flow is great enough that fuel will not leak out and air will not leak in. One face of the seal is spring-loaded to maintain the closest possible fit.

MAINTENANCE

The fuel pump should be serviced as specified in the Scheduled Maintenance Program. Maintenance Instructions for repair and testing of the fuel pump are referenced on the Service Data page.

FUEL FILTER

DESCRIPTION

The engine mounted fuel oil filters, Fig. 11-16, are installed at the right front of the engine. Each filter is a disposable type which is screwed directly to a common head.

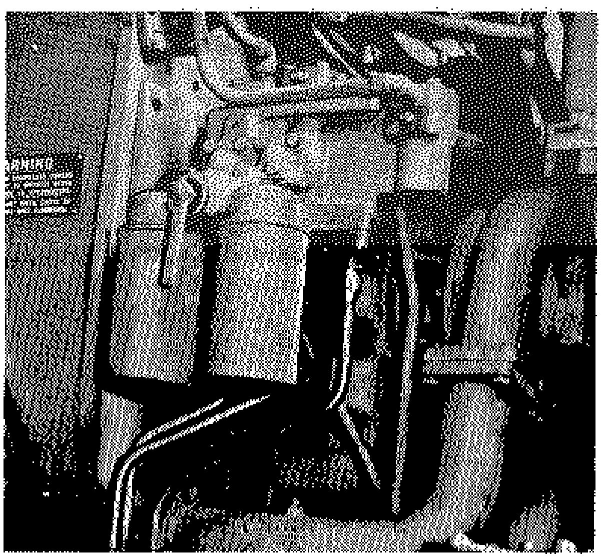


Fig. 11-16 Fuel Filter Assembly

The fuel manifold housing contains internal antiflooding valves on the fuel pump and prime pump supply lines which are piped separately from the fuel suction strainer. The manifold housing also contains a back pressure regulating check valve and a fuel pump pressure relief valve. If the filters become plugged, the relief valve will open to by-pass the fuel back to the fuel tank starving the engine.

The filters are composed of a pleated paper element around a performated metal tube providing an 1100 sq. in. filtering area. The case is an enameled drawn steel shell capable of withstanding internal pressures in excess of 1 034 kPa (150 psi). A neoprene gasket attached to the top of the filter ensures sealing.

A tapered cock-type control valve in the manifold housing directs the flow of fuel to either or both filters. One filter can be cut out of service to permit replacement without stopping the engine. The inlet and outlet connections are located in the manifold housing.

The flow of fuel through the filter is directed and regulated by the position of the control valve. When the control valve lever is set at the center or "BOTH" position, both filters are being used. When it is necessary to change filters, the flow of fuel can be directed through one filter while changing the other one. To do this, the control valve lever is moved to the "L" (left) or "R" (right) position. When the control valve lever is in the "R" position, only the right filter is in use, and the left can be removed. The reverse is true when the control valve lever is in the "L" position.

MAINTENANCE

The filters should be changed as specified in the Scheduled Maintenance Program, or more frequently as determined by operating experience.

1. To change a filter while the engine is running, move the filter selector lever to the letter representing the opposite filter.

2. Unscrew the filter to be changed, using a strap wrench if necessary.

3. Apply a new filter to the filter head and tighten until the neoprene gasket is sealed.

4. With the engine running, move the selector lever to the position of the filter that was changed and check for leakage.

ACCESSORY RACK COMPONENTS

The fuel priming pump and the duplex suction strainer are off-engine components of the fuel system, and are mounted on the accessory rack, Fig. 11-17. The location may vary, based on specific applications, and the arrangement as shown should be considered "typical."

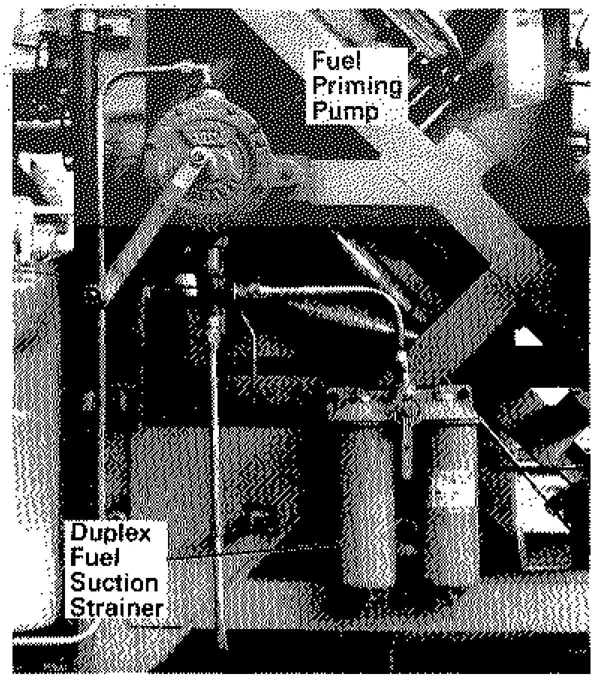


Fig. 11-17 Accessory Rack Fuel System Components

FUEL PRIMING PUMP

DESCRIPTION

The fuel priming pump is a manually operated pump, which is located on the accessory rack, Fig. 11-17. Its primary function is to prime the fuel system after the engine has been shut down for an extended period of time. The pump has a built-in check valve at the discharge side of the pump which closes when the pump lever is repositioned during the suction stroke.

MAINTENANCE

No scheduled maintenance is required. If the pump is not operating properly, it can be disassembled for inspection by removing the lever, and then separating the shell and lid.

DUPLEX FUEL SUCTION STRAINER

DESCRIPTION

The duplex fuel suction strainer, mounted on the accessory rack, Fig. 11-17, is located in the fuel system to remove foreign material from the fuel being taken from the fuel tank. The strainer contains mesh elements. A cutaway view of the strainer is shown in Fig. 11-18. Fuel oil passing through the strainer goes directly to the engine mounted fuel pump.

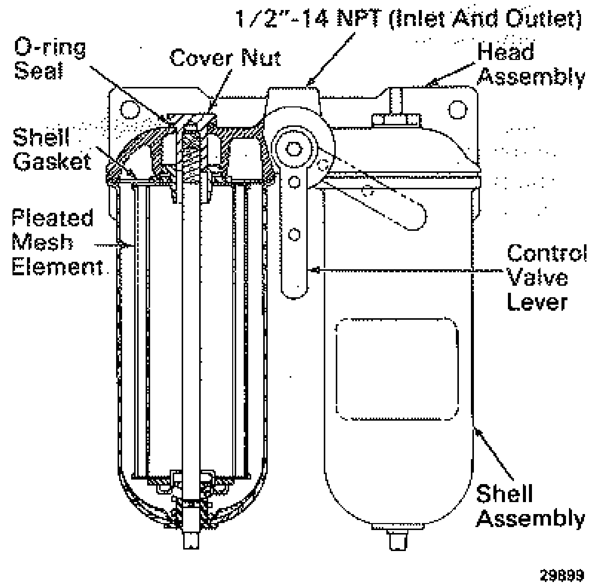


Fig. 11-18 Duplex Fuel Suction Strainer

A tapered cock-type control valve in the head assembly directs the flow of fuel to either or both elements. One element can be cut out of service to permit cleaning without stopping the engine. The inlet and outlet connections are located in the top of the head assembly.

The flow of fuel through the strainer is directed and regulated by the position of the control valve. When the control valve lever is set at the center or "BOTH" position, both elements are being used. When it is necessary to clean elements, the flow of fuel can be directed through one element while cleaning the other one. To do this, the control valve lever is moved to the "L" (left) or "R" (right) position. When the control valve lever is in the "R" position, only the right element is in use, and the left can be removed. The reverse is true when the control valve lever is in the "L" position.

MAINTENANCE

The fuel suction strainer elements should be cleaned and inspected as specified in the Scheduled Maintenance Program, or at shorter time periods, if operating conditions warrant.

1. To clean a strainer element while the engine is running, move the selector lever to the letter representing the opposite element.
2. Remove cover nut holding the strainer shell to the head assembly of the element to be cleaned, and remove shell assembly with element from head assembly.

3. Withdraw the mesh element, and discard the oil and sediment held in the strainer shell.

CAUTION

Chlorinated hydrocarbon solvents and temperatures above 82° C (180° F) will damage the epoxy material bonding the strainer element to the end caps.

4. Clean the mesh element in a container of clean fuel oil. A brush may be used, but no special cleaning tools are necessary.

5. Clean the shell with fuel oil and wipe it clean.

6. Inspect the cover nut "O" ring, and replace it with a new ring if necessary. Replace strainer shell to head assembly gasket.

7. Place the cleaned strainer element in the shell and reapply the shell to the head assembly. Apply cover nut with "O" ring and tighten firmly into place after making certain the '0" ring is properly seated.

SERVICE DATA

FUEL SYSTEM

REFERENCES

Diesel Fuel Recommendations .... M.I. 1750
Fuel And Soakback Pumps .... M.I. 4110

SPECIFICATIONS

Clearance and dimensional limits listed below are defined as follows:

1. *New limits are those to which new parts are manufactured. (Drawing tolerances.)*

2. *Minimum, maximum, and tolerance measurements are provided as service limits. At time of rebuild or any time unscheduled maintenance is performed, the service limits should <u>not</u> be exceeded. Engine components within these limits may be reused with the assurance that they will perform satisfactorily until the next scheduled overhaul.*

Fuel Pump Clearances
Rotor to pump body - Max .... 0.05 mm (.002")
Rotor end - Min. .... 0.03 mm (.001")

EQUIPMENT LIST

	Part No.
Injector timing gauge	8034638
Injector prybar	8041183
Plastic spray cup (extra - used with injector test stand)	8171780
Oil, injector test, storage, and rust prevention - (208 liter [55 gal] drum)	8203258
(19 liter [5 gal] can)	8219007
Injector linkage setting jack	
(UG8)	8259734
(EGB)	8295586
(PGA)	8432485
Injector rack gauge (with adapter)	8339610
Adapter only	8357591
Adapter screw	9421611
Injector holding rack	8431626
Injector tester (complete)	9549015

SECTION 12

GOVERNOR

GOVERNOR

GENERAL

The function of the governor is to maintain the speed of the engine at a setting determined by the engine operator. Either the UG-8 governor, PGA governor, or an EGB actuator, Fig. 12-1 is used, depending upon the application.

NOTE
Where generally used, the term "governor" will be interpreted to include the actuator unless a distinction is made.

GOVERNOR MAINTENANCE

Service work on the governor, other than replenishing the oil supply and making the following adjustments, should not be attempted. Even seemingly minor adjustments on the governor may alter other component operation. It is recommended that, if maintenance or repair is required and it is not considered practical to return the governor to the manufacturer, the services of an authorized factory representative be obtained. Refer to the Service Data at the end of the section for the applicable settings.

GOVERNOR REMOVAL

Remove the governor from the engine as follows:

1. Open drain cock or drain plug from governor and drain oil into suitable container.

2. Remove right and left bank control rods from governor to control rod lever.

3. Disconnect electrical connector and all external lines and hoses.

4. Remove the four stud nuts securing governor to mounting surface, and lift governor off of studs. Remove the gasket from between the governor and the mounting surface.

CAUTION
Use care when handling governor and avoid striking the end of the drive shaft or the terminal shaft. Damage can be done to the shafts, bearings, and governor oil pump gears.

5. Remove governor to control rod lever from governor terminal shaft.

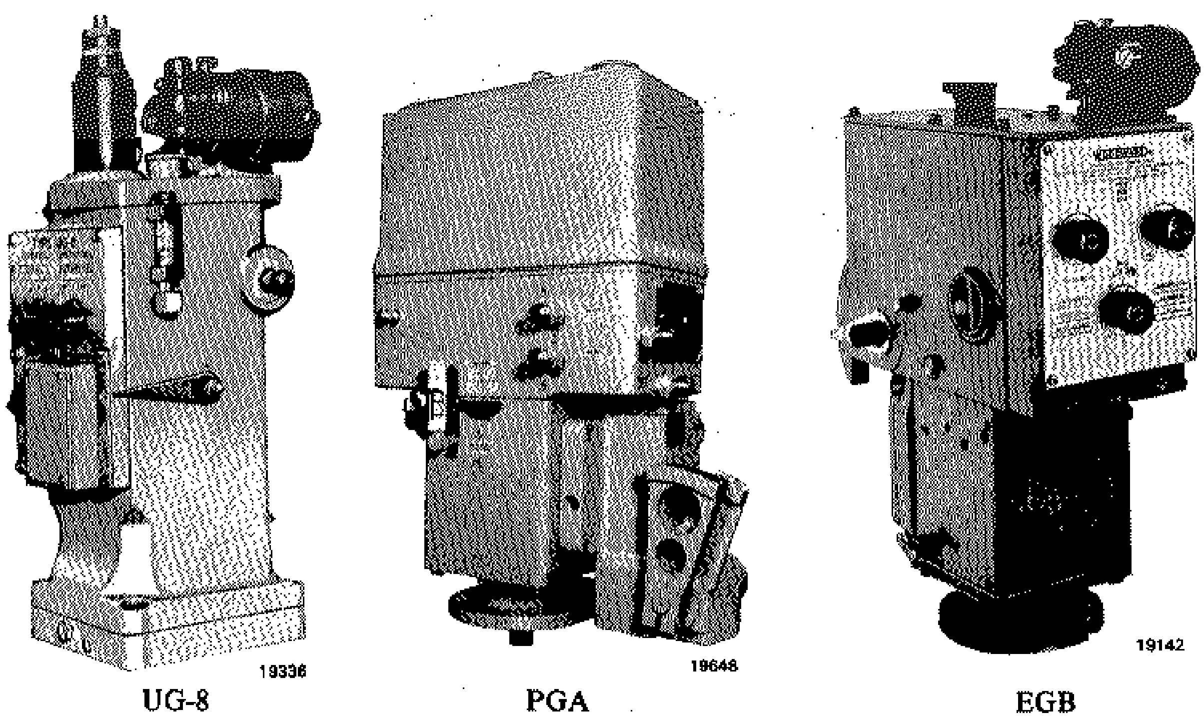


Fig. 12-1 - UG-8 Governor, PGA Governor, And EGB Actuator

GOVERNOR INSTALLATION

Install governor on engine as follows:

1. Apply governor to control rod lever to governor terminal shaft.

CAUTION

Ensure that unsplined area of the lever I.D. is properly aligned to the keyway (missing spline) on the terminal shaft.

2. Install gasket on governor mounting surface.
3. Install governor on mounting surface with terminal shaft pointing toward engine.
4. Apply four stud nuts and torque to specified value.
5. Connect electrical connector and all external lines and hoses.
6. Connect right and left bank control rods to governor to control rod lever.

NOTE

Every time a governor is installed on an engine the injector rack setting should be checked. Due to manufacturing tolerances in governor mounting bolt holes, the position of the governor in relation to the injector linkage can change the rack setting.

GOVERNOR DRIVE ASSEMBLY

DESCRIPTION

The governor drive assembly, Fig. 12-2, is mounted at the front of the engine on the accessory drive cover adjacent to the water pumps. The governor is mounted on the housing and driven through the 900 bevel gear drive. The serrated end of the drive shaft is mated into a drive plate on the governor drive gear in the accessory gear train. Lubrication of the governor drive bearings and gears is provided though drilled passages in the drive housing.

A cover having a removable plug, is provided on the housing so that a tachometer adapter, Fig. 12-2, can be inserted in the drive shaft end. The adapter end is inserted into a reamed hole in the end of the governor drive shaft and has a friction fit.

MAINTENANCE

The governor drive assembly normally does not require servicing except at the time of general engine overhaul or reconditioning. At this time or when conditions warrant, the governor drive assembly should be removed and the parts inspected and checked. After removal of the governor, the % governor drive assembly can be easily removed. A mounting dowel correctly positions the governor drive housing on the accessory drive cover.

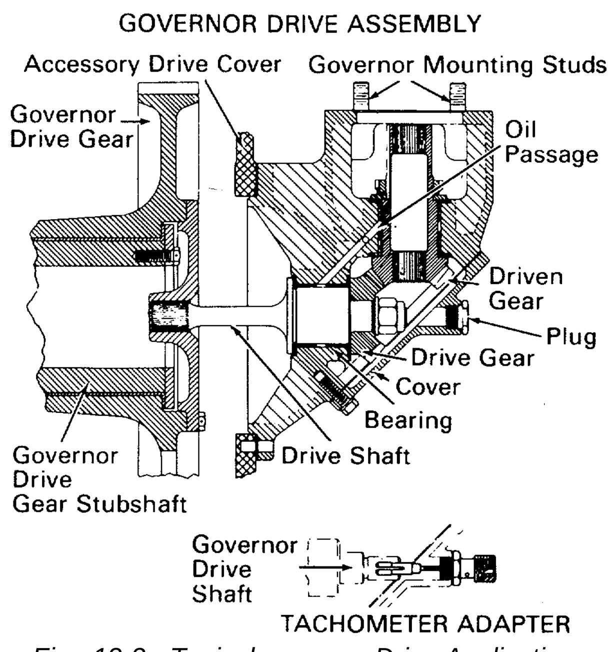


Fig. 12-2 - Typical governor Drive Application

After the governor drive assembly has been removed and disassembled, visually inspect the bushing bores and thrust faces for flaking, imbedded dirt, chipping or scoring. Bushings that are chipped or flaked or have large quantities of imbedded dirt should be replaced with new bushings. Check oil passages in the housing to be sure they are free of restrictions. Inspect bevel gears for nicks, pitting or visible wear on the loaded tooth faces. Nicks, burrs or any high spots should be stoned out or the gears replaced. If it is necessary to replace a gear, it is recommended that both gears be replaced as a set. Check individual parts and assembly to be sure dimensions are within limits given in Service Data at the end of this section.

FLUSHING GOVERNOR

Governor flushing is not recommended as a regular maintenance item. Instead, the governor should be disassembled and cleaned if operation is impaired due to dirt or other foreign particles in the governor. In cases of necessity where the governor is suspected of being dirty and it would not be practical to remove the governor from the engine, it may be flushed on the engine as follows:

1. The engine should be shut down and the drain plug removed from the governor case. Close valve or replace plug and add two pints of filtered kerosene to governor and start engine. Using the hand control lever, vary the speed of the engine from 400 to 500 RPM, for about five minutes. Shut the engine down and drain kerosene from the governor. Repeat this operation several times until the kerosene drained from the governor appears clean.

2. Add two pints of recommended oil to the governor and repeat the above procedure and drain. This will remove any kerosene trapped in the governor.

3. Fill the governor with recommended oil to the proper level and start the engine. The oil level should then be checked and oil added, if necessary.

GOVERNOR OIL SUPPLY

The oil level should be maintained between the marks on the sight glass. Use new oil which will meet the specifications for governor oil. The vent at the top of the sight glass must be open to ensure correct readings. Governor oil specification is listed on Service Data page.

GOVERNOR STORAGE

When a governor is to be stored, governor oil should be drained. If the governor has been operating with oil that meets specifications, no further treatment is necessary. If governor oil does not meet the recommended specifications, drain and fill with the recommended oil, and, if possible, operate the governor for several minutes, then again drain the oil.

The recommended oil should be used when the governor is returned to service.

PGA GOVERNOR

DESCRIPTION

Main components of the PGA governor, Figs. 12-3 and 12-4, are: the speed sensing group, consisting of the speeder spring, speed setting piston, and flyweights; fuel adjustment control group, consisting of power piston and spring; compensating mechanism, consisting of power piston pilot valve and buffer piston and springs; and an oil system for component operation and lubrication consisting of oil pump, oil sump, and accumulators.

In addition to the main components, the governor may be modified to contain auxiliary devices which include speed droop and a load control system.

The lower half of the governor contains essentially the components required to maintain constant engine speed by regulating fuel supplied to the engine. The upper half, consisting of the column, cover, and related internal parts, contains the mechanism for changing the governor speed setting and the engine shutdown and protective devices.

OPERATION

Basic governor operation, reflecting changes in engine speed setting and the resulting governor reaction to regulate the fuel control mechanism, is explained below. Refer to Fig. 12-5 for a schematic arrangement of components.

The governor drive shaft extends through the governor base into the pump drive gear, which is directly connected to the rotating pilot valve bushing. The flyweight head is attached to the top of the bushing, providing a direct drive from the engine to the flyweights. When the governor speed setting and engine speed are the same, the flyweights will be

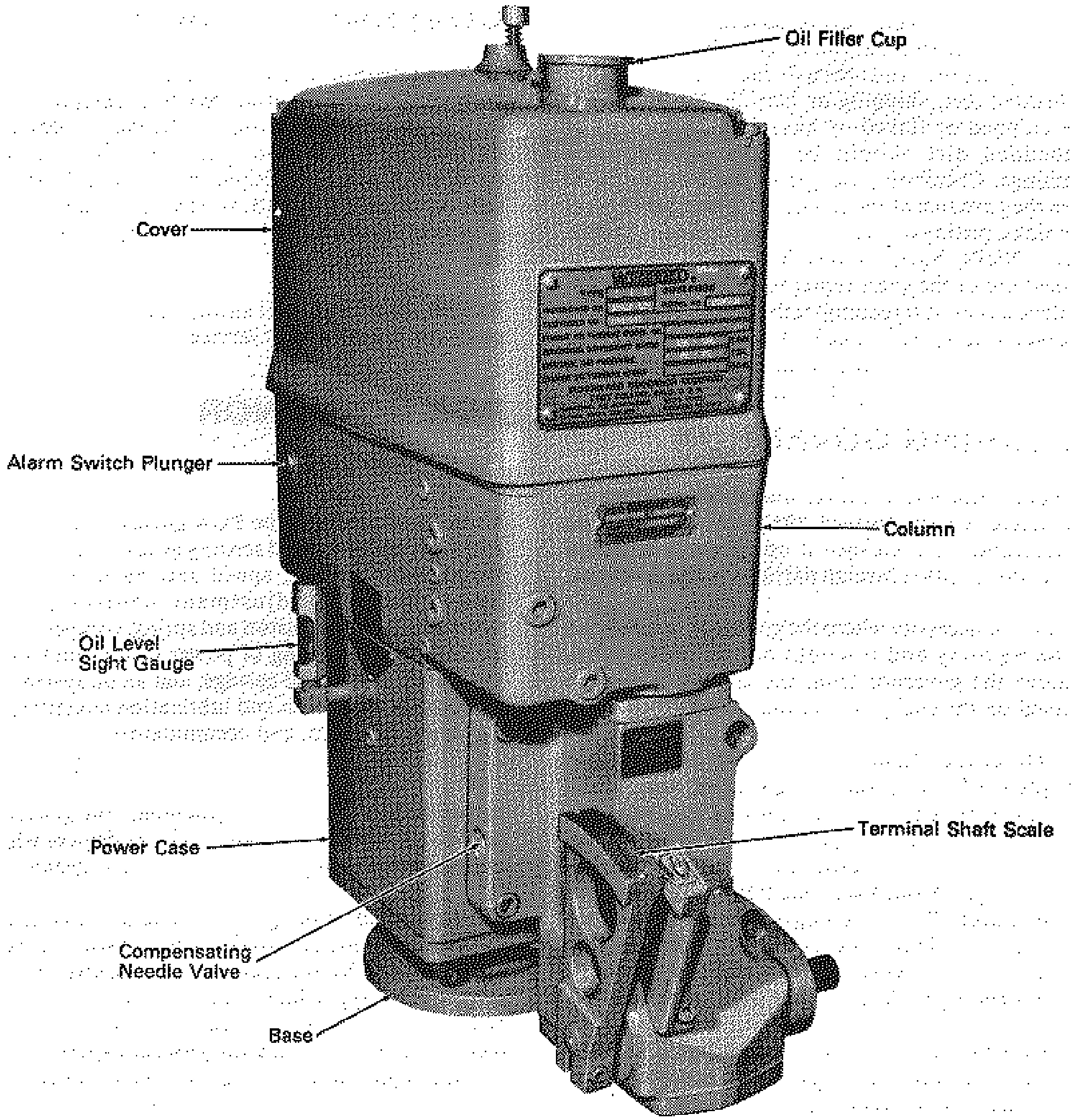


Fig. 12-3 - Model PGA Governor, 3/4 Front View

in a vertical position and the pilot valve plunger will cover the regulating ports in the pilot valve bushing.

When the engine is "on speed" with a steady load, the pilot valve plunger will be slightly off center to supply enough oil through the regulating port to stabilize the power piston against the power spring.

The governor oil pump supplies oil to the accumulators and pilot valve bushing, with the excess oil (at maximum pressure) being bypassed from the accumulator to the governor oil sump.

Power piston movements are transmitted by the piston rod through the rotary terminal shaft to the engine fuel linkage. Regulated oil pressure under the power piston raises the piston to increase fuel, and the power spring above the piston lowers the piston to decrease fuel.

The "buffer" compensating system, consisting of the buffer cylinder and piston, buffer springs and the compensating needle valve, is located between the pilot valve bushing and the power piston. Lowering the pilot valve plunger permits a flow of oil under pressure from the pilot valve bushing into the buffer

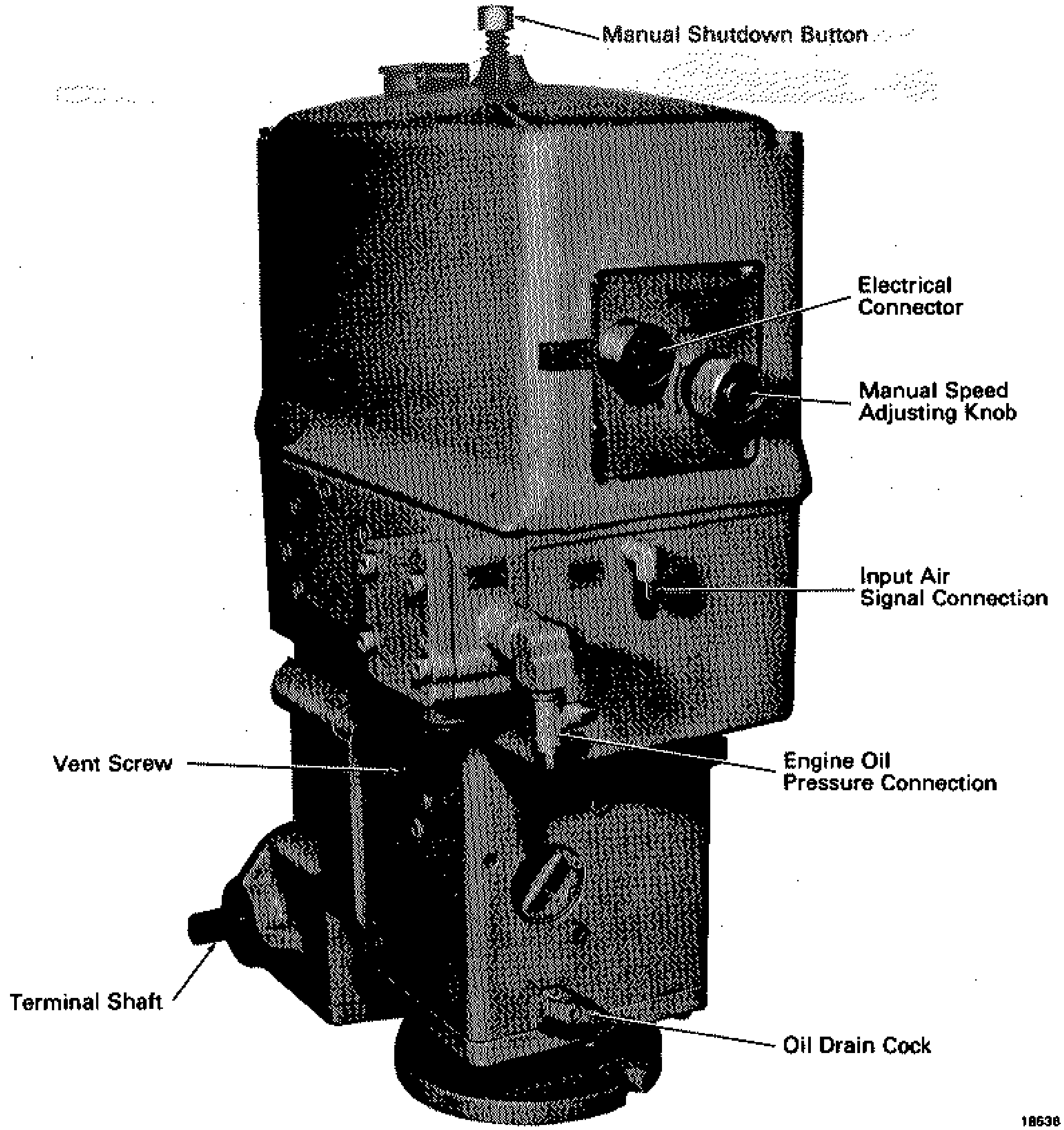


Fig. 12-4 - Model PGA Governor, 3/4 Rear view

system and power cylinder to raise the power piston and increase fuel. Raising the pilot valve plunger results in a flow of oil from the power cylinder and buffer system to the governor sump, and the power spring moves the power piston down to decrease the flow of fuel to the engine.

The flow of oil in the buffer system, in either direction, carries the buffer piston in the direction of flow, compressing one of the springs and relieving the other.

This creates a slight pressure differential of the oil on opposite sides of the piston. The higher oil pressure is on the side opposite the compressed spring. These differential oil pressures are directed above and below the compensating land on the pilot valve plunger, assisting in re-centering the plunger when a fuel correction is made.

NOTE

Every time a governor is installed on an engine the injector rack setting should be checked.

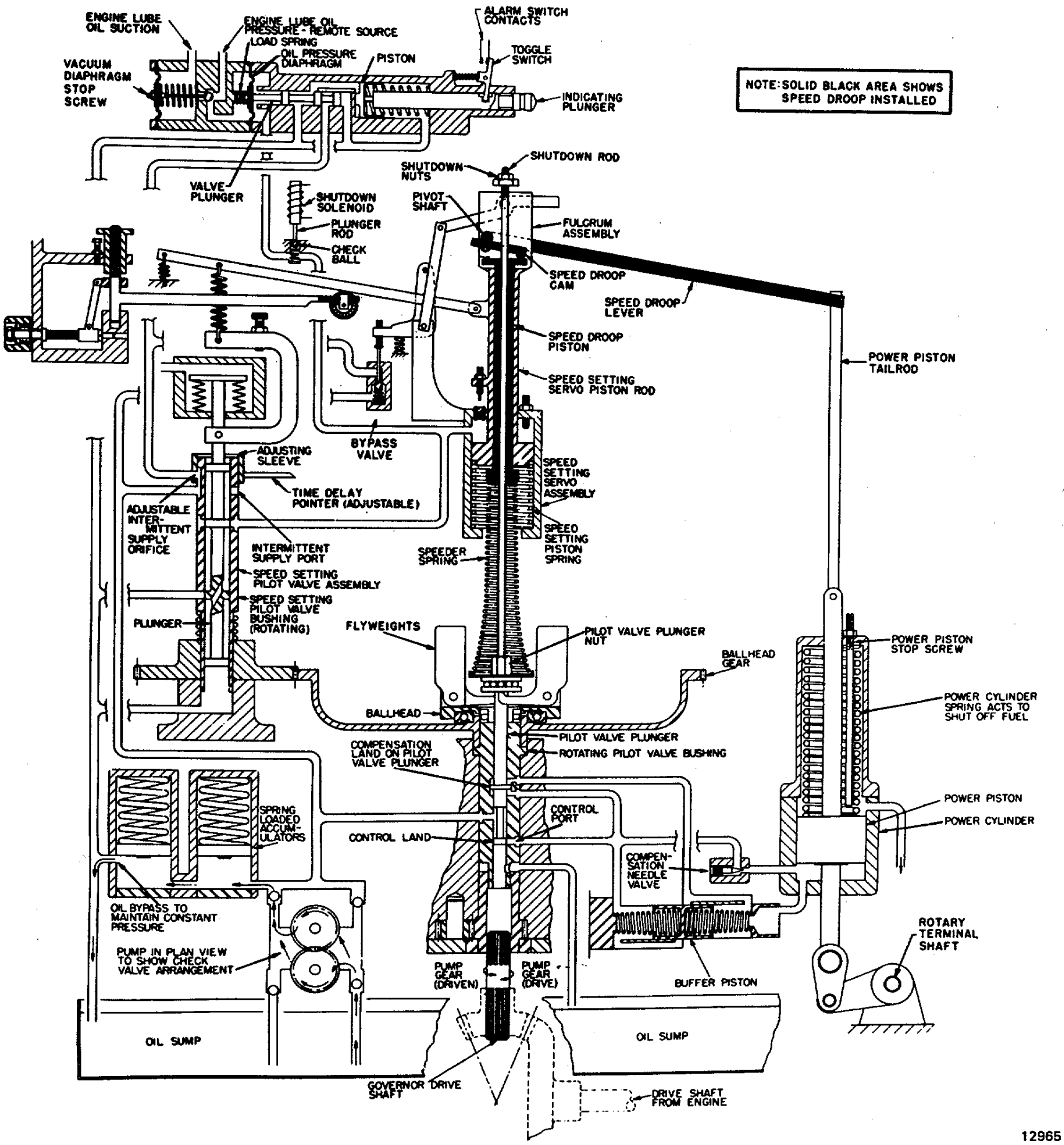


Fig. 12-5 - PGA Governor Schematic diagram

SPEED INCREASE

When the governor speed setting is increased, speeder spring pressure is applied to the flyweight toes and the flyweights move in. This lowers the pilot valve plunger and opens the regulating port allowing oil under pressure into the buffer system. The buffer piston moves to the left and transfers an equal amount of oil to the power cylinder forcing the power piston up, increasing the fuel supply to the engine.

Simultaneously with the movement of the power piston and buffer piston, the differential oil pressures on opposite sides of the buffer piston are transmitted above and below the compensating land on the pilot valve plunger. The higher pressure on the lower side of the compensating land will increase until the pilot valve plunger covers the regulating port and the flyweights return to a vertical position. As soon as the regulating port is covered, the power piston will stop at a new position corresponding to the increased amounts of fuel needed to operate the engine at the higher speed.

As the centrifugal force of the flyweights increases to a higher value with engine acceleration, the oil pressure on the lower side of the compensating land is reduced to zero by the equalization of the oil pressures in the buffer system, through the compensating needle valve. If the needle valve is correctly adjusted, the oil pressures will equalize at the same rate as the increase in the centrifugal force of the flyweights, and the flyweights will remain in a vertical position. The engine will now be running at a higher speed with an increased fuel setting.

SPEED DECREASE

When the governor speed setting is decreased, speeder spring pressure on the flyweight toes is released and the flyweights move out. This raises the pilot valve plunger and opens the regulating port allowing oil to flow from the buffer system to the governor oil sump. The reduced oil pressure in the buffer system allows the power spring to expand, forcing the power piston down and decreasing the fuel supply to the engine.

As the power piston moves in the direction of the oil flow from power cylinder to pilot valve, the right-hand buffer spring is compressed and the left-hand spring is relieved. The trapped oil pressure on the left side of the buffer piston is higher than the pressure on the right side.

Simultaneously with the movement of the power piston and buffer piston, the differential oil pressures are transmitted above and below the compensating land on the pilot valve plunger. The higher pressure on the upper side of the compensating land will increase until the pilot valve plunger covers the regulating port and the flyweights return to a vertical position. As soon as the regulating port is covered, the power piston will stop at a new position corresponding to the reduced amount of fuel needed to operate the engine at a decreased speed.

As the centrifugal force of the flyweight decreases with engine deceleration, the oil pressure on the upper side of the compensating land is reduced to zero by the equalization of the oil pressures in the buffer system, through the compensating needle valve. If the needle valve is correctly adjusted, the oil pressures will equalize at the same rate as the decrease in the centrifugal force of the flyweights, and the flyweights will remain in a vertical position. The engine will now be running at a lower speed with a reduced fuel setting.

PNEUMATIC SPEED SETTING

DESCRIPTION

The precise pneumatic speed setting mechanism, Figs. 12-6 and 12-7, is a force-bellows system, consisting of a bellows assembly, speed setting pilot valve, speed setting servo, and a restoring system for the speed setting pilot valve.

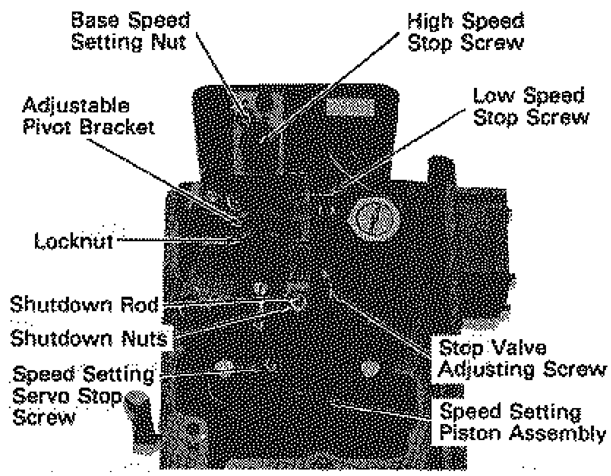


Fig. 12-6 - Speed Setting Components

Governor speed setting is determined by servo piston compression of the speeder spring. Therefore, to change the speed setting requires repositioning the servo piston.

The speed setting pilot valve plunger controls the flow of oil to and from the area above the piston. When the pilot valve plunger is depressed to uncover the regulating port, oil under pressure flows to the speed setting servo pushing the piston down, compressing the speeder spring, and increasing the governor speed setting. When the pilot valve plunger is raised, oil flows from the servo to the governor oil sump, the piston is raised by the servo spring, and the governor speed setting is decreased.

The air pressure input signal is directed to the bellows assembly, which senses changes in the signal air pressure. The bellows is mechanically connected to the pilot valve plunger and movement of the bellows, caused by changes in the signal air pressure, displaces the pilot valve plunger to change the speed setting. When the bellows receives a constant input signal, the downward force on the pilot valve plunger is counterbalanced by the lifting force of the restoring spring attached to the upper end of the pilot valve plunger.

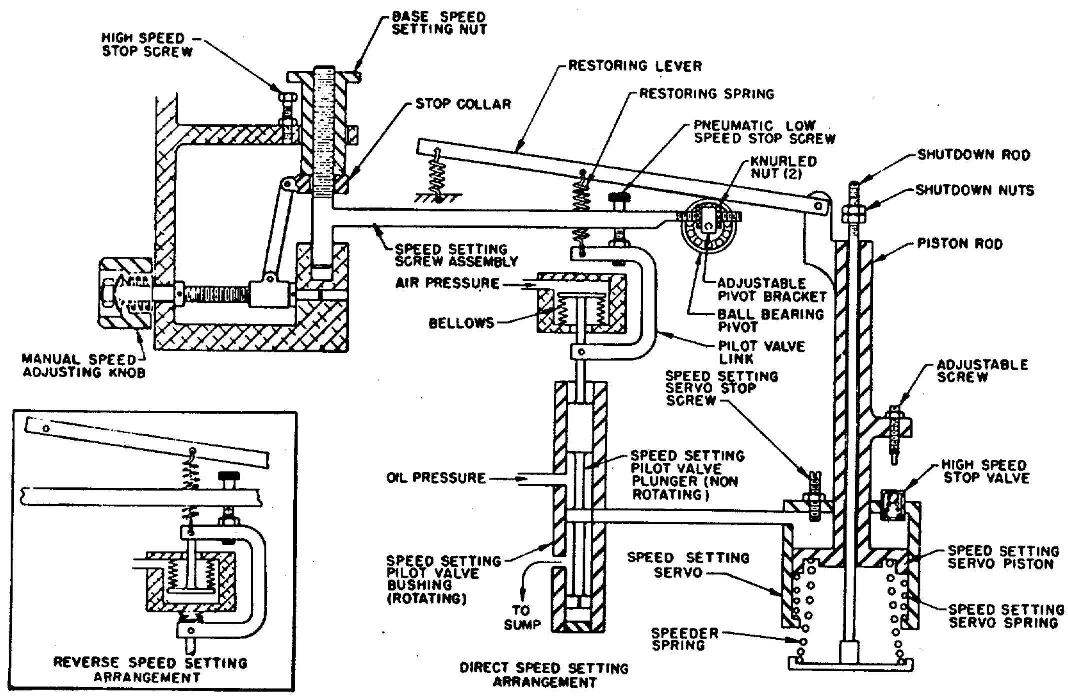


Fig. 12-7 - Pneumatic Speed Setting, Schematic Diagram

One end of the restoring spring is attached to an extension at the upper end of the speed setting servo piston rod. A spring is attached to the other end which pulls the lever down to maintain contact with a ball bearing pivot. Therefore, as the servo piston moves down, the restoring lever turns on top of the ball bearing pivot and increases the "lifting" force of the restoring spring. When the net increase in the "lifting" force of the restoring spring equals the increase in downward force resulting from the increased pressure signal, the pilot valve plunger will return to a center position. With the pilot valve plunger centered, oil flow to the servo is stopped and the servo piston retains its new position.

A decrease in the air pressure signal permits the restoring spring to lift the pilot valve plunger. This releases oil from the top of the servo piston allowing the piston to rise and lessen the loading on the speeder spring, decreasing the governor speed setting. The restoring lever moves up decreasing the lifting force of the restoring spring. When the servo piston moves far enough for the decrease in force of the restoring spring to equal the decrease in force resulting from the reduced air signal, the pilot valve plunger will return to its centered position. Oil can no longer escape from the servo and the servo piston will stop moving.

NOTE

Except while speed setting changes are being made, the pilot valve plunger and bellows assembly assume the same positions regardless of the air signal pressure.

The change in force of the restoring spring for a given movement of the servo piston is dependent upon the position of the ball bearing pivot against which the restoring spring is held. Moving the adjustable pivot bracket towards the servo decreases the speed range resulting from a given input signal range. Moving the pivot bracket away from the servo increases the speed range for a given input signal range.

REVERSE SPEED SETTING

The "reverse" speed setting schematic for governors in which the speed setting is lowered as signal pressure increases differs but slightly from the "direct" speed setting arrangement. The differences are shown in the inset of Fig. 12-7: (1) the bellows housing and bellows assembly are turned upside down so that the air signal raises rather than lowers the speed setting pilot valve plunger, and (2) a spring, acting in the direction to lower the pilot valve plunger, is placed between the bellows housing and pilot valve link. The loading spring on the left end of the restoring lever is omitted in reverse governors since the spring under the bellows housing has the same effect.

Except during a speed setting change, the downward force of the spring under the bellows housing is equal to the combined upward forces of the restoring spring and the air pressure acting upon the bellows assembly. A change in air signal pressure disturbs this balance and results in a speed setting change.

Consider the effect of an increase in signal pressure. The speed setting pilot valve plunger is raised, oil escapes from the speed setting servo, and the servo piston moves up. The restoring lever turns on the ball bearing pivot lowering the free end of the lever and reducing the lifting force of the restoring spring. When the decrease in upward force of the restoring spring equals the increase in upward force resulting from the higher air pressure on the bellows, the speed setting pilot valve plunger will be recentered.

The various movements would be in the opposite direction were the air signal decreased. The decrease in the upward force of the bellows would be offset by the increase in the lifting force of the restoring spring as the servo piston moves down to increase the speed setting.

Governors with "reverse" speed setting will go to maximum speed setting if the air signal is lost.

MAINTENANCE

Conditions other than governor malfunction may cause variations in engine speed. The following checks should be made before concluding that the speed setting mechanism requires adjustment.

1. Check the load on the engine. A fluctuating load will cause a variation in speed.
2. Check engine for proper firing of all cylinders.
3. Check for slack or binding in injector rack linkage which would cause irregular fuel supply to the engine.

It is recommended that the governor be placed on a suitable test stand to perform maintenance adjustments and settings.

SPEED SETTING SERVO STOP SCREW

The speed setting servo stop screw is adjusted to limit the upward movement of the servo piston when the governor shuts down. This is done to minimize the cranking required when the engine is restarted. The stop screw is set and locked to limit the servo piston travel to 3/64" above the point at which low governor speed setting is reached.

SETTING GOVERNOR SPEEDS

"DIRECT" SPEED SETTING

1. Set manual speed adjusting knob at minimum speed position (turn fully counterclockwise) while making pneumatic speed settings.
2. Admit minimum control air pressure signal to bellows chamber; adjust base speed setting nut to obtain the specific minimum speed (turn nut counterclockwise to increase speed).

NOTE

Pneumatic low speed stop screw must not touch restoring lever at this time.

3. Increase control air pressure towards maximum being careful not to overspeed unit. Be sure adjustable screw in lug attached to servo piston rod does not unseat the high speed stop valve.

If the desired high speed is reached before the air signal is increased to maximum, move the pivot bracket with ball bearing pivot towards the speed setting servo. If the desired high speed is not reached with the specified maximum air signal, move the pivot bracket and ball bearing pivot away from the speed setting servo.

Move the pivot bracket and ball bearing pivot in this manner. Loosen the socket head screw holding the ball bearing to the pivot bracket; loosen the knurled nut on the side of the pivot bracket towards which the bracket is to be moved. Now use the other knurled nut to move the pivot bracket; tighten the socket head screw and knurled nuts.

4. After each adjustment of the pivot block, it is necessary to reset the base speed setting nut at minimum control pressure.

Continue to adjust the pivot block until low speed is obtained with low control air pressure and maximum speed is reached just as the maximum control pressure is reached.

(Be sure speed begins to increase as the pressure signal rises above minimum pressure.)

5. Admit maximum control air pressure and allow governor to go to maximum speed. Position the adjustable screw in the lug of the piston rod to just open the high speed stop valve if control air pressure is increased further.

6. With minimum air signal and the governor at minimum speed, lift up on the shutdown rod to take out the slack or lost motion being careful not to raise the governor main pilot plunger so that the governor begins to shut down; set the lower shutdown nut 1/32" above the top of the speed setting piston rod and lock in place with the upper nut.

   Turn the speed setting servo stop screw down until it contacts the top of the servo piston; back off three turns and lock with the locknut.

   a. If the governor IS to go to shutdown when the air signal is lost, set the pneumatic low speed stop screw so that the restoring lever does not contact the stop screw as the governor shuts down.

   b. If the governor is *NOT* to go to shutdown when the air signal is lost, set the pneumatic low speed stop screw to just contact the restoring lever. Lock with the locknut.

7. With the air signal shut off, turn manual speed setting knob clockwise to increase governor speed. Set the high speed stop screw to stop the downward movement of the base speed setting nut at high speed.

"REVERSE" SPEED SETTING

1. Adjust the high speed stop screw so that the underside of the screw head projects approximately 3/16". Turn the manual speed adjusting knob to maximum (fully clockwise) position.

2. Admit maximum air pressure signal to bellows chamber. Adjust base speed setting nut to obtain specified minimum speed (turn nut counterclockwise to increase speed).

NOTE

Pneumatic low speed stop screw must not touch restoring lever at this time.

3. Slowly decrease control air signal pressure towards minimum being careful not to overspeed unit. Be sure adjustable screw in lug attached to servo piston rod does not unseat the high speed stop valve.

   If the desired high speed is reached before the air signal is decreased to minimum, move the pivot bracket with ball bearing pivot towards the speed setting servo. If the desired high speed is not reached with the specified minimum air signal, move the pivot bracket and ball bearing pivot away from the speed setting servo.

   Move the pivot bracket in this manner. Loosen the knurled nut on the side of the pivot bracket towards which the bracket is to be moved. Now use the other knurled nut to move the pivot bracket; tighten the socket head screw and locknuts.

4. After each adjustment of the pivot block, apply maximum control air pressure and, if necessary, use the base speed setting nut to reset low speed.

   Continue to adjust the pivot block until minimum speed is obtained with maximum pressure and maximum speed is reached just as low signal pressure is reached. Be sure speed begins to increase as the pressure signal begins to decrease from maximum.

5. After setting speeds pneumatically, admit minimum control air pressure (governor will go to maximum speed); turn the manual speed adjusting knob fully counterclockwise.

6. Shut off the control air signal. Adjust the base speed setting nut to obtain the specified low speed (turn nut counterclockwise to increase speed).

7. Admit minimum control air pressure to the bellows assembly. Turn the manual speed adjusting knob clockwise and increase governor speed to the specified maximum speed. (If necessary, lower the high speed stop screw under the head of the base speed setting nut.)

   Bring the head of the stop screw into contact with the adjusting nut. Turn the manual knob an additional half turns to confirm that speed does not go above specified maximum; if necessary readjust the stop screw.

8. Turn manual adjusting knob fully counterclockwise; turn off air signal. Use manual knob to increase governor speed to specified maximum. Set adjustable screw over the high speed stop valve to unseat the valve if the manual knob is turned to increase speed further.

9. Admit maximum air signal pressure, and bring the pneumatic low speed stop screw into contact with the restoring lever.

MANUAL SPEED SETTING

DESCRIPTION

A manual speed adjusting knob, Fig. 12-7, can be used to adjust the speed setting to any point within the normal speed range when the air signal is not available.

When there is no air signal, the restoring spring holds the low speed stop screw in contact with the restoring lever. This mechanically connects the pilot valve plunger to the movement of the restoring lever. The grounded loading spring, which keeps the restoring lever in contact with the ball bearing pivot, continually presses the lever down on the bearing and speed setting screw assembly. Turning the manual speed adjusting knob clockwise (to raise governor speed setting) lowers the stop collar under the base speed nut. The speed setting screw assembly and ball bearing pivot will move down with the stop collar until the base speed setting nut contacts the high speed stop screw. The restoring lever also moves down pressing against the low speed stop screw causing the pilot valve plunger to be lowered. This allows oil flow to force the servo piston down, increasing the governor speed setting. The downward movement of the servo piston raises the restoring lever which centers the pilot valve plunger.

Turning the manual speed adjusting knob counterclockwise raises the speed setting screw assembly and ball bearing pivot. This lifts the restoring lever and speed setting pilot valve. As the servo piston moves up to decrease the governor speed setting, the restoring lever movement centers the pilot valve plunger.

GOVERNOR COMPENSATION

DESCRIPTION

The compensating mechanism, Fig. 12-5, prevents the engine from racing or hunting by arresting the movement of the power piston after it has traveled a sufficient amount to give the desired speed. The compensating mechanism includes the integral compensating receiving piston, buffer piston and springs, and compensating needle valve.

When the engine is started the first time or after installation of a new or reconditioned governor or one that has been drained and cleaned and new oil added, the governor will require compensation adjustment. This is necessary to purge the governor oil system of trapped air.

MAINTENANCE

COMPENSATION ADJUSTMENT

1. See that the governor oil is at the proper level in the sight glass. Then start the engine, operating at idle speed.

2. Open the compensating needle valve, Fig. 12-3, several turns. Loosen the vent plug, Fig. 12-4, several turns, but do not remove the plug.

3. The engine will hunt and surge, and air will bleed from the system at the vent plug. When oil only flows from the vent plug, the system is free of air, and the compensating needle valve should be closed slowly until the hunting condition stops or is lessened. Allow the engine to run until normal operating temperature is reached. Tighten the vent plug to prevent oil leakage, and add the oil necessary to obtain the proper level in the governor.

4. After normal temperature has been reached, again open the compensating needle valve and allow the engine to hunt. Then close the needle valve until hunting stops. The needle valve will be open approximately one-quarter to three turns depending upon the engine characteristics.

5. Test the governor stability by manually changing the engine speed to observe governor recovery. If the engine returns to a steady speed, the compensating adjustment is satisfactory. If hunting is resumed, close the compensating needle valve slightly and test again.

6. Keep the compensating needle valve open as far as possible to prevent sluggishness and still maintain even engine operation. After compensation is made, it should not require another adjustment, unless a permanent temperature change effects the viscosity of the governor oil.

SPEED DROOP

DESCRIPTION

The speed droop provision, Fig. 12-5, is not a basic part of the PGA governor. However, because of its frequent application permitting governor interchangeability between parallel engine installations and single engine installations, a description of the system is included in this manual. Speed droop is incorporated in the governor to provide positive control to lower speed as load is increased. This feature provides load division between engines for parallel operation of engines driving a common gear connected to a propeller.

The speed droop piston is in direct contact with the speeder spring. One end of the speed droop lever is attached to the power piston tailrod. The other end is attached to the pivot shaft in the fulcrum assembly, which is on the end of the servo piston rod. If the servo piston moves, the speed droop lever pivots about the tailrod connection, or about the pivot shaft if the power piston moves. Movement of either end of the lever turns the pivot shaft and positions the speed droop cam which moves the speed droop piston to change the loading on the speeder spring.

As the load is increased, the power piston moves up, raising the cam and decreasing the load on the speeder spring, causing the governor and engine to run slower. If the load is decreased, the power piston moves down, lowering the cam and increasing the load on the spring, causing the governor and engine to run faster.

The change in speed setting for a given power piston movement depends upon the position of the cam with respect to the pivot shaft. Moving the cam surface away from the shaft increases the droop. Moving the cam surface towards the shaft decreases the droop.

ROTARY TERMINAL SHAFT

The rotary terminal shaft, Fig. 12-8, provides an efficient connection between the governor and the fuel injector rack linkage. By means of a lever attached to the terminal shaft, and a connecting link between the lever and the governor power piston rod, the reciprocating movement of the power piston is converted to rotary movement at the terminal shaft. The fuel injector rack linkage is connected to one end of the terminal shaft and the rotary movement of the shaft is transmitted to the injector rack linkage, which in turn controls the amount of fuel being injected into the cylinders.

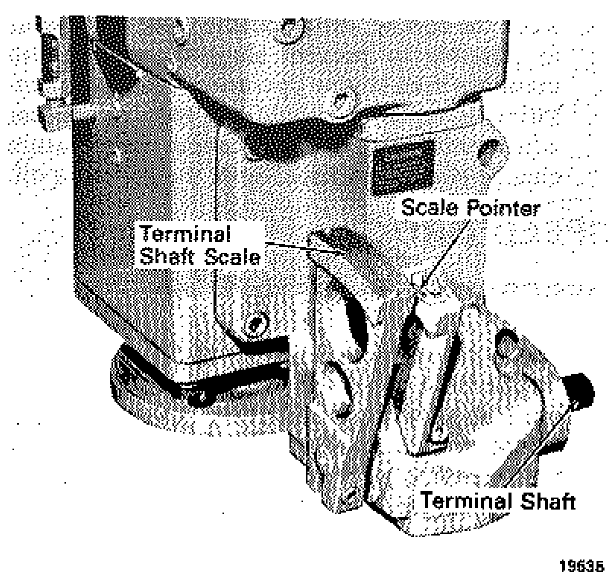


Fig. 12-8 Rotary Terminal Shaft And Scale

On the other end of the terminal shaft is a segment arm on which a graduated scale plate, Fig. 12-8, is mounted. The position of the scale, in relation to the fixed scale pointer, indicates the fuel injector rack length in inches.

MANUAL SHUTDOWN SWITCH

The manual shutdown switch which is operated by the button, Fig. 124, on top of the governor cover is an integral part of the governor. However, functioning as a protective device for the engine, it is described in Section 13 of this manual.

SHUTDOWN SOLENOID

The shutdown solenoid, Fig. 12-5, is also an integral part of the governor which operates in conjunction with the manual shutdown provision as an engine protective device, and is described in Section 13 of this manual.

LOW OIL PRESSURE ALARM

In addition to the engine shutdown provisions in the governor, an alarm device, Fig. 12-5, is incorporated in the governor. This device operates on the basis of a low oil pressure condition in the engine. It operates a low oil pressure alarm switch. Description and maintenance procedures are contained in Section 13 of this manual under the heading of Protective Devices.

UG-8 GOVERNOR

DESCRIPTION

Main components of the UG-8 governor, Fig. 12-9, are: a speed adjusting mechanism or synchronizer; a speed sensing group, consisting of the speeder spring, speed setting piston, and flyweights; fuel adjustment control group, consisting of power piston and spring; compensating mechanism consisting of power piston pilot valve, compensating piston, and compensating linkage; a speed droop system; and an oil system for component operation and lubrication consisting of oil pump, oil sump, and accumulators.

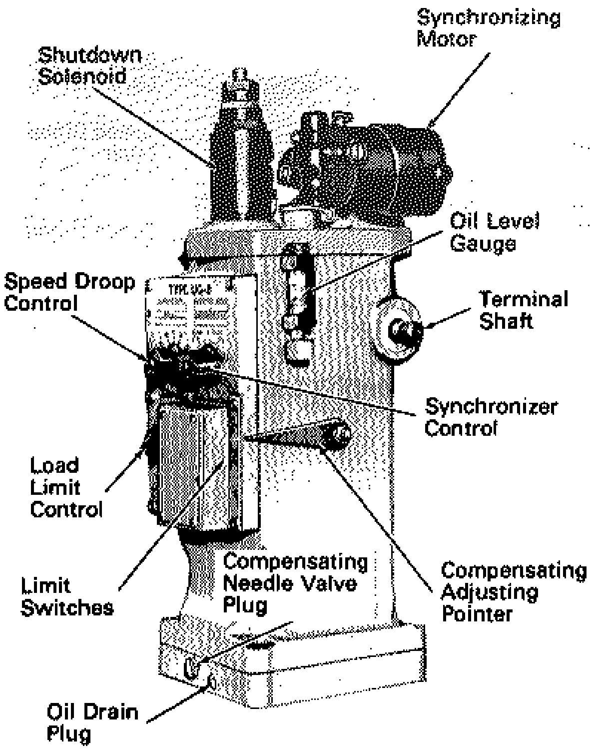


Fig. 12-9 - UG-8 Governor

OPERATION

Basic governor operation, reflecting changes in engine speed setting and the resulting governor reaction to regulate the fuel control mechanism, is explained below. Refer to Fig. 12-10 for a schematic arrangement of the components. The governor drive shaft extends through the governor base into the pump drive gear, which is directly connected to the rotating pilot valve bushing. The flyweight head is attached to the top of the bushing, providing a direct drive from the engine to the flyweights. When governor speed setting and engine speed are the same, the flyweights will be in a vertical position and the pilot valve plunger will cover the regulating ports in the pilot valve bushing. When the engine is "on speed" with a steady load, the pilot valve plunger will be slightly off center to supply enough oil through the regulating port to stabilize the power piston against the power spring.

The governor oil pump supplies oil to the accumulators and pilot valve bushing, with the excess oil (at maximum pressure) being bypassed from the accumulator to the governor oil sump. Power piston movements are transmitted by the piston rod through the rotary terminal shaft to the engine fuel linkage. Regulated oil pressure under the power piston raises the piston to increase fuel, and the power spring above the piston lowers the piston to decrease fuel.

LOAD INCREASED

Assume the load on the engine is increased, resulting in a decrease in speed. As speed decreases the flyweights move in, allowing the speeder spring to lower the speeder rod and the inner end of the floating lever, thus lowering the pilot valve plunger and uncovering the control port of the pilot valve bushing. The opened control port admits pressure oil to the bottom of the power cylinder. Since the bottom area of the power piston is greater than the top area, oil pressure will move the piston up and rotate the terminal shaft in the direction to increase fuel.

As the power piston moves up rotating the terminal shaft, the actuating compensating piston moves down and forces the receiving compensating piston up, compressing the lower compensating spring and raising the outer end of the floating lever and pilot valve plunger. Movement of the power piston, terminal shaft, actuating compensating piston, receiving compensating piston, and pilot valve plunger continues until the control port in the pilot valve bushing is covered by the control land on the plunger. As soon as the control port is covered, the power piston and terminal shaft are stopped at a position corresponding to the increased fuel needed to run the engine at normal speed under increased load.

As the actual unit speed returns to normal, the flyweights and speeder rod return to normal position. The receiving compensating piston is returned to normal position by the compensating spring at the same rate as the flyweights, thus keeping the control port covered by the control land on the pilot valve plunger. Flow of oil through the compensating needle valve determines the rate at which the receiving compensating piston is returned to normal. At the completion of this cycle, flyweight, speeder rod, pilot valve plunger and receiving compensating piston are in normal positions; power piston and terminal shaft are stationary at a position corresponding to increased fuel necessary to run the engine at normal speed under increased load.

LOAD DECREASED

Assume that load on the engine is decreased and speed increases. As the speed increases, the flyweights move out raising the speeder rod and the

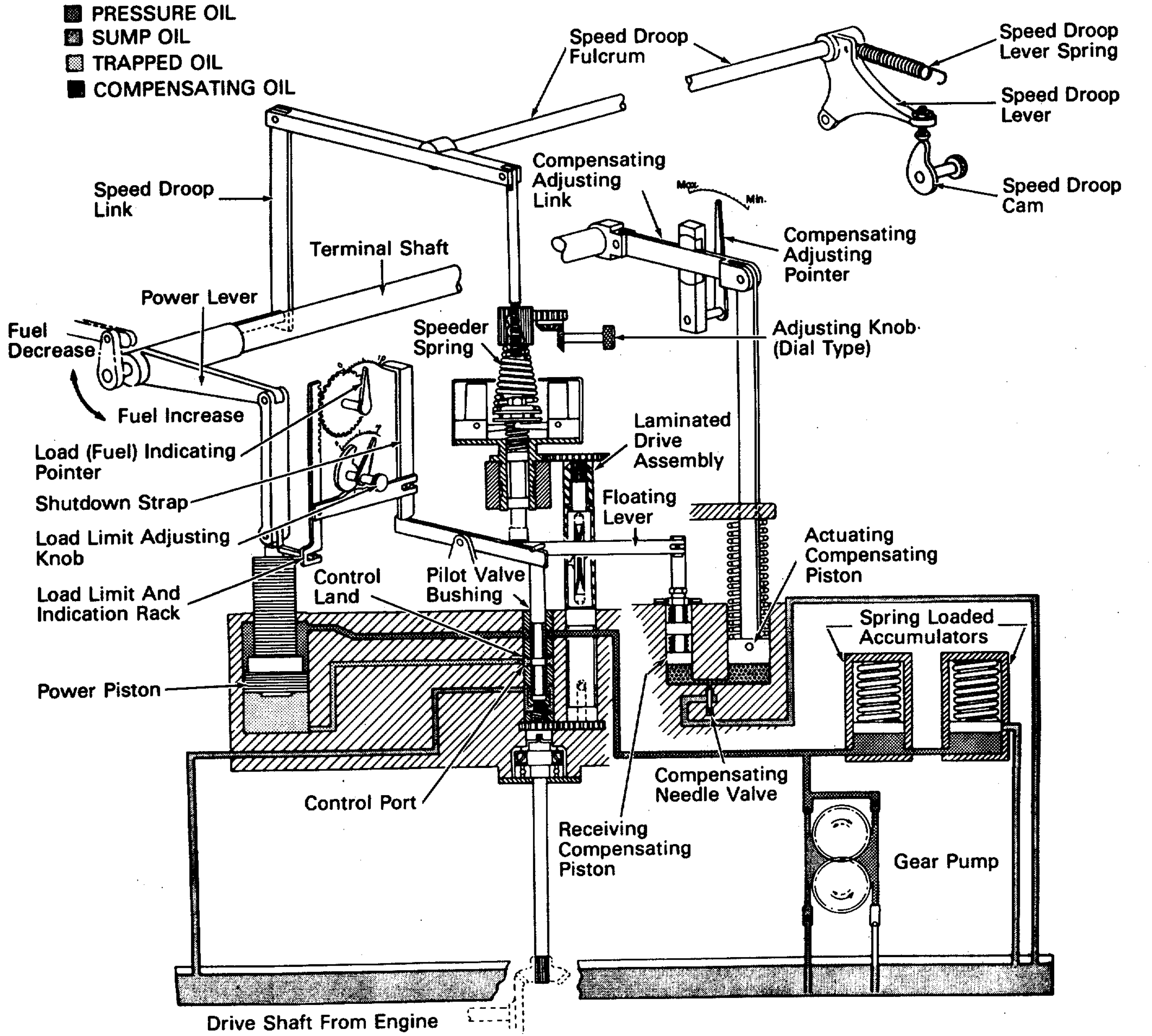


Fig. 12-10 - UG-8 Governor Schematic

inner end of the floating lever, thus raising the pilot valve plunger and uncovering the control port in the pilot valve bushing. As the control port is opened, the bottom of the power cylinder is opened to sump and the oil pressure on the top of the power cylinder forces the power piston down and rotates the terminal shaft in the direction to decrease fuel.

As the power piston moves down, rotating the terminal shaft, the actuating compensating piston moves up and draws the receiving compensating piston down, compressing the upper compensating spring and lowering the outer end of the floating lever and the pilot valve plunger. Movement of the power piston, actuating compensating piston, receiving compensating piston, and pilot valve plunger continues until the control port in the pilot valve bushing is covered by the control land on the pilot valve plunger. As soon as the control port is covered, the power piston and terminal shaft are stopped at a position corresponding to decreased fuel needed to run the engine at normal speed under decreased load.

As speed decreased to normal, the flyweights return to normal position lowering the speeder rod to normal position. The receiving compensating piston is returned to normal position by the compensating spring at the same rate as the flyweights, thus keeping the control port in the pilot valve bushing covered by the control land on the pilot valve plunger. Flow of oil through the compensating needle valve determines the rate at which the receiving compensating piston is returned to normal.

At the completion of this cycle, the flyweights, speeder rod, pilot valve plunger and receiving compensating piston are in normal positions; the power piston and the terminal shaft are stationary at a position corresponding to decreased fuel necessary to run the prime mover at normal speed under decreased load.

In actual operation, the events described occur almost simultaneously, rather than step by step.

SPEED DROOP

Speed droop provides positive control to lower engine speed as load is increased. It allows load division between engines for parallel operation of engines driving the same shaft, or paralleled in an electrical system.

Speed droop is incorporated in the governor through a linkage which varies the compression of the speeder spring as the terminal shaft rotates. Increased fuel reduces spring compression, reduces the governor speed setting accordingly, and the governor will gradually reduce its speed as load is applied. This relationship between load and speed acts as a resistance to load changes when the engine is interconnected with other units either mechanically or electrically.

As speed droop is reduced toward zero the unit becomes able to change load without changing speed. Units running alone should be set at zero droop and interconnected units should be run at the lowest droop setting that will give satisfactory load division.

LOAD LIMIT

The load limit hydraulically limits the load that can be put on the engine by restricting the angular terminal shaft rotation of the governor, and consequently, the quantity of fuel supplied to the engine. The control may also be used for shutting the engine down by turning it to zero.

CAUTION

Do not attempt to manually operate injector linkage with hand control lever unless the load limit knob is set at "10."

COMPENSATION

The compensating mechanism prevents the engine from racing or hunting by arresting the movement of the power piston after it has traveled a sufficient amount to give the desired speed. When the engine is started the first time or after installation of a new or reconditioned governor or one that has been drained and cleaned and new oil added, the governor will require compensation adjustment. This is necessary to purge the governor oil system of trapped air.

MAINTENANCE

Conditions other than governor malfunction may cause variations in engine speed. The following checks should be made before concluding that the speed setting mechanism requires adjustment.

1. Check the load on the engine. A fluctuating load will cause a variation in speed.

2. Check engine for proper firing of all cylinders.

3. Check for slack or binding in injector rack linkage which would cause irregular fuel supply to the engine.

COMPENSATING ADJUSTMENT

After the temperature of the engine and the oil in the governor have reached their normal operating temperatures, the compensation should be adjusted without load on the engine as follows:

1. Loosen the nut holding the compensating adjusting pointer and set the pointer at its extreme upward position. (Max.)

2. Remove the compensating needle valve plug and open the compensating needle valve three or more turns with a screwdriver.

CAUTION

Be sure that the screwdriver fits into the shallow slot of the compensating needle valve and not into the deep slot located at right angles to the shallow screwdriver slot.

3. Allow the engine to hunt and surge for about one-half minute to bleed trapped air from the governor oil passages. Loosen nut holding the compensating adjusting pointer and set the pointer at the extreme lower (Min.) position.

4. Gradually close the needle valve until hunting just stops. Check the amount of needle valve opening by closing the valve completely, noting the fraction of a full turn required to close the valve.

5. Re-open the valve to the point at which hunting stopped. Test the compensating adjustment by manually disturbing the engine speed. If the governor stops hunting with the needle valve open more than 1/8 turn the adjustment is satisfactory.

6. If hunting did not stop with the needle valve open 1/8 to 1/4 turn, then loosen the nut holding the compensating adjusting pointer and raise the pointer two marks above the minimum setting.

7. Repeat Steps 4, 5, and 6 if necessary until the needle valve setting is satisfactory.

NOTE

It is desirable to have as little compensation as possible. Closing the needle valve further than necessary will make the engine slow to return to normal speed after a load change and too much compensation will cause excessive speed change after load change.

8. After correct adjustment is obtained, replace the compensating needle valve plug.

9. Check governor operation under load. Occasionally, slight readjustments are necessary for best operation under load.

ROTARY TERMINAL SHAFT

The rotary terminal shaft provides an efficient connection between the governor and the fuel injector rack linkage. By means of a lever attached to the terminal shaft, and a connecting link between the lever and the governor power piston rod, the reciprocating movement of the power piston is converted to rotary movement at the terminal shaft. The fuel injector rack linkage is connected to one end of the terminal shaft and the rotary movement of the shaft is transmitted to the injector rack linkage, which in turn controls the amount of fuel being injected into the cylinders.

SYNCHRONIZING MOTOR

The Synchronizing motor permits changing the governor speed setting from a remote position. It is used to match the frequency of an alternator with that of other units before synchronizing, or to change load distribution after synchronizing. The motor used is a split field, series wound, reversible type.

A friction type coupling is provided between the motor shaft and the synchronizer adjusting gear to allow the engine operator to adjust engine speed by turning the synchronizer control knob on the governor. Also included are two pairs of switch contacts which may be used for remote indications of maximum or minimum speed settings on the governor.

SHUTDOWN SOLENOID

In some installations, a shutdown solenoid is mounted on the top of the governor, which serves as a protective device. The shutdown solenoid is described in Section 13 of this manual.

EGB-P ACTUATOR

DESCRIPTION

The type EGB-P actuator, Fig. 12-11, is an electrically controlled, proportional output actuator with an integral backup mechanical (centrifugal) governor and is normally used with a Model 2301 integrating electrical control unit to form a complete governing system. The operation of the system as applied to a specific application will be covered in the appropriate Operating Manual. The actuator is physically mounted on the engine governor drive assembly and therefore will be considered as an engine component. The following paragraphs will provide descriptive and maintenance information as applies to the actuator only.

OPERATION

The EGB-P actuator is, in effect, two governors in one: an electric governor and a mechanical governor, each independently capable of positioning the output shaft. During normal operation, the electric governor portion of the actuator controls fuel to the engine. The mechanical governor portion controls the engine during starting and also functions as a backup governor to prevent runaway should the electrical control unit fail in such a manner as to call for maximum fuel. The speed of the mechanical governor is set approximately 5 percent higher than the electrical governor; when the speed reaches the level of the mechanical governor, this portion of the acutator will take over and control the engine. Speed can be reduced, if desired, by lowering the speed setting of the mechanical governor. Should the electric signal be interrupted or the electrical

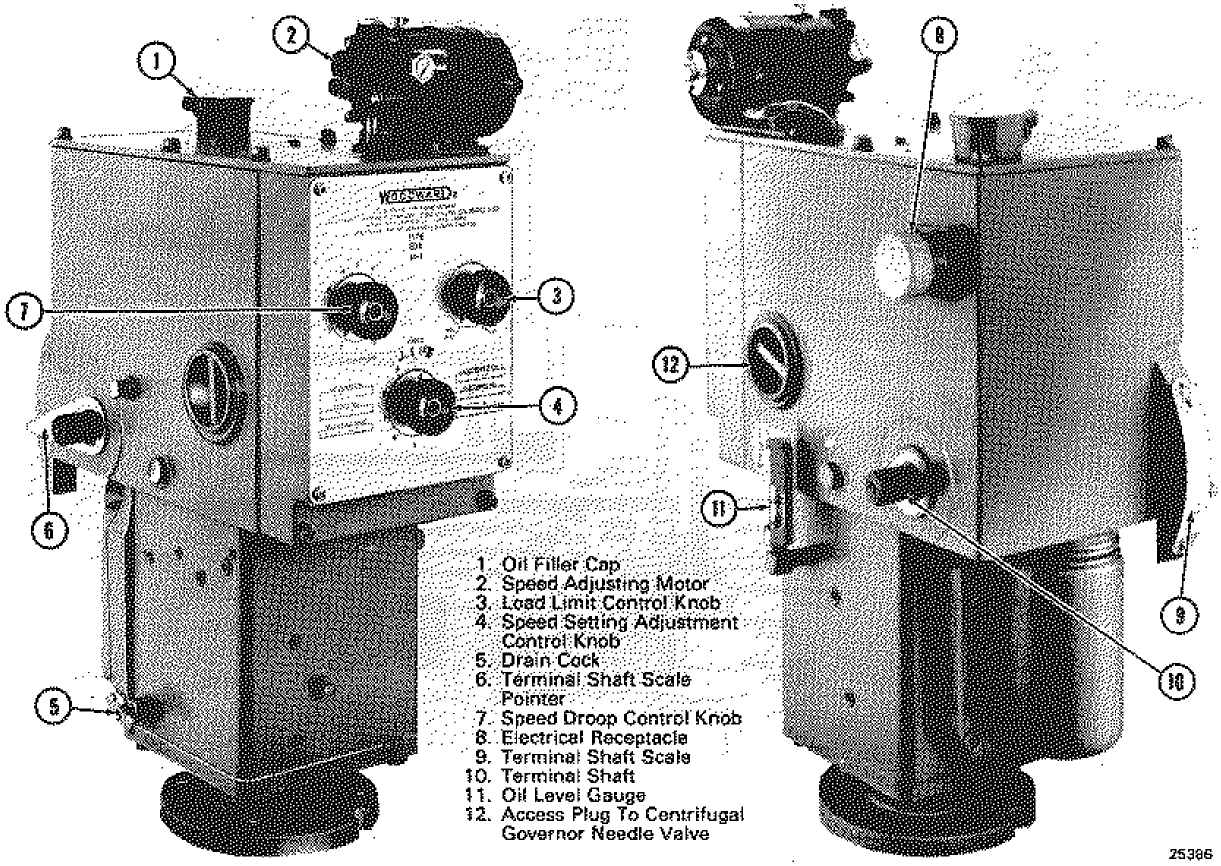


Fig. 12-11 - EGB-P Actuator

control unit fail in such a way as to emit a continuous signal calling for a decrease in fuel, the engine will shut down.

ELECTRIC GOVERNOR

Under normal operating conditions, the electric governor portion of the actuator will be controlling and the mechanical governor power piston will be at the top of its travel. Refer to Fig. 12-12 for schematic diagram and mechanical governor section.

Pressure oil for the electric and mechanical governor portions is provided by the sub-governor oil pump. The pump relief valve plunger, acting against the relief valve spring, maintains the oil pressure required in these sections. As this required oil volume is relatively small, no accumulator is used. The sub-governor oil pump operates in much the same way as the relay oil pump. The electric governor pilot valve plunger controls the flow of oil to and from its power piston. The pilot valve plunger is connected to a magnet which is spring-suspended in the field of a two-coil polarized solenoid. The output signal from the electrical control unit is applied to the polarized coil and produces a force, proportional to the current in the coil, which tends to pull the magnet - and pilot valve plunger - down. A combination of the restoring spring and centering spring force tends always to raise the magnet and balance pilot valve plunger. When the actuator is running under steady-state conditions, these opposing forces are equal and the pilot valve plunger is "centered" (i.e. the control land of the plunger exactly covers the control port in the pilot valve bushing). With the pilot valve plunger centered, no oil flows to or from the power piston.

If the signal from the electrical control unit decreases (due to an increase in engine speed or a decrease in unit speed setting), an unbalanced force results. The combination of the restoring spring and centering spring force, now relatively greater, raises the pilot valve plunger. Oil under the electric governor power piston is thus connected to sump. The oil pressure constantly applied to the upper side of the loading piston and power piston now forces

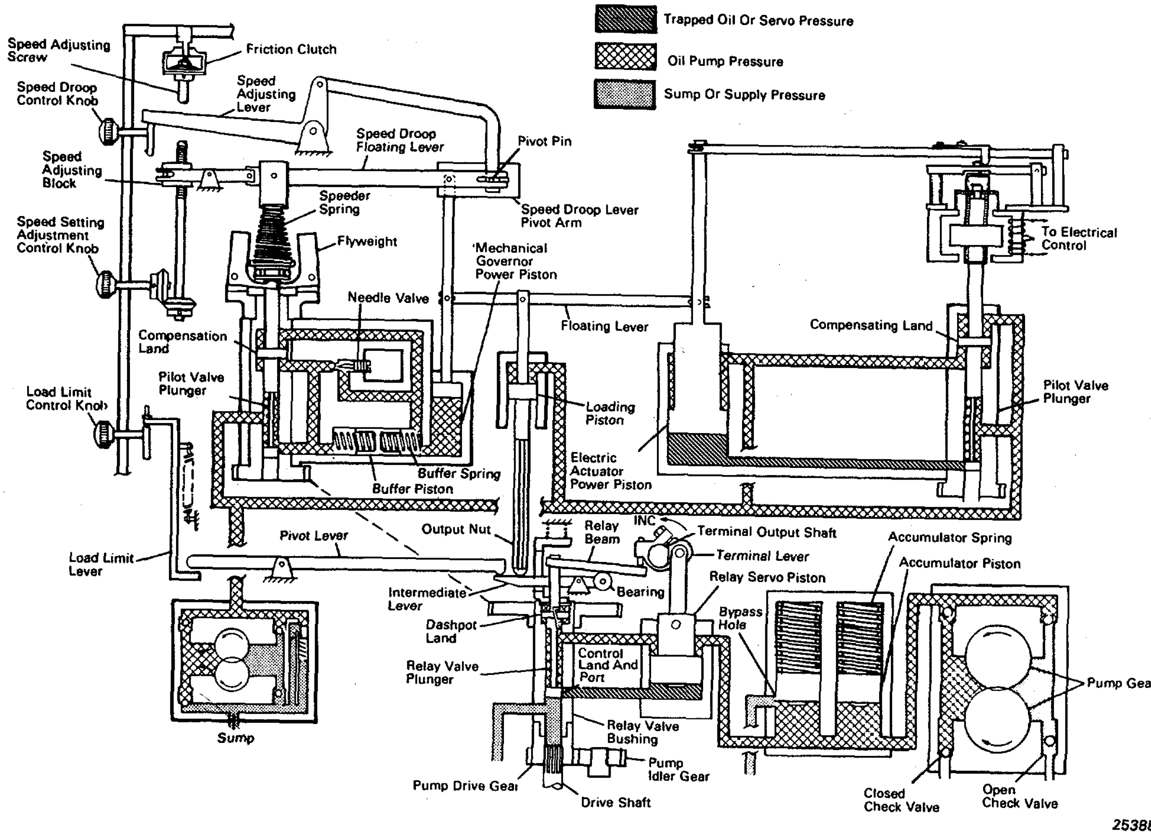


Fig. 12-12 - EGB- Actuator, Schematic Diagram

the pistons down as the floating lever pivots about its connection to the mechanical governor power piston. The loading piston rotates the terminal output shaft in the "decrease" direction.

As the electric governor power piston moves down, it lowers the left end of the first restoring lever. The clamping plate, attached to the first restoring lever, pushes down on the second restoring lever. The loading on the restoring spring is thereby increased and lowers the pilot valve plunger. The loading piston and electric governor power piston move down until the increase in restoring spring force is sufficient to offset the increased force resulting from the decrease in the electrical signal. When the pilot valve plunger is pushed back to its centered position, movement of the power piston, loading piston, and terminal shaft stop.

Thus it can be seen that the position of the terminal output shaft is proportional to the electric input signal to the actuator. If the electric input signal increases - due to a decrease in engine speed or an increase in actuator speed setting - similar movements would occur, but in the opposite directions. The pilot valve plunger would be lowered, pressure oil would flow to the underside of the power piston and push the piston up, the loading piston would be raised thereby rotating the terminal output shaft in the "increase" direction. At the same time, the upward movement of the power piston, acting through the restoring levers, decreases the restoring spring force so that the pilot valve plunger can be recentered to stop movement of the terminal output shaft.

MECHANICAL GOVERNOR

The mechanical governor controls the engine during starting and also functions as a backup governor to prevent runaway should the electrical control unit fail and call for maximum fuel. The mechanical governor pilot valve plunger controls the flow of oil to its power piston. If the plunger is centered, no oil flows through the pilot valve and the power piston is stationary. The greater of two opposing forces moves the pilot valve plunger: The speeder spring force tends to push it down; the centrifugal force developed by the rotating flyweights is translated into an upward force which attempts to raise the plunger. With the pilot valve centered, there is but one speed at which the centrifugal force of the flyweights is equal and opposite to the speeder spring force.

With the speed setting of the mechanical governor set slightly higher than the electric governor, the centrifugal force of the rotating flyweights is not sufficient to lift the pilot valve plunger to its centered position. Consequently, with the electric governor controlling, pressure oil is continually directed to the underside of the mechanical governor power piston to hold it up against its stop. It is for this reason that the power piston of the mechanical governor is up against its stop when the electric governor is controlling. With the actuator running on-speed with the mechanical governor controlling, the pilot valve plunger is centered. If a load is added to the engine, the governor speeds decrease. The pilot valve plunger is then lowered by the centrifugal force of the flyweights. Pressure oil flows to the buffer piston and moves it towards the power piston.

The oil displaced by the buffer piston forces the power piston upward, the loading piston is raised, and the terminal output shaft rotates in the direction to provide the additional fuel needed for the new load.

The movement of the buffer piston towards the power piston partially relieves the compression of the left buffer spring and increases the compression of the right buffer spring. The force of the right buffer spring tending to resist this movement results in a slightly higher oil pressure on the left side of the buffer piston than on the right. The pressure on the left of the buffer piston is transmitted to the underside of the compensation land of the pilot valve plunger; the pressure on the right of the buffer piston is fed to the upperside of the compensation land. The difference in pressures on the two sides of the compensation land produces a force which acts to push the pilot valve plunger back to its centered position.

When the terminal output shaft has been rotated far enough to satisfy the new fuel requirement, the force of the pressure differential on the compensation land plus the centrifugal force of the rotating flyweights will have recentered the pilot valve plunger, even though engine speed is not yet completely back to normal. The power piston - and terminal output shaft - movement is thereby stopped. The continued increase of speed to normal results in continued increase in the centrifugal force developed by the rotating flyweights. However, this increase of speed to normal does not cause the flyweights to lift the pilot valve plunger above center because the leakage of oil through the needle valve orifice equalizes the pressure above and below the compensation land at a rate proportional to the return of the engine speed to normal. Consequently, as the centrifugal force increases, the compensating force decreases.

With the pressures above and below the compensation and equalized, the buffer springs return the buffer piston to its normal, central position. Were the engine load to decrease, the resultant increase in governor speed would cause the flyweights to move outward and raise the pilot valve plunger. With the pilot valve plunger raised, the area to the left of the buffer piston would be connected to sump. The loading piston, continually being urged downward by oil pressure from the sub governor pump, would move down and force the power piston down. The movement would reduce the fuel to meet the new requirement. Again, differential pressure across the compensation land would assist in recentering the pilot valve plunger, and keep the pilot valve ports closed while speed decreases to normal.

The speed at which the mechanical governor controls the engine is determined by the loading or compression of the speeder spring which opposes the centrifugal force of the flyweights.

MECHANICAL GOVERNOR ACCESSORIES

Other than the basic governor components, the mechanical governor has additional features to aid operation when used in the power unit.

SPEED DROOP

Speed droop is used in mechanical governors to automatically divide and balance load between engines driving the same shaft or paralleled in an electrical system. (Speed droop is defined as the decrease in governor speed as its output connection to the engine fuel linkage moves in an increase direction. How far the governor speed decreases for a given stroke, determines the amount of droop.) Speed droop is incorporated in the EGB-P actuator through linkage which varies the loading on the speeder spring as a function of the power piston position. The change in speeder spring force for a given movement of the power piston is determined by the power piston and speeder spring. If the pin is on the same centerline as the speed droop lever pivot arm, there is no change in speeder spring forces as the power piston moves and the mechanical governor responds as an isochronous (constant speed) control. The further the adjustable pin is moved away from the pivot arm centerline, the greater is the change in compression of the speeder spring for a given power piston movement.

With the actuator operating under control of the electric governor portion, the speed droop feature is, in effect, inoperative. This is because that during such operation the mechanical governor power piston remains in the same position of all engine loads (except possibly momentarily during transients). Thus the speed droop linkage does not alter the speeder spring compression when the electric governor portion of the actuator is controlling.

SPEED DROOP CONTROL KNOB

The adjustable pin can be positioned by the speed droop control knob on the front panel of the EGB-P actuator.

SPEED ADJUSTING MOTOR

The speed adjusting motor permits changing the speed setting of the mechanical governor section of the actuator from a remote point. The speed adjusting motor would be used when remote starting of the engine is regulated. The motor is mounted externally on top of the actuator with its output shaft connected to the manual speed adjusting screw through a friction clutch. The clutch allows speed setting changes to be made either remotely using the speed setting motor or at the actuator with the manual speed setting control knob.

The speed adjusting motor used if of the split field series wound, reversible type. It is available in all standard voltages.

LIMIT SWITCHES

Two limit switches may be provided with the speed adjusting motor. The switches are actuated by the dial stops on the manual speed adjusting mechanism and may be connected to limit speed setting motor travel at desired minimum or maximum speeds or to provide remote visual indication when limits have been attained.

LOAD LIMIT CONTROL KNOB

The load limit control knob on the front panel of the actuator positions the load limit lever. Acting through the pivot lever, the load limit lever restricts the upward travel of the left end of the intermediate lever thereby limiting the maximum fuel (and hence, load) allowed the engine.

SHUTDOWN SOLENOID

In some installations, a shutdown solenoid is mounted inside of the governor, which serves as a protective device. The shutdown solenoid is described in Section 13 of this manual.

ROTARY TERMINAL SHAFT

The rotary terminal shaft provides an efficient connection between the governor and the fuel injector rack linkage. By means of a lever attached to the terminal shaft, and a connecting link between the lever and the governor power piston rod, the reciprocating movement of the power piston is converted to rotary movement at the terminal shaft. The fuel injector rack linkage is connected to one end of the terminal shaft and the rotary movement of the shaft is transmitted to the injector rack linkage, which in turn controls the amount of fuel being injected into the cylinders.

MAINTENANCE

Service work on the governor, other than replenishing the oil supply and making the following adjustments, should not be attempted. Even seemingly minor adjustments on the governor may alter other component operation. It is recommended that, if maintenance or repair is required and it is not considered practical to return the governor to the manufacturer, the services of an authorized factory representative be obtained. Refer to the Service Data at the end of the section for the applicable settings.

Conditions other than governor malfunction may cause variations in engine speed. The following checks should be made before concluding that the speed setting mechanism requires adjustment.

1. Check the load on the engine. A fluctuating load will cause a variation in speed.

2. Check engine for proper firing of all cylinders.

3. Check for slack or binding in injector rack linkage which would cause irregular fuel supply to the engine.

MECHANICAL GOVERNOR COMPENSATION

When the engine is started for the first time or after installation of a new or reconditioned actuator or one that has been drained and cleaned and new oil added, the centrifugal governor will require compensation adjustment. This is necessary to purge the actuator oil system of trapped air.

1. See that the actuator oil is at the proper level in the sight glass. Then start the engine, operating at idle speed, and disconnect the electrical portion of the actuator.

2. Remove the access plug, Fig. 12-11 and open the compensating needle valve several turns.

3. The engine will hunt and surge, and air will bleed from the oil passages. After about 30 seconds, close the compensating needle valve slowly until the hunting condition stops or is reduced. Allow the engine to run until normal operating temperature is reached. If necessary, add oil to obtain the proper level in the actuator.

4. After normal temperature has been reached, again open the compensating needle valve and allow the engine to hunt. Then close the needle valve until hunting stops. The needle valve will be open approximately one-quarter to three - turns depending upon the engine characteristics.

5. Test the actuator stability by manually changing the engine speed to observe recovery. If the engine returns to a steady speed, the compensating adjustment is satisfactory. If hunting is resumed, close the compensating needle valve slightly and test again.

6. Keep the compensating needle valve open as far as possible to prevent sluggishness and still maintain even engine operation. After compensation is made, it should not require another adjustment, unless a permanent temperature change effects the viscosity of the actuator oil. Be sure the compensating needle valve access plug is replaced.

BOOSTER SERVOMOTOR
DESCRIPTION

The booster, Fig. 12-13, is used on some applications in connection with the governor to provide a fast engine start. At the same time starting air is applied to the starter motors, air is also applied to the bottom of the booster. This drives the booster pistons up, forcing oil under pressure into the governor. The governor power piston is moved in the "increased fuel" direction and fuel is applied to the injectors for starting the engine.

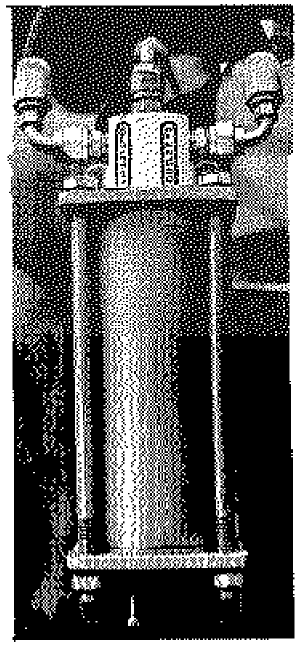


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Fig.12-13 - Booster Servomotor

MAINTENANCE

A limit adjusting screw, located on the bottom of the booster, is provided to adjust the intake stroke of the booster and thus control the volume of oil supplied to the governor. Counterclockwise rotation of the screw increases starting fuel to the engine and clockwise rotation decreases starting fuel. The screw should be adjusted to permit a setting of approximately 1/3 rack during starting.

The booster servomotor should be disassembled, cleaned, and inspected at the interval specified in Scheduled Maintenance Program. Particular attention should be given to cleaning of the inlet and- outlet check valves. All "O" ring seals should be replaced at the time of reassembly.

SERVICE DATA

GOVERNOR

REFERENCES

Governor Oil..M.I. 1764

SPECIFICATIONS

Clearance and dimensional limits listed below are defined as follows:

1. *New limits are those to which new parts are manufactured. (Drawing tolerances.)*

2. *Minimum, maximum, and tolerance measurements are provided as service limits. At time of rebuild or any time unscheduled maintenance is performed, the service limits should not be exceeded. Engine components within these limits may be reused with the assurance that they will perform satisfactorily until the next scheduled overhaul.*

Governor Drive Assembly

Bushing bore diameter (as assembled in housing) - Max...47.739 mm (1.8795")

Distance between bushing thrust faces - Min... 47.42 mm (1.867")

Diameter of drive shaft journal - Min. ....47.536 mm (1.8715")

Governor drive shaft thrust face to shoulder - Max. .... 47.73 mm (1.879")

Driven gear thrust face to shoulder - Max. .... 47.78 mm (1.881")

Diameter of driven shaft journal - Min. ....47.536 mm (1.8715")

Bevel gear backlash - Max .... 0.33 mm (.013")

Thrust clearance.. Limit is governed by gear backlash

EQUIPMENT LIST

Part No.

Hand tachometer (mechanical)..8107967
Shutdown nut adjustment wrench...8208398
Tachometer drive adapter 8210556
Rotary shaft bearing remover - installer 8225658
Rotary shaft oil seal driving rod..8225659
Rotary shaft oil seal remover..8225660
Hand tachometer (digital) 9319424
Hand tachometer shaft extension..9319425

SECTION 13

PROTECTIVE DEVICES AND ALARMS

PROTECTIVE DEVICES AND ALARMS

GENERAL

This section contains a description and some maintenance information for the protective devices and alarms. The devices selected for coverage were chosen as typical for a basic 645E6 marine propulsion/ generating system. Information presented on a protective device or alarm does not mean that it is used on a specific order.

NOTE

Some of these devices are designed to, in some instances, shut down the engine in the event of a malfunction occurring during engine operation while others only produce an alarm.

OVERSPEED TRIP

DESCRIPTION

overspeed mechanism is provided as a safety feature to prevent the injection of fuel into the cylinders if the engine speed becomes excessive.

Fig. 13-1 shows the mechanical overspeed trip installation as applied to left-hand rotating engines. On right-hand rotating engines the operation is essentially the same but with the trip located to the left side of the counterweight. If the engine speed should increase to the specified limits, the overspeed mechanism will shut down the engine.

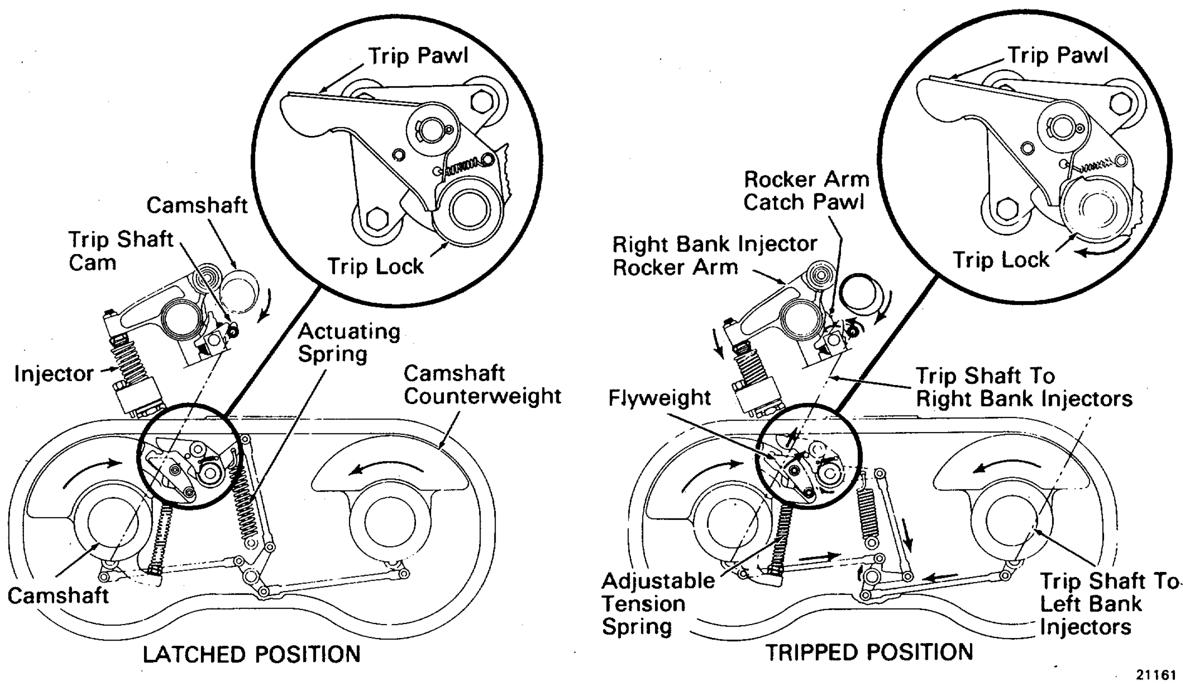

Fig. 13-1 - Overspeed Trip

A trip shaft extending the length of each engine bank under the camshaft has a cam at each cylinder, which when rotated, contacts a spring-loaded catch pawl mounted on each cylinder head, under the injector rocker arm. In the overspeed trip housing, the trip shafts are connected to spring-operated links and a lever mechanism. A reset lever of the trip lock shaft, when pulled towards the right bank, puts tension on an actuating spring. The spring tension is retained by a lever engaging a notch in the reset lever shaft. This holds the cams on the trip shaft away from the rocker arm catch pawls.

The overspeed trip release mechanism is incorporated in the right bank front camshaft counterweight. It consists of a flyweight held by an adjustable tension spring. When engine speed exceeds the set limit, the tension of the spring is overcome by the centrifugal force acting on the flyweight, causing the flyweight to move outward to contact the trip pawl. This allows the actuating spring, acting through connecting links, to rotate the trip shafts. Consequently, the trip shaft cams contact and raise the injector rocker pawls preventing full effective injector rocker arm roller contact on its cam. This prevents fuel injection and stops the engine.

The overspeed mechanism may also be activated by remotely tripping the shutdown lever, Fig. 13-2, using a pull cable.

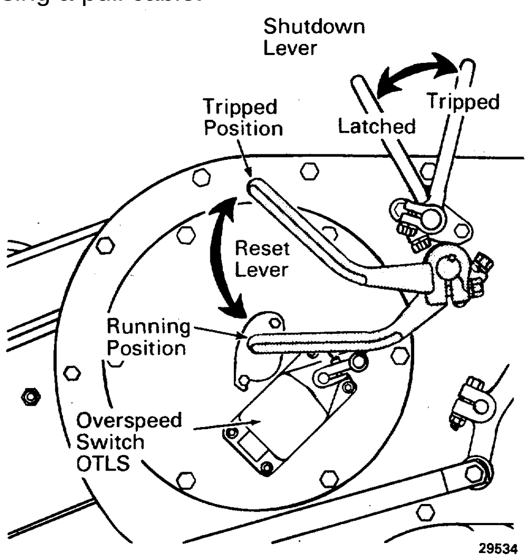

Fig. 13-2 - Reset And Shutdown Lever Positions

Upon resetting, by counterclockwise movement of the reset lever, Fig. 13-2, the trip shaft cams release the rocker arm catch pawls. Rotation of the camshafts on starting the engine lift the rocker arms slightly allowing the catch pawls to resume normal position, releasing the injector rocker arm for normal operation.

OVERSPEED TRIP ALARM

This alarm system is frequently used on units equipped for remote starting or operating of the engine. Engine overspeed causes overspeed trip limit switch OTLS to pick up. This causes the overspeed trip OT relay to pick up, which activates an alarm and turns on the OVERSPEED TRIPPED warning light.

MAINTENANCE

ADJUSTING MECHANICAL

OVERSPEED TRIP

To adjust the overspeed trip, shut engine down (if running) and remove inspection cover from right side of overspeed trip housing.

NOTE

In order to perform adjustment, two thin section jam-nut wrenches are required. If not available, standard open end wrenches can be modified for use by grinding head sides down equal to or less than thickness of jam-nuts.

1. Back off spring tension adjusting nuts, Fig. 13-3, several turns to decrease engine speed at which overspeed trip operates.

NOTE

Adjusting nut and locknut should always be tightened back together (locked) before running engine to test trip speed.

CAUTION

Always apply equal opposing force with wrenches when tightening adjusting nut and locknut - Improperly applied wrench force - all in one direction or at an angle to the nuts can damage the mechanism.

2. Set engine throttle controls to minimum idle speed and start the engine. Allow engine to warm up for a period of approximately 15 minutes, then slowly advance engine speed using injector hand control lever (layshaft) - leaving governor speed set at idle.

3. Using a hand held tachometer set against the center of the right bank camshaft end, run engine speed up until overspeed trip functions to shut engine down. Note and record the speed

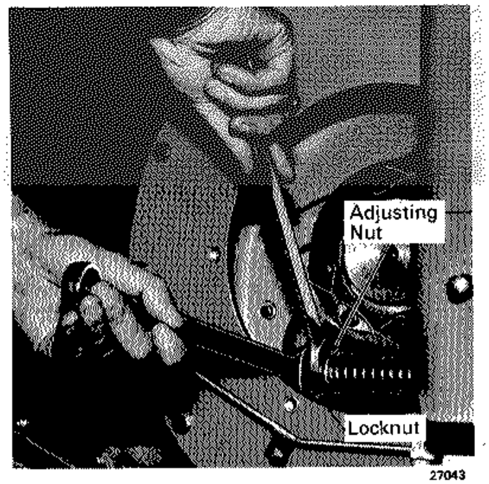

Fig. 13-3 - Overspeed Trip Adjustment

at which this occurs as indicated on tachometer. This initial trip speed, in itself, is not important except as a base reference for making actual adjustments.

4. Tighten adjustment nut on overspeed trip device in steps to increase spring tension. Make these adjustments in the tightening direction only. Tighten locknut and run engine to test trip speed. Repeat adjustment and test until trip function occurs in the range of setting limits specified in the Service Data at end of this section.

NOTE

If adjustment is run past desired setting, back off nuts at least one full turn and begin to tighten again. If initial adjustment is only a few RPM too high, retest trip speed several more times before changing adjustment.

5. When satisfactory trip function is attained, replace right bank inspection cover using new cover gasket.

CRANKCASE PRESSURE DETECTOR ASSEMBLY

DESCRIPTION

The crankcase pressure detector, Fig. 13-4, is a device for detecting a positive, rather than the normally negative, pressure in the crankcase (oil pan). A crankcase pressure switch CPS attached to the bottom of the detector provides the signal to activate the alarm system and shutdown the engine.

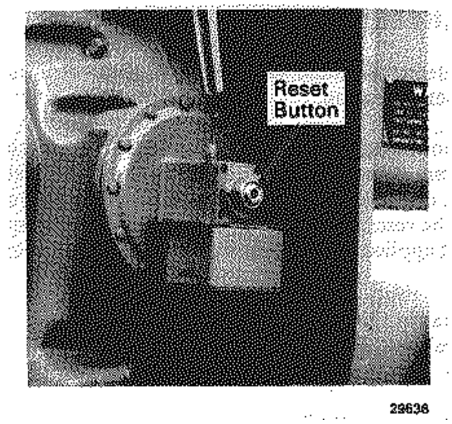

Fig. 13-4 - Crankcase Pressure Detector Assembly

The reset stem is held in a latched position until a positive pressure builds up in the crankcase. The pressure is applied to a diaphragm which, in moving, releases the reset stem. Outward movement of the stem causes a switch lever to close the contacts in the switch which provides a signal to the alarm system.

A shutdown selector switch is optional equipment on marine diesel propulsion systems. This switch allows selection of two different responses to an excessive crankcase pressure. The shutdown selector switch is a two position switch mounted on the engine control cabinet. In the NORMAL SHUTDOWN position, an excessive crankcase pressure will shut down the diesel engine. In the EMERGENCY ALARM position, an excessive crankcase pressure causes only the alarm system to be activated.

WARNING

Following an engine shutdown due to activation of the crankcase pressure detector, do NOT open any handhole or top deck covers to make an inspection until the engine has been stopped and allowed to cool off for at least two hours. Do NOT attempt to restart the engine until the cause of the trip has been determined and corrected.

The action of the pressure detector indicates the possibility of a condition within the engine, such as an overheated bearing, that may ignite the hot oil vapors with explosive force if air is allowed to enter.

If crankcase pressure detector cannot be reset, do NOT operate the engine until the detector has been replaced, since the diaphragm backup plates may be damaged.

MAINTENANCE

The detector should be tested periodically to ensure proper operation.

Without starting the engine, remove the cap from the vent on top of the detector. Using a hydrometer bulb, create a suction on the vent tube. This should trip the reset stem as it simulates a positive pressure being applied to the opposite side of the diaphragm.

CAUTION

Diaphragm can be damaged by applying a positive pressure through vent tube. Exhaust air from bulb before testing. If the test is unsatisfactory, repeat the test. If the detector still does not trip, replace the detector.

The pressure detector can also be tested by using a hand operated vacuum pump. Unscrew the vent tube on top of the detector and connect the vacuum pump to a tee in a line between the vent tube port and a water manometer. Operate the pump slowly until the detector trips. Reset the detector and repeat the procedure, checking the manometer for tripping pressure. See the Service Data for limits.

LOW OIL LEVEL INDICATOR

DESCRIPTION

A float switch-type low oil level indicator LLS, Fig. 13-5, is installed in the side of the oil pan near the oil level gauge. The purpose of the device is to warn the operator of an insufficient oil supply. The switch is connected to the alarm system. When the oil level is reduced to a predetermined level, the float position will open the contacts in the switch, activating the alarm system.

MAINTENANCE

The switch assembly is a sealed unit and consequently must be replaced if found defective. If operating difficulties arise, check the electrical wiring connections for tightness and the floats for binding in the float casing. If this does not produce satisfactory results, replace the assembly with a new one.

LOW OIL PRESSURE ALARM

The low oil pressure alarm device LOS, Fig. 13-6 and 13-7, is not considered an accessory to the engine, but rather as a component of the governor. It is covered in this section due to its function as an engine protective device.

Engines equipped with pneumatic-hydraulic governors have the low oil pressure alarm device as an integral part of the governor. Under a low oil pressure condition, the governor will act to operate the alarm system.

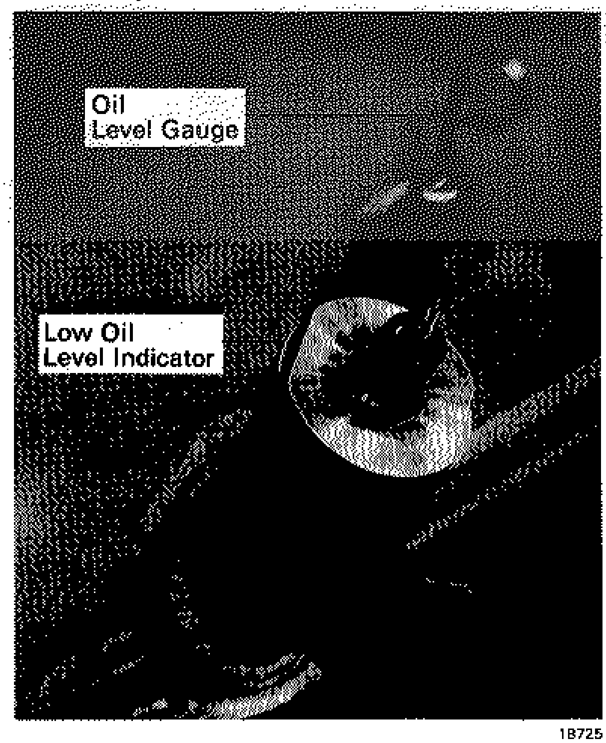

Fig. 13-5 - Low Oil Level Indicator Application

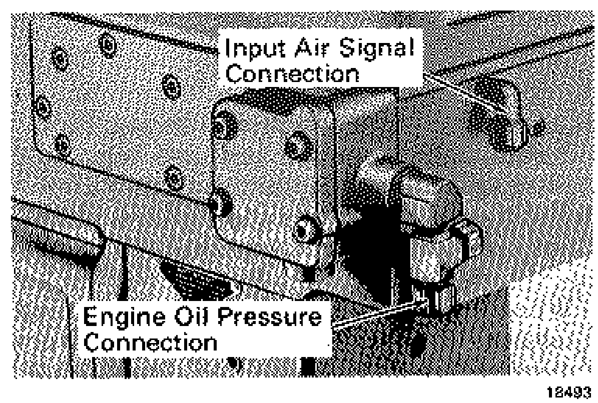

Fig. 13-6 - Low Oil Pressure Alarm Device

A time delay of approximately 35-60 seconds at idle engine speed is provided before the alarm switch trips to allow operating pressures to be reached after starting engine, and to provide time to locate the trouble spot in the event of malfunction. Repeated engine starting to locate cause of alarm should not be attempted. The time delay is voided at engine speed of 475 RPM and over.

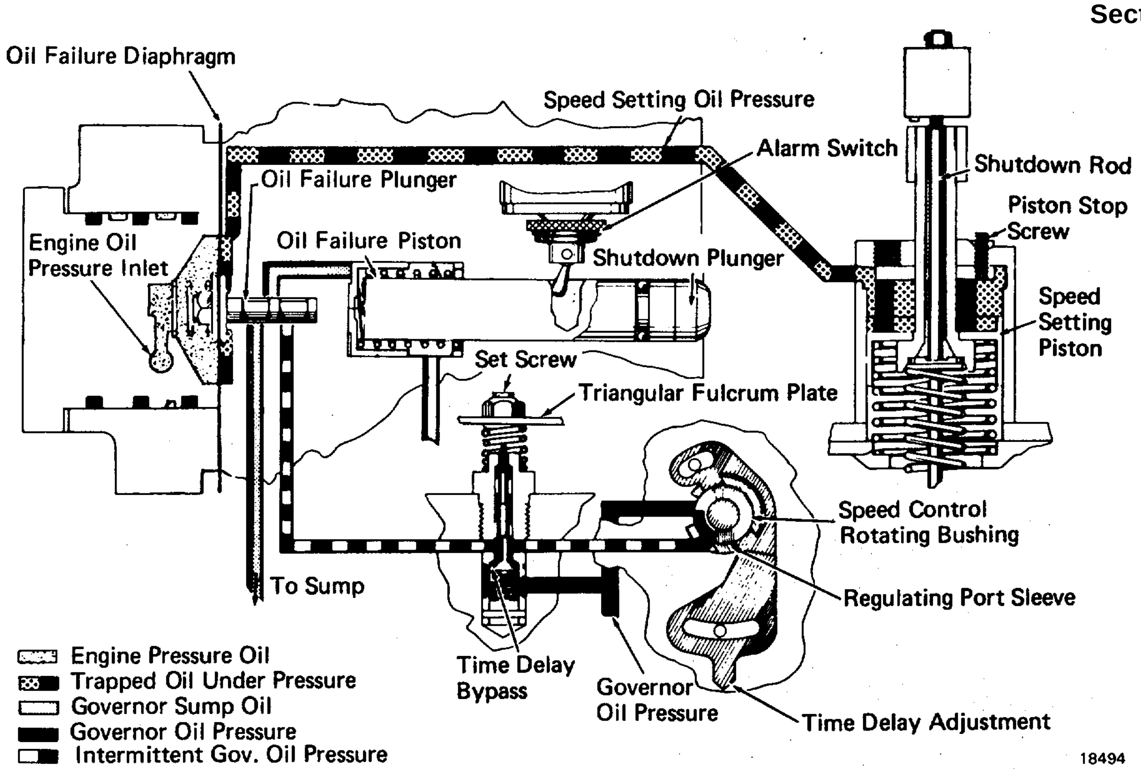

Fig. 13-7 - Low Oil Pressure Alarm Device, Schematic Diagram

Since oil pressure is the lowest at the rear of the engine, an oil line runs from this point to the alarm device in the governor.

The alarm device in the governor, Fig. 13-7, consists of an oil failure diaphragm and plunger, oil failure piston, ball valve, and an alarm switch.

Engine pressure oil is admitted to the left of the oil failure diaphragm. A spring also exerts pressure on the left side of the diaphragm. Pressure oil from the governor speed setting piston pushes against the right side of the oil failure diaphragm. The pressure of the oil from the speed setting piston varies with engine speed. The highest pressure is at full engine speed and the lowest is at idle engine speed. If engine oil pressure is reduced below a safe level, the speed setting piston oil pressure will become greater than engine oil pressure and move the oil failure diaphragm and plunger to the left. This permits governor oil pressure to move the shutdown plunger to the right tripping the alarm switch.

When the shutdown plunger moves out, an alarm switch is actuated and a colored band is visible on the plunger indicating that the device has been tripped. After being tripped, the plunger must be manually pushed in to reset the switch.

The time delay feature of the device is controlled by engine speed. When engine speed is below 475 RPM, governor pressure oil must pass through a bypass valve assembly before reaching the oil failure piston. The time delay is brought about by the governor oil passing through an intermittent flow orifice toward the top of the speed control rotating bushing. At each revolution of the bushing, a slot in the bushing aligns with the oil line to the oil failure piston. The amount of oil discharged through the slot is regulated by adjusting the port sleeve. The amount of oil discharged determines the time required to admit a sufficient amount of oil to operate the oil failure piston. At engine speeds of 475 RPM and above, the speeder spring servo lever lowers the bypass pin which opens the time delay bypass.

When the bypass is open, governor oil goes directly to the oil failure piston, and the alarm switch will be tripped in about two seconds.

SHUTDOWN SOLENOID (PGA GOVERNOR)

DESCRIPTION

The shutdown solenoid, Fig. 13-8, is provided as an electrical means to shut down the engine. The device can be used to effect shutdown either when energized or de-energized.

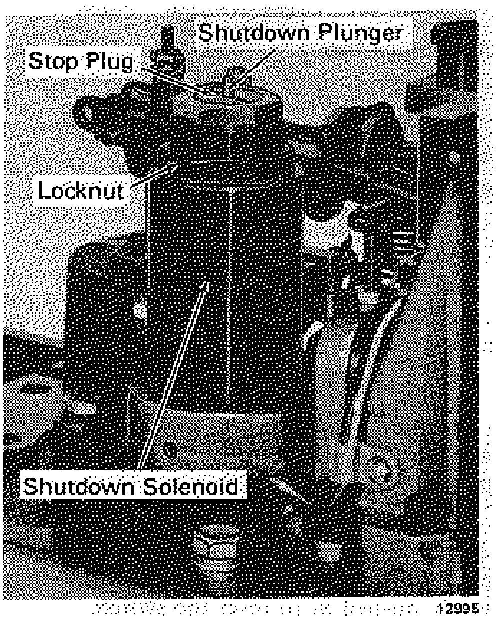

Fig. 13-8 - Shutdown Solenoid

The shutdown device consists essentially of a check valve and solenoid. The check valve is positioned between the speed setting servo assembly and the speed setting pilot valve plunger and bushing. When the ball in the check valve is unseated, oil above the speed setting servo piston escapes to the sump. This allows the speeder spring to expand and push the speeder piston upward. As the piston moves up, the piston rod lifts the shutdown rod and shutdown nuts. Lifting the shutdown rod, in turn, lifts the pilot valve plunger, the power piston goes down, rotating the terminal shaft to the no-fuel position. The engine injector rack linkage, which is connected to the terminal shaft, repositions the rack, shutting off the fuel to the engine.

The check ball seats against either an upper or lower seat in the check valve. In units adjusted to shutdown when the solenoid coil is energized, a spring holds the check ball against the upper seat during normal operation. When the coil is energized, the plunger rod moves down, unseating the check ball. In units adjusted to shut down when the solenoid is de-energized, the plunger rod is adjusted to hold the check ball on the lower seat during normal operation. When the solenoid coil is deenergized, the spring pushes the check ball upward, unseating it.

For maintenance and adjustment of solenoid, refer to manufacturer's bulletin listed in Service Data at the end of this section.

MANUAL SHUTDOWN SWITCH (PGA GOVERNOR)

A spring-loaded manual shutdown switch button is located on the top of the governor cover, Fig. 13-9. When depressed, it pushes down the shutdown solenoid plunger rod displacing the check ball. This permits trapped oil holding the speed setting servo piston to be released and flow to the governor oil sump, and the servo piston to be raised by the piston springs. As the piston moves up, the shutdown rod and nuts are raised. As the shutdown rod is, in effect, an extension of the pilot valve plunger, the raising of the pilot valve plunger permits the power piston to move to the fuel off position, shutting down the engine.

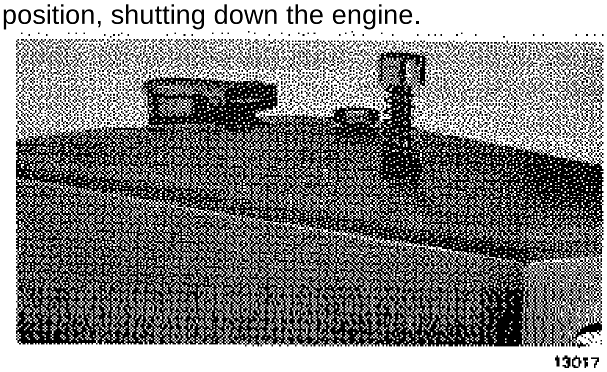

Fig. 13-9 - Manual Shutdown Button

SHUTDOWN SOLENOID (UG-8 GOVERNOR)

DESCRIPTION

A shutdown solenoid, Fig. 13-10, is available for use on either the dial or lever type UG-8 governors. Two models are available. One will cause shutdown when energized and the other when de-energized. Both models can be equipped with a latching device which will not allow restarting after shutdown until the solenoid is manually reset. With an energize-to- run solenoid with latch, if voltage is available you may start without manual reset.

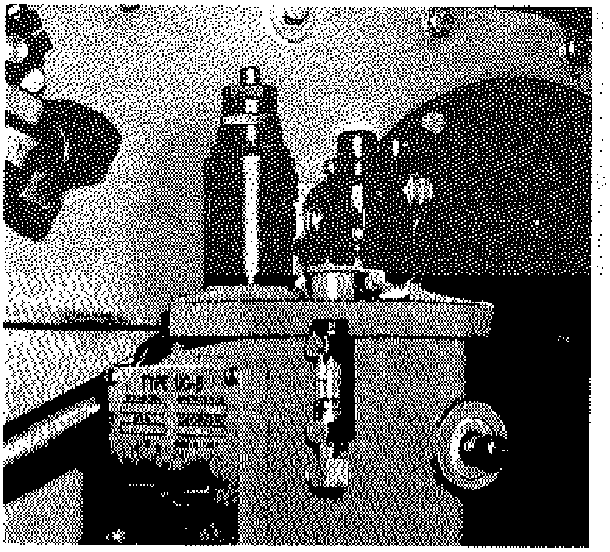

Fig. 13-10 - Shutdown Solenoid

In both models the solenoid plunger moves the load limit strap down to effect shutdown. A detailed description of the operation for the energize to shut down and the de-energize to shut down models is given in the following paragraphs.

OPERATION

DE-ENERGIZE TO SHUT DOWN MODEL

The de-energize to shut down model, Fig. 13-10, will shut the engine down on loss of current to the solenoid. The solenoid plunger moves up to allow the engine to run.

To start an engine when no current is available for energizing the solenoid, lift the solenoid plunger manually by means of the shutdown latch knob. As it approaches the top of its stroke, the lock pin may be pressed in with the finger to latch the shutdown latch knob just below its upper position. This permits starting and running the engine, but no protection is provided.

When current is applied to the solenoid, it will move to the full upward position, unloading the lock pin which is moved outward by the circular latch spring. With loss of current, the load spring will cause the solenoid plunger to move down, lifting the governor pilot valve and closing off fuel.

The de-energize to shut down model can also be supplied without the latching feature.

ENERGIZE TO SHUT DOWN MODEL

The energize to shut down model will shut the engine down as current is applied (even momentarily) to the solenoid. The solenoid plunger moves downward through a tapered plunger stop which contains seven spring-loaded steel balls. The solenoid is prevented from returning by the binding action of the steel balls against the shutdown rod.

To restart the engine, return the plunger to its original position by pressing the reset button, which forces the steel balls away from the plunger and allows spring force to push the load limit strap and the solenoid plunger to their uppermost positions.

The energize to shut down model can be supplied without the latching feature.

For maintenance and adjustment of solenoid, refer to manufacturer's bulletin listed in Service Data at the end of this section.

**SHUTDOWN SOLENOID
(EGB ACTUATORS)**

DESCRIPTION

The shutdown solenoid, Fig. 13-11, is provided as an electrical means to shut down the engine. During normal operation the solenoid is de-energized. When the solenoid is energized, a valve opens in the oil pressure line between the pump and the actuator pilot valve plunger. Pressure oil is allowed to escape through a bleeder bolt and attached tubing, through the open valve to the oil sump. As long as the coil is energized, no oil pressure is available to the power servo and the actuator goes to minimum fuel position.

MAINTENANCE

No maintenance is required on the shutdown solenoid except to check operation periodically by energizing the solenoid while the engine is running. The engine should shut down if the solenoid is operating properly.

**LOW WATER LEVEL
INDICATOR**

DESCRIPTION

A float switch-type water level indicator WLS, Fig. 13-12, is installed in the cooling water expansion tank. The purpose of the device is to warn

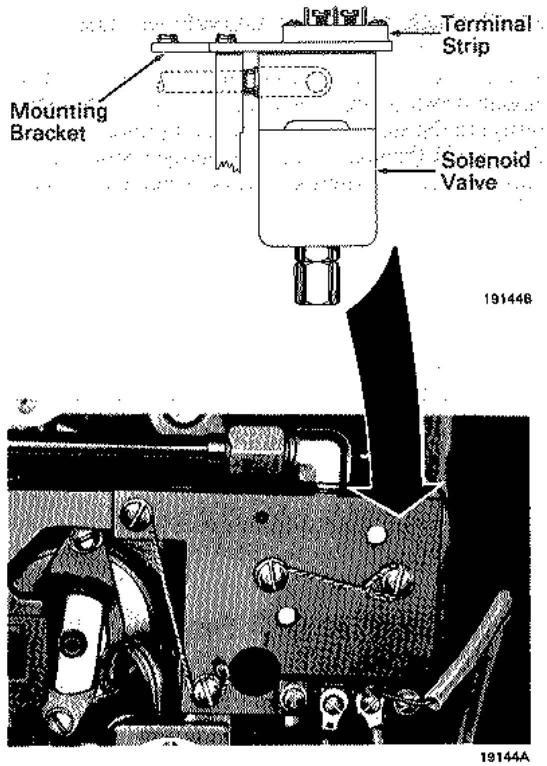

Fig. 13-11 - Shutdown Solenoid

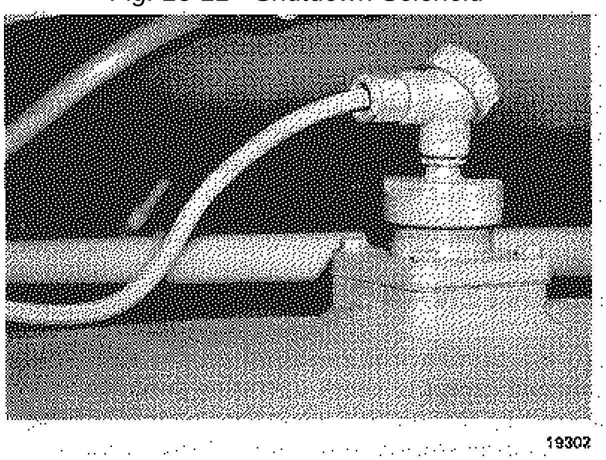

Fig. 13-12 - Low Water Level Indicator

the operator of an insufficient supply of coolant. When the water level is reduced to a predetermined level, the float position will open the contacts in the switch, activating the alarm system.

MAINTENANCE

The switch assembly is a sealed unit and consequently must be replaced if found defective. If operating difficulties arise, check the electrical wiring connections for tightness and the floats for binding in the float casing. If this does not produce satisfactory results, replace the assembly with a new one.

LOW CLUTCH AIR PRESSURE SWITCH

Air pressure is used to operate the clutches that engage the diesel engine with the gear drive. The ship's compressed air supply provides air pressure through a regulator and filter to an air tank and valve arrangement before going to the clutches. The clutch air pressure gauge and a clutch air switch CAS, Fig. 13-13, are connected in the system at the air tank. The gauge monitors the air tank pressure available for clutch engagement. The pressure switch is set at a falling pressure of 758 kPa(110 psi). When air pressure drops to 758 kPa (110 psi), the switch trips causing a low clutch air pressure alarm.

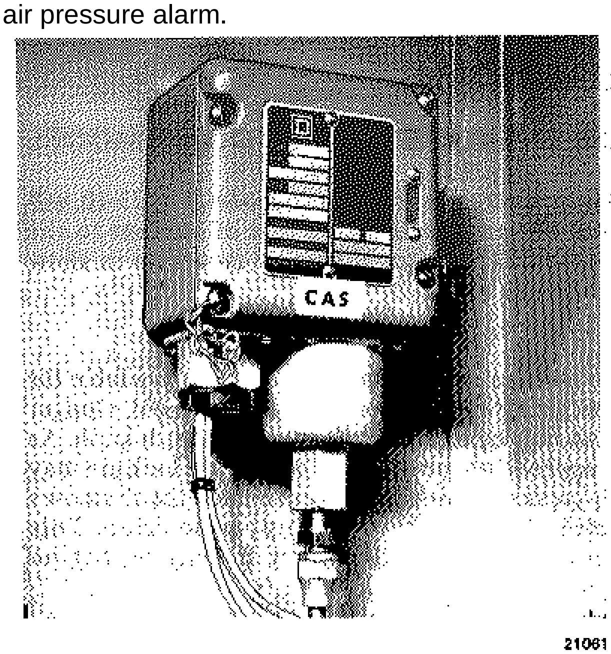

Fig. 13-13 - Low Clutch Air Pressure Switch

For more information about this switch, refer to Maintenance Instruction M.I. 5512.

LUBE OIL PRESSURE SWITCH

The lube oil pressure switch OPS, Fig. 13-14, is connected directly to the engine lube oil system. The purpose of this switch is to prevent an inadvertent starting attempt while the engine is already running. The switch disconnects the starting system when lube oil pressure exceeds 145 kPa (21 psi), indicating the engine is running. When lube oil pressure drops below 117 kPa (17 psi) the starting system can then be operated.

For more information about this switch, refer to Maintenance Instruction M.I. 5512.

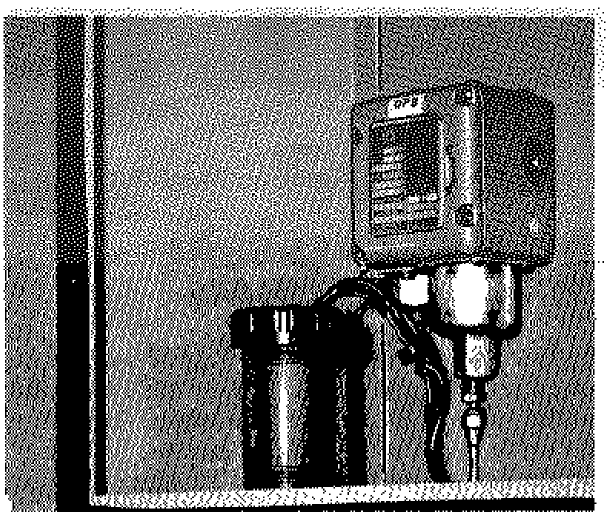

Fig. 13-14 - Lube Oil Pressure Switch

ENGINE TEMPERATURE SWITCH

DESCRIPTION

The engine temperature switch ETS is mounted on the water manifold between the engine water outlet and the rack mounted thermostatic valve, Fig. 13-15. This switch senses water temperature and triggers the alarm system when the water temperature reaches 98° C (208° F). The alarm signal will remain until the temperature is reduced to 92° C (19° F).

The switch is equipped with a test button which can be pressed to test the warning light indication.

For more information about the switch, refer to Maintenance Instruction M.I. 5524.

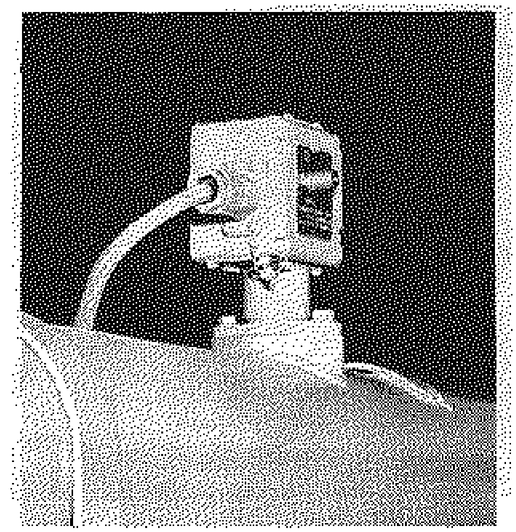

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Fig. 13-15 - Engine Temperature Switch

OIL TEMPERATURE SWITCHES

HIGH OIL TEMPERATURE SWITCH

The high oil temperature switch HOS activates the alarm system when lube oil temperature rises above 104° C (220° F). The alarm signal will remain until the temperature is reduced to 99° C (210° F).

LOW OIL TEMPERATURE SWITCH (OPTIONAL)

The low oil temperature switch LTS may be used on marine units provided with an immersion heater system. This switch will trigger the alarm system when lube oil temperature falls below 29° C (85° F). The alarm signal will remain until the temperature is raised to 35° C (95° F).

Oil temperature switches, when used, will be mounted on the piping between the oil cooler and the oil strainer housing, as typically shown in Fig. 13-16. Either switch is equipped with a test button which can be pressed to test the warning lights. For more information about these switches, refer to Maintenance Instruction M.I. 5524.

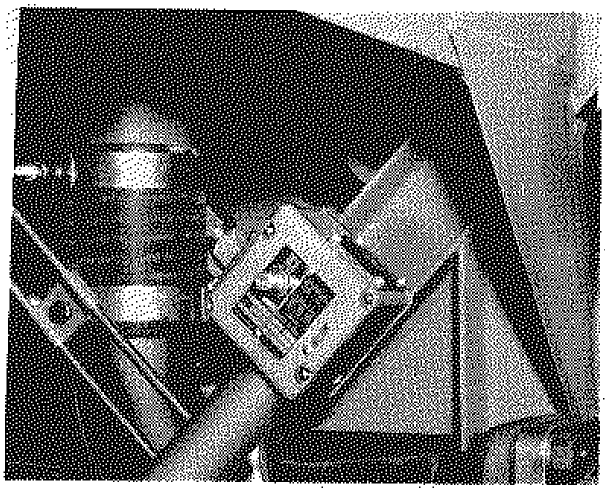


Fig. 13-16 - Typical Oil Temperature Switch

LUBE OIL PRESSURE ALARM (OPTIONAL)

The lube oil pressure alarm system may be used on units equipped with a provision for remote starting of the engine. If the engine oil pressure, monitored by the lube oil pressure switch OPS, fails to reach 145 kPa (21 psi) within 60 seconds after engine fuel pressure reaches 83 kPa (12 psi), or falls below 117 kPa (17 psi) during operation, the lube oil pressure alarm system will activate and engine will shut down.

NOTE

This alarm system may be used in place of an engine governor controlled low oil pressure alarm system.

LOW WATER PRESSURE SWITCH (OPTIONAL)

The low water pressure switch LWS, Fig. 13-17, will be located in the engine control cabinet and connected into the discharge line of an engine cooling water pump. The purpose of this switch is to activate the alarm system if the water pressure drops below 117 kPa (17 psi) during normal high speed engine operation.

NOTE

This alarm system may be specified in place of a low water level alarm.

For more information on this switch, refer to Maintenance Instruction M.I. 5512.

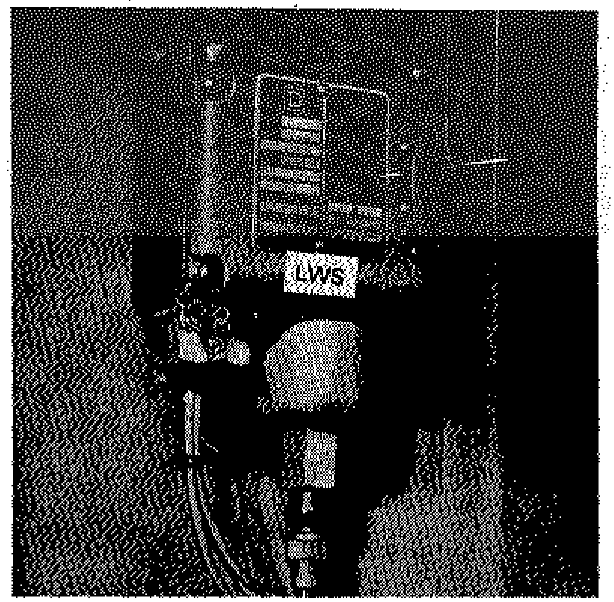


Fig. 13-17 - Low Water Pressure Switch

LOW FUEL PRESSURE SWITCH (OPTIONAL)

The fuel pressure switch FPS, Fig. 13-18, will be located in the engine control cabinet and connected into the fuel system between the engine fuel pump and engine mounted fuel filter. Since the fuel pump is engine driven, the fuel pressure switch can be used

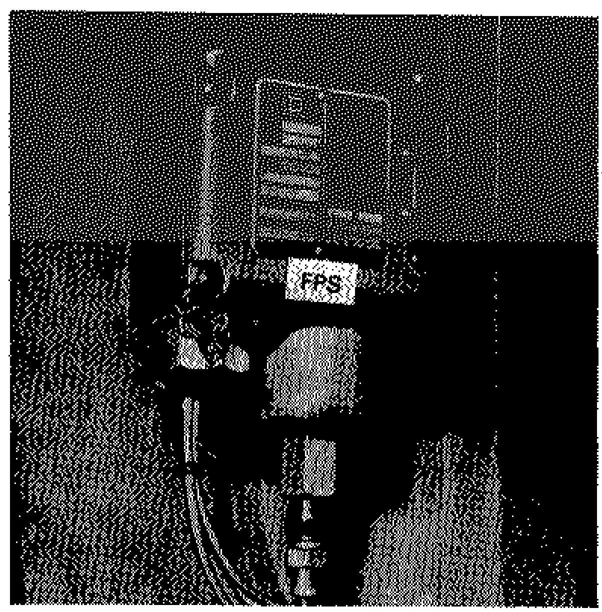


Fig. 13-18 - Low Fuel Pressure Switch

to signal various engine running and shutdown conditions. To determine actual switch application, refer to schematic diagrams and assembly drawings provided for the particular installation.

For more information about this switch, refer to Maintenance Instruction M.I. 5512.

AIR FILTER VACUUM SWITCH (OPTIONAL)

A remote mounted engine air filter assembly has a vacuum switch FVS, Fig. 13-19, that senses the pressure differential between ambient and pressure at the engine air inlet.

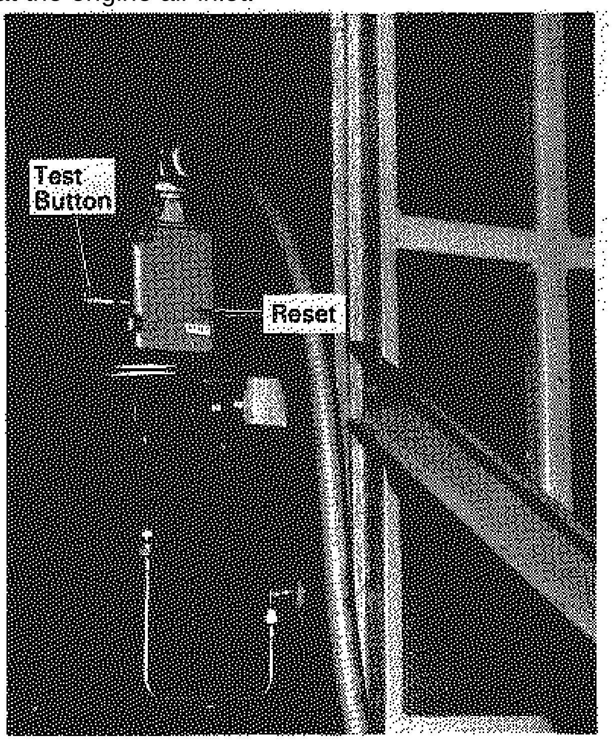


Fig. 13-19 - Air Filter Vacuum Switch

When the switch trips, the alarm system activates to indicate a clogged filter condition.

The vacuum switch is equipped with a shielded test button that may be pressed with a pencil or thin object to test the warning light indication. Always press the reset lever on the vacuum switch after pressing the test button.

For more information about the air filter vacuum switch, refer to Maintenance Instruction M.I. 5525.

LOW START AIR PRESSURE SWITCH (OPTIONAL)

Air pressure is used to engage and drive the air starting motors to crank the engine. The ship's compressed air supply provides air pressure through a strainer and control valve arrangement to the engine air starting motors. The start air pressure gauge and optional start air switch SAS, Fig. 13-20, are located in the upper portion of the control cabinet and connected into the inlet of the air starting system. The gauge monitors the start air pressure available to crank the engine. The pressure switch is normally set at a falling pressure of 862 kPa (125 psi). When start air pressure drops below 862 kPA (125 psi). The switch trips causing a low start air pressure alarm.

For more information about this switch, refer to Maintenance Instruction M.I. 5512.

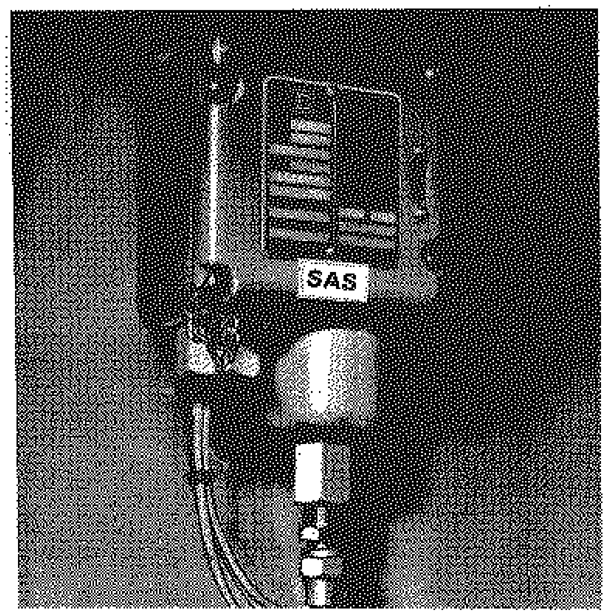


Fig. 13-20 - Low Start Air Pressure Switch

CIRCULATING OIL PRESSURE SWITCH (OPTIONAL)

On marine generating units equipped with an immersion heater, a circulating oil pump and motor are used to circulate warmed oil through the lubricating oil system to maintain the engine in a constant state of readiness for an immediate start. A circulating oil pressure switch COPS, Fig. 13-21, used to monitor the circulating oil pressure, will be mounted in the upper portion of the engine control cabinet. This switch is normally open and is held closed by 145 kPa (21 psi) oil pressure provided by the circulating oil pump which operates to maintain this pressure while engine is shutdown. If circulating oil pressure drops below 117 kPa (17 psi), the switch opens, triggers the alarm system, and interrupts the starting system to prevent an engine start.

For more information about this switch, refer to Maintenance Instruction M.I. 5512.

Fig. 13-21 - Circulating Oil Pressure Switch

SERVICE DATA

PROTECTIVE DEVICES

REFERENCES

Shutdown Solenoid (PGA Governor).. Woodward Bulletin 36650
Shutdown Solenoid (EGB-P Actuator)... Woodward Bulletin 82539
Shutdown Solenoid (UG-8 Governor)... Woodward Bulletin 03013
Pressure Control Switch-Type 9012.. M.I. 5512
Temperature Sensitive Switch-Type 9025... M.I. 5524
Vacuum Switches-Type 9016... M.I. 5525

SPECIFICATIONS

Clearance and dimensional limits listed below are defined as follows:

1. *New limits are those to which new parts are manufactured. (Drawing tolerances.)*

2. *Minimum, maximum, and tolerance measurements are provided as service limits. At time of rebuild or any time unscheduled maintenance is performed, the service limits should not be exceeded. Engine components within these limits may be reused with the assurance that they will perform satisfactorily until the next scheduled overhaul.*

Crankcase Pressure Detector

Tripping Pressure -
*New..20-46 mm (0.8"-1.8") H_20
Used..20-64 mm (0.8"-2.5") H_20

*Meaning new or rebuilt device with less than three months service.

Overspeed Trip

Clearance, trip latch to flyweight - .... Min.0.25 mm (.010")
Trip setting -

	Setting Limits	Checking Limits
750 RPM	850-870 RPM	830-890 RPM
900 RPM	1010-1025 RPM	990-1045 RPM

EQUIPMENT LIST

	Part No.
Hydrometer	8077317
Vacuum pump	8470956

SECTION 14

AIR STARTING SYSTEMS

130E686

AIR STARTING SYSTEMS

DUAL AIR STARTING MOTOR SYSTEMS (12, 16, & 20-CYL.)

DESCRIPTION

A standard dual air starting system consists of two air starting motors, Fig. 14-1, air tanks, strainer, solenoid valve, air start valve, air line lubricator, shutoff valve, and a start button.

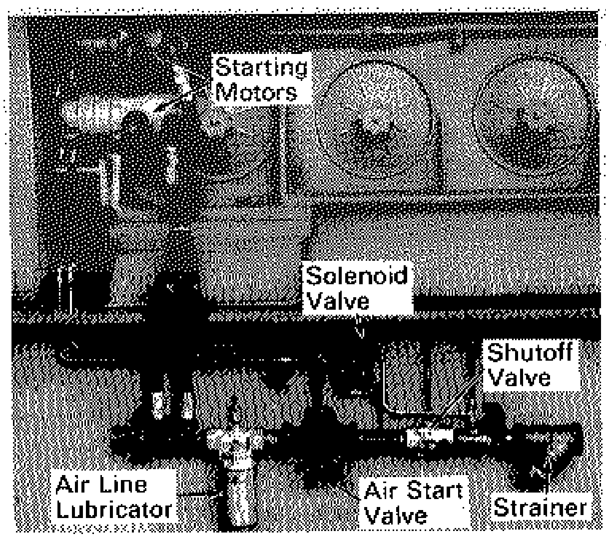


Fig.14-1 - Standard Dual Air Starting System

A special dual air start system, Fig. 14-2, may be provided for use with common low pressure-high volume air supply systems. The system consists of two low pressure air start motors and a high volume dual air manifold with two air start valves, air line lubricators and strainers. Operation and control of this system is basically the same as with the standard system-using a single solenoid valve and an in-line shut off valve.

When the start button is depressed, the solenoid valve is energized, allowing air from the tanks to pass through the solenoid valve to the pinion gear end of the lower starting motor. The entry of air moves the pinion gear forward to engage with the engine ring gear. Movement of the pinion gear uncovers a port allowing air pressure to be released

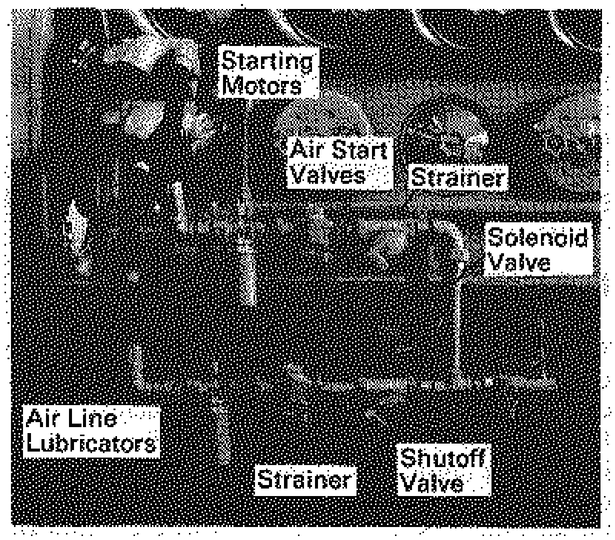


Fig.14-2 - Special Dual Air Starting System

to the upper starting motor which, in turn, engages its pinion gear with the ring gear. Both pinion gears being engaged, the air is released from the uncovered port in the upper motor. In addition to maintaining gear engagement, the air opens the air start valve(s), releasing the main starting air supply. Starting air passes through the air start valve(s) and into the flexible hose assembly attached to each air starting motor. The multivane motors drive the pinion gears, rotating the ring gear, and cranking the engine.

Unless both pinion gears are engaged, the system is designed so that no attempt can be made to start the engine with one motor. There is also a shutoff valve in the system which is manually operated. When maintenance is being performed, the shutoff valve is closed to prevent inadvertent cranking of the engine.

NOTE

In an extreme emergency, engine startup can be made without control using the manual "T" handle override on the start solenoid valve. However, turbocharged engines started in this manner are not pre-lubricated and therefore risk damage to turbocharger bearings.

STANDARD AIR STARTING MOTOR

DESCRIPTION

The standard engine air starting motor, Fig. 14-3, is a multivane type motor consisting of a rotor, which is supported at each end by ball bearings, a planetary gear train, and a Bendix drive. Air striking vanes, which slide in the rotor, causes the rotor pinion to rotate and turn the Bendix drive through a set of planetary gears. The clutch drive pinion gear meshes with the engine ring gear and cranks the engine.

MAINTENANCE

The starting motor requires very little maintenance other than lubrication. Any noticeable loss of power can usually be attributed to worn or damaged vanes. Rapid wear of the vanes is usually caused by inadequate lubrication or the presence of rust, scale, dirt, excessive moisture, or other foreign matter in the air supply. New vanes can be easily and quickly installed by disassembling the motor as described in subsequent paragraphs.

LUBRICATION

Remove the bushing oiler plug (if provided) from the pinion end of the motor and fill with SAE 20W motor oil for temperatures above 30° F or 10W motor oil for lower temperatures. Planet gear frame bearing, and the front and rear rotor bearings are grease packed and sealed at original manufacture. No periodic maintenance should be required. These bearings are normally cleaned and repacked with grease (or replaced) at time of major motor overhaul. Motor gear case should be cleaned and repacked with 0.14-0.17 kg (5-6 oz) of Texaco RB or Ingersoll Rand IR #28 grease at time of overhaul.

Before putting a new air motor into operation, pour about two teaspoons of engine oil into the air inlet so that it will be carried into the multivane motor with the live air. Before storage or lay up, the motor should be fully lubricated with a light oil containing a rust inhibitor.

Air enters the air motor passages through the lubricator, which is in the air line just ahead of the motor. An oil-air mist from the lubricator enters the air motor, providing lubrication. A small portion of the air passing through the lubricator enters the oil bowl of the lubricator through a ball check valve, creating a pressure. The remaining air passes through a venturi in the main air line, lowering its pressure at the venturi. The sight glass oil passage connects into the venturi passage, thereby providing a pressure differential, allowing oil in the bowl to be forced up to the lubricator needle valve. The needle valve controls oil drops entering the main air stream at the venturi, where it is mixed with air, forming an oil-air mist.

The needle valve should be adjusted (opened approximately one and one-half turns) to permit one to two drops-of oil per second to be deposited in the air line when the air is moving. If the exhaust air shows excessive oil, adjust the needle valve to reduce the amount of oil supplied to the air.

Oil is added to the bowl through a filler at the top of the bowl. For normal ambient temperature of 16-49° C (60-120°F), an SAE No. 10 oil is recommended; however, a heavier oil may be used if operating conditions indicate it necessary.

MOTOR REMOVAL

1. Disconnect air supply and exhaust lines.

2. Remove three bolts securing the motor and drive assembly to the motor mounting bracket.

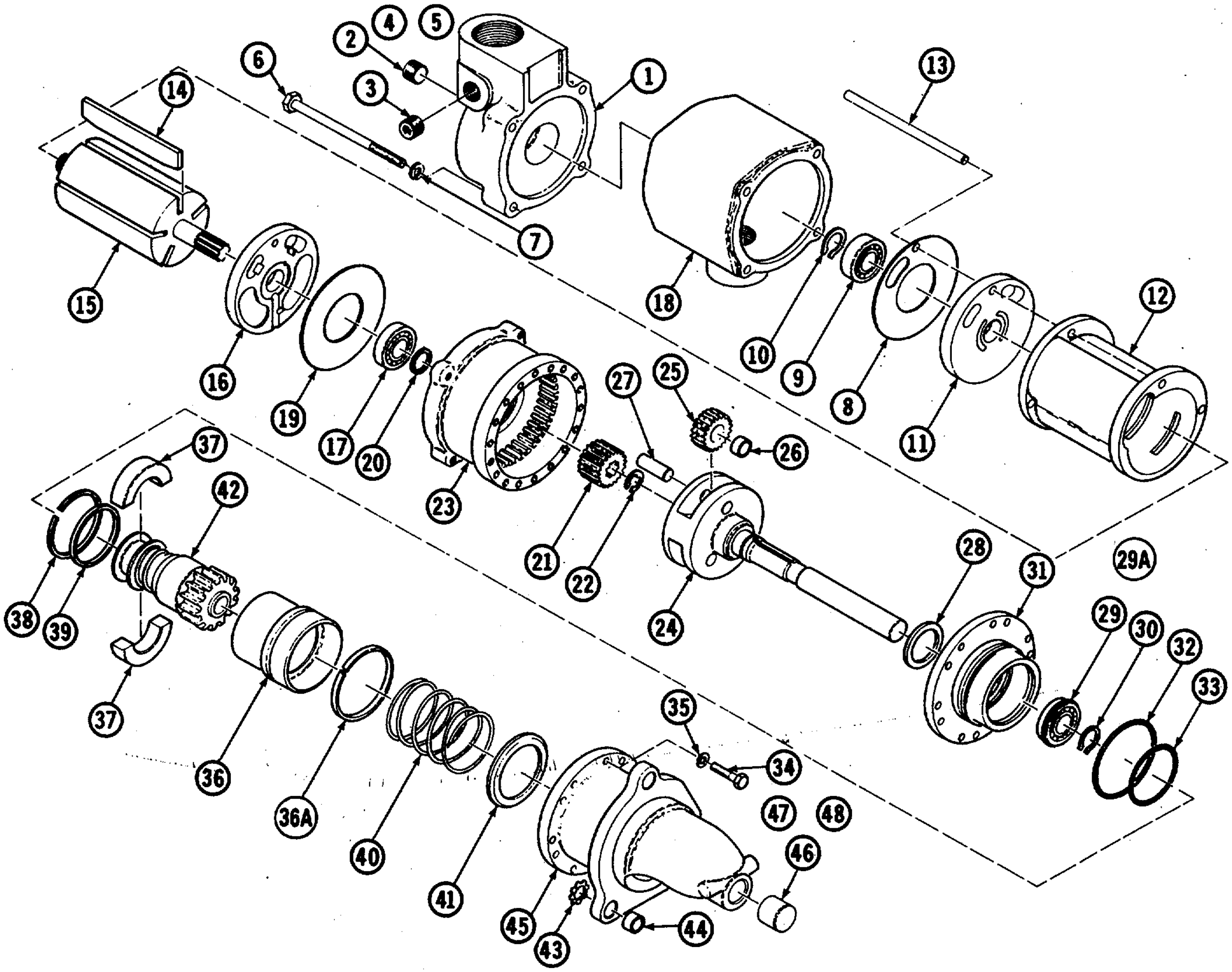
3. Remove starting motor and drive assembly.

MOTOR DISASSEMBLY (Refer To Fig. 14-3)

1. Using a prick punch, mark adjacent spots on the motor housing cover (1), motor housing (18), gear case (23), gear case cover (31), and drive housing (45) so these members will be in the same relative position when the motor is assembled.

2. Unscrew and remove the motor housing cover cap screws (6), and pull the motor housing cover (1) from the motor housing (18).

3. Slide the motor housing off the motor assembly.



1. Motor Housing Cover Assembly
2. Housing Cover End Plug
3. Lubricator Port Plug (2)
4. Oil Adjusting Screw (2)(If Provided)
5. Oiler Felt (2) (If Provided)
6. Motor Housing Cover Cap Screw (4)
7. Cover Cap Screw Lockwasher (4)
8. Motor Housing Cover Gasket
9. Rear Rotor Bearing
10. Rear Rotor Bearing Retainer
11. Rear End Plate
12. Cylinder
13. Cylinder Dowel
14. Vane (5)
15. Rotor
16. Front End Plate
17. Front Rotor Bearing
18. Motor Housing
19. Gear Case Gasket
20. Rotor Pinion Spacer
21. Rotor Pinion
22. Rotor Pinion Retainer
23. Gear Case
24. Planet Gear Frame
25. Planet Gear Assembly (3)
26. Planet Gear Bearing (3)
27. Planet Gear Shaft (3)
28. Planet Gear Frame Thrust Ring
29. Planet Gear Frame Bearing
29A. Planet Gear Frame Bearing Retaining Ring
30. Planet Gear Frame Retaining Ring
31. Gear Case Cover Assembly
32. Gear Case Cover Seal
33. Piston Seal
34. Drive Housing Cap Screw (12)
35. Drive Housing Cap Screw Lockwasher (12)
36. Piston Assembly
36A. Piston Ring
37. Shift Ring (2 Halves)
38. Shift Ring Retainer
39. Shift Ring Spacer
40. Piston Return Spring
41. Return Spring Seat
42. Bendix Starter Drive
43. 3/8" Mounting Bolt Lockwasher (3)
44. 3/8" Mounting Bolt Bushing (3)
45. Drive Housing Assembly
46. Drive Housing Bushing or Bearing
47. Bushing Oiler (If Provided)
48. Bushing Oiler Plug (If Provided)

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Fig.14-3 - Typical Air Starting Motor

4. Pull the multivane motor from the gear case (23).

5. Position the motor assembly vertically, grasping the rotor pinion (21) in copper covered vise jaws. Using a pair of bearing retainer pliers, remove the rear rotor bearing retainer (10) being careful not to distort the retainer any more than necessary.

6. Remove the rear rotor bearing (9), using bearing pullers, then lift off rear end plate (11) and cylinder (12).

7. Position the rotor (15) vertically, pinion end up, and grasp the short hub in copper covered vise jaws. Remove the rotor pinion retainer (22) with a screwdriver, being careful not to distort the retainer any more than necessary.

8. Remove the rotor pinion (21) and pinion spacer (20) from the rotor hub.

9. Support the front end plate (16) as close to the rotor (15) as possible and press the rotor from the front rotor bearing (17), freeing the front end plate. Do not let the rotor fall.

10. Unscrew and remove the drive housing cap screws (34).

11. Remove the drive housing (45) from the gear case cover (31).

12. Lift the drive assembly (42) with all of its attached parts from the planet gear frame (24).

13. Using a pair of needle-nose pliers, remove the shift ring retainer (38) from the internal groove in the piston (36).

14. Lift the piston from the assembly, freeing the shift ring spacer (39) and the two halves of the shift ring (37).

15. Grasp the planet gear frame (24) and pull it, along with the gear case cover (31) and all attached parts, from the gear case (23).

16. Press the drive housing end bushing or bearing (46) from drive housing (45) if new bushing or bearing is to be installed.

DISASSEMBLY OF GEARS
(Refer To Fig. 14-3)

1. Using snap ring pliers, remove planet gear frame bearing retaining ring (29A) from the external groove in the planet gear frame bearing (29).

2. Lift the gear case cover assembly (31) from the planet gear frame bearing (29).

3. Using snap ring pliers, remove planet gear frame retaining ring (30) from the planet gear frame (24).

4. Using bearing pullers, remove planet gear frame bearing (29), from the planet gear frame.

5. Lift planet gear frame thrust ring (28) from the planet gear frame (24).

6. Press out planet gear shaft (27) and remove planet gear assembly (25) from planet gear frame (24).

7. Press the planet gear bearings (26) from the planet gear assembly (25) if new bearings are to be installed.

MOTOR ASSEMBLY (Refer To Fig. 14-3)

1. Position rotor(15) vertically, splined end down, on table of arbor press.

2. Place rear end plate (11), crescent groove side first, onto hub of rotor.

3. Press rear rotor bearing (9) onto hub of rotor until it contacts rear end plate. Check to be certain end plate is not binding against rotor.

4. Apply rear rotor bearing retainer (10) in groove on hub of rotor.

5. Grasp motor housing cover (1) in copper covered vice jaws with motor bore upward. Swivel vice to position which allows direct view of air inlet in housing cover.

6. On right-hand (RH) rotation starters, insert cylinder dowel (13) in dowel hole to left of air inlet, as viewed facing inlet. On left-hand (LH) rotation starters, insert cylinder dowel in dowel hole to right of air inlet, as viewed facing inlet.

7. Apply motor housing cover gasket (8), into bore of motor housing cover, oriented to cylinder dowel and air inlet port.

8. Place assembled rear end plate and rotor into motor housing cover so that cylinder dowel passes through dowel hole in end plate and air port in end plate aligns with port in gasket and motor housing cover.

9. Place cylinder (12) down over rotor so that cylinder dowel passes through dowel hole in cylinder and air port in cylinder aligns with port in rear end plate, gasket, and motor housing cover.

10. Place motor housing (18) down over cylinder. Check to be certain that prick punch marks on motor housing cover and motor housing are aligned.

11. Coat each vane (14) lightly with SAE No. 10 oil and insert one in each rotor vane slot with straight edge outward.

12. Place front end plate (16), crescent groove side first, onto cylinder so that cylinder dowel passes through dowel hole in end plate.

13. Press front rotor bearing (17) onto splined shaft of rotor until it contacts front end plate. Check to be certain end plate is not binding against rotor.

14. Slide rotor pinion spacer (20) onto rotor shaft followed by rotor pinion (21).

15. Apply rotor pinion retainer (22) in groove on rotor shaft with concave side of retainer facing rotor pinion.

16. Apply light coat of grease to gear case gasket (19) and position gasket in motor bore of gear case (23).

17. Place gear case on assembled motor. Check to be certain prick punch marks on gear case align with those on motor housing.

18. Turn entire assembly over so that motor housing cover is in upward position. Apply motor housing cover capscrews (6) with lockwashers (7) and tighten them finger tight, then tighten each one a little at a time to a torque of 34 N-m (25 ft-lbs).

ASSEMBLY OF PLANET GEARS (Refer To Fig. 14-3)

1. Press one planet gear bearing (26) into each planet gear assembly (25).

2. Install each planet gear assembly (25) into the planet gear frame (24) and then press a planet gear shaft (27) into each planet gear assembly.

3. Install planet gear frame thrust ring (28) in place on the collar of the planet gear frame. Then slide the planet gear frame bearing (29) over the small end of the planet gear frame and tap it down flush against the planet gear frame thrust ring.

4. Snap the planet gear frame retaining ring (30) into the groove in the planet gear frame to hold the planet gear bearing in place.

5. Install the gear case cover assembly (31) over the planet gear bearing and snap the planet gear frame bearing retaining ring (29A) in place in the external groove in the bearing.

ASSEMBLY OF PISTON, BENDIX STARTER DRIVE, AND PLANET GEAR FRAME

1. If required, press new bushing or bearing (46) into drive housing end (45).

2. Install the planet gear assembly previously assembled into the gear case (23).

3. Insert the shift ring (37), shift ring spacer (39), and shift ring retainer (38) into the small end of the piston (36).

4. Insert the piston assembly (36) into the gear case cover assembly (31) making sure the piston seal (33) and piston ring (36A) are in place.

5. Install the Bendix starter drive (42), piston return spring (40), and return spring seat (41) over the gear frame shaft, then place the drive housing assembly (45) over the drive assembly. Install and tighten the drive housing cap screws (34).

SPECIAL AIR STARTING MOTOR

DESCRIPTION

The special engine air starting motor, Fig. 14-4, is a multivane type motor consisting of a rotor positioned eccentrically in a housing and supported at each end by ball bearings, a reduction gear train, and a clutch drive. Air striking vanes, which slide in the rotor to rotate and turn an offset shaft through a pinion and drive gear set which turns the clutch drive. The clutch drive pinion gear meshes with the engine ring gear and cranks the engine.

MAINTENANCE

The starting motor requires very little maintenance other than lubrication. Any noticable loss of power can usually be attributed to worn or damaged vanes. Rapid wear of the vanes is usually caused by inadequate lubrication or the presence of rust, scale, dirt, excessive moisture, or other foreign matter in the air supply. New vanes can be easily and quickly installed by disassembling the motor as described in subsequent paragraphs.

1. Motor Housing Cover
2. Housing Cover Pipe Plug (3)
3. Motor Housing Cover Cap Screw (4)
4. Cover Capscrew Lockwasher (4)
5. Rear End Plate
6. Rotor Rear Bearing
7. Rear Shaft O-Ring Seal
8. Rear Bearing O-Ring Seal
9. Rotor Clamp Nut
10. Clamp Nut Lockscrew
11. Cylinder
12. End plate Alignment Pin (2)
13. Cylinder Alignment Pin
14. Cylinder O-Ring Seal (4)
15. Motor Housing
16. Rotor
17. Rotor Vane (5)
18. Front End Plate
19. Rotor Front Bearing
20. Wave Washer (2)
21. Rotor Pinion
22. Rotor Pinion Retaining Screw
23. Gear Case
24. Drive Gear
25. Rear Drive Gear Bearing
26. Drive Gear Bearing Retainer
27. Drive Gear Shaft Bearing Retainer
28. Bulkhead
29. Bulkhead Retainer
30. Bulkhead Outer O-Ring Seal
31. Bulkhead Inner O-Ring Seal
32. Piston
33. Piston O-Ring Seal
34. Piston Seal
35. Clutch Jaw Assembly
36. Clutch Spring Cup Retainer
37. Clutch Spring Cup
38. Clutch Spring
39. Driveshaft
40. Front Drive Gear Bearing
41. Drive Gear Cup
42. Drive Gear Lockwasher
43. Drive Gear Screw
44. Drive Gear Screw O-Ring Seal
45. Large Drive Shaft Bearing Retainer
46. Small Drive Shaft Bearing Retainer
47. Rear Drive Shaft Bearing
48. Piston Return Spring
49. Piston Return Spring Seat
50. Front Drive Shaft Bearing
51. Drive Housing Bearing Seal
52. Drive Housing
53. Drive Housing Capscrew (8)
54. Housing Capscrew Lockwasher (8)
55. Housing O-Ring Seal
55A. Housing Vent Plug
56. Drive Pinion
57. Drive Pinion Retaining Screw
58. Flatwasher
59. Pinion Spring Sleeve
60. Pinion Spring

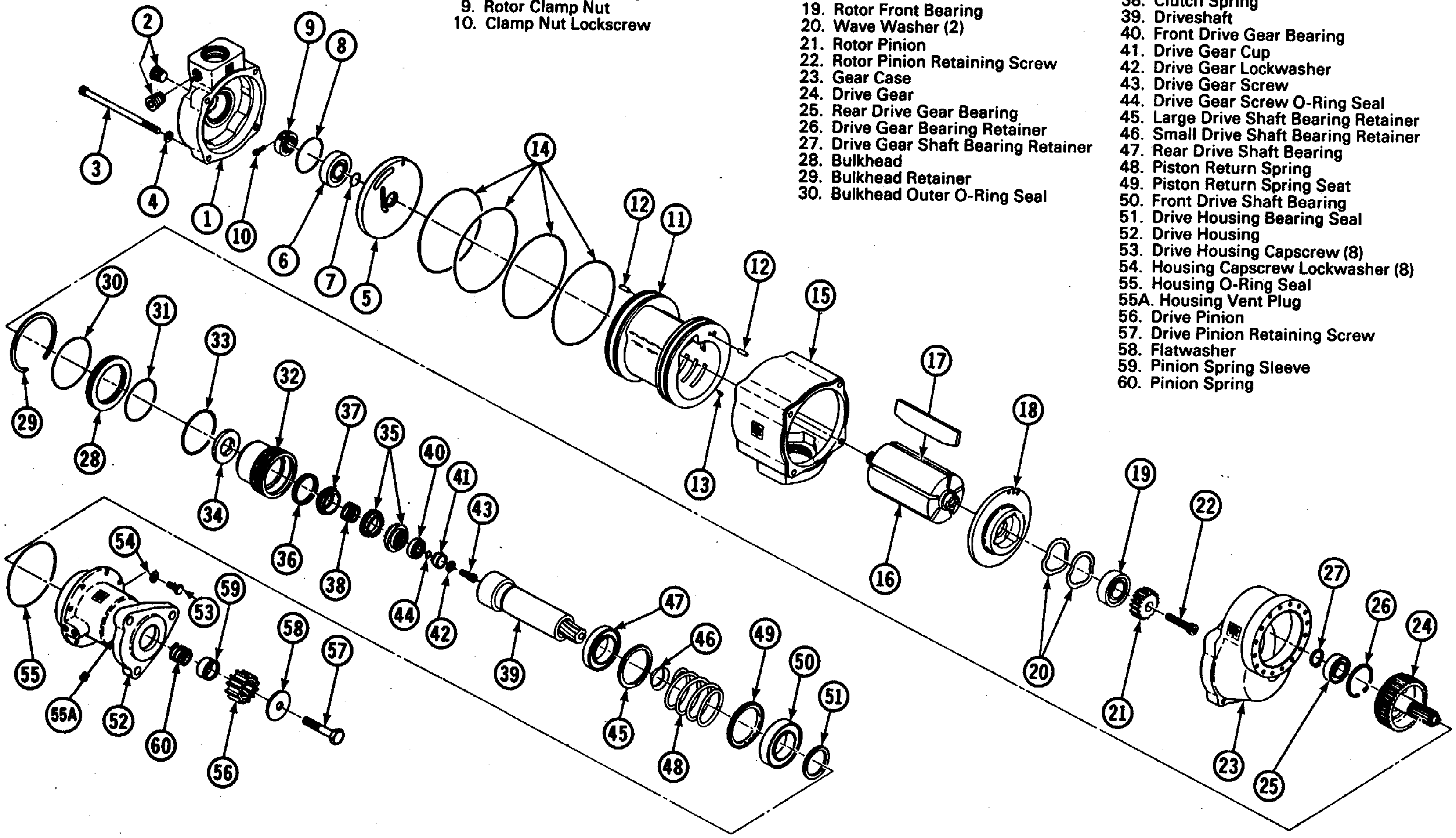


Fig. 14-4 - Special Air Starting Motor

LUBRICATION

Rotor, drive gear, and drive shaft front and rear bearings are grease packed and sealed at original manufacture. No periodic maintenance should be required. These bearings are normally cleaned and repacked with grease (or replaced) at time of major motor overhaul. Motor gear case should be cleaned and repacked with 0.23 kg (8 oz) of Texaco RB or Ingersoll Rand IR #28 grease at time of overhaul.

Before putting a new air motor into operation, pour about two teaspoons of engine oil into the air inlet so that it will be carried into the multivane motor with the live air. Before storage or lay up, the motor should be fully lubricated with a light oil containing a rust inhibitor.

Air enters the air motor passages through the lubricator, which is in the air line just ahead of the motor. An oil-air mist from the lubricator enters the air motor, providing lubrication. A small portion of the air passing through the lubricator enters the oil bowl of the lubricator through a ball check valve, creating a pressure. The remaining air passes through a venturi in the main air line, lowering its pressure at the venturi. The sight glass oil passage connects into the venturi passage, thereby providing a pressure differential, allowing oil in the bowl to be forced up to the lubricator needle valve. The needle valve controls oil drops entering the main air stream at the venturi, where it is mixed with air, forming an oil-air mist.

The needle valve should be adjusted (opened approximately one and one-half turns) to permit one to two drops of oil per second to be deposited in the air line when the air is moving. If the exhaust air shows excessive oil, adjust the needle valve to reduce the amount of oil supplied to the air.

Oil is added to the bowl through a filler at the top of the bowl. For normal ambient temperature of 16-49°C (60-120°F), an SAE No. 10 oil is recommended; however, a heavier oil may be used if operating conditions indicate it necessary.

MOTOR REMOVAL

1. Disconnect air supply and exhaust lines.

2. Remove three bolts securing the motor and drive assembly to the motor mounting bracket.

3. Remove starting motor and drive assembly.

MOTOR DISASSEMBLY
(Refer To Fig. 14-4)

DRIVE HOUSING

1. Using a prick punch, mark adjacent spots on the motor housing cover (1), motor housing (15), gear case (23), and drive housing (52) so these members will be in the same relative position when the motor is assembled.

2. Remove rear housing cover pipe plug (2) from end of motor housing cover.

3. Position motor assembly so that drive pinion (56) is grasped firmly in copper covered vice jaws and assembly is supported on a workbench. Using a wrench, remove drive pinion retaining screw (57).

CAUTION

Retaining screw will have LH thread on RH rotation motor and RH thread on LH rotation motor.

4. Position starter on workbench, and remove drive pinion flatwasher (58) and drive pinion (56). Slide pinion spring sleeve (59) and pinion spring (60) off end of drive shaft (39).

5. Insert a 3/8" square drive extension through motor housing cover (1) to hold rotor (16) from turning. Using a 5/16" x 8.00" long hex socket head wrench inserted into the end of the driveshaft (39), unscrew the drive gear screw (43).

6. Unscrew and remove drive housing cap screws (53) and lockwashers (54).

7. Tap drive housing (52) with a plastic hammer to free it from gear case (23).

8. Place drive housing in an arbor press, piston end up. Apply pressure to the piston (32) to compress piston return spring (48), before removing bulkhead retainer (29).

WARNING

Failure to follow procedure as described in Step 8 above could result in injury to personnel.

9. Using a screwdriver, remove bulkhead retainer, then ease off pressure from arbor press.

CAUTION

Make certain tension of spring has pushed bulkhead out of drive housing before removing drive housing from arbor press.

10. Remove bulkhead (28) from the piston (32), then remove bulkhead outer o-ring seal (30) and inner o-ring seal (31).

11. Slide driveshaft (39) out from drive housing. Pull piston return spring (48) off from drive shaft.

NOTE

Do not remove front drive shaft bearing (50) or drive housing seal (51) unless replacement is necessary and parts are available. Bearing and seal will be damaged upon removal.

12. Remove piston o-ring seal (33) from piston.

13. Insert large blade screwdriver through piston seal (34) until it rests on top of clutch spring cup (37), then pry seal out of piston.

NOTE

Piston seal will be damaged upon removal and will require replacement.

14. Press clutch spring cup (37) down and remove clutch spring cup retainer (36). Remove clutch spring cup and clutch spring-(38).

15. Remove the two clutchjaws (35) as an assembly, then remove the front drive gear bearing (40), drive gear cup (41), drive gear lockwasher (42), drive gear screw (43) and gear screw o-ring seal (44).

16. Using a thin flat blade screwdriver, remove large drive shaft bearing retainer (45).

17. Press rear drive shaft bearing and drive shaft (39) out of the piston. If rear drive shaft bearing needs to be replaced, proceed as follows:

    a. Using a small chisel, cut and remote small drive shaft bearing retainer (46) from drive shaft.

    b. Press rear drive shaft bearing (47) off drive shaft.

MOTOR HOUSING

1. Unscrew and remove the motor housing cover cap screws (3), and pull the motor housing cover (1) from the motor housing (15).

NOTE

It may be necessary to dislodge the motor housing cover by tapping it with a plastic hammer.

2. Tap gear case (23) with the plastic hammer to dislodge it from the motor housing.

3. Grasp the rotor pinion (21) in copper covered vice jaws and remove rotor pinion retaining screw (22) using a wrench. Remove rotor pinion (21) from rotor shaft. Do not let rotor assembly fall.

4. Slide front end plate (18), front rotor bearing (19) and two wave washers (20) off rotor shaft. Remove rotor (16) and rear end plate (5) from cylinder (11).

5. Remove and examine each vane (17). Install a complete new set of vanes if any one vane is cracked, spalled, or worn to a width of 15/16" (24 mm) or less.

6. Grasp rotor in copper covered vice jaws and loosen rotor clamp nut screw (10) using a 5/32" hex socket wrench. Unscrew and remove rotor clamp nut (9).

7. Remove large rear rotor bearing o-ring seal (8).

8. Remove rear end plate (5) and small rear rotor bearing o-ring seal (7) from rotor shaft. If rear rotor bearing (6) needs to be replaced, remove it from rear end plate.

9. Push cylinder (11) out of motor housing (15) and remove cylinder o-ring seals (14) from cylinder.

DISASSEMBLY OF GEARS
(Refer To Fig. 14-4)

1. Place gear case (23) on a workbench. Using retaining ring pliers and working through access holes in gear webb, remove drive gear bearing retainer (26).

2. Pull drive gear (24) out of gear case. Do not disassemble drive gear. If drive gear is defective, install a new or rebuilt unit.

3. Using retaining ring pliers, remove drive gear shaft bearing retainer (27).

4. Remove rear drive gear bearing (25) from drive gear.

ASSEMBLY OF GEARS
(Refer To Fig. 14-4)

1. Place drive gear bearing retainer (26) over rear end of drive gear (24). Using an arbor press, press rear drive gear bearing (25) onto rear end of drive gear.

2. Using retaining ring pliers, apply drive gear shaft bearing retainer (27).

3. With gear case (23) on a workbench, use a plastic hammer to seat rear drive gear bearing into gear case by tapping on opposite end of drive gear.

4. Using retaining ring pliers, and working through access holes in gear webb, apply drive gear bearing retainer (26).

5. Repack drive gear case with approximately 0.23 kg (8 oz) of Texaco RB or Ingersoll-Rand IR #28 grease.

MOTOR ASSEMBLY
(Refer To Fig. 14-4)

MOTOR HOUSING

1. Position rotor (16) with threaded end up in a vice with copper covered jaws. Apply rear rotor bearing (6), if removed, into rear end plate (5).

2. Lubricate small rear rotor bearing o-ring seal (7) with o-ring lubricant and apply it onto rotor shaft - tight against rotor shaft shoulder.

3. Apply rear end plate (5) onto rotor shaft bearing end up.

4. Screw rotor clamp nut (9) onto rotor shaft with shoulder toward the bearing. Tighten nut until there is 0.02 mm (.001") to 0.07 mm (.003") clearance between rear end plate and rotor.

5. Using a 5/32" hex socket wrench, tighten rotor clamp nut screw (10). Recheck clearance between rear end plate and rotor, after tapping end plate away from rotor face with a plastic hammer.

6. Inspect the two end plate alignment pins (12). If pins are bent or broken, remove them from cylinder (11) and press in new pin (or pins).

7. Lubricate two o-ring seals (14) with o-ring lubricant and apply on inside end of cylinder.

8. Position motor housing (15) vertically on two blocks of wood with locating slot upward.

9. Using plastic hammer, tap cylinder into motor housing making certain cylinder alignment pin (13) seats into slot of motor housing.

10. Lubricate two o-ring seals (14) with o-ring lubricant and apply on outside end of cylinder.

11. On right-hand (RH) rotation starters, insert rotor (16) into cylinder with pinion end toward cylinder alignment pin (13). Check to be certain that protruding end plate alignment pin (12) in cylinder aligns with dowel hole in rear end plate (5), with identification number SS800R-12, and that air ports of both cylinder and rear end plate are aligned.

    On left-hand (LH) rotation starters, insert rotor (16) into cylinder with pinion end away from cylinder alignment pin (13). Check to be certain that protruding end plate alignment pin (12) in cylinder aligns with dowel hole in rear end plate (5), with identification number SS800L-12, and that air ports of both cylinder and rear end plate are aligned.

12. Coat each vane (17) lightly with SAE No. 10 oil and insert one in each vane slot with straight edge outward toward cylinder.

13. Slide front end plate (18) over pinion end of rotor.

NOTE

Second protruding end plate alignment pin (12), in face of cylinder, should align with dowel hole in front end plate.

14. Insert two motor wave washers (20) into front end plate well, followed by front rotor bearing (19).

15. Apply rotor pinion (21) on rotor shaft so that lugs on pinion engage those on shaft.

16. Screw rotor pinion retaining screw (22) into end of rotor shaft and tighten to 122 N•m (90 ft-lbs).

17. Lubricate rear rotor bearing o-ring seal (8) with o-ring lubricant and apply it onto rear rotor bearing (6).

18. Check freeness of motor by turning rotor pinion. If necessary, tap front end plate with plastic hammer to align motor.

NOTE

Align prick punch marks on gear case (23), motor housing (15), and motor housing cover (1) for original positioning of members during assembly.

19. Position gear case assembly in a vice with copper covered jaws by grasping the shaft of drive gear (24).

20. Insert pinion end of motor into gear case, tapping motor housing (15) with plastic hammer until seated.

21. Position motor housing cover (1) on motor housing, tapping cover with plastic hammer until seated.

NOTE

A 305 mm (12") long piece of 1-1/2" pipe can be threaded into air inlet to act as a handle to assist alignment of motor housing with cover and gear case.

22. Install four motor housing cover cap screws (3) and lockwashers (4) and tighten them finger tight, then tighten each one a little at a time to a torque value of 81 N•m (60 ft-lbs).

23. Install two of the housing cover pipe plugs (2) into motor housing cover inlet boss and tighten securely.

DRIVE HOUSING

1. Press new rear drive shaft bearing (47) onto drive shaft. Slide small bearing retainer (46), convex side first, onto drive shaft and press it into position as described in instructions provided with new retainer.

2. Assemble drive gear screw (43), drive gear lockwasher (42), drive gear cup (41), and drive gear screw o-ring seal (44).

3. Grasp the drive shaft (39) in copper covered vice jaws, pinion end down, and insert assembled drive gear screw unit (items 41,42,43 & 44) into drive shaft, screw head down.

4. Lubricate inside diameter of drive shaft with Texaco RB or Ingersoll-Rand IR #28 grease, then slide front drive gear bearing (40) into drive shaft.

5. Lubricate clutch jaw assembly (35) with grease and insert into drive shaft with driving clutch jaw teeth facing up and driven clutch jaw teeth facing down.

6. Insert clutch spring (38) followed by clutch spring cup (37) into drive shaft. Press inserted parts into drive shaft and apply clutch spring cup retainer (36).

7. Using an arbor press, press piston seal (34), cover side out, into piston (32) until flush with piston face.

8. Apply piston onto drive shaft until rear drive shaft bearing (47) seats into piston.

9. Using a thin flat blade screwdriver, "coil" large drive shaft bearing retainer (45) into groove of piston to retain outer race of rear drive shaft bearing.

10. Lubricate piston o-ring seal (33) with o-ring lubricant and apply it in groove of piston.

11. Position drive housing (52) in an arbor press, pinion end down, and press drive housing seal (51) into drive housing with lip of seal facing away from drive pinion.

12. Using a sleeve that contacts outer race of front drive shaft bearing (50), press bearing into drive housing until seated. Place piston return spring seat (49) on top of front drive shaft bearing.

13. Slide piston return spring (48) onto drive shaft and "snap" it into front of piston, tight against large drive shaft bearing retainer (45).

14. Lubricate assembled drive shaft with Texaco RB or Ingersoll-Rand IR #28 grease and insert it into drive housing.

15. Lubricate bulkhead outer o-ringer seal (30) and inner o-ring seal (31) with o-ring lubricant and apply both on bulkhead (28). Slide bulkhead onto piston.

16. With drive housing in arbor press, press down on rear face of piston.

CAUTION

Check to be certain drive shaft is passing through front drive shaft bearing properly by feeling at underside of drive housing.

17. Using a screwdriver, apply bulkhead retainer (29) in groove of drive housing.

WARNING

Make certain bulkhead retainer is properly seated in drive housing groove before backing off arbor press.

18. Remove drive housing from arbor press.

19. Lubricate drive housing o-ring seal (55) with o-ring lubricant and apply it in groove on drive housing.

20. Position assembled motor housing and gear case on workbench in an upright position to accept drive housing.

21. Position assembled drive housing (52) onto gear case carefully so as to avoid damaging piston seal (34). Align prick punch marks of gear case and drive housing.

22. Apply eight drive housing capscrews (53) with lockwashers (54) and torque to 38 N•m (28 ft-lbs).

23. Insert a 3/8" square drive extension through motor housing cover (1) to prevent rotor (16) from turning. Using a 5/16" x 8.00" long hex socket head wrench inserted into the end of the drive shaft (39), tighten drive gear screw (43) to a torque of 77 N•m (57 ft-lbs).

24. Lubricate pinion spring (60) with Ingersoll-Rand IR #11 grease and slide it along with pinion spring sleeve (59) over pinion end of drive shaft.

25. Lubricate pinion end of drive shaft with IR #11 grease and apply drive pinion (56).

26. Position starter assembly so that drive pinion is grasped firmly in copper covered vice jaws and assembly is supported on a workbench. Apply drive pinion retaining screw (57) with flat washer (58) and tighten to a torque of 109 N•m (80 ft-lbs).

CAUTION

Retaining screw will have LH thread on RH rotation motor and RH thread on LH rotation motors.

27. Remove starter assembly from vice and place on workbench. Apply rear motor housing cover plug (2) and tighten securely.

MOTOR INSTALLATION

1. Install each starting motor and drive assembly in position on the mounting bracket.

2. Install three bolts to secure each motor to the mounting bracket.

3. Connect air supply and exhaust lines.

SINGLE AIR STARTING MOTOR SYSTEM (8-CYL.)

DESCRIPTION

The use of one starting motor rather than two is the only component difference between this system and a dual system. Minor operation differences are noted in the components descriptions which follow.

MAINTENANCE

Refer to Fig. 14-3 or Fig. 14-4 and to the procedures as detailed under the dual motor systems.

UNATTACHED ACCESSORIES

The air line lubricator, strainer, air start valve, solenoid valve, and shutoff valve are components of the engine air starting system. They are mounted on the side of the engine base below the starting motors.

AIR LINE LUBRICATOR

DESCRIPTION

The air line lubricator, Fig. 14-5, located between the air start valve and the starting motor, emits an oil-air mist into the starting system air to provide lubrication for the starting motor. The main components of the lubricator are the oil bowl, needle valve, siphon tube, and venturi tube.

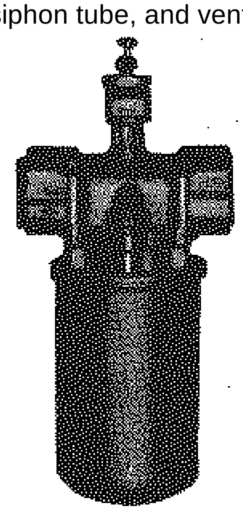


Fig. 14-5 - Air Line Lubricator

As air enters the lubricator, the oil bowl is pressurized by way of the reversible venturi tube. The air flow creates a reduced pressure area as it passes through the venturi section causing the oil in the bowl to go up the siphon tube into the chamber above the drip gland. At this point, the quantity of oil entering the air line is controlled by a needle valve. As the oil enters the air line it is diffused into a mist which is carried into the air starting motor. A sight glass below the needle valve gives visual indication of the flow rate of oil into the air line.

MAINTENANCE

The oil level in the bowl should be checked at intervals as specified in the Scheduled Maintenance Program. In addition to checking oil level, the needle valve should be checked to ensure that the flow rate is one to two drops per second. This can be checked visually through the sight glass in the front of the lubricator. If oil does not flow, remove top plug and drip gland. Clean parts and passages, using kerosene and blow out with compressed air.

Replace any defective gaskets or packing. Reassemble, tightening drip gland firmly, but carefully.

Compounded oils containing graphites, soap, or fillers should not be used in the lubricator.

AIR START VALVE

DESCRIPTION

When the pinion gear in the motor (both motors in dual system) is engaged with the ring gear, air is released from the upper motor to the air start valve. Air enters the air start valve and forces the valve stem up unseating the valve seat, Fig. 14-6, releasing the main starting air supply to the motor. When the starting control valve is released and the air solenoid closes off the control air supply to the motor, the supply of air to the air start valve is shut off, which cuts off the main air supply to the motor.

MAINTENANCE

No periodic maintenance should be required, however, if at any time the valve seat becomes dirty and is not shutting off the main air supply properly, the seat can be removed and cleaned.

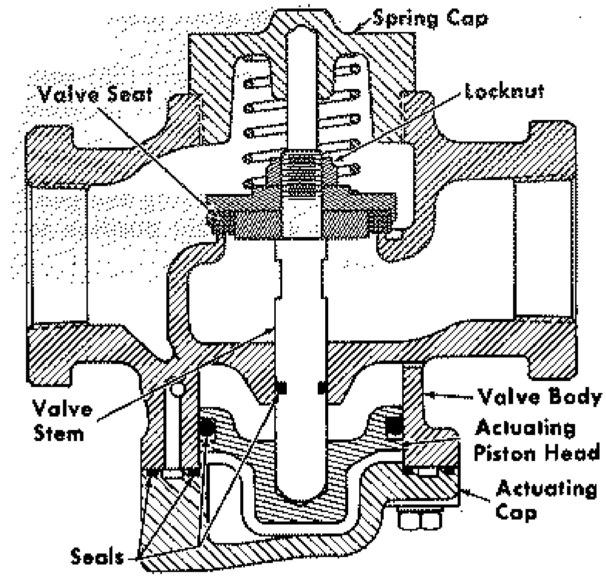


Fig. 14-6 - Air Start Valve

DISASSEMBLY

1. Unscrew the spring cap on top of the valve, Fig. 14-16, and remove the spring.

2. Unscrew the locknut holding the valve seat assembly to the valve stem and remove the valve seat assembly.
3. If the valve seals need replacement due to leakage, remove the bolts holding the actuating cap to the valve body, remove the actuating piston head and replace seals.

SHUTOFF VALVE

DESCRIPTION

A manually operated ball-type shutoff valve, Fig. 14-7, is used in the starting motor systems. The valve closes off air to the starter motor when maintenance work is being performed to prevent inadvertent engine starting. The valve has a locktype handle which provides an additional safety feature in preventing unintentional movement of the valve.

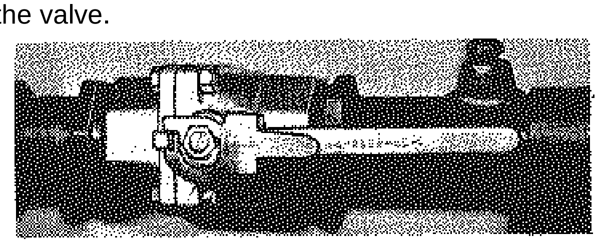


Fig. 14-7 - Shutoff Valve

MAINTENANCE

The wiping action of the ball dislodges any foreign material which may enter the valve, making the valve self-cleaning. In addition, the seat material contains a lubricant which provides the required lubrication for the/ball. The only parts requiring replacement under normal operating conditions are the seats and the "O" rings.

SOLENOID VALVE

DESCRIPTION

The solenoid valve, Fig. 14-8, opens when current is applied to the solenoid, and returns to the normally closed position when the current is cut off. In the energized or open position, control air is directed behind the pinion gear of the lower starting motor. When the pinion gear is engaged with the ring gear, a port is opened in the motor allowing the air to continue on to the upper motor. When both pinion gears are engaged the control air opens the air start valve allowing the main air supply to be released to the motors. A "T" handle override valve is provided for emergency use or, with shutoff valve closed, to engage pinion gear(s) when barring engine over.

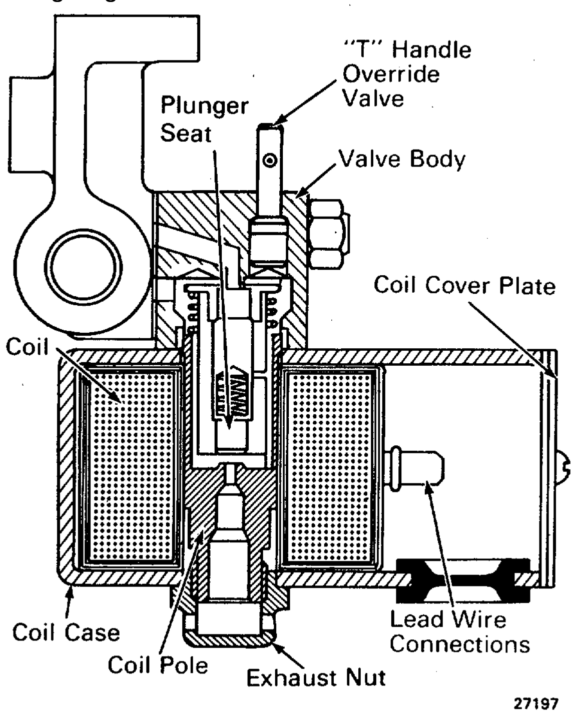


Fig. 14-8 - Solenoid Valve

MAINTENANCE

Before performing any maintenance on the solenoid valve, make sure the electrical power and air pressure have been turned off.

CLEANING

Sluggish valve operation or excessive leakage will indicate that cleaning is required. The frequency of cleaning, however, will be determined by operating conditions. Clean the moving parts and air passages thoroughly, using a good commercial solvent.

COIL REPLACEMENT

Remove front cover plate from coil case and disconnect coil lead wires. Remove the exhaust nut from the bottom of the coil case and slip the coil and coil case off the coil pole. Reassemble the components in the reverse order of disassembly, connect the coil leads, and replace the coil case cover plate.

AIR LINE STRAINER

DESCRIPTION

The air line strainer, Fig. 14-9, is a Y-shaped cast iron housing containing a cylindrical monel mesh screen. The strainer is located ahead of the shutoff valve in the system. One end of the screen fits into a recess in the diagonal wall of the strainer body and

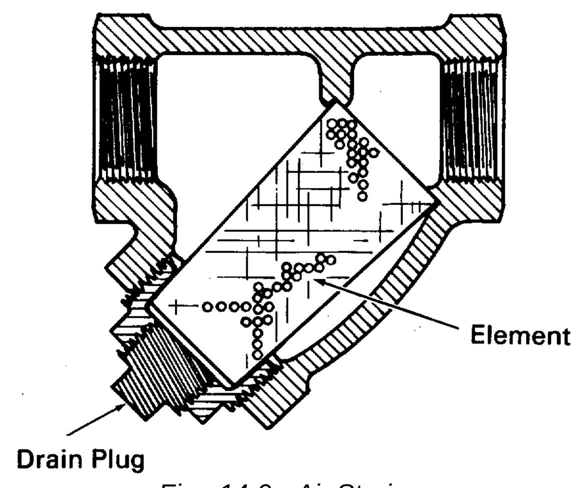


Fig. 14-9 - Air Strainer

the other end is held in position by a bolted end cap. This strainer effectively removes impurities from the air being piped to the air starting system.

MAINTENANCE

The only type of maintenance required on the strainer is to check the condition of the screen periodically and clean if required. The frequency of these inspections will be determined by the conditions under which the equipment has been operating.

SERVICE DATA

AIR STARTING SYSTEM

SPECIFICATIONS

Clearance and dimensional limits listed below are defined as follows:

1. *New limits are those to which new parts are manufactured. (Drawing tolerances.)*

2. *Minimum, maximum, and tolerance measurements are provided as service limits. At time of rebuild or any time unscheduled maintenance is performed, the service limits should not be exceeded. Engine components within these limits may be reused with the assurance that they will perform satisfactorily until the next scheduled overhaul.*

Starting Motors

Backlash between ring gear and starter pinion.. 0.38-1.02 mm (.015"-.040")

Parallelism of pinion and ring gear teeth.. 0.05 mm (.002")

Screw shaft and pinion assembly free travel (with spring compressed).................................. 4.76 mm (3/16")

SECTION 15A

PROPULSION UNIT ENGINE CONTROL CABINET

CONTENTS PAGE

55E880

PROPULSION UNIT ENGINE CONTROL CABINET

The propulsion unit engine control cabinet, Figs. 15A-1 and 15A-2, is mounted on the accessory rack. The cabinet contains the switches, gauges, and controls to operate the unit and contains alarm indicators which signal engine or system malfunctions. This section contains a legend of switches and relays, switch and relay settings, and a brief description of engine control cabinet components. Refer to System Troubleshooting Section for a functional checkout of the alarm circuits.

A particular unit may not have all the switches, relays, or electrical equipment listed. Actual equipment can only be determined from assembly drawings and schematic diagrams for that particular installation.

LEGEND OF ELECTRICAL DEVICES

Switches, relays, and electrical equipment bear names descriptive of their functions or relationship to other components. Identification letters for components are generally direct abbreviations of the names. A legend of switches, relays, and electrical equipment follows.

SWITCH LEGEND

Legend	Description
CAS	Clutch Air
CPS	Crankcase Pressure
ETS	Engine Temperature
FPS	Fuel Pressure
FVS	Filter Vacuum
GCS	Gear Cooler
HOS	High Oil Temperature
IHTS	Immersion Heater Temperature
LLS	Low Oil Level
LOS	Lube Oil Pressure

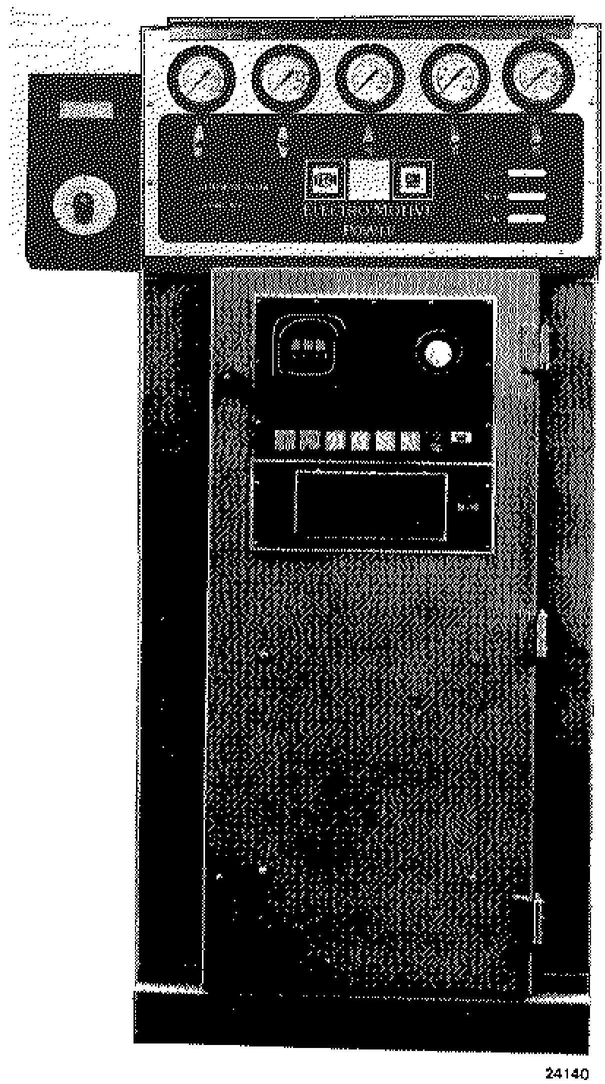


Fig.15A-1 - Typical Engine Control Cabinet, Front Exterior

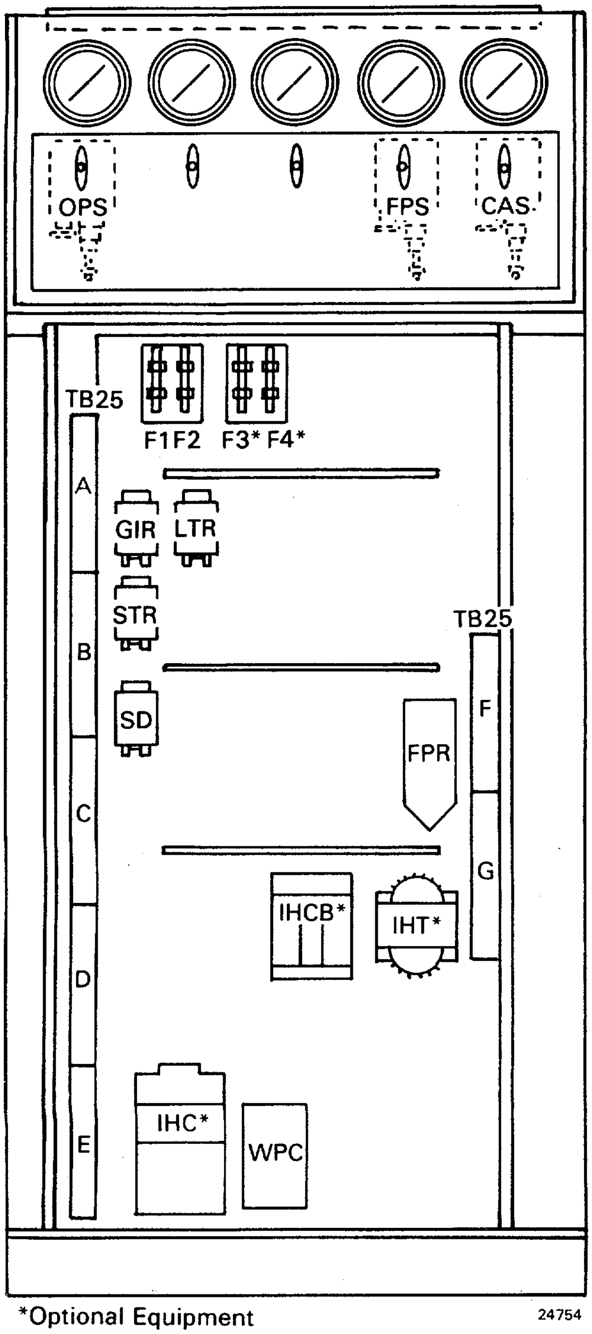


Fig. 15A-2 - Typical Engine Control Cabinet Front Interior

LTS	Low Oil Temperature
LWS	Low Water Pressure
OPS	Oil Pressure
OTLS	Overspeed Trip Limit
WLS	Water Level

RELAY LEGEND'

Annunciator Relays

Legend	Description
OP (K1)	Lube Oil Pressure
CP (K2)	Crankcase Pressure
HE (K3)	Hot Engine
OL (K4)	Lube Oil Level
WL (K6)	Water Level
LW (K6)	Low Water Pressure
HO (K7)	High Oil Temperature
CA (K8)	Low Clutch Air
OT (K9)	Overspeed Tripped
FV (K10)	Filter Vacuum
GC (K11)	Gear Cooler
AR (K13)	Alarm Relay

SYSTEM RELAYS

Legend	Description
FPP	Fuel Prime
FPR	Fuel Pressure
GIR	Governor Idle
LTR	Low Oil Temperature
SD	Shut Down
STR	Start

EQUIPMENT LEGEND

Legend	Description
ETI	Elapsed Time Indicator
FPM	Fuel Prime Motor
GS	Governor Solenoid
IHC	Immersion Heater Contactor

IHCB (CBIH) Immersion Heater Circuit Breaker
IHT Immersion Heater Transformer
SM Starting Magnet Valve
WPC Water Pump contactor

RELAY AND SWITCH SETTINGS

Data relative to pickup and dropout of the system switches follow. Disregard any listing not applicable to a particular installation.

NOTE

The switch and relay settings listed are for a typical propulsion unit. Individual control options and customer supplied equipment may require changing applicable switch and relay settings. All remote monitoring equipment provided by customer must be connected at the appropriate annunciator contacts identified for customer use and not at the switches.

ENGINE CONTROL PANEL

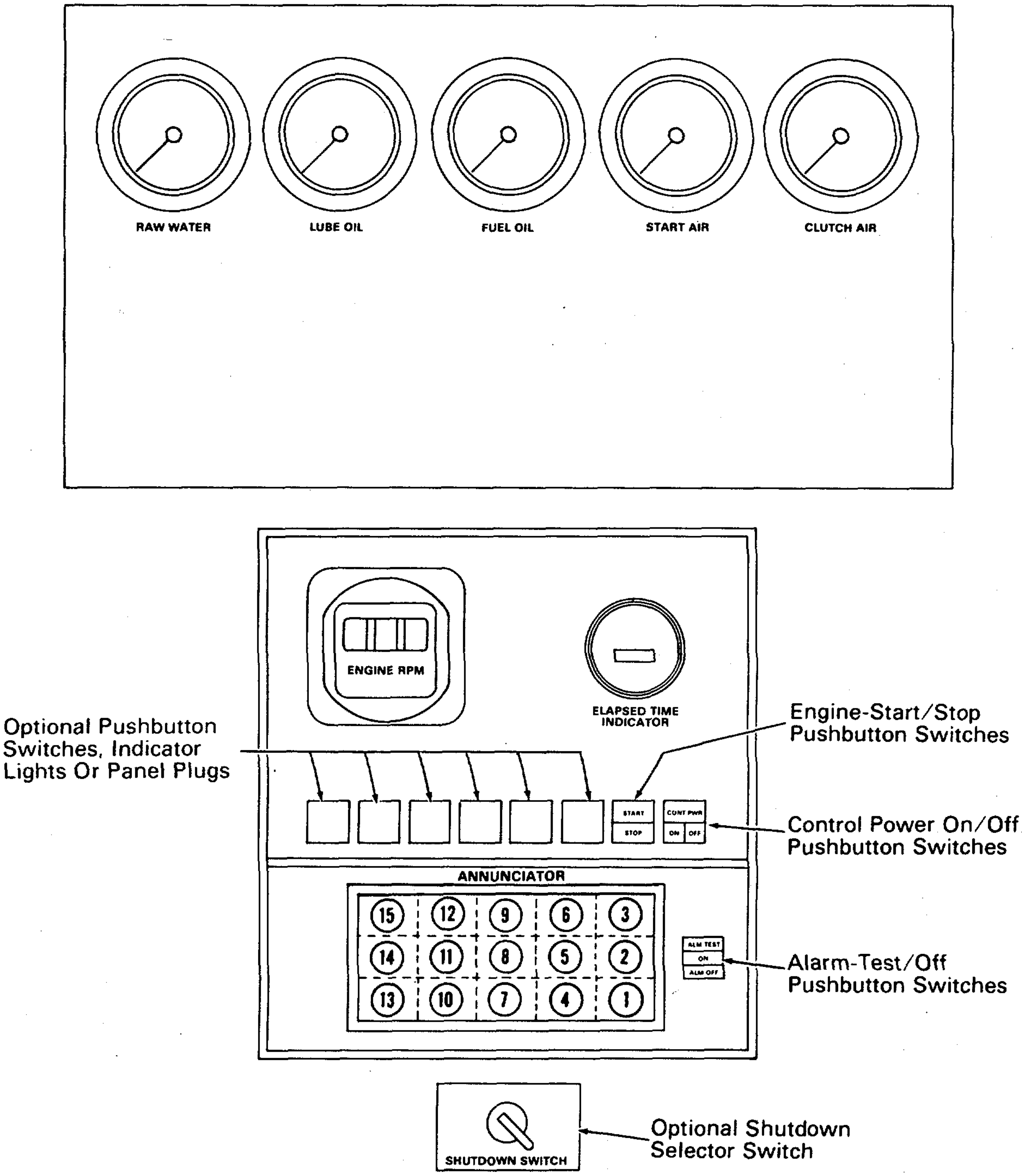
The engine control panel, Fig. 15A-3, contains warning lights, pressure gauges, and controls required to operate the unit.

Relays And Switches	Pickup Value	Dropout Value
CAS	827 kPa (120 psi)	758 kPa (110 psi)
CPS	20-46 mm (0.8"-1.8') H_20	
ETS	98° C (2080 F)	92°C (1980 F)
FPR		60 + 5 -0 Seconds
FPS	83 kPa (12 psi)	62 kPa (9 psi)
FVS	279 mm (11") H_20* 178 mm (7") H_20**	
GCS		35 kPa (5 psi)
HOS	104° C (220° F)	990 C (210° F)
IHTS	51.5° C (125° F)	68.5° C (155° F)
LTS	35° C (95° F)	29° C (85° F)
LWS/OPS	145 kPa (21 psi)	117 kPa (17 psi)

NOTE

All settings without tolerance are nominal. For exact value see device drawing.

*Pleated paper element filter application.
**Bag-type fiberglass element filter application.



1. Circulate Oil Pressure*
2. Lube Oil Level
3. Lube Oil Pressure
4. Low Fuel Pressure*
5. Low Turbo Oil Pressure*
6. Overspeed Tripped
7. Water Level
8. Low Clutch Air*
9. Crankcase Pressure
10. Start Failure*
11. Gear Cooler Pressure*
12. Hot Engine
13. Low Oil Temperature*
14. Engine Air Filter*
15. High Oil Temperature

*Optional Or Unused Warning Lights

24755

Fig. 15A-3 - Engine Control Panel

GAUGES

The following pressure gauges are provided on the engine control cabinet:

Raw Water (Optional)	Start Air
Lube Oil	Clutch Air
Fuel Oil	

SWITCHES

The following switches are available on the engine control cabinet:

CONTROL POWER Pushbuttons

ON and OFF pushbuttons are used to control the input power to the engine control cabinet. Pressing the ON pushbutton turns power on and actuates a "Control Power" indicator light on the control power switch and the "ON" indicator light on the alarm test switch. Pressing the OFF pushbutton turns power and indicator lights off.

ENGINE START/ENGINE STOP Pushbuttons

The ENGINE START and ENGINE STOP pushbuttons are used to manually start and stop the engine at the engine control cabinet. The ENGINE START pushbutton is pressed and held in to start the engine, then released. Engine running speed after start is controlled by the governor. Pressing the stop pushbutton will shut down the engine.

ALARM TEST AND ALARM OFF Pushbuttons

ALARM TEST pushbutton is used to test the operation of the warning lights and alarm device. Pressing the pushbutton will sound the alarm and turn on all the warning lights. Pressing the ALARM OFF pushbutton will silence the alarm and turn off all the warning lights. During an actual alarm event, the ALARM OFF pushbutton is used to silence the alarm, but the respective warning light will remain lit until the malfunction is corrected.

FUEL PRIME Pushbutton (Optional)

A switch used to automatically prime the engine prior to start up. Pressing the FUEL PRIME pushbutton establishes a circuit to the motor driven fuel pump. Button should be held in to operate the pump until fuel pressure is indicated on the FUEL OIL pressure gauge.

IMMERSION HEATER Pushbuttons (Optional)

ON and OFF pushbuttons are used to control power to the immersion heater circuit and the water circulating pump. Pressing the ON pushbutton starts the water circulating pump and energizes the immersion heater. Pressing the OFF pushbutton turns pump and heater off. This switch is normally left in the ON position.

SHUTDOWN SELECTOR Switch (Optional)

A switch used to select one of two possible responses to an alarm event caused by either an excessive crankcase pressure or low oil pressure condition. In the NORMAL SHUTDOWN position, activation of the alarm system due to either condition will cause the engine to shutdown. Placing the selector switch in the EMERGENCY ALARM position turns on a "SHUTDOWN SELECTOR" indicator light and allows only the alarm system to activate in response to these conditions.

WARNING LIGHTS

The following warning lights are available on the engine control cabinet:

C' CASE PRESSURE

Indicates that there is a positive pressure (rather than the normal negative pressure) in the crankcase. A crankcase pressure of 20-46 mm (0.8"-1.8") H_20 will light a warning light, sound the alarm, and cause the engine to shutdown.

HOT ENGINE

Engine water temperature 98°C (208°F) will light a warning light and sound the alarm.

OVERSPEED TRIPPED

If engine RPM should exceed specified limit, a warning light comes on, alarm will sound, and engine will shut down.

HI-OIL TEMP.

Engine lube oil temperature of 104°C (220° F) will light a warning light and sound the alarm.

LOW CLUTCH AIR (Optional)

When clutch air pressure drops to below 758 kPa (110 psi), a warning light comes on and alarm will sound.

LUB OIL LEVEL

Provided to alert operator of an insufficient oil supply. When lube oil supply is reduced to a predetermined level in the crankcase (oil pan) a warning light comes on and the alarm will sound.

LUB OIL PRESSURE

When governor oil pressure drops below 48 kPa (7 psi) at low speed or below 131 kPa(19 psi) at high speed, a warning light comes on and alarm will sound.

ENG. AIR FILTER (Optional)

Provided on engines equipped with disposable bag-type fiberglass or pleated paper element air filters. When air inlet depression in the air filter housing is greater than 279 mm (11') H20 for pleated paper element filters or 178 mm (7') H_20 for fiberglass element filters, a warning light comes on and the alarm will sound.

WATER LEVEL

Provided to alert operator of an insufficient water supply. When water supply is reduced to a predetermined level in the expansion tank, a warning light comes on and the alarm sounds.

GEAR COOLER PRESSURE (Optional)

When skin cooler water pressure in the reduction gear lube oil cooling system drops to below 35 kPa (5 psi), a warning light comes on and the alarm will sound.

PYROMETER AND SELECTOR SWITCH (Optional)

A unit can be equipped with a pyrometer and selector switch mounted on the side of the engine control cabinet, Fig. 15A-4. The pyrometer is to be connected by the customer to outlet boxes mounted along the engine exhaust manifold. Thermocouples are installed in each engine exhaust manifold riser to indicate the exhaust gas temperature. The pyrometer has a temperature range of 0 to 649° C (1200° F) and the selector switch can monitor up to 16 cylinders. Refer to Air Intake And Exhaust Systems section of this manual for outlet box and thermocouple connections.

SYSTEM RELAYS

The system relays, Fig. 15A-5, are located on the back wall of the engine control cabinet. Each relay, Fig. 15A-6, is used in a respective engine start, run, or shutdown system function. Refer to Service Data for relay specifications, operational voltages and hipot test. Refer to Troubleshooting section of this manual for description of circuits involving these relays.

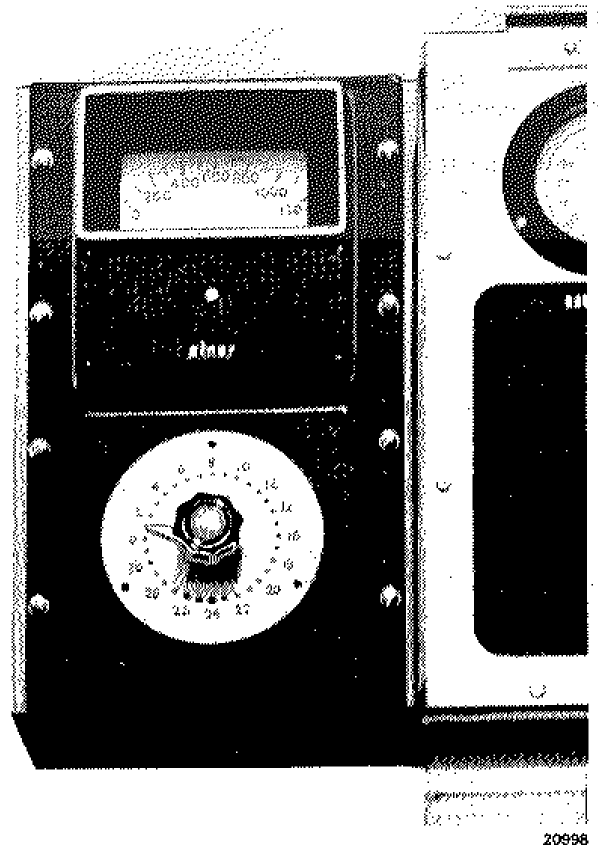


Fig. 15A-4 - Pyrometer And Selector Switch

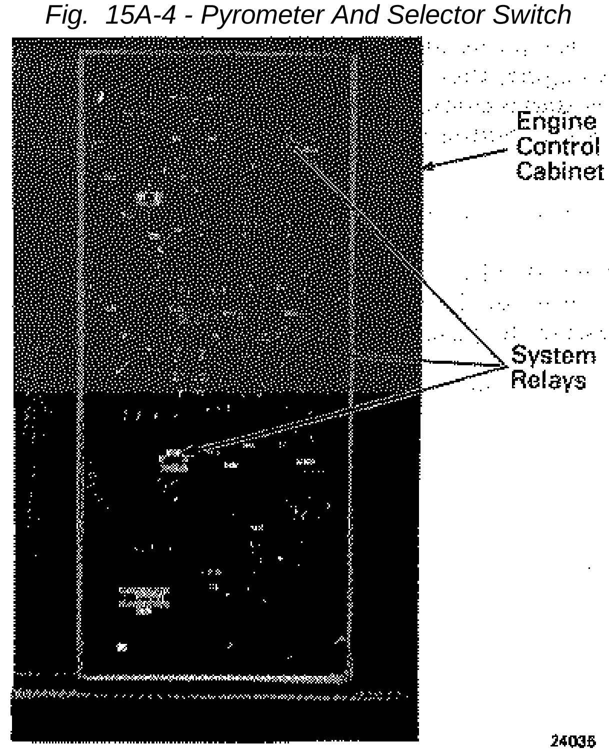


Fig. 15A-5 - System Relays

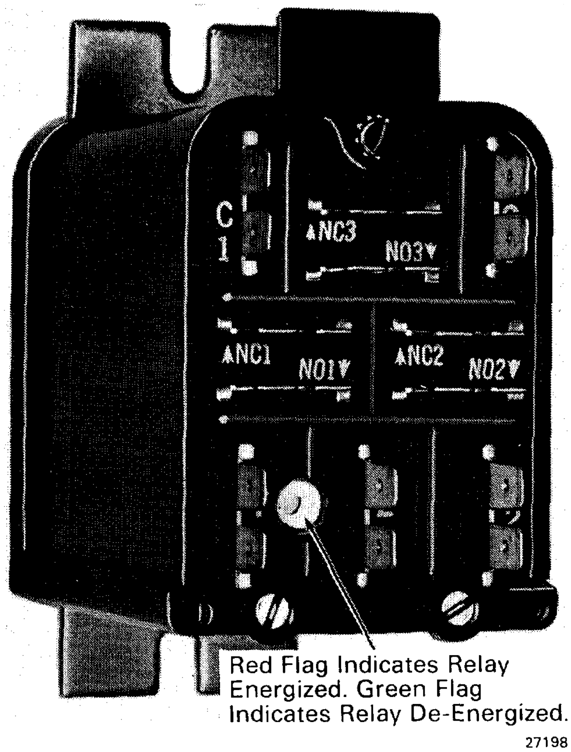


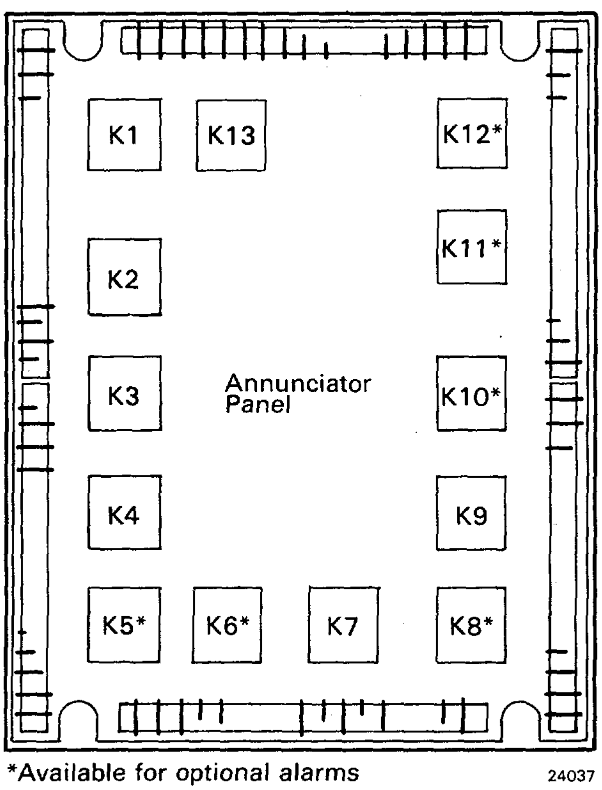
Fig. 15A-6 - System Relay

ANNUNCIATOR RELAYS

Basically, each main engine system is monitored by a switch which keeps a respective annunciator relay energized during normal operation, preventing an alarm. If a malfunction should occur, the switch opens and de-energizes a relay which operates the alarm system. A typical alarm system circuit with switch, corresponding annunciator relay, warning light and alarm is described on page 15A-9.

ANNUNCIATOR RELAY PANEL

The annunciator relay panel, Fig. 15A-7, is located on the inside of the engine control cabinet door. The panel contains the annunciator relays and associated electronics which control the warning lights and alarm bell. Refer to Fig. 15A-8 for annunciator relay schematic diagram Refer to Service Data for relay specifications and operational voltages.



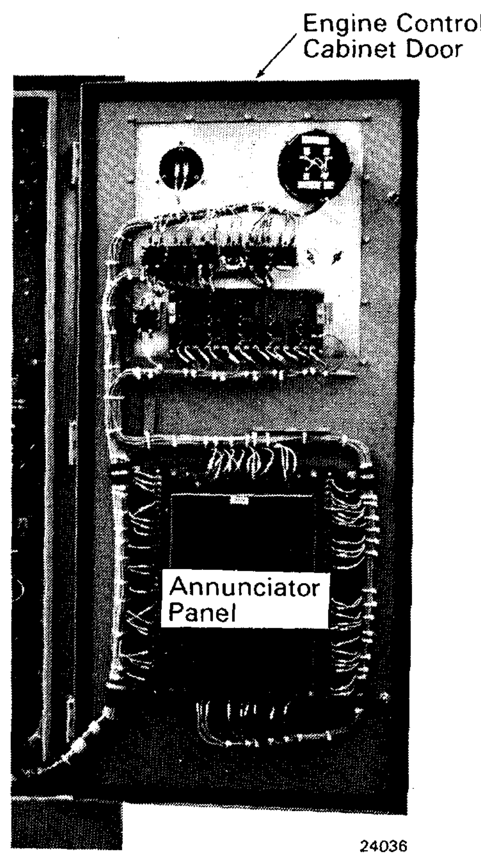


Fig. 15A-7 - Anunciator Relay Panel

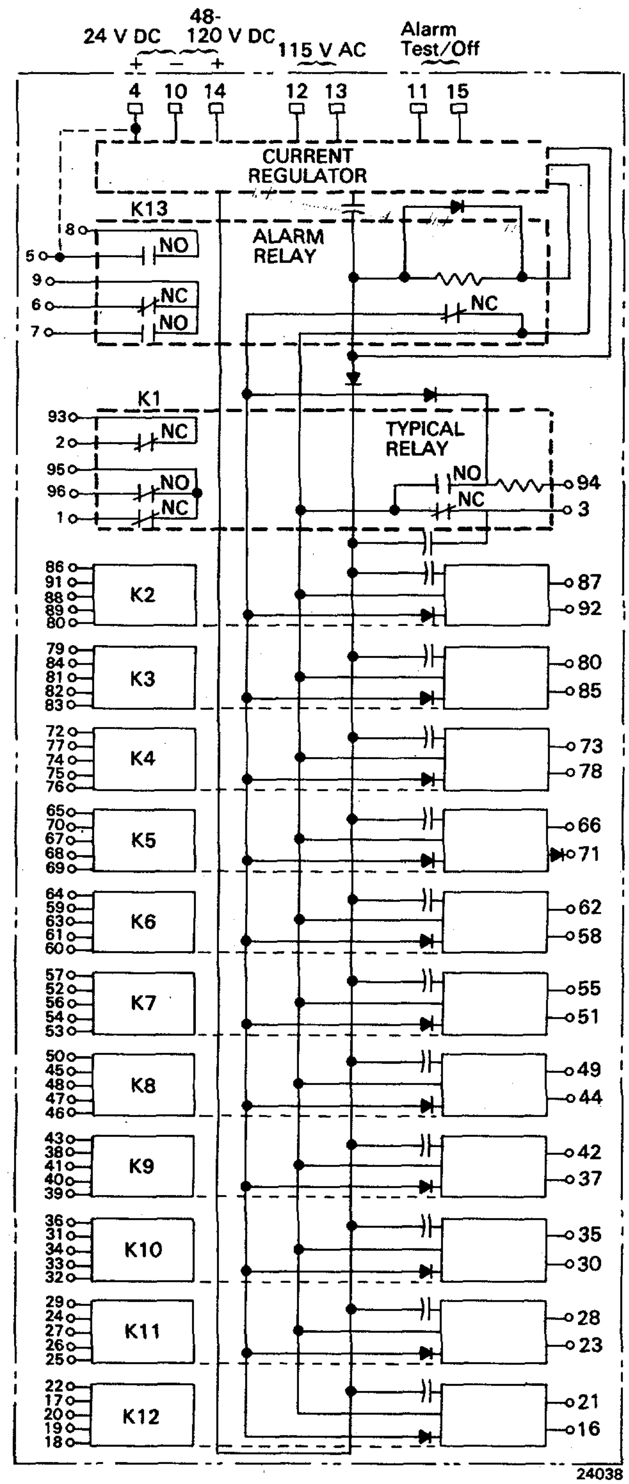


Fig. 15A-8 - Annunciator Relay Schematic Diagram

ALARM SYSTEM LEGEND

System Switch	Annunciator Relay	Warning Light	Alarm Relay
LOS	OP (K1)	Lube Oil Press.	AR (K13)
CPS	CP (K2)	C"Case Press.	AR (K13)
ETS	HE (K3)	Hot Engine	AR (K13)
LLS	OL (K4)	Lube Oil Level	AR (K13)
LWS	LW (K6)	Water Level	AR (K13)
WLS	WL (K6)	Water Level	AR (K13)
HOS	HO (K7)	High Oil Temp.	AR (K13)
CAS	CA (K8)	Low Clutch Air	AR (K13)
OTLS	OT (K9)	Overspeed Tripped	AR (K13)
FVS	FV (K10)	Eng. Air Filter	AR (K13)
GCS	GC (K11)	Gear Cooler Press.	AR (K13)

NOTE

A crankcase pressure malfunction or an overspeed condition will also shut down the engine.

TYPICAL ANNUNCIATOR OPERATION

The annunciator operation is basically the same for all alarms. The hot engine alarm circuit through the annunciator is described to explain typical annunciator operation.

HOT ENGINE ALARM CIRCUIT

During normal operation, the hot engine relay HE coil is picked up through normally closed contacts of the alarm relay AR and latched in by its own normally open contacts. The negative side of the HE relay is connected through the engine temperature switch ETS and the alarm test switch. Dropout of the ETS switch causes the following (Fig. 15A-9):

HE normally closed contacts close.

Completes a circuit to HOT ENGINE warning light located on the hidden legend annunciator light panel.

Provides a positive 24 volt feed to a charging circuit which picks up and holds alarm relay AR coil energized, establishing alarm circuit.

NOTE

Primary alarm device is installed in this circuit at a terminal barrier strip in the engine control cabinet. Additional terminals are provided for a second remote alarm device. Refer to wiring diagrams for the particular installation to identify terminals.

When ALARM OFF pushbutton is pressed:

Positive 24 volt feed to charging circuit is interrupted causing alarm relay AR coil to deenergize and return contacts to normally closed position, breaking circuit to alarm device.

HOT ENGINE warning light remains lit until engine temperature is reduced allowing ETS switch to close.

When ETS switch closes:

HE relay coil picksup returning contacts to normally open position, breaking circuit to HOT ENGINE warning light.

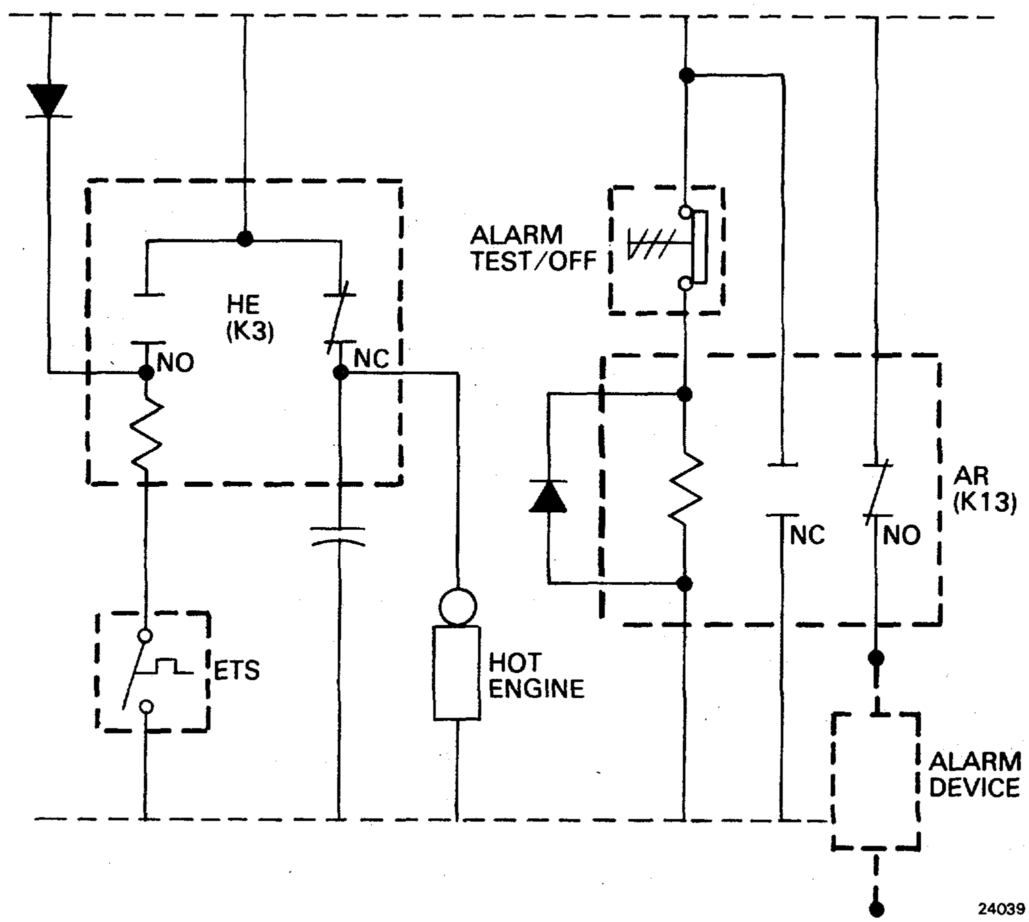


Fig. 15A-9 - Typical Annunciator Circuit
(Shown In Alarm Condition)

SERVICE DATA

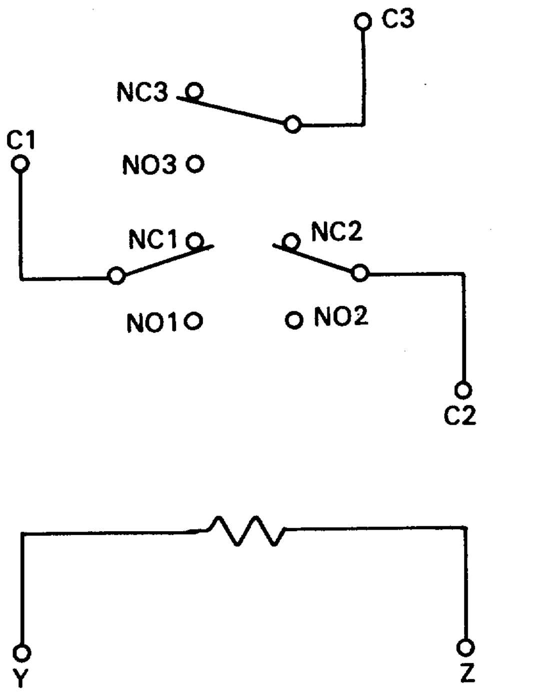
PROPULSION UNIT
ENGINE CONTROL CABINET

SPECIFICATIONS

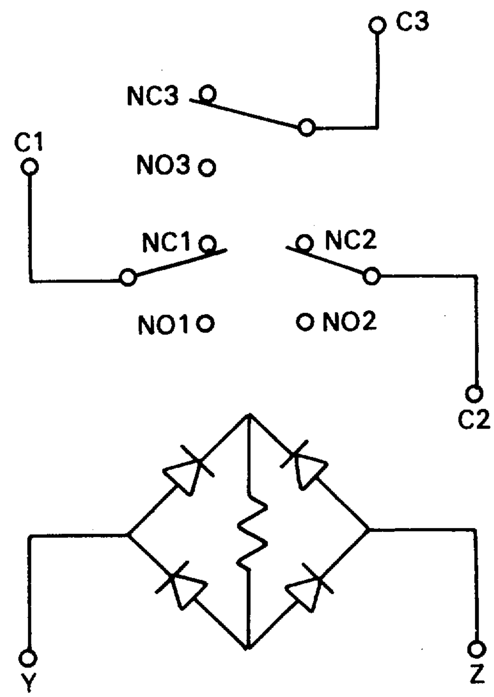
Clearance and dimensional limits listed below are defined as follows:

1. *New limits are those to which new parts are manufactured. (Drawing tolerances.)*

2. *Minimum, maximum, and tolerance measurements are provided as service limits. At time of rebuild or any time unscheduled maintenance is performed, the service limits should not be exceeded. Engine components within these limits may be reused with the assurance that they will perform satisfactorily until the next scheduled overhaul.*



74V DC System Relay Schematic Diagram



120V AC System Relay Schematic Diagram

24143

74V DC System

Contacts

3 Normally Open Or
3 Normally Closed.................... 10 amp, 74 VDC

Coil (at 25° C).............................. 176 ohms ± 10%

Operations (at 25° C)

Working Voltage ....28 VDC

Pickup - Max. ....18 VDC

Dropout..1-9 VDC

120V AC System

Contacts

3 Normally Open Or
3 Normally Closed ....5 amp, 120 VAC

Coil (at 20° C) .... 4320 ohms ± 20%
(Y to Z- 16,500 ohms ± 20%)

Operations (at 20° C)

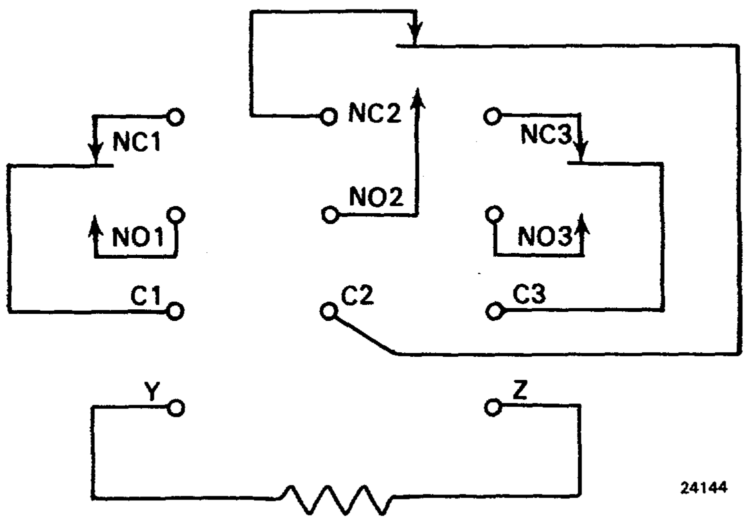
Working Voltage...................................120 VAC

Pickup - Max. .... 98 VAC

Dropout .... 5-65 VAC

74 VDC System Relay - continued		120 VAC System Relay - continued	
Hi-Pot	60 Hz, 1 Minute	Hi-Pot	60 Hz, 1 Minute
Coil To Ground	1000 V RMS	Coil To Ground	
Coil To Contacts	2400 V RMS	Coil To Contacts	1500 V RMS
Contacts To Ground	2400 V RMS	Contacts To Ground	1500 V RMS
Contact To Contact	2400 V RMS	Contact To Contact	1500 V RMS

ANNUNCIATOR RELAY



24 VDC Annunciator Relay Schematic Diagram

Contacts

3 Pole, Double Throw .... 1.5 amp, 74 VDC

Coil (at 25° C) .... 315 ohms ± 10%

Operations (at 25° C)

Working Voltage .... 24 VDC

Pickup-Max. .... 18 VDC

Dropout .... 1-9 VDC

Hi-Pot — 60 Hz, 1 Minute

Coil To Frame .... 1000 V RMS

Coil To Contacts
Contacts To Ground
Contact To Contact } .... 2400 V RMS

SECTION 15B

GENERATING UNIT ENGINE CONTROL CABINET

55E880

ELECTRO-MOTIVE

645E6
Marine Engine/Systems

GENERATING UNIT ENGINE CONTROL CABINET

The generating unit engine control cabinet, Figs. 15B-1 and 15B-2, is mounted on the accessory rack. The cabinet contains the switches, gauges, and controls, Fig. 15B-3, to operate the unit, and contains alarm indicators which signal engine or system malfunctions. This section contains a legend of switches and relays, switch and relay settings, and a brief description of engine control cabinet components of the type cabinet shown in Fig. 15B-1.

A particular unit may not have all the switches, relays, or electrical equipment listed. Actual equipment can only be determined from assembly drawings and schematic diagrams for that particular installation.

LEGEND OF ELECTRICAL DEVICES

Switches, relays, and electrical equipment bear names descriptive of their functions or relationship to other components. Identification letters for components are generally direct abbreviations of the names. A legend of switches, relays, and electrical equipment follows.

SWITCH LEGEND

Legend	Description
COPS	Circulating Oil Pressure
CPS	Crankcase Pressure
ETS	Engine Temperature
FPS	Fuel Pressure
FVS	Filter Vacuum
GCS	Governor Control
HOS	High Oil Temperature
IHTS	Immersion Heater Temperature
LLS	Low Oil Level

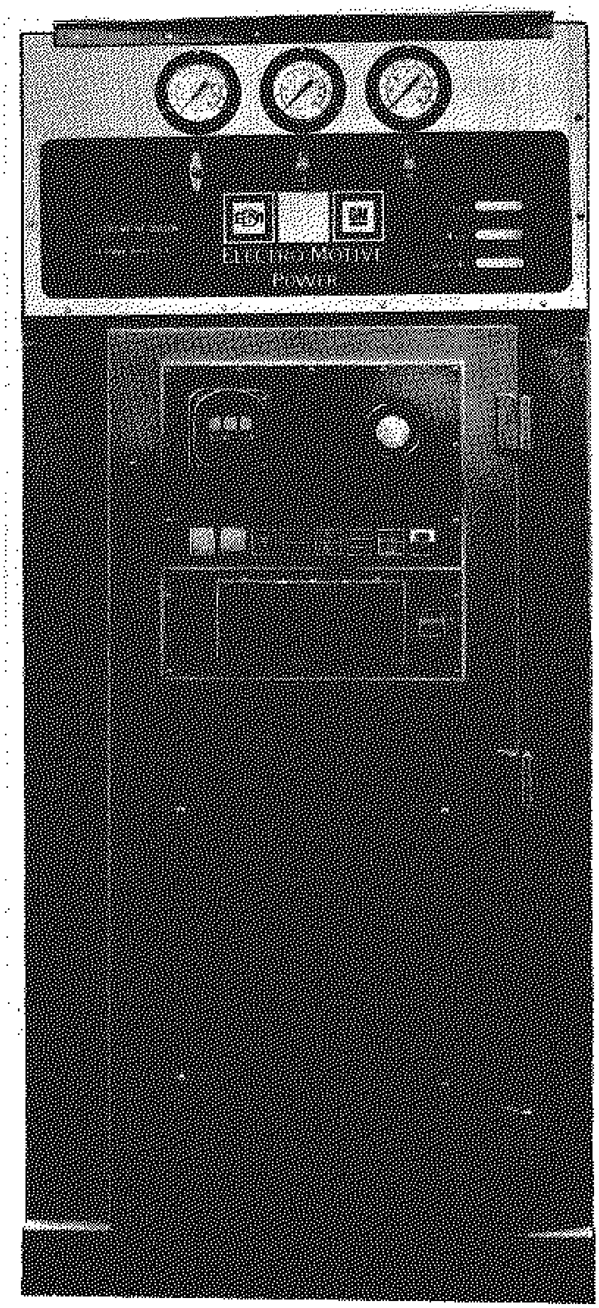


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Fig. 15B-1 - Typical Engine Control Cabinet, Front Exterior

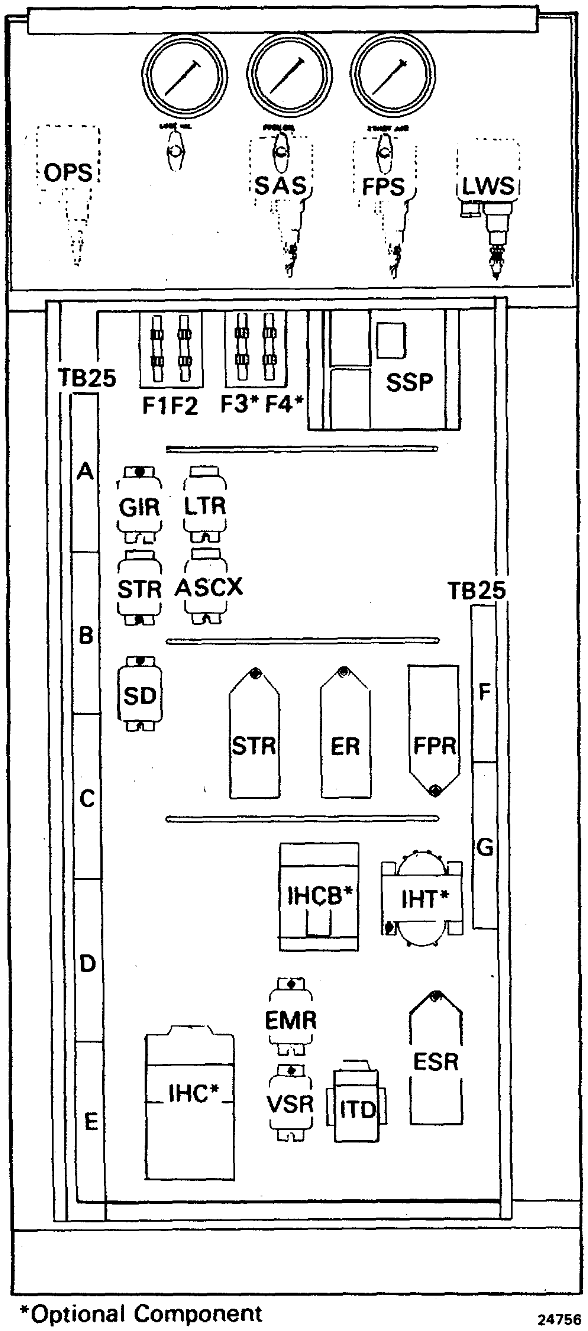

Fig.15B-2 - Engine Control Cabinet, Front Interior

LTS	Low Oil Temperature
LWS	Low Water Pressure
OPS	Oil Pressure
OTLS	Overspeed Trip Limit
SAS	Start Air Pressure
SSP	Speed Sensing Panel
WLS	Water Level

RELAY LEGEND

ANNUNCIATOR RELAYS

Legend	Description
OP (K 1)	Lube Oil Pressure
CP (K 2)	Crankcase Pressure
HE (K 3)	Hot Engine
OL (K 4)	Lube Oil Level
FP (K 5)	Fuel Pressure
WL (K 6)	Water Level
LW (K 6)	Low Water Pressure
HO (K 7)	High Oil Temperature
LO (K 8)	Low Oil Temperature
OT (K 9)	Overspeed Tripped
CO (K 10)	Circulating Oil Pressure
FV (K 10)	Filter Vacuum
SA (K 11)	Low Start Air
SF (K 12)	Start Failure
AR (K 13)	Alarm Relay

SYSTEM RELAYS

Legend	Description
ASCX	Auto Start Control Auxiliary
EC	Engine Cooling
ECA	Engine Cooling Auxiliary
EMR	Emergency Run
ER	Engine Run
ESD	Engine Start Delay

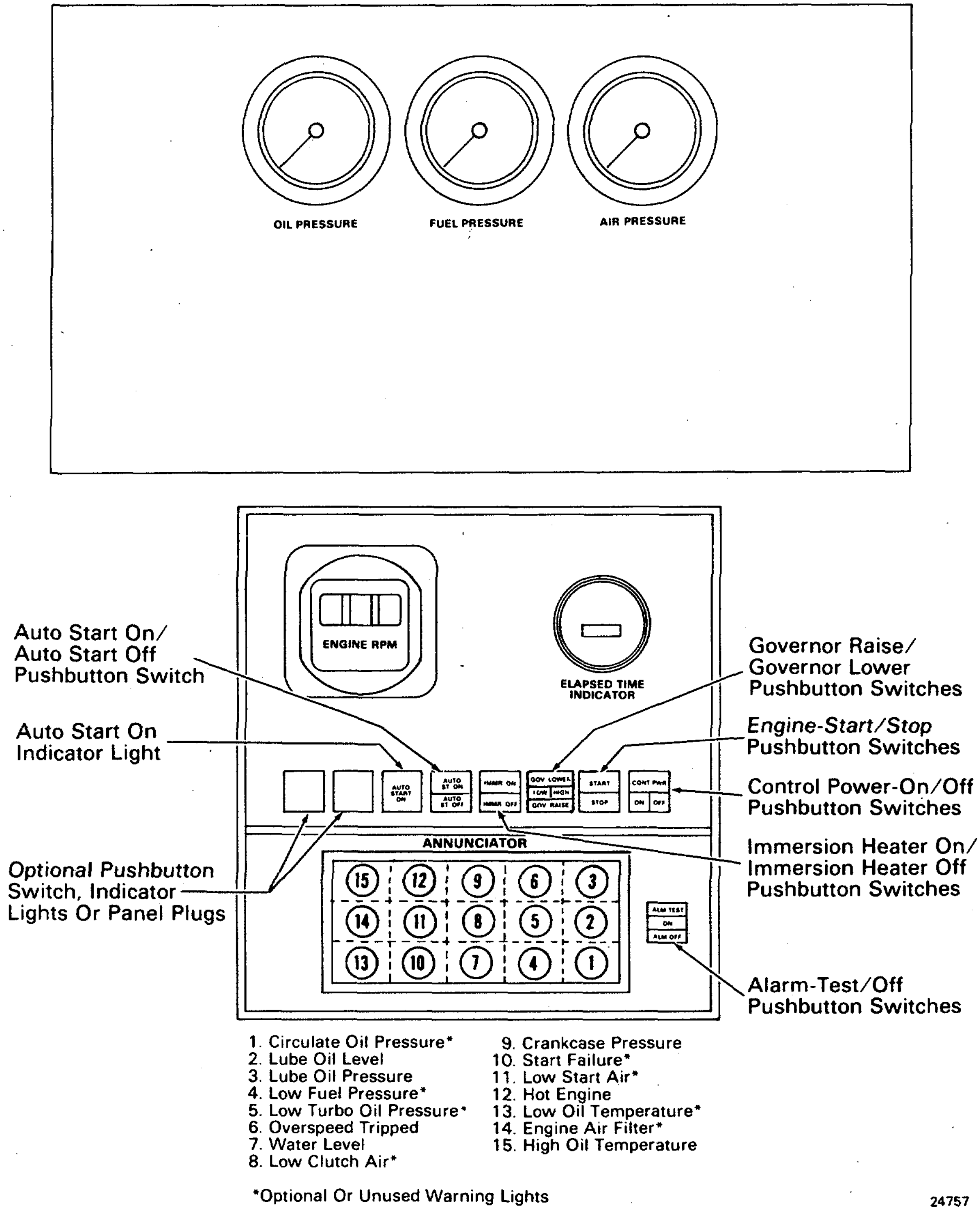

Fig.15B-3 - Engine Control Panel

ESR	Engine Speed (200 RPM)	LTR	Low Oil Temperature
FPP	Fuel Prime	OPSX	Oil Pressure Auxiliary
FPR	Fuel Pressure	SD	Shut Down
GIR	Governor Idle	STR	Start
ITD	Idle Time Delay	VSR	Engine Speed (870 RPM)

EQUIPMENT LEGEND

Legend	Description
CPM	Circulating Pump Motor
ETI	Elapsed Time Indicator
FPM	Fuel Prime Motor
GS	Governor Solenoid
IHC	Immersion Heater Contactor
IHCB (CBIH)	Immersion Heater Circuit Breaker
IHT	Immersion Heater Transformer
SM	Starting Magnet Valve

RELAY AND SWITCH SETTINGS

Data relative to pickup and dropout of the system switches follow. Disregard any listing not applicable to a particular installation.

NOTE

The switch and relay settings listed are for standard generating unit operation. Individual control options and customer supplied equipment may require changing applicable switch and relay settings. All remote monitoring equipment provided by customer must be connected at the appropriate annunciator contacts identified for customer use and not at the switches.

Relays And Switches	Pickup Value	Dropout Value
COPS	145 kPa (21 psi)	117 kPa (17 psi)
CPS	20-46 mm (0.8"-1.8") H_20	
EC		15 ± 0 -2 minutes
ER		10 ± 1 seconds
ES	200 ± 0 -20 RPM	
ESD		10 ± 1 -0 seconds
ESR		150 ± 10 seconds
ETS	88°C (190° F)	82°C (180° F)
ETSI	93°C (200° F)	88°C (190° F)
ETS2	98°C (208° F)	92°C (198° F)
FPR		60 ± 5 -0 seconds
FPS	83 kPa (12 psi)	62 kPa (9 psi)
FVS	279 mm (11") H_20*	
	178 mm (7") H_20**	
HOS	104° C (220° F)	99°C (210° F)
ITD		4 ± 1 seconds
LTS	35°C (95° F)	29°C (85° F)
LWS/OPS	145 kPa (21 psi)	117 kPa (17 psi)
SAS	931 Kpa (135 psi)	862 kPa (125 psi)
STR	15 ± 1 seconds	
VS	870 ± 20 RPM	

NOTE

All settings without tolerance are nominal. For exact value see device drawing.

*Pleated paper element filter application.
**Bag-type fiberglass element filter applications.

ENGINE CONTROL PANEL

The engine control panel, Fig. 15B-3, contains warning lights, pressure gauges, and controls required to operate the unit.

GAUGES

The following pressure gauges are provided on the engine control cabinet.

Gauges	Pickup Location
Oil Pressure	From oil monitor line with pickup at auxiliary drive housing. (Line enters engine at front, right bank, top deck frame.)
Fuel Pressure	In line between engine fuel pump and engine mounted fuel filter.
Air Pressure	At inlet to air starting system on right side of engine frame.

SWITCHES

The following switches are available on the engine control cabinet.

CONTROL POWER Pushbuttons

ON and OFF pushbuttons are used to control the input power to the engine control cabinet. Pressing the ON pushbutton turns power on and actuates a "Control Power" indicator light on the control power switch and the "ON" indicator light on the alarm test switch. Pressing the OFF pushbutton turns power and indicator lights off.

ENGINE START/ENGINE STOP Pushbuttons

The ENGINE START and ENGINE STOP pushbuttons are used to manually start and stop the engine at the engine, control cabinet. The ENGINE START pushbutton is pressed and held in to start the engine, then released. Engine running speed after start is controlled by the governor. Pressing the stop pushbutton will shutdown the engine.

NOTE

Prior to pressing the ENGINE STOP pushbutton, GOVERNOR LOWER control should be used to bring engine speed down to idle speed for a 17 minute cool down period.

ALARM TEST AND ALARM OFF Pushbuttons

ALARM TEST pushbutton is used to test the operation of the warning lights and alarm device. Pressing the pushbutton will sound the alarm and turn on all the warning lights. Pressing the ALARM OFF pushbutton will silence the alarm and turn off all warning lights. During an actual alarm event, the ALARM OFF pushbutton will silence the alarm, but the respective warning light will remain lit until the malfunction is corrected.

FUEL PRIME Pushbutton (Optional)

A switch used to automatically prime the engine. Use of the switch will operate a motor driven fuel pump (optional) to prime the engine prior to start up. AUTO START CONTROL Pushbuttons (Optional)

ON and OFF pushbuttons are used to select a start control mode as follows:

AUTO START ON Allows system to accept either an automatic start signal or a remote manual start signal.

AUTO START OFF System can be started manually from control panel only.

IMMERSION HEATER Pushbuttons (Optional)

ON and OFF pushbuttons are used to control power to the immersion heater circuit and the lube oil circulating pump. Pressing the ON pushbutton starts the lube oil circulating pump and energizes the immersion heater. Pressing the OFF pushbutton turns pump and heater off. This switch is normally left in the ON position.

GOVERNOR CONTROL Pushbuttons

GOVERNOR RAISE and GOVERNOR LOWER pushbuttons are used to manually change the engine speed. Pressing the GOVERNOR RAISE pushbutton will increase engine speed. Pressing the GOVERNOR LOWER pushbutton will decrease engine speed. High and low governor limit switches prevent raising or lowering engine speed beyond specific limits.

WARNING LIGHTS

The following warning lights are available on the engine control cabinet:

C'CASE PRESSURE

Indicates that there is a positive pressure (rather than the normal negative pressure) in the crankcase (oil pan). A crankcase pressure of 20-46 mm (0.8'1.8") H20 will light a warning light, sound an alarm, and shut down the engine.

HOT ENGINE

Engine water temperature 980 C (2080 F) will light a warning light and sound an alarm.

OVERSPEED TRIPPED

If engine RPM should exceed the specified limit, a warning light comes on, alarm will sound and engine will shut down.

HI-OIL TEMP.

Lube oil temperature of 1040 C (2200 F) will light a warning light and sound an alarm.

LOW FUEL PRESSURE (Optional)

Fuel pressure below 62 kPa (9 psi) will light a warning light and sound an alarm.

ENG. AIR FILTER (Optional)

Provided on engines equipped with disposable bag type fiberglass or pleated paper element air filters. When air inlet depression at the engine air inlet is greater than 279 mm (11") H20 for pleated paper element filters and 178 mm (7') H20 for fiberglass element filters, a warning light will come on and sound an alarm.

LOW OIL TEMP. (Optional)

Provided with immersion heater (optional). When engine is at standstill, immersion heater heats engine coolant, which heats the lubricating oil being circulated to enable an immediate engine start. Lube oil temperature of below 29 o C (85 o F) will light a warning light and sound the alarm.

LUB OIL LEVEL

Provided to alert operator of an insufficient oil supply. When lube oil supply is reduced to a predetermined level in the crankcase (oil pan), a warning light will come on and alarm will sound.

LUB OIL PRESSURE

Lube oil pressure below 117 kPa (17 psi) will light a warning light, sound the alarm, and cause engine shutdown.

WATER LEVEL (Optional)

Provided to alert operator of an insufficient water supply. When the water supply is reduced to a predetermined level in the expansion tank, a warning light comes on and alarm will sound.

CIRCULATING OIL PRESSURE (Optional)

Provided with immersion heater (optional). When engine is at standstill, immersion heater heats engine coolant which heats the lubricating oil being circulated. If circulating oil pressure drops below 1 17 kPa (I 17 psi), a warning light will come on, alarm will sound, and the starting system will be interrupted to prevent an engine start.

START FAILURE (Optional)

Provided on engines with automatic start control (optional). If engine fails to start within 15 seconds after a start signal is received, a warning light comes on, alarm will sound, and the starting circuit is interrupted to lockout another starting attempt.

LOW START AIR (Optional)

When start air pressure drops below 862 kPa (125 psi), a warning light comes on and alarm will sound.

SYSTEM AND ANNUNCIATOR RELAYS

The generating unit has the same basic system and annunciator relays as the propulsion unit with some application variations. Refer to Section 15A for description of these relays. Refer to Service Data in Section 15A for relay specifications, operating voltages and hi-pot test data. See Troubleshooting Section of this manual for description of circuits involved in operation of these relays.

SECTION 16

TROUBLESHOOTING

CONTENTS **PAGE**

TROUBLESHOOTING

INTRODUCTION

To derive maximum benefits from this section, it is recommended that the reader refer to the section Table of Contents to locate the specific area of interest.

All references made to other sections of this Engine Maintenance Manual, or to applicable Maintenance Instructions should be reviewed for additional information.

STARTING SYSTEM

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
STARTER WILL NOT CRANK ENGINE AT ALL	UNKNOWN - Whether due to fault in the starter system or a mechanical obstruction in the engine.	a. Note whether starter motors respond when starting switch is operated - If starters do not respond it is a starter malfunction. b. Open all of the cylinder test valves and attempt to rotate crankshaft by engaging the manual barring tool in the flywheel. • If the engine can be barred over one complete revolution, it is a starter system problem - See possible cause "Starter Malfunction." • If the engine can not be barred over one complete revolution - See possible cause "Cranking Prevented By Mechanical Obstruction."
	STARTER MALFUNCTION	
	1. Starter control batteries are inoperative.	Test for proper battery charge and inspect cable connections of control circuit batteries.
	2. Starter controls are incorrectly set.	a. If the equipment has an isolation switch, make sure it is in the "START" position. b. Check that all switches and circuit breakers in the engine control and protective circuits are properly positioned. On a turbocharged engine, make sure that the turbocharger lube pump circuit breaker is closed. c. On engines with electric starting, make sure that the battery knife switch is closed and the starting fuse still has continuity. d. On engines with air starting, check that the starting reservoirs are fully charged to the proper pressure and are free of water accumulation. Check that all valves in the air line to the starter motors are open. If the starters still do not respond, check the following (depending on the system) while the start switch is in the start position: • Establish whether or not there is voltage across the starter motors (on units with separate electric start motors).

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
		• Establish whether or not there is a voltage potential across the generator start winding terminals (on units using main generator for starting). • Establish if there is air pressure available at the starters (on units with air start).
	3. Starter motors inoperative. starter motors and bench test in accordance with instructions in the	If voltage or air pressure is being supplied to the starter motors, remove the Engine Maintenance Manual. On main generator starting systems, examine the generator itself for damage to the bus bars connecting the starter windings, or possible loose connections to this circuit.
	4. Starter control circuit is inoperative. (No power or air is being supplied to starter.)	a. On engines with separate electrical starting motors, check whether or not the ST and STA (if so equipped) contactors have picked up. • If the starting contactor(s) has picked up, then check its internal contacts for damage, and check for loose starting cables. • If the starting contactor(s) has not picked up, trace the starting control circuit for open interlocks, or loose or broken wiring. b. On engines using the main generator for starting, check whether or not the GS contactor has picked up. • If the GS contactor has picked up, check its internal contacts for damage, and check for loose starting cables. • If the GS contactor has not picked up, trace the starting control circuit for possible open interlocks or broken wiring. c. On engines using air starters, check the air start control valve for failure to pick up, and check for restrictions in the starter air supply lines. If the engine is equipped with a turbo pump or priming pump security interlock, make certain that the pump has been activated and the interlock functions properly.

	5. Starter motor pinions do not engage properly.	a. Check gear teeth on pinion and flywheel gear for damage or debris. b. On air start systems, check air lines to engagement mechanism, the solenoid valve and the control valve for proper operation. c. Check that starter motors are mounted and aligned properly. d. Bench test starter motors for proper engagement operation (See Engine Maintenance Manual).
	MECHANICAL OBSTRUCTION	
	1. Damaged engine assemblies or debris.	a. Remove all air box handhole covers and perform a complete visual inspection. Look at all assemblies for broken or damaged components. Check for debris in the airbox and liner port area, including possible loose carbon lodged between a piston and head. b. Remove all oil pan handhole covers and inspect for: • Damaged or bent connecting rods. • Damaged counterweights. • Evidence of overheated main bearings and supporting "A" frames. • Damage to the lower liner skirt of any cylinder liner. c. Check that all piston cooling pipes are in place and intact. If a damaged piston cooling oil pipe is found, the related power assembly should be inspected closely for damage. d. If the engine was recently overhauled, then inspect all fork rod power assemblies for proper matching of serial numbers on the basket assemblies. (A mismatched basket could result in a pinched connecting rod bearing shell.) If these steps have not disclosed any evidence of a failure, attempt to rock the crankshaft back and forth. If it is not possible to rock the crankshaft, perform c a main bearing inspection. If it is possible, proceed to next possible cause.
	2. Accessory, equipment or gear train failure.	a. Check the air compressor for mechanical damage or loss of lubricant.

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
		b. Check the- main generator (where applicable) for signs of bearing over heating or rotor to stator contact.
		c. ,Inspect the front (accessory) and rear (auxiliary) gear trains of the engine. A failed component or gear bushing could cause the gear train to bind which might prevent the engine from cranking.
	3. Turbocharger failure.	On turbocharged engines that can not be barred over in the direction of normal rotation, reverse the direction of the engine barring by installing the barring tool on the opposite side of the engine. If the engine can be barred over in the reverse rotation direction, then carefully inspect the turbocharger for rotor shaft binding. If the rotation of the turbocharger rotor is obstructed or the shaft has failed, the one-way clutch will engage, preventing engine rotation in the normal turning direction. By reversing the direction of rotation, the clutch is disengaged, which takes the turbocharger out of the system.
STARTER ENGAGES BUT CRANKING SPEED IS TOO SLOW TO START ENGINE	On electric starting systems:	
	1. Inadequate power to starters (or main generator).	a. Check for proper battery charge, preferably by testing with a hydrometer. b. Check battery cabling for loose connections or broken cable.
	2. Incorrect starter motor application (if applicable).	Check that the starter motors are of the proper voltage, and are connected correctly for the battery voltage in use. Installations with starter motors connected in parallel across the battery require that the starters have a voltage rating equivalent to battery voltage. Installations with starter motors connected in series across the battery (two motors) require motors which have an individual voltage rating 1 /2 that of the battery. Starter motors with different operating voltage ratings are never mixed in the same installation.
	On air starting systems:	
	1. Inadequate air supply to starters.	Check that there is adequate air pressure in the reservoirs and that they are free of water.
	2. Restrictions in air lines.	a. Check that air line valves are fully open.

		b. Check that there are no restrictions or damaged components in the air supply lines to the starters.
		c. Check that there are no restrictions in the starter exhaust connections.
	Engine mechanical binding.	See the preceding section on "Mechanical Obstructions." Some components may be binding without totally restricting engine rotation.
ENGINE WILL NOT START WHEN CRANKED AT PROPER SPEED	1. Engine protective devices tripped.	Check that governor low oil button is not out. Also check low water/crank-case pressure detector and overspeed trip mechanism to make sure they have
	not tripped. Reset if necessary.	
	2. Improper starting procedure.	Check that the engine was assisted in starting by advancing the injector control lever approximately 1/4 of the total rack travel. If no advance of the injector control lever was made, it takes about 30 seconds of engine cranking for the governor to move the injector rack from fuel off to-idle position resulting in engine start. (On some units, the governor is equipped with an oil booster pump which eliminates the need to manually advance the lever.)
		If the previous steps have not solved the problem, check the fuel supply to the cylinders by opening each cylinder test valve and cranking the engine with the injector control lever advanced. A dense spray of fuel should be emitted from each cylinder. If a dense spray of fuel is observed, proceed to possible cause #3, if not see #4.
	3. Cylinders are not firing with fuel applied.	a. Check for correct injector timing and rack setting.
		b. Inspect the airbox for evidence of broken rings or cylinder scoring, either one can cause compression loss which could prevent starting.
		c. Qualify the engine valve timing by performing an exhaust valve timing check (See instructions in the Engine Maintenance Manual). Only one power assembly in each bank of cylinders needs to be checked. If the engine is out of time, check the condition of the timing gear train by performing an idler gear check in accordance with instructions in the Engine Maintenance Manual.
	4. No fuel is reaching cylinders.	a. On units with an electrical fuel pump, make certain that the control and fuel pump switch is on and that fuel flow can be seen in the return sight glass when the pump switch is in the "FUEL PRIME" position. If no fuel flow is seen, check for adequate fuel level in the fuel tank, possible suction leaks or a plugged suction strainer. If fuel flow is seen in the bypass fuel sight glass, change the engine mounted filters. See "Fuel System."

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
		b. On engine driven/manual prime fuel pump installations, make sure the system was properly primed with the hand priming pump prior to starting. If no resistance was noted while using the hand pump, check for adequate fuel level in the fuel tank, suction leaks, a plugged suction strainer or a jammed fuel line check valve. If extreme resistance was noticed while using the hand pump, check for plugged fuel filters. See "Fuel System."
	5. Lack of fresh air supply to the cylinders.	a. Check engine air filters for plugging or air restrictions. See appropriate service manual for instructions.
		b. Check air ducts for any mechanical damage or flow restrictions. Replace, repair or clean as required.
		c. Remove air box handhole covers as required to check for any air intake restrictions.
		d. On blower type engines, check roots blower mechanisms for any damage or air flow restrictions. Repair or replace as necessary.
	e. On turbocharged engines:	
		•· Inspect aftercooler cores for restriction of air flow. Remove and clean if necessary.
		•· Check turbocharger mechanism for failure. See "Turbocharger."
	6. Exhaust system plugging.	Check for any major plugging of exhaust flow. It is possible that a major exhaust restriction could cause enough of a misfire condition to prevent engine starting. On turbocharged engines, check for exhaust inlet screen plugging.
	7. Engine performance causes shutdown.	Consult appropriate sections in "Engine Performance."

FUEL SYSTEM		
FAULT CONDITION	**POSSIBLE CAUSE**	**RECOMMENDED CHECK OR CORRECTIVE ACTION**
LOW FUEL OIL PRESSURE	1. Inadequate fuel supply.	Check for adequate fuel supply in main or day tank.
	2. Stuck pressure relief valve.	a. On locomotive installations and installations with engine mounted fuel sight glasses, observe the 60 psi bypass sight glass to make certain that the relief valve on the sight glass assembly is not stuck open. b. On installations that have a bypass or pressure relief valve on the sight glass from the inlet side of the fuel filters to a tank return, check that the bypass or relief valve is not open.
	3. Fuel filters need to be replaced.	Observe the pressure drop across the fuel filters. If pressure drop is near or above the changeout value given for the filters, replace the filter elements and again observe fuel pressure. Use only recommended filter elements.
	4. Fuel oil leak into lubricating system.	Check engine oil level to determine if fuel oil might be leaking into the engine lubricating oil system. Inspect the top deck area of both cylinder banks for leakage from injectors, injector jumper lines, or top deck fuel manifolds.
	5. Suction leak or restriction.	a. On installations with no return fuel sight glass or with engine driven fuel pump: • Inspect all suction lines for air leaks into the lines. • Check pipe connections and unions for proper tightness. • Remove and inspect the screen in the suction strainer. Clean if necessary. • Check that all suction piping is the recommended diameter or larger. b. On installations with a return fuel sight glass and electric fuel pump: **NOTE** A slight burst of bubbles during transient injector rack movements is normal.

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
		If bubbles are seen in the fuel sight glass while the engine is running, then shut the engine down, hold the fuel prime/engine start switch in "FUEL PRIME," and continue to observe the sight glass. If the bubbles disappear after the engine is shut down, then the probable cause of the bubbles was an injector with tip leakage. If the bubbles continue after the engine is shut down, then the probable cause is a fuel suction leak. This fuel suction leak may cause air binding in the system and loss of fuel pressure. The following steps should eliminate this fuel suction leak: • Inspect all pipe connections and unions in the fuel suction line for proper tightness. • On locomotive installations, inspect the condition and check for tightness of all piping leading in or out of the fuel tank. • Clean the screen or element of the fuel suction strainer if necessary.
		c. If no leak has been found, or the fuel system needs to be qualified, pressure test the system. Apply a static air pressure (414 kPa [60 psi] for installations with sight glasses and 621 kPa [90 psi] for installations with duplex filters) to system after fully charging with fuel. Check for the amount of pressure loss in 15 minutes. A pressure loss of 4 psi or greater indicates a leak in the engine. If this occurs, check the fuel system thoroughly for leaks. **WARNING** A pressure of greater than 60 psi might fracture fuel sight glasses. Beware of possible fire hazards due to fuel spillage.
	6. Fuel pump malfunction.	a. Inspect the fuel pump for leaks. b. On installations with an engine driven fuel pump: • Inspect the pump drive coupling and check drive shaft keying or lock screws. • Remove pump and qualify pump operation. See an appropriate Maintenance Instruction.

		c. On installations using electric fuel pumps: • Check for an interruption or fault in the fuel pump control circuit. Use an appropriate wiring diagram to qualify switchgear and wiring connections. Check for continuity through electrical interlocks. • Remove pump and qualify pump operation. See an appropriate Maintenance Instruction.
	7. Foreign material in the fuel tank.	Foreign material may be intermittently obstructing the pick up of fuel. Drain the fuel tank. If that doesn't solve the problem, then it may be necessary to open the fuel tank and inspect for foreign material.
	8. Fuel line restrictions in the fuel preheater (if applicable).	a. Inspect the preheater supply and bypass circuits in the fuel suction lines for partially closed valves. b. If problem seems to be within the heater itself, shut off all fuel and water supply to the preheater. This can be done via cutoff and bypass valves. c. Remove the body and end caps and inspect the internal header bends to possible trapped material obstructing the flow of fuel through the heater. Clean or repair as required.

LUBRICATING OIL SYSTEM

Many oil system problems, as well as overall engine troubleshooting problems can be easily identified through lube oil analysis. Refer to applicable Maintenance Instruction for interpretation of the analysis statement.

Use only EMD oil filter elements or an equivalent in the Michiana oil filter tank.

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
LACK OF OIL DELIVERY FROM THE SCAVENGING SYSTEM	1. Restriction in oil system such as plugged filters or plugged coolers.	The preliminary setup for troubleshooting the scavenging oil system should include the installation of a pressure gauge (0-50 psi) at the quick disconnect fitting on the Michiana filter tank. Follow engine prelube procedures if necessary to ensure that engine bearings have an adequate supply of clean lube oil during troubleshooting. Follow one of the following procedures based on specific application. FOR ALL INSTALLATIONS EXCEPT MARINE ENGINES WITH ENGINE MOUNTED RAW WATER PUMP: Before starting the engine: a. Check for adequate supply of oil in the oil pan. b. Make sure the strainer housing is full of oil to within about 51 mm (2') of the screen under the large cover. c. Also under the large cover, make sure that the Michiana tank drain valve (with the "T" handle) is fully closed. d. Remove the scavenging pump coarse strainer element which is held into the strainer box by three bolts. Inspect the interior of the strainer box for foreign material and clean if necessary. Make certain that the clean strainer is installed with a gasket and tighten securely. e. Remove several oil pan handhole covers and inspect the entire length of the oil suction line leading from the governor end of the engine into the oil sump. Any mechanical damage to this line must be repaired before operating the engine.

Start the engine. Check whether the oil level in the strainer box returns to approximately 51 mm (2") of the screen within 45 seconds.

If it does not, take a pressure reading at the Michiana tank with the engine at idle. Shut the engine down by either pulling out the governor low oil pressure button or tripping the overspeed shutdown lever.

- If the pressure reading was low or zero, then the scavenging oil pump and its suction line to the strainer box should be inspected. If necessary, the scavenging oil pump should be removed and overhauled.

- If the pressure reading was higher than 69 kPa (10 psi), then change the oil filter elements and repeat the procedure. If the pressure is still high, remove and clean the oil cooler core.

If it does, operate the engine and slowly increase the speed. Observe the oil level in the strainer box at all speeds. At maximum operating speed take a reading of the Michiana tank pressure.

- If the pressure reading is above 172 kPa (25 psi), change filter elements. (On switcher locomotives and industrial engines with tube bundle and shell [heat exchanger] type oil coolers, the applicable value is 345 kPa [50 psi].)

- If the pressure reading is 69 kPa (10 psi) or more after changing filter elements, temperature test the oil cooler core as discussed in the "High Lube Oil Temperature" section. If necessary, remove and clean the oil cooler. (On switcher locomotives and industrial engines with tube bundle and shell [heat exchange] type oil coolers, the applicable value is 138 kPa [20 psi].)

- If pressure reading is 21 kPa (3 psi) or less, check the Michiana tank bypass valve to determine if it is jammed open. (On switcher locomotives and industrial engines with tube bundle and shell [heat exchange] type oil coolers, the applicable value is 69 kPa (10 psi].)

FOR ALL MARINE INSTALLATIONS WITH ENGINE MOUNTED RAW WATER PUMP:

These engines are considerably different from other EMD engines in that much of the oil system and piping is installed by outside contractors. These variations cause the normal pressure characteristics of the oil system to be altered.

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
		Due to greater oil system capacity and in-line strainer, the scavenging oil pump on 20-cylinder engines (and some 16-cylinder engines) occasionally exhibits a non-linear oil pressure response (oil pressure does not follow engine RPM). Before starting the engine: a. Check for an adequate supply of oil in the oil pan. b. Remove the strainer(s) and check for any obstructions of oil flow. Clean strainers if necessary. Reinstall strainers with a good gasket and tighten securely. c. Check scavenging pump suction line in the oil pan. Any mechanical damage to this line must be repaired before starting the engine. d. Make sure that the lube oil system is primed (hand pump) and the drain valve is fully closed. Start the engine, set at idle, and observe the pressure output of the scavenging pump. If the pressure is less than 69 kPa (10 psi), qualify the following components (in the order listed) and specifically check the valves to make certain they are not stuck open. • Main lube pump suction relief valve. • Filter bypass relief valve. • Lube oil cooler bypass relief valve. • Scavenging oil pump. If the pressure output is greater than 276 kPa (40 psi), perform the following checks: • Check pressure differential across the lube oil filter elements. If the pressure differential exceeds 69 kPa (10 psi), then change filters and retest. • Check the pressure differential across the oil cooler. If the differential exceed 69 kPa (10 psi), temperature test the oil cooler as discussed in the "High Lube Oil Temperature" section.

		Bring the engine up to full speed and check the following: • Check the pressure differential across lube oil filter elements. The pressure differential must not exceed 138 kPa (20 psi). Change filter elements if necessary. • Check the pressure differential across the oil cooler. The pressure differential must not exceed 138 kPa (20 psi). If the differential does exceed this value, temperature test the oil cooler core as described in "High Lube Oil Temperature" section. Remove and clean if necessary.
	2. Oil Leakage.	See fault condition "Excessive Use Of Lubricating Oil."
HIGH LUBRI- CATING OIL TEMPERATURE		**WARNING** When engine shuts down due to hot oil, wait two hours before attempting to inspect the engine. This will preclude the entry of fresh air which could ignite hot oil vapor.
	1. Inadequate oil supply.	Check oil level in the oil pan and monitor main oil pump pressure.
	2. Oil scavenging system/oil filters malfunctioning.	See section on "Lack Of Oil Delivery From The Scavenging System." Poor oil flow could' cause this problem.
	3. Oil cooler not functioning properly.	a. Determine if the engine has had high water temperature problems. (High water temperature reduces the efficiency of the oil cooler thereby causing a higher oil temperature.) If the engine has an above normal water temperature, see "Coolant System." b. Marine and stationary power installations are frequently equipped with a temperature control (thermostatic) valve. If the engine has this equipment, then qualify the opening of the valve. On some installations, failure of the valve to function can deprive the oil cooler of coolant. c. Temperature test the oil cooler as follows: 1. Put inline thermometers or temporary thermometers in the wells provided in the engine cooling water piping. 2. Monitor temperatures in and out of both the oil and water sides of the oil cooler. 3. Compare these readings with a standard chart (locomotive installations) or with installation records to determine oil cooler efficiency. (Reduced efficiency is caused by oil cooler plugging, scale or corrosion.)

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
		4. If oil temperature drop or coolant temperature rise through the cooler are not adequate, then remove the cooler for inspection or cleaning.
	4. Engine component overheating.	Inspect the interior of the oil pan for evidence of overheated metal surfaces or extruded metal around the main and connecting rod bearings. Inspect under the lower end of both gear trains for debris.
EXCESSIVE USE OF LUBRICATING OIL (See specific condition)	OIL LOSS OUT OF THE EXHAUST STACK.	
	1. Worn power pack assemblies.	a. Perform air box inspection and pay particular attention to the condition of the piston, rings and liner.
		b. If ring wear exceeds the recommended limits, renew or replace power assembly. If rings are broken, renew or replace power assembly immediately, regardless of their wear state.
		c. Check the piston crown and port area for signs of oil problems in a specific cylinder. Excessively wet crowns and oil or sludge throw off from the inlet ports may point out cylinders with oil control problems.
	2. Piston rings installed improperly.	See possible cause "Piston Rings Installed Improperly."
	3. Oil separator screen missing.	Disassemble the lube oil separator and check for a missing or disintegrated screen element. On the turbocharged engine, the absence of this screen can cause excessive oil consumption and oil out the stack.
		Oil passage through the separator can occur when the flow rate through the separator exceeds design capacity. This is usually caused by combustion gases, ambient air, or pressurized air box air entering the crankcase. This condition is characterized by a reduction of crankcase vacuum, and can be detected by measurement with a manometer at the oil dipstick tube.
	4. Blower rotor end seals failed (on blower type engines).	Inspect the air ducts from the blower to the air box. If oil is found running down the ducts, the blower should be removed and the blower rotor end seals replaced.
	5. Turbocharger seal failure (on turbocharged engines).	a. Remove the screen and taper joint in the exhaust manifold assembly.

b. Inspect the manifold interior to determine if oil loss is originating from the engine or the turbocharger. In many instances, this inspection will reveal a specific cylinder responsible for oil loss.

c. If the exhaust manifold inspection indicates that the problem is originating in the turbocharger, then inspect the air inlet system for plugged filters. (Plugged filters could cause a high inlet vacuum and drain oil past the turbocharger labyrinth seals.)

d. If the external systems are found to be in good condition, then changeout of the turbocharger may be necessary. See "Turbocharger."

6. Cylinder wall varnishing.	Engines which are operated for extended periods of time under light or no load may experience varnishing of the cylinder walls. This varnishing greatly reduces the effectiveness of the oil rings and may in some cases cause a condition known as oil "souping" (which can result in an oil loss through the exhaust stack). Varnishing can be characterized by light brown or tan deposits on cylinder liner walls. If light load operation is continued, then these varnish deposits may interfere with ring to liner seal effectiveness. In extreme instances of light load operation it may be necessary to load the engine either through temporary change of service or through use of a load box in order to remove these deposits and restore the efficiency of the ring set.
7. Excessively worn head retainer surfaces, worn or "pounded" head seat rings.	Cylinder head retainer surfaces and head seat rings are subject to wear during normal operation. Excessive wear or clearance due to "pounding" of seat rings from improperly torqued head crab nuts will allow oil to be drawn past the seat rings into the exhaust. These conditions can be minimized by following the Scheduled Maintenance Program for in-service tightness checks of head crab nuts on new engines with non-plate type crabs or by assuring that correct torque is applied when installing new or rebuilt power assemblies in engines with either plate or non-plate type crabs.
PISTON RINGS INSTALLED IMPROPERLY.	On EMD engines, piston rings in the No. 4, No. 5, and No. 6 grooves are directionally sensitive at installation and all six rings in the set must be properly oriented in the correct groove.

NO. 1 RING - Labled "Top Groove Only" and stamped with a part number. It may be installed with either side up.

NO. 2, 3 RING - Both rings are identical. They are both stamped with a part number and may be installed with either side up.

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
		NO. 4 RING - Labled "Top" and has a part number stamped on it. It must be installed with the top label upward and only in the No. 4 groove. If this ring is installed upside down, its tapered face will tend to pump oil past the upper compression rings.
		NO. 5 RING - This is a double hook scraper and must be installed with the hooks pointed down. If this ring is installed upside down, it will cause heavy oil loss through the air ports and considerable oil loss into the airbox.
		NO. 6 RING - This is a special spring loaded scalloped oil control ring and must be installed with the scallops downward. If this ring is installed upside down, its oil control efficiency will be greatly reduced and may result in excessive oil loss.
		At the time of overhaul or if rings are removed while troubleshooting excessive use of lube oil, make certain that the oil drain holes under the oil control rings are not clogged.
	LOSS OF OIL FROM AIR BOX DRAIN	
	1. Worn power pack assemblies.	See possible cause "Oil Loss Out Of The Exhaust Stack," Part 1.
	2. Piston rings installed improperly.	See possible cause "Piston Rings Installed Improperly."
	3. Turbocharger or blower seal malfunction.	See possible cause "Oil Loss Out Of The Exhaust Stack," Parts 4 and 5.
	4. Failed power pack assembly External seal.	Inspect for excessive oil leakage from around the power pack assemblies or from the center gallery of the air box. Leakage here might indicate a failed or absent seal, a failed component, or an oil gallery structure failure.
	5. Damaged air box drain piping.	Inspect the air box drain piping in the oil pan for any evidence of leakage or external damage to the piping which could cause oil loss.
	BAD OIL	
	1. Oil in water expansion tank.	This indication is usually seen on installations with shell and tube type oil coolers because in these coolers the local oil pressure is sometimes higher than the cooling water pressure.

		On installations with fin type oil coolers and pressure cooling systems, the water pressure is higher than the oil pressure in the cooler. Because of these pressure differences inside the cooler, an internal leak usually results in water contamination of the lube oil. Pressure test and qualify the oil cooler core for leakage.
	2. Improper viscosity and oil contamination.	See fault condition "Diluted, Contaminated Or Improper Oil."
	OIL LEAKAGE	
	1. External engine leaks.	Leakage of oil from component connections will generally require tightening the affected part or replacement of gaskets.
	2. Loss of oil into the governor.	This condition will be evidenced by rising or overflowing oil from the governor oil level sight glass. Check the governor drive seal and replace if necessary, Check the low oil pressure actuating diaphragm of the governor and replace if necessary.
	3. Load regulator or vane motor leaking (if applicable).	Tighten or replace as necessary.
	4. Pedestal or generator bearing leakage (Marine).	Replace the bearing seals and check return lines for continuity. Check that the orifice is in place on the supply line.
LOW ENGINE OIL PRESSURE	1. Inadequate oil supply.	Check for adequate oil level in engine oil pan.
	2. Diluted oil supply.	See fault condition "Diluted, Contaminated Or Improper Oil."
	3. Clogged turbocharger filter (if applicable).	Change the turbocharger oil filter element. (Make sure that the element isn't installed upside down because this can cause low oil pressure.)
	4. Malfunction in lubricating oil scavenging system.	See fault condition "Lack Of Oil Delivery From Scavenging System." If the oil supply to the main pump is found to be adequate, install test oil pressure gauge (0-150 psi) on the outlet elbow of the main lube oil pump using the 3/4' NPT plug hole. If the pump pressure indicated on the gauge is adequate, proceed to possible cause #10. If not, proceed to possible cause #5.
	5. Clogged strainers or debris in strainer box.	a. Remove the two fine screen strainers in the strainer housing. Clean the strainers and inspect the seals for possible suction leaks. b. Drain the strainer box and inspect the chamber for any foreign material. c. Remove and blow compressed air through the seal vent line to make certain that it is not obstructed.

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
	6. Fault in bearing oil supply lines.	Remove all oil pan handhole covers. Visually inspect the piston pins, the external surfaces of the main and connecting rod bearings for evidence of over heating and look for missing or loose components.
	7. Stuck pressure relief valve.	Operate the engine at idle speed. Remove the low water/crankcase pressure detector leaving oil lines intact, and swing the detector away from the accessory housing hole. (On older models without flexible oil line connections on the detector, some oil lines may have to be capped or plugged.) Check the pressure relief valve (located directly behind the detector), for excessive oil loss. If the valve is found to be stuck in the open position, it should be removed and replaced with a qualified valve.
	8. Oil line leakage and suction leaks.	Check for suction leaks at the main pump inlet elbow where it mates to the main pump and to the strainer housing (if applicable). Replace gasket if necessary. See "Excessive Use Of Lubricating Oil."
	9. Main lube oil pump malfunction.	Remove and qualify the main lube oil pump per instructions in the Engine Maintenance Manual.
	10. Main oil pressure gauge malfunction.	a. Qualify the main engine oil pressure gauge.
		b. Check for any closed valves in the supply line to the gauge.
		c. Inspect the 1/8" diameter line leading through the right bank top deck of the engine to the pressure gauge. Inspect this line carefully for damage. If necessary, blow air through it to make certain it is clear of obstructions.
	11. Defective engine protective	a. Disconnect and block the connecting line from the oil pressure sensing device line to the low water/crankcase pressure detector and the hot oil shut down device (if so equipped). If this results in restoration of normal oil pressure reading on the main engine gauge, it indicates that either:
		• The "O" ring seals in the low water/crankcase pressure detector may have failed.
		• The activating section of the hot oil detector may be jammed open.
		b. Qualify both of these devices.

	12. Rear gear train oil line malfunction.	a. Use the recommended tool to check the clearance in the No. 1 idler stub-shaft bushing. Inspect the interior of the end housing for debris under the gear train. b. On turbocharged engines, remove the auxiliary generator drive (if so equipped) or the cover plate on the rear right bank. Inspect the manifolding to the turbocharger filter for loose or missing components or seals. Make sure that the upper pipe plug is installed in the gauge line connecting block and inspect the camshaft manifolds. c. On blower engines, remove the auxiliary generator drive (if so equipped) or the engine oil separator housing. Inspect the oil jumper lines to the camshaft bearing brackets for loose or missing components or seals.
DILUTED, CONTAMINATED, OR IMPROPER OIL		Check for this condition as follows: a. The brand name and viscosity of the lubricating oil should be compared to EMD standards. Use of oils should be confined to those that meet qualifications published by EMD. b. Immediately take a lube oil sample for analysis. Follow the specified corrective action as indicated in applicable Maintenance Instruction.
	1. Fuel leakage into lubricating oil.	a. Check all fuel jumper tubes to the injectors for cracks and proper seating. b. Inspect all brazed joints in the top deck fuel manifold and check all manifold pipe plugs for leakage. c. Check injectors and injector filter cap gaskets for leaks. d. Check for piston rings which are not free to rotate in the piston groove. e. Pressure fuel system as required to isolate the source of leak. See "Fuel System."
	2. Water contamination of lube oil.	a. Visually inspect for water in the oil pan and on top of the cylinder heads. b. Visually check for leaks in water manifolds and piping. c. Pressure test as required to isolate the source of the leak. See "Coolant System."'

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
TURBOCHARGER PRELUBRICATION (Soak Back) SYSTEM FAILURE		If the soak back pump fails to operate when the engine is shut down, then immediately restart the engine and allow it to idle for 15 minutes. This allows the oil temperature to drop which cools the turbocharger bearings. The engine can then be shut down and the electrical control and soak back pump circuits can be investigated to determine the cause of the malfunction.
		CAUTION If the engine can not be restarted within 2 minutes of shutdown, then do not restart the engine until the operation of the soak back pump has been restored and the engine has been allowed to cool down.
	1. Open lube oil check valve.	Inspect the camshaft bearings on the engine top deck while the soak back pump is operating. If oil flow is observed around the bearings, it is an indication that the check valve (located in the turbocharger filter housing) is jammed open. Remove the housing and inspect the check valve. (This condition will allow oil contaminants to be backflushed into the main oil gallery.)
	2. Oil bypassing soak back filters.	On most engine applications, the soak back pump filter is mounted in a small canister close to the pump. There is no backup filtration system, if the filter clogs, the bypass valve will allow dirty oil to reach the turbocharger bearings. Replace soak back pump filter. Use only EMD recommended filter elements.
	3. Clogged turbocharger oil filter.	The turbocharger oil filter is in the large canister on the back of the right bank of the engine. There is no bypass valve for the turbocharger oil filter so clogging of the filter may result in a low oil pressure shut down. Replace the filter element using only EMD recommended elements.
	4. Lack of oil delivery from soak back pump.	a. Remove the rear oil pan handhole cover on the left bank of the engine. Inspect under the gear train for oil return draining from the turbocharger. b. If oil drainage is not evident, check the following for failure or restriction of oil delivery: The motor to pump coupling, the pump, and the motor. (See Engine Maintenance Manual instructions.)

COOLING SYSTEM

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
LOW WATER PRESSURE (ON PRESSURE COOL-ING SYSTEMS ONLY).		Install a pressure gauge in the cooling system and monitor the pressure rise at the expansion tank as the engine heats up to normal operating temperature. Check to see that the pressure reading matches the system or cap specifications. See an applicable service manual for pressure testing details. If pressure is low check for:
	1. Failed expansion tank vent valve.	Place a bucket of water so that the end of the vent line extends several inches below the surface of the water. The release of bubbles or coolant inhibitor through the water indicates that the vent valve is not seating properly and must be replaced. **WARNING** Do not get hands or face close to the water bucket while performing this test.
	2. Damaged filler components.	a. Shut the engine down. Blow down the tank pressure by opening the manual vent valve. b. When the tank pressure is completely dissipated, remove and inspect the expansion tank fill valve. c. Check the filler neck condition for any type of damage. d. Check for proper seating of the snifter valve (metal disc) in the center of the cap and check the condition of the gasket. Make certain the pressure range marked on the cap is correct for the installation. If there is any indication of a faulty filler cap, remove and check it on an external pressure tester. Replace cap if necessary. On installations with manual vent (blowdown) valves, use only the expansion tank caps with the crosswise bar. This is a protective system designed to prevent injury of personnel from expansion of hot coolant, but its purpose is defeated if a plain expansion tank cap is used.
	3. Poor coolant delivery.	See fault conditions "Poor Coolant Delivery" and "Excessive Coolant Loss."
POOR COOLANT DELIVERY	1. Inadequate coolant supply.	Check coolant level in expansion or supply tank.

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
	2. Coolant piping damage or flow restrictions.	a. Check all coolant manifolds and piping for mechanical damage which might restrict flow.
		b. Verify coolant flow in various locations of the coolant system in order to pinpoint any hidden flow restrictions.
	3. Coolant piping leakage.	See fault condition "Excessive Coolant Loss."
	4. Water pump failure.	Remove and qualify the water pump(s) per instructions in the Engine Maintenance Manual.
EXCESSIVE COOLANT LOSS	1. Open drain valves.	Check that all drain valves and plugs are not leaking. Check that all vent valves on the expansion tank (if so equipped) are in the proper position. Check that coolant expansion or supply tank is adequately capped. On locomotives, check that all cab heater drains are closed.
	2. Missing or loose pipe connections.	Check that all coolant system piping connections are tight and that all gaskets are in good condition. Leakage on the pressure or output side of the water pump will cause coolant loss and decreased coolant pressure throughout the system. (Leakage on the suction or output side of the water pump will draw air into the system which results in cavitation at the pump.)
	3. Coolant system leaks.	Hydro-Test the cooling system for leaks. Do not exceed 172 kPa (25 psi) during the hydro-test. This limit is notably conservative to account for older equipment that might have some long service deterioration. The engine alone can be blanked off and tested with air and water at 620 kPa (90 psi).
HIGH COOLANT TEMPERATURE	ON INSTALLATIONS WITH RADIATORS:	
	1. Inadequate coolant supply.	Check the coolant level in the expansion or supply tank.
	2. Low coolant pressure.	See fault condition "Low Coolant Pressure." (Applicable to pressure cooling systems only.)
	3. Coolant is not flowing through system.	See fault condition "Poor Coolant Delivery."
	4. Inoperative radiator shutters (if applicable).	a. Cycle the shutters with the temperature switch test button or the shutter test valve. Check that the shutters are opening completely.

		b. Check the temperature at which the temperature switch operates. This can be done by either operating the engine until it reaches the temperature at which the shutters open or by removing the temperature switch and testing it separately. Place the heat sensing element in a pan of hot water and check the operating point with a thermometer.
	5. Inoperative cooling fans.	a. On installations with electric cooling fans, check for proper operation of all fan motors and temperature control switches. Check all the fan fuses for continuity and proper rating.
		b. On installations with belt driven cooling fans, inspect the belts and make certain that they are properly tensioned.
	6. Poor air flow through radiators.	Inspect the exterior of the radiators for clogging and restriction of air flow. Clean radiator baffles (fins) if necessary. Carefully check cores for leaks.
	7. Improperly connected radiator and water pump vent lines.	Make certain that all radiator and water pump vent lines are in place and not obstructed. Poorly connected radiator vent lines can cause air binding in the radiators which results in a loss of cooling efficiency. Water pump vent lines that are loose or an incorrect size can cause cavitation of the water pump (which results in a loss of coolant delivery pressure).
	ON INSTALLATIONS WITH HEAT EXCHANGERS, KEEL COOLERS, OR RAW WATER COOLING:	
	1. Inadequate coolant supply.	Check coolant level in expansion or supply tank.
	2. Low coolant pressure.	See fault condition "Low Coolant Pressure." (Applicable to pressure cooling systems only.)
	3. Poor coolant delivery.	See fault condition "Poor Coolant Delivery."
	4. Inoperative temperature control valve.	Check the operation of the temperature control (thermostatic) valve (if so equipped). See instructions in the Engine Maintenance Manual.
	5. Poor raw water delivery.	a. Check that all valves are open in the suction and discharge circuits of the pump.
		b. Make certain that piping connections are properly sealed and tightened and that gaskets are in good condition.

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
		c. On installations with belt or shaft driven raw water pumps, check the shaft couplings and belt tension.
		d. If none of the above steps have located the problem, remove and qualify the raw water pump per instructions in the Engine Maintenance Manual.
	6. Clogged heat exchanger.	Monitor the temperature change across the engine cooling side of the heat exchanger and, if possible, across the raw water pump from suction to the discharge side. If the temperature change is too small across the cooling side of the heat exchanger (this is a temperature drop) or raw water pump (this should be a temperature rise), then clean the radiating surfaces. It may be necessary to rod out the exchanger (shell and tube types).

ENGINE PERFORMANCE

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
UNEXPECTED ENGINE SHUTDOWN	1. Engine was stopped. activated.	a. Check that emergency fuel cutoff or the engine stop switch was not b. On locomotive installations, check that the engine was not inadvertently shut down by moving the throttle handle beyond the dentent to the "STOP" position. This will also shut down all other locomotive units connected in tandem (consist). Before proceeding with any further troubleshooting steps, check annunciator panel (if so equipped) for fault indications.
	2. Overspeed trip lever was activated.	Check the position of the overspeed trip lever. If it has tripped, see fault condition "Overspeed Shutdown."
	3. Inadequate fuel supply.	a. Check the fuel level in the supply or day tank. b. See "Fuel System."
	4. Crankcase pressure detector trips.	See fault condition "Crankcase Pressure Shutdown."
	5. Low water detector trips (if applicable).	See the appropriate sections in "Cooling System." **NOTE** Quite often on startup and occasionally on shutdown, the engine protector buttons may be activated by pressure differential transients. These may cause a false indication of engine problems during routine startup and shutdown.
	6. Hot oil detector tripped (if applicable).	See fault condition "High Lubricating Oil Temperature" in "Lubricating Oil System." **WARNING** When engine shuts down due to hot oil, wait two hours before attempting to inspect the engine. This will preclude the entry of fresh air which could ignite hot oil vapor.

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
	7. Low oil pressure shutdown.	This type of shutdown is either indicated by a governor low oil button which has popped out or an annunciator indication, depending on the installation. In either case, perform the following: a. Check that the shutdown was not caused by another protective device. The other detectors function by dropping all oil pressure to the governor. See the appropriate possible cause. **WARNING** If the low oil button is popped and the hot engine condition is suspected, wait two hours before attempting to inspect the engine. This will preclude the entry of fresh air which could ignite hot oil vapor. b. See the "Low Engine Oil Pressure" section of "Lubricating Oil System." c. If none of the above inspections disclose any reason for the low oil pressure shutdown on an installation with a hot oil detector, load the engine and watch the engine temperature gauge closely for possible overheating. The oil detector might have shut the engine down and then reset itself during cool off.
	8. Turbocharger clutch failure.	If the engine unexpectedly shut down when the throttle was reduced, accompanied by bogging of the engine and heavy smoke, the turbocharger clutch may be failing to engage properly.
	9. Severe air intake plugging.	It may be possible in an extreme case of filter plugging, that the air supply could be cut off to the engine and shut it down. Check air intake filters for plugging. Check all air intake ducts for air flow restrictions. (This condition should be indicated by an annunciator light.)
CRANKCASE PRESSURE SHUTDOWN		**WARNING** Following an engine shutdown because the engine pressure detector has been actuated, do not open any handhole or top deck covers to make an inspection until the engine has been stopped and allowed to cool off for at least two hours. Do not attempt to restart the engine until the cause of this trip has been determined and corrected. The action of the pressure detector indicates the possibility of a condition within the engine such as an overheated bearing that may ignite the hot oil vapors with an explosive force, if air is allowed to enter. If crankcase pressure detector can not be reset, do not operate the engine until the pressure detector has been replaced, since the diaphragm backup plates may be damaged.

	1. Aspirator system malfunction.	a. Check for a plugged screen in the lube oil separator. b. Check for plugged or damaged aspirator piping. Repair or replace as required. **NOTE** Do not remove any of the calibrating orifices that are part of the total crankcase aspirator system installed at the factory.
	2. High engine oil level.	Check oil level. High oil can cause a shutdown due to foaming action or from throw off oil hitting the actuating diaphragm of the engine protector causing a false crankcase pressure indication.
	3. Plugged eductor tube (if applicable).	On turbocharged units, check if there is carbon blocking the angled end of the eductor tube which projects into the exhaust stack riser.
	4. Engine component failure.	After the engine has been shut down for two hours, remove the oil pan and air box handhole covers. Check for: • Cracked pistons. • Broken and unseated cylinder crab bolts, and loose crab bolt retainers. • Cracked cylinder head. • Badly worn valve guides. • Hardened or broken lower liner seals. • Inadequate injector crab nut torque. • Extreme cylinder scoring which could cause air box blowdown past oil control rings. • Improperly installed or broken rings. • Evidence of carbon combustion in the air box which could cause seal hardening and component failure. • Any indication of overheated metal surfaces. • Debris under the gear trains at both ends of the engine.

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
	5. Incorrectly installed oil pressure relief valve.	a. Remove the detector from the accessory drive housing. b. Check that the port on the oil pressure relief valve (located directly behind the detector) is facing downward and 90° away from the end sheet of the engine. If the relief valve is installed either facing the end sheet or at 180° to the end sheet, then the oil discharge may hit the actuating diaphragm of the engine protector causing a false crankcase pressure indication.
OVERSPEED SHUTDOWN	1. Engine load dropped.	a. Check the possibility that engine load was dropped. Look for annunciator or engine control cabinet indications. b. Check the operation of overcurrent protective relays and excitation limiting relays. Check for other electrical malfunctions which might cause this problem. See an appropriate service manual. c. Marine operations in extremely rough or shallow water may cause considerable load fluctuations.
	2. Overspeed mechanism failure.	a. Run the engine to maximum speed with no load and check the engine speed with a hand held tachometer. This can be done via the access cover on the camshaft counterweight cover. b. Increase fuel injection with the injector control layshaft lever until the overspeed device trips. Note the speed at which the device trips. • If the overspeed does not trip when the engine RPM reaches 10% over rated speed, back off the injector control lever and shut the engine down. Remove the front cam counterweight cover and readjust the overspeed mechanism. See the Engine Maintenance Manual for instructions. • If the overspeed tripped at an RPM that was too low, remove the front cam counterweight cover and readjust the overspeed mechanism. See the Engine Maintenance Manual for instructions. Retest until proper RPM trip value is obtained.
	3. Engine speed hunting.	See fault condition "Engine Speed Hunting."

ENGINE SPEED HUNTING (SPEED DEPARTURE)	1. Malfunctioning injector control linkage.	Check that the injector control linkage is working properly. Replace any injector which shows evidence of rackbinding.
	2. Fuel supply problems.	If bubbles are evident in fuel return sight glass (if so equipped), see "Fuel System." On other installations, check for proper flow through the-fuel lines.
	3. Incorrect governor oil level.	Check the governor for correct oil level. Either too high or too low oil level in the governor may cause engine hunting. If the governor "manufactures" oil (constantly rising oil) or if the governor oil becomes excessively dirty after a short operating time, then engine lube oil is getting into the governor oil. Check for the following failure conditions: a. The governor oil pressure sensing diaphragm may have ruptured: b. The governor drive seal may have failed. c. The load control pilot valve seal may have failed.
	4. Trapped air in governor.	With the engine running, vent the air bleed screw in the governor body to remove any trapped air from the governor control passages. Adjust the compensating needle valve to limit the hunting condition as much as possible.
	5. Incorrect governor compensation adjustment.	On locomotive installations, with engine at idle, turn adjustment screw inward until hunting stops or is lessened. Set locomotive brakes and put unit on self-load, then advance throttle to notch #1-engine should not bog down excessively. Turn screw outward to decrease bog, if necessary, or position to minimize both hunting and bogging conditions.
	6. Electrical control malfunction.	a. On locomotive installations, the operation of protective devices such-as current overload relays and excitation limiting may be causing hunting. Check the electrical system to make certain that the excitation circuits are functioning properly. b. On drill rig and DC power generating installations, the cycling of calibrating and overload relays may cause hunting. Check the circuits for proper operation.
	7. Load fluctuation.	In some cases, a load fluctuation condition may cause an apparent hunting condition. Marine engine gear box installations may exhibit a load fluctuation . in rough or shallow water which should not be confused with hunting.

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
CYLINDER MISFIRE		METHODS OF LOCATING A MISFIRING CYLINDER: 1. Exhaust temperature check. a. On engine installations with exhaust stack pyrometers, check the readings between cylinders with the engine running under load. Do not use only one set of pyrometer readings as a basis for an exploratory teardown of a power assembly. Always compare the readings of individual pyrometers by switching the sensing bulbs between the suspected defective cylinder and one cylinder that is indicating properly. b. On engine installations without exhaust stack pyrometers, an approximation of individual cylinder exhaust temperature can be obtained with a hand-held pyrometer. Take a comparison reading at each riser leg while the engine is under load. Because the pyrometer is being positioned outside the manifold, the readings alone should not be used as a basis for power assembly teardown. Only the range relationship between cylinders is meaningful to detect a suspicious cylinder. 2. Stack sound check. a. Using a four foot length of 1/2" to 3/4" pipe held against the riser leg, listen to the sound of the exhaust in each stack riser. Excessive or abnormal noise indicates the possibility of a misfiring cylinder or a defective exhaust valve. b. Disconnect the injector rack link on the suspect cylinder. With the engine at idle speed, slowly open the rack for that cylinder and then return it to idle position. If the injector is functioning properly, a pronounced laboring of the cylinder will be evident with the rack advanced. 3. Cylinder pressure check. A cylinder with a pressure leak can be caused by a badly leaking exhaust cm valve, excessive ring blow-by, a cracked piston, etc. An exhaust valve can be detected, when standing beside an engine, by a pronounced blow in the exhaust stack, with engine idling.

To locate the leaking cylinder, shut down the engine and remove the cylinder test valve from the cylinder to be checked. Using an exhaust valve tester, shown in Fig. 1, install the adapter and air gauge assembly in the cylinder test valve hole. Before attaching the air line to the adapter, turn on the air valve and regulate the air pressure to read 414 kPa (60 psi) on the line air gauge. Rotate the crankshaft until the piston of the cylinder being checked is at approximately top dead center. Attach the air line coupling to the adapter and note the adapter gauge pressure. Valve leakage is indicated if the gauge reads below 386 kPa (56 psi). Repeat the check on the remaining cylinders.

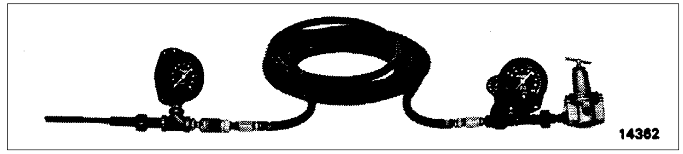

Fig.1-Exhaust Valve Tester

NOTE

Details for construction of the exhaust valve tester can be obtained from the Electro-Motive Service Department by requesting a copy of file drawing No. 695.

4. Injector pressure check.

(See the Engine Maintenance Manual for testing injectors on a test stand set up.)
Special tool 8414877 is used to pressure test injectors for leakage while they are installed in the engine. Pressure test injectors as follows:

a. Ensure that engine fuel lines are fully charged.
b. Place a straightedge across the exhaust and injector cam rollers. If the injector cam roller is higher than the exhaust cam rollers, bar the engine over until the injector roller is below the exhaust rollers.

c. Apply the test tool to the injector rocker arm of the injector being tested. The tool should straddle the rocker arm with the lower end of the tines under the rocker arm shaft and the top end of the tool covering the rocker arm adjusting screw lock nut.

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
		d. Remove the retainer spring and clevis pin securing the injector control lever to the adjusting link. e. Place the injector rack in the full fuel position. f. Apply 1/2" drive torque wrench to the pressure test tool and apply 107 N•m (80 ft-lb) of torque. Hold the torque for a minimum of five seconds. If the torque indication drops off, orif the wrench must be moved to maintain torque, the injector is leaking and must be replaced. If the torque remains constant for five seconds without movement of the wrench, the injector is acceptable. 5. Air box inspection. Heavy cylinder scoring and badly worn or broken compression rings can cause smoking, high oil consumption, knocking or loading and operational problems. Remove all airbox handhole covers and inspect each power assembly through the liner air intake ports. (Consult the appropriate "One Revolution" inspection sequence charts provided.) Check for excessive component "sludge" deposits and any port blockage.
	1. Wrong injectors.	Inspect the part numbers on the bodies of all injectors to verify that the entire engine set is correct for the installation. **CAUTION** EMD does not make hollow rack injectors. Hollow rack injectors can not be set correctly with an EMD injector rack tool. If they are mixed in an EMD engine set with EMD injectors, and set with an EMD tool, these cylinders will be too light on fuel volume (rack too long). This can result in misfire, vibration, poor overall fuel economy, and possible engine damage. Do not rely on body grooves or any other superficial means of identifying injectors. Check the injectors only by the part number and then make certain, through the appropriate EMD Parts Catalog, that all of the injectors in an engine are correct for that installation.
	2. Low fuel oil pressure.	a. On installations with fuel sight glasses, check for adequate fuel flow through the return sight glass. If the fuel flow is inadequate or bubbles are evident in the return fuel sight glass, see "Fuel System."

		b. On installations with fuel block and duplex filters, check for adequate fuel supply pressure. If the fuel pressure is inadequate, see "Fuel System."
	3. Injector timing is off.	See instructions in the Engine Maintenance Manual.
	4. Incorrect exhaust valve lash adjustment.	a. Check exhaust valve lash adjustment as described in the Engine Maintenance Manual. b. Remove and test any valve bridge which shows inadequate lash adjuster tension or which operates loudly when the engine is running.
	5. Injector malfunction.	Pressure test all injectors as described in "Methods Of Locating A Misfiring Cylinder" (in this section).
	6. Power assembly damage (rings, valves, piston, etc).	a. Pressure test suspect cylinders as described in "Methods Of Locating A Misfiring Cylinder." b. Perform an airbox inspection of all power assemblies as described in "Methods Of Locating A Misfiring Cylinder." Check closely for any sign of liner scoring.
	7. Exhaust valve timing is off.	See instructions in the Engine Maintenance Manual.
	8. Mixed power assembly components.	In some cases, mixing components, such as between 567 and 645 engines or between blower and turbocharged type engines, may cause misfire or knocking condition. This may range from having no effect to rapid component destruction.
ENGINE KNOCKING	1. Engine overloading.	Check for engine overloading or overheating problems. Observe load and temperature gauges with the engine in operation. If necessary, refer to an applicable section of the troubleshooting guides for corrective action.
	2. Cylinder misfiring.	See fault condition "Cylinder Misfire."
	3. Damaged connecting rods.	If none of the steps above provided a solution to knocking problems, take lead wire readings to check for bent rods or piston pin insert distress.
	4. Excessively worn cylinder liner or piston.	Perform an airbox inspection of all power assemblies as described in "Methods Of Locating A Misfiring Cylinder."
EXCESSIVE VIBRATION	1. Rotating equipment mis-alignment.	If the installation has been subjected to any shock loadings, check engine to generator or engine to gearbox alignment.

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
	2. Injector or fuel system malfunction.	Open top deck covers and perform a visual inspection of all injectors, racks, rocker arms, and rocker arm shaft mounting studs. Check that all injector racks are engaged to the transfer arms and that all pins and linkages are in place and properly tightened. See sections pertaining to injectors and the fuel system in the "Cylinder Misfire" fault condition.
	3. Engine coupling failure.	Inspect the engine to generator or gearbox couplings and coupling disc for any sign of failure. Replace if necessary. On marine installations, inspect torque tube couplings for evidence of failure.
	4. Drive shaft failure.	Inspect all drive shafts for failure. Replace if necessary.
	5. Crankshaft component malfunction.	Remove all oil pan handhole covers. Visually inspect the crankshaft area for loose or damaged main bearing caps and connecting rod baskets or damaged crankshaft counterweights. Look for signs of overheated or extruded metal.
	6. Gear train component failure.	Inspect for debris under the gear trains at both ends of the engine. Visually qualify the crankshaft damper. Check engine records to make certain that the crankshaft damper is not past its changeout date.
	7. Camshaft counterweights are misapplied.	a. Check that counterweight size application is correct. Compare part numbers or weights to those listed in an appropriate EMD parts catalog b. Check counterweight timing as shown in the Engine Maintenance Manual.
	8. Broken generator pole bolts.	Check for broken bolts on generator poles (if applicable). Replace if necessary.
	9. Loose mounting bolts.	Check engine and base mounting bolts for any damage or improper torque.
LOSS OF POWER (WITH A CLEAN STACK-NO SMOKE)	1. Top deck component failure.	With engine shut down, open all top deck covers and visually inspect the injectors, racks, and followers. Make certain that all injector racks are engaged to the transfer arms and that all pins and linkages are in place and properly tightened. Check fuel jumpers, rocker arms and exhaust valve bridges for any abnormal conditions.

2. Fuel supply system failure.	With top deck covers closed and engine prepared for normal startup, perform the following: a. Check fuel level in supply or day tank. b. Prime engine fuel system and check for adequate return fuelflow (on installations with sight glasses) or fuel supply pressure (on installations with duplex filters). c. Start the engine and allow it to reach normal operating temperature. Check fuel system delivery or pressure. If the fuel system shows any indication of inadequate operation, see "Fuel System."
3. Governor malfunction or load regulator system malfunction.	**NOTE** The following procedures apply only to engines with notched or continuous throttles; and Woodward PG, PGR or PGA governors. With the engine not under load, attempt to slowly increase engine speed from idle to maximum RPM. On installations with PG or PGR governors, check that all assigned engine speeds are properly activated. On installations with a PGA governor, check that the engine responds evenly to increased throttle throughout the operating range, from idle to maximum RPM. Use a hand tachometer to check that the engine has reached maximum speed. If the engine failed to reach maximum RPM, check the governor solenoids on PG or PGR governors and the control air supply and pressure settings on PGA governors. Check for a worn solenoid fulcrum plate mechanism. Return engine speed to idle and attempt to load the engine. Advance the throttle slowly and smoothly from minimum to maximum speed. Qualify the maximum speed of the engine with a hand tachometer. If the engine can not reach its maximum speed rating under load, examine the position of the rack as indicated by the quadrant on the governor and refer to the following instructions as applicable. If the governor rack is shorter than the specified maximum position on the governor nameplate (while under full load), and the engine is running at or below maximum rated RPM then: a. On locomotive installations, check the position of the load regulator.

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
		• If the load regulator has moved to minimum field position, the problem is most likely of a mechanical nature. Carefully inspect the mechanical condition of the injectors and check them for correct part numbers. Pressure test the injectors as described under fault condition "Cylinder Misfire." The governor part number should be checked to make sure it is correct for the installation. If necessary, the governor should be removed to check the load control pilot valve. • If the load regulator has moved to maximum field position, the problem could be of a mechanical or an electrical nature. Injectors should be checked for proper part number and pressure tested as described under fault condition "Cylinder Misfire." The electrical excitation system should be qualified according to the procedures established in the appropriate Locomotive Service Manual. b. On marine or power generating installations, an overload condition or a mechanical problem with the fuel injectors is most likely. Check the injectors for correct part numbers and pressure test them as described under fault condition "Cylinder Misfire." Check that the governor part number is correct for the installation. If these checks have not solved the problem, an electrical or mechanical overload condition is probable. On power generating installations, refer to load rating conditions in the applicable manuals. On marine gear box installations, refer to applicable propeller cube curves to determine if an overload condition has been caused by incorrect propeller pitch. If the governor rack is longer than the specified maximum position on the governor nameplate, and the engine is operating below its maximum speed, attempt to increase fuel injection (shorten rack dimension) by manually advancing the injector rack layshaft lever. a. If increased resistance prevented the injector control lever from being manually advanced to the specified maximum position, then suspect either an engine injector rack is binding or the governor stop adjustment on the power piston is improperly set. b. If it was possible to manually advance the injector control lever to the maximum fuel position, and the engine speed increased, then suspect:

		• Improper governor setting (high speed unloader limit). • Deliberate speed limiting setting (marine only). • Improper governor adjustment (locomotive only). PG and PGR governors (rail and drill rig installations) should be removed from the engine and operated on a governor test stand to make adjustments.
ENGINE EMITTING BLACK OR GRAY SMOKE (MAY BE ACCOMPANIED BY A LOSS OF POWER)	1. Top deck component malfunction.	With the engine shut down, open the top deck covers and perform a visual inspection of all injectors, racks, and followers. Check that all injector racks are engaged to the transfer arms and that all pins and linkages are in place and properly tightened. Check fuel jumpers, rocker arms and exhaust valve bridges for any abnormal conditions.
	2. Faulty injectors.	a. Check all injector part numbers to make certain that they are correct for the installation. b. Pressure test all injectors as described under fault condition "Cylinder Misfire" in "Methods Of Locating A Misfiring Cylinder."
	3. Broken rings or failed power assembly component.	Perform a complete airbox inspection. Check closely for broken compression rings. Consult the appropriate "One Revolution" inspection sequence charts.
	4. Air flow restrictions in the air box.	Check for excessive airbox accumulations blocking liner air intake ports. Check air duct and airbox areas for major air restrictions. On turbocharged units, make sure that the aftercoolers air passages are not blocked or plugged.
	5. Failed roots blower (if applicable).	On blower-type engines, inspect for leaking shaft end seals by checking whether there is oil flow or leakage on the air box end of the air ducts. Leaking end seals can be an indication of impending bearing failure with possible rotor damage.
	6. Turbocharger malfunction.	On turbocharged engines, remove the inlet boot and inspect the inlet impeller for damage. Remove the section of the exhaust manifold adjacent to the turbocharger. (If the engine is equipped with an exhaust screen inspection port, the manifold section does not have to be removed.) Examine the condition of the exhaust inlet screen and clean if necessary. Inspect the interior of the exhaust manifold for debris. Inspect the turbine exhaust blades and qualify the turbocharger per instructions in "Turbocharger."

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
		NOTE A plugged turbocharger exhaust inlet screen may have been caused by a coolant leak. See "Coolant System."
	7. Fuel system failure.	With top deck covers closed and engine prepared for normal startup, perform the following: a. Check fuel level in supply or day tank. b. Prime the engine fuel system and check for adequate return fuel flow (on installations with sight glasses) or fuel supply pressure (on installations with duplex filters). c. Start the engine and allow it to reach normal operating temperature. Check fuel system delivery or pressure. If the fuel system shows any indication of inadequate operation, see "Fuel System."
	8. Governor malfunction.	With the engine at normal operating temperature and not under load, slowly advance the throttle from idle to maximum speed. Check that all engine speeds are reached smoothly and verify maximum engine speed with a hand tachometer. If performance is inadequate, see probable cause #3. under "Loss Of Power (with a clean stack-no smoke)."
	9. Engine overloading.	Check the governor rack quadrant with the engine at maximum speed and full load. If the governor rack dimension is shorter than the limit on the governor identification plate, then the engine is either overloaded or lacking fuel. See preceding checks for solving fuel problems. Check the maximum RPM with a hand tachometer on the end of the camshaft. If the engine is running below its maximum rated RPM and short on rack, perform the following steps: a. On locomotive and power generating installations, set the system to rated horsepower output and check all calibratingand load control adjustments. b. On marine gearbox installations, it may be necessary to adjust pitch or diameter of the propeller if continual overloading is experienced.

10. Plugged air filters.

With the engine at maximum speed, with no load applied, use a water manometer to check engine air inlet depression. If air inlet depression exceeds the value provided in the "Air Filter Pressure Drop" table, either change or clean filters.

NOTE

All air filter pressure drops are measured in clean air plenum downstream of the filter elements.

Application	Turbocharged Engines						Blower-Type Engines					
	Paper		*Fiberglass*		*Oil*		*Paper*		*Fiberglass*		*Oil*	
	mm	In.	mm	In.	mm	In.	mm	In.	mm	In.	mm	In.
Marine	356*	14*	178	7	406*	16*	457**	18**	178	7	508**	20**
Marine Drill	356*	14*	178	7	406*	16*	457**	18**	178	7	508**	20**
Stationary	356*	14*	178	7	406*	16*	457**	18**	178	7	508**	20**
Drill Rig											508**	20**
	Inertial + Paper		Inertial + Fiberglass		Inertial + Oil		Inertial + Paper		Inertial + Fiberglass		Inertial + Oil	
	mm	In.	mm	In.	mm	In.	mm	In.	mm	In.	mm	In.
Locomotive	356	14	356	14	406	16	457	18	457	18	368	14.5

NOTE

Inertial filter readings should not exceed 140 mm (5.5").

*For remote mounted filter applications, subtract 76 mm (3") of water.
**For remote mounted filter application, subtract 254 mm (10") of water.

Air Filter Pressure Drop

24886

11. High exhaust back pressure.

With the engine at maximum speed, with full load applied, use a water manometer to check exhaust back pressure. Take readings as follows:
On 567 and 645 turbocharged engines, a 1/16" diameter hole should be drilled into the turbocharger exhaust duct on the engine side of the turbocharger as shown in Fig. 2. This hole should be free of all burrs after drilling. A 1/8" NPT coupling can then be welded over the hole and a 1/8" NPT pipe plug used for sealing of the tap. (Only this location should be used when measuring back pressure.) The maximum allowable exhaust back pressure is 127 mm (5") of water.

NOTE

Consult your Electro-Motive representative for exhaust back pressure specifications on 710 engines.

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION

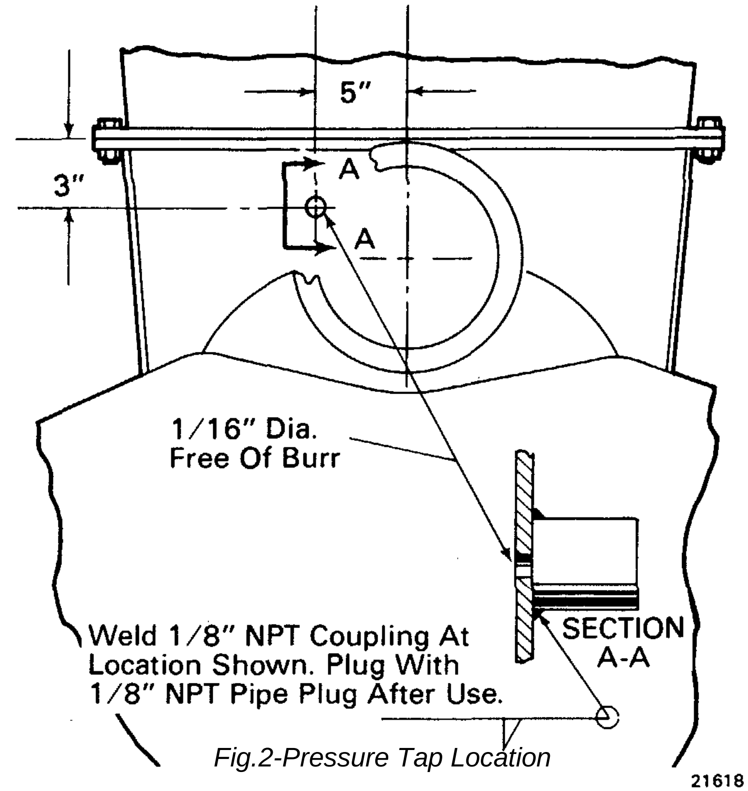

Fig.2-Pressure Tap Location

On blower-type engines without an external exhaust ducting system (locomotive and some other installations), drill a 4 mm (0.159") diameter hole (#21 drill size) in the center of each exhaust leg 230 mm (4") above the manifolds engine mounting flange. Using a static pressure pick up, shown in Fig. 3, read the static pressure in each leg-the probe is inserted through the hole in the leg androtated slowly until the maximum pressure is obtained. After readings are taken, the holes should be plugged with 10-32 self tapping screws (with the screw head tack welded to the exhaust leg). The average of all of the readings should not exceed 1 208 mm (47.5') of water. No individual reading should exceed 1 381 mm (54.4") of water.

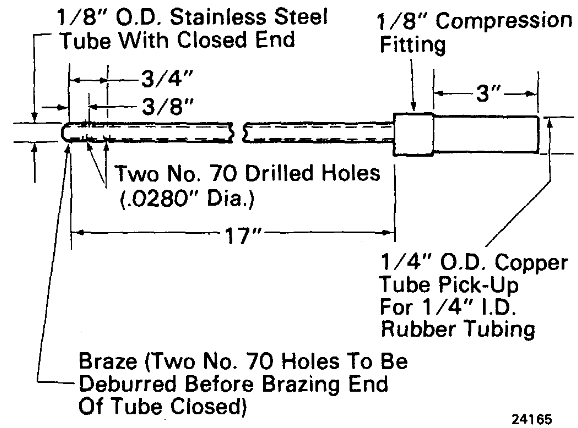

Fig.3 - Static Pressure Pickup

On blower-type engine installations with an external exhaust ducting system (mostly marine installations), drill a 4 mm (0.159") diameter hole (#21 drill size) in the exhaust ducting at a point close to where the ducts join to the engine exhaust manifolds. Insert the static pressure pickup, shown in Fig. 3, into the hole and rotate until the maximum pressure reading is obtained. After readings are taken, the holes should be plugged with 10-32 self tapping screws (with the screw head tack welded to the duct). The measured back pressure should not exceed 559 mm (22") of water.

If back pressure readings are too high, then check for obstructions in the exhaust risers, stack extensions, or manifolds downstream of the point where readings were taken.

	12. Faulty exhaust valve timing.	Check exhaust valve timing on both cylinder banks as described in the Engine Maintenance Manual.
ENGINE EMITTING BLUE SMOKE	Oil leaks or burning oil.	See fault condition "Excessive Use Of Lubricating Oil" in "Lubricating Oil System."

TURBOCHARGER

More than 50% of all turbocharger failures are caused by conditions external to the turbocharger. If these conditions are not corrected, the replacement turbocharger may also fail in a very short time. In other cases, an engine problem is attributed to a failed turbocharger while in fact nothing is wrong with the turbocharger. Therefore, troubleshooting a turbocharger requires two decisions.

1. Whether or not the turbocharger has actually failed and requires replacement.

2. The actual cause of the failure.

Any turbocharger suspected of being defective should be inspected for obvious damage. Perform the following inspections before proceeding to any further steps:

PRELIMINARY TROUBLESHOOTING INSPECTION

1. Inspect the entire housing for cracks and oil leaks. Some oil leaks can be repaired merely by tightening a pipe plug or by applying silastic rubber sealant. An excessive leak from a crack or from an inaccessible area requires turbocharger changeout.

2. Remove the rubber air intake boot and flange.

3. Inspect the impeller for broken or nicked vanes or any visible signs or rubbing. On Unit Exchange turbochargers, do not confuse smooth blends in the impeller surface or on the vane with sharp nicks caused by foreign material.

4. Turn the impeller by hand to check for a locked-up condition or a badly damaged clutch. It should turn freely in the counter-clockwise direction, but engage when turned clockwise.

5. Displace the impeller laterally, vertically, fore and aft to determine excessive radial or end thrust clearance.

6. Inspect the clearance between the impeller and the cover to reveal any impeller contact.

7. If any defective condition was found in the preceding steps, the turbocharger must be replaced. If no defective condition is found, reinstall the flange and the boot.

8. Bar the engine over to determine if it is damaged before a starting attempt is made and inspection continued. (Often a reported turbocharger failure is actually a failure of some other engine component.)

TROUBLESHOOTING RUNNING TURBOCHARGER

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
TURBOCHARGER MAKING UNUSUAL NOISE		Identical turbocharger components can make varied sounds due to the tolerances within which the components are manufactured. The sum of these individual sounds results in a wide range of noises such as whining, chirping, singing and humming. A different sounding turbocharger is not necessarily defective. Obvious exceptions are severe humming or the loud screech of distressed metal associated with gear failures or bearing failures. Normally these noises are accompanied by visual damage, leaving little doubt about the failure. When a turbocharger is reported defective because of noise, the following should be checked:
	1. Impeller damage.	Perform the "Preliminary Troubleshooting Inspection."
	2. Gear train failure.	Remove a handhole cover and check for metallic debris under the crankshaft gear. Such debris is indicative of a gear train problem.
TURBOCHARGER THROWING OIL OUT OF EXHAUST STACK		Inspect the exhaust stack to ensure that the oil is actually coming out of the stack. A plugged and leaking turbocharger seal can not be found through external inspection so it must be determined by process of elimination only if no other faulty condition is discovered. Troubleshooting steps for this fault conditioncan be found in the "Oil Loss Out Of The Exhaust Stack" cause under fault condition "Excessive Use Of Lubricating Oil," in the "Lubricating Oil System."
TURBOCHARGER EXHAUST LEAK		Start the engine and determine if it is actually leaking exhaust. Some turbo-chargers look sooty because of exhaust leaks at expansion joints or manifold gaskets. Most turbocharger exhaust leaks occur at cracks in the exhaust inlet scroll or at the sealing areas on either side of the exhaust duct. These types of leaks can not be repaired in the field and require turbocharger changeout. Improper application of lifting chains (allowing them to press against the exhaust duct while the turbocharger is suspended) can lead to bending of the lap joint between the exhaust duct and the compressor bearing support. Once this joint is deformed, a permanent exhaust leak may result.

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
TURBOCHARGER BURPING (HONK-ING) AND SMOKING EXCESSIVELY	UNKNOWN-preliminary check.	Compare the air box pressure to that of engines that are operating satisfactorily. Using the same gauge (0-270 kPa [0-30 psi]), take an air box pressure reading at full speed and no load on the engine being inspected and the reference engines. Ideally, the readings should not vary more than 6.9 kPa (1 psi) if everything is in good condition. Based on the pressure results, make the following checks, after inspecting the impeller per "Preliminary Troubleshooting Inspection" instructions:
	HIGH AIR BOX PRESSURE - Gas flow restriction downstream of the airbox causing momentary air flow reverses through the compressor.	
	1. Cylinder air intake.	Check for heavy air box deposits around the cylinder intake ports. Clean if necessary.
	2. Poor exhaust valve timing.	Check exhaust valve timing as described in the Engine Maintenance Manual. Adjust if necessary.
	3. Plugged turbocharger exhaust inlet screen.	Remove the section of the exhaust manifold adjacent to the turbocharger. (If the engine is equipped with an exhaust screen inspection port, the manifold section does not have to be removed.) Examine the condition of the exhaust inlet screen and clean if necessary. **NOTE** A common cause of exhaust screen plugging is extended operation under light load. This plugging is due to "souping", which is the tendency of relatively cold, viscous engine lube oil to bypass the oil control rings on the pistons. Under light load operation, frequent exhaust screen inspection and cleaning may be necessary.
	4. Turbocharger damage.	Examine the nozzles and the leading edges of the turbine blades for foreign material damage or deposits. This may be done by viewing through the turbine inlet scroll. The leading edges of the blades can be viewed through the nozzles located between the 1:00 and 2:00 o'clock positions, and all blades can be viewed by rotating the impeller. Examine for nicked blades, broken blades, and blades that have stretched and are rubbing on the shroud, Figs. 4 and 5. These conditions require turbocharger changeout. **NOTE** On Unit Exchange turbochargers, do not confuse smooth blends with sharp nicks caused by foreign material.

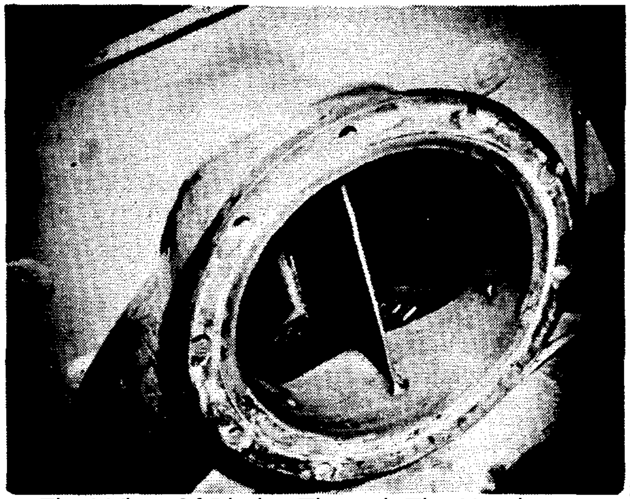

Fig.4-View Of Blades Through The Nozzles Between The 1:00 And 2:00 O' Clock Positions

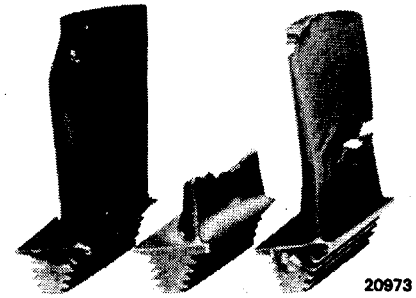

Fig.5-Stretched, Broken, And Nicked Blades

LOW AIR BOX PRESSURE - pressure leak or air intake restriction.

1. Impeller damage.

This should have been found in previous impeller inspections.

2. Air filter plugging.

Check engine air filters for restrictions or a plugged condition. See the air filter section under "Engine Emitting Black Smoke" in "Engine Performance."

3. Air box leak.

Check for any signs of air box leaks at handhole covers at crankcase structural members, and at the turbocharger discharge scroll gaskets.

FAULT CONDITION	POSSIBLE CAUSE	RECOMMENDED CHECK OR CORRECTIVE ACTION
	4. Aftercooler plugging.	Inspect aftercooler air passages for plugging or debris accumulation. Check the pressure drop action across the aftercoolers and correct if necessary.
	5. Exhaust leaks.	Check for exhaust leaks at manifold mounting flanges, manifold joints, and expansion joints. Check for leaky gaskets ora leaking pipe plug on top of the turbocharger exhaust inlet scroll.
	6. Failed turbocharger clutch.	A low pressure reading can occur when a clutch is in extremely bad condition so that is will slip when the turbocharger is driven by the gear train. This condition may cause poor starting as well as smoking or burping. Take off the rubber boot and clear the area around the turbocharger inlet of all foreign material. Observe the impeller while attempting to start the engine. A badly damaged clutch will slip consistently. A failed clutch requires turbocharger changeout on 567 and 645 engines. On 710 engines, turbocharger must be removed to repair or replace clutch drive gear assembly.
	NORMAL AIR BOX PRESSURE-failed turbocharger clutch.	It is usual for a malfunctioning clutch to slip only intermittently, therefore only occasionally causing burping and smoking by its failure to engage. Check for clutch failure by performing the following: a. Idle the engine. b. Operate the injector rack manual control lever to increase engine speed to about 700 RPM. Then pull the manual control lever to the "NO FUEL" position. This action will allow the turbocharger to spin free from decelerating engine and disengage the clutch. c. When the engine has almost stopped, return the injector rack manual control lever to the idle position. The engine will accelerate and the clutch should disengage. d. Repeat the procedure until the clutch fails to engage. A worn clutch may fail to engage only once in as many as 30 attempts. When it fails to engage, the injector racks will move toward "FULL FUEL" position and the engine will produce heavy black smoke and rumbling noises.

TROUBLESHOOTING ENGINE WITH FAILED TURBOCHARGER

After turbocharger failure has been verified, it is very important to determine the cause of the failure and take preventative measures to ensure that the replacement turbocharger will not fail. After the turbocharger is removed from the engine, inspect the turbocharger areas.

1. Impeller.
2. Exhaust duct.
3. Inlet scroll (nozzles and turbine blades).
4. Gear train (also inspect for debris at both turbo oil drain passages).

Any sign that failure was caused by an external source should be investigated and corrective action taken before the unit is returned to service. The following paragraphs list some common failures.

FOREIGN MATERIAL DAMAGE TO THE IMPELLER

This failure, Fig. 6, usually results from one of the following:

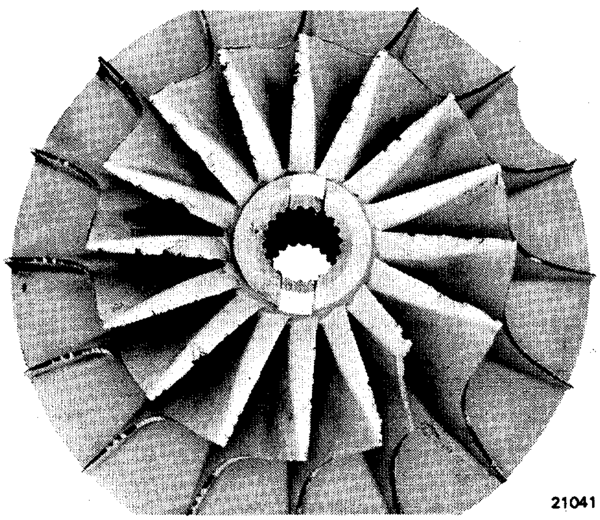

Fig.6-Impeller Damaged By Foreign Material

1. Previous Turbocharger Failure-When a turbocharger is operating and pieces are broken off the impeller, the force drives the pieces into the air filter. Later, they may be pulled loose and damage the new impeller.

2. Misapplication Of The Compressor Inlet Boot-If the boot travels, a clamp may enter the impeller and destroy it.

3. Loose Material In The Air Filter Housing- Material left in the housing can enter the impeller;

   If an impeller has rubbed the cover or has pieces broken out, the air filter housing, ducts, and filters should be inspected. Paper or fiberglass elements should be scrapped if the inspection reveals aluminum in the air duct, filter housing, or in the filters.

   As the turbocharger rotating assembly slows down during a failure, pieces of the impeller may enter the air duct and damage the after-coolers. The aftercooler area should be inspected following damage to the impeller.

CAUTION

In many cases, rubbing and loss of pieces from the impeller are caused by an unbalanced condition within the turbocharger. Therefore, the turbocharger should be inspected for other defects which cause imbalance when impeller rubbing and loss of pieces are found.

FOREIGN MATERIAL DAMAGE TO TURBINE BLADES

Foreign material damage can be found by inspecting blades and nozzles as detailed in the section under "Turbocharger Reported Burping And Smoking Excessively." The nozzles may be dented or closed, and at times, larger pieces of foreign material may be stuck in them. If the rotating assembly is not frozen, inspect the leading edges of all the blades by turning the impeller. The leading edges of some or all of the blades will be, nicked and, in some cases, a blade may break at a nick, Fig. 7.

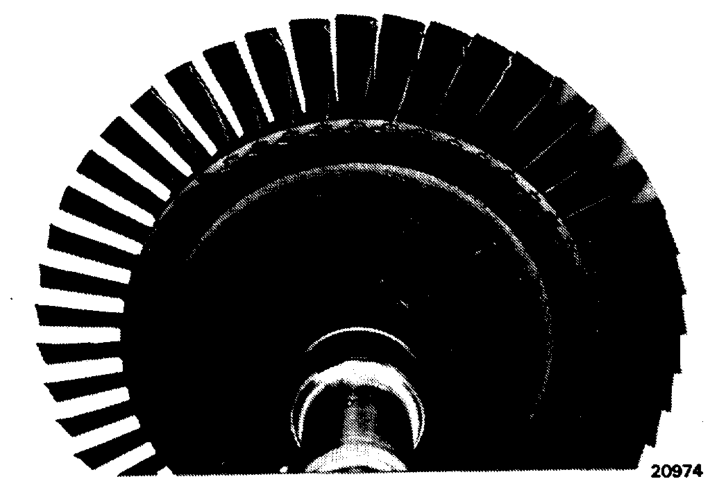

Fig.7-Nicked Blades

The mechanical breakup of any part of the power assemblies or the exhaust system may result in foreign material damage to the turbine blades and nozzles. The most common sources are broken exhaust valves and broken piston rings. The turbocharger is protected from this material by the inlet screen, but the screen is not 100% effective, since it is designed to pass a large volume of air while inducing only a small drop in pressure. It will, however, stop and hold most pieces of material. This material must be removed at the earliest opportunity, or it will break up and pass through the screen, causing turbine blade damage.

A newly designed screen with a trap at the bottom is now available. The trap collects foreign material and prevents it from continuously hitting the screen, breaking up, and entering the turbocharger. The screen assembly is now applied to new engines and is available from Electro-Motive Parts Centers.
Failures can be reduced by performing preventive maintenance to:

1. Preclude ring breakage. Top ring side clearance measurement can be used as a method to determine when the ring is entering a dangerous stage.

2. Prevent valve blow from progressing to valve breakage. Maintain valve and injector timing as specified in the Engine Maintenance Manual.

3. Determine if power assembly or exhaust system pieces are missing, and locating and removing them from the exhaust system.

OVERHEAT/OVERSPEED
Overheat/overspeed is the most destructive and costly type of failure and may result in almost total destruction of the turbocharger. Since it is caused by excessive heat energy in the exhaust system which increases turbine wheel speed to an unacceptable level, the only cure is to remove the source of the heat energy.

An overheat/overspeed failure can be recognized by:
1. Turbine blades that are stretched and have rubbed the shroud; some of the blades may have pulled apart. Often the turbocharger is frozen and the impeller cannot be rotated, therefore, only a limited view of the blades is available, Fig. 8.

2. Viewing down the exhaust duct; the exhaust diffuser may be warped and the shroud may be bulged. Both may be torn by broken blades, Figs. 9 and 10.

NOTE

Units with exhaust duct connected to an elbow or silencer which prevents viewing diffuser down duct can be inspected by removing eductor tube assembly and using a light and mirror through the eductor tube connection.

3. An impeller that rubs the cover; the overheat/overspeed condition may result in a bearing failure that allows the impeller to move forward, or an unbalanced condition may occur when blades are pulled apart.

The usual sources of excess heat are:
1. Air box fire. White ash should be visible in the inner air box, on the stress plates, end plates, or liners. The paint on the handhole covers may be blistered. Clean if necessary.

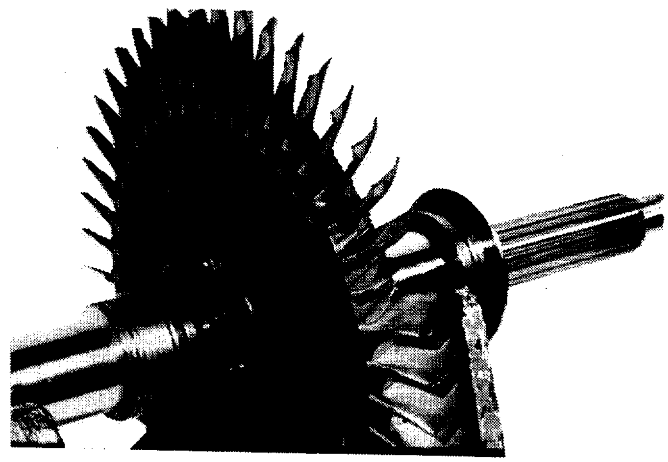

Fig.8-Stretched Blades That Have Rubbed the Shroud

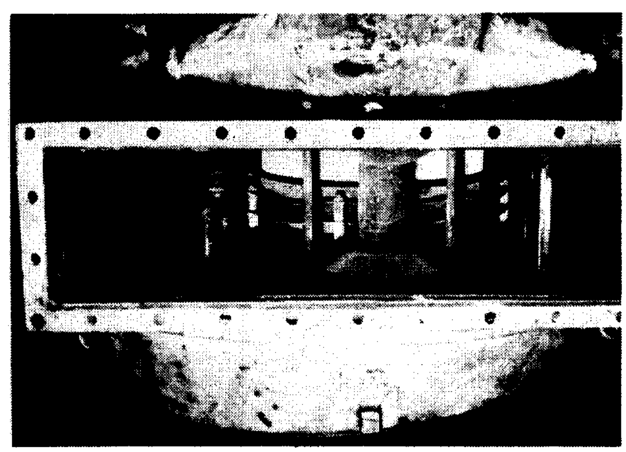

Fig.9-View Down the Exhaust Stack-Warped Diffuser

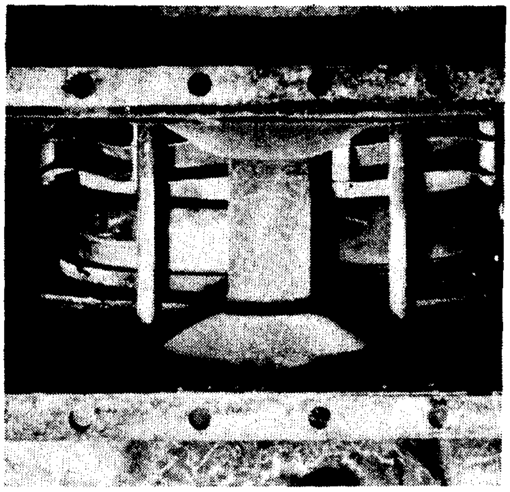

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Fig.10-View Down The Exhaust Stack Of A Warped Diffuser And Damage From Broken Blades

Any condition that increases either the air box temperatures or the amount of deposit formation in the air box should be corrected. These conditions are:

a. Dirty aftercoolers.

b. Broken compression rings.

c. Late injector timing.

d. Incorrect valve timing.

e. Plugged turbocharger exhaust inlet screen.

f. Plugged air filters or other restrictions in the air intake system.

2. Damaged injectors.

3. Broken valves (sometimes causing damaged injectors).

4. Mis-timed engine, valves, and injectors.
5. Exhaust manifold fire.
6. Excessive electrical overload.

BEARING FAILURE

A bearing failure is characterized by:
1. Heavy rubbing of the impeller vanes.
2. Excessive rotor end thrust.
3. Possible excessive up and down play in the rotor bearings.
4. No sign of turbine overheat/overspeed or foreign material damage.

Some bearing failures are avoidable. Starting or stopping the engine with no turbo lube pump oil flow can result in a bearing failure. The turbo lube pump provides oil to the turbocharger's hydro-dynamic bearings when the engine is started or stopped. At engine start, the oil lubricates the bearing and, after engine shutdown, the oil cools the bearing and protects against residual heat in the turbocharger.

Scheduled monthly inspections should include visual inspection through a rear oil pan handhole cover to verify oil flow down the gear train after the engine is shut down. A check at the top deck should also be made to ensure that oil is not flowing from the camshaft bearings, indicating an inoperative check valve that is allowing oil from the turbo lube pump to backflush the turbocharger filter into the engine bearings. Also, when an engine is shut down, any battery switch, fuse, or circuit breaker that de-activates the turbo lube pump must remain closed until the bearing has cooled.

Bearing failures can also occur due to turbocharger housing distortion from misalignment of the aftercooler air ducts. Follow the procedures outlined in the Engine Maintenance Manual when installing the air ducts.

GEAR TRAIN FAILURE

When turbocharger gear train damage is evident, the following should be performed:
1. Check for debris in the lube oil system, oil pan, strainers, and filters.
2. Inspect the timing gear housing for debris.

3. Inspect the entire engine gear train, including clutch drive gear assembly on 710 engines, to determine when gears require replacement. For engines using spring drive or clutch drive gear assemblies, the gear retaining bolts should be checked for tightness. Discard any loose bolts and apply new bolts.

NOTE

The eight bolts holding the turbocharger drive gear to the spider on spring drive gear assemblies or doweling assembly on clutch drive gear units should be 31.8 mm (1-1/4") long, with hardened washers between the gear and bolt heads.

"ONE REVOLUTION" INSPECTION SEQUENCE CHARTS

The following engine "One Revolution" inspection sequence charts are designed to speed up air box inspection of power assembly components and minimize required engine manual barring. The charts show the power assembly checks that can be made during one revolution of the crankshaft.

Select the chart which is applicable to the number of cylinders and the direction of rotation of the engine to be inspected. (The right-hand rotation charts are applicable only to right-hand rotation marine engines.)

The column headings can be interpreted as follows:

FLYWHEEL DEGREES-Flywheel location as indicated by the flywheel pointer.

BLOWER-Indicates the flywheel setting required on a blower-type engine to perform the applicable inspections.

TURBOCHARGED-Indicates the flywheel setting required on a turbocharged engine to perform the applicable inspections.

SET INJECTOR-The number appearing in this column opposite "flywheel degrees" indicates that the injector of that cylinder can be timed.

NO. 1 RING-This indicates that the top compression ring of that cylinder can be inspected.

UP-The number appearing in this column indicates that the compression rings in that cylinder are moving upward past the ports of the liner, and can be inspected.

DOWN-The number appearing in this column indicates that the compression rings in that cylinder are moving downward past the ports of the liner, and can be inspected.

PISTON COOLING OIL PIPE-The number appearing in this column indicates that the clearance between the piston cooling oil pipe and the piston carrier can be observed and the alignment gauge can be used.

PISTON-The number appearing in this column indicates that the skirt of the piston in that cylinder can be inspected through the liner ports.

LINER-The number appearing in this column indicates that the piston in that cylinder is at or near bottom dead center, which allows inspection of the liner bore through the liner ports.

8-CYLINDER ENGINE (LEFT-HAND ROTATION) "ONE REVOLUTION" INSPECTION SEQUENCE

FLYWHEEL DEGREES									
BLOWER	STD. TURBO-CHARGED	A.T.D.C. +1°	A.T.D.C. +2°	SET INJECTOR	NO. 1 RING UP	NO. 1 RING DOWN	PISTON COOLING OIL PIPE	PISTON	LINER
356	0	1	2	1					4
18½	22½	23½	24½		7	2			
41	45	46	47	5					8
63½	67½	68½	69½		4	6	4-6	1-7	
86	90	91	92	3					2
108½	112½	113½	114½		8	1			
131	135	136	137	7					6
153½	157½	158½	159½		2	5	2-5	3-8	
176	180	181	182	4					1
198½	202½	203½	204½		6	3			
221	225	226	227	8					5
243½	247½	248½	249½		1	7	1-7	4-6	
266	270	271	272	2					3
288½	292½	293½	294½		5	4			
311	315	316	317	6					7
333½	337½	338½	339½		3	8	3-8	2-5	

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12-CYLINDER ENGINE (LEFT-HAND ROTATION) "ONE REVOLUTION" INSPECTION SEQUENCE

FLYWHEEL DEGREES									
BLOWER	STD. TURBO-CHARGED	A.T.D.C. +1°	A.T.D.C. +2°	SET INJECTOR	NO. 1 RING UP	NO. 1 RING DOWN	PISTON COOLING OIL PIPE	PISTON	LINER
356	0	1	2	1	3	2	3-2	8	
15	19	20	21	12	10	11	10-11	4	
									5
41	45	46	47	7	9	8	9-8	3-6	
									2
66	70	71	72					10-1	
									11
90	94	95	96	4	5	6	5-6	9-12	
									8
116	120	121	122	3	2	1	2-1	7	
135	139	140	141	10	11	12	11-12	5	
									6
161	165	166	167	9	8	7	8-7	2-4	
									1
186	190	191	192				11-3		
									12
210	214	215	216	5	8	4	8-4	8-10	
									7
236	240	241	242	2	1	3	1-3	9	
255	259	260	261	11	12	10	12-10	6	
									4
281	285	286	287	8	7	9	7-9	1-5	
									3
306	310	311	312					12-2	
									10
330	334	335	336	6	4	5	4-5	7-11	
									9
356	0	1	2	1	3	2	3-2	8	

29287

16-CYLINDER ENGINE (LEFT-HAND ROTATION) "ONE REVOLUTION" INSPECTION SEQUENCE

FLYWHEEL DEGREES				SET INJECTOR	NO. 1 RING		PISTON COOLING OIL PIPE	PISTON	LINER
BLOWER	STD. TURBO-CHARGED	A.T.D.C. +1°	A.T.D.C. +2°		UP	DOWN			
356	0	1	2	1	6	13	6-13	7-16	4
18½	22½	23½	24½	8	11	2			5
41	45	46	47	9	14	7			12
63½	67½	68½	69½	16	4	10	4-10	1-11	13
86	90	91	92	3	5	15	5-15	8-14	2
108½	112½	113½	114½	6	12	1			7
131	135	136	137	11	13	8			10
153½	157½	158½	159½	14	2	9	2-9	3-12	15
176	180	181	182	4	7	16	7-16	6-13	1
198½	202½	203½	204½	5	10	3			8
221	225	226	227	12	15	6			9
243½	247½	248½	249½	13	1	11	1-11	4-10	16
266	270	271	272	2	8	14	8-14	5-15	3
288½	292½	293½	294½	7	9	4			6
311	315	316	317	10	16	5			11
333½	337½	338½	339½	15	3	12	3-12	2-9	14

20-CYLINDER ENGINE (LEFT-HAND ROTATION) "ONE REVOLUTION" INSPECTION SEQUENCE

FLYWHEEL DEGREES			SET INJECTOR	NO. 1 RING		PISTON COOLING OIL PIPE	PISTON	LINER
STD. TURBO-CHARGED	A.T.D.C. +1°	A.T.D.C. +2°		UP	DOWN			
0	1	2	1	15	3	15-6	4	10
9	10	11	19	17	6	15-6	16	12
36	37	38	8	17	6	17-4	9	3
45	46	47	11	12	4	17-4	14	20
72	73	74	5	12	4	12-9	1	6
81	82	83	18	20	9	12-9	19	13
108	109	110	7	20	9	20-1	8	4
117	118	119	15	13	1	20-1	11	16
144	145	146	2	13	1	13-8	5	9
153	154	155	17	16	8	13-8	18	14
180	181	182	10	16	8	16-5	7	1
189	190	191	12	14	5	16-5	15	19
216	217	218	3	14	5	14-7	2	8
225	226	227	20	19	7	14-7	17	11
252	253	254	6	19	7	19-2	10	5
261	262	263	13	11	2	19-2	12	18
288	289	290	4	11	2	11-10	3	7
297	298	299	16	18	10	11-10	20	15
324	325	326	9	18	10	18-3	6	2
333	334	335	14	15	3	18-3	13	17
360	361	362	1	15	3	15-6	4	10

130E686

(MARINE ONLY) 8-CYLINDER ENGINE (RIGHT-HAND ROTATION) "ONE REVOLUTION" INSPECTION SEQUENCE

FLYWHEEL DEGREES				SET INJECTOR	NO. 1 RING		PISTON COOLING OIL PIPE	PISTON	LINER
BLOWER	STD. TURBO-CHARGED	A.T.D.C. +1°	A.T.D.C. +2°		UP	DOWN			
356	0	1	2	1					4
18½	22½	23½	24½		8	3			
41	45	46	47	6					7
63½	67½	68½	69½		4	5	4-5	1-8	
86	90	91	92	2					3
108½	112½	113½	114½		7	1			
131	135	136	137	8					5
153½	157½	158½	159½		3	6	3-6	2-7	
176	180	181	182	4					1
198½	202½	203½	204½		5	2			
221	225	226	227	7					6
243½	247½	248½	249½		1	8	1-8	4-5	
266	270	271	272	3					2
288½	292½	293½	294½		6	4			
311	315	316	317	5					8
333½	337½	338½	339½		2	7	2-7	3-6	
356	0	1	2	1					4

(MARINE ONLY) 12-CYLINDER ENGINE (RIGHT-HAND ROTATION) "ONE REVOLUTION" INSPECTION SEQUENCE

FLYWHEEL DEGREES				SET INJECTOR	NO. 1 RING		PISTON COOLING OIL PIPE	PISTON	LINER
BLOWER	STD. TURBO-CHARGED	A.T.D.C. +1°	A.T.D.C. +2°		UP	DOWN			
356	0	1	2	1	2	3	2-3	8	
									9
22	26	27	28	6	5	4	5-4	7-11	
									10
46	50	51	52					2-12	
									3
71	75	76	77	8	9	7	9-7	1-5	
									4
97	101	102	103	11	10	12	10-12	6	
116	120	121	122	2	3	1	3-1	9	
									7
142	146	147	148	5	4	6	4-6	8-10	
									12
166	170	171	172					11-3	
									1
191	195	196	197	9	7	8	7-8	2-4	
									6
217	221	222	223	10	12	11	12-11	5	
236	240	241	242	3	1	2	1-2	7	
									8
262	266	267	268	4	6	5	6-5	9-12	
									11
286	290	291	292					10-1	
									2
311	315	316	317	7	8	9	8-9	3-6	
									5
337	341	342	343	12	11	10	11-10	4	
356	0	1	2	1	2	3	2-3	8	

29291

(MARINE ONLY) 16-CYLINDER ENGINE (RIGHT-HAND ROTATION) "ONE REVOLUTION" INSPECTION SEQUENCE

FLYWHEEL DEGREES				SET INJECTOR	NO. 1 RING		PISTON COOLING OIL PIPE	PISTON	LINER
BLOWER	STD. TURBO-CHARGED	A.T.D.C. +1°	A.T.D.C. +2°		UP	DOWN			
356	0	1	2	1	13	6			4
18½	22½	23½	24½	15	12	3			14
41	45	46	47	10	5	16	5-16	8-13	11
63½	67½	68½	69½	7	4	9	4-9	1-12	6
86	90	91	92	2	14	8			3
108½	112½	113½	114½	13	11	1			16
131	135	136	137	12	6	15	6-15	7-14	9
153½	157½	158½	159½	5	3	10	3-10	2-11	8
176	180	181	182	4	16	7			1
198½	202½	203½	204½	14	9	2			15
221	225	226	227	11	8	13	8-13	5-16	10
243½	247½	248½	249½	6	1	12	1-12	4-9	7
266	270	271	272	3	15	5			2
288½	292½	293½	294½	16	10	4			13
311	315	316	317	9	7	14	7-14	6-15	12
333½	337½	338½	339½	8	2	11	2-11	3-10	5
356	0	1	2	1	13	6			4

29292

(MARINE ONLY) 20-CYLINDER ENGINE (RIGHT-HAND ROTATION) "ONE REVOLUTION" INSPECTION SEQUENCE

FLYWHEEL DEGREES				SET INJECTOR	NO. 1 RING		PISTON COOLING OIL PIPE	PISTON	LINER
BLOWER	STD. TURBO-CHARGED	A.T.D.C. +1°	A.T.D.C. +2°		UP	DOWN			
356	0	1	2	1	13	6			4
18½	22½	23½	24½	15	12	3			14
41	45	46	47	10	5	16	5-16	8-13	11
63½	67½	68½	69½	7	4	9	4-9	1-12	6
86	90	91	92	2	14	8			3
108½	112½	113½	114½	13	11	1			16
131	135	136	137	12	6	15	6-15	7-14	9
153½	157½	158½	159½	5	3	10	3-10	2-11	8
176	180	181	182	4	16	7			1
198½	202½	203½	204½	14	9	2			15
221	225	226	227	11	8	13	8-13	5-16	10
243½	247½	248½	249½	6	1	12	1-12	4-9	7
266	270	271	272	3	15	5			2
288½	292½	293½	294½	16	10	4			13
311	315	316	317	9	7	14	7-14	6-15	12
333½	337½	338½	339½	8	2	11	2-11	3-10	5
356	0	1	2	1	13	6			4

29292

FIRING ORDER AND TOP DEAD CENTER FOR 645 ENGINES

LEFT-HAND ROTATION ENGINE — RIGHT-HAND ROTATION ENGINE

8-CYLINDER		8-CYLINDER	
FIRING ORDER	TOP DEAD CENTER	FIRING ORDER	TOP DEAD CENTER
1	0°	1	0°
5	45°	6	45°
3	90°	2	90°
7	135°	8	135°
4	180°	4	180°
8	225°	7	225°
2	270°	3	270°
6	315°	5	315°
12-CYLINDER		**12-CYLINDER**	
FIRING ORDER	TOP DEAD CENTER	FIRING ORDER	TOP DEAD CENTER
1	0°	1	0°
12	19°	6	26°
7	45°	8	75°
4	94°	11	101°
3	120°	2	120°
10	139°	5	146°
9	165°	9	195°
5	214°	10	221°
2	240°	3	240°
11	259°	4	266°
8	285°	7	315°
6	334°	12	341°
16-CYLINDER		**16-CYLINDER**	
FIRING ORDER	TOP DEAD CENTER	FIRING ORDER	TOP DEAD CENTER
1	0°	1	0°
8	22-1/2°	15	22-1/2°
9	45°	10	45°
16	67-1/2°	7	67-1/2°
3	90°	2	90°
6	112-1/2°	13	112-1/2°
11	135°	12	135°
14	157-1/2°	5	157-1/2°
4	180°	4	180°
5	202-1/2°	14	202-1/2°
12	225°	11	225°
13	247-1/2°	6	247-1/2°
2	270°	3	270°
7	292-1/2°	16	292-1/2°
10	315°	9	315°
15	337-1/2°	8	337-1/2°
20-CYLINDER		**20-CYLINDER**	
FIRING ORDER	TOP DEAD CENTER	FIRING ORDER	TOP DEAD CENTER
1	0°	1	0°
19	9°	14	27°
8	36°	9	36°
11	45°	16	63°
5	72°	4	72°
18	81°	13	99°
7	108°	6	108°
15	117°	20	135°
2	144°	3	144°
17	153°	12	171°
10	180°	10	180°
12	189°	17	207°
3	216°	2	216°
20	225°	15	243°
6	252°	7	252°
13	261°	18	279°
4	288°	5	288°
16	297°	11	315°
9	324°	8	324°
14	333°	19	351°

24174

NOTE

Locomotive, drilling rig, and power generating installations are available only with left-hand rotating engines.

Only marine and industrial installations are available with either a left or right-hand rotating engine.

LINER/PISTON VISUAL INSPECTION GUIDE

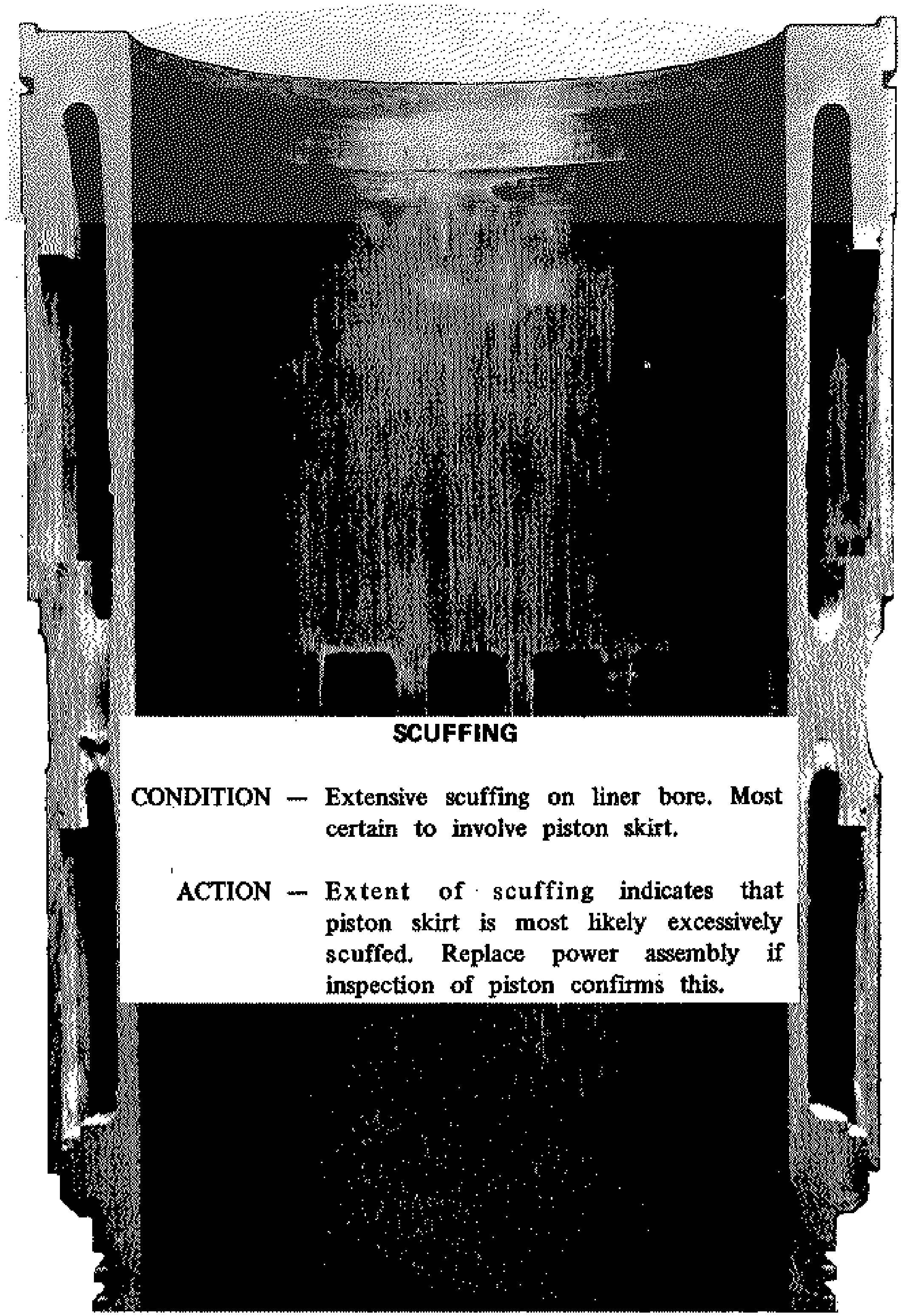
During an "in engine" liner/piston inspection, a correct diagnosis is important to prevent the unnecessary removal of still serviceable parts, or the continued operation of a non-serviceable part, possibly resulting in a complete failure. The illustrations show the conditions most likely to be observed, and the captions give the correct terms to define them. Consistent use of these terms, when describing liner and piston conditions, will permit an accurate evaluation of the problem at hand, and be understandable to anyone familiar with such conditions.

When liner bores are inspected and abnormal conditions are observed, check piston ring and piston skirt conditions BEFORE changing out a power assembly. Do not remove an assembly based on liner appearance only. Refer to the applicable illustration in the guide for the action to be taken based on the observed conditions.

Continued usage or replacement of the liner and/or piston, based on the recommended "ACTION," can contribute significantly to extended component service life and the prevention of engine damage.

NOTE

Pistons used in late model EMD turbocharged engines have a tin plate skirt treatment, the color of which turns from silver matte to a dull flat pewter gray during service. This pewter gray coloring may be mistaken for scuffing during inspections. Scuffing indications that are valid include distressed skirt surfaces where obvious metal tearing can be seen and felt, and similar liner distress is apparent when viewed through the ports.



SCUFFING

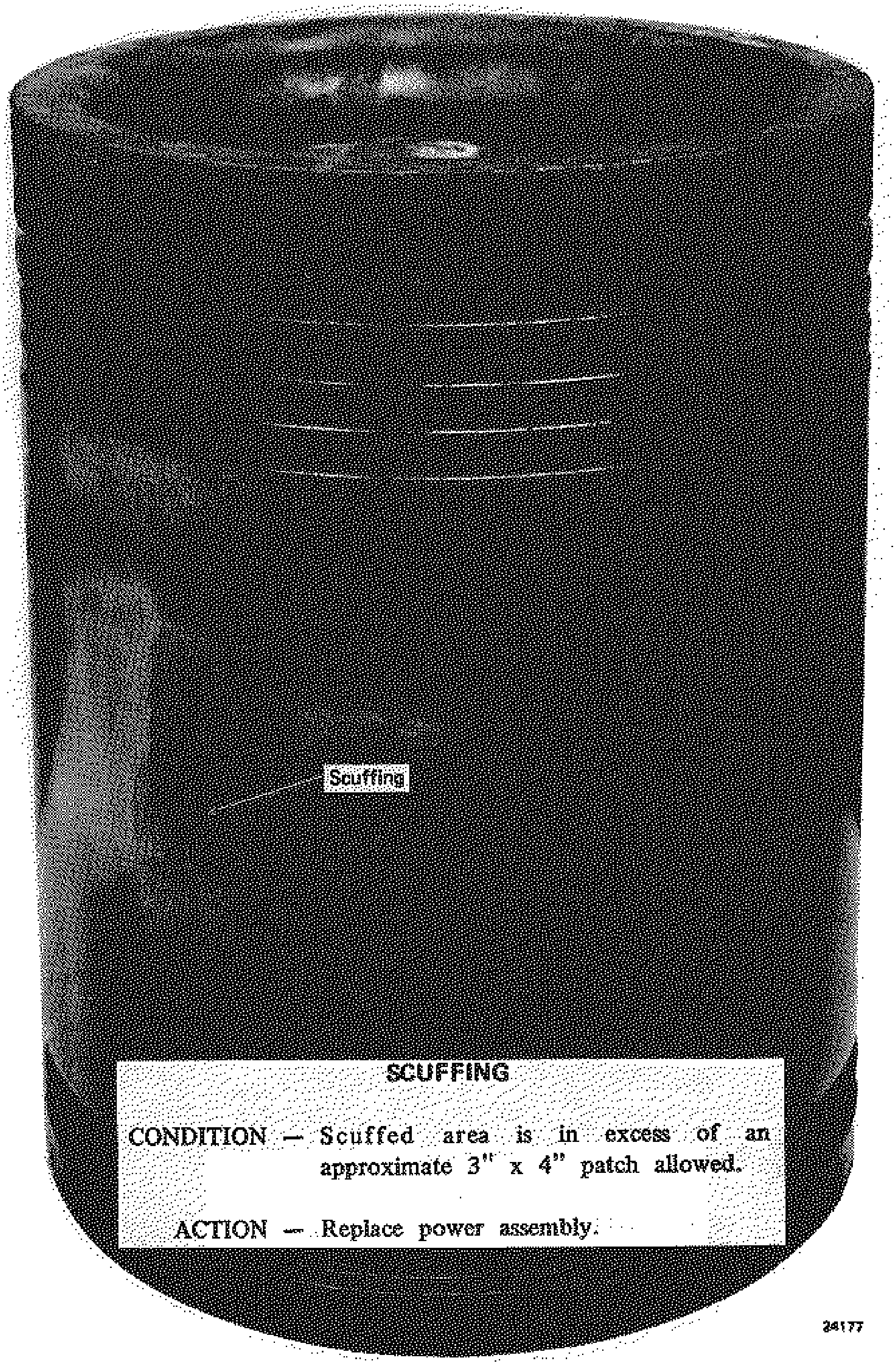
CONDITION — Extensive scuffing on liner bore. Most certain to involve piston skirt.

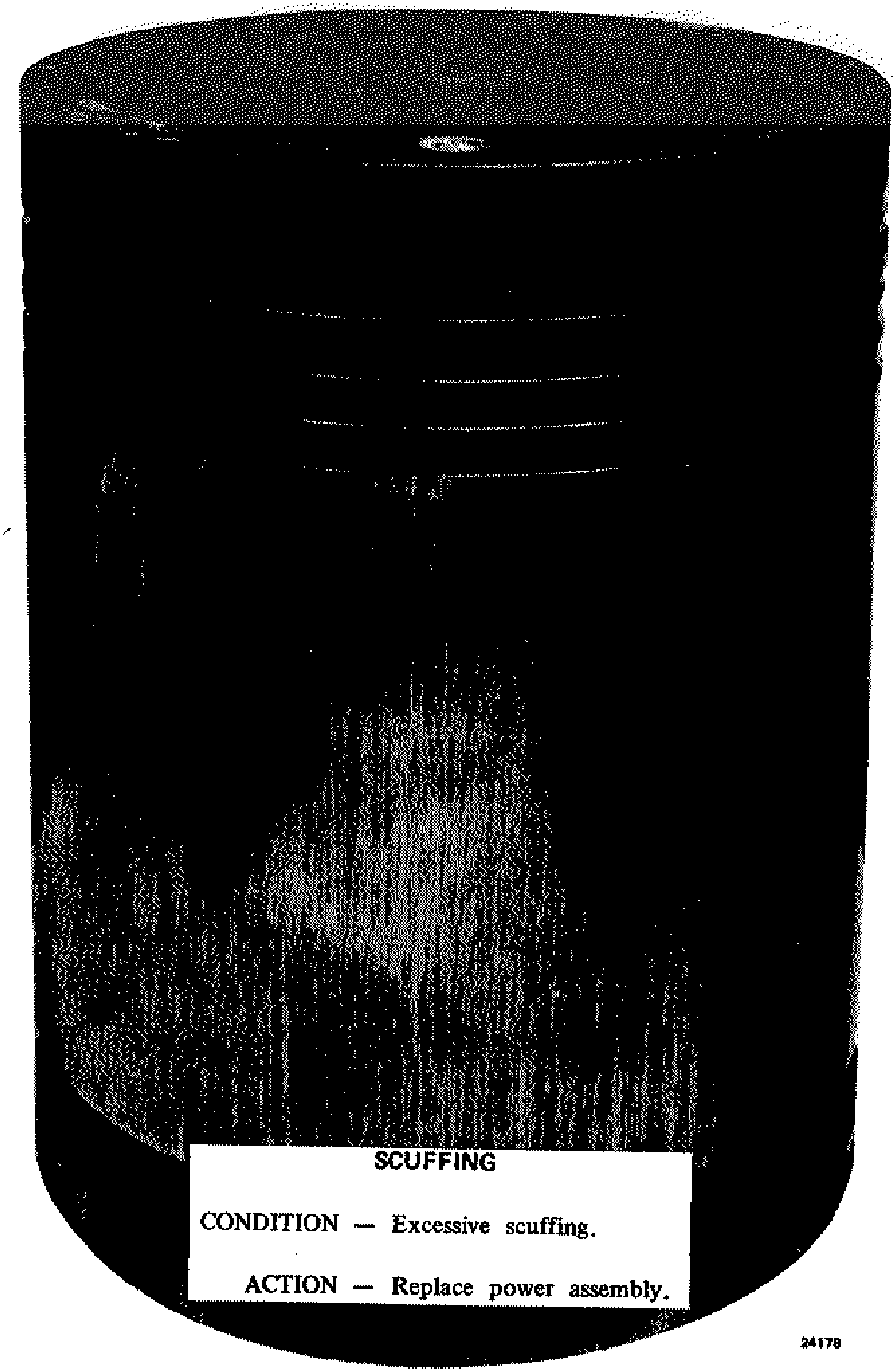
ACTION — Extent of scuffing indicates that piston skirt is most likely excessively scuffed. Replace power assembly if inspection of piston confirms this.

24176

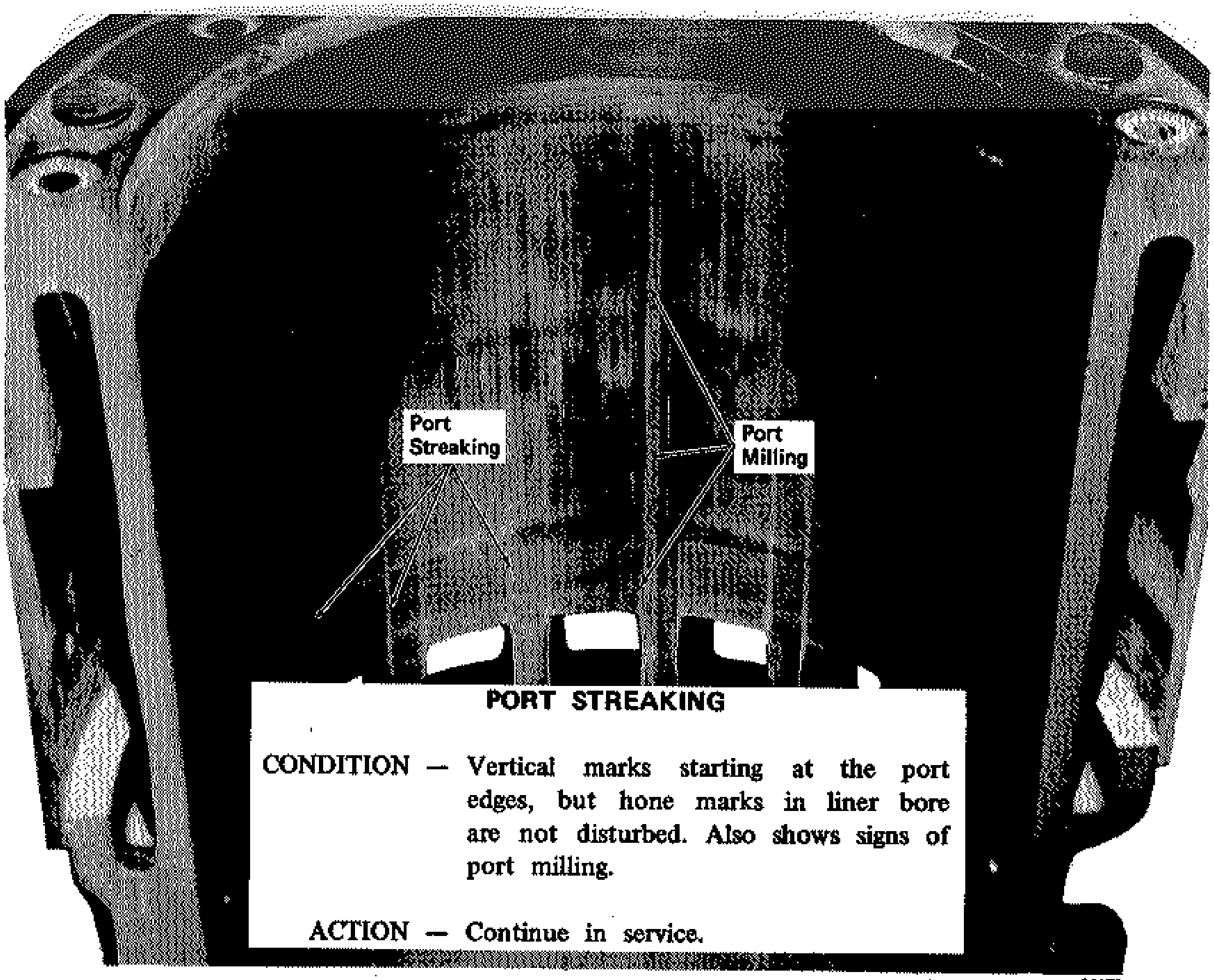

NORMAL WEAR
CONDITION — Normal wear pattern.
ACTION — Continue in service.

24176


Scuffing
SCUFFING
CONDITION — Scuffed area is in excess of an approximate 3" x 4" patch allowed.
ACTION — Replace power assembly.
24177


SCUFFING
CONDITION — Excessive scuffing.
ACTION — Replace power assembly.

24178

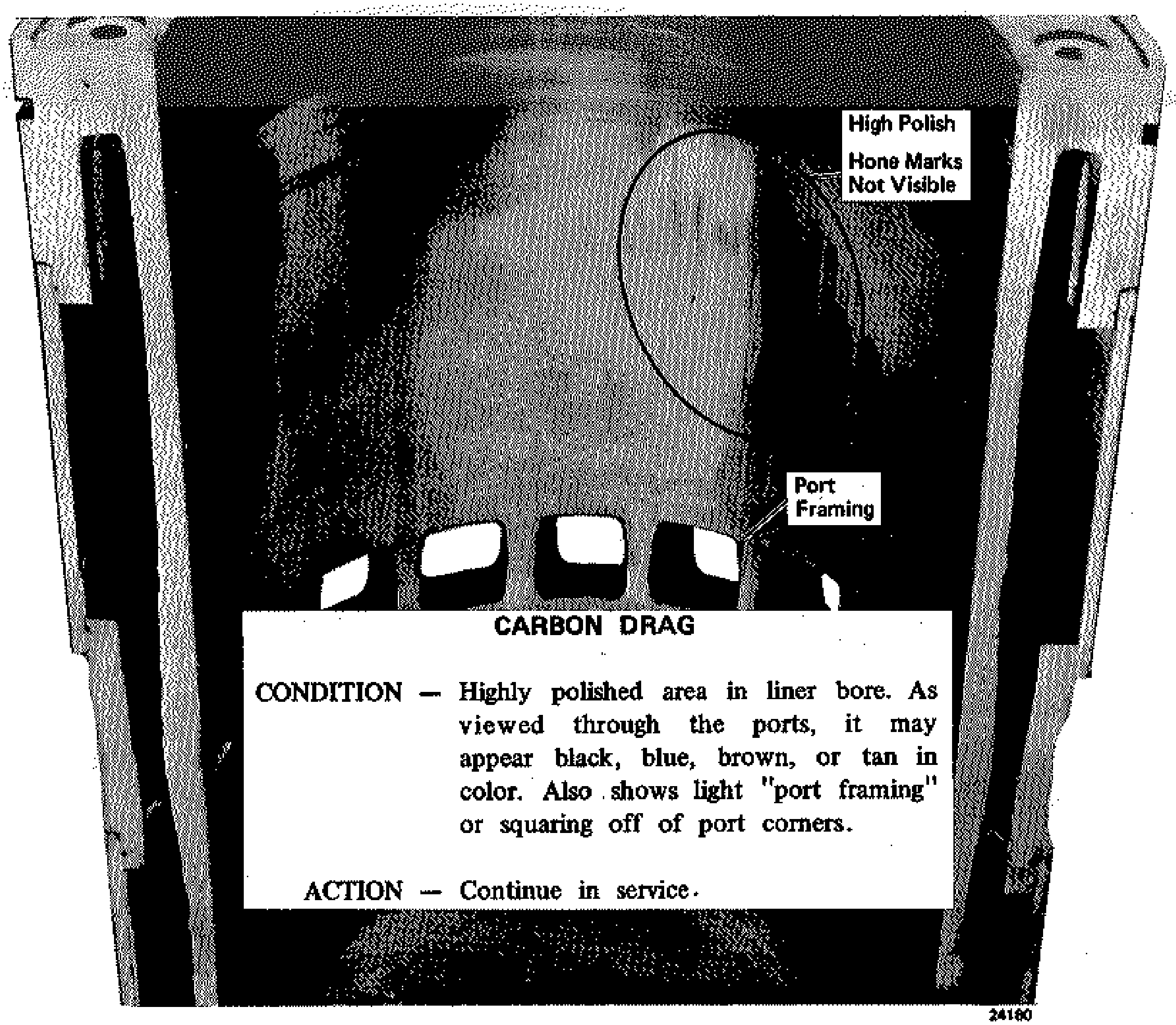


PORT STREAKING

CONDITION — Vertical marks starting at the port edges, but hone marks in liner bore are not disturbed. Also shows signs of port milling.

ACTION — Continue in service.

24179



CARBON DRAG

CONDITION — Highly polished area in liner bore. As viewed through the ports, it may appear black, blue, brown, or tan in color. Also shows light "port framing" or squaring off of port corners.

ACTION — Continue in service.

PROPULSION SYSTEM TROUBLESHOOTING

GENERAL

Since most operating difficulties will be signaled by the engine control cabinet annunciator alarms, troubleshooting will usually start by observing the annunciator indications.

This portion of the section contains a description of each alarm circuit of a propulsion unit. Each alarm monitors a respective system. In describing the alarm circuit, mechanical or electrical malfunctions have been assumed to describe the relays and switches which would be involved.

The alarm sequence and point by point description of each alarm circuit is presented as an aid to troubleshooting.

LOW OIL PRESSURE ALARM AND SHUTDOWN CIRCUIT

The low oil pressure alarm is initiated by a low oil pressure alarm device of the governor. For a detailed description of this device, refer to Protective Devices Section of this manual. The device controls contacts of the governor low oil pressure switch LOS. LOS is normally closed and opens at 48 kPa (7 psi) during low speed (under 475 RPM) and 131 kPa (19 psi) during high speed (over 475 RPM). A time delay of 50-60 seconds at low engine speed is provided before the alarm switch trips to allow operating pressure to be reached after starting the engine. At high speed, the alarm will be tripped in approximately 2 seconds. A description of the low oil pressure alarm and shutdown circuit follows.

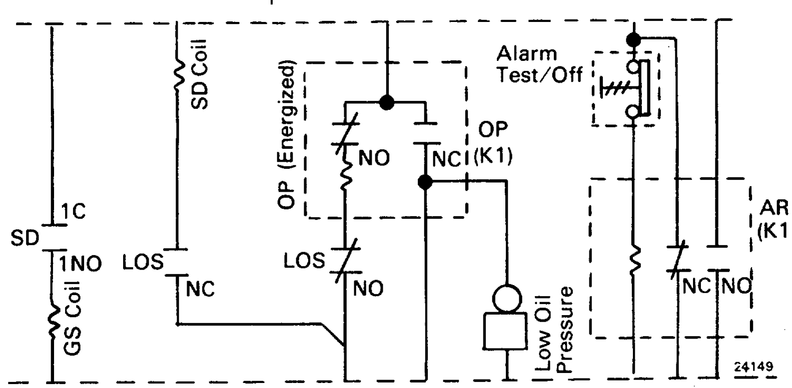
NOTE

Oil pressure switch OPS in the starting circuit is not in this alarm circuit.

OPS contact 1B remains closed, completing circuit to the starting magnet valve SM coil until engine lube oil pressure reaches 145 kPa (21 psi). At 145 kPa (21 psi), OPS opens contact 2B to disable starting circuit while engine is running to prevent damage to starting components in case ENGINE START push- button is accidentally pressed.

OPS contact 1A remains open, interrupting circuit to elapsed time indicator ETI until engine lube oil pressure reaches 145 kPa (21 psi). At 145 kPa, OPS closes contact 1A to complete circuit to ETI.

Step	Procedure Or Condition	Result
1	Governor oil pressure above 48 kPa (7 psi) at engine low speed or over 131 kPa(19 psi) at engine high speed.	Governor lube oil pressure switch LOS normally open contacts are closed, which keeps oil pressure relay OP coil energized. Energized OP coil holds OP normally closed contacts open to prevent a warning light and alarm.



Step	Procedure Or Condition	Result
2	Governor oil pressure not up to 48 kPa (7 psi) at engine low speed or up to 131 kPa (19 psi) at engine high	LOS normally open contacts open, OP de-energized. LOS normally closed contacts close, energizing shutdown SD coil. speed.
3	OP de-energized.	OP normally closed contacts close.
a.	OP normally closed contacts close.	LOW OIL PRESS warning light comes on.
		Provides a feed to alarm relay AR coil which sounds alarm.
b.	SD energized.	SD contacts IC and INO close, governor solenoid GS energizes.
4	GS energized.	Stops engine by causing governor to move fuel injector rack to no-fuel position.

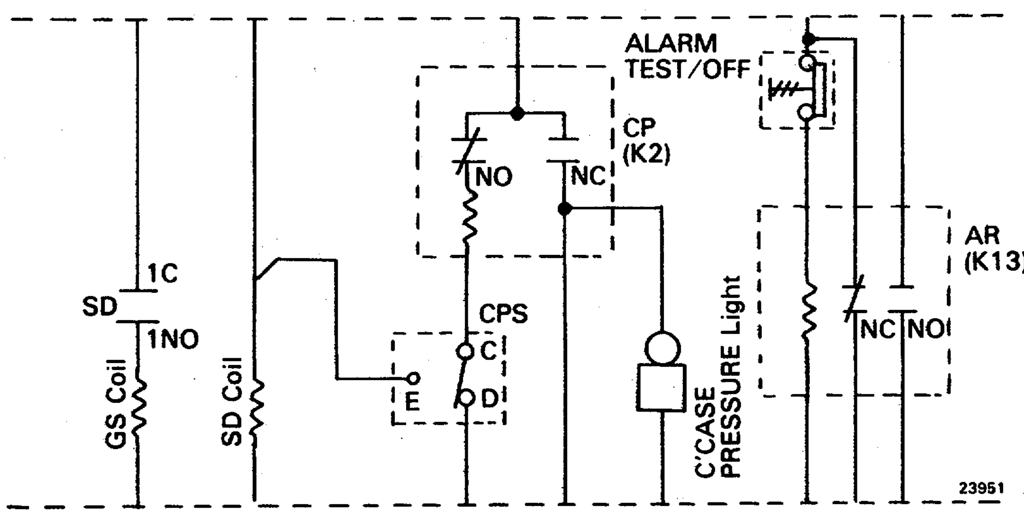
CRANKCASE PRESSURE ALARM AND SHUTDOWN CIRCUIT

The crankcase pressure alarm and shutdown circuit is initiated by the crankcase pressure switch CPS. For a detailed description of CPS, refer to Protective Devices Section of this manual.

When a positive pressure of from 20-46 mm (0.8"-1.8") H_2O is developed in the crankcase, CPS changes position, C'CASE PRESSURE light comes on, alarm sounds, and the engine shuts down.

The crankcase pressure switch must be manually reset after tripping. A description of the crankcase pressure alarm and shutdown circuit follows.

Step	Procedure Or Condition	Result
1	Crankcase Pressure at normal negative pressure.	Crankcase pressure switch CPS contacts C-D closed, which keeps crankcase pressure relay CP coil energized. Energized CP coil holds CP normally closed contacts open to prevent a warning light and alarm.



Step	Procedure Or Condition	Result
2	Crankcase pressure builds up over 20 mm (0.8") H20.	CPS contacts C-D open, closing contacts C-E.
3	CPS contacts C-D open.	CP coil de-energized. CP normally closed contacts close.
4	CP normally closed contacts close.	C'CASE PRESSURE warning light comes on. Provides a feed to alarm relay AR coil which sounds alarm.

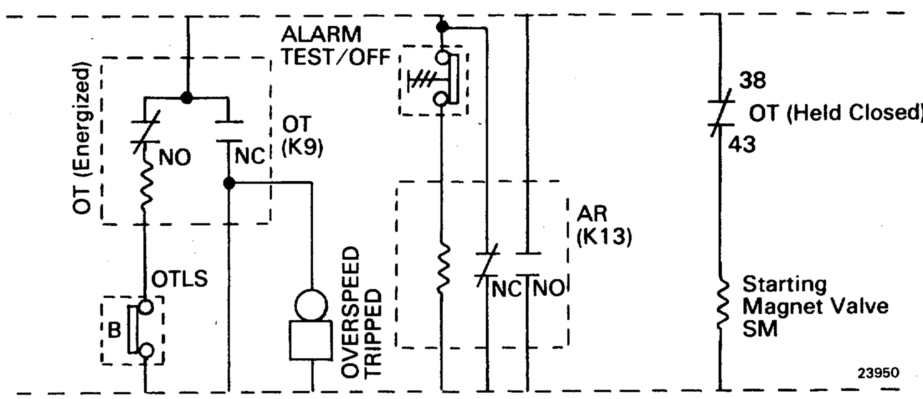
Step	Procedure Or Condition	Result
5	CPS contacts C-E close.	Shutdown SD coil energized. SD contacts IC and INO close.
6	SD contacts IC and INO close.	Governor solenoid GS energized.
7	GS energized.	Stops engine by causing governor to move to no-fuel position.

OVERSPEED TRIPPED ALARM CIRCUIT

The overspeed tripped alarm is initiated by the overspeed trip limit switch OTLS. The unit also has an overspeed trip shutdown mechanism which is provided as a safety feature to stop injection of fuel into the cylinders, causing engine shutdown. The overspeed trip mechanism is a mechanical device. For a detailed description of OTLS and the overspeed trip mechanism, refer to Protective Devices Section of this manual.

OTLS is closed when overspeed trip mechanism is in the latched position. The overspeed trip mechanism opens when engine speed increases to the specified limits and engages OTLS. OTLS opens, OVER-SPEED TRIPPED light comes on, and alarm sounds. The overspeed trip mechanism must be manually reset before the engine can be restarted. A description of the overspeed tripped alarm circuit follows.

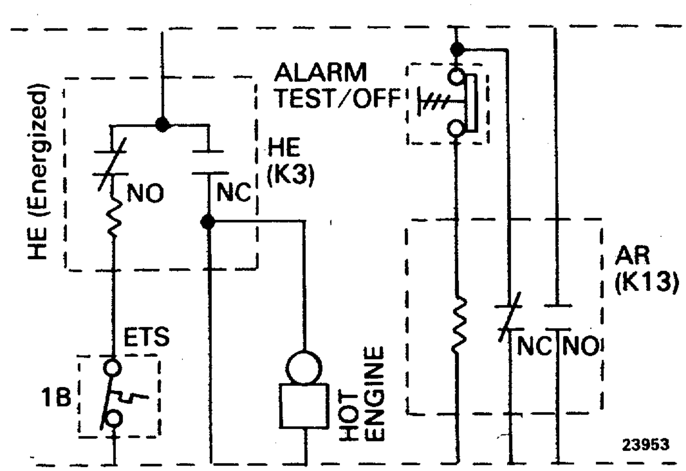
Step	Procedure Or Condition	Result
1	Engine at desired speed.	Overspeed trip limit switch OTLS contact B closed, which keeps overspeed trip relay OT coil energized. Energized OT coil holds normally closed contacts open to prevent an alarm and holds normally open contacts closed to allow engine start.



2	Engine exceeds specified speed limit.	Overspeed trip mechanism trips; engine shuts down. OTLS opens contact B, OT de-energized.
3	OT de-energized.	OT normally closed contacts close, normally open contacts 38-43 open.
4	OT normally closed contacts close.	OVERSPEED TRIP warning light comes on. Provides a feed through closed contacts to alarm relay AR coil which sounds alarm.
5	OT normally open contacts 38-43 open.	Interrupts circuit to starting magnet valve SM, preventing another starting attempt until overspeed mechanism is reset.

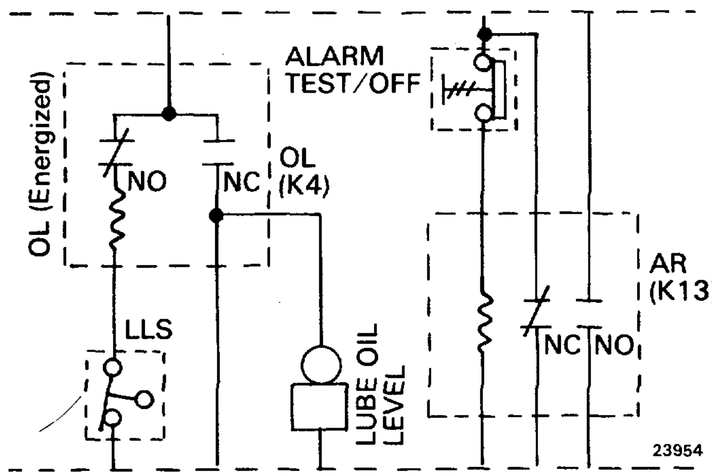
HOT ENGINE ALARM CIRCUIT

The hot. engine alarm is initiated by the engine temperature switch ETS. For a detailed description of ETS, refer to Protective Devices Section of this manual. ETS is normally closed and opens at 980 C (208° F). When engine water temperature reaches 98° C (208° F), ETS opens, HOT ENGINE light comes on, and alarm sounds. The hot engine alarm can only be corrected by reducing the engine temperature to below 92° C (198° F). A description of the hot engine alarm circuit follows.

Step	Procedure Or Condition	Result
1	Engine water temperature normal (or below 98°C [208° F).	Engine temperature switch ETS contact IB is closed which keeps hot engine relay HE coil energized. Energized HE coil holds HE normally closed contacts open to prevent a warning light and alarm bell. 
2	Engine water temperature reaches 98° C (208° F).	ETS opens contact IB, HE de-energized.
3	HE de-energized.	HE normally closed contacts close.
	HE normally closed contacts close.	HOT ENGINE warning light comes on. Provides a feed to alarm relay AR coil, which sounds the alarm.

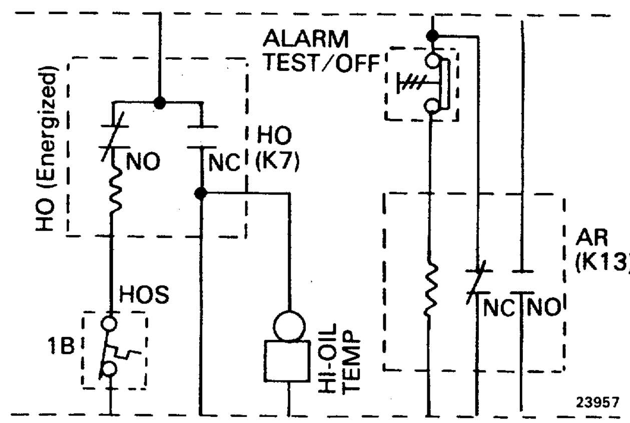
LUBE OIL LEVEL ALARM CIRCUIT

The lube oil level alarm circuit is initiated by the lube oil level switch LLS located in the low oil level indicator. For a detailed description of the low oil level indicator, refer to Protective Devices Section of this manual. LLS is closed when oil level is acceptable and opens when oil level reaches a predetermined level. When oil is at this level, LLS opens, LUB OIL LEVEL warning light comes on, and alarm sounds. A description of the low oil level alarm follows.

Step	Procedure Or Condition	Result
1	Oil at acceptable level.	Lube oil level switch LLS is closed, which keeps oil level relay OL coil energized. Energized OL coil holds OL normally closed contacts open to prevent a warning light and alarm. 
2	Oil below acceptable level.	LLS opens, OL coil de-energized.
3	OL de-energized.	OL normally closed contacts close.
	OL normally closed contacts close.	LUBE OIL LEVEL warning light comes on. Provides a feed to alarm relay AR coil which sounds alarm.

HIGH OIL TEMPERATURE ALARM CIRCUIT

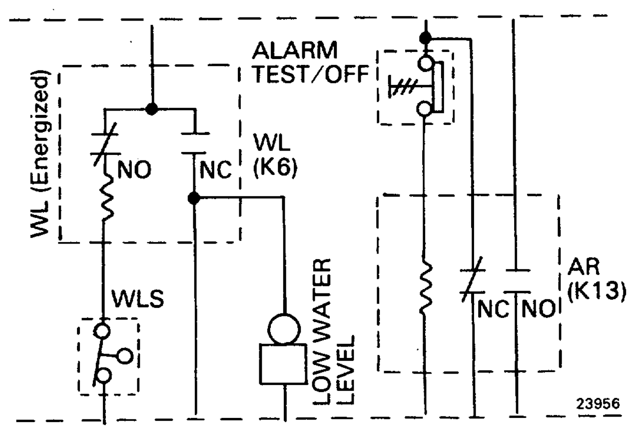
The high oil temperature alarm circuit is initiated by the high oil temperature switch HOS. For a detailed description of the high oil temperature switch, refer to Protective Devices Section of this manual. HOS is normally closed and opens at 104° C (220° F). When oil temperature reaches 104° C (220° F), HOS opens, HI-OIL TEMP warning light comes on, and alarm sounds. The high oil temperature alarm can only be corrected by reducing the oil temperature to below 99° C (210° F). A description of the high oil temperature alarm circuit follows.

Step	Procedure Or Condition	Result
1	Oil temperature below 104° C (220° F).	High oil temperature switch HOS contact 1B is closed, which keeps high oil temperature HO coil energized. Energized HO coil holds normally closed contacts open to prevent a warning light and alarm. 
2	Oil temperature reaches 104° C (220° F).	HOS opens, HO coil de-energized.
3	HO coil de-energized.	HO normally closed contacts close.
	HO normally closed contacts close.	HI-OIL TEMP warning light comes on.
		Provides a feed through closed contacts to alarm relay AR coil which sounds alarm.

WATER LEVEL ALARM CIRCUIT

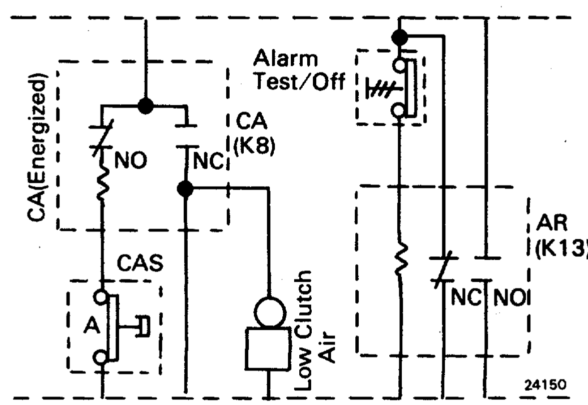
The water level alarm circuit is initiated by the water level switch WLS. For a detailed description of WLS, refer to Protective Devices Section of this manual.

WLS is normally closed and opens when water level recedes to a predetermined level. When water is at this level, WLS opens, WATER LEVEL warning light comes on, and alarm sounds. A description of the water level alarm circuit follows.

Step	Procedure Or Condition	Result
1	Water at acceptable level.	Water level switch WLS is closed, which keeps water level relay WL coil energized. Energized WL coil holds WL normally closed contacts open to prevent an alarm. 
2	Water below acceptable level.	WLS opens contact, WL de-energized.
3	WL de-energized.	WL normally closed contacts close.
4	WL normally closed contacts close.	LOW WATER LEVEL warning light comes on. Provides a feed to alarm relay AR coil which sounds alarm.

LOW CLUTCH AIR PRESSURE ALARM CIRCUIT

The low clutch air pressure alarm circuit is initiated by the clutch air pressure switch CAS. For a detailed description of the clutch air pressure switch, refer to Protective Devices Section of this manual. CAS is closed when clutch air pressure is above 827 kPa (120 psi) and opens when clutch air pressure drops below 758 kPa (110 psi). When clutch air pressure is below 758 kPa (110 psi), CAS opens, LOW CLUTCH AIR warning light comes on, and alarm sounds. A description of the low clutch air pressure alarm follows.

Step	Procedure Or Condition	Result
1	Clutch air pressure normal (or above 827 kPa [120 psi]).	Clutch air pressure switch CAS contact 1A is closed which keeps clutch air relay CA coil energized. Energized CA coil holds CA normally closed contacts open to prevent a warning light and alarm. 
2	Clutch air pressure below 758 kPa (110 psi).	CAS opens, CA coil de-energized.
	CA coil de-energized.	CA normally closed contacts close.
	CA normally closed contacts close.	LOW CLUTCH AIR warning light comes on.
		Provides a feed through closed contacts to alarm relay AR coil which sounds alarm.

GENERATING SYSTEM TROUBLESHOOTING

GENERAL

Since most operating difficulties will be signaled by the engine control cabinet annunciator alarms, troubleshooting will usually start by observation of the annunciator indications. Because of individual options and customer supplied equipment, the engine control cabinet furnished on a generating unit can vary. If the unit is equipped with annunciator alarm circuits common to both propulsion and generating control cabinets described in Section 15A, refer to Propulsion System Troubleshooting.

This section contains descriptions of alarm circuits specified primarily for generating unit control' systems.

Each alarm monitors a respective system. In describing the alarm circuit, mechanical or electrical malfunctions have been assumed to describe the relays and switches which would be involved. The alarm sequence and point by point description of each alarm circuit is presented as an aid to troubleshooting.

LUBE OIL PRESSURE ALARM AND SHUTDOWN CIRCUIT

The lube oil pressure alarm and shutdown circuit is initiated by the oil pressure switch OPS. For a detailed description of the OPS switch, refer to Protective Devices Section of this manual. OPS closes at 145 kPa (21 psi). If the oil pressure of the engine does not reach 145 kPa (21 psi) within 1 minute after engine fuel pressure reaches 83 kPa (12 psi), LUBE OIL PRESSURE warning light comes on, the alarm sounds, and the engine is shut down. A description of the lube oil pressure alarm and shutdown circuit follows.

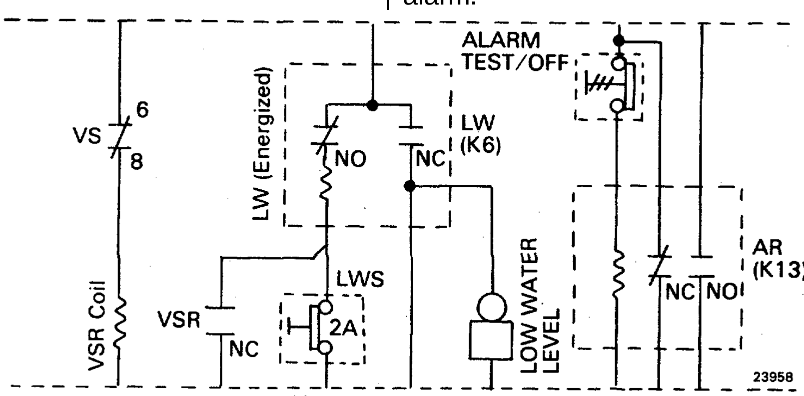
Step	Procedure Or Condition	Result
1	Engine fuel pressure reaches 83 kPa (12 psi).	Fuel pressure switch FPS opens contact B. Fuel pressure relay FPR de-energizes.
2	FPR de-energizes.	FPR times for 60 seconds then opens contact B, interrupting circuit to OP annunciator relay coil.
3	Engine oil pressure reaches 145 kPa (21 psi) within 1 minute.	Oil pressure switch OPS contact 2A closes energizing oil pressure auxiliary relay OPSX. OPSX provides circuit to OP annunciator relay coil to prevent alarm.
4	Engine oil pressure not up to 145 kPa (21 psi).	OPS contact 2A open, OPSX de-energized.
5	OPSX de-energized.	OP annunciator relay coil de-energizes, OP normally closed contacts close.
	OP normally closed contacts close.	LUBE OIL PRESSURE warning light comes on.
		Provides a feed to alarm relay AR coil which sounds the alarm.
	OPSX normally closed contacts close.	Shutdown SD coil energized, SD contacts 1C and 1NO close.
6	SD contacts IC and INO close.	Energizes governor solenoid GS.
7	GS energized.	Stops engine by causing governor to move fuel injector rack to no-fuel position.

LOW WATER PRESSURE ALARM CIRCUIT

The low water pressure alarm circuit is initiated by the low water pressure switch LWS. For a detailed description of the LWS switch, refer to Protective Devices Section of this manual. LWS is open at 117 kPa (17 psi) and picks up at 145 kPa (21 psi).

If the engine water pressure does reach 145 kPa (21 psi) when the engine speed reaches 870 RPM or if water pressure drops below 117 kPa (17 psi) during operation at 870 RPM, the LOW WATER warning light comes on and alarm will sound. A description of the low water pressure alarm circuit follows.

Step	Procedure Or Condition	Result
1	Engine starts.	Engine speed relay VSR normally closed contacts closed provide circuit to hold low water relay LW coil energized to prevent an alarm.
2	Engine running, engine water pressure builds up to 145 kPa (21 psi).	Low water pressure switch LWS picks up. LWS contact. A closes providing circuit to hold LW coil energized.
3	Engine speed reaches 870 RPM.	Engine speed relay VSR energized. VSR normally closed contacts open.
4	'Water pressure does not reach145 kPa (21 psi) before VSR energizes or drops below 117 kPa (17 psi) during engine operation at 870 RPM.	LWS contact A open. LW relay de-energized.
a.	LW de-energized.	LW normally closed contacts close.
b.	LW normally closed contacts close.	WATER LEVEL warning light comes on. Provides circuit to alarm relay AR to sound alarm.



LOW OIL TEMPERATURE ALARM CIRCUIT

The low oil temperature alarm is installed to ensure the immersion heater (where applicable) is operating properly. The low oil temperature alarm circuit is controlled by the low oil temperature switch LTS. For a detailed description of the LTS switch, refer to Protective Devices Section of this manual. LTS closes if lube oil temperature decreases to 29°C (85°F), LOW OIL TEMP light comes on, and alarm sounds. A description of the low oil temperature alarm circuit follows.

Step	Procedure Or Condition	Result
1	Engine oil temperature decreases to 29° C (85° F).	Low oil temperature switch LTS opens contact A. LTR relay coil de-energizes, circuit to LO annunciator relay opens.
2	LTR coil de-energized. Circuit to LO annunciator relay opens.	LO de-energized. LO normally closed contacts close.
3	LO normally closed contacts close.	LOW OIL TEMP warning light comes on. Energizes alarm relay AR coil which sounds the alarm.

AIR FILTER ALARM CIRCUIT

The air filter alarm is initiated by the filter vacuum switch FVS. For a detailed description of the FVS switch, refer to Protective Devices Section of this manual. FVS is normally closed, and opens when the air intake filters become clogged. FVS senses. a pressure drop through the filters and opens at 279 mm (11 ") H_2O when using pleated paper filters or 178 mm (7") H_2O when using fiberglass filters. AIR FILTER warning light comes on and the alarm sounds. A description of the air filter alarm follows.

Step	Procedure Or Condition	Result
1	Engine running.	
	Air intake filters clogged.	Filter vacuum switch FVS contact B opens at 279 mm (11") H_2O when using pleated paper filters or 178 mm (7") H_2O when using fiberglass filters. FV de-energized. FV normally closed contacts close.
2	FV normally closed contacts close.	AIR FILTER warning light comes on. Energizes alarm relay AR coil which sounds the alarm.

START FAILURE ALARM CIRCUIT

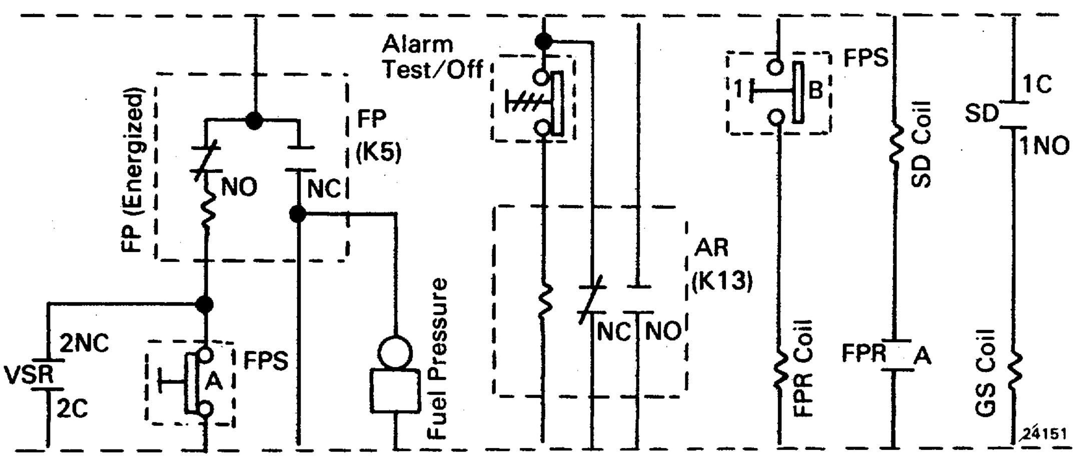
The start failure alarm circuit is initiated by the start relay STR which holds the start failure relay SF energized for 15 seconds after a start signal is received. If the engine does not start within 15 seconds, the SF relay drops out, the START FAILURE warning light comes on and the alarm sounds. The SF relay also locks out another start attempt. A description of the start failure alarm circuit follows.

Step	Procedure Or Condition	Result
1	Start signal is received.	Start relay STR picks up and times for 15 seconds.
2	Engine does not start or does not reach 200 RPM.	
3	STR times out.	STR opens contact B. SF de-energizes. SF normally closed contacts close, normally open contacts 17-22 open.
4	SF normally closed contacts close.	START FAILURE warning light comes on. Energizes alarm relay AR coil which sounds the alarm.
5	SF contacts 17-22 open.	Interrupts starting circuit, locking out another starting attempt. **NOTE** After the starting malfunction is corrected, the ALARM OFF push-button must be pressed to set up the starting circuit for the next starting attempt.

LOW FUEL PRESSURE ALARM AND SHUTDOWN CIRCUIT

The low fuel pressure alarm and shutdown circuit is initiated by the fuel pressure switch FPS. For a detailed description of the fuel pressure switch, refer to Protective Devices Section of this manual. FPS switch picks up at 83 kPa (12 psi). If fuel pressure does not reach 83 kPa (12 psi) when the engine speed reaches 870 RPM or falls below 62 kPa (9 psi) during engine operation at 870 RPM, FUEL PRESSURE warning light comes on, alarm sounds, and the engine shuts down. A description of the low fuel pressure alarm and shutdown circuit follows.

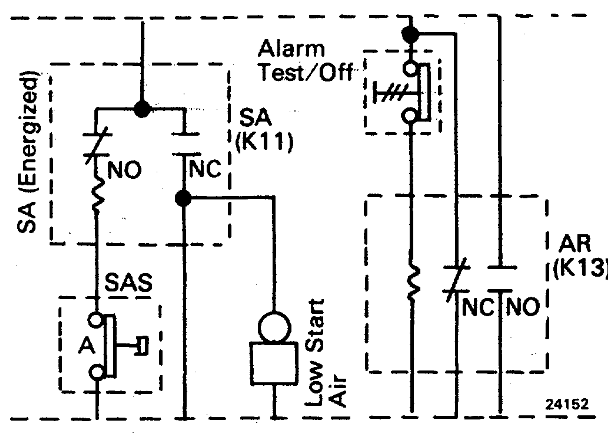
Step	Procedure Or Condition	Result
1	Engine speed reaches 870 RPM.	Engine speed relay VSR normally closed contacts open. Fuel pressure switch FPS contact A is normally open, and closes at 83 kPa (12 psi). If fuel pressure has not reached 83 kPa (12 psi) before VSR closed contacts open, FPS contact A will remain open, breaking circuit to annunciator relay FP coil. FP normally closed contacts close.



Step	Procedure Or Condition	Result
2	FP normally closed contacts close.	Energizes alarm relay AR. Alarm bell rings. FUEL PRESSURE warning light comes on.
3	Fuel pressure drops to below 62 kPa (9 psi).	Fuel pressure switch FPS contact B closes energizing fuel pressure relay FPR coil.
4	FPR energized.	FPR contact A closes, and energizes shutdown SD coil. SD contacts IC and INO close.
5	SD contacts IC and INO close.	Energizes governor solenoid GS.
6	GS energized.	Stops engine by causing governor to move fuel injector rack to no-fuel position.

LOW START AIR PRESSURE ALARM CIRCUIT

The low start air pressure alarm circuit is initiated by the start air pressure switch SAS. For a detailed description of the start air pressure switch, refer to Protective Devices Section of this manual. SAS is closed when start air pressure is above 931 kPa (135 psi) and opens when start air pressure drops below 862 kPa (125 psi). When start air pressure is below 862 kPa, (125 psi), SAS opens, LOW START AIR warning light comes on, and alarm sounds. A description of the low start air pressure alarm follows.

Step	Procedure Or Condition	Result
1	Start air pressure normal (or above 931 kPa [135 psi]).	Start air pressure switch SAS contact 1A is closed which keeps start air relay SA coil energized. Energized SA coil holds SA normally closed contacts open to prevent a warning light and alarm. 
2	Start air pressure below 862 kPa (125 psi).	SAS opens, SA coil de-energized.
	SA coil de-energized.	SA normally closed contacts close.
	SA normally closed contacts close.	LOW START AIR warning light comes on.
	.	Provides a feed through closed contacts to alarm relay AR coil which sounds alarm

CIRCULATING OIL PRESSURE ALARM CIRCUIT (OPTIONAL)

The circulating oil pressure alarm circuit is initiated by the circulating oil pressure switch COPS. For a detailed description of the COPS switch, refer to Section 13, Protective Devices.

COPS is normally open and is held closed by 145 kPa (21 psi) oil pressure provided by the circulating oil pump which operates in conjunction with immersion heater system to maintain engine oil at operating pressure and temperature while engine is shutdown. If circulating oil pressure drops below 117 kPa (17 psi), COPS opens, CIRCULATING OIL PRESSURE warning light comes on, alarm sounds, and starting circuit is interrupted. A description of the circulating oil pressure alarm circuit follows.

Step	Procedure Or Condition	Result
1	Circulating oil pressure above 145 kPa (21 psi).	Circulating oil pressure switch COPS contact 1A closed which keeps circulating oil pressure relay CO coil energized to prevent an alarm. COPS contact 2A closed in circuit to starting magnet valve SM enables engine start.
2	Circulating oil pressure drops below 117 kPa (17 psi).	COPS opens contacts 1A and 2A.
3	COPS contact IA open.	CO de-energized. CO normally closed contacts close.
4	CO↓. CO normally closed contacts close.	CIRCULATING OIL PRESSURE warning light comes on. Energizes alarm relay AR coil which sounds the alarm.
5	COPS contact 2A open.	Interrupts circuit to starting magnet valve SM, locking out starting attempt.

APPENDIX A

MAINTENANCE ALLOCATION CHART (MAC)

SECTION I. INTRODUCTION

A-1. THE ARMY MAINTENANCE SYSTEM MAC.

a. This introduction (Section I) provides a general explanation of all maintenance and re- pair functions authorized at various maintenance levels under the standard Army Maintenance System concept.

b. The Maintenance Allocation Chart (MAC) in Section II designates overall authority and responsibility for the performance of maintenance functions on the identified end item or component. The application of the maintenance functions to the end item or component will be consistent with the capacities and capabilities of the designated maintenance levels, which are shown in the MAC in column (4) as:

Unit - includes two subcolumns: C (operator/crew) and O (unit) maintenance.
Direct Support - includes an F subcolumn.
General Support - includes an H subcolumn.
Depot - includes a D subcolumn.

c. Section III lists the tools and test equipment (both special tools and common tools sets) required for each maintenance function as referenced from Section II.

d. Section IV contains supplemental instructions and explanatory notes for a particular maintenance function as referenced from Section II.

A-2. MAINTENANCE FUNCTIONS. Maintenance functions will be limited to and defined as follows:

a. Inspect. To determine the serviceability of an item by comparing its physical, mechanical, and/or electrical characteristics with established standards through examination (i.e., by sight, sound, or feel).

b. Test. To verify serviceability by measuring the mechanical, pneumatic, hydraulic, or electrical characteristics of an item and comparing those characteristics with prescribed standards.

c. Service. Operations required periodically to keep an item in proper operating condition, i.e., to clean (includes decontamination, when required), to replace filters, to preserve, to drain, to paint, or to replenish fuel, lubricants, chemical fluids, or gases.

d. Adjust. To maintain or regulate, within prescribed limits, by bringing into proper or ex- act position, or by setting the operating characteristics to specified parameters.

e. Align. To adjust specified variable elements of an item to bring about optimum or de- sired performance.

f. Calibrate. To determine and cause corrections to be made or to be adjusted on instruments or test, measuring, and diagnostic equipment used in precision measurement. Consists of comparisons of two instruments, one of which is a certified standard of known accuracy, to detect and adjust any discrepancy in the accuracy of the instrument being compared.

g. Remove/install. To remove and install the same item when required to perform service or other maintenance functions. Install may be the act of emplacing, seating, or fixing into position a spare, repair part, or module (component or assembly) in a manner to allow the proper functioning of an equipment or system.

h. Replace. To remove an unserviceable item and install a serviceable counterpart in its place. Replace is authorized by the MAC and is shown as the 3rd position code of the SMR code.

i. Repair. The application of maintenance services[1] including fault location/trouble- shooting[2], removal/installation, and disassembly/assembly[3] procedures, and maintenance actions[4] to identify troubles and restore serviceability to an item by correcting specific damage, fault, malfunction, or failure in a part, subassembly, module (component or assembly), and item, or system.

j. Overhaul. That maintenance effort (service/action) prescribed to restore an item to a completely serviceable/operational condition as required by maintenance standards in appropriate technical publications (i.e., DMWR). Overhaul in normally the highest degree of maintenance performed by the Army. Overhaul does not normally return an item to like new condition.

k. Rebuild. Consists of those service/actions necessary for the restoration of unserviceable equipment to a like new condition in accordance with original manufacturing standards. Re- build is the highest degree of material maintenance applied to Army equipment. The rebuild operation includes the act of returning to zero those age measurements (hours, miles, etc.) considered in classifying Army equipment and components.

A-3. EXPLANATION OF COLUMNS IN THE MAC, SECTION II

a. Column 1 - Group Number. Column 1 lists functional group code numbers, the purpose of which is to identify maintenance significant components, assemblies, subassemblies, and modules with the next higher assembly.

b. Column 2 - Component/Assembly. Column 2 contains the names of components, assemblies, subassemblies, and modules for which maintenance is authorized.

c. Column 3 - Maintenance Function. Column 3 lists the functions to be performed on the item listed in column 2. (For detailed explanation of these functions, see paragraph A-2.)

d. Column 4 - Maintenance Category. Column 4 specifies, by the listing of a work time figure in the appropriate subcolumn(s), the category of maintenance authorized to perform the function listed in Column 3. This figure represents the active time required to perform that maintenance function at the indicated category of maintenance. If the number or complexity of the tasks within the listed maintenance function varies at different maintenance categories, appropriate work time figures will be shown for each category. The work time figure represents the average time required to restore an item (assembly, subassembly, component, module, end item, or system) to a serviceable condition under typical field operating conditions. This time includes preparation time (including any necessary disassembly/assembly time), troubleshooting/fault location time, and quality assurance/quality control time in-addition to the time required to perform the specific tasks identified for the maintenance functions authorized in the maintenance allocation chart. The symbol designations for the various maintenance categories are as follows:

C	Operator or Crew
O	Unit Maintenance
F	Direct Support Maintenance (DS)
H	General Support Maintenance (GS)
D	Depot Maintenance

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[1]Service - Inspect, test, service, adjust, align, calibrate, and/or replace.

[2]Fault location/troubleshooting - The process of investigating and-detecting the cause of equipment malfunctioning; the act of isolating a fault within a system or unit under test (UUT).

[3]Disassembly/assembly - The step-by-step breakdown (taking apart) of a spare/functional group coded item to the level of its least component, that is assigned an SMR code for the level of maintenance under consideration (i.e., identification as maintenance significant).

[4]Actions - Welding, grinding, riveting, straightening, facing, machining, and/or resurfacing.

e. Column 5 - Tools and Equipment. Column 5 specifies, by number code, those common tool sets (not individual tools); special tools; Test, Measurement, and Diagnostic Equipment (TMDE); and support equipment required to perform the designated function, which shall be keyed to the tools listed in Section III.

f. Column 6 - Remarks. This column shall, when applicable, contain a letter code, in alphabetic order, which shall be keyed to the remarks contained in Section IV.

A-4. EXPLANATION OF COLUMNS IN TOOL AND TEST EQUIPMENT REQUIREMENTS, SECTION III.

a. Column 1 - Reference Code. The tool and test equipment reference code correlates with a number code used in the MAC, Section II, Column 5.

b. Column 2 - Maintenance Category. The lowest category of maintenance authorized to use the tool or test equipment.

c. Column 3 - Nomenclature. Name or identification of the tool or test equipment.

d. Column 4 - National Stock Number. The National stock number (NSN) of the tool or test equipment.

e. Column 5 - Tool Number. The manufacturer's part number.

A-5. EXPLANATION OF COLUMNS IN REMARKS, SECTION IV.

a. Column 1 - Reference Code. The letter code recorded in Column 6, Section II.

b. Column 2 - Remarks. This column lists information pertinent to the maintenance function being performed as indicated in the MAC, Section II.

SECTION II. MAINTENANCE ALLOCATION CHART

(1) GROUP NUMBER	(2) COMPONENT/ ASSEMBLY	(3) MAINTENANCE FUNCTION	(4) MAINTENANCE CATEGORY C	O	F	H	D	(5) TOOLS AND EQPT	(6) REMARKS
01	ENGINE, MAIN, ASSEMBLY 645E6	Inspect	3.8					1,2	
		Test		1.5		0.5		1,2, 8	
		Service	3.1					1,2	
		Adjust	0.9					1,2	
		Replace	2.0			89.5		1,2	A
		Repair	1.0			155		1,2	
		Overhaul					X	X	1
0101	ENGINE CONTROLS	Inspect	0.9					2	
		Test	1.0					2	
		Adjust	0.2					2	
		Replace				2.0		1,2, 7	
		Repair	1.0			2.5		1,2,7	B
0102	GOVERNOR	Inspect	0.5						
		Test	0.5						
		Replace		2.0				1, 2	
		Repair					X	X	C
0103	SERVOMOTOR PUMP BOOSTER	Service	0.4					1	H
		Adjust	0.2					1	
		Replace	1.0					1	
		Repair				1.0		1,2	
0104	INTAKE AIR AND EXHAUST	Service	0.5					1,2	D
		Replace				2.0		1,2, 9	
		Repair					X	X	C
0105	AIR STARTING SYSTEM	Inspect	0.2					1,2	
		Service	0.4					1,2	D
		Replace		2.0				1	
		Repair				2.5		1,2	

SECTION II. MAINTENANCE ALLOCATION CHART - Continued

(1) GROUP NUMBER	(2) COMPONENT/ ASSEMBLY	(3) MAINTENANCE FUNCTION	(4) MAINTENANCE CATEGORY C	O	F	H	D	(5) TOOLS AND EQPT	(6) REMARKS
0106	FUEL SYSTEM	Inspect	0.2					1	
		Test				0.5		1,2	
		Service	0.4					1	D
		Adjust	0.3					1	
		Replace		2.0		0.5		1,2	
		Repair				4.5		1,2	
010601	PUMP, FUEL	Replace		1.0				1	
		Repair				2.0		1,2	
010602	FILTER, FUEL, ASSEMBLY	Service	0.4					1	D
		Replace				0.5		1,2	
		Repair				1.5		1,2	
010603	INJECTOR, FUEL	Inspect	0.2	1					
		Test				0.5		1,2,10	
		Adjust	0.3					1	
		Replace		1.0				1,3	
		Repair				1.0		1,2,10	
0107	OIL SYSTEM, LUBRICATING	Inspect	0.4					1	
		Adjust	0.2					1	
		Service	1.4					1	D
		Replace		1.0		6.5		1,2	E
		Repair				7.7		1,2	
010701	LUBE OIL SEPARATOR	Service	0.4					1	D
		Replace				1.0		1,2	
010702	PUMP, PISTON, LUBE OIL	Replace		1.0				1	
		Repair				1.7		1,2	
010703	PUMP, LUBE OIL, SCAVENGING	Replace				2.0		1.2	
		Repair					X	X	

SECTION II. MAINTENANCE ALLOCATION CHART - Continued

(1) GROUP NUMBER	(2) COMPONENT/ ASSEMBLY	(3) MAINTENANCE FUNCTION	(4) MAINTENANCE CATEGORY C	O	F	H	D	(5) TOOLS AND EQPT	(6) REMARKS
010704	OIL MANIFOLD	Replace				1.0			
		Repair				1.5			G
010705	LUBE OIL PRESSURE RELIEF VALVE	Inspect	0.4					1	
		Adjust	0.2					1	
		Replace	1.0					1,2	
010706	OIL STRAINER HOUSING	Service	1.0					1	D
		Replace				1.5		1,2	
		Repair				2.0		1,2	G
0108	COOLING SYSTEM	Inspect	0.2					1	
		Replace		2.0				1,4	F
		Repair				2.5		1,2,11	
010801	PUMP, FRESH WATER	Inspect	0.2					1	
		Replace		1.5				1,4	F
		Repair				2.5		1,11	
0109	CAMSHAFT GEAR ASSEMBLY	Replace				8.0		1,2	
		Repair				17.0		1,2	F
0110	CYLINDER POWER ASSEMBLY	Inspect	1.0					1,5	
		Replace		19.5				1,6	F
		Repair				35.3		13	
011001	CYLINDER HEAD WITH LINER ASSEMBLY	Replace		5.0				1,6	F
		Repair				10.0		13	
011002	PISTON ASSEMBLY	Replace		5.0				1,6	F
		Repair				8.0		13	
011003	CONNECTING ROD, BEARINGS, CARRIER, AND PISTON PIN	Replace		9.5				1,6	F
		Repair				17.3		13	
0111	CRANKSHAFT ASSEMBLY AND DRIVE GEAR TRAIN	Replace				33.5		1,12,14	F
		Repair				43.0		1,12, 14	

SECTION II. MAINTENANCE ALLOCATION CHART - Continued

(1) GROUP NUMBER	(2) COMPONENT/ ASSEMBLY	(3) MAINTENANCE FUNCTION	(4) MAINTENANCE CATEGORY C	O	F	H	D	(5) TOOLS AND EQPT	(6) REMARKS
0112	CRANKSHAFT AND OIL PAN								
		Inspect	0.4						
		Replace				35.0		1,14	
		Repair				40.0		1,14	G

SECTION III. TOOL AND TEST EQUIPMENT REQUIREMENTS

TOOL OR TEST EQUIPMENT REF CODE	MAINTENANCE CATEGORY	NOMENCLATURE	NATIONAL/NATO STOCK NUMBER	TOOL NUMBER
1	C, O	Tool Kit, General Mechanical	5180-00-629-9783	
2	C, O	Tool Kit, Electrical	5180-00-391-1087	
3	C, O	REPLACE: INJECTOR		
		Injector Holding Rack	4910-00-366-1465	8431626
		Injector Timing Gauge	5120-00-447-9669	8034638
4	C, O	REPLACE: WATER PUMP		
		Water Pump Mounting Bolt Wrench		9519601
5	C, O	TEST: VALVES		
		Test Valve Wrench		8032587
6	C, O	REPLACE: CYLINDER HEAD AND PISTON		
		Cylinder Liner Lifter	5120-00-366-1446	8116358
		Piston Puller Eyebolt	5306-00-366-1385	8040413
		Fork Rod Support	5120-00-366-1496	8052958
		Cylinder Head Carrying Basket	4910-00-366-1382	8060247
		Blade Rod Protector Boot		8062033
		Fork Rod Protector Boot		8062034
		Piston Cooling Pipe Alignment Gauge	5120-00-366-1422	8071720
		Cylinder Head Removing Fixture	5120-00-366-1472	8075894
		Piston Cooling Pipe Cleaning Tool	5120-01-276-5941	8087086
		Lash Adjuster Minimum Clearance Gauge	5120-00-366-1419	8107788
		Snap Ring Remover	5120-00-323-9429	8171633
		Piston Ring Expander	5120-00-177-7053	8349892
		Lifting Clamp Assembly	5120-00-176-8614	8417858
		Piston Holding Tool	5120-00-176-8616	8417859
		Connecting Rod Positioning Clamp Assembly	5120-00-176-8617	8417881
		Piston Ring Compressor and Guide	5120-01-276-5953	9333846
		Piston Carrier-Holding Fixture	5120-01-274-4238	9534635
		Fork Connecting Rod Basket Thread Gauge		8265955
		Sweeny: Torque Wrench with Multiplier		220-1
7	C, O	ADJUST: ENGINE CONTROLS		
		Thin Wrench Set		LTA-81 OK
8	C, O	CRANKOVER TOOLS SET		
		Crankover Tool		9561844
		Electric Drive Unit		9543867
		Air Drive Kit		9560333
		Remote Control		9560338

SECTION III. TOOL AND TEST EQUIPMENT REQUIREMENTS

TOOL OR TEST EQUIPMENT REF CODE	MAINTENANCE CATEGORY	NOMENCLATURE	NATIONAL/NATO STOCK NUMBER	TOOL NUMBER
9	H	REMOVE: BLOWER		
		Blower Lifting Plate	4940-00-366-1452	8072929
		Blower Nut Ratchet Wrench		8177166
10	H	REPAIR AND TEST: INJECTOR		
		Injector Rack Gauge	5120-00-880-7549	8339610
		Injector Tester (Complete)		9549015
11	H	REPAIR: WATER PUMP		
		Impeller Installer	5120-00-465-6052	8052929
		Pump Impeller/Gear Puller	5120-00-998-7663	8354367
12	H	REPLACE AND REPAIR: DRIVE GEAR TRAIN		
		Feeler Gauge Set		8067337
		Dial Indicator		8255423
13	H	REPAIR: CYLINDER HEAD AND LINER		
		Crab Stud Protector Tubes	4910-00-366-1500	8034600
		Valve Set Reconditioning Tool Set		8035775
		Valve Checking Tram	4910-00-366-1498	8042773
		Cylinder Test Valve Seat Reamer	5110-00-366-1467	8064804
		Valve Bridge Spring Compressor		8070883
		Wire Brush (Stones)		8078883
		Stone and Guide Block Set (W47-J43)		8084163
		Reamer Speed Reducer (Use with 8374969)		8228304
		Liner Bore Gauge		8275258
		Master Gauge (Use with 8275258)		8374970
		Gauge Locator		8278541
		Cylinder Liner Ridge Reamer		8374969
		Crab Nut Tap 1 3/4" - 12		8050688
		Stud Thread File		9549346
		Crab Nut Wrench Set	5180-00-935-4642	9551713
		Valve Bridge Lock Ring	5120-00-399-5558	8070903
		Lash Adjuster Installer	5120-00-366-1463	8072927
		Lash Ring Remover - Lash Adjuster	5120-00-366-1475	8080632
		Valve Guide Cleaner		8141439
		Tapered Pilot Checking Fixture		8073996
		Cylinder Head Stud Hole Cleaner		8211907
		Valve Seat Seal Tester		8213518
		Valve Guide Installer-Remover		8224241
		Lash Adjuster Puller	5120-00-366-1459	8394719
		Lash Adjuster Puller Arm		8395481
		Valve Spring Compressor		9546582

SECTION III. TOOLS AND TEST EQUIPMENT REQUIREMENTS - Cont

TOOL OR TEST EQUIPMENT REF CODE	MAINTENANCE CATEGORY	NOMENCLATURE	NATIONALNATO STOCK NUMBER	TOOL NUMBER
14	H	REPAIR: CRANKSHAFT		
		Upper Main Bearing Shell Remover	5120-00-366-1474	8055837
		Main Bearing Cap Application and Removal Tool		8487487
		Upper Main Bearing Remover Tool		8488833
		Main Bearing Nut Cap 1 1/4"- 12		8060387
		Main Bearing Nut Offset Ratchet Wrench		8191591
		Main Bearing Power Wrench Set		8474807

SECTION IV. REMARKS

REFERENCE CODE	REMARKS
A	Special tools and time involved in removal and replacement of main engine.
B	Repair at "C" involves time to replace protective devices. Repair at "H" level involves complete replacement of control panel.
C	Only manufacturers repair and adjustment are authorized.
D	Clean and replace filters.
E	Replacement of the piston lube oil pump will be done at "0" level only.
F	ABS requires onboard spares and can be replaced by crew.
G	All weld repair will be done at "H" level.
H	The Servomotor Booster Pump should be disassembled, cleaned, and inspected and O-Ring seals should be replaced.
I	"Depot" level maintenance will be performed on a case-by-case basis subject to approval and funding by the National Maintenance Point (NMP).

☆U.S. GOVERNMENT PRINTING OFFICE: 1994 - 555-028/00102 PIN: 062931-001

SECTION III TOOL AND TEST EQUIPMENT REQUIREMENTS FOR

TOOL OR TEST EQUIPMENT REF CODE	MAINTENANCE CATEGORY	NOMENCLATURE	NATIONAL/NATO STOCK NUMBER	TOOL NUMBER
14	H	REPAIR: CRANKSHAFT		
		Upper Main Bearing Shell Remover	8055837	
		Main Bearing Cap Application and Removal Tool	8487487	
		Upper Main Bearing Remover Tool	8488833	
		Main Bearing Nut Tap 1¼" - 12	8060387	
		Main Bearing Nut Offset Ratchet Wrench	8191591	
		Main Bearing Power Wrench Set.	8474807	

SECTION IV. REMARKS

REFERENCE CODE	REMARKS
A	Special tools and time involved in removal and replacement of main engine.
B	Repair at crew involves time to replace protective devices. Repair at H Level involves complete replacement of control panel.
C	Only manufacturers repair and adjustment are authorized.
D	Clean or replace filters.
E	Replacement of the piston lube oil pump will be done at 0 Level only.
F	ABS requires onboard spares and can be replaced by crew.
G	All weld repair will be done at H Level.
H	The Servomotor Booster Pump should be disassembled, cleaned and inspected and "o" Ring seals should be replaced.

By Order of the Secretary of the Army:

CARL E. VUONO
General, United States Army
Chief of Staff

Official:

R. L. DILWORTH
Brigadier General, United States Army
The Adjutant General

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THE METRIC SYSTEM AND EQUIVALENTS

Linear Measure

1 centimeter = 10 millimeters = .39 inch
1 decimeter = 10 centimeters = 3.94 inches
1 meter = 10 decimeters = 39.37 inches
1 dekameter = 10 meters = 32.8 feet
1 hectometer = 10 dekameters = 328.08 feet
1 kilometer = 10 hectometers = 3.2808.8 feet

Weights

1 centigram = 10 milligrams = .15 grain
1 decigram = 10 centigrams = 1.54 grains
1 gram = 10 decigram = .035 ounce
1 dekagram = 10 grams = .35 ounce
1 hectogram = 10 dekagrams = 3.52 ounces
1 kilogram = 10 hectograms = 2.2 pounds
1 quintal = 100 kilograms = 220.46 pounds
1 metric ton = 10 quintals = 1.1 short tons

Cubic Measure

1 cu. centimeter = 1000 cu. millimeters = .06 cu. inch
1 cu. decimeter = 1000 cu. centimeters = 61.02 cu in.
1 cu. meter = 1000 cu. decimeters = 35.31 cu. feet

Square measure

1 sq. centimeter = 100 sq. millimeters =.155 sq. in.
1 sq. decimeter = 100 sq. centimeters = 15.5 inches
1 sq. meter (centare) = 100 sq. decimeters = 10.76 feet
1 sq. dekameter (are) = 100 sq. meters = 1.076.4 sq. ft.
1 sq. hectometer (hectare) = 100 sq. dekameters = 2.47 acres
1 sq. kilometer = 100 hectometers = .386 sq. miles

Liquid Measure

1 dekaliter = 10 liters = 2.64 gallons
1 hectoliter = 10 dekaliters = 26.42 gallons
1 kiloliter = 10 hectoliters = 264.18 gallons
1 liter = 10 deciliters = 33.81 fl. ounces
1 centiliter = 10 milliliters = .34 fl. ounce
1 deciliter = 10 centiliters = 3 38 fl. ounces
1 metric ton = 10 quintals = 1.1 short tons

Approximate Conversion Factors

To change	To	Multiply by
inches	centimeters	2.540
feet	meters	.305
yards	meters	.914
miles	kilometers	1.609
sq. inches	sq. centimeters	6.451
sq. feet	sq. meters	.093
sq. yards	sq. meters	.836
sq. miles	sq. kilometers	2.590
acres	sq. hectometers	.405
cubic feet	cubic meters	.028
cubic yards	cubic meters	.765
fluid ounces	milliliters	29.573
pints	liters	.472
quarts	liters	.946
gallons	liters	3.785
ounces	grams	28.349
pounds	kilograms	.454
short tons	metric tons	.907
pound inches	newton-meters	.11296

To change	To	Multiply by
ounce inches	newton-meters	.0070062
centimeters	inches	.394
meters	feet	3.280
meters	yards	1.094
kilometers	miles	.621
sq. centimeters	sq. inches	.155
sq. meters	sq. yards	10.764
sq. kilometers	sq. miles	1.196
sq. hectometers	acres	2.471
cubic meters	cubic feet	35.315
milliliters	fluid ounces	.034
liters	pints	2.113
liters	quarts	1.057
grams	ounces	.035
kilograms	pounds	2.205
metric tons	short tons	1.102
pound-feet	newton-meters	1.356

Temperature (Exact)

°F Fahrenheit temperature	5/9 (after subtracting 32)	Celsius Temperature °C

PIN: 062931-000