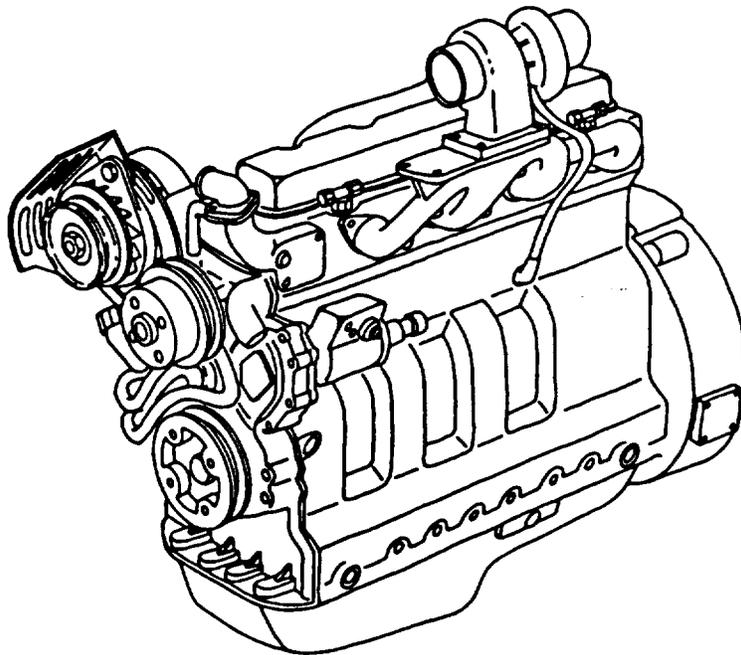


TECHNICAL MANUAL  
UNIT, DIRECT SUPPORT AND GENERAL SUPPORT  
MAINTENANCE INSTRUCTIONS

DIESEL ENGINE  
MODEL 4039T  
4 CYLINDER 3.9 LITER  
NSN: 2815-01-350-2208



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WASHINGTON, D.C., 30 October 1996

NO. 3

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**Unit, Direct Support and General Support**  
**Maintenance Instructions**

**DIESEL ENGINE**  
**MODEL 4039T**  
**4 CYLINDER 3.9 LITER**  
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## SAFETY SUMMARY

For first aid, refer to FM 21-11.

### Warning

The noise level when operating could cause hearing damage. Ear protection must be worn.

### Warning

Where applicable, prior to performing engine maintenance, ensure batteries are disconnected.

### Warning

If the engine has been operating and coolant is hot, allow engine to cool before you slowly loosen filler cap and relieve pressure from cooling system. Failure to observe this warning could result in severe personal injury.

### Warning

Use care when rotating engine on engine maintenance stand. If necessary, use a lifting device to avoid severe personal injury.

### Warning

Do not drain coolant until the coolant temperature is below operating temperature prior to removal of water pump. Severe personal injury can occur.

### Warning

Exercise care when bench testing starter. Ensure metal objects do not contact connection points as severe arcing will occur. Failure to observe this warning could result in personal injury.

**SAFETY SUMMARY - Continued**

**Warning**

After operating engine, allow exhaust system to cool before removal of turbocharger. Failure to observe this warning could result in personal injury.

**Warning**

Compressed air used for cleaning can create airborne particles that may enter the eyes. Pressure will not exceed 30 psig (207 kPa). Eye protection required.

**Warning**

Oil pressure regulating valve spring (3, FIGURE 3-32) is under pressure and can cause personal injury when plug (1) is removed.

**Warning**

Cleaning solvent is flammable and toxic to eyes, skin, and respiratory tract. Skin/eye protection required. Avoid repeated/prolonged contact. Good general ventilation is normally adequate.

**Warning**

Escaping diesel fuel under pressure can have sufficient force to penetrate the skin, causing serious injury. Before disconnecting fuel lines, be sure to relieve pressure. Before applying pressure to the system, be sure all connections are tight and lines, pipes, and hoses are not damaged. Keep hands and body away from pinholes and nozzles which eject fuel under pressure. Use a piece of cardboard or wood, rather than hands, to search for suspected leaks.

**Warning**

If any diesel fuel is injected into the skin, it must be surgically removed within a few hours by a doctor familiar with this type injury or gangrene can result.

**SAFETY SUMMARY - Continued**

**Warning**

Diesel fuel is flammable and toxic to eyes, skin, and respiratory tract. Skin/eye protection required. Avoid repeated/prolonged contact. Good general ventilation is normally adequate.

**Warning**

Diesel fuel and cleaning solvent are flammable and toxic to eyes, skin, and respiratory tract. Skin/eye protection required. Avoid repeated/prolonged contact. Good general ventilation is normally adequate.

**Warning**

If nuts (19, FIGURE 3-41) are removed prior to shaft gear separation, fuel injection pump will fall out which can cause personal injury and/or equipment damage.

**Warning**

Compressed air can be hazardous when not used properly.

**Warning**

The fuel nozzle tip should always be directed away from operator. Fuel from spray orifices can penetrate clothing and skin causing serious personal injury. Enclosing nozzle in a transparent cover is recommended.

**Warning**

Before applying pressure to fuel nozzle tester, be sure that all connections are tight, and that fittings are not damaged. Fluid escaping from a very small hole can be almost invisible. Using a piece of cardboard or wood, rather than hands, to search for suspected leaks.

**SAFETY SUMMARY - Continued**

**Warning**

If injured by escaping fuel, see a doctor immediately. Any fluid injected into skin must be surgically removed within a few hours or gangrene can result.

**Warning**

Place a clear, protective shield around fuel nozzle spray zone during testing to avoid possible personal injury from spray.

**Warning**

Ensure each end of cylinder head is supported on blocks of wood to prevent serious injury or death when using valve spring compressor.

**Warning**

Do not stand in front of valve springs while compressing them to avoid personal injury.

**Warning**

Caustic solutions are highly toxic to the skin, eyes, and respiratory tract. Avoid all contact. Skin and eye protection and vapor control are required.

**Warning**

Flywheel is heavy. Provide adequate lifting device to support weight. Failure to follow this procedure could result in personal injury.

**SAFETY SUMMARY - Continued**

**Warning**

**Oil fumes or oil can ignite above 380°F (193°C) - Use a thermometer and do not exceed 360°F (182°C). Do not allow a flame or heating element to be in direct contact with oil. Heat oil in a well ventilated area. Plan a safe handling procedure to avoid burns.**

**Warning**

**Wear protective gloves to help prevent burns from handling hot ring gear.**

**Warning**

**Crankshaft is very heavy, do not attempt to remove crankshaft by hand. Use proper lifting equipment.**

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TECHNICAL MANUAL

HEADQUARTERS  
DEPARTMENTS OF THE ARMY, AIR FORCE  
AND HEADQUARTERS, U.S. MARINE CORPS  
WASHINGTON, D.C., 15 September 1993

NO. 9-2815-255-24

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**DIESEL ENGINE**  
**MODEL 4039T**  
**4 CYLINDER 3.9 LITER**  
**NSN: 2815-01-350-2208**

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## CHAPTER 1

### INTRODUCTION

#### Section I. GENERAL INFORMATION

##### **1-1. SCOPE.**

1-1.1. Type of Manual. This manual contains unit, direct support, and general support maintenance instructions for the Model 4039T Diesel Engine, hereafter referred to as engine. Also included are descriptions of major systems/components and their functions in relation to other systems/components.

1-1.2. Purpose of Equipment. The engine provides a driving force for generators or other equipment requiring this size (HP rating) and compatibility.

##### **1-2. MAINTENANCE FORMS, RECORDS, AND REPORTS.**

1-2.1. Reports of Maintenance and Unsatisfactory Equipment. Department of the Army forms and procedures used for equipment maintenance will be those prescribed by DA Pam 738-750, Army Maintenance Management System (TAMMS). Air Force personnel will use AFR 66-1, Air Force Maintenance Management Policy, for maintenance reporting and TO-00-35D54 for unsatisfactory equipment reporting.

1-2.2. Reporting of Item and Packaging Discrepancies. Fill out and forward SF 364 (Report of Discrepancy (ROD)) as prescribed in AR 735-1-2/DLAR 414-55/SECNAVINST 4355.18/AFR 400-54/MCO 4430.3J.

1-2.3. Transportation Discrepancy Report (TDR) (SF 361). Fill out and forward Transportation Discrepancy Report (TDR) (SF 361) as prescribed in AR 55-38/NAVSUPINST 4610.33C/AFR 75-18/MCO P4610.19D/DLAR 4500.15.

##### **1-3. REPORTING EQUIPMENT IMPROVEMENT RECOMMENDATIONS (EIR).**

1-3.1. Army. If your Military Standard Engine needs improvement, let us know. Send us an EIR. You, the user, are the only one who can tell us what you don't like about your equipment. Let us know why you don't like the design or performance. Put it on an SF 368 (Product Quality Deficiency Report). Mail it to us at: Commander, U.S. Army Aviation and Troop Command, ATTN: AMSAT-I-MDO, 4300 Goodfellow Boulevard, St. Louis, Missouri 63120-1798. We will send you a reply.

1-3.2. Air Force. Air Force personnel are encouraged to submit EIR's in accordance with AFR 9004.

##### **1-4. DESTRUCTION OF ARMY MATERIEL TO PREVENT ENEMY USE.**

Refer to 750-244-3 for procedures to destroy equipment to prevent enemy use.

##### **1-5. PREPARATION FOR STORAGE OR SHIPMENT.**

Refer to TB 740-97-2 for procedures to place the equipment into storage.

##### **1-6. WARRANTY.**

The engine is warranted for a specific period of time. Refer to Warranty Technical Bulletin for the end item. The warranty starts on the date found in block 23, DA Form 24089, in the equipment log book. Report all defects in material or workmanship to your supervisor, who will take appropriate action.

#### Section II. EQUIPMENT DESCRIPTION AND DATA

##### **1-7. GENERAL.**

The diesel engine (FIGURE 1-1) is four cylinder, four cycle, fuel injected, turbocharged, and liquid cooled. The firing order is 1-3-4-2. The number one cylinder is toward the fan end of the engine. The serial number is found on right side of the cylinder block in the vicinity of the starter. Rotation of engine is counterclockwise as viewed from flywheel.

**NOTE**

All locations referenced herein are given facing the flywheel end (rear) of the engine.

**1-8. DETAILED DESCRIPTION.**

1-8.1. Turbocharger. A turbocharger, operated by exhaust gases, compresses intake air and routes it to the combustion chamber.

1-8.2. Camshaft. The camshaft is driven by an intermediate gear in the timing gear train which meshes with the crankshaft gear. Camshaft rotates in honed machined bores in cylinder block; no bushings are used. The camshaft lobes determine the time and rate of opening of each valve and actuates the fuel supply pump.

1-8.3. Intake and Exhaust Valves. Intake and exhaust valves are operated by cam followers, push rods, and rocker arm assembly. Valve seat inserts in cylinder head are used for intake and exhaust valves.

1-8.4. Crankshaft. The crankshaft is a one-piece, heat treated, steel forging which operates in replaceable two-piece main bearings. The rear thrust bearing has a flange on each side to support crankshaft thrust and to limit end play.

1-8.5. Cylinder Liners and Pistons. Cylinder liners are "wet" (surrounded by coolant) and are individually replaceable. O-rings are used to seal the connection between cylinder block and liners. Pistons are made of cast high-grade aluminum alloy with internal ribbing. The skirt is cam ground to allow for expansion when heated during operation. The piston crown has a cut-out swivel cup with a truncated cone in the center. Two compression rings and one oil control ring are used. The top compression ring is a keystone type ring. All piston rings are located above the piston pin. The hardened piston pins are fully-floating and held in position by means of retainer rings. Spray jets (piston cooling orifices) in cylinder block direct pressurized oil to lubricate piston pins and cool pistons. Connecting rods are of forged steel and have replaceable bushing and bearing inserts.

1-8.6. Balancer Shafts. Two balancer shafts are used to reduce vibration. They are gear driven by the timing gears and rotate on bushing in cylinder block. They counter-rotate at twice the engine speed.

1-8.7. Cooling System. The cooling system consists of a radiator, water pump, cooling fan, thermostat, and connecting hoses. The fan is mounted on shaft of water pump and both are belt driven from the crankshaft pulley. The thermostats control engine temperature and are installed in top of engine. The function of the cooling system is to maintain a specific operating temperature of 175 to 185°F (79 to 85°C) for the engine.

1-8.8. Lubrication System. The lubrication system consists of oil pan (sump), a gear type pump, full flow spin-on oil filter with built-in bypass valve, oil cooler with built-in bypass valve, pressure regulating valve, bypass valve, and the internal passages.

1-8.9. Fuel System. The function of the fuel system is to inject a metered quantity of clean atomized fuel into the engine cylinders at a precise time near the end of the compression stroke of each piston. The fuel system consists of the fuel tank, fuel filter/water separator, fuel supply pump, fuel injection pump, and the fuel injectors. The fuel tank is not mounted on the engine. The fuel supply pump is mounted to the block and is driven by the camshaft. The fuel injection pump is mounted on the front plate and is driven by an intermediate gear in the timing gear train meshing with crankshaft gear.

1-8.10. Electrical System. The electrical system is 24 VDC operation and consists of a battery charging alternator, starter, externally mounted batteries, and other items as required. The battery charging alternator is mounted on front of engine and is belt driven. When engine is operating, the battery charging alternator supplies 24 VDC to recharge the batteries and maintain them at a full state of charge. The starter is mounted on the flywheel housing and when energized, engages the ring gear of the flywheel to rotate the engine.

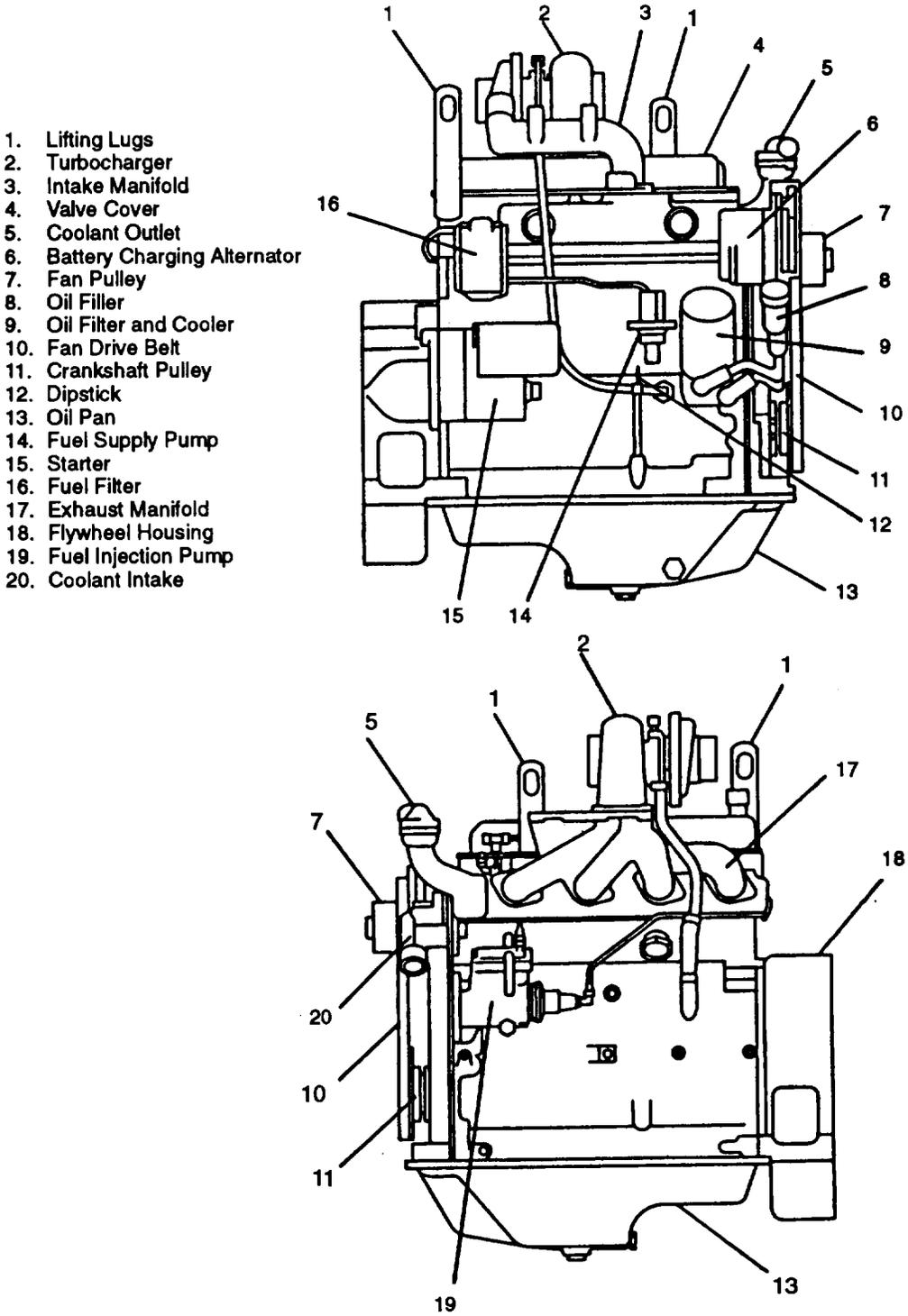


FIGURE 1-1. Engine Components

**1-9. EQUIPMENT DATA.**

1-9.1. Leading Particulars. For a list of Leading Particulars, refer to TABLE 1-1.

**TABLE 1-1. Table of Specifications**

---

Model .....	John Deere 4039T
Type .....	Four cylinder, four cycle, turbocharged diesel
Bore .....	4.19 in. (106.5 mm)
Stroke.....	4.33 in. (110.0 mm)
Displacement.....	239 cu in. (3.9 liters)
Compression Ratio .....	17.8:1
Firing Order .....	1-3-4-2
Width.....	21.1 in. (536 mm)
Height.....	39.1 in. (993 mm)
Length .....	34.2 in. (869 mm)
Weight.....	960 lbs (435.5 kg)
Injection Pump/Governor .....	Stanadyne Model DB2
Injection Starting Pressure	
New.....	3650-3750 psi (25,167 - 25,856 kPa)
Used.....	3330 psi (22,960 kPa) Min.
Cylinder Compression Pressure.....	350 psi (2400 kPa)
Lubrication System Capacity .....	15 qts (14.1 liters)
Coolant System Capacity (engine only) .....	11 qts (10.4 liters)
Alternator.....	Prestolite 24 volt DC - 42 amp
Starter .....	Nippondenso 24 volt DC - 4.5 kw

---

**Section III. PREPARATION FOR USE**

**1-10. INSPECTING AND SERVICING ENGINE.**

This section provides information and guidance for inspecting, servicing, and installing the engine. For additional information, refer to end item maintenance manual.

1-10.1. Inspection.

- a. Check that all packing materials have been removed.
- b. Check engine identification plate for positive identification.
- c. Inspect engine exterior for shipping damage.
- d. Check fan drive belt for proper tension. Refer to end item maintenance manual.
- e. Inspect engine for loose or missing mounting hardware, or damaged or missing parts.

1-10.2. Service. Except for servicing the lubrication system all other servicing must be accomplished after engine is mounted in the end item. Refer to the end item maintenance manual.

## CHAPTER 2

### OPERATION

#### Section I. PRINCIPLES OF OPERATION

##### **2-1. INTRODUCTION.**

This section contains functional descriptions of the engine systems and how they are connected to the end item.

##### **2-2. COOLING SYSTEM.**

The cooling system consists of a radiator, hoses, thermostat, belt driven fan, water pump, and cooling jackets within the engine. The water pump forces coolant through passages (coolant jackets) in the engine block and oil cooler where coolant absorbs heat from the engine. When the coolant temperature is below operating temperature, the thermostat is closed and coolant is bypassed to the water pump inlet. As coolant temperature increases to 180°F (82°C), the thermostat fully opens, shutting off all bypass flow and providing full flow through the radiator. Air forced through the fins of the radiator by the fan cools the coolant pumped through the radiator. Items are added to the engine to monitor coolant temperature and to warn if temperature exceeds a predetermined value.

##### **2-3. LUBRICATION SYSTEM.**

The pressure lubrication system consists of a positive displacement gear-driven pump, filter strainer in the suction pipe, full flow oil filter, oil cooler, oil pressure regulating valve, and oil by-pass valve. Additionally, the oil cooler and oil filter have their own bypass valve. The pump draws lubrication oil from the crankcase through a strainer and a suction line. The oil is then pumped through an oil line to the oil cooler, oil filter, and through the main oil gallery of the cylinder block. From the oil gallery, oil is forwarded under pressure to the main bearings and spray jets to cool the pistons. Drilled cross-passages in the crankshaft distribute oil from the main bearings to connecting rod bearings. Lube oil holes in Nos. 1, 3, and 5 main bearing oil grooves are provided to direct oil to the camshaft bearings. A drilled passage from the rear camshaft bearing through the cylinder block and cylinder head supplies lubricating oil to the rocker arm shaft. An oil passage direct from the main oil gallery provides lubricating oil to the shaft of the turbocharger. Items are added to monitor oil pressure and to warn/stop engine if pressure drops to a dangerously low value.

##### **2-4. FUEL SYSTEM.**

The fuel system consists of an external fuel tank, fuel supply pump, fuel filter/water separator, fuel injection pump, fuel injectors, and piping. The fuel supply pump draws fuel from the tank and pressurizes it. This pressure permits the fuel to flow through the fuel filter/water separator and charge the transfer pump of the fuel injection pump. With the fuel injection pump charged with fuel by the fuel supply pump, the fuel injection pump plungers pressurize the fuel to approximately 7255 psi (50,000 kPa). Delivery (pressure) lines are used to route this high pressure fuel to the fuel injection nozzles. Fuel enters the injection nozzle at a pressure which easily overcomes the pressure required to open the nozzle valve. When the nozzle valve opens, fuel is forced out through the orifices in the nozzle tip and atomizes as it enters the combustion chamber. The fuel that is not used by the injectors and injection pump is returned to the fuel tank via an excess fuel return line.

##### **2-5. ELECTRICAL SYSTEM.**

The electrical system consists of external mounted batteries, starter, battery charging alternator, and related relays and switches for control of the system. Battery power supplied to the starter during the start cycle energizes the starter which engages the ring gear of the flywheel causing the engine to turn over. When engine start is complete the starter is deenergized and disengages from the flywheel. The battery charging alternator is belt driven. It is a 42 ampere, 24 VDC alternator that when operating supplies voltage to recharge the batteries and maintain them at a full state of charge.

#### Section II. OPERATING INSTRUCTIONS

##### NOTE

Refer to end item operator's manual.

CHAPTER 3  
 MAINTENANCE

Section I. PREVENTIVE MAINTENANCE CHECKS AND SERVICES (PMCS)

3-1. PMCS PROCEDURES.

3-1.1. General.

To ensure that engine is ready for operation at all times, it must be inspected so defects can be discovered and corrected before they result in serious damage or failure. Perform operator's PMCS prior to or in conjunction with performance of engine PMCS. For engine PMCS, refer to TABLE 3-1.

TABLE 3-1. Preventive Maintenance Checks and Services (PMCS)

Item No.	Interval						Item to be Inspected	Procedures Check for and have repaired or adjusted as necessary	Equipment is Not/Ready Available If:
	M	Q	S	A	B	H			
1						300	Oil Filter	Refer to paragraph 3-16.1.  <b>NOTE</b>  <b>Oil filter change interval is a hard time replacement to be used when AOAP lab is not available.</b>	
2						3000	Engine Valve Tappets	Adjust engine valve tappets. Refer to paragraph 3-32.1.	
3						3000	Engine Fuel Injectors	Remove, clean, and test injectors. Refer to paragraph 3-5.	
4						1500	Engine Compression	Check engine compression. Refer to paragraph 3-5.	Engine compression is low.
5						1500	Engine Oil Pressure	Check engine oil pressure. Refer to paragraph 3-21.4.	Engine oil pressure not as specified.

## Section II. TROUBLESHOOTING

### 3-2. TROUBLESHOOTING PROCEDURES.

#### 3-2.1. Purpose of Troubleshooting Table.

This section contains troubleshooting information for locating and correcting operating troubles which may develop in the engine. Each malfunction for an individual component, unit, or system is followed by a list of tests or inspections which will help you to determine probable causes and corrective action to take. You should perform tests/inspections and corrective actions in order listed.

This table cannot list all malfunctions that can occur, nor all tests or inspections and corrective actions. If a malfunction is not listed or cannot be corrected by listed corrective actions, notify your supervisor.

#### NOTE

**Before you use this table, be sure you have performed your PMCS. Prior to performing troubleshooting procedures within this manual, perform your operator's troubleshooting and the end item maintenance manual troubleshooting procedures.**

#### SYMPTOM INDEX

Malfunction	Troubleshooting Procedures Page
Engine Will Not Crank	3-3
Starter Operates But Engine Does Not Turn Over	3-3
Engine Hard To Start Or Will Not Start	3-3
Engine Hard To Start Or Will Not Start In Cold Weather	3-4
Engine Misfires Or Runs Irregularly Or Stalls Frequently	3-5
Engine Does Not Develop Full Power	3-6
Engine Overheating	3-6
Excessive Oil Consumption	3-7
Low Oil Pressure	3-7
Excessive Fuel Consumption	3-9
Black or Gray Smoke	3-10
Blue Exhaust Smoke	3-11
Engine Knocks	3-11
Engine Makes Abnormal Noise	3-11
Engine Makes a Gas Leaking Noise	3-13
Detonation or Pre-Ignition	3-13
Battery Charge Ammeter Shows No Charge When Batteries Are Low	3-14
Battery Charge Ammeter Shows Excessive Charging After Prolonged Period	3-14

TABLE 3-2. Troubleshooting

MALFUNCTION	TEST OR INSPECTION	CORRECTIVE ACTION
1. <u>ENGINE WILL NOT CRANK.</u>		
	Step 1. Check for defective end item starting system.	Troubleshoot per end item maintenance manual. If not defective, do step 2.
	Step 2. Check for defective starter solenoid.	a. Listen for audible clink during attempted start. If click is heard, do step 3. b. Replace defective starter solenoid. Refer to paragraph 3-12.
	Step 3. Check for defective starter motor.	Replace defective starter, refer to paragraph 3-12.
2. <u>STARTER OPERATES BUT ENGINE DOES NOT TURN OVER.</u>		
	Step 1. Check for worn or broken starter pinion gear and/or flywheel ring gear.	a. Remove starter and inspect pinion gear and flywheel ring gear for damage. If not defective, do step 2. b. Replace defective clutch assembly and/or flywheel ring gear. Refer to paragraphs 3-12 and 3-35.
	Step 2. Crank shaft rotation restricted.	a. Attempt to manually rotate engine. b. Repair and/or replace engine as necessary.
3. <u>ENGINE HARD TO START OR WILL NOT START.</u>		
	Step 1. Check for fuel being supplied to fuel injection pump.	

TABLE 3-2. Troubleshooting - Continued

MALFUNCTION	TEST OR INSPECTION	CORRECTIVE ACTION
		<ul style="list-style-type: none"><li>a. Test supply pump capacity. Refer to paragraph 3-25.2. If supply pump not defective, do step 2.</li><li>b. Repair or replace fuel supply pump. Refer to paragraph 3-25.</li></ul>
	Step 2. Check for clogged fuel filter/water separator.	Replace filter cartridge. Refer to paragraph 3-24.1. if not clogged, do step 3.
	Step 3. Check for air in fuel system lines.	Bleed fuel system. Refer to paragraph 3-23. If fuel system is free of air, do step 4.
	Step 4. Check for fuel injector starting pressure too low or spray condition improper.	<ul style="list-style-type: none"><li>a. Remove, clean, and test fuel injector. Refer to paragraphs 3-29.1., 3-29.2., and 3-29.3. if not defective, do step 5.</li><li>b. If defective replace fuel injector. Refer to paragraph 3-29.</li></ul>
	Step 5. Check for improper fuel injection pump timing.	<ul style="list-style-type: none"><li>a. Check fuel injection pump timing. Refer to paragraph 3-28. If fuel injection pump timing is correct, do step 6.</li><li>b. Adjust fuel injection pump timing. Refer to paragraph 3-28.</li></ul>
	Step 6. Check for defective fuel injection pump.	<ul style="list-style-type: none"><li>a. Test fuel injection pump. Refer to paragraph 3-27.7.</li><li>b. Repair or replace defective fuel injection pump. Refer to paragraph 3-27.</li></ul>
4. <u>ENGINE HARD TO START OR WILL NOT START IN COLD WEATHER.</u>		
	Step 1. Check for faulty cold start system.	<ul style="list-style-type: none"><li>a. Refer to end item maintenance manual. If not defective, do step 2.</li><li>b. Repair cold start system. Refer to end item maintenance manual.</li></ul>

TABLE 3-2. Troubleshooting - Continued

---

**MALFUNCTION**

**TEST OR INSPECTION**

**CORRECTIVE ACTION**

---

Step 2. Refer to Malfunction 3, and perform steps 1 thru 6.

5. ENGINE MISFIRES OR RUNS IRREGULARLY OR STALLS FREQUENTLY.

Step 1. Check for fuel being supplied to fuel injection pump.

- a. Test fuel supply pump capacity. Refer to paragraph 3-25.2. If supply pump not defective, do step 2.
- b. Repair or replace fuel supply pump. Refer to paragraph 3-25.

Step 2. Check for air in fuel system lines.

Bleed fuel system. Refer to paragraph 3-23. If no air, do step 3.

Step 3. Check for low coolant temperature.

- a. If coolant temperature not low, do step 4.
- b. Replace defective thermostat. Refer to paragraph 3-9.

Step 4. Check for fuel injector nozzle dirty, defective, or leaking.

- a. Remove, clean, and test fuel injector. Refer to paragraphs 3-29.1., 3-29.2., and 3-29.3. If not defective, do step 5.
- b. Replace fuel injector nozzle. Refer to paragraph 3-29.

Step 5. Check for improper fuel injection pump timing.

Adjust fuel injection pump timing. Refer to paragraph 3-28. If adjusted properly, do step 6.

Step 6. Check for defective fuel injection pump.

- a. Test fuel injection pump. Refer to paragraph 3-27.7. If not defective, do step 7.
- b. Replace fuel injection pump. Refer to paragraph 3-27.

Step 7. Check for valves properly adjusted.

TABLE 3-2. Troubleshooting - Continued

---

**MALFUNCTION**

**TEST OR INSPECTION**

**CORRECTIVE ACTION**

---

Adjust valves. Refer to paragraph 3-32.1. If properly adjusted, do step 8.

Step 8. Check for low engine compression.

- a. Perform engine compression check. Refer to paragraph 3-6.
- b. If engine defective, repair or replace engine.

6. ENGINE DOES NOT DEVELOP FULL POWER.

Step 1. Check for blocked air intake system.

Remove blockage as found. If no blockage is found, do step 2.

Step 2. Check for clogged fuel filter/water separator.

Replace fuel filter cartridge. Refer to paragraph 3-24.1. If not clogged, do step 3.

Step 3. Engine overheated.

If engine overheated, refer to Malfunction 7. If not a problem, refer to Malfunction 5.

7. ENGINE OVERHEATING.

Step 1. Inspect coolant level.

- a. Check engine for coolant leaks, If engine has no leaks, do step 2.
- b. Repair coolant leaks.

Step 2. Check for defective thermostat.

- a. If thermostat is suspected of being defective, replace thermostat. Refer to paragraph 3-9.
- b. If engine continues to overheat, do step 3.

TABLE 3-2. Troubleshooting Continued

---

MALFUNCTION	TEST OR INSPECTION	CORRECTIVE ACTION
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---

Step 3. Check for defective water pump.

- a. Remove and check water pump for damage, refer to paragraphs 3-10.1. and 3-10.2. If not defective, do step 4.
- b. Replace defective water pump. Refer to paragraph 3-10.

Step 4. Check improper fuel injection pump timing.

Adjust fuel injection pump timing. Refer to paragraph 3-28.

8. EXCESSIVE OIL CONSUMPTION.

Step 1. Check for oil leakage.

- a. Inspect engine for oil leaks. If no leaks, do step 2.
- b. Repair or replace defective components.

Step 2. Check for blocked air intake system.

Remove blockage as found. If not blockage, do step 3.

Step 3. Check for defective intake or exhaust valve seals or valve guides.

- a. Repair or replace defective components. Refer to paragraph 3-34.
- b. Disassemble and inspect valve seals and guides. Refer to paragraphs 3-34.3. and 3-34.4. If not defective, replace engine.

9. LOW OIL PRESSURE

Step 1. Check for improper grade of oil.

- a. Refer to end item Lubrication Order. If proper grade of oil, do step 2.
- b. If improper grade of oil, refer to paragraph 3-16. and change oil and filter.

TABLE 3-2. Troubleshooting - Continued

MALFUNCTION	TEST OR INSPECTION	CORRECTIVE ACTION
	Step 2. Check for engine running hot.	<ul style="list-style-type: none"><li>a. Refer to Malfunction 7.</li><li>b. If engine not overheating, do step 3.</li></ul>
	Step 3. Check for defective regulating valve.	<ul style="list-style-type: none"><li>a. Inspect oil pressure regulating valve. Refer to paragraph 3-17.2. If setting is normal, do step 4.</li><li>b. Replace defective regulating valve. Refer to paragraph 3-17.</li></ul>
	Step 4. Check for clogged oil pump strainer.	Remove and clean strainer. Refer to paragraph 3-21.2. If not clogged, do step 5.
	Step 5. Check for defective oil pump.	<ul style="list-style-type: none"><li>a. Remove and inspect oil pump for defective parts. Refer to paragraph 3-21.1. and 3-21.2. If not defective, do step 6.</li><li>b. Replace oil pump. Refer to paragraph 3-21.</li></ul>
	Step 6. Check for worn rocker arm bushings.	<ul style="list-style-type: none"><li>a. Replace rocker arm bushings. Refer to paragraph 3-33.</li><li>b. Remove and inspect rocker arm bushings. Refer to paragraphs 3-33.1. and 3-33.3. If not worn, replace engine.</li></ul>

TABLE 3-2. Troubleshooting - Continued

---

MALFUNCTION	TEST OR INSPECTION	CORRECTIVE ACTION
-------------	--------------------	-------------------

---

10. EXCESSIVE FUEL CONSUMPTION.

Step 1. Check for leak in fuel system.

- a. Check fuel system for leaks. If no leaks, do step 2.
- b. Repair fuel system.

Step 2. Check for blocked air intake system.

Remove blockage as found. If no blockage is found, do step 3.

Step 3. Check for defective fuel injector.

- a. Remove, clean, and test fuel injectors. Refer to paragraphs 3-29.1., 3-29.2., and 3-29.3. If not defective, do step 4.
- b. Replace fuel injectors. Refer to paragraph 3-29.

Step 4. Check for improper fuel injection pump timing.

Adjust fuel injection pump timing. Refer to paragraph 3-28. If timing is correct, do step 5.

Step 5. Defective fuel injection pump.

- a. Test fuel injection pump. Refer to paragraph 3-27.7. If not defective, do step 6.
- b. Replace fuel injection pump. Refer to paragraph 3-27.

TABLE 3-2. Troubleshooting - Continued

---

**MALFUNCTION**

**TEST OR INSPECTION**

**CORRECTIVE ACTION**

---

Step 6. Check for defective turbocharger.

- a. Inspect turbocharger for damage. Refer to paragraph 3-13.2. If not defective, do step 7.
- b. Replace defective turbocharger. Refer to paragraph 3-13.

Step 7. Check for valves improperly adjusted.

- a. Adjust valves. Refer to paragraph 3-32.1.
- b. Do step 8.

Step 8. Check for low engine compression.

- a. Perform engine compression check. Refer to paragraph 3-5.
- b. If defective, repair or replace engine.

11. BLACK OR GRAY SMOKE

Step 1. Check for blocked air intake system.

Remove blockage as found. If no blockage is found, do step 2.

Step 2. Check for defective fuel injectors.

- a. Test fuel injectors. Refer to paragraph 3-29.3. If not defective, do step 3.
- b. Replace fuel injectors. Refer to paragraph 3-29.

Step 3. Check for improper fuel injection timing.

Adjust fuel injection timing. Refer to paragraph 3-28. Go to step 4.

TABLE 3-2. Troubleshooting - Continued

---

**MALFUNCTION**

**TEST OR INSPECTION**

**CORRECTIVE ACTION**

---

Step 4. Defective fuel injection pump.

- a. Remove and test fuel injection pump. Refer to paragraphs 3-27.1. and 3-27.7.
- b. Repair or replace fuel injection pump. Refer to paragraph 3-27.

12. BLUE EXHAUST SMOKE.

Step 1. Check for blocked air intake system.

Remove blockage as found. If no blockage is found, do step 2.

Step 2. Check for defective intake or exhaust valve seals or valve guides.

- a. Repair or replace defective components. Refer to paragraph 3-34.
- b. Disassemble and inspect valve seals and guides. Refer to paragraphs 3-34.3. and 3-34.4. if not defective, replace engine.

13. ENGINE KNOCKS.

Step 1. Improper fuel injection pump timing.

Check fuel injection pump timing. Refer to paragraph 3-28. If improperly timed, do step 2.

Step 2. Check for defective fuel injector.

- a. Remove, clean, and test fuel injectors. Refer to paragraphs 3-29.1., and 3-29.2., and 3-29.3. If not defective, do step 3.
- b. Replace fuel injectors. Refer to paragraph 3-29.

Step 3. Check defective engine compression.

- a. Check compression. Refer to paragraph 3-5.
- b. If engine defective, repair or replace engine.

TABLE 3-2. Troubleshooting - Continued

MALFUNCTION	TEST OR INSPECTION	CORRECTIVE ACTION
14. <u>ENGINE MAKES ABNORMAL NOISE.</u>		
	Step 1. Check for worn or damaged water pump bearing.	
		a. Check for excessive water pump shaft play at cooling fan. If not excessive, do step 2. b. Replace defective water pump. Refer to paragraph 3-10.
	Step 2. Defective battery charging alternator.	
		a. Remove and inspect battery charging alternator for damage. Refer to paragraphs 3-11.1. and 3-11.3. If not defective, do step 3. b. Repair or replace battery charging alternator. Refer to paragraph 3-11.
	Step 3. Check for improperly adjusted valves.	
		Check valve clearance and adjust as necessary. Refer to paragraph 3-32.1. If properly adjusted, do step 4.
	Step 4. Check for damaged rocker arm.	
		a. Inspect rocker arms for damage. Refer to paragraph 3-33.3. If not damaged, do step 5. b. Repair or replace damaged rocker arm(s). Refer to paragraph 3-33.
	Step 5. Check for loose flywheel.	
		a. Tighten bolts to specified torque. Refer to paragraph 3-35.3. b. Check tightness of flywheel attaching bolts. If not loose, repair or replace engine

TABLE 3-2. Troubleshooting - Continued

MALFUNCTION	TEST OR INSPECTION	CORRECTIVE ACTION
15. <u>ENGINE MAKES A GAS LEAKING NOISE.</u>		
	Step 1. Check for loose or damaged exhaust manifold.	
		a. Inspect for damage and loose attaching hardware. If not damaged or loose, do step 2. b. Tighten or replace exhaust manifold. Refer to paragraph 3-14.3.
	Step 2. Check for loose fuel injection nozzles.	
		a. Inspect fuel injection nozzles for looseness. If not loose, do step 3. b. If loose, replace washers and tighten fuel injection nozzles. Refer to paragraph 3-29.
	Step 3. Check for damaged cylinder head gasket.	
		a. Inspect area around cylinder head gasket for evidence for gas leakage. b. Remove cylinder head and replace gasket. Refer to paragraph 3-34.
16. <u>DETONATION OR PRE-IGNITION.</u>		
	Step 1. Improper fuel injection pump timing.	
		Adjust fuel injection pump timing. Refer to paragraph 3-28. If timing is correct, do step 2.
	Step 2. Defective fuel injector nozzles.	
		a. Test fuel injector nozzles. Refer to paragraph 3-29.3. If not defective to step 3. b. Replace fuel injector nozzles. Refer to paragraph 3-29.
	Step 3. Carbon build-up in compression chamber.	
		a. Remove cylinder head and inspect for carbon build-up. Refer to paragraphs 3-34.1. and 3-34.4. b. Remove carbon and/or replace components as necessary.

TABLE 3-2. Troubleshooting - Continued

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**MALFUNCTION**

**TEST OR INSPECTION**

**CORRECTIVE ACTION**

---

17. BATTERY CHARGER AMMETER SHOWS NO CHARGE WHEN BATTERIES ARE LOW.

Step 1. Check for broken or loose fan belts.

- a. Inspect fan belts. Refer to end item maintenance manual. If belts not loose or broken, do step 2.
- b. Adjust or replace fan belts. Refer to end item maintenance manual.

Step 2. Test for defective battery charging alternator.

- a. Inspect and test battery charging alternator. Refer to paragraph 3-11. If alternator not defective, do step 3.
- b. Repair or replace battery charging alternator. Refer to paragraph 3-11.

Step 3. Check for breaks or loose connections in charging circuit.

If breaks or loose connections are found, repair charging circuit. Refer to end item maintenance manual.

18. BATTERY CHARGE AMMETER SHOWS ECESSIVE CHARGING AFTER PROLONGED PERIOD.

Step 1. Check for defective batteries.

- a. Test batteries. Refer to end item maintenance manual. If batteries not defective, do step 2.
- b. Replace batteries. Refer to end item maintenance manual.

Step 2. Test for defective battery charging alternator.

- a. Inspect and test battery charging alternator. Refer to paragraph 3-11. If alternator not defective, do step 3.
- b. Repair or replace battery charging alternator. Refer to paragraph 3-11.

TABLE 3-2. Troubleshooting - Continued

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MALFUNCTION	TEST OR INSPECTION	CORRECTIVE ACTION
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Step 3. Check for short in charging circuit.

If shorted, repair charging circuit. Refer to end item maintenance manual.

### Section III. GENERAL MAINTENANCE

#### 3-3. GENERAL.

This section provides general maintenance not found in other sections of Chapter 3.

##### 3-3.1. General Instructions.

#### Warning

**Where applicable, prior to performing engine maintenance, ensure batteries are disconnected to prevent serious injury or death.**

#### NOTE

**Refer to end item maintenance manual for removal of any components necessary to gain access to engine.**

- a. It is strongly recommended that bolts or nuts securing cylinder heads, covers, and doors be tightened in proper sequence.
- b. When assembling an engine, it is always advisable to replace nuts, bolts, and lockwashers that have been removed from high stress locations, in particular nuts and or bolts from connecting rods and cylinder heads should be replaced.
- c. When assembling an engine it is always advisable to apply a small quantity of new engine lubricating oil (MIL-L-2104) to all moving parts. After any maintenance work on engine has been completed lubricating oil and fuel levels must be checked and all safety guards installed before operating.
- d. When a new fan drive belt has been installed, check belt tension after first 20 hours of operation.
- e. Wear protective overalls, and keep items of loose clothing clear of all hot and moving parts.
- f. Whenever possible, clean components and surrounding area before removing or disassembling. Take care to exclude all dirt and debris from fuel injection equipment while it is being serviced.
- g. Some parts are cemented with gasket compound with others being dry. Before assembly, remove all traces of old gasket and compound. Take extreme care to exclude dirt from all gasket surfaces and gasket compound from all tapped holes unless otherwise specified.
- h. It is recommended that all oil seals are replaced once they have been removed from their original position. Seals must be installed square in housing and all lip seals must be installed with lip facing lubricant to be retained.

A service tool should be used to install all oil seals and care must be taken to prevent damaging new seal when it passes over shafts.

- i. Replace all nuts, bolts, capscrews, and studs with damaged threads. Do not use a tap or die to repair damaged threads which may impair the strength and closeness of the threads and is not recommended.
- j. Do not allow grease or oil to enter a blind threaded hole as hydraulic action present when bolt or stud is screwed in could split or stress housing.
- k. To check or re-torque a bolt or nut, item is slackened a quarter of a turn and then tightened to specified value.
- l. A steel ISO metric bolt, capscrew, or nut can be identified by the letter M either on head or one hexagon flat. The strength grade will also be marked on top or one flat.
- m. On nuts with identification marks on one face the frictional area of that surface will be reduced, therefore nut should be installed with unmarked face towards component.
- n. Service tools are designed to aid disassembly and assembly procedures and their use will prevent possible unnecessary damage to components. It is recommended that service tools are always used, some operations cannot be safely carried out without aid of relevant tool.
- o. When removing/disconnecting fuel and lubrication lines and coolant hoses, cover/cap all openings to prevent entry of foreign material. Remove covers and caps upon installation.

### **3-4. DISASSEMBLY AND ASSEMBLY SEQUENCE FOR OVERHAUL**

The following paragraphs provide the sequence of disassembly and assembly for complete overhaul of the engine. Step-by-step procedures can be found in remaining sections of Chapter 3.

#### **3-4.1. Disassembly.**

##### **Warning**

**If the engine has been operating and coolant is hot, allow engine to cool before you slowly loosen filler cap and relieve pressure from cooling system. Failure to observe this warning could result in severe personal injury.**

##### **Warning**

**Use care when rotating engine on engine maintenance stand. If necessary, use a lifting device to avoid severe personal injury.**

- a. Drain all coolant and engine oil, refer to end item maintenance manual. Check engine oil for metal contaminants.
- b. Remove fan belt and battery charging alternator, refer to paragraph 3-11.1.
- c. Remove turbocharger and exhaust manifold, refer to paragraphs 3-13.1. and 3-14.1.
- d. Remove valve cover, refer to paragraph 3-31.1.
- e. Remove water manifold/thermostat housing with thermostat, refer to paragraph 39. 1.
- f. Remove oil cooler piping, water pump, and hoses, refer to paragraph 3-10.1.
- g. Remove dipstick, oil filter, and engine oil cooler, refer to paragraphs 3-19.1. and 3-16.1. Discard oil cooler if oil contained metal particles.
- h. Remove oil pressure regulating valve assembly, refer to paragraph 3-17.1.
  - i. Remove fuel filter, fuel supply pump, and fuel lines, refer to paragraphs 3-24.2., 3-25.1., and 3-26.1.
  - j. Remove injection lines, injection pump, and injection nozzles, refer to paragraph 3-27.1.

- k. Remove starter, refer to paragraph 3-12.2.
  - l. Remove rocker arm assembly and pushrods, refer to paragraph 3-33.1. Keep rods in sequence. Check for bent pushrods and condition of wear pad contact surfaces on rockers.
  - m. Remove cylinder head and cylinder head gasket, refer to paragraph 3-34.1. Check piston protrusion.
  - n. Remove cam followers, refer to paragraph 334.1. Keep in same sequence as removed.
  - o. Remove flywheel, rear oil seal, and flywheel housing, refer to paragraphs 3-35.1., 3-36.1., and 3-37.1.
  - p. Remove oil pan, refer to paragraph 3-20.1.
  - q. Remove crankshaft pulley, refer to paragraph 3-38.1.
  - r. Remove timing gear cover, refer to paragraph 3-39.1.
  - s. Remove oil pump drive gear, oil outlet tube, (and its O-ring in block), and pump body, refer to paragraph 3-21.1.
  - t. Remove oil slinger, timing gears, and camshaft, refer to paragraphs 3-40.1. and 3-42.1. Perform wear checks.
  - u. Remove balancer shafts, refer to paragraph 341.1.
  - v. Remove engine front plate, refer to paragraph 3-43.1.
  - w. Remove lube oil system by-pass valve, refer to paragraph 3-22.1.
  - x. Stamp cylinder number on rod (if required). Remove pistons and rods, refer to paragraph 3-45. 1. Perform wear checks with bearing gage (PLASTIGAGEPR1). Remove two at a time.
  - y. Remove crankshaft and main bearings, refer to paragraph 3-44.1. Perform wear checks with bearing gage.
  - z. Remove cylinder liners and mark each one with cylinder number from which removed, refer to paragraph 3-45.2.
  - aa. Remove piston cooling orifices, refer to paragraph 3-45.1.
  - ab. Remove cylinder block plugs and serial number plate (as required) when block is to be put in a 'hot tank'.
  - ac. Clean out liner bores (upper and lower areas) with nylon brush.
  - ad. Measure cylinder block, refer to paragraph 3-47.3.
  - ae. Cap/cover all openings to prevent entry of foreign material.
- 3-4.2. Assembly.

**NOTE**

**Remove all caps/covers.**

- a. Install all plugs (and serial number plates) in cylinder block that were removed to service block.
- b. Install clean piston cooling orifices.
- c. Install cylinder liners without O-rings and measure stand-out. Install liners with O-rings, refer to paragraph 3-50.2.
- d. Install crankshaft and main bearings, refer to paragraph 3-44.4. Bearing gage bearings.
- e. Install flywheel housing, rear oil seal, and flywheel, refer to paragraphs 3-37.3., 3-36.2., and 3-35.3.
- f. Install pistons and rods, refer to paragraph 3-50.3. Measure piston protrusion for proper piston selection.
- g. Install lube oil system by-pass valve, refer to paragraph 3-22.3.
- h. Install engine front plate, refer to paragraph 3-43.5.
- i. Install balancer shafts, refer to paragraph 3-41.4. Check end play.
- j. Install oil outlet tube, O-ring in block, and oil pump, refer to paragraph 3-21.3.
- k. Install injection pump on front plate, refer to paragraph 3-27.8.

- l. Install camshaft, timing gears, and oil slinger, refer to paragraph 3-40.3.
- m. Time all gears Top Dead Center (TDC), No. 1 cylinder on compression stroke.
- n. Install timing gear cover (with new front seal), refer to paragraph 3-39.3.
- o. Install oil pan, refer to paragraph 3-20.3.
- p. Install oil pressure regulating valve, refer to paragraph 3-17.3.
- q. Install cam followers in the same sequence as removed, refer to paragraph 3-34.
- r. Install cylinder head gasket, cylinder head, pushrods, and rocker arm assembly, refer to paragraphs 3-34.7 and 3-33.5.
- s. Install starter, refer to paragraph 3-12.7.
- t. Install injection nozzles (with new seals) and injection lines, refer to paragraph 3-29.4.
- u. Install fuel filter, fuel supply pump, and fuel lines, refer to paragraphs 3-24.4. and 3-26.3.
- v. Install engine standard flow oil cooler, new oil filter, and dipstick, refer to paragraphs 3-16.3. and 3-17.2. (Never clean or reuse a contaminated engine oil cooler. Install a new one.)
- w. Install water manifold/thermostat housing with thermostat, refer to paragraph 3-9.4.
- x. Install exhaust manifold and turbocharger, refer to paragraphs 3-14.3. and 3-13.4. Prelube the turbocharger.
- y. Install oil cooler piping, water pump, and hoses, refer to paragraph 3-10.4.
- z. Install crankshaft pulley, refer to paragraph 3-38.3.
- aa. Install battery charging alternator, fan, and fan belt, refer to paragraph 3-11.6.
- ab. Adjust valves, refer to paragraph 3-32.1.
- ac. Install valve cover, refer to paragraph 3-31.2.
- ad. Fill engine with proper oil and coolant, refer to end item maintenance manual.
- ae. Perform engine break-in and perform normal standard performance checks.

### **3-5. TEST ENGINE COMPRESSION PRESSURE.**

#### **NOTE**

**Before beginning test, ensure that batteries are fully charged and injection nozzle area is thoroughly cleaned.**

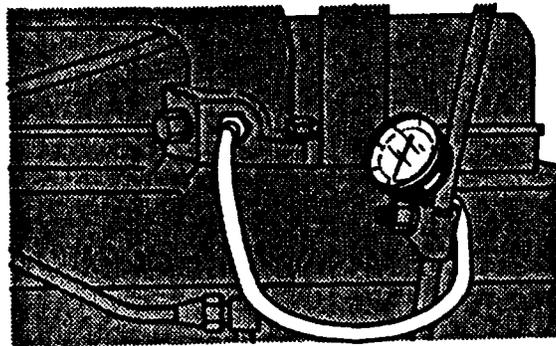
- a. Run engine to bring up to normal operating temperature. (From a cold start, operate engine 10 to 15 minutes at slow idle.)
- b. Remove fuel injection nozzles, refer to paragraph 3-29.1.
- c. Install adapter (JT01679) with O-ring in injection nozzle bore. Use holding clamp (JT02017) to hold adapter in position. Install hold down screw in clamp and tighten screw to 27 ft-lbs (37 Nm). Attach test gage (JT01 682) to adapter.
- d. Refer to end item maintenance manual, and using DEAD CRANK switch, (or other applicable device), turn crankshaft for 10 to 15 seconds with starter (150 rpm minimum cranking speed). Record pressure reading.
- e. Compare readings from all cylinders.
- f. Compression pressure must be 350 psi (2400 kPa) minimum. The difference between the highest and lowest cylinder must be less than 50 psi (350 kPa).
- g. If pressure is much lower than shown, remove gage and apply oil to ring area of piston through injection nozzle bore. Do not use too much oil. Do not get oil on the valves.
- h. Test compression again. If pressure is high, worn or stuck rings are indicated. If pressure is still low, it is possible that valves are worn or sticking.

**3-6. MEASURE ENGINE BLOW-BY.**

- a. Place a hose with a standard gas gage in end of crankcase vent tube.
- b. Run engine at rated speed and load (engine at operating temperature and run-in, with at least 100 operating hours).
- c. Measure blow-by over a period of 5 minutes. Multiply figure obtained by 12 (hourly rate). Maximum allowable blow-by is 225 cu ft/h (6.0 cu m/h)
- d. If blow-by is lower, there probably is no undue wear between piston rings and liners. If blow-by is higher, there could be excessive wear between piston rings and liners, resulting in loss of engine power.

**3-7. INTAKE MANIFOLD PRESSURE CHECK.**

- a. Remove plug from intake manifold and connect suitable gage to intake manifold, refer to FIGURE 3-1.



**FIGURE 3-1. Connecting Test Gage to Intake Manifold**

- b. Run engine to bring up to normal operating temperature. (From a cold start, operate engine 10 to 15 minutes at slow idle.)

**NOTE**

**Engine speed and load should be stabilized before taking readings on gage. Be sure that gage works properly.**

**NOTE**

**Pressure checks are only a guide to determine if there is an engine problem (valve leakage, defective nozzles, etc). Low readings are not a valid reason for increasing injection pump fuel delivery. Pump adjustment should be within specification.**

- c. Observe pressure reading on gage. Reading should be at least 9 psi (60 kPa/0.6 bar) when engine is developing rated power at full load rated speed.
- d. If boost pressure is too high, remove and test fuel injection pump for high fuel delivery.
- e. If boost pressure is too low, check for the following:
  - (1) Restricted air filter elements.
  - (2) Restricted fuel filter elements.
  - (3) Incorrect fast idle adjustment.
  - (4) Incorrect injection pump timing.
  - (5) Exhaust manifold leaks.
  - (6) Intake manifold leaks.
  - (7) Faulty fuel transfer pump.
  - (8) Low compression pressure.
  - (9) Faulty fuel injection nozzles.
  - (10) build-up in turbocharger.
  - (11) compressor or turbine wheel rubbing housing.
  - (12) fuel injection pump fuel delivery.
  - (13) exhaust.
- f. Remove test gage and install plug in intake manifold.

**Section IV. COOLING SYSTEM MAINTENANCE**

**3-8. GENERAL**

This section provides maintenance for cooling system components. Components of cooling system not mentioned in this section can be found in the end item maintenance manual.

**Warning**

**If the engine has been operating and coolant is hot, allow engine to cool before you slowly loosen filler cap and relieve pressure from cooling system. Failure to observe this warning could result in severe personal injury.**

**3-9. THERMOSTAT AND HOUSING.**

**3-9.1. Removal.**

- a. Drain coolant system if not already drained, refer to end item maintenance manual.
- b. Loosen hose clamp and remove outlet hose from cover (3, FIGURE 3-2).

- c. Remove two capscrews (1), and lockwashers (2) securing cover (3) to housing (8); remove cover (3) and gasket (4). Discard gasket (4) and lockwashers (2).
- d. Lift thermostat (5) from housing (8).
- e. Loosen two hose clamps (9) and remove by-pass hose (10) from housing adapter (11) and water pump housing.

**NOTE**

**If installed, remove temperature sending unit.**

- f. Remove two capscrews (6) and lockwashers (7) securing housing (8); remove housing (8) and gasket (12). Discard gasket (12) and lockwashers (7).

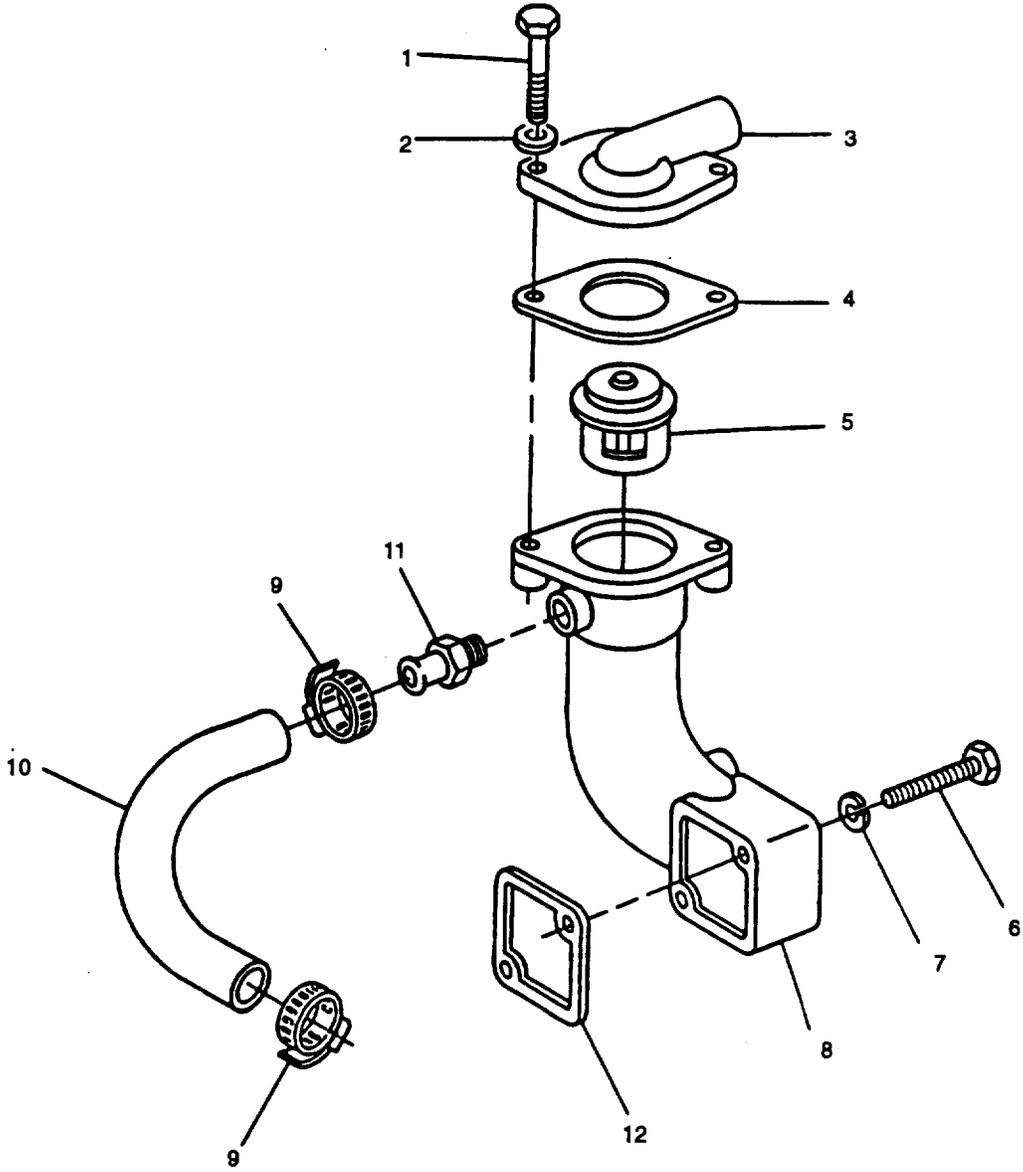


FIGURE 3-2. Thermostat and Housing

- g. Remove adapter (11) if replacing housing (8).
- h. Cover all openings to prevent entry of foreign material.

3-9.2. Inspection.

- a. Inspect thermostat for excessive wear or damage.
- b. Inspect housing for cracks, corrosion, or other damage.

3-9.3. Replacement.

**NOTE**

**If thermostat is suspected of being defective, replace thermostat.**

- a. Replace thermostat if worn or damaged.
- b. Replace housing if badly corroded or damaged.

3-9.4. Installation.

**NOTE**

**Remove all covers.**

- a. Ensure all old gasket material is removed from gasket surfaces.
- b. Install adapter (11, FIGURE 3-2) in housing (8).
- c. Position housing (8) and new gasket (12) on engine and secure with two capscrews (6) and new lockwashers (7). Tighten screws to 35 ft-lbs (47 Nm).

**NOTE**

**If required, install temperature sending unit.**

- d. Install by-pass hose (10) on adapter (11) and water pump housing and secure with two hose clamps (9).
- e. Apply a thin coat of sealing compound (FORMAGASKET2) on thermostat housing (8) and cover (3).
- f. Position thermostat (5) in housing (8).
- g. Position cover (3) and new gasket (4) on housing (8) and secure with capscrews (1) and new lockwashers (2). Tighten screws to 20 ft-lbs (27 Nm).
- h. Install outlet hose and secure with hose clamp.

**NOTE**

**Air must be expelled from system when refilled with coolant. Loosen temperature sending unit fitting at rear of cylinder head or plug in thermostat housing to allow air to escape when filling system. Retighten fitting or plug when all the air has been expelled.**

- i. Service coolant system, refer to end item maintenance manual.

### 310. WATER PUMP.

#### 3-10.1. Removal.

#### WARNING

**Do not drain coolant until coolant temperature is below operating temperature prior to removal. Severe personal injury can occur.**

- a. Drain coolant system if not already drained. Refer to end item maintenance manual.
- b. Loosen hose clamp and remove inlet hose from water pump inlet.
- c. Loosen four hose clamps (1, FIGURE 3-3) and disconnect cooler hoses (2) at water pump.
- d. Remove screw (3) and washer (4) and remove clamp (5). Disconnect and remove hoses (2).
- e. Loosen hose clamp and remove by-pass hose from water pump.
- f. Remove fan drive belts, refer to end item maintenance manual.
- g. Remove fan and spacer, refer to end item maintenance manual.

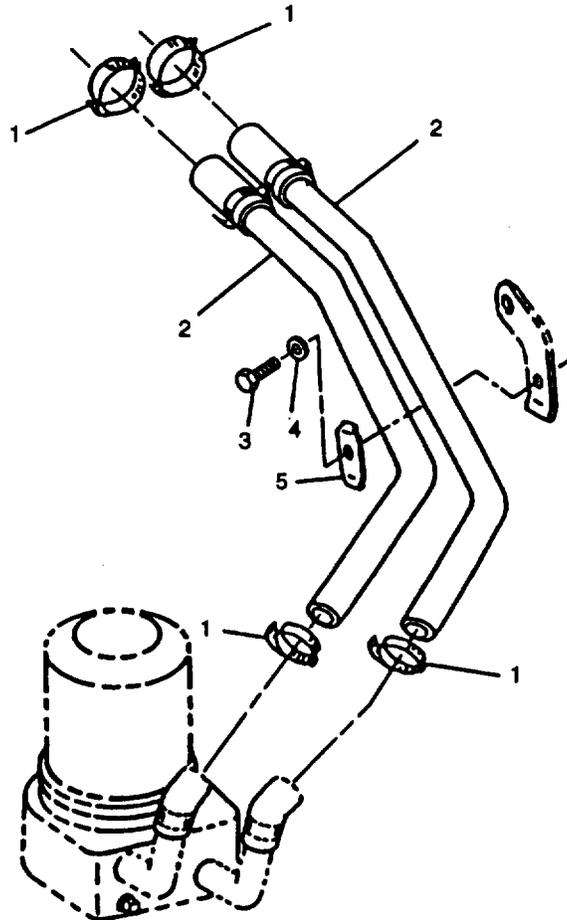


FIGURE 3-3. Engine Oil Cooler Hoses

- h. Remove capscrew (1, FIGURE 3-4) and lockwashers (2) attaching alternator adjusting strap (3); move strap out of the way. Discard lockwasher.

**NOTE**

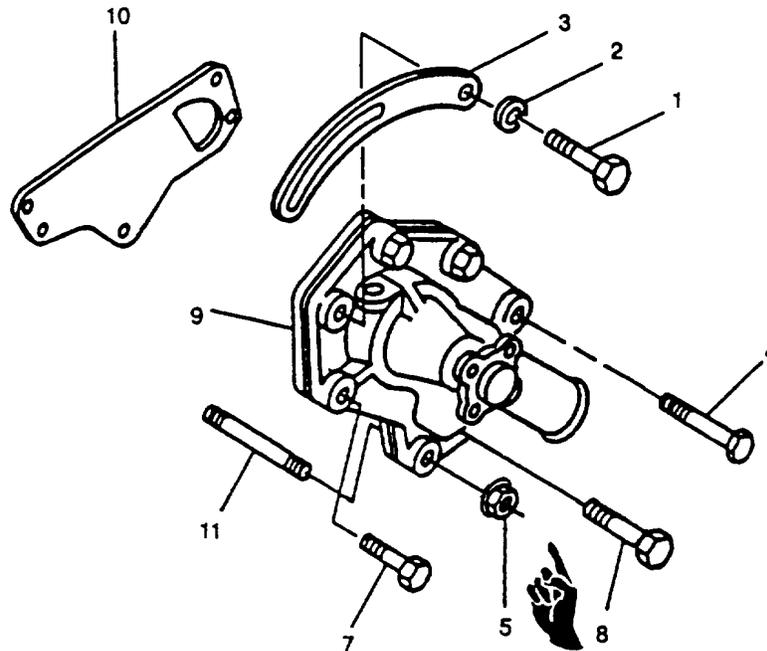
**location of shorter capscrew (7) for installation purposes.**

- i. Remove capscrew (4), nut (5), and capscrew (7). Using an assistant to support water pump (9), turn capscrew (8) and remove water pump (9). Remove and discard gasket (10).

**CAUTION**

**Failure to cover all openings can result in damage to engine or pump.**

- j. Cover all openings to prevent entry of foreign material.



**FIGURE 3-4. Water Pump Assembly**

3-10.2. Inspection.

- Inspect pump rotation for abnormal noise, binding, or other abnormal conditions.
- Inspect pump housing and stud (1, FIGURE 3-4) for cracks, corrosion, or any other damage.

3-10.3. Replacement.

Replace water pump if inspection reveals debris, cracks, or damage to pump housing and cover.

3-10.4. Installation.

- Remove all covers installed during removal procedure.
- Position new gasket (10, FIGURE 3-4) and water pump (9) on engine block and secure with capscrews (4, 7, and 8), and nut (5). Tighten fasteners to 35 ft-lbs (47 Nm).
- Position alternator adjusting strap (3) and secure with capscrew (1) and new lockwasher (2). Tighten capscrew to 35 ft-lbs (47 Nm).
- Install fan and spacer, refer to end item maintenance manual.

- e. Install fan drive belts, refer to end item maintenance manual.
- f. Install by-pass hose on water pump and secure with a hose clamp.
- g. Install two oil cooler hoses (2, FIGURE 3-3) and secure to water pump and engine oil cooler with four hose clamps (1). Install clamp (5) with screw (3) and washer (4).
- h. Install inlet hose on pump inlet and secure with a hose clamp.

**NOTE**

**Air must be expelled from system when system is refilled. Loosen temperature sending unit fitting at rear of cylinder head or plug in thermostat housing to allow air to escape when filling system. Retighten fitting or plug when all the air has been expelled.**

- i. Service coolant system, refer to end item maintenance manual.

**Section V. ELECTRICAL SYSTEM MAINTENANCE**

3-11. BATTERY CHARGING ALTERNATOR.

3-11.1. Battery Charging Alternator Test (Installed)

- a. Check for battery voltage in alternator between terminals POS and ground, and EXC and ground with the master switch (S1) in the PRIME & RUN POSITION. Note voltage.
- b. Start and operate generator refer to TM 9-6115-645-10 and recheck voltage on alternator terminal POS and ground for 28 " 2 VDC.

**WARNING**

**Prior to removing alternator, ensure negative battery lead is disconnected from battery to prevent serious injury or death.**

3-11.2. Removal.

- a. Tag and disconnect electrical leads from battery charging alternator.
- b. Remove fan belts, refer to end item maintenance manual.
- c. Remove capscrew (1, FIGURE 3-5), lockwasher (2), and washer (3); securing bracket (4) and battery charging alternator (5). Discard lockwasher (2).
- d. Support weight of battery charging alternator and remove capscrew (6), lockwasher (7), and nut (8); securing bracket (4) and alternator (5). Remove bracket (4) and alternator (5). Discard lockwasher (7).
- e. If necessary, remove capscrew (9) and lockwasher (10) securing adjusting strap (11) to water pump mounting hole. Remove adjusting strap. Discard lockwasher (10).
- f. If necessary, remove two capscrews (12), washers (13), spacers (16), and nuts (14) securing mounting brackets (15 and 17). Remove brackets (15 and 17).
- g. If necessary, loosen and remove nuts (19) from terminals POS plus OUTPUT and SEN. Remove jumper wire (18).

3-11.3. Disassembly.

- a. Remove terminal nuts (1, FIGURE 3-6), washers (2), bolts (3), back cover (4), and gasket (5) from rear housing (20).
- b. Remove nuts (6), strap (7), washer (32), and brush assembly (8) from voltage regulator (11).
- c. Remove bolts (9), insulating washers (10), and voltage regulator (11) from rear housing (20).
- d. Remove nut (12) and washer (13) and straighten strap (14).
- e. Remove screws (15). Tag and remove stator (22) leads from diode-trio (17).

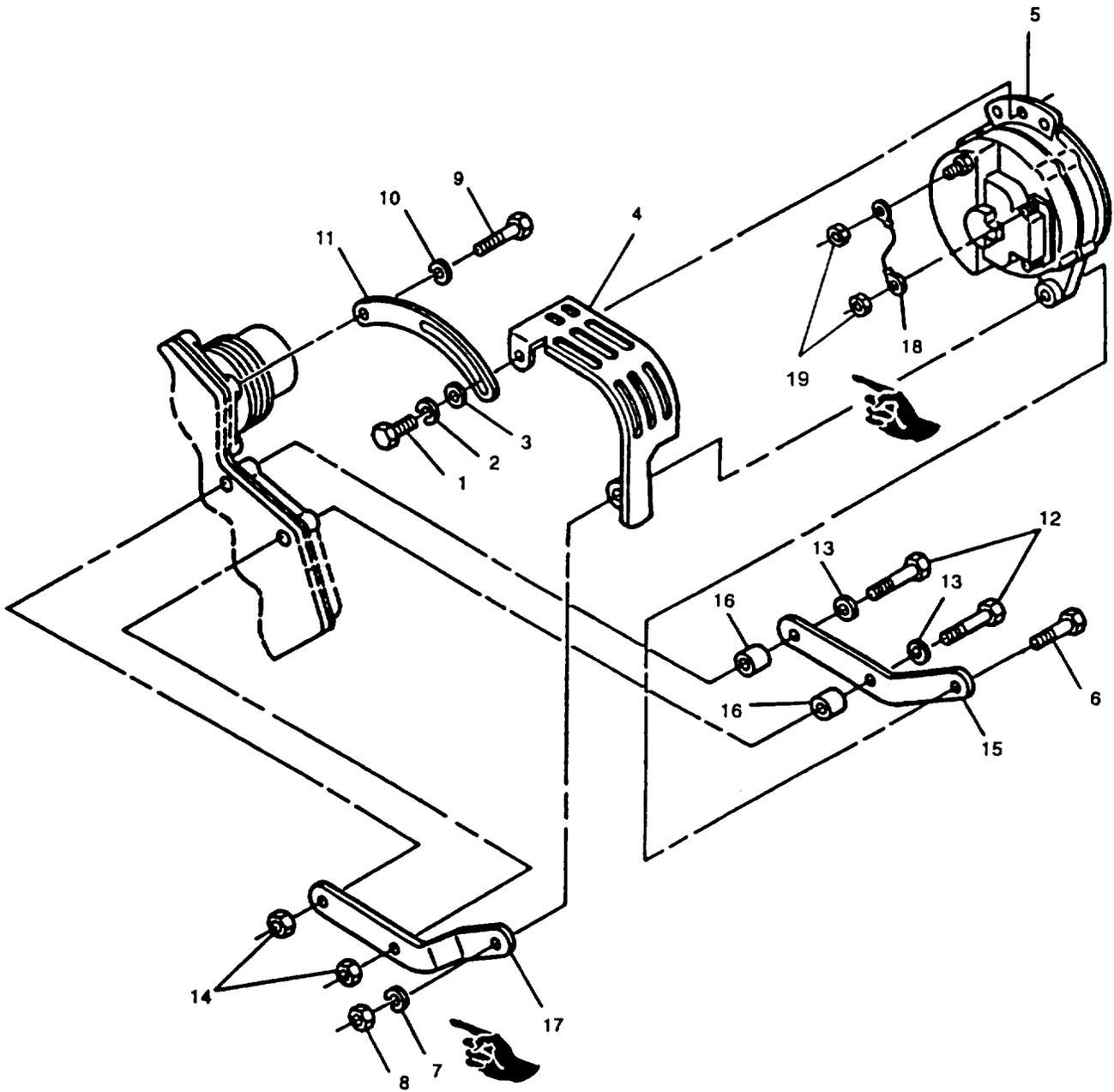


FIGURE 3-5. Battery Charging Alternator and Mounting Brackets

- f. Remove bolts (16), diode-trio (17), strap (14), and rectifier bridge (18) from rear housing (20).

**CAUTION**

**Do not Insert screwdriver blades deeper than 1/16 Inch (1.587 mm) to avoid damaging stator winding.**

- g. Match mark front and rear housings, and remove through bolts (19). Insert two flat tip screwdrivers in opposite openings between stator (22) and rear housing (20), refer to FIGURE 3-7.
- h. Pry units apart and remove rear housing (20, FIGURE 3-6) and stator (22) from front housing (30).

**NOTE**

**To remove nut (23), place rotor assembly in a soft-jawed vise.**

- i. Remove nut (23), lockwasher (24), pulley (25), fan (26), spacer (27), and woodruff key (28) from rotor assembly (29) shaft.
- j. Using arbor press, remove rotor assembly (29) from front housing (30).
- k. Remove bearing retaining screws (31) and press bearing (32) from front housing (30).

3-11.4. Inspection.

- a. Inspect brushes for cracks, grooves on sides, being oil soaked, and that they are at least 0.1875 inch (4.7625 mm) long.
- b. Inspect rear housing for cracked or broken casting, stripped threads, and severe wear of rear bearing bore.
- c. Inspect fan for cracked or broken fins and for worn mounting hole.
- d. Inspect front housing for cracked or broken casting, stripped threads, and bore of mounting foot for elongation.

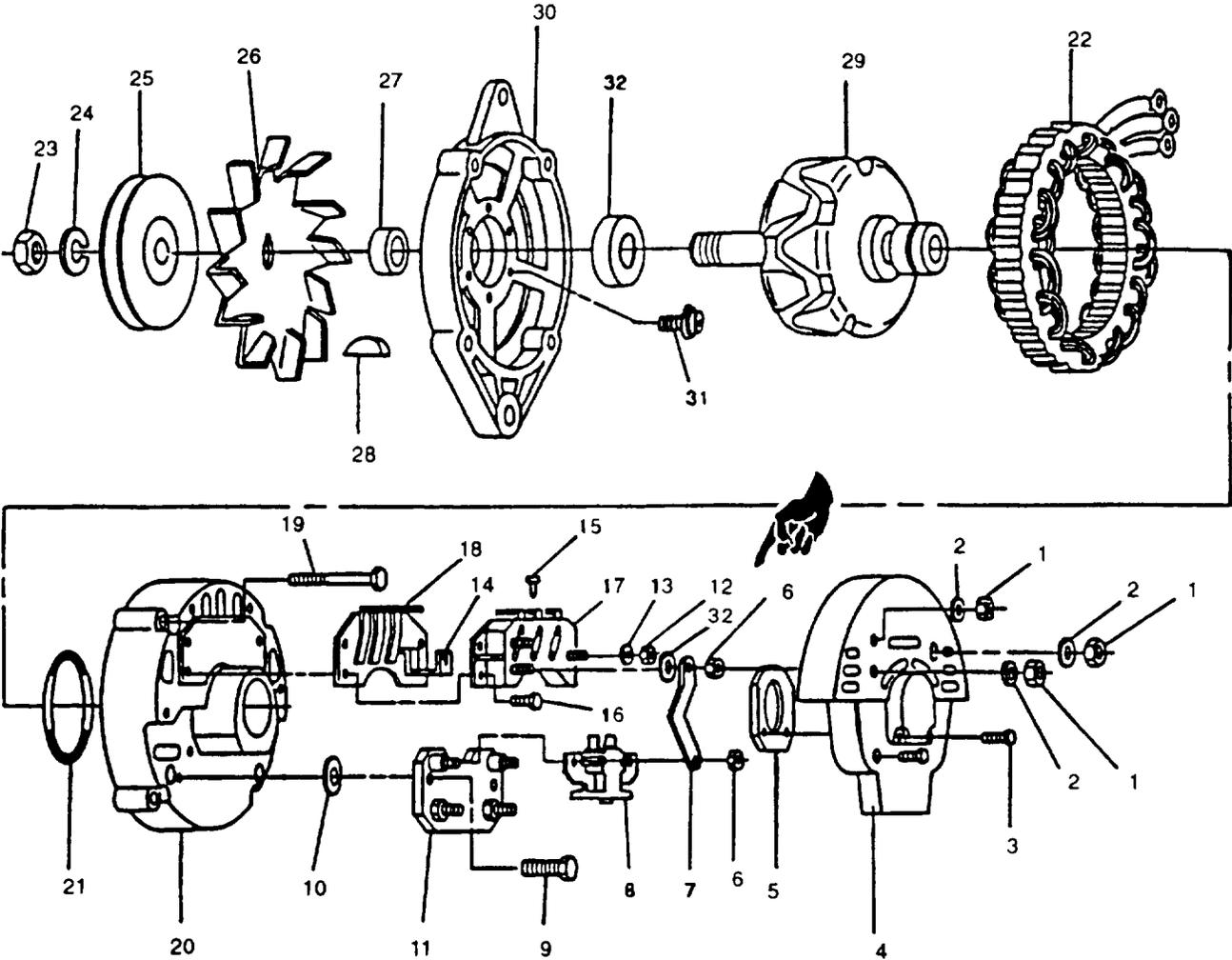
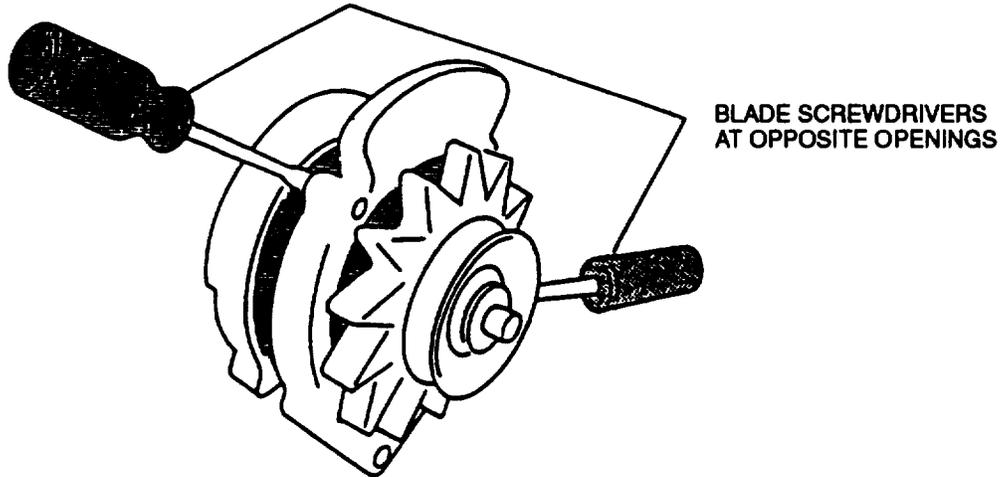


FIGURE 3-6. Battery Charging Alternator Assembly

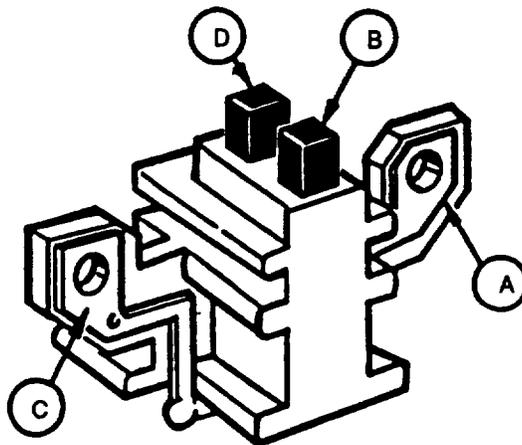


**FIGURE 3-7. Stator and Rear Housing Separation**

- e. Inspect other components for damage such as broken terminals or insulation, discoloration, stripped threads, and other obvious damage.
- f. Replace damaged components as necessary.

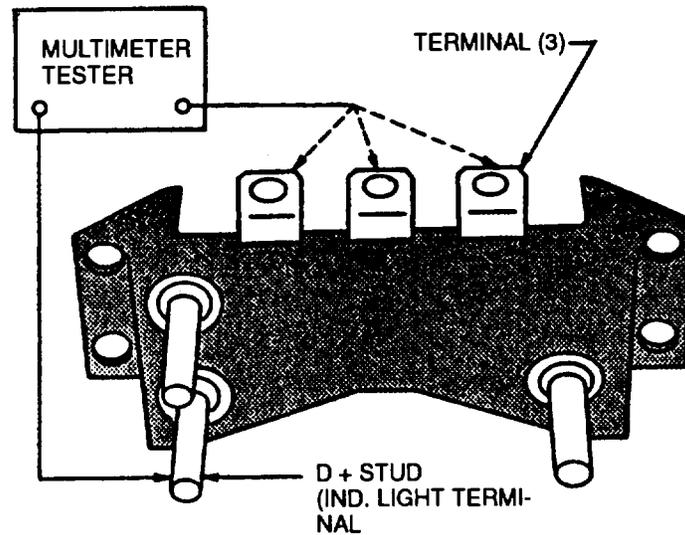
311.5. Testing.

- a. Set multimeter for ohms and check brush assembly (refer to FIGURE 3-8) for continuity between mount A and brush B, and mount C and brush D. Check for open circuits between mount A and mount C, mount A and brush D, mount C and brush B, and brush B and brush D. Replace brush assembly if indications are other than stated.



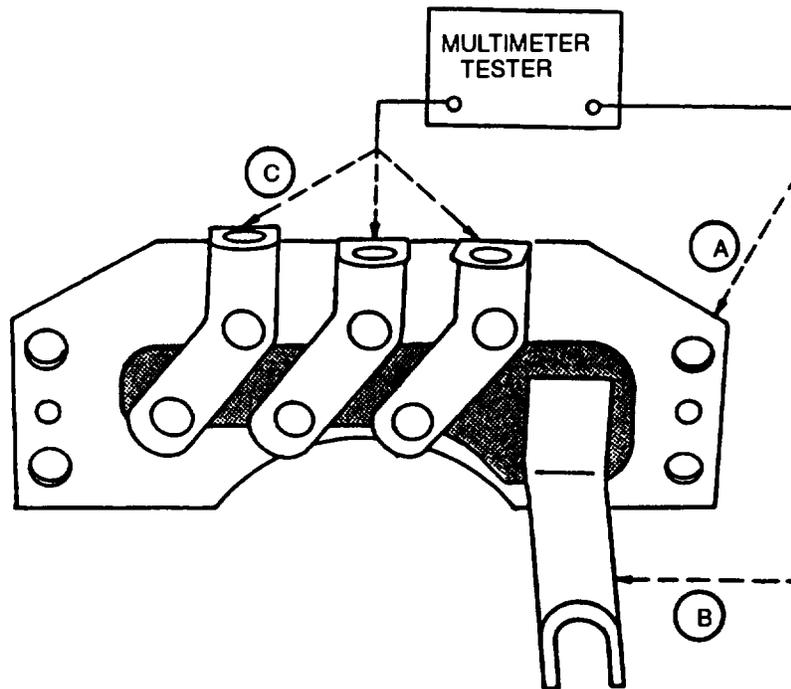
**FIGURE 3-8. Testing Brush Assembly**

- b. Set multimeter for ohms and check diode-trio assembly (refer to FIGURE 39) by noting multimeter indications between D+ stud and each of stator terminals. Reverse multimeter leads, repeat checks and note indications. If readings are the same in both directions for any diode, replace entire diode-trio assembly. A good diode will show a high indication in one direction and a low indication in the other.



**FIGURE 3-9. Testing Diode-Trio**

- c. Set multimeter for ohms and check rectifier bridge assembly (refer to FIGURE 3-10) by noting multimeter indications between point A and each point C, and between point B and each point C. Reverse leads, repeat checks, and note indications. If readings are the same in both directions for any diode, replace entire rectifier bridge assembly. A good diode will have a high indication in one direction and a low indication in the other.



**FIGURE 3-10. Testing Rectifier Bridge**

- d. Set multimeter for ohms and check stator (refer to FIGURE 3-11) for open circuits between point D (lamination) and each terminal A, B, and C. If continuity is noted between lamination and any terminal, stator is defective and must be replaced.
- e. Set multimeter for ohms and check stator windings (refer to FIGURE 3-11) for continuity between terminals A-B, A-C, and B-C. If open, replace stator.
- f. Set multimeter for ohms and check rotor assembly (refer to FIGURE 3-12) for 12.0 to 13.0 ohms indication between slip rings. Also check that open circuits are indicated between pole fingers and each slip ring. Replace entire rotor assembly if indications are other than stated.

3-11.6. Assembly.

- a. Using press, install front bearing (32, FIGURE 3-6) in front housing (30).

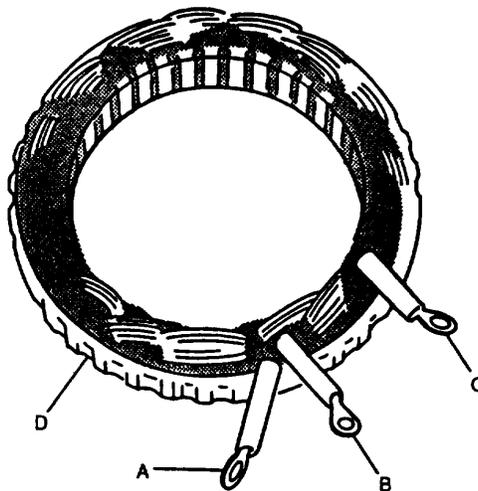


FIGURE 3-11. Testing Stator Windings

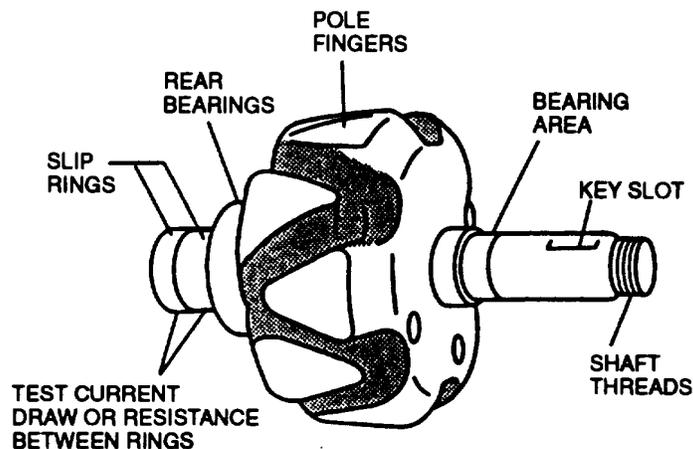


FIGURE 3-12. Testing Rotor

- b. Install front bearing retaining screws (31). Torque screws 25 to 35 in-lbs (2.82 to 3.95 Nm).
- c. Using arbor press, press front housing (30) over rotor assembly (29) until inner bearing race contacts shoulder on shaft.
- d. Position pulley spacer (27), woodruff key (28), fan (26), and pulley (25) on rotor assembly (29) shaft.
- e. Install lockwasher (24) and nut (23) on rotor assembly (29) shaft. Place rotor assembly in soft jawed vise and torque nut 35 to 50 ft-lbs (47.5 to 67.8 Nm).
- f. Position stator (22) in front housing (30) with stator leads at top and notches in lamination aligned with bolt holes.
- g. If damaged, replace retainer (21) in rear housing (20).
- h. Position rear housing (20) over slip rings of rotor assembly (29) with front and rear housing bolt holes aligned and stator leads extending through openings at top of rear housing (20).
  - i. Install through bolts (19) and tighten evenly 50 to 60 in-lbs (5.65 to 6.78 Nm).
  - j. If necessary, remove through bolts (19) and rotate rear housing (20) and stator (22) to align housings as match marked on disassembly. Reinstall bolts and torque evenly 50 to 60 in-lbs (5.65 to 6.78 Nm).
- k. Insert strap (14) of rectifier bridge (18) through slot in diode-trio (17) body. Bend strap (14) over B+ terminal and secure with cone washer (13) and nut (12).
- l. Apply thin film of heat sink compound (5202217) to back of rectifier bridge (18) and mating area of rear housing (20)
- m. Install diode-trio (17) and rectifier bridge (18) on rear housing (20) with bolts (16) and connect stator leads with screws (15). Remove tags.
- n. Install voltage regulator (11) to rear housing (20) with insulating washers (10) and bolts (9).
- o. Install brush assembly (8) and strap (7) with washer (32) and nuts (6).
- p. Position felt gasket (5) in back cover (4) and install back cover on rear housing (20) with bolts (3).
- q. Install terminal washers (2), terminal nuts (1), and jumper (18, FIGURE 3-5).
- r. Perform battery charging alternator performance test as follows:
  - (1) Mount battery charging alternator on test fixture capable of providing 5000 alternator rpm.

**CAUTION**

**Make sure connections are tight to avoid possible damage to instruments, battery charging alternator, or wiring due to short circuits.**

- (2) Set up test circuit as shown in FIGURE 3-1.

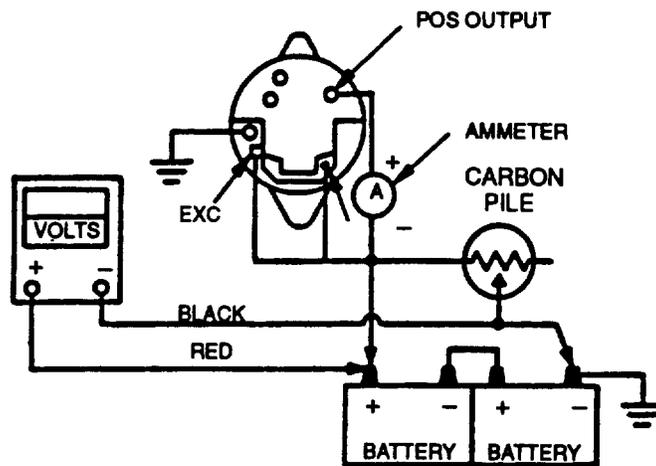


FIGURE 3-13. Battery Charging Alternator Test Circuit

**NOTE**

**Carbon pile and ammeter must be capable of handling the alternator rated output.**

- (3) Starting with the carbon pile off, slowly increase load while observing ammeter and maintaining 5000 rpm. Increase load until an output voltage of 27.0 to 29.0 VDC is achieved. Record the output current at this point. Acceptable current is 38 amperes at 70 to 80°F (21.1 to 26.7°C).

3-11.7. Installation.

- a. If removed, install jumper wire (18, FIGURE 3-5) and nuts (19).
- b. If removed, position mounting brackets (15 and 17) on timing gear cover mounting holes; secure with two capscrews (12), washers (13), spacers (16), and nuts (14).
- c. If removed, position adjusting strap (11) on water pump mounting hole; secure with capscrew (9) and new lockwasher (10).
- d. Position battery charging alternator (5) and bracket (4) between mounting brackets (15 and 17) and secure with capscrew (6), new lockwasher (7), and nut (8). Do not tighten.
- e. Secure battery charging alternator (5) and bracket (4) to adjusting strap (11) with capscrew (1), new lockwasher (2), and washer (3). Do not tighten.
- f. Install fan belts on battery charging alternator pulley, refer to end item maintenance manual.
- g. Connect electrical leads to alternator as tagged during removal.

3-12. STARTER.

**WARNING**

**Exercise care when bench testing starter. Ensure metal objects do not contact connection points as severe arcing will occur. Failure to observe this warning could result in personal injury.**

3-12.1. Bench Test.

- a. Remove starter, refer to paragraph 3-12.2.

- b. Turn overrunning clutch drive clockwise by hand. Pinion should turn freely.
- c. Turn pinion counterclockwise. A definite resistance should be felt. If clutch assembly is defective disassemble the starter clutch.
- d. If armature turns freely and the clutch is not defective, test starter under no-load conditions.

**CAUTION**

**Never operate starter longer than 30 seconds. Allow at least two minutes for cooling and battery recovery before operating again. Overheating, caused by excessive operation, will seriously damage starter.**

**NOTE**

**Do not conduct the no-load test unless the armature turns freely.**

- e. Connect a 24 VDC source (A) to starter battery terminal (B) and starter frame (C) as shown. Use heavy duty cables, refer to FIGURE 3-14.
- f. Connect a remote start switch (D) between switch terminal (E) and battery terminal (B).
- g. When switch is activated, starter should engage and run.
- h. If solenoid only chatters, hold-in winding is open-circuited. If nothing happens, either pul-in winding is open-circuited or mechanical parts are sticking. To check for sticking, remove solenoid end cover and push plunger by hand.

**NOTE**

**The solenoid cannot be repaired.**

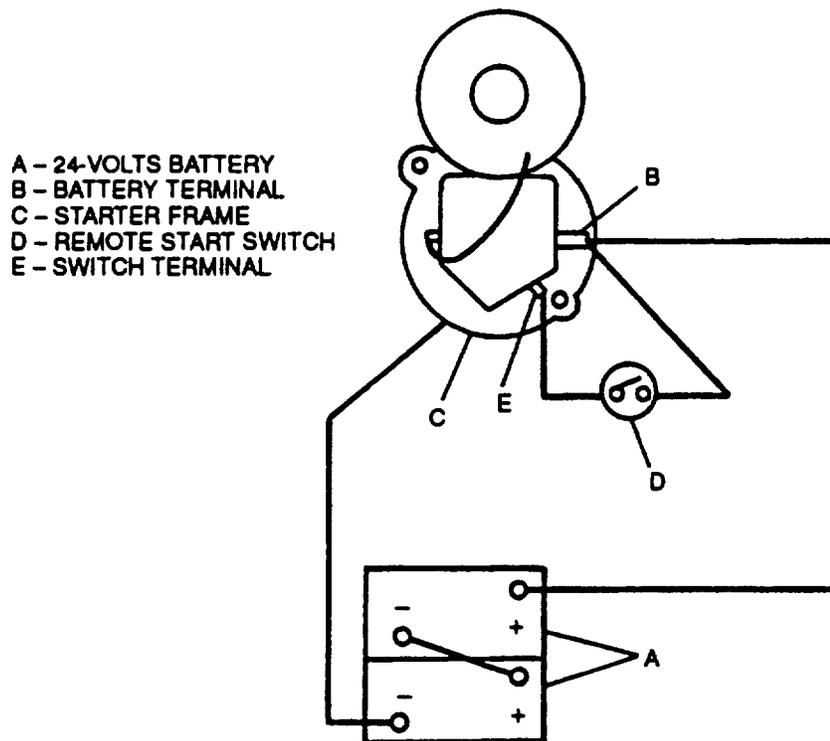
- i. If solenoid engages properly, but starter does not run, check main contact points, bearings, brushes, reduction gears, armature, and field windings.

**WARNING**

**Prior to removing starter, ensure negative battery lead is disconnected from battery to prevent serious injury or death.**

3-12.2. Removal.

- a. Ensure negative battery lead is disconnected from battery.
- b. Remove coolant overflow bottle and mounting plate, refer to end item maintenance manual.
- c. Tag and disconnect electrical leads from starter.

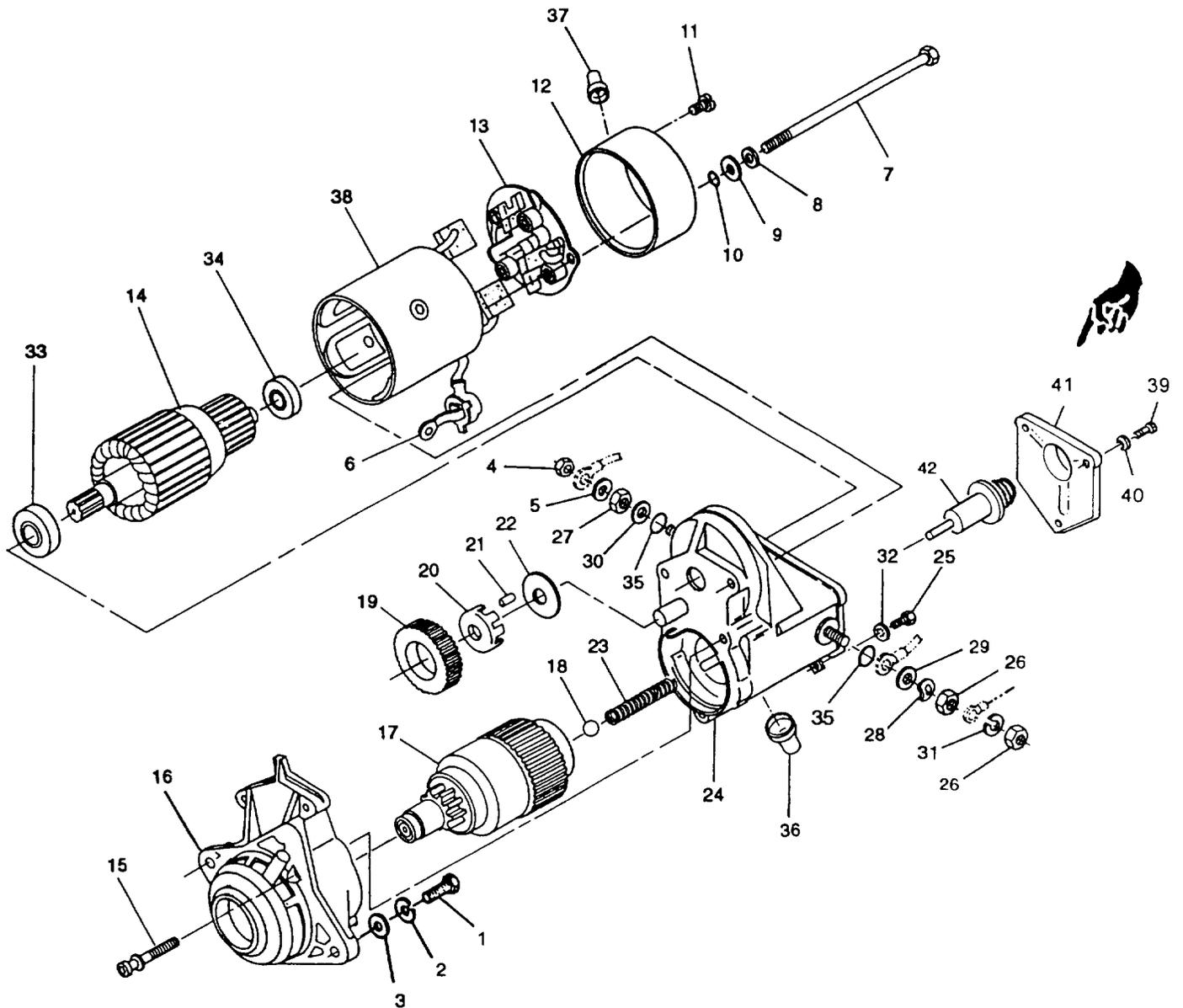


**FIGURE 3-14. Starter Bench Test Setup**

- d. Support weight of starter and remove two screws (1, FIGURE 3-15), lockwashers (2), and washers (3) securing starter to flywheel housing. Remove starter and discard lockwashers (2).
- e. Cover opening in flywheel housing.
- f. Bench test starter, refer to paragraph 3-12.1.

3-12.3. Disassembly.

- a. Remove nut (4, FIGURE 3-15) and washer (5).
- b. Disconnect yoke assembly lead wire (6) at magnetic switch assembly (24).
- c. Remove two through bolts (7), lockwashers (8), washers (9), and preformed packings (10). Discard lockwashers (8) and preformed packings (10).
- d. Remove two screws (11) and starter end frame (12). Remove yoke assembly (38).
- e. Lift brush springs and remove brushes from brush holder (13). Remove brush holder assembly (13), refer to FIGURE 3-16.
- f. Remove armature (14, FIGURE 3-15) from magnetic switch assembly (24).
- g. Remove three screws (15) from housing (16). Remove housing (16) from magnetic switch assembly (24).



**FIGURE 3-15. Starter Assembly**

- h. Remove overrunning clutch (17) from magnetic switch assembly (24).
- i. Remove steel ball (18) from overrunning clutch (17).
- j. Remove starter pinion (19), retainer (20), and five rollers (21) from housing (16).
- k. Remove washer (22) and spring (23) from magnetic switch assembly (24).
- l. If necessary, remove screw (25), nuts (26 and 27), washers (28 thru 30), and lockwashers (31 and 32) from terminal studs on magnetic switch assembly (24).
- m. Remove screws (39), washers (40), end plate (41), and contact (42) from magnetic switch assembly (24).

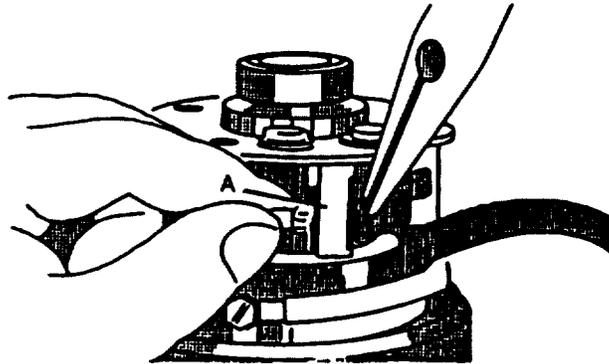


FIGURE 3-16. Removing Brush Holder Assembly

3-12.4. Inspect and Measure/Repair.

- a. Check armature commutator run-out as follows:
  - (1) Place armature bearings on V-blocks.
  - (2) Zero dial indicator on commutator.
  - (3) Rotate armature and record run-out. Standard is 0.0008 inch (0.02 mm), with a limit of 0.00197 inch (0.5 mm).
  - (4) If run-out exceeds limit, replace armature.
- b. Using a micrometer, measure OD of commutator. If measurement is less than 1.38 inches (35 mm), replace armature.
- c. Measure commutator segment mica depth as shown in FIGURE 3-17. If depth is less than 0.0079 inch (0.2 mm), undercut the mica.
- d. Check commutator surface for bum spots. This usually indicates an open circuit. Remove these spots using #400 abrasive paper.
- e. Inspect bearings (33 and 34, FIGURE 3-15) for wear and damage. If damaged or worn, replace bearings using a press.

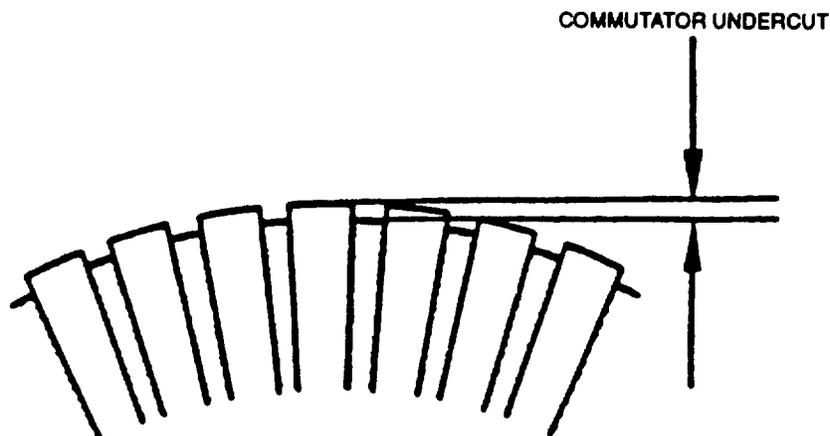


FIGURE 3-17. Measuring Segment Mica Depth

- f. Check field windings of yoke for wear or damage. Check all connections for clean and tight solder joints.
- g. Measure brush length. If less than 0.51 inch (13 mm), replace brush holder and/or yoke assembly.
- h. Check brush springs for damage or corrosion. If damaged or corroded, replace brush holder.
- i. Check that overrunning clutch rotates freely in direction of starter rotation and that it will be locked when trying to rotate in opposite direction.

3-12.5. Test.

3-12.5.1 Testing Starter Motor (Installed).

- a. Make sure batteries are fully charged and that all battery and starter cables are serviceable and properly installed.
- b. Set multimeter for DC volts, and connect as shown in FIGURE 3-18, Test A. If voltage is indicated solenoid is defective.

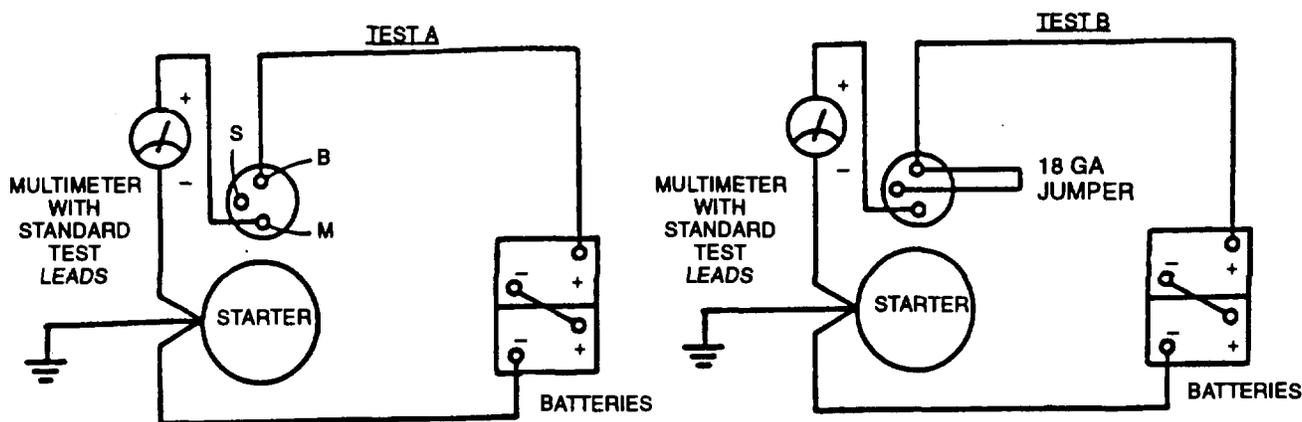
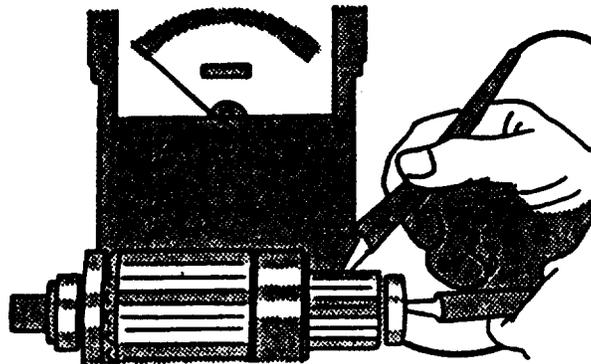


FIGURE 3-18. Starter Solenoid Test Circuit

- c. Momentarily connect a jumper as shown in FIGURE 3-18, Test B. Multimeter should indicate battery voltage and starter should crank the engine. If multimeter does not read battery voltage, the solenoid is defective. If multimeter indicates battery voltage, but starter does not operate, starter is defective.

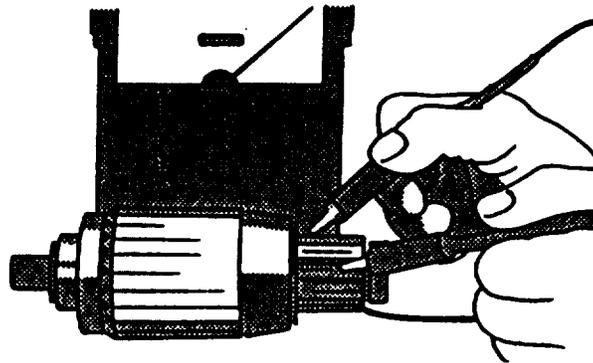
3-12.5.2 Testing Starter Components (Removed).

- a. Using a growler tester, place armature on it and hold a hack saw blade against armature core while slowly rotating armature. A short circuited armature causes blade to vibrate and be attracted to core. An armature which is short circuited must be replaced.
- b. Set multimeter for ohms and touch one probe to a commutator segment and other one to armature core, refer to FIGURE 3-19. There should be no continuity. If there is continuity, armature is grounded. Replace armature if grounded.



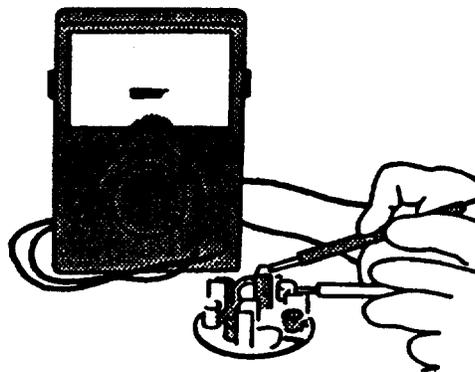
**FIGURE 3-19. Testing for Grounded Windings**

- c. Set multimeter for ohms and touch probes to two segments, refer to FIGURE 3-20. There should be continuity at any point. If there is no continuity, winding is open circuited. Replace the armature if open circuited.



**FIGURE 3-20. Checking for Open Circuit Windings**

- d. Set multimeter for ohms and touch one probe to positive brush holder plate and other one to the holder plate, refer to FIGURE 3-21. There should be no continuity. If there is continuity, replace brush holder.



**FIGURE 3-21. Checking Brush Holder**

- e. Using a multimeter, touch one probe to field winding end of brush and other one to bare surface of yoke body, refer to FIGURE 3-22. There should be no continuity. If there is continuity, field windings are grounded. Replace the yoke assembly.

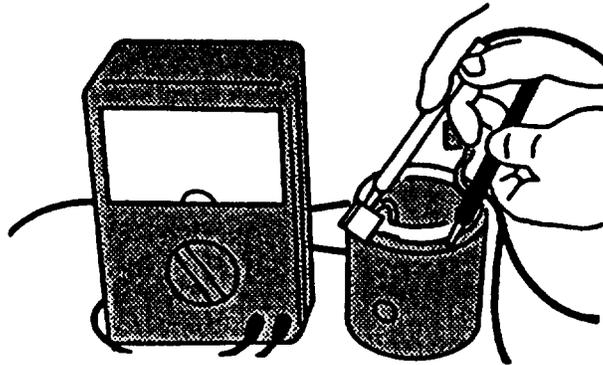


FIGURE 3-22. Checking Field Coils

- f. Using a multimeter, touch one probe to lead wire and other one to brush, refer to FIGURE 3-23. There should be continuity. If there is no continuity, field windings are open circuited. Replace the yoke assembly.

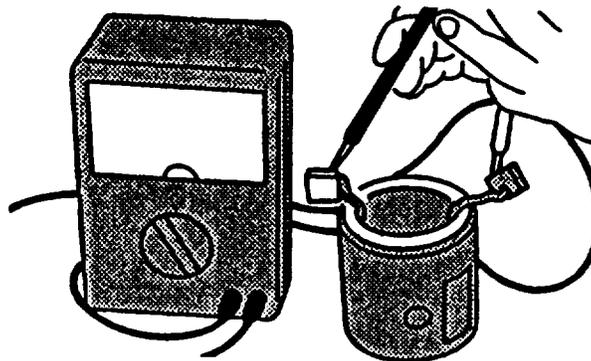


FIGURE 3-23. Checking for Open Field Coil

#### 3-12.6. Assembly.

- a. Install contact (42, FIGURE 3-15), end plate (41), washers (40), and screws (39) in magnetic switch assembly (24).
- b. If removed, install nuts (26 and 27), washers (28 thru 30), lockwashers (31 and 32), and screw (25)
- c. Apply general purpose grease (630AA) to retainer (20), rollers (21), overrunning clutch (17), steel ball (18), spring (23), and bearings (33 and 34).
- d. Install washer (22) and spring (23) in magnetic switch assembly (24).

- e. Install five rollers (21), retainer (20), and starter pinion (19) in housing (16).
- f. Place steel ball (18) in overrunning clutch (17) and install both in housing (16).
- g. Position assembled housing (16) on magnetic switch assembly and secure with three screws (15). Tighten screws 5.1 to 8.7 ft-lbs (6.9 to 11.8 Nm).
- h. Install armature (14) in magnetic switch assembly (24).
- i. Position brush holder (13). Lift springs and install brushes, refer to FIGURE 3-16. Ensure negative brushes (connected to brush holder) are installed in negative holes (not insulated) and positive brushes (connected to yoke) are installed in positive holes (separated from plate with insulator). Ensure positive brush leads are not grounded.
- j. Position cover (12, FIGURE 3-15) on yoke (38) engaging tab on cover with lead wire grommet. Secure with two screws (11). Tighten screws 1.95 to 3.40 ft-lbs (2.6 to 4.6 Nm).
- k. Position yoke assembly (38) on magnetic switch assembly (24) engaging tab on yoke assembly with notch in magnetic switch. Secure with two through bolts (7), new lockwashers (8), washers (9), and new preformed packings (10). Tighten through bolts 5.1 to 8.7 ft-lbs (6.9 to 11.8 Nm).
- l. Connect yoke assembly lead wire (6) to terminal on magnetic switch assembly with washer(s) and nut (4). Tighten nut to 18.1 to 26.0 ft-lbs (24.5 to 35.3 Nm). Ensure rubber boot (36) is installed securely.

3-12.7. Installation.

**NOTE**

**To aid in installing starter and spacer, place a 3/8 inch x 3 inches (9.52 mm x 7.62 cm) guide stud in one of the starter mounting holes in flywheel housing.**

- a. Remove cover in flywheel housing.
- b. Place starter on flywheel housing and secure with two screws (1, FIGURE 3-15), new lockwashers (2), and washers (3). Tighten screws 30 to 35 ft-lbs (41 to 47 Nm).
- c. Connect electrical leads to starter as tagged during removal.
- d. Install coolant overflow bottle and mounting plate, refer to end item maintenance manual.
- e. Connect negative battery lead to battery.

**Section VI. INTAKE AND EXHAUST SYSTEM MAINTENANCE**

**3-13. TURBOCHARGER.**

3-13.1. Removal.

**Warning**

**After operating engine, allow exhaust system to cool before removal. Failure to observe this warning could result in personal injury.**

**CAUTION**

**When cleaning turbocharger, do not spray directly into compressor cover or turbine housing. If turbocharger inspection is required, do not clean exterior prior to removal. Doing so may wash away evidence of a potential failure mode.**

- a. Thoroughly clean exterior of turbocharger and surrounding area to prevent entry of dirt into air intake system during removal.
- b. Remove air intake line and exhaust line from turbocharger (11, FIGURE 3-24), refer to end item maintenance manual.
- c. Loosen clamps securing air intake manifold hose to turbocharger, refer to paragraph 3-15.
- d. Disconnect oil inlet line (1) from fitting (2) on top of turbocharger (11).

**NOTE**

**If it is necessary to remove oil lines, drain lubrication system, refer to end item maintenance manual.**

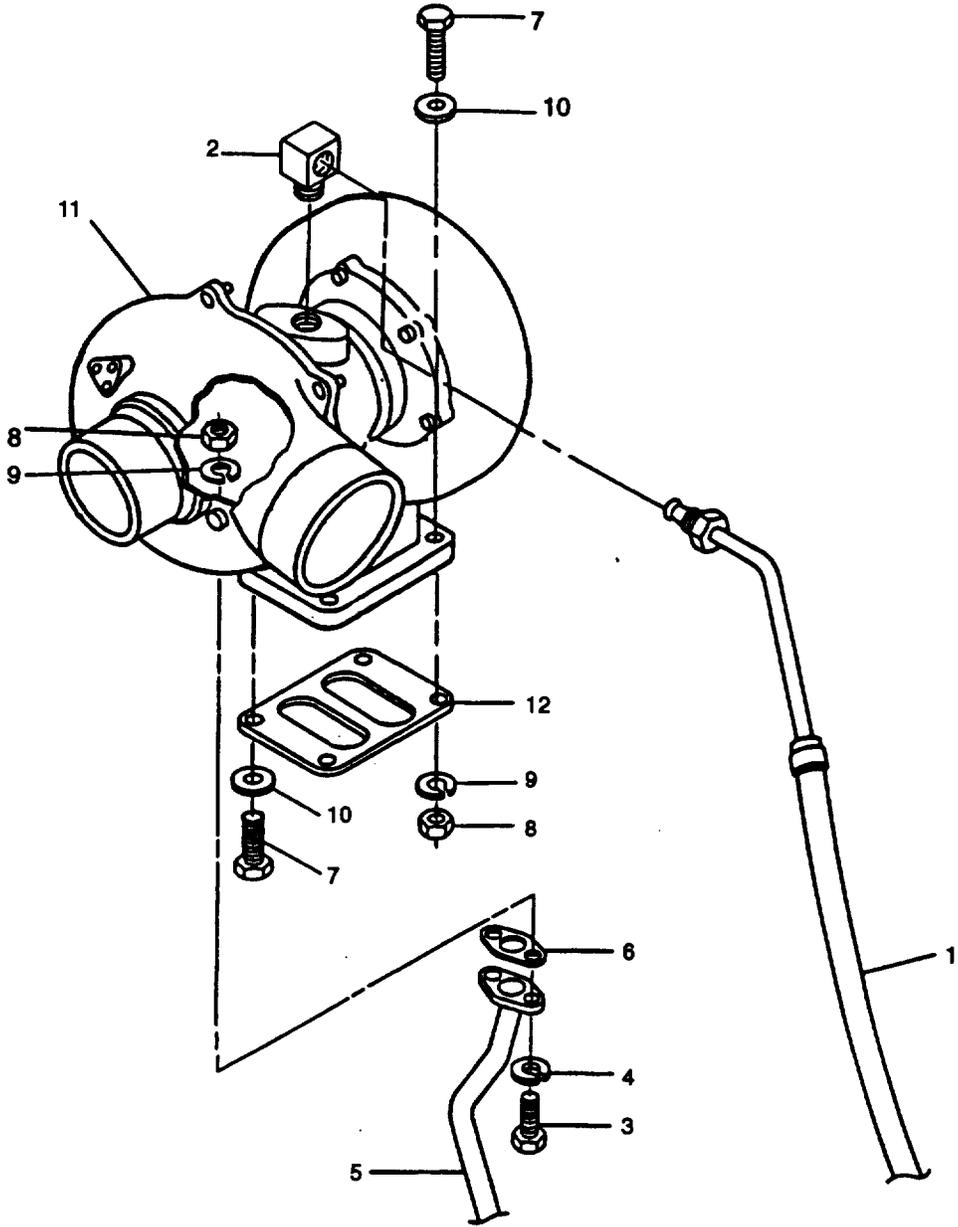


FIGURE 3-24. Turbocharger

- e. Remove two capscrews (3) and lockwashers (4), securing oil drain line (5) to turbocharger. Disconnect line (5) from turbocharger and remove gasket (6); discard lockwashers (4) and gasket (6).
- f. Remove four capscrews (7), nuts (8), lockwashers (9), and flatwashers (10), securing turbocharger (11) to exhaust manifold. Remove turbocharger and stainless steel gasket (12); discard lockwashers (9) and gasket (12).
- g. Cover all openings.

### 3-13.2. Inspection.

#### 3-13.2.1 General.

The following inspection procedure is recommended for systematic failure analysis of a suspected turbocharger failure. This procedure will help to identify when a turbocharger has failed, and why it has failed so primary cause of failure can be corrected. Proper diagnosis of a "non-failed" turbocharger is important for two reasons. First, identification of a "non-failed" turbocharger will lead to further investigation and repair of the cause of a performance complaint. Second, proper diagnosis eliminates unnecessary expense incurred when a "non-failed" turbocharger is replaced. Seven recommended inspection steps, (refer to FIGURE 3-25) which are explained in detail in following paragraphs, are:

- a. Compressor Housing Inlet and Compressor wheel.
- b. Compressor Housing Outlet.
- c. Turbine Housing Inlet.
- d. Turbine Housing Outlet and Turbine wheel.
- e. External Center Housing and Joints.
- f. Internal Center Housing.
- g. Turbo Bench Test.

#### **NOTE**

**To enhance turbocharger inspection, an inspection chart (TABLE 3-3) can be used that lists inspection steps in the proper order and shows potential failure modes for each step. Check off each step as you complete inspection and note any problems.**

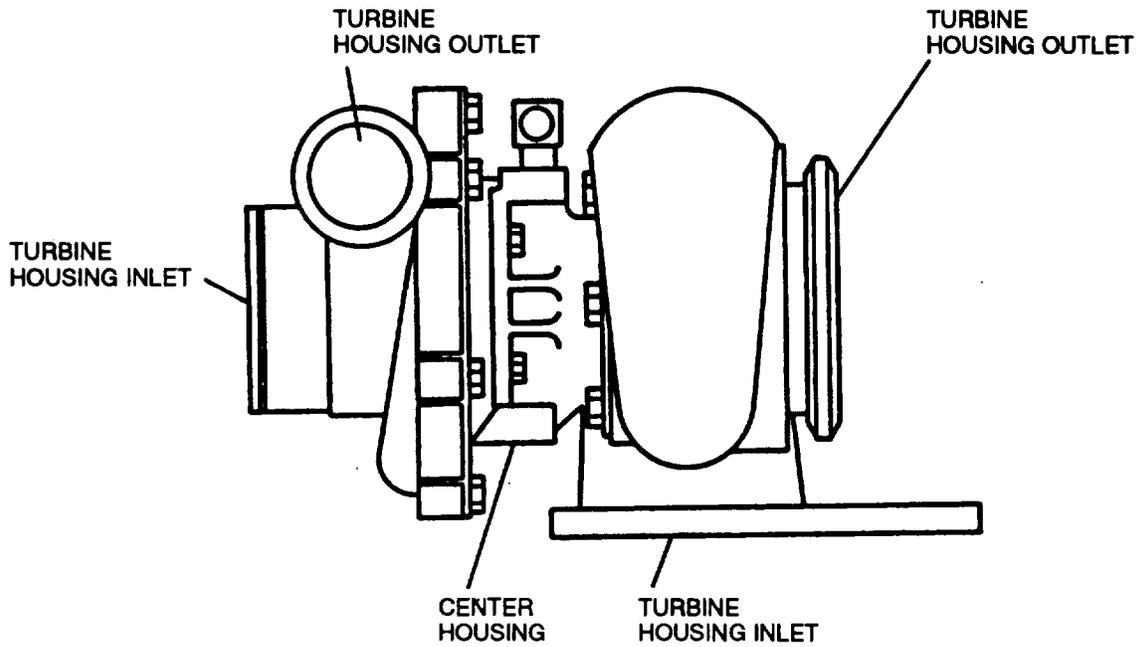


FIGURE 3-25. Turbocharger Inspection Points

3-13.2.2 Compressor Housing Inlet and Compressor Wheel.

- a. Check compressor inlet and compressor wheel for foreign object damage.

**NOTE**

Foreign object damage may be extensive or minor. In either case, the source of the foreign object must be found and corrected to eliminate further damages.

TABLE 3-3. Turbocharger Inspection Chart

CUSTOMER NAME _____	
VEHICLE MODEL _____	VEHICLE SERIAL NO. _____
ENGINE MODEL _____	ENGINE SERIAL NO. _____
TURBO PART NO. _____	TURBO SERIAL NO. _____
DESCRIPTION OF PROBLEM _____	

INSPECTION STEPS	FAILURE MODES	CHECK APPROPRIATE BOXES
1	COMPRESSOR HOUSING INLET AND COMPRESSOR WHEEL	Foreign Object Damage ..... <input type="checkbox"/> Compressor Wheel Rub ..... <input type="checkbox"/> No Defects ..... <input type="checkbox"/>
2	COMPRESSOR HOUSING OUTLET	Oil and/or Dirt in Housing ..... <input type="checkbox"/> No Defects ..... <input type="checkbox"/>
3	TURBINE HOUSING INLET	Oil in Housing ..... <input type="checkbox"/> Center Wall Eroded ..... <input type="checkbox"/> No Defects ..... <input type="checkbox"/>
4	TURBINE HOUSING OUTLET AND TURBINE WHEEL	Foreign Object Damage ..... <input type="checkbox"/> Turbine Wheel Rub ..... <input type="checkbox"/> Oil and/or Excess Carbon ..... <input type="checkbox"/> No Defects ..... <input type="checkbox"/>
5	EXTERNAL CENTER HOUSING AND CONNECTIONS INTERNAL	Leaks from Casting ..... <input type="checkbox"/> Leaks at Connection ..... <input type="checkbox"/> No Defects ..... <input type="checkbox"/>
6	INTERNAL CENTER HOUSING	Excessive Carbon Build-Up in Housing or on Shaft ..... <input type="checkbox"/> Excessively Discolored Shaft ..... <input type="checkbox"/> No Defects ..... <input type="checkbox"/>
7	TURBO BENCH TEST	Restricted Shaft Rotation ..... <input type="checkbox"/> Excessive Shaft Radial Play ..... <input type="checkbox"/> Excessive Shaft Endplay ..... <input type="checkbox"/> No Defects ..... <input type="checkbox"/>

NOTES \_\_\_\_\_

- b. Mark findings on checklist and continue inspection.

**NOTE**

**You will need a good light source for this check.**

- c. Check compressor inlet for wheel rub on housing. Look very closely for any score marks on the housing itself and check tips of the compressor wheel blades for damage.

3-13.2.3 Compressor Housing Outlet.

- a. Check compressor housing outlet. Outlet should be clean and free of dirt or oil.
- b. Mark it on checklist if dirt or oil is found and continue inspection.

3-13.2.4 Turbine Housing Inlet.

- a. Check turbine housing inlet ports for oil in housing, excessive carbon deposit, or erosion of center walls.

**NOTE**

**If inlet is wet with oil, or has excessive carbon deposits, an engine problem is likely. Center wall erosion (cracking or missing pieces), indicates excessive exhaust temperature.**

- b. Record defects on checklist and continue inspection.

3-13.2.5 Turbine Housing Outlet and Turbine Wheel.

- a. Use a flashlight to look up inside turbine housing outlet and check blades for foreign object damage.
- b. Note any damage on checklist because inspection of the engine will be required.
- c. Inspect wheel blades and housing for evidence of wheel rub. wheel rub can bend the tips of the blades with housing showing wear or damage.
- d. Note any excessive oil or carbon build-up on checklist.

3-13.2.6 External Center Housing and Joints.

Visually check outside of center housing, all connections to compressor, and turbine housing for oil.

**NOTE**

**If oil is present, make sure it is not coming from a leak at the oil supply or return line.**

3-13.2.7 Internal Center Housing.

- a. Using a flashlight, look through oil return hole to check condition of shaft and/or bearings. There should not be excess carbon deposits on shaft or in housing.
- b. Excessive "blueing" or "coking" of oil along the complete length of shaft indicates a possible lack of lubrication caused by an engine failure, or improper operation, such as hot shutdowns.

3-13.2.8 Turbo Bench Test.

- a. Mount turbocharger in a vise.
- b. Rotate shaft, using both hands, to check rotation and clearance. Shaft should turn freely, however, there may be a slight amount of drag.
- c. Next, pull up on the compressor end of shaft and press down on the turbine end while rotating shaft. Neither compressor wheel nor turbine wheel should contact housing at any point.

**NOTE**

**There will be some play because bearings inside center housing are free floating.**

- d. Next, check shaft end-play by moving shaft back and forth while rotating. There will be some end-play but not to extent that wheels contact housings.

3-13.3. Test

3-13.3.1 Radial Bearing Clearance Test.

**NOTE**

**This test will give an indication of condition of radial bearings within center housing and rotating assembly.**

- a. Fasten a plunger-type dial indicator to turbocharger mounting base. Assemble an extension adapter and a 2.0 inch (51 mm) indicator extension rod onto dial indicator.
- b. Position indicator tip (through center housing oil return) on center of shaft. Preload indicator tip and zero dial on indicator.
- c. Grasp rotating shaft at both ends and move shaft toward indicator then away from indicator. Use care to move shaft in same direction as dial indicator tip travels and apply equal pressure at both ends of shaft.
- d. Observe and record total indicator reading. Bearing clearance specification is 0.003 to 0.006 inch (0.08 to 0.15 mm) e. If total indicator reading is not within specification, replace turbocharger.

3-13.3.2 Axial End Play Bearing Test.

**NOTE**

**This test will give an indication of condition of thrust bearing within center housing and rotating assembly.**

- a. Mount base dial indicator so that indicator tip rests on end of shaft. Preload indicator tip and zero dial on indicator.
- b. Move shaft axially back and forth by hand.
- c. Observe and record total dial indicator reading. Bearing end play specification is 0.001 to 0.004 inch (0.025 to 0.10 mm).
- d. If bearing end play is not within specification, replace turbocharger.

3-13.4. Installation.

**CAUTION**

**If turbocharger failed because of foreign material entering the air intake system, be sure to examine the system and clean as required to prevent a repeat failure.**

**CAUTION**

**Inspect the rubber hose at the end of the turbo oil return line for damage or cracks. Replace as necessary. Since the greatest amount of suction occurs between the air cleaner and turbocharger, it is essential that the hose connections are tight to prevent entry of dirt into the engine.**

- a. Prime turbocharger lubrication system prior to mounting turbocharger on engine. Fill center housing with new engine lubricating oil (MIL-L-2104) through oil drain hole. Turn rotating assembly by hand to lubricate bearings.
- b. Inspect air cleaner-to-turbocharger hose to see that it is in good condition. Replace hose if it is hard, cracked, or shows any signs of deterioration.
- c. Remove all covers.
- d. Position new stainless steel gasket (12, FIGURE 3-24) and turbocharger (11) on exhaust manifold and secure with four capscrews (7), flatwashers (10), nuts (8) and new lockwashers (9). Tighten capscrews to 35 ft-lbs (47 Nm).
- e. Position new gasket (6) and oil drain line (5) on turbocharger and secure with two capscrews (3) and new lockwashers (4). Tighten screws to 20 ft-lbs (27 Nm).
- f. Connect oil inlet line (1) to fitting (2) on top of turbocharger.
- g. Connect air intake manifold hose to turbocharger using clamps.
- h. Connect air intake line and exhaust line to turbocharger, refer to end item maintenance manual.
- i. Service engine lubrication system, refer to end item maintenance manual.
- j. Before starting engine after installing turbocharger, perform the following:

**NOTE**

**A new or rebuilt turbocharger does not have an adequate oil supply.**

- (1) Place throttle system so engine cannot start.
- (2) Crank engine using starter until oil reaches turbocharger.

**3-14. EXHAUST MANIFOLD.**

3-14.1. Removal.

- a. Remove turbocharger, refer to paragraph 3-13.1.

**NOTE**

**Note location of different size capscrews for use during installation.**

- b. Remove eight capscrews (1, 3, 4, and 5, FIGURE 3-26) and washers (2), securing exhaust manifold (6) to engine. Remove manifold and four gaskets (7); discard gaskets.
- c. Remove all residue and gasket material from gasket surfaces.
- d. Thoroughly clean passages in exhaust manifold.
- e. Cover all openings.

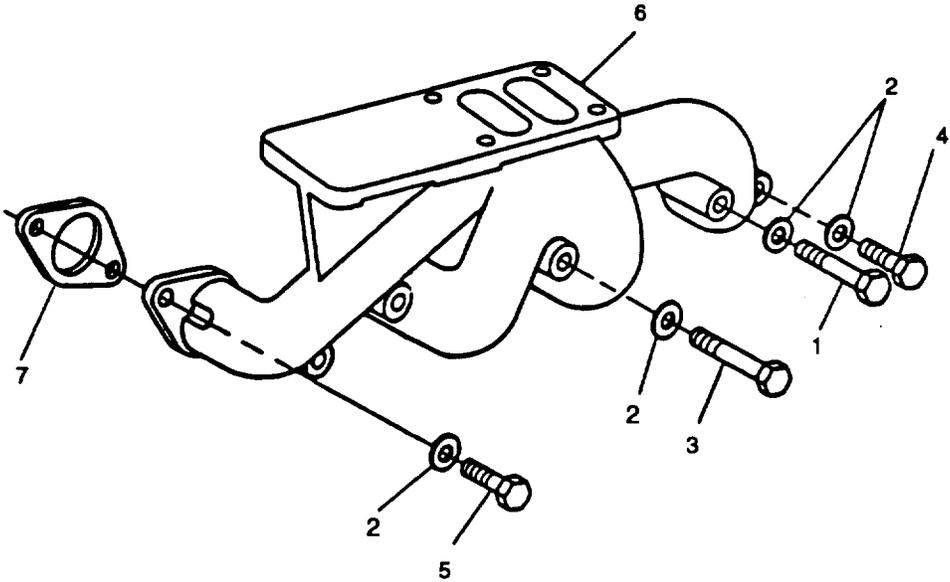
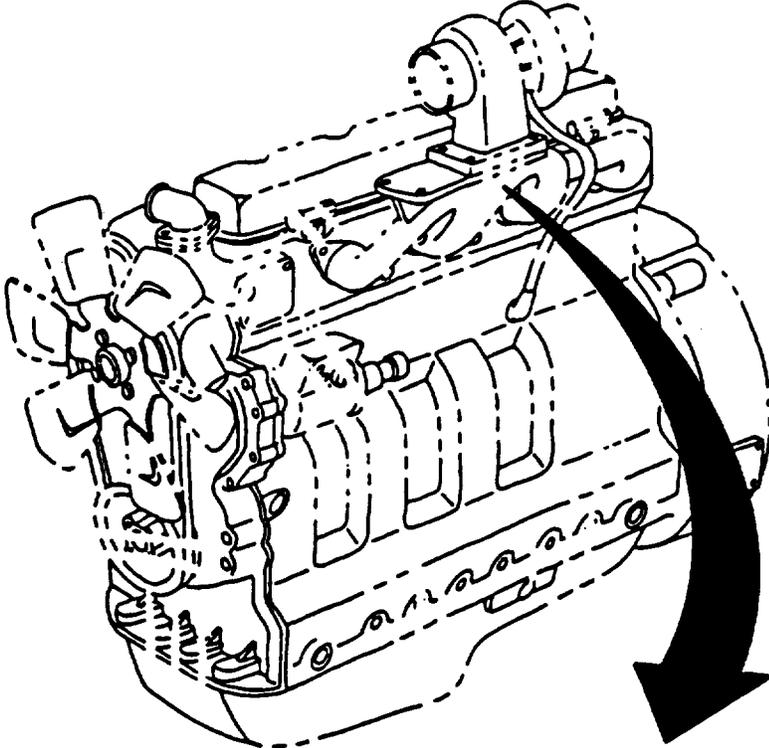


FIGURE 3-26. Exhaust Manifold

3-14.2. Inspection.

Inspect exhaust manifold for cracks or damage. Inspect machined mounting surfaces for burrs or other defects which might prevent gaskets from sealing properly. Replace as necessary.

3-14.3. Installation.

- a. Remove all covers.

**NOTE**

**When using gaskets with one steel-backed side, the non steel-backed side must face towards the cylinder head.**

- b. Using four new gaskets (7, FIGURE 3-26) position exhaust manifold (6) on cylinder head. Coat all eight capscrews (1, 3, 4, and 5) with antiseize compound (CP-8) and install with washers (2) in locations as noted during removal. Tighten capscrews to 35 ft-lbs (47 Nm).
- c. Install turbocharger, refer to paragraph 3-13.4.

**3-15. INTAKE MANIFOLD.**

3-15.1. Removal.

- a. Loosen two clamps (1, FIGURE 3-27) securing hose (2) to turbocharger and air inlet elbow (5). Remove clamps and hose.
- b. Disconnect cold weather starting aid.
- c. Remove two capscrews (3) and lockwashers (4) securing air inlet elbow (5) to cylinder head. Remove elbow and gasket (6); discard lockwashers (4) and gasket (6).
- d. Cover all openings.

3-15.2. Inspection.

- a. Intake manifold hose and capscrew connections should be inspected periodically for tightness and kept tight.
- b. Inspect intake manifold for serviceability. Replace, if it is cracked or otherwise damaged.

**WARNING**

**Compressed air used for cleaning can create airborne particles that may enter the eyes. Pressure will not exceed 30 psig (207 kPa). Eye protection required.**

- c. Inspect machined mating surfaces of cylinder head and intake manifold. Clean as required, using a scraper and/or wire brush and compressed air.

3-15.3. Installation.

- a. Remove all covers.
- b. Position new gasket (6, FIGURE 3-27) and air intake elbow (5) on cylinder head and secure with two capscrews (3) and new lockwashers (4). Tighten capscrews to 35 ft-lbs (47 Nm).
- c. Ensure hose (2) is in good condition and install it between turbocharger and air intake elbow (5) and secure with two clamps (1).

**CAUTION**

**All Intake manifold connections at the turbocharger and engine cylinder head must be tight to prevent loss of power resulting from lower manifold pressure.**

- d. Connect cold weather starting aid.

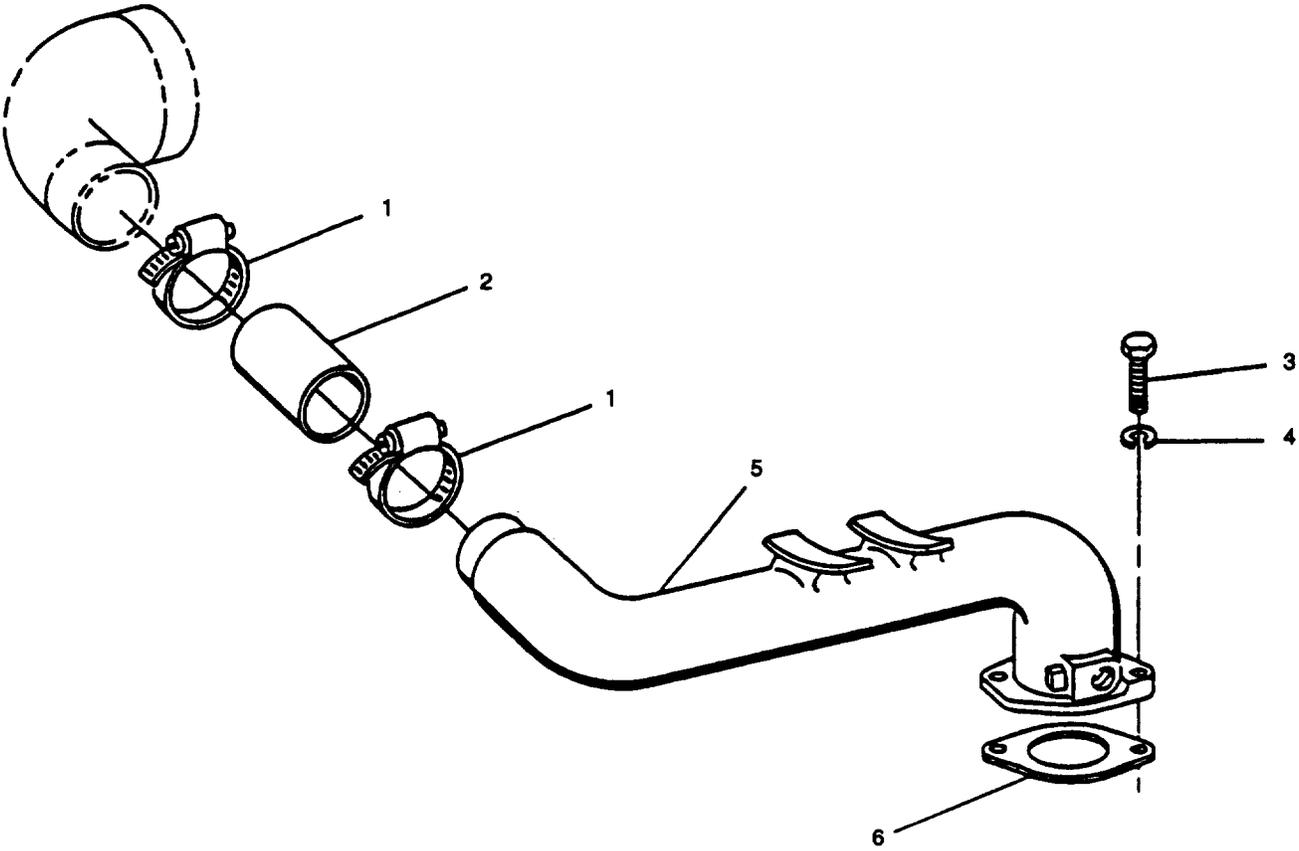


FIGURE 3-27. Intake Manifold

## Section VII. LUBRICATION SYSTEM MAINTENANCE

### 3-16. OIL FILTER AND COOLER.

#### 3-16.1. Removal.

#### WARNING

If the engine has been operating and coolant is hot, allow engine to cool before you slowly loosen filler cap and relieve pressure from cooling system. Failure to observe this warning could result in severe personal injury.

- a. Drain engine lubrication system and coolant system, refer to end item maintenance manual.
- b. Using a strap filter wrench, remove filter element (1, FIGURE 3-28) from oil cooler.

#### NOTE

**Drain coolant into suitable container.**

- c. Remove plug (2) from oil cooler to drain coolant.
- d. Loosen four clamps (3 and 4), securing hoses (5 and 6) and tubes (7 and 8). Remove hoses (5 and 6) and clamps (3 and 4).
- e. Remove nipple (9) securing oil cooler (10) to engine block. Remove oil cooler (10) and preformed packing (11). Discard preformed packing (11).
- f. Remove four clamps (13) and two hoses (14).
- g. Remove screw (15), flatwasher (16), and clamp (17) securing tubes (7 and 8); remove tubes.

Change 3 3-55

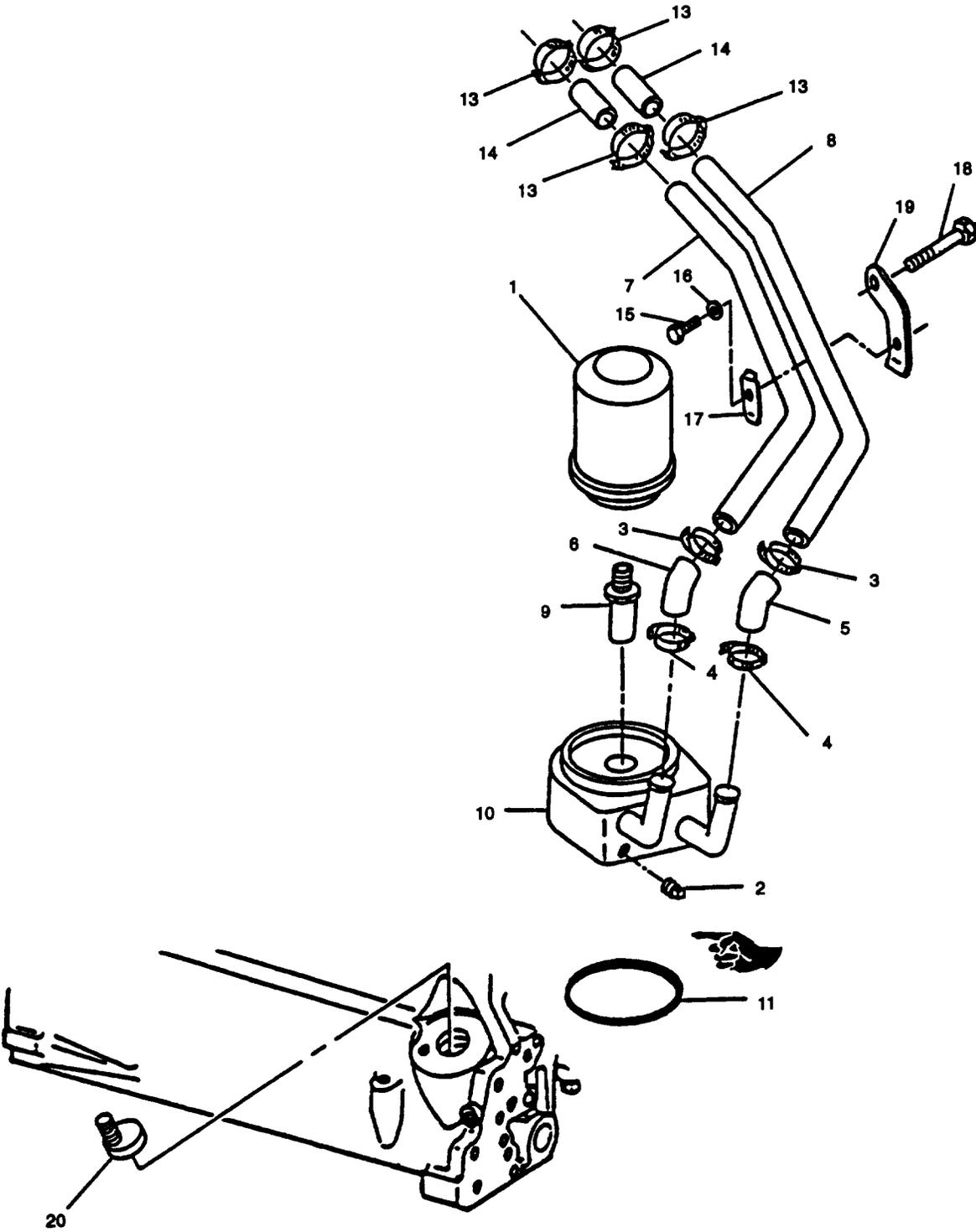
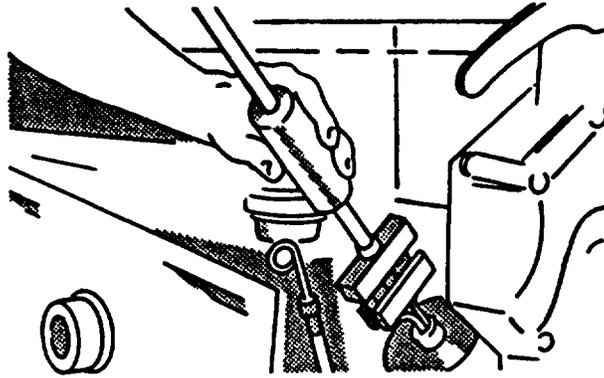


FIGURE 3-28. Oil Filter and Cooler

- i. If defective, remove screw (18) securing strap (19) to engine; remove strap.
- j. Remove oil filter nipple (20) from cylinder block with a suitable pilot bearing puller, refer to FIGURE 3-29.
- k. Cover all openings.



**FIGURE 3-29. Removing Oil Filter Nipple**

3-16.2. Inspection.

- a. Inspect hoses for cracks, brittleness, or any other defects. Replace as necessary.
- b. Inspect relief valve for damage. Replace as necessary.

**WARNING**

**Compressed air used for cleaning can create airborne particles that may enter the eyes. Pressure will not exceed 30 psig (207 kPa). Eye protection required.**

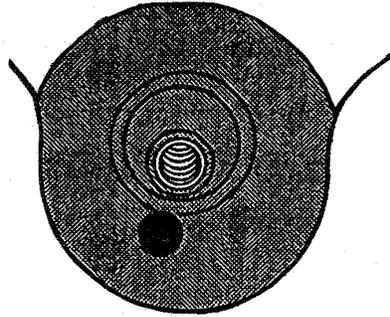
- c. Inspect coolant passage through cooler for a restriction caused by scale or sludge. Use compressed air and blow through passage to make sure it is open. If engine lubricating oil was contaminated with metallic particles, discard oil cooler.

3-16.3. Installation.

**NOTE**

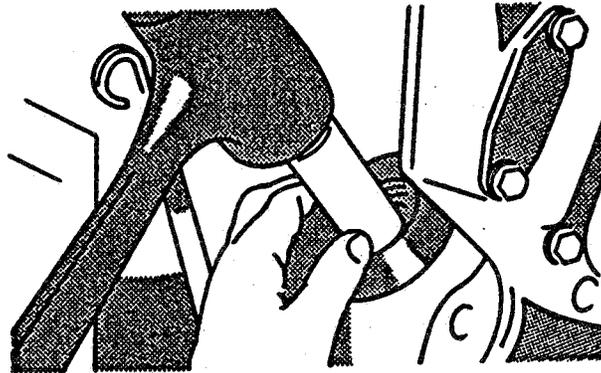
**Remove all covers.**

- a. Install oil filter nipple (20, FIGURE 3-28) in engine block as follows: (1) Put oil filter nipple over its bore in cylinder block. Turn oil filter nipple so oil hole is as low as possible, refer to FIGURE 3-30.



**FIGURE 3-30. Installing Oil Filter Nipple**

- (2) Using a tubular driver, push oil filter nipple into cylinder block until it is flush with cylinder block, refer to FIGURE 3-31.



**FIGURE 3-31. Driving Oil Filter Nipple**

- b. Position new preformed packing (11, FIGURE 3-28) and oil cooler on engine block and secure with nipple (9). Tighten nipple to 27 ft-lbs (37 Nm).
- c. Install two hoses (5 and 6) and two clamps (4) on oil cooler. Do not tighten clamps.
- d. Install two hoses (14) and two clamps (13) on water pump. Tighten clamps.
- e. Connect tube (7) to hoses (6 and 14) using two clamps (3 and 13).
- f. Connect tube (8) to hoses (5 and 14) using two clamps (3 and 13). Tighten all clamps.
- g. Secure strap (19) to engine using existing screw (18).
- h. Secure tubes (7 and 8) to strap (19) using screw (15), flatwasher (16), and clamp (17).
- i. Install plug (2) in oil cooler.

**NOTE**

**Apply a light coating of engine lubricating oil (MIL-L-2104) to gasket surface prior to installing new element.**

- j. Install new filter element (1) on oil cooler.
- k. Service engine lubrication and cooling systems, refer to end item maintenance manual.

**3-17. OIL PRESSURE REGULATING VALVE.**

3-17.1. Removal.

- a. Drain engine lubrication system, refer to end item maintenance manual.

**WARNING**

**Spring (3, FIGURE 3-32) is under pressure and can cause personal injury when plug (1) is removed.**

- b. Remove oil pressure regulating valve plug (1) and washer (2).
- c. Remove oil pressure regulating valve poppet (4) and spring (3).
- d. Pull valve seat out of cylinder block with a suitable pilot bearing puller.

3-17.2. Inspection.

- a. Check valve core for excessive wear and damaged sealing face.
- b. Check spring for cracks or other damage.

3-17.3. Installation.

**CAUTION**

**To prevent damage to valve seat bore, do not drive against raised inner rim of valve seat.**

- a. Drive valve seat into cylinder block with oil pressure relief valve bushing driver (JD248A) and handle (JDG536) until seat bottoms.

**NOTE**

**If engine is being repaired due to low oil pressure, replace spring (3, FIGURE 3-32). If due to high oil pressure, install an additional washer (2).**

- b. Install oil pressure regulating valve poppet (4) and spring (3) in engine block.
- c. Install washer (2) and plug (1). Tighten plug to 70 ft-lbs (95 Nm).

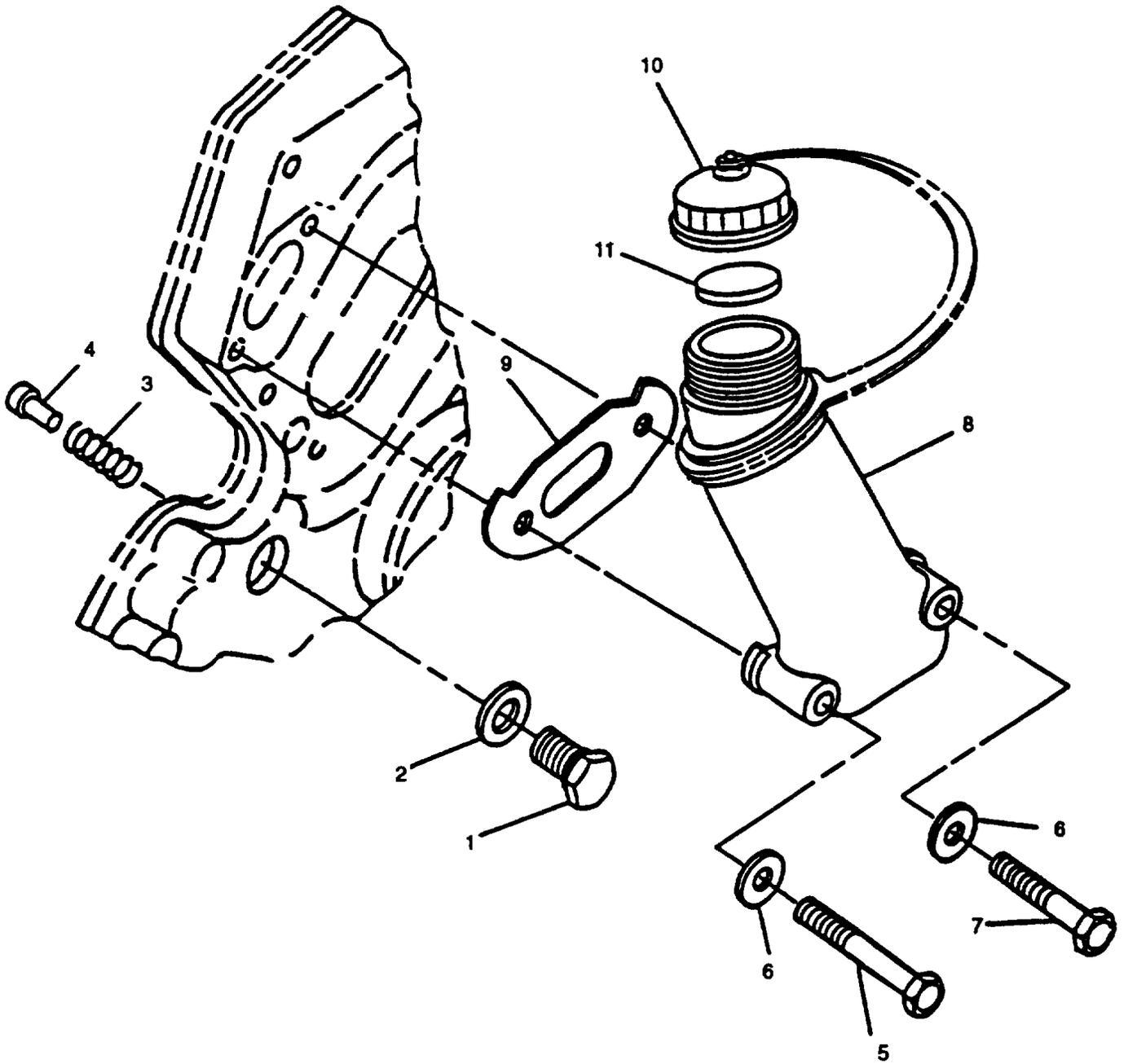


FIGURE 3-32. Oil Pressure Regulating Valve and Oil Filler Assembly

d. Service engine lubrication system, refer to end item maintenance manual.

### **3-18. OIL FILLER ASSEMBLY.**

#### 3-1 8.1. Removal.

- a. Drain engine lubrication system, refer to end item maintenance manual.
- b. Remove two capscrews (5 and 7, FIGURE 3-32) and washers (6) securing filler neck (8) to engine block. Remove filler neck (8) and gasket (9); discard gasket.
- c. Cover all openings.

#### 3-18.2. Inspection.

- a. Inspect filler neck for cracks or other damage.
- b. Inspect filler cap (10, FIGURE 3-32) and gasket (11) for damage. Replace as necessary.

#### 3-1 8.3. Installation.

- a. Remove covers.
- b. Position new gasket (9, FIGURE 332) and filler neck (8) on engine block and secure with two capscrews (5 and 7) and washers (6).
- c. Service engine lubrication system, refer to end item maintenance manual.

### **3-19. Oil DIPSTICK.**

#### 3-19.1. Removal.

- a. Remove dipstick (1, FIGURE 3-33) from tube (3). Remove and discard preformed packing (2).

#### **NOTE**

**Count number of threads exposed above jam nut (4) before loosening. This will aid in proper installation of tube (3).**

- b. Loosen jam nut (4) and unscrew tube (3) from engine block. Remove jam nut (4) from tube.

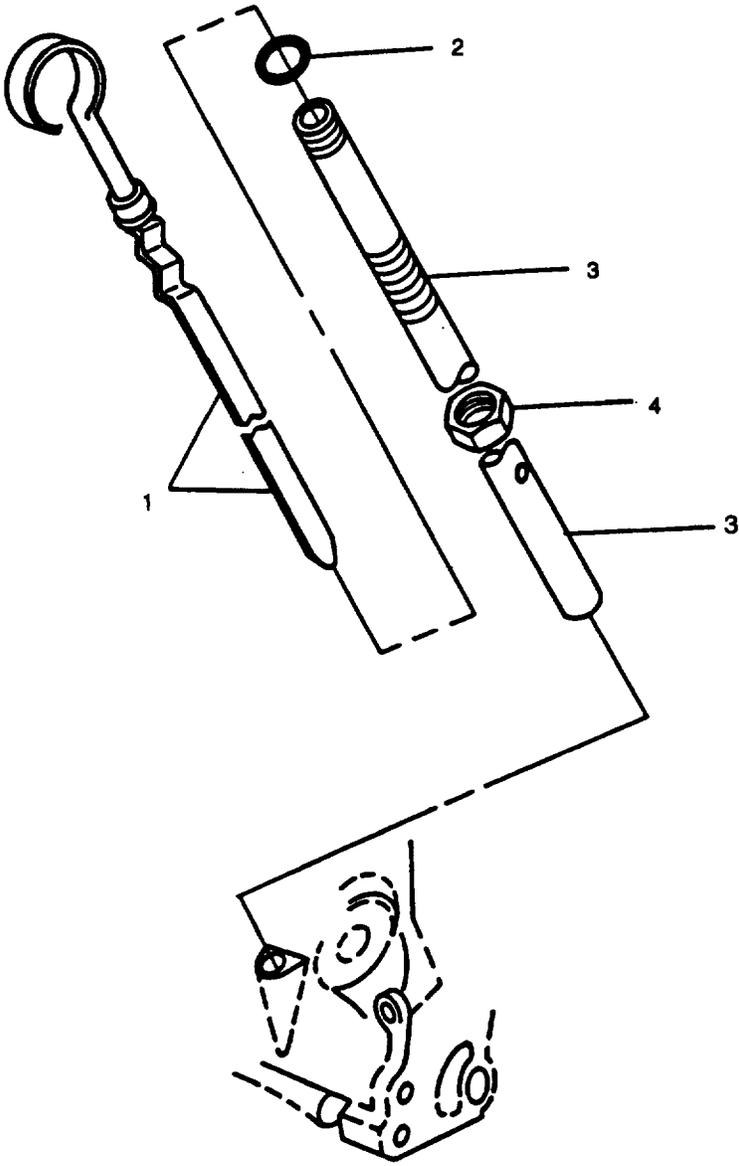


FIGURE 3-33. Dipstick

3-19.2. Installation.

- a. Install jam nut (4, FIGURE 333) on tube (3) exposing number of threads above nut as noted during removal.
- b. Screw tube (3) into engine block and tighten jam nut (4).
- c. If in doubt of level accuracy, perform following:

**NOTE**

**Engine should be cold and new filter installed before filling.**

- (1) Run engine to circulate oil, drain and fill engine with proper amount of new engine oil, refer to end item maintenance manual.
  - (2) Loosen jam nut (4) and adjust tube until dipstick shows oil level at full mark. Tighten jam nut (4).
- d. Install new preformed packing (2) and dipstick (1).

**3-20. OIL PAN.**

3-20.1. Removal.

- a. Drain engine lubrication system, refer to end item maintenance manual.

**NOTE**

**Eight of the 28 bolts are longer than the other bolts. Note their location for use during installation.**

- b. Support oil pan and remove eight bolts (1, FIGURE 3-34), twenty bolts (2), and twenty-eight lockwashers (3), securing oil pan (4) to engine block. Remove oil pan (4) and gasket (5); discard gasket (5).
- c. Remove all traces of old gasket from oil pan and oil pan rail.

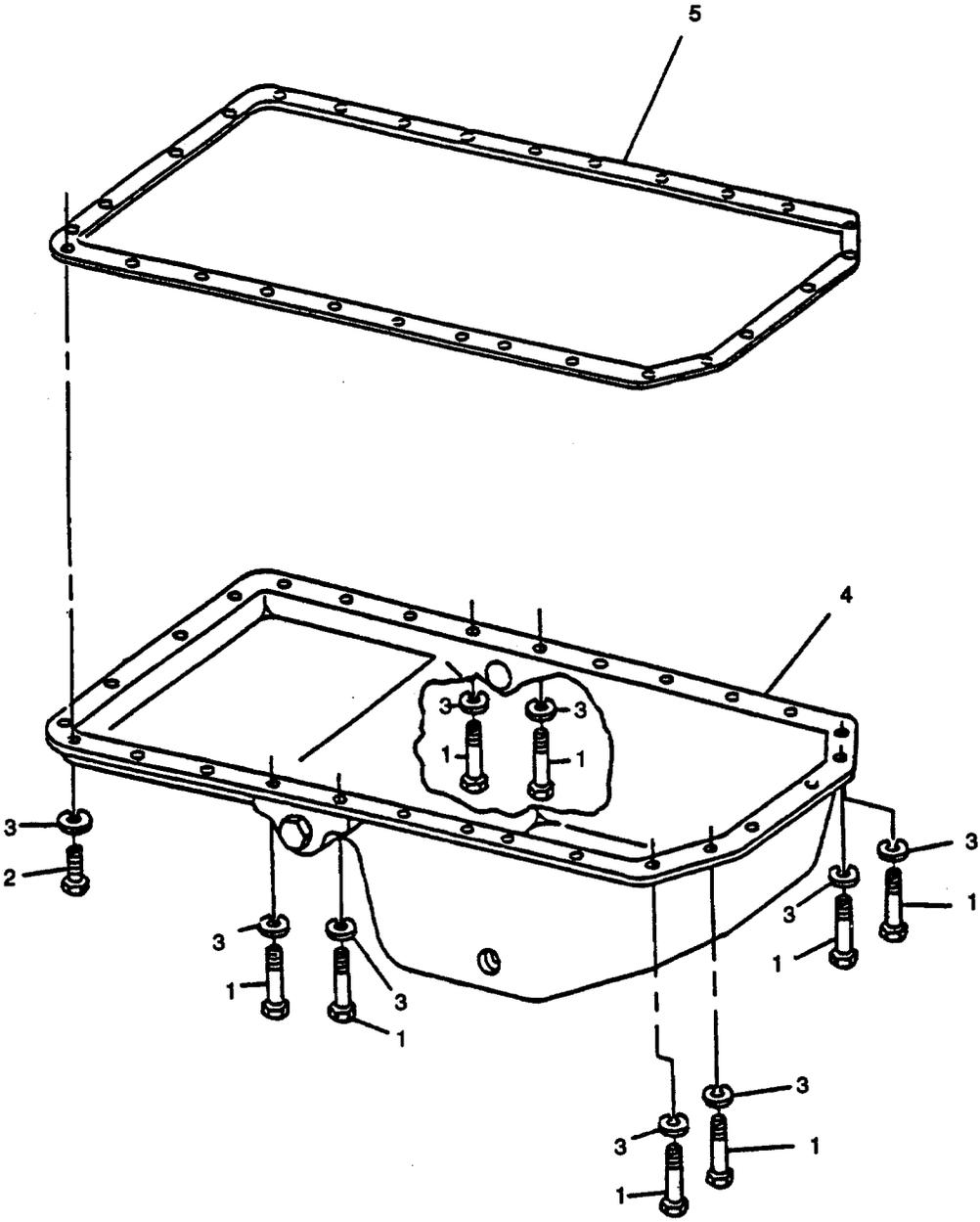


FIGURE 3-34. Oil Pan

3-20.2. Inspection.

- a. Inspect oil pan for cracks, dents, or other damage and replace as necessary.
- b. Inspect plug holes for damage threads and signs of leakage.

3-20.3. Installation.

- a. Put a bead of sealing compound (FORMAGASKET2) on oil pan rail where flywheel housing, front plate, and timing gear cover attach to cylinder block.
- b. Place a new gasket (5, FIGURE 3-34) and oil pan (4) on engine block and secure with eight bolts (1), twenty bolts (2), and twenty-eight new lockwashers (3). Install the eight longer bolts (1) in locations noted during removal.

**CAUTION**

**Do not overtighten oil pan-to-timing gear cover capscrews.**

- c. Tighten oil pan-to-timing gear cover capscrews to 27 ft-lbs (37 Nm). Tighten all others to 35 ft-lbs (47 Nm).
- d. Service lubrication system, refer to end item maintenance manual.

**3-21. OIL PUMP ASSEMBLY.**

3-21.1. Removal.

- a. Remove oil pan, refer to paragraph 3-20.1.
- b. Remove nut (1, FIGURE 3-35) and pull gear (2) using a suitable puller. If a suitable puller is not available, loosen nut (1) several turns and apply force between front plate and gear (2) on two sides of gear with a small pry bar. Strike nut end of shaft while applying force to gear until gear is free of tapered shaft. Remove nut (1) and gear (2).

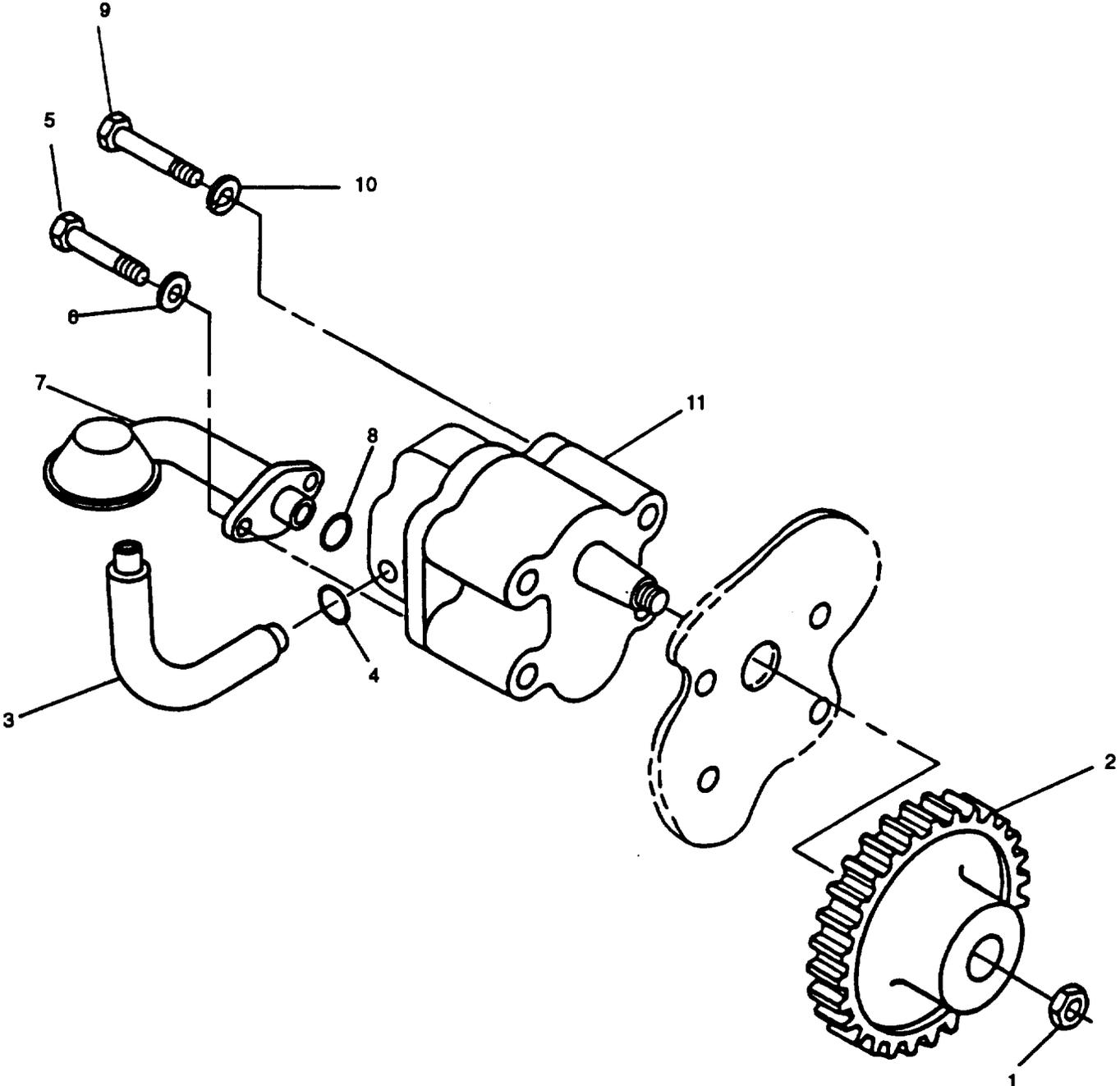


FIGURE 3-35. Oil Pump Assembly

- c. Remove outlet tube (3) and preformed packing (4).
- d. Remove two bolts (5) and flatwashers (6). Remove oil pump intake tube (7). Remove and discard preformed packing (8).
- e. Remove two bolts (9), flatwashers (10), and oil pump (11).

3-21.2. Inspect And Measure.

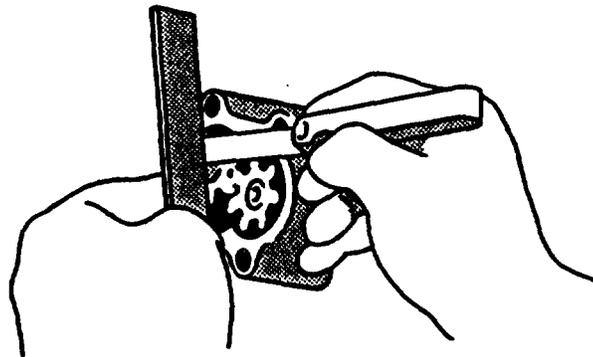
**Warning**

**Cleaning solvent is flammable and toxic to eyes, skin, and respiratory tract. Skin/eye protection required. Avoid repeated/prolonged contact Good general ventilation is normally adequate.**

**Warning**

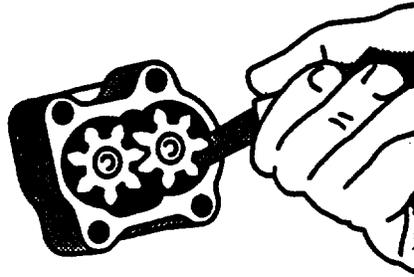
**Compressed air used for cleaning can create airborne particles that may enter the eyes. Pressure will not exceed 30 psig (207 kPa). Eye protection required.**

- a. Clean all oil pump parts in dry cleaning solvent (P-D-680). Dry with compressed air.
- b. Visually inspect all oil pump components for excessive wear.
- c. Inspect pump intake tube-to-flange weld for cracks. If cracks or other defects are found, replace tube.
- d. Using straight edge and feeler gage, check axial clearance between gear and pump cover, refer to FIGURE 3-36. Clearance standard is 0.002 to 0.007 inch (0.05 to 0.017 mm). Maximum permissible axial clearance is 0.0085 inch (0.22 mm).



**FIGURE 3-36. Measuring Oil Pump Axial Clearance**

- e. Using feeler gage, check radial clearance between gear and pump housing, refer to FIGURE 3-37. Clearance standard is 0.004 to 0.006 inch (0.10 to 0.16 mm). Maximum permissible radial clearance is 0.008 inch (0.20 mm).



**FIGURE 3-37. Measuring Oil Pump Radial Clearance**

3-21.3. Installation.

- a. Install new preformed packing (8, FIGURE 335) on oil pump intake tube (7) cover.
- b. Install outlet tube (3) with new preformed packing (4).
- c. Install pump (11) with oil pump intake tube (7) on front plate and secure with two bolts (5), two bolts (9), and flatwashers (6 and 10). Tighten bolts to 35 ft-lbs (47 Nm).
- d. Rotate oil pump shaft by hand to ensure it turns freely.
- e. Install drive gear (2) and nut (1). Tighten nut to 55 ft-lbs (75 Nm).
- f. Stake nut (1) to shaft by applying three center punch marks.
- g. Install oil pan, refer to paragraph 3-20.3.

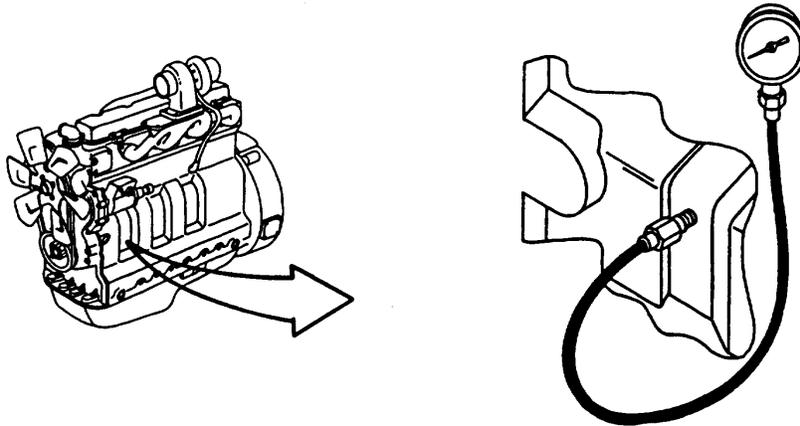
3-21.4. Test.

- a. Attach pressure gage at pressure port shown on FIGURE 3-38.

**CAUTION**

**Before checking the oil pressure, warm up engine to allow the lubricating oil to reach operating temperature or high oil pressure readings will occur.**

- b. At 850 rpm engine speed and 220°F (102°C) operating temperature, gage should show a minimum pressure of 15 psi (103 kPa).
- c. At rated speed (1800 to 2500 rpm) and 220°F (105°C) operating temperature, gage should show a pressure between 40 and 70 psi (277 to 483 kPa).

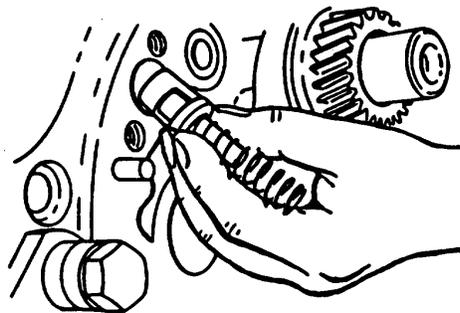


**FIGURE 3-38. Oil Pressure Test Setup**

**3-22. OIL BYPASS VALVE ASSEMBLY.**

**3-22.1. Removal.**

- a. Remove four bolts (1, FIGURE 3-34), two capscrews (2), and six lockwashers (3) from front of oil pan.
- b. Remove timing gear cover and front plate, refer to paragraphs 3-39.1. and 3-43.1.
- c. Remove oil bypass valve and spring, refer to FIGURE 3-39.



**FIGURE 3-39. Oil Bypass Valve Installation**

**3-22.2. Inspect and Measure.**

- a. Inspect valve and spring for damage.
- b. Using a spring tester apply 21 to 25 pounds (92 to 112 N) valve spring. Length should be 1.34 inches (34 mm). Replace spring if not within specifications.

3-22.3. Installation.

- a. Install valve and spring in bore of engine block, refer to FIGURE 3-39.
- b. Install front plate and timing gear cover, refer to paragraphs 3-43.5. and 3-39.3.

**CAUTION**

**Do not overtighten oil pan- to-timing gear cover capscrews.**

- c. Install four bolts (1, FIGURE 3-34), two capscrews (2), and six new lockwashers (3) in front oil pan. Tighten oil pan-to-timing cover capscrews to 27 ft-lbs (37 Nm). Tighten others to 35 ft-lbs (47 Nm).

**Section VIII. FUEL SYSTEM MAINTENANCE**

**Warning**

Escaping diesel fuel under pressure can have sufficient force to penetrate the skin, causing serious injury. Before disconnecting fuel lines, be sure to relieve pressure. Before applying pressure to the system, be sure all connections are tight and lines, pipes, and hoses are not damaged. Keep hands and body away from pinholes and nozzles which eject fuel under pressure. Use a piece of cardboard or wood, rather than hands, to search for suspected leaks.

**Warning**

If any fluid is injected into the skin, it must be surgically removed within a few hours by a doctor familiar with this type injury or gangrene can result.

**3-23. BLEEDING FUEL SYSTEM.**

**Warning**

Diesel fuel is flammable and toxic to eyes, skin, and respiratory tract. Skin/eye protection required. Avoid repeated/prolonged contact. Good general ventilation is normally adequate.

**NOTE**

**Catch fuel in suitable container.**

3-23.1. General.

Any time fuel system has been opened up for service (lines disconnected or filter removed), it will be necessary to bleed air from system. The fuel system can be bled at one of several locations.

3-23.2. Bleed At Fuel Filter.

- a. Loosen air bleed screw (17, FIGURE 3-40) on front of fuel filter.
- b. Operate primer lever of fuel supply pump (22) until fuel flow is free from air bubbles. Tighten bleed screw securely, continue operating hand primer until pumping action is not felt. Push hand primer inward (toward block) as far as it will go.

3-23.3. Bleed At Fuel Injection Pump.

**CAUTION**

**Always use two wrenches when loosening or tightening fuel lines at nozzles and/or Injection pump to avoid damage.**

- a. Loosen fuel supply line at fuel injection pump.
- b. Operate primer lever of fuel supply pump until fuel flow is free from air bubbles. Tighten fuel supply line to 22 ft-lbs (30 Nm). Continue operating hand primer until pumping action is not felt. Pull hand primer outward (away from block) as far as it will go.

3-23.4. Bleed At Fuel Injection Nozzles.

- a. Place throttle lever in fast idle position.

**CAUTION**

**Always use two wrenches when loosening or tightening fuel lines at nozzles and/or Injection pump to avoid damage.**

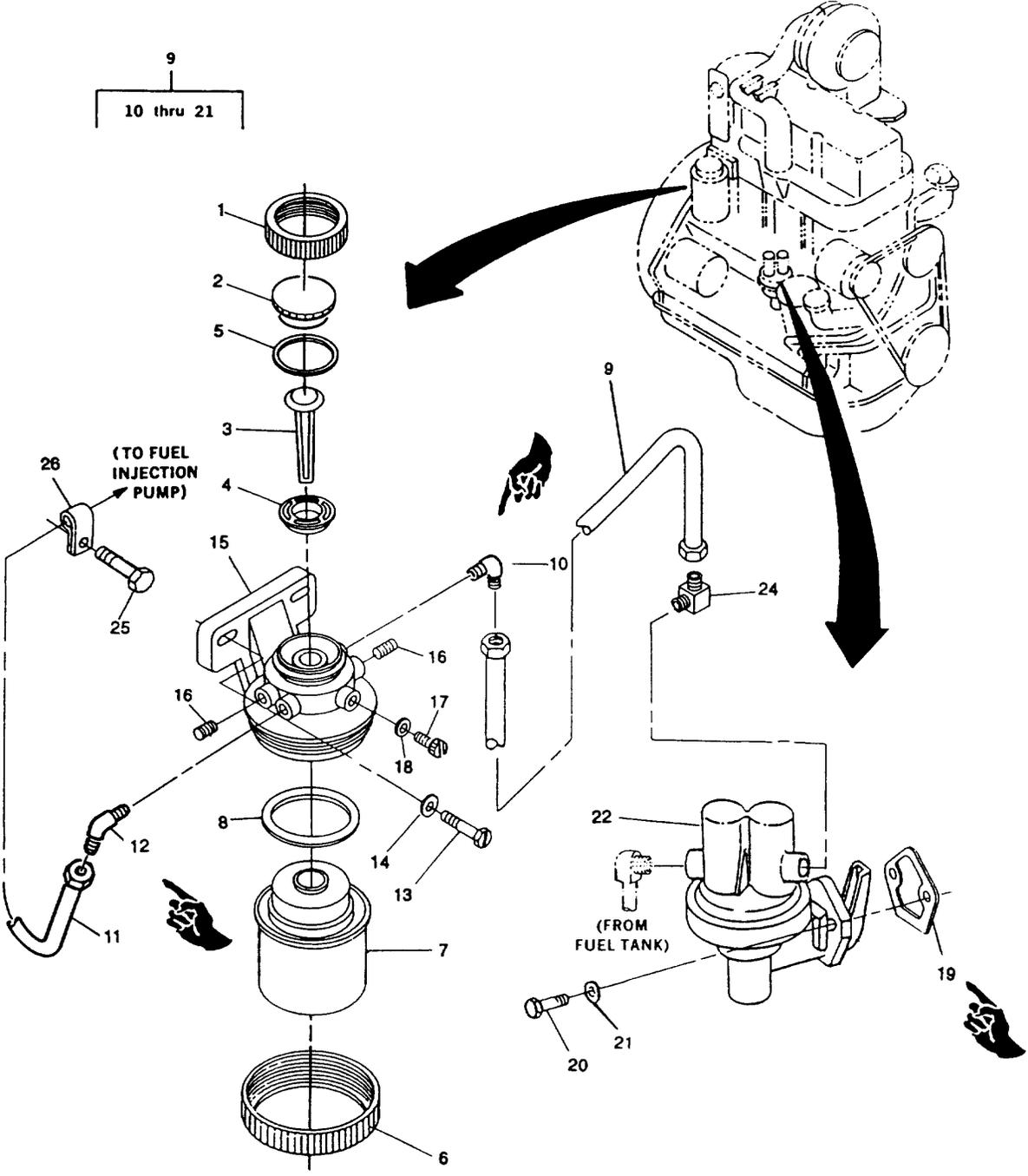


FIGURE 3-40. Fuel Filter and Fuel Supply Pump

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- b. Using two wrenches, loosen fuel line connection at injection nozzle.
- c. Crank engine over with starter (but do not start engine), until fuel free from bubbles flows out of loosened connection. Tighten connection to 20 ft-lbs (27 Nm).
- d. Repeat procedure for remaining injection nozzles (if necessary) until engine starts or until air has been removed from fuel system.

### 3-24. **FUEL FILTER/WATER SEPARATOR.**

#### 3-24.1. Prefilter and Element Replacement.

##### **WARNING**

**Diesel fuel is flammable and toxic to eyes, skin, and respiratory tract. Skin/eye protection required. Avoid repeated/prolonged contact. Good general ventilation is normally adequate.**

##### **NOTE**

**Retain any items removed from fuel filter that are not part of the filter for installation purposes.**

##### **NOTE**

**Catch fuel in suitable container.**

- a. Remove cap retaining ring (1, FIGURE 3-40), header (2), volume plug (3), and prefilter (4). Inspect seal (5) for damage and replace as necessary. Install new prefilter (4), seal (5), volume plug (3), header (2), and cap retaining ring (1).
- b. Loosen and remove retaining ring (6) and filter element (7) from filter head. Discard packing (8). Install new filter element (7) with new packing (8) and secure with retaining ring (6).

#### 3-24.2. Removal.

##### **CAUTION**

**Always use two wrenches when removing/installing fittings and/or fuel lines to avoid damage.**

- a. Disconnect fuel line (9, FIGURE 3-40) from elbow (10) at filter head (15). Cap openings.
- b. Disconnect fuel line (11) from elbow (12) in outlet of filter head. Cap openings.
- c. Remove two capscrews (13) and washers (14) securing filter head (15) to engine block; remove filter assembly.

#### 3-24.3. Repair.

- a. Remove fuel filter, refer to paragraph 3-24.2.
- b. Remove two elbows (10 and 12, FIGURE 3-40) from filter head (15).
- c. Remove bleed screw (17) and preformed packing (18). Discard preformed packing (18).
- d. Install new preformed packing (18) and bleed screw (17).
- e. Install two elbows (10 and 12) in ports of filter head.

3-24.4. Installation.

**CAUTION**

**Always use two wrenches when removing/installing fittings and/or fuel lines to avoid damage.**

- a. Position filter head (15, FIGURE 3-40) on engine mounting and secure with two capscrews (13) and washers (14).
- b. Remove caps and connect fuel line (11) to elbow (12) in outlet of filter head.
- c. Remove caps and connect fuel line (9) to elbow (10) in inlet of filter head.
- d. Bleed fuel system, refer to paragraph 3-23.

**3-25. FUEL SUPPLY PUMP.**

3-25.1. Removal.

**WARNING**

**Diesel fuel is flammable and toxic to eyes, skin, and respiratory tract. Skin/eye protection required. Avoid repeated/prolonged contact. Good general ventilation is normally adequate.**

**CAUTION**

**Always use two wrenches when removing/installing fittings and/or fuel lines to avoid damage.**

**NOTE**

**Catch fuel in suitable container**

- a. Disconnect fuel line (9, FIGURE 3-40) from elbow in fuel supply pump (22) outlet. Cap openings.
- b. Disconnect fuel line from fuel supply pump inlet. Cap openings.
- c. Remove two capscrews (20) and washers (21) securing fuel supply pump (22) to engine block. Remove pump and gasket (19); discard gasket (19).
- d. Cover opening in block and cap fuel lines.
- e. Remove elbow (24) from fuel supply pump outlet.

3-25.2. Inspection/Test.

3-25.2.1 Vacuum/Pressure Test.

**NOTE**

**This test will give a good indication of condition of both inlet and outlet valves, as well as diaphragm. Numerical values obtained on both vacuum and pressure sides are not important; rather it is the needle movement that is important (very slow for a good pump; very fast or not at all for a defective pump).**

- a. Remove inlet and outlet fittings.
- b. Install vacuum/pressure gage to inlet side of pump.
- c. Move primer lever all the way upward. Release lever and at same time observe gage.
  - (1) Gage needle should move to some value, and then very slowly go back to zero (0). This indicates inlet valve and diaphragm are in good condition. Proceed to step d.
  - (2) If gage needle does not move at all, or needle moves rapidly to zero (0), pump is defective and must be replaced.
- d. Remove vacuum/pressure gage and install onto outlet side of pump.
- e. Move priming lever all the way to upward position. Release lever and at same time observe gage.
  - (1) Gage needle should initially read 4 to 6 psi (28 to 41 kPa), then return to zero (0) very slowly. This indicates outlet valve and diaphragm are in good condition. Fuel supply pump is operating properly.
  - (2) If needle reaches some value on gage and then falls immediately back to zero (0), pump is defective and must be replaced.

#### 3-25.2.2. Leakage Test.

##### **NOTE**

**Leakage test should be performed on a fuel supply pump suspected of leaking fuel externally or internally, into engine crankcase.**

- a. Install an air line on inlet side of pump and apply 20 psi (140 kPa) pressure.
- b. Hold finger over outlet side of pump or install a plug. Submerge pump into a container of water.
  - (1) If air bubbles (indicating leakage) occur around banded connection holding two halves of pump together, replace pump if leakage is observed.
  - (2) If diaphragm is bad, there will be leakage through vent holes and around the rocker arm. Replace pump if necessary.

#### 3-25.3. Installation.

##### **CAUTION**

**Always use two wrenches when removing/installing fittings and/or fuel lines to avoid damage.**

##### **NOTE**

**Use adhesive (242) on elbow threads before installing fittings.**

- a. Install elbow (24, FIGURE 3-40) in fuel supply pump outlet.
- b. Position new gasket (19) and fuel supply pump (22) on engine block and secure with two capscrews (20) and washers (21).
- c. Remove caps and connect fuel line to fuel supply pump inlet.
- d. Remove caps and connect fuel line (9) to elbow (24) in fuel supply pump outlet.
- e. Bleed fuel system, refer to paragraph 3-23.

### 3-26. FUEL LINES.

#### 3-26.1. Removal.

#### **Warning**

**Diesel fuel is flammable and toxic to eyes, skin, and respiratory tract. Skin/eye protection required. Avoid repeated/prolonged contact. Good general ventilation is normally adequate.**

#### **CAUTION**

**Always use two wrenches when removing/installing fittings and/or fuel lines to avoid damage.**

#### **NOTE**

**Catch fuel in suitable container.**

- a. If necessary, remove fuel line (11, FIGURE 3-40) by disconnecting it at fuel injection pump using two wrenches. Remove capscrew (25) securing clamp (26) and remove fuel line.
- b. If necessary, remove fuel line (9) by disconnecting it at elbows (10 and 24).
- c. Remove two loop clamps (1, FIGURE 3-41).
- d. Remove loop clamp (2).
- e. At cylinder No. 4 fuel injector, loosen coupling nut (3) and disconnect return line to fuel tank. Remove coupling nut (3) and bushing (4). Discard bushing (4).
- f. Between injectors Nos. 3 and 4, loosen coupling nuts (5) and disconnect return tube (6). Remove nuts (5). Disconnect other end of tube (6) from fitting (15).
- g. Loosen coupling nuts (8) securing tubes (10) to injectors. Remove tubes (10), coupling nuts (8), rivet (7), and bushings (9). Discard bushings (9).
- h. Tag and disconnect four fuel injection lines (11, 12, 13, and 14) from fuel injectors and fuel injection pump.
- i. Cap all openings.

#### 3-26.2. Inspection.

- a. Inspect all fuel lines for wear, kinks, or fitting damage. Replace as necessary.
- b. Ensure all connections are open.

#### 3-26.3. Installation.

#### **CAUTION**

**Always use two wrenches when installing fittings and/or fuel lines to avoid damage.**

- a. Remove all caps and connect four fuel injection lines (11, 12, 13, and 14, FIGURE 3-41) to fuel injectors and fuel injection pump as tagged during removal.

- b. Install new bushings (9) and coupling nuts (8) on tubes (10). Install tubes (10) to fuel injectors and secure with coupling nuts (8). Do not overtighten coupling nuts.
- c. Connect tube (6) to fitting (15). Connect other end of tube between injector Nos. 3 and 4 using new bushing(9) and coupling nuts (5). Do not overtighten coupling nuts.
- d. Connect fuel tank return line to No. 4 injector using new bushing (4) and coupling nut (3). Do not overtighten coupling nut.
- e. Secure fuel injection lines (11, 12, 13, and 14) with loop clamps (1 and 2).
- f. Install fuel line (9, FIGURE 3-40) at elbows (10 and 24).
- g. Install fuel line (11) at fuel injection pump and at elbow (12). Install damp (26) with capscrew (25).
- h. Bleed fuel system, refer to paragraph 3-23.

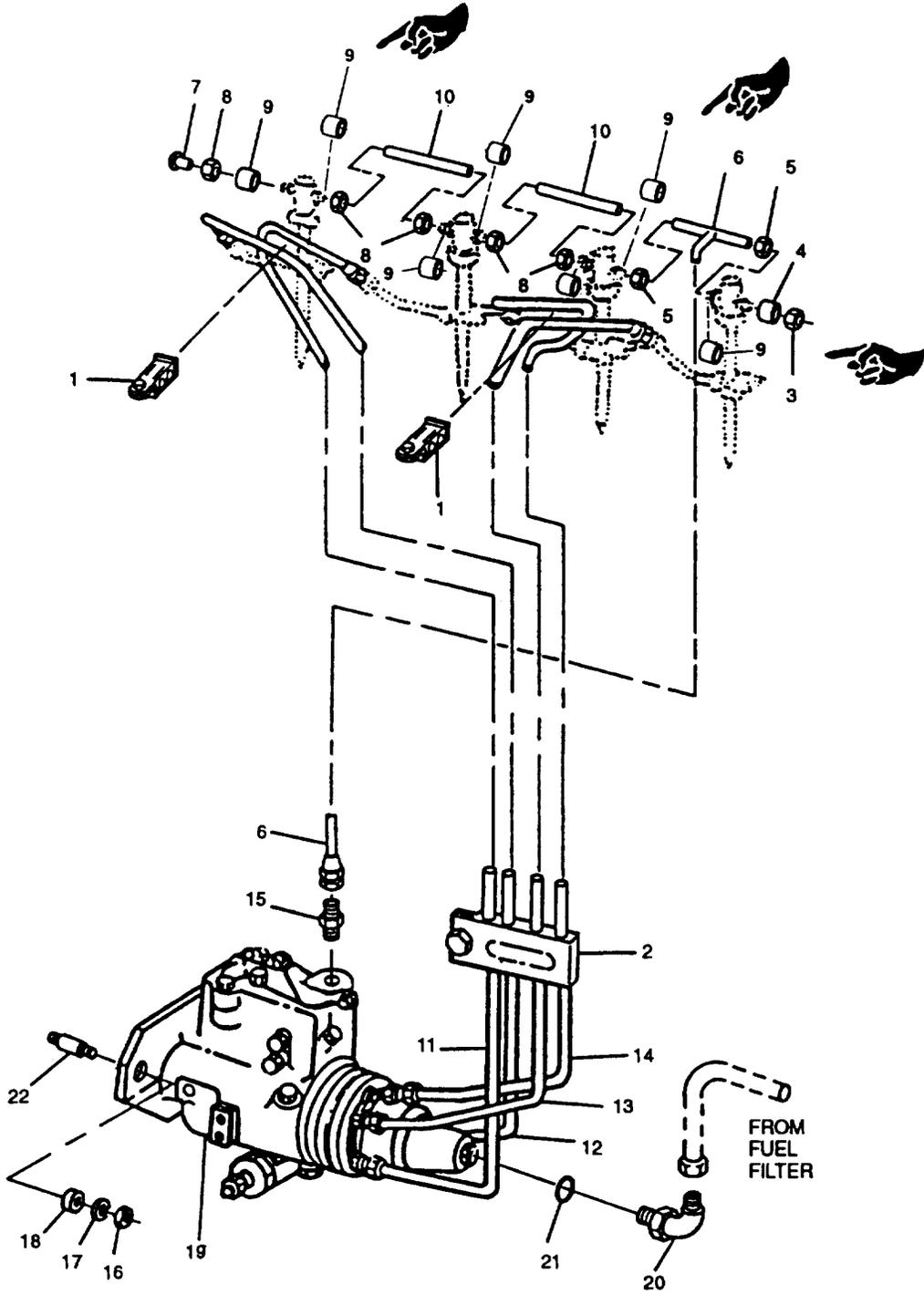


FIGURE 3-41. Fuel Lines and Injection Pump Installation

### 3-27. FUEL INJECTION PUMP.

#### 3-27.1. Removal.

##### **Warning**

**Diesel fuel and cleaning solvent are flammable and toxic to eyes, skin, and respiratory tract. Skin/eye protection required. Avoid repeated/prolonged contact to prevent serious injury and death. Good general ventilation is normally adequate.**

##### **CAUTION**

**Always use two wrenches when removing/installing fittings and/or fuel lines to avoid damage.**

##### **CAUTION**

**Never steam clean or pour cold water on a fuel injection pump while pump is running or while it is warm. Doing so may cause seizure of internal rotating pump parts.**

##### **NOTE**

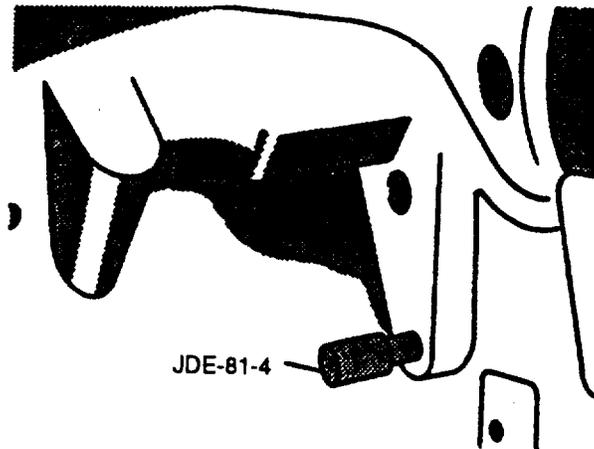
**Catch fuel in suitable container.**

- a. If not removed, disconnect electrical leads to fuel injection pump.
- b. Clean fuel injection pump, lines,, and area around pump with dry cleaning solvent (P-D-680) or a steam cleaner.
- c. Using center bolt on harmonic balancer, rotate crankshaft until No. 1 piston is at TDC on compression stroke.

##### **NOTE**

**The injection pump can be removed without engine being positioned at No. 1 TDC, however, this aids installation if pump position is not changed.**

- d. Remove timing hole cover plate from side of fuel injection pump housing and check timing marks.
  - (1) If there is a mark on cam ring and governor weight retainer, proceed with removal.
  - (2) If there is no mark on governor weight retainer, scribe a mark on weight retainer (front mark) directly in line with mark on cam ring (rear mark).
  - (3) Remove capscrew from left side of flywheel housing to gain access to timing hole in flywheel and insert locking pin (JDE-81-4), refer to FIGURE 3-42.



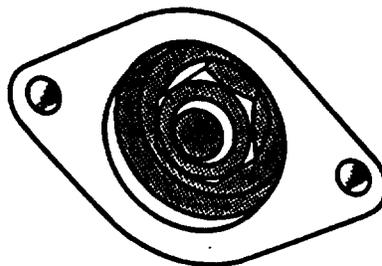
**FIGURE 3-42. Flywheel Locking Tool**

- e. Disconnect throttle control system, refer to end item maintenance manual.
- f. Disconnect fuel supply line (FIGURE 3-41) from fuel injection pump.
- g. Disconnect fuel tube assembly (6, FIGURE 3-41) from fitting (15) on fuel injection pump.
- h. Disconnect four fuel injection lines (11, 12, 13, and 14) from fuel injection pump.
- i. Remove injection pump cover plate from timing gear cover, refer to FIGURE 3-43, cover shown removed.

**NOTE**

**Be careful not to drop nut and/or washer inside engine.**

- j. Remove nut and washer securing fuel injection pump drive gear to shaft.
- k. Install injection pump drive gear puller (JDG670) to injection pump gear and shaft. Follow mounting instructions provided with tool set, refer to FIGURE 3-44.

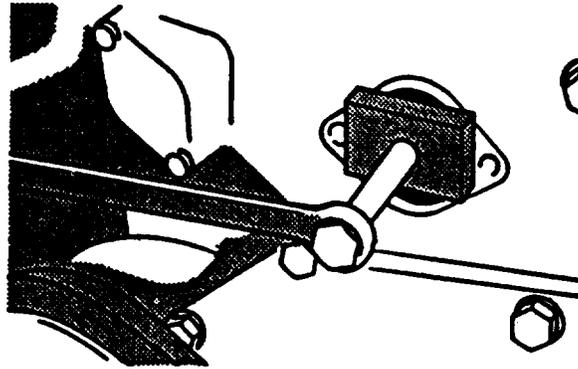


**FIGURE 3-43. Fuel Infection Pump Gear Access (Cover Removed)**

**Warning**

**If nuts (16), FIGURE 3-41) are removed prior to shaft/gear separation, fuel injection pump will fall out which can cause personal injury and/or equipment damage.**

- l. Loosen three nuts (16, FIGURE 3-41) several turns to permit pump shaft/drive gear separation.
- m. Tighten large hex head capscrew on puller clockwise until drive gear is held firmly against front plate.



**FIGURE 3-44. Separating Gear and Shaft**

- n. Support weight of fuel injection pump (19) and remove three nuts (16), lockwashers (17), and washers (18) securing pump. Remove pump (19).
- o. Remove puller from drive gear.
- p. Cover all openings in pump and place pump in a clean area.

327.2. Disassembly.

327.2.1. General.

**Warning**

**Compressed air used for cleaning can create airborne particles that may enter the eyes. Pressure will not exceed 30 psig (207 kPa). Eye protection required.**

Before commencing disassembly of pump, cover inlet and outlet holes. Remove all external grease and dirt by washing pump with diesel fuel and blowing dry with filtered compressed air. To prevent dirt from entering fuel system, it is essential that a clean work space, clean tools, and clean hands be used. During disassembly, remove and tag all seals, gaskets, insulating washers, preformed packings, and lockwashers to aid in identifying replacement parts. A clean pan should be available to place parts in during disassembly. A clean deep pan with rounded corners and filled with clean diesel fuel or calibrating oil must be available to flush parts.

3-27.2.2. Procedure.

- a. Using a flat-blade screwdriver, remove pilot tube seal (1, FIGURE 3-52) from mounting flange end of pump.

**CAUTION**

**Always use holding fixture (refer to FIGURE D-1, Appendix D) to prevent pump from becoming damaged. Never clamp pump in a vise.**

- b. Mount pump in holding fixture.
- c. If damaged, remove connector (1, FIGURE 3-45) and preformed packing (2) from cover.
- d. Remove two screws (3), lockwashers (4), and washers (5) securing governor control cover (6). Remove cap (86), screw (87), and cup (88). Remove cover (6) with solenoid (16) and gasket (7).
- e. Remove two self-locking nuts (8) from solenoid studs. Remove terminal strap (9), lockwasher (10), and washer (11).

**Change 3 3-82**

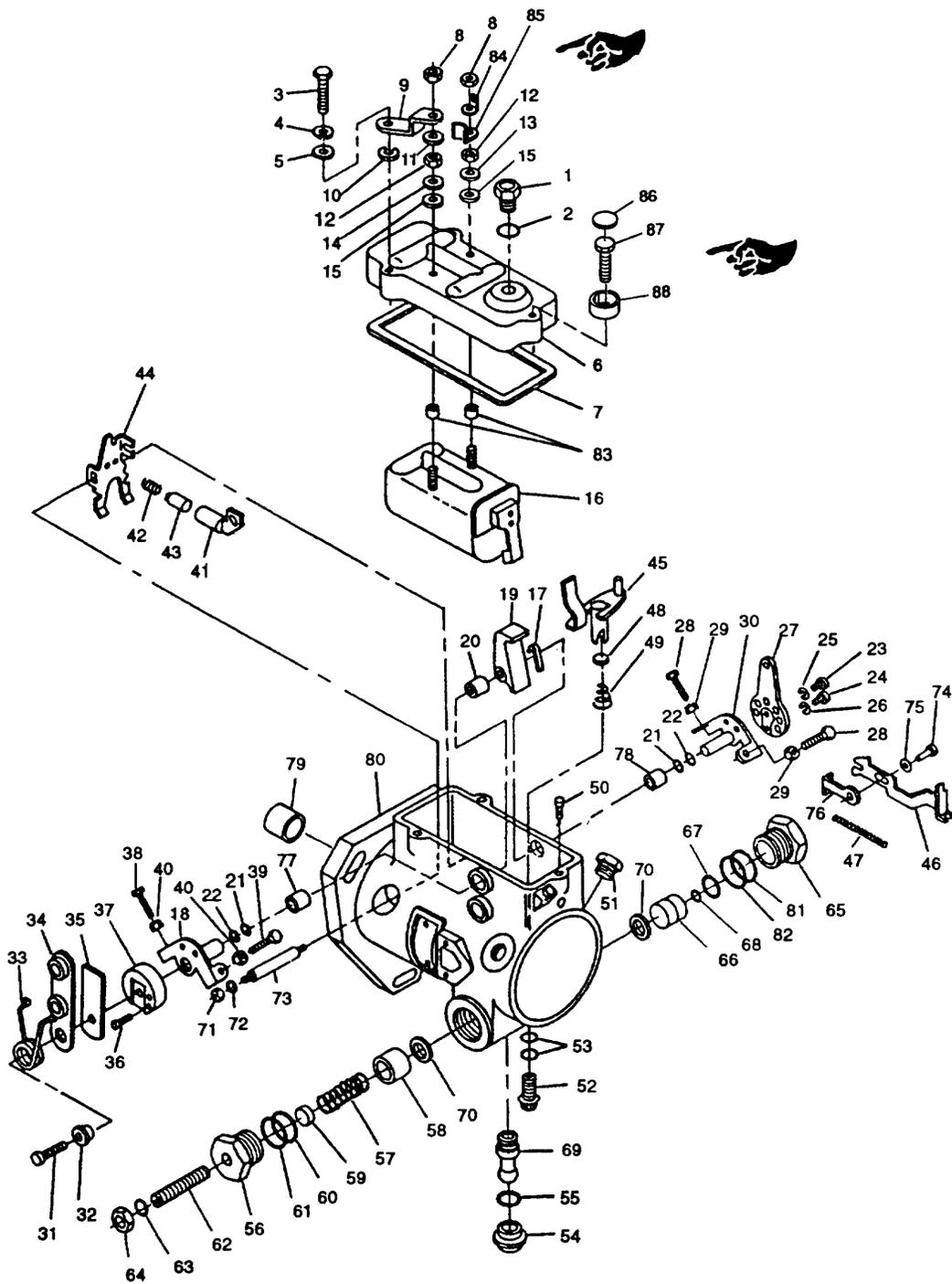


FIGURE 3-45. Fuel Injection Pump Assembly

Change 3 3-83

- f. Remove two nuts (12), insulator (84), terminal (85), one lockwasher (13), one washer (14), and two insulator washers (15) securing solenoid (16) to cover (6); remove solenoid.

**NOTE**

**Never reuse shut-off cam (17). Always use a new one.**

- g. Rotate shut-off arm (27) to wide open throttle (WOT) position. Using needle nose pliers, pry gently, sliding cam (17) off shut-off shaft assembly (30).

**NOTE**

**To aid in correct reassembly, note position of throttle shaft lever (19) key in relationship to groove of throttle shaft assembly (18).**

- h. Withdraw throttle shaft assembly (18) and throttle shaft lever (19) from shut-off shaft assembly (30). Remove throttle shaft lever (19), spacer (20), two rubber seal rings (21), and two washers (22).  
i. If damaged, disassembly shut-off lever shaft assembly as follows:

**NOTE**

**Note location of screw (23) in adjustment shut-off arm (27) and shut-off shaft assembly (30).**

- (1) Remove screw (23), adjustment shut-off screw (24), and two washers (25 and 26) securing adjustment shut-off arm (27) to shut-off shaft assembly (30).
- (2) Remove two screws (28) and nuts (29) from shut-off shaft assembly (30).
- (3) Remove shut-off shaft assembly (30).

- j. If damaged, disassemble throttle shaft assembly as follows:

**NOTE**

**Note location of screw (36) in shaft assembly (18).**

- (1) Remove screw (31), retainer (32), spring (33), lever (34), adjusting arm (35), screw (36), and spacer (37) from shaft assembly (18).
- (2) Remove screw (38), screw (39), and two nuts (40) from shaft assembly (18).

- k. Disassemble droop control (FIGURE 3-46) as follows:

- (1) Remove cap (1).
- (2) Pull adjusting cap (2) straight out. Remove and discard seal (3).
- (3) Remove clip (4) from end of control rod assembly (5).
- (4) Remove guide (6) and washer (9).
- (5) Remove control rod assembly (5), spring (7), and barrel assembly (41, FIGURE 3-45).

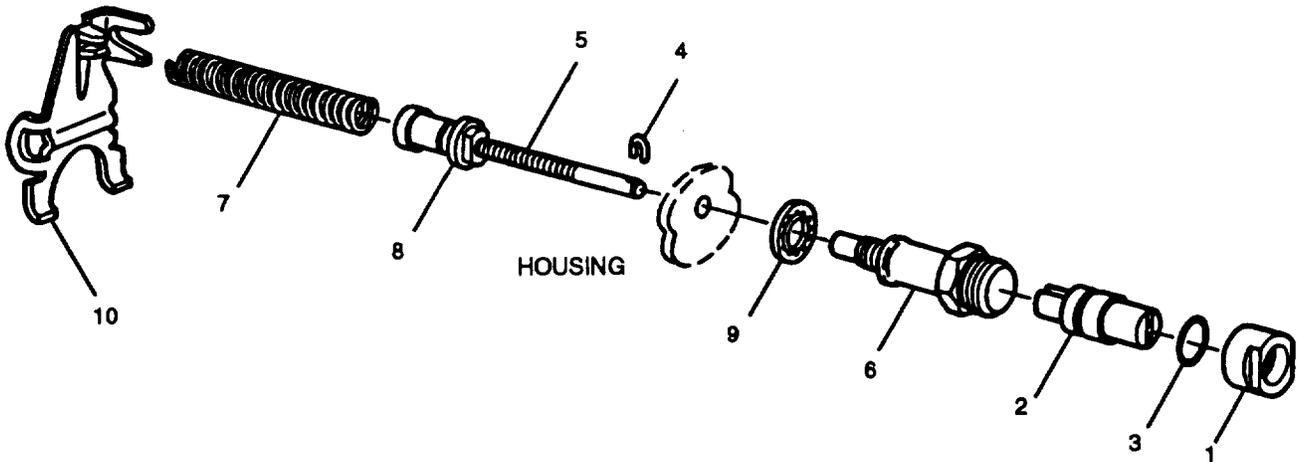


FIGURE 3-46. Speed Droop Governor

NOTE

Unless they are damaged, spring (42) and piston assembly (43) should be left attached to governor arm (44). (6) If damaged, remove spring (42) and piston assembly (43) from governor arm (44).

- i. Depress metering valve and arm (45) and raise governor linkage hook assembly (46) from metering valve arm pin. While holding governor arm (44) forward, pull linkage hook back slightly to disengage it from governor arm. Place linkage hook assembly over side of housing, refer to FIGURE 3-47. Do not disengage linkage spring (47, FIGURE 3-45).

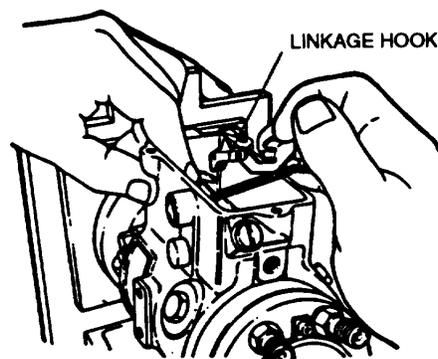
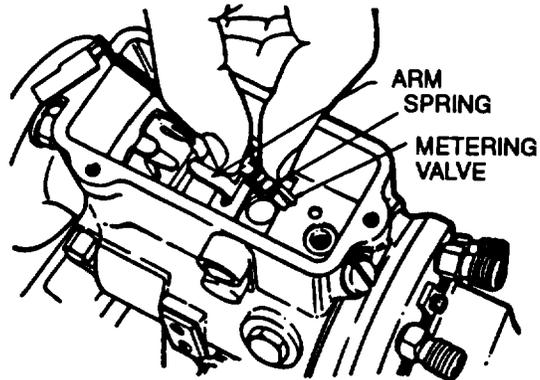


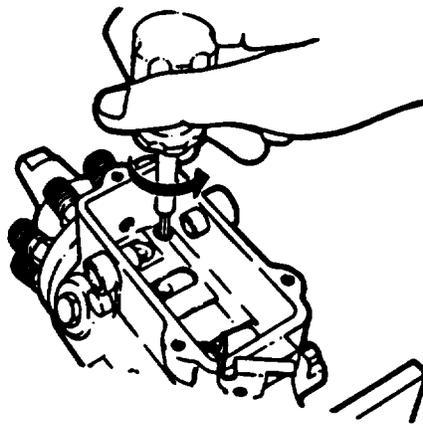
FIGURE 3-47. Disengaging Governor Linkage (Typical)

- m. Remove metering valve and arm (45), shim (48), and spring (49) from housing, refer to FIGURE 3-48.



**FIGURE 3-48. Removing Metering Valve (Typical)**

- n. Remove vent wire screw assembly (50, FIGURE 3-45), refer to FIGURE 3-49.



**FIGURE 3-49. Removing Vent Wire Screw (Typical)**

- o. Remove transfer pump end cap locking screw (2, FIGURE 3-52), retaining plate (3), and seal (4) from hydraulic head, refer to FIGURE 3-0.

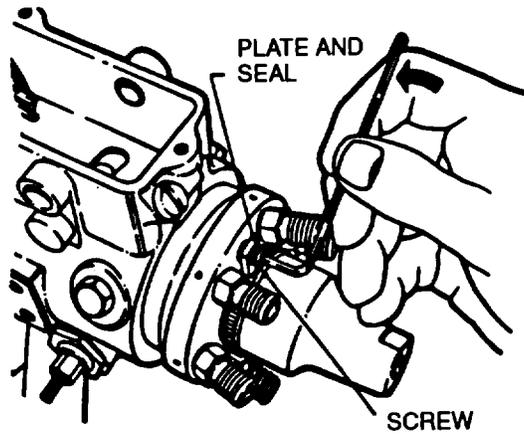


FIGURE 3-50. Removing Transfer Pump Screw (Typical)

- p. Using end cap socket (20548), remove transfer pump end cap (5, FIGURE 3-52). Remove element strainer (6) and regulator assembly, refer to FIGURE 3-51.

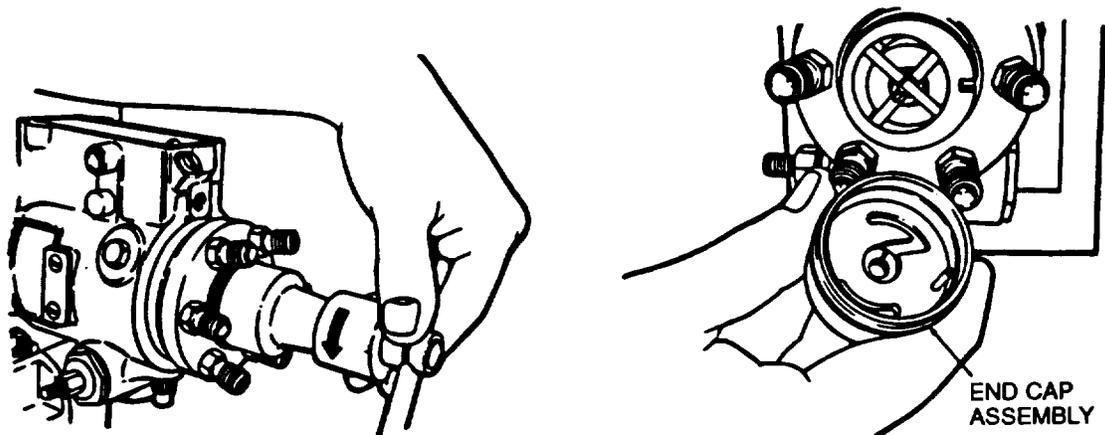


FIGURE 3-51. Removing Transfer Pump End Cap (Typical)

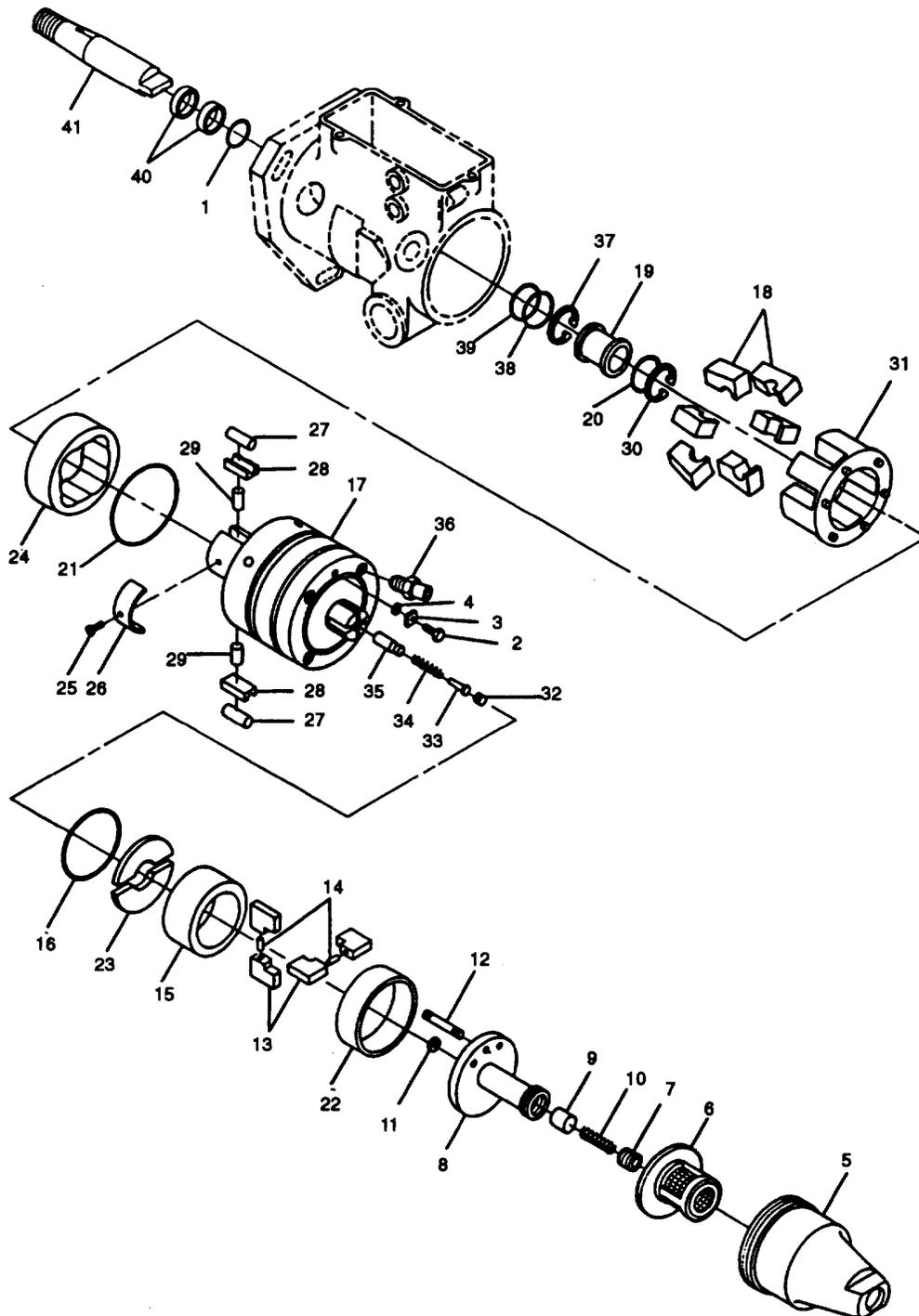


FIGURE 3-52. Fuel Injection Pump Hydraulic Head Assembly

q. Disassemble transfer pump regulator components as follows:

- (1) Remove end plate adjusting plug (7, FIGURE 3-52). Shake regulator (8) to remove piston (9) and spring (10).
- (2) Using O-ring pick, remove piston seal (11) from regulator (8).
- (3) If damaged, remove roll pin (12) from regulator (8), refer to FIGURE 3-53.

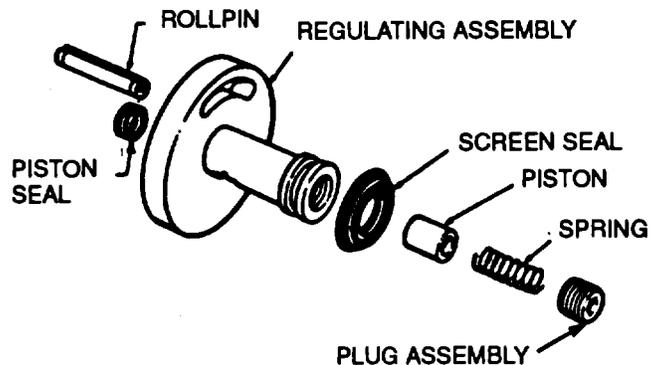


FIGURE 3-53. Transfer Pump Regulator Components

r. Remove four blades (13, FIGURE 3-52), two springs (14), and liner (15), refer to FIGURE 3-54.

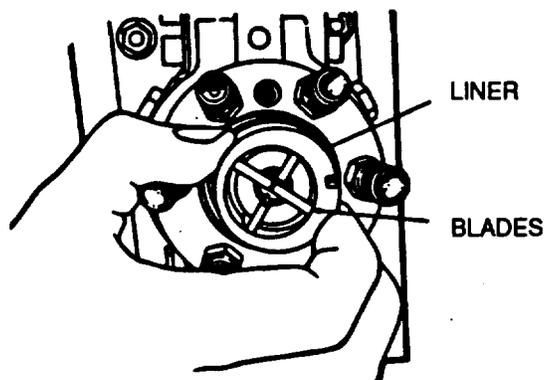


FIGURE 3-54. Removing Transfer Pump Blades (Typical)

s. Using a piece of wire with a hook, remove preformed packing (16, FIGURE 3-52) from groove in hydraulic head, refer to FIGURE 3-55.

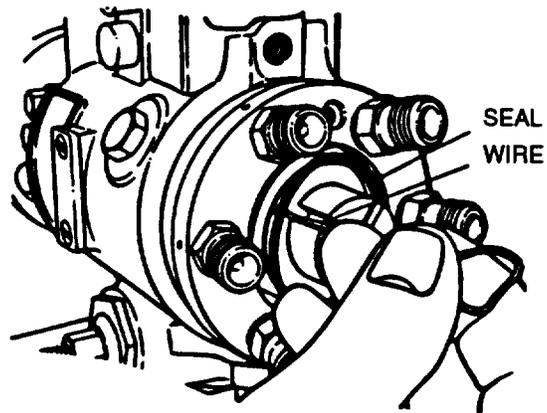


FIGURE 3-55. Removing End Cap Seal (Typical)

- t. Loosen two head locking bolts (51, FIGURE 3-45) and remove one of them, refer to FIGURE 3-56.

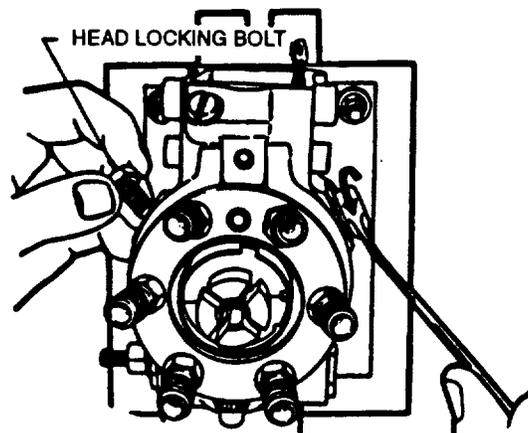
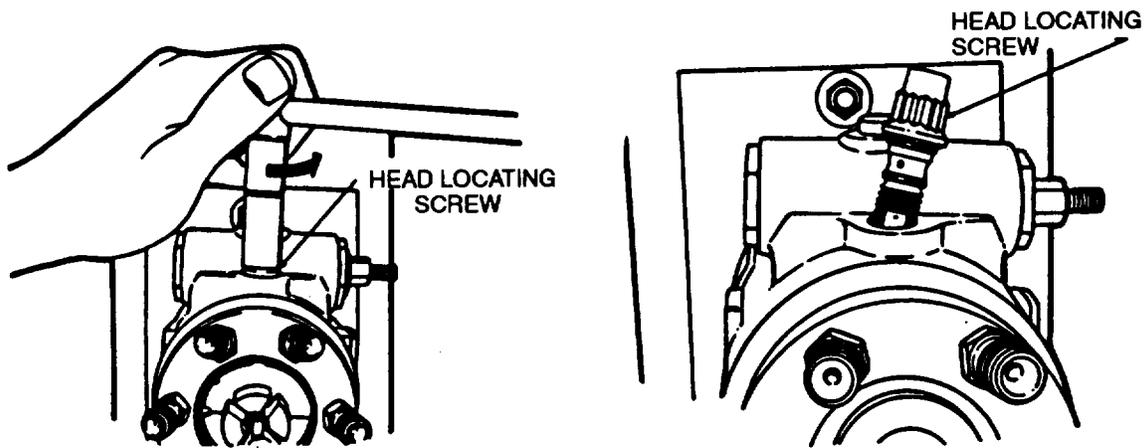


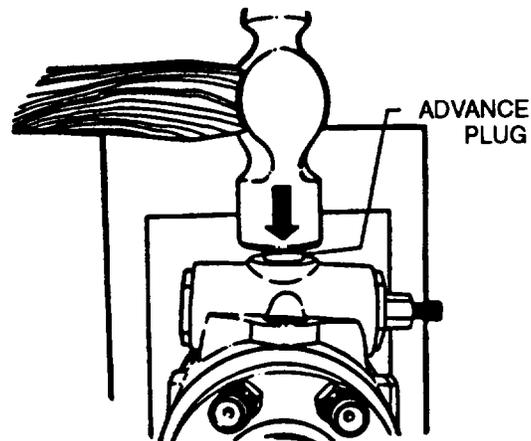
FIGURE 3-56. Removing Head Locking Bolt (Typical)

- u. Invert pump and holding fixture in vise.
- v. Remove head locating screw (52, FIGURE 3-45) using hex socket. Remove preformed packings (53) from screw (52), refer to FIGURE 3-57



**FIGURE 3-57. Removing Head Locating Screw (Typical)**

- w. Using a hammer, lightly tap advance screw hole plug (54, FIGURE 345) to loosen it, refer to FIGURE 3-58.



**FIGURE 3-58. Advance Screw Hole Plug (Typical)**

- x. Remove advance screw hole plug (54, FIGURE 3-45) and seal (55), refer to FIGURE 3-59.

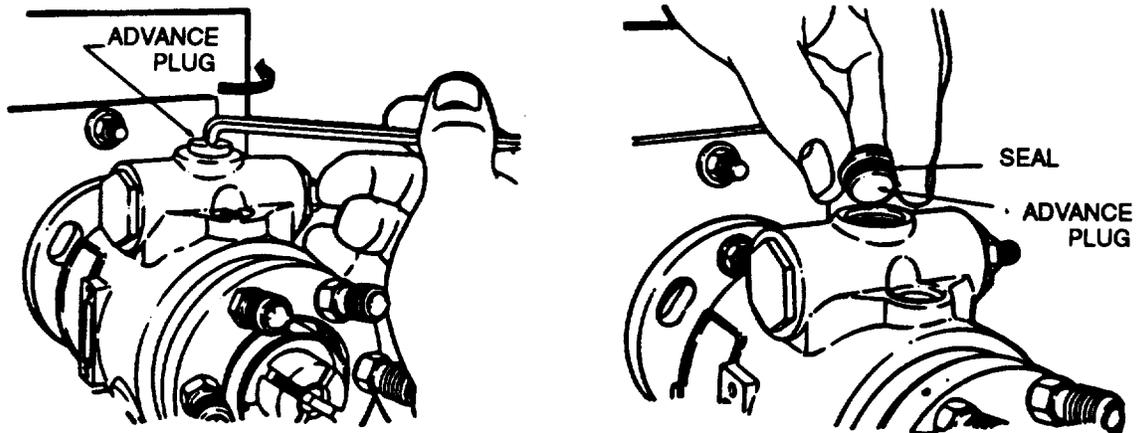


FIGURE 3-59. Removing Advance Screw Hole Plug (Typical)

- y. Remove spring side advance piston hole plug (56, FIGURE 3-45), springs (57 and 58), and spring guide (59), refer to FIGURE 3-60.

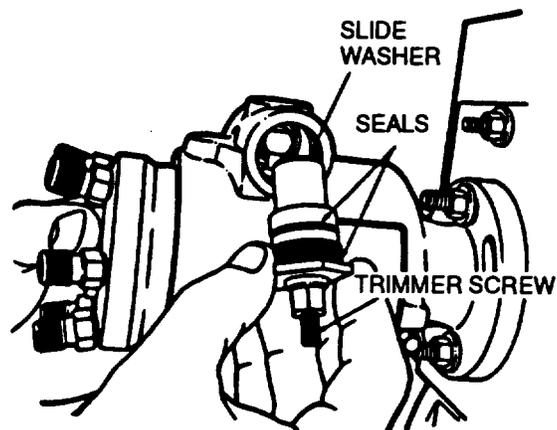
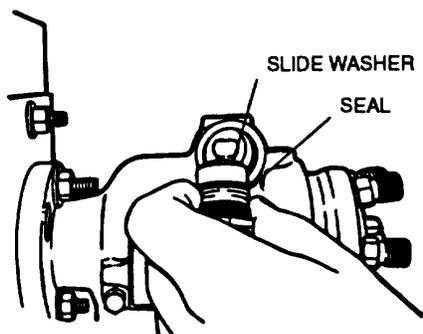


FIGURE 3-60. Removing Spring Side Advance Plug (Typical)

- z. Remove two preformed packings (60 and 61, FIGURE 3-45) from hole plug (56). If damaged, remove set screw (62), rubber seal ring (63), and nut (64) from hole plug (56).
- aa. Remove power side advance piston hole plug (65) and power piston (66), refer to FIGURE 3-61.

**NOTE**

Sides of housing, just above advance boss, bear a 'C' marking to denote pump rotation. Power side of piston (66, FIGURE 3-45) is located in side of housing which is marked with letter indicating rotation.



**FIGURE 3-61. Power Side Advance Piston (Typical)**

- ab. Remove power piston (66, FIGURE 3-45) from its plug (65) by holding plug in one hand and rapping it sharply into palm of other hand; piston will slide out. Remove piston ring (67), gasket (68), and, if necessary, preformed packings (81 and 82) from piston (66).
- ac. Remove advance screw (69).
- ad. Remove slide washers (70).
- ae. Return pump and holding fixture as unit to its initial position in vise with rear of hydraulic head tilted slightly downward.

**NOTE**

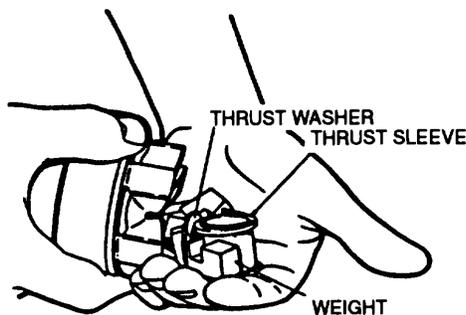
**When hydraulic head assembly (17, FIGURE 3-52) is inverted, weight (18), sleeve (19), and thrust washer (20) will fall out.**

- af. Remove remaining head locking bolt (51, FIGURE 3-45). Remove hydraulic head assembly (17, FIGURE 3-52) by grasping with both hands and withdrawing it with a slight rotary motion.

**NOTE**

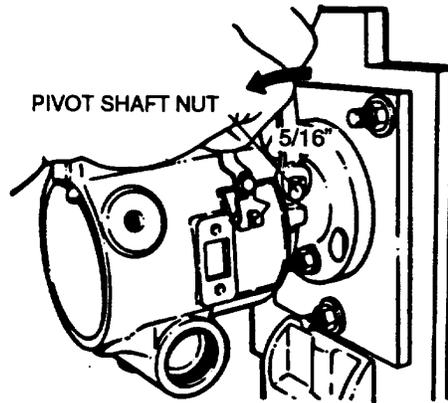
**When hydraulic head assembly (17) is inverted, weights (18), sleeve (19), and thrust washer (20) will fall out.**

- ag. To disassemble governor, invert hydraulic head and let six weights (18), sleeve (19), and thrust washer (20) fall into your hand. Remove preformed packing (21) from hydraulic head, refer to FIGURE 3-62.



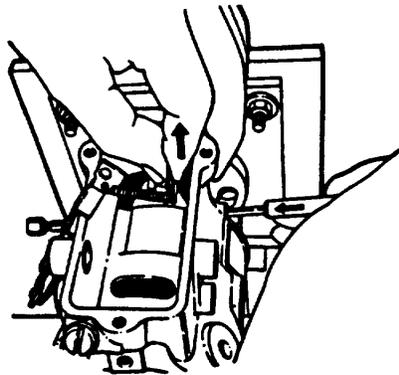
**FIGURE 3-62. Disassembling Governor**

- ah. Place head and rotor assembly on top of holding fixture (FIGURE D-1, Appendix D).
- ai. Loosen and remove one governor shaft retainer nut (71, FIGURE 3-45) and seal (72), refer to FIGURE 3-63.



**FIGURE 3-63. Removing Shaft Retaining Nut**

- aj. Remove governor shaft (73, FIGURE 3-45), governor arm (44), and linkage hook assembly (46), refer to FIGURE 3-64.



**FIGURE 3-64. Removing Governor Arm**

- ak. Remove other nut (71, FIGURE 3-45) and seal (72) from governor shaft (73).
- al. If damaged, disconnect spring (47) from governor arm (44) and linkage hook assembly (46).
- am. If damaged, disassemble linkage hook assembly, remove screw (74) and washer (75) to separate link assembly (76) from link hook (46).
- an. Lift liner locating ring (22, FIGURE 3-52) from rotor retainers (23). Remove two rotor retainers (23), refer to FIGURE 3-65.

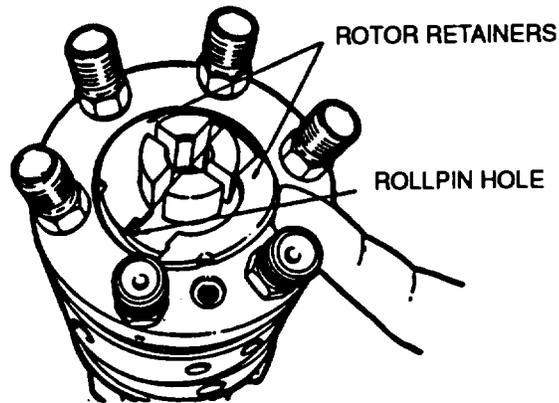


FIGURE 3-65. Removing Rotor Retainers (Typical)

**CAUTION**

**Do not handle precision ground surface of rotor to avoid damage.**

- ao. Lift hydraulic head (17, FIGURE 3-52) off rotor and remove cam ring (24), refer to FIGURE 3-66.

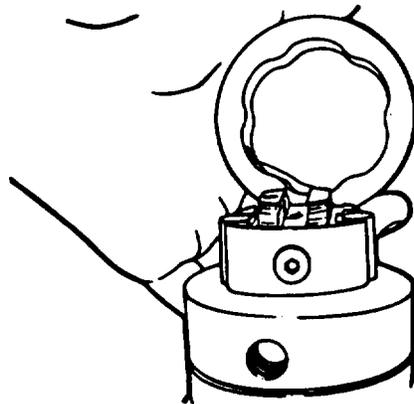
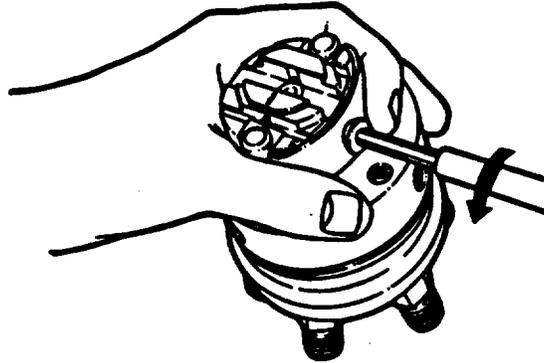


FIGURE 3-66. Removing Cam Ring (Typical)

**CAUTION**

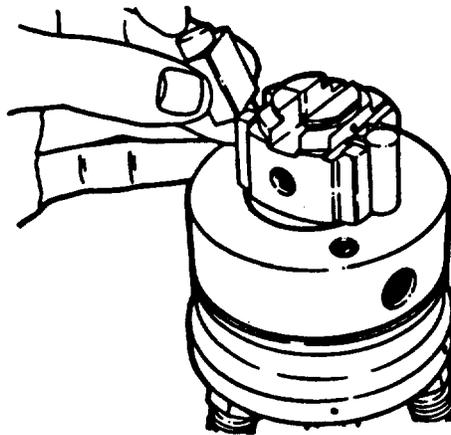
**Maintaining existing relationship of rotor parts is essential to proper operation of the pump. Do not disassemble rotor assembly any further than specifically directed.**

- ap. Remove leaf spring adjusting screws (25, FIGURE 3-52) and leaf springs (26), refer to FIGURE 3-67.



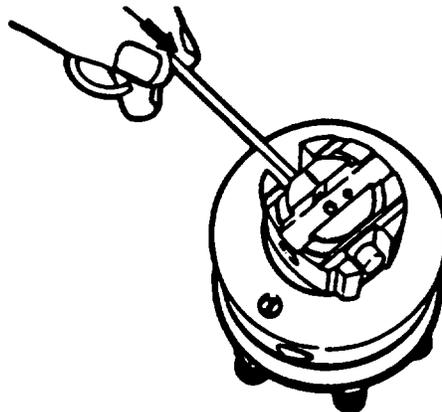
**FIGURE 3-67. Removing Leaf Spring (Typical)**

aq. Remove two rollers (27, FIGURE 3-52) and shoes (28) from rotor, refer to FIGURE 3-68.



**Figure 3-68. Removing Rollers (Typical)**

ar. Using brass rod, push pumping plungers (29, FIGURE 3-52) from their bores, refer to FIGURE 3-69.



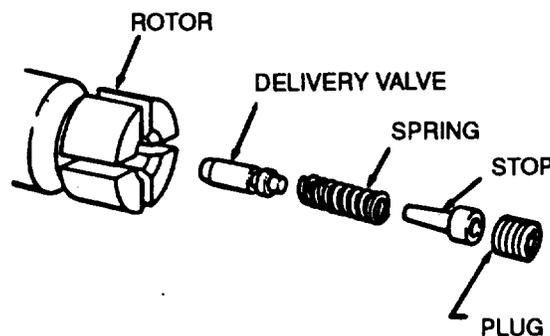
**FIGURE 3-69. Removing Pumping Plungers (Typical)**

- as. Remove snap ring (30, FIGURE 3-52) and carefully lift rotor from weight retainer (31). Replace head on rotor. Reinstall rotor retainer and liner locating ring, refer to FIGURE 3-70.



**FIGURE 3-70. Removing Weight Retainer (Typical)**

- at. Remove screw (32, FIGURE 3-52), valve stop (33), spring (34), and delivery valve (35) from rotor. If delivery valve does not slide out freely from bore, use extractor (13383) to remove it, refer to FIGURE 3-71.



**FIGURE 3-71. Removing Delivery Valve**

- au. If damaged, remove four fuel connectors (36, FIGURE 3-52) from head.  
av. Remove retaining ring (37), spring washer (38), thrust washer (39), and drive shaft (41).  
aw. Remove drive shaft seals (40).  
ax. If required, press bushings (77, 78, and 79, FIGURE 3-45) from housing (80) and replace.

### 3-27.3. Cleaning.

#### **Warning**

**Cleaning solvent is flammable and toxic to eyes, skin, and respiratory tract. Skin/eye protection required. Avoid repeated/prolonged contact. Good general ventilation is normally adequate.**

Parts should be washed in dry cleaning solvent (P-D-680) and then placed in a clean pan containing clean diesel fuel or calibrating oil.

3-27.4. Inspect and Measure.

3-27.4.1 General.

- a. Inspect all components for excessive wear, foreign material or corrosion, nicks or chipping, scratches or scores, thread damage, cracks, distortion, and freedom of movement. Examine springs for fretting, wear, distortion, or breakage. Clean and carefully check all bores, grooves, and seal seats for damage or wear of any kind.
- b. Disassemble rotor assembly (as necessary) as follows:

**CAUTION**

**Do not handle precision machined surface of rotor.**

- (1) Carefully remove each roller (27, FIGURE 3-52) and shoe (28) while retaining each roller in its shoe and lay roller and shoe pairs out on a clean surface in a manner such that they can be returned to same slots in rotor in the same direction they were removed.
- (2) Carefully remove the plungers and lay them out on a clean surface so they can be returned to same bore in rotor in same direction that they were removed.

3-27.4.2 Drive Shaft.

Measure distance across flats of drive tang which must not be less than 0.305 inch (7.75 mm). Shaft diameter in drive shaft seal area must be free of nicks and scratches for seals to function properly. Moderate shaft wear from seal lips is normal.

3-27.4.3 Hydraulic Head.

**Warning**

**Compressed air used for cleaning can create airborne particles that may enter the eyes and cause serious injury. Pressure will not exceed 30 psig (207 kPa). Eye protection required.**

**CAUTION**

**Do not immerse head in solvent for extended periods, as sealant damage will result.**

**NOTE**

**Five vent wire screw assembly (50, FIGURE 3-45) sizes are available. If specific oil return flow is not obtained during test, replace screw with appropriate size.**

Check vent wire screw assembly (50) for freedom of movement. Flush head and blow out all passages with clean, dry air. If vent wire is stuck, replace screw assembly with screw of same part number.

3-27.4.4 Rotor.

**CAUTION**

**Do not touch machine finished surfaces. Damage due to corrosion could occur.**

**NOTE**

**If damage or excessive wear is apparent, head and rotor must be replaced as a matched set. Final check for excessive wear on rotor should be performed on test stand by checking for minimum cranking delivery.**

Examine radii contacted by leaf spring and tang slot for excessive wear. Check all slots and charging and discharge ports for chipping of edges or dirt, and rotor shank for major scratches. Slight erosion on edge of discharge port is considered normal.

3-27.4.5 Delivery Valve.

Inspect delivery valve retraction cuff for chipping or erosion of edges.

**CAUTION**

**Do not force plungers into their bore and do not handle precision parts of rotor.**

3-27.4.6 Plungers.

While holding rotor under clean oil, insert plungers into their bores facing same direction as they were removed. With thumb and forefinger over shoe slots, tilt rotor from side to side several times to determine complete freedom of movement. If new plungers are being installed, interchanging their positions may be necessary as rotor and plungers become matched parts. If plungers are sticking, but not visibly damaged, clean both plungers and bore with a soft brush and dry cleaning solvent (P680).

3-27.4.7 Cam Rollers and Shoes.

**CAUTION**

**Never attempt to press a roller into a shoe from outer edges, as groove width at this point is less than roller outside diameter and shoe breakage may result.**

Check each roller in its shoe for freedom of movement. Inspect top edge of each shoe, where retained by leaf spring, for chipping or excessive wear. Inspect roller and shoe for abrasive wear patterns.

3-27.4.8 Leaf Spring and Screw.

**CAUTION**

**To prevent possible improper positioning of parts and unnecessarily disturbing leaf spring adjustment, do not remove screws (25, FIGURE 3-52) and leaf springs (26) unless they are being replaced or a new rotor and head assembly is being installed.**

- a. If damaged, remove screws (25, FIGURE 3-52) and leaf springs (26).
- b. Check for excessive wear at points where spring contacts radii on rotor and along steps that retain roller shoes. Check adjusting screw for tightness in rotor.

#### 3-27.4.9 Cam Ring.

Only working portions of lobes on inside diameter are ground, so any tool marks between lobes should not be considered as damage. The mottled appearance of cam is from heat treatment rather than from operation. Carefully inspect cam lobes and edges of all flat surfaces. If there is evidence of spilling or flaking out, replace with a new cam.

#### 3-27.4.10 Governor Weights.

Check pivot points (heel or toe) of all weights for excessive wear.

#### 3-27.4.11 Transfer Pump Blades.

Inspect with utmost care. Check for chipping on any edges, including spring bore edges, pitting, imbedded foreign particles, or scoring on rounded edges. Determine blade wear by measuring length (0.538 inch [13.67 mm] minimum). Inspect flat surfaces visually for deep scores. If any discrepancies are noted, replace both blade sets and springs.

#### 3-27.4.12 Housing.

Inspect housing for chips, cracks, damaged threads, imbedded foreign particles, or any other abnormal conditions. Replace if damaged.

#### 3-27.4.13 Bushings, Drive Shaft, and Throttle Shaft.

Inspect for excessive wear, cracks, loose fit in housing, or any other abnormal conditions. Replace if damaged.

#### 3-27.5. Replacement.

##### 3-27.5.1 Delivery Valve.

Delivery valves of various retraction values are used for different applications. Correct part numbers are found on individual pump specifications. Letters 'OV' etched on base of rotor indicate a 0.001 inch oversize delivery valve bore. A rotor so marked must use a 0.001 inch oversize delivery valve. Part numbers for both standard and oversized valves are listed on individual pump specifications. An oversized valve is also identified by blackening on both ends and in groove on delivery valve shank.

##### 3-27.5.2 Plungers.

Since plungers are positioned centrally in their bores during operation and their travel is extremely short, wear of plungers is negligible. However, replacement may be made in instances where rust or damage in handling has occurred. Plungers of any given nominal diameter are graded in four select fit sizes (A, B, C, and D). The rotor is etched with a letter indicating bore size, this mark is found on base of rotor. If plunger replacement is required, check size designation on rotor and use plunger of corresponding part number. For example; the basic plunger is part number 11086 and graded sizes, A through D, are part numbers 11087 through 11090. Therefore, a replacement plunger for a pump with a rotor marked 'C' would use part number 11089.

#### 3-27.6. Assembly.

##### **Warning**

**Diesel fuel is flammable and toxic to eyes, skin, and respiratory tract. Skin/eye protection required. Avoid repeated/prolonged contact. Good general ventilation is normally adequate.**

##### **CAUTION**

**Throughout assembly procedures it is stated to use grease on various parts. Do so sparingly as it can plug return fittings and pump will not bleed air from housing during startup.**

**CAUTION**

Do not handle precision machined rotor surfaces. Damage due to corrosion could occur.

**NOTE**

In addition to the parts supplied with the repair kits, cam (17, FIGURE 3-45), delivery valve stop (35, FIGURE 3-52), and connector assembly (1, FIGURE 3-45) must be replaced during assembly.

**NOTE**

Parts which must be replaced and are not included in the repair kits are lockwashers, delivery valve stop (35, FIGURE 3-52), insulator washers (15, FIGURE 3-45), and pilot tube (1, FIGURE 3-52).

- a. Rinse rotor thoroughly in clean diesel fuel or calibrating oil.
- b. Place rotor on weight retainer (31, FIGURE 3-52) and secure in a vise.

**NOTE**

Do not mistake slight interference of retractor collet in bore for delivery valve sticking. If valve is not secured straight and tight in retractor collect, collet diameter can drag in rotor bore.

- c. Using extractor (13383), install delivery valve (35) into bore of rotor. Ensure it slides freely in its bore, refer to FIGURE 3-72.

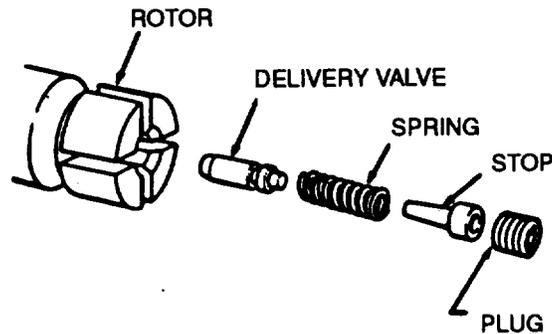


FIGURE 3-72. Delivery Valve Replacement

**CAUTION**

Always use a new delivery valve stop (33, FIGURE 3-52). Installation of a used stop can result in leakage and low output at cranking speed.

**CAUTION**

**Excessive tightening of screw (32) can cause seizure of hydraulic head and rotor assembly. Insufficient torque may cause leaking and hard starting.**

- d. Install delivery valve spring (34) and new delivery valve stop (33) in rotor bore. Using hex end of extractor (13383), install screw (32). Tighten screw 85 to 90 in-lbs (9.5 to 10 Nm).
- e. If removed, install four new fuel connectors (36) in head. Tighten them 58 to 66 ft-lbs. (78.6 to 89.5 Nm).
- f. Remove rotor from weight cage and submerge it in clean calibrating oil.

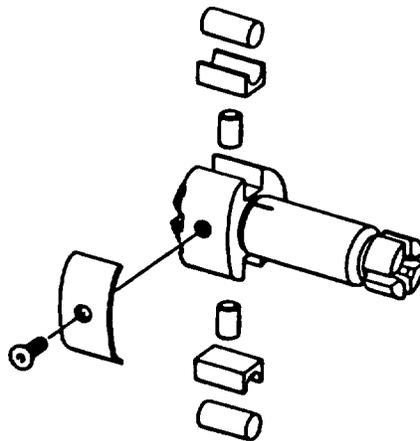
**CAUTION**

**Do not force plungers into bore. Never attempt to press a roller into a shoe from outer edges, as groove width at this point is less than roller outside diameter and shoe breakage can result.**

**NOTE**

**If replacing hydraulic head and rotor, or if replacing leaf springs do steps n thru s.**

- g. Install two leaf springs (26, FIGURE 3-52) on rotor. Secure with two screws (25).
- h. If removed, install new plungers (29) in their bores and check for freedom of movement. Install two shoes (28) and rollers (27) on rotor, refer to FIGURE 3-73.



**FIGURE 3-73. Installing Rollers and Shoes (Typical)**

- i. Carefully handle rotor, holding rollers, and shoes in their slots, and install rotor assembly in fixture (19969) on air inlet side.

**Warning**

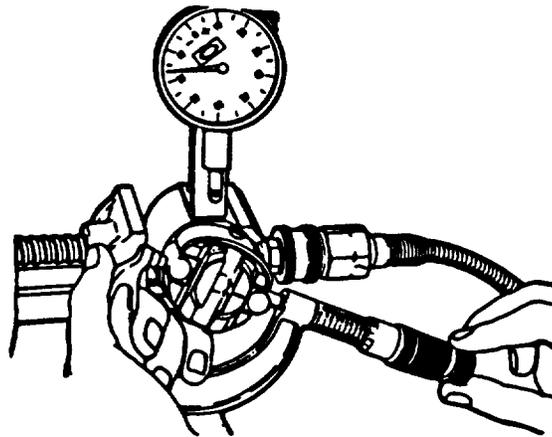
**Compressed air can be hazardous when not used properly.**

- j. Install fixture (19969) in vise (clamping on flat area) so that air inlet hole is not covered by vise. Install a 1/4 18 NPT fitting in air inlet of fixture. Connect fitting to a supply of clean filtered, compressed air, regulated to a pressure of 40 to 100 psi (275 to 689 kPa).

**NOTE**

**To set roller-to-roller dimension to specification, turn leaf spring screw (25) inward (clockwise) to increase, and outward (counterclockwise) to reduce roller-to-roller dimension.**

- k. Using a micrometer, measure roller-to-roller dimension (distance between outer surfaces of opposed cam rollers). Dimension should be 1.9845 to 1.9875 inches (50.032 to 50.118 mm), refer to FIGURE 3-74.



**FIGURE 3-74. Measuring Roller-To-Roller Dimension**

**NOTE**

**The roller-to-roller setting provides a completely accurate maximum fuel adjustment and it should not differ from value of 95.5 to 96.5 cu mm/stroke (1564.9 to 1581.3 cm<sup>3</sup>).**

- l. Perform a centrality check as follows. Maximum allowable tolerance is 0.004 inch (0.102 mm).
- (1) After setting roller-to-roller dimension, rotate rotor until one roller is aligned with dial indicator plunger. Slide indicator inward until plunger depresses it at least 0.010 inch (0.25 mm). Lock indicator retaining screw zero dial indicator on high point of roller by rotating knurled dial.
  - (2) Rotate rotor (either direction) until other roller depresses dial indicator plunger.
  - (3) If roller centrality is beyond specified tolerance, roller and/or shoes can be interchanged. Recheck centrality after each change and recheck roller-to-roller dimension.
- m. Rinse hydraulic head assembly in clean calibrating oil.
- n. Remove rotor assembly from fixture, ensuring shoes and rollers remain in their respective slots. Rinse assembly in clean calibrating oil.
- o. Insert rotor assembly into hydraulic head.

**NOTE**

**If cam ring (24, FIGURE 3-52) is installed incorrectly, pump will not be in time with engine.**

- p. Place cam ring (24) onto rotor assembly with directional arrow indicating direction of pump rotation. (Pump rotation is as viewed from drive end.)

- q. Check or relocate timing mark on governor weight retainer (31) as follows:
  - (1) Place weight retainer (31) on timing line locator tool (20401).
  - (2) Rotate hub of weight retainer and rotor hub in direction indicated on tool until movable pointer lines up with 131.5 degree mark.
  - (3) Check to see if timing mark on rotor hub is aligned within  $\pm$  one degree with fixed arrow point on tool.
  - (4) If not, remove existing mark, repeat step (1) thru (3) and scribe a new mark on hub. New hubs will have no timing mark. The timing mark will have to be added.
- r. Place holding fixture (FIGURE D-1, Appendix D) in vise.
- s. Place weight retainer on rotor. Ensure that assembly timing marks on rotor and weight retainer line up. Using snap ring pliers, install new snap ring (30) in its groove in weight retainer.
- t. While holding weight retainer carefully so rotor will not fall out, invert entire unit so it rests on weight retainer (31).
- u. Position two rotor retainers (23) on head and rotor with cutout portions meeting over spring pin hole in hydraulic head.
- v. Position liner locating ring (22) over rotor retainers (23) and bottom it against head. Position split in ring 90 degrees from split in retainers.

**NOTE**

**Preformed packing (16) has an oval cross section and can be identified by rolling it between fingers.**

- w. Install new preformed packing (16) in groove on hydraulic head (17). Be sure to push packing all the way into its groove.

**CAUTION**

**Use care not to cock blades during installation, as sharp edge on liner (15) can score blade ends.**

- x. Install liner (15) so slot is lined up with hole in which regulator assembly roll pin (12) enters.

**NOTE**

**Blade springs (14) must be fully compressed as they are installed.**

- y. Assemble springs (14) to blades (13) and install blades in their slots in rotor.
- z. Assemble transfer pump components as follows:
  - (1) If necessary, install new spring pin (12) in correct hole in regulator (8) for clockwise rotation. On face of regulator 'C' is stamped for clockwise pump operation.
  - (2) Using small flat screwdriver, install new piston seal (11) in groove of regulator (8). Do not roll seal over when assembling.

**CAUTION**

**To prevent excessive transfer pump pressure and damage to pump when nt is operated, ensure adjusting plug (7) is flush with end of regulator.**

**NOTE**

**The plug contains a viscosity compensating orifice and should be installed so top of screw is flush with end of regulator assembly.**

- (3) Install piston (9) in the regulator with hollow end facing spring or threaded end of bore. Install spring (10) and adjusting plug (7).
- (4) Using O-ring pick, check piston for freedom of movement in its bore.
- aa. Install assembled regulator on liner (15). Coat beveled surface on element strainer base (6) with general purpose grease (630AA).
- ab. Install element strainer (6) onto transfer pump regulator assembly.
- ac. Coat beveled surface and threads on OD of end cap (5) with general purpose grease (630AA).
- ad. Install end cap (5) and thread into hydraulic head by applying a slight pressure on top of end cap. Rotate end cap counterclockwise until a slight click is heard, then turn cap clockwise by hand until tight.
- ae. If disassembled, attach link assembly (76, FIGURE 3-45) to link hook (46) with screw (74) and washer (75).
- af. If disconnected, connect spring (47) to governor arm (44) and linkage hook assembly (46).
- ag. Install drive shaft (41, FIGURE 3-52), seals (40), thrust washer (39), spring washer (38), and retaining ring (37) as follows:

**CAUTION**

**Extreme care must be used when installing seals or leaks will result from distortion and/or damage to teflon sealing element. Calibration oil may be used to facilitate seal installation.**

- (1) Apply a light coat of general purpose grease (630AA) to seals (40).
- (2) Install seals (40) on shaft (41).

**CAUTION**

**Do not invert drive shaft seals (40) when installing drive shaft (41). If resistance is felt, stop and inspect seal. If seal was forced back, stop and replace seal.**

**NOTE**

**Before installing shaft (41), find small drilled hole (off-center) on drive shaft tang. There is a similar hole drilled in the distributor rotor. When installed, the drive shaft and distributor rotor holes must be aligned.**

- (3) Compress seals (40) and install drive shaft (41) in pump housing.
  - (4) Slide thrust washer (39), aligned with flat, and then spring washer (38) onto drive shaft. Secure with retaining ring (37).
- ah. Place governor arm (44, FIGURE 3-45) into position in housing. Insert governor shaft (73) through hole in housing so knife edge mates with groove in governor arm, refer to FIGURE 3-75.

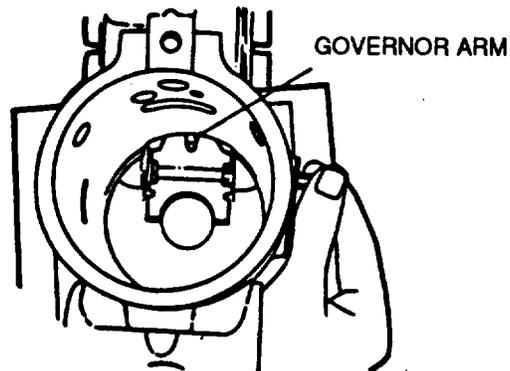


FIGURE 3-75. Installing Governor Arm

**CAUTION**

Threads on governor shaft (73) can break off if bent or dropped.

- ai. Install new seals (72, FIGURE 3-45) coated with general purpose grease (630AA) on each end of pivot shaft and install nuts (71). Tighten nuts successively 10 to 15 in-lbs (1.1 to 1.7 Nm).
- aj. Install six weights (18, FIGURE 3-52) into weight retainer (31), refer to FIGURE 3-76.

**NOTE**

The two deep grooves of sleeve (19, FIGURE 3-52) should face upward. Sight across tops of assembled weights. They should be level and collapsed against thrust sleeve.

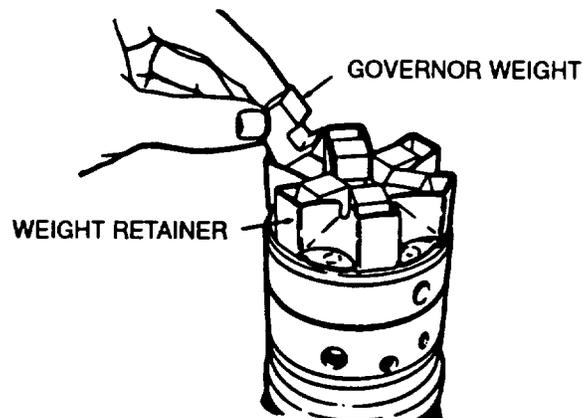


FIGURE 3-76. Installing Weights

- ak. Insert governor thrust washer (20, FIGURE 3-52) and sleeve (19) into lower slots of weights (18) by tilting weights outward slightly, refer to FIGURE 3-77.

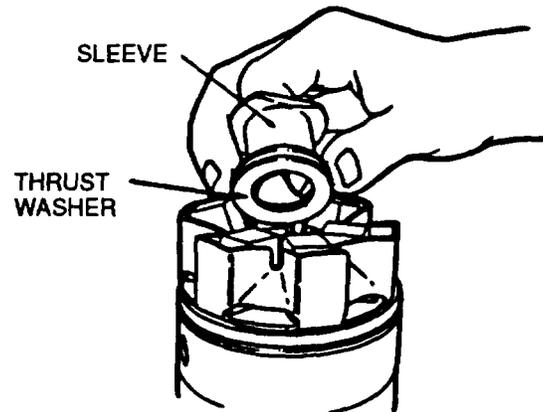


FIGURE 3-77. Installing Thrust Washer and Sleeve

- al. Apply a light film of clean general purpose grease (630AA) to preformed packing (21, FIGURE 3-52) and install in groove in hydraulic head.
- am. Apply a light film of general purpose grease (630AA) around inside edge of housing and tilt housing slightly downward at rear to aid in assembly.
- an. Rotate cam ring (24) so threaded hole is in line with metering valve bore. This ensures proper position of cam.

**CAUTION**

**Exercise care not to insert head assembly too far into housing. Pushing head in too far will damage seal on hydraulic head and result in leakage. Ensure timing mark on drive corresponds with timing mark on rotor.**

- ao. Grasp hydraulic head firmly in both hands and insert it into housing bore with a slight rotary motion. Do not force. If assembly should jam during insertion, withdraw and start over, refer to FIGURE 3-78.

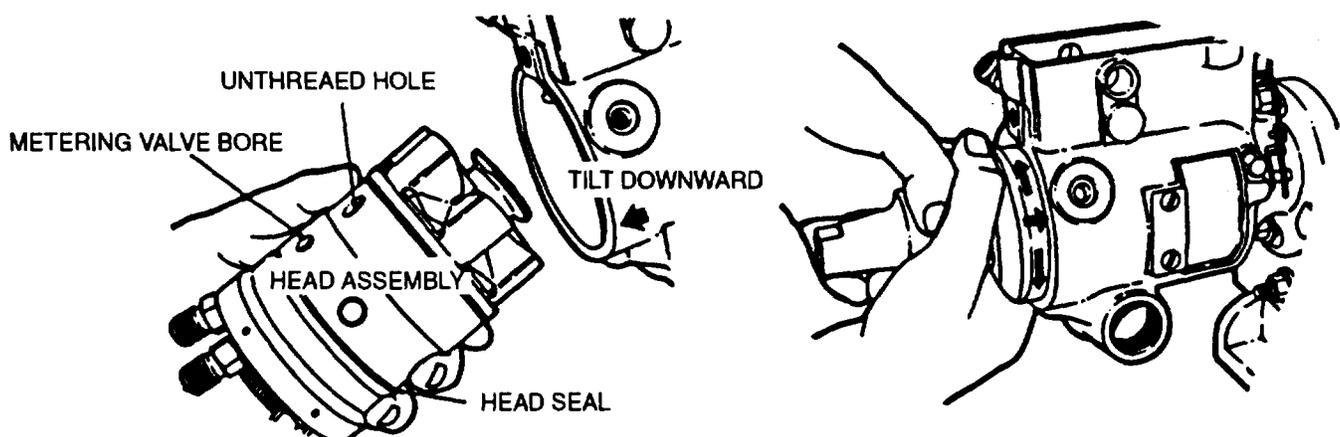


FIGURE 3-78. Inserting Hydraulic Head (Typical)

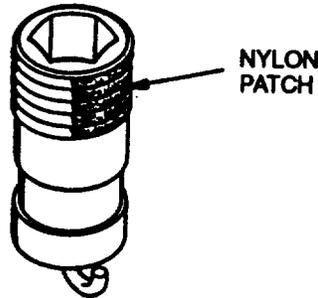
- ap. Rotate head assembly until head locking bolt holes line up with their corresponding holes in housing. Insert two locking bolts (51, FIGURE 3-45) finger tight.

- aq. To prevent governor weights from becoming dislodged when pump is fully assembled, throttle should be wired in wide open throttle (WOT) position.

**NOTE**

**Ensure nylon patch on vent wire screw assembly (50) is intact.**

- ar. Install vent wire screw assembly (50), refer to FIGURE 3-79.

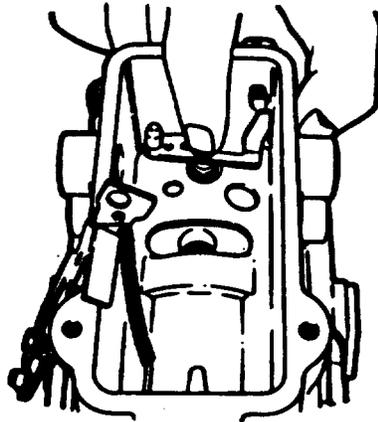


**FIGURE 3-79. Vent Wire Screw Assembly**

**CAUTION**

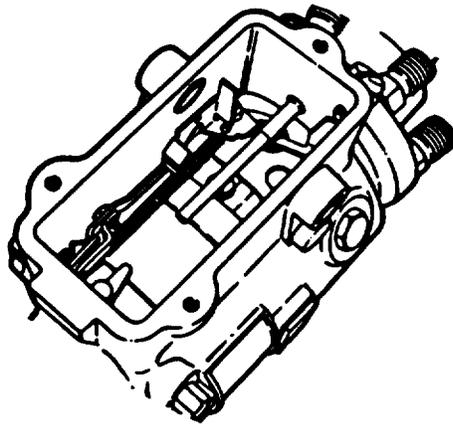
**To prevent damage to special surface treatment, never use an abrasive to clean metering valve (45).**

- as. Install spring (49), shim (48), and metering valve/arm assembly into bore in housing. Depress and rotate valve several times to ensure freedom of movement. If valve sticks, dean off with clean calibrating oil, refer to FIGURE 3-80.



**FIGURE 3-80. Installing Metering Valve**

- at. Pull back governor linkage hook (46, FIGURE 3-45), stretching spring (47) just enough to assemble hook correctly to fork on governor arm (44). Position opposite end of hook (46) over pin on arm of metering valve assembly (45), refer to FIGURE 3-81. Check all governor parts for freedom of movement.



**FIGURE 3-81. Installing Governor Linkage**

- au. Ensure bushing (8, FIGURE 3-46) on control rod assembly (5) is against control spring guide on control rod.
- av. If removed, thread spring (42, FIGURE 3-45) on tab of governor arm (44).
- aw. Thread piston assembly (43) on loose end of spring (42).
- ax. From inside pump housing (80), install control rod assembly through threaded hole.
- ay. Slide control rod guide (6, FIGURE 3-46) with washer (9) in place over end of control rod assembly and thread into housing finger tight while pushing down on metering valve assembly (45, FIGURE 3-45). Tighten 70 to 80 in-lbs (8 to 9 Nm).
- az. Insert control rod pin (4, FIGURE 3-46) into hole at end of control rod (5) and insert control rod into control rod guide (6).
- be. Install adjusting cap seal (3) into seal groove on adjusting cap (2). Apply thin film of general purpose grease (630AA) to seal.
- bb. Align roll pin slot in adjusting cap (2) with control rod pin (4) at end of control rod and slide control rod into control rod guide (6).
- bc. Thread droop control locking cap (1) onto control rod guide (6) and tighten while supporting control rod guide in place.
- bd. With bushing (8) threaded against control spring guide on control rod assembly (5), thread control spring (7) five full turns onto control spring guide. Slip free end of control spring (7) over tabs of governor arm (10) with bent-in end part of control spring between the two tabs.
- be. If necessary, assemble throttle shaft assembly as follows:
  - (1) Install a nut (40, FIGURE 3-45) on each screw (38 and 39). Install screws in shaft assembly (18).

**NOTE**

**FIGURE 3-82 indicates alignment hole for spacer (37) for this application.**

- (2) Position spacer (37) on shaft assembly (18) and secure with screw (36) in hole shown on FIGURE 3-82. Install adjusting arm (35), lever (34), spring (33), and retainer (32) on shaft assembly (18) and secure with screw (31).

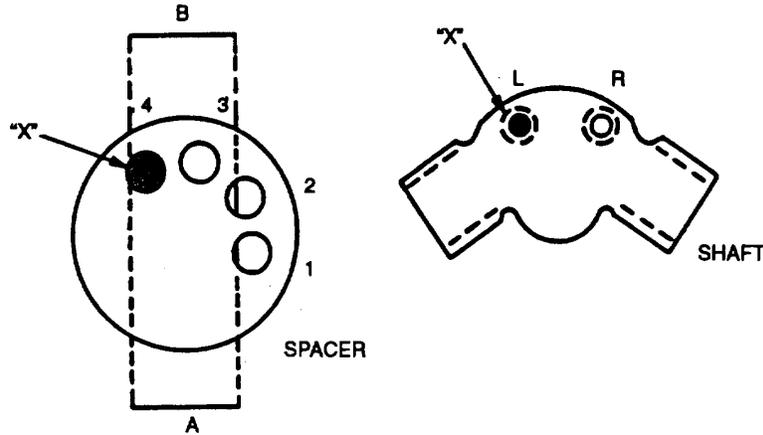


FIGURE 3-82. Alignment of Spacer

bf. If necessary, assemble shutoff lever shaft assembly as follows:

- (1) Install a nut (29) on each screw (28) and install screws (28) in shaft assembly (30).

**NOTE**

FIGURE 3-83 indicates alignment hole for adjustment shutoff arm (27) for this application.

- (2) Position adjustment shutoff arm (27) on shaft assembly (30) and secure with two washers (25 and 26), screw (23), and adjustment shutoff screw (24)

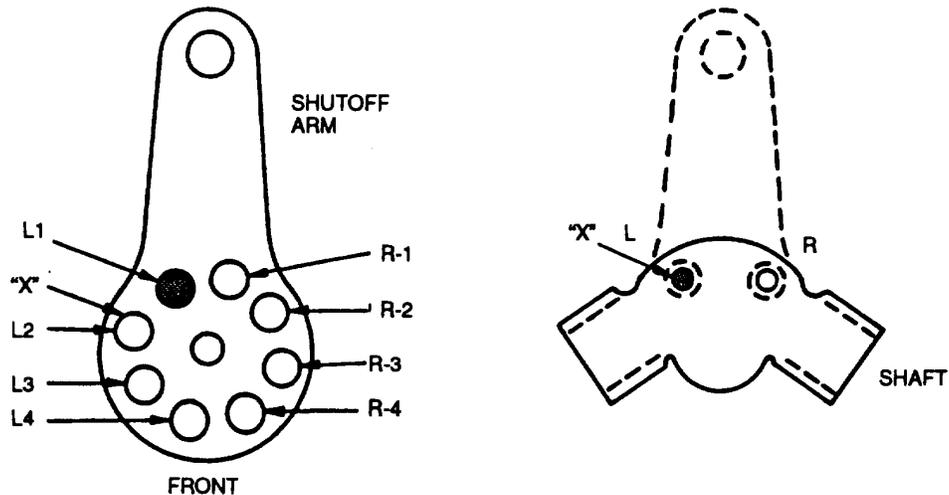
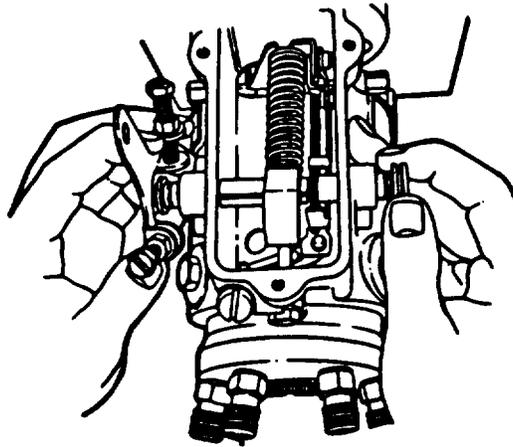


FIGURE 3-83. Alignment of Shutoff Arm

bg. Install two new washers (22) and rubber seal rings (21) using suitable tool on throttle shaft (18) and shutoff lever shaft assembly (30). Apply a light film of general purpose grease (630AA) to each seal.

- bh. Install throttle shaft assembly (18) partially through its bore in housing. Slide barrel and spacer (20) and throttle shaft lever (19) over throttle shaft so that projection in lever (19) engages rear key way on shaft. Position forked end of throttle lever so it straddles guide stud, refer to FIGURE 3-84.
- bi. Slide damper barrel assembly (41) over damper piston (43) and slide throttle shaft assembly (18) through damper barrel (41), throttle shaft spacer (20), and throttle lever (19).
- bj. With throttle shaft assembly (18) in low idle position and governor control spring relaxed, forked end of throttle lever (19) should straddle and engage flats on bushing (8, FIGURE 3-46). Adjust low idle screw (39, FIGURE 3-45) until forks of lever make contact with flats on bushing. Tighten low idle lock nut (40) 30 to 35 in-lbs (3.5 to 4 Nm).



**FIGURE 3-84. Installing Throttle Shaft Assembly (Typical)**

- bk. Turn adjusting cap (2, FIGURE 3-46) counterclockwise (from transfer pump end) to end of adjustment, then turn clockwise 1/16 of a turn. This prevents binding between control rod bushing (8) and throttle shaft lever (19, FIGURE 3-45).
- bl. Install shutoff shaft assembly (30) through its bore using a slight rotary motion so as not to damage seal ring (22). H throttle shaft lever (19) is correctly installed, rotating throttle shaft assembly rearward will cause compression of governor spring (7, FIGURE 3-46).
- bm. Invert pump and holding fixture in vise.

**CAUTION**

**If head locating screw (52, FIGURE 3-45) is not seated properly into head, seal may be sheared during tightening.**

- bn. Install new preformed packings (53) on head locating screw (52). Apply a light film of general purpose grease (630AA) to screw. Insert screw and thread deeply into head, hand tight. Using deep well socket, tighten screw 15 to 18 ft-lbs (20.3 to 24.4 Nm).

**NOTE**

**Sides of housing near advance boss are marked 'C' to denote pump rotation. The power piston side is located on side marked 'C' for clockwise rotation.**

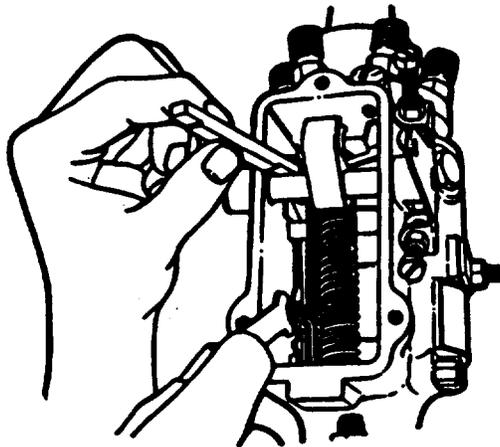
- bo. Install slide washers (70).
- bp. If necessary, install new seals (81 and 82) on plug (65)

- bq. Install gasket (68) and piston ring (67) on advance piston (66).
- br. Install advance piston (66) in plug (65).
- bs. Install piston and plug in side of housing on side marked C'.
- bt. Align advance pin hole in advance piston with unthreaded hole in cam ring. Install advance pin (69).
- bu. Install seal (55) on advance screw hole plug (54). Install plug.
- by. If necessary, install new performed packings (60 and 61), screw (62), seal (63), and nut (64) in plug (56).
- bw. Insert advance adjustment screw guide (59) in plug (56) with step facing spring.
- bx. Insert springs (57 and 58) in plug (56). Install plug (56) with inserted components into housing.
- by. Tighten advance piston hole plugs (56 and 65) 18 to 22 ft-lbs (24.4 to 29.8 Nm).
- bz. Tighten plug (54) 40 to 60 in-bs (4.5 to 6.8 Nm).
- ca. Invert pump and fixture in vise.
- cb. Hold throttle lever (19) in wide open position and rotate drive shaft clockwise until a slight click is heard as toes of governor arm (44) engage slots in thrust sleeve (19, FIGURE 3-52).

**CAUTION**

**Never back out low idle screw (38, FIGURE 3-45) or disengagement of throttle lever (19) from guide bushing could result.**

- cc. With throttle lever (19) held in wide open position, use linkage gage (18914) to check clearance between rear of shutoff shaft (30) and vertical tab on linkage hook (46), refer to FIGURE 3-85. Clearance should be 0.125 to 0.145 inch (3.175 to 3.683 mm). Adjustment of this clearance is made using a 1/4 inch wrench to change effective length of linkage hook.



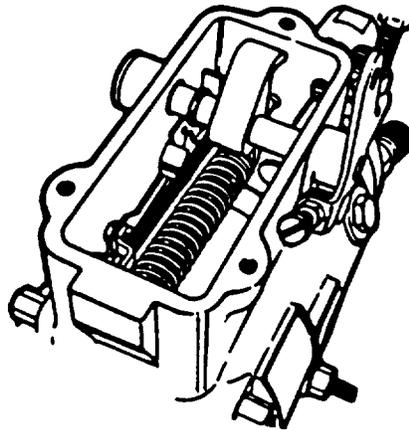
**FIGURE 3-85. Checking Clearance at Linkage Hook**

- cd. Use wrench and loosen adjusting screw (74, FIGURE 3-45). Slide linkage to maximum open length.
- ce. Insert linkage gage as above and slide linkage hook (46) together from rear until face of tab is flush against gage.
- cf. Tighten screw (74) and recheck adjustment.

**NOTE**

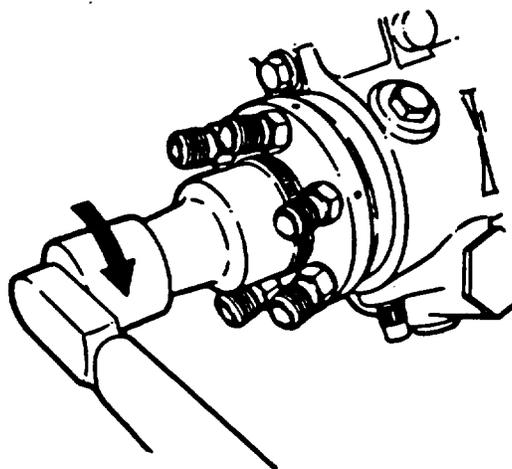
**Cam should snap into position when installed correctly.**

- cg. Compress both sides of throttle shaft (18) and shutoff shaft (30) and install a new shutoff cam (17) with straight inner edge engaging slot, refer to FIGURE 3-86.



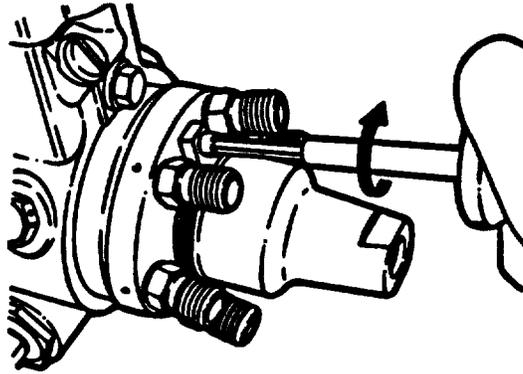
**FIGURE 3-86. Installing Shutoff Cam**

- ch. Install two insulating tubes (83, FIGURE 3-45) on solenoid terminals. Position solenoid (16) in cover (6) and secure with two new insulator washers (15), one washer (14), one new lockwasher (13), insulator (84), terminal (85), and two nuts (12).
- ci. Position washer (11), new lockwasher (10), and terminal strap (9) on solenoid studs. Secure with two self-locking nuts (8).
- cj. Position new gasket (7) and cover (6) on housing and secure with two screws (3), new lockwashers (4), and washers (5). Tighten screws 35 to 45 in-lbs (4 to 5 Nm). Install cup (88), screw (87), and cap (86).
- ck. If removed, install new preformed packing (2) and connector (1) in cover (6). Tighten connector 43 to 53 in-lbs (5 to 6 Nm).
- cl. Using end cap socket (20548), tighten end cap (5, FIGURE 3-52) using appropriate end cap wrench 30 to 33 ft-lbs (41 to 44 Nm), refer to FIGURE 3-87.



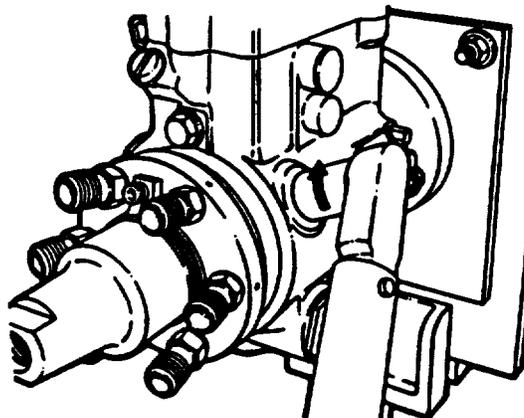
**FIGURE 3-87. Installing End Cap (Typical)**

- cm. Install new seal (4, FIGURE 3-52), retaining plate (3), and locking screw (2) in head. Tighten screw 70 to 80 in-lbs (8 to 9 Nm), refer to FIGURE 3-88.



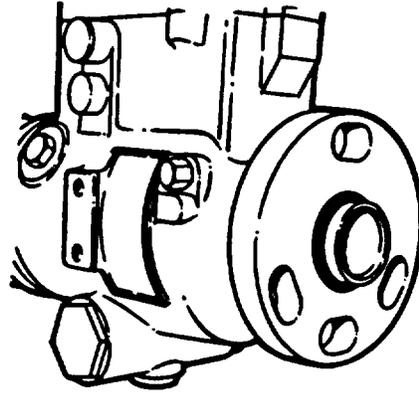
**FIGURE 3-88. Installing Retaining Plate (Typical)**

cn. Tighten both head locking bolts (51, FIGURE 3-45) 15 to 18 ft-lbs (20 to 25 Nm), refer to FIGURE 3-89.



**FIGURE 3-89. Installing Locking Head Bolts (Typical)**

- co. Remove pump from holding fixture.
- cp. Install pilot tube seal (1, FIGURE 3-52) in mounting flange end of pump, refer to FIGURE 3-90.



**FIGURE 3-90. Installing Pilot Tube Seal (Typical)**

3-27.7. Testing.

3-27.7.1 Special Test Bench Requirements.

Any test is only as good as testing equipment employed. Incorporation of quality test equipment and adherence to specifications and following test procedures will reduce testing inaccuracies to a minimum.

- a. A calibrating nozzle is required to test pump. Be sure to use only type nozzle called for in TABLE 3-4. Use of SAE/150 or if ice plate nozzle is described in SAE recommended practices J968C and J969B.
- b. Refer to TABLE 3-4 for length and ID of injection lines.
- c. Guidelines for calibrating oil are listed in SAE Recommended Practice J969b. Oil should be changed every three months or after testing 200 pumps, whichever comes first. Oil temperature in test bench must be maintained within 110 to 115°F (43.3 to 46.1 °C). Temperature reading should be taken as close to inlet as possible. Test bench should be equipped to maintain this temperature.
- d. Test bench coupling should be of self-aligning, zero backlash type. Install drive hub (67-3303). Mount and drive injection pump in accordance with test bench manufacturer's instructions.

3-27.7.2 General Test Procedure.

- a. Install applicable transfer pump inlet connector, using two wrenches so pump outlet fitting does not get moved at same time.
- b. Remove locking screw (2, FIGURE 3-52), retaining plate (3), and screw (4). Install transfer pressure gage connector (21900). Install a shutoff valve to isolate gage when not in use. Connect a pressure gage to shutoff valve.
- c. Remove timing line cover and install cam movement readout device (23745).

**NOTE**

**Rotation is clockwise when viewed from drive end.**

- d. Energize electric shutoff device with 24 VDC at lowest speed. Move pump throttle lever to full load position. When transfer pump is primed, allow fuel to bleed for several seconds from loosened injection line nuts at nozzles. After bleeding, tighten nuts securely.

### Warning

Compressed air used for cleaning can create airborne particles that may enter the eyes. Pressure will not exceed 30 psig (207 kPa). Eye protection required.

### CAUTION

Under no circumstances should 130 psi (896.4 kPa) transfer pump pressure be exceeded, to prevent damage to the pump.

### NOTE

TABLE 3-4 lists fuel delivery in cubic millimeters/stroke. Some test benches measure fuel flows in cubic centimeters (milliliters). To convert from mm<sup>3</sup>/stroke to CC's, use the following formula:

$$\text{CC's} = (\text{mm}^3/\text{stroke} \times \text{No. of strokes})/1000$$

- e. Operate pump at 250 pump rpm wide open throttle (WOT) for ten minutes. Completely dry pump off using compressed air. Observe for leaks and correct as necessary.

### CAUTION

Never back out low Idle screw or disengagement of throttle lever from guide bushing could result.

- f. Back out high idle screw.
- g. Refer to TABLE 3-4 for correct sequence of test stand adjustments.
- h. Pressurize transfer pump inlet from 1.5 to 2.5 psi (10.3 to 17 kPa).
- i. Close valve in fuel supply line. With pump running 200 pump rpm, the transfer pump must be capable of creating a vacuum of at least 18 inches (45.7 cm) of mercury. If it does not, check for air leaks between pump inlet and shutoff valve or deficiency in transfer pump.
- j. Fill graduates to bleed air from test stand and to wetten graduates.
- k. Check return oil quantity by directing return oil flow into a calibrated container for a given time. Refer to TABLE 34 for allowable quantity and pump rpm at which to make the check.

### CAUTION

Under no circumstances should 130 psi (896.4 kPa) transfer pump pressure be exceeded.

- l. Operate pump at specified speeds with wide open throttle (WOT) and observe transfer pump pressure. Pressure should be 78 to 80 psi (537.8 to 551.6 kPa). To adjust pressure, remove lines to transfer pump inlet connector and use a 5/32 inch hex key wrench to adjust pressure regulating spring plug. Clockwise adjustment increases pressure. Do no over-adjust.

**NOTE**

**Transfer pump pressure gage must be isolated by shutoff valve at injection pump when checking fuel delivery and advance movement.**

- m. Check for minimum delivery at cranking speed.
- n. Operate at high speed and adjust high idle screw to obtain specified delivery. Recheck transfer pump pressure upon completion of this adjustment.

**TABLE 3-4. Fuel Injection Pump Specifications**

Full Load RPM: 900

Governor Regulation: 3 to 5%

**NOTE**

**All speeds listed are in pump rpm unless otherwise noted.**

**Test Stand:**

1. Calibrating High Pressure Pipes SAE J1418/ISO 4093: .063" (1.6 mm) I.D. x 25" (635 mm) long
2. Calibrating Injectors SAE J968/ISO 7440: 0.5 mm Orifice Plate NOP: 3000 psi (207 Bar)
3. Calibration Fluid SAE J967/ISO 4113
  - a. Temperature at Inlet 110° - 115°F (43°-46°C)
  - b. Supply Pressure: 1.5 to 2.5 psi (10.3 to 17 kPa) at Pump Inlet
4. Cam Movement Read-Out Device: #23745
5. All fuel readings are at 1000 strokes.

**Pump Installation:**

1. Rotation Clockwise ★
2. Name Plate Left side ★★
3. No. 1 cylinder 5 O'clock ★★
4. Throttle Left Side ★★
5. Timing Mark 131.5 degrees.

★ Viewed from drive end

★★ Viewed from transfer pump end Pump Operating Speed: Half Engine Speed.

**Pump Accessories:**

1. Speed Advance
2. Speed Droop
3. Governor Dash Pot
4. Thin Fuel Components
5. Ext. Gov. Linkage
6. E.S.O. (24 E.T.R.)
7. Snubber Rotor

**Pump Calibration Checks: As Received For Service**

1. 500 RPM WOT: Operate Pump for 10 min. to bring to operating temperature and clear air from system.
2. 975 RPM: Prior to checking pump performance, reset high idle screw to obtain 10-12 mm<sup>3</sup>/stroke.
3. 875 RPM (WOT): Check housing pressure: 4 to 10 psi (28 to 69 kPa).
4. Check Points: (Sequence must be followed as listed).

**TABLE 3-4. Fuel Injection Pump Specifications - continued**

<u>RPM</u>	<u>THRTL. POS.</u>	<u>mm<sup>3</sup>/Stroke</u>	<u>Advance</u>
75	WOT	30 Min.	---
200	WOT★	4 Max.	---
262.5	WOT	---	1° - 3°
650	WOT	---	4° - 5°
875	WOT	94-98	---
875	WOT★	4 Max.	---
935	WOT	10-12	---
960	WOT	5 Max.	---

★E.S.O. De-Energized.

Pump Settings: Following Pump Service.

1. Roller to Roller Dimension: 1.986 ± .0015 (50.05 to 50.13 mm) Maximum Eccentricity: .004 in. (0.10 mm) T.I.R.
2. Gov. Linkage Gap: .125 to .165 in. (3.2-4.2 mm)
3. 500 RPM (WOT): Operate pump for 10 minutes to bring to operating temperature and clear air from system.
4. 200 RPM (WOT):
  - a. Check Shut Off: 4 mm<sup>3</sup>/Stroke, Max.
  - b. Check for minimum transfer pump lift of 18 in. HG. (60 kPa).
5. 875 RPM (WOT):
  - a. Check test stand boost pressure for 1.5 to 2.5 psi (10.3 to 17 kPa)
  - b. Set transfer pump pressure for 78 to 80 psi (538-522 kPa).
  - c. Adjust return oil to 225-475 cc/min. Substitute vent wire screws as required. Recheck transfer pump pressure.
  - d. Check housing pressure for 4-8 psi (28-59 kPa).
6. 262.5 RPM (WOT): Set advance trimmer screw for 2°.
7. 875 RPM (WOT): Set roller to roller fuel delivery 95.5-96.5 mm<sup>3</sup>/Stroke, refer to paragraph 3-27.6, steps k and l.
8. Turn speed droop adjusting cap in 2 full turns clockwise.
9. 935 RPM (WOT): Adjust high idle screw to obtain 10-12 mm<sup>3</sup>/Stroke.
10. Check points:

**NOTE: Maximum cylinder variation should be ± 4 mm<sup>3</sup>/Stroke from average flow of all cylinders.**

<u>RPM</u>	<u>THRTL. POS.</u>	<u>mm<sup>3</sup>/STROK</u>	<u>ADVANCE</u>	<u>T.P. PRESS</u>
75	WOT	32 Min.	---	★★10 Min.
200	WOT ★	4 Max.	---	---
262.5	WOT	---	1°-3°	---
650	WOT	---	4°-5°	---
875	WOT	95.5-96.5	---	★★★78-80
875	WOT★	4 Max.	---	---
935	WOT	10-12	---	---
960	WOT	5 Max.	---	---
650	WOT	---	4° - 5°	---

- ★ E.S.O. Deenergized
- ★★ (69 kPa)
- ★★★ (538-552 kPa)

**TABLE 3-4. Fuel Injection Pump Specifications - continued**

11. Special Notes:

- a. Torque all fasteners.
- b. Assemble throttle lever in B4-L position.
- c. Install shut-off arm in L1-L position.
- d. Check electric shut-off.
- e. Test bench transfer pump pressure valve should be closed except when making pressure checks.
- f. Adjust speed droop.
- g. Seal fasteners.

**LEGEND**

WOT - Wide Open Throttle  
ESO - Electric Shut Off  
ETR - Energized To Run  
NOP - Nozzle Opening Pressure  
TIR - Total Indicator Reading  
TP - Transfer Pump

**CAUTION**

**Never back out low idle screw or disengagement of throttle lever from guide bushing could result.**

- o. Adjust low idle screw to correct low idle delivery.
- p. Check cam position at specified points in speed range. Adjust trimmer screw (64, FIGURE 3-45), as required, to obtain proper advance operation. Each line on cam movement readout device (23745) equals 1/4 pump degree. After setting advance, check to see that cam returns to its initial position at zero (0) rpm. Recheck transfer pump pressure after setting advance and correct if necessary.
- q. Record fuel delivery at check points shown in TABLE 3-4. Roller settings should not be adjusted on test bench. Use of a micrometer and dial indicator settings provide more consistent, accurate results in performance.
- r. Check governor cutoff at specified speed.
- s. Check electric shutoff at speeds indicated in TABLE 3-4.
- t. Remove pump from test stand and assemble all sealing wires.

3-27.8. Installation.

**CAUTION**

**If the injection pump drive gear was removed from engine, it must be timed when reinstalled. Refer to paragraph 328..**

**NOTE**

**Time injection pump by locking No. 1 cylinder at TDC compression stroke, and align timing mark on pump cam ring with mark on governor weight retainer and/or align timing marks on pump flange with reference mark on front plate.**

NOTE

If engine front plate must be replaced, refer to paragraph 3-43.4. for transferring timing mark. No timing mark will be found on new front plate, a mark must be established and scribed.

- a. Using center bolt on harmonic balancer, rotate crankshaft until No. 1 piston is at TDC on compression stroke. Insert timing pin (JDE-81-4).
- b. Make sure woodruff key (1, FIGURE 3-91) is installed in pump shaft (2) and that it is not loose in shaft.

CAUTION

Do not drop shaft nut (4), or washer (5) into timing gear area while installing injection pump.

- c. Slide injection pump (3) onto mounting studs while inserting pump shaft into drive gear (6). Install lockwasher (5) and drive gear-to-shaft nut (4) on pump shaft (2).
- d. Install three nuts (7) new lockwashers (8), and washers (9). Tighten finger tight only at this time.

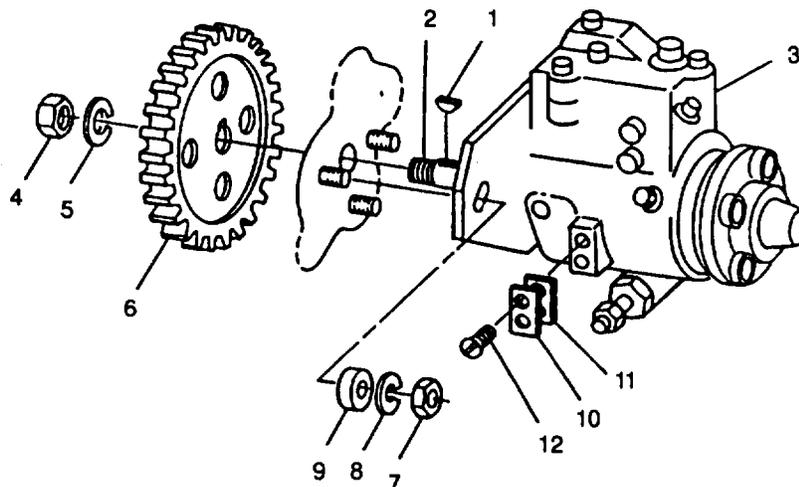


FIGURE 3-91. Fuel Injection Pump Installation

- e. Tighten drive gear-to-shaft nut (4) to 45 ft-lbs (60 Nm). Install access cover plate using a new gasket.
- f. First, pivot pump housing away from cylinder block as far as slots will allow. Then, pivot it back again, but only far enough to align timing mark on the pump flange exactly with timing mark on the cylinder block front plate. This is to take up any possible gear backlash.
- g. Tighten three mounting nuts (7) securing pump to front plate to 20 ft-lbs (27 Nm).
- h. Remove all caps and connect injection pump pressure lines. Beginning with outlet for one fuel injection line (12, FIGURE 3-41 ) and continue around the pump head in counterclockwise direction, attaching lines in same order as engine firing (1-3-4-2).

### CAUTION

**When tightening fuel pressure lines at fuel Injection pump, be sure not to turn fuel Injection pump fittings. Turning of these fittings may cause Internal pump damage.**

- i. Tighten fuel injection lines (11, 12, 13, and 14) at pump to 20 ft-lbs (27 Nm).
- j. Connect fuel tube assembly (6) to fitting (15) on fuel pump.
- k. Connect fuel supply line to fuel pump.
- l. Connect throttle control system, refer to end item maintenance manual.
- m. Position timing hole cover plate (10, FIGURE 3-91) with new gasket (11) on pump. Install two screws (12) and secure cover. Tighten screws to 17 in-lbs (2 Nm).
- n. Bleed fuel system, refer to paragraph 3-23.
- o. Remove timing pin.

### 3-28. FUEL INJECTION PUMP TIMING.

#### 3-28.1. Timing Using Flange Timing Mark.

- a. Check alignment of mark on pump flange with mark on front plate.

### NOTE

**If a timing mark does not exist on the front plate, use timing procedure in paragraph 3-28.2.**

- b. If marks are not aligned, disconnect fuel lines to pump and loosen three mounting nuts (7, FIGURE 3-91).
- c. Pivot pump housing first away from cylinder block as far as slots will allow. Then pivot it back again, but only far enough to align timing mark on the pump flange exactly with timing mark on the cylinder block front plate.
- d. Tighten three mounting nuts (7) securing pump to front plate to 20 ft-lbs (27 Nm).
- e. Connect injection pump pressure lines. Start with outlet for one fuel injection line (12, FIGURE 3-41) and continue around pump head in counter-clockwise direction, attaching lines in same order as engine firing (1-3-4-2).

### CAUTION

**When tightening fuel pressure lines at fuel Injection pump, be sure not to turn fuel Injection pump fittings. Turning of these fittings may cause internal pump damage.**

- f. Tighten fuel injection lines at pump to 20 ft-lbs (27 Nm).
- g. Connect fuel return line and fuel supply line to pump.
- h. Connect throttle control system, refer to end item maintenance manual.

#### 3-28.2. Timing Using Internal Timing Mark.

- a. Clean area around timing hole cover plate on side of pump and remove cover plate (10, FIGURE 3-91).
- b. Using center bolt on harmonic balancer, rotate crankshaft with No. 1 piston at TDC on compression stroke.
- c. Check alignment of governor weight retainer and cam ring timing marks.

- d. If marks are not aligned, disconnect fuel lines from pump and loosen mounting nuts (7, FIGURE 3-91).
- e. Rotate pump counterclockwise (viewed from flywheel end) and then in opposite direction until timing marks on cam ring and governor weight retainer are aligned.
- f. Tighten mounting nuts (7) to 20 ft-lbs (27 Nm).
- g. Install timing hole cover plate (10, FIGURE 3-91) with new gasket (11). Install screws (12) and torque to 17 in-lbs (2 Nm).
- h. Connect injection pump pressure lines. Start with outlet for one fuel injection line (12, FIGURE 3-41) and continue around pump head in counterclockwise direction, attaching lines in same order as engine firing (1 -3-4-2).

#### CAUTION

**When tightening fuel pressure lines at fuel Injection pump, be sure not to turn fuel Injection pump fittings. Turning of these fittings may cause internal pump damage.**

- i. Tighten fuel injection lines at pump to 20 ft-lbs (27 Nm).
- j. Connect fuel return line and fuel supply line to pump.
- k. Connect throttle control system, refer to end item maintenance manual.

### 3-29. FUEL INJECTION NOZZLE

#### 3-29.1. Removal.

#### Warning

**Compressed air used for cleaning can create airborne particles that may enter the eyes. Pressure will not exceed 30 psig (207 kPa). Eye protection required.**

#### NOTE

**Before removal, carefully remove all dirt from cylinder head around fuel injection nozzles. Clean with compressed air to prevent dirt from entering cylinders or valve seats. Plug bore in cylinder head after each fuel injection nozzle has been removed. Cap fuel line openings as soon as they are disconnected.**

#### NOTE

**Immediately fit protective caps over nozzle tips and line connections to avoid handling damage.**

#### NOTE

**Do not bend fuel delivery lines, as this may affect their durability. When loosening fuel pressure lines, hold male union of nozzle line stationary with a second wrench.**

- a. Loosen coupling nut (3, FIGURE 3-92) and remove tee (1) from nozzle (5). Remove and discard grommet (2).

**NOTE**

**When all fuel injection nozzles have to be removed, disconnect leak-off line assembly at fuel tank, at injection pump, and at each nozzle tee-fitting. Lift off complete leak-off line as an assembly.**

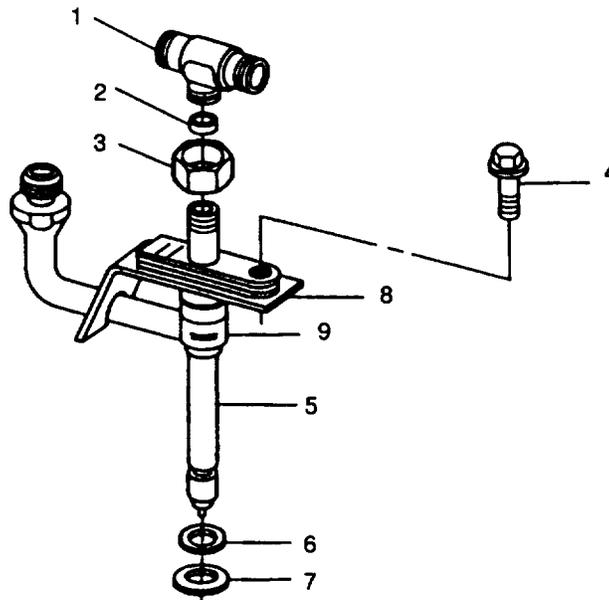
- b. Disconnect fuel injection line from nozzle. Cap openings.
- c. Remove bolt (4) securing nozzle (5) to cylinder head.
- d. Pull injection nozzle out of cylinder head with a suitable prying tool placed between bracket (8) and spacer (9).
- e. Clean nozzle bore with nozzle bore cleaning tool. Blow debris from bore with compressed air and plug bore to prevent entry of foreign material.

3-29.2. Cleaning.

**Warning**

**Cleaning solvent is flammable and toxic to eyes, skin, and respiratory tract. Skin/eye protection required. Avoid repeated/prolonged contact. Good general ventilation is normally adequate.**

- a. Remove carbon stop seal (6, FIGURE 3-92) and upper sealing washer (7), using a needlenose pliers. Discard seal and washer.



**FIGURE 3-92. Fuel Injection Nozzle**

- b. Suspend nozzles (so carbon stop seal groove is just covered) in dry cleaning solvent (P-D-680) for a few minutes.

**CAUTION**

**Do not scrape or disturb teflon coating on nozzle body above carbon stop seal groove. This coating will become discolored during normal operation, but this is not harmful. Do not use a motor-driven brush to clean nozzle body.**

- c. After soaking, clean tip with a nylon brush.

3-29.3. Testing.

3-29.3.1 General.

**Warning**

**The nozzle tip should always be directed away from operator. Fuel from spray orifices can penetrate clothing and skin causing serious personal injury. Enclosing nozzle in a transparent cover is recommended.**

**Warning**

**Before applying pressure to nozzle tester, be sure that all connections are tight, and that fittings are not damaged. Fluid escaping from a very small hole can be almost invisible. Use a piece of cardboard or wood, rather than hands, to search for suspected leaks.**

**Warning**

**If injured by escaping fluid, see a doctor immediately. Any fluid injected into skin must be surgically removed within a few hours or gangrene can result.**

- a. Connect injection nozzle to a nozzle tester.
- b. Position tip of nozzle below top of beaker and back out 30 degrees from vertical. This is necessary to contain all spray in beaker, as nozzle spray pattern is at an angle to nozzle centerline. Leave connections slightly loose.
- c. Pump tester handle for five strokes to flush air from lines and fittings and to determine pumping rate required for proper atomization. Tighten all connections securely after all air has been expelled from nozzle and line.

**CAUTION**

**Make sure that nozzle tester is in good condition and that gage works properly.**

- d. Isolate test pump gage by closing valve and flush nozzle by operating test pump rapidly.

3-29.3.2 Opening Pressure Test.

**NOTE**

**Actual opening pressure is less important than equal opening pressure of all nozzles. Maximum opening pressure difference between cylinders is 100 psi (700 kPa).**

- a. Actuate nozzle tester rapidly several times to allow valve to seat rapidly.
- b. Open gage valve and raise pressure to a point where gage needle falls rapidly. This is nozzle opening pressure, and should be a minimum of 3330 psi (22,957 kPa) for a used nozzle and 3650 to 3750 psi (25,100 to 25,800 kPa) for a new nozzle.
- c. If nozzle opening pressure is not within specified range, replace injector, refer to paragraph 3-29.4.

3-29.3.3 Chatter and Spray Pattern Test.

- a. Check nozzle chatter as follows:
  - (1) Operate nozzle tester at a pumping rate that will cause nozzle to chatter.
  - (2) Nozzle should chatter softly, and spray pattern should be broad and finely atomized.

**NOTE**

**Until the chattering range is reached, fuel will emerge in non-atomized streams.**

- (3) Using pumping rate for proper atomization, refer to paragraph 3-29.3.1, step c., operate tester for ten strokes. The nozzle must atomize on at least eight of the ten strokes without consecutive misses.
- (4) If nozzle fails to meet this requirement, repeat procedure. Nozzles which do not meet requirement after second test should be replaced.
- b. Check Spray Pattern.
  - (1) Operate nozzle tester at a pumping rate that will cause the nozzle to chatter.
  - (2) Observe spray pattern and check for plugged orifices. Partially dogged, chipped, or eroded orifices will cause the spray to deviate from correct angle. Spray will be streaky, rather than finely atomized.
  - (3) If nozzle fails to spray properly, replace it.

3-29.3.4 Leakage Test.

- a. Check nozzle for fuel leakage past valve seat as follows:
  - (1) Position nozzle on nozzle tester with nozzle tip down.
  - (2) Operate pump handle rapidly to firmly seat valve.
  - (3) Raise pressure at nozzle to about 400 to 500 psi (2800 to 3500 kPa) under specified opening pressure.
  - (4) Watch for an accumulation of fuel around the nozzle orifices.
  - (5) If fuel drips from nozzle within 5 seconds, nozzle is considered defective, and must be replaced.
- b. Check nozzle for valve stem and guide wear as follows:
  - (1) Position nozzle with tip slightly above the horizontal plane.

**Warning**

**Place a clear, protective shield around spray zone to avoid possible personal injury from spray.**

- (2) Raise pressure to 1500 psi (10,300 kPa) on test gage.
- (3) Look for leakage from return end of nozzle.
- (4) After one drop, leakage should be 3 to 10 drops in 30 seconds. Rate based on use of No. 2 diesel fuel or an equivalent viscosity of test oil at 65 to 75°F (18 to 24°C) ambient temperature.
- (5) If nozzle leakage is not within specified range, nozzle must be replaced.

#### 3-29.4. Installation.

##### 3-29.4.1 Install Seals On Nozzle.

### CAUTION

**Each time an injection nozzle is removed from cylinder head, replace carbon stop seal (6, FIGURE 3-92) with a new one.**

- a. Position protector cap (1, FIGURE 3-93) over nozzle tip. A nozzle protector cap can be found on every new or replacement nozzle.
- b. Position a new carbon stop seal (2) on protector cap. Use a new seal washer (3) to help slide the carbon seal (2) into place until it seats in its groove on nozzle body.
- c. Continue to slide seal washer (3) onto nozzle body until it seats against inlet fitting.

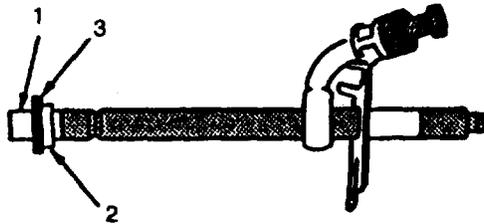


FIGURE 3-93. Fuel Injection Nozzle Seals

### NOTE

**If nozzle is not going to be installed at this time, install a nozzle protector cap over nozzle tip. Plug all other openings in nozzle to prevent contamination.**

##### 3-29.4.2 Install Injection Nozzle.

### Warning

**Compressed air used for cleaning can create airborne particles that may enter the eyes. Pressure will not exceed 30 psig (207 kPa). Eye protection required.**

### CAUTION

**Before installing Injection nozzles, make sure nozzles are clean and free from oil or grease.**

- a. Remove plug (if installed previously) from nozzle bore in cylinder head and blow out bore with compressed air.
- b. Make sure that sealing surface of the cylinder head (on which the seal washer (7, FIGURE 3-92) will be resting) is smooth and free of damage or dirt. This could prevent proper sealing. Dirt and roughness could also cause distortion to nozzle when the attaching bolt (4) is tightened, making the valve stick.
- c. Install nozzle (5) in cylinder head using a slight twisting motion as nozzle is seated in bore.
- d. Install bolt (4). Do not tighten bolt (4) at this time.

#### CAUTION

**Always use two wrenches when loosening or tightening fuel lines at nozzles to avoid damage to equipment.**

- e. Remove caps and connect fuel pressure line to nozzle. Leave connection slightly loose until air is bled from system.
- f. Tighten nozzle hold-down bolt (4) to 27 ft-lbs (37 Nm).
- g. Install leak-off line assembly. Secure with new grommet (2) and coupling nut (3).
- h. Bleed fuel system, refer to paragraph 3-23.

### 3-30. AFTER ENGINE INSTALLATION TESTING.

#### 3-30.1. Test Fuel Injection Nozzles (Engine Running).

- a. Operate engine at intermediate speed and no load.

#### CAUTION

**Always use two wrenches when loosening or tightening fuel lines at nozzles to avoid damage to equipment.**

- b. Slowly loosen fuel pressure line at one nozzle until fuel escapes at the connection (fuel not opening nozzle valve).
- c. If engine speed changes, injection nozzle is probably working satisfactory. If engine speed does not change, nozzle is faulty and must be checked and/or replaced.
- d. Repeat test for each remaining nozzle assembly.
- e. Remove faulty injection nozzles and replace, refer to paragraph 3-29.

#### 3-30.2. Fuel Drain Back Test.

#### NOTE

**Fuel draining back through fuel system may cause hard starting. This procedure will determine if air is entering system at connections and allowing fuel to siphon back to fuel tank.**

- a. Disconnect fuel supply line and fuel return line at fuel tank, refer to end item maintenance manual.

#### CAUTION

**Fuel return line must extend below fuel level in fuel tank before performing this test. Fill fuel tank if necessary.**

### Warning

**Diesel fuel is flammable and toxic to eyes, skin, and respiratory tract. Skin/eye protection required. Avoid repeated/prolonged contact. Good general ventilation is normally adequate.**

- b. Drain all fuel from system, including fuel transfer pump, fuel injection pump, and fuel filter into suitable container.
- c. Securely plug off end of fuel return line.

### CAUTION

**Maximum air pressure should be 15 psi (103 kPa) when performing this test**

- d. Using a low pressure air source, pressurize the fuel system at the fuel supply line.
- e. Apply liquid soap and water solution to all joints and connections in the fuel system and inspect for leaks.

### NOTE

**Connections may allow air to enter the system without allowing fuel to leak out f. If any leaks are found, take necessary steps to repair.**

- g. Reconnect supply and return lines and prime system.
- h. Start engine and run for approximately 10 minutes.
- i. Allow engine to sit for eight hours or overnight, then try starting engine.

## Section IX. CYLINDER HEAD ASSEMBLY MAINTENANCE

### 3-31. VALVE COVER.

#### 3-31.1. Removal.

- a. Remove eight bolts (1, FIGURE 3-94) securing valve cover (2); remove valve cover (2) and gasket (3). Discard gasket (3).
- b. Remove preformed packing (4). Discard packing (4).

#### 3-31.2. Installation.

### NOTE

**Install gasket (3, FIGURE 3-94) dry (no sealant).**

- a. Position new gasket (3, FIGURE 3-94) and valve cover (2) on cylinder head and secure with eight bolts (1). Tighten bolts to 7 ft-lbs (11 Nm).
- b. Install new preformed packing (4) in valve cover.

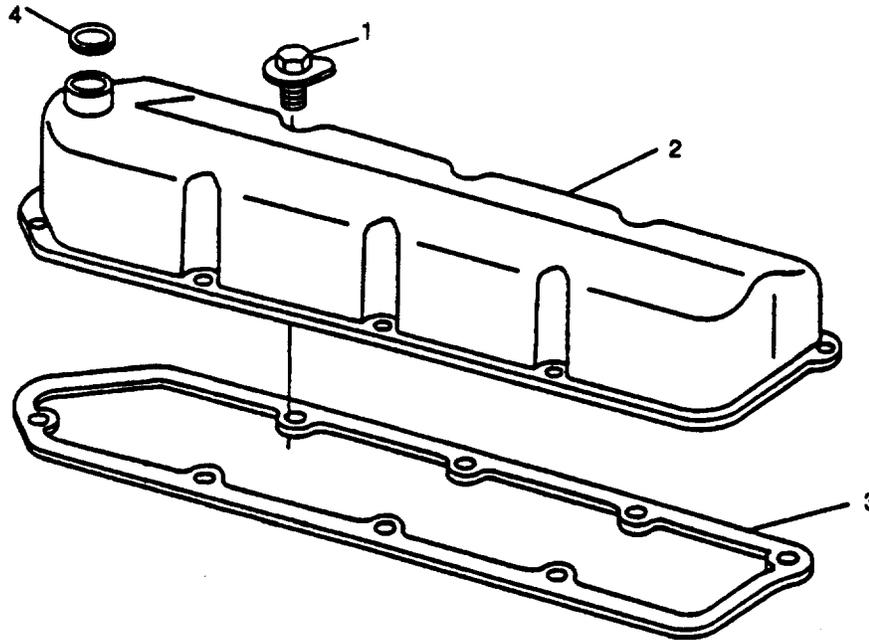


FIGURE 3-94. Valve Cover

**3-32. INTAKE AND EXHAUST VALVE CHECKS.**

3-32.1. Check and Adjust Valve Clearance.

**NOTE**

Valve clearance can be checked with engine cold or warm.

- a. Remove valve cover with ventilator tube, refer to paragraph 3-31.1.
- b. Remove plastic plugs in engine timing holes.
- c. Using center bolt on harmonic balancer, rotate crankshaft clockwise until No. 1 piston is at TDC on compression stroke.

**NOTE**

If rocker arms for No. 1 cylinder are loose, engine is at No. 1 TDC compression.

- d. Valve clearance (rocker arm-to valve tip) is:
  - (1) Intake Valve ..... 0.014 in. (0.35 mm)
  - (2) Exhaust Valve ..... 0.018 in. (0.45 mm)
- e. If valve clearance is not within specification, refer to following steps and adjust valve clearance.

**NOTE**

Excessive valve clearance indicates wear on camshaft and/or cam followers.

**NOTE**

Firing order is 1-3-4-2. Intake and exhaust valve locations are designated I and E in FIGURE 3-95.

- f. Set No. 1 piston at TDC compression stroke and install timing pin (JDE81-4) in flywheel, refer to FIGURE 3-97.

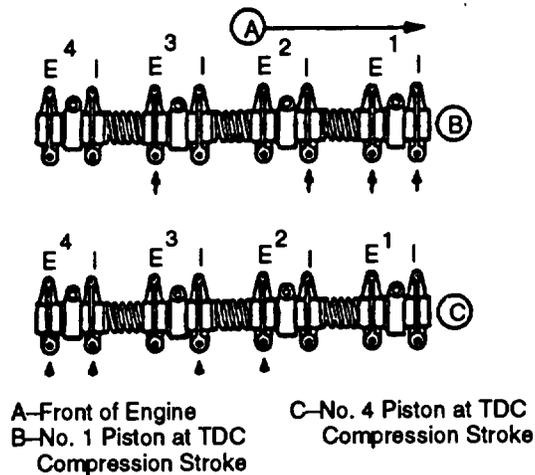


FIGURE 3-95. Adjusting Valve Clearance

- g. Adjust valve clearance on No. 1 and 3 exhaust valves and No. 1 and 2 intake valves, refer to FIGURE 3-96.  
 h. Turn crankshaft 360 degrees so that No. 4 piston is at TDC compression stroke and reinsert timing pin.  
 i. Adjust valve clearance on No. 2 and 4 exhaust valves and No. 3 and 4 intake valves.

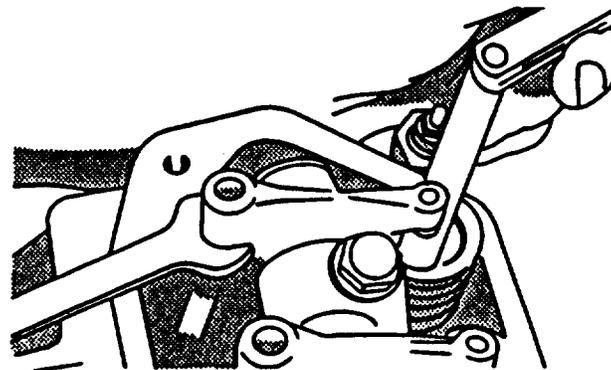


FIGURE 3-96. Checking Valve Clearance

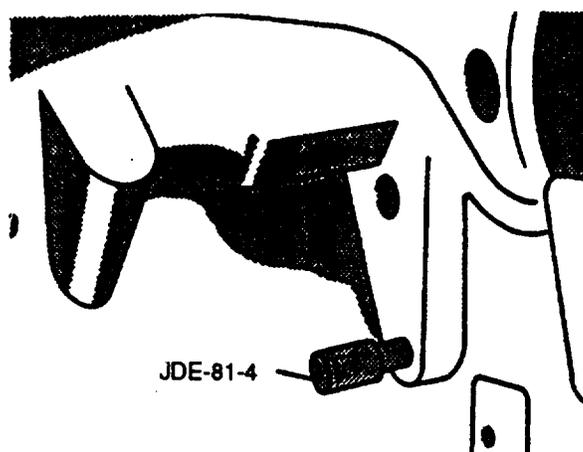
### 3-32.2. Measure Valve Lift.

Measuring valve lift can give an indication of excess wear on cam lobes, followers, and/or pushrods.

#### CAUTION

**For a more accurate measurement, it is recommended that valve lift be measured at 0.00 inch (0.00 mm) rocker arm-to-valve tip clearance.**

- a. Remove valve cover, refer to paragraph 3-31.1.  
 b. Using center bolt on harmonic balancer, rotate crankshaft clockwise and observe No. 1 pushrods. When both pushrods can be rotated freely engine is on compression stroke. Continue to rotate engine until timing pin (JDE81-4) can be installed in flywheel, refer to FIGURE 3-97.



**FIGURE 3-97. Installing Timing Pin**

- c. Set rocker arm-to-valve tip clearance to 0.00 inch (0.00 mm) by turning adjustment nut clockwise until pushrod cannot be turned by hand for No. 1 and 3 exhaust and No. 1 and 2 intake valves, refer to FIGURE 3-96.

**NOTE**

**Refer to FIGURE 3-95 for engine valve locations.**

- d. Place dial indicator tip on top of valve spring cap or rotator. Preload indicator tip and set dial at 0.00 inch (0.00 mm).
- e. Remove timing pin from flywheel and manually turn engine in running direction one full revolution (360 degrees).
- f. Observe dial indicator reading as valve is moved to full open. Record readings and compare with specifications given below.
 

Intake Valves.....	0.455 to 0.487 in. (11.56 to 12.37 mm)
Wear Tolerance.....	0.438 in. (11.13 mm)
Exhaust Valves.....	0.444 to 0.477 in. (11.28 to 12.12 mm)
Wear Tolerance.....	0.427 in. (10.85 mm)
- g. Measure all remaining valves in accordance with steps d, e, and f and record readings.
- h. If valve lift is not within specification, remove and inspect entire valve train and camshaft.
- i. If valve lift is within specification, adjust valves to specified clearance, as outlined in paragraph 3-32.1. and continue measuring lift on remaining valves.

**CAUTION**

**Rocker arm shaft bolts must be loosened and tightened a little bit at a time to avoid warping shaft.**

- j. Rotate engine clockwise and observe No. 4 pushrods. When both pushrods can be rotated freely, engine is on compression stroke. Continue to rotate engine until timing pin (JDE-81-4) can be installed in flywheel.
- k. Set rocker arm-to-valve tip clearance to 0.00 inch (0.00 mm) for No. 2 and 4 exhaust and No. 3 and 4 intake valves.

- I. Repeat step g.

### 3-33. ROCKER ARM ASSEMBLY.

#### 3-33.1. Removal.

- a. Remove valve cover, refer to paragraph 3-31.1.

#### **CAUTION**

**Capscrews (1, FIGURE 3-98) must be loosened sequentially, a little at a time, to prevent warping of shaft (7).**

- b. Remove four capscrews (1) and washers (2) securing four supports (3) to cylinder head; remove rocker arm assembly from head.
- c. Remove eight pushrods (4) and tag them as to their location. This will aid in installation.

#### 3-33.2. Disassembly.

- a. Remove plug (5, FIGURE 3-98) from one end of shaft (7). Remove two spring washers (6).

#### **NOTE**

**As each item is removed, tag it as to its location for use during assembly.**

- b. Remove eight rocker arms (8), four supports (3), and three springs (9) from shaft (7).

#### 3-33.3. Inspect and Measure.

- a. Inspect rocker arm shaft springs and measure spring tension. Spring tension at 1.81 inches (46 mm) compressed height is 4 to 6 pounds (18 to 27 N).

#### **NOTE**

**If rocker arm has been damaged by a valve failure, replace it along with the corresponding pushrod, valve rotator, and keepers.**

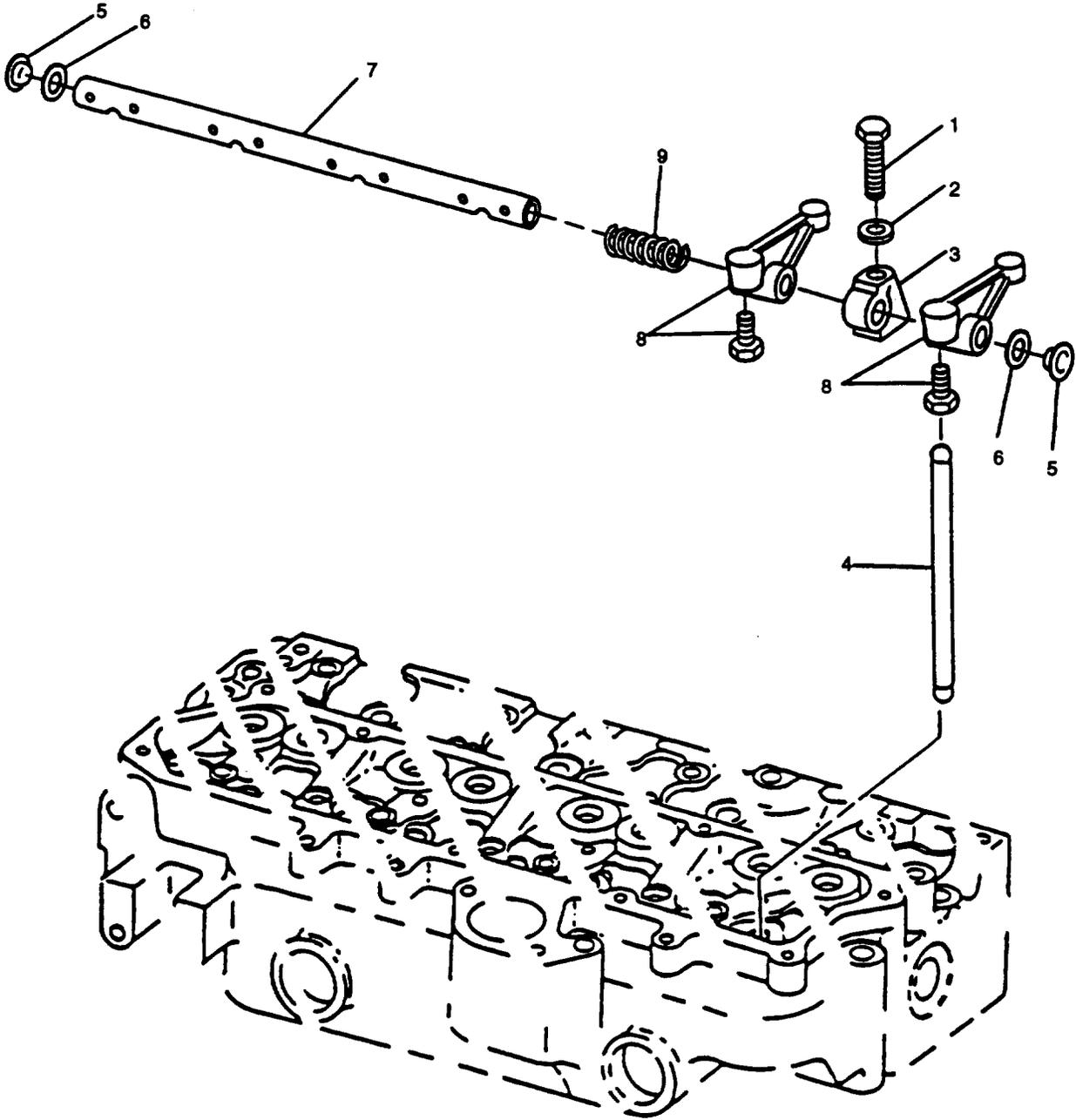


FIGURE 3-98. Rocker Arm Assembly

- b. Inspect rocker arm shaft for severe scratching, scoring, or excessive wear at points of rocker arm contact. Wear could indicate weak valve springs, bent pushrods, or loose rocker arm shaft clamps.
- c. Roll rocker arm shaft on a flat surface to check for bends or distortion. Replace shaft as necessary.
- d. Measure rocker arm shaft OD at each rocker arm location. New rocker arm shaft OD is 0.787 to 0.788 inch (19.99 to 20.02 mm). If rocker arm shaft OD is smaller than 0.785 inch (19.94 mm), install a new shaft.
- e. Inspect and measure each rocker arm shaft support ID. If ID is more than 0.794 inch (20.17 mm), install a new shaft support.
- f. Inspect and measure rocker arm ID. New rocker arm ID is 0.790 to 0.792 inch (20.07 to 20.12 mm). If rocker arm ID is over 0.794 inch (20.17 mm), install a new rocker arm.
- g. Check rocker arm adjusting screw for damage. Visually inspect rocker arm for hairline cracks. Replace if necessary.
- h. Check for cups or concave wear on ends of rocker arms where they contact valve tips. If wear exists, replace rocker arm.

**WARNING**

**Cleaning solvent is flammable and toxic to eyes, skin, and respiratory tract. Skin/eye protection required. Avoid repeated/prolonged contact. Good general ventilation is normally adequate.**

**WARNING**

**Compressed air used for cleaning can create airborne particles that may enter the eyes. Pressure will not exceed 30 psig (207 kPa). Eye protection required.**

- i. Thoroughly clean all rocker arm assembly components with dry cleaning solvent (P-D-680). Dry with compressed air.
- j. Clean pushrods with dry cleaning solvent (P-D-680) and compressed air.
- k. Check pushrods for straightness by rolling on a flat surface.
- l. Inspect pushrods for wear, damage, or any physical distortion.
- m. Replace defective pushrods that do not pass inspection.

3-33.4. Assembly.

- a. Lubricate OD of shaft (7, FIGURE 3-98), bores of rocker arms (8), and supports (3) with clean engine lubricating oil (MIL-L-2104).

**CAUTION**

**Make sure during assembly that main oil supply hole on rocker arm shaft (7) faces flywheel end, to avoid engine damage.**

- b. Slide spring (9), rocker arms (8), and rocker arm supports (3) onto shaft (7). Assemble in same order as they were before disassembly.

- c. Install spring washers (6) and plugs (5) on shaft (7). Plug must be firmly seated against end of shaft.

3-33.5. Installation.

- a. Install pushrods (4, FIGURE 3-98) in same location from which they were removed.

**NOTE**

**Valve stem tips are specially hardened, wear caps are not required.**

- b. Position rocker arm assembly on engine.

**CAUTION**

**Make sure that oil supply hole of rocker arm shaft (7) faces flywheel end of engine and faces downward when rocker shaft is installed, to avoid engine damage.**

- c. Lubricate all rocker arms (8) with engine lubricating oil (MIL-L-2104) and make sure they move freely.
- d. Position six supports (3) and secure with capscrews (1) and washers (2). Tighten capscrews to 35 ft-4bs (47 Nm).
- e. Adjust valve clearance, refer to paragraph 3-32.1.
- f. Install valve cover, refer to paragraph 3-31.2.

**3-34. CYLINDER HEAD ASSEMBLY.**

3-34.1. Removal.

- a. Drain engine coolant system, refer to end item maintenance manual.
- b. Remove air intake and exhaust system, refer to end item maintenance manual.
- c. Remove turbocharger, refer to paragraph 3-13. 1.
- d. Remove intake and exhaust manifolds, refer to paragraphs 3-15.1. and 3-14.1.
- e. Remove thermostat housing, refer to paragraph 3-9.1.
- f. Remove fuel filter, refer to paragraph 3-24.2.
- g. Remove fuel injector piping, refer to paragraph 3-26.1.
- h. Remove fuel injectors, refer to paragraph 3-29.1.
- i. Remove valve cover, refer to paragraph 3-31.1.
- j. Remove rocker arm assembly and pushrods, refer to paragraph 3-33.1.
- k. If a blown head gasket is suspected, check and record each cylinder head capscrew (1, FIGURE 3-99), torque before removing them as follows:
  - (1) Make a reference mark (in-line) on head of capscrew and cylinder head surface.
  - (2) Loosen capscrew at least 1/2 turn, then retighten capscrew (using a torque wrench) until reference marks align and record torque.
- l. Remove eighteen capscrews (1) securing cylinder head to engine block.

**CAUTION**

**To avoid damage, do not use screwdriver or pry bar between cylinder block and cylinder head to loosen head-to-block gasket seal.**

- m. Using lifting device, lift cylinder head (2) from block. If cylinder head sticks, use a soft hammer to tap the cylinder head.
- n. Remove cylinder head gasket (3), inspect for possible oil, coolant, or combustion chamber leaks. Also, check for evidence of incorrect or defective head gasket being used.

**CAUTION**

**Do not rotate crankshaft with cylinder head removed unless all cylinder liners are secured with cap screws and large flat washers.**

- o. Remove eight cam followers from bores in engine block and tag them as to their location for assembly purposes.

3-34.2. Inspect and Measure Prior to Disassembly.

- a. Measure and record valve recess dimensions for all valves using a depth micrometer or magnetic base dial indicator.

**CAUTION**

**Measurements should be made a maximum of 0.12 Inch (3.0 mm) In from edge of valve head OD.**

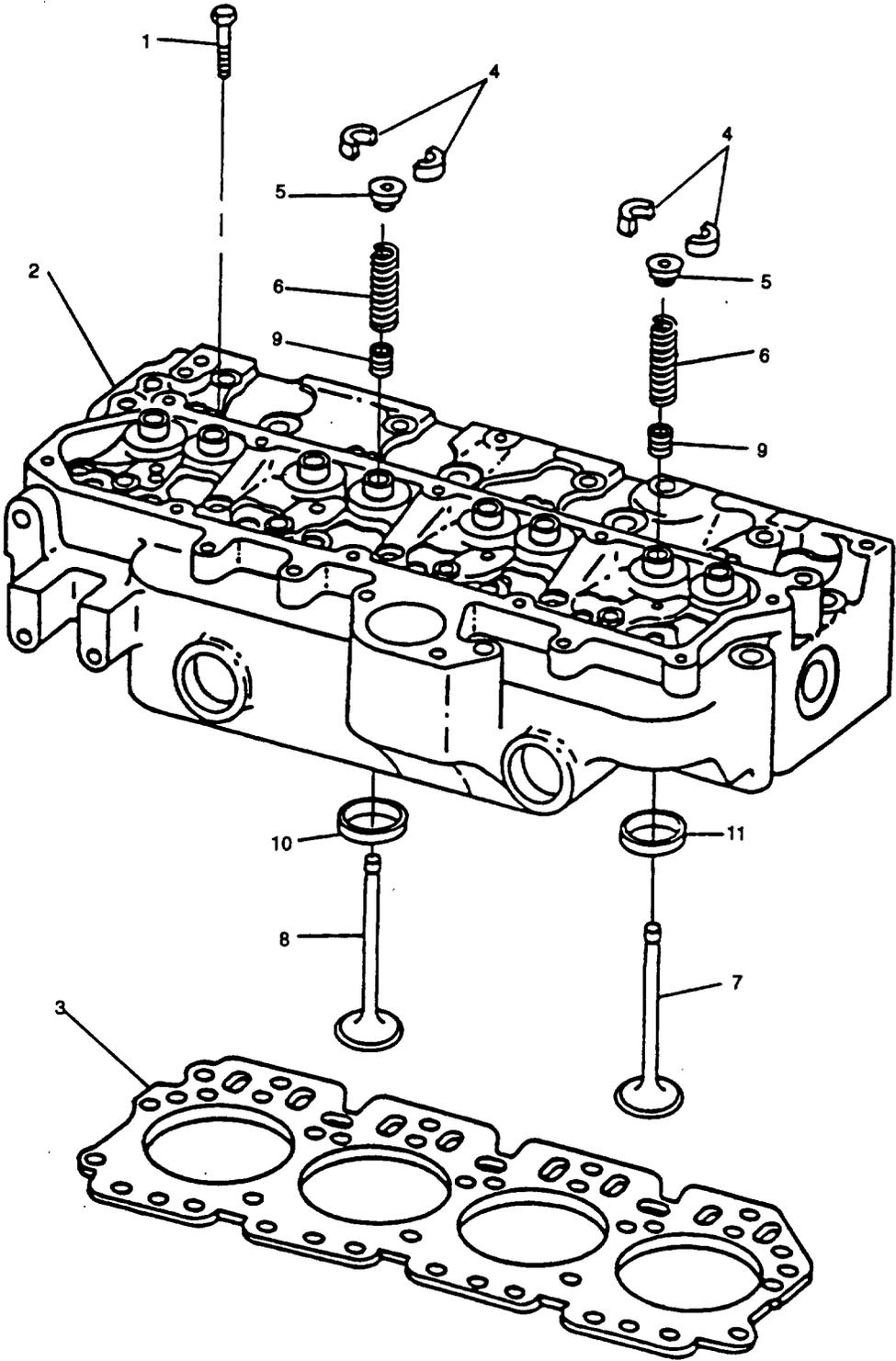


FIGURE 3-99. Cylinder Head Assembly

- b. Intake valve recess should be 0.024 to 0.044 inch (0.61 to 1.11 mm) with a maximum recess limit of 0.064 inch (1.63 mm). Exhaust valve recess should be 0.048 to 0.068 inch (1.22 to 1.72 mm) with a maximum recess limit of 0.089 inch (2.26 mm).
- c. If measurement exceeds maximum limit, install either new valves or inserts, or both to obtain proper valve recess. Grind valve seat inserts as required, refer to paragraph 3-34.4.

3-34.3. Disassembly.

- a. Make preliminary inspection of cylinder head and valve assembly during disassembly, looking for following:
  - (1) Scored Valve Stems
  - (2) Burned, Pitted, or Worn Valves and Seats
  - (3) Loose Valve Seat Inserts
  - (4) Defective Valve Rotators
  - (5) Worn Valve Guides
  - (6) Cracked Cylinder Head

**WARNING**

**Ensure each end of cylinder head is supported on blocks of wood to prevent serious Injury or death when using valve spring compressor.**

- b. Place solid blocks of wood under each end of cylinder head (2, FIGURE 399).

**WARNING**

**Do not stand in front of valve springs while compressing them to avoid personal Injury.**

- c. Using valve spring compressor, compress valve spring (6) far enough to remove valve spring locks (4).
- d. Release spring (6) tension and remove valve rotator (5) and valve spring (6).
- e. Remove valve (7 or 8) from cylinder head.

**NOTE**

**Identify all parts for correct reassembly. Use a valve board or other suitable means of keeping valves in order.**

- f. Remove valve stem seal (9) from valve guide tower.
- g. Repeat steps a through d for remaining seven valves (7 and 8).

3-34.4. Inspection and Measure.

**WARNING**

Cleaning solvent is flammable and toxic to eyes, skin, and respiratory tract. Skin/eye protection required. Avoid repeated/prolonged contact. Good general ventilation is normally adequate.

**WARNING**

Compressed air used for cleaning can create airborne particles that may enter the eyes. Pressure will not exceed 30 psig (207 kPa). Eye protection required.

- a. Inspect cam followers as follows:
  - (1) Thoroughly clean cam followers in dry cleaning solvent (P-D680) and dry with compressed air.
  - (2) Measure cam follower OD. New follower OD is 1.245 to 1.246 inches (31.62 to 31.65 mm). If cam follower OD is less than specified, install a new follower.
  - (3) Measure cam follower bore diameter in block and determine if clearance is within specification, refer to paragraph 3-47.3.c (4).
  - (4) Check crown on follower face. If flat or concave, replace follower and check camshaft lobes for wear, refer to paragraph 3-40.2.
  - (5) Coat cam followers in general purpose grease (630AA) and install in same bore from which removed.
- b. Inspect valve springs as follows:
  - (1) Inspect valve springs for alignment, wear, and damage.
  - (2) Put springs on a flat surface to see that they are square and parallel.
  - (3) Using spring compression tester, check valve spring tension.
    - (a) Spring free length is approximately 2.125 inches (54 mm). Free length of springs can differ slightly, but compressed height must be within specification.
    - (b) With a compression of 54 to 62 pounds (240 to 280 N), spring height should be 1.81 inches (46 mm). With a compression of 133 to 135 pounds (590 to 680 N), spring height should be 1.36 inches (34.5 mm).
- c. Inspect valve rotators as follows:
  - (1) There is no repair for valve rotators. Whenever valves are replaced or reground, replace the valve rotators also.
  - (2) Ensure that valve rotators turn freely in both directions. Replace if defective.
- d. Clean, inspect, and measure valves as follows:
  - (1) Thoroughly clean and inspect valves to help determine if they can be restored to a serviceable condition. Replace valves that are burned, cracked, eroded, or chipped.
  - (2) Hold each valve firmly against a soft wire wheel on a bench grinder.
  - (3) Make sure all carbon is removed from valve head, face, and unplated portion of stem.

**CAUTION**

Any carbon left on the stem will affect alignment in valve refacer if valve needs to be refaced. Do not use a wire wheel on plated portion of valve stem. Polish the valve stems with steel wool or crocus cloth to remove any scratch marks left by wire brush.

- (4) Inspect valve stem tip for excess wear from rocker arm contact.

**NOTE**

Valve stem tips are specially hardened, therefore, wear caps are not required.

- (5) Inspect valve retainer lock groove on valve stem for damage. Also, inspect stems for signs of scuffing, which may indicate insufficient valve guide-to-valve stem clearance. Replace if defects are evident.
- (6) Measure valve stem OD. Record measurements and compare with valve guide ID found in step j.
- (7) Intake valve stem OD should be 0.3096 to 0.3104 inch (7.864 to 7.884 mm) and exhaust valve stem OD should be 0.3090 to 0.3100 inch (7.848 to 7.874 mm).
- (8) Use valve inspection center (D-05058ST) to determine if valves are out of round, bent, or warped. Maximum permissible runout of valve face is 0.0015 inch (0.038 mm)
- e. Grind valves as follows:

**CAUTION**

When valve faces are ground, do not nick valve head-to-stem radius with facing stone. A nick could cause valve to break. Break all sharp edges after grinding.

Valves determined to be serviceable should be refaced to a face angle of 29.00 to 29.5 degrees, refer to FIGURE 3-1 00.

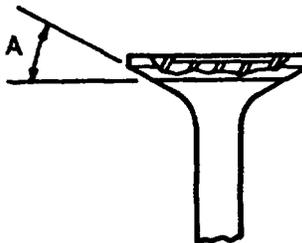


FIGURE 3-100. Valve Face Angle

- f. Inspect and clean cylinder head as follows:

**WARNING**

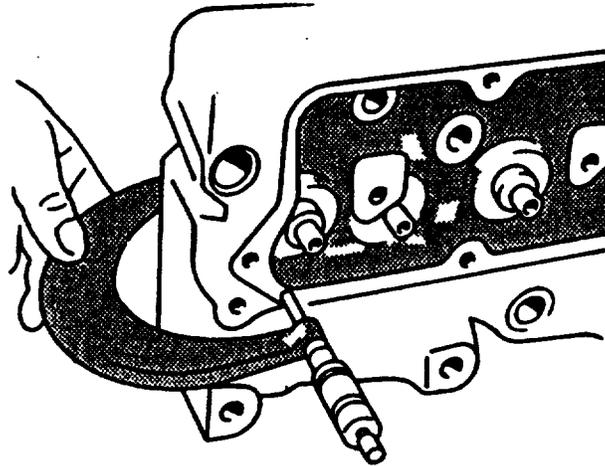
Caustic solutions are highly toxic to the skin, eyes, and respiratory tract. Avoid all contact. Skin and eye protection and vapor control are required.

- (1) Inspect all cylinder head passages for restrictions. Heads with restricted or clogged passages can be cleaned by soaking them in tank of hot caustic solution.
  - (2) Scrape all old gasket material from head. Use a powered wire brush to clean sealing surfaces.
  - (3) If cylinder head is not put in a chemical hot tank for cleaning, clean with dry cleaning solvent (P-D1680) and a brush. Dry with compressed air and be sure to blow out all passages.
- g. Clean injection nozzle bores as follows:

**CAUTION**

**To keep cleaning tool from getting dull, always turn tool clockwise through bore, even when pulling back (1) Clean carbon deposits from nozzle bores with nozzle bore cleaning tool.**

- (2) Blow debris from bore with compressed air.
- h. Check cylinder head flatness as follows:
- (1) Check cylinder head for flatness using precision straightedge and feeler gage. Check lengthwise and crosswise in several places. A good secondary check is one that is on a diagonal.
  - (2) The out-of-flat measurement must not exceed 0.005 inch (0.13 mm) for the entire length or width of head, or 0.001 inch (0.025 mm) for every 5.90 inches (150 mm) of length or width of head.
  - (3) If any measurement exceeds this specification, the cylinder head must be either reconditioned or replaced. Refer to step i and measure cylinder head thickness.
- i. Measure cylinder head thickness (FIGURE 3-101) as follows: (1) If cylinder head thickness is less than minimum allowable thickness of 4.104 inches (104.24 mm), do not resurface it. Install a new cylinder head.



**FIGURE 3-101. Measuring Cylinder Head Thickness**

- (2) If necessary to resurface cylinder head, the cylinder head thickness can be no less than 4.104 inches (104.24 mm). Remove only what is necessary to restore flatness.
- (3) After resurfacing, check for flatness as described in step h and check surface finish on combustion face of head.
- (4) Measure and record valve recess dimension for all valves, refer to paragraph 3-34.2.

- (5) Combustion face surface finish (surface grind only) should be 75AA minimum to 130AA maximum. Maximum wave depth should be 0.0005 inch (0.012 mm).
- j. Clean and measure valve guides as follows: (1) Use a plastic brush to clean valve guides before inspection or repair.

**NOTE**

**A few drops of light oil or kerosene will help to fully clean the guide.**

- (2) Using a telescopic gage, measure valve guides for wear.
  - (3) ID of valve guide bore in a new cylinder head is 0.312 to 0.313 inch (7.912 to 7.938 mm).
  - (4) New guide-to-valve stem clearance is 0.002 to 0.004 inch (0.05 to 0.10 mm).
  - (5) Maximum permissible clearance is 0.006 inch (0.015 mm).
  - (6) If valve guide oil clearance is more than maximum allowable, but not more than 0.008 inch (0.20 mm), valve guides can be knurled. Refer to step k.
  - (7) If valve guide oil clearance is over 0.008 inch (0.20 mm), intake and exhaust valves with oversize stems are available. Valve guides can be knurled and then reamed to fit oversize valve stems. Oversize valve stems are available for service in 0.015 inch (0.38 mm) or 0.030 inch (0.76 mm) sizes.
- k. Knurl, thread, and ream valve guides as follows:

**CAUTION**

**Always knurl valve guides before threading. Hand ream after threading to assure proper valve guide-to-stem clearance.**

- (1) Use knurling tool set to knurl valve guides. Use tool set exactly as directed by the manufacturer.
  - (2) After knurling, thread full circumference of valve guides for entire length of bore using a 5/1624NF modified internal thread tap with a major OD of 0.317 to 0.320 inch (8.05 to 8.09 mm).
  - (3) After threading, hand ream valve guide to finished size to provide specified stem-to-guide clearance. A 0.3105 inch (7.887 mm) OD pin must pass freely through entire length of bore after reaming.
- l. Clean and inspect valve seats as follows:
- (1) Use an electric hand drill with end brush to remove all carbon on valve seats.
  - (2) Check seats for cracks, pits, or excessive wear.
  - (3) Check entire combustion face for rust, scoring, pitting, or cracks.

**CAUTION**

**Grind valve seats to obtain correct valve recess and valve head-to-seat contact angle. Refer to paragraph 3-34.2. for recess inspection. Be sure valve guide bores are clean and serviceable (refer to step j) before grinding valve seats to maintain valve guide bore-to-seat runout. Always maintain sure footing and a balanced position. Give the work your undivided attention, otherwise engine performance will be poor.**

**NOTE**

**Always keep work area clean when grinding valve seats.**

m. Using valve seat grinding set, grind valve seats as follows:

- (1) Select a 0.3125 inch (7.9 mm) arbor that will extend approximately 2.754 inches (6.9 cm) above the valve seat. Wipe the arbor stem with an oily cloth and insert into the valve stem guide.
- (2) Select a 30 degree angle, 1.75 inch (4.4 cm) grinding stone which is in good condition and install the stone in the hex drive.
- (3) Carefully lower the stone and hex drive unit on the arbor until the stone almost contacts the seat.

**NOTE**

**Do not grind too long. only a few seconds are required to recondition the average seat. Avoid tendency to grind off too much. Do not apply excessive pressure.**

- (4) While holding the drive motor in line with the stone, grind the seat with a light tapping motion.
- (5) Remove grinding unit and arbor from head.
- (6) Check valve recess, refer to paragraph 3-34.2.
- (7) Check valve seat width and contact pattern between seat and valve with blue bearing dye (HISPOTBLUE 107). Maintain valve seat width within 0.059 to 0.079 inch (1.50 to 2.00 mm). Use a vernier caliper or scale to measure seat width.

**CAUTION**

**valve seat width is too narrow, valve may bum or erode.**

- (8) If necessary, reduce valve seat width by repeating steps (1) thru (5) using a 45 degree, 1.75 inch (4.4 cm) stone. This reduces the width by increasing the smaller diameter of the valve seating area.
  - (9) Remove arbor and recheck valve seat width, refer to step (7).
- n. Remove valve seat inserts as follows:

**CAUTION**

**Be careful not to damage cylinder head when removing valve seats.**

- (1) Valve seat inserts are made of sintered (powdered) metal. To remove inserts:
    - (a) Carefully heat insert(s) with an oxygen-acetylene torch at four opposite points until it becomes red hot.
    - (b) Use a screwdriver or similar tool and carefully pry out insert(s) from bore.
  - (2) After removal of inserts, thoroughly clean area around valve seat bore and inspect for damage or cracks. Replace cylinder head as necessary. If valve with an oversize stem is to be used, an oversize valve seat insert must be installed.
- o. Measure valve seat bore in cylinder head as follows:
- (1) Compare dimensions of bore with valve seat insert. Insert must have a press fit.
  - (2) If bore dimensions are not within specification (or head has to be bored to accept a new insert when one was not previously used), machine head to specifications listed on FIGURE 3-102.

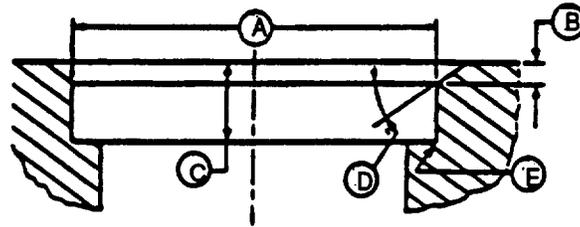
3-34.5. Assembly.

- a. Install valve inserts (10 and 11, FIGURE 3-99) as follows: NOTE If valve with an oversize stem is to be used, an oversize valve seat insert must be installed.
  - (1) Use pilot driver (JDG-676) and valve seat insert installing adapter (JDG-675) to install valve seat inserts (10 and 11) in cylinder head (2).
  - (2) Use one end of adapter (JDG-675) to install intake valve seat inserts and the other end to install exhaust valve seat inserts.
  - (3) Install valve and check valve recess, refer to paragraph 3-34.2.
  - (4) Grind valve seats as required to maintain correct valve recess and valve-to-valve seat seal, refer to paragraph 3-34.4. step m.
- b. Apply clean engine lubricating oil (MIL-L-2104) to valve stems (7 and 8) and guides.

**NOTE**

**Valves must move freely in guide bore and seat properly in head to form an effective seal.**

- c. Insert valves (7 and 8) in head (if valves are reused, insert in same guide bore from which removed).
- d. Use soft rubber mallet to install slide valve stem seals (9) over valve stems and onto valve guide tower.
- e. Position valve springs (6) in machined counterbore of head.
- f. Install valve rotators (5).
- g. Compress valve springs (6) using valve spring compressor and install valve spring locks (4) on valves.
- h. After installing valves, strike end of each valve three or four times with a soft rubber mallet to ensure proper positioning of valve spring locks (4).



Exhaust Valve Seat Insert Bore Specifications:

A.....	1.6570 to 1.6934 inches (42.087 to 43.013 mm)
B.....	0.150 inch (3.82 mm) Reference
C.....	0.3557 to 0.3962 inch (9.036 to 10.064 mm)
D.....	38 to 42 degrees
E.....	Maximum Radius 0.019 inch (0.5 mm)

Intake Valve Seat Insert Bore Specifications:

A.....	1.8516 to 1.8545 inches (47.030 to 47.104 mm)
B.....	0.136 inch (3.45 mm) Reference
C.....	0.3557 to 0.3962 inch (9.036 to 10.064 mm)
D.....	38 to 42 degrees
E.....	Maximum Radius 0.019 inch (0.5 mm)

Replacement Valve Seat Insert OD:

Intake.....	1.8565 to 1.8575 inches (47.155 to 47.181 mm)
Exhaust.....	1.6944 to 1.6954 inches (43.038 to 43.064 mm)

**FIGURE 3-102. Valve Seat Bore Specifications**

3-34.6. Inspect and Measure Before Installation.

- a. After grinding valve seats, install refaced or new valves in cylinder head and check valve recess in accordance with paragraph 3-34.2.
- b. Inspect cylinder head capscrews for corrosion damage and overall condition of threads. Any capscrew with corrosion or other defects must be replaced.
- c. Check ventilator outlet hose on rocker arm cover for bent or damaged condition. Replace if necessary. Clean ventilator hose and tube if they are restricted.
- d. Clean and inspect top deck of cylinder block as follows: (1) Remove all old gasket material, corrosion, carbon, and other foreign material from top deck. Gasket surface must be clean.

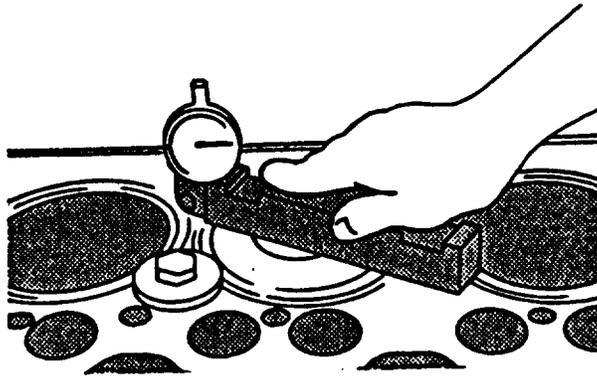
**WARNING**

**Cleaning solvent is flammable and toxic to eyes, skin, and respiratory tract. Skin/eye protection required. Avoid repeated/prolonged contact. Good general ventilation is normally adequate.**

**WARNING**

Compressed air used for cleaning can create airborne particles that may enter the eyes. Pressure will not exceed 30 psig (207 kPa). Eye protection required.

- (2) Use compressed air to remove all loose foreign material from cylinders and top deck.
  - (3) Remove cam followers from block. Wash in dry cleaning solvent (P-D-680). Lubricate with clean engine lubricating oil (MIL-L-2104) and reinstall in the same bore from which removed.
  - (4) Before cylinder head is reinstalled, clean the threaded holes in cylinder block (for cylinder head capscrews) using 1/2-13 UNC-2A tap about 4.0 inches (102 mm) long. Use compressed air to remove debris and any fluids which may be present in the capscrew holes. Replace block if there is evidence of physical damage.
  - (5) Inspect top deck for flatness and serviceability, refer to paragraph 3-47.3.
- e. Measure cylinder liner height as follows:
- (1) Bolt down liners using capscrews and flatwashers. Flatwashers should be at least 1/8 inch (3.18 mm) thick. Tighten capscrews to 50 ft-lbs (68 Nm), refer to FIGURE 3-103.
  - (2) Using gage (JDG451) and dial indicator, measure liner height.



**FIGURE 3-103. Measuring Cylinder Liner Height**

**NOTE**

Variations in measurement readings can occur within one cylinder and/or between adjacent cylinders.

- (3) Measure each liner in four places, approximately at 1, 5, 7, and 11 o'clock positions as viewed from the rear of the engine (flywheel end). Record all measurements.
- (4) Liner height above block should be 0.0004 to 0.0040 inch (0.010 to 0.100 mm).
- (5) Shim or replace any liner that does not meet height (standout) specification at any location. Refer to paragraph 3-45.2. for liner replacement instructions.
- (6) Maximum permissible height difference at nearest point of two adjacent liners is 0.0020 inch (0.060 mm).
- (7) If liner height is less than minimum specified, one liner shim only may be installed under liner flange. Two sizes of shims are available 0.002 inch (0.05 mm) and 0.004 inch (0.10 mm).

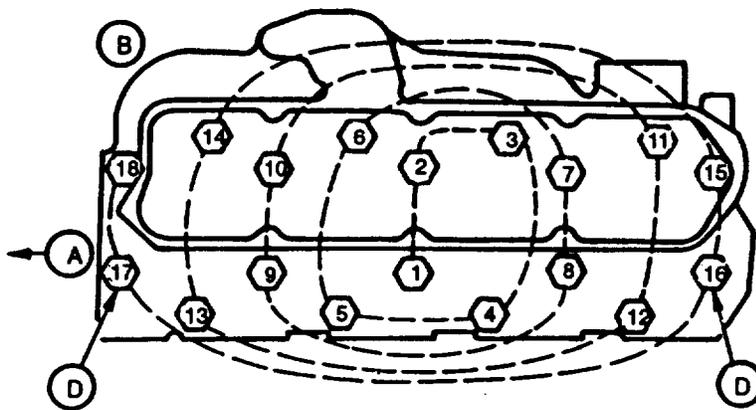
3-34.7. Installation.

- a. Perform procedures in paragraph 3-34.6.
- b. Place new cylinder head gasket (3, FIGURE 3-99) on cylinder block. Do not use sealant; install dry.

**CAUTION**

**Without guide studs, viton O-ring seal bonded in cylinder head gaskets (at rocker arm lube oil passage) could become damaged in cylinder head requires repositioning on engine block to align capscrew hole.**

- c. Install two guide studs in cylinder block (for piloting cylinder head) at locating holes 16 and 17 shown in FIGURE 3-104.



**FIGURE 3-104. Cylinder Head Capscrew Tightening Sequence**

- d. Using a lifting device, position cylinder head (2, FIGURE 3-99) over guide studs and lower into place on cylinder block.
- e. Dip entire capscrew (1) in clean engine lubricating oil (MIL-L-2104). Remove excess oil from screw.
- f. Remove guide studs. Install eighteen cylinder head capscrews (1).
- g. Tighten capscrews (1) in sequence shown in FIGURE 3-104 to torque specified below, beginning with No. 1 capscrew. Complete each step on all capscrews before proceeding to next step.
  - (1) Step 1 - Tighten all capscrews to 75 ft-lbs (100 Nm).
  - (2) Step 2 - Tighten all capscrews to 110 ft-lbs (150 Nm).
  - (3) Step 3 - Wait 5 minutes and verify 110 ft-lbs (150 Nm).
- h. After tightening capscrews (in proper sequence) to 110 ft-lbs (150 Nm), follow the steps below for each capscrew in same sequence as outlined in step g.
  - (1) Make a mark on socket and make a second mark 116 turn (60 10 degrees) counterclockwise from the first.
  - (2) Make a mark on cylinder head next to each capscrew.
  - (3) Place socket on capscrew so that first mark aligns with mark on cylinder head.
  - (4) Tighten (in sequence) all capscrews until second mark on socket aligns with mark on cylinder head.

**NOTE**

**Retorque of cylinder head cap-screws after engine break-in is not required when using the recommended torque procedure along with specified flanged-head capscrews.**

- i. Install pushrods and rocker arm assembly, refer to paragraph 3-33.5.
- j. Install valve cover, refer to paragraph 3-31.2.
- k. Install fuel injectors, refer to paragraph 3-29.4.
- l. Install fuel injector piping, refer to paragraph 3-26.3.
- m. Install fuel filter, refer to paragraph 3-24.4.
- n. Install thermostat housing, refer to paragraph 3-9.4.
- o. Install intake and exhaust manifolds, refer to paragraphs 3-15.3. and 3-14.3.
- p. Install turbocharger, refer to paragraph 3-13.4.
- q. Install air intake and exhaust system, refer to end item maintenance manual.
- r. Service lubrication and coolant systems, refer to end item maintenance manual.
- s. Run engine at specified slow idle no load for 2 minutes, check for liquid leaks.
- t. Increase engine rpm to specified fast idle, then load down to 50 rpm above specified rated speed for 20 minutes.
- u. Recheck valve clearances and adjust, as necessary, refer to paragraph 3-32.1.
- v. Install valve cover, refer to paragraph 3-31.2.

**Section X. FLYWHEEL AND HOUSING ASSEMBLY MAINTENANCE**

**3-35. FLYWHEEL.**

**335.1. Removal.**

- a. Remove starter, refer to paragraph 312.2.

**WARNING**

**Flywheel is heavy. Provide adequate lifting device to support weight. Failure to follow this procedure could result in personal injury.**

- b. Remove two capscrews (1, FIGURE 3-105) and washers (2). Replace these with two guide studs.
- c. Remove other two capscrews (1) and washers (2). Install these two capscrews in threaded holes of flywheel (3).
- d. Use two capscrews in step b to jack flywheel (3) off crankshaft.
- e. Remove flywheel (3) and two capscrews (1).

**3-35.2. Repair.**

- a. If ring gear (4, FIGURE 3-105) is damaged, place the flywheel (3) on a solid flat surface.
- b. Drive ring gear (4) off with a brass drift and hammer.

**WARNING**

Oil fumes or oil can ignite above 380°F (193°C). Use a thermometer and do not exceed 360°F (182°C). Do not allow a flame or heating element to be in direct contact with oil. Heat oil in a well ventilated area. a safe handling procedure to avoid burns. Wear protective clothing, gloves, apron, etc.

**WARNING**

Wear protective gloves to help prevent burns from handling hot ring gear (4).

**CAUTION**

If flame heat is used, be sure gear is heated uniformly around circumference. Do not overheat. Overheating may also destroy original heat treatment of gear.

- c. Heat new ring gear (4) to 300°F (148°C) using either heated oil, oven heat, or flame heat.
- d. Turn gear so side with chamfer is toward engine with flywheel installed.
- e. Install ring gear (4) against shoulder of flywheel.

3-35.3. Installation.

**WARNING**

Flywheel is heavy. Provide adequate lifting device to support weight. Failure to follow this procedure could result in personal injury.

**NOTE**

Flywheel must be clean and free of any oil, grease, or debris.

- a. Apply adhesive (LOCTITE 242) to threads of four new capscrews (1, FIGURE 3-105).
- b. Install two guide studs in crankshaft capscrew threaded holes. Place flywheel (3) on studs and slide into position against crankshaft.

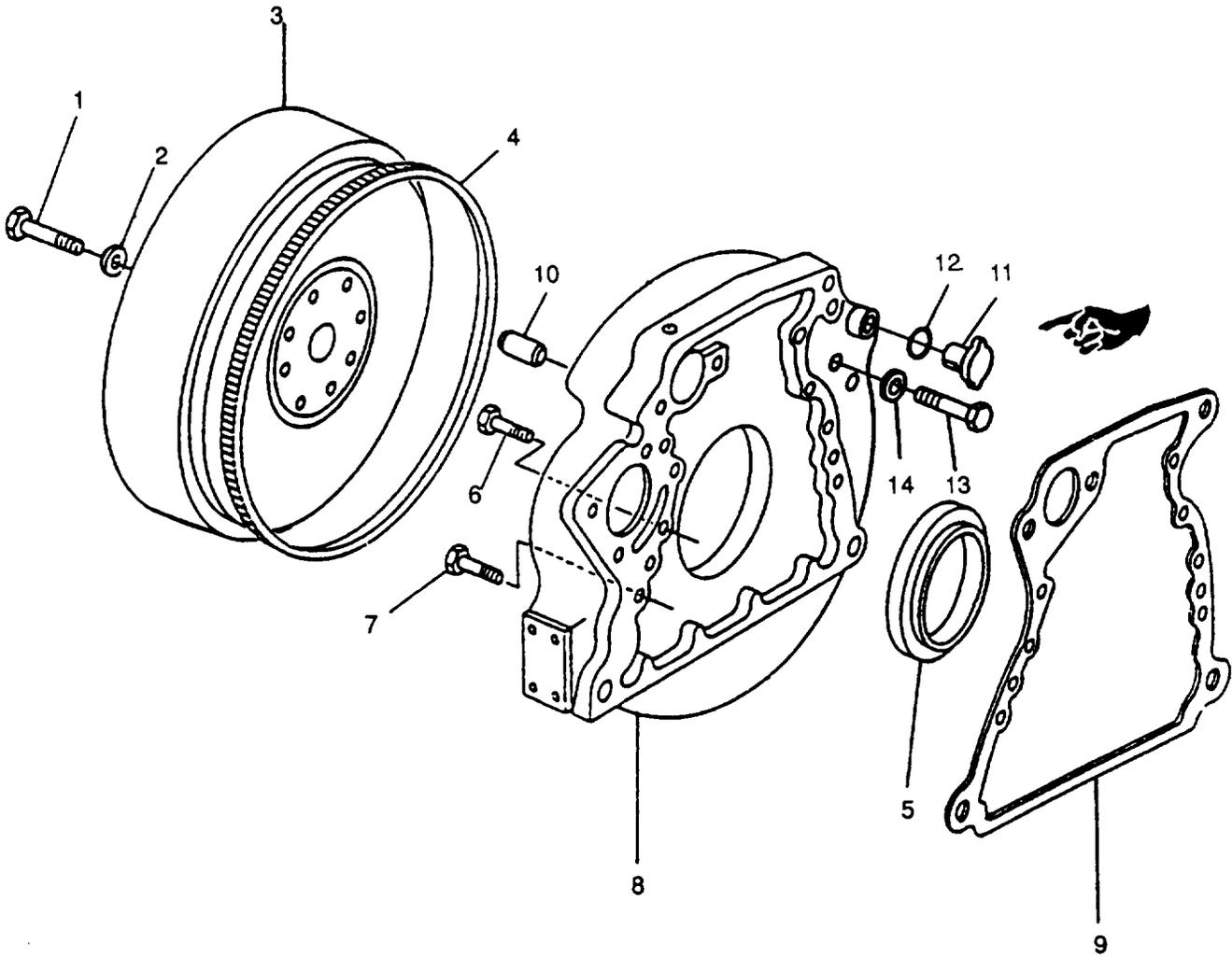


FIGURE 3-105. Flywheel and Housing Assembly

- c. Stan two capscrews (1) and washers (2) in crankshaft. Do not tighten until guide studs are removed and other two capscrews (1) and washers (2) are started.
- d. Install timing pin (JDE-81-4) to hold flywheel in place while tightening capscrews.
- e. Tighten capscrews (1) to 120 ft-lbs (163 Nm).
- f. Install starter, refer to paragraph 3-12.7.

### 3-36. REAR CRANKSHAFT OIL SEAL/WEAR SLEEVE ASSEMBLY.

#### 3-36.1. Removal.

- a. Remove flywheel, refer to paragraph 3-35.1.
- b. Drill a small hole through seal casing at three locations (equally spaced).
- c. Use a slide hammer/puller and a sheet metal screw to pull seal (5, FIGURE 3-105) from housing. Discard seal.

#### **CAUTION**

**Do not gouge flange of crankshaft with chisel. Nicks or burrs should be removed with a medium grit stone or polishing cloth (180 grit or finer).**

- d. Carefully cut wear sleeve off crankshaft flange using a small cold chisel.

#### **WARNING**

**Cleaning solvent is flammable and toxic to eyes, skin, and respiratory tract Skin/eye protection required. Avoid repeated/prolonged contact. Good general ventilation is normally adequate.**

#### **NOTE**

**The unitized design will not allow the seal to be separated from the wear sleeve without destroying the sleeve.**

- e. Clean OD of crankshaft flange with cleaning solvent P-D-680 remove sealant from flange.
- f. Look for nicks or burrs on wear ring surface and bore in flywheel housing. If necessary, use polishing cloth.
- g. Finish cleaning by wiping flange with a clean rag.

#### 3-6.2. Installation

#### **WARNING**

**Cleaning solvent is flammable and toxic to eyes, skin, and respiratory tract Skin/eye protection required. Avoid repeated/prolonged contact Good general ventilation is normally adequate. Failure to follow this procedure could result in personal injury or death.**

- a. For proper adhesion and sealing, clean OD of crankshaft flange and ID of wear ring with dry cleaning solvent (P-680) just prior to application of sealant. Make sure that OD of crankshaft flange and ID of seal housing bore are free from nicks or burrs.

- b. Apply a light coating of sealing compound (MIL-R-46082) retaining sealant completely around the leading edge of crankshaft flange. Wipe away any sealant that may have gotten on seal housing bore.
- c. Install pilot from tool set (JT30040) on end of crankshaft using two capscrews. Tighten both capscrews securely. Make sure tool contacts face of crankshaft.
- d. Carefully start oil seal/wear sleeve over pilot and crankshaft flange with open side of seal toward engine.
- e. Attach driver and thrust washer to guide plate with capscrew. Tighten the capscrew until driver bottoms on pilot.
- f. Remove capscrew thrust washer, driver, two capscrews, and guide plate.
- g. Install flywheel, refer to paragraph 3-35.3.

### **3-37. FLYWHEEL HOUSING.**

#### **3-37.1. Removal.**

- a. Remove flywheel, refer to paragraph 3-35.1.
- b. Remove oil seal/wear sleeve (5, FIGURE 3-105), refer to paragraph 3-36.1.
- c. Support weight of flywheel housing (8) and remove eight 3/8-inch capscrews (6) and four 5/8-inch capscrews (7) securing housing to engine block; remove housing (8) and gasket (9). Discard gasket (9).

#### **3-37.2. Inspect and Measure.**

- a. Inspect flywheel housing for cracks or other damage.
- b. Remove all traces of gasket from mating surfaces of flywheel housing and engine block.
- c. Inspect dowel pins (10, FIGURE 3-105) for damage. Replace if damaged.
- d. Remove and inspect plug (11) and preformed packing (12) for damage. Replace if damaged. Otherwise, install preformed packing (12) and plug (11).
- e. Remove and inspect bolt (13) for damage. Replace if damaged. Otherwise, install bolt (13).
- f. Check Total Indicator Reading (TIR) of flywheel housing seal bore ID.

- (1) Attach magnetic base of dial indicator to flywheel end of crankshaft.
- (2) Position dial indicator against ID of seal bore in flywheel housing.
- (3) Turn crankshaft 360 degrees at front of engine, using center bolt on harmonic balancer. Maximum permissible TIR is 0.006 inch (0.152 mm). If run-out exceeds limit, replace flywheel housing.

3-37.3. Installation.

**CAUTION**

**Flywheel housing gasket must contain a silicone bead. If no bead is present, apply a thin bead of sealing compound (LOCTITE 77BR) to gasket to prevent oil leakage.**

- a. Install new silicone bead/gasket (9, FIGURE 3-105) on block. Gasket should be a silicone bead.

**NOTE**

**Dip threads of capscrews (6 and 7) in clean engine lubricating oil (MIL-L-2104).**

- b. Position flywheel housing (8) on engine block.
- c. Install eight 3/8-inch capscrews (6) and four 5/8-inch capscrews (7). Torque 3/8-inch capscrews (6) to 22 ft-lbs (30 Nm) initially and retorque to 35 ft-lbs (47 Nm). Torque 5/8-inch capscrews (7) to 170 ft-lbs (230 Nm).
- d. Install crankshaft rear oil seal/wear sleeve (5), refer to paragraph 3-36.2.
- e. Install flywheel, refer to paragraph 3-35.3.
- f. Service engine lubrication system, refer to end item maintenance manual.

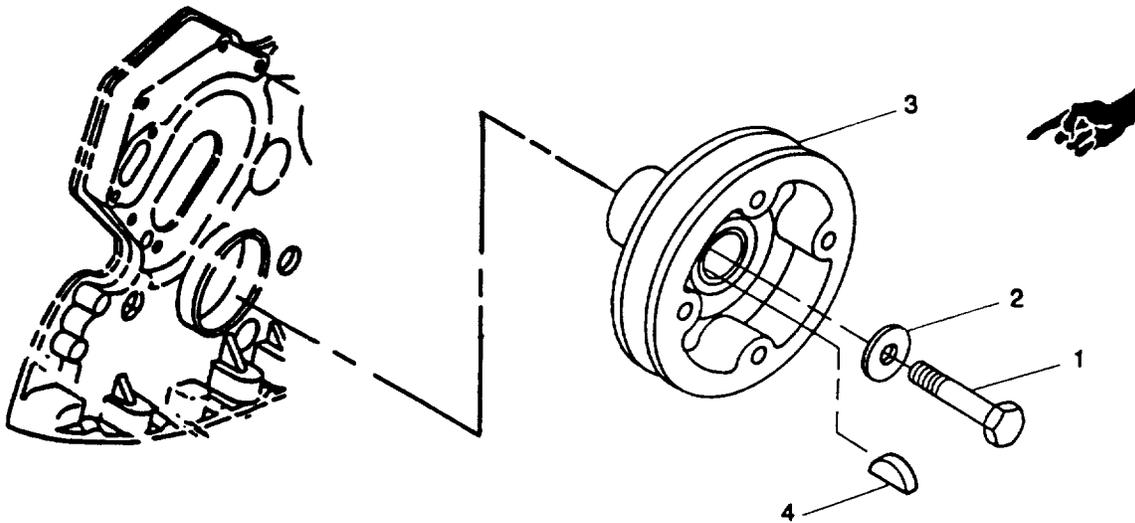
- f. Service engine lubrication system, refer to end item maintenance manual.

## Section XI. CRANKSHAFT PULLEY AND TIMING GEAR COVER ASSEMBLY MAINTENANCE

### 3-8. CRANKSHAFT PULLEY.

#### 3-38.1. Removal.

- a. Remove fan drive belt, refer to end item maintenance manual.
- b. Remove fan, refer to end item maintenance manual.
- c. Remove capscrew (1, FIGURE 3-106) and washer (2) securing crankshaft pulley (3).
- d. Using suitable puller, remove pulley (3) from crankshaft. Remove key (4).



**FIGURE 3-106. Crankshaft Pulley**

#### 38.2. Inspection.

- a. Inspect pulley for cracks and wear.
- b. Inspect key for damage.

#### 3-38.3. Installation.

- a. Install key (4, FIGURE 3-106) in crankshaft.
- b. Install crankshaft pulley (3) on crankshaft and secure with capscrew (1) and washer (2). Tighten capscrew to 110 ft-lbs (150 Nm)
- c. Install fan, refer to end item maintenance manual.
- d. Install fan drive belts, refer to end item maintenance manual.

### 3-39. TIMING GEAR COVER.

#### 3-39.1. Removal.

- a. Drain lubrication system, refer to end item maintenance manual.
- b. Remove fan drive belts and fan, refer to end item maintenance manual.

- c. Remove water pump, refer to paragraph 3-10.1.
- d. Remove battery charging alternator and alternator mounting bracket, refer to paragraph 3-11.1.
- e. Remove oil filler assembly, refer to paragraph 3-18.1.
- f. Remove oil cooler hoses and mounting bracket, refer to paragraph 3-16.1.
- g. Remove crankshaft pulley, refer to paragraph 3-38.1.
- h. Remove gasket between timing gear cover and oil pan.
- i. Remove oil pressure regulating valve, refer to paragraph 3-17.1.
- j. Remove ten capscrews (1, FIGURE 3-107), two capscrews (2), fourteen washers (3), and two nuts (4) securing timing gear cover (6); remove cover (6) and gasket (7) from engine block. Discard gasket (7).
- k. Using suitable driver, remove seal (5) from front cover.
  - l. Remove two studs (9) from engine block.
- m. Remove two capscrews (10) and washers (11) securing access cover (12); remove cover and gasket (8). Discard gasket.

3-39.2. Inspection.

**WARNING**

**Cleaning solvent is flammable and toxic to eyes, skin, and respiratory tract. Skin/eye protection required. Avoid repeated/prolonged contact. Good general ventilation is normally adequate.**

**WARNING**

**Compressed air used for cleaning can create airborne particles that can enter the eyes. Pressure will not exceed 30 psig (207 kPa). Eye protection required.**

- a. Remove all old gasket material and sealant from gasket surface on cylinder block and timing gear cover.
- b. Clean cover in dry cleaning solvent (P-D-680) and dry with compressed air.
- c. Inspect cover for cracks or damage. Make sure that seal bore is clean and not nicked.

3-39.3. Installation.

- a. Install access cover (12, FIGURE 3-107) and new gasket (8) on timing gear cover (6) and secure with two capscrews (10) and washers (11).
- b. Install two studs (9) in engine block.

**CAUTION**

**Do not install seal (8) with timing gear cover mounted on engine, otherwise damage to cover resulting in leakage could occur. Use wood blocks to support back side of timing gear cover, otherwise damage could occur.**

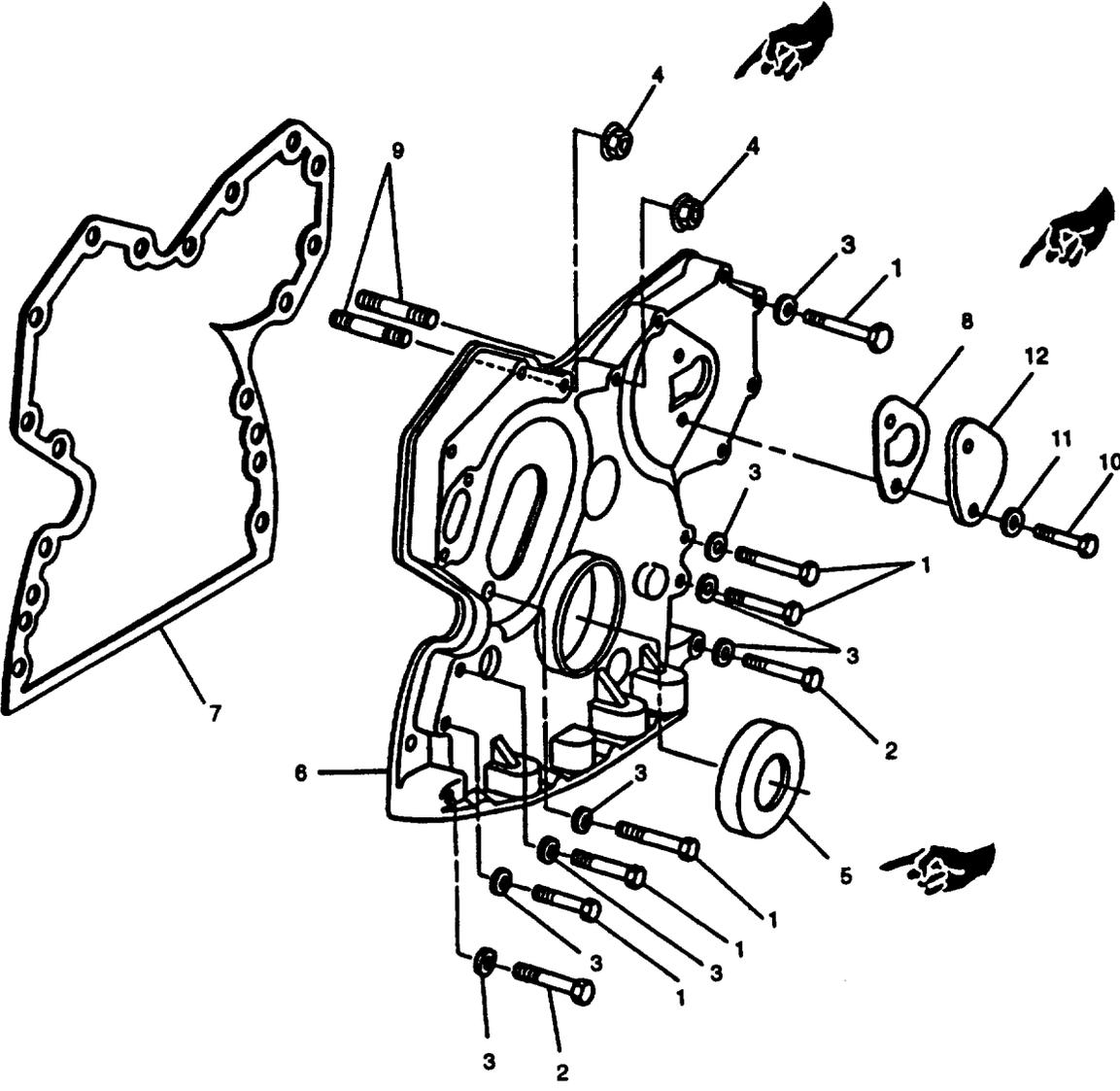


FIGURE 3-107. Timing Gear Cover

**NOTE**

**Seal case has dry sealant, do not add sealant.**

- c. Support back side of timing gear cover with wood blocks.
- d. Using a seal installer, install oil seal (5) to bottom of bore with spring loaded lip facing inward while supporting seal bore area from back side of cover.
- e. Make sure gasket surfaces on cover (6) and front plate are clean.
- f. Apply a light coating of sealing compound (FORMAGASKET2) to cylinder block side of a new gasket (7). Position gasket (7) on timing gear cover (6) and trim bottom of gasket (7).
- g. Put light coating of engine lubricating oil (MIL-L-2104) on oil seal (5) lips.

**CAUTION**

**Do not invert crankshaft front oil seal main (inner) lip. Make sure that this seal lip faces inward towards crankcase to prevent oil leakage. Dust lip (outer) faces installer away from crankcase.**

- h. Install timing gear cover (6) on engine.
- i. Rotating cover back and forth slightly to engage seal (8) lip as cover is pushed into position, secure U timing gear cover (6) with two nuts (4), fourteen washers (3), two capscrews (2), and ten capscrews (1). Tighten fasteners to 35 ft-lbs (47 Nm).
- j. Install oil pressure regulating valve, refer to paragraph 3-17.3.
- k. Make and install gasket between timing gear cover and oil pan.
- l. Install crankshaft pulley, refer to paragraph 3-38.3.
- m. Install oil filler assembly, refer to paragraph 3-18.3.
- n. Install battery charging alternator and alternator mounting bracket, refer to paragraph 3-11.6.
- o. Install water pump, refer to paragraph 3-10.4.
- p. Install fan and fan drive belts, refer to end item maintenance manual.
- q. Service lubrication system, refer to end item maintenance manual.

**Section XII. CAMSHAFT ASSEMBLY MAINTENANCE**

**3-40. CAMSHAFT.**

3-40.1. Removal.

**NOTE**

**Measuring valve lift can give an indication of wear on cam lobes or cam followers.**

- a. Measure valve lift, refer to paragraph 3-32.2.
- b. Remove rocker arm assembly and pushrods, refer to paragraph 3-33.1.
- c. Remove timing gear cover, refer to paragraph 3-39.1.
- d. Measure camshaft end play, refer to paragraph 3-40.2.
- e. When removing camshaft (3, FIGURE 3-108) with engine on rollover stand, roll engine to a horizontal position with oil pan side up.

**NOTE**

**It is not necessary to remove cylinder head to remove camshaft. If camshaft lobes show excessive wear, then cylinder head should be removed so cam followers (2) can be removed for inspection.**

- f. Remove fuel supply pump, refer to paragraph 3-25.1.
- g. Turn crankshaft until capscrews (1) can be removed through holes in gear (5).
- h. Remove two capscrews (1).

**CAUTION**

**Do not allow camshaft lobes to drag on cylinder block honed bore surfaces while removing camshaft.**



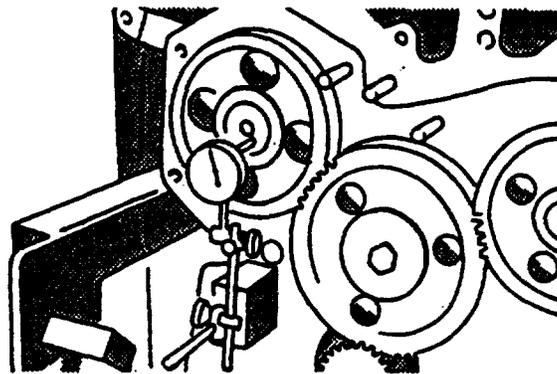
- i. Pull camshaft (3) straight up, out of cylinder block Remove thrust plate (4).
- j. If necessary, remove gear (5) from camshaft (3) using an arbor press. Remove key (6).

3-40.2. Inspect and Measure.

- a. Use a dial indicator and measure camshaft end play, refer to FIGURE 3-109. New camshaft end play is 0.002 to 0.009 inch (0.05 to 0.23 mm). Maximum allowable end play is 0.015 inch (0.38 mm).

**NOTE**

**If end play is excessive, check thrust plate thickness using a new thrust plate and a feeler gage after camshaft is removed, refer to step c. If camshaft end play is correct, measure timing gear backlash.**



**FIGURE 3-109. Measuring Camshaft End Play**

- b. Clean and inspect camshaft and thrust plate as follows:

**WARNING**

**Cleaning solvent is flammable and toxic to eyes, skin, and respiratory tract. Skin/eye protection required. Avoid repeated/prolonged contact. Good general ventilation is normally adequate.**

**WARNING**

**Compressed air used for cleaning can create airborne particles that may enter the eyes. Pressure will not exceed 30 psig (207 kPa). Eye protection required.**

- (1) Clean camshaft and thrust plate in dry cleaning solvent (P-680). Dry with compressed air.
- (2) Visually inspect camshaft lobes and journals for wear or damage. Replace as necessary. New cam followers can be used with old camshaft (if camshaft is serviceable). However, do not reuse old cam followers with a new camshaft.

**NOTE**

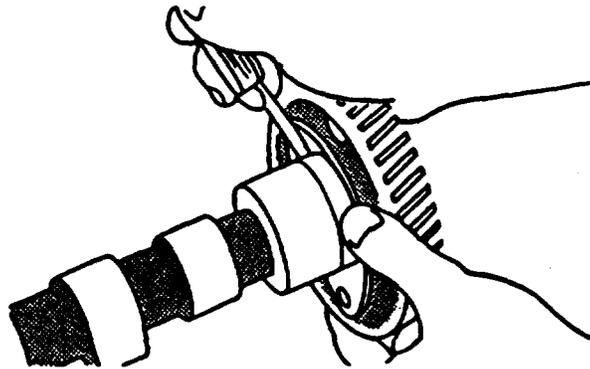
Very light score marks can be found, but are acceptable if valve lift is within specification. Pitting or galling dictates replacement. Refer to paragraph 3-32.2. for valve lift measurement.

- c. Measure camshaft thrust plate clearance as follows:

**NOTE**

**Thrust plate clearance determines camshaft end play.**

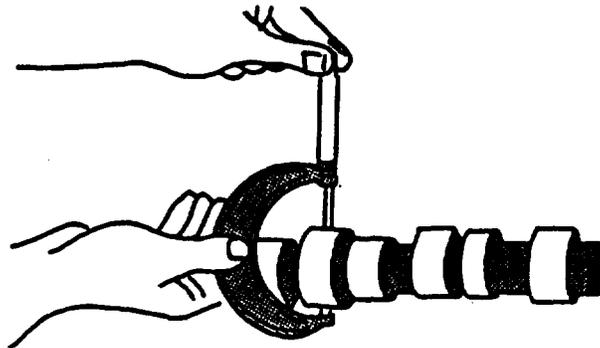
- (1) Check thrust plate clearance using a feeler gage, refer to FIGURE 3-110.
- (2) New part clearance is 0.003 to 0.009 inch (0.08 to 0.23 mm). Maximum allowable clearance is 0.015 inch (0.38 mm). Replace parts as necessary.



**FIGURE 3-110. Measuring Thrust Plate Clearance**

- d. Measure camshaft journals as follows:

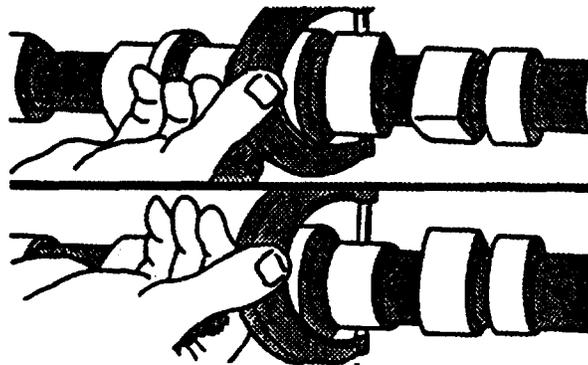
- (1) Use a micrometer to take measurements, refer to FIGURE 3-111.
- (2) New camshaft journal diameter is 2.200 to 2.201 inches (55.87 to 55.90 mm). Maximum wear tolerance is 0.001 inch (0.025 mm).
- (3) If a camshaft journal diameter is less than 2.199 inches (55.85 mm), install a new camshaft.
- (4) Measure camshaft bearing bore diameter in cylinder block; 2.204 to 2.205 inches (55.98 to 56.01 mm). Maximum clearance between bore and camshaft journal; 0.007 inch (0.18 mm).



**FIGURE 3-111. Measuring Camshaft Journals**

e. Measure camshaft lobe height as follows:

- (1) Measure each camshaft lobe at highest point and at narrowest point, refer to FIGURE 3-112. Subtract narrowest dimension from highest dimension to find camshaft lobe height. If height is not correct on any lobe, install a new camshaft.
- (2) Intake lobe should be 0.273 to 0.292 inch (6.93 to 7.42 mm), with a minimum acceptable lobe height of 0.263 inch (6.68 mm).
- (3) Exhaust lobe should be 0.266 to 0.286 inch (6.76 to 7.26 mm), with a minimum acceptable lobe height of 0.256 inch (6.50 mm)



**FIGURE 3-112. Measuring Camshaft Lobe Height**

f. Inspect cam followers in accordance with instructions in paragraph 3-34.4.

### 3-40.3. Installation.

a. Install gear (5, FIGURE 3-108) as follows:

- (1) Install key (6) in camshaft.
- (2) Install gear (5) with timing mark facing away from camshaft (3), aligning slot in gear with key (6).
- (3) Using a tubular driver, press gear (5) on camshaft (3) until gear is flush with shoulder on camshaft.

b. Coat camshaft lobes and cam followers (2) with a general purpose grease (630AA).

c. Make sure engine is at TDC, (No. 1 piston on compression stroke) with timing pin engaged in flywheel.

**CAUTION**

Do not allow camshaft lobes to drag on engine block honed bore surfaces while installing camshaft. Machine surfaces may become scratched or scored. Revolve camshaft during installation to avoid obstruction in any bore.

- d. Put clean engine lubricating oil (MIL-L-2104) on camshaft bearing journals.
- e. Install camshaft (3) and thrust plate (4) in engine block.
- f. Install two capscrews (1) and tighten to 35 ft-lbs (47 Nm).
- g. Time camshaft as follows:

**NOTE**

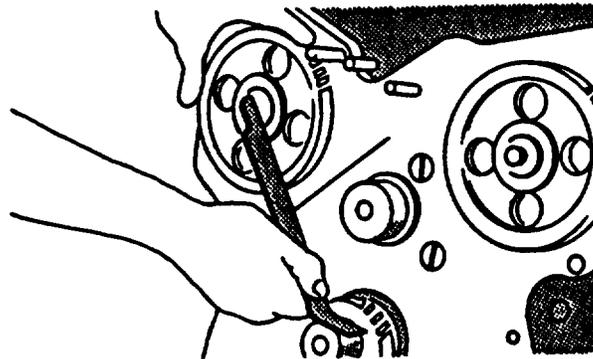
If not removed, remove upper idler gear, refer to paragraph 3-42.1.

- (1) With timing tool (JD-254) resting on nose of crankshaft, turn camshaft (3) until timing mark aligns with center of camshaft gear (5), refer to FIGURE 3-113.
- (2) Check injection pump gear timing with timing tool (JD-254). Timing mark with 4" beside it, must align with center of injection pump gear.

**NOTE**

Use the timing mark corresponding to the number of cylinders.

- (3) Install upper idler gear (3, FIGURE 3-115) on its shaft without turning camshaft gear (5) or injection pump gear.
- (4) Install washer (2) so hole and spring pin align. Install capscrew (1). Tighten capscrew (1) to 65 ft-lbs (90 Nm).



**FIGURE 3-113. Aligning Timing Mark and Camshaft Gear**

- (5) Recheck gear timing to make sure it is still correct.
- h. Install timing gear cover, refer to paragraph 3-39.3.
- i. Install rocker arm assembly and pushrods, refer to paragraph 3-33.5.
- j. Install fuel supply pump, paragraph 3-25.3.

### 3-41. **BALANCER SHAFTS AND BUSHINGS.**

#### 3-41.1. Removal.

- a. Remove timing gear cover, refer to paragraph 3-39.1.
- b. Remove lower idler gear, refer to paragraph 3-42.1.
- c. Remove oil pump gear, refer to paragraph 3-21.1.
- d. Measure balancer shaft end play, refer to paragraph 3-41.2.
- e. Remove two capscrews (7, FIGURE 3-108) and lockwashers (8) securing each thrust plate (9 and 10); remove thrust plates (9 and 10). Discard lockwashers.

#### **CAUTION**

**During removal, identify left and right balancer shafts (13 and 14) for correct assembly. Journals are lapped for one direction of rotation and Interchanging shaft locations could cause premature wear of shafts and bushings.**

- f. Remove balancer shafts (13 and 14).
- g. If necessary, remove gear (11 or 12) from balancer shaft (13 or 14) using an arbor press and gear puller. Remove key (15) from shaft.
- h. If necessary, use balancer shaft bushing driver (JD-249) and drive bushings (16) out of engine block.

#### 3-41.2. Inspect and Measure.

- a. Use a dial indicator and measure balancer shaft end play. New balancer shaft end play is 0.002 to 0.010 inch (0.05 to 0.26 mm). Maximum allowable end play is 0.015 inch (0.38 mm).

#### **NOTE**

**If end play of balancer shafts exceeds specifications, then check thickness of thrust plate as this determines end play. Refer to step d.**

- b. With bushings (16, FIGURE 3-108) removed, check for cracked or broken block bosses.
- c. Inspect for broken, cracked, or excessively worn gears (11 and 12).
- d. Check thrust plates (9 and 10) for scoring or other excessive wear. New thrust plate thickness is 0.117 to 0.119 inch (2.97 to 3.02 mm).
- e. Inspect bushings (16) in engine block for wear or damage.
- f. Measure balancer shaft bushing (16) ID.
  - (1) New standard bushing diameter is 1.5030 to 1.5054 inches (38.177 to 38.237
  - (2) New oversize bushing diameter is 1.5035 to 1.5045 inches (38.194 to 38.220
- g. Measure balancer shaft journal diameter. New part diameter is 1.5014 to 1.5024 inches (38.137 to 38.163 mm).
- h. Subtract journal diameter from bushing diameter. New part oil clearance is 0.001 to 0.004 inch (0.02 to 0.10 mm). Maximum allowable oil clearance is 0.006 inch (0.15 mm)
- i. Install new bushings (16) and/or a new balancer shaft (13 or 14) if oil clearance is not within specification.

#### **NOTE**

**Oversize bushings are available. If used, engine block must be line bored to 1.7015 to 1.7025 inches (43.237 to 43.263 mm), refer to paragraph 3-41.3.**

3-41.3. Repair.

If oversized balancer shaft bushings are used, engine block must be line bored.

- a. Line bore engine block to specification listed below. Refer to FIGURE 3-114 for References A through E.

**NOTE**

**Reference all line boring dimensions from front left dowel pin (E).**

- (1) A.. 1.653 to 1.655 inches (41.985 to 42.035 mm)
  - (2) B.. 10.157 to 10.159 inches (257.985 to 258.035 mm)
  - (3) C.. 2.558 to 2.560 inches (64.986 to 65.036)
  - (4) D.. 1.7015 to 1.7025 inches (43.237 to 43.263 mm)
- b. Make a chamfer 20 to 25 degrees x 0.060 inch (1.5 mm toward front of engine for front and middle bores and toward rear for rear bore to make bushing installation easier.
  - c. Check bores for smoothness after machining.

3-41.4. Installation.

**CAUTION**

**Make sure oil hole in bushing (16, FIGURE 3-108) is aligned with oil passage in block for proper bushing and journal lubrication.**

- a. If removed, use balancer shaft bushing driver (JD-249) to drive new bushings (16) into engine block.

**NOTE**

**Adequate bushing-to-balancer shaft clearance exists, if shaft can be rotated by hand with a slight-to-moderate drag. It is not necessary to hone bushing to obtain specified oil clearance. Excessive clearance can result in shaft seizure.**

- b. If gear (11 or 12) was removed, install as follows:
  - (1) Install key (15) in slot on shaft.
  - (2) Position balancer shaft (13 or 14) in balancer shaft holding tool (JD-247).
  - (3) Install thrust plate (9 or 10) and gear (11 or 12) on balancer shaft. Be sure timing mark on gear faces away from balancer shaft.
  - (4) Press gear onto shaft with a tube-type driver and arbor press. Press gear until a clearance of 0.002 to 0.008 inch (0.005 to 0.20 mm) exists between thrust plate and gear/shoulder.
- c. Make sure engine is at TDC (No. 1 piston on compression stroke), with timing pin engaged in flywheel.

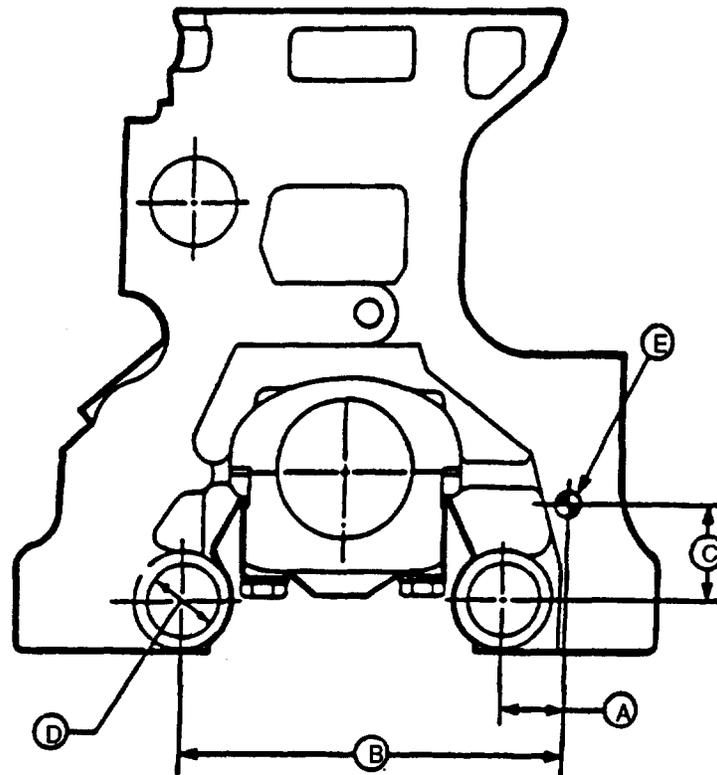


FIGURE 3-114. Balancer Shaft Bushing Line Boring References

- d. Apply a liberal amount of clean engine lubricating oil (MIL-L-2104) to bushings (16) in engine block and to balancer shaft (13 and 14) journals.

**CAUTION**

**Do not intermix shafts (13 and 14) or gears (11 and 12) in location from which they were removed. Shafts are lapped for one direction of rotation, and exchanging locations could cause premature wear of shafts and bushings. If doubt exists as to which shaft is left or right-hand, always replace the balancer shaft bushings (16).**

- e. Install balancer shafts (13 and 14) and thrust plates (9 and 10).
- t. Secure each thrust plate (9 and 10) with two capscrews (7) and new lockwashers (8). Tighten capscrews to 35 ft-lbs (47 Nm).
- g. Time balancer shafts as follows:
- (1) Turn right (camshaft side) balancer shaft (14) so timing mark is under timing tool (JD-254). Timing mark on both balancer shaft gears (11 and 12) must align with centerline of crankshaft when correctly timed.
  - (2) Install lower idler gear, and without turning balancer shaft, secure gear. Spring pin must enter hole in washer when it is installed.
  - (3) Install new bolt with washer from oil pump side and new nut on front plate gear side. Secure nut with adhesive (LOCTITE 242) and tighten to 70 ft-lbs (95 Nm). Stake nut to capscrew by applying three center punch marks.

- (4) Turn left (injection pump side) balancer shaft (13) so timing mark is under timing tool (JD-254).
  - (5) Install oil pump and oil pump drive gear. Tighten hex nut (to retain gear) 55 ft-lbs (75 Nm). Stake nut to shaft in three places using a punch and hammer.
  - (6) Recheck gear timing for both balancer shafts (13 and 14).
- h. Install timing gear cover. Refer to paragraph 3-39.3.

### Section XIII. IDLER GEARS AND FRONT PLATE ASSEMBLY MAINTENANCE

#### 3-42. IDLER GEARS AND SHAFTS

##### 3-42.1. Removal.

- a. Remove timing gear cover, refer to paragraph 3-39.1.
- b. Remove oil pan, refer to paragraph 3-20.1.
- c. Remove front crankshaft sleeve bearing (8, FIGURE 3-118), preformed packing (9), and dirt deflector (10).
- d. Measure idler gear end play, refer to paragraph 3-42.2.
- e. Measure idler (timing) gear backlash, refer to paragraph 3-42.2.
- f. Remove bolt (1, FIGURE 3-115) and thrust washer (2) securing upper idler gear (3) to shaft (5); remove idler gear (3).
- g. Remove nut (8) and thrust washer (10) securing lower idler gear (11); remove idler gear (11).
- h. If necessary, use an arbor press and remove bearings (4 and 12) from gears (3 and 11).
- i. Remove bolt (13) and washer (14) from lower idler gear shaft (15).
- j. Remove lower idler gear shaft (15) from front plate by using a pry bar. Remove thrust washer (9).
- k. Remove upper idler gear shaft (5) from front plate by using a pry bar. Remove thrust washer (7).
- l. Remove spring pins (6 and 16) from shafts.

##### 3-42.2. Inspect and Measure.

- a. Measure idler gear end play as follows:
  - (1) Using a dial indicator, check end play of upper and lower idler gears.
  - (2) New end play is 0.006 to 0.012 inch (0.14 to 0.29 mm), and maximum acceptable is 0.016 inch (0.40 mm).

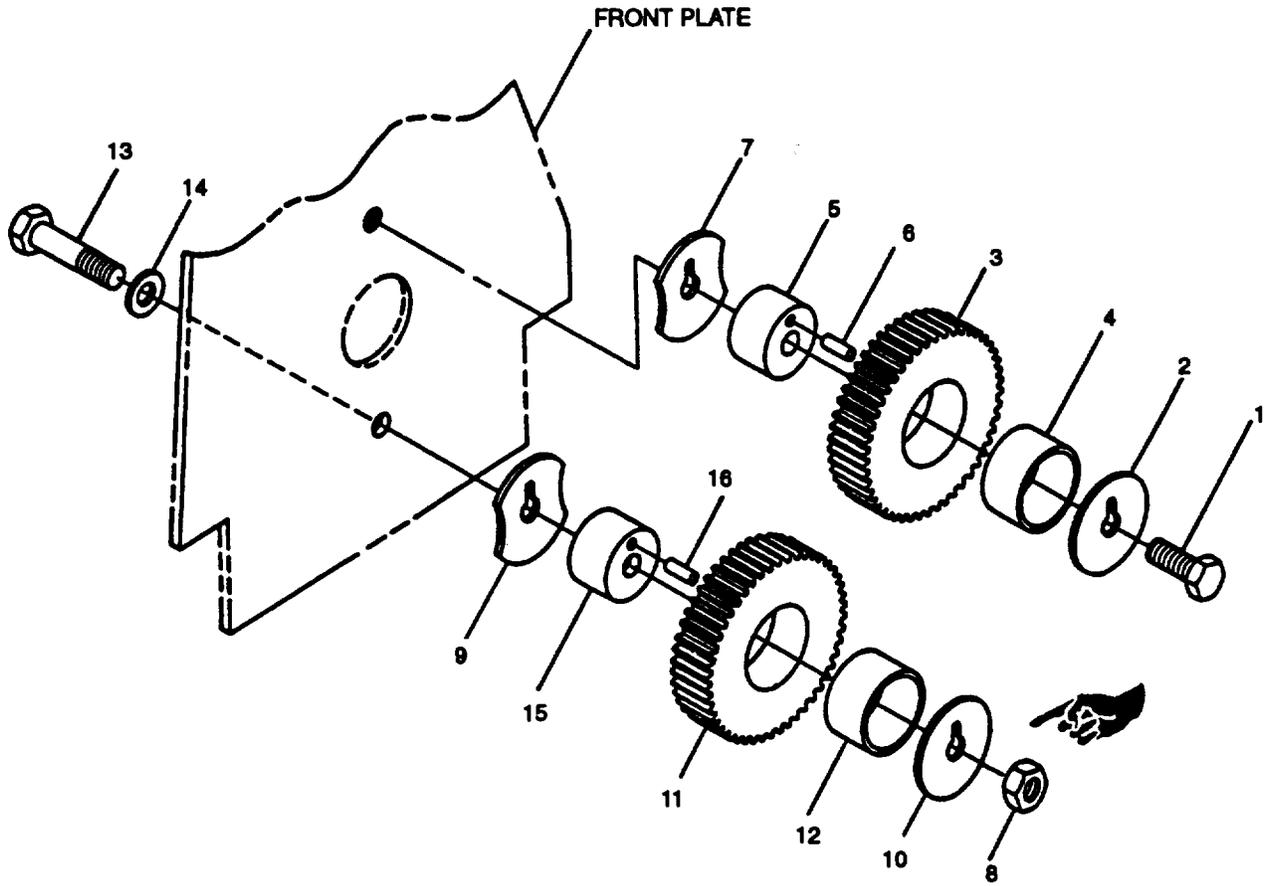


FIGURE 3-115. Idler Gears

Change 3 3-168

- b. Using a dial indicator, measure backlash between timing gears. Specification given is for new parts.
- (1) Camshaft to upper idler 0.003 to 0.014 inch (0.07 to 0.35 mm).
  - (2) Injection pump to upper idler 0.003 to 0.014 inch (0.07 to 0.35 mm)
  - (3) Upper idler to crankshaft 0.003 to 0.012 inch (0.07 to 0.30 mm).
  - (4) Crankshaft to lower idler 0.003 to 0.014 inch (0.07 to 0.35 mm).
  - (5) Balancer shaft to oil pump 0.002 to 0.014 inch (0.05 to 0.35 mm)
  - (6) Oil pump to lower idler 0.0016 to 0.015 inch (0.04 to 0.36 mm).
  - (7) Lower idler to balancer shaft 0.002 to 0.016 inch (0.05 to 0.40 mm).
  - (8) If backlash is not within specification, install new gears.
- c. Measure sleeve bearing ID. New part ID is 1.751 to 1.753 inches (44.47 to 44.54 mm).
- d. Measure shaft OD. New part OD is 1.750 to 1.751 inches (44.44 to 44.47 mm).
- e. Oil clearance (sleeve bearing ID to shaft OD) should be 0.001 to 0.004 inch (0.02 to 0.10 mm). Maximum wear limit is 0.006 inch (0.15 mm). If oil clearance exceeds limit, replace worn parts.

### 342.3. Installation.

- a. Install spring pins (6 and 16, FIGURE 3-115) with end of pin protruding as shown in FIGURE 3-116.
- b. Install upper thrust washer (7, FIGURE 3-115) and idler gear shaft (5) with spring pin (6) in notch. Drive shaft into front plate until thrust washer (7) is fully seated with oil hole facing up.
- c. Install lower thrust washer (9) and idler gear shaft (15) with spring pin (16) in notch. Drive shaft into front plate until thrust washer (9) is fully seated with oil hole facing up. Install capscrew (13) and washer (14) through rear of front plate and tighten capscrew to 70 ft-lbs (90 Nm).

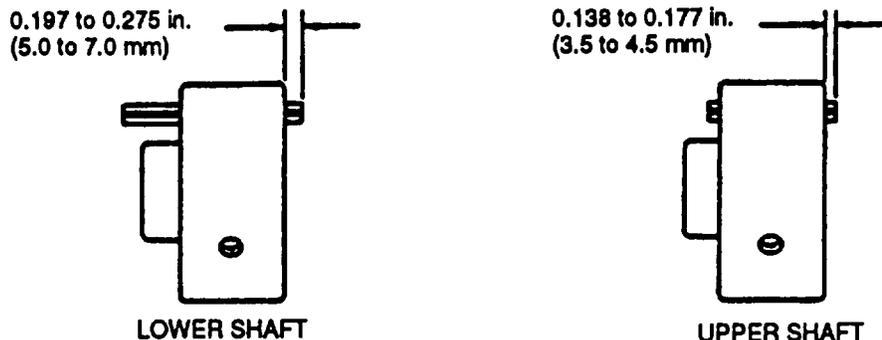


FIGURE 3-116. Spring Pin Protrusion

#### CAUTION

Upper and lower idler gear sleeve bearings (4 and 12, FIGURE 3-115) have the same ID, but are different. Sleeve bearing with spiral oil groove goes in lower idler gear. Sleeve bearing without groove goes in upper idler gear (pressure lubed). Do not intermix sleeve bearings or premature sleeve bearing failure will result.

- d. If sleeve bearings (4 and 12) were removed, use an arbor press, driver (JD-252), and handle (10914188) to install sleeve bearing (4) in idler gear (3) and sleeve bearing (12) in idler gear (11).
- e. Install lower idler gear (11), thrust washer (10), and nut (8).
- f. Time camshaft and install upper idler gear (3), thrust washer (2), and capscrew (1), refer to paragraph 3-40.3.
- g. Install dirt deflector (10, FIGURE 3-118), new preformed packing (9), and crankshaft sleeve bearing (8).
- h. Install oil pan, refer to paragraph 3-20.3.
- i. Install timing gear cover, refer to paragraph 3-39.3.

### **3-43. FRONT PLATE.**

#### **3-43.1. Removal.**

- a. Remove timing gear cover, refer to paragraph 3-39.1.
- b. Remove camshaft, refer to paragraph 3-40.1.
- c. Remove fuel injection pump and drive gear, refer to paragraph 3-27.1.
- d. Remove oil pump and drive gear, refer to paragraph 3-21.1.
- e. Remove idler gears, refer to paragraph 3-42.1.
- f. Remove balancer shaft, refer to paragraph 3-41.1.
- g. Remove five screws (1, FIGURE 3-117) and lockwashers (2) securing front plate (3); remove front plate (3) and gasket (4). Discard gasket (4) and lockwashers (2).
- h. Remove oil bypass valve (6) and spring (5).
- i. If new front plate (3) is to be installed, remove setscrew plugs (7). Discard plugs.

#### **3-43.2. Inspection.**

#### **WARNING**

**Cleaning solvent is flammable and toxic to eyes, skin, and respiratory tract. Skin/eye protection required. Avoid repeated/prolonged contact. Good general ventilation is normally adequate.**

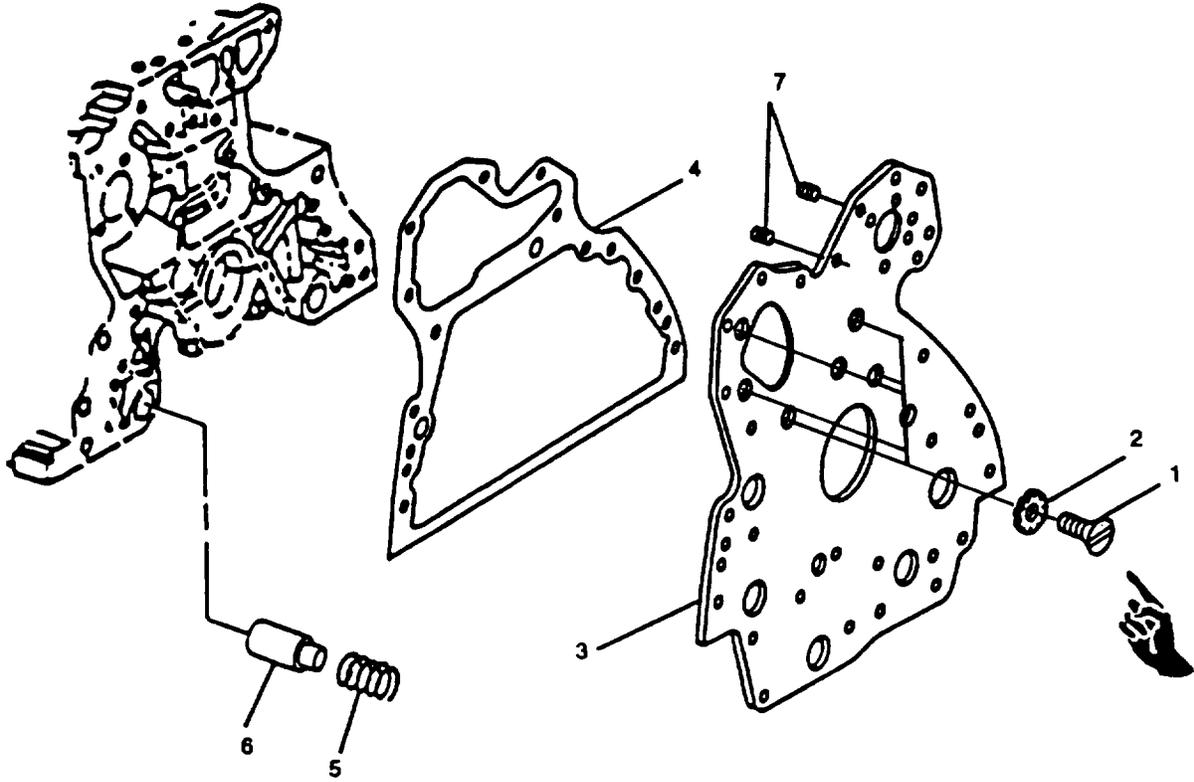


FIGURE 3-117. Front Plate

Change 3 3-171

**Warning**

**Compressed air used for cleaning can create airborne particles that can enter the eyes. Pressure will not exceed 30 psig (207 kPa). Eye protection required.**

- a. Remove all old gasket material from front plate and engine block.
- b. Clean plate with dry cleaning solvent (P680) and dry with compressed air. Wipe front face of engine block with a cleaning cloth. Be sure gasket surface on engine block is clean.
- c. Inspect front plate for wear or damage. Replace if necessary.

3-43.3. Replacement.

**NOTE**

**New replacement front plates do not have a timing mark for the fuel injection pump. A new timing mark must be established at reassembly.**

**NOTE**

**Apply sealing compound (LOCTITE 242) to threads of studs and setscrew plugs (7, FIGURE 3-117) before installing in front plate.**

- a. Install mounting studs in appropriate location on front plate for your pump application. Install setscrew plugs (7) in threaded holes not used for mounting studs.
- b. Transfer injection pump timing mark from original front plate onto replacement plate, refer to paragraph 3-43.4.

3-43.4. Transferring Fuel Injection Pump Timing Mark.

**CAUTION**

**Replacement front plates are supplied without Injection pump timing mark. It is extremely important that timing be accurately transferred from original front plate to replacement plate in the exact location for correct Injection pump timing.**

- a. Position locally manufactured template (FIGURE D-2, Appendix D) on front plate and secure with three 3/8-16 capscrews.
- b. Transfer injection pump timing mark from previous front plate onto template using a fine tip marker and straightedge. Remove template from front plate being replaced.
- c. Attach template (with timing mark) to new front plate and tighten capscrews securely.
- d. Transfer timing mark from the template to the new front plate using a scribe. Scribe deep enough so mark becomes a permanent reference.
- e. Remove template from front plate.

3-43.5. Installation.

- a. Install oil bypass valve (6, FIGURE 3-117) and spring (5) in engine block bore.
- b. Apply a light coating of sealing compound (FORMAGASKET2) to engine block side of new gasket (4).
- c. Install gasket (4) and front plate (3).
- d. Secure front plate (3) with five screws (1) and new lockwashers (2). Tighten screws to 25 ft-lbs (34 Nm).

**NOTE**

**Cut off protruding edge of gasket only after timing gear cover has been installed and tightened.**

- e. Install balancer shafts, refer to paragraph 3-41.4.
- f. Install idler gears, refer to paragraph 3-42.3.
- g. Install oil pump and drive gear, refer to paragraph 3-21.3.
- h. Install fuel injection pump and drive gear, refer to paragraph 3-27.8.
- i. Install camshaft, refer to paragraph 3-40.3.
- j. Install timing gear cover, refer to paragraph 3-39.3.

**Section XIV. CRANKSHAFT AND MAIN BEARINGS MAINTENANCE**

**3-44. CRANKSHAFT AND MAIN BEARINGS.**

3-44.1. Removal.

- a. Check crankshaft end play, refer to paragraph 3-44.2.
- b. Remove oil pan, refer to paragraph 3-20.1.
- c. Remove oil pump, refer to paragraph 3-19.1.
- d. Remove rocker arm assembly, pushrods, and cam followers, refer to paragraph 333.1.
- e. Remove front plate, refer to paragraph 3-43.1.
- f. Remove flywheel housing, refer to paragraph 3-37.1.

**NOTE**

**Leave front and rear main bearing caps installed until all of connecting rod caps have been removed. Push pistons and rods away from crankshaft.**

- g. Remove connecting rod bearing caps, refer to paragraph 3-43.1.
- h. Check main bearing caps (3 and 4, FIGURE 3-118) for arrows (cast in bearing cap) and numbers stamped on cap and oil pan rail. Arrow points toward camshaft side of engine. If there are no numbers, stamp corresponding numbers on cap and oil pan rail. This will assure correct placement location of main bearing caps during reassembly.
- i. Remove capscrews (1) and washers (2) securing main bearing caps (3 and 4); remove main bearing caps.

**NOTE**

**Visually inspect condition of bearing inserts (5 and 6) as main bearing caps are removed. Keep caps and inserts together and in correct order.**

- j. Check bearing (5 and 6) clearances as follows:
  - (1) Place a strip of bearing gage (PLASTIGAGEPR1) in the center of the main bearing cap about three fourths of width of bearing.
  - (2) Use oil on bearing gage to prevent smearing.
  - (3) Install cap and tighten capscrews (1) to 85 ft-lbs (115 Nm).
  - (4) Remove cap and compare width of bearing gage with scale provided, to determine clearance. Maximum permissible clearance is 0.006 inch (0.15 mm).

**WARNING**

**Crankshaft Is very heavy, do not attempt to remove crankshaft by hand. Use proper lifting equipment.**

**NOTE**

**Use of bearing gage will determine wear, but will not determine condition of either bearing or journal.**

- k. Attach a nylon sling (or other suitable lifting sling) to journals of crankshaft (7).

**NOTE**

**An alternate method of attaching sling is to install a capscrew on both ends of crankshaft and attach sling to screws.**

- l. Using proper lifting equipment, carefully raise crankshaft out of engine block.
- m. Place crankshaft (7) on a clean flat surface and support journals with wooden blocks.

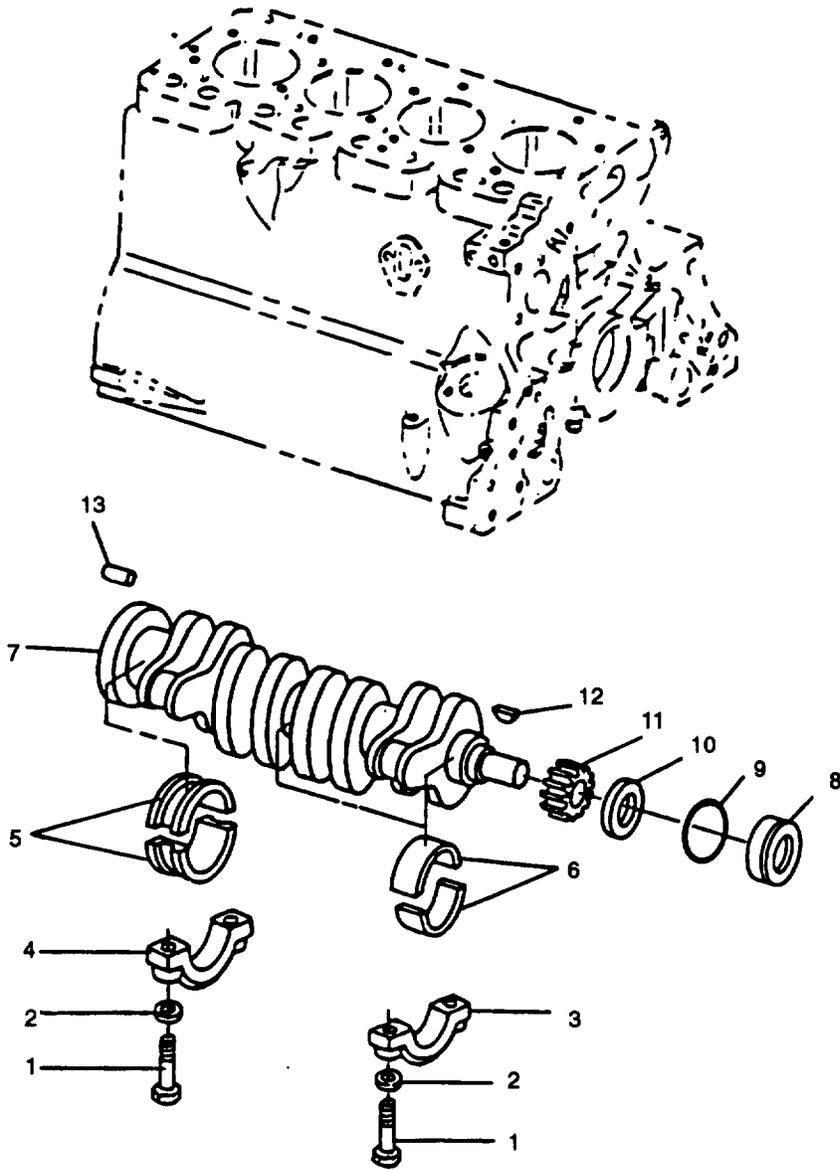


FIGURE 3-118. Crankshaft and Main Bearings

- n. If bearings (5 and 6) are to be replaced, remove inserts from engine block. Otherwise, leave bearing inserts in block until assembled ID has been measured.
- o. Remove sleeve bearing (8), preformed packing (9), and dirt deflector (10) from front end of crankshaft.
- p. Using an arbor press and gear puller, pull gear (11) from crankshaft (7). Remove key (12) from crankshaft.

### 3-44.2. Inspect And Measure.

#### **WARNING**

**Cleaning solvent is flammable and toxic to eyes, skin, and respiratory tract. Skin/eye protection required. Avoid repeated/prolonged contact. Good general ventilation is normally adequate.**

#### **WARNING**

**Compressed air used for cleaning can create airborne particles that may enter the eyes. Pressure will not exceed 30 psig (207 kPa). Eye protection required.**

- a. Inspect gear for wear or damage.
- b. Check crankshaft end play as follows:

#### **NOTE**

**It is recommended that crankshaft end play be measured prior to removing crankshaft to determine condition of thrust bearings. Crankshaft and play may also be checked at front end of crankshaft.**

- (1) Position dial indicator on face of flywheel.
- (2) Push crankshaft as far to rear of engine as possible.
- (3) Zero dial indicator.

#### **CAUTION**

**Do not apply too much pressure with bar, as this could damage bearings.**

- (4) Using a bar, gently pry crankshaft as far forward as possible.
- (5) End play for new two piece thrust bearing is 0.002 to 0.008 inch (0.05 to 0.20 mm). Maximum serviceable end play is 0.015 inch (0.38 mm).

#### **NOTE**

**New thrust bearings will usually restore proper end play. If end play is not within specification on two piece flanged thrust bearings, install a two piece thrust bearing (without flange) and oversized thrust washers.**

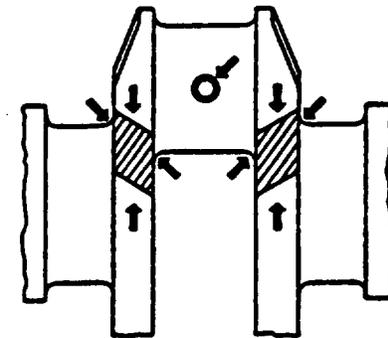
- c. Inspect crankshaft as follows:
  - (1) Clean crankshaft using dry cleaning solvent (P-D-680) and compressed air.

- (2) Inspect oil passages to make sure they are open. Use compressed air and a small piece of wire.
- (3) Inspect crankshaft for any signs of load stress, cracks, scoring, or scratches on journals. (An inspection must be made if the crankshaft damper was found to be damaged or defective.) FIGURE 3-119 shows critical areas of load stress in a crankshaft.

**NOTE**

**When inspecting crankshaft for cracks, a method (such as the Fluorescent Magnetic Particle Method) must be used that is capable of detecting minute cracks that are not visible to the eye. This method magnetizes the crank, employing magnetic particles which are fluorescent and glow under black light. Replace crankshaft if cracks are found. The crankshaft must be demagnetized after the test.**

- (4) Check each journal for evidence of excessive overheating or discoloration. If either condition exists, replace crankshaft since heat treatment has probably been destroyed.



**FIGURE 3-119. Critical Areas of Crankshaft Load Stress**

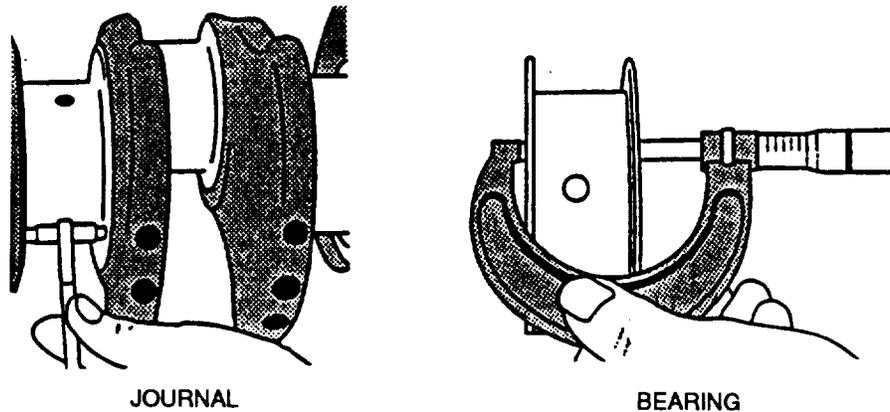
- d. Measure assembled ID of bearings and OD of crankshaft journals as follows:
  - (1) With crankshaft out of engine block, install main bearing inserts and caps (be sure inserts are installed correctly).
  - (2) Tighten main bearing capscrews to 85 ft-lbs (115 Nm).
  - (3) Measure ID of all bearings with an inside micrometer. ID of assembled insert should be 3.125 to 3.127 inches (79.39 to 79.44 mm).
  - (4) Measure OD of all respective crankshaft journals at several points around journal. OD of main bearing journal should be 3.123 to 3.124 inches (79.34 to 79.36 mm)

**NOTE**

**If engine has previously had a major overhaul and undersized bearing inserts were used, above listed ID and OD dimensions may not be the same as those recorded. However, oil clearance should be within specifications. Oil clearance is 0.0012 to 0.004 inch (0.030 to 0.10 mm). The maximum serviceable clearance is 0.006 inch (0.15 mm).**

- (5) Use crankshaft journal OD measurements to determine if journal is out-of-round or tapered. Journal out-of-roundness wear limit is 0.003 inch (0.08 mm). Journal taper-per-inch of journal length wear limit is 0.0001 inch (0.025 mm)
- (6) If journals are tapered, out-of-round, scored, or damaged, crankshaft should be ground. Refer to paragraph 3-44.3. Proper undersize bearings should be installed after grinding.

- e. Measure main thrust journal width and thrust bearing width, refer to FIGURE 3-120, as follows:
- (1) Measure width of main thrust journal with an inside micrometer.
  - (2) New main thrust journal width is 1.531 to 1.535 inches (38.90 to 39.00 mm).
  - (3) If width is not within specification, recondition crankshaft and install an oversize thrust washer set. If width is correct, measure main thrust bearing width.



**FIGURE 3-120. Measuring Main Thrust Journal and Thrust Bearing Width**

- (4) Measure width of thrust bearing using an outside micrometer.
  - (5) New main thrust bearing width (standard size) is 1.528 to 1.530 inches (38.80 to 38.85 mm).
  - (6) New main thrust bearing clearance (thrust journal width minus thrust bearing width) is 0.002 to 0.008 inch (0.05 to 0.20 mm).
  - (7) Maximum allowable thrust bearing clearance is 0.015 inch (0.38 mm). Oversize thrust washer sets have thrust washers that are 0.007 inch (0.18 mm) oversize.
- f. Measure assembled ID of main bearing caps as follows:
- (1) Remove bearing inserts from caps and engine block. Keep inserts in correct order if they are to be reused.
  - (2) Clean caps in dry cleaning solvent (P-D-680) and dry with compressed air.
  - (3) Inspect caps for serviceability. Small burrs or nicks on flat surfaces may be removed with a file. Use a medium-grit abrasive cloth to dress up curved bearing surfaces.
  - (4) Install bearing caps in engine block. Tighten capscrews to 85 ft-lbs (115 Nm).
  - (5) Measure ID of bore without bearings. Main bearing bore ID without bearings should be 3.325 to 3.326 inches (84.45 to 84.48 mm).
  - (6) If bearing caps are damaged or bore is not within specification, replace cap and bore to specification.

**CAUTION**

**Main bearing cap line boring should be done only by experienced personnel on equipment capable of maintaining the bore specifications. Make sure that dimension from centerline of core-to-top deck of engine block does not exceed 11.889 to 11.894 Inches (301.98 to 302.11 mm)**

**NOTE**

**Replacement bearing caps are supplied with bearing bore unfinished.**

- g. Inspect piston cooling orifices as follows:
- (1) Inspect each cooling orifice to make sure it is not plugged or damaged.
  - (2) Use a soft wire and compressed air to clean orifice. Replace, if condition is questionable.

**CAUTION**

**A piston cooling orifice failure could cause damage to pistons, piston pins, rod pin bushings, and liners. If a piston cooling orifice is left out of block during assembly, low or no oil pressure will result.**

- (3) Install all the orifices and tighten to 84 in-lbs (10 Nm).

3-44.3. Repair.

If crankshaft is to be reground, use following recommended guidelines.

**CAUTION**

**Crankshaft grinding should be done only by experienced personnel on equipment capable of maintaining crankshaft size and finish specifications.**

**CAUTION**

**If undersize bearings are used, check bearing clearance after bearing caps have been tightened to specified torque. If undersize bearings are too tight and clearance is not within specifications, Journal and bearing will be wiped clean of all oil. This would result in premature wear of parts.**

**CAUTION**

**When grinding crankshaft, also grind fillet radii to specifications. This is necessary to prevent stress risers in fillet areas during grinding.**

**NOTE** In addition to standard size main and connecting rod bearings, 0.002, 0.010, 0.020, and 0.030 inch (0.05, 0.25, 0.51, and 0.76 mm) undersize bearings are available.

**NOTE**

**The 0.002 inch (0.05 mm) undersize bearings are used normally to compensate for slight even wear on crankshafts. Regrinding is usually unnecessary when this size bearing is used.**

**NOTE**

**To maintain the correct end play, the two piece main bearing with three piece thrust washer set can be used to replace the two piece flanged main bearings if desired.**

- a. Compare crankshaft journal measurements taken during inspection and determine size which journals are to be reground.
- b. If one or more main or connecting rod journals requires grinding, then grind all of main journals or all of connecting rod journals to same required size. Grind clockwise (opposite engine rotation).
- c. AD journal fillets radii must be free of any sharp grind marks or scratches. Fillet must blend smoothly into journal and crank cheek. Radius may be checked with a fillet gage.
- d. Care must be taken to avoid localized heating which often produces grinding cracks. Use coolant generously to cool crankshaft while grinding. Do not crowd grinding wheel into work.
- e. Polish or lap (counterclockwise) ground surfaces to specified finish. Reground journals will be subject to excessive wear unless polished smooth.

**NOTE**

**When thrust surfaces are reground and an oversize washer is used, crankshaft end play specification must be maintained.**

- f. If thrust surfaces of crankshaft are worn or grooved excessively, they must be reground and polished. Care must be taken to maintain specified radius between each thrust surface and bearing journal. An oversize thrust washer set is available.
- g. Stone edge of all oil holes in journal surfaces smooth to provide a radius of approximately 0.060 inch (1.50 mm).
- h. After grinding has been completed, inspect crankshaft by fluorescent magnetic particle method, or other similar method to determine if cracks have originated due to grinding operation.
- i. Demagnetize crankshaft.

**WARNING**

**Cleaning solvent is flammable and toxic to eyes, skin, and respiratory tract. Skin/eye protection required. Avoid repeated/prolonged contact. Good general ventilation is normally adequate.**

**WARNING**

**Compressed air used for cleaning can create airborne particles that may enter the eyes. Pressure will not exceed 30 psig (207 kPa). Eye protection required.**

- j. Thoroughly dean crankshaft and oil passages with dry cleaning solvent (P-680). Dry with compressed air.

3-44.4. Installation.

- a. Install gear (11, FIGURE 3-118) on crankshaft as follows:

**WARNING**

**Oil fumes or oil can ignite above 380°F (193°C). Use a thermometer and do not exceed 360°F (182°C). Do not allow a flame or heating element to be in direct contact with oil. Heat oil in a well ventilated area. Plan a safe handling procedure to avoid burns. Wear protective clothing, gloves, apron, etc.**

- (1) Heat gear (11), in oil, to 360°F (182°C).

**NOTE**

**A properly heated gear may not require a driver for installation.**

- (2) Install key (12) in crankshaft (7) slot, and using driver (JDH-7), drive heated gear (11) onto crankshaft.

- b. Install main bearing (6) inserts. Make sure that tang on inserts is engaged with slot in engine block and main bearing caps. Also make sure that oil holes line up with oil passages in block.

**CAUTION**

**If new thrust bearing inserts or thrust bearing washers are installed, they must be installed as a set.**

- c. Install main thrust bearing (5) in rear web of engine block  
d. Apply a liberal coating of clean engine lubricating oil (MIL-L-2104) to bearing surfaces and crankshaft journals.  
e. Using proper lifting equipment, lower crankshaft (7) onto main bearings.  
f. Dip entire bearing capscrews (1) in clean engine lubricating oil (MIL-L-2104) and position them in the main bearing caps. Apply a liberal amount of oil to bearing inserts in caps.

**NOTE**

**Make sure bearing caps are installed on the bearing bosses from which they were removed. The numbers stamped on the caps should be on the same side as the numbers on the block. If there is an arrow on cap, arrow must point toward camshaft side of block.**

- g. Install each bearing cap (3 and 4), bearings (5 and 6), and capscrews (1) with washers (2) with the recesses and tabs aligned in matching order. Make sure bearing tabs also match up before tightening capscrews.

**CAUTION**

**Do not use pneumatic wrench to install main bearing capscrews, as damage may occur to the threads.**

- h. Before tightening capscrews on main bearing caps, align upper and lower thrust washers or flanges on main thrust bearings (5). Using a soft-face hammer, tap crankshaft to the rear and then to the front to line up thrust bearing surfaces.

- i. Tighten all capscrews (1) to 85 ft-lbs (115 Nm).
- j. Turn crankshaft (7) by hand. If it does not turn easily, disassemble parts and determine the cause.

**CAUTION**

**Using pneumatic wrenches to install capscrews may cause damage to the threads. Never reuse connecting rod capscrews.**

- k. Install connecting rod caps and bearings. Use new capscrews and tighten to specification, refer to paragraph 3-50.3.
- l. Check crankshaft for specified end play, refer to paragraph 3-44.2.
- m. Install flywheel housing, refer to paragraph 3-37.3.
- n. Install front plate, refer to paragraph 3-43.5.
- o. Install rocker arm assembly, pushrods, and cam followers, refer to paragraph 3-33.5.
- p. Install oil pump, refer to paragraph 3-21.3.
- q. Install oil pan, refer to paragraph 3-20.3.

**Section XV. PISTONS, CONNECTING RODS, CYLINDER LINERS, AND ENGINE BLOCK MAINTENANCE**

**3-345. REMOVAL**

3-45.1. Pistons and Connecting Rods.

**WARNING**

**Compressed air used for cleaning can create airborne particles that may enter the eyes. Pressure will not exceed 30 psig (207 kPa). Eye protection required.**

- a. Drain coolant and lubrication system, refer to end item maintenance manual.
- b. If engine is to be completely disassembled, perform steps b through l of paragraph 3-4.1.
- c. Remove cylinder head, refer to paragraph 3-34.1.
- d. Remove cam followers and keep in exact order, refer to paragraph 3-34.1.
- e. Clean engine block top deck. Remove all old gasket material, corrosion, carbon, and other foreign material from top deck Use compressed air to remove loose material.
- f. Use short capscrews (1) and 1/8 inch (3.18 mm) thick washers (2) to bolt down cylinder liners (3). Fasten liners in five locations, refer to FIGURE 3-121. Tighten caps crews to 50 ft-lbs (68 Nm).

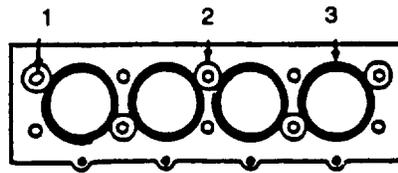


FIGURE 3-121. Fastening Cylinder Liners

**CAUTION**

Do not rotate crankshaft with cylinder head removed unless liners are bolted down. Bolt liners down before removing pistons.

**CAUTION**

Capscrews and washers must be tightened to the above specification to achieve an accurate reading when checking liner height above block.

- g. Remove carbon from liner bore with a scraper or reamer, refer to FIGURE 3-122. Use compressed air to remove loose material from cylinders.

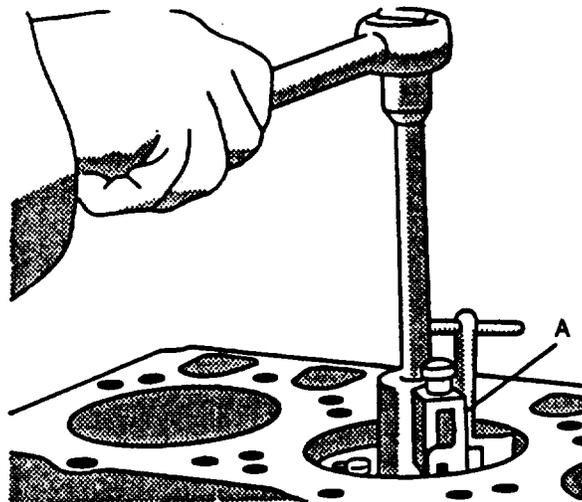


FIGURE 3-122. Removing Carbon From Cylinder Liner

- h. Before removing pistons, visually inspect condition of cylinder liners with pistons at bottom dead center (BDC). Liners will require replacement if:
  - (1) The crosshatch honing pattern is not visible immediately below the top ring turn around area.
  - (2) Liners are pitted or contain deep vertical scratches that can be detected by the fingernail.
  - (3) No further inspection is required if any one of the above conditions are found.
- i. Remove oil pan, refer to paragraph 3-20.1.
- j. Remove oil pump and outlet tube, refer to paragraph 3-21.1.

- k. Check rod bearing to journal oil clearance, refer to paragraph 3-47.2., step a.

**CAUTION** Using pneumatic wrenches can cause thread damage.

**CAUTION**

Keep bearing inserts (3, FIGURE 3-124) with their respective rods (4) and caps (2). Mark rods (4), pistons (7), and caps (2) to ensure correct assembly in same location.

- l. Remove bolt (1) securing bearing cap (2) to connecting rod (4); remove cap (2) and bearing inserts (3).
- m. Repeat step l. for remaining pistons.

**CAUTION**

If cylinder liners (9) are to be reused, be extremely careful not to let connecting rod (4) hit liner bore when removing piston/rod assembly to prevent damage to liner bore.

- n. Gently tap piston (7) through top engine block from the bottom.

**CAUTION**

Once piston rings have cleared cylinder liner (9), hold on to piston to prevent piston from dropping.

3-45.2. Cylinder Liner.

- a. Measure cylinder liner height, refer to paragraph 3-47.3., step d.
- b. Remove capscrews and washers securing liners to engine block.
- c. Number cylinder liners (9, FIGURE 3-124) and pistons (7). Stamp front of liner to assure correct assembly. Do not stamp liner flange; stamp on fire dam only (raised part of liner), refer to FIGURE 3-123.

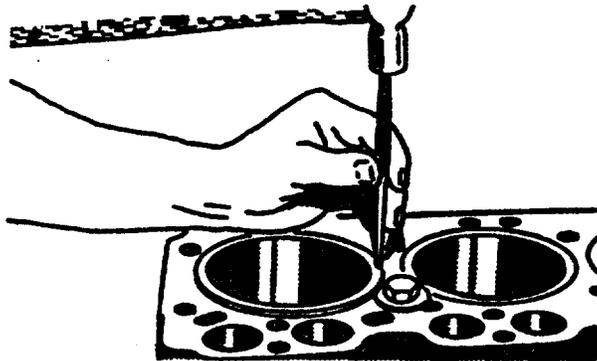


FIGURE 3-123. Marking Cylinder Liners

**CAUTION**

Each cylinder liner (9, FIGURE 3-124) must be reinstalled in cylinder bore from which it was removed. Always keep matched pistons and liners together.

**CAUTION**

Do not over-tighten liner puller to remove liners. Doing so could easily break liners.

- d. Pull liners (9) out of engine block using suitable puller or tap liners out of engine block using a suitable wooden block and hammer. Be sure that jaw of puller is correctly positioned before attempting to remove liner, refer to FIGURE 3-125.

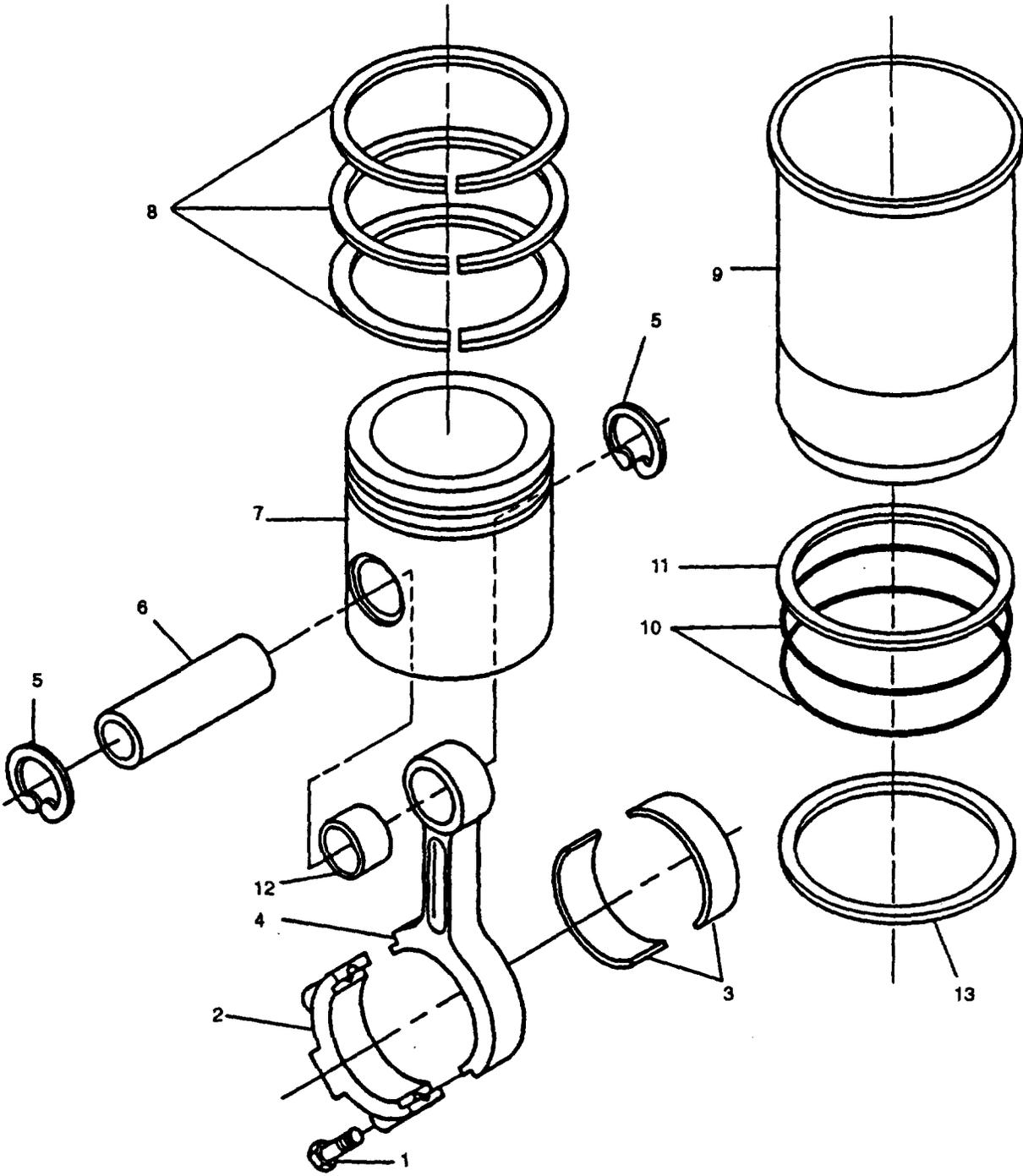


FIGURE 3-124. Pistons, Connecting Rods, and Cylinder Liners

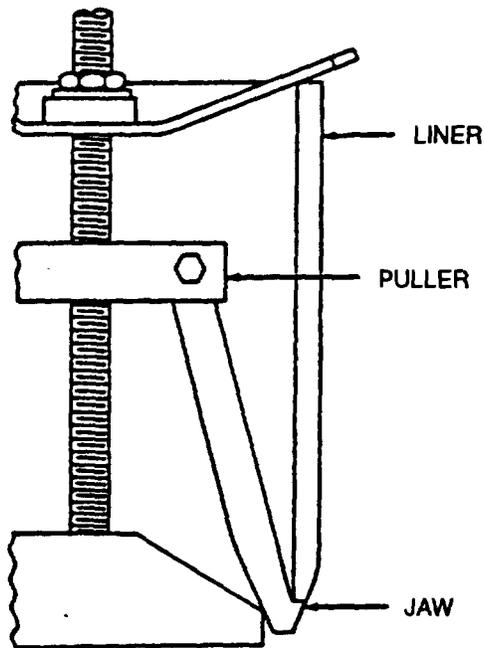


FIGURE 3-125. Use of Cylinder Liner Puller

- e. Remove cylinder liner O-rings (10, FIGURE 3-124) from grooves in engine block. Also remove packing (11) from cylinder liner (9), refer to FIGURE 3-126. Discard -rings and packing.

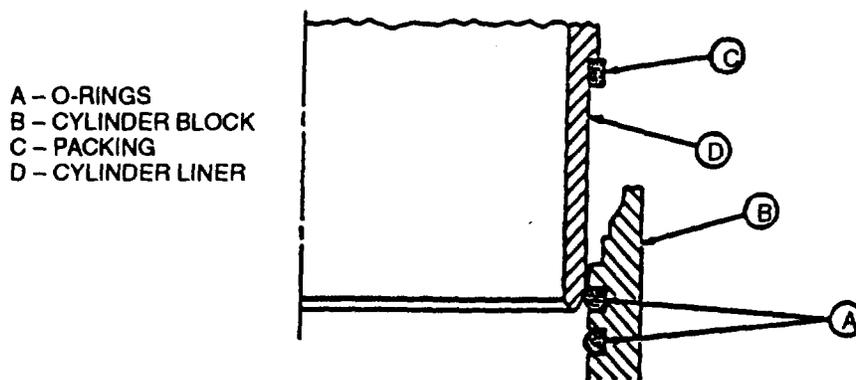


FIGURE 3-126. Cylinder Liner O-Rings and Packing

### 3-46. DISASSEMBLY.

3-46.1. Engine Block. If complete disassembly of block is required and the following has not been removed, proceed with the following.

- a. Remove crankshaft pulley, refer to paragraph 3-38.1.
- b. Remove oil pressure regulating valve, refer to paragraph 3-17.1.
- c. Remove timing gear cover, refer to paragraph 339.1.
- d. Remove idler gears, refer to paragraph 3-42.1.

- e. Remove camshaft, refer to paragraph 3-40.1.
- f. Remove balancer shafts and bushings, refer to paragraph 3-41.1.
- g. Remove engine front plate and oil bypass valve, refer to paragraphs 3-43.1. and 3-22.1.
- h. Remove crankshaft and main bearings, refer to paragraph 3-44.1.
- i. Remove pistons and liners, refer to paragraph 3-45.1 and 3-45.2.
- j. Remove piston cooling nozzles (13, FIGURE 3-127).
- k. Remove water galley plugs (1, 4, and 8).
- l. If necessary to place block in hot tank, remove oil galley plugs (6 and 12).

3-46.2. Piston and Rod.

**NOTE**

**Discard piston rings and rod bushing. Do not reuse.**

- a. Remove piston rings (8, FIGURE 3-124) from piston (7) using piston ring expander. Discard piston rings.
- b. Remove two retaining rings (5) and remove piston pin (6). Discard retaining rings.
- c. Separate piston (7) and rod (4). Keep these parts in place with their respective cylinder liner (9).

**3-47. INSPECT MEASURE.**

3-47.1. Pistons And Cylinder Liners.

- a. Match piston with correct liner and check for scoring (arrows). Wear of this type could be caused by engine over heating, or foreign material entering cylinder through oiling system. Check for any cracks or other obvious failures. If any defects are found, replace piston and liner as required. If no defects are found, proceed to next step.
- b. Visually inspect piston. If piston ring face and ring land have excessive wear, replacement is necessary for both piston and liner. If no defects are found, proceed to next step.

**WARNING**

**Compressed air used for cleaning can create airborne particles that may enter the eyes. Pressure will not exceed 30 psig (207 kPa). Eye protection required.**

**CAUTION**

**When washing pistons, always use a stiff bristle brush, not a wire brush, to loosen carbon residue. Failure to observe this caution could result in damage to pistons.**

- c. Clean pistons with hot water and liquid detergent, soak pistons in a 50 percent solution of liquid household detergent and hot water for 30 to 60 minutes. Use a stiff bristle brush and loosen carbon residue. Dry with compressed air.
- d. Carefully use a stiff bristle brush to remove all debris and scale from OD of liners. Make certain there are no nicks or burrs in areas where packings will seat.

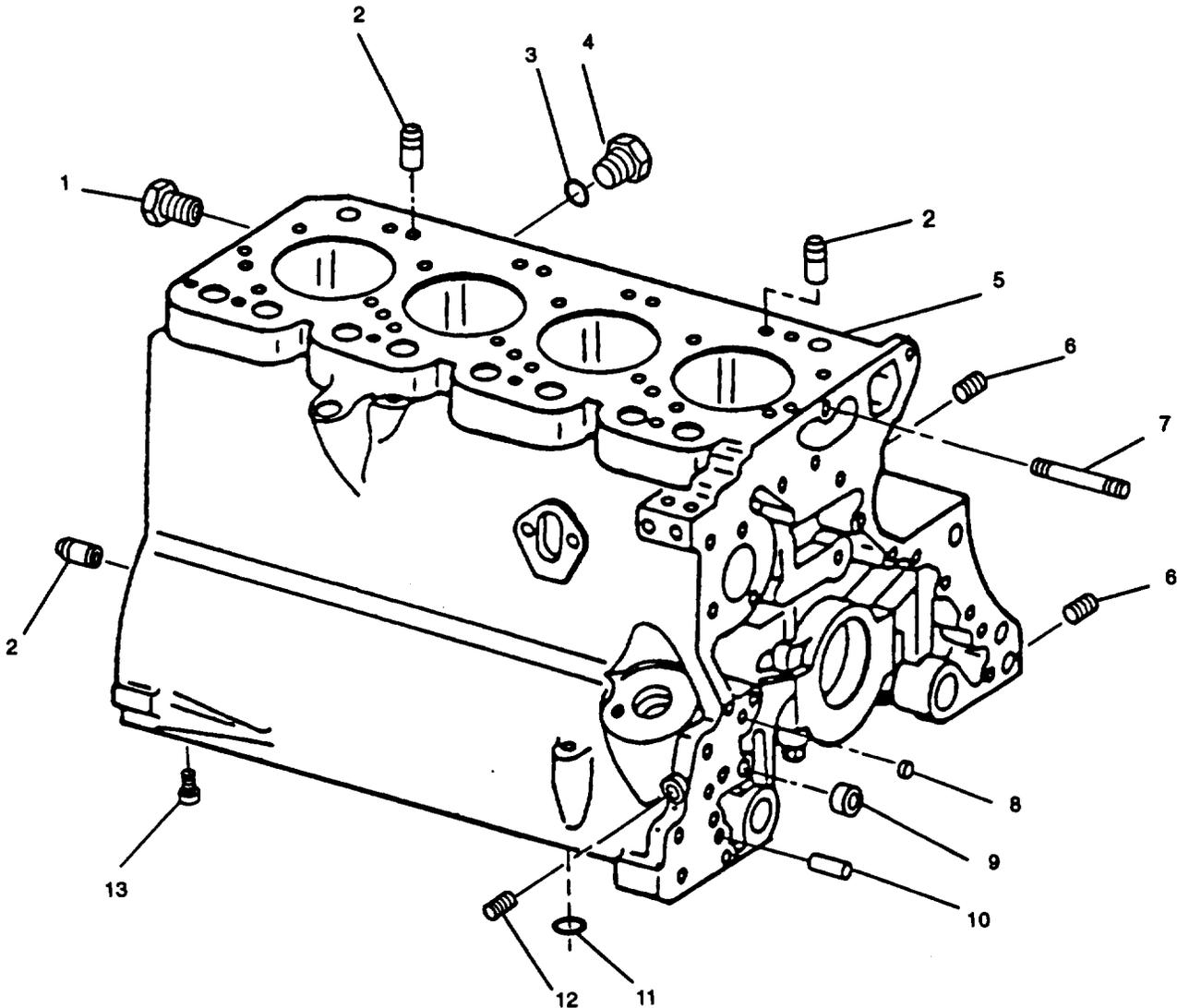
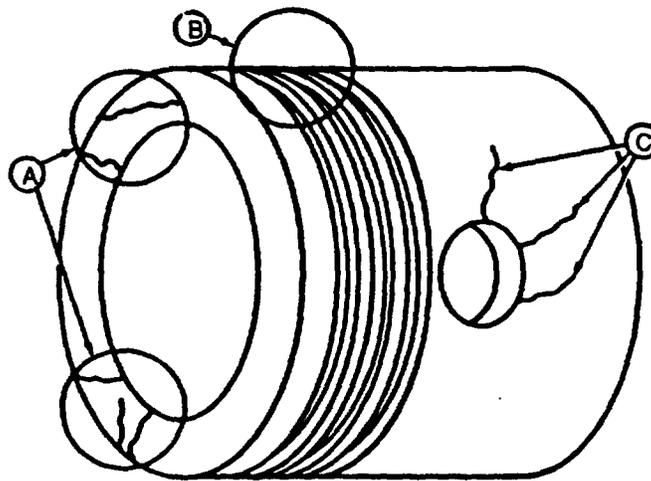


FIGURE 3-127. Engine Block

**CAUTION**

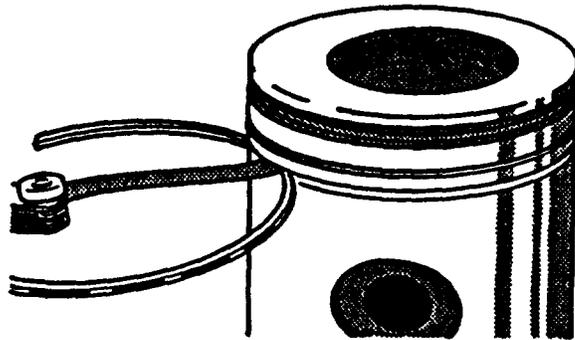
**Do not use gasoline, kerosene, or commercial solvents to clean liners. Solvents will not remove all the abrasives from liner walls.**

- e. Thoroughly clean liner ID with a 50 percent solution of hot water and liquid detergent.
- f. Rinse thoroughly and wipe dry with a clean, dry rag.
- g. Swab out liner as many times as necessary with clean SAE 10W engine lubricating oil (MIL-L-2104).
- h. Continue to clean liner until a clean, white rag shows no discoloration.
- i. Look for fine cracks in piston head, refer to FIGURE 3-128.
- i. Inspect for bent or broken ring lands.
- k. Inspect inner and outer ends of piston pin bore for cracks in skirt.



**FIGURE 3-128. Piston Inspection**

- l. If the original machining marks are not visible, or the piston skirt is worn to depth of original machining marks, replace both piston and liner. If any defects are found, replace piston and liner as a matched set. If no defects are found, proceed to next step.
- m. Check top ring groove using a new piston ring and feeler gage, refer to FIGURE 3-129. Ring groove clearance must not exceed 0.008 inch (0.20 mm) when measured between top of ring and ring land. If ring groove is worn, replace piston and liner as a matched set. If ring groove is good, proceed to next step.



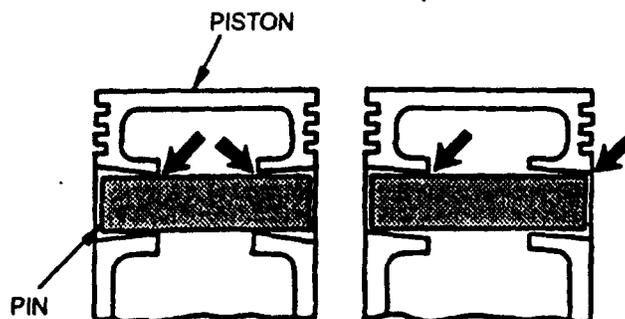
**FIGURE 3-129. Checking Piston Ring Groove Clearance**

- n. Check second and third ring grooves using a new piston ring and a feeler gage. Ring groove clearance must not exceed 0.008 inch (0.20 mm). Replace piston if clearance exceeds specification.

**NOTE**

**Piston pin must be in good condition and not worn beyond specification given in step q.**

- o. Dip piston pin in clean engine lubricating oil (MIL-L-2104)
- p. Install pin (6, FIGURE 3-124) through piston.
- (1) Pin should pass through piston using only light thumb pressure.
- (2) Check taper in piston pin bore by inserting pin from both sides, refer to FIGURE 3-130. If pin enters freely, but binds in center, bore could be tapered. If bore is not tapered, insert pin to check for bore alignment. Pin should not click or need to be forced into bore on opposite side.



**FIGURE 3-130. Checking Piston Pin Clearance**

- q. Check piston pin and piston bore specifications. If either are not within specification, replace pin and/or piston/liner set.
  - (1) Piston large pin OD should be 1.624 to 1.625 inches (41.27 to 41.28 mm).
  - (2) Piston pin OD wear tolerance is 0.005 inch (0.13 mm).
  - (3) Piston bore for large pin should be 1.625 to 1.626 inches (41.28 to 41.30 mm).

**NOTE**

Some piston pin bores are elliptical, the width being 0.0015 inch (0.038 mm) larger than the bore specifications.

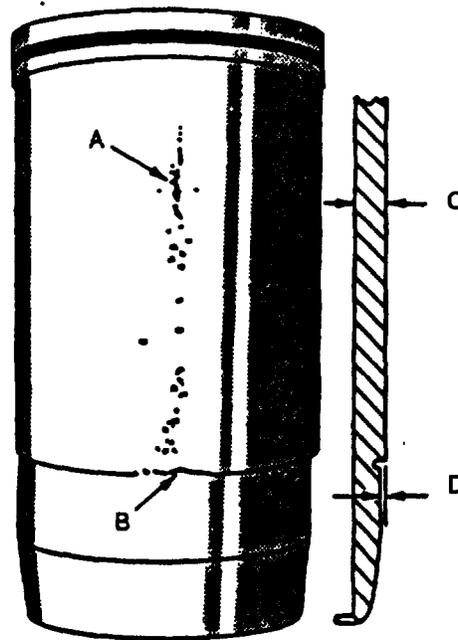
- r. Inspect exterior length of liner for pitting (A, FIGURE 3-131). Check packing step for erosion (B). If pitting or erosion is observed, measure depth of pits and erosion with a fine wire or needle. Replace liner if (C) depth of any pit is one-half or more of liner thickness, or (D) depth of erosion is one-half or more of the packing step. If no defects are found, proceed to next step.

**NOTE**

If pitting has occurred, check condition of coolant.

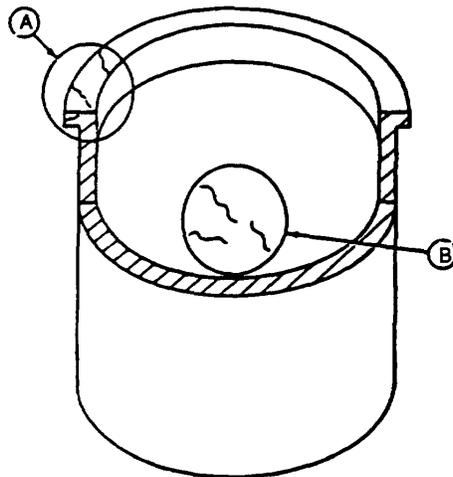
**NOTE**

Liners are reusable if depth of pits or erosion is less than amount specified. When installing reusable liners, rotate 90 degrees from original position. The liners should be deglazed and new ring sets installed on pistons, refer to paragraph 3-47.1.



**FIGURE 3-131. Inspecting Cylinder Liner Pitting**

- s. Carefully examine cylinder liner for signs of fatigue, such as fine cracks in flange area (A, FIGURE 3-132) and cracks in the ring travel area (B). If any defects are found, replace the piston and liner. If no defects are found, proceed to next step. If pistons and liners have passed all previous checks, proceed to check both for proper specifications, listed in steps t and u.

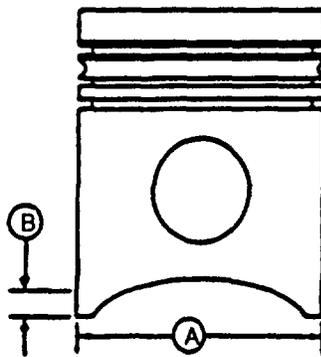


**FIGURE 3-132. Inspecting Cylinder Liner for Cracks**

**NOTE**

**Inspect block for cracks or erosion in O-ring packing area. Replace block if any of these defects are found.**

- t. Measure piston skirt (A, FIGURE 3-133) 90 degrees to piston pin bore and 0.74 inch (19 mm) from bottom of piston (B). Record measurement. OD should be 4.188 to 4.189 inches (106.38 to 106.40 mm).



**FIGURE 3-133. Measuring Piston Skirt**

- u. Measure piston to liner clearance as follows:
  - (1) Put piston (without rings) in matched liner with piston FRONT and liner FRONT aligned. Move piston down until bottom edge of piston skirt is 1.00 inch (25.4 mm) above bottom of liner. Refer to FIGURE 3-134 (1).
  - (2) Use a feeler gage to measure distance (FIGURE 3-134 (2)) between piston skirt and liner 90 degrees to piston pin bore. Record measured distance and compare with specifications given. Clearance should be 0.003 to 0.006 inch (0.08 to 0.15 mm).
  - (3) Turn piston 90 degrees in liner. Use a feeler gage to measure distance between piston skirt and liner 90 degrees to piston pin bore. Record measured distance and compare with specifications given.

- (4) The difference between the two measurements in steps (2) and (3) is distance liner is out of round at bottom.
- (5) Remove piston from liner. Put piston in liner upside down with piston FRONT and liner FRONT aligned. Move piston so bottom edge of piston skirt is 1.00 inch (25.4 mm) (1) below top of liner. Use a feeler gage to measure clearance (2) between piston skirt and liner at 90 degrees to piston pin bore. Record the measured clearance.

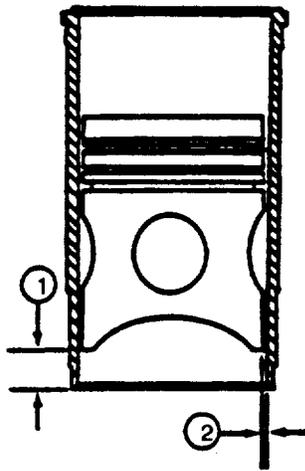


FIGURE 3-134. Measuring Piston to Liner Clearance

- (6) Turn piston 90 degrees in liner. Use a feeler gage to measure clearance between piston skirt and liner 90 degrees to piston pin bore. Record the measured clearance.
- (7) The difference between the two measurements in steps (5) and (6) is the amount the liner is out of round at the top of the liner.
- (8) If liner is out of round more than 0.002 inch (0.05 mm) at top or bottom, install a new piston and liner set.
- (9) Find difference between clearance measured in step (2) and clearance measured in step (5). This is the amount the liner is tapered.
- (10) If liner is tapered more than 0.002 inch (0.05 mm) install a new piston and liner set.

#### 3-47.2. Connecting Rod.

- a. Check bearing to journal oil clearance as follows using bearing gage (PLASTIGAGEPR1).

#### CAUTION

Never use new connecting rod caps crews when checking rod bearing ID. Use new capscrews only for final assembly of connecting rods.

#### CAUTION

Using pneumatic wrenches may cause thread damage.

**CAUTION**

**Keep bearing Inserts with their respective rods and caps. Mark rods, pistons, and caps to ensure correct assembly In same location.**

**NOTE**

**Use bearing gage (PLASTIGAGEPR1) as directed by manufacturer. Remember, use of bearing gage will determine bearing to journal clearance, but will not indicate the condition of either surface.**

- (1) Remove connecting rod cap. Place a piece of bearing gage (PLASTIGAGEPR1) in center of bearing. Install cap and initially tighten old capscrews to 41 ft-lbs (56 Nm). Tighten capscrews an additional 90 to 100 degrees, refer to paragraph 3-50.3.i for Torque-Turn Method for proper torque.
- (2) Remove cap and compare width of bearing gage with scale provided on side of package to determine clearance. Maximum permissible clearance is 0.0062 inch (0.16 mm).

b. Inspect and measure connecting rod bearing as follows:

**CAUTION**

**Never use new connecting rod caps crews when checking rod bearing ID. Use new capscrews only for final assembly of connecting rods.**

- (1) With crankshaft removed, measure connecting rod journal OD at several points. OD should be 2.748 to 2.749 inches (69.80 to 69.82 mm).
- (2) Install connecting rod cap on rod with bearings using old capscrews.
- (3) Install rod capscrews and initially tighten to 41 ft-lbs (56 Nm). Tighten capscrews an additional 90 to 100 degrees, refer to paragraph 3-0.3.i for Torque-Turn Method for proper torque.
- (4) Using an inside micrometer, measure assembled ID of rod bearing. ID should be 2.750 to 2.752 inches (69.85 to 69.90 mm)
- (5) Subtract OD of crankshaft journals from ID of rod bearings to obtain oil clearance. Oil clearance for new parts should be 0.0012 to 0.004 inch (0.03 to 0.10 mm). Maximum serviceable clearance is 0.0062 inch (0.16 mm).
- (6) Inspect connecting rod bearings for wear or damage. If bearings are worn or are out of specification, replace both connecting rod bearings.

c. Inspect rod and cap as follows:

- (1) Inspect rod and cap for wear or damage, such as chips or cracks in joint area.
- (2) Inspect in and around capscrew holes in cap. if any defects are found, replace rod and cap.
- (3) Carefully clamp rod in a soft-jawed vise (cap end upward).

**CAUTION**

**Never use new connecting rod caps crews when checking rod bore ID. Use new capscrews only for final engine assembly.**

- (4) Install cap without bearing inserts.

- (5) Initially tighten capscrews to 41 ft-lb (56 Nm). Tighten screws an additional 90 to 100 degrees, refer to paragraph 3-50.3.i for Torque-Turn Method for proper torque.
- (6) Using an inside micrometer, measure rod bore at center of bore and record measurements as follows:
  - (a) At right angle to rod/cap joint.
  - (b) At 45 degrees left of measurement step (a).
  - (c) At 45 degrees right of measurement step (a).
  - (d) Rod bore ID should be 2.900 to 2.901 inches (73.66 to 73.69 mm).
- (7) Compare measurements. If difference between greatest and least measurement is more than 0.0015 inch (0.038 mm), rod and cap are out of round. Replace both connecting rod and cap.

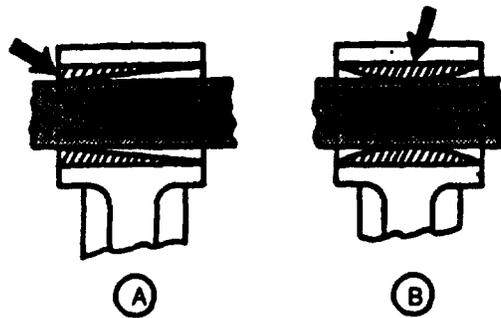
d. Inspect piston pins and bushings as follows:

- (1) Visually inspect piston pin for general overall condition. Pin must be replaced if it shows signs of fretting.

**CAUTION**

**Piston pin has a highly polished surface. Do not attempt to polish or refinish.**

- (2) Using outside micrometer, measure piston pin OD. Replace if not within 1.624 to 1.625 inches (41.27 to 41.28 mm).
- (3) Inspect piston pin bushing for damage or excessive wear. Lubrication hole must be open.
- (4) Compare pin bushing ID with pin OD for specified oil clearance.
- (5) Insert pin from either side of rod bushing. If pin is free on one end, but tight on other, bore could be tapered (A, FIGURE 3-135). If pin enters freely from both sides, but is tight in center, bore is bell mouthed (B). Pin-to-bushing clearance should be 0.0008 to 0.0024 inch (0.02 to 0.06 mm), with a maximum of 0.004 inch (0.10 mm).



**FIGURE 3-135. Checking Piston Pin Bushing**

e. Replace connecting rod bushing.

- (1) Using driver (JD-286), remove connecting rod bushing (12, FIGURE 3-124).
- (2) Clean bore of rod with medium grit polishing cloth.
- (3) Inspect rod bore for cracks. Ensure lube oil hole is open.

**NOTE**

**If bushing has spun or its rod bore diameter is not within specifications, replace connecting rod.**

- (4) Using inside micrometer, measure rod bore diameter in two places, 90 degrees apart. Rod bore diameter should be 1.625 to 1.626 inches (41.29 to 41.30 mm).

**CAUTION**

**Ensure that lube oil hole in bushing (12) is aligned with bore in connecting rod.**

- (5) Using driver (JD-286), install bushing (12) in connecting rod (4). If required, hone bushing to obtain piston pin clearance of 0.0008 to 0.0024 inch (0.02 to 0.06 mm).

3-47.3. Engine Block.

**WARNING**

**Cleaning solvent is flammable and toxic to eyes, skin, and respiratory tract. Skin/eye protection required. Avoid repeated/prolonged contact. Good general ventilation is normally adequate.**

**WARNING**

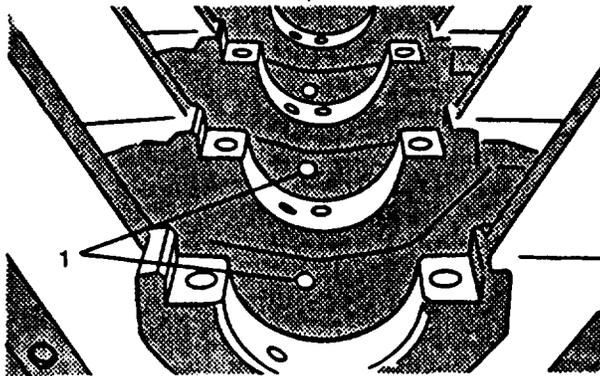
**Compressed air used for cleaning can create airborne particles that can enter the eyes. Pressure will not exceed 30 psig (207 kPa). Eye protection required.**

- a. Inspect and clean engine block as follows:

**NOTE**

**All components (including piston cooling nozzles, soft plugs, and oil gallery plugs) must be removed from the cylinder block for inspection and cleaning.**

- (1) Inspect each piston cooling nozzle (1, FIGURE 3-136) to make sure it is not plugged or damaged. Cooling nozzles deliver approximately 0.4 gallon per min (1.50 liters/min) oil flow.



**FIGURE 3-136. Inspecting piston Cooling Nozzles**

- (2) Use a soft wire and compressed air to clean nozzle. Replace if condition is questionable, refer to paragraph 3-49.2.b.

**CAUTION**

A piston cooling nozzle failure could cause damage to pistons, piston pins, rod pin bushings, and liners. If a piston cooling-nozzle is left out at assembly, low or no oil pressure will result.

**CAUTION**

If engine block is cleaned in a hot tank, be sure to remove any aluminum parts (such as nameplates). Aluminum parts can be damaged or destroyed by hot tank solutions.

- (3) Clean block thoroughly using dry cleaning solvent (P-D-680), pressure steam, or a hot tank.
- (4) Make sure all passages and crevices are cleared of sludge and grease.
- (5) All coolant passages must be cleared of any lime deposits and scale.

**NOTE**

Do not file liner support flange excessively. Excess filing can damage liner support flange and allow an improper liner fit. Thoroughly clean all filings from cylinder block (B, FIGURE 3-137).

- (6) Be sure liner support flange (A, FIGURE 3-137) is free of any burrs. If burrs are present, use a small half-moon file and lightly file (in a circular motion) burr off at approximately a 60 degree angle. Do not let file hit top of cylinder block while filing.
- (7) Carefully inspect cylinder block for cracks or damage. Replace block if there is evidence of physical damage.
- (8) When determined that cylinder block is serviceable, clean out threads for cylinder head capscrews in top deck of cylinder block using 1/2-13 UNC-2A x 4.00 inches (101.6 mm) long tap (C). Use compressed air to remove any debris or fluid which may be present in the tapped holes after cleaning.

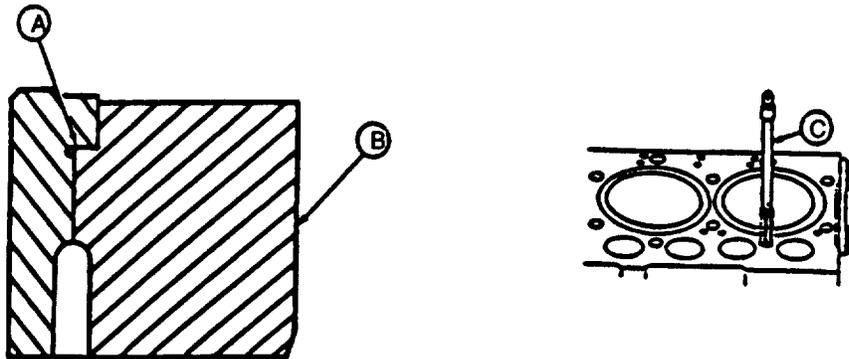
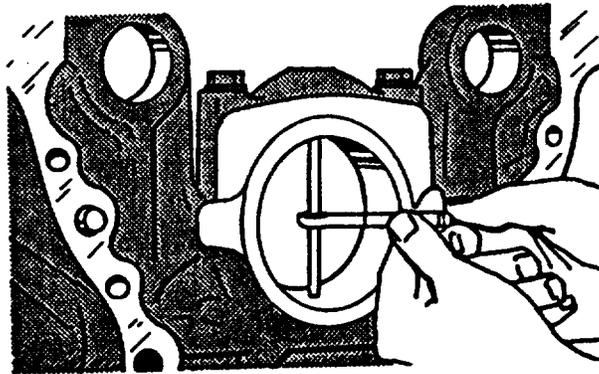


FIGURE 3-137. Inspecting Cylinder Block

- b. Clean O-ring bore using O-ring bore cleaning brush as follows.
- (1) Chuck bore cleaning brush in 1/2 inch drill. Rotate brush and move in an up and down motion in O-ring bore.
  - (2) Thoroughly clean all corrosion and lime deposits from O-ring bore.
- c. Measure cylinder block as follows:
- (1) Measure main bearing bore diameter, refer to FIGURE 3-138. Main bearing bore diameter must be 3.325 to 3.326 inches (84.46 to 84.48 mm).
  - (2) Measure engine block main thrust bearing width. With must be 1.3235 to 1.3275 inches (33.62 to 33.72 mm)
  - (3) If bearing caps are damaged, or bore is not within specification, replace cylinder block.

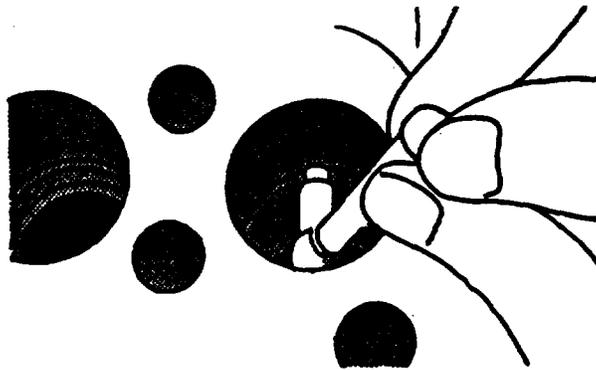


**FIGURE 3-138. Measuring Main Bearing Bore Diameter**

**NOTE**

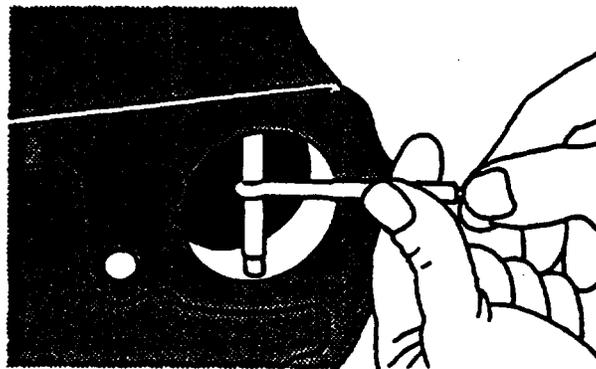
**Replacement bearing caps are supplied with bearing bore unfinished.**

- (4) Measure cam follower bore diameter, refer to FIGURE 3-139. New diameter is 1.248 to 1.250 inches (31.70 to 31.75 mm). If diameter is more than specified, install a new engine block. Service bushings are not available. New cam follower diameter is 1.245 to 1.246 inches (31.62 to 31.65 mm). Maximum cam follower clearance is 0.005 inch (0.13 mm)



**FIGURE 3-139. Measuring Cam Follower Bore Diameter**

- (5) Measure camshaft bore diameter, refer to FIGURE 3-140. New diameter is 2.204 to 2.205 inches (55.98 to 56.01 mm). If diameter is more than specified, install a new engine block. New camshaft journal clearance (camshaft bore ID minus camshaft journal OD is 0.003 to 0.005 inch (0.08 to 0.13 mm). Maximum clearance is 0.006 inch to (0.15 mm).



**FIGURE 3-140. Measuring Camshaft Bore Diameter**

- (6) Measure balancer shaft bushing bore diameters in engine block New bore diameter is 1.625 to 1.626 inches (41.26 to 41.29 mm). If diameter is more than specified, install oversize balancer shaft bushings.
- (7) Measure cylinder block top deck flatness using precision straightedge, refer to FIGURE 3-141. New flatness is 0.003 inch (0.08 mm). If flatness is not as specified, resurface engine block

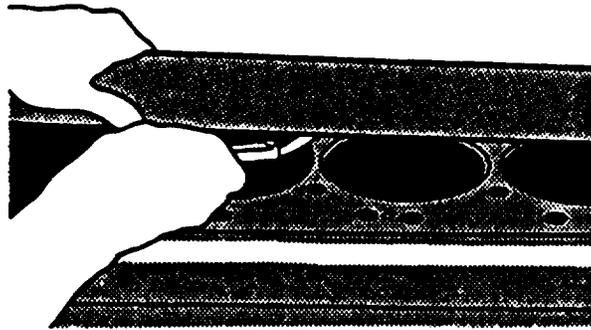


FIGURE 3-141. Measuring Cylinder Block Top Deck Flatness

**CAUTION**

When cylinder block is machined (top deck or crankshaft bearing bores), the dimension from centerline of crankshaft bearing bore to top deck will be changed. Make sure that this dimension will not be less than 11.889 Inches (301.98 mm). Otherwise, piston may contact cylinder head.

**CAUTION**

If cylinder block top deck is resurfaced, also measure depth of liner counter bores. Bore depth must be within 0.234 to 0.236 Inch (5.95 to 5.99 mm).

- d. Measure cylinder liner height as follows:

**NOTE**

If liner height was not checked when liners were removed, refer to paragraph 334.6., step e, or a new liner is being installed in a new or used cylinder block, liner height must be checked.

- (1) Be sure liner bore in cylinder block is clean.
- (2) Install liners without -rings and packing.

**CAUTION**

Liner should rotate smoothly by hand when installed. If remove liner and polish bottom liner pilot bore in cylinder block with emery cloth. Use a shop towel or other suitable means to collect debris when polishing bore.

- (3) Install liner with its mark toward the front of the engine. Secure with capscrews and washers. Tighten screws to 50 ft-lbs (68 Nm).
- (4) Using gage (JDG451) and dial indicator, measure each liner height in four places, at approximately 1, 5, 7, and 11 o'clock positions as viewed from the rear of the engine (flywheel end). Record all measurements.
- (5) Liner height specification is 0.0004 to 0.004 inch (0.01 to 0.10 mm). Maximum permissible difference between readings within one cylinder or between adjacent cylinders is 0.002 inch (0.06 mm).

- (6) If liner height is above specification, check cylinder block for burrs on liner support flange or incorrect counterbore depth.

**CAUTION**

**Only one shim (1, FIGURE 3-142) is allowed per cylinder. If liner requires more than one shim, install either a new liner or engine block,**

- (7) If liner height is below specification, install one liner shim on bottom of liner flange. Two sizes of shims are available:
- (a) 0.002 inch (0.05 mm) - Part No. CD15466.
  - (b) 0.004 inch (0.10 mm) - Part No. R65833.

**3-48. REPAIR.**

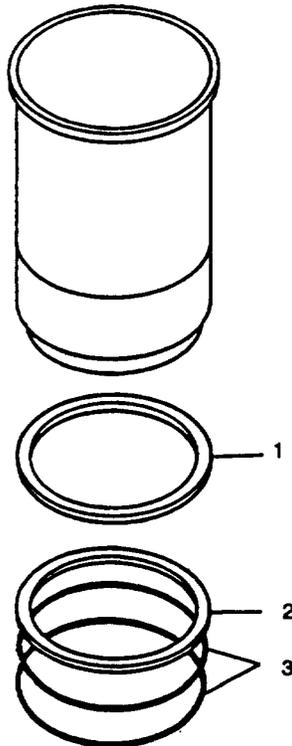
**3-48.1. Cylinder Liners.**

- a. Deglaze cylinder liners as follows:

- (1) Fabricate cylinder liner holding fixture (FIGURE D-3, Appendix D). (2) Secure cylinder liner in holding fixture.

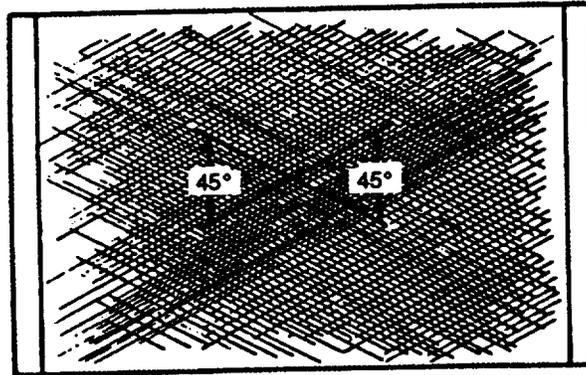
**NOTE**

**Use honing oil (MB-30) along with deglazer when deglazing liners.**



**FIGURE 3-142. Location of Cylinder Liner Shim**

- (3) Use deglazer, to deglaze liner and obtain a 45 degree cross hatch pattern, refer to FIGURE 3-143.



**FIGURE 3-143. Deglazed 45 Degree Cross Hatch Pattern**

- (a) Chuck deglazer in a 1/2 inch slow speed drill.
- (b) Apply honing oil (MS- 30) into cylinder liner. Insert deglazer into cylinder liner.
- (c) Move deglazer in an up and down direction 10 to 12 complete strokes per cylinder. Move deglazer rapidly enough to obtain a 45 degree crosshatch pattern as shown in FIGURE 3-143.
- (d) Thoroughly clean cylinder liners after deglazing.

### **3-49. ASSEMBLY.**

#### **3-49.1. Piston and Rod.**

- a. Connect piston (7, FIGURE 3-124) to connecting rod (4) as follows:

#### **CAUTION**

**If a new piston and liner assembly is to be installed, do not remove piston from liner. Push piston out of liner bottom only far enough to install piston pin.**

- (1) Lubricate piston pin (6) and piston pin bore with clean engine lubricating oil (MIL-L-2104).

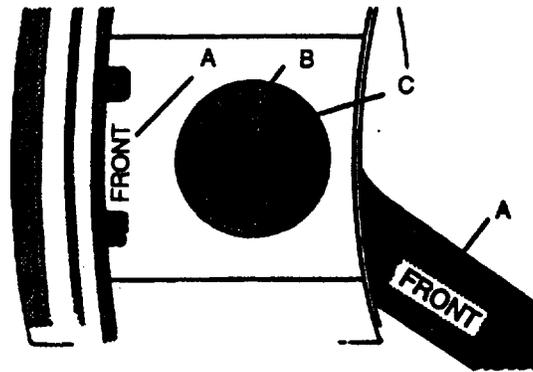
#### **CAUTION**

**Pistons (7) must be installed on connecting rods (4) from which they were removed.**

- (2) Assemble pistons (7) and connecting rods (4), making sure word FRONT (A, FIGURE 3-144) on side or top of piston and side of connecting rod are on same side.

#### **CAUTION**

**If FRONT is not visible on side or top of piston, install piston on rod so that offset in combustion bowl of piston is opposite camshaft side of engine. The long side of the connecting rod should face camshaft side of block.**



**FIGURE 3-144. Assembled Piston, Pin, and Connecting Rod**

- (3) Insert piston pin (B) into piston pin bore. Install new piston pin retaining rings (C) with sharp edge of ring facing away from piston pin. Check to be sure retaining rings are seated in grooves of piston pin bore.

**CAUTION**

**Always refer to manufacturer's specifications for ring identification markings and locations before installation. Failure to install rings in the proper locations will result in equipment damage.**

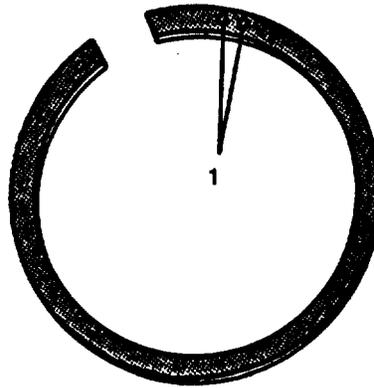
- b. Install new piston rings (8, FIGURE 3-124) as follows:

- (1) Using piston ring expander, install oil ring expander in bottom ring groove. Position end gap over either end of piston pin.
- (2) Install oil control ring in bottom ring groove over ring expander. Install with end gap on opposite side of piston from ring expander gap.

**NOTE**

**A dye stain is added to rectangular and keystone compression rings for added identification.**

- (3) Rectangular compression ring (FIGURE 3-145) is marked with two depressions or with word TOP to identify top side of ring. Install rectangular compression ring in center ring groove with mark toward top of piston.



**FIGURE 3-145. Compression Ring Identification Marks**

- (4) Position gap in rectangular compression ring on opposite side of piston from oil control ring gap.
- (5) Keystone compression ring has a mark to identify top side of ring. Install keystone compression ring in top ring groove with mark toward top of piston.
- (6) Position gap in keystone compression ring on opposite side of piston from rectangular compression ring gap.

3-49.2. Cylinder Block.

- a. If removed, install oil galley and water galley plugs, refer to FIGURE 3-127.
- b. Install piston cooling nozzles, refer to FIGURE 3-136, and tighten to 84 in-lbs (9.5 Nm).
- c. Install cylinder liners, refer to paragraph 3-50.2.
- d. Install crankshaft and main bearings, refer to paragraph 3-44.4.
- e. Install engine front plate and oil bypass valve, refer to paragraphs 3-43.5. and 3-22.3.
- f. Install balancer shafts and bushings, refer to paragraph 3-41.4.
- g. Install camshaft, refer to paragraph 3-40.3.
- h. Install idler gears, refer to paragraph 3-42.3.
- i. Install timing gear cover, refer to paragraph 3-39.3.
- j. Install oil pressure regulating valve, refer to paragraph 3-17.3.
- k. Install crankshaft pulley, refer to paragraph 3-38.3.

3-50. INSTALLATION.

3-50.1. General.

**NOTE**

**Always install a new (matched set) liner when replacing a piston. Distance from top of piston to top of keystone ring groove is 0.158 inch (4 mm).**

**CAUTION**

Do not stamp top of high ring piston. Piston can be damaged.

**NOTE**

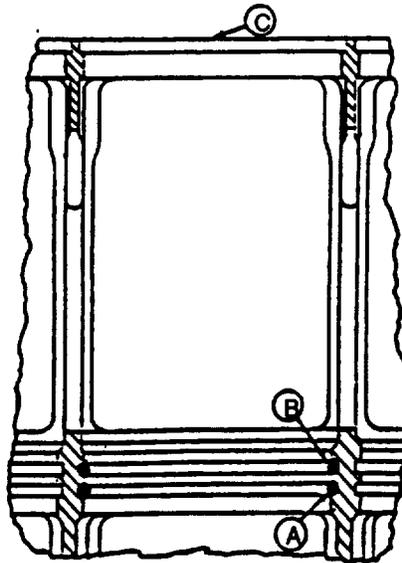
New rings are furnished with the correct end gap; therefore, fitting to the liner is not necessary.

3-50.2. Cylinder Liners.

**CAUTION**

Do not use oil or hand cleaner soap on cylinder liner packings (A, FIGURE 3-146). Petroleum products will cause the red (or white) packing to swell, which may result in packing damage during liner installation.

- a. Pour liner lubricant (AR54749) into a suitable container. Dip packings (A and B, FIGURE 3-146) in lubricant.
- b. Install black packing (A) in lower packing groove in cylinder block.

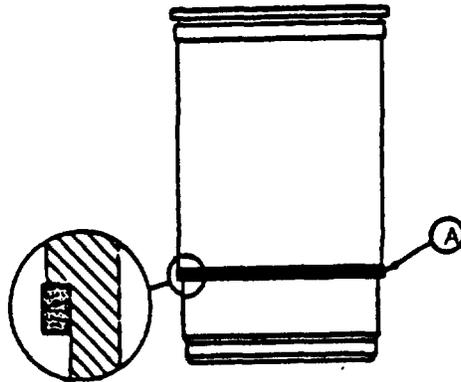


**FIGURE 3-146. Location of Cylinder Liner Packings**

- c. Install red (or white) packing (B) in upper packing groove in cylinder block.
- d. Turn cylinder liner upside-down. Dip the square packing (A, FIGURE 3-147) in liner lubricant and install over outside of liner.

**CAUTION**

Make sure packing is not twisted, otherwise poor sealing and equipment damage will occur.



**FIGURE 3-147. Location of Cylinder Liner Square Packing**

- e. Slide packing down firmly against shoulder on liner.
- f. Coat liner packings (A and B, FIGURE 3-146), sealing area of the cylinder liner and engine block packing (A, FIGURE 3-147) with liner lubricant.
- g. Carefully place cylinder liner, with packing installed, into cylinder block bore. Do not scuff packing across upper bore.

**CAUTION**

When OD of liners are pitted or eroded, but still within the acceptable service limit, rotate liners 90 degrees from their removed position. Rotate pitted section of liner either toward front or rear of engine. If liners are not pitted or eroded, rotation will not be necessary. Install liners with mark toward the front of engine.

**NOTE**

A resistance will be felt when cylinder liner is aligned in pilot bore.

- h. Seat liners (9, FIGURE 3-124) with wood block and hammer.
- i. Cylinder liner (9) will protrude over top of cylinder block more than normal due to uncompressed packings.

**CAUTION**

If you suspect that a packing may have sheared or displaced while installing liner, remove and examine liner and packing assembly. If no damage is found, check packings for proper position, relubricate packings and reinstall liner assembly.

- j. With liners installed, hold in place with large flatwashers and capscrews, refer to FIGURE 3-121. Turn capscrews snug but do not tighten.

- k. Clean cylinder liner bores with waterless hand cleaner after installation.
- l. Wipe dry with clean towels.
- m. Apply a thin coat of clean engine lubricating oil (MIL-L-2104) immediately to ID of liners to prevent corrosion.

3-50.3. Pistons and Connecting Rods.

- a. Ensure piston ring gaps are staggered as described in paragraph 3-49.1., and as shown on FIGURE 3-148.
- b. Coat pistons liners and inside of ring compressor with clean engine lubricating oil (MIL-L-2104).
- c. Carefully place ring compressor with piston and rod over liner.

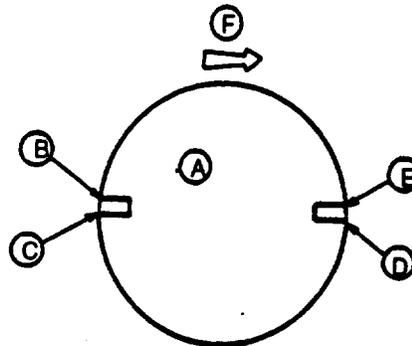


FIGURE 3-148. Staggered Piston Ring Gaps

**CAUTION**

Be sure crankshaft journals and liner walls are not damaged by rod when installing piston and rod in liner.

**CAUTION**

Be sure word **FRONT** on side of rod and side or top of piston faces toward front of engine. If **FRONT** is not visible on side or top of pistons, install piston on rod so that offset in combustion bowl is opposite camshaft side of engine. Long side of connecting rod should face camshaft side of block.

- d. With piston centered in ring compressor and rings staggered correctly, push piston into liner.
- e. Install one bearing insert in connecting rod with tang (A, FIGURE 3149) in groove (B). Put clean engine lubricating oil (MIL-L-2104) on insert and crankshaft journal. Carefully pull connecting rod with insert to crankshaft journal.

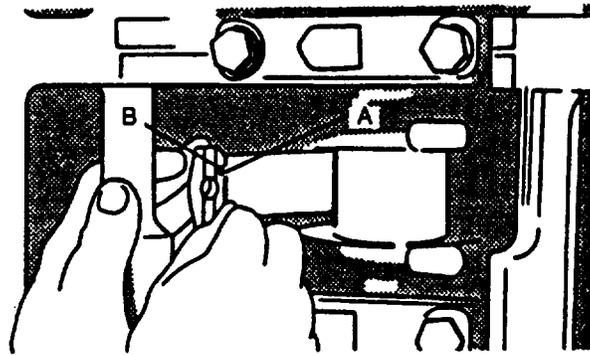


FIGURE 3-149. Installing Connecting Rod Bearing

- f. Install other bearing insert in connecting rod cap with tang (A, FIGURE 3-150) in groove (B). Put clean engine lubricating oil (MIL-L-2104) on insert.

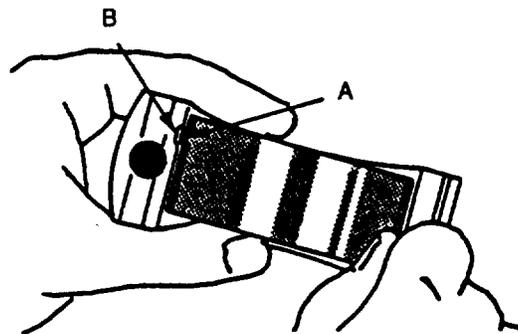


FIGURE 3-150. Installing Connecting Rod Cap Bearing

- g. Install cap on connecting rod with tang (A, FIGURE 3-151) to same side.

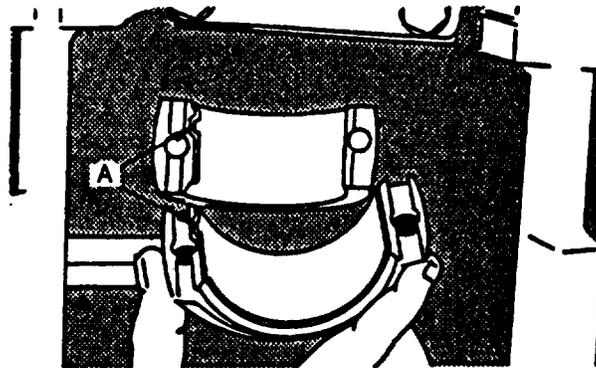
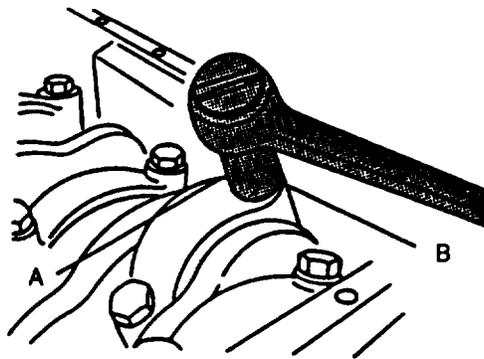


FIGURE 3-151. Installing Connecting Rod Cap

**CAUTION**

**Never use connecting rod capscrews (1, FIGURE 3-123) more than once for final engine assembly.**

- h. Dip new connecting rod capscrews (1) in clean engine lubricating oil (MIL-L-2104) and install. Tighten capscrews alternately to 41 ft-lbs (56 Nm).
- i. Torque-turn all capscrews 90 to 100 degrees as follows:
  - (1) After tightening capscrews (1) to the values given above, mark connecting rod cap (A, FIGURE 3-152) and socket.
  - (2) Make a second mark on socket 90 degrees counterclockwise from first mark.
  - (3) Tighten 1/4 turn (90 to 100 degrees) clockwise until mark (B) is in line with mark (A) on cap.
- j. Check engine rotation for excessive tightness as follows:
  - (1) Rotate crankshaft several revolutions to be sure engine rotates without excessive tightness.
  - (2) Check liners (9, FIGURE 3-124) for deep scratches which would indicate an improperly installed or broken piston ring(s).



**FIGURE 3-152. Tightening Connecting Rod Caps**

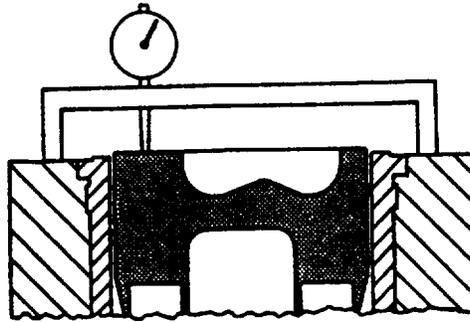
- (3) Check for proper side clearance in all rods. Each rod should have slight side-to-side movement.

- k. Measure piston protrusion as follows:

**NOTE**

**Press down on top of piston to remove oil clearances before measuring piston protrusion.**

- (1) Mount a dial indicator in gage (JDG451). Place gage on top of cylinder block in such a manner that dial indicator can be set at 'zero' with top of block.
- (2) Position gage across piston with outer ends on block so dial indicator plunger can contact top of piston, refer to FIGURE 3-153. Press down on top of gage and rotate crankshaft until piston is at TDC. Piston height must be checked at outer most diameter of piston.
- (3) Piston protrusion should be 0.003 to 0.012 inch (0.08 to 0.30 mm) to prevent piston-to-exhaust valve contact.



**FIGURE 3-153. Measuring Piston Protrusion**

- l. Install oil pump and outlet tube, refer to paragraph 3-21.3.
- m. Install oil pan, refer to paragraph 3-20.3.
- n. Install cam followers, refer to paragraph 3-34.7.
- o. Install cylinder head, refer to paragraph 3-34.7.
- p. If engine was completely disassembled, perform steps s through ae of paragraph 3-4.2.

**3-211/(3-212 blank)**

APPENDIX A

REFERENCES

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**A-1. SCOPE.**

This appendix lists all forms, field manuals, technical manuals and miscellaneous publications references in this manual.

**A-2. FORMS.**

Air Force Reporting of Errors Form .....	AFTO Form 22
Marine Corps Reporting of Errors Form .....	NAVMC Form 10772
Product Quality Deficiency Report .....	SF 368
Recommended Changes to DA Publications .....	DA Form 2028-2
Recommended Changes to Publications and Blank Forms .....	DA Form 2028
Report of Discrepancy (ROD) .....	SF 364
Reporting of Item and Packaging Discrepancies .....	AR 735-11-2
Reporting of Transportation Discrepancies in Shipment .....	AR 55-38
Transportation Discrepancy Report .....	SF 361
Equipment Control Records .....	DA Form 2408-9

**A-3. FIELD MANUALS.**

First Aid for Soldiers .....	FM 21-11
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**A-4. TECHNICAL MANUALS.**

Destruction of Materiel .....	TM 750-244-3
Repair Parts and Special Tools List	
Engine, Diesel Model 4039T .....	TM 9-2815-255-24P

**A-5. MISCELLANEOUS PUBLICATIONS.**

Maintenance Management Policy .....	AFR 66-1
Preservation of USAMECOM Mechanical Equipment	
for Shipment and Storage .....	TB 740-97-2
Suggestion Program .....	AFR 9004
The Army Maintenance Management System (TAMMS) .....	DA PAM 738-750
USAF Materiel Deficiency Reporting .....	TO-35D54

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## APPENDIX B

### MAINTENANCE ALLOCATION CHART

---

#### Section I. INTRODUCTION

##### **B-1. THE ARMY MAINTENANCE SYSTEM MAC.**

a. This introduction (section I) provides a general explanation of all maintenance and repair 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 constant 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 0 (unit) maintenance.

Direct Support - includes an F subcolumn.

General Support - includes an H subcolumn.

Depot - includes an 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.

##### **B-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 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 preserve, 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 exact position, or by setting the operating characteristics to specified parameters.

e. Aline. To adjust specified variable elements of an item to bring about optimum or desired 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<sup>1</sup> including fault location/troubleshooting<sup>2</sup>, removal/installation, and disassembly/assembly<sup>3</sup> procedures, and maintenance actions<sup>4</sup> 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 is 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. Rebuild 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.

### **B-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 B-2.)

---

<sup>1</sup>Service - Inspect, test, service, adjust, align, calibrate, and/or replace

<sup>2</sup>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).

<sup>3</sup>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 as SMR code for the level of maintenance under consideration (i.e., identification as maintenance significant).

<sup>4</sup>Actions - Welding, grinding, riveting, straightening, facing, machining, and/or resurfacing.

- 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
H	General Support Maintenance
D	Depot Maintenance

- e. Column 5 - Tools and Equipment. Column 5 specifies, by code, those common tool sets (not individual tools) and special tools, TMDE, and support equipment required to perform the designated function.
- 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.

**B-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 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 of the tool or test equipment.
- e. Column 5 - Tool Number. The manufacturer's part number.

**B-5. EXPLANATION OF COLUMNS IN REMARKS, SECTION IV.**

- a. Column 1 - Reference Code. The 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  
 FOR DIESEL ENGINE MODEL 4039T

(1) Group Number	(2) Component/ Assembly	(3) Maint. Function	(4) MAINTENANCE LEVEL					(5) Tools and Equipment	(6) Remarks
			Unit		Direct Support	General Support	Depot		
			C	O	F	H	D		
00	ENGINE ASSEMBLY 30KW	INSPECT SERVICE TEST ADJUST REPAIR R/I REPLACE OVERHAUL	.2 .3	.5 .5 1.0 1.0	1.0 2.0 4.0 4.0			4, 6, 26, 27	A
0100	COOLING SYSTEM	INSPECT SERVICE REPAIR		.1 .2 .5	.1 1.0	A 5			
0101	THERMOSTAT AND HOUSING	INSPECT R/I REPAIR		.7 .5 .5				1,5 1,5	C
0102	WATER PUMP	INSPECT R/I REPAIR		.1 2.0 2.0	1,5 1,5	C			
0200	ELECTRICAL SYSTEM	INSPECT REPAIR	.1	.1 .5	A 2.0				
0201	ALTERNATOR ASSEMBLY	INSPECT TEST R/I REPLACE REPAIR		.1 .5 1.0 1.0	1.0 2.0			1 5 5	C
0202	STARTER MOTOR ASSEMBLY	INSPECT TEST R/I REPLACE REPAIR		.1 .5 1.0 1.0 1.0		1, 2, 5		1, 2, 4 5 5	C
0300	AIR INTAKE & EXHAUST SYSTEM	INSPECT REPAIR	.1	.1	2.0 2.0			1, 2, 5	A
0301	TURBOCHARGER	INSPECT TEST R/I REPAIR			.1 1.0 2.0 2.0	.1		4,5 1,5	
0302	EXHAUST MANIFOLD	INSPECT R/I REPAIR		.1	.1 3.0 3.0	1,5	C	1,5 1,5	C
0400	LUBRICATION SYSTEM	INSPECT SERVICE REPAIR	.1 .1	.1 .2 1.0	2.0				C A

ARMY TM 9-2815-255-24  
AIR FORCE TO 38G1-95-2  
MARINE CORPS TM 2815-24/4

(1)  Group Number	(2)  Component/ Assembly	(3)  Maint. Function	(4) MAINTENANCE LEVEL					(5)  Tools and Equipment	(6)  Remarks
			Unit		Direct Support	General Support	Depot		
			C	O	F	H	D		
0401	OIL FILTER	INSPECT		.1					
		REPLACE		.2	.1				
0402	COOLER, LUBRICATING	INSPECT		.1				1,5	
		R/I		1.0				1, 5	C
0403	OIL PRESSURE REGULATING VALVE ASSEMBLY	REPLACE		1.0					
		INSPECT			.1				
		R/I			1.0			1,4, 5,15, 21	
		REPLACE			1.0			1,4, 5,15, 21	C
		REPAIR			1.5			1,4, 5,15,,21	
0404	OIL PAN	INSPECT		.1	.1				
		R/I			4.0			1,5	
		REPLACE			4.0			1,5	C
0405	OIL PUMP ASSEMBLY	INSPECT			.1				
		TEST			1.0			3, 4, 5	
		R/I			6.0			1, 5,12	C
		REPLACE			6.0			1, 5,12	
0406	BY-PAS VALVE ASSEMBLY	INSPECT			.1				
		TEST			2			4	
		R/I			4.5				
		REPLACE			4.5				C
		REPAIR			4.5				
0500	FUEL SYSTEM	INSPECT	.1	.1					A
		SERVICE	.1						
		REPAIR		1.0	2.0	4.0			
0501	FUEL FILTER	INSPECT	.1	.1					
		SERVICE	.1	.4	.5				
		REPLACE		.2	.5				
0502	FUEL SUPPLY PUMP	INSPECT		.1					
		TEST		.5				1,5	
		R/I		1.0	.5				
0503	FUEL LINES	REPLACE		1.0	.5				C
		INSPECT		1					
		R/I		1.0				5, 24	
		REPLACE		1.0				5, 24	C
		REPAIR		1.5	.5				D
0504	FUEL INJECTION PUMP	INSPECT		.1	.1	.2			
		TEST			1.0	1.0		5,19,30,31,32,33	
		R/I			2.0			1,5,12,24,28	
		REPLACE			2.0			1,5,12,24,28	C
		REPAIR				4.0		1,2,5,20,21,22, 29,34	

ARMY TM 9-2815-255-24  
AIR FORCE TO 38G1-95-2  
MARINE CORPS TM 2815-24/4

(1)  Group Number	(2)  Component/ Assembly	(3)  Maint. Function	(4) MAINTENANCE LEVEL					(5)  Tools and Equipment	(6)  Remarks
			Unit		Direct Support	General Support	Depot		
			C	O	F	H	D		
0505	FUEL INJECTION NOZZLE ASSEMBLY	INSPECT TEST R/I REPLACE		.1	.1 .5 2.0 2.0			2 1, 5 1,5	C
0600	CYLINDER HEAD ASSEMBLY	INSPECT R/I REPLACE REPAIR			.5 2.0 2.0 4.0			1,5 1,5	C
0601	ROCKER ARM ASSEMBLY	INSPECT ADJUST TEST R/I REPLACE REPAIR			.1 .5 .2 2.0 2.0 2.0			5,12 3, 4 1,5 1,5 1, 5	C
0602	VALVE SPRINGS	INSPECT TEST R/I REPLACE REPAIR			.1 .5 1.0 1.0 2.0			3 3, 5 3, 5	C
0603	INTAKE/EXHAUST VALVES	INSPECT TEST R/I REPLACE REPAIR			.1 .5 3.0 3.0 4.0			3, 4 3, 5 3, 5 3	C
0604	CYLINDER HEAD	INSPECT TEST RW REPLACE REPAIR			.2 1.0 4.0 4.0 6.0			3, 4 1,5 1,5 3,13	C
0700	FLYWHEEL & HOUS- ING ASSEMBLIES	INSPECT REPLACE			.1 6.0			4	
0701	FLYWHEEL ASSEMBLY	INSPECT R/I REPLACE REPAIR			.1 5.0 5.0 6.0			1, 5 1, 5 1, 5	C
0702	REAR CRANK- SHAFT OIL SEAL	INSPECT REPLACE			.1 6.0			5, 18	
0800	CRANKSHAFT PULLEY	INSPECT RWI REPLACE			.1 1.0 1.0			1, 4, 5 1, 4, 5	C
0900	TIMING GEAR COVER ASSEMBLY	INSPECT R/I REPLACE REPAIR			.1 2.0 2.0 .5			1,5 1,5	C

ARMY TM 9-2815-255-24  
AIR FORCE TO 38G1-95-2  
MARINE CORPS TM 2815-24/4

(1)  Group Number	(2)  Component/ Assembly	(3)  Maint. Function	(4) MAINTENANCE LEVEL					(5)  Tools and Equipment	(6)  Remarks
			Unit		Direct Support	General Support	Depot		
			C	O	F	H	D		
0901	CRANKSHAFT FRONT OIL SEAL SHORT BLOCK ASSEMBLY	INSPECT			.1				
1000		REPLACE			.5	.5			
		INSPECT				.5		1,5	
		R/I				10.0		1,5	
		REPLACE				10.0			C
		REPAIR				20.0			
1001	CAMSHAFT ASSEMBLY	INSPECT				.2			
		ADJUST				.5		10	
		TEST				.5		3, 4, 5	
		R/I				4.5		5	
		REPLACE				4.5		5	C
		REPAIR				.5		4	E
1002	BALANCER SHAFTS & BUSHINGS	INSPECT				.2			
		ADJUST				.5		10	
		TEST				.5		3, 4, 5	
		R/I				4.5		1,5	
		REPLACE				4.5		1, 5	C
		REPAIR				5.5		2, 3, 5,7, 8	
1003	IDLER GEAR ASSEMBLIES	INSPECT				.2			
100301		REPLACE				2.0			
	IDLER GEARS	INSPECT				.2			
		TEST				.5		3, 4	
		R/I				2.5		1, 5	
		REPLACE				2.5		1, 5	C
		REPAIR				3.0		2, 9,15	
100302	IDLER GEAR SHAFTS	INSPECT				.2			
		TEST				.5		4	
		REPLACE				2.5		1,5	
1004	CRANKSHAFT	INSPECT				.2			
		TEST				.5		3, 4	
		R/I				10.0		1, 5	
		REPLACE				10.0		1, 5	C
		REPAIR				12.0		3, 4, 16	
1005	MAIN BEARINGS	INSPECT				.2			
		TEST				.5		1,4	
		R/I				10.5		1, 5	
		REPLACE				10.5		1,5	C
1006	PISTON & CON- NECTING ROD ASSEMBLY	INSPECT				.2			
		R/I				10.0		1,4, 5	
		REPLACE				10.0		1, 4, 5	C
		REPAIR				12.0			

(1)  Group Number	(2)  Component/ Assembly	(3)  Maint. Function	(4) MAINTENANCE LEVEL					(5)  Tools and Equipment	(6)  Remarks
			Unit		Direct Support	General Support	Depot		
			C	O	F	H	D		
100601	PISTON ASSEMBLY	INSPECT				.2			
		TEST				.5		4, 5	
		R/I				11.0		1,4	
	CONNECTING ROD	REPLACE				11.0		1,4	C
100602		REPAIR				11.5		1,4	
		INSPECT				.2			
	PISTON PIN	TEST				.5		1,4	
		R/I				11.0		1,4	
		REPLACE				11.0		1,4	C
	CYLINDER LINER	REPAIR				11.5		1, 25	
100603		INSPECT				.2			
		TEST				.5		4	
	CYLINDER BLOCK	R/I				11.0		1,4	
		REPLACE				11.0		1,4	C
1007		INSPECT				.2			
	CYLINDER LINER	TEST				.5		3, 5,14	
		R/I				12.0		4, 5,14	
		REPLACE				12.0		4, 5,14	C
	CYLINDER BLOCK	REPAIR				13.0		1,3	
1008		INSPECT				.5			
		TEST				1.0		3, 4	
	CYLINDER BLOCK	REPLACE				15.0		1, 5	
		REPAIR				15.0		1, 5	

Section III. TOOLS AND TEST EQUIPMENT REQUIREMENTS  
 FOR  
 DIESEL ENGINE MODEL 4039T

Tool or Test Equipment Ref Code	Maintenance Category	Nomenclature	National/NATO Stock Number	Tool Number
1	O	SHOP EQUIPMENT, AUTOMOTIVE MAINTENANCE AND REPAIR: ORGANIZATIONAL MAINTENANCE COMMON NO. 1, LESS POWER	4910-00-754-0654	SC4910-95-CL-A74
2	F, H	SHOP EQUIPMENT, FUEL AND ELECTRICAL SYSTEM FIELD MAINTENANCE, BASIC, LESS POWER	4940-00-754-0714	SC4910-95-CL-B20
3	H	SHOP EQUIPMENT, AUTOMOTIVE MAINTENANCE AND REPAIR: FIELD MAINTENANCE, SUPPLEMENTAL SET NO. 2, LESS POWER	4910-00-754-0707	SC4910-95-CL-A63
4	F, H	TOOL SET, BASIC, FIELD MAINTENANCE	4910-00-754-0705	SC4910-95-CL-A31
5	O, F, H	TOOL KIT, GENERAL MECHANIC'S	5180-00-177-7033	SC5180-90-CL-N26
6	F	COMPRESSION GAGE		JT01682
7	H	HOLDING TOOL, BALANCE		JD-247
8	H	DRIVER, BUSHING		JD-249
9	H	DRIVER, IDLER GEAR		JD-252
10	H	TOOL, GEAR TIMING	5120-01-353-1121	JD-254
11	F	DRIVER, PILOT		JDG-676
12	F, H	PIN, ECCENTRIC	5315-01-321-6068	JDE-81-4
13	F	ADAPTER, VALVE INSERT		JDG-975
14	H	GAGE, PISTON/LINER	5210-01-351-5114	JDG451
15	F, H	HANDLE, OIL SEAL DRIVER	5120-00-034-0881	10914188
16	H	DRIVER, GEAR		JDH-7
17	F	DRIVER, BUSHING		JD248A
18	F, H	INSTALLER SET, SEAL	5120-01-334-7012	JT30040
19	F	STAND, CALIBRATION	4910-01-121-6869	77-7028
20	H	EXTRACTOR	5120-00-816-7059	13383
21	H	FIXTURE	5120-01-200-4526	19969
22	H	GAGE, LINKAGE	5120-00-816-7031	18914
23	F	HANDLE, OIL REGULATING VALVE BUSHING DRIVER		JDG-536
24	F	WRENCH, CROWSFOOT, 11/16"	5120-00-189-7896	GGG-C-507 TY1CL2

**Section III. TOOLS AND TEST EQUIPMENT REQUIREMENTS  
 FOR  
 DIESEL ENGINE MODEL 4039T - Continued**

<b>Tool or Test Equipment Ref Code</b>	<b>Maintenance Category</b>	<b>Nomenclature</b>	<b>National/NATO Stock Number</b>	<b>Tool Number</b>
25	H	DRIVER, BUSHING		JD-286
26	F	ADAPTER, COMPRESSION GAGE		JT01679
27	F	HOLDING CLAMP, COMPRESSION GAGE ADAPTER		JT02017
28	F	GEAR PULLER		JDG670
29	H	CAP SOCKET	5120-01-207-5563	20548
30	H	DRIVER HUB		67-3303
31	H	PRESSURE GAGE CONNECTOR		21900
32	H	CAM MOVEMENT READOUT DEVICE	5120-01-249-0368	23745
33	H	ADAPTER		67-5116
34	H	TIMING LINE INDICATOR TOOL		20395

**Section IV. REMARKS  
 FOR  
 DIESEL ENGINE MODEL 4039T**

<b>Reference Code</b>	<b>Remarks</b>
A	Refer to end item operator's manual.
B	Refer to end item maintenance manual.
C	Replace function is identical to remove/install function.
D	Repair is limited to replacement of damaged parts (refer to remove/install function).
E	Repair limited to replacement of gear.

**APPENDIX C**

**EXPENDABLE/DURABLE SUPPLIES AND MATERIALS LIST**

**Section I. INTRODUCTION**

**C-1. SCOPE.**

This appendix lists expendable/durable supplies and materials you will need to operate and maintain the engine: These items are authorized to you by CTA 50-970, Expendable/Durable Items (except medical, class V repair parts, and heraldic items).

**C-2. EXPLANATIONS OF COLUMNS.**

- a. Column 1. Item number. This number is assigned to the entry in the listing and is referenced in the narrative instructions to identify the Item (e.g. "Use cleaning compound, item 5, Appendix E".)
- b. Column 2. Level. This column identifies the lowest level of maintenance that requires the item.

- C - Operator/crew
- O - Unit maintenance
- F - Direct support maintenance
- H - General support maintenance

- c. Column 3. National stock number. This is the national stock number assigned to the item which you can use to requisition it.
- d. Column 4. Item name, description, Commercial and Government Entity Code (CAGEC), and part number. This provides the other information you need to identify the item.
- e. Column 5. Unit of measure. This code shows the physical measurement or count of an item, such as gallon, dozen, gross, etc.

**Section II. EXPENDABLE/DURABLE SUPPLIES LIST**

(1) Item Number	(2) Level	(3) National Stock Number	(4) Description	(5) U/M
1	DS/ GS	8040-01-250-3969	Adhesive, LOCTITE 242	TU
2	O, F	6850-00-181-7929	Antifreeze, MIL-A-46153, 1 Gal. Can	GL
3	O, F	6850-00-181-7933	Antifreeze, MIL-A-46153, 5 Gal. Can	GL
4	O, F	6850-00-181-7940	Antifreeze, MIL-A-46153, 55 Gal. Drum	GL
5	O, F	6850-00-174-1806	Antifreeze, MIL-A-11756	GL
6	DS/ GS	8030-01-234-2792	Antiseize Compound, CP-8	TU
7	DS/ GS	6850-00-311-6172	Bearing Dye, Blue, HISPOTBLUE 107	EA
8	Unit/ DS/ GS	7920-01-338-3329	Cloth, Cleaning, TX-1 250	EA
9	DS	6080-01-143-4853	Compound, Heat Sink, 5202217	OZ
10	Unit/ DS/ GS	6850-00-281-1985	Dry Cleaning Solvent, ASTM D235 TY1	GL
11	DS/ GS	5210-00-640-6178	Gage, Bearing Clear, PLASTIGSGEPR1	BX
12	Unit/ DS/ GS	9150-00-663-1770	General Purpose Grease, 630AA	TU
13	GS	9150-01-024-6059	Honing Oil, MB-30	CN

**Section II. EXPENDABLE/DURABLE SUPPLIES LIST - Continued**

(1) Item Number	(2) Level	(3) National Stock Number	(4) Description	(5) U/M
14	GS	9150-01-115-1649	Lubricant, Liner, Cyl, AR54749	OZ
15	Unit/V DS/ GS	9510-00-189-6727	Lubricating Oil, Eng, 10W, BRAYCO421C	QT
16	Unit/ DS/ GS	9150-00-152-4117	Lubricating Oil, Eng, 15/40W, MIL-1-21 04	QT
17	Unit/V DS/ GS	9150-00-186-6681	Lubricating Oil, Eng, 30W, ALLIEDC030	QT
18	Unit/ DS/GS	9150-00-402-2372	Lubricating, Oil, Eng, MIL-L-46167	OT
19	Unit/ DS/ GS	5350-00-543-3600	Paper, Abrasive, ALOXGRIT80	SHT
20	Unit/V DS/ GS	5350-00-224-7201	Paper, Abrasive, #400	SHT
21	Unit/ DS/ GS	8030-00-849-0071	Sealing Compound, FORMAGASKET2	TU
22	DS/ GS	8030-00-891-8358	Sealing Compound (LOCTITE 609); MIL-R-46082	TU
23	DS/ GS	8030-01-299-1762	Sealing Compound LOCTITE 77BR	OZ
24	Unit/ DS/ GS	6850-00-264-9038	Solvent, Dry Cleaning, P-D-680, 5 Gal. Can	GL

APPENDIX D

FABRICATION OF TOOLS

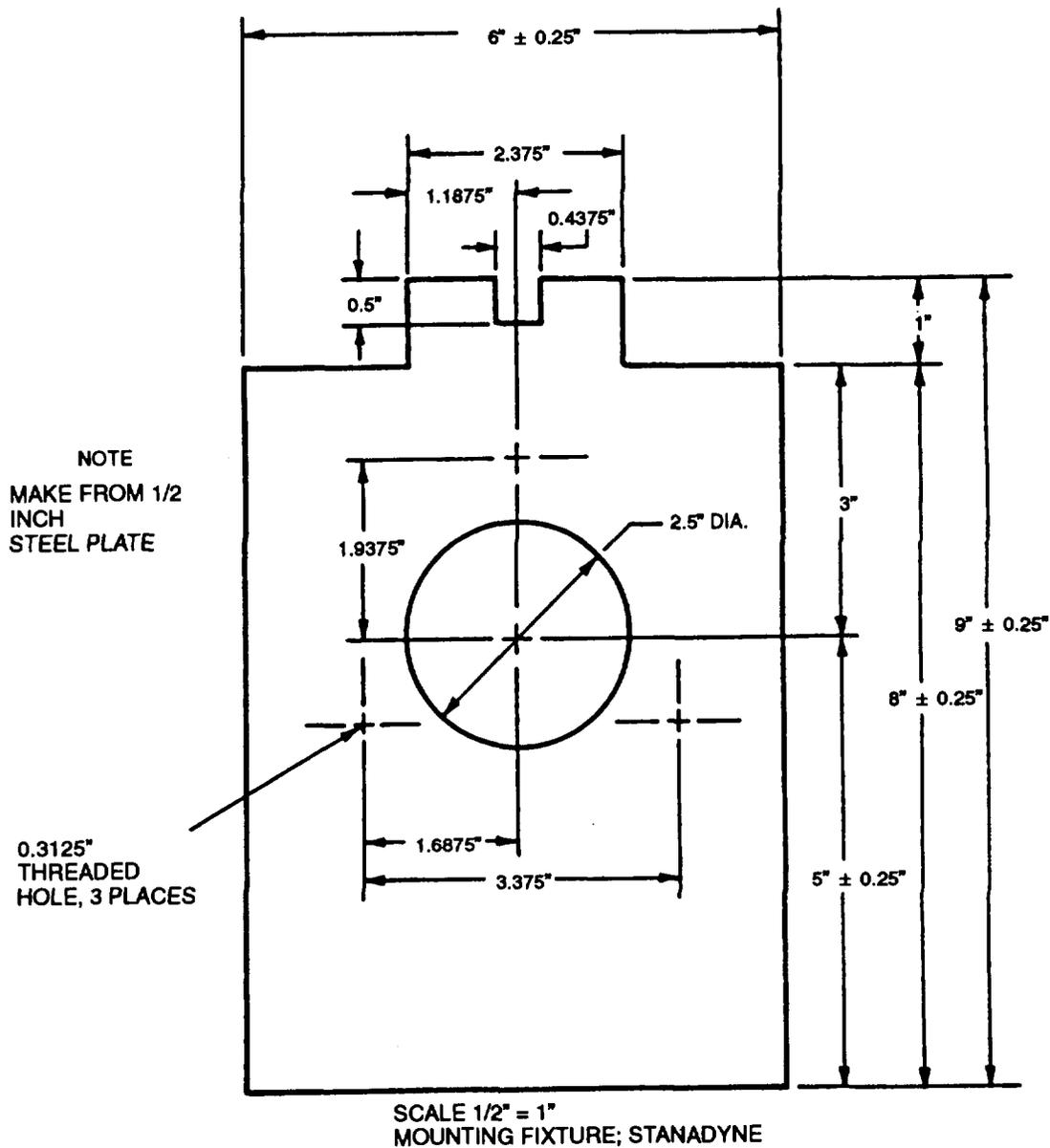


FIGURE D-1. Fuel Injection Pump Holding Fixture

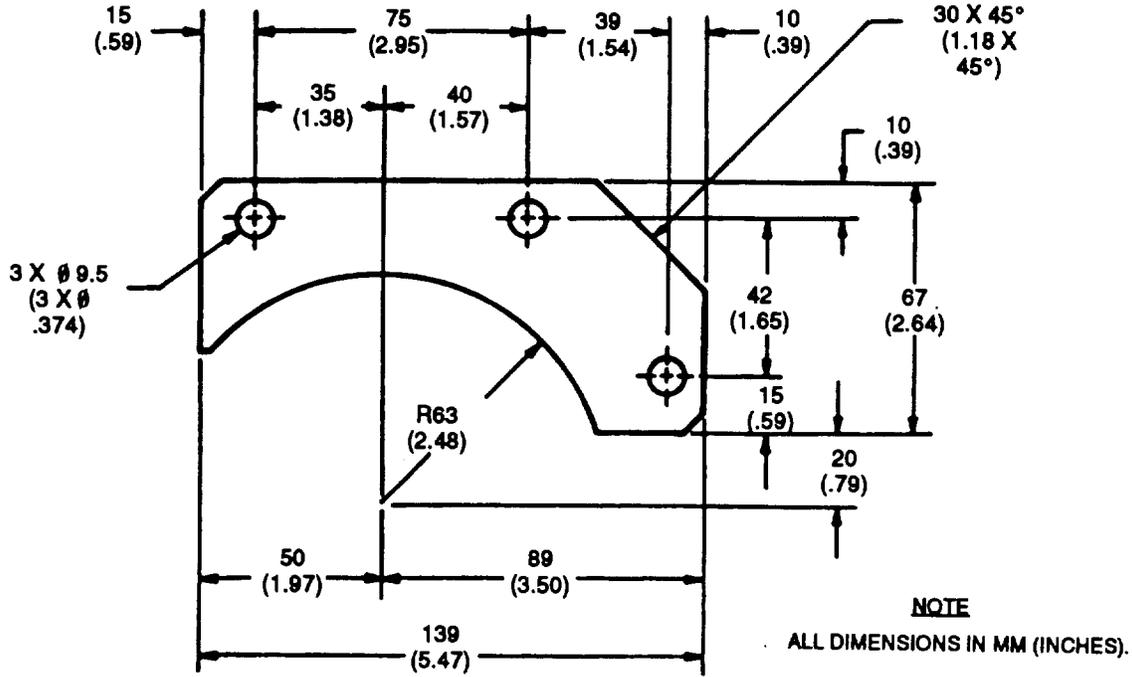


FIGURE D-2. Fuel Injection Pump Timing Mark Template

1. 10 inches (254.0 mm)
2. 5 inches (127.0 mm)
3. 1.5 inches (38.1 mm)
4. 16 inches (405.4 mm)
5. 13 inches (330.2 mm)
6. 0.38 inch (9.52 mm)
7. 0.5 inch (12.7 mm)
8. 1.25 inches (31.8 mm)
9. 2.5 inches (63.5 mm)
10. 1.0 inches (25.4 mm)
11. 0.25 inch (6.35 mm)
12. 6.0 inches (152.4 mm)
13. 0.328 inch drill through
14. 5/16 inch - 18 tap
15. 2 used
16. 12.0 inches (304.8 mm)
17. 5.16 inch -18 tap
18. 2.75 inches (69.85 mm) radius
19. 4 inches (101.6 mm)
20. 4.38 inches (111.25 mm)
21. 2.38 inches (60.45 mm)
22. 5/16 inch x 1.0 inch capscrew
23. 1.5 inches (38.1 mm) angle iron

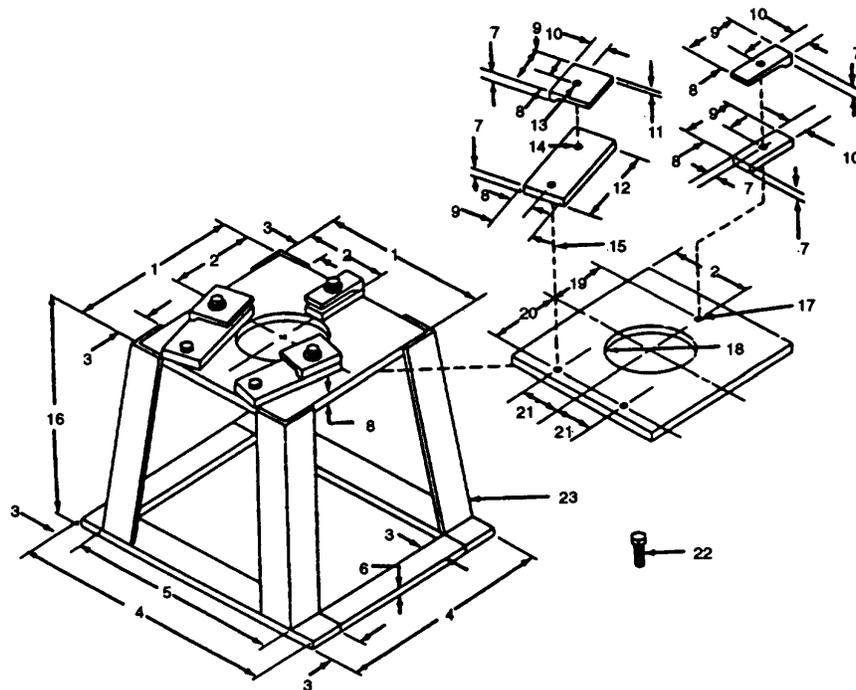


FIGURE D-3. Cylinder Liner Holding Fixture

D-3/(D-4 blank)

**Appendix E. MAINTENANCE PROCEDURE  
 AND AUTHORIZED LEVEL OF MAINTENANCE**

**Section I. INTRODUCTION**

**SCOPE.** This appendix shall be used when a Commercial Off The Shelf (COTS) manual is used by the Military services. This appendix is divided into three sections. Section I gives a brief description of the sections within this appendix. Section II list the paragraphs to the associated maintenance level. Section III list the maintenance level to the associated paragraphs.

**Section II. PARAGRAPH TO MAINTENANCE LEVEL**

Paragraph	Maintenance Level
3-3	ALL
3-4	ALL
3-5	F
3-6	F
3-7	F
3-8	O
3-9	O
3-10	O
3-11	O, F
3-12	O, F
3-13	F, H
3-14	O, F
3-15	O, F
3-16	O, F
3-17	O, F
3-18	O, F
3-19	F
3-20	O, F
3-21	F
3-22	F
3-23	O
3-24	O
3-25	O
3-26	O
3-27	O, F, H
3-28	F, H
3-29	F
3-30	F

**Section II. PARAGRAPH TO MAINTENANCE LEVEL - Cont.**

Paragraph	Maintenance Level
3-31	F
3-32	F
3-33	F
3-34	F
3-35	F
3-36	F
3-37	F
3-38	F
3-39	F
3-40	F
3-41	F
3-42	H
3-43	H
3-44	H
3-45	H
3-46	H
3-47	H
3-48	H
3-49	H
3-50	H

**Section III. MAINTENANCE LEVEL TO PARAGRAPHS**

Maintenance Level	Paragraphs
ALL	3-3, 3-4, 3-8, 3-9, 3-10, 3-11
O	3-12, 3-13, 3-14, 3-15, 3-16, 3-17, 3-18, 3-20, 3-23, 3-24, 3-25, 3-26, 3-27
F	3-5, 3-6, 3-7, 3-11, 3-12, 3-13, 3-14, 3-15, 3-16, 3-18, 3-19, 3-20, 3-21, 3-22, 3-27, 3-28, 3-29, 3-30, 3-31, 3-32, 3-33, 3-34,
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## These are the instructions for sending an electronic 2028

The following format must be used if submitting an electronic 2028. The subject line must be exactly the same and all fields must be included; however only the following fields are mandatory: 1, 3, 4, 5, 6, 7, 8, 9, 10, 13, 15, 16, 17, and 27.

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To: mpmt%avma28@st-louis-emh7.army.mil

Subject: DA Form 2028

1. **From:** Joe Smith
2. Unit: home
3. **Address:** 4300 Park
4. **City:** Hometown
5. **St:** MO
6. **Zip:** 77777
7. **Date Sent:** 19-OCT-93
8. **Pub no:** 55-2840-229-23
9. **Pub Title:** TM
10. **Publication Date:** 04-JUL-85
11. Change Number: 7
12. Submitter Rank: MSG
13. **Submitter FName:** Joe
14. Submitter Manama: T
15. **Submitter LName:** Smith
16. **Submitter Phone:** 123-123-1234
17. **Problem:** 1
18. Page: 2
19. Paragraph: 3
20. Line: 4
21. NSN: 5
22. Reference: 6
23. Figure: 7
24. Table: 8
25. Item: 9
26. Total: 123
27. **Text:**

This is the text for the problem below line 27.

RECOMMENDED CHANGES TO EQUIPMENT TECHNICAL PUBLICATIONS

<h2 style="margin: 0;">SOMETHING WRONG WITH PUBLICATION</h2>				
 <p style="margin: 0;"><i>THEN...JOT DOWN THE DOPE ABOUT IT ON THIS FORM. CAREFULLY TEAR IT OUT, FOLD IT AND DROP IT IN THE MAIL.</i></p>		FROM: (PRINT YOUR UNIT'S COMPLETE ADDRESS)		
PUBLICATION NUMBER		DATE SENT		
PUBLICATION DATE		PUBLICATION TITLE		
<b>BE EXACT PIN-POINT WHERE IT IS</b>				
PAGE NO.	PARA-GRAPH	FIGURE NO.	TABLE NO.	IN THIS SPACE, TELL WHAT IS WRONG AND WHAT SHOULD BE DONE ABOUT IT.
PRINTED NAME, GRADE OR TITLE AND TELEPHONE NUMBER			SIGN HERE	

## 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 = 3,280.8 feet

### Weights

1 centigram = 10 milligrams = .15 grain  
 1 decigram = 10 centigrams = 1.54 grains  
 1 gram = 10 decigrams = .035 ounce  
 1 decagram = 10 grams = .35 ounce  
 1 hectogram = 10 decagrams = 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

### Liquid Measure

1 centiliter = 10 milliliters = .34 fl. ounce  
 1 deciliter = 10 centiliters = 3.38 fl. ounces  
 1 liter = 10 deciliters = 33.81 fl. ounces  
 1 dekaliter = 10 liters = 2.64 gallons  
 1 hectoliter = 10 dekaliters = 26.42 gallons  
 1 kiloliter = 10 hectoliters = 264.18 gallons

### Square Measure

1 sq. centimeter = 100 sq. millimeters = .155 sq. inch  
 1 sq. decimeter = 100 sq. centimeters = 15.5 sq. inches  
 1 sq. meter (centare) = 100 sq. decimeters = 10.76 sq. feet  
 1 sq. dekameter (are) = 100 sq. meters = 1,076.4 sq. feet  
 1 sq. hectometer (hectare) = 100 sq. dekameters = 2.47 acres  
 1 sq. kilometer = 100 sq. hectometers = .386 sq. mile

### Cubic Measure

1 cu. centimeter = 1000 cu. millimeters = .06 cu. inch  
 1 cu. decimeter = 1000 cu. centimeters = 61.02 cu. inches  
 1 cu. meter = 1000 cu. decimeters = 35.31 cu. feet

## Approximate Conversion Factors

To change	To	Multiply by	To change	To	Multiply by
inches	centimeters	2.540	ounce-inches	Newton-meters	.007062
feet	meters	.305	centimeters	inches	.394
yards	meters	.914	meters	feet	3.280
miles	kilometers	1.609	meters	yards	1.094
square inches	square centimeters	6.451	kilometers	miles	.621
square feet	square meters	.093	square centimeters	square inches	.155
square yards	square meters	.836	square meters	square feet	10.764
square miles	square kilometers	2.590	square meters	square yards	1.196
acres	square hectometers	.405	square kilometers	square miles	.386
cubic feet	cubic meters	.028	square hectometers	acres	2.471
cubic yards	cubic meters	.765	cubic meters	cubic feet	35.315
fluid ounces	milliliters	29.573	cubic meters	cubic yards	1.308
pints	liters	.473	milliliters	fluid ounces	.034
quarts	liters	.946	liters	pints	2.113
gallons	liters	3.785	liters	quarts	1.057
ounces	grams	28.349	liters	gallons	.264
pounds	kilograms	.454	grams	ounces	.035
short tons	metric tons	.907	kilograms	pounds	2.205
pound-feet	Newton-meters	1.356	metric tons	short tons	1.102
pound-inches	Newton-meters	.11296			

## Temperature (Exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C
----	------------------------	----------------------------	---------------------	----

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