## THE FOUR CYCLE PRINCIPLE FOR DIESEL ENGINES

The diesel engine is an internal combustion engine, in which the energy of burning fuel is converted into energy to work the cylinder of the engine. In the diesel engine, air alone is compressed in the cylinder, raising its temperature significantly. After the air has been compressed, a charge of fuel is sprayed into the cylinder and ignition is accomplished by the heat of compression. The four piston strokes of the cycle occur in the following order: intake, compression, power and exhaust. See Figure 1.

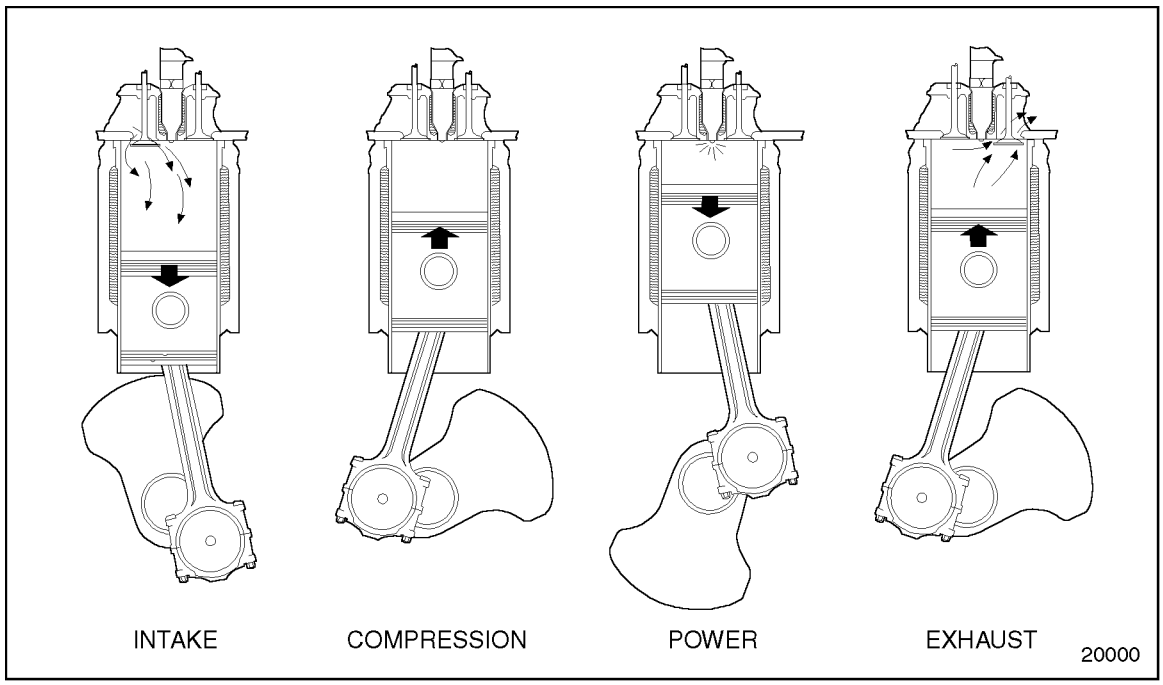



**Figure 1 The Four Stroke Cycle (Diesel)**

### Intake Stroke

During the intake stroke, the piston travels downward, the intake valves are open, and the exhaust valves are closed. The down stroke of the piston facilitates air from the intake manifold to enter the cylinder through the open intake valve. The turbocharger, by increasing the air pressure in the engine intake manifold, assures a full charge of air is available for the cylinder.

The intake charge consists of air only with no fuel mixture.

### 1.3.2.2 Inspection of Rocker Arm Assemblies and Camshaft Lobes

Prior to inspection:

1. Install new cup plugs with installer tool (J–36326) until they are 1.0-1.3 mm (0.040-0.050 in.) below the surface of the shaft. See Figure 1-59.

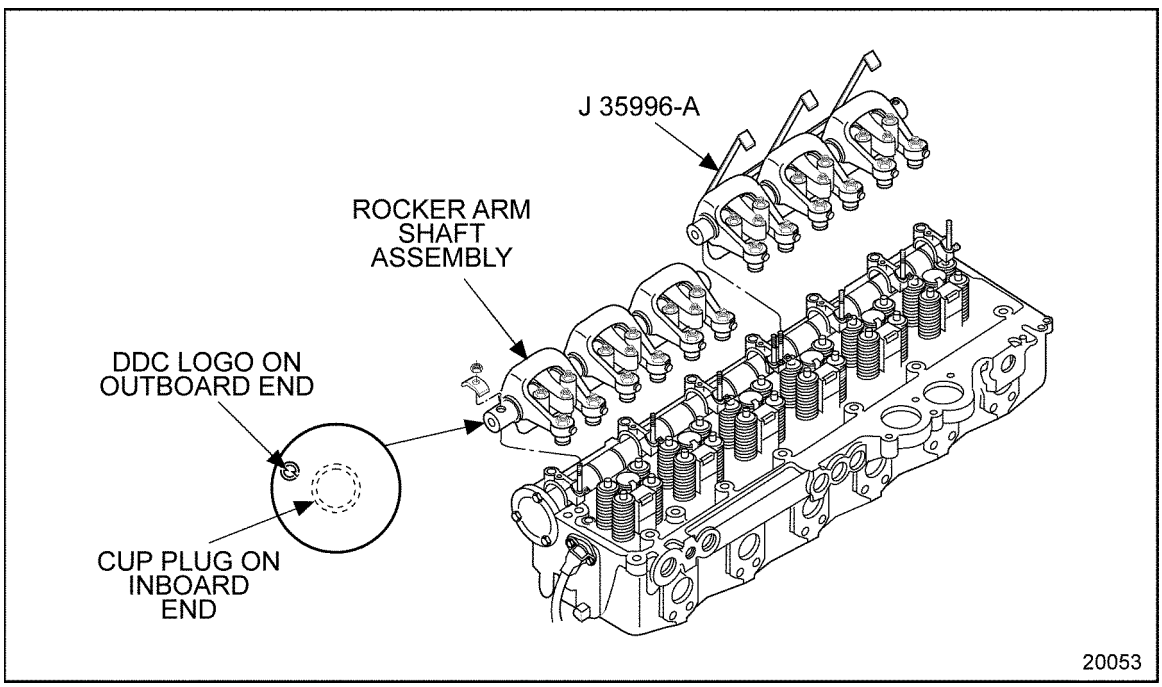



**Figure 1-59 Rocker Arm Shaft Identification Mark**

2. Remove all of the old gasket sealer from the joint face of the Number 1 and Number 7 camshaft bearing caps and the cylinder head. Refer to "Gasket Eliminator Removal" in the "General Information" section.

2. Install two guide studs (J–35686–2, part of tool set J–35686–B) through the holes provided in the center guide assembly (J–35686–1, part of tool set J–35686–B) and into two of the tapped holes in the crankshaft 180 degrees apart. Tighten the guide studs using the appropriate wrench on the flats of the studs. The base must be tight against the end of the crankshaft. See Figure 1-137.
3. Install the spacers to the center screw of the base. Refer to Table 1-4 and Figure 1-138.

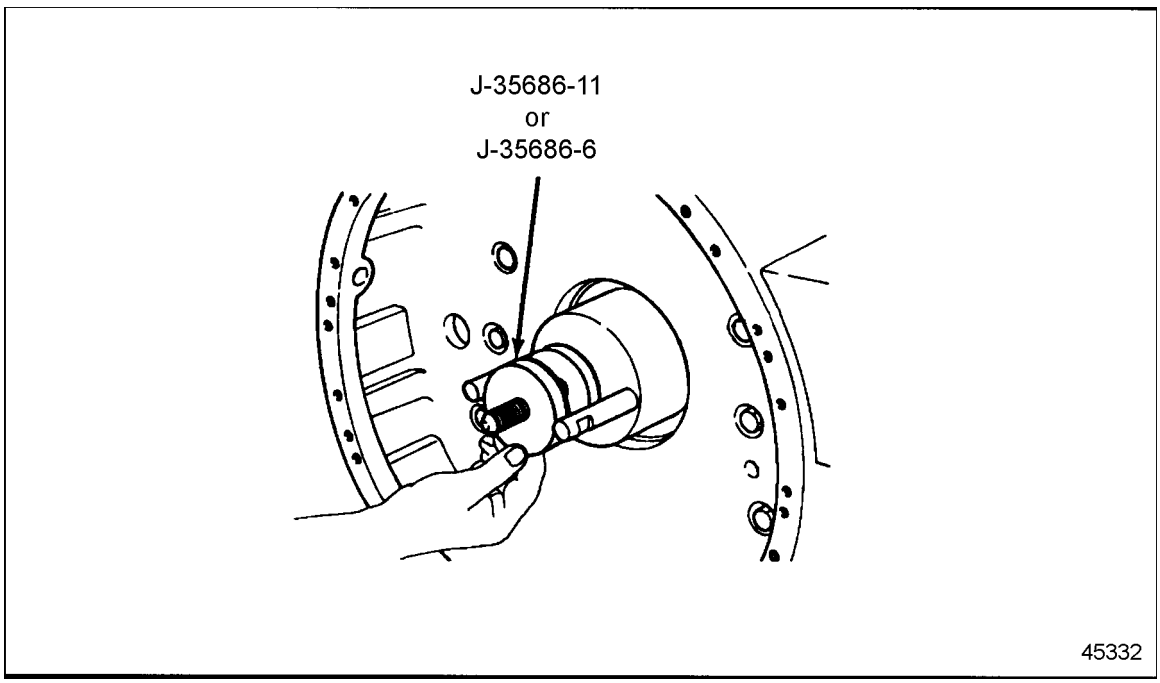



**Figure 1-138 Spacer Installation**

2. Install the oil control ring by hand. See Figure 1-279.

**NOTE:**
The oil control ring may be installed in either direction.

**NOTE:**
Install expander into inside diameter groove of ring with expander spring gap located 180° from the oil control ring gap.

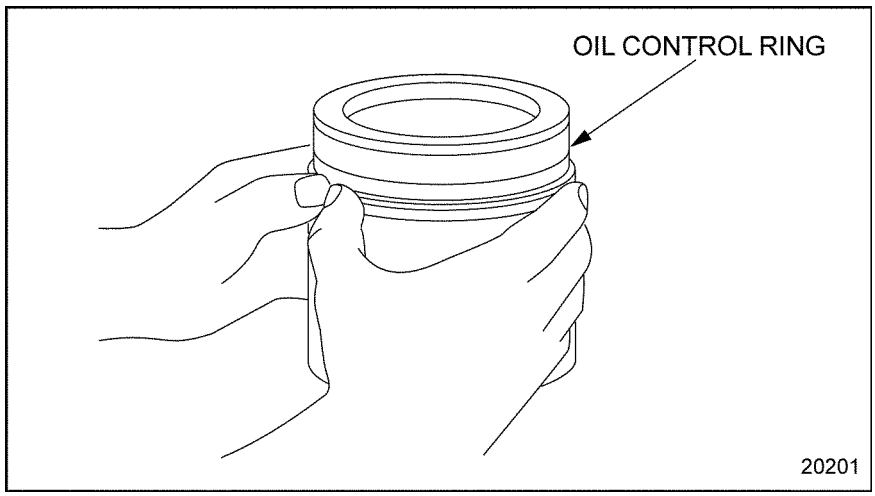
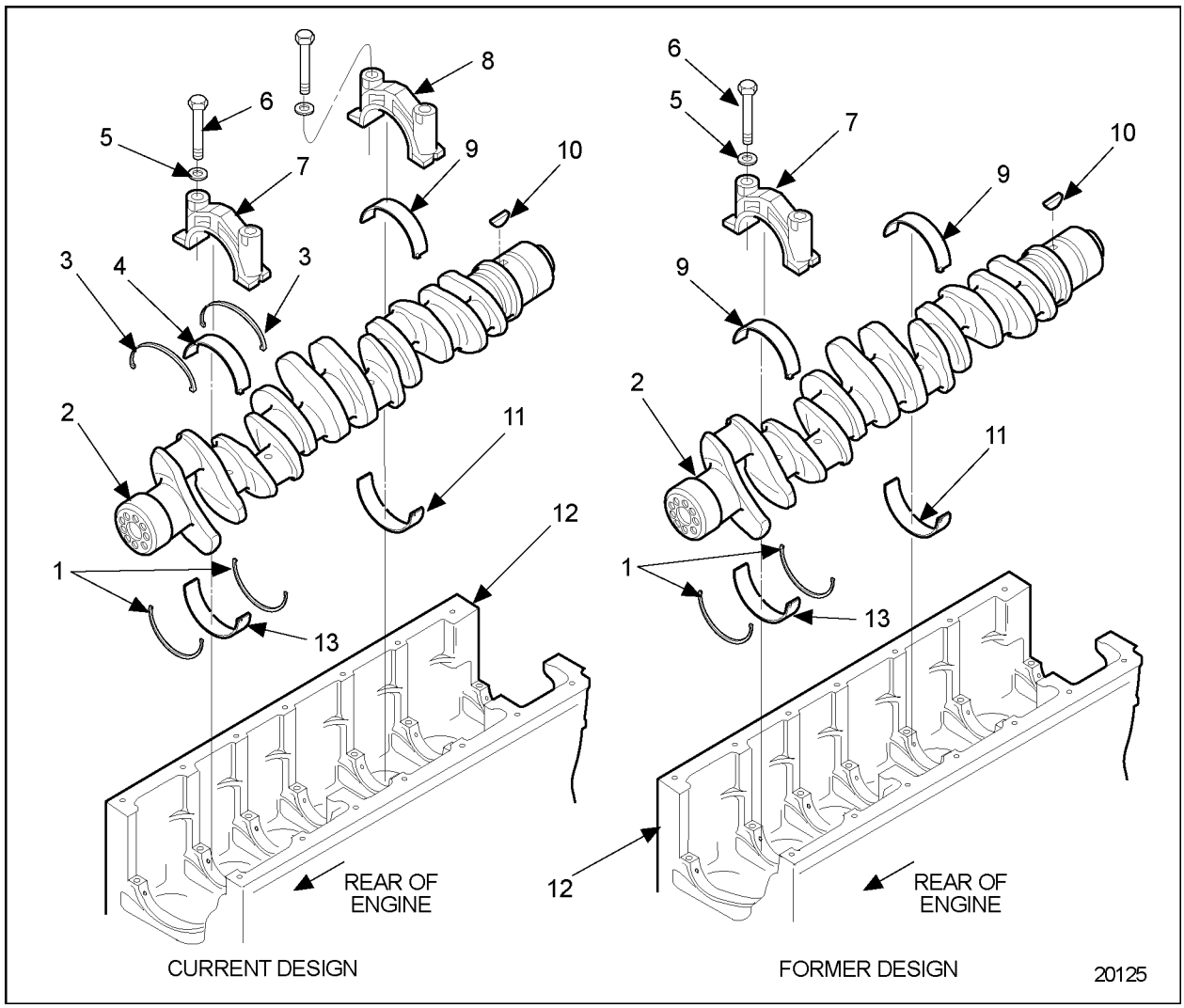



**Figure 1-292 Oil Control Ring Installation (Diesel)**

**NOTE:**
The oil control ring expander has a identifying paint stripe. Make sure the paint mark can be seen after the oil control ring is installed at ring gap.

## 1.9 CRANKSHAFT MAIN BEARINGS

The crankshaft main bearing shells are precision made and are replaceable without machining. They consist of an upper bearing shell seated in each cylinder block main bearing support and a lower bearing shell seated in each main bearing cap. See Figure 1-141.




1. Upper No. 6 Thrust Washers
2. Crankshaft
3. Lower No. 6 Thrust Washers
4. Lower No. 6 Thrust Bearing Shell
5. Washer
6. Bolt
7. No. 6 Main Cap
8. Main Cap No. 1, 2, 3, 4, 5 & 7
9. Lower Thrust Bearing Shell
10. Woodruff Key
11. Upper Thrust Bearing Shell No. 1, 2, 3, 4, 5 & 7
12. Cylinder Block
13. Upper No. 6 Thrust Bearing Shell

**Figure 1-141 Main Bearing Caps, Bearing Shells and Crankshaft Thrust Washers**

### 1.9.1 Repair or Replacement of Crankshaft Main Bearings

To determine if repair is possible or replacement is necessary, perform the following procedure. See Figure 1-143.

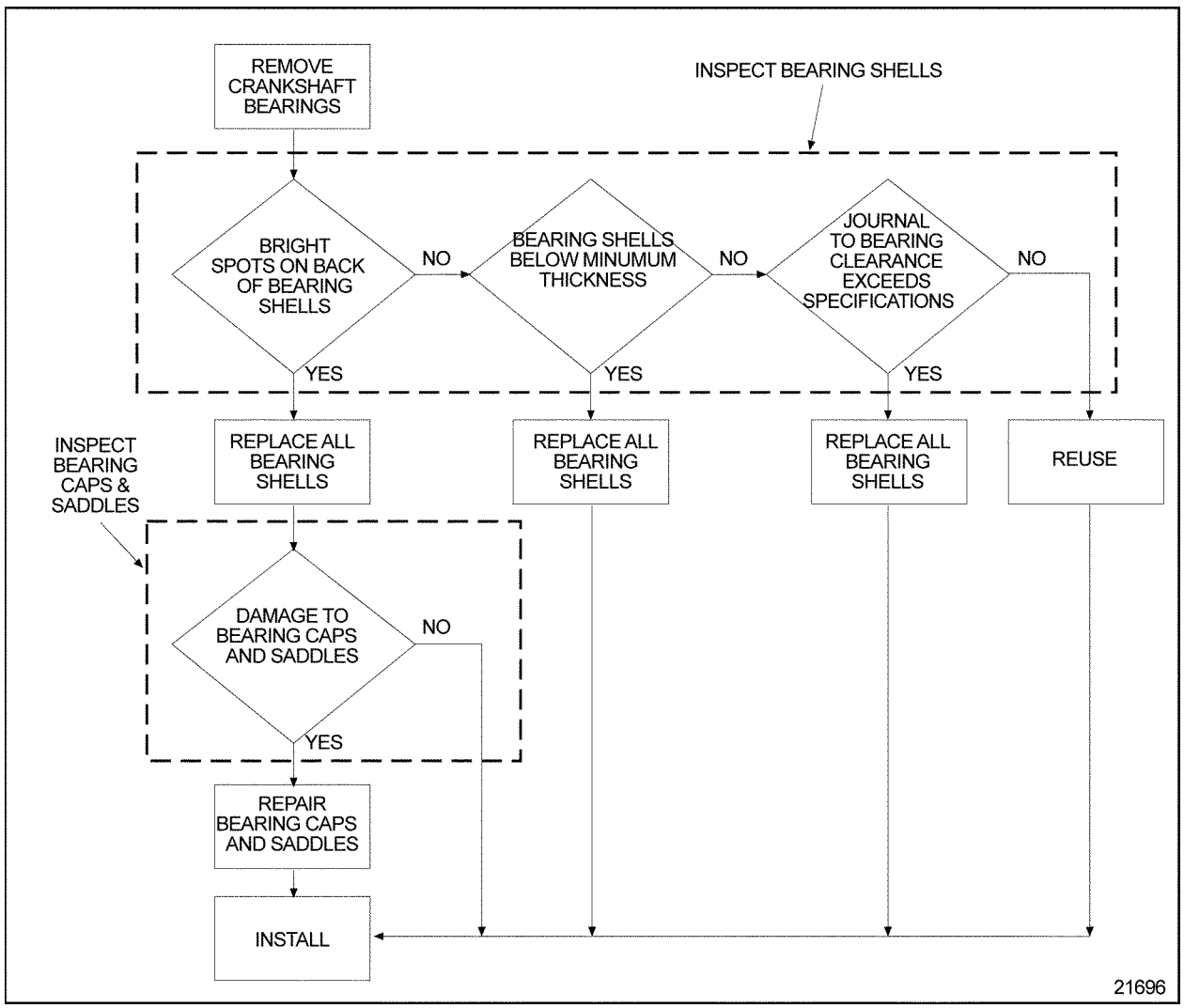



**Figure 1-143 Flowchart for Repair or Replacement of Crankshaft Main Bearings**

### 1.9.2 Removal of Main Bearing Shells

The main bearing caps are numbered consecutively, indicating their respective positions. When removed, the bearing caps (and the bearing shells, if they are to be reinstalled) must always be reinstalled in their original position.

1. Drain the oil pan, refer to section 14.6.1and remove the oil pan to expose the main bearing caps refer to section 3.11.2.
2. Remove the oil pump pickup and outlet pipes, and the oil pump. Refer to section 3.2.2.

worked on. The word "Front" stamped on the tool must face the front of the engine. Be sure that the roll pin in the oil delivery hole registers with the cutout section of the bearing shell tool before tightening the main bearing cap bolts. See Figure 1-147.

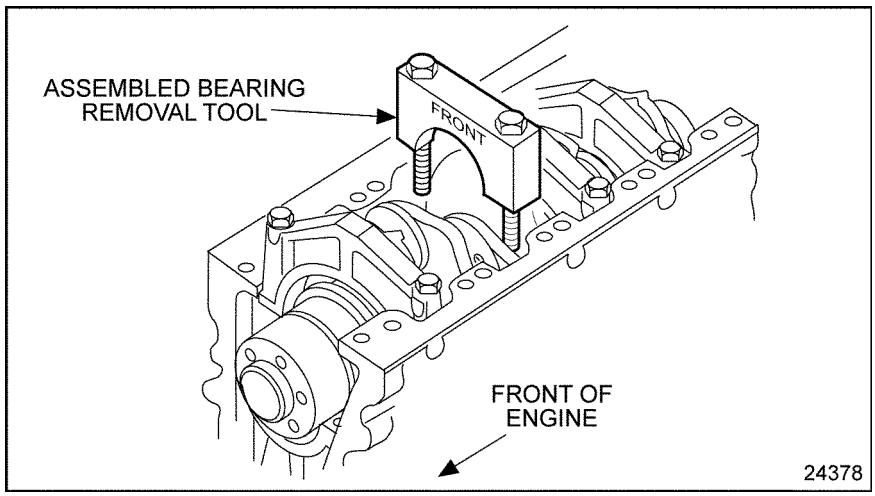



**Figure 1-147 Upper Main Bearing Shell Remover Tool Installation**

**NOTE:**
Only the No. 6 main bearing shell requires use of the thrust washers on the sides of the remover tool. For main bearings No. 1, 2, 3, 4, 5, and 7, it will not be necessary to install the thrust washers to the tool.

9. Torque the main bearing cap bolts until they are snug 13-27 N·m (10-20 lb·ft).
10. Using the square hole in the middle of the crankshaft pulley, bar the engine over in a clockwise direction when viewed from the front, approximately 180 degrees until the tang of the upper main bearing contacts the block. This will roll the bearing shell tool (and the thrust washers for No. 6 main bearing) into the upper main bearing saddle.

**NOTE:**
Keep all bearing shells and thrust washers segregated by number, so that they may be reinstalled exactly as removed if the bearing shells are reused. Shells and washers may be marked with a permanent marker or equivalent. Do not punch mark or otherwise disturb the surface of the shells and washers to mark them.

11. Remove the main bearing cap tool from the saddle.
12. Remove the upper shell (and two thrust washers when working on No. 6 main) from the tool.
13. Inspect the bearing shells (and thrust washers for No. 6 main). Refer to section 1.9.2.2.
14. Install the upper main bearing to be used, in the main bearing installer and remover with the word "Front" facing the front of the engine. If the No. 6 main bearing is being done, install the thrust washers to the bearing. Refer to step 7 in this procedure.

13. Inspect the bull gear and camshaft idler gear access opening in the gear case and remove any foreign material.
14. Install two bull gear guide studs (J–35785) to the cylinder block. See Figure 1-215.

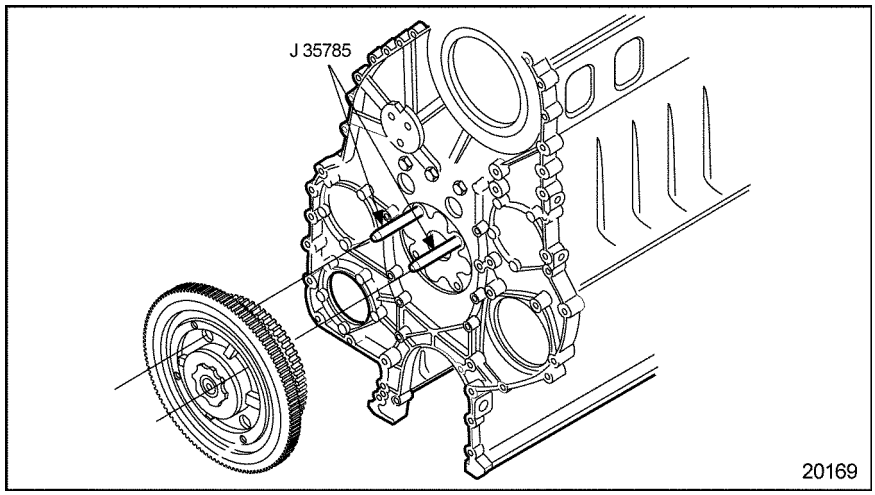



**Figure 1-215 Bull Gear Guide Stud Installation**

| NOTICE: |
| --- |
| Always install crankshaft protector when installing the bull gear and camshaft idler gear assembly to prevent damaging the crankshaft oil seal contact surface. |

15. Install the crankshaft protector (J–35994) to the oil seal contact area of the crankshaft. This will help to protect the crankshaft seal surface when installing the bull gear and camshaft idler gear assembly.
16. Install the bull gear and camshaft idler gear assembly to the guide studs. Align the timing marks on the bull gear and the crankshaft timing gear and the camshaft idler gear and adjustable idler gear; see Figure 1-214, and slide the bull gear and camshaft idler gear assembly forward to seat it in the recess in the gear case and cylinder block.
17. Working through the lightening holes in the bull gear, install two of the bull gear assembly mounting bolts through the hub and into the cylinder block. Finger-tighten the bolts.
18. Remove the two bull gear guide studs. Install the remaining two bull gear assembly mounting bolts. Torque the bolts to 101-126 N·m (75-93 lb·ft). Tighten in a clockwise sequence.
19. Check the timing marks on the gears to ensure the gear train is properly timed. See Figure 1-214.
20. Perform the following:
    [a] For crankshaft timing gear-to-oil pump gear lash measurement. Perform step 2, refer to section 1.24.2.1.

### 1.22.2 Removal and Cleaning of the Connecting Rod

Before removal, make sure the connecting rods and caps are stamped with their correct cylinder location. If not marked, stamp location (1-6) on the tang side (cooler side) of the rod and cap.

Refer to section 1.21.2 for piston and connecting rod assembly removal procedure.

### 1.22.3 Disassembly of Connecting Rod

Disassemble the connecting rod as follows:

**NOTE:**
It is best to disassemble, inspect and assemble each connecting rod separately. It is very important to keep the connecting rod cap, and the upper and lower bearing shells to the original connecting rod.

1. Loosen and remove the two connecting rod nuts. See Figure 1-319.
2. Remove connecting rod cap and bearings shells. See Figure 1-319.

#### 1.22.3.1 Inspection of Connecting Rod

Clean the bearings prior to inspection as follows:

1. Clean the bearings with fuel oil.

| **WARNING:** |
| --- |
| **EYE INJURY** |
| **To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 276 kPa (40 psi) air pressure.** |

2. Dry the bearings with compressed air.

Inspect the open-end connecting rod as follows:

1. Inspect the connecting rod saddle at the piston pin contact surface for traces of fretting and corrosion.
2. To repair, wet with fuel oil and smooth with crocus cloth.

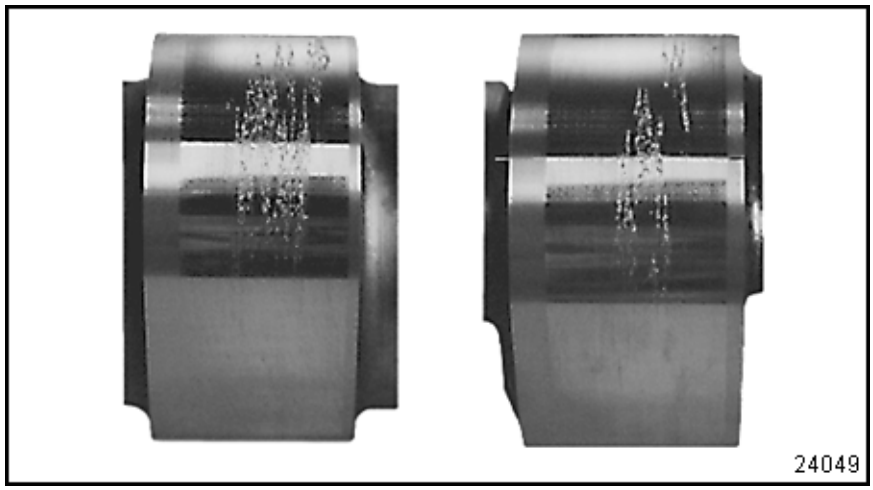



**Figure 1-390 Camshafts Acceptable for Reuse**

**NOTE:**
Camshafts exhibiting extensive wear and pitting must be replaced. See Figure 1-391.

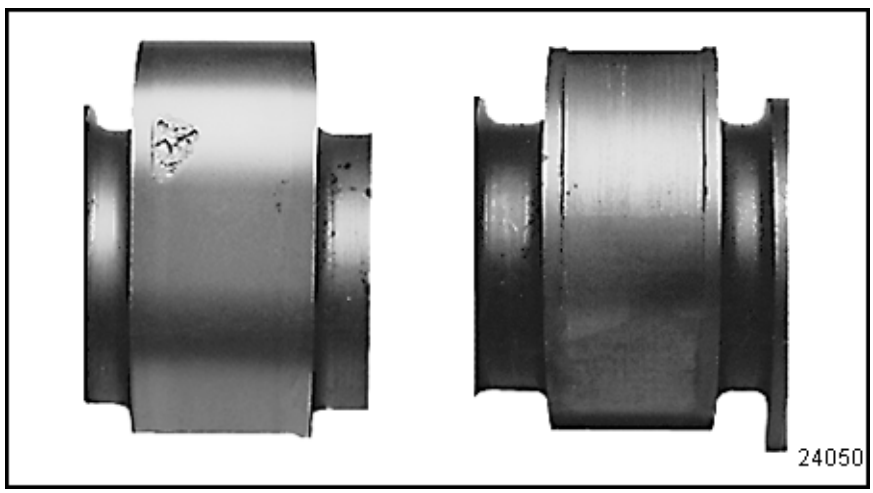



**Figure 1-391 Camshafts Not Acceptable for Reuse**

### 2.4.6.1 Check Injector Tip Protrusion

To check the injector tip protrusion:

1. Insert J–33880–3 (part of tool set J–33880), into injector tube bore of cylinder head. See Figure 2-22.
2. Insert J–33880–7 (part of tool set J–33880), into pilot. See Figure 2-27.

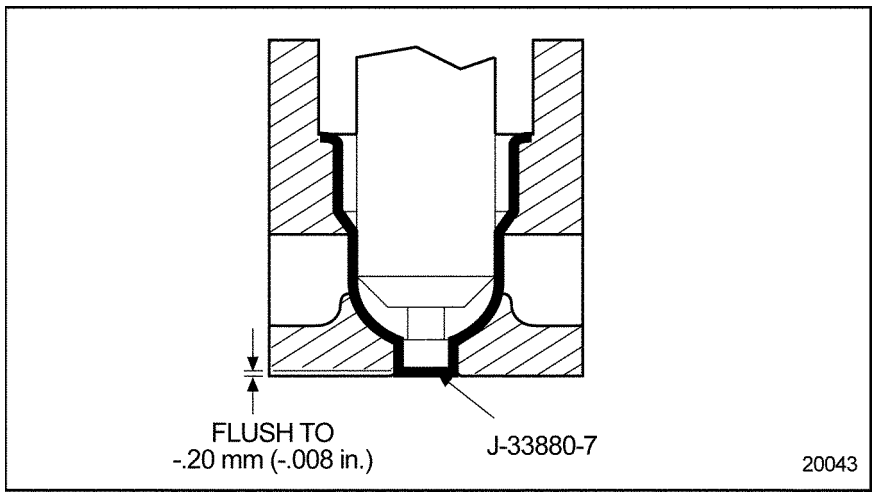



**Figure 2-27 Checking Injector Tip Protrusion**

3. Check injector tip protrusion using J–22273–01. Hold protrusion gage against pilot while measuring tip protrusion. This measurement should be flush to -0.20 mm (-0.008 in.).

## 2.8.6 Installation of Air Compressor-Driven Fuel Pump (One-piece Drive Shaft)

Perform the following steps for air compressor-driven fuel pump installation:

**NOTE:**
New fittings have sealant already applied. If reusing fittings, coat the threads lightly with Loctite® Pipe Sealant, PT-7260, or equivalent before installing. To prevent sealant from entering fuel system, do not apply it to the first two (2) threads of the fitting. Do not use teflon tape or paste on the fittings.

1. If removed, install inlet and outlet fittings in the rear cover of the fuel pump.
2. Install drive coupling in drive hub of the fuel pump and affix a new gasket to the mounting flange of the pump.

**NOTE:**
When correctly positioned, the outlet fitting on the pump should be in approximately the 8 o'clock position when viewed from the rear, and the drain opening in the pump body facing down.

3. Index the drive coupling with the drive hub on the end of the air compressor crankshaft and align the pump mounting bolt holes with those in the air compressor rear cover.
4. Seat the fuel pump squarely against the air compressor. Install three (3) fuel pump mounting bolts and torque them to 30-38 N·m (22-28 lb·ft).
5. Connect the fuel inlet and outlet lines to the fuel pump and tighten.
6. Prime the fuel system before starting engine.
7. Refer to section2.8.5 for the exhaust caution before proceeding. Start and run the engine. Visually observe fuel pump for any leaks. Repair as necessary.
8. Shut down engine upon completion of test.

Oil leaving the pump is forced through the full-flow filters to the oil cooler and bypass passage and then into the oil gallery in the cylinder block. From there the oil is distributed to the various engine bearings and moving parts. Prior to 1993, a bypass type, spin-on filter was used in addition to the two full-flow oil filters. A portion of the oil is continually fed through the bypass filter and returned to the engine oil pan. Drains from the cylinder head and other engine parts return oil back to the oil pan.

Oil from the cooler is directed to a longitudinal main oil gallery on the cooler side of the cylinder block. See Figure 3-1. This gallery distributes the pressurized oil to the main bearings and to a horizontal, transverse passage at each end of the cylinder block. From each of these two horizontal passages, oil flows into two vertical bores (one at each end of the cylinder block) to vertical passages in the cylinder head.

These passages in the cylinder head deliver oil from the cylinder block to the No. 1 and 7 lower camshaft bearing saddles. From there, the oil is directed upward (through the enlarged stud hole) to the No. 1 and 7 upper camshaft bearing caps. A drilled passage in each of these caps exits at the rocker arm shaft seat area, where it indexes rocker arm bushings and intermediate upper camshaft bearings. Some of the oil supplied goes to the rocker arm camshaft follower, roller pin and bushing.

The rocker is also drilled to supply oil to the valve adjusting screw, valve button, retainer clip, intake and exhaust valve stems and the fuel injector follower. The No. 4 camshaft cap is Y drilled, forming an oil path connection between the front and rear rocker arm shafts, to ensure complete lubrication. The oil then drains through passages in the cylinder head and block, and back to the oil pan.

Oil for lubricating the connecting rod bearings, piston pins and for cooling the piston dome is provided through the drilled crankshaft from the adjacent forward main bearings.

10. Insert J–35988–3A (part of tool set J–35988–C) in end of drive shaft. See Figure 4-10.

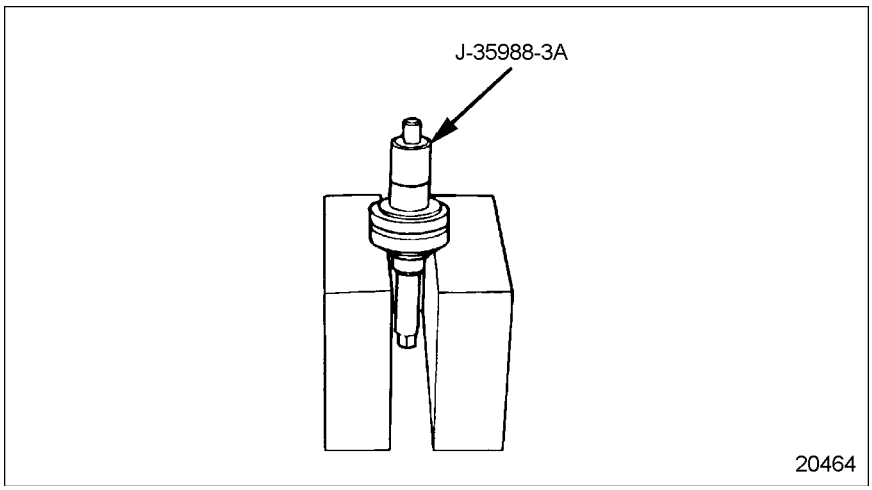



**Figure 4-10 Removing Bearing Assemblies**

11. Press the drive shaft out until it is clear of both bearing and race assemblies. Discard the used bearings, races, and the two spacer rings located between the bearing packs.

### 4.2.3.1 Inspection of Water Pump (GCM)

Visually inspect the parts for cracks, wear or other damage. If parts are cracked, worn, or other damage is evident, replace damaged or worn parts. If no damage is found, reuse remaining components.

### 4.2.4 Cleaning of Water Pump (GCM)

Clean the water pump as follows:

1. Wash all of the pump parts in clean fuel oil.

**⚠ WARNING:**

**EYE INJURY**

**To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 276 kPa (40 psi) air pressure.**

2. Dry the parts with compressed air.

### 7.3.4 Cleaning of Three-piece Exhaust Manifold without Fey Rings

Perform the following steps to clean the exhaust manifold.

1. Remove any loose scale and carbon that may have accumulated on the internal walls of the manifold sections.
2. Clean the manifold sections exterior with a wire brush.
3. When cleaning is complete, refer to section 7.3.5.

### 7.3.5 Installation of Three-Piece Exhaust Manifold without Fey Rings

Perform the following steps to install the exhaust manifold.

1. If disassembled, assemble the three pieces of the exhaust manifold.
2. Install four exhaust manifold guide studs (J–36107) into the cylinder head to hold the three exhaust manifold gaskets in the correct position, and facilitate manifold installation. For the modified bolt boss on the reusable center section, include one P/N: 23511667 exhaust manifold spacer under the bolts.

**NOTE:**
The bolt tightening pattern on cylinders 1, 2, and 3 reverses between middle-mount and high-mount exhaust manifolds. The exhaust gasket can be positioned either way. Ensure the guide studs and gaskets are positioned correctly for the manifold being installed.

3. Install the exhaust gaskets to the guide studs.
4. Install the assembled manifold to the guide studs.
5. Remove the four guide studs one at a time and install a bolt and spacer to secure the exhaust manifold to the cylinder head. Finger-tighten the bolts.
6. Install the remaining four bolts and spacers.
7. Remove the necessary bolts to install the exhaust heat shields.
8. Torque the bolts to 58-73 N·m (43-54 lb·ft) using the tightening sequence. See Figure 7-14.
9. Install the turbocharger. Refer to section 6.5.7.
10. Install any other equipment that was removed for this procedure.