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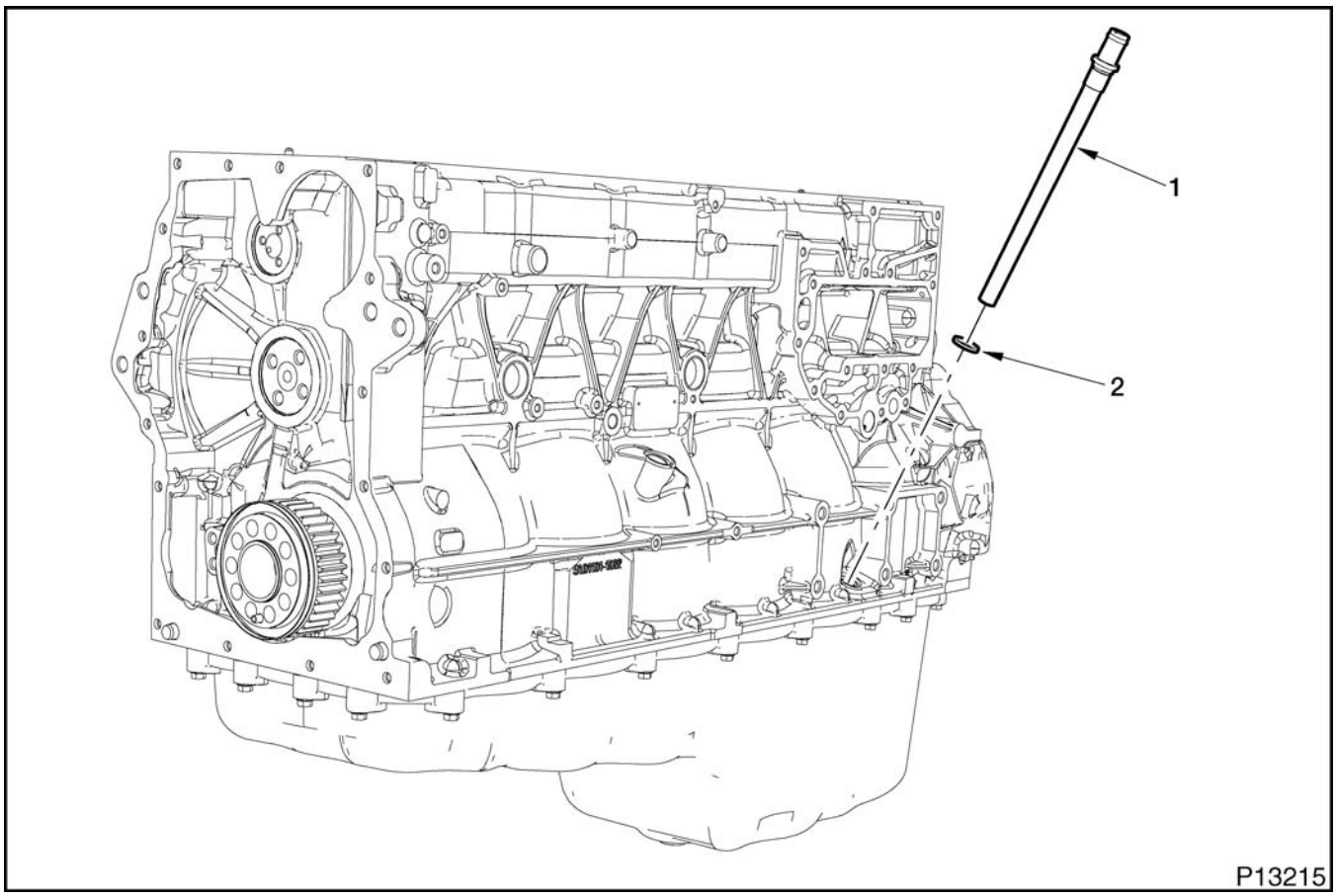

Figure 629 Oil return pipe (front sump)

1. Oil return pipe
2. Copper washer

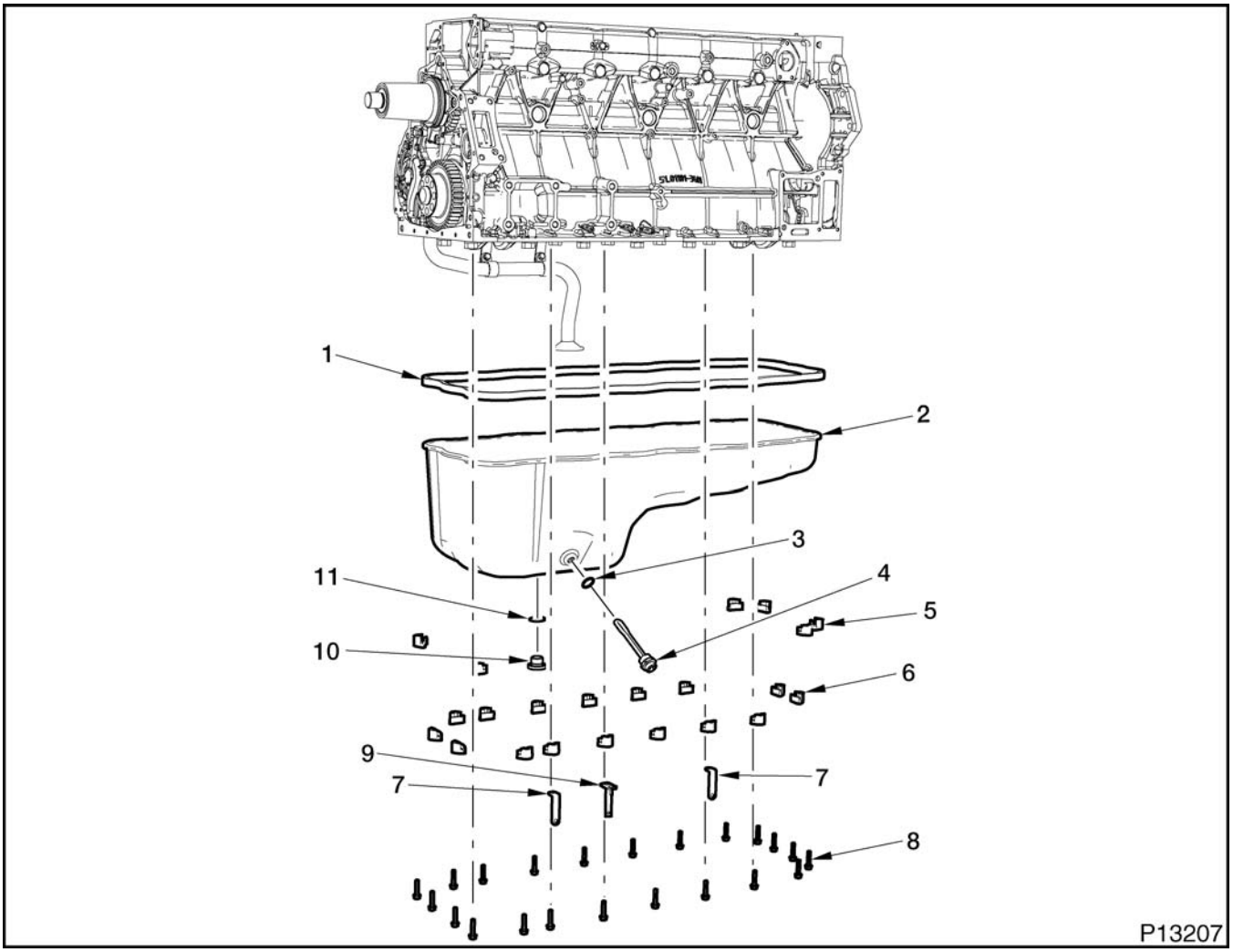

Figure 630 Oil sump (front sump shown, rear sump similar)

1. Oil sump gasket
2. Oil sump (front sump)
3. Preheater gasket (optional equipment)
4. Preheater (optional equipment)
5. Oil sump retainer (concave groove) (6)
6. Oil sump retainer (convex groove) (16)
7. Bracket (2) (right angle bracket)
8. M8 x 40 hex bolt (22)
9. Bracket (T-bracket)
10. M27 x 2 drain plug
11. Drain plug gasket

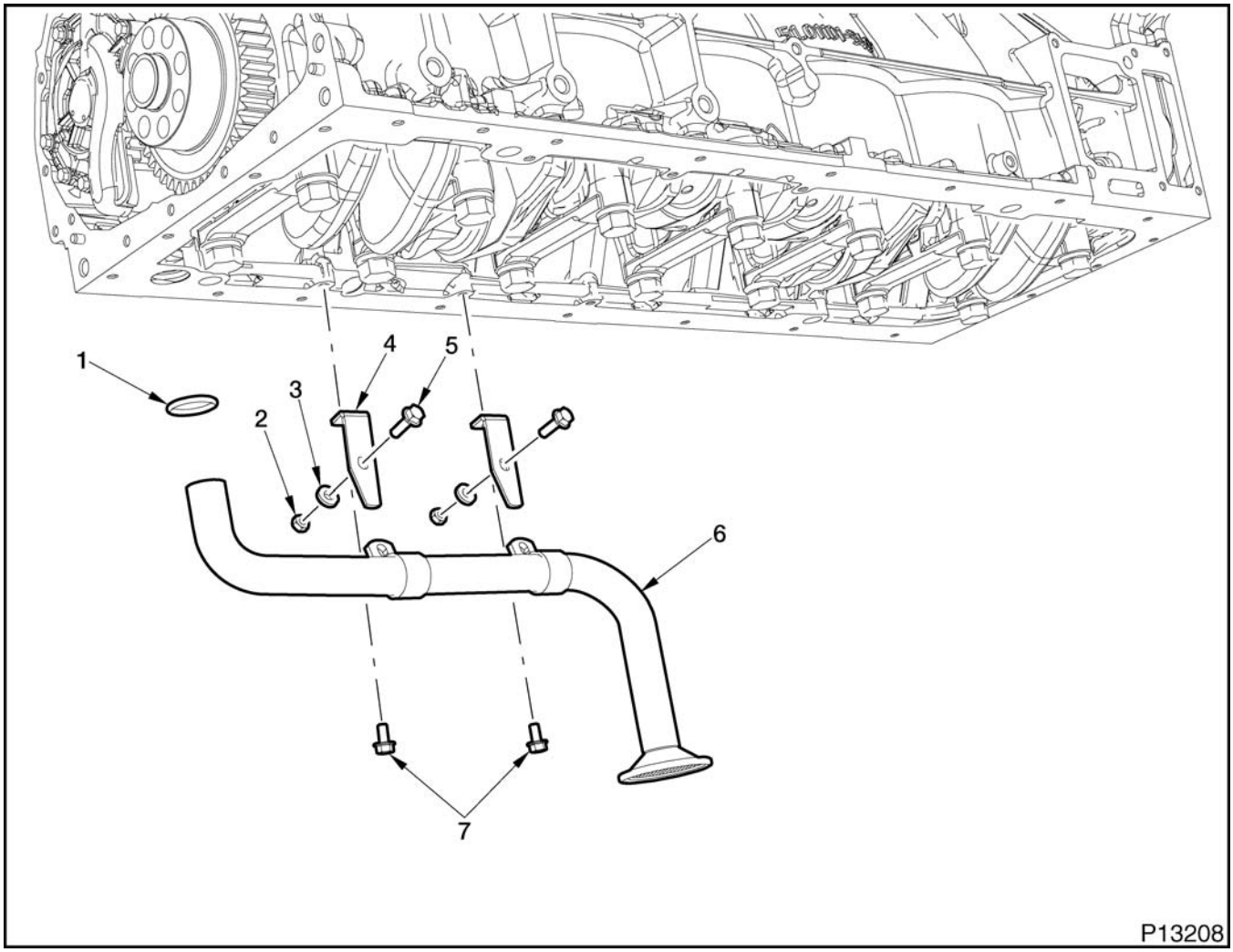

Figure 631 Oil suction line — Front sump

1. O-ring
2. BM8-8 hexagon nut (2)
3. D9/19/4 washer (2)
4. Oil suction line bracket (2)
5. M8 x 25 hex bolt (2)
6. Oil suction line
7. M8 x 16 hex bolt (2)

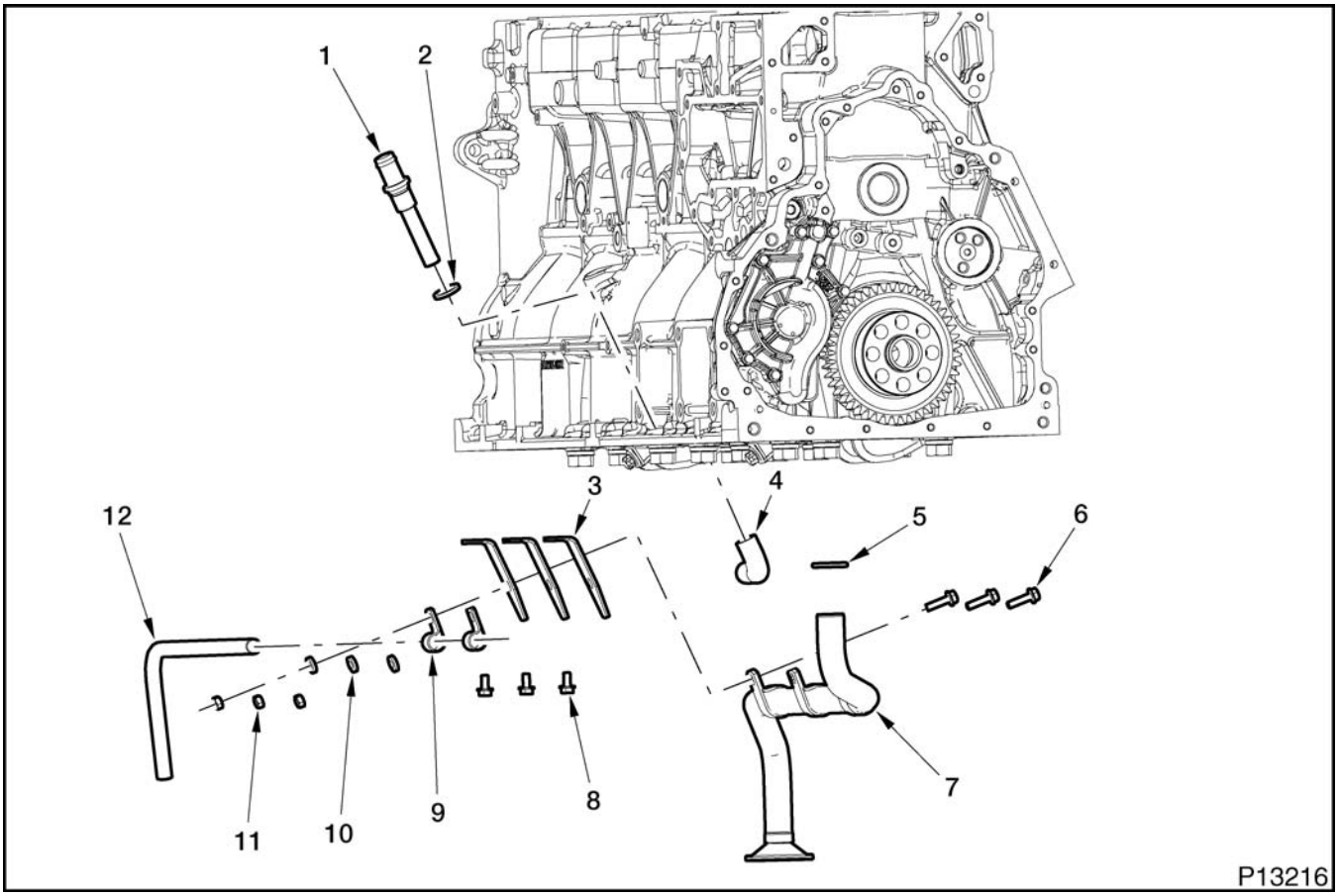

Figure 632 Oil suction line — Rear sump

1. Oil return pipe (Rear sump)
2. Copper washer
3. Oil suction line bracket (3)
4. Rubber elbow
5. O-ring
6. M8 x 25 hex bolt (3)
7. Oil suction line
8. M8 x 16 hex bolt (3)
9. Clamp (2)
10. D9/19/4 washer (3)
11. BM8-8 hexagon nut (3)
12. Oil return line

Removal

WARNING: To prevent personal injury or death, read all safety instructions in the "Safety Information" section of this manual.

WARNING: To prevent personal injury or death, shift the transmission to park or neutral, set the parking brake, and block the wheels before doing diagnostic or service procedures.

WARNING: To prevent personal injury or death, make sure the engine has cooled before removing components.

WARNING: To prevent personal injury or death, remove the ground cable from the negative terminal of the main battery before disconnecting or connecting electrical components. Always connect the ground cable last.

WARNING: To prevent personal injury or death, do not let engine fluids stay on your skin. Clean skin and nails using hand cleaner and wash with soap and water. Wash or discard clothing and rags contaminated with engine fluids.

GOVERNMENT REGULATION: Engine fluids (oil, fuel, and coolant) may be a threat to the environment. Recycle or dispose of engine fluids according to applicable regulations. Never put engine fluids in the trash, on the ground, in sewers or bodies of water.

NOTE: Refer to the following service sections for information on removal of components prior to this section.

- Engine Electrical — required for preheater removal.

Oil Sump

WARNING: To prevent personal injury or death, dispose of oil or discard components, according to applicable regulations.

1. On front sump engines, remove oil return pipe and discard copper washer.
2. Remove M27 x 2 drain plug and gasket and drain oil into a suitable container.
3. If equipped, remove preheater. On vehicles not equipped with preheater, remove drain plug and gasket.
4. Remove and discard preheater gasket.

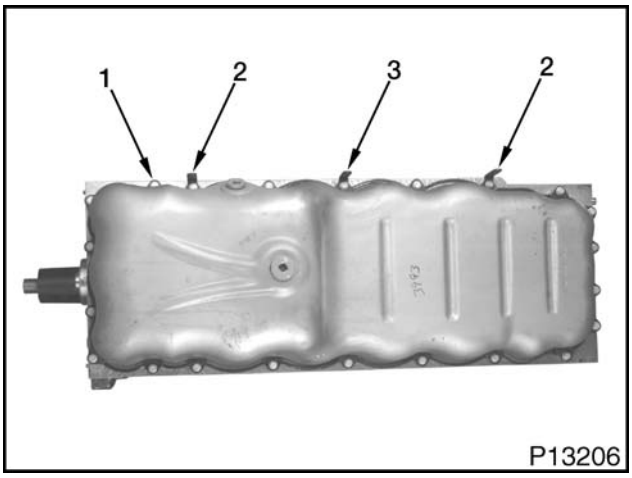

Figure 633 Oil sump (front sump shown)

1. M8 x 40 hex bolt (22)
2. Bracket (right angle) (2)
3. Bracket (T-bracket)

NOTE: Record style and location of brackets for correct placement during installation.

5. Remove 22 M8 x 40 hex bolts and three brackets.

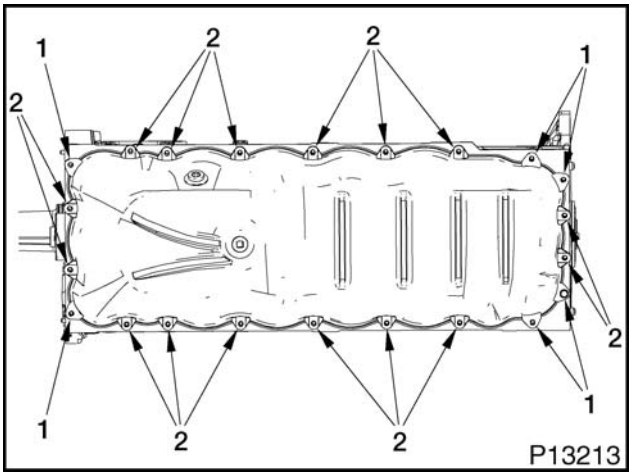

Figure 634 Oil sump retainers

1. Oil sump retainer (concave groove) (6)
2. Oil sump retainer (convex groove) (16)

6. Remove six oil sump retainers (concave groove).
7. Remove 16 oil sump retainers (convex groove).
8. Remove oil sump and oil sump gasket as an assembly.
9. Clean and inspect the oil sump gasket. Discard oil sump gasket if damaged.

Oil Suction Line — Front Sump

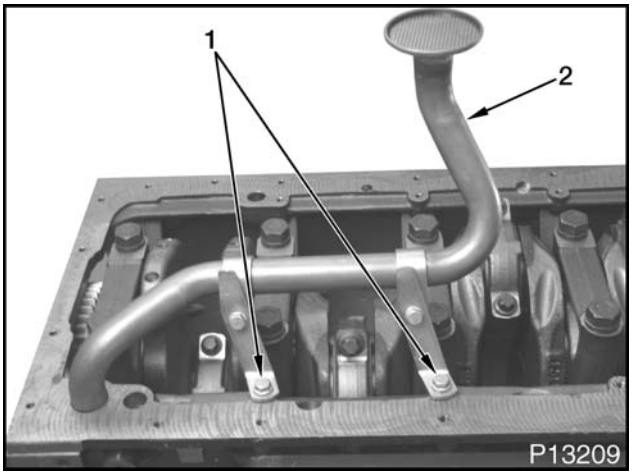

Figure 635 Oil suction line

1. M8 x 16 hex bolt (2)
2. Oil suction line

1. Remove two M8 x 16 hex bolts and oil suction line.
2. If required, remove the two M8 x 25 hex bolts, BM8–8 hexagon nuts, D9/19/4 washers and oil suction line brackets.

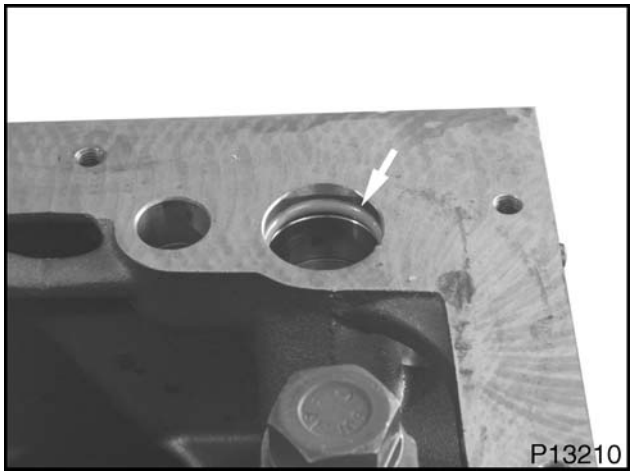

Figure 636 Oil suction line o-ring

3. Remove and discard oil suction line o-ring.

Oil Suction Line — Rear Sump

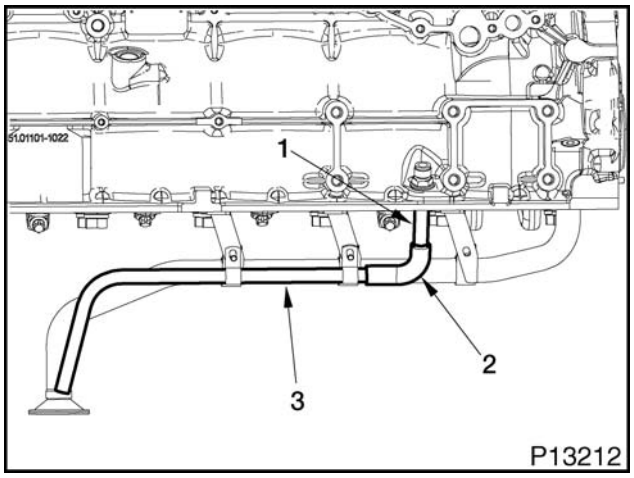

Figure 637 Oil return pipe

1. Oil return pipe
2. Rubber elbow
3. Oil return line

1. Remove three M8 x 16 hex bolts holding oil suction line brackets to crankcase.

2. Disconnect rubber elbow from oil return pipe.
3. Remove oil suction line and oil return line as an assembly.
4. If required, remove three M8 x 25 hex bolts, BM8–8 hexagon nuts and D9/19/4 washers and remove oil return line, clamps and rubber elbow.
5. Unscrew the oil return pipe and discard copper washer.

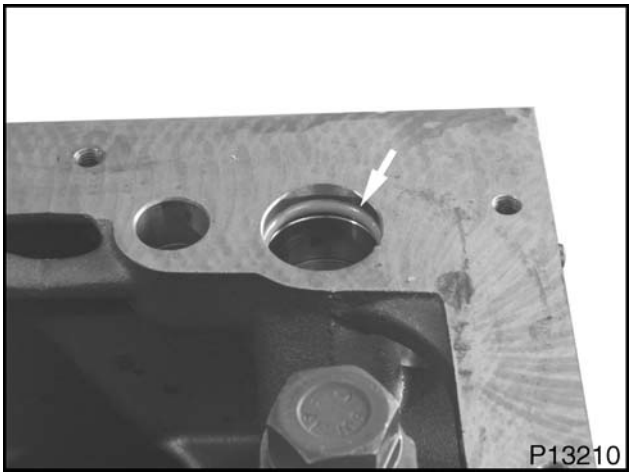

Figure 638 Oil suction line o-ring

6. Remove and discard oil suction line o-ring.

Cleaning and Inspection

WARNING: To prevent personal injury or death, wear safety glasses with side shields. Limit compressed air pressure to 207 kPa (30 psi).

Oil Sump

1. Inspect bottom of oil sump for metallic debris or other evidence of engine damage. Investigate any abnormalities as required.
2. Clean oil sump with a suitable solvent.
3. Dry with filtered compressed air.
4. Look for warping, dents, and cracking. Replace the oil sump if necessary.

Oil Suction Line

1. Clean oil suction line and bracket with a suitable solvent.
2. Dry with filtered compressed air.
3. Inspect oil suction line and bracket for cracking. Replace if necessary.

Oil Return Line

1. Clean oil return line and clamps in suitable solvent.
2. Dry with filtered compressed air.
3. Inspect oil return line and clamps for cracking. Replace if necessary.

Oil Return Pipe

1. Clean oil return pipe in suitable solvent.
2. Clean mating crankcase threads of oil residue.

Installation

Oil Suction Line — Front sump

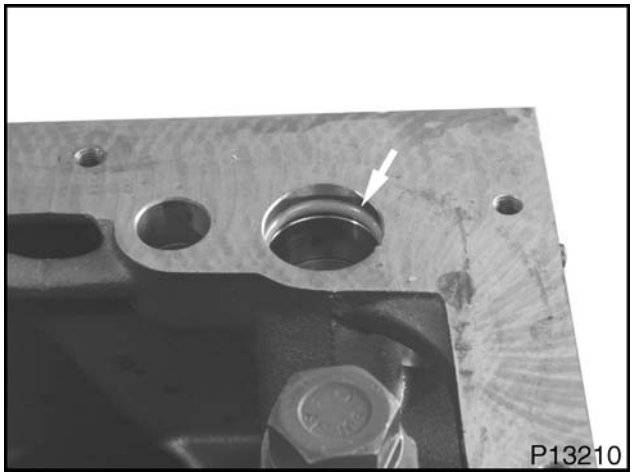

Figure 639 Oil suction line o-ring

1. Install a new oil suction line o-ring. Lubricate o-ring with clean engine oil.
2. If required, position two oil suction line brackets and loosely install two M8 x 25 hex bolts, BM8–8 hexagon nuts, D9/19/4 washers.

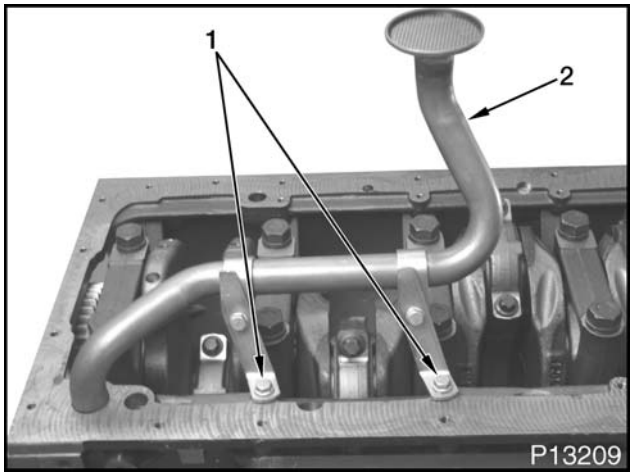

Figure 640 Oil suction line

1. M8 x 16 hex bolt (2)
2. Oil suction line

3. Install oil suction line and two M8 x 16 hex bolts.
4. Tighten two M8 x 16 hex bolts to standard torque (page 455).
5. Tighten two BM8–8 hexagon nuts to standard torque (page 455).

Oil Suction Line — Rear Sump

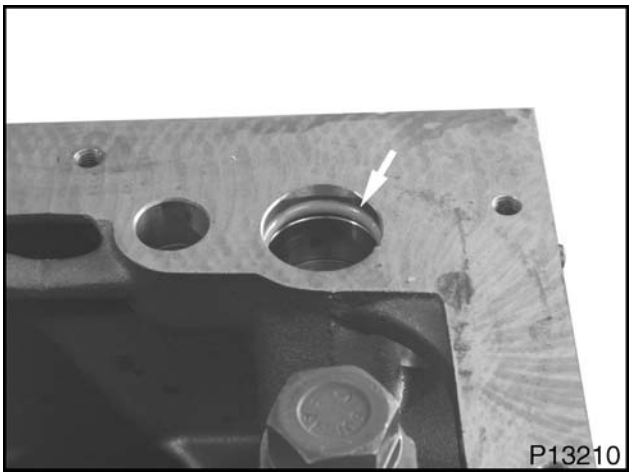

Figure 641 Oil suction line o-ring

1. Install a new oil suction line o-ring. Lubricate o-ring with clean engine oil.

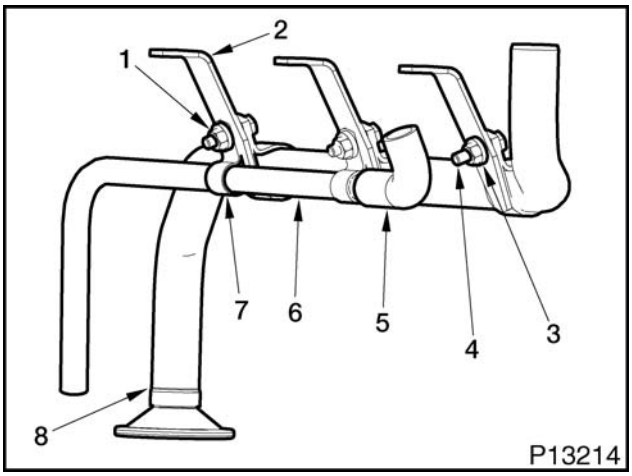

Figure 642 Rear sump oil line assembly

1. BM8-8 hexagon nut (3)
2. Oil suction line bracket (3)
3. D9/19/4 washer (3)
4. M8 x 25 hex bolt (3)
5. Rubber elbow
6. Oil return line
7. Clamp (2)
8. Oil suction line

2. Apply Loctite® 242 (page 380) or equivalent to oil return pipe threads.
3. Install a new copper washer and screw in the oil return pipe. Tighten oil return pipe to special torque (page 380).
4. If required, position oil return line, rubber elbow, clamps and brackets as an assembly onto oil suction line.
5. If removed, loosely install three M8 x 25 hex bolts, D9/19/4 washers and BM8–8 hexagon nuts.
6. Install oil suction line and oil return line as an assembly.

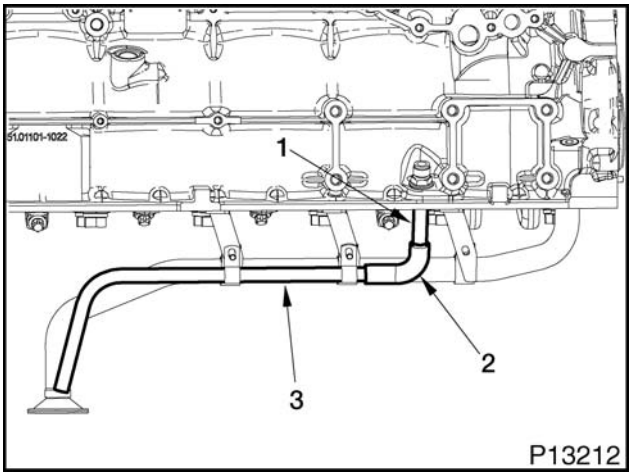

Figure 643 Oil return pipe

1. Oil return pipe
2. Rubber elbow
3. Oil return line

7. Connect rubber elbow to oil return pipe.
8. Install three M8 x 16 hex bolts through oil suction line brackets.
9. Tighten three M8 x 16 hex bolts to standard torque (page 455).
10. Tighten three M8 x 25 bolts to standard torque (page 455).

Oil Sump

1. Install oil sump gasket on oil sump.
2. Position oil sump and oil sump gasket as an assembly on crankcase.

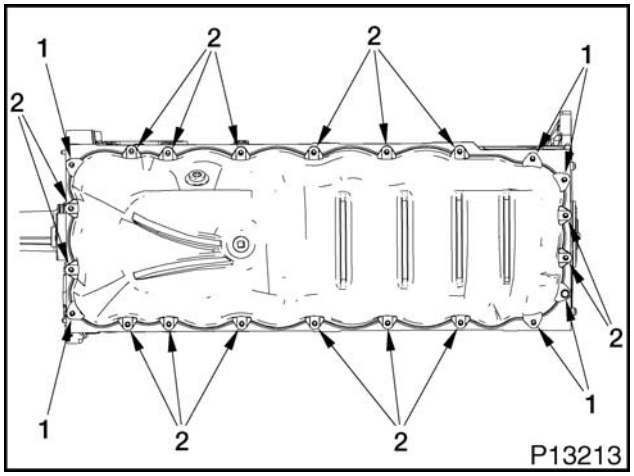

Figure 644 Oil sump retainers

1. Oil sump retainer (concave groove) (6)
2. Oil sump retainer (convex groove) (16)

3. Position 16 oil sump retainers (convex groove) on oil sump.
4. Position six oil sump retainers (concave groove) on oil sump.

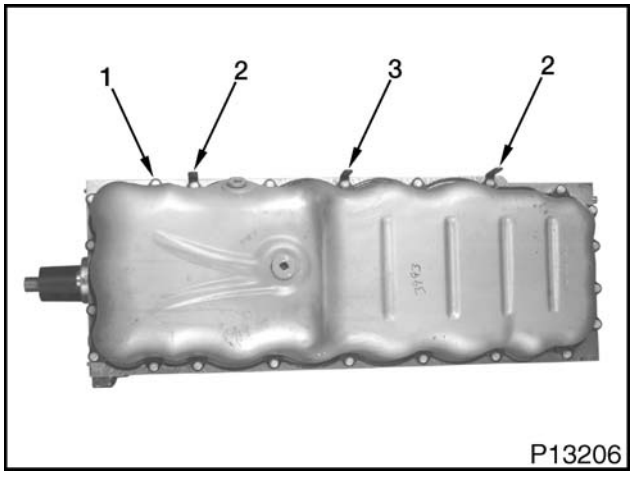

Figure 645 Oil sump (front sump)

1. M8 x 40 hex bolt (22)
2. Bracket (right angle bracket) (2)
3. Bracket (T-bracket)

5. Position three brackets on oil sump retainers in original locations.
6. Install 22 M8 x 40 hex bolts.

7. Tighten 22 M8 x 40 hex bolts to special torque (page 380).
8. If equipped, install preheater with new gasket. Tighten to special torque (page 380).

   On vehicles not equipped with preheater, install drain plug with new gasket. Tighten to special torque (page 380).
9. Install M27 x 2 drain plug with new gasket. Tighten to special torque (page 380).
10. On front sump engines, apply Loctite® 242 (page 380) or equivalent to oil return pipe threads.
11. Install a new copper washer and screw in the oil return pipe. Tighten oil return pipe to special torque (page 380).

Special Torque

Table 32 Oil Sump Components

Drain plug	75 N·m (55 lbf·ft)
Oil return pipe	4 N·m (35 lbf·in)
Oil sump bolts	35 N·m (26 lbf·ft)
Preheater or replacement drain plug	75 N·m (55 lbf·ft)

Special Service Tools

Table 33 Oil Sump System

Description	Tool Number
Loctite ® 242	Obtain locally

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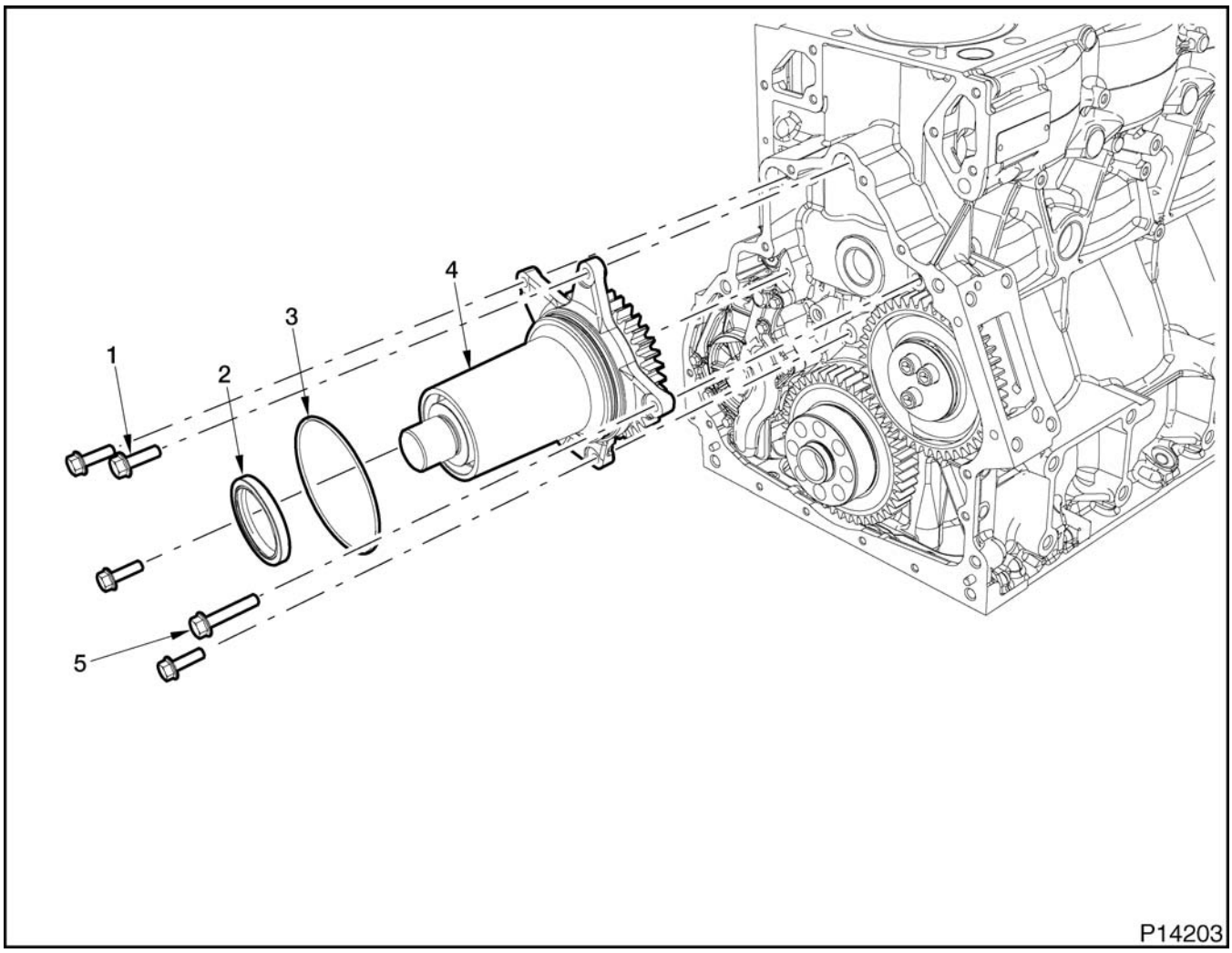

Figure 646 Fan drive

1. M8 x 25 hex bolts (4)
2. Radial shaft seal
3. O-ring
4. Fan drive
5. M8 x 40 hex bolt

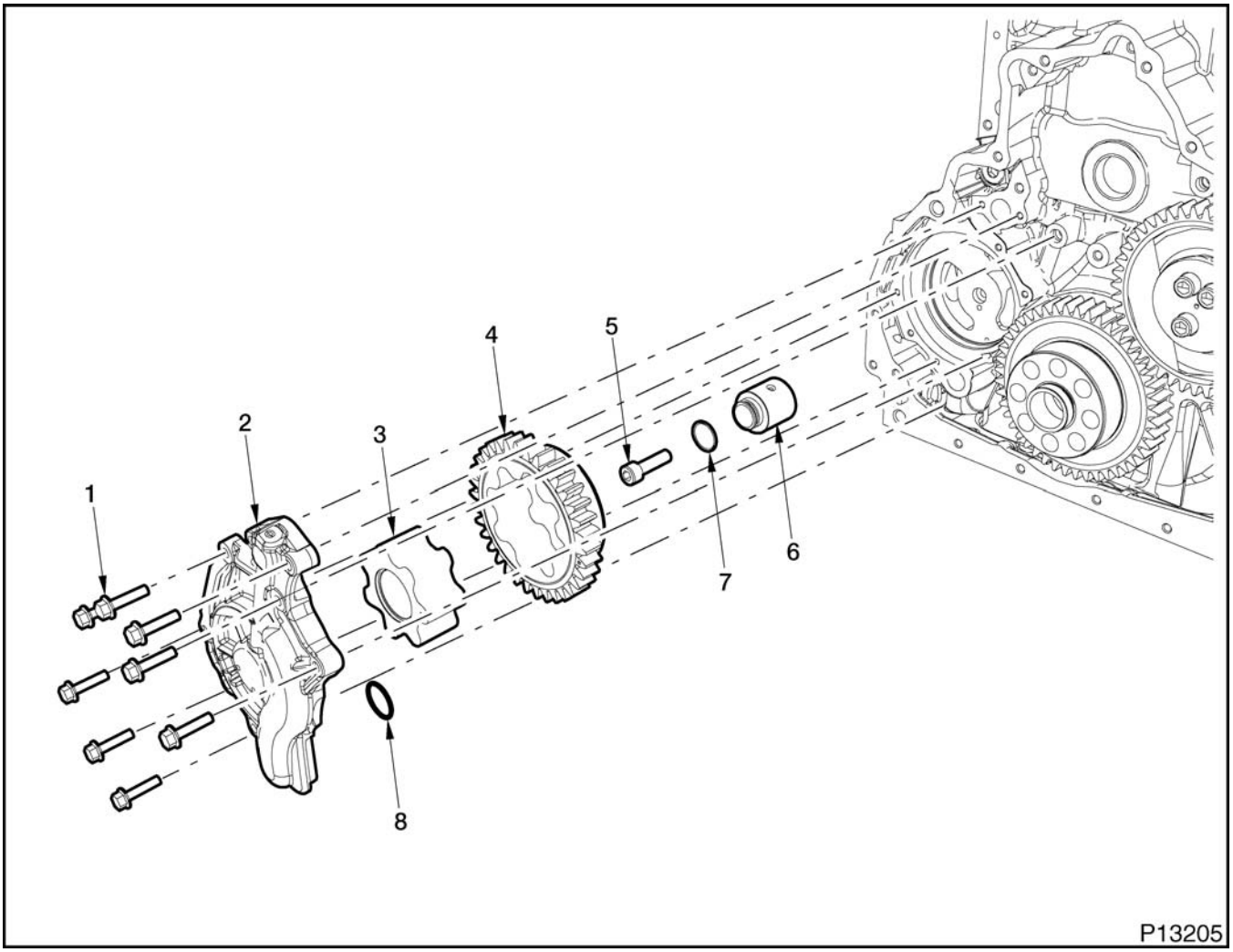

Figure 647 Oil pump

1. M6 x 25 hex bolts (8)
2. Oil pump cover
3. Oil pump pinion
4. Oil pump ring gear
5. M10 x 35 cylinder screw
6. Axle
7. O-ring
8. O-ring

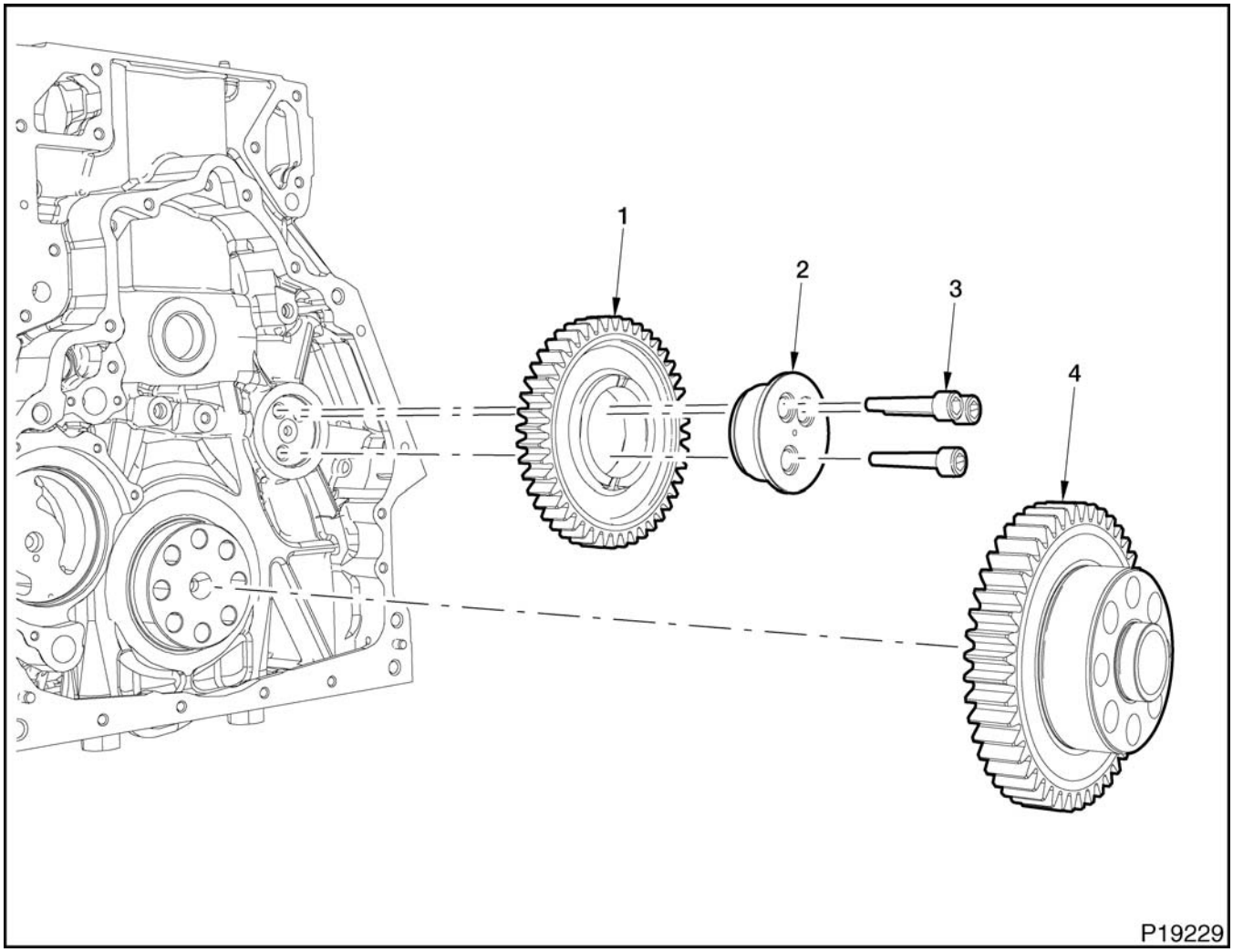

Figure 648 Front timing gears

1. Front intermediate gear
2. Front gear stud
3. M12 x 50 cylinder screws (3)
4. Crankshaft timing gear

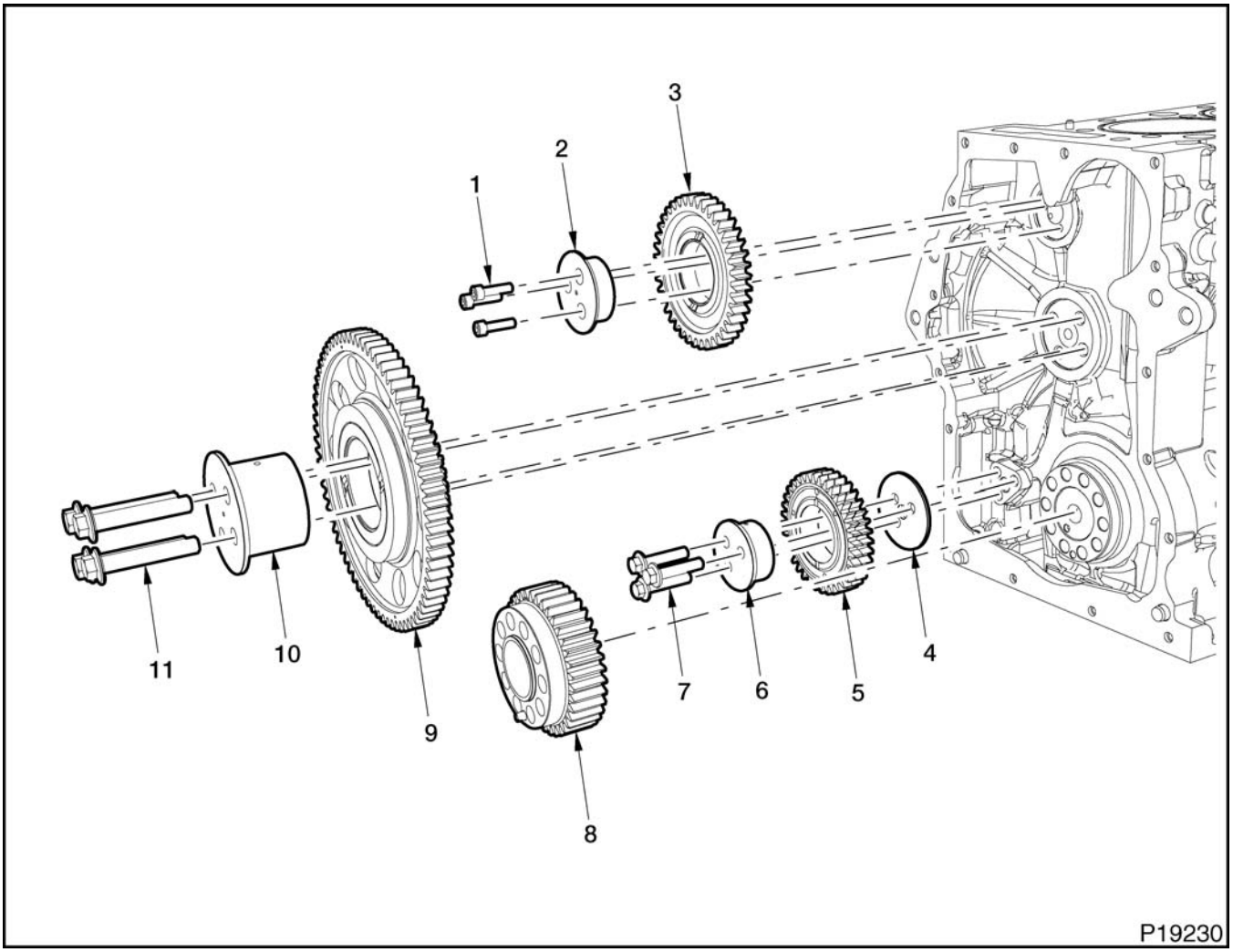

Figure 649 Rear timing gears

1. M8 x 30 cylinder screws (3)
2. Small gear stud
3. Crankcase intermediate gear
4. Air compressor thrust washer
5. Air compressor intermediate gear
6. Air compressor gear stud
7. M12 x 55 hex bolts (3)
8. Crankshaft timing gear
9. Big intermediate gear
10. Big gear stud
11. M14 x 80 hex bolts (4)

Removal

WARNING: To prevent personal injury or death, read all safety instructions in the "Safety Information" section of this manual.

WARNING: To prevent personal injury or death, shift the transmission to park or neutral, set the parking brake, and block the wheels before doing diagnostic or service procedures.

WARNING: To prevent personal injury or death, make sure the engine has cooled before removing components.

WARNING: To prevent personal injury or death, remove the ground cable from the negative terminal of the main battery before disconnecting or connecting electrical components. Always connect the ground cable last.

WARNING: To prevent personal injury or death, do not let engine fluids stay on your skin. Clean skin and nails using hand cleaner and wash with soap and water. Wash or discard clothing and rags contaminated with engine fluids.

GOVERNMENT REGULATION: Engine fluids (oil, fuel, and coolant) may be a threat to the environment. Recycle or dispose of engine fluids according to applicable regulations. Never put engine fluids in the trash, on the ground, in sewers or bodies of water.

NOTE: Refer to the following service sections for information on removal of components prior to this section.

- Front Cover, High Mount Fan Drive, Cooling System, and Related Components
- Cylinder Head, Camshaft and Valve Train
- Flywheel and Flywheel Housing

Preliminary Checks

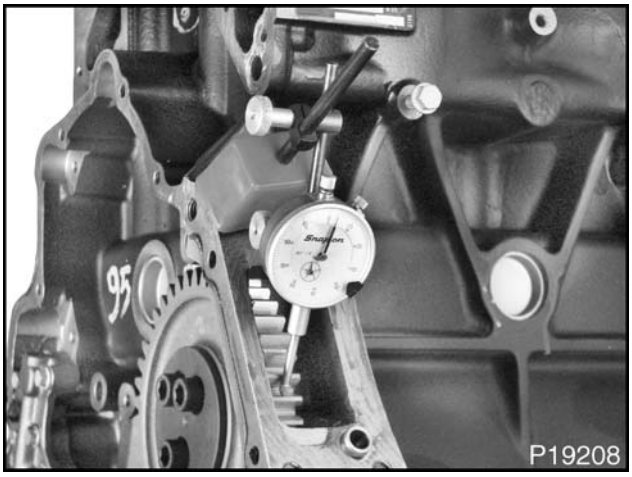

Figure 650 Front intermediate gear backlash measurement

1. Rotate engine and look for any damaged gear teeth. Replace damaged gears as necessary.
2. Place dial indicator with magnetic base (page 397) on front of crankcase with indicator tip on front intermediate gear.
3. Turn front intermediate gear clockwise and zero dial indicator.
4. Turn front intermediate gear back and forth while reading dial indicator. Compare dial indicator reading with specifications (page 397).
5. If backlash exceeds specified limits, replace front intermediate gear.

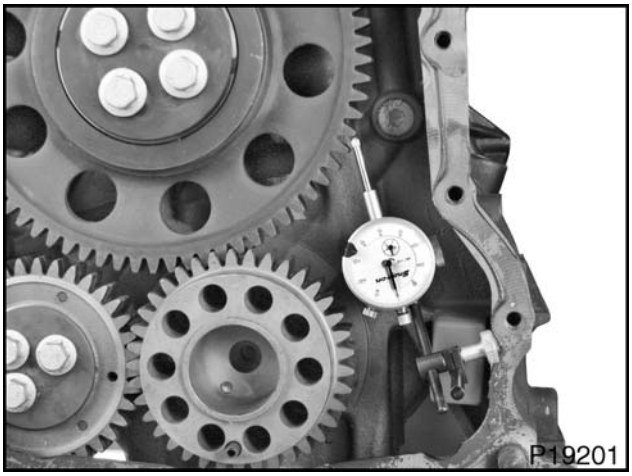

Figure 651 Big intermediate gear backlash measurement

6. Place dial indicator with magnetic base (page 397) on rear of crankcase with indicator tip on big intermediate gear.
7. Turn big intermediate gear clockwise and zero dial indicator.
8. Turn big intermediate gear back and forth while reading dial indicator. Compare dial indicator reading with specifications (page 397).
9. If backlash exceeds specified limits, replace big intermediate gear.

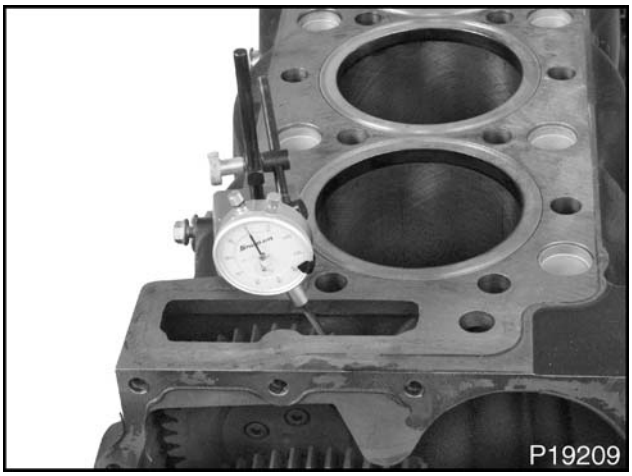

Figure 652 Crankcase intermediate gear backlash measurement

10. Place dial indicator with magnetic base (page 397) on top rear of crankcase with indicator tip on crankcase intermediate gear.
11. Turn crankcase intermediate gear clockwise and zero dial indicator.
12. Turn crankcase intermediate gear back and forth while reading dial indicator. Compare dial indicator reading with specifications (page 397).
13. If backlash exceeds specified limits, replace crankcase intermediate gear.

Radial Shaft Seal

WARNING: To prevent personal injury or death, wear safety glasses with side shields when doing the following procedure.

1. With an awl and hammer, punch two holes 180° apart in radial shaft seal.

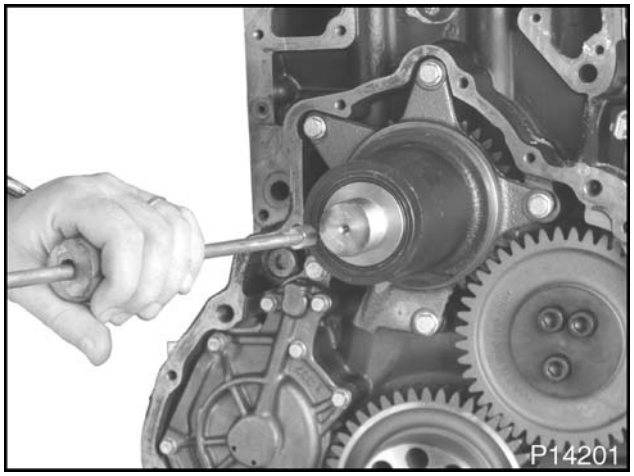

Figure 653 Radial shaft seal removal

2. Thread a slide hammer (page 397) with correct size screw in one of the two holes.
3. Slide hammer until one side of seal begins to pull out of fan drive. Move slide hammer to other hole and repeat until radial shaft seal is removed. Discard radial shaft seal.

Fan Drive

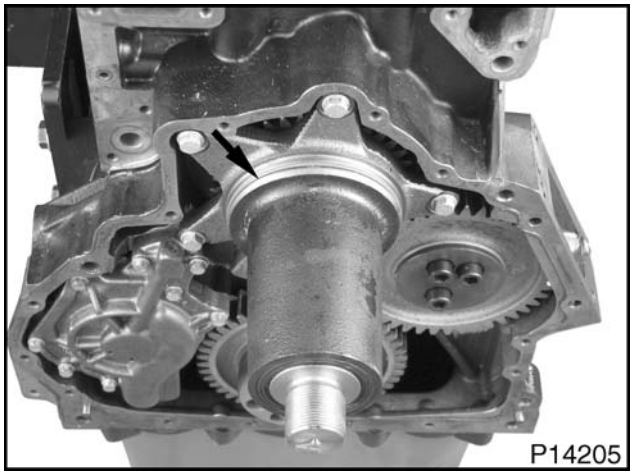

Figure 654 O-ring

1. Remove and discard O-ring.

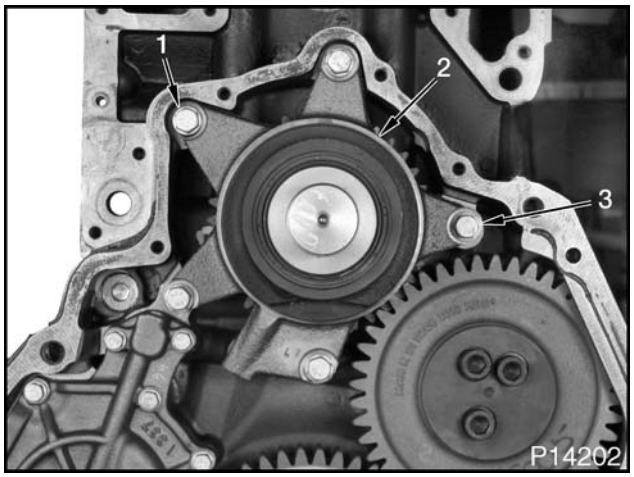

Figure 655 Fan drive

1. M8 x 25 hex bolts (4)
2. Fan drive
3. M8 x 40 hex bolt

2. Remove four M8 x 25 hex bolts, one M8 x 40 hex bolt and fan drive.

Oil Pump

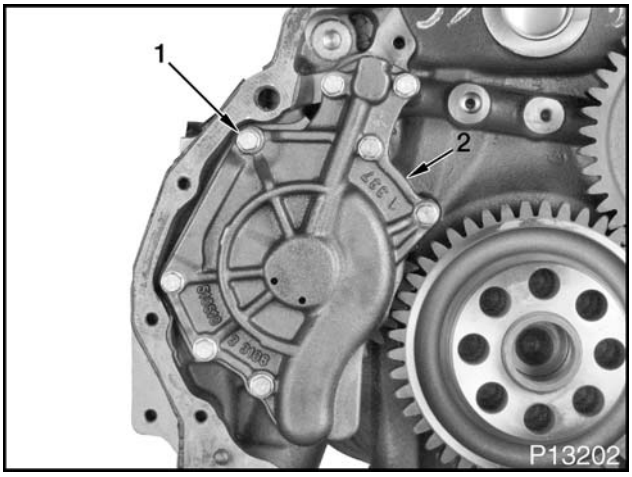

Figure 656 Oil pump cover

1. M6 x 25 hex bolts (8)
2. Oil pump cover

1. Remove eight M6 x 25 hex bolts.
2. Remove oil pump cover.
3. Remove and discard O-ring.

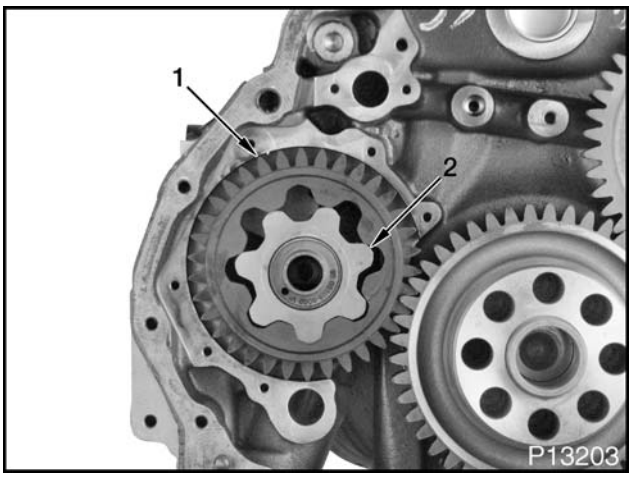

Figure 657 Oil pump pinion and oil pump ring gear

1. Oil pump ring gear
2. Oil pump pinion

CAUTION: To prevent engine damage, use permanent markers to identify internal components or their orientation. Do not use paint or temporary markers.

4. Use a permanent marker to mark the front of oil pump pinion and oil pump ring gear for correct assembly orientation.
5. Remove oil pump pinion and oil pump ring gear.

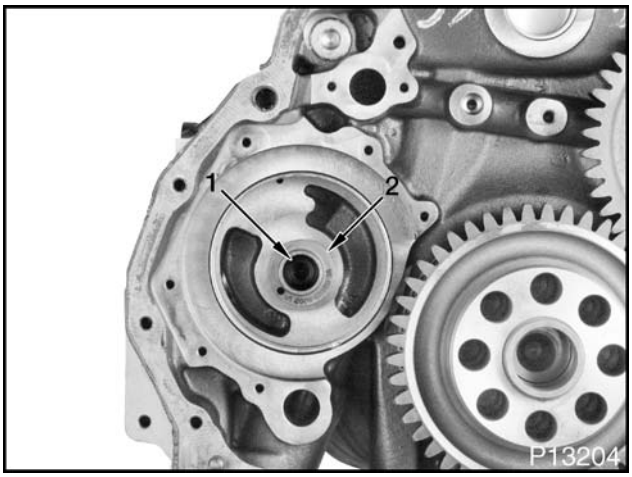

Figure 658 Axle

1. M10 x 35 cylinder screw
2. Axle

6. Remove M10 x 35 cylinder screw and axle.
7. Remove and discard O-ring.

Front Timing Gears

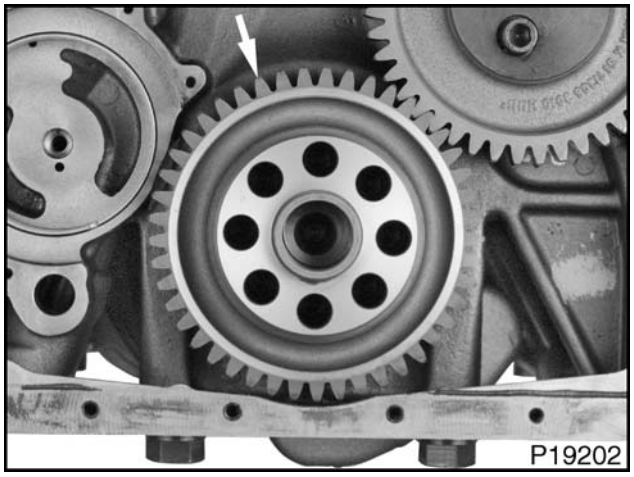

Figure 659 Crankshaft timing gear

1. Using a gear puller (page 397), remove crankshaft timing gear.

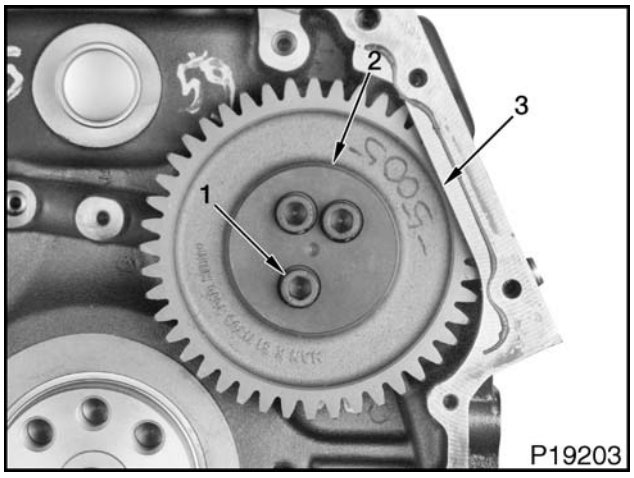

Figure 660 Front intermediate gear

1. M12 x 50 cylinder screws (3)
2. Front gear stud
3. Front intermediate gear

2. Remove three M12 x 50 cylinder screws, front gear stud, and front intermediate gear.

Rear Timing Gears

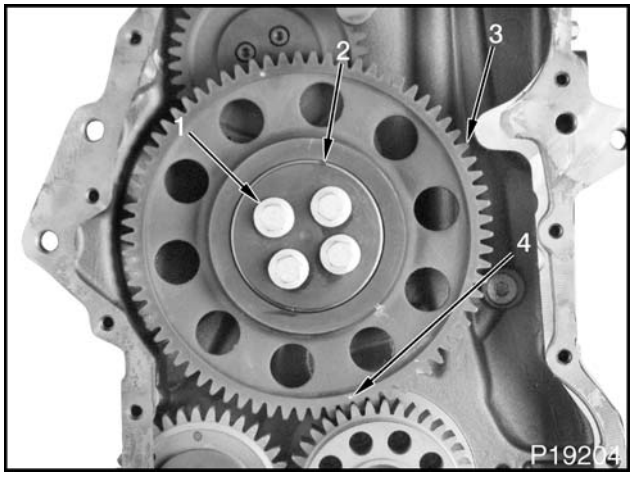

Figure 661 Big intermediate gear

1. M14 x 80 hex bolts (4)
2. Big gear stud
3. Big intermediate gear
4. Timing mark

1. Remove four M14 x 80 hex bolts, big gear stud, and big intermediate gear.

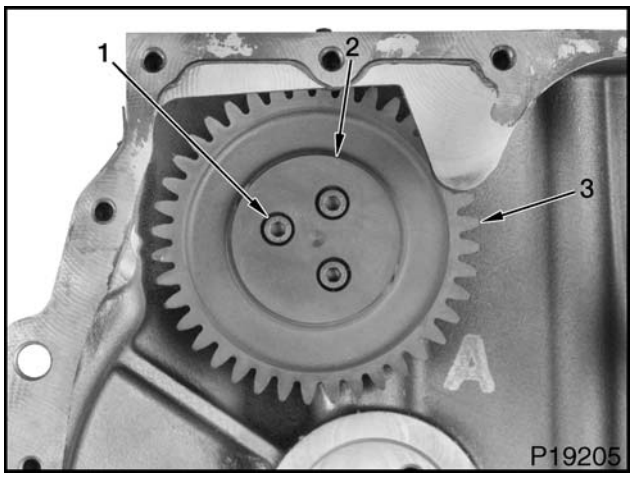

Figure 662 Crankcase intermediate gear

1. M8 x 30 cylinder screws (3)
2. Small gear stud
3. Crankcase intermediate gear

2. Remove three M8 x 30 cylinder screws, small gear stud, and crankcase intermediate gear.

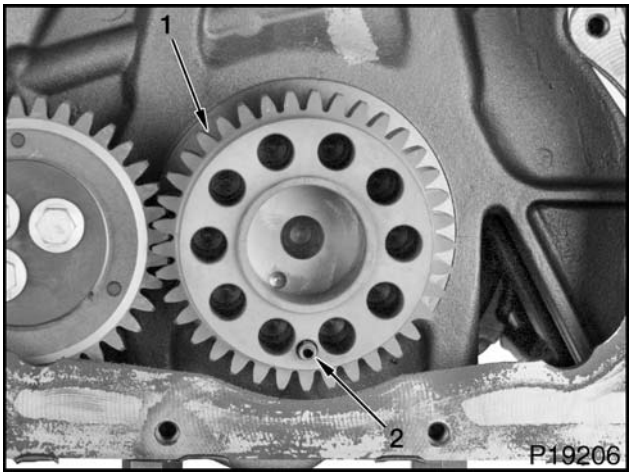

Figure 663 Crankshaft timing gear

1. Crankshaft timing gear
2. Pin, 8 x 60

3. Using a gear puller (page 397), remove crankshaft timing gear.

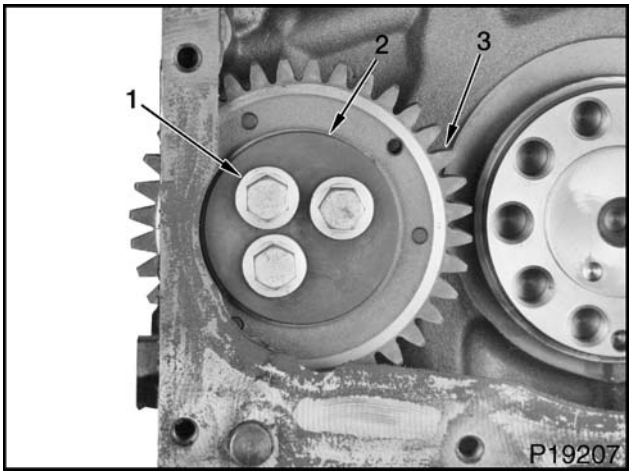

Figure 664 Air compressor intermediate gear

1. M12 x 55 hex bolts (3)
2. Air compressor gear stud
3. Air compressor intermediate gear
4. Air compressor thrust washer (not shown, behind gear)

4. Remove three M12 x 55 hex bolts and air compressor gear stud, air compressor intermediate gear, and air compressor thrust washer.

Cleaning and Inspection

Timing Gears

WARNING: To prevent personal injury or death, wear safety glasses with side shields. Limit compressed air pressure to 207 kPa (30 psi).

1. Wash timing gears and gear pins with a stiff brush and suitable solvent. Dry all with filtered compressed air.
2. Inspect timing gears for irregular wear pattern and worn or damaged teeth. Replace as necessary.
3. Inspect timing gear studs for worn or damaged bearing surfaces. Replace as necessary.

Oil Pump

1. Wash all parts thoroughly in a suitable solvent.

WARNING: To prevent personal injury or death, wear safety glasses with side shields. Limit compressed air pressure to 207 kPa (30 psi).

2. Dry with filtered compressed air.
3. Inspect oil pump pinion, oil pump ring gear, and oil pump cover for nicks, burrs or scoring.
4. Replace any damaged components.
5. Temporarily install oil pump components (page 395) in crankcase without O-ring and tighten M6 x 25 bolts to special torque (page 397).

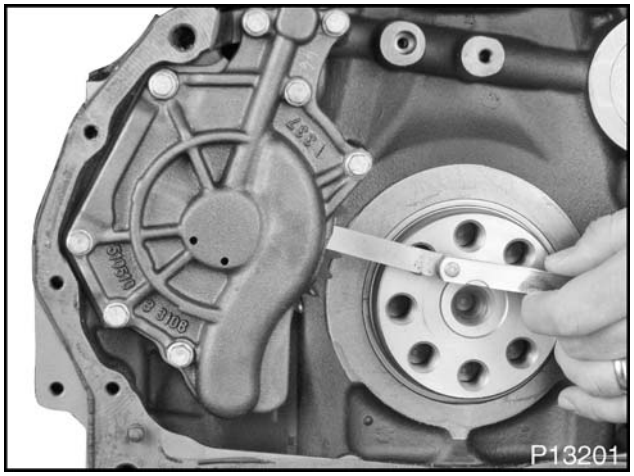

Figure 665 End play measurement

6. Using a feeler gauge (page 397), measure end play between oil pump cover and oil pump gears.

NOTE: There are two oil pump assemblies. When replacing oil pump parts, be sure you are ordering the correct set.

7. If end play exceeds specification (page 397), replace oil pump cover, oil pump pinion, and oil pump ring gear as a set.
8. Remove oil pump components for final assembly.

Installation

Rear Timing Gears

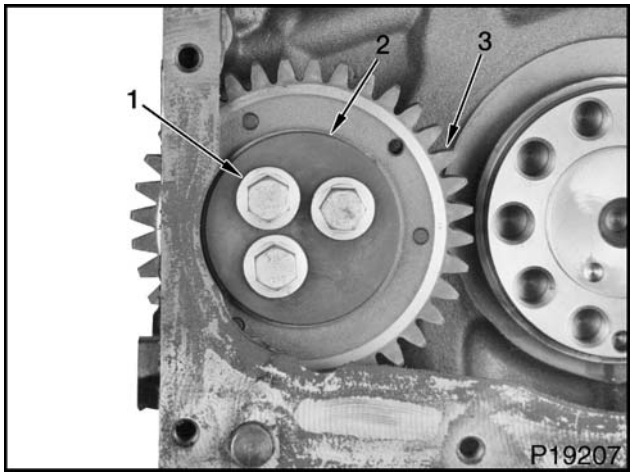

Figure 666 Air compressor intermediate gear

1. M12 x 55 hex bolts (3)
2. Air compressor gear stud
3. Air compressor intermediate gear
4. Air compressor thrust washer (not shown, behind gear)

1. Install air compressor thrust washer, air compressor gear stud, and air compressor intermediate gear.
2. Install three air compressor intermediate gear M12 x 55 hex bolts. Tighten bolts to special torque (page 397).

Figure 667 Crankshaft alignment pin hole

3. Rotate crankshaft so that alignment pin hole is at 6 o'clock position. This positions cylinder No. 1 at Top Dead Center (TDC).

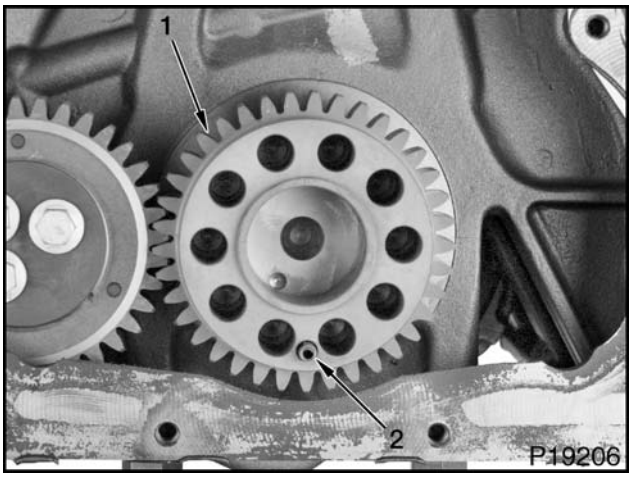

Figure 668 Crankshaft timing gear

1. Crankshaft timing gear
2. Pin, 8 x 60

WARNING: To prevent personal injury or death, wear safety glasses with side shields when doing the following procedure.

4. Using a hammer and brass drift, install crankshaft timing gear so pin in gear engages crankshaft alignment pin hole.

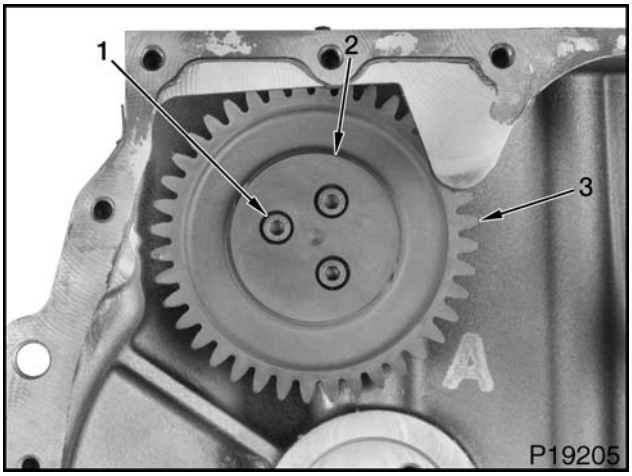

Figure 669 Crankcase intermediate gear

1. M8 x 30 cylinder screws (3)
2. Small gear stud
3. Crankcase intermediate gear

5. Install crankcase intermediate gear and small gear stud.
6. Install three crankcase intermediate gear M8 x 30 cylinder screws. Tighten screws to special torque (page 397).

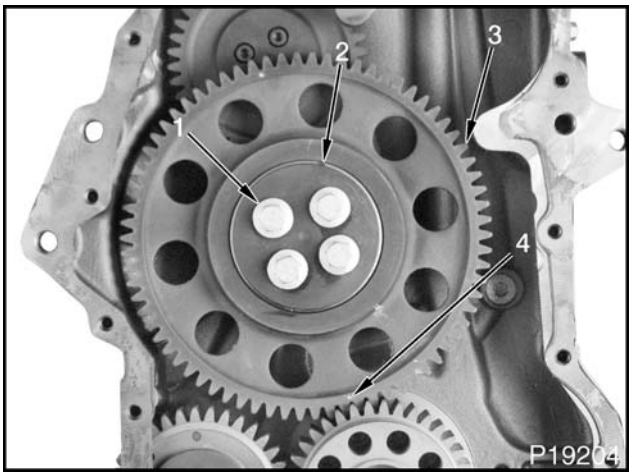

Figure 670 Big intermediate gear

1. M14 x 80 hex bolts (4)
2. Big gear stud
3. Big intermediate gear
4. Timing mark

NOTE: This gear has two timing marks 180° apart; either may be used.

7. Install big gear stud and big intermediate gear, aligning timing mark with mark on crankshaft timing gear (flywheel side).
8. Install four big intermediate gear M14 x 80 hex bolts. Tighten bolts to special torque (page 397).

Front Timing Gears

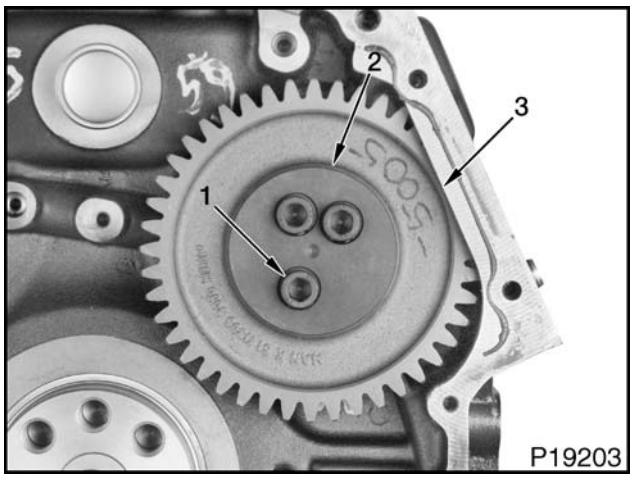

Figure 671 Front intermediate gear

1. M12 x 50 cylinder screws (3)
2. Front gear stud
3. Front intermediate gear

1. Install front intermediate gear and front gear stud.
2. Install three front intermediate gear M12 x 50 cylinder screws. Tighten screws to special torque (page 397).

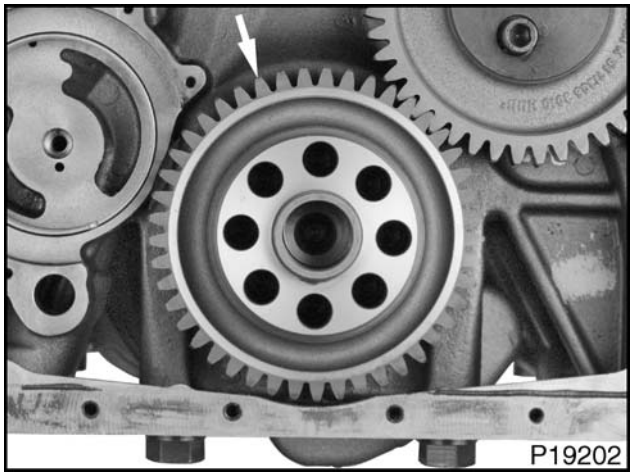

Figure 672 Crankshaft timing gear

3. Install two suitable bolts 180° apart through crankshaft timing gear into front of crankshaft.

WARNING: To prevent personal injury or death, wear safety glasses with side shields when doing the following procedure.

4. Using a hammer and brass drift, install crankshaft timing gear.
5. Remove two bolts.

Oil Pump

1. Lubricate new axle O-ring with clean engine oil and install on axle.

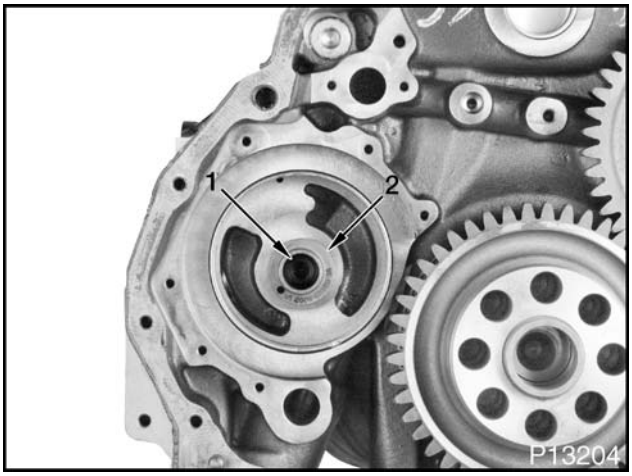

Figure 673 Axle

1. M10 x 35 cylinder screw
2. Axle

2. Install axle and M10 x 35 cylinder screw. Tighten screw to special torque (page 397).

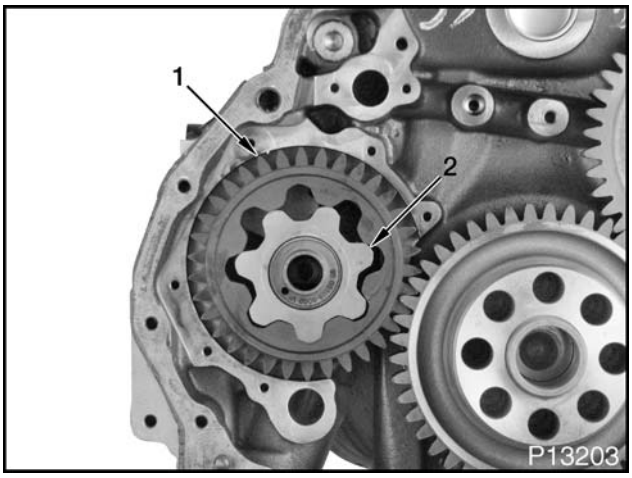

Figure 674 Oil pump pinion and oil pump ring gear

1. Oil pump ring gear
2. Oil pump pinion

3. Lubricate oil pump pinion and oil pump ring gear with clean engine oil.
4. Install oil pump pinion and oil pump ring gear, with previously made index marks facing towards front.
5. Lubricate new oil pump cover O-ring with clean engine oil and install on cover.

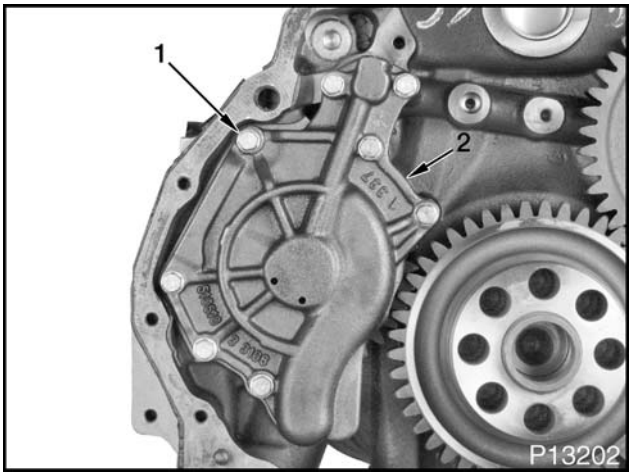

Figure 675 Oil pump cover

1. M6 x 25 hex bolts (8)
2. Oil pump cover

6. Install oil pump cover.
7. Install eight M6 x 25 hex bolts. Tighten bolts to special torque (page 397).

Fan Drive

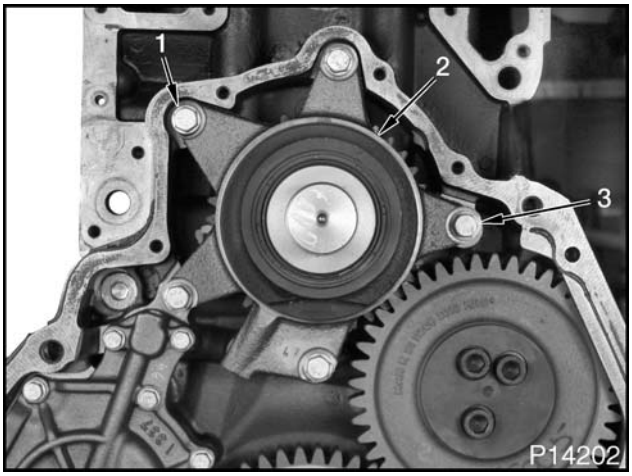

Figure 676 Fan drive

1. M8 x 25 hex bolts (4)
2. Fan drive
3. M8 x 40 hex bolt

1. Install fan drive, M8 x 40 hex bolt and four M8 x 25 hex bolts. Tighten bolts to special torque (page 397).

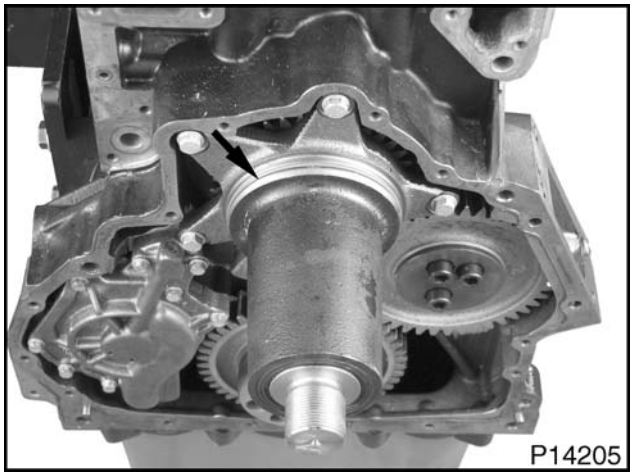

Figure 677 O-ring

2. Lubricate new O-ring with clean engine oil and install on fan drive.

Radial Shaft Seal

1. Lubricate radial shaft seal with clean engine oil.

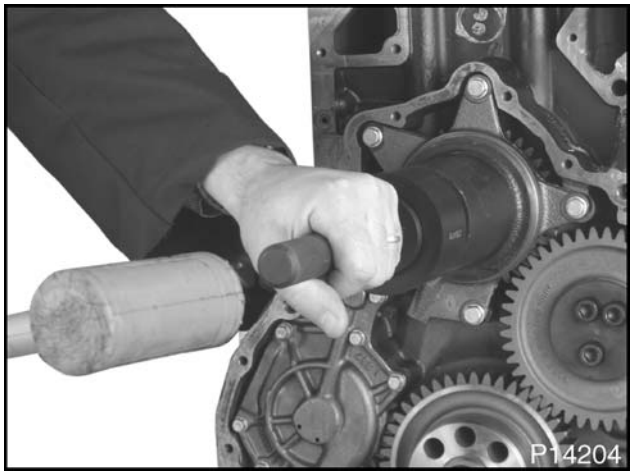

Figure 678 Radial shaft seal installation

2. Using Fan Hub High Pressure Drive Seal Installer (page 397), install new radial shaft seal until it seats within bore.

Specifications

Table 34 Oil Pump, Low Mount Fan Drive, and Timing Gears

Front Timing Gears	
Front intermediate gear backlash	0.057 - 0.183 mm (0.0022 - 0.0072 in)
Oil Pump	
Oil pump pinion and oil pump ring gear end play	0.0030 - 0.090 mm (0.0012 - 0.0035 in)
Rear Timing Gears	
Big intermediate gear backlash	0.052 - 0.176 mm (0.0020 - 0.0069 in)
Crankcase intermediate gear backlash	0.052 - 0.176 mm (0.0020 - 0.0069 in)

Special Torque

Table 35 Oil Pump, Low Mount Fan Drive, and Timing Gears

Front intermediate gear cylinder screws	105 N·m (77 lbf·ft)
Air compressor intermediate gear hex bolts	115 N·m (85 lbf·ft)
Crankcase intermediate gear cylinder screws	30 N·m (22 lbf·ft)
Big intermediate gear hex bolts	175 N·m (129 lbf·ft)
Fan drive hex bolts	35 N·m (26 lbf·ft)
Oil pump cover hex bolts	15 N·m (133 lbf·in)
Axle cylinder screw	65 N·m (48 lbf·ft)

Special Service Tools

Table 36 Oil Pump, Low Mount Fan Drive, and Timing Gears

Description	Tool Number
Dial Indicator with Magnetic Base	Obtain locally
Fan Hub High Pressure Drive Seal Installer	ZTSE4776
Feeler Gauge	Obtain locally
Gear Puller	Obtain locally
Slide Hammer	Obtain locally

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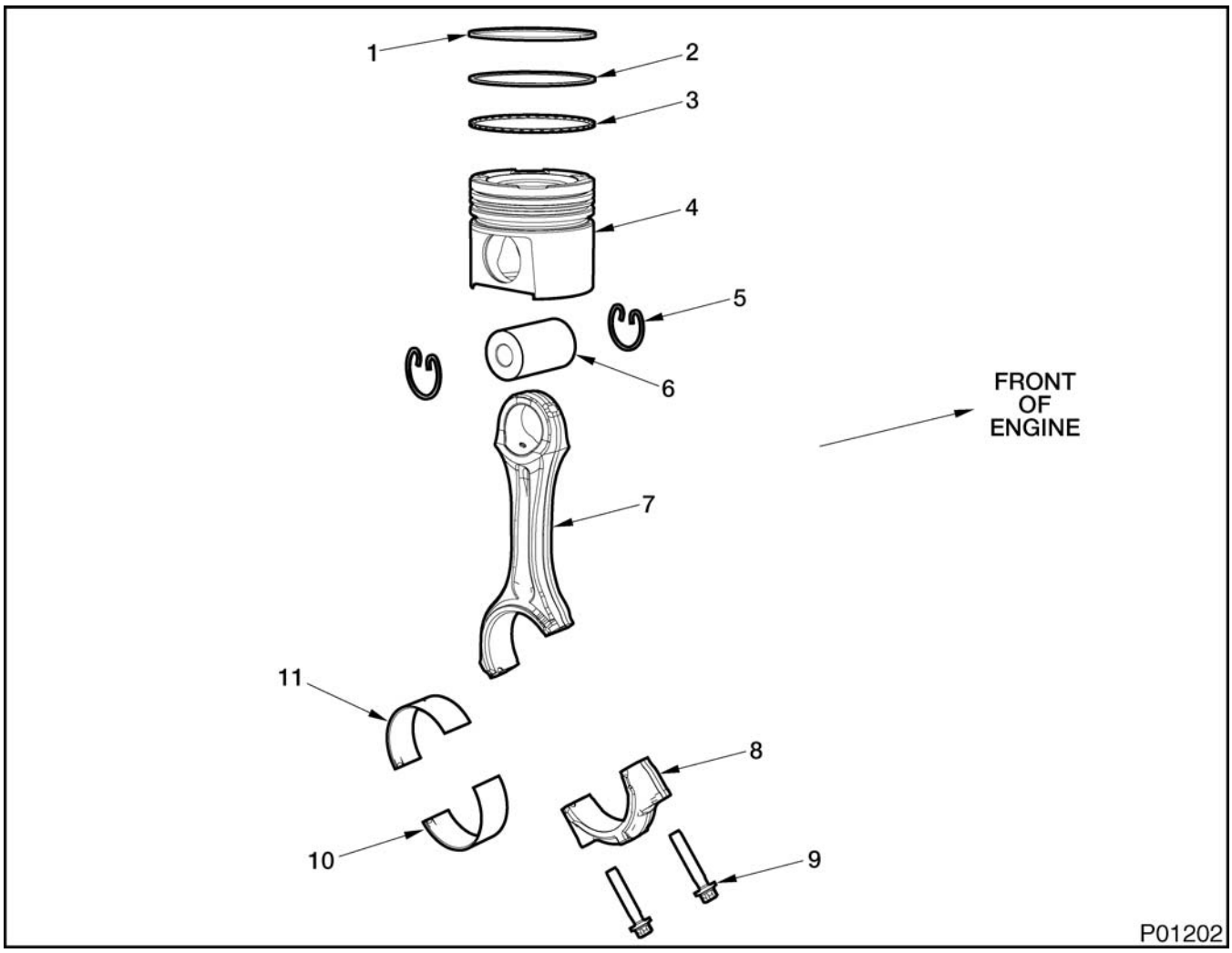

Figure 679 Piston and connecting rod

1. Keystone ring (6)
2. Taper face compression ring (6)
3. Bevelled oil scraper ring (6)
4. Piston (6)
5. Circlip (12)
6. Piston pin (6)
7. Connecting rod (6)
8. Connecting rod cap (6)
9. M12 x 64 screw (12)
10. Lower bearing shell (6)
11. Upper bearing shell (6)

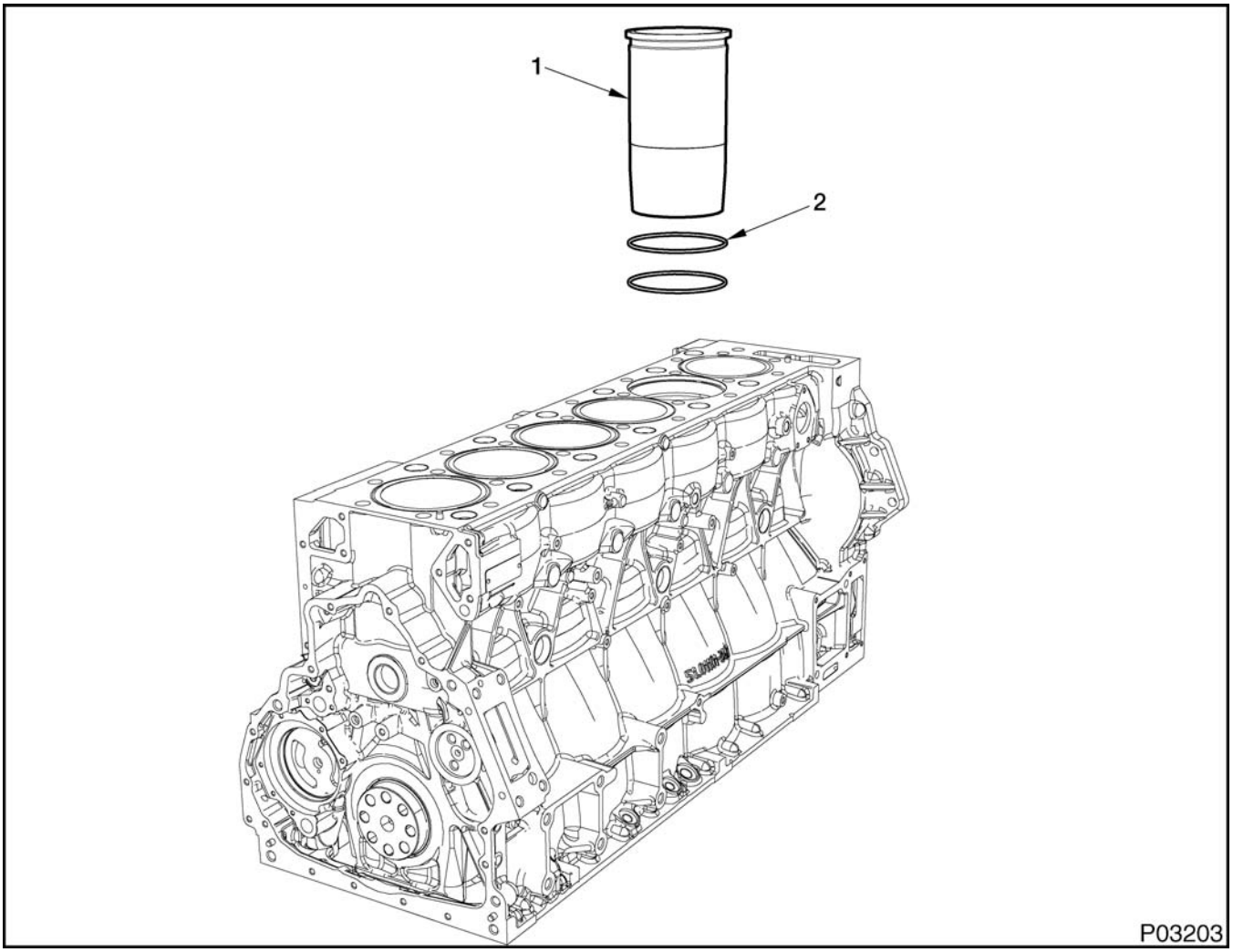

Figure 680 Cylinder liner

1. Cylinder liner (6)
2. 139 seal (12)

Removal

WARNING: To prevent personal injury or death, read all safety instructions in the "Safety Information" section of this manual.

WARNING: To prevent personal injury or death, shift transmission to park or neutral, set parking brake, and block wheels before doing diagnostic or service procedures.

WARNING: To prevent personal injury or death, make sure the engine has cooled before removing components.

WARNING: To prevent personal injury or death, do not let engine fluids stay on your skin. Clean skin and nails using hand cleaner and wash with soap and water. Wash or discard clothing and rags contaminated with engine fluids.

GOVERNMENT REGULATION: Engine fluids (oil, fuel, and coolant) may be a threat to the environment. Recycle or dispose of engine fluids according to applicable regulations. Never put engine fluids in the trash, on the ground, in sewers or bodies of water.

NOTE: Refer to the following service sections for information on removal of components prior to this section.

- Engine Electrical
- Cold Start Assist
- Aftertreatment System
- Engine Braking System
- Turbochargers
- Fuel System
- Oil Cooler, Filter Housing, and Crankcase Ventilation
- Exhaust Gas Recirculating (EGR) System
- Air Inlet Duct and Exhaust Manifold
- Cylinder Head, Camshaft, and Valve Train
- Flywheel and Flywheel Housing (as needed)
- Oil Pan and Oil Suction Tube

Preliminary Checks

NOTE: Evaluate piston protrusion before removing any piston and connecting rod assemblies. This helps identify bent or twisted connecting rods.

Figure 681 Checking piston protrusion

NOTE: Piston protrusion readings are done in line with piston pin, eliminating rocking movement of piston at any other position of measurement.

1. Check piston protrusion as follows:
   a. Make sure crankcase deck surface is clean.

b. Zero dial indicator with magnetic base (page 416) on crankcase deck surface.

c. Position dial indicator tip over piston head at 3 o'clock position.

d. Rotate crankshaft in direction of normal rotation to raise piston to its maximum outward protrusion at cylinder Top Dead Center (TDC). Read this maximum protrusion on dial indicator.

e. Reposition dial indicator tip on piston head at 9 o'clock position.

f. Rotate crankshaft to raise piston to its maximum protrusion. Read maximum protrusion on dial indicator.

g. Average the two readings. Replace piston and connecting rod if protrusion is not within specifications (page 414).

Piston and Connecting Rod

CAUTION: To prevent engine damage, check for a carbon ridge on top of cylinder liners. If found, remove carbon ridge with a razor knife before removing rod and piston assemblies.

1. Scrape carbon ridge from top of cylinder bore, if necessary. Use care not to damage liner bore surface.

CAUTION: To prevent engine damage, stamp, mark, or tag each connecting rod and cap with the correct cylinder number.

This engine has fractured connecting rods. Do not alter or damage fractured mating surfaces of the rod and cap. A cap from one connecting rod is not interchangeable with another connecting rod. The matching connecting rod and cap numbers or symbols indicate a matched set.

CAUTION: To prevent engine damage, use permanent markers to identify internal components or their orientation. Do not use paint or temporary markers.

2. Rotate crankshaft to position journals for removal of connecting rod assemblies. Mark connecting rod locations.

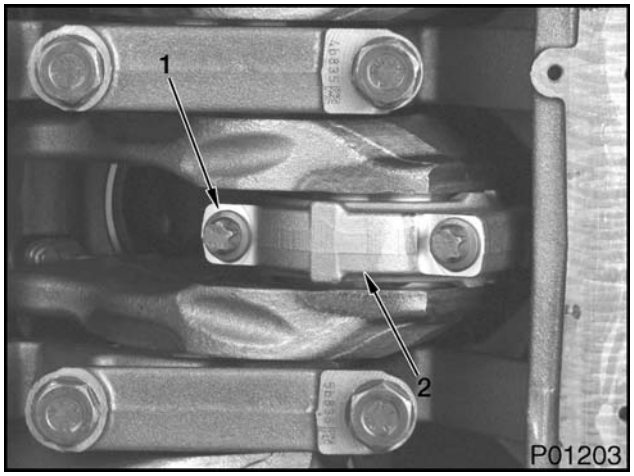

Figure 682 Connecting rod cap

1. M12 x 64 screw (2)
2. Connecting rod cap

CAUTION: To prevent engine damage, keep the fractured mating surfaces of the connecting rod and cap clean and free of lint and debris. Do not allow the mating surfaces to rest on other surfaces. Do not bump the mating surfaces or drop the connecting rod or cap. This could chip or mar the mating surfaces, causing incorrect mating of rod and cap.

CAUTION: To prevent engine damage, assemble connecting rod cap and connecting rod with their fractured mating surfaces in the original orientation. Matching numbers must be next to each other.

NOTE: When removed, make sure matching connecting rod and connecting rod cap numbers stay together as a set. A cap from one connecting rod is not interchangeable with any other connecting rod.

3. Using Connecting Rod Bolt Torx Socket (page 416) remove two M12 x 64 screws and connecting rod cap. Save screws for reuse during connecting rod bore check procedure.

CAUTION: To prevent engine damage, do not push on fractured surface of connecting rod.

CAUTION: To prevent engine damage, do not damage oil sprayer nozzle when removing connecting rod and piston assembly. If nozzle is bent during piston assembly removal, replace nozzle.

4. Remove piston and connecting rod assemblies from cylinder liners as follows:

   a. Rotate engine to a vertical position.

b. Use a wooden or plastic handle and push piston and connecting rod assembly from cylinder liner.

c. Once piston rings are free of cylinder bore, remove piston and connecting rod assembly from cylinder liner.

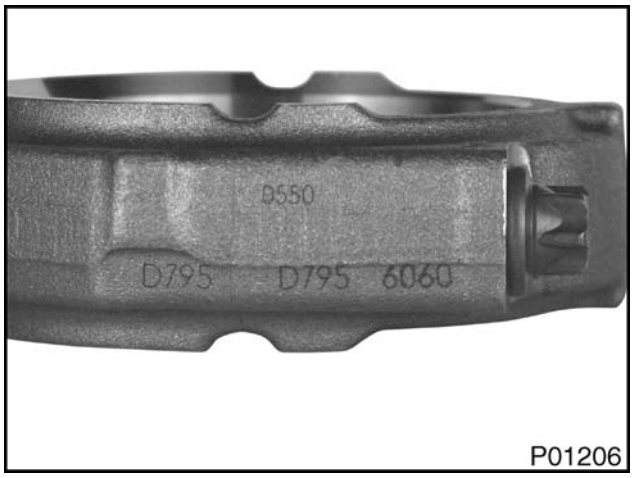

Figure 683 Correct connecting rod and cap joint fit

CAUTION: To prevent engine damage, use permanent markers to identify internal components or their orientation. Do not use paint or temporary markers.

5. Remove connecting rod upper and lower bearing shells by pushing out. Mark connecting rod bearing shells for position and orientation and set aside for inspection.

Piston Disassembly

WARNING: To prevent personal injury or death, wear safety glasses with side shields when removing piston pin retaining rings.

CAUTION: To prevent engine damage, mark pistons with cylinder number from which each was removed. If pistons will be reused, reinstall in correct cylinder bore.

CAUTION: To prevent engine damage, do not stamp marks on any machined surface of piston. If piston must be marked with a stamp, place mark on a non-machined as-cast surface only.

CAUTION: To prevent engine damage, use permanent markers to identify internal components or their orientation. Do not use paint or temporary markers.

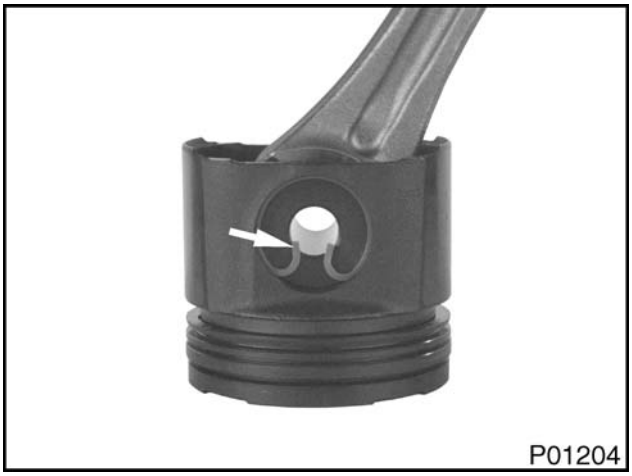

Figure 684 Circlip

1. Using a pair of pliers, remove two circlips.

CAUTION: To prevent engine damage, do not mark piston pin for cylinder and location on outer diameter; place mark only on flat end or tapered inside surface.

2. Remove piston pin from its bore by hand, and separate connecting rod from piston.

Figure 685 Piston ring removal (typical)

NOTE: Only expand piston rings enough to fit over top of piston.

NOTE: Keep piston rings organized for each cylinder.

3. Using piston ring expansion pliers (page 416) , remove keystone ring, taper face compression ring, and bevelled oil scraper ring.

Cylinder Liners

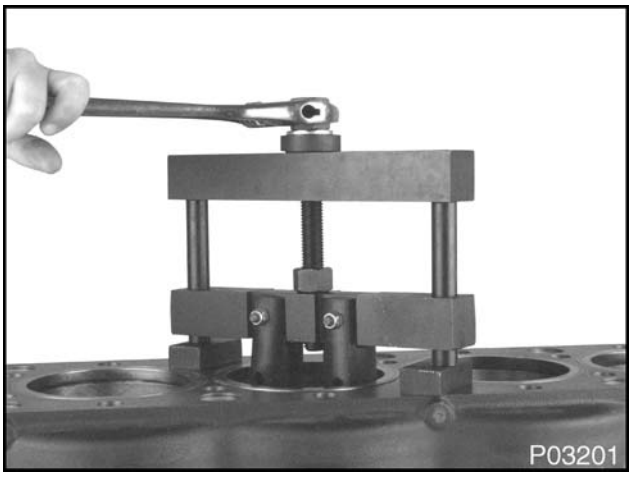

Figure 686 Cylinder liner removal

CAUTION: To prevent engine damage, use permanent markers to identify internal components or their orientation. Do not use paint or temporary markers.

NOTE: Care must be taken not to damage oil sprayer nozzles during cylinder liner removal.

1. Remove six cylinder liners from crankcase as follows:
   a. Insert Cylinder Liner Puller (page 416) into cylinder liner.
   b. Engage removal tool hooks under bottom edge of cylinder liner.
   c. Position removal tool feet diagonally on crankcase deck surface.
   d. Turn threaded shaft clockwise to extract cylinder liner.
   e. Mark cylinder liners for position and set aside for inspection.
2. Remove and discard two 139 seals from each crankcase cylinder liner bore.

Cleaning and Inspection

Cleaning

CAUTION: To prevent engine damage, do not use caustic solvents, wire brushes or bead blasting media to clean aluminum pistons.

CAUTION: To prevent engine damage, do not use solvents or a wire brush to clean the fractured mating surface of connecting rods.

1. Use a soap and water solution to clean pistons. Soak piston first, and then clean with a non-metallic brush.
2. Clean piston ring grooves thoroughly.
3. The following disassembled components may be cleaned using a suitable solvent:
   - Piston pins
   - Circlips
4. Thoroughly clean connecting rod bolt holes and threads.

Piston Inspection

1. Inspect pistons for scuffed or scored skirts, cracked or worn ring lands, and cracked or scuffed pin bores. Replace damaged pistons.

Figure 687 Second and third ring groove clearance check (typical)

NOTE: It is not possible to measure side clearance of keystone ring groove.

2. Check side clearance of taper face compression ring groove as follows:
   a. Place edge of a new taper face compression ring in its respective ring groove. Roll taper face compression ring all around ring groove to ensure ring is free in its groove.
   b. With edge of taper face compression ring in taper face compression ring groove, use a feeler gauge (page 416) to measure side clearance between ring and groove.
   c. Compare taper face compression ring side clearance to specifications (page 414). Excessive side clearance indicates ring groove wear and requires piston replacement.
3. Check side clearance of bevelled oil scraper ring groove as follows:
   a. Place edge of a new bevelled oil scraper ring in its respective ring groove. Roll bevelled oil scraper ring all around ring groove to ensure ring is free in its groove.
   b. With edge of bevelled oil scraper ring in the bevelled oil scraper ring groove, use a feeler gauge (page 416) to measure side clearance between ring and groove.
   c. Compare bevelled oil scraper ring side clearance to specifications (page 414). Excessive side clearance indicates ring groove wear and requires piston replacement.

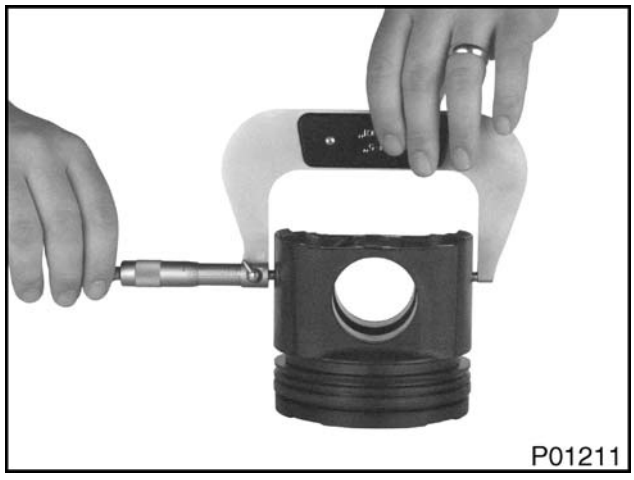

Figure 688 Piston skirt diameter

4. Using a 4–5 inch micrometer (page 416), measure diameter of piston at intervals given in Specifications (page 414). If measurements do not meet specification, replace piston.

Piston Ring Inspection

CAUTION: To prevent engine damage, install new piston rings if a piston is removed. Faulty piston rings cannot always be detected visually.

1. Inspect new piston rings for cleanliness.

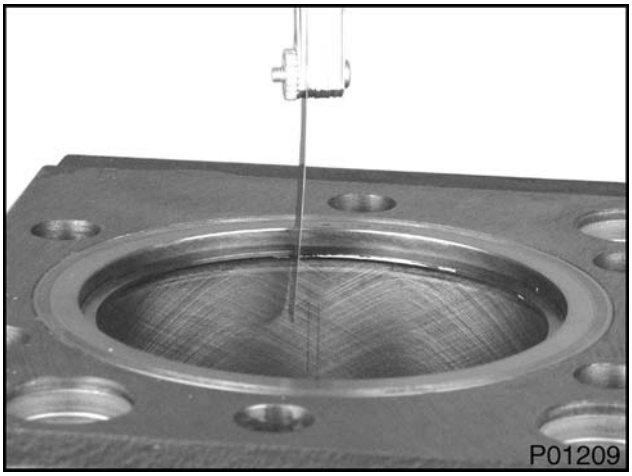

Figure 689 Piston ring end gap clearance in cylinder bore

2. Before installing new piston rings, check ring gap for each ring as follows:
   a. Push piston ring down into cylinder bore. Make sure the piston ring is square with cylinder wall. An inverted piston head can be used to push piston ring to desired location of measurement (usually at top of piston stroke).
   b. Use a feeler gauge (page 416) to measure gap between ends of each piston ring.
   c. If gap does not meet specifications (page 414), select another ring or recheck cylinder liner wear.

Connecting Rod Inspection

CAUTION: To prevent engine damage, keep the fractured mating surfaces of the connecting rod and cap clean and free of lint and debris. Do not allow the mating surfaces to rest on other surfaces. Do not bump the mating surfaces or drop the connecting rod or cap. This could chip or mar the mating surfaces, causing incorrect mating of rod and cap.

CAUTION: To prevent engine damage, do not use solvents or a wire brush to clean the fractured mating surface of connecting rods.

1. Inspect connecting rod screw threads for nicks or damage. Replace as required.
2. Inspect connecting rod and cap mating surfaces and bearing bore for any indication of damage. Bore must be smooth and free of scoring or nicks. Replace connecting rod if necessary.

Figure 690 Inside diameter of piston pin bore

3. Inspect connecting rod piston pin bore for wear as follows:
   a. Using a telescoping gauge (page 416) and a 2-3 inch micrometer (page 416), measure piston pin bore at two locations 90° apart.
   b. If inside diameter of piston pin bore exceeds specification (page 414), replace connecting rod.

Connecting Rod Bore Check

CAUTION: To prevent engine damage, do not use air powered tools to install connecting rod bolts; this can seize rod bolts.

1. Lubricate used connecting rod M12 x 64 screws with clean engine oil. Assemble cap to connecting rod without bearing shell. Tighten screws to initial and final torque values (page 415).

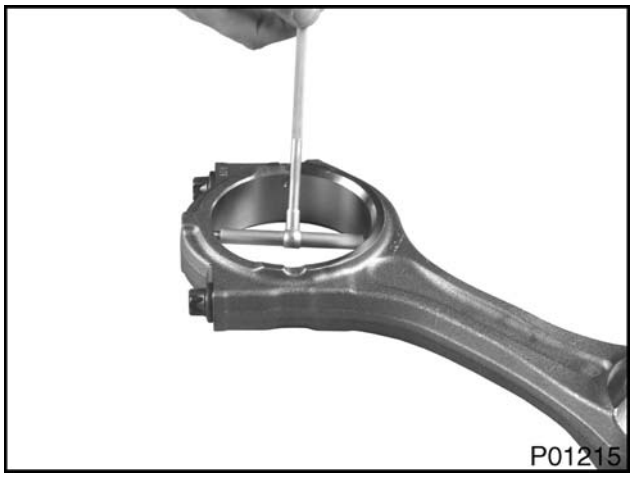

Figure 691 Measurement of connecting rod bore

2. Using a telescoping gauge (page 416) and a 3–4 inch micrometer (page 416), measure connecting rod bearing bore diameter in three locations. If connecting rod bore diameter does not meet specifications (page 414), replace connecting rod.
3. After all connecting rod bores are inspected, disassemble connecting rods and discard used M12 x 64 screws.
4. With connecting rod cap removed, inspect surface finish of connecting rod bearing bore. Bore must be smooth and free of scoring, nicks or burrs. Replace connecting rod as necessary.

Piston Pin Inspection

1. Inspect piston pins for scoring or wear. Replace as necessary.

Figure 692 Piston pin wear

2. Using a 2–3 inch micrometer (page 416), measure piston pin outside diameter at two locations 90° apart.
3. Measure each end of pin. If outside diameter of any piston pin is less than minimum specifications (page 414), replace piston pin.

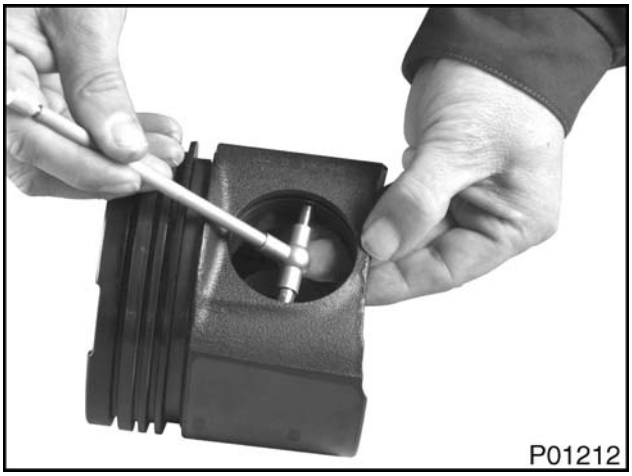

Figure 693 Inside diameter measurement of piston pin bore

4. Using a telescoping gauge (page 416) and 2–3 inch micrometer (page 416), measure each piston pin bore inside diameter, at two locations 90° apart. If piston pin bore inside diameter is not within specifications (page 414), replace piston.
5. To check piston pin running clearance, subtract outside diameter of piston pin from inside

diameter of piston pin bore. If clearance exceeds specifications (page 414), replace piston pin and check piston pin clearance using new piston pin.

Cylinder Liner Inspection

1. Install six cylinder liners (without seals) into crankcase.

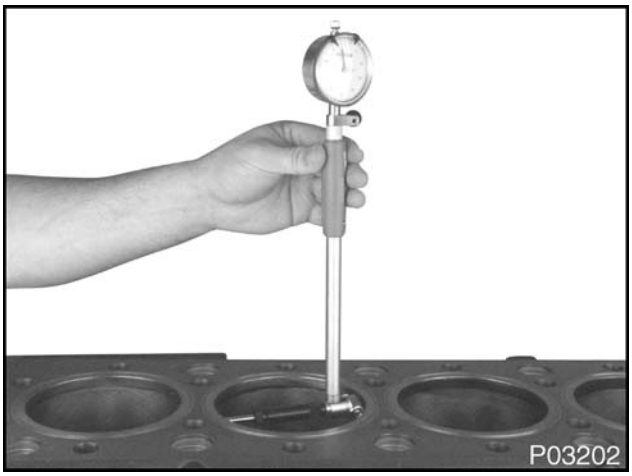

Figure 694 Cylinder liner bore measurement

2. Using a dial bore gauge (page 416), measure the cylinder liner inside diameter at 120° intervals, at four different depths of cylinder liner. If cylinder liner inside diameter is not within specification (page 414), replace cylinder liner.

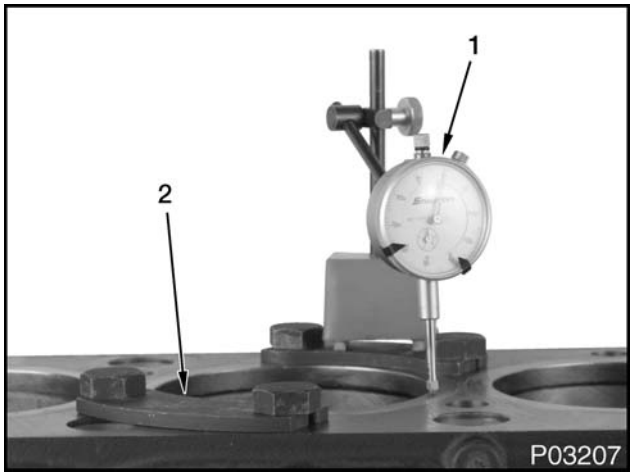

Figure 695 Cylinder liner protrusion measurement

1. Dial indicator with magnetic base
2. Cylinder Liner Protrusion Tool

3. Check cylinder liner protrusion above crankcase deck as follows:
   a. Install Sleeve Protrusion Hold Down Clamps (page 416) using four included bolts. Torque bolts to special torque (page 415).
   b. Place dial indicator with magnetic base (page 416) on crankcase deck surface.
   c. Position dial indicator tip on crankcase deck adjacent to cylinder liner flange. Zero dial indicator.
   d. Carefully pivot dial indicator until tip is resting on cylinder liner flange. Record reading.
   e. Measure cylinder liner protrusion at three locations evenly spaced around the cylinder liner. Average the three readings to determine cylinder liner protrusion.
   f. If cylinder liner protrusion is not within specification (page 414), fit new cylinder liner and repeat steps a through e.
   g. If after trying all available new piston liners and specification still cannot be met, contact Tech Central at 1-800-336-4500.
   h. Remove six cylinder liners and continue with installation.

Installation

Cylinder Liners

1. Lubricate two new 139 seals for cylinder liner with clean engine oil and install in crankcase cylinder liner bore.
2. Using a soft-faced hammer, install cylinder liner by striking evenly until seated.

Piston Assembly

WARNING: To prevent personal injury or death, wear safety glasses with side shields when doing the following procedure.

Figure 696 Piston ring installation (typical)

CAUTION: To prevent engine damage, install piston rings correctly. Both intermediate and compression rings have the same identification markings. The marking must face up for the ring to be installed correctly. The intermediate ring has a rectangular cross section and goes in the middle groove. The top compression ring has a keystone cross section and goes in the top groove.

NOTE: Only expand piston rings enough to fit over top of piston.

1. Using piston ring expansion pliers (page 416) , install piston rings.
   a. Install expansion spring component of bevelled oil scraper ring into bottom piston groove.
   b. Install oil scraper component of bevelled oil scraper ring over expansion spring with the gap 180° from the spring wire latch.
   c. Install taper face compression ring into middle piston groove. Make sure ring is installed with identification mark facing up.
   d. Install keystone ring into top piston groove. Make sure ring is installed with identification mark facing up.
2. Space ring gaps approximately 120° apart after ring installation.
3. Connect piston to connecting rod as follows:
   a. Lubricate connecting rod piston pin bore, piston pin bore, and piston pin with clean engine oil.
   b. Set piston face down, so arrow mark stamped on piston crown is at 6 o'clock position.
   c. Hold connecting rod so open end faces 3 o'clock position of piston when installed.
   d. Place connecting rod into piston.

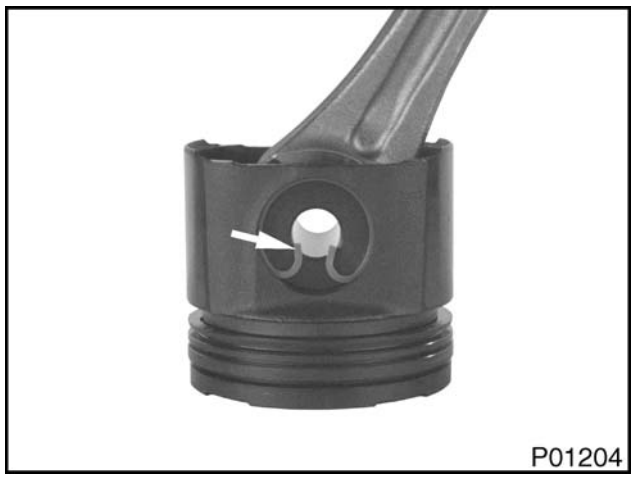

Figure 697 Circlip

   e. Using a pair of pliers, install first circlip at one end of piston pin bore.
   f. Slide piston pin through bored holes, stopping at installed circlip.
   g. Using a pair of pliers, install second circlip.

Piston and Connecting Rod

1. Turn crankshaft so crank pin is at bottom of its stroke.
2. Lightly coat piston and piston rings with clean engine oil.
3. Coat cylinder liner walls, crankshaft journals, and piston ring compressor (page 416) with clean engine oil.
4. Place piston in piston ring compressor (page 416).
5. Install connecting rod bearing shells in connecting rod and cap. Coat bearing shells with clean engine oil.

Figure 698 Arrow mark on piston

CAUTION: To prevent engine damage, the arrow stamped on top of piston must face front of engine.

CAUTION: To prevent engine damage, do not damage oil sprayer nozzle when installing connecting rod and piston assembly. If nozzle is bent during piston assembly installation, replace nozzle.

NOTE: Before installing piston and connecting rod assembly, make sure all oil sprayer nozzles are installed.

6. Carefully put piston and piston ring compressor combination and connecting rod assembly in cylinder liner with arrow mark facing towards front of engine.

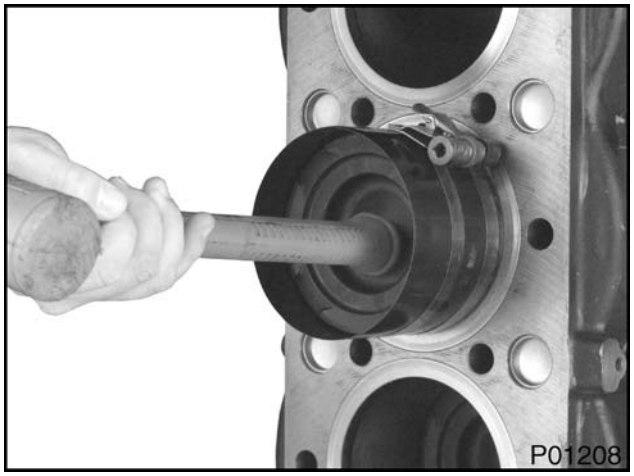

Figure 699 Installation of piston in cylinder bore

7. Once piston and connecting rod assembly have been inserted in cylinder liner, use a handle (wood or plastic) of a hammer to tap piston into cylinder liner. Guide connecting rod in place on crankshaft.

CAUTION: To prevent engine damage, lightly lubricate bolt threads and mating surfaces of bolt flanges with clean engine oil. Too much oil will cause hydrostatic lock and give incorrect torque reading.

8. Apply clean engine oil to bolt threads for connecting rod and upper and lower bearing shell in cap before installing screws.

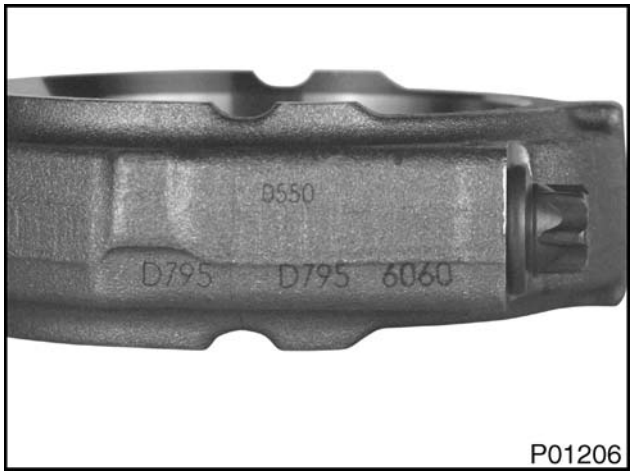

Figure 700 Correct connecting rod and cap joint fit

CAUTION: To prevent engine damage, install connecting rods with correct caps in the correct direction. If a rod cap is reversed, an offset will be seen at the mating surfaces. If a reverse assembly is installed on the crankshaft, the connecting rod must be replaced. Also, check crank pin fillets for damage that would require replacement of the crankshaft.

9. Assemble cap to connecting rod with matching identification code on same crankshaft journal from which it was removed. Be certain that longer leg of connecting rod is positioned towards left side of crankcase.

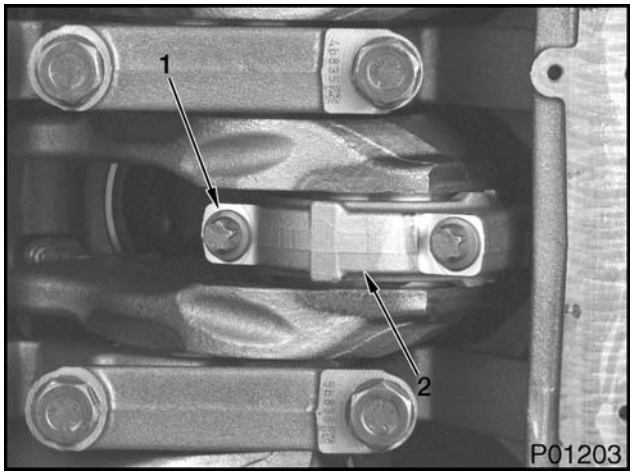

Figure 701 Connecting rod cap

1. M12 x 64 screw (2)
2. Connecting rod cap

CAUTION: To prevent engine damage, do not use air powered tools to install connecting rod bolts; this can seize rod bolts.

CAUTION: To prevent engine damage, do not rotate crankshaft until connecting rod is fully tightened, as this may cause bearing shells to rotate in place.

10. Install two new M12 x 64 screws.
11. Using Connecting Rod Bolt Torx Socket (page 416) tighten screws evenly to initial and final torque values (page 415).
12. Repeat installation procedure for remaining connecting rod and piston assemblies.

Specifications

Table 37 Power Cylinders

Connecting Rods	
Piston pin bore inside diameter	52.06 ± 0.005 mm (2.0496 ± 0.0001 in)
Connecting rod bearing bore diameter (crankshaft end)	95.000 to 95.022 mm (3.7402 to 3.7402 in)
Pistons — 11L	
Skirt diameter measured 16 mm from piston bottom edge	119.88 ± 0.009 mm (4.7197 ± 0.0004 in)
Piston protrusion measured from crankcase deck to piston	0.3 ± 0.22 mm (0.0118 ± 0.009 in)
Piston pin bore inside diameter	52.010 - 52.016 mm (2.0476 - 2.0479 in)
Piston pin running clearance	0.010 - 0.024 mm (0.0004 - 0.0009 in)
Pistons — 13L	
Skirt diameter measured 26.9 mm from piston bottom edge	125.950 ± 0.013 mm (4.9587 ± 0.0005 in)
Piston protrusion measured from crankcase deck to piston	0.3 ± 0.22 mm (0.0118 ± 0.009 in)
Piston pin bore inside diameter	52.04 - 52.05 mm (2.0490 - 2.0492 in)
Piston pin running clearance	0.040 - 0.058 mm (0.0016 - 0.0023 in)
Piston Pins	
Outside diameter	51.992 - 52.000 mm (2.0469 - 2.0472 in)
Piston Rings — 11L	
Keystone ring	
Ring gap	0.4 - 0.55 mm (0.0157 - 0.0217 in)
Taper face compression ring	
Ring gap	0.90 - 1.00 mm (0.0354 - 0.0393 in)
Side clearance	0.07 - 0.13 mm (0.0028 - 0.0051 in)
Bevelled oil scraper ring	
Ring gap	0.25 - 0.55 mm (0.0098 - 0.0217 in)

Table 37 Power Cylinders (cont.)

Side clearance	0.03 - 0.07 mm (0.0012 - 0.0028 in)
Piston Rings — 13L	
Keystone ring	
Ring gap	0.4 - 0.55 mm (0.0157 - 0.0217 in)
Taper face compression ring	
Ring gap	1.00 - 1.02 mm (0.0394 - 0.0402 in)
Side clearance	0.02 - 0.11 mm (0.0008 - 0.0043 in)
Bevelled oil scraper ring	
Ring gap	0.25 - 0.50 mm (0.0098 - 0.0197 in)
Side clearance	0.05 - 0.09 mm (0.0020 - 0.0035 in)
Liner dimensions — 11L	
Liner protrusion	0.050 - 0.085 mm (0.0019 - 0.0033 in)
Liner inside diameter	120 ± 0.01 mm (4.7244 ± 0.0004 in)
Liner dimensions — 13L	
Liner protrusion	0.050 - 0.085 mm (0.0019 - 0.0033 in)
Liner inside diameter	126 ± 0.01 mm (4.9606 ± 0.0004 in)

Special Torque

Table 38 Power Cylinders

Connecting rod screws	Initial	100 N·m (74 lbf·ft)
	Final	90°
Cylinder Liner Protrusion Tool bolts		80 N·m (59 lbf·ft)

Special Service Tools

Table 39 Power Cylinders

Description	Tool Number
2–3 inch Micrometer	Obtain locally
3–4 inch Micrometer	Obtain locally
4–5 inch Micrometer	Obtain locally
Connecting Rod Bolt Torx Socket	ZTSE4843
Cylinder Liner Puller	ZTSE2536
Dial Bore Gauge	Obtain locally
Dial Indicator with Magnetic Base	Obtain locally
Feeler Gauge	Obtain locally
Piston Ring Compressor	Obtain locally
Piston Ring Expansion Pliers	Obtain locally
Sleeve Protrusion Hold Down Clamps	ZTSE4825
Telescoping Gauge Set	Obtain locally

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Exploded View

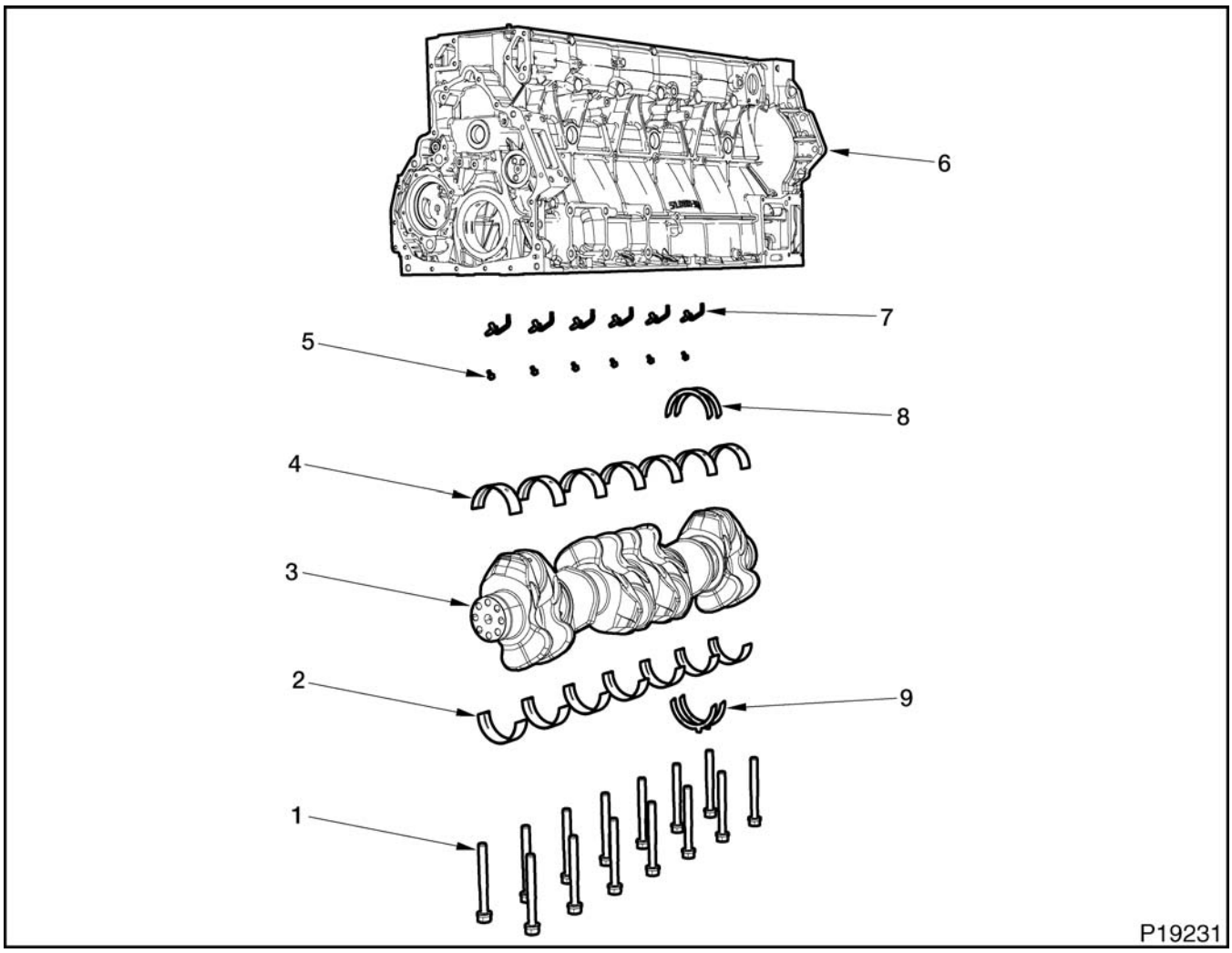

Figure 702 Crankcase and crankshaft

1. Hex collar bolt (14)
2. Lower main bearing (7)
3. Crankshaft
4. Upper main bearing (with oil hole) (7)
5. M6 x 12 hex bolt (6)
6. Crankcase
7. Oil sprayer nozzle (6)
8. Upper main bearing thrust washer (2)
9. Lower main bearing thrust washer (2)

Removal

WARNING: To prevent personal injury or death, read all safety instructions in the "Safety Information" section of this manual.

WARNING: To prevent personal injury or death, shift transmission to park or neutral, set parking brake, and block wheels before doing diagnostic or service procedures.

WARNING: To prevent personal injury or death, make sure the engine has cooled before removing components.

WARNING: To prevent personal injury or death, do not let engine fluids stay on your skin. Clean skin and nails using hand cleaner and wash with soap and water. Wash or discard clothing and rags contaminated with engine fluids.

GOVERNMENT REGULATION: Engine fluids (oil, fuel, and coolant) may be a threat to the environment. Recycle or dispose of engine fluids according to applicable regulations. Never put engine fluids in the trash, on the ground, in sewers or bodies of water.

NOTE: Refer to the following service sections for information on removal of components prior to this section.

- Engine Electrical
- Cold Start Assist
- Aftertreatment System
- Engine Braking System
- Turbochargers
- Air Compressor and Power Steering Pump
- Fuel System
- Oil Cooler and Filter Housing
- Exhaust Gas Recirculating (EGR) System
- Intercooler Elbow and Exhaust Manifolds
- Front Cover, High Mount Fan Drive, Cooling System, and Related Components
- Cylinder Head, Camshaft, and Valve Train
- Flywheel and Flywheel Housing
- Oil Pan and Oil Suction Tube
- Oil Pump, Low Mount Fan Drive, and Timing Gears
- Power Cylinders

Preliminary Checks

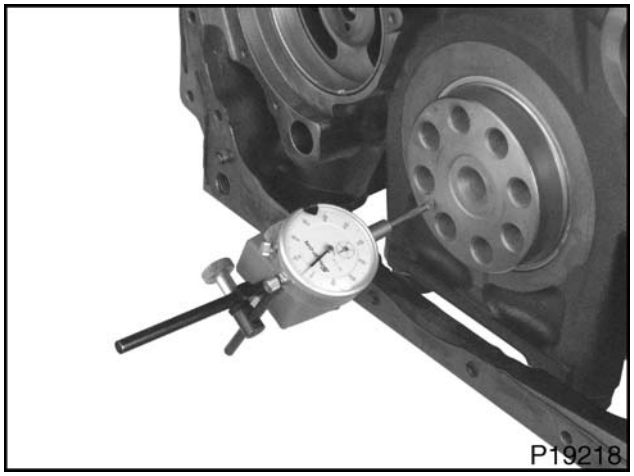

Figure 703 Crankshaft end play

1. Check crankshaft end play as follows:

a. Mount dial indicator with magnetic base (page 429) on crankcase with indicator tip on end of crankshaft as shown.

b. Move crankshaft forward with pry bar and zero the dial indicator.

c. Move crankshaft back and forth while reading dial indicator. Compare dial indicator reading with specifications (page 429).

d. If end play exceeds specified limits, replace main bearing thrust washers.

Crankshaft

1. Position engine so that bottom of main bearing caps are facing upwards.

CAUTION: To prevent engine damage, use permanent markers to identify internal components or their orientation. Do not use paint or temporary markers.

2. Mark main bearing caps for location and orientation.

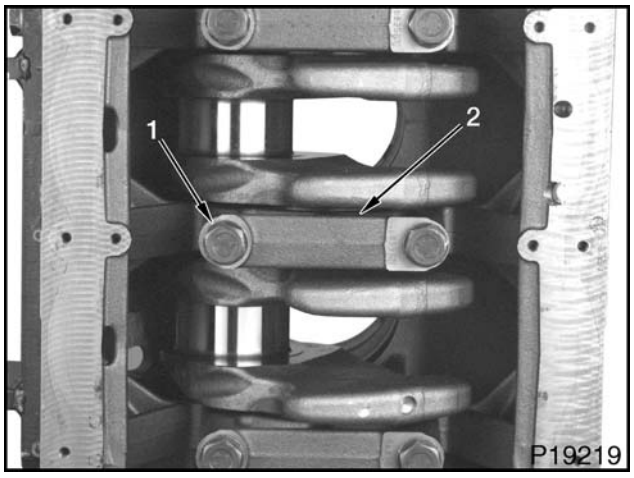

Figure 704 Main bearing caps

1. Hex collar bolt (14)
2. Main bearing cap (7)

CAUTION: To prevent engine damage, do not drop main bearing caps. Damage to the fractured mating surface of a main bearing cap will require replacement of the crankcase and mated main bearing caps.

3. Remove 14 hex collar bolts and seven main bearing caps. Save bolts for Main Bearing Inspection Procedure (page 424).

4. Remove lower main bearings and lower main bearing thrust washers from main bearing caps by pushing out.

CAUTION: To prevent engine damage, use permanent markers to identify internal components or their orientation. Do not use paint or temporary markers.

5. Number removed lower main bearings and lower main bearing thrust washers and set aside for inspection.

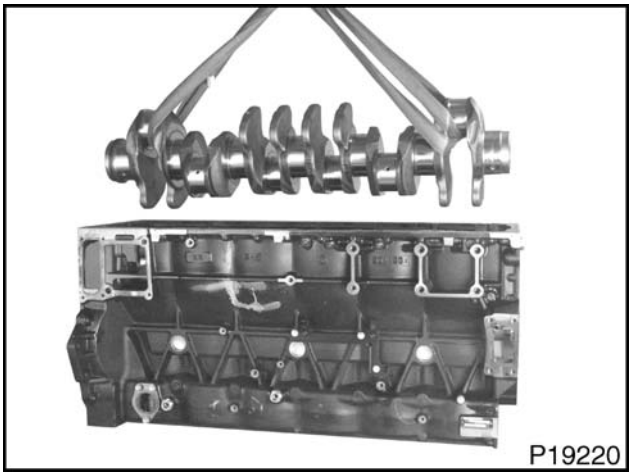

Figure 705 Crankshaft removal

WARNING: To prevent personal injury or death, use a correct size lifting sling and hoist with a safety latch on hook.

CAUTION: To prevent engine damage, do not bend, drop or mar crankshaft.

NOTE: Use only a soft-sided lifting sling. Do not use chains or steel cables.

6. Attach lifting sling (page 429) to crankshaft. Lift crankshaft up and out of crankcase and set aside for inspection.

7. Remove upper main bearings and upper main bearing thrust washers from crankcase by pushing out.

CAUTION: To prevent engine damage, use permanent markers to identify internal components or their orientation. Do not use paint or temporary markers.

8. Number removed upper main bearings and upper main bearing thrust washers to match the previously removed lower main bearings and lower main bearing thrust washers and set aside for inspection.

Oil Sprayer Nozzles

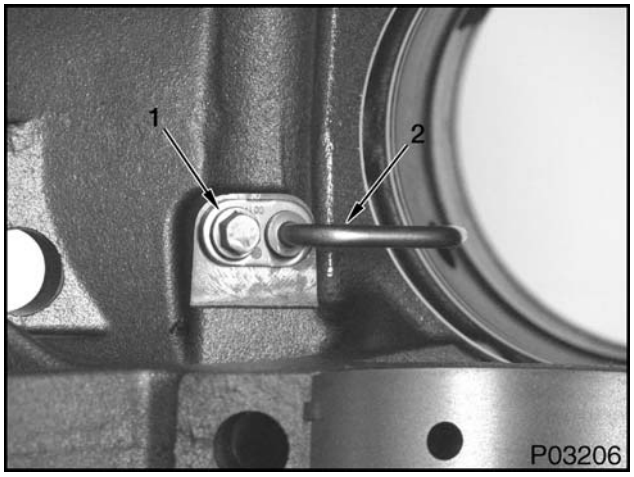

Figure 706 Oil sprayer nozzle

1. M6 x 12 hex bolt (6)
2. Oil sprayer nozzle (6)

Remove six M6 x 12 hex bolts and six oil sprayer nozzles.

Cleaning, Inspection, and Testing

Crankcase

CAUTION: To prevent engine damage, do not use chlorinated solvents on bolts or crankcase tapped holes. Parts should be clean, dry, and free of any chemicals other than engine oil.

NOTE: Thoroughly clean and inspect crankcase before and after reconditioning.

1. Clean crankcase in a chemical bath or hot tank. This removes all carbonized material and mineral deposits in coolant passages.

WARNING: To prevent personal injury or death, wear safety glasses with side shields. Limit compressed air pressure to 207 kPa (30 psi).

CAUTION: To prevent engine damage, do not use solvents or a wire brush to clean the fractured mating surface of crankcase and main bearing caps.

2. If a hot tank is not available, do the following steps:
   a. Use non-metallic stiff bristle brushes and scrapers to clean gasket material from machined surfaces of crankcase.
   b. Clean crankcase in solvent.
   c. Dry with filtered compressed air.

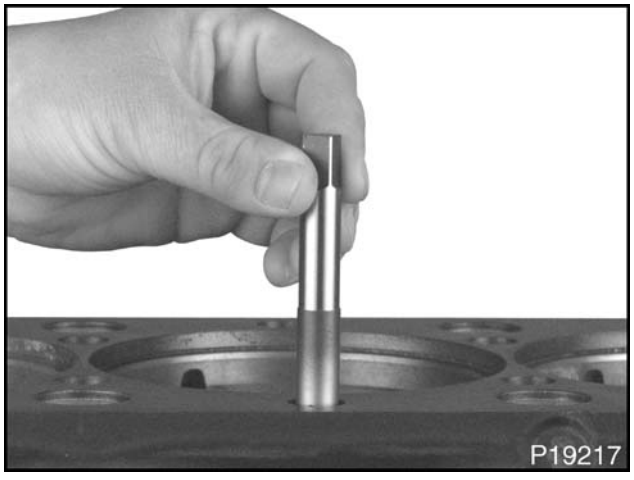

Figure 707 Cylinder head bolt holes

CAUTION: To prevent engine damage, clean and dry threads in the crankcase bolt holes with filtered compressed air. Dirt or oil in holes may cause binding and incorrect torque readings.

3. Clean cylinder head bolt holes with Head Bolt Bottoming Tap ZTSE4855 (page 429).
4. Clean hex collar bolt holes with Main Bolt Bottoming Tap ZTSE4854 (page 429).

WARNING: To prevent personal injury or death, wear safety glasses with side shields. Limit compressed air pressure to 207 kPa (30 psi).

5. Clean out debris with filtered compressed air.

Crankshaft

1. Clean and inspect crankshaft and main bearings.
2. Clean crankshaft with a suitable solvent.

WARNING: To prevent personal injury or death, wear safety glasses with side shields. Limit compressed air pressure to 207 kPa (30 psi).

3. Dry with filtered compressed air.
4. Use a stiff nylon brush to clean oil passages in crankshaft. Loosen accumulated dirt, sludge, and deposits.
5. Flush oil passages with a suitable solvent.
6. Inspect crankshaft journals (main and connecting rod) for scratches, grooves, and scoring.
7. Inspect main bearings for scratches, grooves, scoring, pitting, and inconsistent coloring.

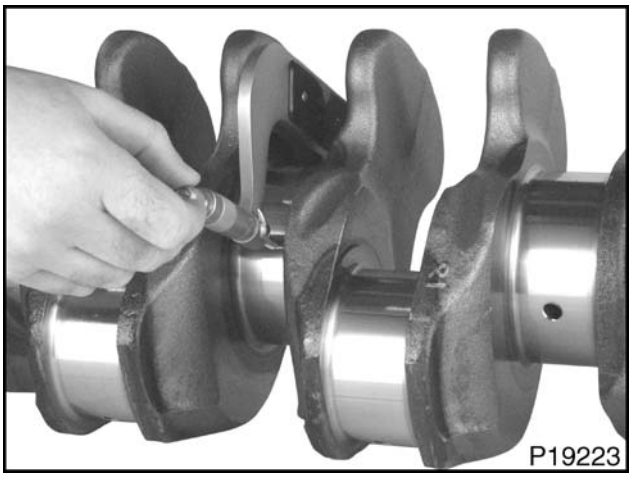

Figure 708 Measurement of crankshaft main bearing journal

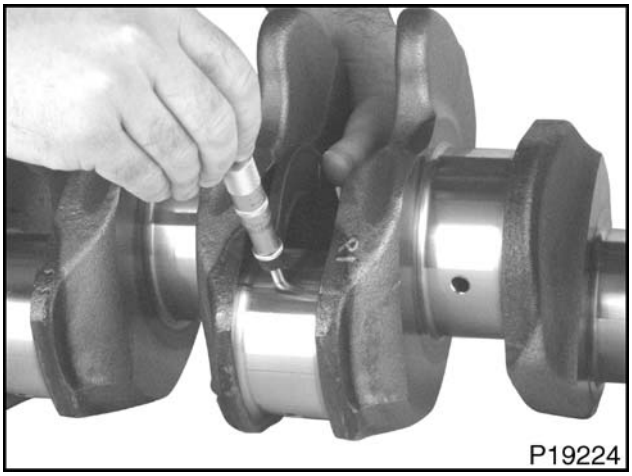

Figure 709 Measurement of crankshaft connecting rod bearing journal

CAUTION: To prevent engine damage, do not rework bearings or bearing caps to reduce journal-to-bearing running clearances. Grind or install new crankshaft.

8. Use a 3–4 inch micrometer (page 429) to measure diameter of each connecting rod journal, and a 4–5 inch micrometer (page 429) to measure diameter of each main journal. Measure each journal at both sides next to fillet radius at two directions 90° apart. Move micrometer over entire width of journal. If journal wear exceeds specification (page 429), have crankshaft machined or replace crankshaft.

Main Bearings

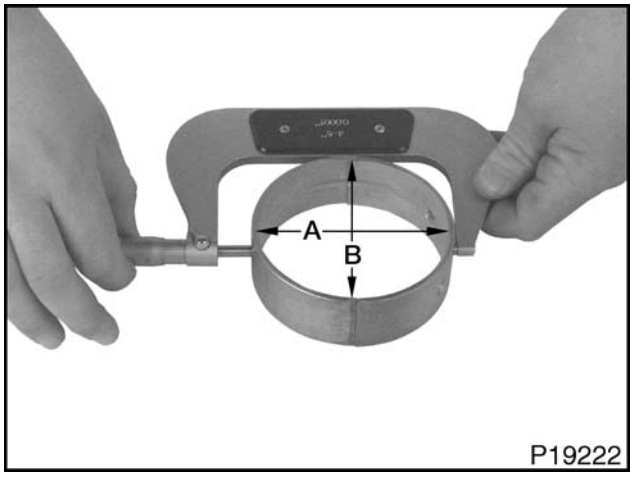

Figure 710 Main bearing free spread measurement

1. Inspect each main bearing. Replace scored, chipped or worn bearings.
2. Using a flat surface, place matching upper and lower main bearings together as shown.
3. Using a 4–5 inch micrometer (page 429), measure and note dimensions A and B as shown.
4. Calculate difference between dimensions A and B. If difference exceeds free spread specification (page 429), replace main bearings.
5. Install upper main bearings into crankcase and lower main bearings into main bearing caps in their original positions and orientation.

CAUTION: To prevent engine damage, install main bearing caps with their fractured mating surfaces in the original orientation.

6. With crankshaft still removed, install seven main bearing caps and 14 previously removed hex collar bolts. Do not use new bolts for this inspection procedure.
7. Tighten hex collar bolts as follows:
   a. Tighten No. 6 (thrust bearing) main bearing cap bolts to 10 N·m (88 lbf·in).
   b. Tighten remaining main bearing cap bolts to 10 N·m (88 lbf·in).
   c. Tighten No. 6 (thrust bearing) main bearing cap bolts to 100 N·m (74 lbf·ft).

d. Tighten remaining main bearing cap bolts to 100 N·m (74 lbf·ft).

e. Tighten No. 6 (thrust bearing) main bearing cap bolts to 300 N·m (221 lbf·ft).

f. Tighten remaining main bearing cap bolts to 300 N·m (221 lbf·ft).

g. Turn No. 6 (thrust bearing) main bearing cap bolts an additional 90°.

h. Turn remaining main bearing cap bolts an additional 90°.

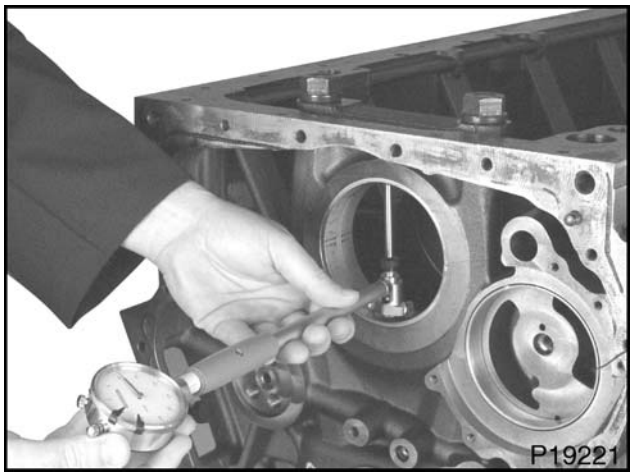

Figure 711 Main bearing installed diameter measurement

8. Using a dial bore gauge (page 429), measure main bearing installed inside diameter. If measurement does not meet specification (page 429), replace main bearings.

9. Remove 14 hex collar bolts, seven main bearing caps, upper main bearings, and lower main bearings. Discard used hex collar bolts.

Oil Sprayer Nozzles

1. Hold each oil sprayer nozzle under running water. Water should stream from nozzle end.

⚠ WARNING: To prevent personal injury or death, wear safety glasses with side shields. Limit compressed air pressure to 207 kPa (30 psi).

2. Clear blocked oil sprayer nozzles using filtered compressed air. Replace oil sprayer nozzle if blockage cannot be cleared.

3. Replace any cracked or bent nozzles.

Installation

Oil Sprayer Nozzles

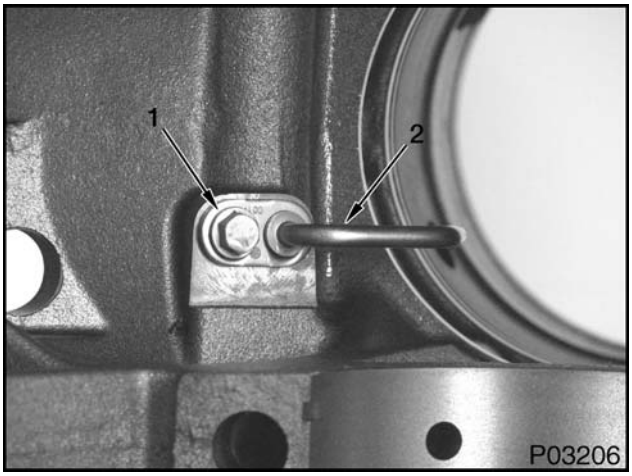

Figure 712 Oil sprayer nozzle

1. M6 x 12 hex bolt (6)
2. Oil sprayer nozzle (6)

1. Install six oil sprayer nozzles and six M6 x 12 hex bolts.
2. Tighten hex bolts to special torque (page 429).

Crankshaft

NOTE: Make sure crankshaft and bearings have been inspected per instructions in this section before proceeding.

1. Use a lint-free cloth to wipe crankcase bearing saddles free of oil.

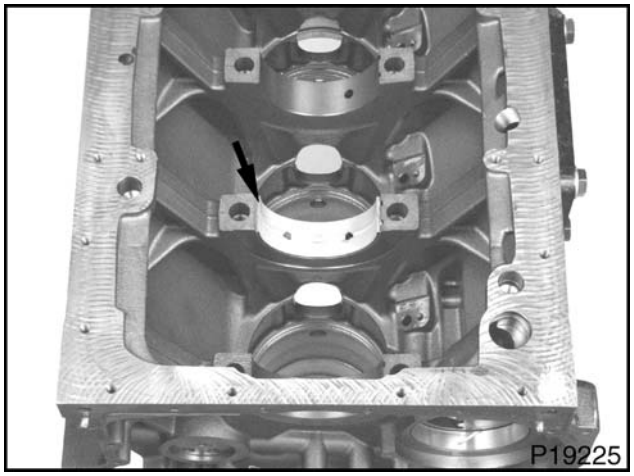

Figure 713 Main bearing (above) installation

NOTE: When inserting main bearings, make sure oil is not between back side of bearing and crankcase bearing saddles.

2. Place upper main bearings in crankcase. Make sure locking tabs on bearings are snapped into saddle, and oil holes in bearings line up with oil holes in crankcase.
3. Lubricate bearings with clean engine oil.

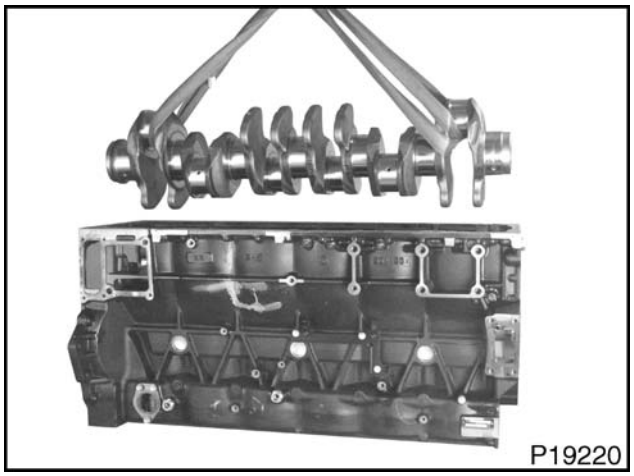

Figure 714 Crankshaft installation

⚠ WARNING: To prevent personal injury or death, use a correct size lifting sling and hoist with a safety latch on hook.

CAUTION: To prevent engine damage, do not bend, drop or mar crankshaft.

NOTE: Use only a soft-sided lifting sling. Do not use chains or steel cables.

4. Attach lifting sling (page 429) to crankshaft. Lower crankshaft down into crankcase.

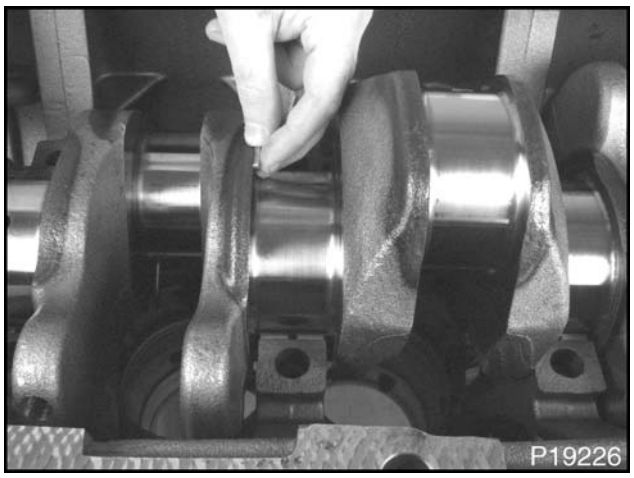

Figure 715 Thrust washer installation

NOTE: Make sure oil grooves on thrust washers face outward towards crankshaft thrust surface.

5. Install two upper main bearing thrust washers into crankcase at No. 6 main location as follows:
   a. Set upper main bearing thrust washer on top of crankshaft at No. 6 main journal.
   b. Allow upper main bearing thrust washer to pivot around crankshaft and down into position.
6. Install two lower main bearing thrust washers onto #6 main bearing cap. Make sure washer locking tabs align with notches in main bearing cap.
7. Place lower main bearings in main bearing caps. Make sure locking tabs on bearings are snapped into main bearing caps.
8. Lubricate bearings with clean engine oil.

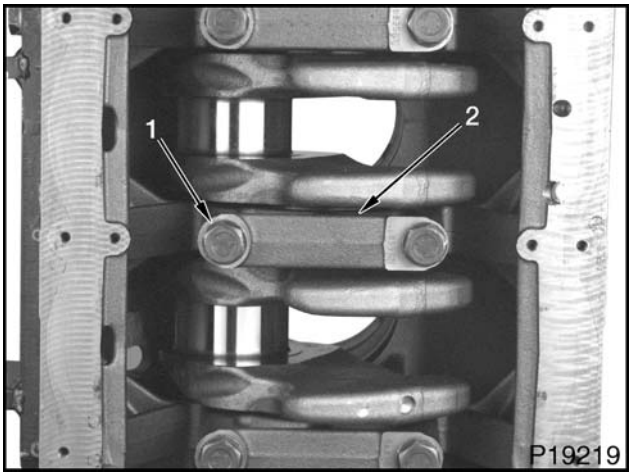

Figure 716 Main bearing caps

1. Hex collar bolt (14)
2. Main bearing cap (7)

CAUTION: To prevent engine damage, install main bearing caps with their fractured mating surfaces in the original orientation.

CAUTION: To prevent engine damage, do not drop main bearing caps. Damage to the fractured mating surface of a main bearing cap will require replacement of the crankcase and mated main bearing caps.

9. Install seven main bearing caps and 14 new hex collar bolts.

NOTE: Rotate crankshaft after completion of each main bearing cap torque procedure to verify crankshaft does not bind. Correct as required.

10. Tighten hex collar bolts as follows:
    a. Tighten No. 6 (thrust bearing) main bearing cap bolts to 10 N·m (88 lbf·in).
    b. Tighten remaining main bearing cap bolts to 10 N·m (88 lbf·in).
    c. Tighten No. 6 (thrust bearing) main bearing cap bolts to 100 N·m (74 lbf·ft).
    d. Tighten remaining main bearing cap bolts to 100 N·m (74 lbf·ft).
    e. Tighten No. 6 (thrust bearing) main bearing cap bolts to 300 N·m (221 lbf·ft).
    f. Tighten remaining main bearing cap bolts to 300 N·m (221 lbf·ft).

g. Turn No. 6 (thrust bearing) main bearing cap bolts an additional 90°.

h. Turn remaining main bearing cap bolts an additional 90°.

Specifications

Table 40 Crankcase and Crankshaft

Crankshaft	
Main Bearing:	
Journal diameter	103.98 - 104.00 mm (4.0937 - 4.0945 in)
Installed inside diameter	104.06 - 104.106 mm (4.0969 - 4.0987 in)
Free spread	0.20 - 1.40 mm (0.0079 - 0.0551 in)
Connecting Rod Bearing:	
Journal diameter	89.98 - 90.00 mm (3.5425 - 3.5433 in)
Crankshaft end play:	
Maximum service	0.200 - 0.401 mm (0.0079 - 0.0158 in)

Special Torque

Table 41 Crankcase and Crankshaft

Main bearing cap hex collar bolts	See tightening procedure and sequence (page 427)
Oil sprayer nozzle hex bolts	13 N·m (115 lbf·in)

Special Service Tools

Table 42 Crankcase and Crankshaft

Description	Tool Number
3–4 inch Micrometer	Obtain locally
4–5 inch Micrometer	Obtain locally
Dial Bore Gauge	Obtain locally
Dial Indicator with Magnetic Base	Obtain locally
Head Bolt Bottoming Tap	ZTSE4855
Lifting Sling	Obtain locally
Main Bolt Bottoming Tap	ZTSE4854

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Abbreviations and Acronyms

Abbreviations and Acronyms

A or amp – Ampere
ABDC – After Bottom Dead Center
ABS – Antilock Brake System
AC – Alternating Current
A/C – Air Conditioner
ACC – Air Conditioner Control
ACCEL – Accelerator
ACD – Air Conditioner Demand
ACM – Aftertreatment Control Module
ACT PWR GND – Actuator Power Ground
A/F – Air to Fuel ratio
AFD – Aftertreatment Fuel Drain
AFI – Aftertreatment Fuel Injector
AFP – Aftertreatment Fuel Pressure
AFS – Aftertreatment Fuel Supply
AFT – Aftertreatment
AIT – Air Intake Temperature
Amb – Ambient
amp or A – Ampere
AMS – Air Management System
API – American Petroleum Institute
APS – Accelerator Position Sensor
APS/IVS – Accelerator Position Sensor / Idle Validation Switch
ASTM – American Society for Testing and Materials
ATA – American Trucking Association
ATDC – After Top Dead Center
AWG – American Wire Gauge

B+ or VBAT – Battery Voltage
BAP or BARO – Barometric Absolute Pressure
BARO or BAP – Barometric Absolute Pressure
BBDC – Before Bottom Dead Center
BCP – Brake Control Pressure
BCS – Boost Control Solenoid
BDC – Bottom Dead Center
bhp – Brake Horsepower
BNO – Brake Normally Open
BOO – Brake On / Off
BPS – Brake Pressure Switch
BSV – Brake Shut-off Valve
BTDC – Before Top Dead Center
BTU – British Thermal Unit

C – Celsius
CAC – Charge Air Cooler
CAN – Controller Area Network
CAP – Cold Ambient Protection
CARB – California Air Resources Board
cc – Cubic centimeter
CCA – Cold Cranking Ampere
CCV – Coolant Control Valve
CDR – Crankcase Depression Regulator
CID – Cubic Inch Displacement
cfm – Cubic feet per minute
cfs – Cubic feet per second
CFV – Coolant Flow Valve
CKP – Crankshaft Position
CKPO – Crankshaft Position Out
cm – Centimeter
CMP – Camshaft Position
CMPO – Camshaft Position Out
CMV – Coolant Mixer Valve
CO – Carbon Monoxide
COO – Cruise On / Off switch
CPU – Central Processing Unit
CSS – Cold Start Solenoid
CSR – Cold Start Relay
CTC – Coolant Temperature Compensation
Cyl – Cylinder

DB – Decibel
DCA – Diesel Coolant Additive
DDI – Digital Direct Fuel Injection
DDS – Driveline Disengagement Switch
DLC – Data Link Connector
DME – Dimethyl Ether
DMM – Digital Multimeter
DOC – Diesel Oxidation Catalyst
DPF – Diesel Particulate Filter
DT – Diesel Turbocharged
DTC – Diagnostic Trouble Code
DTRM – Diesel Thermo Recirculation Module

EBC – Exhaust Brake Controller
EBP – Exhaust Back Pressure
EBPD – Exhaust Back Pressure Desired
ECI – Engine Crank inhibit
ECL – Engine Coolant Level
ECM – Engine Control Module
ECM PWR – Engine Control Module Power
ECT – Engine Coolant Temperature
ECT2 – Engine Coolant Temperature 2
EFAN – Electronic Engine Fan
EFANS – Electronic Engine Fan Speed
EFP – Engine Fuel Pressure
EFRC – Engine Family Rating Code
EFT – Engine Fuel Temperature
EG – Ethylene Glycol
EGC – Electronic Gauge Cluster
EGDP – Exhaust Gas Differential Pressure

EGR – Exhaust Gas Recirculation
EGRH – Exhaust Gas Recirculation High control
EGRL – Exhaust Gas Recirculation Low control
EGRP – Exhaust Gas Recirculation Position
EGT1 – Exhaust Gas Temperature 1
EGT2 – Exhaust Gas Temperature 2
EGT3 – Exhaust Gas Temperature 3
EIM – Engine Interface Module
ELS – Exhaust Lambda Sensor
EMI – Electromagnetic Interference
EOP – Engine Oil Pressure
EOT – Engine Oil Temperature
EPA – Environmental Protection Agency
EPR – Engine Pressure Regulator
ESC – Electronic System Controller
ESN – Engine Serial Number
EST – Electronic Service Tool
EVB – Exhaust Valve Brake
EWPS – Engine Warning Protection System

F – Fahrenheit
FCV – Fuel Coolant Valve
FEL – Family Emissions Limit
fhp – Friction horsepower
FMI – Failure Mode Indicator
FPC – Fuel Pump Control
FPCV – Fuel Pressure Control Valve
fpm – Feet per minute
fps – Feet per second
FRP – Fuel Rail Pressure
ft – Foot
FVCV – Fuel Volume Control Valve

GND – Ground (electrical)
gal – Gallon
gal/h – U.S. Gallons per hour
gal/min – U. S. Gallons per minute
GCW – Gross Combined Weight
GCWR – Gross Combined Weight Rating
GPC – Glow Plug Control
GPD – Glow Plug Diagnostic
GPR – Glow Plug Relay
GVW – Gross Vehicle Weight

H_2O – Water
HC – Hydrocarbon
HCI – Hydrocarbon Injection
HFCM – Horizontal Fuel Conditioning Module
Hg – Mercury
hp – Horsepower
HPCAC – High Pressure Charge Air Cooler
hr – Hour
Hyd – Hydraulic

IAT – Intake Air Temperature
IAHC – Inlet Air Heater Control
IAHD – Inlet Air Heater Diagnostic
IAHR – Inlet Air heater Relay
IC – Integrated Circuit
ICP – Injector Control Pressure
ID – Inside Diameter
IDM – Injector Drive Module
IGN – Ignition
ILO – Injector Leak Off
in – Inch
inHg – Inch of mercury
inH_2O – Inch of water
INJ – Injector
IPR – Injection Pressure Regulator
ISIS® – International® Service Information System
IST – Idle Shutdown Timer
ITP – Internal Transfer Pump
ITV – Intake Throttle Valve
ITVH – Intake Throttle Valve High control
ITVL – Intake Throttle Valve Low control
ITVP – Intake Throttle Valve Position
IVS – Idle Validation Switch

JCT – Junction (electrical)

kg – Kilogram
km – Kilometer
km/h – Kilometers per hour
km/l – Kilometers per liter
KOEO – Key-On Engine-Off
KOER – Key-On Engine-Running
kPa – Kilopascal

L – Liter
L/h – Liters per hour
L/m – Liters per minute
L/s – Liters per second
lb – Pound
lbf – Pound-force
lb/s – Pounds per second
lbf·ft – Pound-force foot
lbf·in – Pound-force inch
lbm – Pounds of mass
LPCAC – Low Pressure Charge Air Cooler
LSD – Low Sulfur Diesel

m – Meter
m/s – Meters per second
MAF – Mass Air Flow
MAG – Magnetic
MAP – Manifold Absolute Pressure

MAP/IAT – Manifold Absolute Pressure/Intake Air Temperature Sensor
MAT – Manifold Air Temperature
mep – Mean effective pressure
mi – Mile
mm – Millimeter
mpg – Miles per gallon
mph – Miles per hour
MPR – Main Power Relay
MSDS – Material Safety Data Sheet
MSG – Micro Strain Gauge
MSM – Multiplex System Module
MY – Model Year

NC – Normally closed (electrical)
NETS – Navistar Electronics Technical Support
Nm – Newton meter
NO – Normally Open (electrical)
NO_x – Nitrogen Oxides

OAT – Organic Acid Technology
OCC – Output Circuit Check
OCP – Overcrank Protection
OD – Outside Diameter
OL – Over Limit
ORH – Out-of-Range High
ORL – Out-of-Range Low
OSHA – Occupational Safety and Health Administration
OWL – Oil/Water Lamp

PID – Parameter Identifier
PN – Part Number
ppm – Parts per million
PROM – Programmable Read Only Memory
psi – Pounds per square inch
psia – Pounds per square inch absolute
psig – Pounds per square inch gauge
pt – Pint
PTO – Power Take-off
PWM – Pulse Width Modulate
PWR – Power (voltage)

qt – Quart

RAM – Random Access Memory
RAS – Resume / Accel Switch (speed control)
REPTO – Rear Engine Power Takeoff
RFI – Radio Frequency Interference
rev – Revolution
rpm – Revolutions per minute
RPRE – Remote Preset
RSE – Radiator Shutter Enable
RVAR – Remote Variable

SAE – Society of Automotive Engineers®
SCA – Supplemental Coolant Additive
SCCS – Speed Control Command Switches
SCS – Speed Control Switch
SHD – Shield (electrical)
SID – Subsystem Identifier
SIG GRD – Signal Ground
S/N – Serial Number
SW – Switch (electrical)
SYNC – Synchronizer

TACH – Tachometer output signal
TBD – To Be Determined
TCAPE – Truck Computer Analysis of Performance and Economy
TDC – Top Dead Center
TCM – Transmission Control Module
TTS – Transmission Tailshaft Speed

ULSD – Ultra Low Sulfur Diesel
UVC – Under Valve Cover

V – Volt
VBAT or B+ – Battery Voltage
VC – Volume Control
VEPS – Vehicle Electronics Programming System
VGT – Variable Geometry Turbocharger
VIGN – Ignition Voltage
VIN – Vehicle Identification Number
VOP – Valve Opening Pressure
VRE – Vehicle Retarder Enable
VREF – Reference Voltage
VSO or VSS_CAL – Vehicle Speed Output
VSS – Vehicle Speed Sensor
VSS_CAL or VSO – Vehicle Speed Output

WEL – Warn Engine Lamp
WIF – Water In Fuel
WTEC – World Transmission Electronically Controlled automatic transmissions (Allison)

XMNS – Transmission

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Terminology

Terms

Accessory work – The work per cycle required to drive engine accessories (normally, only those essential to engine operation).

Actuator – A device that performs work in response to an input signal.

Aeration – The entrainment of air or combustion gas in coolant, lubricant, or fuel.

Aftercooler (Charge Air Cooler) – A heat exchanger mounted in the charge air path between the turbocharger and engine intake manifold. The aftercooler reduces the charge air temperature by transferring heat from the charge air to a cooling medium (usually air).

Ambient temperature – The environmental air temperature in which a unit is operating. In general, the temperature is measured in the shade (no solar radiation) and represents the air temperature for other engine cooling performance measurement purposes. Air entering the radiator may or may not be the same ambient due to possible heating from other sources or recirculation. (SAE J1004 SEP81)

Ampere (amp) – The standard unit for measuring the strength of an electrical current. The flow rate of a charge in a conductor or conducting medium of one coulomb per second. (SAE J1213 NOV82)

Analog – A continuously variable voltage.

Analog to digital converter (A/D) – A circuit in the ECM processing section that converts an analog signal (DC or AC) to a usable digital signal for the microprocessor.

American Trucking Association (ATA) Datalink – A serial datalink specified by the American Trucking Association and the SAE.

Boost pressure – 1. The pressure of the charge air leaving the turbocharger.

2. Inlet manifold pressure that is greater than atmospheric pressure. Obtained by turbocharging.

Bottom Dead Center (BDC) – The lowest position of the piston during the stroke.

Brake Horsepower (bhp) – The power output from an engine, not the indicated horsepower. The power output of an engine, sometimes-called flywheel horsepower is less than the indicated horsepower by the amount of friction horsepower consumed in the engine.

Brake Horsepower (bhp) net – Net brake horsepower is measured with all engine components. The power of an engine when configured as a fully equipped engine. (SAE J1349 JUN90)

Calibration – The data values used by the strategy to solve equations and make decisions. Calibration values are stored in ROM and put into the processor during programming to allow the engine to operate within certain parameters.

Catalyst – A substance that produces a chemical reaction without undergoing a chemical change itself.

Catalytic converter – An antipollution device in the exhaust system that contains a catalyst for chemically converting some pollutants in the exhaust gases (carbon monoxide, unburned hydrocarbons, and oxides of nitrogen) into harmless compounds.

Cavitation – A dynamic condition in a fluid system that forms gas-filled bubbles (cavities) in the fluid.

Cetane number – 1. The auto-ignition quality of diesel fuel.

2. A rating applied to diesel fuel similar to octane rating for gasoline.

3. A measure of how readily diesel fuel starts to burn (self-ignites) at high compression temperature.

Diesel fuel with a high cetane number self-ignites shortly after injection into the combustion chamber. Therefore, it has a short ignition delay time. Diesel fuel with a low cetane number resists self-ignition. Therefore, it has a longer ignition delay time.

Charge air – Dense, pressurized, heated air discharged from the turbocharger.

Charge Air Cooler (CAC) – See **Aftercooler**.

Closed crankcase – A crankcase ventilation that recycles crankcase gases through a breather, then back to the clean air intake.

Closed loop operation – A system that uses a sensor to provide feedback to the ECM. The ECM uses the sensor to continuously monitor variables and adjust to match engine requirements.

Cloud point – The point when wax crystals occur in fuel, making fuel cloudy or hazy. Usually below -12 °C (10 °F).

Cold cranking ampere rating (battery rating) – The sustained constant current (in amperes) needed to produce a minimum terminal voltage under a load of 7.2 volts per battery after 30 seconds.

Continuous Monitor Test – An ECM function that continuously monitors the inputs and outputs to ensure that readings are within set limits.

Coolant – A fluid used to transport heat from one point to another.

Coolant level switch – A switch sensor used to indicate low coolant level.

Crankcase – The housing that encloses the crankshaft, connecting rods, and allied parts.

Crankcase breather – A vent for the crankcase to release excess interior air pressure.

Crankcase pressure – The force of air inside the crankcase against the crankcase housing.

Current – The flow of electrons passing through a conductor. Measured in amperes.

Damper – A device that reduces the amplitude of torsional vibration. (SAE J1479 JAN85)

Deaeration – The removal or purging of gases (air or combustion gas) entrained in coolant or lubricating oil.

Deaeration tank – A separate tank in the cooling system used for one or more of the following functions:

- Deaeration
- Coolant reservoir (fluid expansion and afterboil)
- Coolant retention
- Filling
- Fluid level indication (visible)

Diagnostic Trouble Code (DTC) – Formerly called a Fault Code or Flash Code. A DTC is a three digit numeric code used for troubleshooting.

Digital Multimeter (DMM) – An electronic meter that uses a digital display to indicate a measured value. Preferred for use on microprocessor systems because it has a very high internal impedance and will not load down the circuit being measured.

Disable – A computer decision that deactivates a system and prevents operation of the system.

Displacement – The stroke of the piston multiplied by the area of the cylinder bore multiplied by the number of cylinders in the engine.

Driver (high side) – A transistor within an electronic module that controls the power to an actuator circuit.

Driver (low side) – A transistor within an electronic module that controls the ground to an actuator circuit.

Duty cycle – A control signal that has a controlled on/off time measurement from 0 to 100%. Normally used to control solenoids.

Engine lamp – An instrument panel lamp that comes on when DTCs are set. DTCs can be read as flash codes (red and amber instrument panel lamps).

Engine OFF tests – Tests that are done with the ignition switch ON and the engine OFF.

Engine rating – Engine rating includes **Rated hp** and **Rated rpm**.

Engine RUNNING tests – Tests done with the engine running.

Exhaust brake – A brake device using engine exhaust back pressure as a retarding medium.

Exhaust manifold – Exhaust gases flow through the exhaust manifold to the turbocharger exhaust inlet and are directed to the EGR cooler.

Fault detection/management – An alternate control strategy that reduces adverse effects that can be caused by a system failure. If a sensor fails, the ECM substitutes a good sensor signal or assumed sensor value in its place. A lit amber instrument panel lamp signals that the vehicle needs service.

Filter restriction – A blockage, usually from contaminants, that prevents the flow of fluid through a filter.

Flash code – See **Diagnostic Trouble Code (DTC)**.

Fuel inlet restriction – A blockage, usually from contaminants, that prevents the flow of fluid through the fuel inlet line.

Fuel pressure – The force that the fuel exerts on the fuel system as it is pumped through the fuel system.

Fuel strainer – A pre-filter in the fuel system that keeps larger contaminants from entering the fuel system.

Fully equipped engine – A fully equipped engine is an engine equipped with only those accessories necessary to perform its intended service. A fully equipped engine does not include components that are used to power auxiliary systems. If these components are integral with the engine or for any reason are included on the test engine, the power absorbed may be determined and added to the net brake power. (SAE J1995 JUN90)

Fusible link (fuse link) – A fusible link is a special section of low tension cable designed to open the circuit when subjected to an extreme current overload. (SAE J1156 APR86)

Gradeability – The maximum percent grade which the vehicle can transverse for a specified time at a specified speed. The gradeability limit is the grade upon which the vehicle can just move forward. (SAE J227a)

Gross Combined Weight Rating (GCWR) – Maximum combined weight of towing vehicle (including passengers and cargo) and the trailer. The GCWR indicates the maximum loaded weight that the vehicle is allowed to tow.

Gross brake horsepower – The power of a complete basic engine, with air cleaner, without fan, and alternator and air compressor not charging.

Hall effect – The development of a transverse electric potential gradient in a current-carrying conductor or semiconductor when a magnetic field is applied.

Hall effect sensor – Generates a digital on/off signal that indicates speed and timing.

High speed digital inputs – Inputs to the ECM from a sensor that generates varying frequencies (engine speed and vehicle speed sensors).

Horsepower (hp) – Horsepower is the unit of work done in a given period of time, equal to 33,000 pounds multiplied by one foot per minute. **1hp = 33,000 lb x 1 ft /1 min**.

Hydrocarbons – Unburned or partially burned fuel molecules.

Idle speed –

- Low idle is minimum rpm at no load.
- High idle is maximum rpm at no load.

Intake manifold – A collection of tubes through which the fuel-air mixture flows from the fuel injector to the intake valves of the cylinders.

International NGV Tool Utilized for Next Generation Electronics (INTUNE) – The diagnostics software for chassis related components and systems.

Low speed digital inputs – Switched sensor inputs that generate an on/off (high/low) signal to the ECM. The input to the ECM from the sensor could be from a high input source switch (usually 5 or 12 volts) or from a grounding switch that grounds the signal from a current limiting resistor in the ECM that creates a low signal (0 volts).

Lubricity – Lubricity is the ability of a substance to reduce friction between solid surfaces in relative motion under loaded conditions.

Lug (engine) – A condition when the engine is operating at or below maximum torque speed.

Manometer – A double-leg liquid-column gauge, or a single inclined gauge, used to measure the difference between two fluid pressures. Typically, a manometer records in inches of water.

MasterDiagnostics® (MD) – The diagnostics software for engine related components and systems.

Microprocessor – An integrated circuit in a microcomputer that controls information flow.

Nitrogen Oxides (NO_x) – Nitrogen oxides form by a reaction between nitrogen and oxygen at high temperatures and pressures in the combustion chamber.

Normally closed – Refers to a switch that remains closed when no control force is acting on it.

Normally open – Refers to a switch that remains open when no control force is acting on it.

Ohm (Ω) – The unit of resistance. One ohm is the value of resistance through which a potential of one volt will maintain a current of one ampere. (SAE J1213 NOV82)

On demand test – A self test that the technician initiates using the EST and is run from a program in the processor.

Output Circuit Check (OCC) – An On demand test done during an Engine OFF self test to check the continuity of selected actuators.

pH – A measure of the acidity or alkalinity of a solution.

Particulate matter – Particulate matter includes mostly burned particles of fuel and engine oil.

Piezometer – An instrument for measuring fluid pressure.

Power – Power is a measure of the rate at which work is done. Compare with **Torque**.

Power TakeOff (PTO) – Accessory output, usually from the transmission, used to power a hydraulic pump for a special auxiliary feature (garbage packing, lift equipment, etc).

Pulse Width Modulate (PWM) – The time that an actuator, such as an injector, remains energized.

Random Access Memory (RAM) – Computer memory that stores information. Information can be written to and read from RAM. Input information (current engine speed or temperature) can be stored in RAM to be compared to values stored in Read Only Memory (ROM). All memory in RAM is lost when the ignition switch is turned off.

Rated gross horsepower – Engine gross horsepower at rated speed as declared by the manufacturer. (SAE J1995 JUN90)

Rated horsepower – Maximum brake horsepower output of an engine as certified by the engine manufacturer. The power of an engine when configured as a basic engine. (SAE J1995 JUN90)

Rated net horsepower – Engine net horsepower at rated speed as declared by the manufacturer. (SAE J1349 JUN90)

Rated speed – The speed, as determined by the manufacturer, at which the engine is rated. (SAE J1995 JUN90)

Rated torque – Maximum torque produced by an engine as certified by the manufacturer.

Ratiometric Voltage – In a Micro Strain Gauge (MSG) sensor pressure to be measured exerts force on a pressure vessel that stretches and compresses to change resistance of strain gauges bonded to the surface of the pressure vessel. Internal sensor electronics convert the changes in resistance to a ratiometric voltage output.

Reference voltage (V_{REF}) – A 5 volt reference supplied by the ECM to operate the engine sensors.

Reserve capacity – Time in minutes that a fully charged battery can be discharged to 10.5 volts at 25 amperes.

Signal ground – The common ground wire to the ECM for the sensors.

Speed Control Command Switches (SCCS) – A set of switches used for cruise control, Power TakeOff (PTO), and remote hand throttle system.

Steady state condition – An engine operating at a constant speed and load and at stabilized temperatures and pressures. (SAE J215 JAN80)

Strategy – A plan or set of operating instructions that the microprocessor follows for a desired goal. Strategy is the computer program itself, including all equations and decision making logic. Strategy is always stored in ROM and cannot be changed during calibration.

Stroke – Stroke is the movement of the piston from Top Dead Center (TDC) to Bottom Dead Center (BDC).

Substrate – Material that supports the washcoating or catalytic materials.

System restriction (air) – The static pressure differential that occurs at a given air flow from air entrance through air exit in a system. Usually measured in inches (millimeters) of water. (SAE J1004 SEP81)

Tachometer output signal – Engine speed signal for remote tachometers.

Thermistor – A semiconductor device. A sensing element that changes resistance as the temperature changes.

Thrust load – A thrust load pushes or reacts through a bearing in a direction parallel to the shaft.

Top Dead Center (TDC) – The uppermost position of the piston during the stroke.

Torque – A force having a twisting or turning effect. For a single force, the cross product of a vector from some reference point to the point of application of the force within the force itself. Also known as moment of force or rotation moment. Torque is a measure of the ability of an engine to do work.

Truck Computer Analysis of Performance and Economy (TCAPE) – Truck Computer Analysis of Performance and Economy is a computer program that simulates the performance and fuel economy of trucks.

Turbocharger – A turbine driven compressor mounted to the exhaust manifold. The turbocharger increases the pressure, temperature and density of intake air to charge air.

Variable capacitance sensor – A variable capacitance sensor measures pressure. The pressure forces a ceramic material closer to a thin metal disc in the sensor, changing the capacitance of the sensor.

Vehicle Electronic System Programming System – The computer system used to program electronically controlled vehicles.

Vehicle Retarder Enable/Engage – Output from the ECM to a vehicle retarder.

Vehicle Speed Sensor (VSS) – Normally a magnetic pickup sensor mounted in the tailshaft housing of the transmission, used to indicate ground speed.

Viscosity – The internal resistance to the flow of any fluid.

Viscous fan – A fan drive that is activated when a thermostat, sensing high air temperature, forces fluid through a special coupling. The fluid activates the fan.

Volt (v) – A unit of electromotive force that will move a current of one ampere through a resistance of one Ohm.

Voltage – Electrical potential expressed in volts.

Voltage drop – Reduction in applied voltage from the current flowing through a circuit or portion of the circuit current multiplied by resistance.

Voltage ignition – Voltage supplied by the ignition switch when the key is ON.

Washcoat – A layer of alumina applied to the substrate in a monolith-type converter.

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Fuel System

Table 43 Fuel System

Fuel strainer filtration	300 microns
Fuel filter element filtration	3-5 microns

Air Inlet Duct and Exhaust Manifolds

Table 44 Exhaust Manifolds

Exhaust manifold maximum allowable warpage	0.1 mm (0.003 in)

Cylinder Head, Camshaft and Valve Train

Table 45 Cylinder Head, Camshaft and Valve Train

Camshaft	
Camshaft end play	0.25 – 0.85 mm (0.0098 – 0.0334 in)
Camshaft bearing inside diameter	39.925 – 39.950 mm (1.57185 – 1.57283 in)
Valve Lash Adjustment	
Intake valve clearance	0.5 mm (0.0196 in)
Exhaust valve clearance	0.8 mm (0.0314 in)
Counterpiece clearance	0.6 mm (0.0236 in)
Cylinder Intermediate Gear Access Cover	
Cover recess	2.3 mm (0.9 in)

Flywheel and Flywheel Housing

Table 46 Flywheel and Flywheel Housing

Flywheel minimum thickness (dimension “A”)	46 mm (1.811 in)

Oil Pump, Low Mount Fan Drive, and Timing Gears

Table 47 Oil Pump, Low Mount Fan Drive, and Timing Gears

Front Timing Gears	
Front intermediate gear backlash	0.057 - 0.183 mm (0.0022 - 0.0072 in)
Oil Pump	
Oil pump pinion and oil pump ring gear end play	0.0030 - 0.090 mm (0.0012 - 0.0035 in)
Rear Timing Gears	
Big intermediate gear backlash	0.052 - 0.176 mm (0.0020 - 0.0069 in)
Crankcase intermediate gear backlash	0.052 - 0.176 mm (0.0020 - 0.0069 in)

Power Cylinders

Table 48 Power Cylinders

Connecting Rods	
Piston pin bore inside diameter	52.06 ± 0.005 mm (2.0496 ± 0.0001 in)
Connecting rod bearing bore diameter (crankshaft end)	95.000 to 95.022 mm (3.7402 to 3.7402 in)
Pistons — 11L	
Diameter measured 16 mm from piston bottom edge	119.88 ± 0.009 mm (4.7197 ± 0.0004 in)
Piston protrusion measured from crankcase deck to piston	0.3 ± 0.22 mm (0.0118 ± 0.009 in)
Piston pin bore inside diameter	52.010 - 52.016 mm (2.0476 - 2.0479 in)
Piston pin running clearance	0.010 - 0.024 mm (0.0004 - 0.0009 in)
Pistons — 13L	
Diameter measured 26.9 mm from piston bottom edge	125.950 ± 0.013 mm (4.9587 ± 0.0005 in)
Piston protrusion measured from crankcase deck to piston	0.3 ± 0.22 mm (0.0118 ± 0.009 in)
Piston pin bore inside diameter	52.04 - 52.05 mm (2.0490 - 2.0492 in)
Piston pin running clearance	0.040 - 0.058 mm (0.0016 - 0.0023 in)
Piston Pins	

Table 48 Power Cylinders (cont.)

Outside diameter	51.992 - 52.000 mm (2.0469 - 2.0472 in)
Piston Rings — 11L	
Keystone ring	
Ring gap	0.4 - 0.55 mm (0.0157 - 0.0217 in)
Taper face compression ring	
Ring gap	0.90 - 1.00 mm (0.0354 - 0.0393 in)
Side clearance	0.07 - 0.13 mm (0.0028 - 0.0051 in)
Bevelled oil scraper ring	
Ring gap	0.25 - 0.55 mm (0.0098 - 0.0217 in)
Side clearance	0.03 - 0.07 mm (0.0012 - 0.0028 in)
Piston Rings — 13L	
Keystone ring	
Ring gap	0.4 - 0.55 mm (0.0157 - 0.0217 in)
Taper face compression ring	
Ring gap	1.00 - 1.02 mm (0.0394 - 0.0402 in)
Side clearance	0.02 - 0.11 mm (0.0008 - 0.0043 in)
Bevelled oil scraper ring	
Ring gap	0.25 - 0.50 mm (0.0098 - 0.0197 in)
Side clearance	0.05 - 0.09 mm (0.0020 - 0.0035 in)
Liner dimensions — 11L	
Liner protrusion	0.050 - 0.085 mm (0.0019 - 0.0033 in)
Liner inside diameter	120 ± 0.01 mm (4.7244 ± 0.0004 in)
Liner dimensions — 13L	
Liner protrusion	0.050 - 0.085 mm (0.0019 - 0.0033 in)
Liner inside diameter	126 ± 0.01 mm (4.9606 ± 0.0004 in)

Crankcase and Crankshaft

Table 49 Crankcase and Crankshaft

Crankshaft	
Main Bearing:	
Journal diameter	103.98 - 104.00 mm (4.0937 - 4.0945 in)
Installed inside diameter	104.06 - 104.106 mm (4.0969 - 4.0987 in)
Free spread	0.20 - 1.40 mm (0.0079 - 0.0551 in)
Connecting Rod Bearing:	
Journal diameter	89.98 - 90.00 mm (3.5425 - 3.5433 in)
Crankshaft end play:	
Maximum service	0.200 - 0.401 mm (0.0079 - 0.0158 in)

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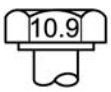
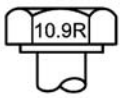
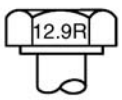
General Torque

Bolt Identification

INTERNATIONAL Class	ISO R 898 I	MATERIAL	THERMAL TREATMENT	HEAD MARKING Preferred	HEAD MARKING Optional
5.8	5.8	Low or medium Carbon steel	Non required		
8.8	8.8	Medium carbon, Medium carbon Alloy steel or low Carbon boron steel	Quench and tempered		
9.8	–	Medium carbon, Medium carbon Alloy steel or low Carbon boron steel	Quench and tempered		
10.9	10.9	Medium carbon, Medium carbon Alloy steel or low Carbon boron steel	Quench and tempered		

M03100

Figure 717 Metric fasteners – Classification and identification

INTERNATIONAL designation	MATERIAL	THERMAL TREATMENT	HEAD MARKING Preferred	HEAD MARKING Optional
CLASS		METRIC FASTENERS		
10.9R	Medium carbon, Medium carbon Alloy steel	Quench and tempered, Roll threaded after heat treatment		
12.9R	Medium carbon Alloy steel	Quench and tempered, Roll threaded after heat treatment		

M03101

Figure 718 Special fasteners – Classification and identification

General Torque Guidelines

CAUTION: To prevent engine damage, do not substitute fasteners. All original equipment fasteners are hardened and phosphate coated.

NOTE: Inspect parts for cleanliness and defects before assembly.

Many conditions affect torque and the results of torque applications. The major purpose in tightening a fastener to a specified torque is to obtain a clamping load which exceeds any possible loading imposed on parts.

New phosphate coated fasteners do not require oil lubrication during assembly and torque application. Reused fasteners (even if originally phosphate coated) do require oil lubrication to threads and under head area for correct torque application.

Threads that are dry, excessively rough, battered, or filled with dirt require considerable effort just to rotate. Then when the clamping load is developed or the bolt tension is applied, the torque reading mounts rapidly (due to thread friction) to the specified torque value. However, the desired bolt tension and correct clamping load is not achieved. This condition can lead to failure of the fastener to maintain component integrity. The correct bolt tension and clamping effect can never be attained if the fastener is dry. Fastener threads must be new condition phosphate coated or have a film of clean lubricant (engine oil) to be considered lubricated.

Standard Torque Charts

CAUTION: To prevent engine damage, do not use this standard torque chart with other International brand engines or engines made by other manufacturers.

Standard torque chart provides tightening values for all hardware that do not require special torque.

Standard Torque Values - Class 10.9 Metric Flange Head Bolts and Studs

Thread Diameter (mm)	Thread Pitch (mm)	Torque
6	1	13 N·m (115 lbf·in)
8	1.25	31 N·m (23 lbf·ft)
10	1.5	62 N·m (45 lbf·ft)
12	1.75	107 N·m (79 lbf·ft)
14	2	172 N·m (127 lbf·ft)
15	2	216 N·m (159 lbf·ft)
16	2	266 N·m (196 lbf·ft)
18	2.5	368 N·m (272 lbf·ft)
20	2.5	520 N·m (384 lbf·ft)

Example: Tighten four M6 x 12 pulley bolts to standard torque. What is the size and standard torque for these four bolts?

M6 x 12 refers to the bolts thread diameter and length. These bolts have a thread diameter of 6 mm and are 12 mm long.

To find the standard torque for a M6 x 12 bolt look at the torque chart above. We see the standard torque for a 6 mm thread diameter class 10.9 bolt should be 13 N·m (115 lbf·in).

Using a Torque Wrench Extension

Occasionally an extension, crowfoot, or other adapter is necessary to use with a torque wrench to torque a bolt or line fitting. Adding adapters or extensions will alter the torque on the fastener from what the torque wrench reads. Use the following formula to calculate the correct torque wrench setting to achieve a specific torque value.

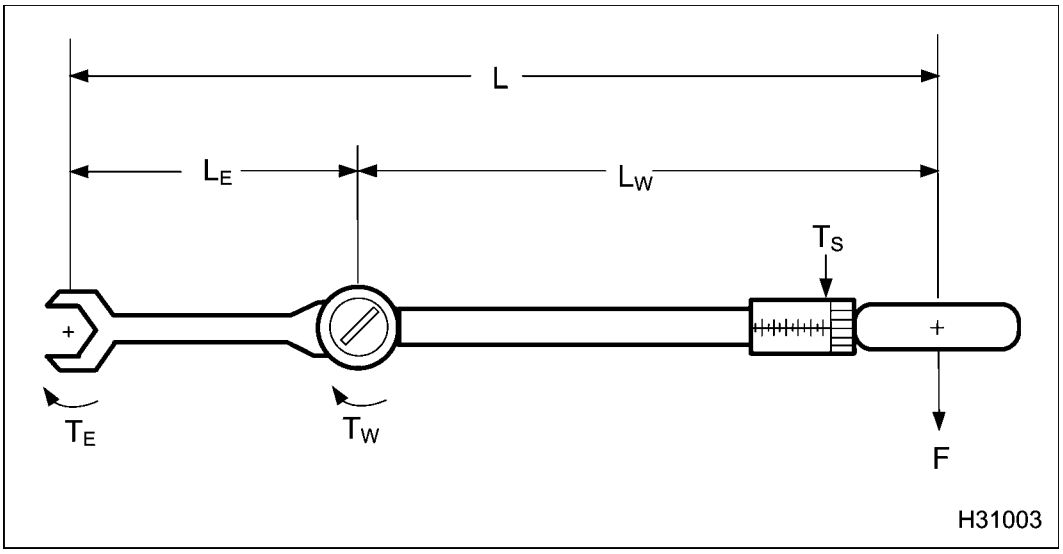


Figure 719 Torque wrench and extension

- F - Force applied by technician
- L - Total length through which force is applied to fastener
- T_W - Torque applied at end of torque wrench

$T_S = T_E (L_W / (L_W + L_E))$

- T_S - Torque wrench setting
- T_E - Torque specified at fastener
- L_W - Length of torque wrench
- L_E - Length of extension

Example: A component requires a specified torque value of 65 lbf·ft and a 6 inch extension is required to reach it. What should the torque wrench setting (T_S) be to compensate for the extension?

- Torque specified at fastener (T_E) = 65 lbf·ft
- Length of torque wrench (L_W) = 12 inches
- Length of extension (L_E) = 6 inches

$T_S = T_E (L_W / (L_W + L_E))$

T_S = 65 lbf·ft (12 inches / (12 inches + 6 inches)

T_S = 65 lbf·ft (12 inches / (18 inches)

T_S = 65 lbf·ft (0.666)

T_S = 43.33 lbf·ft

Special Torques

Mounting Engine on Stand

Table 50 Mounting Engine on Stand

Oil pan drain plug	75 N·m (55 lbf·ft)
Engine support hex bolts	230 N·m (170 lbf·ft)

Engine Electrical

Table 51 Engine Electrical

Camshaft Position (CMP) sensor bolt	8 N·m (71 lbf·in)
Crankshaft Position (CKP) sensor bolt	8 N·m (71 lbf·in)
Engine Coolant Temperature (ECT) sensor	45 N·m (33 lbf·ft)
Engine Coolant Temperature 2 (ECT2) sensor	45 N·m (33 lbf·ft)
Engine Fuel Pressure (EFP) sensor	45 N·m (33 lbf·ft)
Exhaust Lambda Sensor (ELS)	50 N·m (37 lbf·ft)
Fuel Rail Pressure (FRP) sensor	140 N·m (103 lbf·ft)
Manifold Absolute Pressure/Intake Air Temperature 2 (MAP/IAT2) sensor bolts	9 N·m (80 lbf·in)
Manifold Air Temperature (MAT) sensor	45 N·m (33 lbf·ft)

Cold Start Assist

Table 52 Cold Start Assist

Adapter	15 N·m (11 lbf·ft)
Cold start relay (CSR) hex bolts	8 N·m (71 lbf·in)
Size 6 hollow screw	15 N·m (11 lbf·ft)
Size 8 hollow screw	15 N·m (11 lbf·ft)
MV-glow plug fuel line fitting nuts	10 N·m (11 lbf·ft)
Cold start solenoid (CSS) valve hex bolts	6 N·m (53 lbf·in)
Glow plug locking nut	25 N·m (18 lbf·ft)

Aftertreatment System

Table 53 Aftertreatment System (in order of installation)

Turbo exhaust pipe hex bolt	31 N·m (23 lbf·ft)
Profiled clamp	6 N·m (44 lbf·in)
Aftertreatment fuel injector (AFI) hex bolts	See tightening steps in procedure.
Coolant return assembly P-clamp hex bolts	31 N·m (23 lbf·ft)
Parker® vee 12 onto AFI	41 N·m (30 lbf·ft)
Parker® ew12 onto Parker® vee 12	41 N·m (30 lbf·ft)
Coolant return assembly fitting nut to Parker® ew12	See tightening steps in procedure.
Parker® wee 12 into coolant elbow	41 N·m (30 lbf·ft)
Coolant supply line fitting nuts	See tightening steps in procedure.
Straight fitting into HC cut-off valve	24 N·m (18 lbf·ft)
M10 x 1 threaded union into HC cut-off valve	23 N·m (11 lbf·ft)
M14 x 1.5 threaded union into HC cut-off valve	35 N·m (26 lbf·ft)
Hydrocarbon (HC) cut-off valve hex bolts	31 N·m (23 lbf·ft)
M6 x 40 fuel supply assembly (upper line) P-clamp hex bolts	13 N·m (11 lbf·ft)
M8 x 16 fuel supply assembly (lower line) P-clamp hex bolt	31 N·m (23 lbf·ft)
Fuel supply assembly (upper line) fitting nut at connection of upper and lower lines	40 N·m (30 lbf·ft)
Fuel supply assembly (lower line) fitting nut at HC cut-off valve	27 N·m (20 lbf·ft)
Fuel supply assembly fitting nut (upper line) at Parker® 4C6MXSS	27 N·m (20 lbf·ft)
Parker® 4C6MXSS into AFI	15 N·m (11 lbf·ft)

Engine Retarder Control

Table 54 Retarder Control System Components

DMR 114 profiled clamp	10 N·m (89 lbf·in)
Pressure line P-clamp stud bolt	35 N·m (26 lbf·ft)
Retarder control hex bolts	35 N·m (26 lbf·ft)
Size 6 hollow screw	20 N·m (15 lbf-ft)
Pressure line fitting nut to straight union	30 N·m (22 lbf·ft)
Pressure line fitting nut to ring union	30 N·m (22 lbf·ft)
Straight union	See tightening steps in procedure.
Pressure air line fitting nut to retarder control	12 N·m (106 lbf·in)
Pressure air line fitting nut to exhaust manifold with butterfly	12 N·m (106 lbf·in)
Air supply line assembly fitting nut to retarder control	12 N·m (106 lbf·in)

Turbochargers

Table 55 Turbochargers

High pressure turbocharger to low pressure turbocharger hexagon nuts	See tightening steps in procedure.
Banjo bolt	10 N·m (89 lbf·in)
Air intake manifold cylinder screw	10 N·m (89 lbf·in)
M32 x 1.5 threaded union (air intake duct)	See tightening steps in procedure.
M26 x 1.5 threaded union (air intake duct)	See tightening steps in procedure.
Rubber pad	10 N·m (89 lbf·in)
Straight union (for low pressure turbocharger oil pressure connection flange)	See tightening steps in procedure.
L12A straight union	See tightening steps in procedure.
Low pressure turbocharger oil pressure pipe fitting nuts	See tightening steps in procedure.
High pressure turbocharger oil pressure pipe fitting nuts	See tightening steps in procedure.
Low pressure turbocharger oil return pipe fitting nut	See tightening steps in procedure.
Low pressure turbocharger oil return pipe (to crankcase)	See tightening steps in procedure.

Air Compressor and Power Steering

Table 56 Air Compressor and Power Steering

1-1/16" 90 degree elbow lock nut	55 N·m (40 lbf·ft)
1/2" 90 degree tube elbow lock nut	45 N·m (33 lbf·ft)
Air compressor hex bolts	35 N·m (26 lbf·ft)
Air compressor suction pipe M8 x 65 hex bolts	35 N·m (26 lbf·ft)
High pressure tube fitting nut	62 N·m (45 lbf·ft)
Low pressure tube fitting nut	164 N·m (120 lbf·ft)
Power steering pump heavy bolts	67 N·m (49 lbf·ft)

Fuel System

Table 57 Fuel System

Bleeder valve	35 N·m (26 lbf·ft)
Fuel filter housing assembly hex bolts	35 N·m (26 lbf·ft)
Fuel filter bracket hex bolts	35 N·m (26 lbf·ft)
High pressure pump hex bolts	60 N·m (44 lbf·ft)
Hollow screws (all sizes in this section)	30 N·m (21 lbf·ft)
Fuel drip line fitting nuts	40 N·m (30 lbf·ft)
Fuel filter screw cap	20 N·m (15 lbf·ft)
Fuel primer pump assembly hex bolts	45 N·m (33 lbf·ft)
Fuel strainer cover	10 N·m (89 lbf·in)
Injection line fitting nuts	10 N·m (89 lbf·in) + 60°
L10-A4C adapter	40 N·m (30 lbf·ft)
Pressure line fitting nuts	10 N·m (89 lbf·in) + 60°
Pressure pipe rail hex bolts	30 N·m (21 lbf·ft)
M14 x 1.5 threaded unions	30 N·m (21 lbf·ft)

Oil Cooler, Filter Housing and Crankcase Ventilation

Table 58 Oil Module and Breather System

Engine Oil Pressure (EOP) sensor	47 N·m (35 lbf·ft)
Engine Oil Temperature (EOT) sensor	47 N·m (35 lbf·ft)
Oil cooler hex bolts	25 N·m (18 lbf·ft)
Oil filter cover	40 N·m (30 lbf·ft)
Oil module hex bolts	75 N·m (55 lbf·ft)
Oil pressure relief valve	40 N·m (30 lbf·ft)
M10 x 1.0 plug	75 N·m (55 lbf·ft)
M38 x 1.5 plug	80 N·m (59 lbf·ft)
M33 x 2 plugs	80 N·m (59 lbf·ft)
Flange elbow hex bolts	25 N·m (18 lbf·ft)
Water pump hex bolt	35 N·m (26 lbf·ft)
M26 x 1.5 threaded union	25 N·m (18 lbf·ft)
M12 straight fitting	25 N·m (18 lbf·ft)

Exhaust Gas Recirculation (EGR) System

Table 59 Exhaust Gas Recirculation (EGR) System

Air line assembly threaded fitting	12 N·m (106 lbf·in)
Air supply line assembly threaded fitting	12 N·m (106 lbf·in)
Coolant elbow (middle) hex bolt	35 N·m (28 lbf·ft)
Coolant elbow (upper) hex bolts and stud bolt	35 N·m (28 lbf·ft)
Coolant elbow (lower) hex bolts	35 N·m (28 lbf·ft)
Coolant pipe low temperature radiator (LTR) supply pipe clamp	4 N·m (35 lbf·in)
EGR throttle valve cylinder screws	35 N·m (26 lbf·ft)
EGR module hex bolts	75 N·m (55 lbf·ft)
Front inner and outer tubes hex bolts	35 N·m (28 lbf·ft)
Rear inner and outer tubes cylinder screws	35 N·m (28 lbf·ft)
Heat protection plates (front and rear) hex bolts	22 N·m (16 lbf·ft)

Air Inlet Duct and Exhaust Manifolds

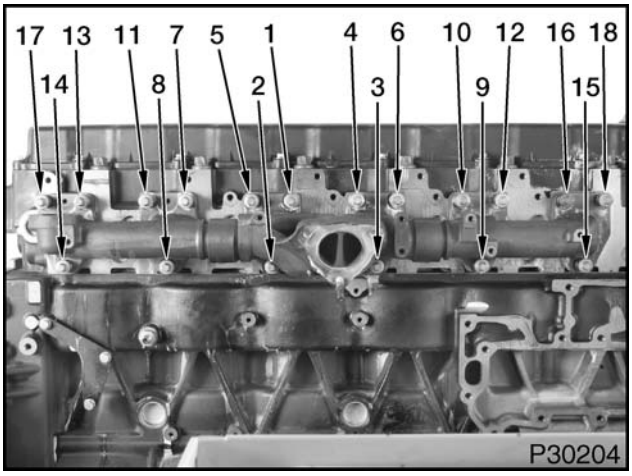


Figure 720 Exhaust manifold tightening sequence

Table 60 Air Inlet Duct and Exhaust Manifolds

Exhaust manifold screws	See tightening procedure and sequence
Air inlet duct hex bolts	15 N·m (11 lbf·ft)

Front Cover, High Mount Fan Drive, Cooling System, Related Components

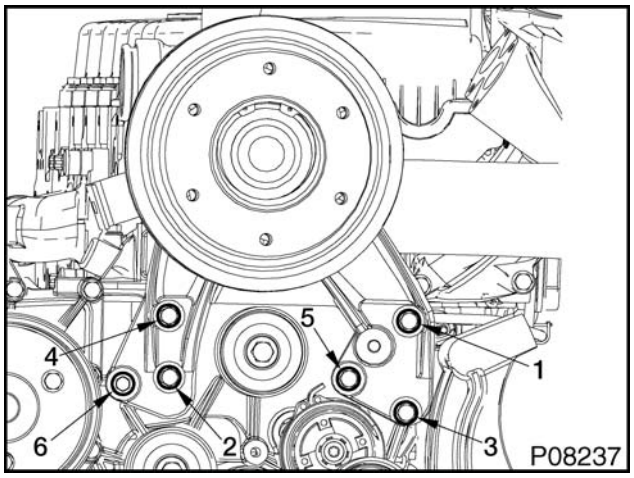


Figure 721 Tensioner bracket tightening sequence

Table 61 Front Cover, High Mount Fan Drive, Cooling System, Related Components

Air clutch fan drive hex bolt	See tightening steps in procedure
Automatic belt tensioner countersunk screw	47 N·m (35 lbf·ft)
Cable roller hex bolts	60 N·m (44 lbf·ft)
Coolant Control Valve (CCV) hex bolts	31 N·m (23 lbf·ft)
Coolant elbow (to Exhaust Gas Recirculation (EGR) module) hex bolts	35 N·m (26 lbf·ft)
Coolant elbow (to radiator) hex bolts	35 N·m (26 lbf·ft)
Distributor case hex bolts	35 N·m (26 lbf·ft)
Drive housing hex bolts	115 N·m (85 lbf·ft)
High mount fan bracket	See tightening steps in procedure
High mount fan tensioner countersunk screw	47 N·m (35 lbf·ft)
Hub and pulley hex bolts to vibration damper	45 N·m (33 lbf·ft)
High mount fan pulley assembly shoulder bolt	62 N·m (45 lbf·ft)
M8 x 20 front crankcase cover hex bolts	35 N·m (26 lbf·ft)
M8 x 25 front crankcase cover hex bolts	35 N·m (26 lbf·ft)
M8 x 40 front crankcase cover hex bolts	35 N·m (26 lbf·ft)
M12 x 30 Drive housing pulley hex bolt	115 N·m (85 lbf·ft)
M12 x 70 front crankcase cover hex bolts	115 N·m (85 lbf·ft)
M14 x 30 front crankcase cover hex bolts	115 N·m (85 lbf·ft)
Thermostat housing assembly hex bolts	35 N·m (26 lbf·ft)
Water pump hex bolts	35 N·m (26 lbf·ft)
Water pump pulley hex bolts	35 N·m (26 lbf·ft)
Vibration damper cylinder screws	See tightening steps in procedure

Cylinder Head, Camshaft and Valve Train

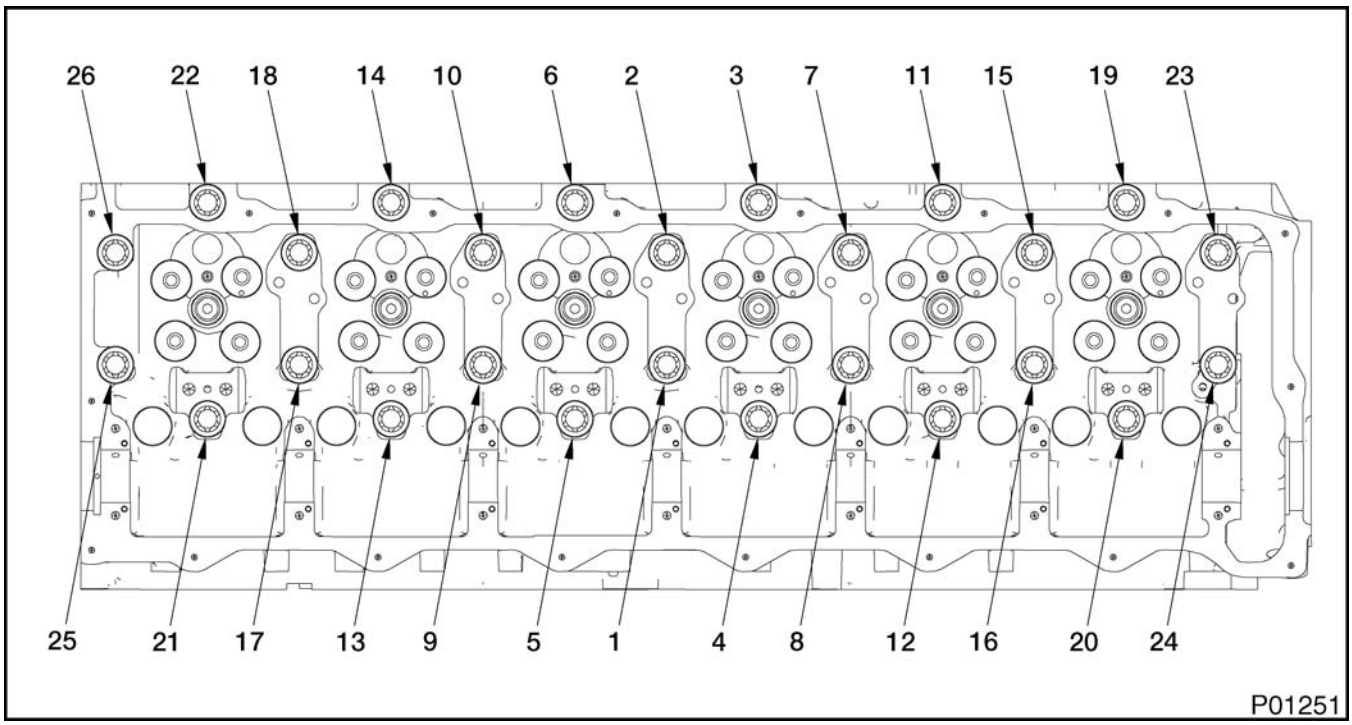


Figure 722 Cylinder head bolts tightening sequence

Table 62 Cylinder Head, Camshaft and Valve Train

Air inlet duct hex bolts	15 N·m (11 lbf·ft)
Cylinder head bearing cap hex bolt	35 N·m (26 lbf·ft)
Camshaft gear hex bolts	See tightening steps in procedure
Cylinder head collar bolts	See tightening steps in procedure
Cylinder intermediate gear cylinder screws	30 N·m (22 lbf·ft)
Counterpiece adjustment M14 hexagon nuts	45 N·m (33 lbf·ft)
Counterpiece hex bolts	75 N·m (55 lbf·ft)
Exhaust valve lash adjustment M10 hexagon nuts	45 N·m (33 lbf·ft)
Injector harness nuts	1.5 N·m (13 lbf·in)
Injector pressure flange hex bolts	See tightening steps in procedure
Intake valve lash adjustment M10 hexagon nuts	45 N·m (33 lbf·ft)
Pressure pipe nuts	See tightening steps in procedure
Rocker gear cylinder screws	105 N·m (77 lbf·ft)
Valve cover screw with damper elements	11 N·m (97 lbf·in)

Flywheel and Flywheel Housing

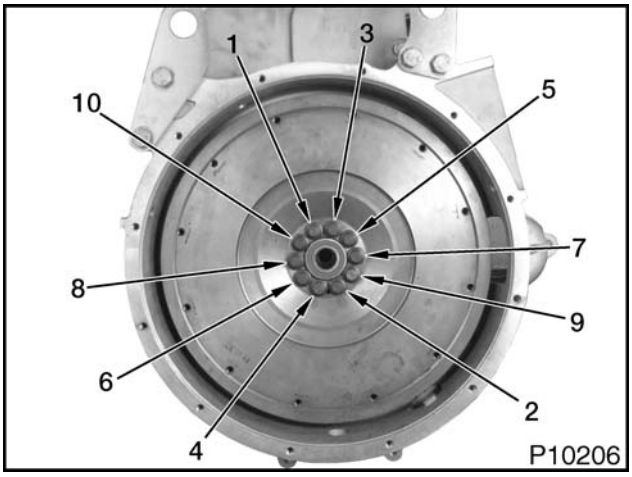


Figure 723 Flywheel tightening sequence

Table 63 Flywheel and Flywheel Housing

12KT flywheel bolts	See tightening steps in procedure.
Flywheel housing hex bolts	75 N·m (55 lbf·ft)
Lifting eye hex bolts	180 N·m (133 lbf·ft)

Oil Pan and Oil Suction Tube

Table 64 Oil Sump Components

Drain plug	75 N·m (55 lbf·ft)
Oil return pipe	4 N·m (35 lbf·in)
Oil sump bolts	35 N·m (26 lbf·ft)
Preheater or replacement drain plug	75 N·m (55 lbf·ft)

Oil Pump, Low Mount Fan Drive, and Timing Gears

Table 65 Oil Pump, Low Mount Fan Drive, and Timing Gears

Front intermediate gear cylinder screws	105 N·m (77 lbf·ft)
Air compressor intermediate gear hex bolts	115 N·m (85 lbf·ft)
Crankcase intermediate gear cylinder screws	30 N·m (22 lbf·ft)
Big intermediate gear hex bolts	175 N·m (129 lbf·ft)
Fan drive hex bolts	35 N·m (26 lbf·ft)
Oil pump cover hex bolts	15 N·m (133 lbf·in)
Axle cylinder screw	65 N·m (48 lbf·ft)

Power Cylinders

Table 66 Power Cylinders

Connecting rod screws	Initial	100 N·m (74 lbf·ft)
	Final	90°
Cylinder Liner Protrusion Tool bolts		80 N·m (59 lbf·ft)

Crankcase and Crankshaft

Table 67 Crankcase and Crankshaft

Main bearing cap hex collar bolts	See tightening procedure and sequence
Oil sprayer nozzle hex bolts	13 N·m (115 lbf·in)

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Special Tools

Special tools for the MaxxForce™ 11 and 13 engines with ZTSE numbers can be ordered from the SPX Corporation, 1-800-520-2584.

Mounting Engine on Stand

Table 68 Mounting Engine on Stand

Description	Tool Number
Engine Stand Adapter Plate	ZTSE4789
Disposable Air and Fuel Caps	ZTSE4891

Engine Electrical

Table 69 Engine Electrical

Description	Tool Number
Disposable Air and Fuel Caps	ZTSE4891

Aftertreatment System

Table 70 Aftertreatment System

Description	Tool Number
Parker® ThreadMate™	Obtain locally
High-Temperature Nickel-Graphite Anti-Seize Compound	Obtain locally
Fuel Line Disconnect Tool 11.8 mm	ZTSE4773

Engine Retarder Control

Table 71 Engine Retarder Control

Description	Tool Number
P-80 ® Rubber Lubricant or equivalent	Obtain locally

Turbochargers

Table 72 Turbochargers

Description	Tool Number
Charge Air Cooler Tester Kit	ZTSE4341
High Pressure CAC Test Plate	ZTSE4909
P-80 ® Rubber Lubricant or equivalent	Obtain locally

Air Compressor and Power Steering Pump

Table 73 Air Compressor

Description	Tool Number
Coolant Line Release Tool	ZTSE4778
Loctite® 5900 Sealant or equivalent	Obtain locally

Fuel System

Table 74 Fuel System

Description	Tool Number
Crowfoot Wrench	Obtain locally
Disposable Air and Fuel Caps	ZTSE4891
Fuel Line Disconnect Tool 11.8 mm	ZTSE4773

Oil Cooler, Filter Housing and Crankcase Ventilation

Table 75 Oil Cooler

Description	Tool Number
Air Pressure Regulator	Obtain locally
Oil Cooler Pressure Test Plates	ZTSE4879
P-80®Rubber Lubricant or equivalent	Obtain locally

Exhaust Gas Recirculation (EGR) System

Table 76 Exhaust Gas Recirculation (EGR) System

Description	Tool Number
Air Pressure Regulator	Obtain locally
EGR Cooler Pressure Test Plates	ZTSE4877
P-80® Rubber Lubricant or equivalent	Obtain locally

Air Inlet Duct and Exhaust Manifolds

Table 77 Air Inlet Duct and Exhaust Manifolds

Description	Tool Number
Feeler Gauge	Obtain locally
Straightedge	Obtain locally
Loctite® 5900 Sealant or equivalent	Obtain locally

Front Cover, High Mount Fan Drive, Cooling System, and Related Components

Table 78 Front Cover, High Mount Fan Drive, Cooling System, and Related Components

Description	Tool Number
Fan Hub High Pressure Drive Seal Installer	ZTSE4776
Front Crankshaft Seal Installer	ZTSE4873
Liquid Gasket (RTV)	Obtain locally
Loctite® 5900 Sealant or equivalent	Obtain locally
P-80® Rubber Lubricant or equivalent	Obtain locally
Slide Hammer	Obtain locally

Cylinder Head, Camshaft and Valve Train

Table 79 Cylinder Head, Camshaft and Valve Train

Description	Tool Number
1–2 inch Micrometer	Obtain locally
Bearing Installer	Obtain locally
Cylinder Head Lifting Bracket	ZTSE4869
Dial Indicator with Magnetic Base	Obtain locally
Disposable Air and Fuel Caps	ZTSE4891
Engine Rotating Tool	ZTSE4786
Feeler Gauge	Obtain locally
Fuel Injector Tip Cleaning Brush	ZTSE4301
Fuel Injector Rack Holder	ZTSE4299B
Fuel Injector Cups	ZTSE4892
Head Bolt Bottoming Tap	ZTSE4855
Head Bolt Torx Socket	ZTSE4835
Injector Installer	ZTSE4777
Injector Puller	ZTSE4770
Injector Sleeve Brushes	ZTSE4751
Loctite® 262™ Threadlocker	Obtain locally
Loctite® 5900 sealant or equivalent	Obtain locally
M8 x 20 class 10.9 bolts	Obtain locally
Telescoping Gauge Set	Obtain locally

Flywheel and Flywheel Housing

Table 80 Flywheel and Flywheel Housing

Description	Tool Number
1–2 Inch Micrometer	Obtain locally
Blind Hole Puller	Obtain locally
Pilot Bearing Installation Tool	ZTSE4898
Brake Cleaner (non-caustic)	Obtain locally
Dial Indicator With Magnetic Base	Obtain locally
Loctite 5900 or Equivalent	Obtain locally
Rear Oil Seal Installer	ZTSE4875
Slide Hammer	Obtain locally

Oil Pan and Oil Suction Tube

Table 81 Oil Sump System

Description	Tool Number
Loctite ® 242	Obtain locally

Oil Pump, Low Mount Fan Drive, and Timing Gears

Table 82 Oil Pump, Low Mount Fan Drive, and Timing Gears

Description	Tool Number
Dial Indicator with Magnetic Base	Obtain locally
Fan Hub High Pressure Drive Seal Installer	ZTSE4776
Feeler Gauge	Obtain locally
Gear Puller	Obtain locally
Slide Hammer	Obtain locally

Power Cylinders

Table 83 Power Cylinders

Description	Tool Number
2–3 inch Micrometer	Obtain locally
3–4 inch Micrometer	Obtain locally
4–5 inch Micrometer	Obtain locally
Connecting Rod Bolt Torx Socket	ZTSE4843
Cylinder Liner Puller	ZTSE2536
Dial Bore Gauge	Obtain locally
Dial Indicator with Magnetic Base	Obtain locally
Feeler Gauge	Obtain locally
Piston Ring Compressor	Obtain locally
Piston Ring Expansion Pliers	Obtain locally
Sleeve Protrusion Hold Down Clamps	ZTSE4825
Telescoping Gauge Set	Obtain locally

Crankcase and Crankshaft

Table 84 Crankcase and Crankshaft

Description	Tool Number
3–4 inch Micrometer	Obtain locally
4–5 inch Micrometer	Obtain locally
Dial Bore Gauge	Obtain locally
Dial Indicator with Magnetic Base	Obtain locally
Head Bolt Bottoming Tap	ZTSE4855
Lifting Sling	Obtain locally
Main Bolt Bottoming Tap	ZTSE4854

Special Tools

Essential Tools

Figure 724 ZTSE4770 injector puller

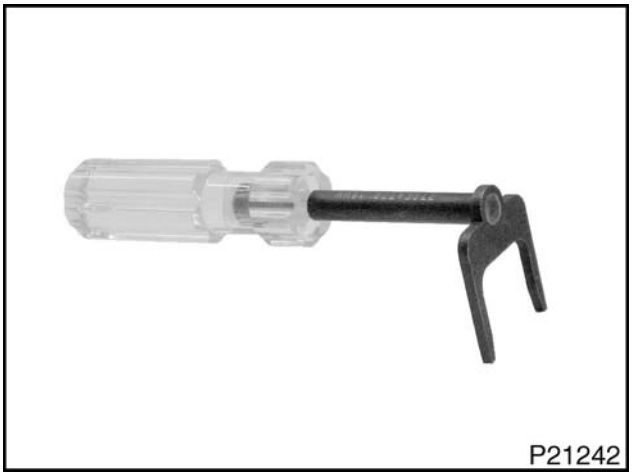

Figure 725 ZTSE4773 fuel line disconnect tool 11.8 mm

Figure 726 ZTSE4776 fan hub high pressure drive seal installer

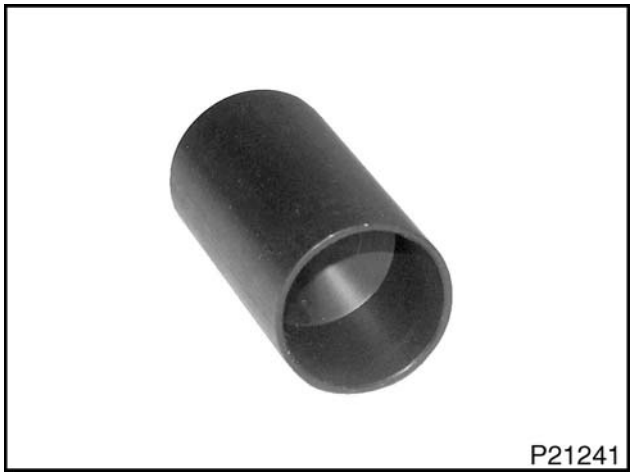

Figure 727 ZTSE4777 injector installer

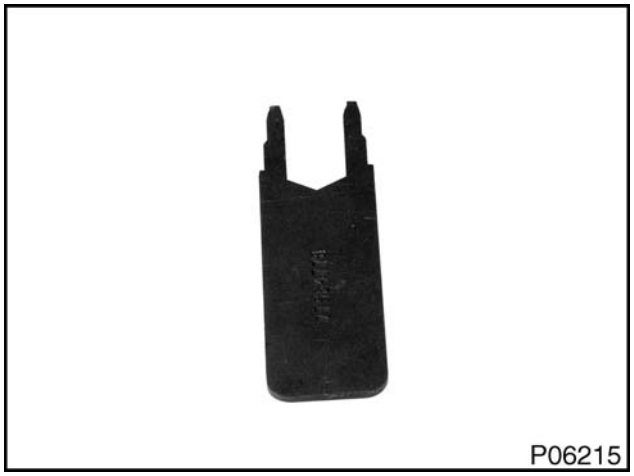

Figure 728 ZTSE4778 coolant line release tool

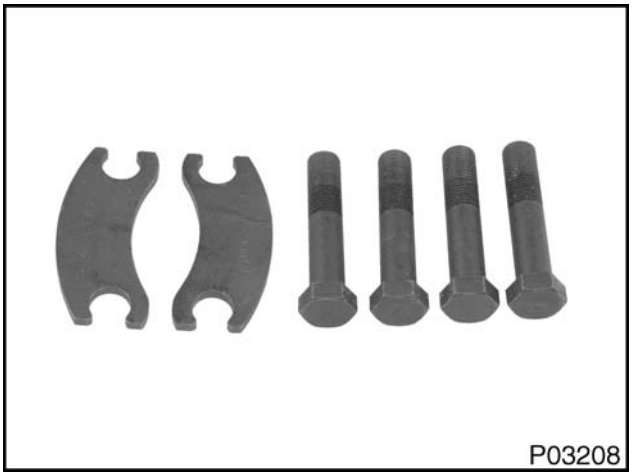

Figure 730 ZTSE4825 sleeve protrusion hold down clamps

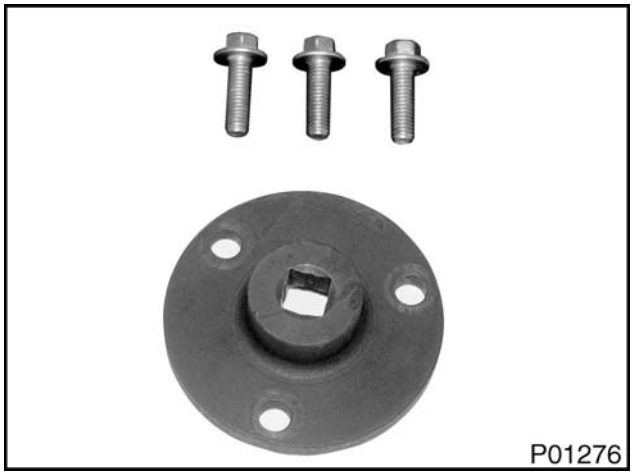

Figure 729 ZTSE4786 engine rotating tool

Figure 731 ZTSE4835 head bolt torx socket

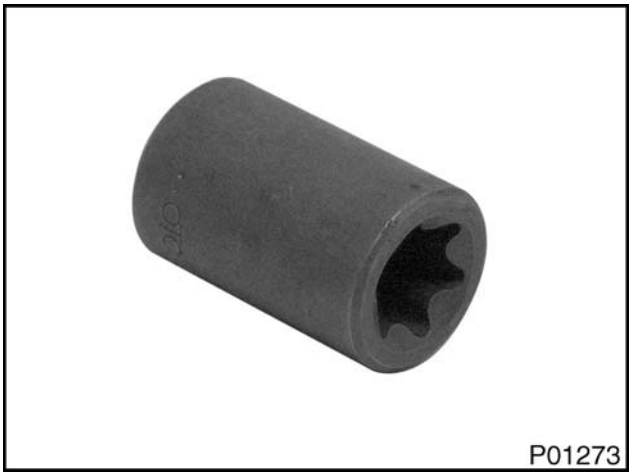

Figure 732 ZTSE4843 connecting rod bolt torx socket

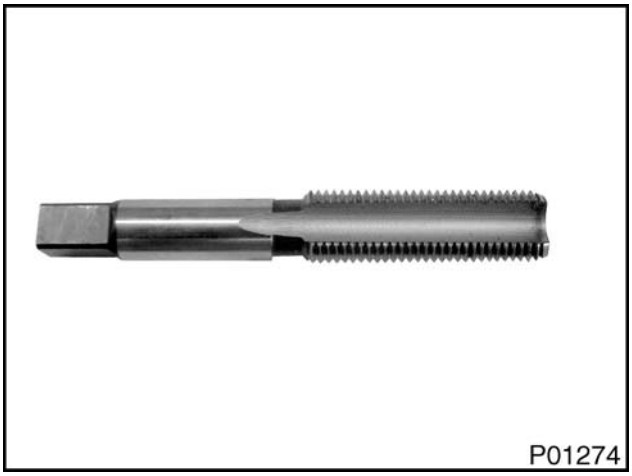

Figure 733 ZTSE4854 main bolt bottoming tap

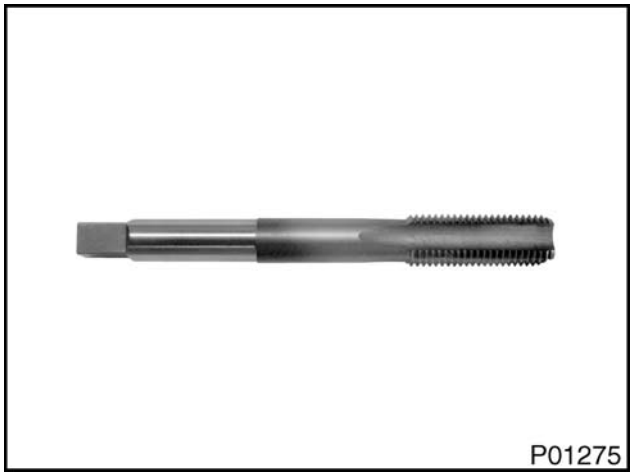

Figure 734 ZTSE4855 head bolt bottoming tap

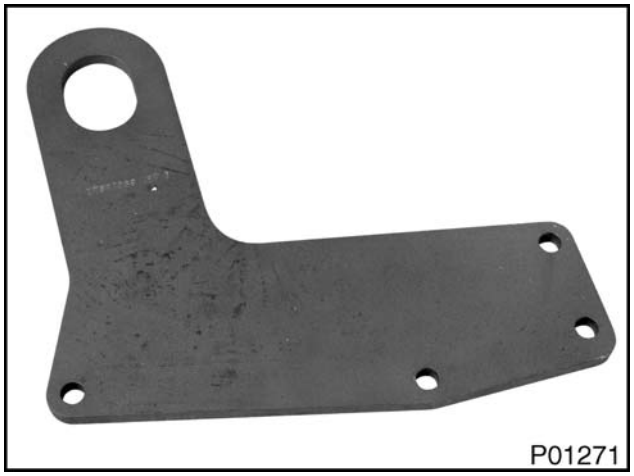

Figure 735 ZTSE4869 cylinder head lifting bracket

Figure 736 ZTSE4873 front crankshaft seal installer

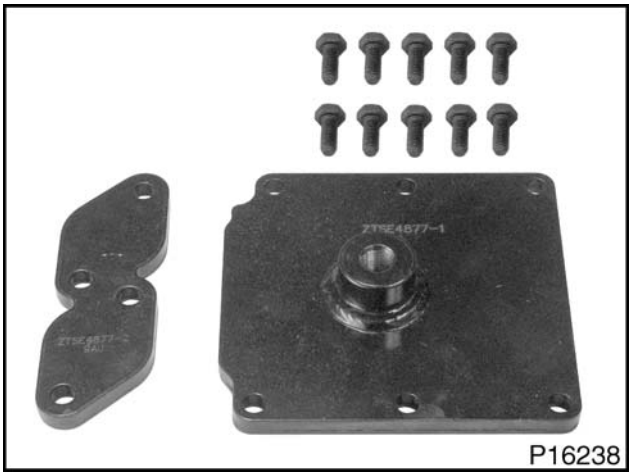

Figure 738 ZTSE4877 EGR cooler pressure test plates

Figure 737 ZTSE4875 rear oil seal installer

Figure 739 ZTSE4879 oil cooler pressure test plates

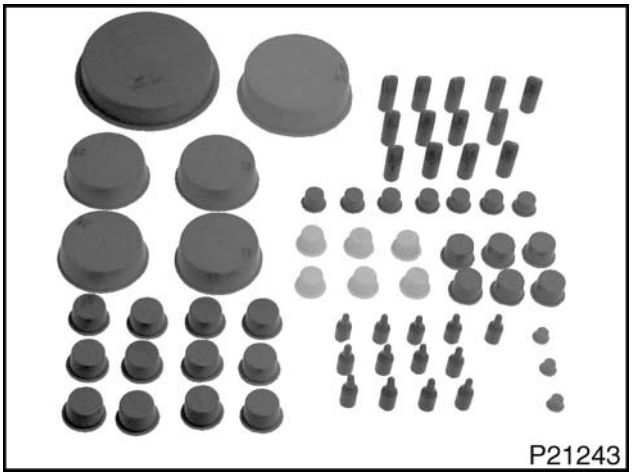

Figure 740 ZTSE4891 disposable air and fuel caps

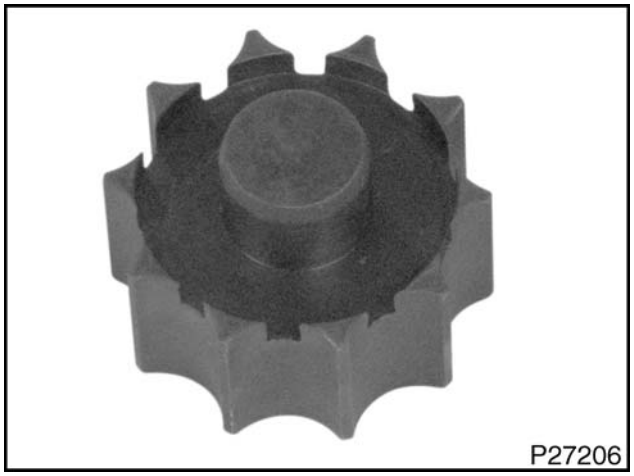

Figure 742 ZTSE4898 pilot bearing installation tool

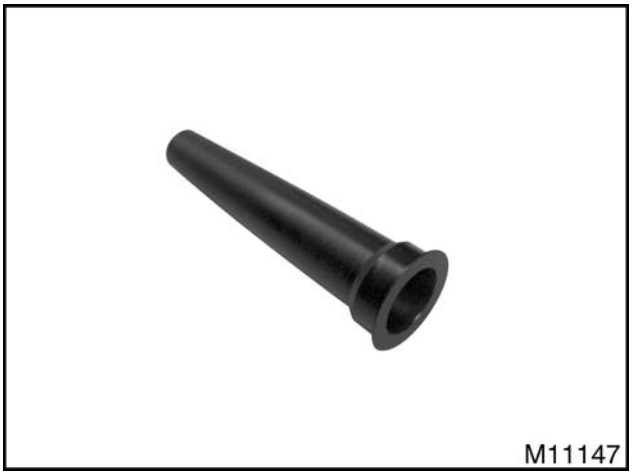

Figure 741 ZTSE4892 fuel injector caps (6)

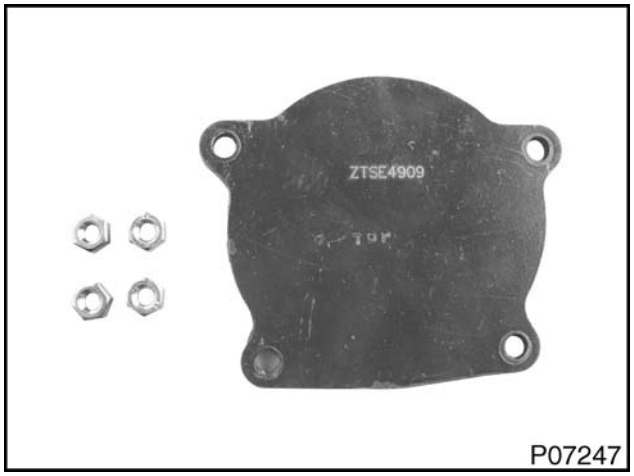

Figure 743 ZTSE4909 high pressure CAC test plate

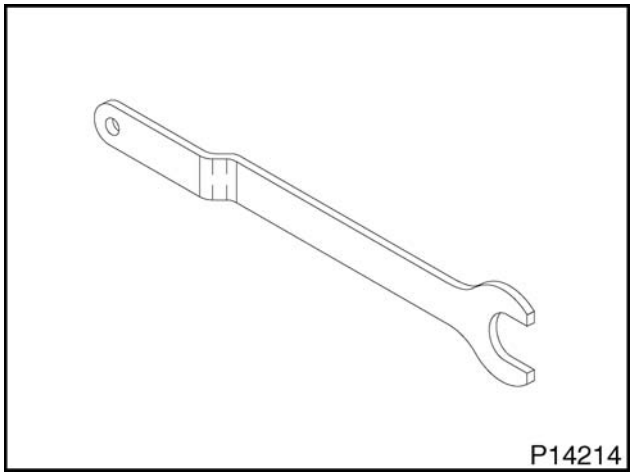

Figure 744 ZTSE4913 fan clutch nut wrench

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