Table of Contents

Exploded Views

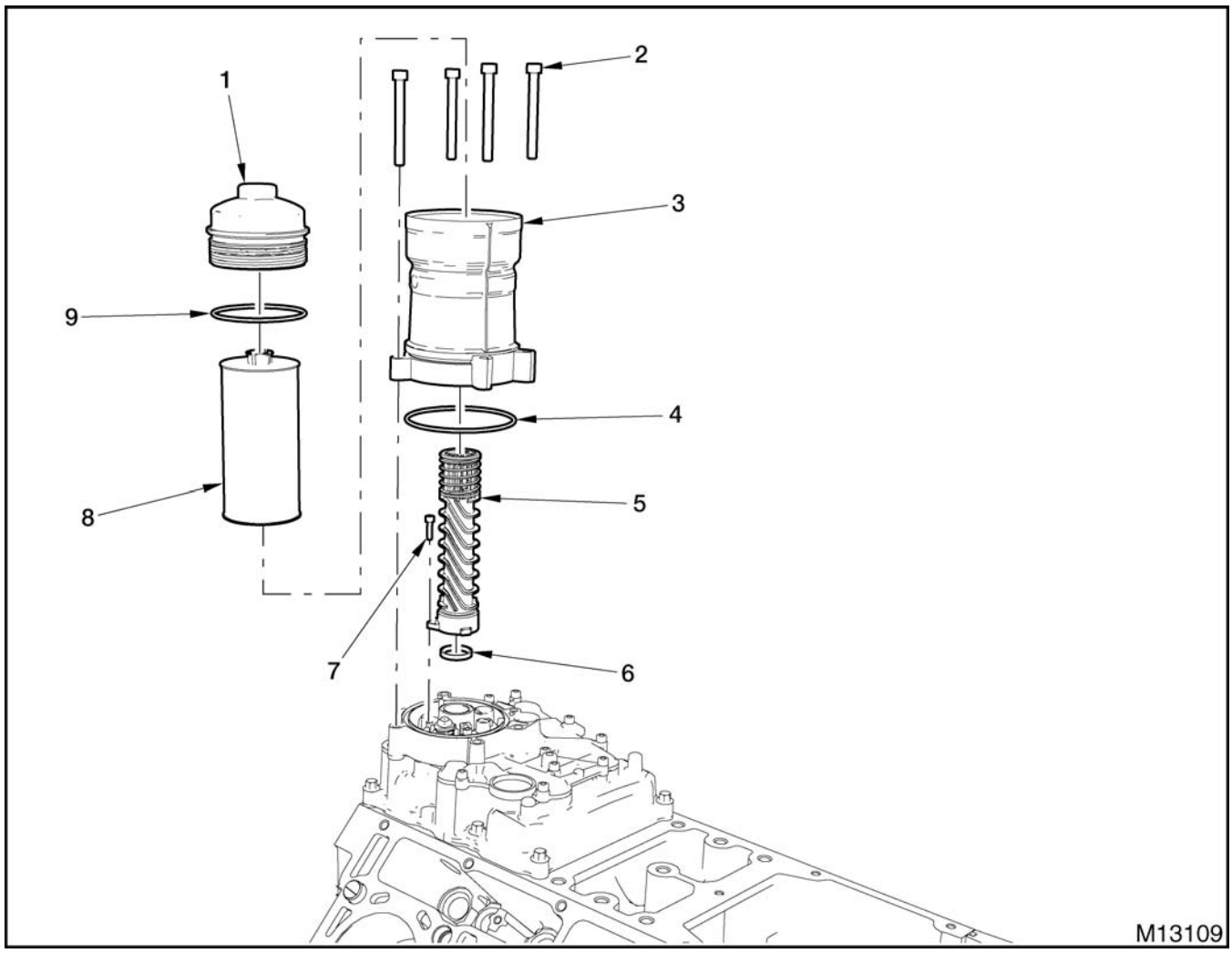


Figure 441 Oil filter housing assembly

1. Oil filter cap
2. M8 x 75 bolt (4)
3. Oil filter housing
4. O-ring seal
5. Oil filter return tube assembly
6. Return tube gasket
7. M5 x 18 screw
8. Oil filter element
9. Oil filter cap seal

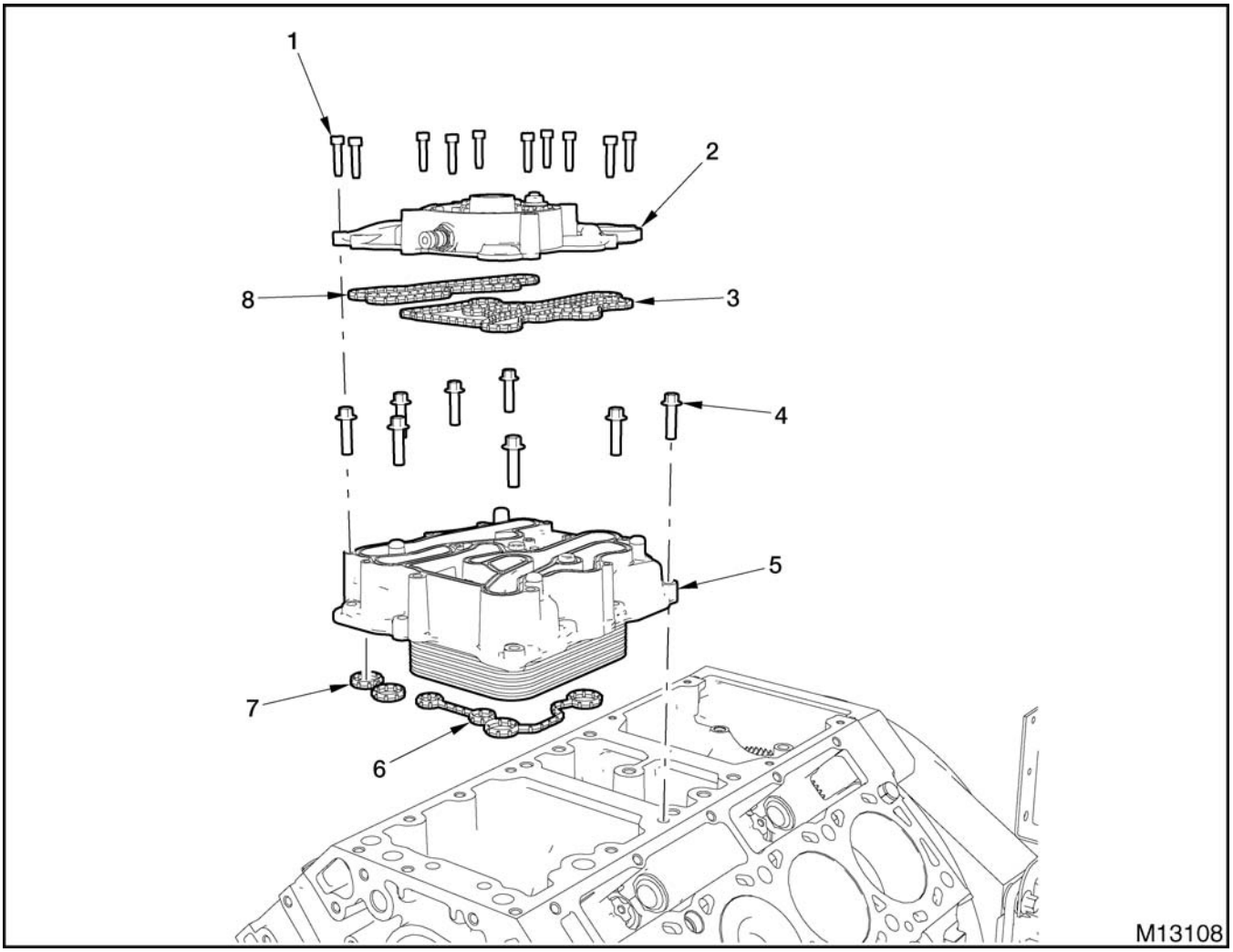


Figure 442 Oil filter base and oil cooler cover assemblies

1. M6 X 25 screw (10)
2. Oil filter base assembly
3. Base to cover gasket (oil side)
4. M8 x 30 bolt (8)
5. Oil cooler cover assembly
6. Oil cooler cover gasket (oil side)
7. Oil cooler cover gasket (coolant side)
8. Base to cover gasket (coolant side)

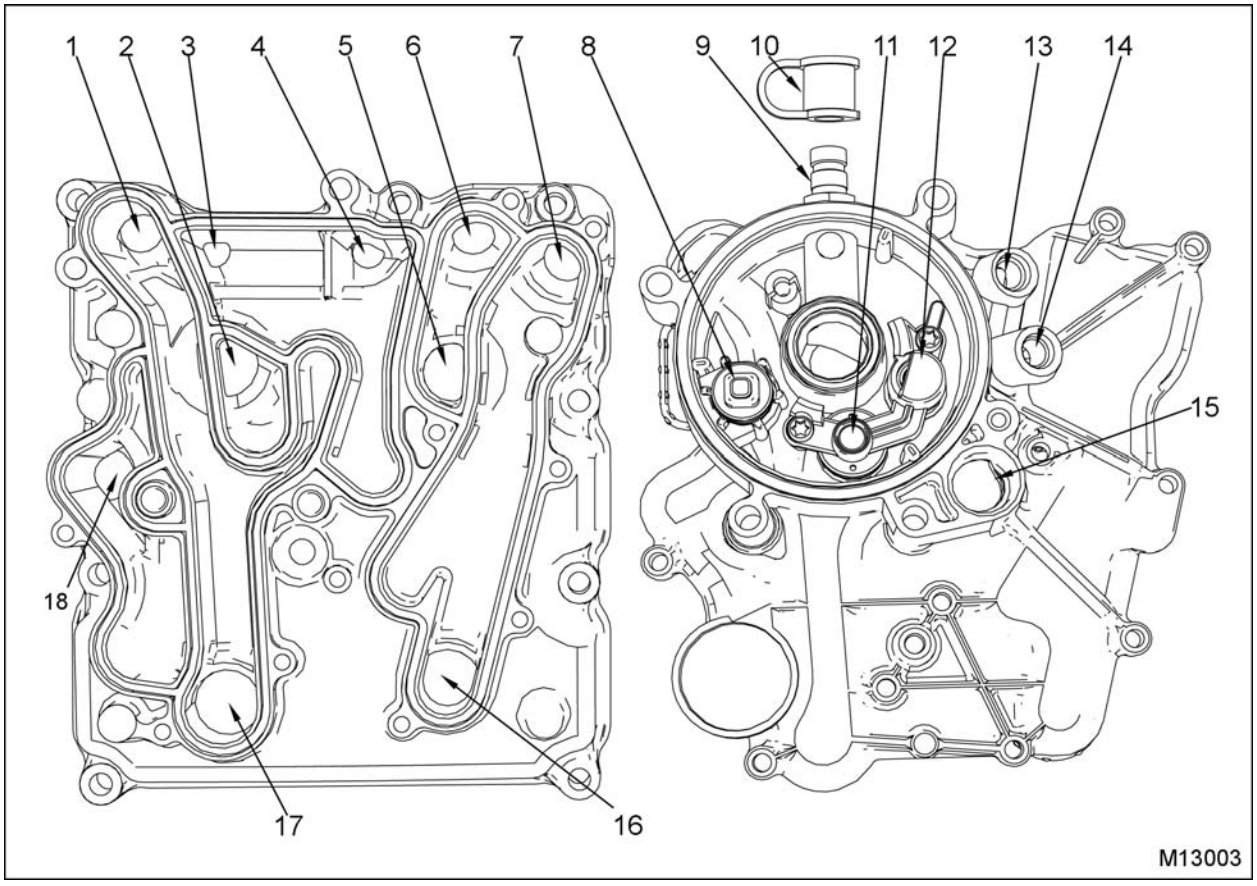


Figure 443 Oil cooler cover assembly and oil filter base assembly location details

1. Unfiltered oil flow from pump
2. Oil cooler outlet (oil)
3. Filtered oil to crankcase galleries and other components
4. Filtered oil to crankcase galleries and other components
5. Coolant inlet to oil cooler
6. Coolant inlet from water pump
7. Coolant outlet to cooling system
8. Oil drain valve assembly
9. Diagnostic coupling assembly
10. Diagnostic coupling dust cap
11. Filter inlet check valve
12. Oil cooler bypass valve
13. Engine Oil Temperature (EOT) sensor port
14. Engine Oil Pressure (EOP) sensor port
15. Turbocharger oil supply port
16. Coolant outlet from oil cooler
17. Oil cooler inlet (oil)
18. Oil drain to sump

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
- Exhaust Gas Recirculating (EGR) System
- Variable Geometry Turbocharger (VGT)
- Fuel System

Oil Filter Housing and Oil Filter Base Assemblies

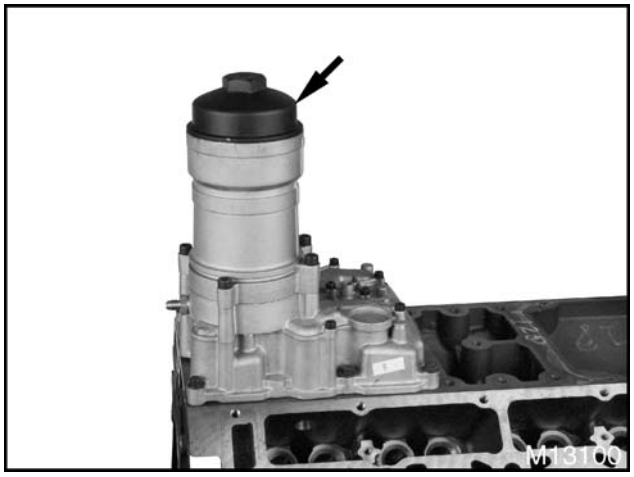


Figure 444 Oil filter cap

1. Remove oil filter cap and oil filter element. Discard oil filter element and oil filter cap seal.

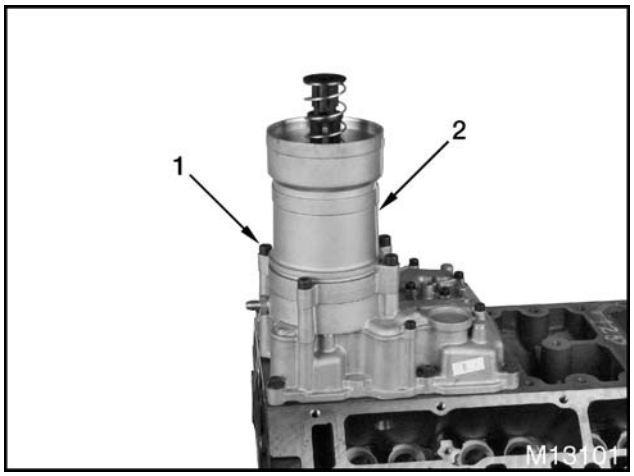


Figure 445 Oil filter housing

1. M8 x 75 bolt (4)
2. Oil filter housing

2. Remove four M8 x 75 bolts and oil filter housing.
3. Remove and discard O-ring seal.

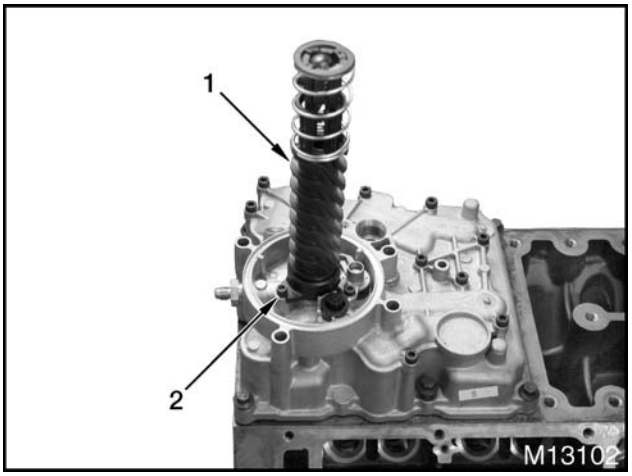


Figure 446 Oil filter return tube assembly

1. Oil filter return tube assembly
2. M5 x 18 screw

4. Remove M5 x 18 screw.
5. Turn oil filter return tube assembly counterclockwise and remove from oil filter base assembly.
6. Remove and discard return tube gasket.

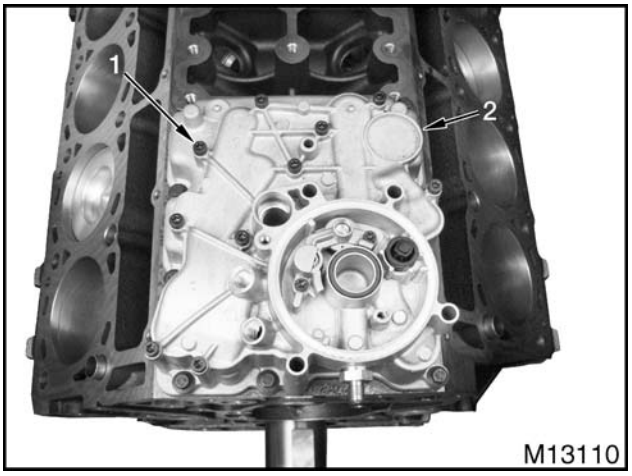


Figure 447 Oil filter base assembly

1. M6 x 25 screw (10)
2. Oil filter base assembly

7. Remove ten M6 x 25 screws and oil filter base assembly.

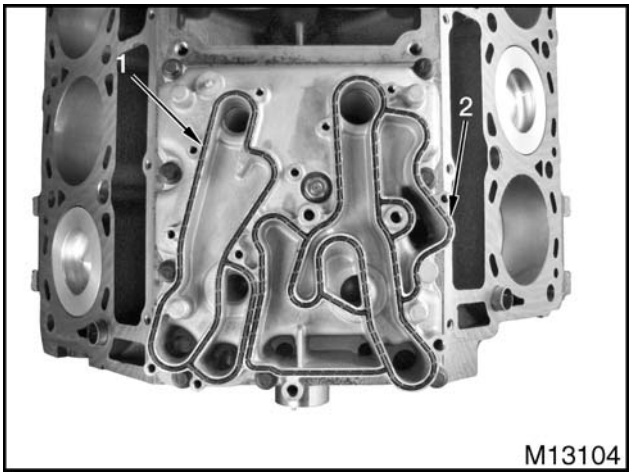


Figure 448 Oil filter base assembly gaskets

1. Base to cover gasket (coolant side)
2. Base to cover gasket (oil side)

8. Remove and discard base to cover gasket (coolant side).
9. Remove and discard base to cover gasket (oil side).

Oil Cooler Cover Assembly

CAUTION: To prevent engine damage after a catastrophic engine failure, install a new oil cooler cover assembly and oil cooler. Debris cannot be removed from the oil cooler.

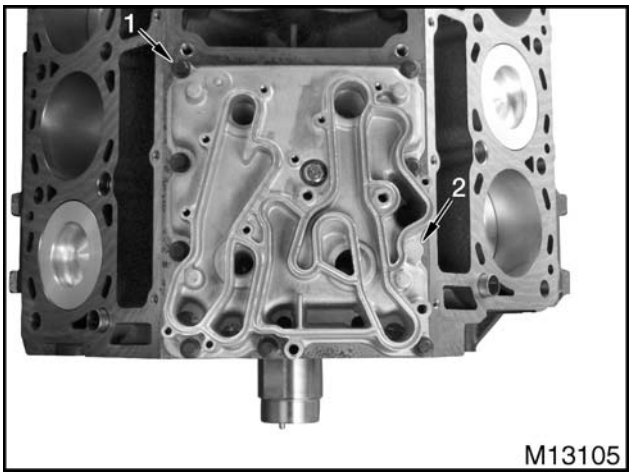


Figure 449 Oil cooler cover assembly

1. M8 x 30 bolt (8)
2. Oil cooler cover assembly

1. Remove eight M8 x 30 bolts and oil cooler cover assembly.

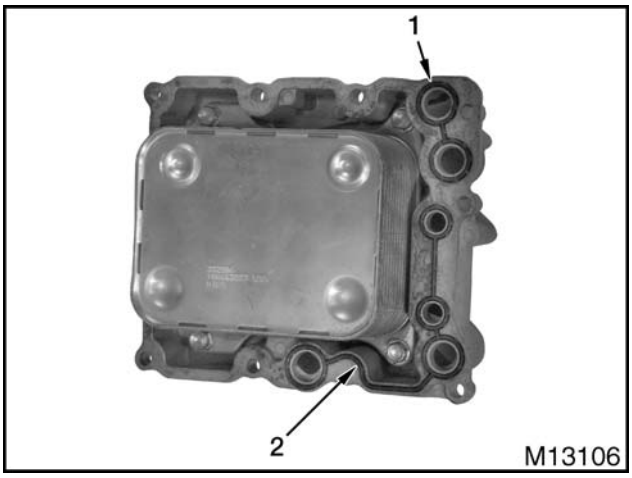


Figure 450 Oil cooler cover assembly gaskets

1. Oil cooler cover gasket (coolant side)
2. Oil cooler cover gasket (oil side)

2. Remove and discard oil cooler cover gasket (coolant side).
3. Perform air pressure leakage test for oil cooler cover assembly leaks (coolant side) (page 261).
4. Remove and discard oil cooler cover gasket (oil side).

Cleaning, Inspection, and Testing

Oil Cooler Cover and Oil Filter Base Assemblies

1. Drain and flush oil cooler cover assembly, oil filter base assembly, and oil filter housing assembly to remove internal residue.

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

2. Dry all components thoroughly with compressed air.

Oil Cooler Cover Assembly Leaks (Coolant Side)

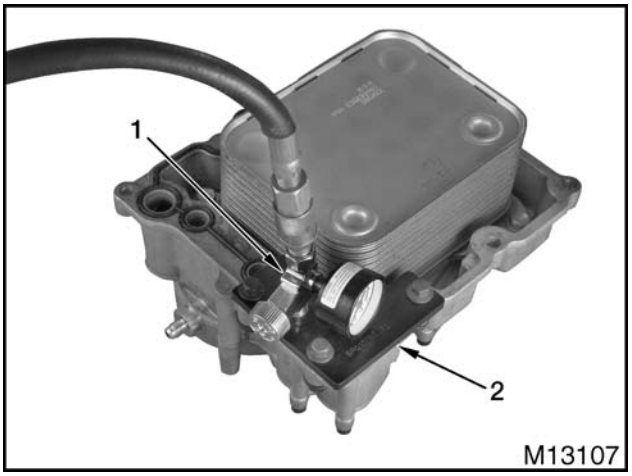


Figure 451 Oil cooler cover assembly pressure test

1. Air pressure regulator
2. Oil Cooler Pressure Test Plate ZTSE4730

NOTE: The oil filter base assembly and new gaskets must be installed on the oil cooler cover assembly before a pressure test can be done. The new gaskets can be reused for final assembly.

1. Install Oil Cooler Pressure Test Plate ZTSE4730 (page 265) on oil cooler cover assembly.

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

2. Attach an air pressure regulator (page 265) to oil cooler pressure test plate. Connect to compressed air supply and adjust air pressure to approximately 172 to 207 kPa (25 to 30 psi).

CAUTION: To prevent engine damage, do not submerge the oil cooler in water. This will introduce water into oil passages.

3. Spray soapy water on oil cooler and between oil cooler and oil cooler cover.
4. Inspect for air bubbles on the oil cooler as well as between oil cooler and oil cooler cover.
5. If leaks are detected, install a new oil cooler cover assembly.

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

6. Remove soapy water residue and blow off with compressed air.

Installation

Oil Cooler Cover Assembly

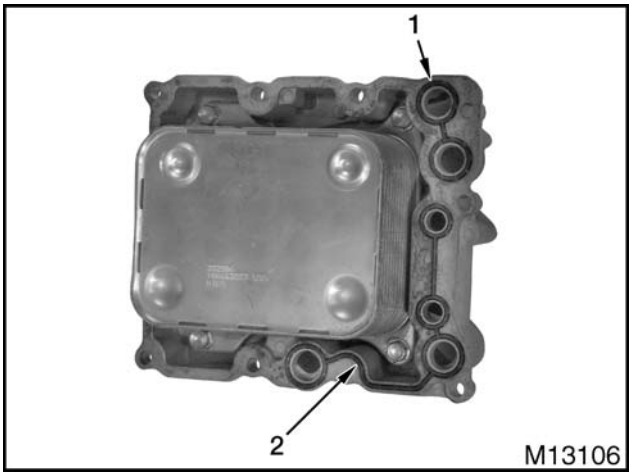


Figure 452 Oil cooler cover gaskets

1. Oil cooler cover gasket (coolant side)
2. Oil cooler cover gasket (oil side)

1. Install new oil cooler cover gasket (coolant side).
2. Install new oil cooler cover gasket (oil side).

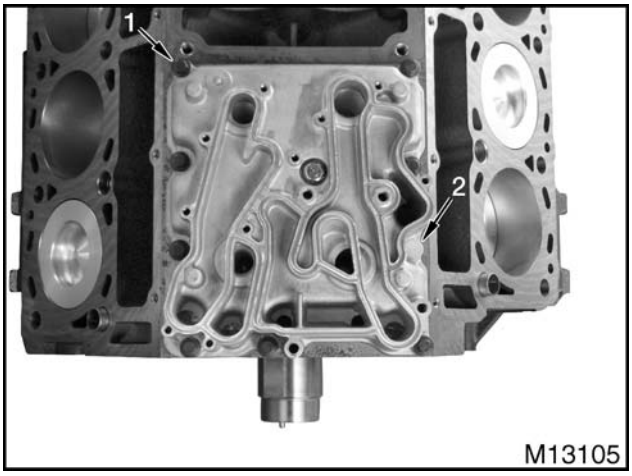


Figure 453 Oil cooler cover assembly

1. M8 x 30 bolt (8)
2. Oil cooler cover assembly

3. Install oil cooler cover assembly and eight M8 x 30 bolts. Tighten bolts to special torque (page 265).

Oil Filter Housing and Oil Filter Base Assemblies

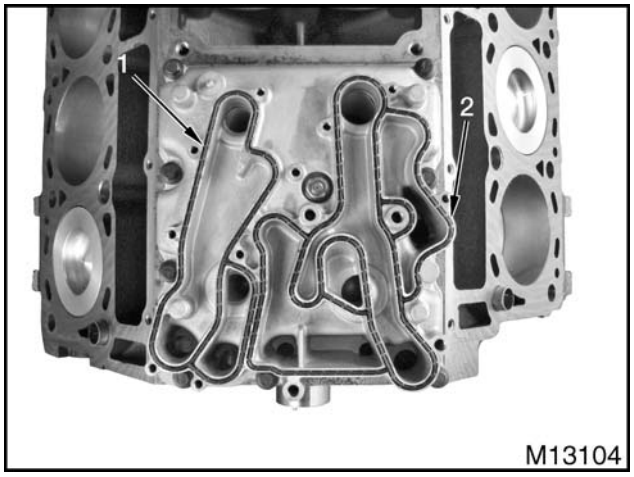


Figure 454 Oil filter base assembly gaskets

1. Base to cover gasket (coolant side)
2. Base to cover gasket (oil side)

1. Install new base to cover gasket (coolant side).
2. Install new base to cover gasket (oil side).

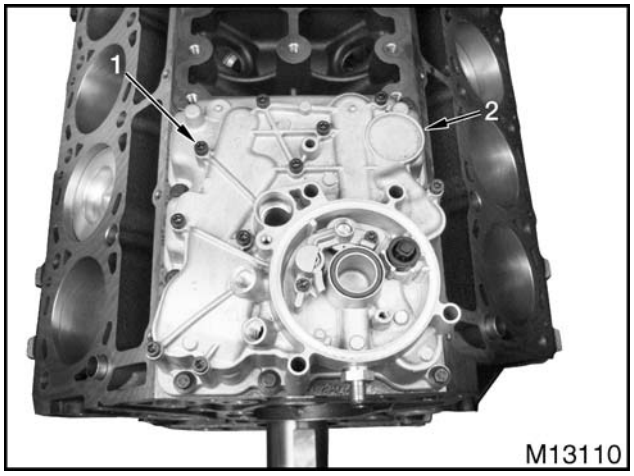


Figure 455 Oil filter base assembly

1. M6 x 25 screw (10)
2. Oil filter base assembly

3. Install oil filter base assembly and ten M6 x 25 screws. Tighten screws to special torque (page 265).

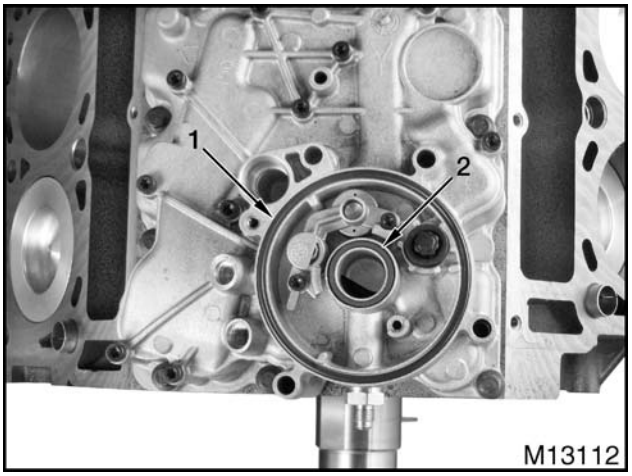


Figure 456 Return tube gasket and O-ring seal

1. O-ring seal
2. Return tube gasket

4. Install a new oil filter return tube gasket and filter housing O-ring seal. Lubricate gasket and seal with clean engine oil.

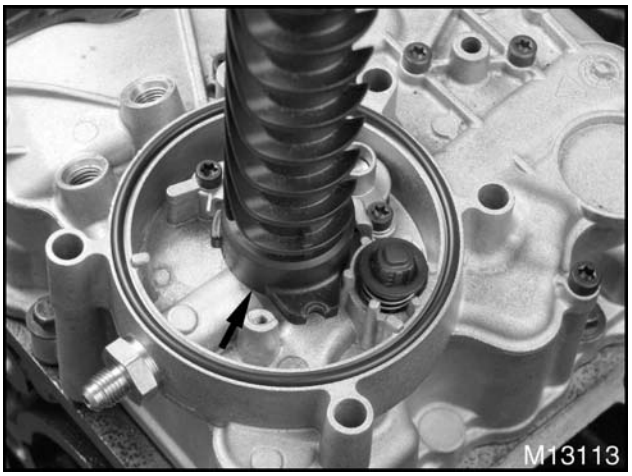


Figure 457 Oil Filter return tube assembly position

5. Install and rotate oil filter return tube assembly clockwise to align hold down tab with screw hole in oil filter base assembly.

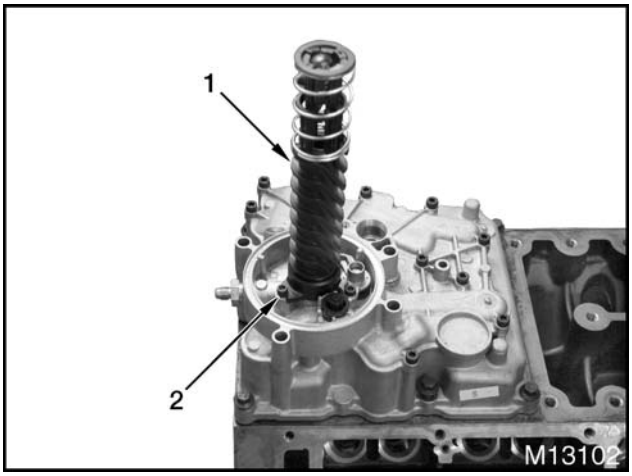


Figure 458 Oil filter return tube assembly

1. Oil filter return tube assembly
2. M5 x 18 screw

6. Install and tighten M5 x 18 oil filter return tube assembly screw to special torque (page 265).

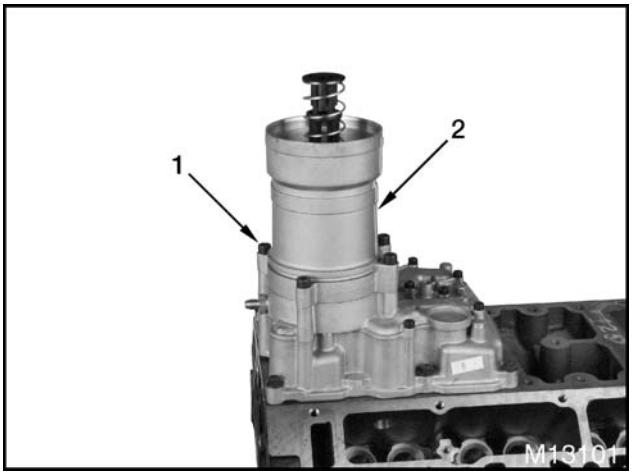


Figure 459 Oil filter housing

1. M8 x 75 bolt (4)
2. Oil filter housing

7. Install oil filter housing and four M8 x 75 bolts. Tighten bolts to special torque (page 265).

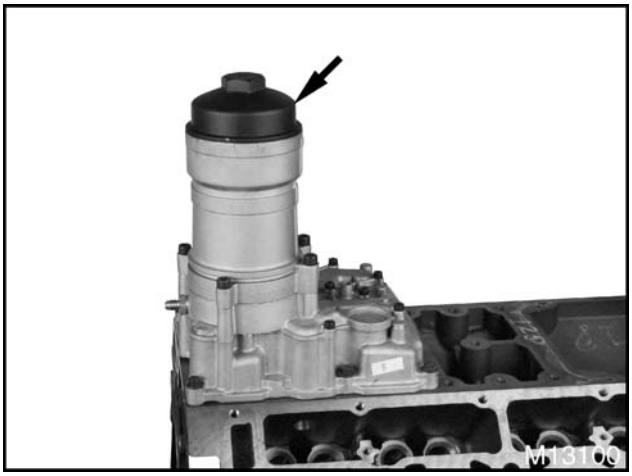


Figure 460 Oil filter cap

8. Install a new oil filter element.
9. Install oil filter cap seal. Lubricate seal with clean engine oil.
10. Install oil filter cap and tighten to special torque (page 265).

Specifications

Table 24 Oil Cooler and Oil Filter

Oil Cooler	
Type	Full flow, fin
Location	Engine valley (forward)
Oil Filter	
Type	Cartridge, full flow - disposable
Location	Front, oil cooler mounted
Filter bypass location	Oil filter return tube assembly

Special Torque

Table 25 Oil Cooler Cover and Oil Filter Housing

Oil cooler cover assembly bolts	31 N·m (23 lbf·ft)
Oil filter cap	26 N·m (18 lbf·ft)
Oil filter return tube assembly screw – with new oil filter base assembly	7 N·m (62 lbf·in)
Oil filter return tube assembly screw – with reinstalled oil filter base assembly	5 N·m (44 lbf·in)
Oil filter housing bolts	22 N·m (125 lbf·in)
Oil filter base assembly screws – with new oil cooler cover assembly	10 N·m (89 lbf·in)
Oil filter base assembly screws – with reinstalled oil cooler cover assembly	7 N·m (62 lbf·in)

Special Service Tools

Table 26 Oil Cooler

Description	Tool Number
Air Pressure Regulator	Obtain locally
Oil Cooler Pressure Test Plate	ZTSE4730

Table of Contents

Exploded Views

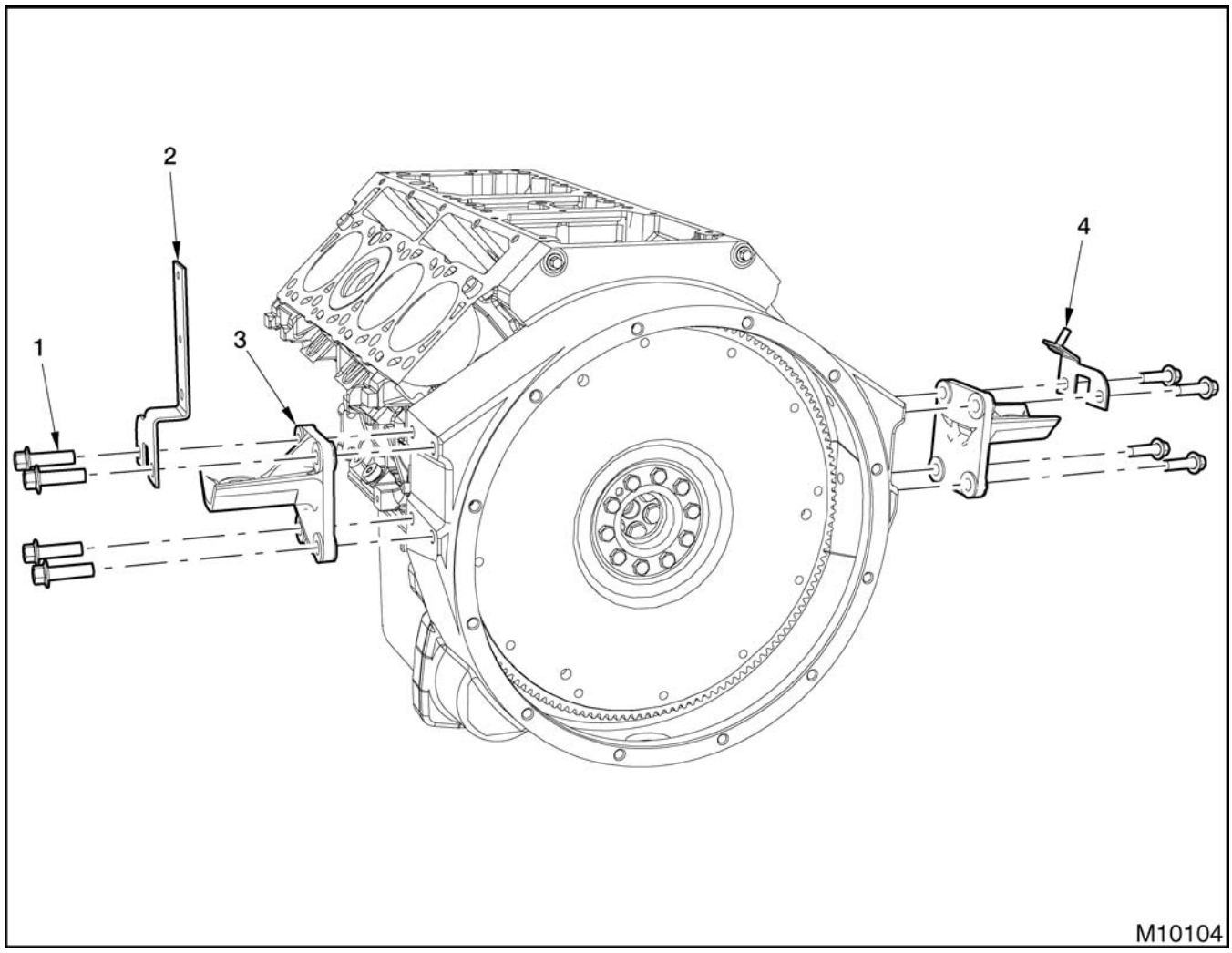


Figure 461 Engine mount rear brackets

1. M12 x 40 bolt (8)
2. Pipe clip bracket
3. Engine mount rear bracket (2)
4. Extension clip

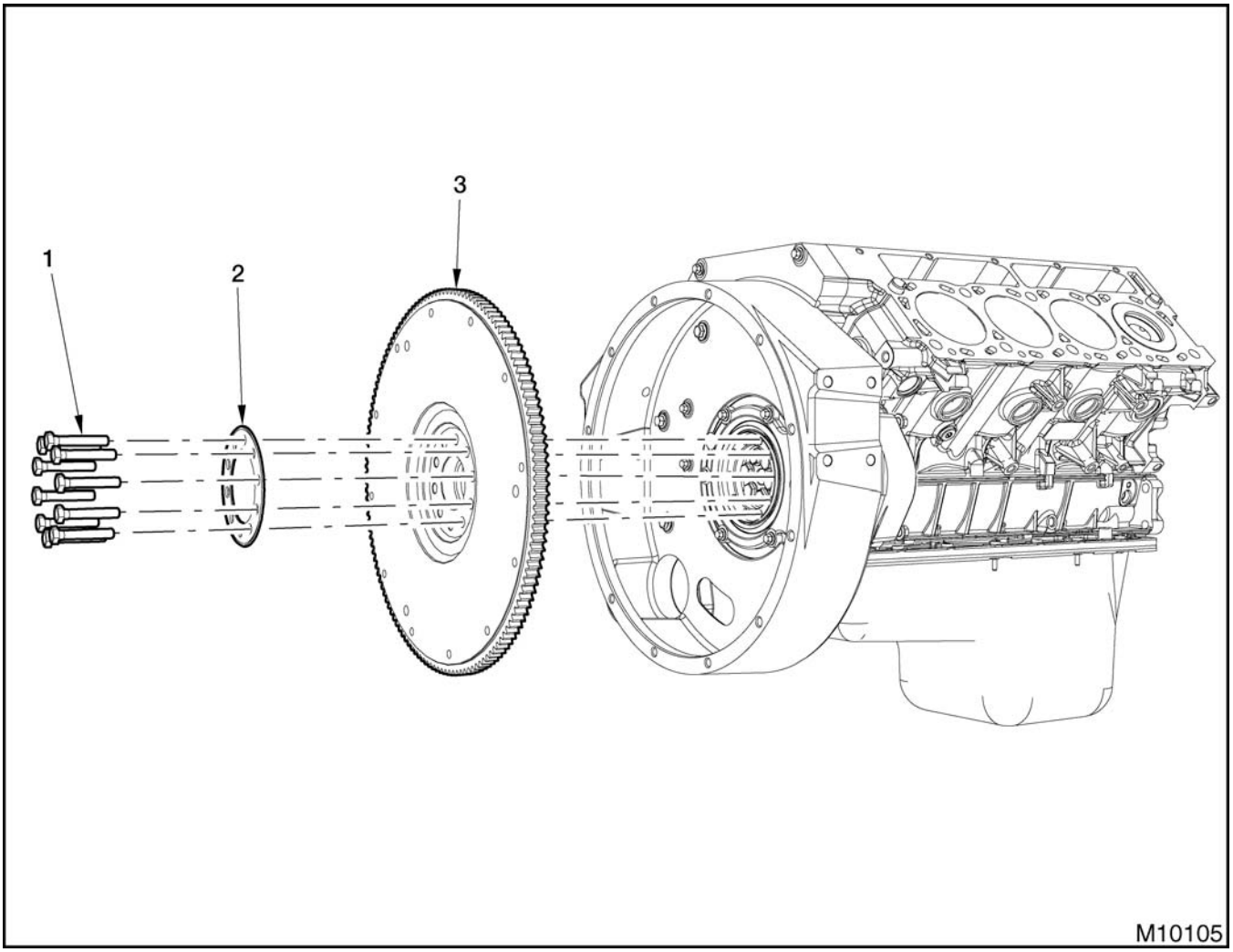


Figure 462 Flywheel assembly (manual transmission)

1. M10 x 55 bolt (10)
2. Reinforcement ring
3. Flywheel assembly

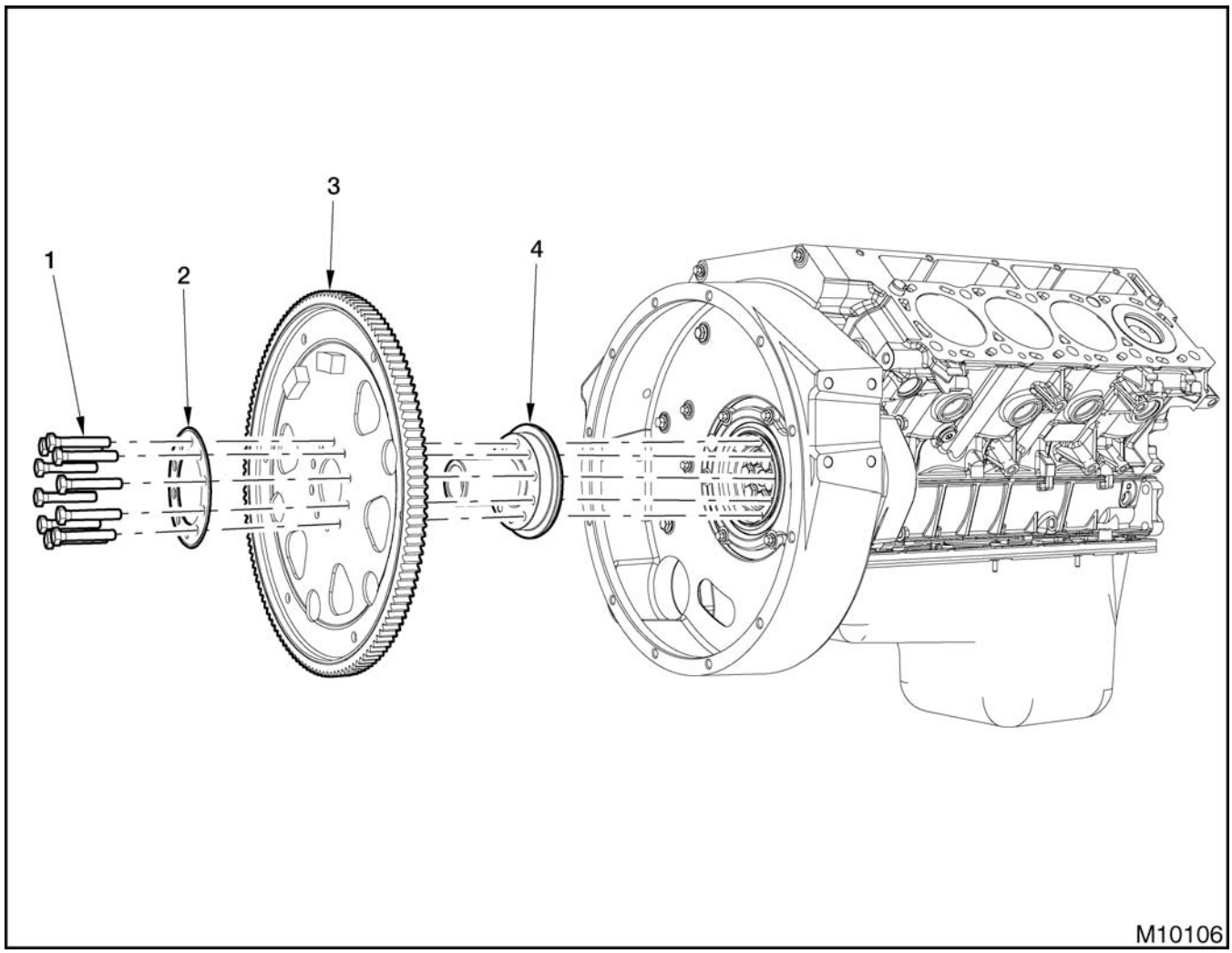


Figure 463 Flexplate assembly (automatic transmission)

1. M10 x 55 bolt (10)
2. Reinforcement ring
3. Flexplate assembly
4. Adapter hub

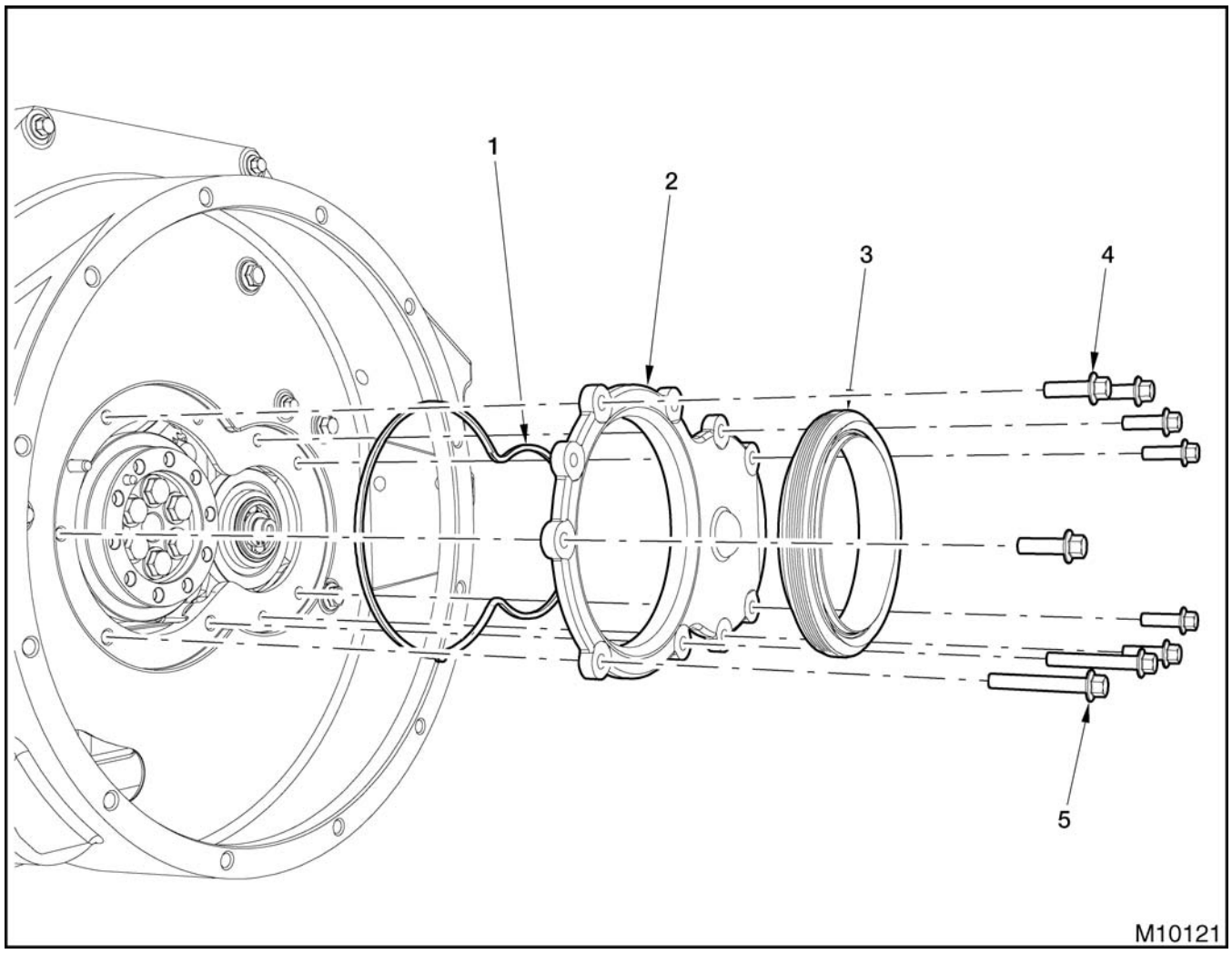


Figure 464 Crankshaft rear oil seal and crankshaft rear oil seal carrier

1. Rear seal carrier gasket
2. Crankshaft rear oil seal carrier
3. Crankshaft rear oil seal
4. M8 x 25 bolt (7)
5. M8 x 55 bolt (2)

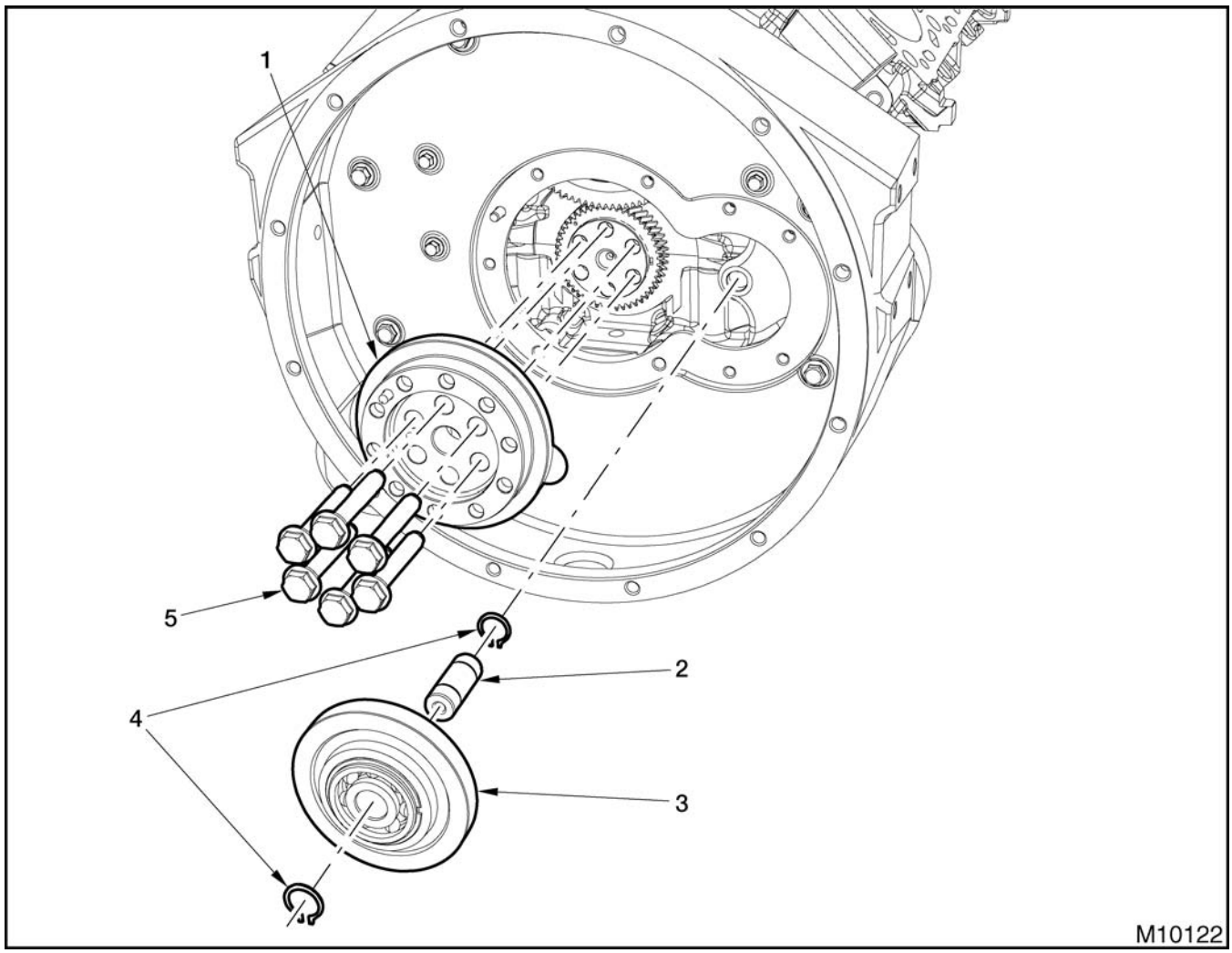


Figure 465 Crankshaft flange and power steering idler gear assembly

1. Crankshaft flange
2. Power steering idler shaft
3. Power steering idler gear assembly
4. External retaining ring (2)
5. M12 x 68 bolt (6)

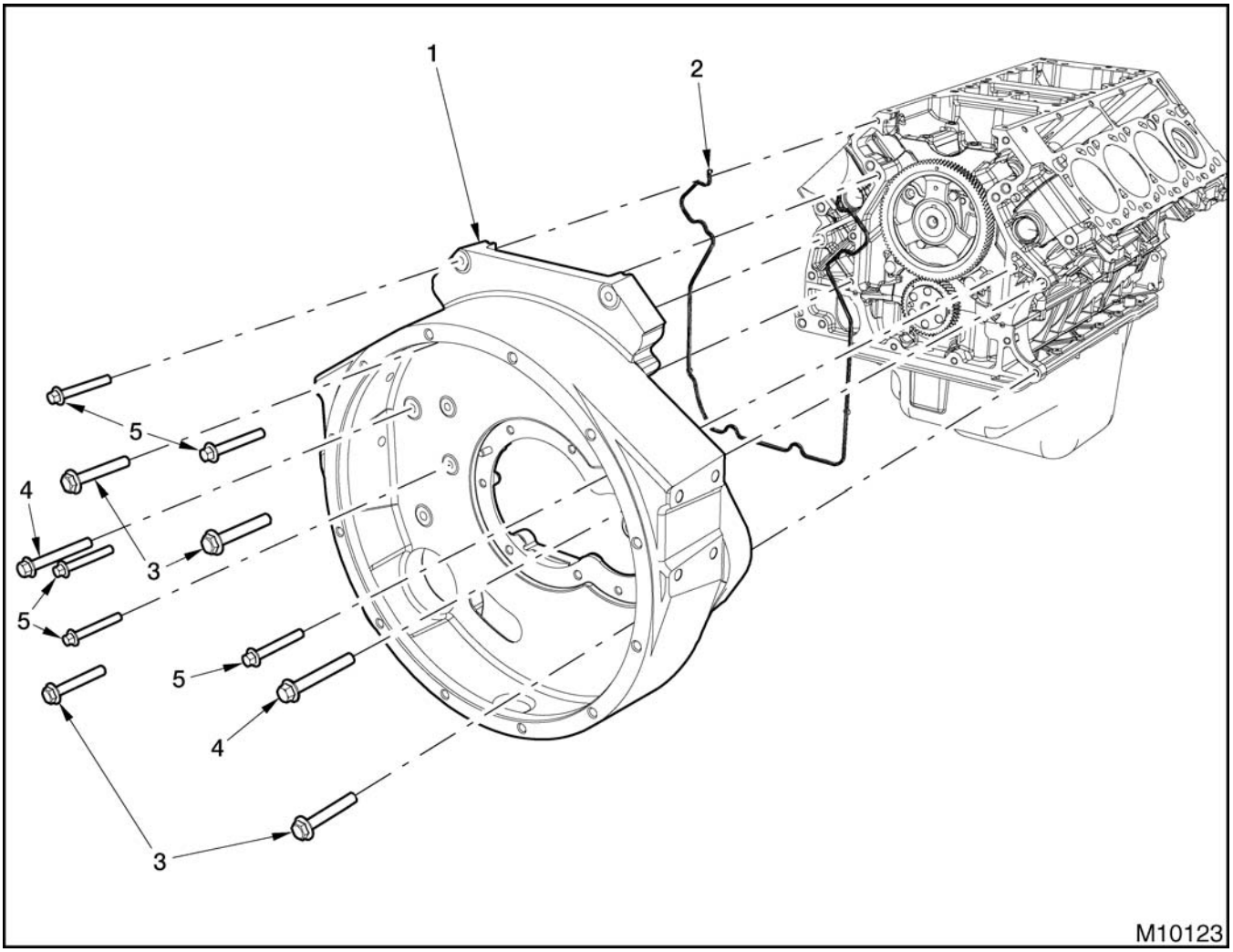


Figure 466 Crankcase rear cover

1. Crankcase rear cover
2. Rear gear cover gasket
3. M10 x 60 bolt (4)
4. M10 x 70 bolt (2)
5. M8 x 55 bolt (5)

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.

- Air Compressor and Power Steering/Fuel Pump

Preliminary Checks

Flexplate Assembly (Automatic Transmission)

CAUTION: To prevent engine damage, install new flexplate if damaged. Flexplates for automatic transmissions cannot be resurfaced.

1. Inspect flexplate assembly for cracks around webbing and ring gear weld points.
2. Inspect all ring gear teeth for starter pinion damage.
3. Replace flexplate assembly if necessary.

Flywheel Assembly (Manual Transmission)

1. Inspect flywheel assembly for cracks around webbing and bolt holes.
2. Inspect flywheel assembly for heat checks and extensive scoring.
3. Inspect all ring gear teeth for starter pinion damage.
4. Replace flywheel assembly if necessary.

Flywheel Assembly Surface Runout

CAUTION: To prevent engine damage, check runout of flywheel surface for correct alignment of engine to transmission. Failure to ensure correct bore concentricity and face runout may reduce life of clutch or transmission.

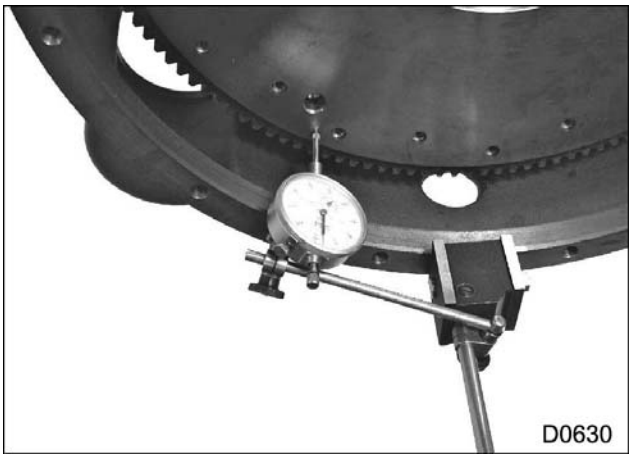


Figure 467 Flywheel assembly surface runout

1. Attach dial indicator with magnetic base (page 290) to crankcase rear cover. Place indicator tip against surface of flywheel assembly between ring gear and outer bolt circle.

NOTE: Keep crankshaft end play at zero and in same direction for all measurements.

2. Zero the dial indicator.
3. Rotate crankshaft slowly. Verify reading is within specification (page 289).

Crankcase Rear Cover Runout

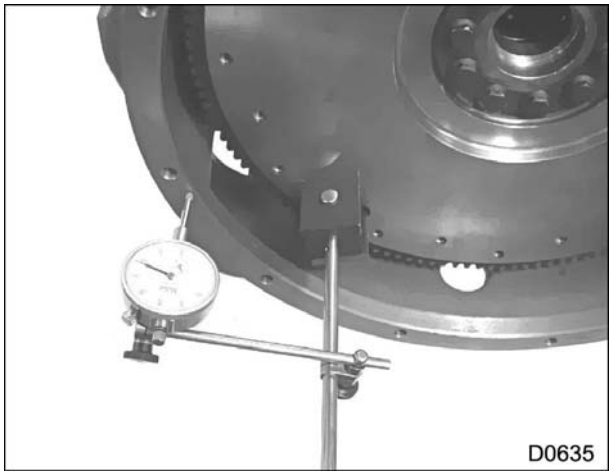


Figure 468 Crankcase rear cover runout

1. Attach dial indicator with magnetic base (page 290) to surface of flywheel assembly. Place indicator tip against crankcase rear cover.

NOTE: Keep crankshaft end play at zero and in same direction for all measurements.

2. Zero the dial indicator.
3. Measure at four points 90° apart for total face variation. Verify the readings are within specification (page 289).

Backlash Test for Power Steering Idler Gear Assembly

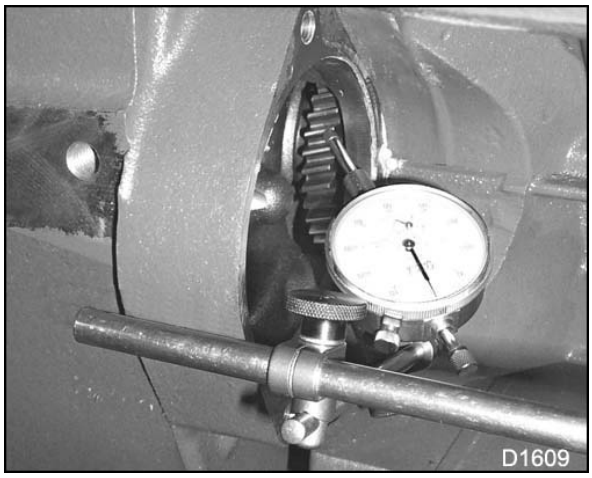


Figure 469 Power steering idler gear assembly backlash

1. Attach dial indicator with magnetic base (page 290) to crankcase rear cover.
2. Place indicator tip against power steering idler gear assembly.

NOTE: Lock crankshaft flange for an accurate measurement.

3. Lock crankshaft flange.
4. Zero the dial indicator.
5. Move power steering idler gear assembly and record dial indicator reading. Verify reading is within specification (page 289).

Engine Mount Rear Brackets

WARNING: To prevent personal injury or death, support engine (if in chassis) before removing rear cover or engine mounts.

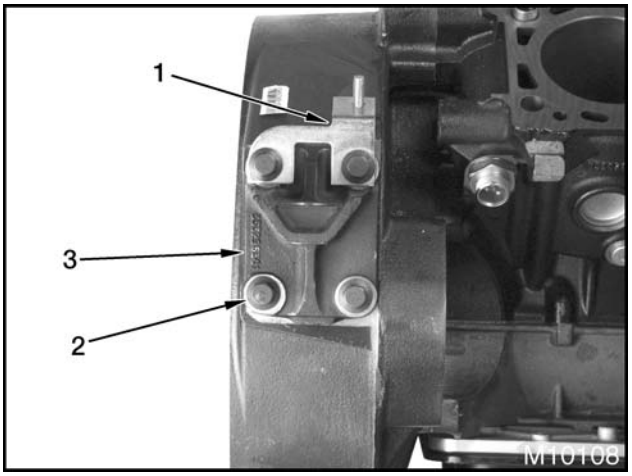


Figure 470 Right engine mount rear bracket

1. Extension clip
2. M12 x 40 bolt (4)
3. Right engine mount rear bracket

1. Remove four M12 x 40 bolts, extension clip, and right engine mount rear bracket.

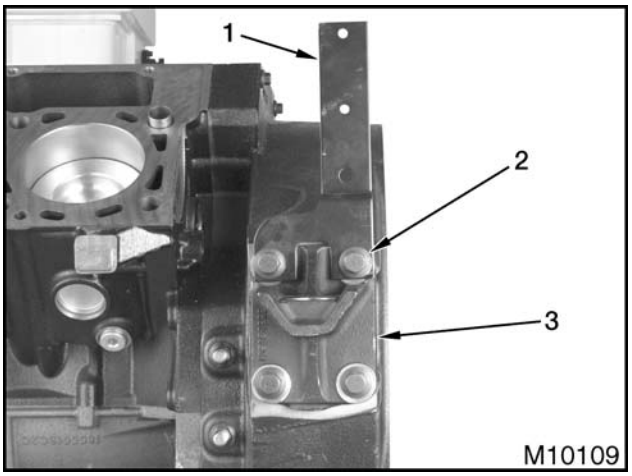


Figure 471 Left engine mount rear bracket

1. Pipe clip bracket
2. M12 x 40 bolt (4)
3. Left engine mount rear bracket

2. Remove four M12 x 40 bolts, pipe clip bracket, and left engine mount rear bracket.

Flywheel Assembly (Manual Transmission)

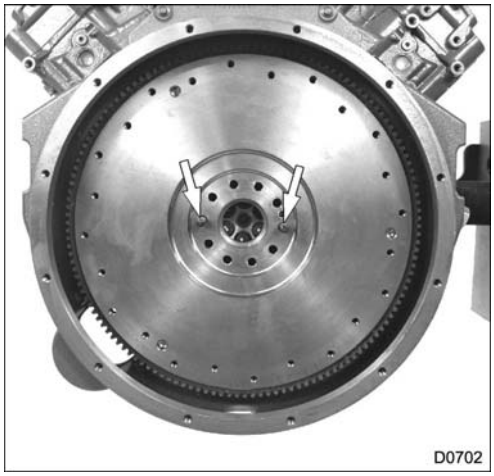


Figure 472 Flywheel assembly guide pins

1. Remove and discard two M10 x 55 bolts at approximately 3 o'clock and 9 o'clock position.
2. Install two guide pins (make locally).
3. Remove and discard remaining eight M10 x 55 bolts.
4. Remove reinforcement ring.

Figure 473 Flywheel assembly removal

5. Slide flywheel assembly off guide pins and out of crankcase rear cover.
6. Remove guide pins from crankshaft flange.

Flexplate Assembly (Automatic Transmission)

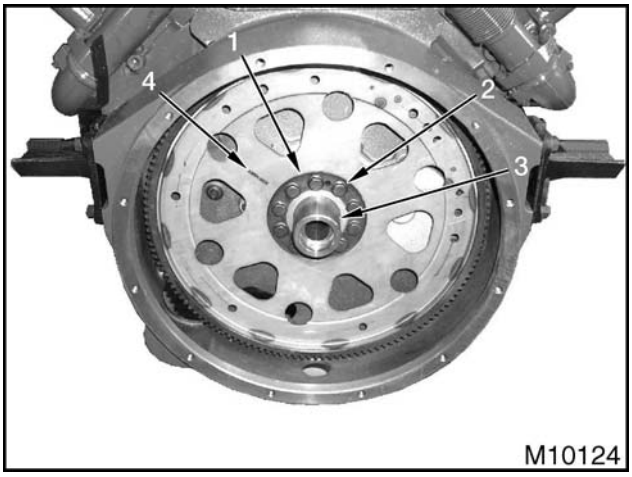


Figure 474 Flexplate assembly

1. Reinforcement ring
2. M10 x 55 bolt (10)
3. Adapter hub
4. XMSN-SIDE stamp

1. Remove and discard 10 M10 x 55 bolts.

CAUTION: To prevent engine damage, carefully remove and store flywheel adapter or adapter hub. Damage to sealing surface of the adapter can cause a rear oil seal leak.

2. Remove reinforcement ring, flexplate assembly, and adapter hub.

Crankshaft Rear Oil Seal and Wear Sleeve

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

1. Use an awl or 1/8 inch drill bit to make two small starter holes 180° apart in crankshaft rear oil seal.

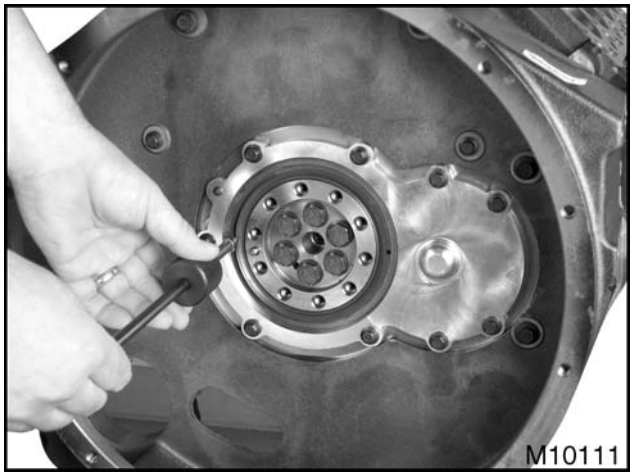


Figure 475 Crankshaft rear oil seal removal

2. Thread slide hammer (page 290) screw into one of the starter holes.

NOTE: To remove seal evenly, slide hammer on one side, and then alternate to other side.

3. Remove and discard crankshaft rear oil seal from crankshaft rear oil seal carrier.

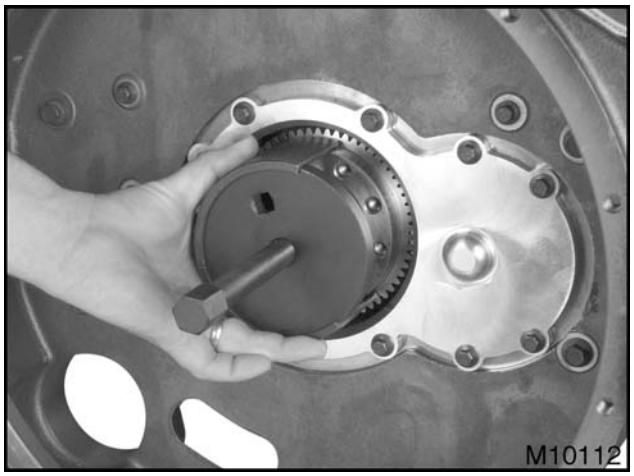


Figure 476 Rear wear sleeve removal tool ZTSE4518 installation

NOTE: When replacing crankshaft rear oil seal, note that production engines will not have a wear sleeve. Wear sleeves are only available as a service item included with replacement crankshaft rear oil seal.

4. Install rear wear sleeve removal tool ZTSE4518 (page 290).

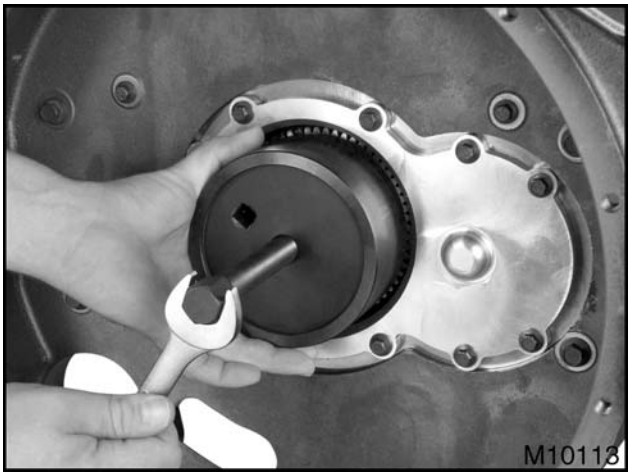


Figure 477 Wear sleeve removal

NOTE: Before applying force to threaded shaft, make sure shells of wear sleeve removal tool are secured behind wear sleeve.

5. Turn threaded shaft clockwise until wear sleeve is free of crankshaft flange.

Crankshaft Flange

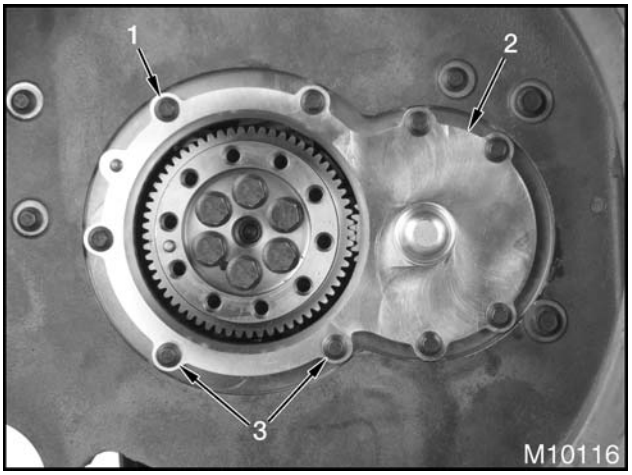


Figure 478 Crankshaft rear oil seal carrier

1. M8 x 25 bolt (7)
2. Crankshaft rear oil seal carrier
3. M8 x 55 bolt (2)

1. Remove seven M8 x 25 bolts and two M8 x 55 bolts from crankshaft rear oil seal carrier.
2. Remove crankshaft rear oil seal carrier and discard rear seal carrier gasket.

NOTE: Perform power steering idler gear assembly backlash test (page 276).

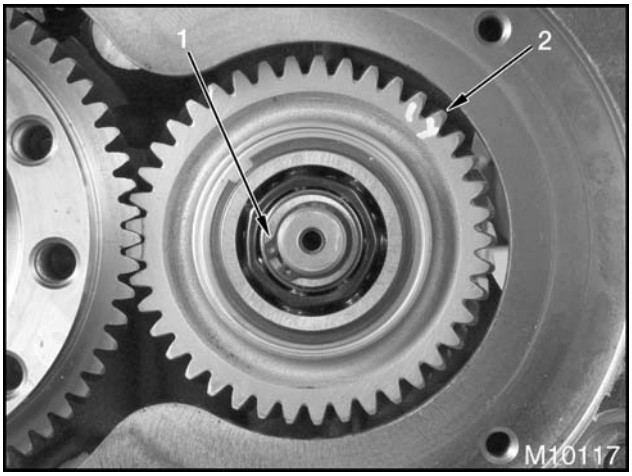


Figure 479 Power steering idler gear assembly

1. External retaining ring
2. Power steering idler gear assembly

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

3. Remove external retaining ring from power steering idler gear assembly.
4. Remove power steering idler gear assembly.

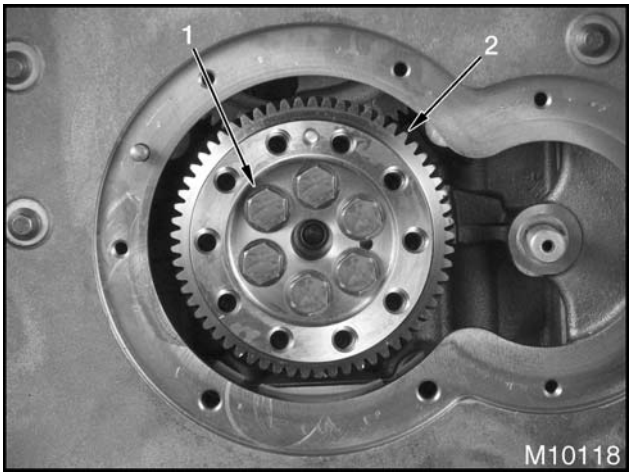


Figure 480 Crankshaft flange

1. M12 x 68 bolt (6)
2. Crankshaft flange

NOTE: Save crankshaft flange bolts for installation procedure.

5. Remove six M12 x 68 bolts from crankshaft flange.

CAUTION: To prevent engine damage, do not mar sealing surface of crankshaft flange.

6. Use a bar type gear puller (page 290) and remove crankshaft flange from crankshaft.

Crankcase Rear Cover and Power Steering Idler Shaft

WARNING: To prevent personal injury or death, support engine (if in chassis) before removing rear cover or engine mounts.

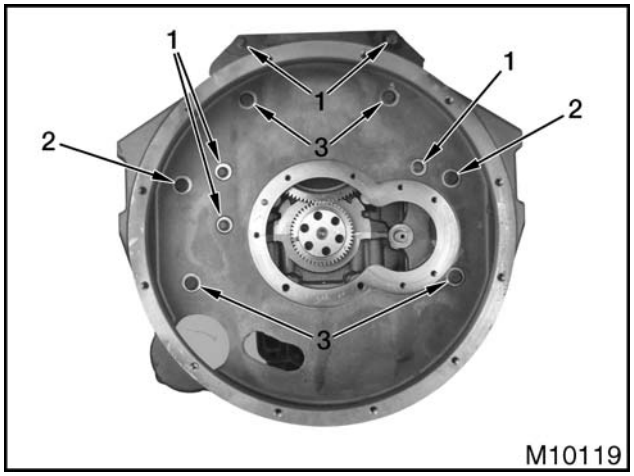


Figure 481 Crankcase rear cover mounting bolts

1. M8 x 55 bolt (5)
2. M10 x 70 bolt (2)
3. M10 x 60 bolt (4)

1. Remove 11 mounting bolts from crankcase rear cover.

CAUTION: To prevent engine damage, when removing crankcase rear cover, do not pull out gasket between upper and lower crankcase.

2. Use a thin gasket scraper to separate sealant between rear gear cover gasket and upper and lower crankcase joint. This will avoid pulling the gasket out when removing crankcase rear cover assembly.

WARNING: To prevent personal injury or death, get help when removing or installing the crankcase rear cover.

3. Remove crankcase rear cover with aid of an assistant.
4. Remove and discard rear gear cover gasket.
5. If necessary, use a slide hammer (page 290) to remove power steering idler shaft.

Cleaning

All Components

1. Clean foreign material from gasket surfaces of upper and lower crankcase assemblies and crankcase rear cover. Use a scraper or wire brush to remove sealant from gasket surfaces.
2. Gasket surfaces must be oil-free for good adhesion of liquid gasket during assembly. Use a commercially available, non-caustic brake cleaner to clean gasket surfaces of upper and lower crankcase assemblies and crankcase rear cover.

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

3. Wash crankshaft rear oil seal carrier, flywheel assembly or flexplate assembly, and crankcase rear cover. Dry all with filtered compressed air.
4. Wash crankcase flange, power steering idler gear assembly, and power steering idler shaft with a stiff brush and suitable solvent. Dry all with filtered compressed air.

Installation

Crankcase Rear Cover and Power Steering Idler Shaft

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

1. If removed, install power steering idler shaft into crankcase rear cover. Make sure bore of crankcase rear cover is clean.

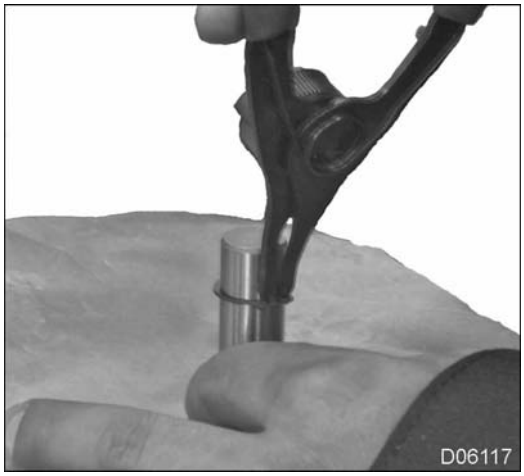


Figure 482 External retaining ring on power steering idler shaft

2. Place external retaining ring on end of power steering idler shaft without threaded hole.

Figure 483 Power steering idler shaft and external retaining ring in power steering idler shaft installation tool ZTSE4719

3. Put threaded hole end of power steering idler shaft into power steering idler shaft installation tool ZTSE4719 (page 290) to set correct installed height (page 289).

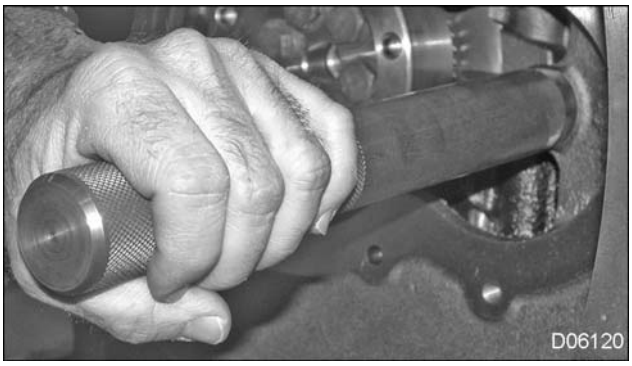


Figure 484 Power steering idler shaft installation

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

CAUTION: To prevent engine damage, do not allow external retaining ring to contact crankcase rear cover. Contact can distort external retaining ring, affecting its function as a gear thrust surface.

4. Align power steering idler shaft in crankcase rear cover at correct location. Using power steering idler shaft installation tool ZTSE4719 (page 290), drive power steering idler shaft into bore in transmission side of crankcase rear cover, until power steering idler shaft installation tool bottoms out.

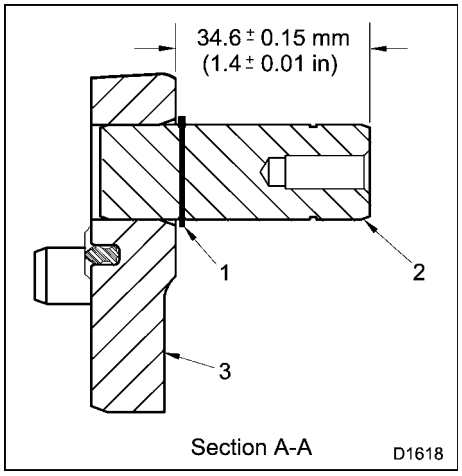


Figure 485 Power steering idler shaft installation height

1. External retaining ring
2. Power steering idler shaft
3. Crankcase rear cover

5. If installation tool is not available, use brass drift to install power steering idler shaft in crankcase rear cover to correct height.

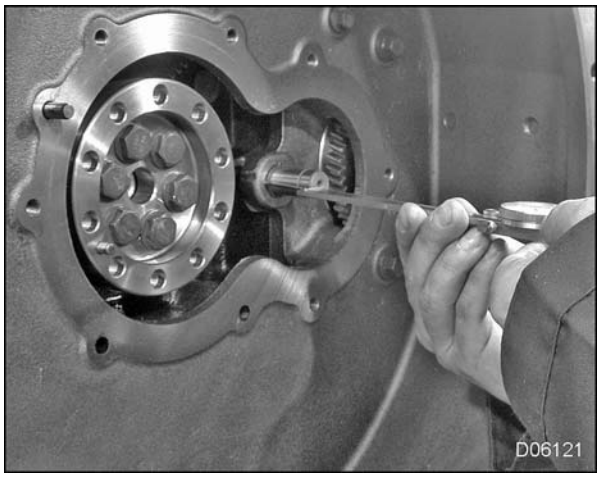


Figure 486 Power steering idler shaft height measurement

6. Measure power steering idler shaft height, using a dial caliper (page 290). Power steering idler shaft height should match specification (page 289).
7. Install new rear gear cover gasket.

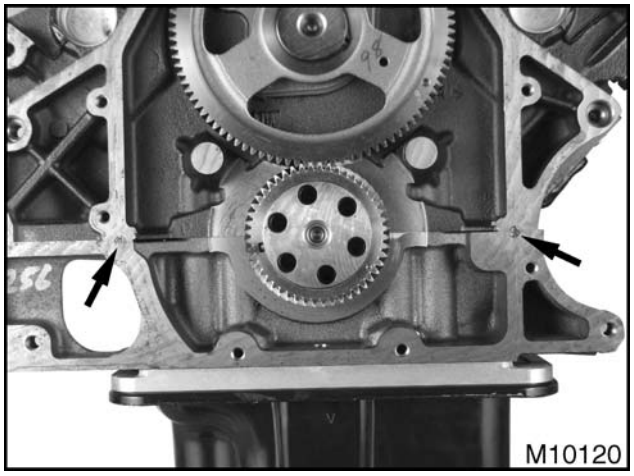


Figure 487 Application of sealant

WARNING: To prevent personal injury or death, get help when removing or installing the crankcase rear cover.

CAUTION: To prevent engine damage, do not allow Liquid Gasket (RTV) to set longer than 5 minutes before tightening joint.

8. Apply Liquid Gasket (RTV) (page 290) at ends where crankcase and lower crankcase meet.
9. Install crankcase rear cover with aid of an assistant.

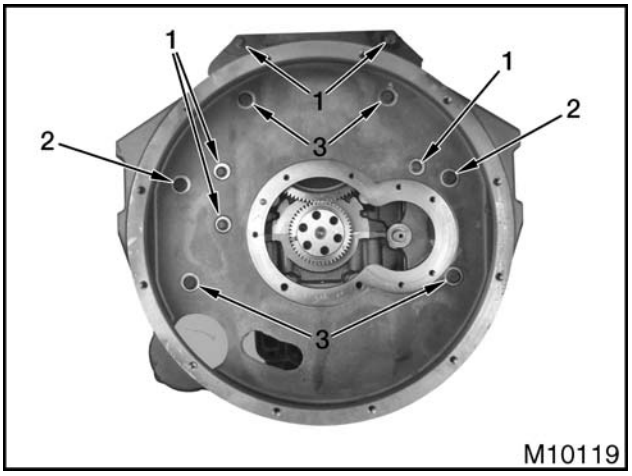


Figure 488 Crankcase rear cover mounting bolts

1. M8 x 55 bolt (5)
2. M10 x 70 bolt (2)
3. M10 x 60 bolt (4)

10. Install 11 crankcase rear cover bolts. Tighten all bolts to special torque (page 289).

Crankshaft Flange

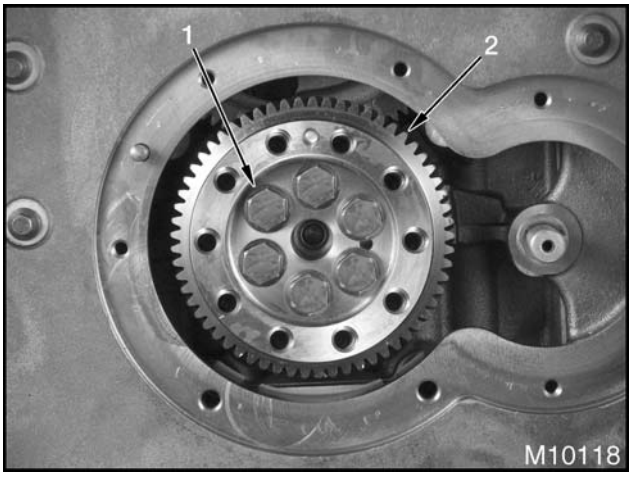


Figure 489 Crankshaft flange

1. M12 x 68 bolt (6)
2. Crankshaft flange

CAUTION: To prevent engine damage, the crankshaft flange must be properly timed to maintain correct engine balance.

1. Rotate crankshaft until cylinder number 1 is at Top Dead Center (TDC).
2. Inspect the crankshaft gear and crankshaft flange mating surfaces. Make sure they are free of debris, nicks, and dirt.
3. Install two guide pins (made locally) into crankshaft gear bolt holes.

WARNING: To prevent serious personal injury or death, wear heat protective gloves when installing hot crankshaft flange.

4. Heat crankshaft flange to 177° C (350° F).

CAUTION: To prevent engine damage, do not mar sealing surface of crankshaft flange.

NOTE: Make sure dowel pin is installed correctly in crankshaft flange.

5. Install crankshaft flange over guide pins and onto crankshaft, with dowel pin pointing at 12 o'clock position.
6. Remove guide pins and install six old M12 x 68 bolts. Tighten bolts alternately to seat crankshaft flange.

7. Check face runout of crankshaft flange, using dial indicator with magnetic base (page 290). If face runout exceeds specification (page 289), replace crankshaft flange.

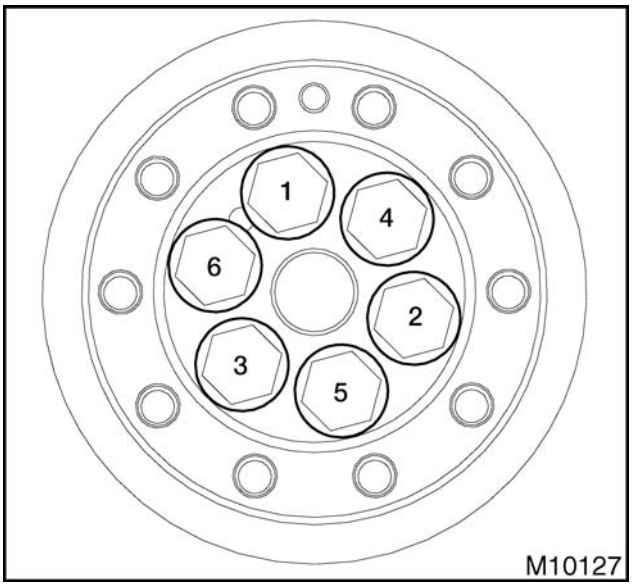


Figure 490 Crankshaft flange torque sequence

CAUTION: To prevent engine damage, always install new crankshaft flange mounting bolts.

8. Remove and discard six old bolts and loosely install six new M12 x 68 bolts. Tighten bolts as follows using above sequence:
   a. Tighten bolts to 41 N·m (30 lbf·ft)
   b. Rotate bolts 90 degrees using above sequence.
   c. Rotate bolts an additional 90 degrees using above sequence.

CAUTION: To prevent engine damage, install gear with circular witness groove facing out.

9. Install power steering idler gear assembly on power steering idler shaft.
10. Verify correct gear orientation and gear tooth engagement.

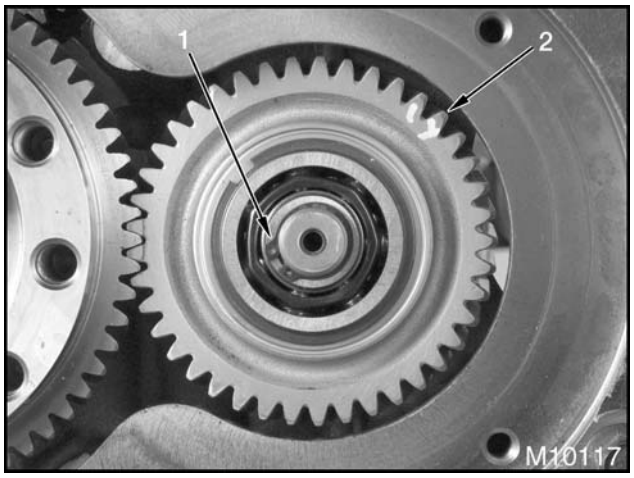


Figure 491 Power steering idler gear assembly

1. External retaining ring
2. Power steering idler gear assembly

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

11. Install external retaining ring onto power steering idler shaft for power steering idler gear assembly.
12. Perform power steering idler gear assembly backlash test (page 276).
13. Install new rear seal carrier gasket on crankshaft rear oil seal carrier.

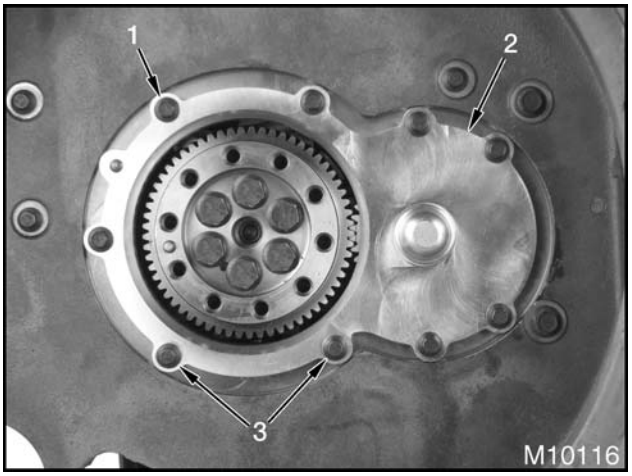


Figure 492 Crankshaft rear oil seal carrier

1. M8 x 25 bolt (7)
2. Crankshaft rear oil seal carrier
3. M8 x 55 bolt (2)

14. Install crankshaft rear oil seal carrier on crankcase rear cover.
15. Install two M8 x 55 bolts in lower holes of crankshaft rear oil seal carrier. Tighten bolts to special torque (page 289).
16. Install seven M8 x 25 bolts in crankshaft rear oil seal carrier. Tighten bolts to special torque (page 289).

Crankshaft Rear Oil Seal and Wear Sleeve

NOTE: When replacing crankshaft rear oil seal, note that production engines will not have a wear sleeve. Wear sleeves are only available as a service item included with replacement crankshaft rear oil seal.

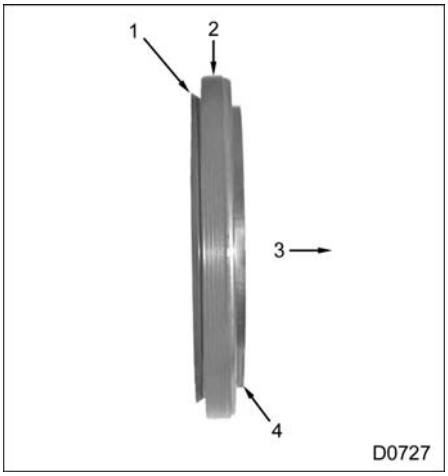


Figure 493 Orientation of crankshaft rear oil seal and wear sleeve

1. Dust seal lip
2. Crankshaft rear oil seal
3. Crankshaft side (forward)
4. Wear sleeve (internal bevel)

CAUTION: To prevent engine damage, do not separate wear sleeve from new oil seal; this will damage seal.

NOTE: Before assembly, lubricate outer diameter of crankshaft rear oil seal with a solution of dish soap and water (approximately 50/50 mix). Do not use other lubricants.

1. Put a 360° bead of hydraulic sealant, such as Loctite® 569 (page 290) or equivalent, onto rear edge of crankshaft flange.

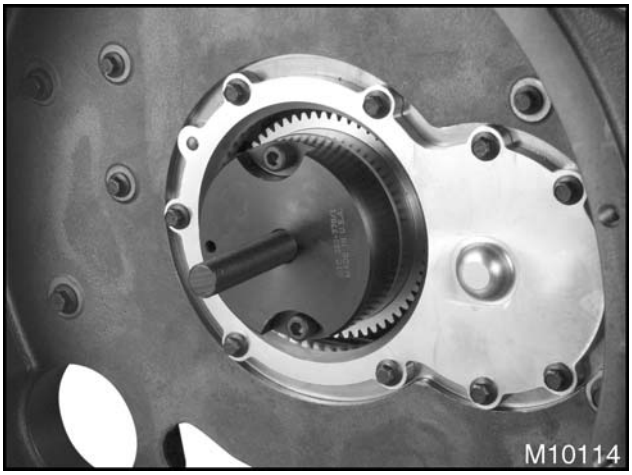


Figure 494 Rear wear sleeve installer ZTSE4515

2. Attach hub of rear wear sleeve installer ZTSE4515 (page 290) on end of crankshaft. Make sure crankshaft alignment dowel fits in recess hole in rear/wear sleeve installer hub.
3. Position a new crankshaft rear oil seal and wear sleeve onto rear wear sleeve installer hub.

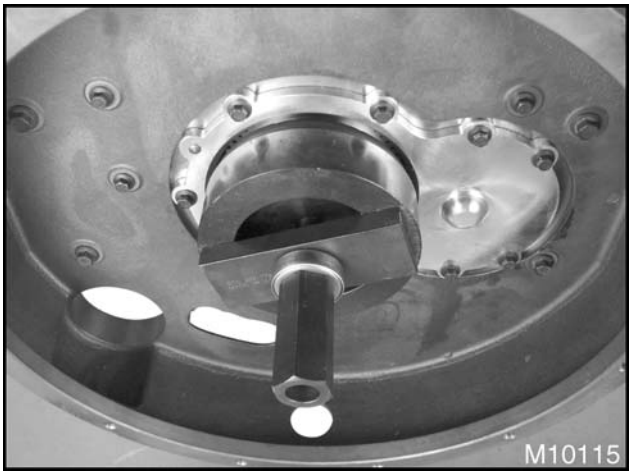


Figure 495 Crankshaft rear oil seal and wear sleeve installation

NOTE: Do not use an air impact wrench to install new crankshaft rear oil seal.

4. Place forcing collar, thrust bearing, and drive nut on threaded shaft. Tighten nut until crankshaft rear oil seal bottoms out in crankshaft rear oil seal carrier.

Flexplate Assembly (Automatic Transmission)

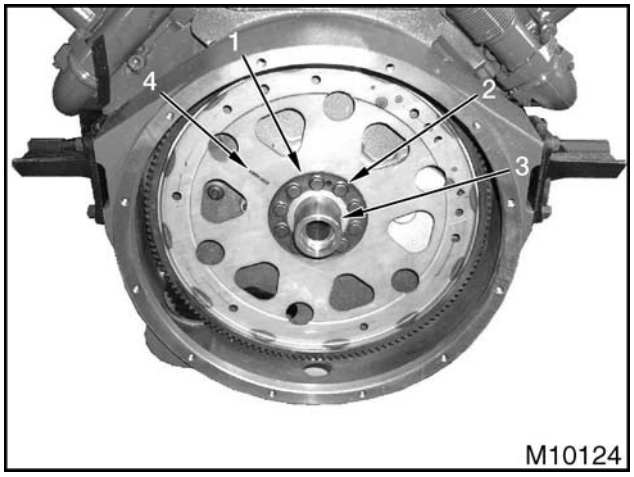


Figure 496 Flexplate assembly

1. Reinforcement ring
2. M10 x 55 bolt (10)
3. Adapter hub
4. XMSN-SIDE stamp

1. Position flexplate assembly on adapter hub and align hub over crankshaft flange dowel. Make sure XMSN-SIDE stamp is facing transmission.

CAUTION: To prevent engine damage, always install new flywheel or flexplate mounting bolts.

CAUTION: To prevent engine damage, do not use anti-seize compounds or grease on new flywheel or flexplate mounting bolts.

NOTE: Make sure lip on outer circumference of reinforcement ring faces transmission and align bolt holes to position reinforcement ring.

2. Install two new M10 x 55 bolts 180° apart through reinforcement ring, flexplate assembly, and adapter hub. Hand tighten two bolts to hold assembly.
3. Install eight remaining new M10 x 55 bolts.

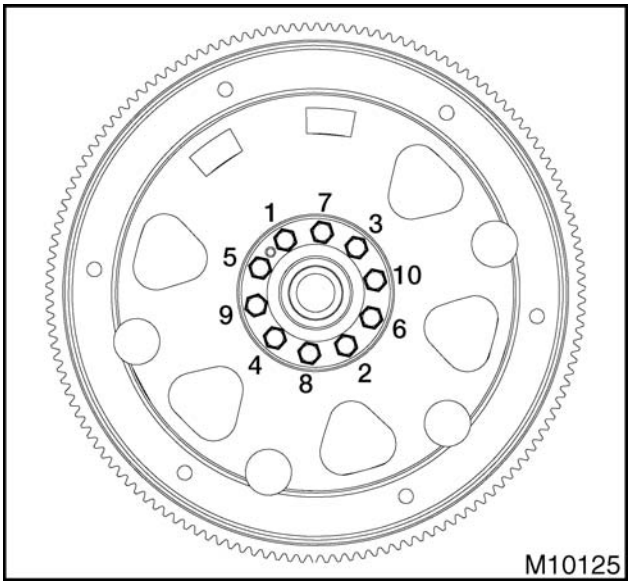


Figure 497 Torque sequence for flexplate assembly

NOTE: New phosphate coated bolts do not require oil before torquing.

4. Tighten all bolts in sequence shown (Figure 497) to initial torque of 4 N·m (35 lbf·in).
5. Tighten all bolts in sequence shown (Figure 497) to final torque of 94 N·m (69 lbf·ft).

Flywheel Assembly (Manual Transmission)

Figure 498 Flywheel assembly installation

WARNING: To prevent personal injury or death, inspect flywheel for cracks or heat checks after resurfacing. Do not install flywheel if damaged or questionable. Flywheel resurfacing information is provided for guidance only. INTERNATIONAL does not assume responsibility for work done by service personnel.

1. Install two guide pins (made locally) in crankshaft flange at approximately 3 o'clock and 9 o'clock.
2. Align dowel hole in flywheel assembly with crankshaft flange dowel and slide flywheel assembly onto guide pins.
3. Align reinforcement ring with dowel and slide over guide pins. Make sure lip on outer circumference of ring faces transmission.

CAUTION: To prevent engine damage, always install new flywheel or flexplate mounting bolts.

CAUTION: To prevent engine damage, do not use anti-seize compounds or grease on new flywheel or flexplate mounting bolts.

4. Install two new M10 x 55 bolts to secure flywheel assembly to crankshaft flange. Remove both guide pins.
5. Install eight remaining new M10 x 55 bolts.

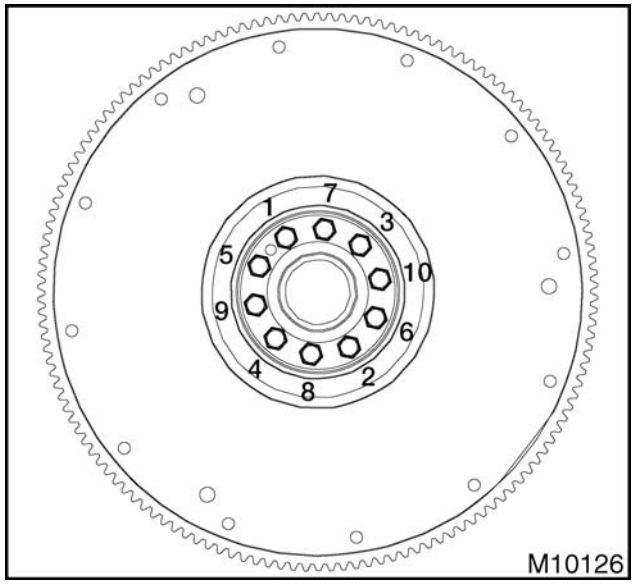


Figure 499 Torque sequence for flywheel assembly

NOTE: New phosphate coated bolts do not require oil before torquing.

6. Tighten all bolts in sequence shown (Figure 499) to initial torque of 4 N·m (35 lbf·in).
7. Tighten all bolts in sequence shown (Figure 499) to final torque of 94 N·m (69 lbf·ft).

Engine Mount Rear Brackets

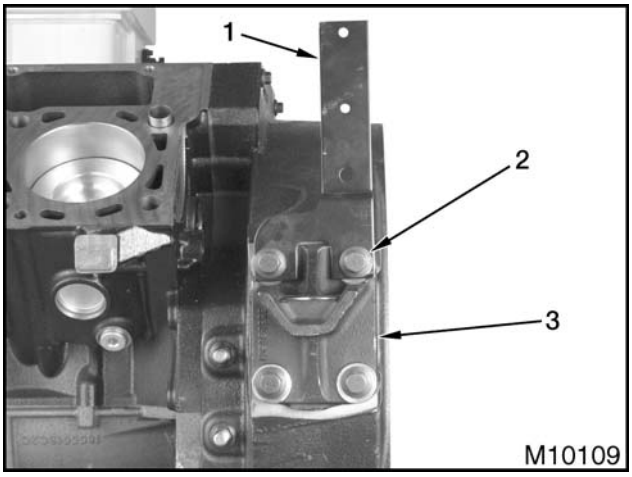


Figure 500 Left engine mount rear bracket

1. Pipe clip bracket
2. M12 x 40 bolt (4)
3. Left engine mount rear bracket

1. Install left engine mount rear bracket, pipe clip bracket, and four M12 x 40 bolts. Tighten bolts to special torque (page 289).

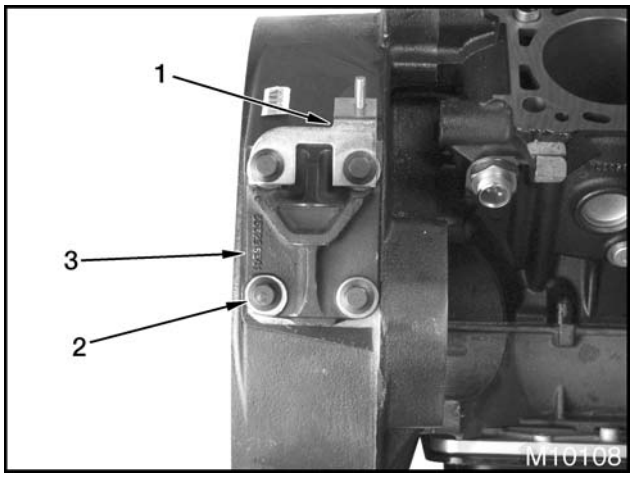


Figure 501 Right engine mount rear bracket

1. Extension clip
2. M12 x 40 bolt (4)
3. Right engine mount rear bracket

2. Install right engine mount rear bracket, extension clip, and four M12 x 40 bolts. Tighten bolts to special torque (page 289).

Specifications

Table 27 Flywheel and Flywheel Housing

Flywheel Assembly	
Flywheel assembly surface maximum runout (manual)	0.25 mm (0.010 in)
Power Steering Idler Shaft	
Power steering idler shaft height	34.6 ± 0.15 mm (1.4 ± 0.01 in)
Crankcase Rear Cover	
Crankcase rear cover maximum runout	0.51 mm (0.020 in)
Crankshaft Flange and Power Steering Idler Gear Assembly	
Face runout:	
Crankshaft flange	0.050 mm (0.002 in) maximum
Backlash:	
Power steering idler gear assembly	0.066 to 0.290 mm (0.0026 to 0.0114 in)

Special Torque

Table 28 Flywheel and Flywheel Housing

Crankshaft flange bolts	See tightening steps in procedure.
Crankshaft rear oil seal carrier bolts	31 N·m (23 lbf·ft)
Engine mount rear bracket bolts	107 N·m (79 lbf·ft)
Flexplate assembly bolts	See tightening steps in procedure.
Flywheel assembly bolts	See tightening steps in procedure.
M8 crankcase rear cover bolts	31 N·m (23 lbf·ft)
M10 crankcase rear cover bolts	61 N·m (45 lbf·ft)

Special Service Tools

Table 29 Flywheel and Flywheel Housing

Description	Tool Number
Dial caliper	Obtain locally
Dial indicator with magnetic base	Obtain locally
Gear puller (bar type)	Obtain locally
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Loctite® 569 hydraulic sealant or equivalent	Obtain locally
Power steering idler shaft installation tool	ZTSE4719
Rear wear sleeve installer	ZTSE4515
Rear wear sleeve removal tool	ZTSE4518
Slide hammer	Obtain locally

Table of Contents

Exploded Views

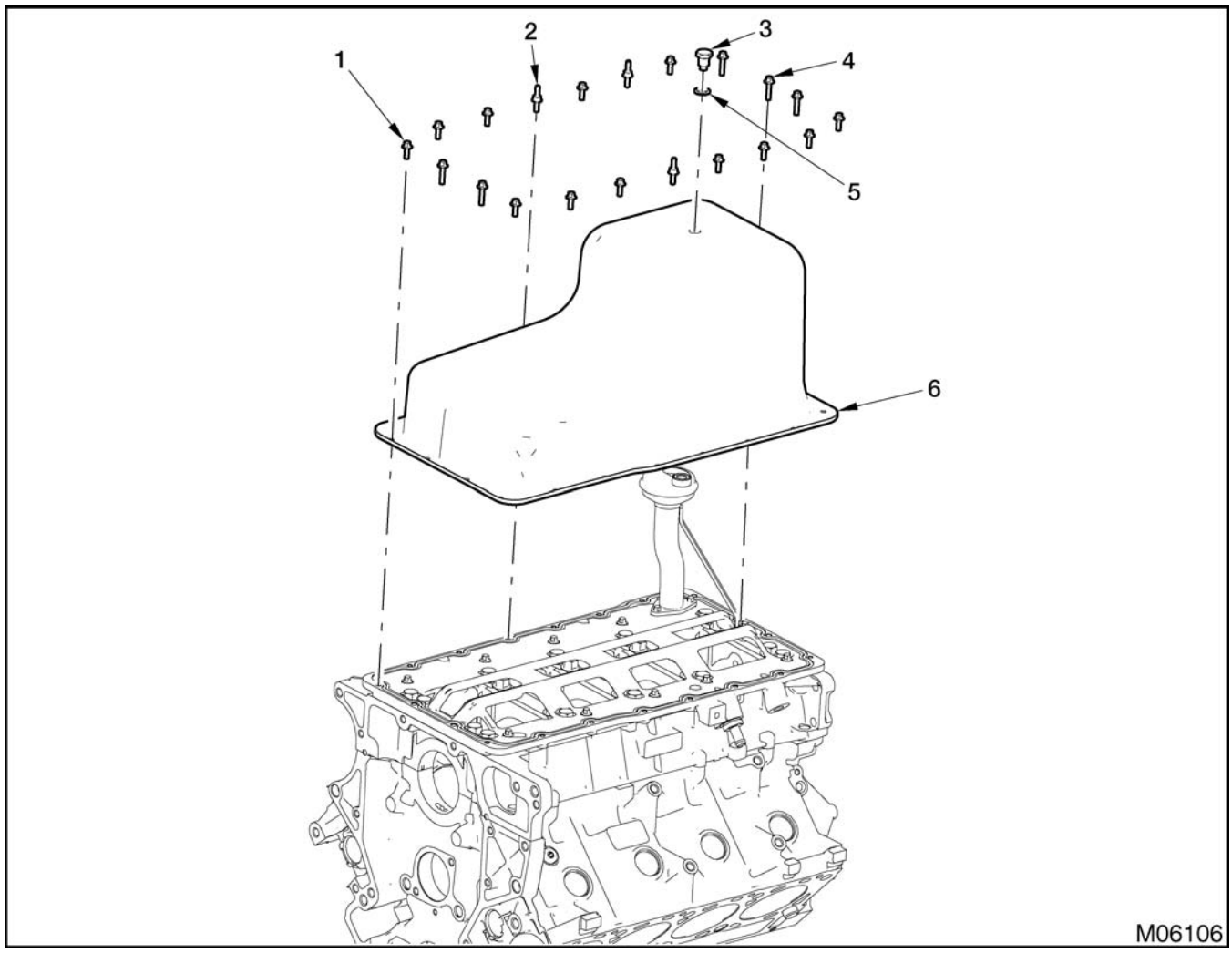


Figure 502 Lower oil pan

1. M6 x 16 bolt (12)
2. M6 x 16 stud bolt (3)
3. Oil pan drain plug
4. M6 x 25 bolt (5)
5. Drain plug gasket
6. Lower oil pan

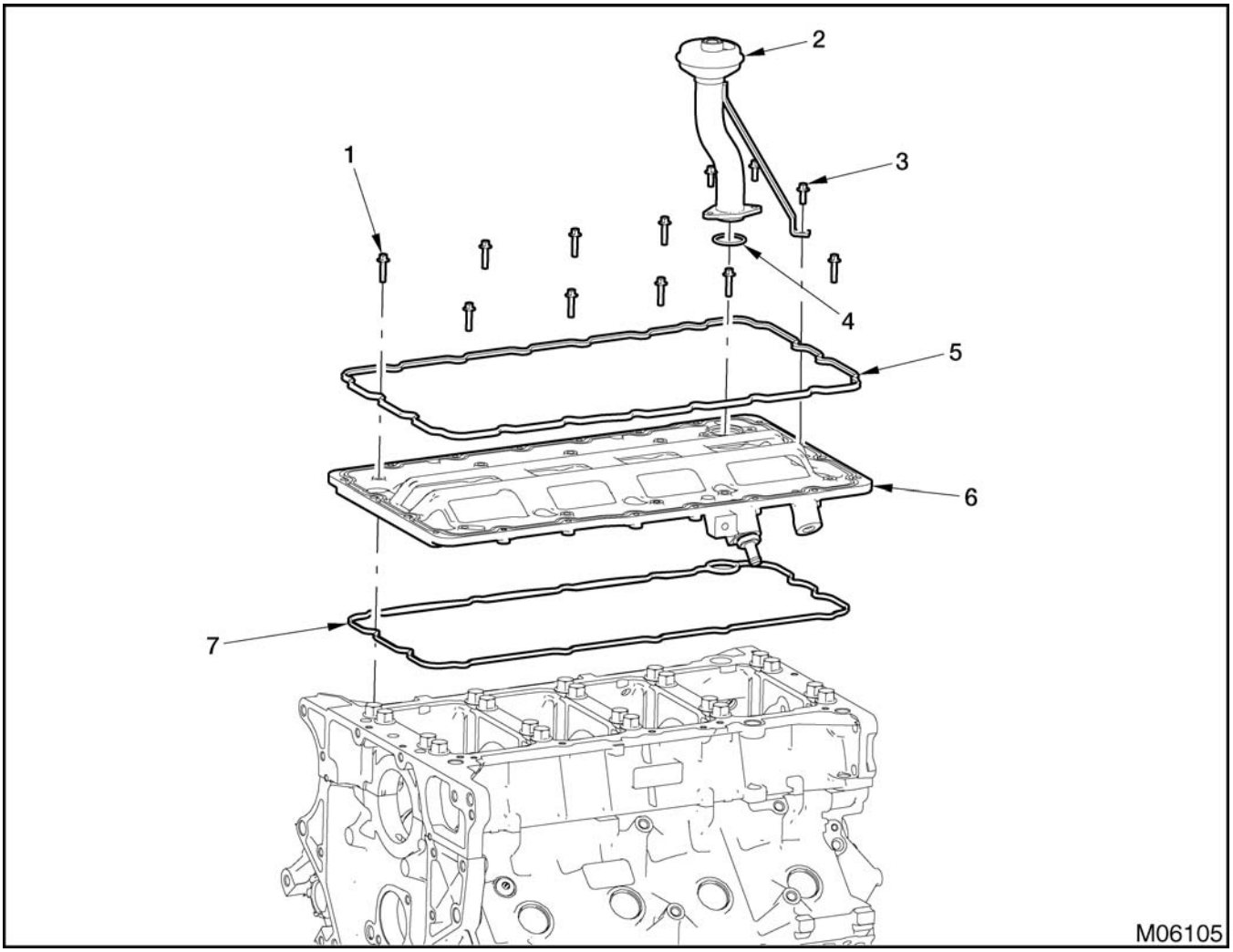


Figure 503 Oil pickup tube and upper oil pan

1. M6 x 25 bolt (9)
2. Oil pickup tube
3. M6 x 16 bolt (3)
4. Oil pickup tube O-ring
5. Lower oil pan gasket
6. Upper oil pan
7. Upper oil pan gasket

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
- Air Compressor and Power Steering/Fuel Pump

Lower Oil Pan

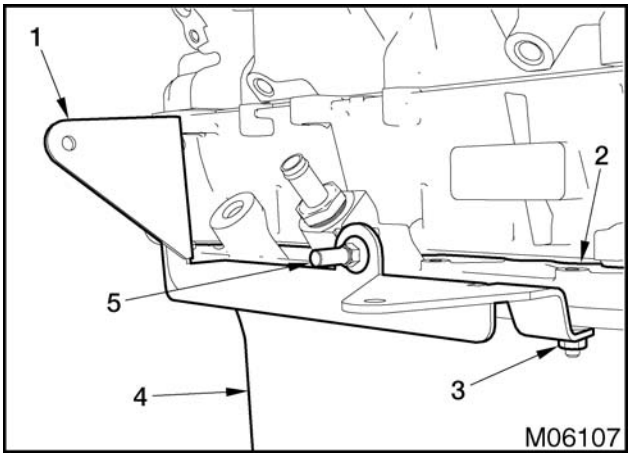


Figure 504 Harness bracket mounting

1. Harness bracket
2. Upper oil pan
3. M6 nut
4. Lower oil pan
5. M8 stud bolt

1. Remove M8 stud bolt.
2. Remove M6 nut and harness bracket.

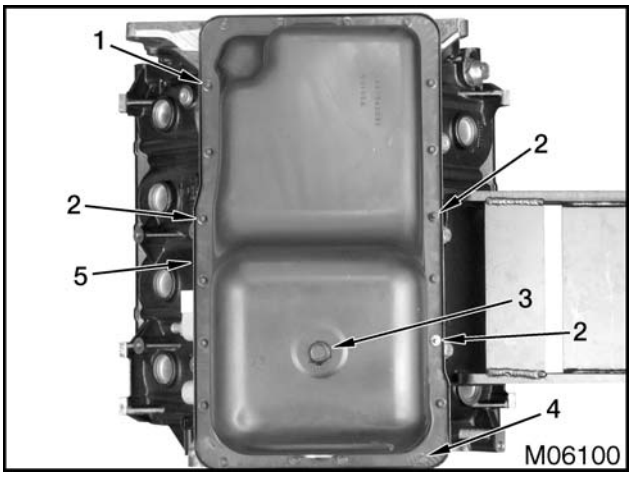


Figure 505 Lower oil pan and oil pan drain plug

1. M6 x 16 bolt (12)
2. M6 x 16 stud bolt (3)
3. Oil pan drain plug
4. M6 x 25 bolt (5)
5. Lower oil pan

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

3. Remove oil pan drain plug and drain oil into a suitable container.
4. Remove three M6 x 16 stud bolts.
5. Remove five M6 x 25 bolts.
6. Remove 12 M6 x 16 bolts and lower oil pan.

Oil Pickup Tube

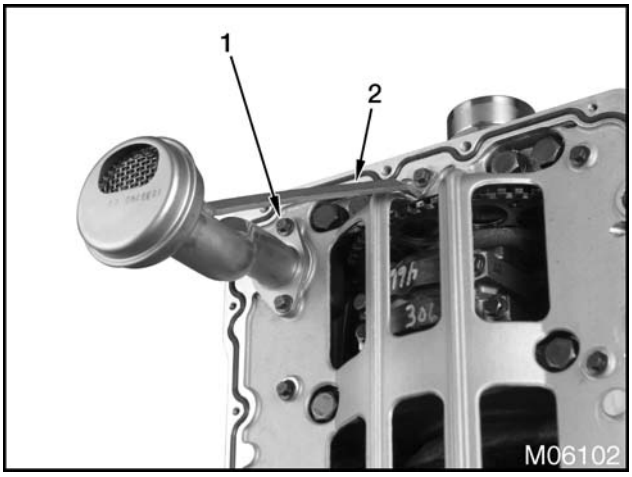


Figure 506 Oil pickup tube

1. M6 X 16 bolt (3)
2. Oil pickup tube

1. Remove three M6 x 16 bolts and oil pickup tube.

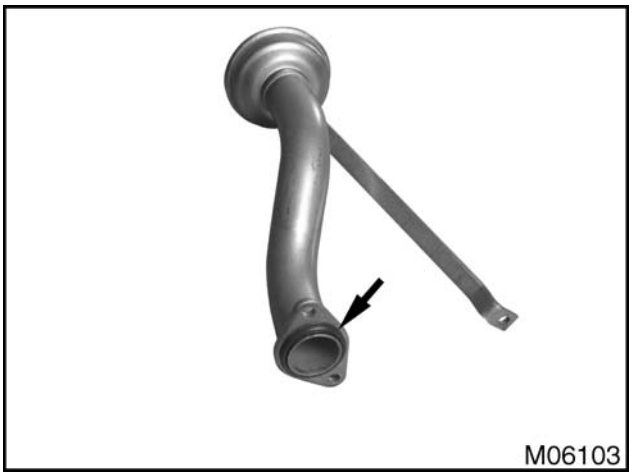


Figure 507 Oil pickup tube O-ring

2. Remove and discard oil pickup tube O-ring.

Upper Oil Pan

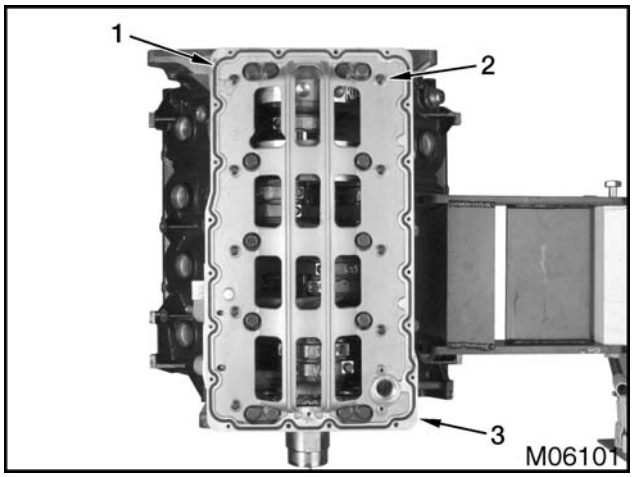


Figure 508 Upper oil pan

1. Lower oil pan gasket
2. M6 X 25 bolt (9)
3. Upper oil pan

1. Remove nine M6 X 25 bolts and upper oil pan.
2. Remove and discard upper oil pan gasket.
3. Remove and discard lower oil pan gasket.

Cleaning and Inspection

Lower Oil Pan

1. Inspect bottom of lower oil pan for metallic debris or other evidence of engine damage. Investigate any abnormalities as required.
2. Clean lower oil pan 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. Look for warping, dents, and cracking. Replace the lower oil pan if necessary.

Oil Pickup Tube

1. Clean oil pickup tube in 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 pickup tube and bracket for cracking. Replace if necessary.

Upper Oil Pan

1. Clean upper oil pan in 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 for warping or cracking. Replace upper oil pan if necessary.

Installation

Upper Oil Pan

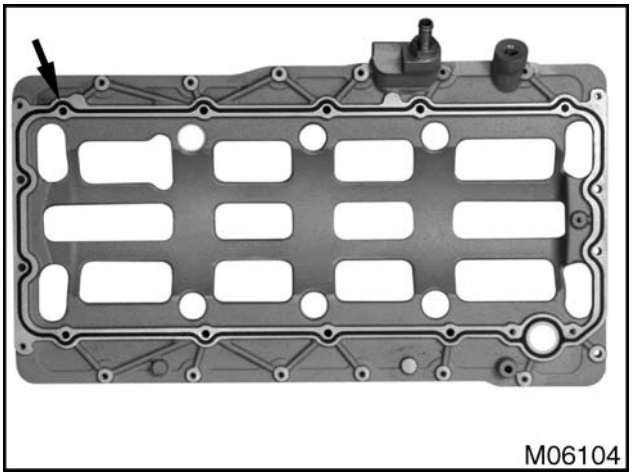


Figure 509 Upper oil pan gasket

1. Install a new upper oil pan gasket.

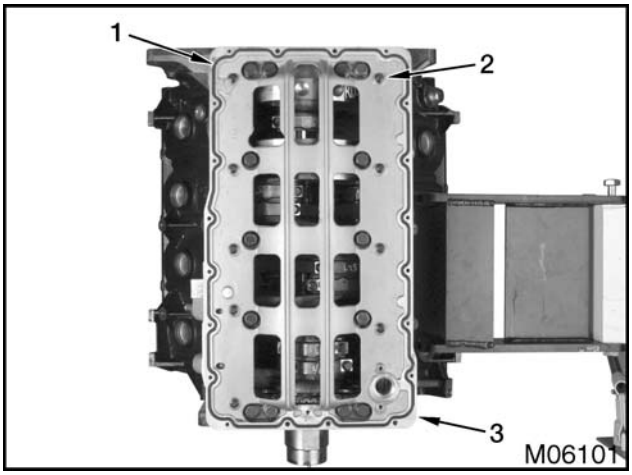


Figure 510 Upper oil pan

1. Lower oil pan gasket
2. M6 X 25 bolt (9)
3. Upper oil pan

2. Install upper oil pan and nine M6 x 25 bolts. Tighten bolts to standard torque (page 369).
3. Install a new lower oil pan gasket.

Oil Pickup Tube

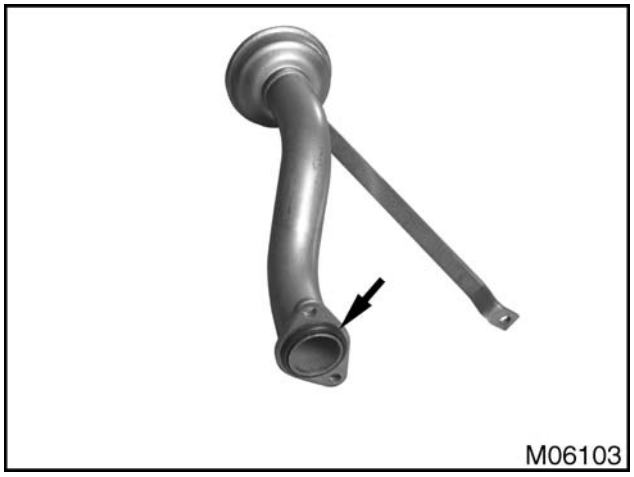


Figure 511 Oil pickup tube O-ring

1. Install a new oil pickup tube O-ring. Lubricate O-ring with clean engine oil.

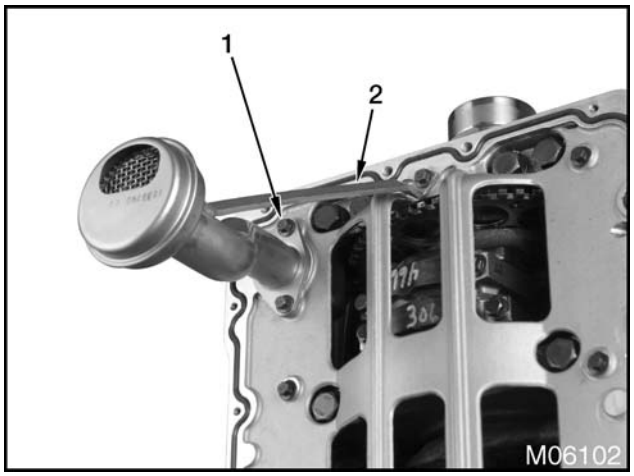


Figure 512 Oil pickup tube

1. M6 X 16 bolt (3)
2. Oil pickup tube

2. Install oil pickup tube and three M6 x 16 bolts. Do not tighten at this time.
3. Tighten two M6 x 16 bolts on oil pickup tube flange to standard torque (page 369).
4. Tighten M6 x 16 bolt on oil pickup tube bracket to standard torque (page 369).

Lower Oil Pan

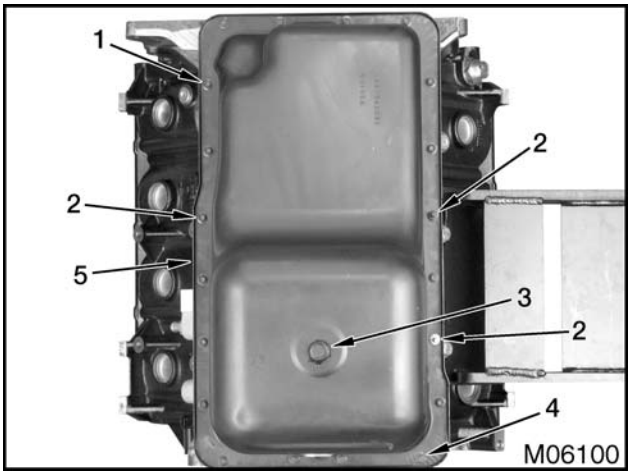


Figure 513 Lower oil pan and oil pan drain plug

1. M6 x 16 bolt (12)
2. M6 x 16 stud bolt (3)
3. Oil pan drain plug
4. M6 x 25 bolt (5)
5. Lower oil pan

1. Position lower oil pan on upper oil pan mating surface.
2. Install 12 M6 x 16 bolts.
3. Install five M6 x 25 bolts.
4. Install three M6 x 16 stud bolts.
5. Tighten lower oil pan bolts and stud bolts to special torque (page 300).
6. Install oil pan drain plug with new O-ring, and tighten to special torque (page 300).

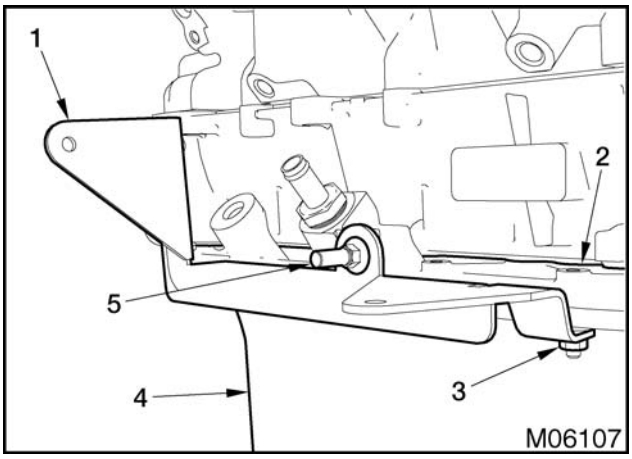


Figure 514 Harness bracket mounting

1. Harness bracket
2. Upper oil pan
3. M6 nut
4. Lower oil pan
5. M8 stud bolt

7. Position harness bracket and install M8 stud bolt. Tighten stud bolt to standard torque (page 369).
8. Install M6 harness bracket nut. Tighten nut to standard torque (page 369).

Special Torque

Table 30 Lower Oil Pan

Oil pan drain plug	25 N·m (18 lbf·ft)
Lower oil pan bolts and stud bolts	13 N·m (115 lbf·in)

Table of Contents

Exploded View

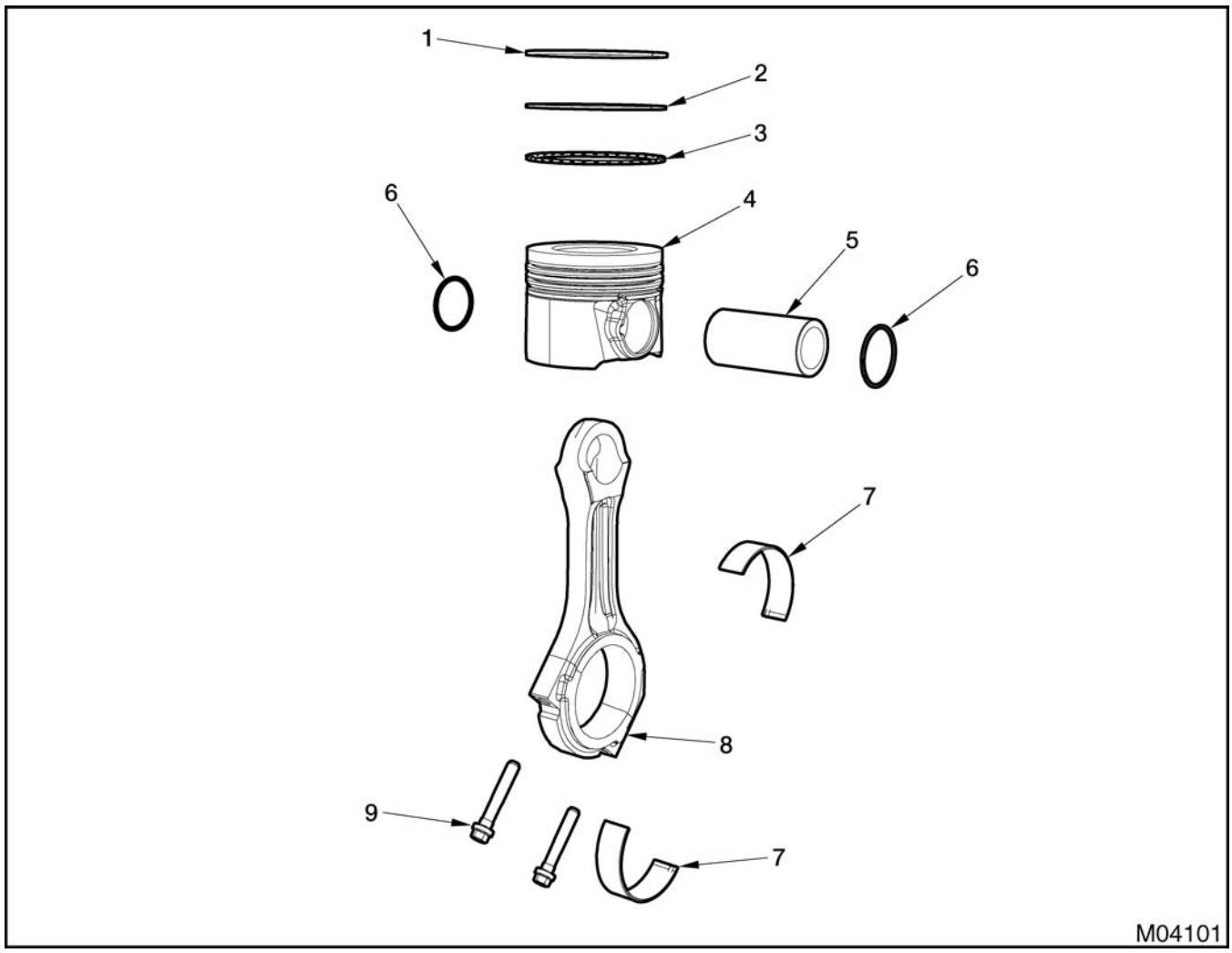


Figure 515 Power cylinder and components

1. Top compression ring (8)
2. Intermediate ring (8)
3. Oil control ring (8)
4. Piston (8)
5. Piston pin (8)
6. Piston pin retainer ring (16)
7. Connecting rod bearing (16)
8. Connecting rod and cap (8)
9. Connecting rod bolt (16)

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
- Exhaust Gas Recirculating (EGR) System
- Variable Geometry Turbocharger (VGT)
- Air Compressor and Power Steering/Fuel Pump
- Fuel System
- Intake and Exhaust Manifolds
- Front Cover, Cooling System, and Related Components
- Cylinder Head and Valve Train
- Oil Cooler and Filter Housing
- Flywheel and Flywheel Housing
- Lower Oil Pan, Upper Oil Pan and Oil Pickup Tube

Preliminary Checks

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

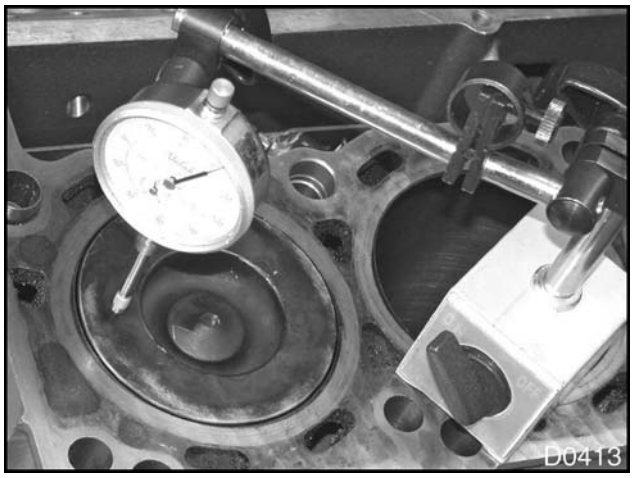


Figure 516 Checking piston protrusion

NOTE: Before checking piston protrusion, make sure upper crankcase assembly deck surface is flat and level. See Crankcase Inspection (page 328).

NOTE: Piston protrusion readings are done at 3 and 9 o'clock positions. These positions are in line with piston pin, eliminating rocking movement of piston at any other position of measurement.

1. Check piston protrusion above upper crankcase assembly as follows:
   a. Zero dial indicator with magnetic base (page 318) on upper crankcase assembly deck surface.
   b. Position dial indicator tip over piston head at 3 o'clock position.
   c. 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.
   d. Reposition dial indicator tip on piston head at 9 o'clock position.
   e. Rotate crankshaft to raise the piston to its maximum protrusion. Read maximum protrusion on dial indicator.
   f. Average the two readings. Replace piston and connecting rod if protrusion is outside specifications (page 317).

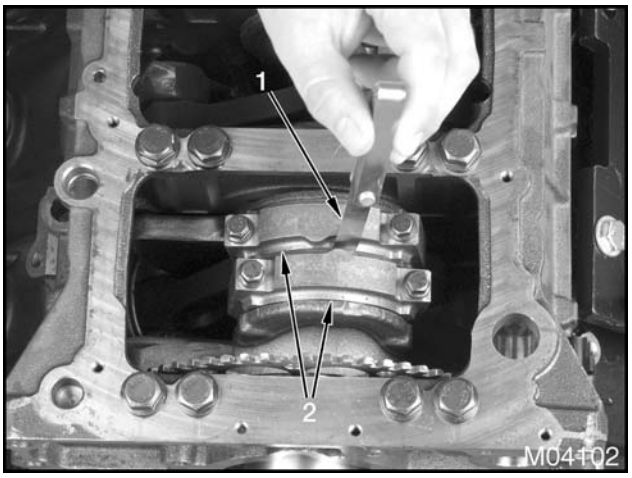


Figure 517 Side clearance check for connecting rod and cap

1. Feeler gauge
2. Connecting rod and cap

2. Use a feeler gauge (page 318) to check connecting rod side clearance as follows:
   a. Pry apart a pair of connecting rods on a crankshaft rod journal. Insert largest possible feeler gauge between connecting rods to check side clearance.
   b. Repeat for each pair of connecting rods on each crankshaft rod journal and compare with specification (page 317).

   NOTE: Lack of clearance could indicate a damaged connecting rod or a connecting rod bearing out of position. Excessive clearance may require replacement of connecting rods or crankshaft assembly. Correct as required.

Connecting Rod and Piston Assembly

CAUTION: To prevent engine damage, check for a carbon ridge on top of cylinder bores. 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 cylinder 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.

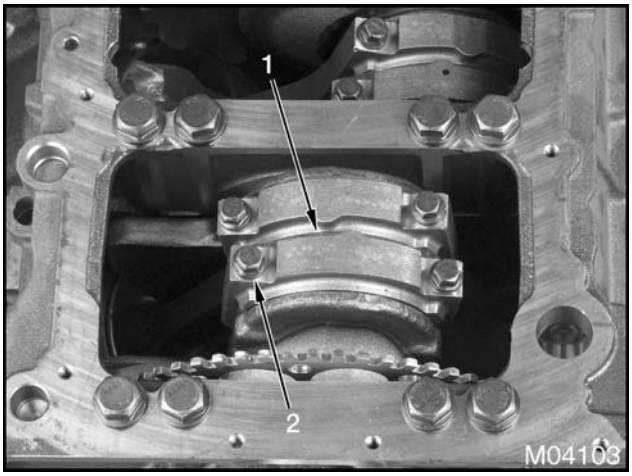


Figure 518 Connecting rod cap bolts

1. Connecting rod cap (8)
2. Connecting rod bolt (16)

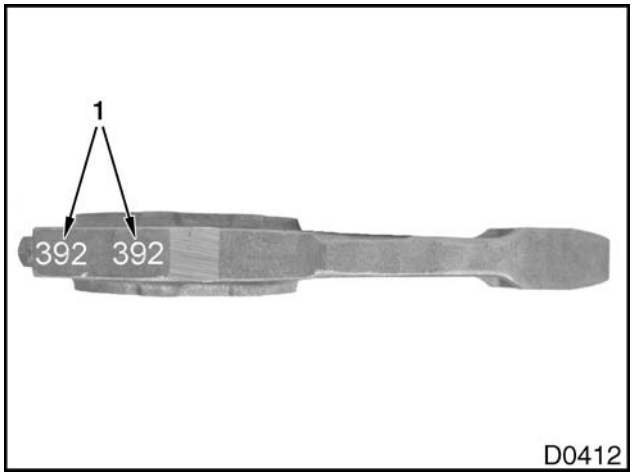


Figure 519 Cap and rod numbers

1. Matching numbers or symbols

3. Loosen two connecting rod bolts and remove connecting rod cap.

CAUTION: To prevent engine damage, do not alter or deface the fractured mating surfaces of connecting rod and cap. Do not reverse the connecting rod cap location.

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

4. Remove piston and connecting rod assemblies from upper crankcase assembly 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 bore.
   c. Once piston rings are free of cylinder bore, remove piston and connecting rod assembly from upper crankcase assembly.

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.

5. 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.
6. Check the crankpin fillets for damage. If crankpin fillets are damaged, replace crankshaft assembly. See Crankshaft Assembly (page 324).

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.

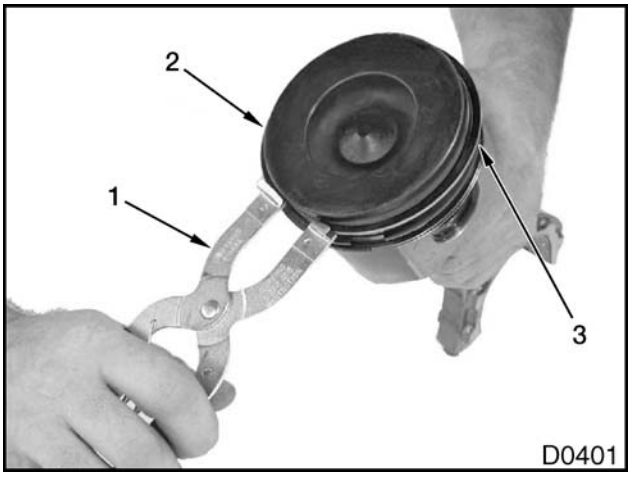


Figure 520 Piston ring removal

1. Piston ring expansion pliers
2. Piston
3. Piston ring (top compression ring shown)

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

NOTE: Keep piston rings organized for each cylinder.

1. Use piston ring expansion pliers (page 318) to remove top compression ring, intermediate ring, and oil control ring.

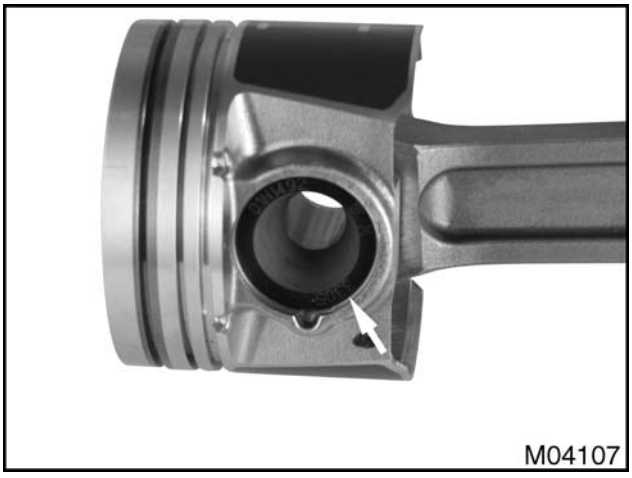


Figure 521 Piston pin retainer ring

2. Use a small pick to remove both piston pin retainer rings.

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.

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

Cleaning and Inspection

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 aluminum 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
   - Piston pin retainer rings
   - Connecting rods
4. Thoroughly clean connecting rod bolt holes and threads.

Pistons

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

NOTE: Top compression ring groove is a keystone design which requires measurement over gauge pins to determine ring groove wear.

2. Check top compression ring groove for wear.

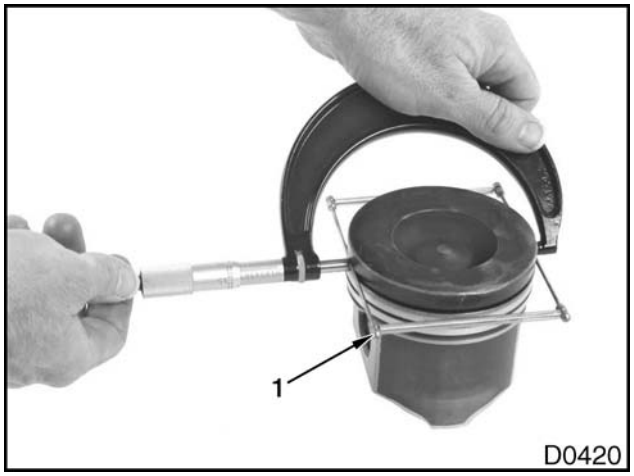


Figure 522 Top compression ring groove

1. Piston gauge pins (2.0828 mm [0.082 in]) ZTSE4513

3. Install piston gauge pins (2.0828 mm [0.082 in]) ZTSE4513 (page 318) in top compression ring groove. Piston gauge pins must be parallel.
4. Use a 3 - 4 inch micrometer (page 318) to measure diameter over piston gauge pins.
5. If measurement over gauge pin is not within specifications (page 317), excessive piston groove wear exists. Replace piston.

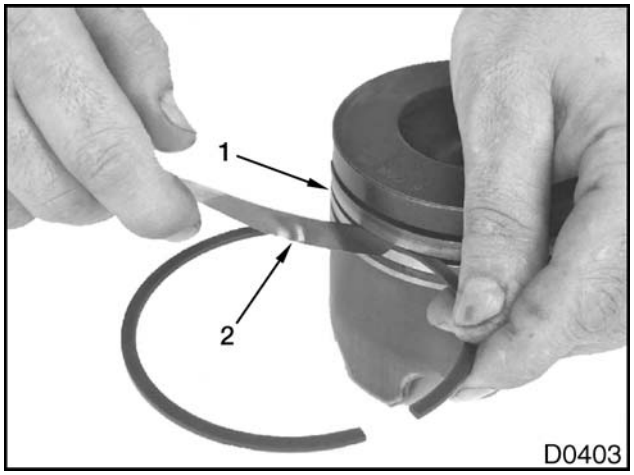


Figure 523 Second and third ring groove clearance check (intermediate ring shown)

1. Intermediate ring groove
2. Feeler gauge

6. Check side clearance of intermediate ring groove as follows:
   a. Place outer edge of new ring in its respective ring groove.
   b. Roll ring entirely around piston in its respective groove. Make sure ring is able to move freely in its groove.
   c. Use a feeler gauge (page 318) to check side clearance of each ring in its respective groove (page 317). Excessive side clearance indicates ring groove wear and requires piston replacement.
7. Check side clearance of oil control ring groove as follows:
   a. Place outer edge of new ring in oil control ring groove.
   b. Roll ring entirely around piston in its respective groove. Make sure ring moves freely in groove.
   c. Use a feeler gauge (page 318) to check side clearance of oil control ring in its respective groove (page 317). Excessive side clearance indicates ring groove wear and requires piston replacement.

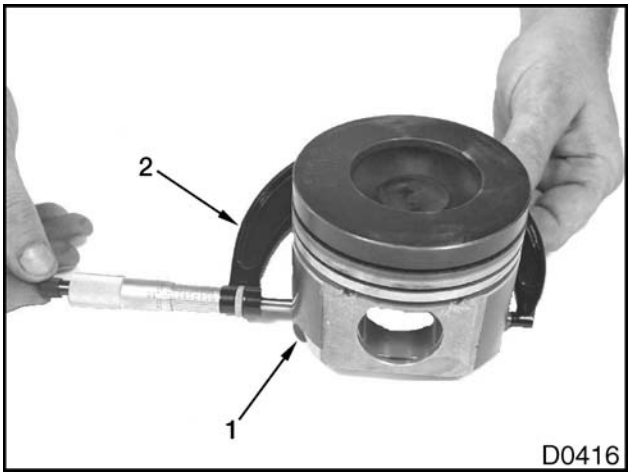


Figure 524 Piston skirt diameter

1. Piston skirt
2. 3 - 4 inch micrometer

8. When considering piston replacement, check cylinder bore out-of-round specifications. See Crankcase Inspection (page 328).
9. If not within specification (page 317), cylinder boring may be required. Bore reconditioning requires oversize service pistons. Verify piston size by measuring skirt diameter under conditions indicated in specifications (page 317).

NOTE: In addition to standard size service piston, the following oversize pistons are available.

- 0.254 mm (0.010 in)
- 0.508 mm (0.020 in)
- 0.762 mm (0.030 in)

10. If cylinder walls have minor surface damage, but are otherwise within specification (out-of-round), it may be possible to remove such damage by honing. If cylinder bore is suitable for use without reconditioning, deglaze bore using a glaze breaker brush (page 318), then reassemble.

NOTE: See Cylinder Deglazing (page 329) for correct procedure.

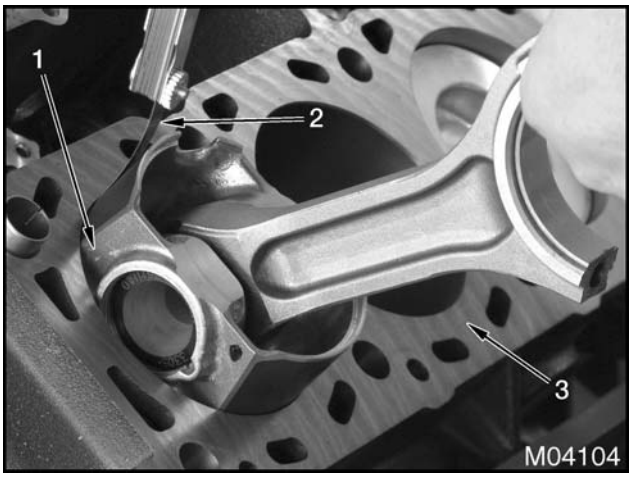


Figure 525 Piston skirt clearance check in cylinder bore

1. Piston
2. Feeler gauge
3. Crankcase

11. Check piston skirt clearance in cylinder bore (page 317). Correct as required.

Piston Rings

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.
2. Before installing new piston rings, check 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 318) to measure gap between ends of each piston ring.

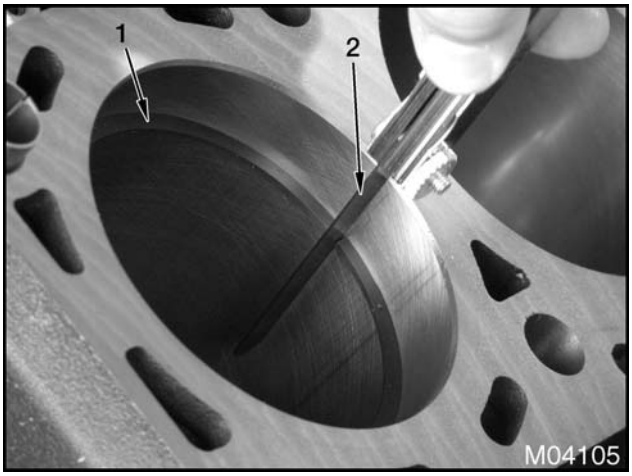


Figure 526 Piston ring end gap clearance in cylinder bore

1. Piston ring
2. Feeler gauge

   c. If gap does not meet specifications (page 317), select another ring or recheck cylinder bore wear.

Connecting Rods

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 bolt 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.

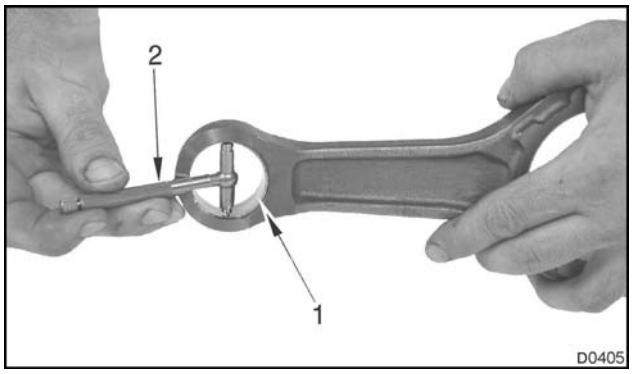


Figure 527 Inside diameter of piston pin bore

1. Piston pin bore
2. Telescoping gauge

3. Inspect connecting rod piston pin bore for wear as follows:
   a. Use a telescoping gauge (page 318) and a 1-2 inch micrometer (page 318) to measure piston pin bore at two locations 90° apart.
   b. If inside diameter of piston pin bore exceeds specification (page 317), replace connecting rod.

Connecting Rod Bore Out-of-round Check

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

1. Lubricate connecting rod bolts with clean engine oil. Assemble cap to rod without bearing insert. Tighten bolts to initial and final torque values (page 318).

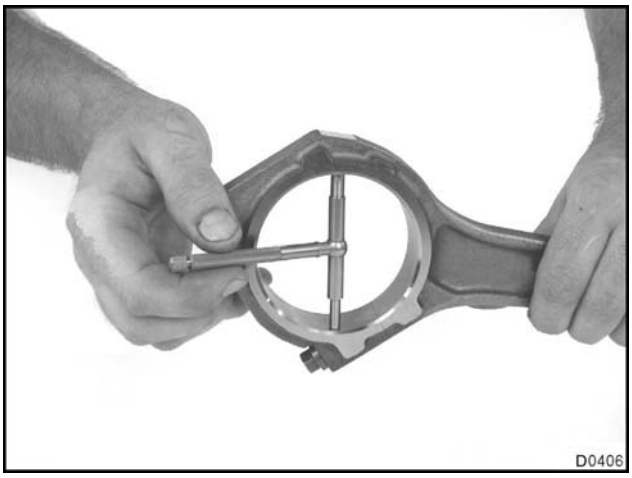


Figure 528 Measurement for out-of-round of connecting rod

2. Using a telescoping gauge (page 318), measure connecting rod bearing bore at two locations, 90° apart.
3. If the difference between dimension A and B exceeds out-of-round specifications (page 317), replace connecting rod.
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 as required.

Connecting Rod Bearing Fit Check

NOTE: Bearing shells must fit tightly in the bore. When bearing shells are inserted into connecting rod and cap, they protrude above parting line. This protrusion is required to achieve bearing crush.

Bearing shells across open ends are slightly larger than the diameter of connecting rod bore into which they are assembled. This condition is designed into bearing shell, causing it to spread outward at parting line when bearing crush load is applied by tightening bolts. Some flexibility may be lost in normal use, but bearing replacement is not required because of a nominal loss of flexibility.

When assembly is drawn up tight, bearing is compressed, ensuring positive contact between backside of bearing and bore.

1. Lubricate connecting rod bolts with clean engine oil. Assemble cap to connecting rod with new bearing shells installed. Tighten bolts to initial and final torque values (page 318).
2. Using a telescoping gauge (page 318), measure inside diameter of connecting rod bearing at two locations 90° apart. Average the two inside diameters.
3. Use a 2–3 inch micrometer (page 318) to measure each crankshaft rod journal diameter.
4. Subtract crankshaft rod journal diameter from respective connecting rod bearing inside diameter to obtain connecting rod bearing running clearance. Repeat for each crankshaft rod 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.

NOTE: Plastigage® may be used as an alternate method, to determine running clearance.

5. If connecting rod bearing running clearances exceed specifications (page 317) because of wear on crankshaft, replace or grind crankshaft and install under-size precision type bearing shells.

Piston Pin Inspection

NOTE: Some wear of the piston pin coating should be considered normal. If there is evidence of material transfer on the piston pin, replace the piston pin, connecting rod, and piston.

1. Inspect piston pins for corrosion or wear. Replace as required.

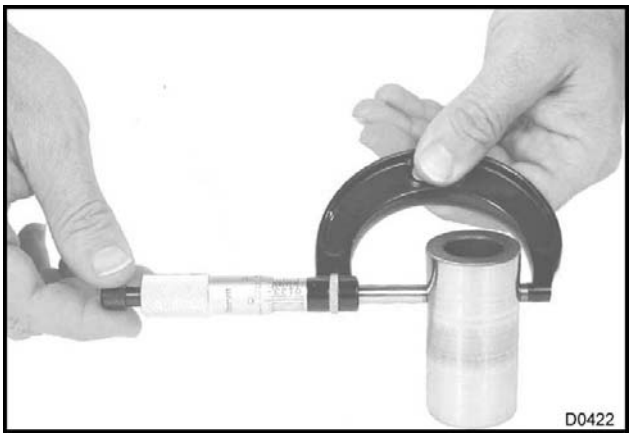


Figure 529 Piston pin wear

2. Use a 1-2 inch micrometer (page 318), measure piston pin outside diameter at two locations 90° apart.
3. Measure each end of the pin. If piston pin wear exceeds specifications (page 317), replace piston pin.

Figure 530 Inside diameter measurement of piston pin bore

4. Using a telescoping gauge (page 318) and 1–2 inch micrometer (page 318), measure each piston pin bore inside diameter, at two locations 90° apart.
5. To check piston pin clearance, subtract outside diameter of piston pin from inside diameter of piston pin bore. If clearance exceeds specifications (page 317), replace piston pin and check piston pin clearance using new piston pin.

Installation

Piston Assembly

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

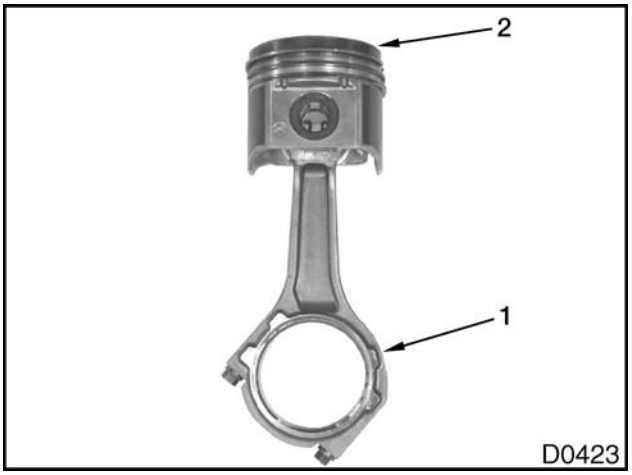


Figure 531 Correct position of installed connecting rod

1. Longer leg of connecting rod (cam side)
2. CAM SIDE stamp on cam side of piston crown

1. 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. Position the longer leg of the connecting rod with the side of the piston showing the CAM SIDE stamped in its crown.
   c. Place connecting rod into piston.

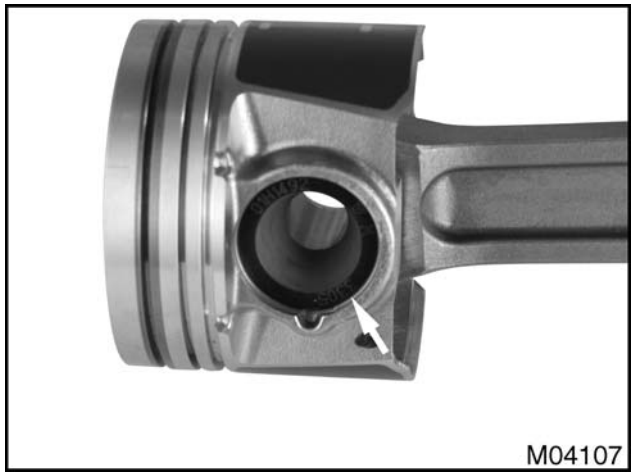


Figure 532 Piston pin retainer ring

   d. Using a suitable tool, install piston pin retainer ring at one end of piston pin bore.
   e. Slide piston pin through bored holes, stopping at installed piston pin retainer ring.
   f. Use a suitable tool to install second piston pin retainer ring.
   g. Check the piston pin end clearance (page 317).

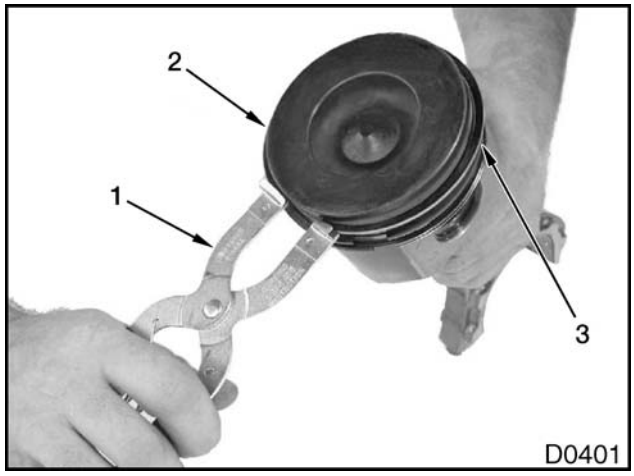


Figure 533 Piston rings installed

1. Piston ring expansion pliers
2. Piston
3. Piston ring (top compression ring shown)

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.

2. Use piston ring expansion pliers (page 318) to install piston rings.
   a. Install expansion spring component of two piece oil control ring into bottom piston groove.
   b. Install oil scraper component of two piece oil control ring over expansion spring with the gap 180° from the spring wire latch.

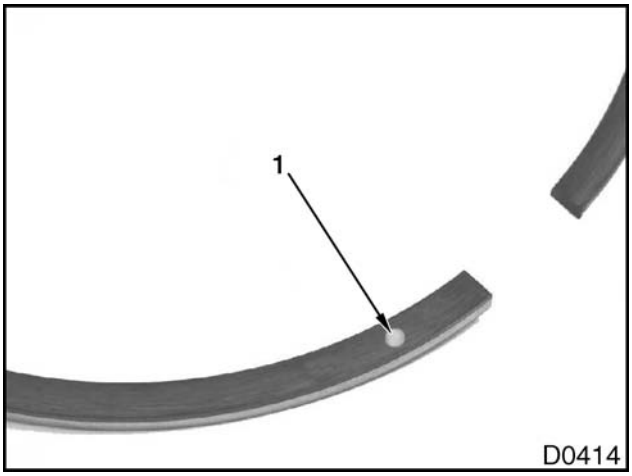


Figure 534 Piston ring identification mark (top compression ring)

1. Identification mark

   c. Install intermediate ring into middle piston groove. Make sure ring is installed with identification mark facing up.
   d. Install top compression ring into top piston groove. Make sure ring is installed with identification mark facing up.

3. Space ring gaps approximately 120° apart after ring installation.

Connecting Rod and Piston Assembly

1. Turn crankshaft so number 1 crank pin is at bottom of its stroke.

Figure 535 Piston and piston ring lubrication

2. Lightly coat piston and piston rings with clean engine oil.

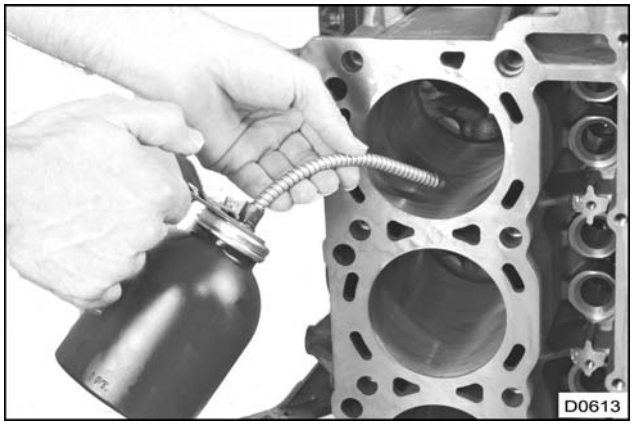


Figure 536 Cylinder wall lubrication

3. Coat cylinder walls, crankshaft journals, and piston ring compressor (cope) ZTSE4514 (page 318) with clean engine oil.

Figure 537 Piston installed in piston ring compressor (cope) ZTSE4514

4. Place piston in piston ring compressor (cope) ZTSE4514 (page 318).
5. Install bearing shells in connecting rod and cap. Coat bearing shell in connecting rod with clean engine oil.

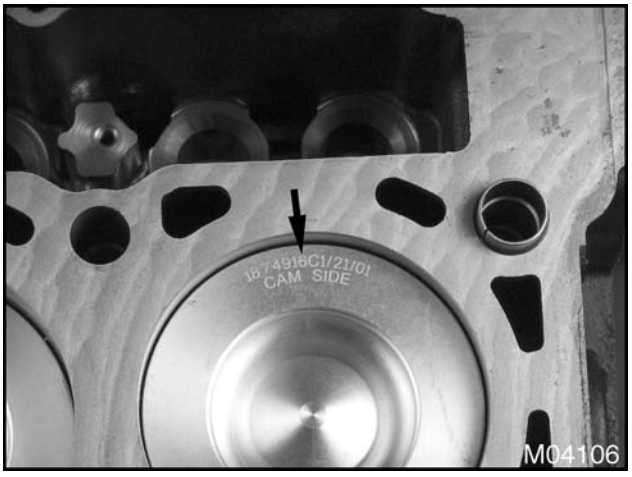


Figure 538 CAM SIDE stamp on piston

CAUTION: To prevent engine damage, CAM SIDE stamped on top of piston must face camshaft side of crankcase.

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

NOTE: Before installing piston and connecting rod assembly, make sure all piston cooling tubes are installed.

6. Carefully put piston and piston cope combination and connecting rod assembly in cylinder bore.

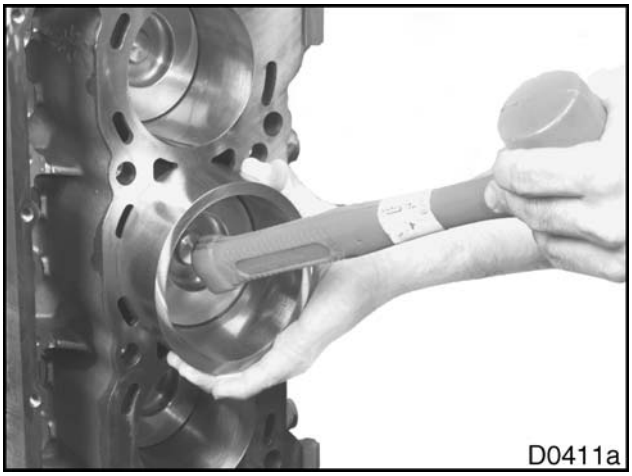


Figure 539 Installation of piston in cylinder bore

7. Once piston and connecting rod assembly have been inserted in cylinder bore, use a handle (wood or plastic) of a hammer to tap piston into crankcase bore. 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 hole threads for connecting rod and bearing shell in cap before installing bolts.

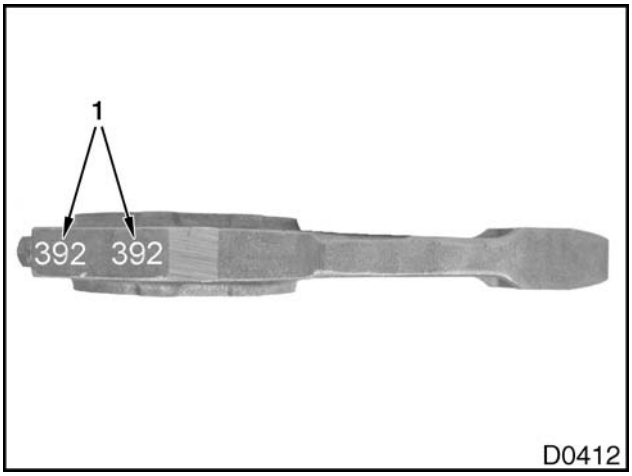


Figure 540 Connecting rod and cap

1. Matching numbers or symbols

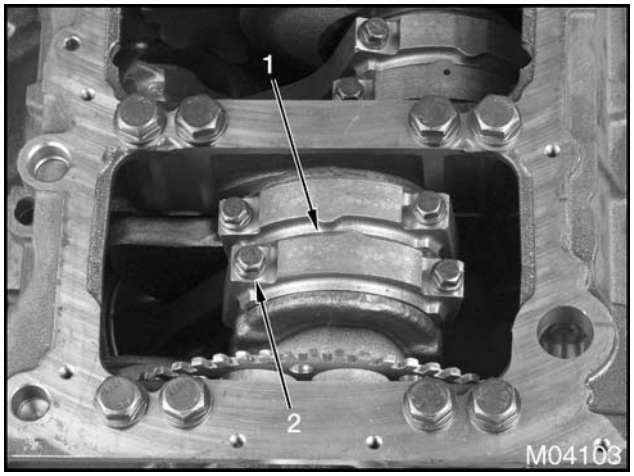


Figure 541 Connecting rod cap

1. Connecting rod cap (8)
2. Connecting rod bolt (16)

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 and CAM SIDE stamp on piston crown are positioned towards camshaft.

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 and tighten connecting rod bolts evenly to initial and final torque values (page 318).
11. Repeat installation procedure for remaining connecting rod and piston assemblies.
12. Check connecting rod side clearance with feeler gauge. See procedure in removal section (page 305).

Specifications

Table 31 Power Cylinders

Connecting Rods	
Connecting rod length (center to center)	176 mm (6.929 in)
Piston pin bore inside diameter	38.542 to 38.849 mm (1.5174 to 1.5295 in)
Material	I-Beam section - powdered metal
Bearing bore diameter (crankshaft end)	75.987 to 76.013 mm (2.9916 to 2.9926 in)
Bearing bore maximum out-of-round	0.013 mm (0.0005 in)
Connecting rod bearing inside diameter	72.031 to 72.073 mm (2.8359 to 2.8375 in)
Connecting rod bearing running clearance (diameter)	0.015 to 0.089 mm (0.0006 to 0.0035 in)
Connecting rod side clearance	0.230 to 0.730 mm (0.0091 to 0.0287 in)
Weight (complete rod without bearing)	1274.89 to 1295.89 g (2.811 to 2.857 lb)
Pistons	
Material	Aluminum Alloy
Skirt diameter [1]	98.114 to 98.146 mm (3.863 to 3.864 in)
[1] Measure 15.5 mm (0.610 in) from bottom, at 90° to the piston pin. Measure only at room temperature of 19 to 21°C (66 to 70°F).	
Service Piston:	
Standard size	98.114 to 98.146 mm (3.863 to 3.864 in)
0.254 mm (0.010 in) oversize	98.368 to 98.400 mm (3.873 to 3.874 in)
0.508 mm (0.020 in) oversize	98.622 to 98.654 mm (3.883 to 3.884 in)
0.762 mm (0.030 in) oversize	98.876 to 98.908 mm (3.893 to 3.894 in)
Top compression ring groove width (measured over 2.10 mm (0.082 in) gauge pins):	
Upper limit	96.606 mm (3.8033 in)
Replacement limit	96.406 mm (3.7955 in)
Piston height above crankcase deck (protrusion)	0.609 to 0.863 mm (0.0240 to 0.0340 in)
Piston skirt clearance	0.045 to 0.095 mm (0.0018 to 0.0037 in)
Piston Pins	
Length	74.6 to 75.0mm (2.9371 to 2.9528 in)
Diameter	38.491 to 38.501 mm (1.5154 to 1.5158 in)
Pin fit at room temperature of 19 to 21°C (66 to 70°F):	
Clearance in connecting rod (piston pin bore)	0.041 to 0.058 mm (0.0016 to 0.0022 in)
Clearance in piston (piston pin bore)	0.011 to 0.027 mm (0.0004 to 0.0011 in)
End clearance	0.84 mm (0.0331 in)

Table 31 Power Cylinders (cont.)

Piston Rings	
Ring diameter (standard):	98.2 mm (3.866 in)
Ring groove (side clearance):	
Intermediate compression	0.050 to 0.096 mm (0.0020 to 0.0038 in)
Oil control	0.040 to 0.095 mm (0.00157 to 0.00374 in)
Ring gap in bore:	
Top compression	0.29 to 0.55 mm (0.011 to 0.021 in)
Intermediate compression	1.42 to 1.68 mm (0.0559 to 0.0661 in)
Oil control	0.24 to 0.50 mm (0.009 to 0.019 in)

Special Torque

Table 32 Power Cylinders

Connecting rod bolts	Initial	45 N·m (33 lbf·ft)
	Final	68 N·m (50 lbf·ft)

Special Service Tools

Table 33 Power Cylinders

Description	Tool Number
1–2 inch micrometer	Obtain locally
2–3 inch micrometer	Obtain locally
3–4 inch micrometer	Obtain locally
Dial indicator with magnetic base	Obtain locally
Feeler gauge	Obtain locally
Glaze breaker brush	Obtain locally
Piston gauge pins (2.0828 mm [0.082 in])	ZTSE4513
Piston ring compressor (cope)	ZTSE4514
Piston ring expansion pliers	Obtain locally
Telescoping gauge set	Obtain locally

Table of Contents

Exploded View

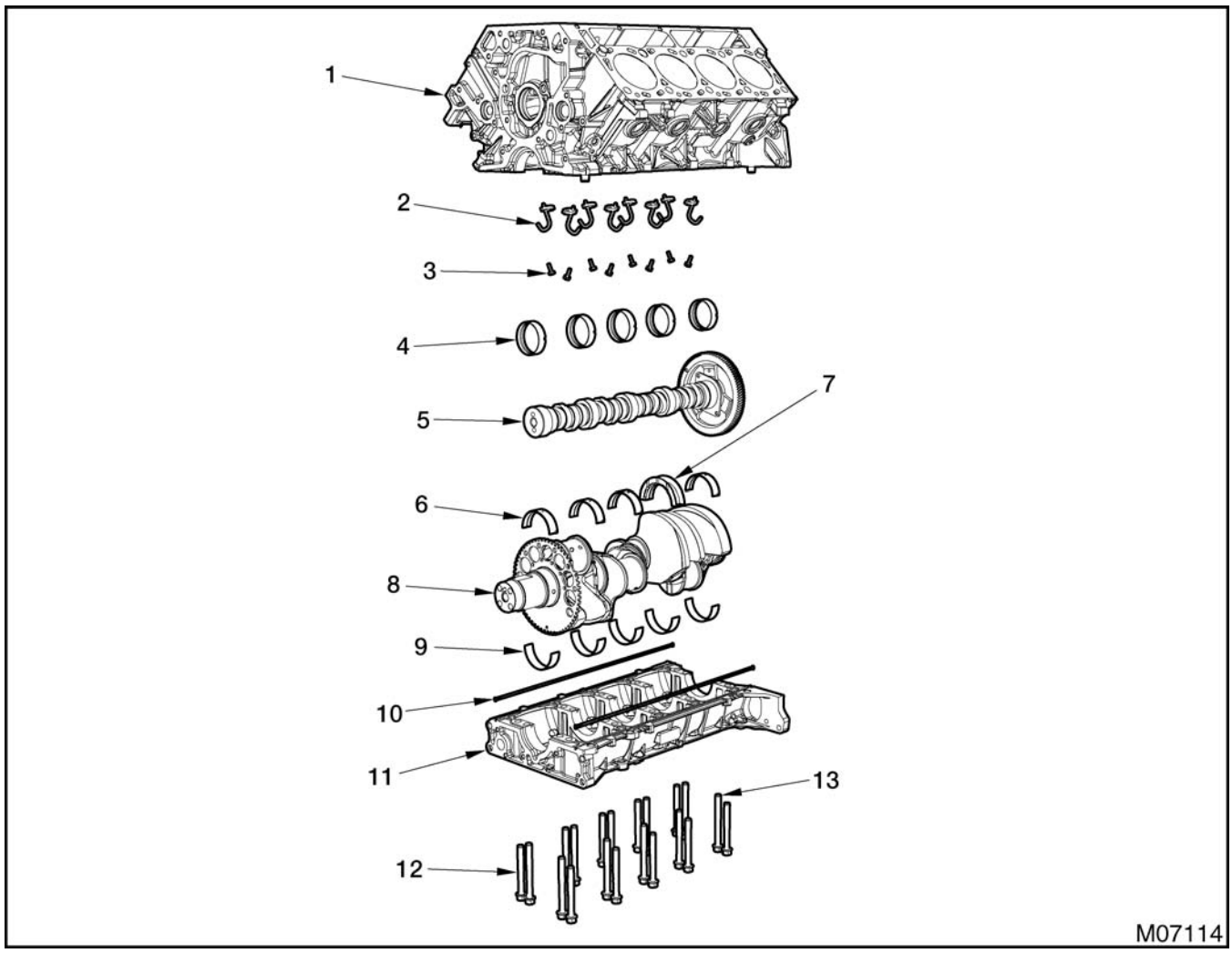


Figure 542 Crankcase, Crankshaft, and Camshaft

1. Upper crankcase assembly
2. Piston cooling tube assembly (8)
3. M6 x 18 bolt (8)
4. Camshaft bushing (5)
5. Camshaft assembly
6. Upper main bearing (4)
7. Upper thrust bearing
8. Crankshaft assembly
9. Crankshaft lower main bearing (5)
10. Crankcase lower seal (2)
11. Lower crankcase assembly
12. M14 x 114 main bearing bolt (10)
13. M14 x 127 main bearing bolt (10)

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
- Exhaust Gas Recirculating (EGR) System
- Variable Geometry Turbocharger (VGT)
- Air Compressor and Power Steering/Fuel Pump
- Fuel System
- Intake and Exhaust Manifolds
- Front Cover, Cooling System, and Related Components
- Cylinder Head and Valve Train
- Oil Cooler and Filter Housing
- Flywheel and Flywheel Housing
- Lower Oil Pan, Upper Oil Pan and Oil Pickup Tube
- Power Cylinders

Preliminary Checks

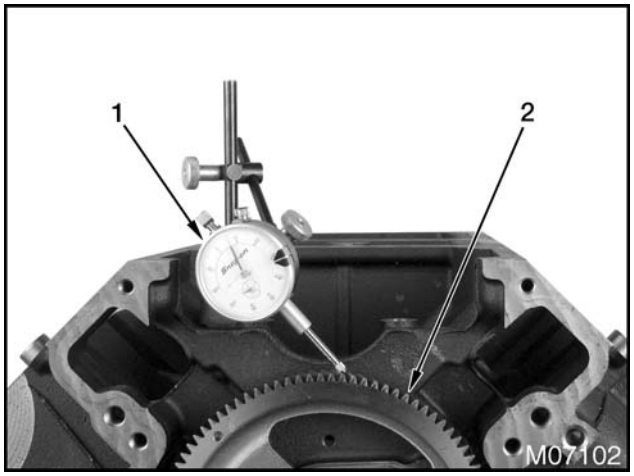


Figure 543 Camshaft assembly gear backlash check (camshaft gear to crankshaft gear)

1. Dial indicator with magnetic base
2. Camshaft gear

1. Check and record camshaft gear backlash as follows:
   a. Mount dial indicator with magnetic base (page 340) on rear of engine.

b. Position dial indicator tip on a gear tooth and remove lash by slowly turning camshaft gear until all play is gone.

c. Zero the dial indicator.

d. Turn gear back and forth by hand and read indicator.

e. If camshaft gear backlash exceeds specified limits (page 339), replace camshaft assembly.

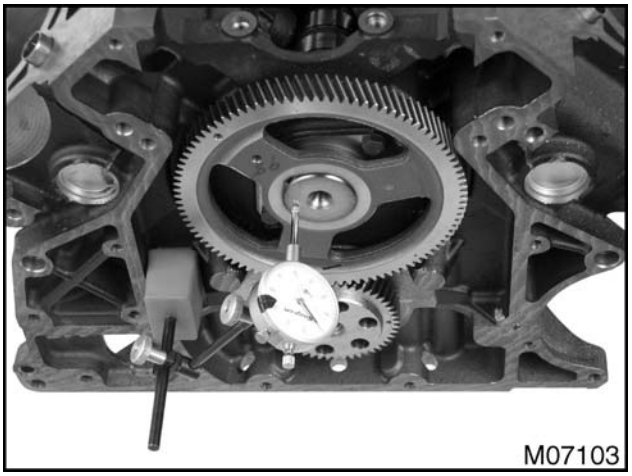


Figure 544 Camshaft end play

2. Reposition dial indicator and check camshaft end play as follows:

   a. Push camshaft to front of engine.

   b. Zero the dial indicator.

   c. Place a small pry bar between camshaft gear and crankcase and gently pry camshaft forward. Compare dial indicator reading with specifications (page 339).

   d. If end play exceeds specified limits, replace camshaft assembly.

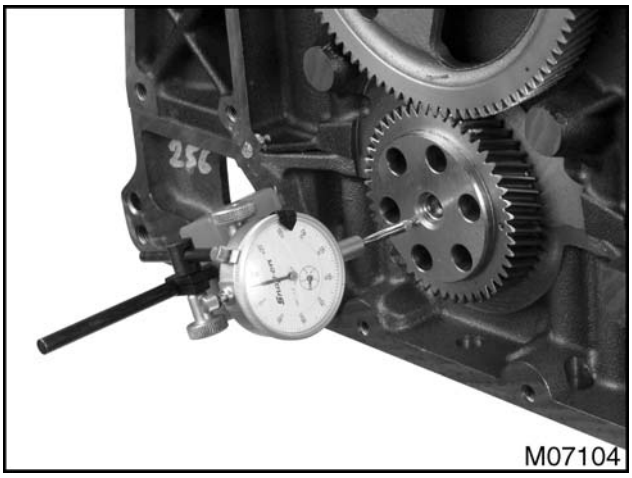


Figure 545 Crankshaft end play

3. Check crankshaft end play as follows:

   a. Mount dial indicator on lower crankcase assembly with indicator tip on end of crankshaft gear 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 339).

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

Lower Crankcase Assembly

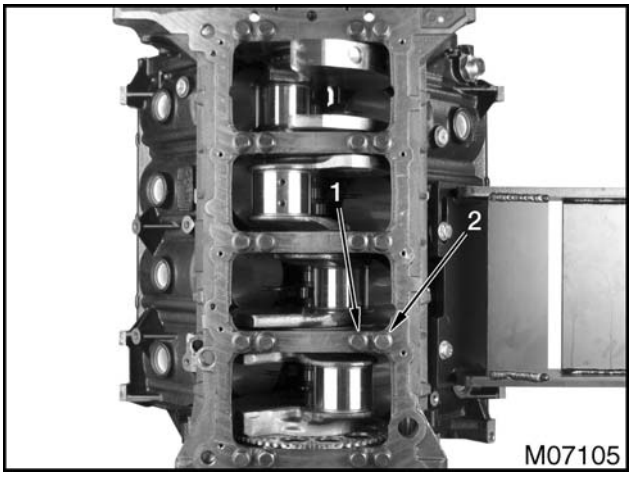


Figure 546 Main bearing bolts

1. M14 x 127 main bearing bolt (10)
2. M14 x 114 main bearing bolt (10)

NOTE: Save main bearing bolts to perform main bearing fit check.

1. Remove 10 M14 x 127 main bearing bolts.
2. Remove 10 M14 x 114 main bearing bolts.

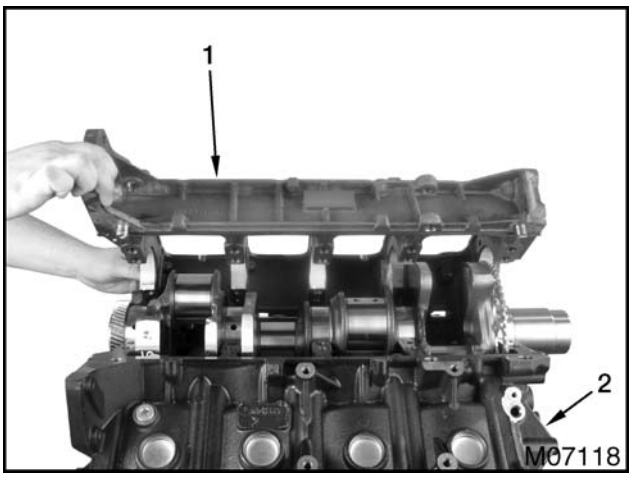


Figure 547 Lower crankcase assembly

1. Lower crankcase assembly
2. Upper crankcase assembly

3. Separate and remove lower crankcase assembly from upper crankcase assembly.
4. Remove main bearing shells from lower crankcase by pushing bearing shells out of bearing saddles.

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

5. Beginning from front of engine, number lower shells with bearing number (1 to 5) and put shells aside for inspection.

Crankshaft Assembly

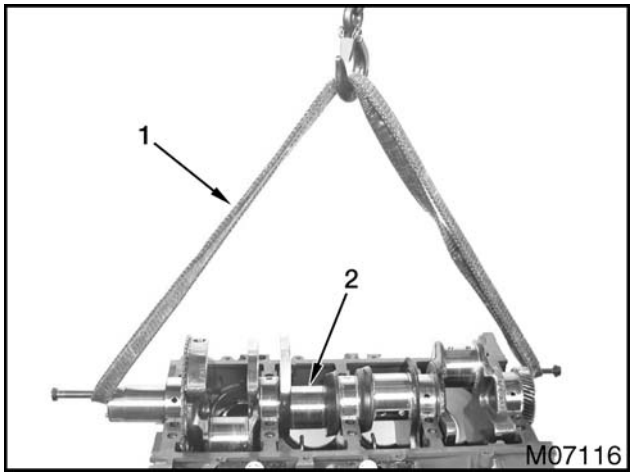


Figure 548 Lifting sling

1. Lifting sling
2. Crankshaft assembly

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

1. Install a bolt in each end of crankshaft.

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

2. Attach lifting sling to crankshaft over bolts installed in crankshaft. Lift crankshaft straight up and out of lower crankcase assembly.
3. Remove bearings from upper main bearing saddles by pushing bearings out.

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

4. Number upper bearings to match lower bearings and put aside for inspection.

Piston Cooling Tubes

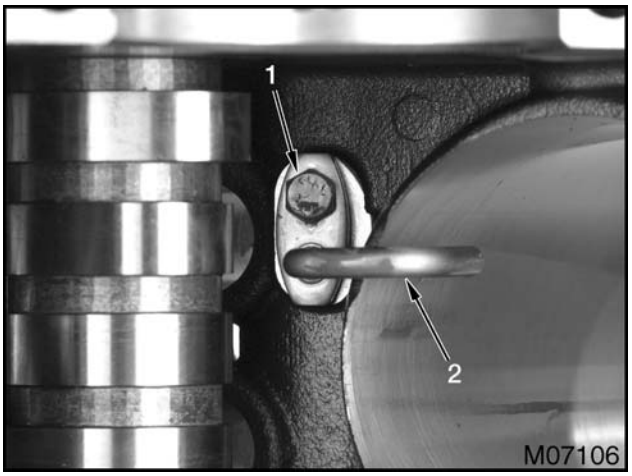


Figure 549 Piston cooling tube

1. M6 x 18 bolt (8)
2. Piston cooling tube (8)

Remove each piston cooling tube by removing its special patch type mounting bolt (M6 x 18). The bolts are reusable, providing bolt is cleaned and inspected, and Liquid Gasket (RTV) (page 340) is added to bolt threads before installation.

Camshaft Assembly

Figure 550 Camshaft thrust plate bolts

1. M8 x 16 bolt (2)
2. Camshaft gear

1. Remove two M8 x 16 camshaft thrust plate bolts.

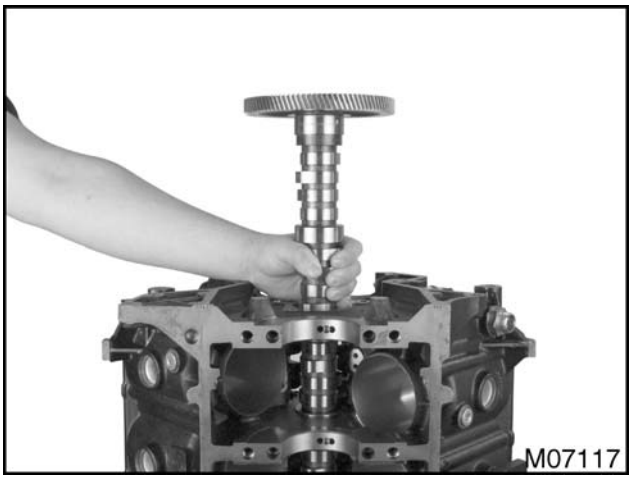


Figure 551 Camshaft assembly

NOTE: If engine is mounted on a revolving stand, rotate engine face up, allowing for easy removal of camshaft.

2. Remove camshaft from upper crankcase assembly by lifting assembly straight up and out.

Camshaft Bushings

1. Determine necessity of replacing bushings based on running clearance (page 332).

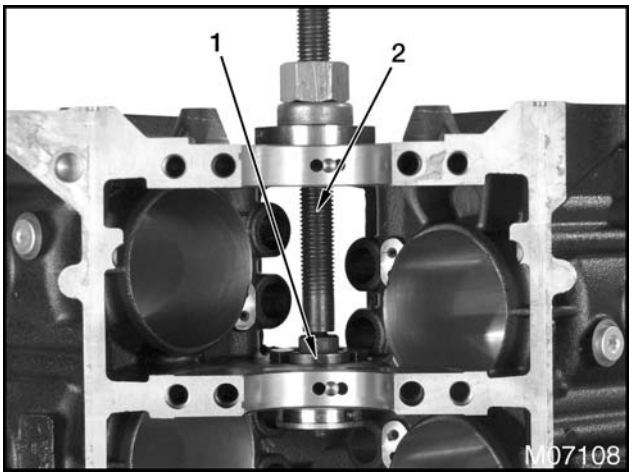


Figure 552 Camshaft bushing

1. Camshaft bushing remover/installer (expanding collet) ZTSE4489
2. Pulling screw (from camshaft bushing kit ZTSE2893A)

2. Use camshaft bushing kit ZTSE2893A (page 340) with camshaft bushing remover/installer (expanding collet) ZTSE4489 (page 340) to remove all camshaft bushings. Install camshaft bushing remover/installer (expanding collet in collapsed state) in camshaft bushing.

NOTE: Hold a wrench on end of pulling screw to prevent screw from turning.

3. Assemble pulling screw in camshaft bushing remover/installer (expanding collet) and tighten backup nut until collet fits tightly in camshaft bushing. To avoid nicks on bushings, be careful when inserting or removing threads of pulling screw.
4. Attach pulling plate, thrust bearing, and drive nut on pulling screw. Tighten nut against thrust bearing and pulling plate. Continue to tighten nut on pulling screw until camshaft bushing is free from upper crankcase assembly.

Coolant Heater

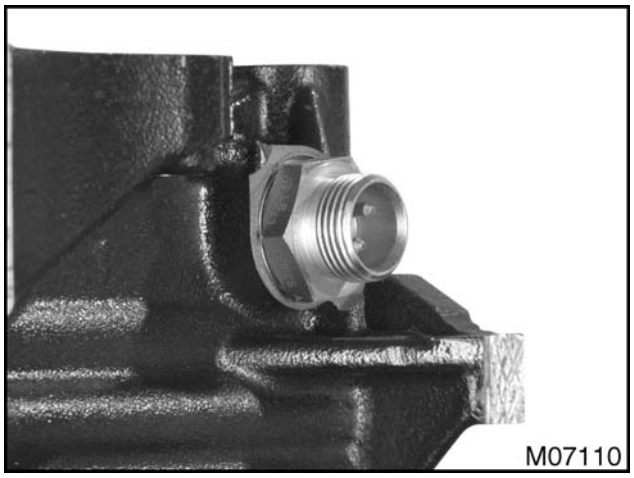


Figure 553 Coolant heater

Remove coolant heater from right rear side of upper crankcase assembly and discard O-ring.

Cleaning, Inspection, and Testing

Crankcase Assembly

Crankcase Cleaning

NOTE: Thoroughly clean and inspect upper and lower crankcase assemblies before and after reconditioning.

1. Clean upper and lower crankcase assemblies 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).

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 upper crankcase assembly.
   b. Clean cylinder bore with soap, water, and a stiff nylon brush.
   c. Clean upper and lower crankcase assemblies in solvent.
   d. Dry with filtered compressed air.
3. Remove main oil gallery cup plugs (in rear of upper crankcase assembly) using a punch and hammer near edge of plug and striking with hammer.
4. Remove plugs from upper crankcase assembly and discard.

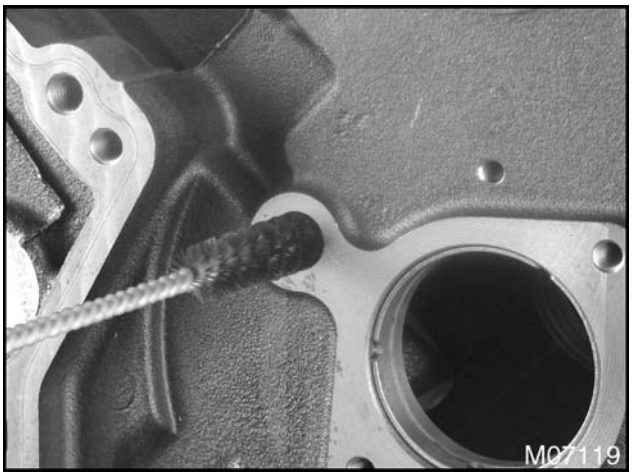


Figure 554 Main oil gallery cleaning

5. Clean main oil galleries with oil gallery cleaning brush ZTSE4511 (page 340).

CAUTION: To prevent engine damage, install gasket and cover within 5 minutes of Liquid Gasket (RTV) application to inhibit the formation of a skin and ensure a leak proof joint.

NOTE: Use Liquid Gasket (RTV) (page 340) before installing main oil gallery cup plugs.

6. Coat edges of new oil gallery cup plugs with Liquid Gasket (RTV) (page 340). Use oil gallery plug driver ZTSE4512 (page 340) and install new oil gallery cup plugs. The oil gallery plug driver installs oil gallery cup plugs to correct depth. They should be flush with upper crankcase assembly surface to approximately 1.50 mm (0.060 in) below surface.

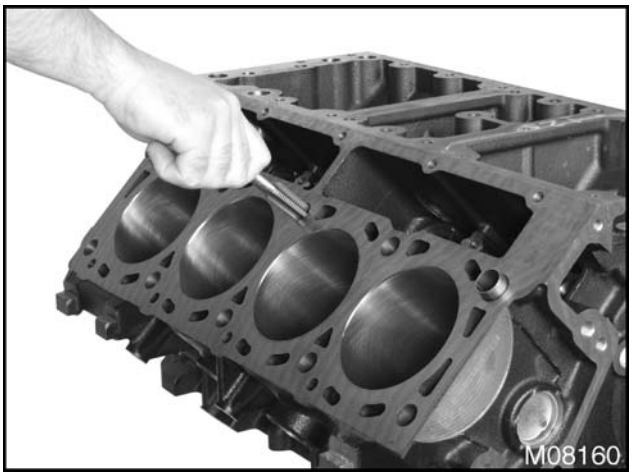


Figure 555 Cylinder head bolt holes

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

7. Clean cylinder head bolt holes with head bolt bottoming tap ZTSE4508 (page 340).

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

8. Blow out chips with filtered compressed air.

Crankcase Inspection

1. After cleaning, inspect upper crankcase assembly for cracks, scoring, roughness or wear at cylinder bores.

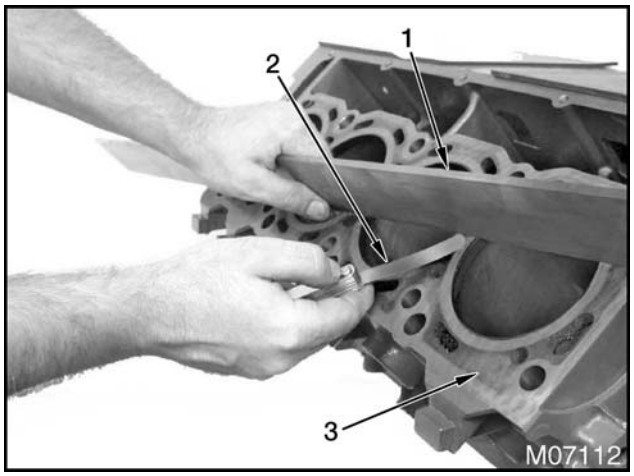


Figure 556 Flatness check for top surface of upper crankcase assembly

1. Straightedge
2. Feeler gauge
3. Upper crankcase assembly top surface

CAUTION: To prevent engine damage, do not resurface the crankcase if surface defects exceed specifications.

2. Use a straightedge (page 340) to check top surface of upper crankcase assembly (firing deck) for flatness. Insert a feeler gauge (page 340) between straightedge and upper crankcase assembly head surface.
   a. Measure entire deck surface. If gap exceeds specifications (page 339), replace upper crankcase assembly.

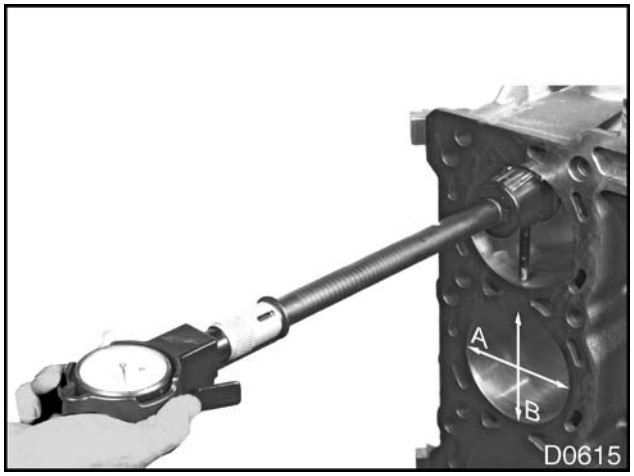


Figure 557 Out-of-round cylinder bore check

CAUTION: To prevent engine damage, if cylinder bores are deeply scored, out-of-round or exceed specifications, bore out cylinders to oversize specification.

NOTE: If cylinder walls have minor surface damage, but are otherwise within out-of-round specifications, it may be possible to remove damage by deglazing (page 329) .

3. Use a cylinder bore gauge (page 340) to check cylinder bore out-of-round conditions.
   a. Measure diameter of each cylinder bore at top of piston ring travel. Be sure to measure at a right angle to center line of crankshaft assembly (dimension A).
   b. Measure each bore so gauge reading coincides with center line of crankshaft assembly (dimension B).
   c. The difference between dimension A and dimension B is out-of-round condition at top of cylinder bore.
4. Repeat procedure at bottom of ring travel to check for out-of-round condition.

NOTE: If cylinder bore is suitable for use without reconditioning, deglaze cylinder bore before assembling. See Cylinder Deglazing (page 329) for further details.

5. If cylinder bore is within specifications (page 339), standard size pistons and rings may be used.

Cylinder Deglazing

NOTE: Remove piston cooling tubes before deglazing cylinder bores.

1. Use deglazing hone (four inch) ZTSE4349 (page 340) to deglaze cylinder bore. This brush quickly deglazes cylinder walls and produces a crosshatch pattern on cylinder wall surface in a single operation. The brush contours itself to cylinder wall and conditions wall surface without altering cylinder bore.

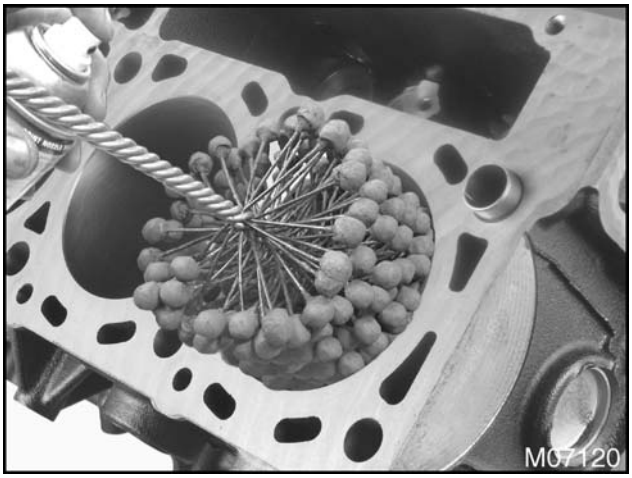


Figure 558 Deglazing hone (four-inch) ZTSE4349

2. Spray cylinder and deglazing hone with penetrating fluid or equivalent.

NOTE: For a successful procedure 100 to 120 rpm is required.

3. Attach deglazing hone to a variable speed electric or air powered drill.

NOTE: Do not allow deglazing hone to spin in one place. Deglazing hone must be moved in a constant up and down motion to maintain crosshatch pattern.

4. Deglaze cylinder wall for about 15 seconds. Stroke bore up and down at a rate of one complete up and down stroke per second.
5. Withdraw deglazing hone from cylinder bore while rotating. Wipe portion of cylinder wall and inspect crosshatch pattern.

NOTE: The crosshatch pattern left by the abrasive tool should be approximately 45°. If pattern is flatter than required, increase up and down stroke speed or slow down drill rotation as required.

6. Continue deglazing cylinder bore for 10 to 15 seconds or 20 to 25 strokes.
7. Wipe cylinder bore clean and inspect bore for correct 45° crosshatch pattern.
8. After deglazing, thoroughly clean cylinder bores with soft bristle brush, soap and water.

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

9. Dry with filtered compressed air.
10. Lubricate bores with clean engine oil

Crankshaft Assembly

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 559 Measurement of crankshaft main journal

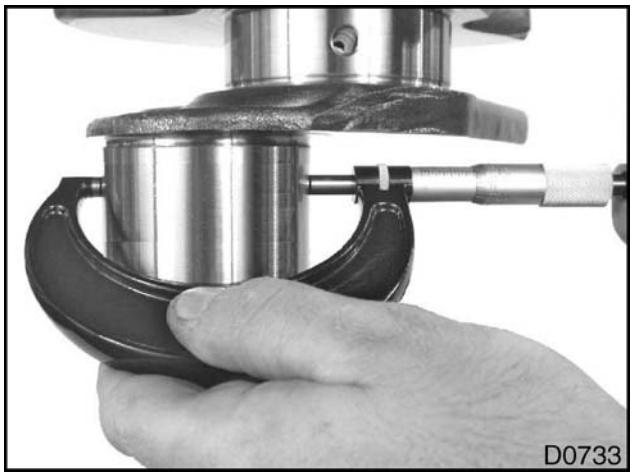


Figure 560 Measurement of crankshaft connecting rod journal

CAUTION: To prevent engine damage, grind or install new crankshaft if journals exceed maximum out-of-round or taper specifications.

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 340) to measure diameter of each journal (main and connecting rod). Measure each journal at two points 90° apart. Move micrometer over entire width of journal. If journal wear exceeds specifications (page 339), grind or replace crankshaft.

Main Bearing Fit Check

NOTE: Bearing shells must fit tightly in the bore. When bearing shells are inserted into upper and lower crankcase assembly, they protrude above parting line. This protrusion is required to achieve bearing crush.

Bearing shells across open ends are slightly larger than the diameter of main bearing bore into which they are assembled. This condition is designed into bearing shell, causing it to spread outward at parting line when bearing crush load is applied by tightening bolts. Some flexibility may be lost in normal use, but bearing replacement is not required because of a nominal loss of flexibility.

When assembly is drawn up tight, bearing is compressed, ensuring positive contact between backside of bearing and bore.

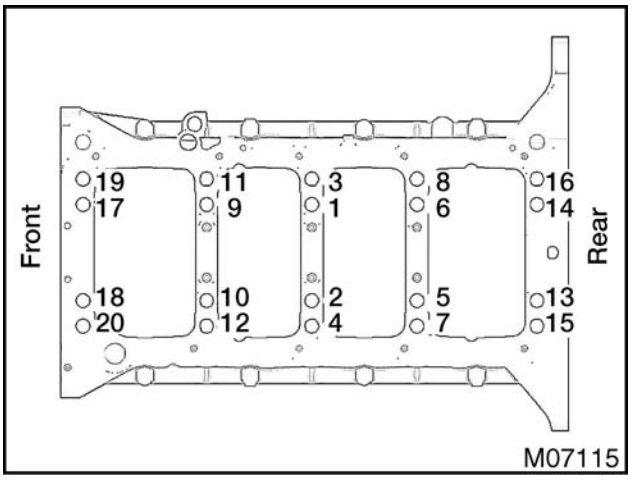


Figure 561 Torque sequence for main bearing bolts

CAUTION: To prevent engine damage, install longer main cap bolts (M14 x 127) inboard and shorter main cap bolts (M14 x 114) outboard.

1. Lubricate old main bearing bolts with clean engine oil. Assemble lower crankcase assembly to upper crankcase assembly with new bearing shells installed.
2. Tighten bolts using above sequence as follows:
   - Tighten bolts to 149 N·m (110 lbf·ft).
   - Tighten bolts to 176 N·m (130 lbf·ft).
   - Tighten bolts to 231 N·m (170 lbf·ft).
3. Using a telescoping gauge (page 340), measure inside diameter of main bearing at two locations 90° apart. Average the two inside diameters.
4. Use a 3–4 inch micrometer (page 340) to measure each crankshaft main journal diameter.
5. Subtract crankshaft main journal diameter from respective main bearing inside diameter to obtain bearing-to-crankshaft running clearance. Repeat for each crankshaft main 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.

NOTE: Plastigage® may be used as an alternate method to determine running clearance.

6. If bearing-to-crankshaft running clearances exceed specifications (page 339) because of wear on crankshaft, replace or grind crankshaft and install under-size precision type bearing shells.

Piston Cooling Tubes

1. With piston cooling tubes removed, run a correct size wire through each tube to ensure no blockage.

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

2. Use dry filtered compressed air to blow out any remaining debris.
3. Replace any cracked or bent tubes.

Camshaft Assembly

NOTE: This engine uses hydraulic valve tappets with roller followers. A roller follower guide is needed to maintain correct orientation of roller to cam lobe. Normal clearance between the valve tappet roller and guide allows for slight tracking of roller across cam lobe.

Tracking of the roller is normal when the roller accelerates and decelerates during engine operation. Consequently, a typical wear pattern on cam lobes will exhibit tracks from side to side, have wide and narrow areas from the loading and unloading of follower. The wear pattern (tracking) is normal and the camshaft does not require replacement.

1. Inspect camshaft. If any lobes are scuffed, scored or cracked, replace camshaft assembly.
2. After inspection, evaluate camshaft main journal and lobe condition as follows:

   NOTE: When measuring the camshaft with a micrometer, always take two measurements 90° apart.

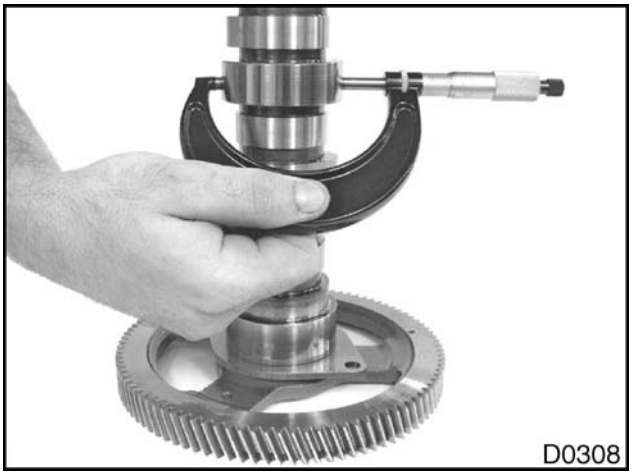


Figure 562 Measurement of camshaft bearing journal

   a. Use a 2-3 inch micrometer (page 340) to measure journal diameter of camshaft bearing. If bearing journals are worn beyond specification (page 339), install a new camshaft assembly.

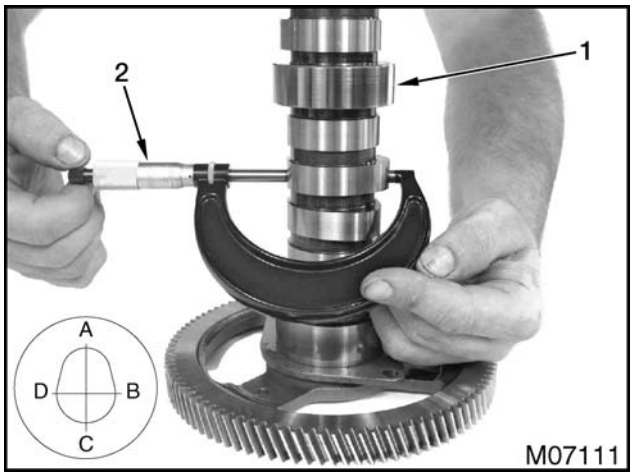


Figure 563 Measurement of camshaft intake and exhaust lobes

1. Camshaft assembly
2. Micrometer

   b. To check camshaft intake and exhaust lobes, measure across (A to C) and across (B to D). Subtract (B to D) from (A to C). This will give cam lobe lift. Subtract this amount from maximum lobe lift in specifications (page 339) to obtain cam lobe wear measurement. Replace camshaft assembly if cam lobe wear exceeds specifications (page 339).

3. Inspect thrust plate for wear, cracks or distortion. Use a 0–1 inch micrometer (page 340) to measure thrust plate thickness. If thickness does not meet specification (page 339), replace camshaft assembly.
4. Inspect camshaft gear for worn or damaged teeth.
5. Wash camshaft in cleaning solvent with a soft brush.

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

6. Dry with filtered compressed air.

Measuring Camshaft Bushings

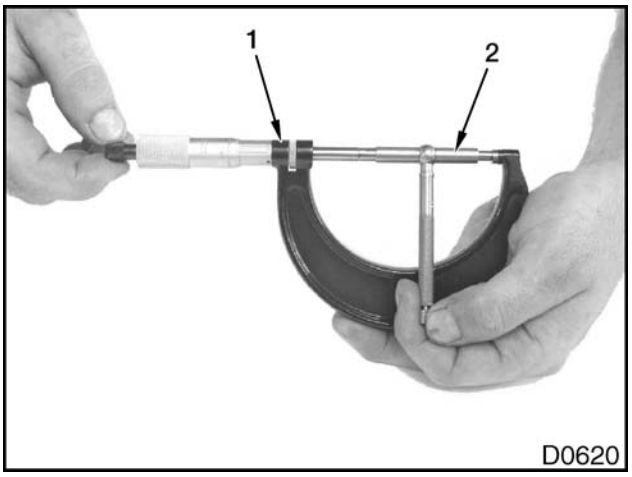


Figure 564 Measurement of camshaft bushing inside diameter

1. Telescoping gauge
2. Outside micrometer

Inspect five camshaft bushings for wear and correct running clearance as follows:

1. Use a telescoping gauge set (page 340) and 2-3 inch micrometer to measure camshaft bushing inside diameters with bushings installed in crankcase.
2. To determine running clearance, subtract previous camshaft journal diameter readings from camshaft bushing inside diameter readings.
3. If maximum allowable running clearance is exceeded (page 339), replace camshaft bushings. See camshaft bushing removal (page 326) in this section.
4. Inspect each bushing bore in upper crankcase assembly for burrs or debris that could damage new bushings.
5. Remove burrs and clean bores thoroughly before installing new camshaft bushings.

Coolant Heater

1. Inspect heater for continuity.
2. Check insulator at terminal for cracks.

Installation

Camshaft Bushings

1. Lubricate new camshaft bushings and crankcase bores with clean engine oil.

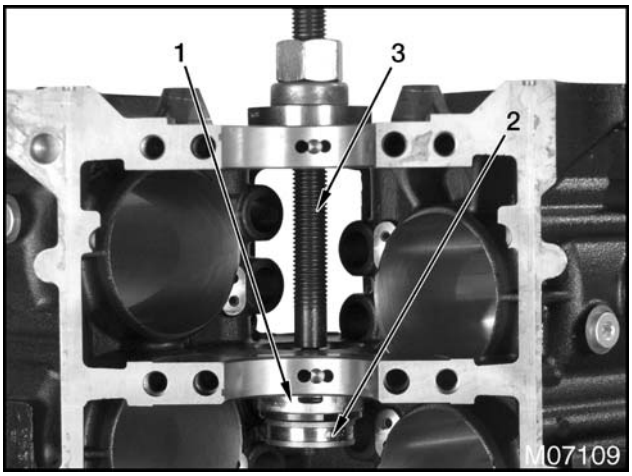


Figure 565 Installation of cam bushing

1. Camshaft bushing
2. Camshaft bushing remover/installer (expanding collet) ZTSE4489
3. Pulling screw (from camshaft bushing kit ZTSE2893A)

2. Slide a new bushing onto camshaft bushing remover/installer (expanding collet) ZTSE4489 (page 340).
3. Thread pulling screw (from camshaft bushing kit ZTSE2893A), backup nut, and camshaft bushing remover/installer (expanding collet) ZTSE4489 (page 340) together.
4. Tighten expanding collet by turning backup nut until bushing is securely held on camshaft bushing remover/installer (expanding collet) ZTSE4489 (page 340).

CAUTION: To prevent engine damage, ensure correct oil circulation through the crankcase. Align camshaft bushing oil holes with corresponding oil supply holes machined in crankcase.

5. To aid in alignment of bushing and upper crankcase assembly oil holes, use a marker to indicate oil hole location on backup nut of installation tool. Repeat this step for each camshaft bushing.
6. Install all camshaft bushings through rear of upper crankcase assembly. Pull bushings in place at rear of upper crankcase assembly by turning pulling nut on pulling screw until bushing is flush on both sides with upper crankcase assembly. Remove camshaft bushing remover/installer (expanding collet) ZTSE4489 (page 340) and inspect oil hole alignment.

Camshaft Assembly

1. Coat camshaft lobes and bushing journals with clean engine oil.

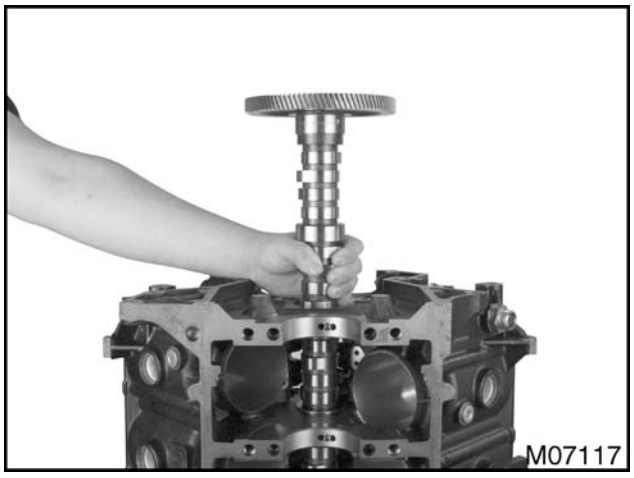


Figure 566 Camshaft assembly

NOTE: Do not nick or scratch camshaft bushings with cam lobes.

2. Position upper crankcase assembly with rear of engine facing up on engine stand and install camshaft assembly.

Figure 567 Camshaft thrust plate bolts

1. M8 x 16 bolt (2)
2. Camshaft gear

3. Install two M8 x 16 camshaft thrust plate bolts. Tighten bolts to standard torque (page 369).
4. Verify that camshaft end play is within specifications (page 339).

Piston Cooling Tubes

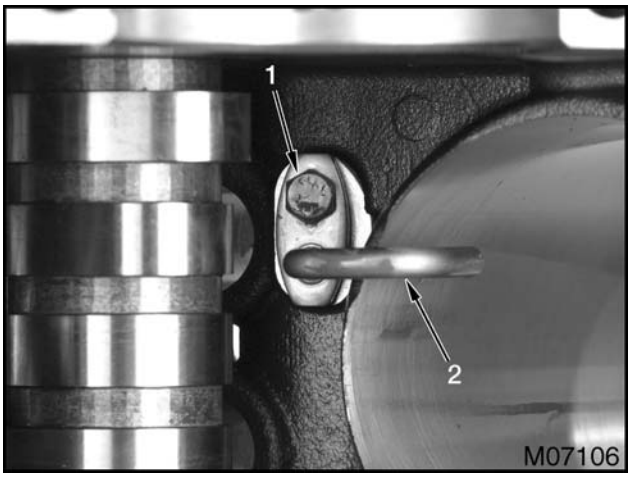


Figure 568 Piston cooling tube

1. M6 x 18 bolt (8)
2. Piston cooling tube (8)

CAUTION: To prevent engine damage, install special patch type bolts to mount piston cooling tubes.

NOTE: The bolt-on piston cooling tubes are self-aligning.

1. Place piston cooling tubes on upper crankcase assembly mounting pad.
2. When installing piston cooling tube bolts, do one of the following:
   a. Install new special patch type mounting bolts (M6 x 18).
   b. Remove oil residue and apply Liquid Gasket (RTV) (page 340) to threads of existing special patch type mounting bolts (M6 x 18).
3. Install and tighten bolts to standard torque (page 369).

Crankshaft Assembly

NOTE: Make sure crankshaft assembly has been inspected per instructions in this section before proceeding.

1. Use a lint-free cloth to wipe upper crankcase assembly bearing supports free of oil.
2. Inspect each bearing. Replace scored, chipped or worn bearings.

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

NOTE: Make sure upper thrust bearing is installed at number four upper main bearing journal.

3. Place upper main bearings in upper crankcase assembly. Make sure locking tabs on bearings are snapped in saddle and oil holes in bearings line up with oil holes in upper crankcase assembly.

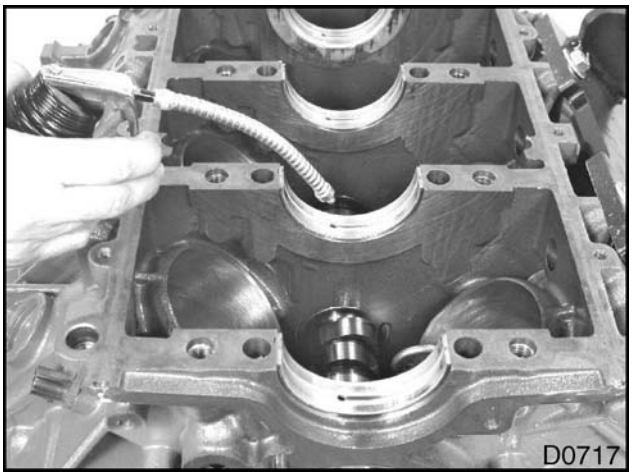


Figure 569 Upper main bearings lubrication

4. Lubricate bearings with clean engine oil.
5. Rotate camshaft so timing mark on camshaft gear is pointing upwards.

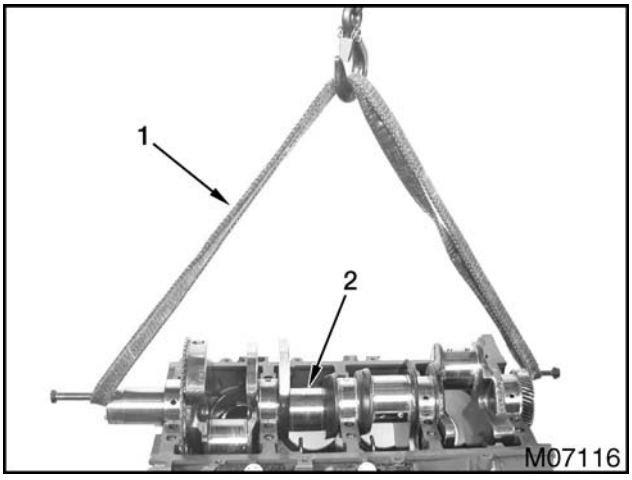


Figure 570 Lifting sling

1. Lifting sling
2. Crankshaft assembly

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.

6. Install a bolt in each end of the crankshaft assembly (if removed). Attach hoist and lifting sling around crankshaft bolts and lower it onto five main bearings.

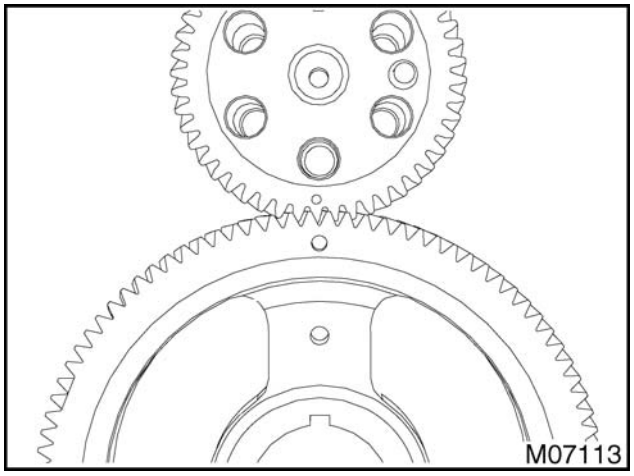


Figure 571 Crankshaft and camshaft timing marks

7. Install crankshaft so timing mark on gear aligns with timing mark on camshaft gear.

Lower Crankcase Assembly

With acceptable bearing clearance as determined in Main Bearing Fit Check (page 331), install lower crankcase assembly as follows:

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

1. Place crankshaft lower main bearings in lower crankcase assembly. Make sure locking tabs on bearings are snapped in saddle.
2. Install new lower crankcase assembly seals.
3. Apply clean engine oil to lower bearing inserts, crankshaft journals, and main bearing bolts.

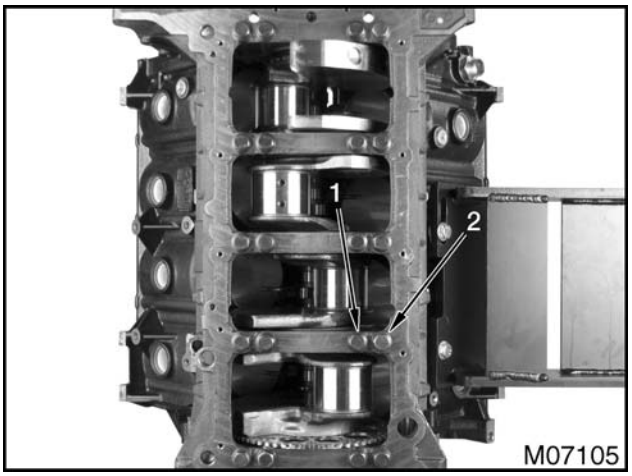


Figure 572 Main bearing bolts

1. M14 x 127 main bearing bolt (10)
2. M14 x 114 main bearing bolt (10)

CAUTION: To prevent engine damage, install new bolts for lower crankcase assembly if lower crankcase assembly is serviced.

CAUTION: To prevent engine damage, install longer main cap bolts (M14 x 127) inboard and shorter main cap bolts (M14 x 114) outboard.

4. Install 10 new M14 x 127 main bearing bolts.
5. Install 10 new M14 x 114 main bearing bolts.

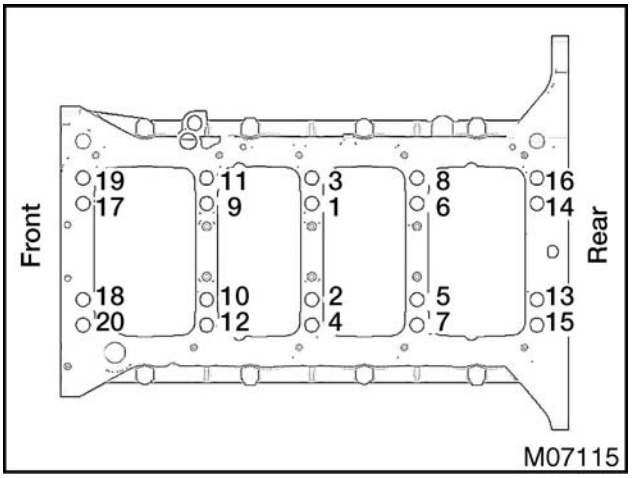


Figure 573 Torque sequence for main bearing bolts

6. Tighten bolts using above sequence as follows:
   - Tighten bolts to 149 N·m (110 lbf·ft).
   - Tighten bolts to 176 N·m (130 lbf·ft).
   - Tighten bolts to 231 N·m (170 lbf·ft).

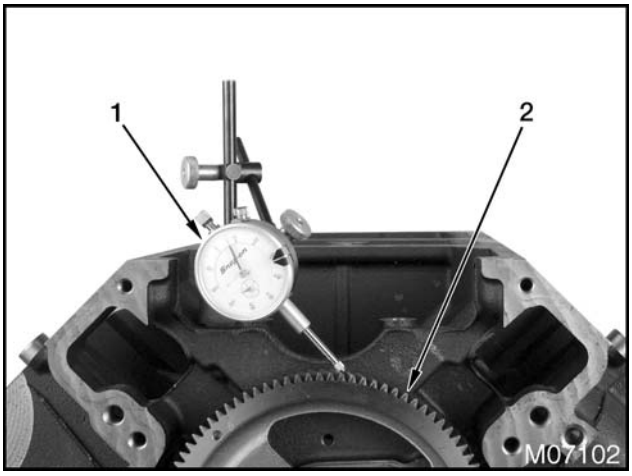


Figure 574 Camshaft assembly gear backlash check (camshaft gear to crankshaft gear)

1. Dial indicator with magnetic base
2. Camshaft gear

NOTE: Confirm that camshaft gear backlash is within specifications.

NOTE: Crankshaft gear must be fixed and not allowed to rotate; the camshaft gear must rotate, for a correct reading.

7. Check and record backlash for camshaft gear-to-crankshaft gear as follows:
   a. Mount dial indicator with magnetic base (page 340) on rear of engine.
   b. Position dial indicator tip on a gear tooth and remove lash.
   c. Zero the dial indicator.
   d. Rotate gear by hand and read indicator.
   e. If backlash exceeds specified limits (page 339), replace camshaft assembly.

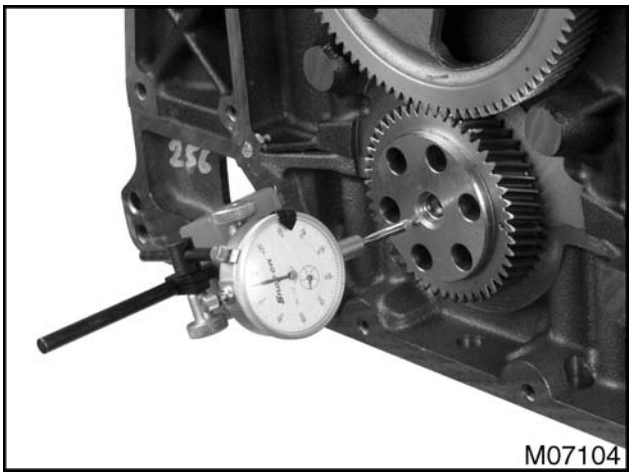


Figure 575 Crankshaft end play

8. Check crankshaft end play as follows:
   a. Mount dial indicator on lower crankcase assembly with indicator tip on end of crankshaft gear 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 339).
   d. If end play exceeds specified limits, replace upper thrust bearing.

Coolant Heater

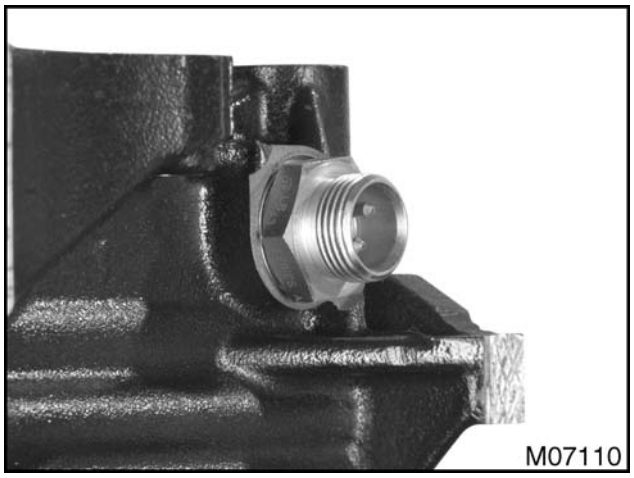


Figure 576 Coolant heater

1. Lubricate a new O-ring and install on coolant heater.
2. Install coolant heater in upper crankcase assembly and tighten to special torque (page 340).

Specifications

Table 34 Crankcase, Crankshaft, and Camshaft

Upper Crankcase Assembly	
Maximum firing deck gap	0.130 mm (0.005 in)
Maximum cylinder bore out-of round allowance	0.0125 mm (0.005 in)
Cylinder bore diameter:	
Standard size	98.200 mm (3.8661 in)
0.254 mm (0.010 in) over size	98.454 mm (3.8761 in)
0.508 mm (0.020 in) over size	98.708 mm (3.8861 in)
0.762 mm (0.030 in) over size	98.962 mm (3.8961 in)
Crankshaft Assembly	
Main Bearing Journal Diameter:	
Standard size	80.9873 to 81.0127 mm (3.188 to 3.150 in)
0.254 mm (0.010 in) under size	80.7333 to 80.7587 mm (3.178 to 3.140 in)
0.508 mm (0.020 in) under size	80.4793 to 80.5047 mm (3.168 to 3.130 in)
0.762 mm (0.030 in) under size	80.2253 to 80.2507 mm (3.158 to 3.120 in)
Main bearing thrust face maximum runout	0.050 mm (0.002 in)
Main bearing to crankshaft running clearance	0.020 to 0.086 mm (0.0008 to 0.0034 in)
Connecting Rod Journal Diameter:	
Standard size	71.987 to 72.013 mm (2.834 to 2.835 in)
0.254 mm (0.010 in) under size	71.733 to 71.759 mm (2.824 to 2.825 in)
0.508 mm (0.020 in) under size	71.479 to 71.505 mm (2.814 to 2.815 in)
0.762 mm (0.030 in) under size	71.225 to 71.251 mm (2.804 to 2.805 in)
Crankshaft end play:	
Nominal new	0.203 mm (0.008 in)
Maximum service	0.508 mm (0.020 in)
Camshaft Assembly	
Bearing journal diameter (all journals)	61.987 to 62.013 mm (2.440 to 2.441 in)
Bearing inside diameter (installed)	62.05 to 62.14 mm (2.443 to 2.446 in)
Camshaft journal and bushing running clearance	0.037 to 0.153 mm (0.0015 to 0.0060 in)
Camshaft end play	0.051 to 0.211 mm (0.002 to 0.008 in)
Camshaft gear backlash	0.179 to 0.315 mm (0.007 to 0.012 in)
Maximum permissible cam lobe wear	0.51 mm (0.02 in)
Camshaft thrust plate thickness	3.589 to 3.649 mm (0.1413 to 0.1436 in)

Table 34 Crankcase, Crankshaft, and Camshaft (cont.)

Camshaft lobe lift (maximum):	
Intake	5.820 mm (0.2291 in)
Exhaust	5.906 mm (0.2325 in)

Special Torque

Table 35 Crankcase, Crankshaft, and Camshaft

Main bearing bolts	See tightening procedure and sequence
Coolant heater	41 N·m (30 lbf·ft)

Special Service Tools

Table 36 Crankcase, Crankshaft, and Camshaft

Description	Tool Number
0–1 inch micrometer	Obtain locally
2–3 inch micrometer	Obtain locally
3–4 inch micrometer	Obtain locally
Camshaft bushing kit	ZTSE2893A
Camshaft bushing remover/installer (expanding collet)	ZTSE4489
Cylinder bore gauge	Obtain locally
Deglazing hone (four inch)	ZTSE4349
Dial indicator with magnetic base	Obtain locally
Feeler gauge	Obtain locally
Head bolt bottoming tap	ZTSE4508
Lifting sling	Obtain locally
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Oil gallery cleaning brush	ZTSE4511
Oil gallery plug driver	ZTSE4512
Straightedge	Obtain locally
Telescoping gauge set	Obtain locally

Table of Contents

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 – Accelerate
ACD – Air Conditioner Demand
ACT PWR GND – Actuator Power Ground
AF – Air to Fuel ratio
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
BARO – 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
CID – Cubic Inch Displacement
cfm – Cubic feet per minute
cfs – Cubic feet per second
CKP – Crankshaft Position
CKPO – Crankshaft Position Out
cm – Centimeter
CMP – Camshaft Position
CMPO – Camshaft Position Out
CO – Carbon Monoxide
COO – Cruise On / Off switch
CPU – Central Processing Unit
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

EBP – Exhaust Back Pressure
EBPD – Exhaust Back Pressure Desired
ECI – Engine Crank inhibit
ECL – Engine Coolant Level
ECM – Electronic Control Module
ECM PWR – Electronic Control Module Power
ECT – Engine Coolant Temperature
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 Recirculating
EGRH – Exhaust Gas Recirculation High control
EGRL – Exhaust Gas Recirculation Low control
EGRP – Exhaust Gas Recirculating Position
EGT1 – Exhaust Gas Temperature 1
EGT2 – Exhaust Gas Temperature 2
EGT3 – Exhaust Gas Temperature 3
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
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 – Feet
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 – Hydrocarbons
HFCM – Horizontal Fuel Conditioning Module
Hg – Mercury
hp – Horsepower
HPFP – High-Pressure Fuel Pump
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 – Pounds of force
lb/s – Pounds per second
lbf ft – Pounds of force per foot
lbf in – Pounds of force per inch
lbm – Pounds of mass
LSD – Low Sulfur Diesel

m – Meter
m/s – Meters per second
MAF – Mass Air Flow
MAG – Magnetic
MAP – Manifold Absolute Pressure
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
P/N – 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 Takeoff
PWM – Pulse Width Modulate
PWR – Power (voltage)

qt – Quart

RAM – Random Access Memory
RAS – Resume / Accelerate 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 Cooling 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 – Synchronization

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 – Vehicle Speed Output
VSS – Vehicle Speed Sensor

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

XMSN – Transmission

Table of Contents

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 is 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.

Table of Contents

Variable Geometry Turbocharger (VGT)

Table 37 Variable Geometry Turbocharger (VGT) Shaft

Turbine shaft axial end play	0.05 - 0.10 mm (0.002 - 0.004 in).

Fuel System

Table 38 Fuel Filter

Fuel Filter	
Primary fuel filter type	10 micron with water separation
Secondary fuel filter type	4 micron with water separation
Normal fuel pressure (after secondary fuel filter)	48 - 69 kPa (7 - 10 psi)

Intake and Exhaust Manifolds

Table 39 Intake, Inlet, and Exhaust Manifolds

Exhaust Manifold	
Maximum allowable warpage	0.08 mm (0.003 in)

Front Cover, Cooling System, and Related Components

Table 40 Front Cover, Cooling System, and Related Components

Vibration Damper	
Face runout (maximum)	0.635 mm (0.025 in)
Rubber bulging (maximum)	1.5 mm (0.060 in)
Lubricating Oil Pump	
Type	Gerotor
Drive	Crankshaft
Location	Oil pump housing assembly
Pressure Regulating Valve:	
Engine oil pressure, low idle (min. @ 110°C (230°F) oil temp.)	69 kPa (10 psi)
Engine oil pressure, high idle (min. @ 110°C (230°F) oil temp.)	276 kPa (40 psi)
Oil pump discharge pressure (2,500 rpm)	483 to 621 kPa (70 to 90 psi)
End clearance (inner and outer oil pump gerotor to oil pump housing assembly)	0.025 to 0.095 mm (0.001 to 0.004 in)
Radial clearance (between outer oil pump gerotor and oil pump housing assembly)	0.15 to 0.28 mm (0.006 to 0.011 in)
Thermostat Assembly With Bypass	
Type	Balanced pressure, wax pellet
Minimum recommended coolant operating temperature	71° C (160° F)
Start-to-open temperature, 0.20 mm (0.009 in) stroke	92 to 96° C (198 to 205° F)
Full-open temperature, 10 mm (0.394 in) stroke	106° C (222.8° F)
Thermostat Assembly Without Bypass	
Type	Balanced pressure, wax pellet
Minimum recommended coolant operating temperature	71° C (160° F)
Start-to-open temperature, 0.20 mm (0.009 in) stroke	86.7 to 91° C (188 to 196° F)
Full-open temperature, 10 mm (0.394 in) stroke	104° C (219.1° F)

Cylinder Head and Valve Train

Table 41 Cylinder Head and Valve Train

Exhaust Valves	
Stem diameter	6.946 to 6.964 mm (0.2735 to 0.2742 in)

Table 41 Cylinder Head and Valve Train (cont.)

Stem to guide running clearance (max. allowable before replacement) diametrically	0.1846 mm (0.00727 in)
Valve face angle from center line	50.5 – 50.75°
Valve margin (minimum)	1.53 mm (0.060 in)
Valve recession in head	0.37 – 0.73 mm (0.0146 – 0.0287 in)
Intake Valves	
Stem diameter	6.946 to 6.964 mm (0.2735 to 0.2742 in)
Stem to guide running clearance (max. allowable before replacement)	0.1846 mm (0.00727 in)
Valve face angle from center line	53.0 – 53.25°
Valve margin (minimum)	1.40 mm (0.055 in)
Valve recession in head	0.37 – 0.73 mm (0.0146 – 0.0287 in)
Cylinder Heads	
Valve guide inside diameter	7.003 to 7.029 mm (0.276 to 0.277 in)
Valve guide bore runout	0.06 mm (0.00236 in)
Valve guide taper (maximum)	0.10 mm (0.004 in)
Valve seat width (intake)	1.80 to 2.56 mm (0.071 to 0.101 in)
Valve seat width (exhaust)	1.48 to 2.24 mm (0.058 to 0.088 in)
Valve seat angle (intake) from center line of valve guide	52.5 – 52.75°
Valve seat angle (exhaust) from center line of valve guide	50.0 – 50.25°
Gasket surface flatness	0.025 mm per 25 x 25 mm Maximum 0.10 mm (0.004 in) per total surface area
Overall thickness of cylinder head (deck-to-deck)	95 ± 0.48 mm (3.74 ± 0.018 in)
Valve Spring:	
Solid height	36.1 mm (1.42 in)
Compressed*	46.50 mm @ 340 ± 17 N (1.83 in @ 76.5 ± 3.8 lbf)
Compressed*	38.30 mm @ 850 ± 43 N (1.51 in @ 191.1 ± 9.7 lbf)
* Spring must be compressed to a solid height before checking test loads.	
Push Rods	
Runout (maximum)	0.5 mm (0.02 in)

Oil Cooler and Filter Housing

Table 42 Oil Cooler and Oil Filter

Oil Cooler	
Type	Full flow, fin
Location	Engine valley (forward)
Oil Filter	
Type	Cartridge, full flow - disposable
Location	Front, oil cooler mounted
Filter bypass location	Oil filter return tube assembly

Flywheel and Flywheel Housing

Table 43 Flywheel and Flywheel Housing

Flywheel Assembly	
Flywheel assembly surface maximum runout (manual)	0.25 mm (0.010 in)
Power Steering Idler Shaft	
Power steering idler shaft height	34.6 ± 0.15 mm (1.4 ± 0.01 in)
Crankcase Rear Cover	
Crankcase rear cover maximum runout	0.51 mm (0.020 in)
Crankshaft Flange and Power Steering Idler Gear Assembly	
Face runout:	
Crankshaft flange	0.050 mm (0.002 in) maximum
Backlash:	
Power steering idler gear assembly	0.066 to 0.290 mm (0.0026 to 0.0114 in)

Table 44 Power Cylinders

Connecting Rods	
Connecting rod length (center to center)	176 mm (6.929 in)
Piston pin bore inside diameter	38.542 to 38.849 mm (1.5174 to 1.5295 in)
Material	I-Beam section - powdered metal
Bearing bore diameter (crankshaft end)	75.987 to 76.013 mm (2.9916 to 2.9926 in)
Bearing bore maximum out-of-round	0.013 mm (0.0005 in)
Connecting rod bearing inside diameter	72.031 to 72.073 mm (2.8359 to 2.8375 in)
Connecting rod bearing running clearance (diameter)	0.015 to 0.089 mm (0.0006 to 0.0035 in)
Connecting rod side clearance	0.230 to 0.730 mm (0.0091 to 0.0287 in)

Table 44 Power Cylinders (cont.)

Weight (complete rod without bearing)	1274.89 to 1295.89 g (2.811 to 2.857 lb)
Pistons	
Material	Aluminum Alloy
Skirt diameter [1]	98.114 to 98.146 mm (3.863 to 3.864 in)
[1] Measure 15.5 mm (0.610 in) from bottom, at 90° to the piston pin. Measure only at room temperature of 19 to 21°C (66 to 70°F).	
Service Piston:	
Standard size	98.114 to 98.146 mm (3.863 to 3.864 in)
0.254 mm (0.010 in) oversize	98.368 to 98.400 mm (3.873 to 3.874 in)
0.508 mm (0.020 in) oversize	98.622 to 98.654 mm (3.883 to 3.884 in)
0.762 mm (0.030 in) oversize	98.876 to 98.908 mm (3.893 to 3.894 in)
Top compression ring groove width (measured over 2.10 mm (0.082 in) gauge pins):	
Upper limit	96.606 mm (3.8033 in)
Replacement limit	96.406 mm (3.7955 in)
Piston height above crankcase deck (protrusion)	0.609 to 0.863 mm (0.0240 to 0.0340 in)
Piston skirt clearance	0.045 to 0.095 mm (0.0018 to 0.0037 in)
Piston Pins	
Length	74.6 to 75.0mm (2.9371 to 2.9528 in)
Diameter	38.491 to 38.501 mm (1.5154 to 1.5158 in)
Pin fit at room temperature of 19 to 21°C (66 to 70°F):	
Clearance in connecting rod (piston pin bore)	0.041 to 0.058 mm (0.0016 to 0.0022 in)
Clearance in piston (piston pin bore)	0.011 to 0.027 mm (0.0004 to 0.0011 in)
End clearance	0.84 mm (0.0331 in)
Piston Rings	
Ring diameter (standard):	98.2 mm (3.866 in)
Ring groove (side clearance):	
Intermediate compression	0.050 to 0.096 mm (0.0020 to 0.0038 in)
Oil control	0.040 to 0.095 mm (0.00157 to 0.00374 in)
Ring gap in bore:	
Top compression	0.29 to 0.55 mm (0.011 to 0.021 in)
Intermediate compression	1.42 to 1.68 mm (0.0559 to 0.0661 in)
Oil control	0.24 to 0.50 mm (0.009 to 0.019 in)

Crankcase, Crankshaft, and Camshaft

Table 45 Crankcase, Crankshaft, and Camshaft

Upper Crankcase Assembly	
Maximum firing deck gap	0.130 mm (0.005 in)
Maximum cylinder bore out-of round allowance	0.0125 mm (0.005 in)
Cylinder bore diameter:	
Standard size	98.200 mm (3.8661 in)
0.254 mm (0.010 in) over size	98.454 mm (3.8761 in)
0.508 mm (0.020 in) over size	98.708 mm (3.8861 in)
0.762 mm (0.030 in) over size	98.962 mm (3.8961 in)
Crankshaft Assembly	
Main Bearing Journal Diameter:	
Standard size	80.9873 to 81.0127 mm (3.188 to 3.150 in)
0.254 mm (0.010 in) under size	80.7333 to 80.7587 mm (3.178 to 3.140 in)
0.508 mm (0.020 in) under size	80.4793 to 80.5047 mm (3.168 to 3.130 in)
0.762 mm (0.030 in) under size	80.2253 to 80.2507 mm (3.158 to 3.120 in)
Main bearing thrust face maximum runout	0.050 mm (0.002 in)
Main bearing to crankshaft running clearance	0.020 to 0.086 mm (0.0008 to 0.0034 in)
Connecting Rod Journal Diameter:	
Standard size	71.987 to 72.013 mm (2.834 to 2.835 in)
0.254 mm (0.010 in) under size	71.733 to 71.759 mm (2.824 to 2.825 in)
0.508 mm (0.020 in) under size	71.479 to 71.505 mm (2.814 to 2.815 in)
0.762 mm (0.030 in) under size	71.225 to 71.251 mm (2.804 to 2.805 in)
Crankshaft end play:	
Nominal new	0.203 mm (0.008 in)
Maximum service	0.508 mm (0.020 in)
Camshaft Assembly	
Bearing journal diameter (all journals)	61.987 to 62.013 mm (2.440 to 2.441 in)
Bearing inside diameter (installed)	62.05 to 62.14 mm (2.443 to 2.446 in)
Camshaft journal and bushing running clearance	0.037 to 0.153 mm (0.0015 to 0.0060 in)
Camshaft end play	0.051 to 0.211 mm (0.002 to 0.008 in)
Camshaft gear backlash	0.179 to 0.315 mm (0.007 to 0.012 in)
Maximum permissible cam lobe wear	0.51 mm (0.02 in)
Camshaft thrust plate thickness	3.589 to 3.649 mm (0.1413 to 0.1436 in)

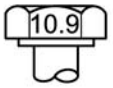
Table 45 Crankcase, Crankshaft, and Camshaft (cont.)

Camshaft lobe lift (maximum):	
Intake	5.820 mm (0.2291 in)
Exhaust	5.906 mm (0.2325 in)

Table of Contents

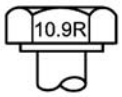
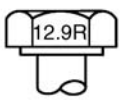
General Torque

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 577 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 578 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.

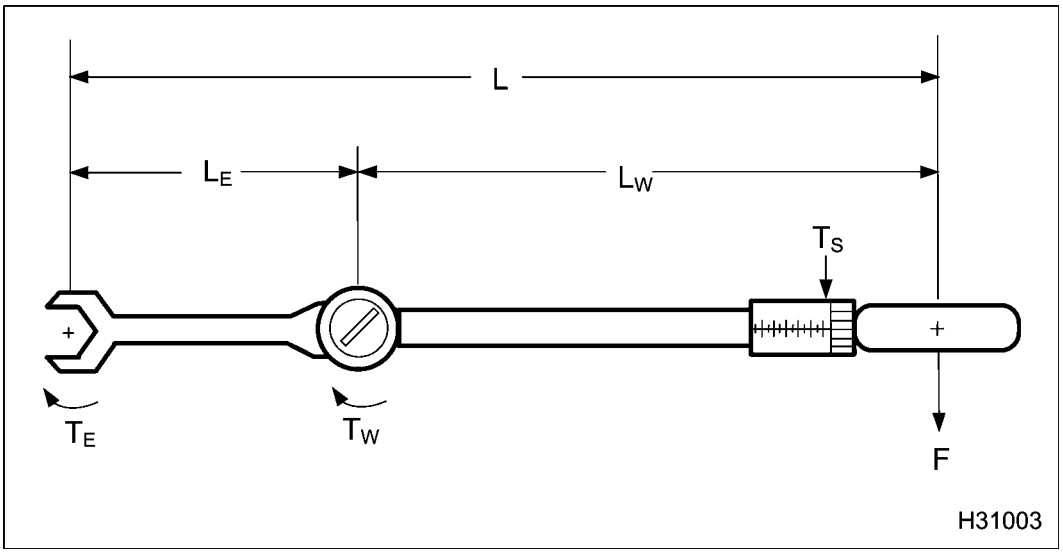


Figure 579 Torque wrench and extension

- 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 46 Mounting Engine on Stand

Oil pan drain plug	25 N·m (18 lbf·ft)

Engine Electrical

Table 47 Engine Electrical

Crankshaft Position sensor (CKP) bolt	10 N·m (89 lbf·in)
Camshaft Position sensor (CMP) bolt	10 N·m (89 lbf·in)
Engine Coolant Temperature (ECT) sensor	18 N·m (159 lbf·in)
Fuel Temperature Sensor (FTS)	18 N·m (159 lbf·in)
Engine Oil Pressure (EOP) sensor	12 N·m (106 lbf·in)
Engine Oil Temperature (EOT) sensor	18 N·m (159 lbf·in)
Fuel Pressure Sensor (FPS)	12 N·m (106 lbf·in)
Rail Fuel Pressure (RFP) sensor	7 N·m (62 lbf·in)
Manifold Air Temperature (MAT) sensor	18 N·m (159 lbf·in)
Manifold Absolute Pressure (MAP) sensor	12 N·m (106 lbf·in)
Exhaust Back Pressure (EBP) sensor	20 N·m (177 lbf·ft)
Electronic Control Module (ECM) bolts	13 N·m (115 lbf·in)
ECM support nuts	13 N·m (115 lbf·in)

Exhaust Gas Recirculating (EGR) System

Table 48 Exhaust Gas Recirculating (EGR) System

EGR cooler outlet bolts	25 N·m (18 lbf·ft)
EGR cooler clamps	See tightening step in procedure.
Coolant hose clamps	4 N·m (35 lbf·in)
EGR top bracket nuts	57 N·m (42 lbf·ft)
EGR valve assembly bolts	11 N·m (97 lbf·in)
Intake Throttle Valve (ITV) bolts	11 N·m (97 lbf·in)

Variable Geometry Turbocharger (VGT)

Table 49 Turbocharger Assembly Bolts and Clamps

Turbo air inlet duct clamp	5 N·m (48 lbf·in)
Exhaust tube to exhaust manifold nuts	31 N·m (23 lbf·ft)
Exhaust tube to turbocharger assembly bolts	31 N·m (23 lbf·ft)
Turbo oil supply tube assembly to turbocharger bolt and stud bolt	31 N·m (23 lbf·ft)
Turbo oil supply tube assembly to oil filter base assembly bolt	13 N·m (115 lbf·in)
Turbocharger assembly exhaust outlet V-clamp	10 N·m (89 lbf·in)
Turbo support bolts	50 N·m (37 lbf·ft)
Turbocharger assembly bolts and stud bolts	72 N·m (53 lbf·ft)
Turbo heat shield bolts	10 N·m (89 lbf·in)
Exhaust Back Pressure (EBP) sensor tube fitting nut	20 N·m (177 lbf·in)
EBP sensor tube fitting	27 N·m (239 lbf·in)

Air Compressor and Power Steering/Fuel Pump

Table 50 Air Compressor and Power Steering/Fuel Pump

Air compressor to bracket bolts	72 N·m (53 lbf·ft)
Air compressor bracket to cylinder head bolts	61 N·m (45 lbf·ft)
Air compressor belt tensioner bolt	61 N·m (45 lbf·ft)
Air compressor idler bolts	61 N·m (45 lbf·ft)
Air compressor oil supply hose fitting nut	20 N·m (177 lbf·in)
Suction power steering tube flared tube nut	90 N·m (66 lbf·ft)
Pressure power steering tube flared tube nut	45 N·m (33 lbf·ft)
Tube clamp saddle stud bolts (front)	31 N·m (23 lbf·ft)
Air compressor pulley nut	120 N·m (88 lbf·ft)

Fuel System

Table 51 Fuel System Components

High-pressure Fuel Pump (HPFP) assembly bolts	61 N·m (45 lbf·ft)
Pump right tube assembly nuts	See tightening step in procedure.
Pump left tube assembly nuts	See tightening step in procedure.
Fuel pump cover bolts	13 N·m (116 lbf·in)
Injector leak off check valve	45 N·m (33 lbf·ft)
High-pressure pump to cooler tube assembly cap nut	38 N·m (28 lbf·ft)
Banjo bolts	38 N·m (28 lbf·ft)
Filter to pump tube assembly cap nut	38 N·m (28 lbf·ft)
Hose clamps	3 N·m (26 lbf·in)
3/8” O-ring face seal nuts	41 N·m (30 lbf·ft)
Fuel filter cap (secondary)	27 N·m (20 lbf·ft)

Intake and Exhaust Manifolds

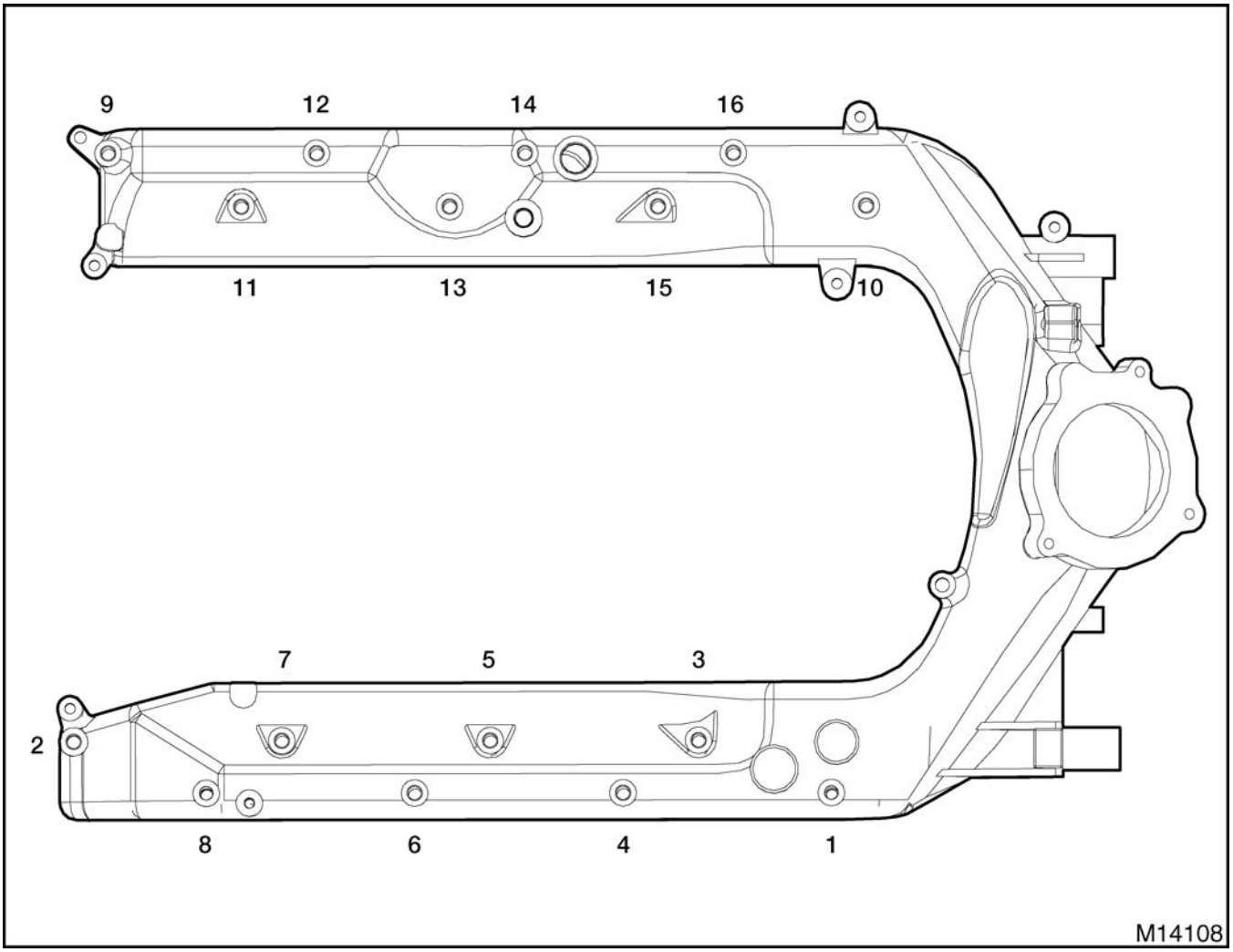


Figure 580 Torque sequence for intake manifold mounting bolts

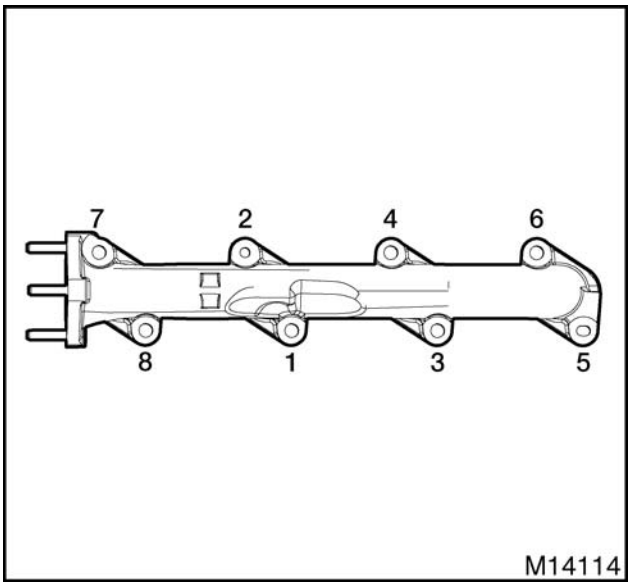


Figure 581 Torque sequence for right exhaust manifold mounting bolts

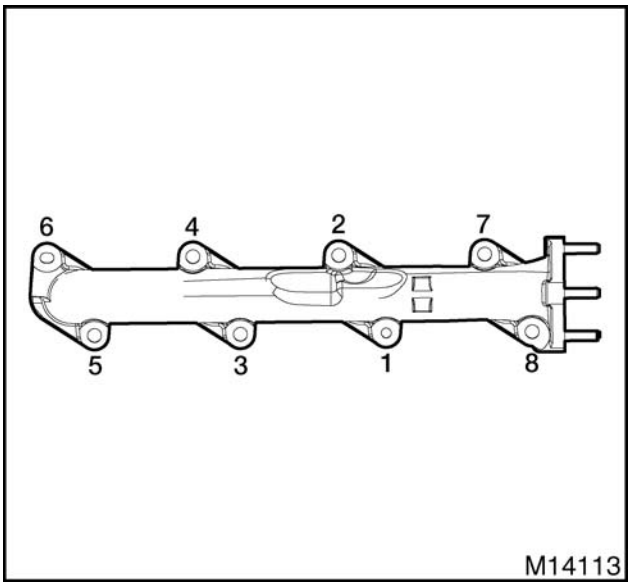


Figure 582 Torque sequence for left exhaust manifold mounting bolts

Table 52 Intake, Inlet, and Exhaust Manifolds

Intake manifold bolts and stud bolts (use special torque sequence)	11 N·m (100 lbf·in)
Exhaust manifold heat shield nuts, bolts, and spacers	30 N·m (22 lbf·ft)
Exhaust manifold bolts and stud bolts (use special torque sequence)	30 N·m (22 lbf·ft)

Front Cover, Cooling System, and Related Components

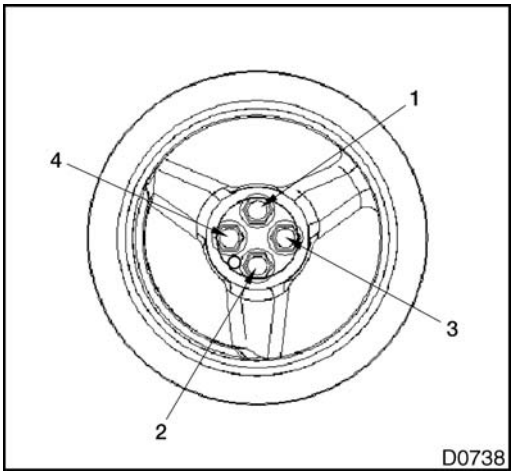


Figure 583 Torque sequence for vibration damper bolts

Table 53 Front Cover, Cooling System, and Related Components

Alternator and Freon® mounting bracket cap screws	72 N·m (53 lbf·ft)
Belt tensioner bolt	61 N·m (45 lbf·ft)
Fan and pulley mounting hub bolts	31 N·m (23 lbf·ft)
Fan pulley bolts	31 N·m (23 lbf·ft)
Front crankcase cover bolts	31 N·m (23 lbf·ft)
Front engine mount bracket bolts	107 N·m (79 lbf·ft)
Oil pump housing assembly bolts	22 N·m (16 lbf·ft)
Front Power Takeoff (PTO) pulley bolts	61 N·m (45 lbf·ft)
Thermostat housing stud bolt and bolts	13 N·m (115 lbf·in)
Vibration damper bolts	68 N·m (50 lbf·ft) + 90° rotation
Water pump assembly bolts	31 N·m (23 lbf·ft)

Cylinder Head and Valve Train

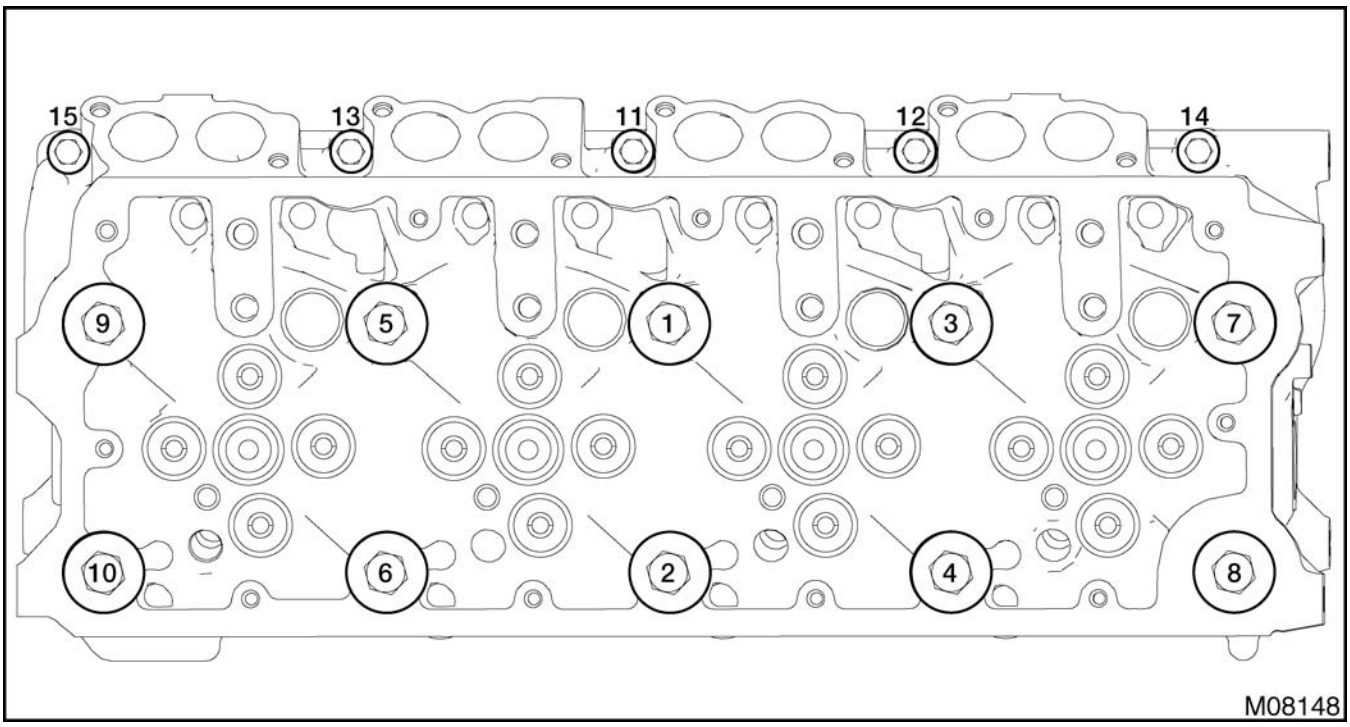


Figure 584 Cylinder head bolts tightening sequence

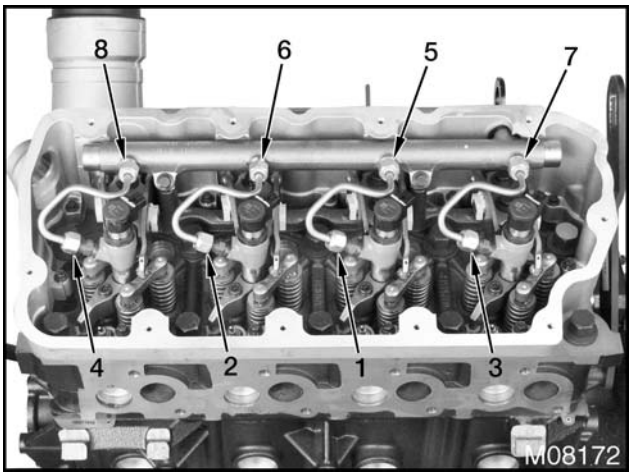


Figure 585 Fuel rail to injector tube assemblies tightening sequence (typical)

Table 54 Cylinder Head and Valve Train

Lifting eye flat countersunk screws (left cylinder head)	41 N·m (30 lbf·ft)
Lifting eye bolts (right cylinder head)	61 N·m (45 lbf·ft)
Breather inlet adapter	14 N·m (124 lbf·in)
Exhaust Back Pressure (EBP) tube assembly nut	9 N·m (80 lbf·in)
Cylinder head bolt	See tightening steps in procedure
Injector clamp bolt	See tightening steps in procedure
Dual fulcrum plate assembly bolts	See tightening steps in procedure
Rail assembly bolts	See tightening steps in procedure
Fuel rail to injector tubes	See tightening steps in procedure
Glow plugs	18 N·m (159 lbf·in)
Breather oil drain assembly to crankcase M12 fitting	25 N·m (18 lbf·ft)
Breather support nuts	13 N·m (115 lbf·in)
Valve cover bolt and stud bolt assemblies	9 N·m (80 lbf·in)
Oil fill extension	14 N·m (126 lbf·in)
Lifter guide bolts with washer assembly	13 N·m (115 lbf·in)
Valve cover base assembly bolts	13 N·m (115 lbf·in)
Fuel rail plug assembly	27 N·m (20 lbf·ft)

Oil Cooler and Filter Housing

Table 55 Oil Cooler Cover and Oil Filter Housing

Oil cooler cover assembly bolts	31 N·m (23 lbf·ft)
Oil filter cap	26 N·m (18 lbf·ft)
Oil filter return tube assembly screw – with new oil filter base assembly	7 N·m (62 lbf·in)
Oil filter return tube assembly screw – with reinstalled oil filter base assembly	5 N·m (44 lbf·in)
Oil filter housing bolts	22 N·m (125 lbf·in)
Oil filter base assembly screws – with new oil cooler cover assembly	10 N·m (89 lbf·in)
Oil filter base assembly screws – with reinstalled oil cooler cover assembly	7 N·m (62 lbf·in)

Flywheel and Flywheel Housing

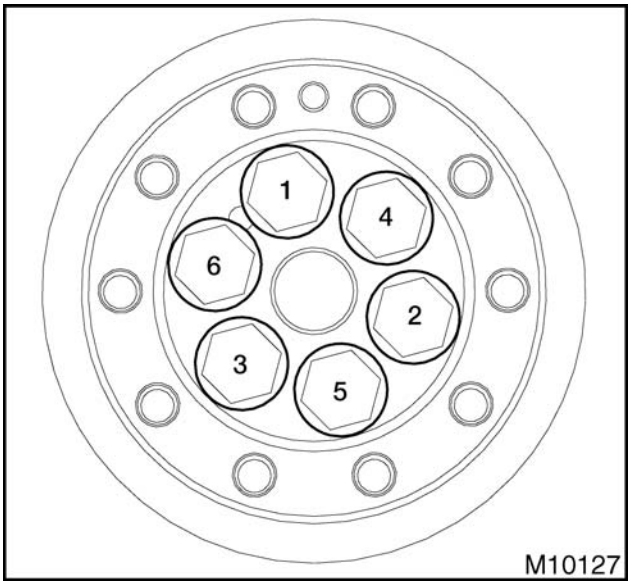


Figure 586 Crankshaft flange torque sequence

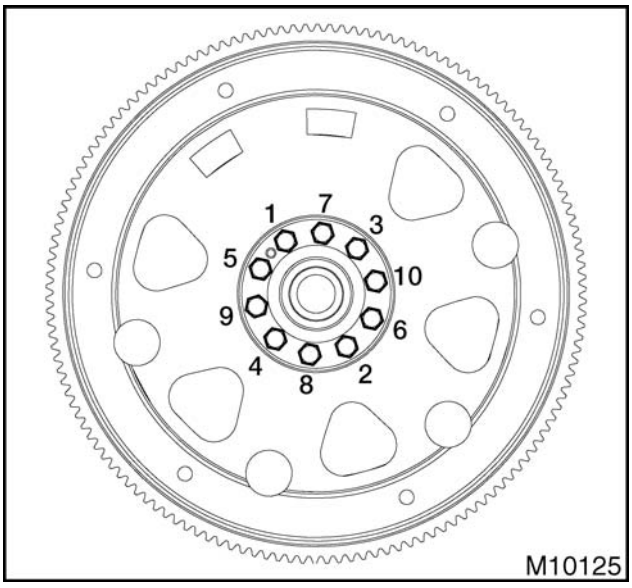


Figure 587 Torque sequence for flexplate assembly

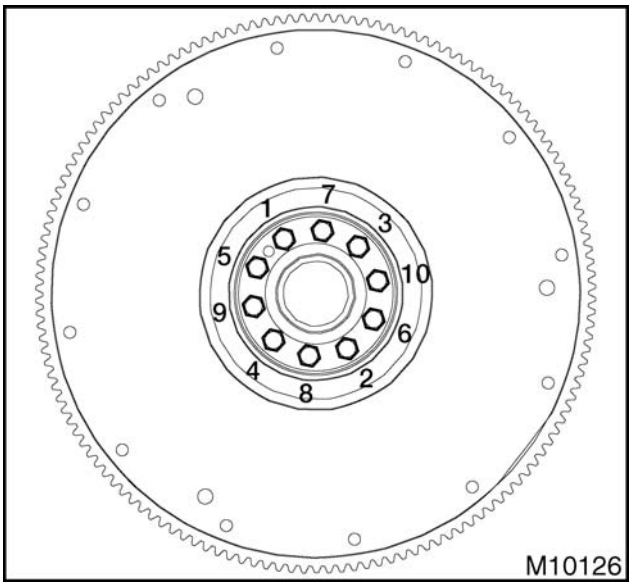


Figure 588 Torque sequence for flywheel assembly

Table 56 Flywheel and Flywheel Housing

Crankshaft flange bolts	See tightening steps in procedure.
Crankshaft rear oil seal carrier bolts	31 N·m (23 lbf·ft)
Engine mount rear bracket bolts	107 N·m (79 lbf·ft)
Flexplate assembly bolts	See tightening steps in procedure.
Flywheel assembly bolts	See tightening steps in procedure.
M8 crankcase rear cover bolts	31 N·m (23 lbf·ft)
M10 crankcase rear cover bolts	61 N·m (45 lbf·ft)

Lower Oil Pan, Upper Oil Pan, and Oil Pickup Tube

Table 57 Lower Oil Pan

Oil pan drain plug	25 N·m (18 lbf·ft)
Lower oil pan bolts and stud bolts	13 N·m (115 lbf·in)

Power Cylinders

Table 58 Power Cylinders

Connecting rod bolts	Initial	45 N·m (33 lbf·ft)
	Final	68 N·m (50 lbf·ft)

Crankcase, Crankshaft, and Camshaft

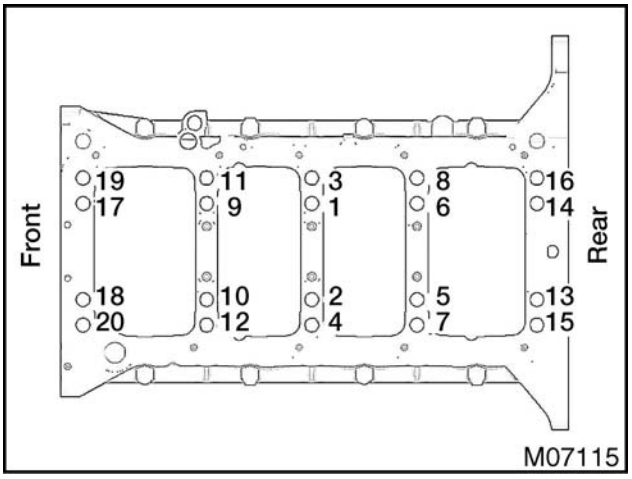


Figure 589 Torque sequence for main bearing bolts

Table 59 Crankcase, Crankshaft, and Camshaft

Main bearing bolts	See tightening procedure and sequence
Coolant heater	41 N·m (30 lbf·ft)

Table of Contents

Special Tools

Special tools for the Maxx Force™ 7 engine can be ordered from the SPX Corporation, 1-800-520-2584.

Mounting Engine on Stand

Table 60 Mounting Engine on Stand

Description	Tool Number
Engine Stand Mounting Bracket	ZTSE4507

Engine Electrical

Table 61 Engine Electrical

Description	Tool Number
Injector connector release tool	ZTSE4650

Exhaust Gas Recirculating (EGR) System

Table 62 Exhaust Gas Recirculating (EGR) System

Description	Tool Number
EGR Valve Brush	ZTSE4751
EGR Valve Puller	ZTSE4703
EGR Cooler Test Plates	ZTSE4707

Variable Geometry Turbocharger (VGT)

Table 63 Turbocharger

Description	Tool Number
Cap kit (All)	ZTSE4610
Dial indicator with magnetic base	Obtain locally
Turbo Oil Supply Block	ZTSE4785–1
Turbo Oil Drain Plug	ZTSE4785–2

Air Compressor and Power Steering/Fuel Pump

Table 64 Power Steering/Fuel Pump

Description	Tool Number
Cap kit (All)	ZTSE4610

Fuel System

Table 65 Fuel System

Description	Tool Number
Fuel System Caps	ZTSE4710
Spring lock coupling disconnect tool	Obtain locally
Liquid Gasket (RTV) (6 oz. tube)	1830858C1

Intake and Exhaust Manifolds

Table 66 Intake, Inlet, and Exhaust Manifolds

Description	Tool Number
Feeler Gauge	Obtain locally
Straightedge	Obtain locally
Intake port covers (cylinder heads)	ZTSE4559

Front Cover, Cooling System, and Related Components

Table 67 Front Cover, Cooling System, and Related Components

Description	Tool Number
Dial indicator with magnetic base	Obtain locally
Feeler gauge	Obtain locally
Front seal/wear sleeve installer	ZTSE4516
Front wear sleeve remover	ZTSE4517
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Loctite® 569 hydraulic sealant or equivalent	Obtain locally
Slide hammer	Obtain locally
Straightedge	Obtain locally

Cylinder Head and Valve Train

Table 68 Cylinder Head and Valve Train

Description	Tool Number
Cylinder Head Bolt Tap	ZTSE4744
Cylinder Head Lifting Bracket	ZTSE4535
Cylinder Head Pressure Test Plate	ZTSE4534
Dye Penetrant Kit	PT-7191
Fuel Gallery Cleaning Brush	ZTSE4541
Injector Cup	ZTSE4709
Fuel Injector Rack Holder	ZTSE4299B
Fuel Injector Tip Cleaning Brush	ZTSE4301
Fuel System Caps	ZTSE4710
Glow Plug Sleeve Brush (nylon)	ZTSE4533
Glow Plug Sleeve Installer	ZTSE4532
Glow Plug Sleeve Remover	ZTSE4531
Glow Plug Sleeve Seat Wire Brush	ZTSE4589
Injector Sleeve Brushes	ZTSE4751
Injector Sleeve Installer	ZTSE4733
Injector Sleeve Remover	ZTSE4732
Lithium Grease	Obtain locally
Loctite® 620 Retaining Compound	Obtain locally
P-80® Rubber Lubricant or equivalent	Obtain locally
Slide Hammer Kit	ZTSE4398
Straightedge	Obtain locally
Valve Guide Gauge Tool	ZTSE4577
C Type Valve Spring Compressor	ZTSE1846
Valve Spring Tester	ZTSE2241
Dial Caliper	Obtain locally
Feeler Gauge	Obtain locally
Pressure Test Regulator and Gauge	Obtain locally
0-1 inch Micrometer	Obtain locally
3-4 inch Micrometer	Obtain locally
Inspection Mirror	Obtain locally

Oil Cooler and Filter Housing

Table 69 Oil Cooler

Description	Tool Number
Air Pressure Regulator	Obtain locally
Oil Cooler Pressure Test Plate	ZTSE4730

Flywheel and Flywheel Housing

Table 70 Flywheel and Flywheel Housing

Description	Tool Number
Dial caliper	Obtain locally
Dial indicator with magnetic base	Obtain locally
Gear puller (bar type)	Obtain locally
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Loctite® 569 hydraulic sealant or equivalent	Obtain locally
Power steering idler shaft installation tool	ZTSE4719
Rear wear sleeve installer	ZTSE4515
Rear wear sleeve removal tool	ZTSE4518
Slide hammer	Obtain locally

Power Cylinders

Table 71 Power Cylinders

Description	Tool Number
1–2 inch micrometer	Obtain locally
2–3 inch micrometer	Obtain locally
3–4 inch micrometer	Obtain locally
Dial indicator with magnetic base	Obtain locally
Feeler gauge	Obtain locally
Glaze breaker brush	Obtain locally
Piston gauge pins (2.0828 mm [0.082 in])	ZTSE4513
Piston ring compressor (cope)	ZTSE4514
Piston ring expansion pliers	Obtain locally
Telescoping gauge set	Obtain locally

Crankcase, Crankshaft, and Camshaft

Table 72 Crankcase, Crankshaft, and Camshaft

Description	Tool Number
0–1 inch micrometer	Obtain locally
2–3 inch micrometer	Obtain locally
3–4 inch micrometer	Obtain locally
Camshaft bushing kit	ZTSE2893A
Camshaft bushing remover/installer (expanding collet)	ZTSE4489
Cylinder bore gauge	Obtain locally
Deglazing hone (four inch)	ZTSE4349
Dial indicator with magnetic base	Obtain locally
Feeler gauge	Obtain locally
Head bolt bottoming tap	ZTSE4508
Lifting sling	Obtain locally
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Oil gallery cleaning brush	ZTSE4511
Oil gallery plug driver	ZTSE4512
Straightedge	Obtain locally
Telescoping gauge set	Obtain locally

Special Tools

Essential Tools

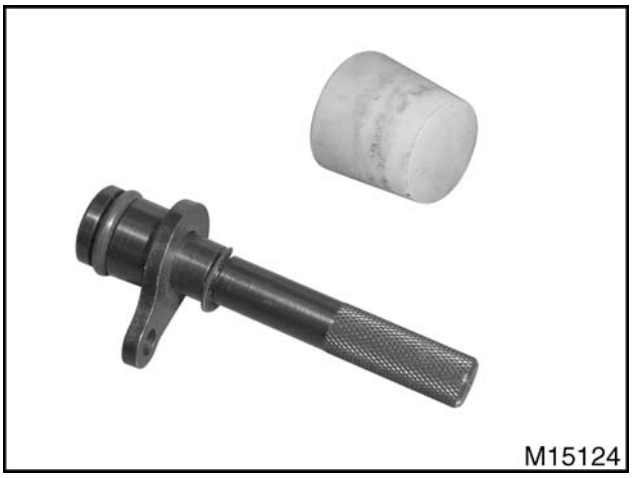


Figure 590 ZTSE4785 turbo oil supply block off plug kit

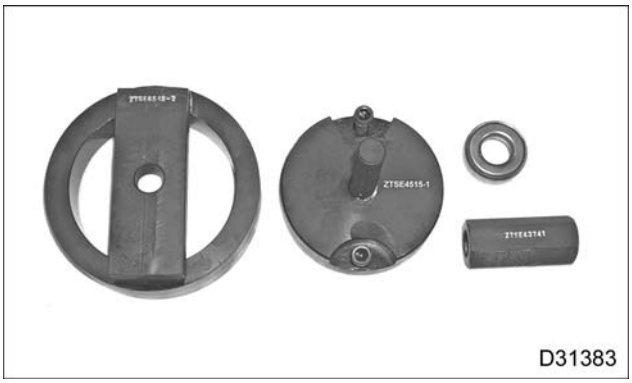


Figure 591 ZTSE4515–2C rear seal installer w/ 40mm cap screws

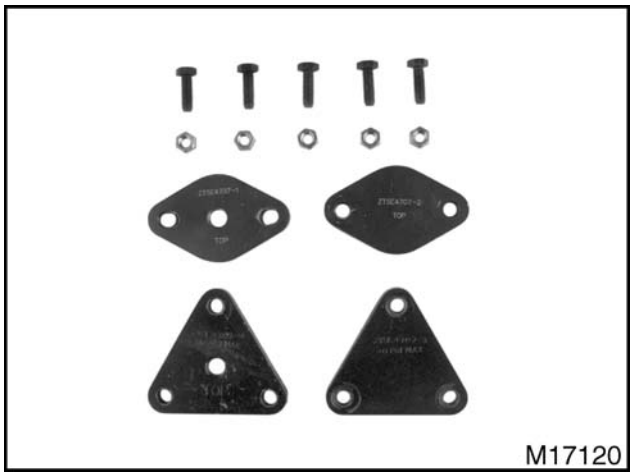


Figure 592 ZTSE4707 EGR cooler test plates

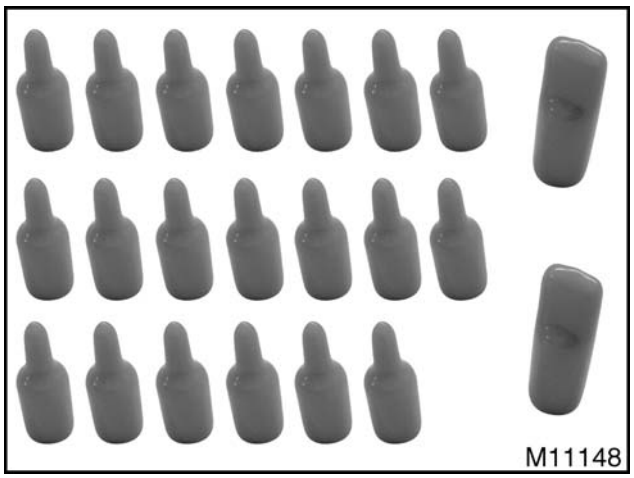


Figure 593 ZTSE4710 fuel system caps

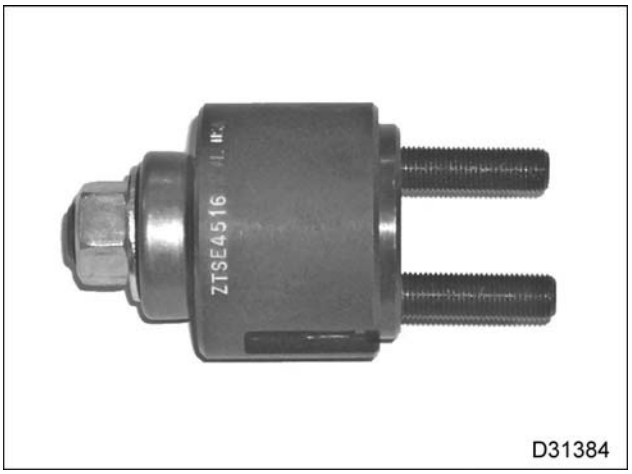


Figure 594 ZTSE4691 front seal installer

Figure 596 ZTSE4709 injector cups for ZTSE4299 (8)

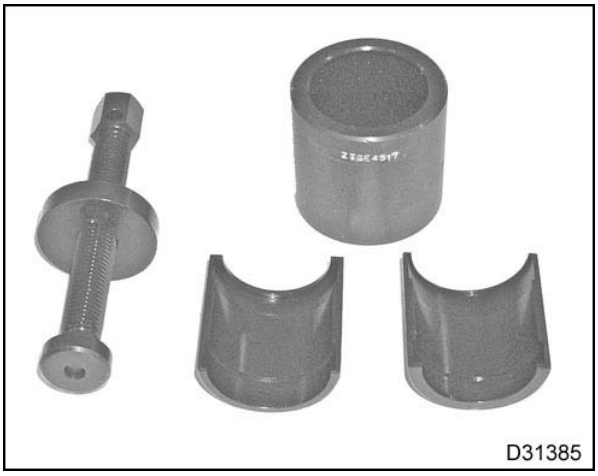


Figure 595 ZTSE4705 front wear sleeve remover

Figure 597 ZTSE4714 piston ring compressor

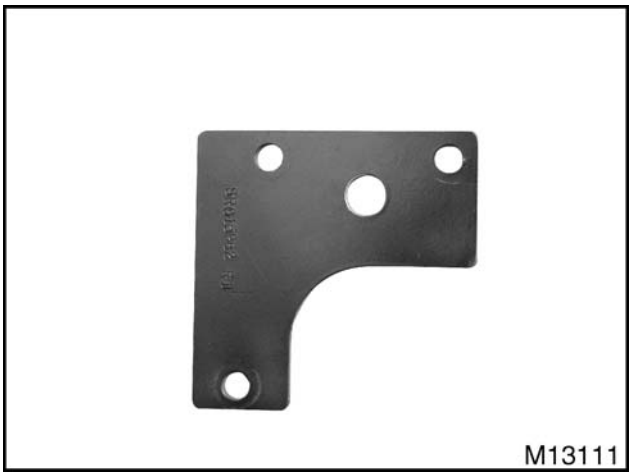


Figure 598 ZTSE4730 oil cooler pressure test plate

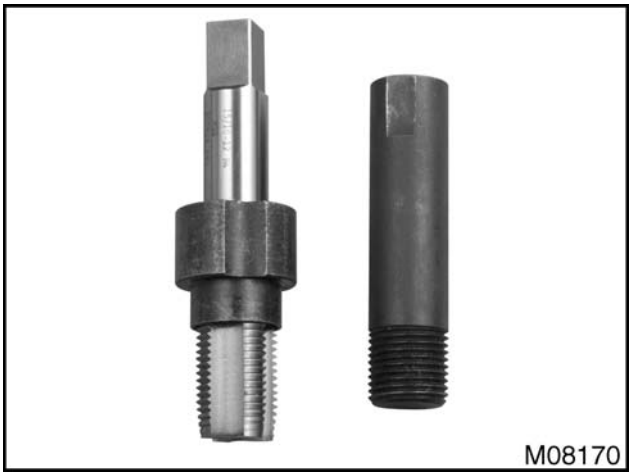


Figure 599 ZTSE4732 injector sleeve remover

Figure 600 ZTSE4733 injector sleeve installer

Figure 601 ZTSE4743 EGR valve puller

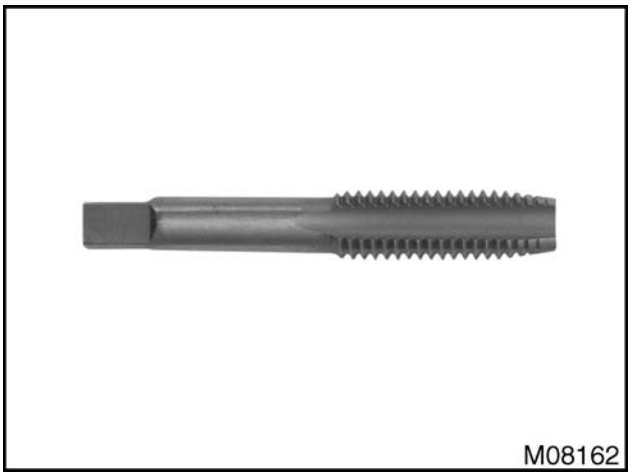


Figure 602 ZTSE4744 cylinder head bolt tap

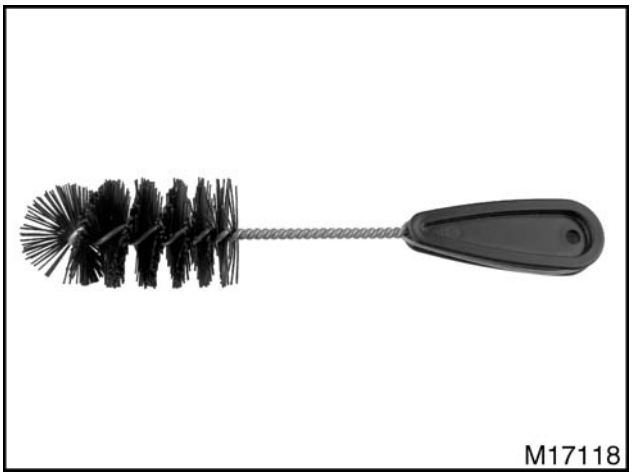


Figure 604 ZTSE4753 EGR valve bore cleaning brush

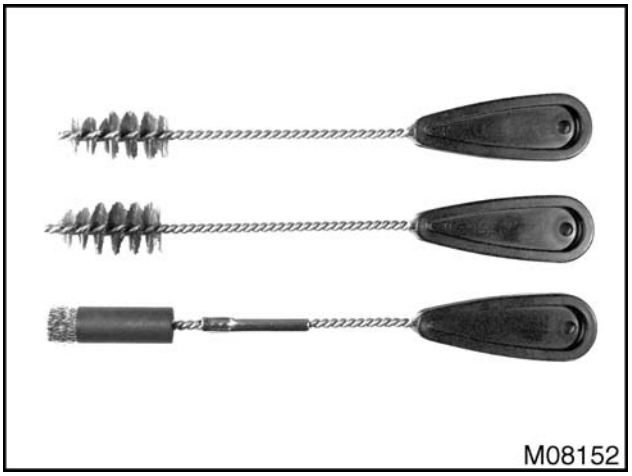


Figure 603 ZTSE4751 injector sleeve brushes

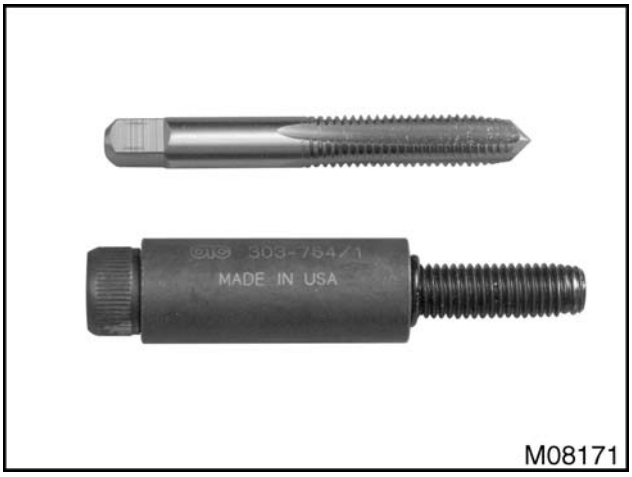


Figure 605 ZTSE4783 glow plug installer sleeve

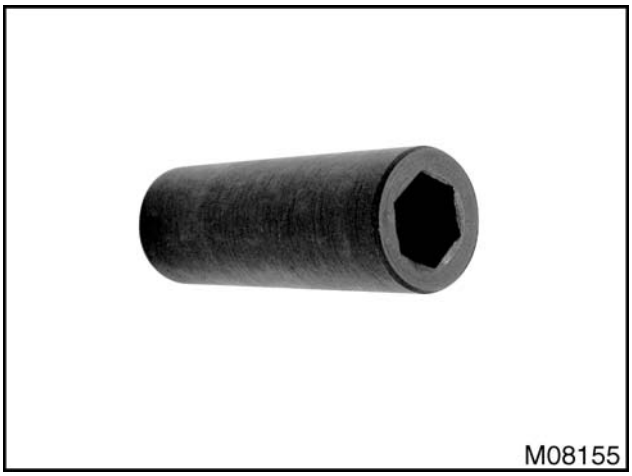


Figure 606 ZTSE4723 glow plug socket

Printed in the United States of America