Table of Contents

Exploded Views....285

Removal....287
- **Flywheel....287**
- **Rear Main Seal and Wear Sleeve....289**
  - **CityStar™ Applications....289**
  - **Stripped Chassis Applications....290**
- **Crankshaft Secondary Flange (Stripped Chassis Only)....291**
- **Rear Cover....292**

Cleaning, Inspection, and Testing....294
- **Measure Rear Cover Face Runout (Stripped Chassis)....294**
- **Ring Gear Runout Measurement....295**
- **Clean and Inspect....295**

Installation....296
- **Rear Cover 296**
- **Crankshaft Secondary Flange (Stripped Chassis)....299**
- **Rear Main Oil Seal and Wear Sleeve....300**
  - **CityStar™ Applications....300**
  - **Stripped Chassis Applications....302**
- **Flywheel....304**

Specifications....305

Special Torque....305

Special Service Tools....305

Exploded Views

NOTE: There are two different rear cover assemblies available, depending upon vehicle application.

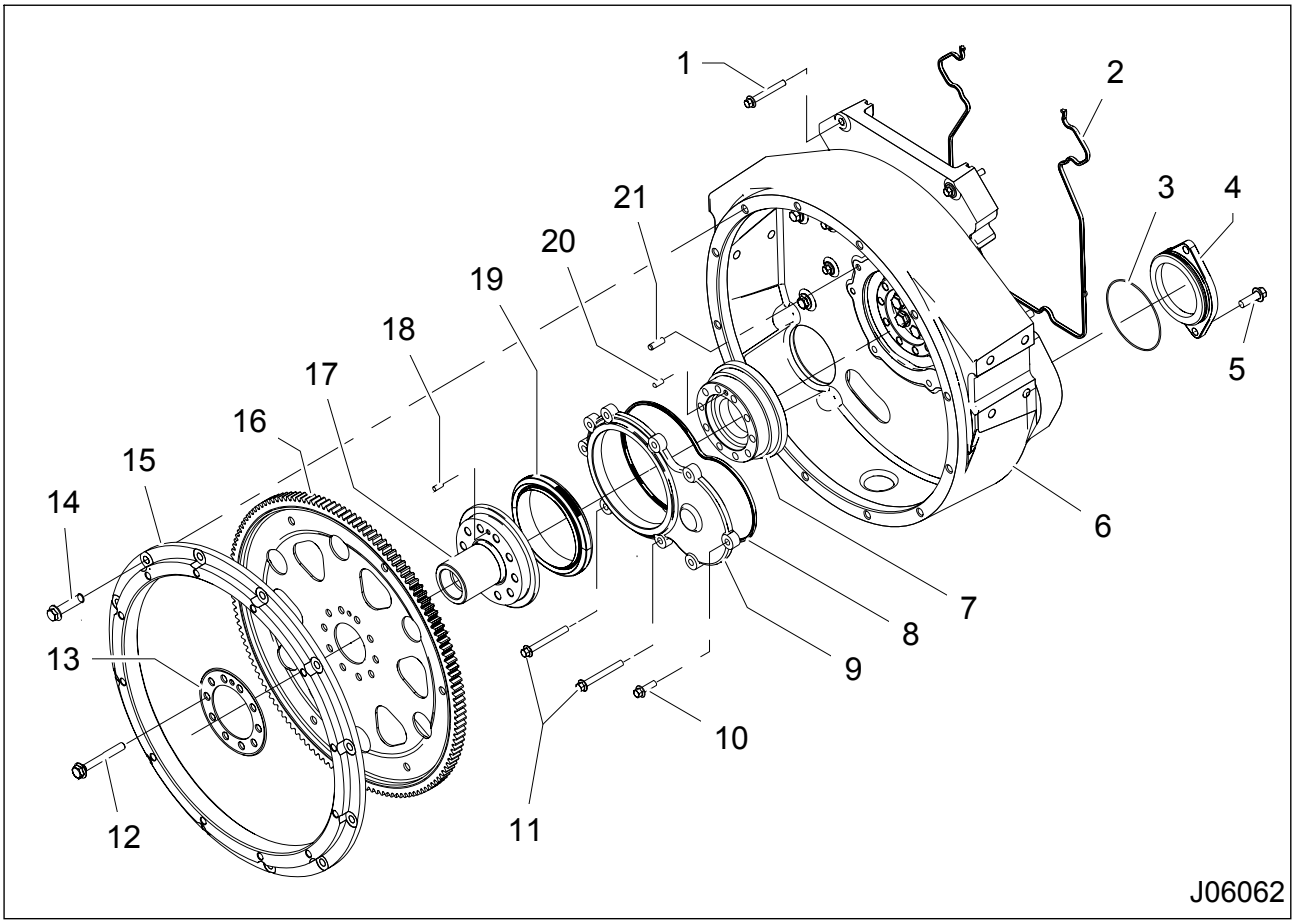

Figure 399 Rear cover and related components (stripped chassis)

1. Bolt, M8 x 55 (5), Refer to (Figure 413)
2. Gasket
3. O-ring seal
4. Cover
5. Bolt, M8 x 55 (2)
6. Rear cover (SAE 2)
7. Crankshaft flange
8. Rear seal carrier gasket
9. Rear oil seal carrier assembly
10. Bolt, M8 x 25 (6)
11. Bolt, M8 x 70 (2)
12. Bolt, M10 x 77 (10)
13. Reinforcement ring
14. Bolt, M10 x 35 (12)
15. Converter housing adapter
16. Flywheel assembly
17. Adapter hub
18. Dowel pin, 0.250 x 0.625 mm
19. Crankshaft rear oil seal assembly (service)
20. Dowel pin, 1/4 x 5/8 in.
21. Dowel pin, M8 x 25

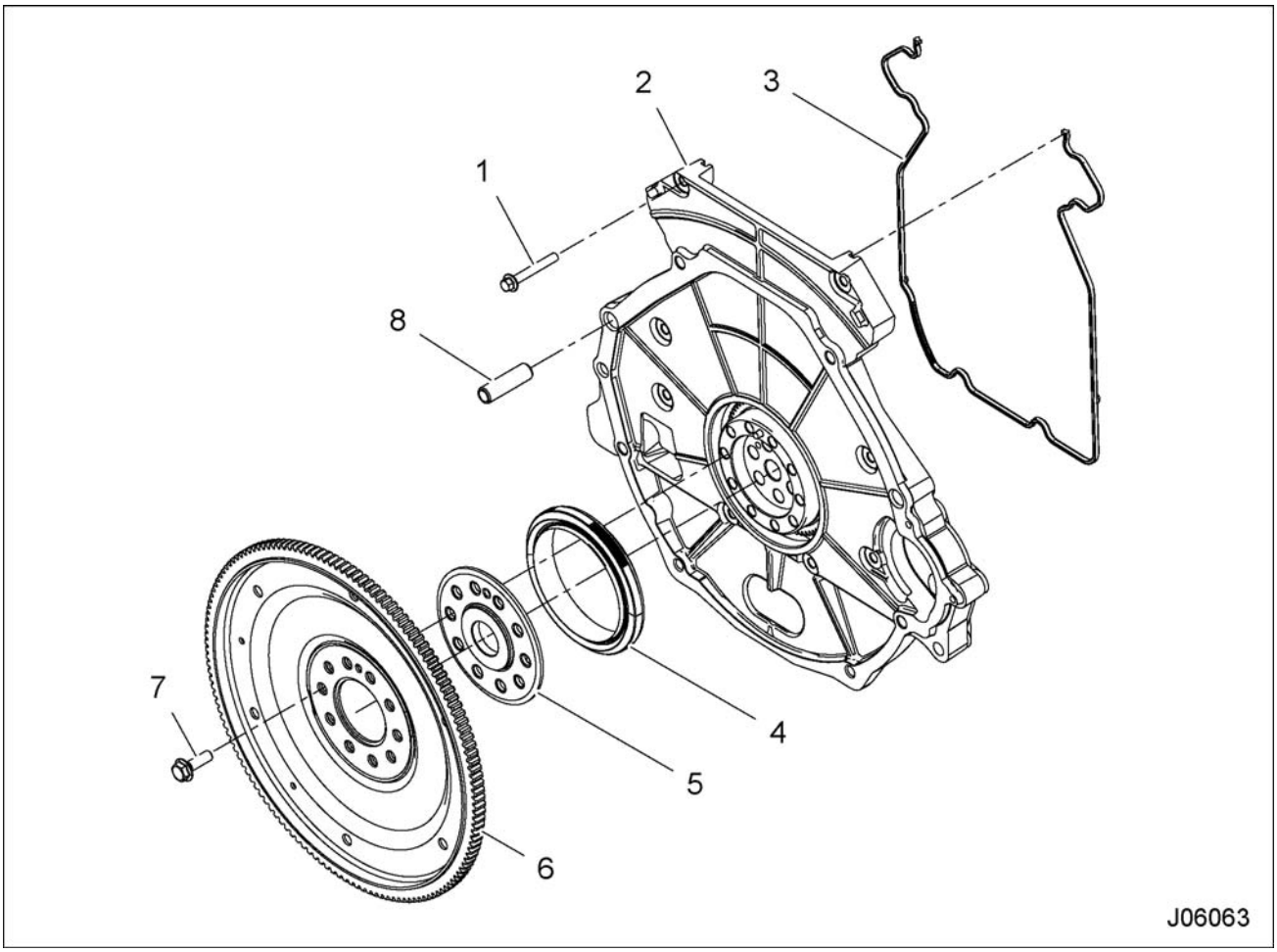

Figure 400 Rear cover and related components (CityStar™)

1. Bolt, M8 x 35 (8)
2. Rear cover
3. Gasket
4. Crankshaft rear oil seal (service)
5. Flywheel adapter
6. Flywheel
7. Bolt, M10 x 31 (10)
8. Dowel sleeve (2)

Removal

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

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

WARNING: To prevent personal injury or death, disconnect ground (-) cable from battery before doing service or diagnostic procedures.

WARNING: To prevent personal injury or death, use a suitable lifting device to support the transmission assembly during removal and installation.

WARNING: To prevent personal injury or death, support engine (if in chassis) before removing any engine mounting bracket or flywheel housing bolts.

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

Flywheel

1. Measure ring gear runout (page 295).

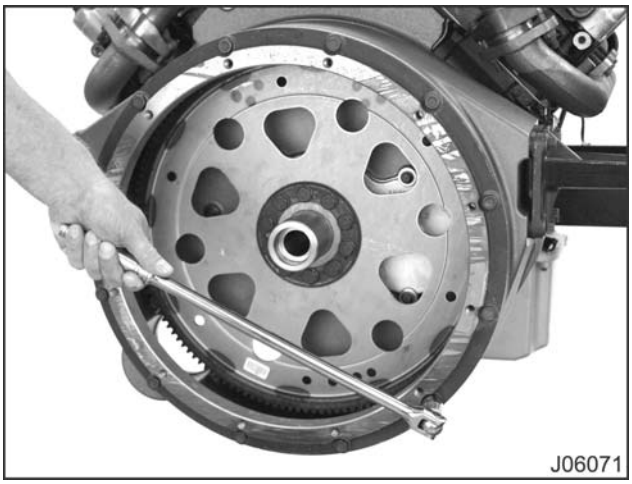

Figure 401 Transmission adapter ring bolt removal (stripped chassis)

2. Stripped chassis applications, remove 12 bolts (M10 x 35) securing the transmission adapter ring to the rear cover.

Figure 402 Flywheel bolts (typical)

3. Remove and discard 10 flywheel mounting bolts (M10 x 31 - CityStar™) (M10 x 77 - stripped chassis).
4. Remove flywheel assembly.

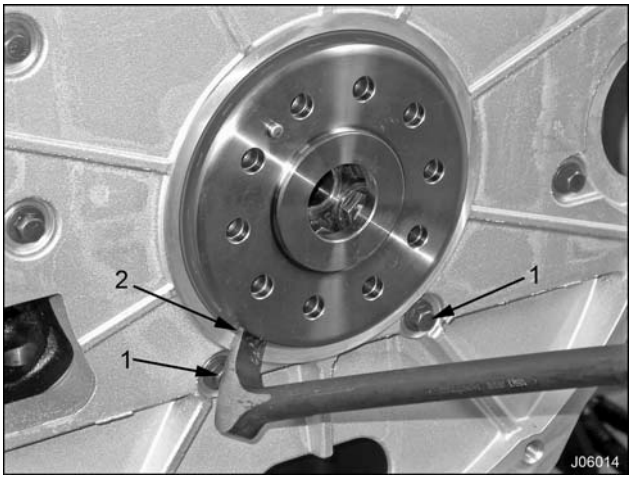

Figure 403 Flywheel adapter removal (CityStar™)

1. Rear cover bolt head locations
2. Placement of the heel bar

CAUTION: (CityStar™ applications only) – To prevent engine damage, place a heel bar onto the head of a rear cover bolt to remove the flywheel adapter. This will prevent cracking the aluminum rear cover.

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

5. For CityStar™ applications only, place a heel bar on the head of the rear cover bolt and the hook under the lip of the flywheel adapter. Alternate between the two rear cover head bolts to pry off the flywheel adapter.

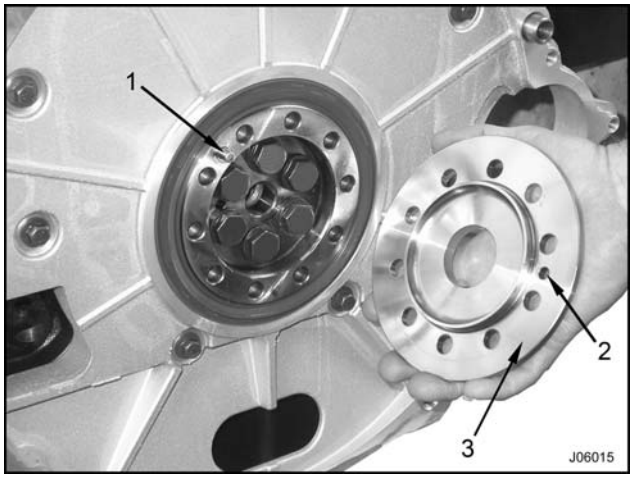

Figure 404 Flywheel adapter removed (CityStar™)

1. Dowel pin
2. Pin recess
3. Dust seal lip surface

Rear Main Seal and Wear Sleeve

WARNING: To prevent personal injury or death, wear safety glasses with side shields.

CityStar™ Applications

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

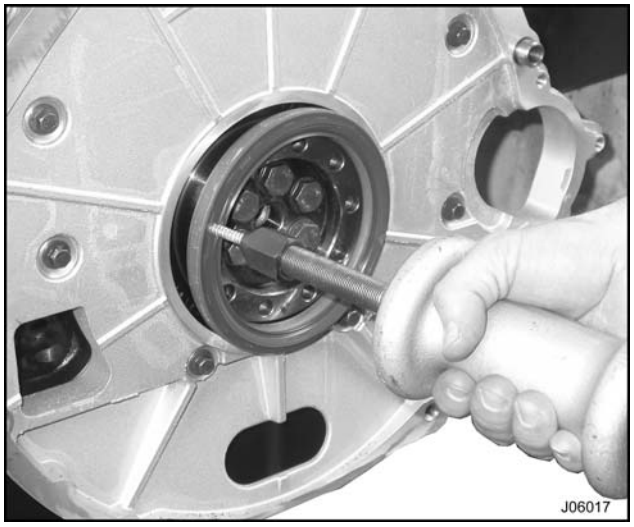

Figure 405 Rear main oil seal removal (CityStar™)

2. Thread slide hammer screw into one of the starter holes. To remove seal evenly, use Slide Hammer (page 305) on one side then alternate to other side.
3. Remove and discard rear main oil seal.

NOTE: When removing the rear main oil seal, it should be noted that production engines not previously serviced, will not have a wear sleeve. Wear sleeves are only available as a service item included with the rear main oil seal service kit.

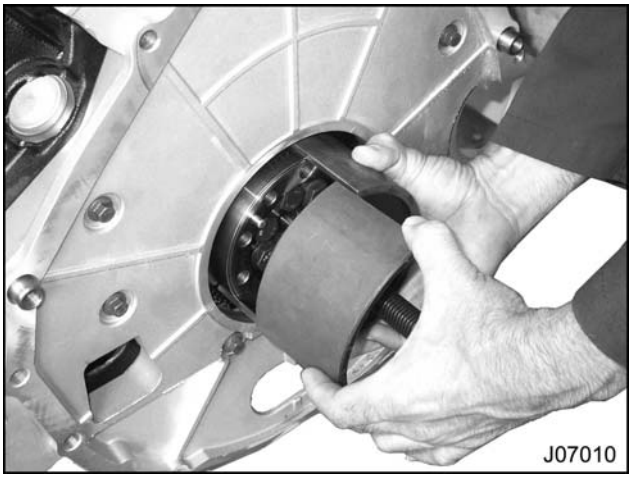

Figure 406 Rear Wear Sleeve Remover (CityStar™)

4. Install threaded shaft and two shell halves of the Rear Wear Sleeve Remover (page 305).

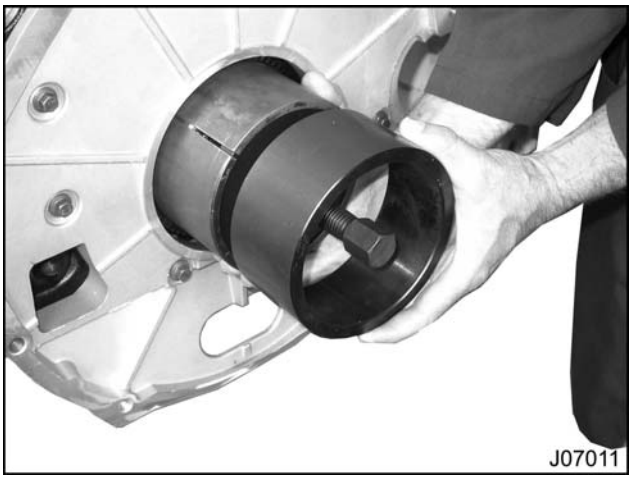

Figure 407 Outer ring (CityStar™)

5. Install the outer ring of the Rear Wear Sleeve Remover. Make sure wear sleeve remover shells are securely in place behind wear sleeve before applying force to threaded shaft.
6. Thread puller shaft tool in and remove wear sleeve.

Stripped Chassis Applications

WARNING: To prevent personal injury or death, wear safety glasses with side shields.

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

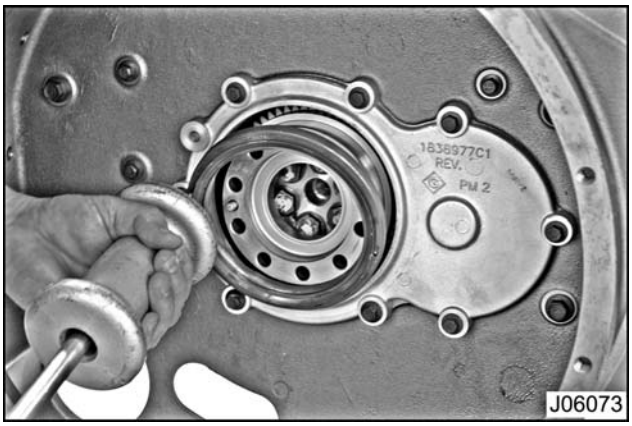

Figure 408 Rear main oil seal removal (stripped chassis)

2. Thread slide hammer screw into one of the starter holes. To remove seal evenly, use slide hammer on one side then alternate to other side.
3. Remove and discard rear main oil seal.

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

4. Install threaded shaft and two shell halves of the Rear Wear Sleeve Remover (page 305).

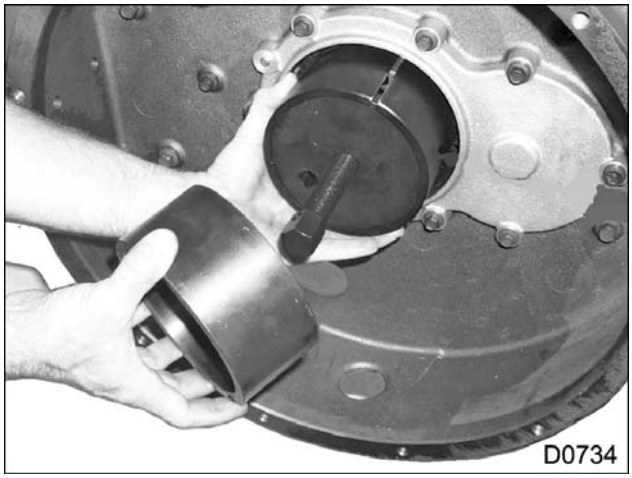

Figure 409 Wear sleeve removal (stripped chassis)

5. Install the outer ring of the Rear Wear Sleeve Remover. Make sure wear sleeve removal tool shells are securely in place behind wear sleeve before applying force to threaded shaft.

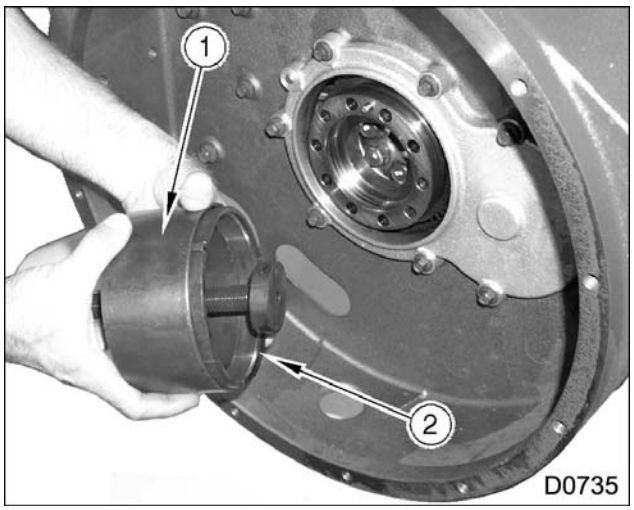

Figure 410 Wear sleeve removed (stripped chassis)

1. Rear Wear Sleeve Remover
2. Wear sleeve

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

Crankshaft Secondary Flange (Stripped Chassis Only)

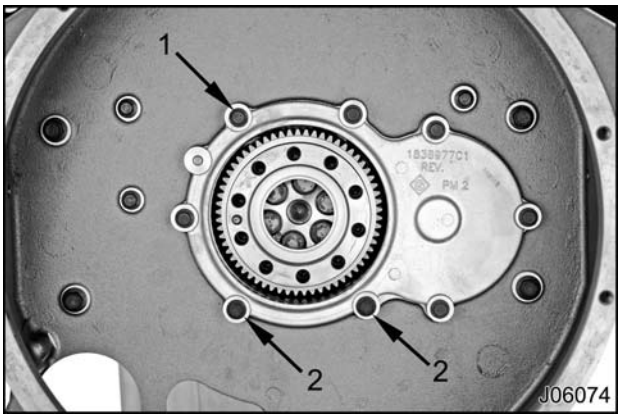

Figure 411 Rear oil seal carrier bolts (stripped chassis)

1. Bolts, M8 x 25 (6)
2. Bolts, M8 x 70 (2)

1. Remove eight rear oil seal carrier bolts (M8).
2. Remove rear oil seal carrier and discard gasket.

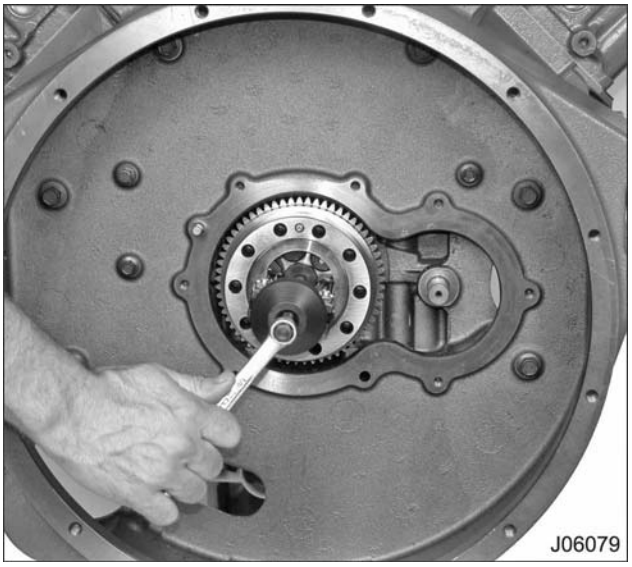

Figure 412 Crankshaft secondary flange removal (stripped chassis)

3. Use Gear Puller (page 305) to remove the crankshaft secondary flange.

Rear Cover

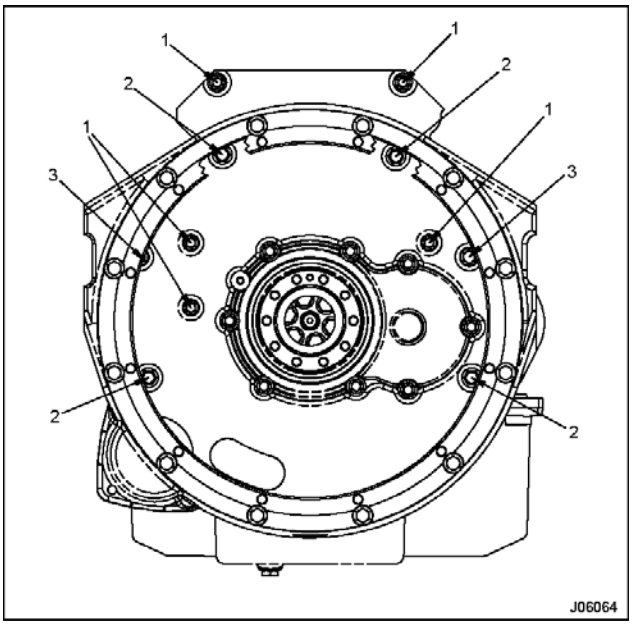

Figure 413 Rear cover bolt arrangement (stripped chassis)

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

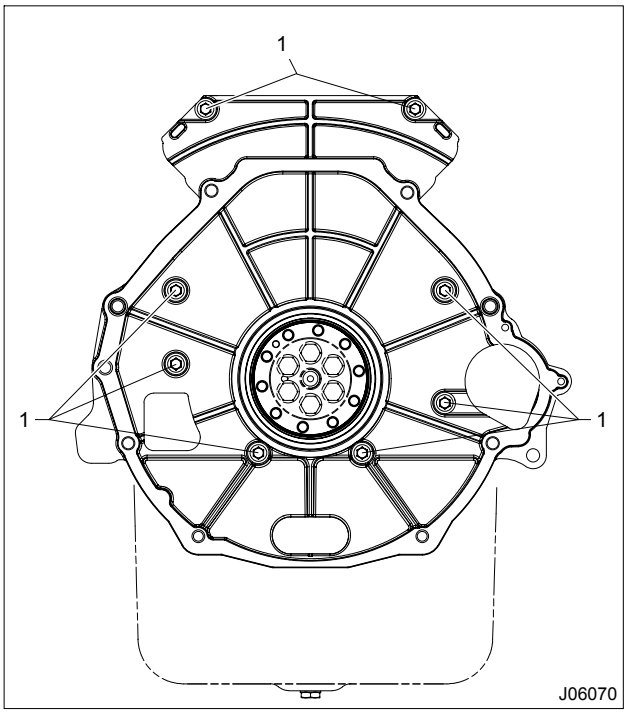

Figure 414 Rear cover bolt arrangement (CityStar™)

1. Bolt, M8 x 35 (8)

CAUTION: To prevent engine damage when removing the rear cover, cut the sealant where the crankcase and lower crankcase meet. Cut sealant where the crankcase, high-pressure oil pump cover and rear cover meet. Failure to adequately cut sealant before removing the rear cover can result in upper and lower crankcase gaskets being pulled out. Engine removal and disassembly is required to replace the lower crankcase gasket.

CAUTION: To prevent engine damage, (if high-pressure oil pump cover is in place), make sure the high-pressure oil pump cover gasket does not pull out when removing the rear cover.

1. Stripped Chassis – Remove necessary rear cover mounting bolts. Refer to (Figure 413) for rear cover bolt pattern.

   CityStar™ Chassis – Remove eight rear cover mounting bolts (M8 x 35). Refer to (Figure 414) for rear cover bolt pattern.

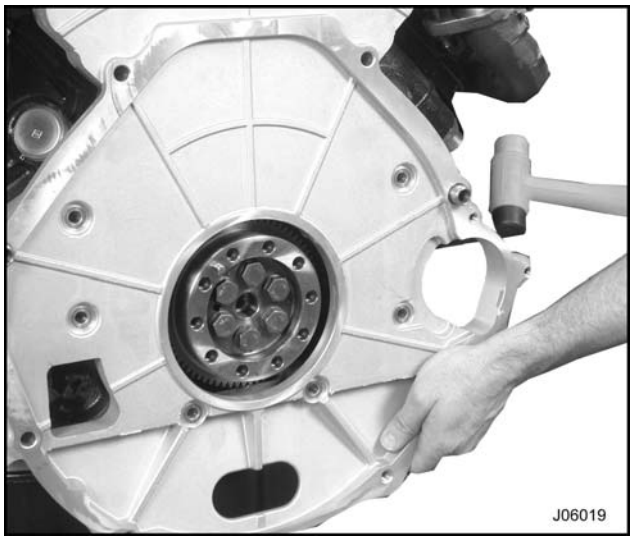

Figure 415 Rear cover removal with a rubber hammer (typical)

2. Use a rubber hammer to help loosen the rear cover from its seat.
3. When the rear cover becomes loose, pull back on the rear cover but do not remove completely.
4. Cut the rear cover gasket from under the high-pressure pump housing in order to remove the rear cover. Pull the rear cover back, but do not remove.

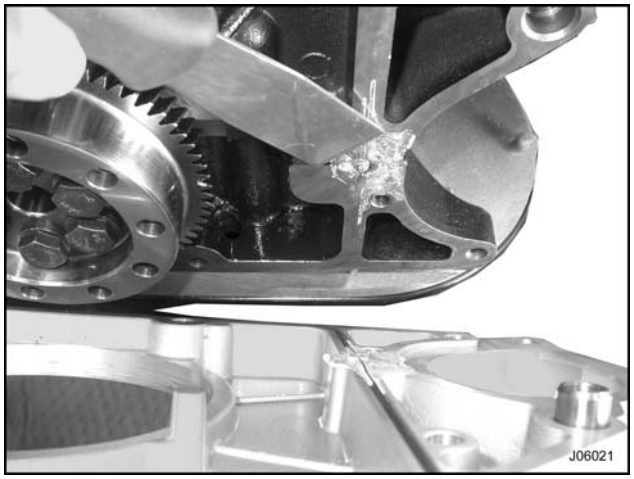

Figure 416 Rear cover and lower crankcase sealant cut location (typical)

5. Use a thin gasket scraper to separate sealant between the upper and lower crankcase seals and rear cover assembly. When removing the rear cover assembly, separate the sealant at all joints with the rear cover to avoid pulling these gaskets out.

⚠ WARNING: (Stripped chassis applications only) – To prevent personal injury or death, have an assistant help with removal of the rear cover as it is considerably heavier than the CityStar™ chassis version.

6. Remove the rear cover assembly.

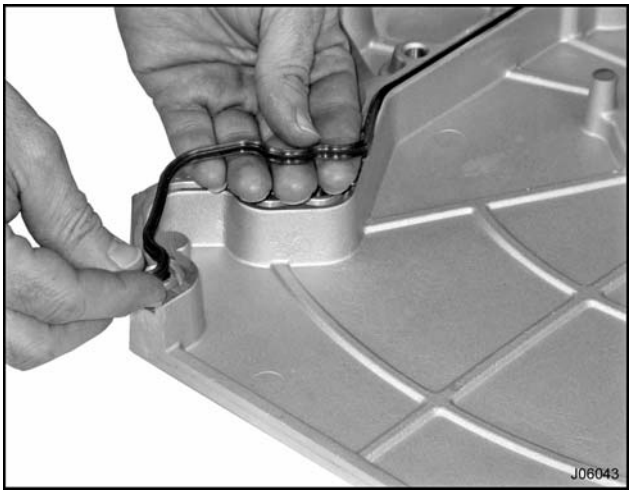

Figure 417 Rear cover gasket removal (typical)

7. Remove the rear cover gasket and discard.

Cleaning, Inspection, and Testing

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

Measure Rear Cover Face Runout (Stripped Chassis)

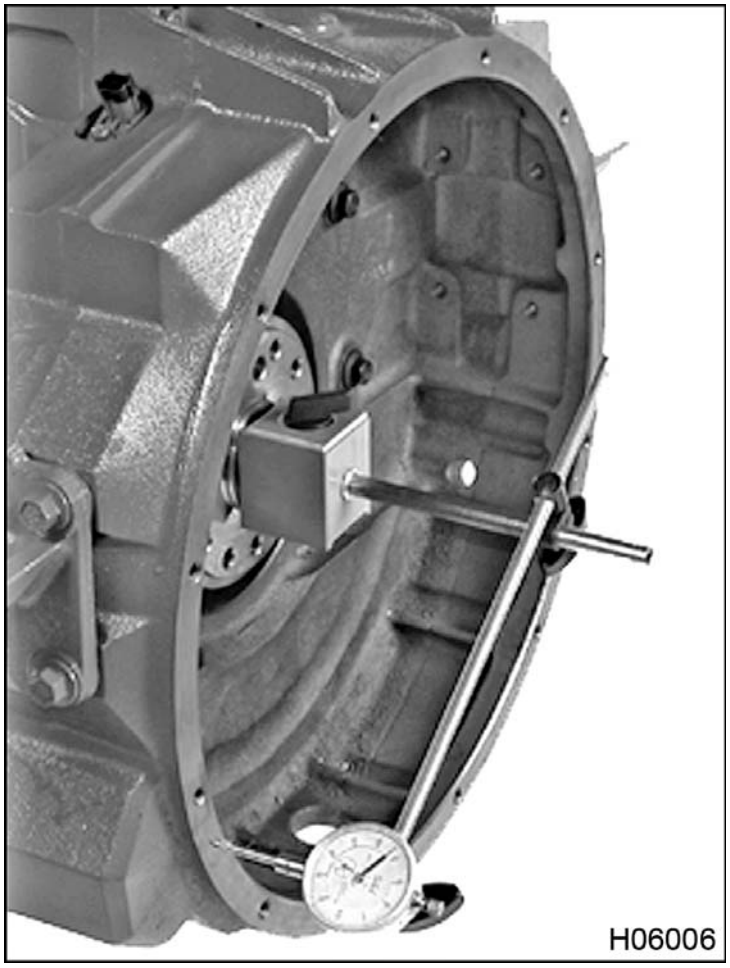

Figure 418 Rear Cover face runout measurement

1. Push the crankshaft in by hand to bring crankshaft end play to zero.
2. Center the magnetic base of a dial indicator set (page 305) on the end of the crankshaft.
3. Place the dial indicator tip against the face of the rear cover.
4. Zero dial indicator.
5. Slowly rotate crankshaft 360 degrees while keeping crankshaft end play at zero and observe dial indicator measurements.
6. Compare the total dial indicator variation (highest – lowest reading) to rear cover face runout Specifications (page 305).

Ring Gear Runout Measurement

1. Check for ring gear damage associated with the starter pinion. If damage is found, replace flywheel.

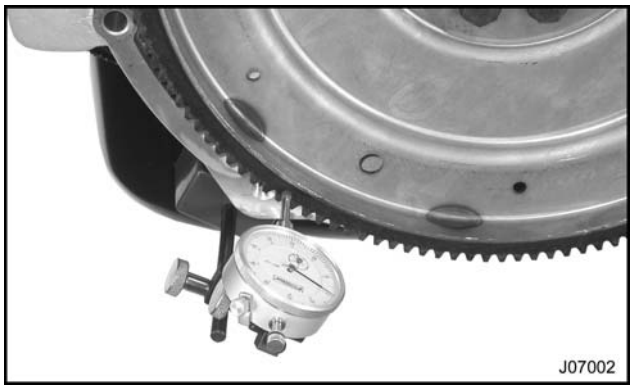

Figure 419 Ring gear run out measurement (typical)

2. Measure flywheel ring gear for surface run out.

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

   A. Attach a dial indicator with magnetic base (page 305) onto engine. Place dial indicator tip against surface of ring gear.

   B. Zero the dial indicator.

   C. Rotate crankshaft slowly (clockwise) and record total indicator runout. See Specifications (page 305).

3. Replace ring gear if total indicator runout is out of specifications.

Clean and Inspect

1. Clean all foreign material from crankcase and rear cover gasket surfaces. Use a scraper or wire brush to remove sealant from any gasket surfaces.
2. Gasket surfaces must be kept oil free for good adhesion of liquid gasket during assembly. Use a commercially available, non-caustic brake cleaner to clean crankcase and rear cover gasket surfaces.
3. Clean sealant from under the hydraulic oil pump cover while it is still in place.
4. Wash flywheel, rear cover, flywheel adapter or adapter hub with a suitable solvent. Dry with filtered compressed air.
5. Inspect flywheel for evidence of cracking around webbing and ring gear weld locations. Replace flywheel if any evidence of cracking is found.
6. Inspect ring gear teeth and flywheel for damage. Replace flywheel is damaged.

Installation

Rear Cover

CAUTION: To prevent engine damage, before installing the rear cover, replace dowel sleeves in crankcase if damaged or missing.

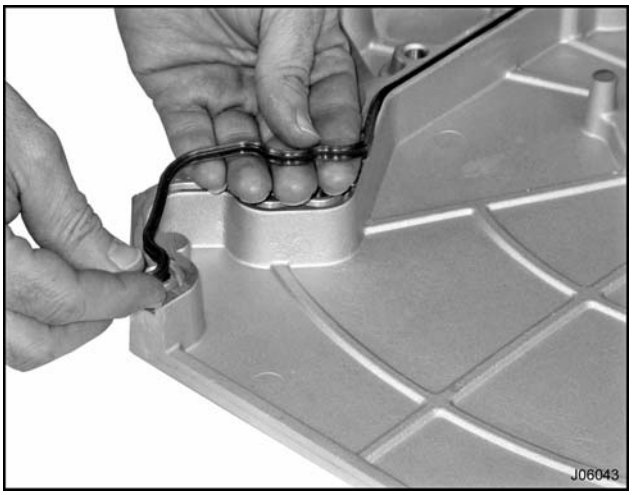

Figure 420 Rear cover gasket (typical)

1. Install a new rear cover gasket onto rear cover.

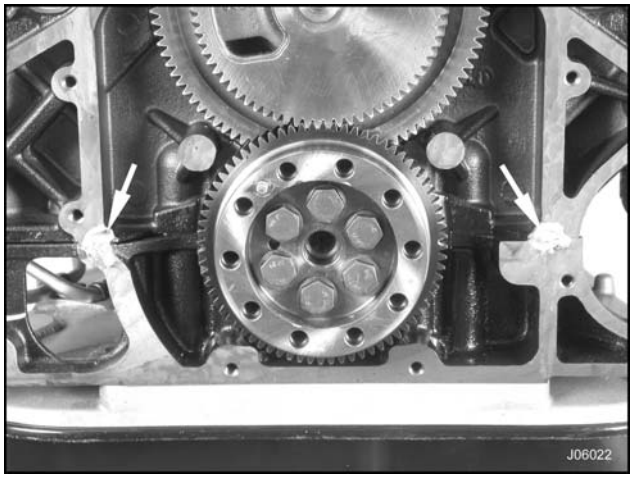

Figure 421 RTV locations, upper and lower crankcase (typical)

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

2. Apply Liquid Gasket (RTV) (page 305) at two locations, where the crankcase and lower crankcase join.

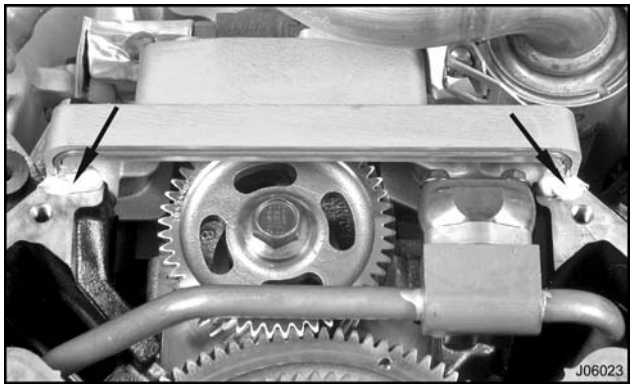

Figure 422 Liquid Gasket (RTV) locations under the high-pressure pump cover (typical)

3. Apply a small amount of RTV under the high-pressure pump cover.

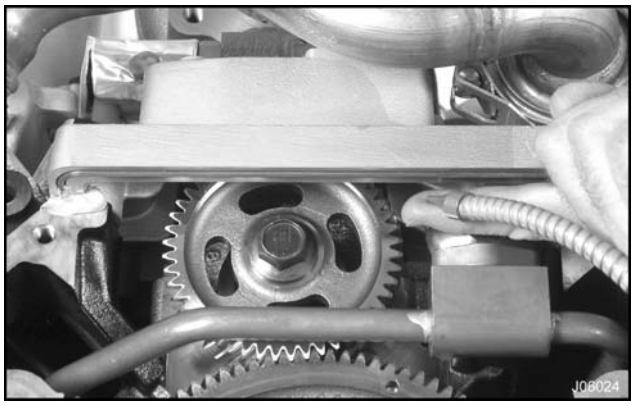

Figure 423 High-pressure pump cover gasket (typical)

4. Apply a small amount of oil to the high-pressure pump cover gasket.

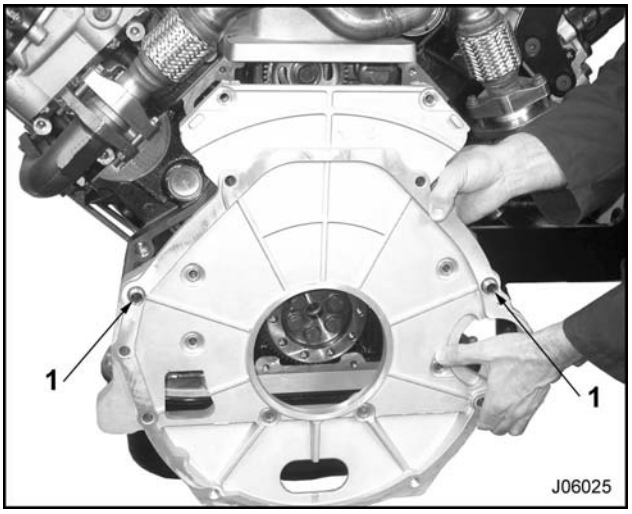

Figure 424 Rear cover installation (CityStar™)

1. Dowel pins (2)

WARNING: (Stripped chassis applications only) – To prevent personal injury or death, have an assistant help with installation of the rear cover.

5. Install rear cover assembly by aligning dowel sleeves on crankcase with rear cover. Push rear cover onto dowel sleeves.

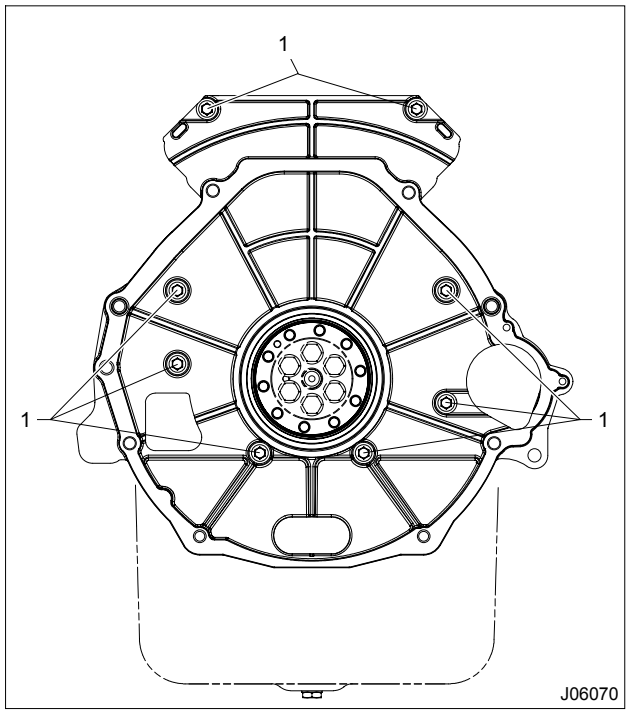

Figure 425 Rear cover bolts (CityStar™)

1. Bolt, M8 x 35 (8)

6. CityStar™ Chassis, install eight rear cover mounting bolts (M8 x 35) and tighten to standard torque (page 400).

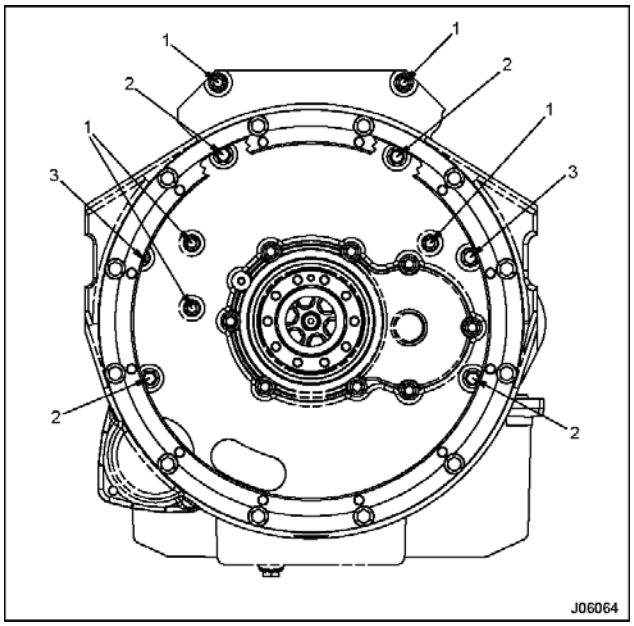

Figure 426 Rear cover bolts (stripped chassis)

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

Stripped Chassis, install and tighten rear cover mounting bolts to standard torque (page 400).

Crankshaft Secondary Flange (Stripped Chassis)

Figure 427 Crankshaft secondary flange sealant location

1. Place a 360° bead of Loctite® Hydraulic Sealant (page 305) onto the forward edge of the crankshaft secondary flange (primary flange mating surface).
2. Install crankshaft secondary flange by aligning the dowel pin hole with the crankshaft dowel pin.

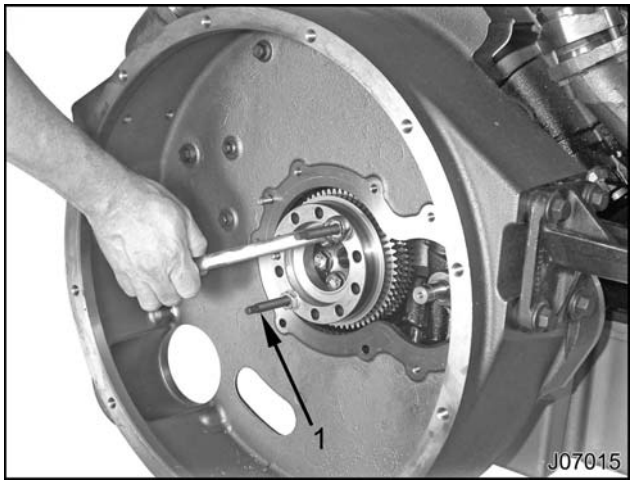

Figure 428 Crankshaft secondary flange installation

1. Crankshaft Secondary Flange Installation Studs (2)

3. Install two Crankshaft Secondary Installation Studs (page 305) 180° apart into the crankshaft primary flange. Thread studs completely into the crankshaft primary flange.
4. Install crankshaft secondary flange by alternately tightening stud nuts until flange is seated on the crankshaft.
5. Remove studs after flange is completely seated.

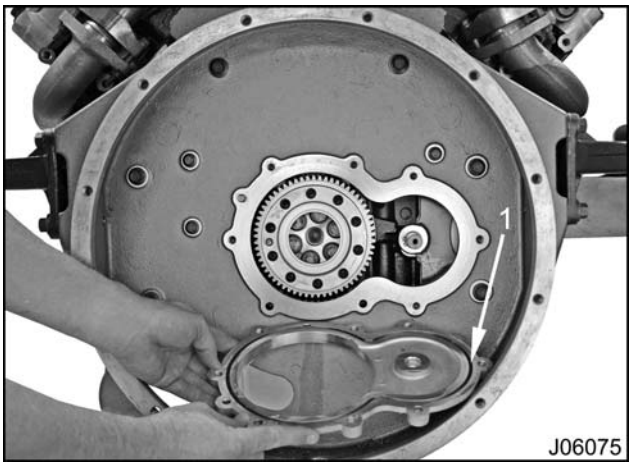

Figure 429 Rear oil seal carrier (stripped chassis)

1. Gasket

6. Install a new gasket onto rear oil seal carrier.

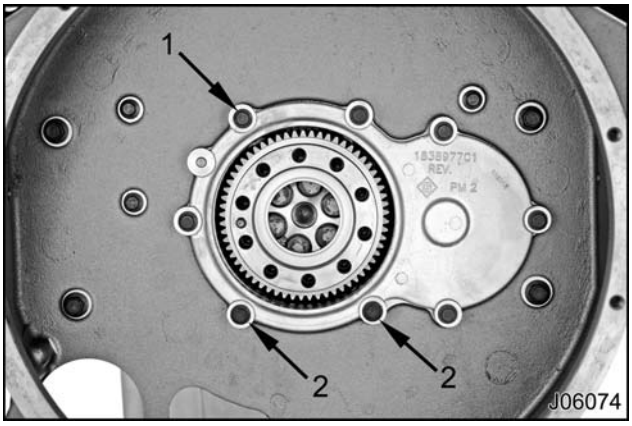

Figure 430 Rear oil seal carrier bolts (stripped chassis)

1. Bolts, M8 x 25 (6)
2. Bolts, M8 x 70 (2)

7. Install two M8 x 70 bolts in lower holes (Figure 430). Install six M8 x 25 bolts. Tighten eight bolts to standard torque (page 400).

Rear Main Oil Seal and Wear Sleeve

CityStar™ Applications

CAUTION: To prevent engine damage, do not separate wear sleeve from the new oil seal, damage to seal and engine will result.

NOTE: When replacing the rear main oil seal it should be noted that production engines not previously serviced, will not have a wear sleeve. Wear sleeves are only available as a service item included with a rear main oil seal service kit.

1. Clean primary crankshaft flange a with suitable solvent. Dry with filtered compressed air.

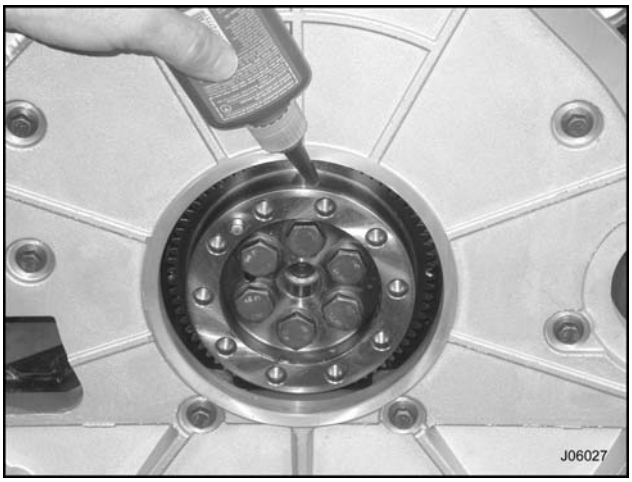

Figure 431 Sealant application to crankshaft primary flange (CityStar™)

2. Place a 360° bead of Loctite® Hydraulic Sealant (page 305) onto the rear edge of the crankshaft primary flange prior to wear sleeve and rear main oil seal installation.

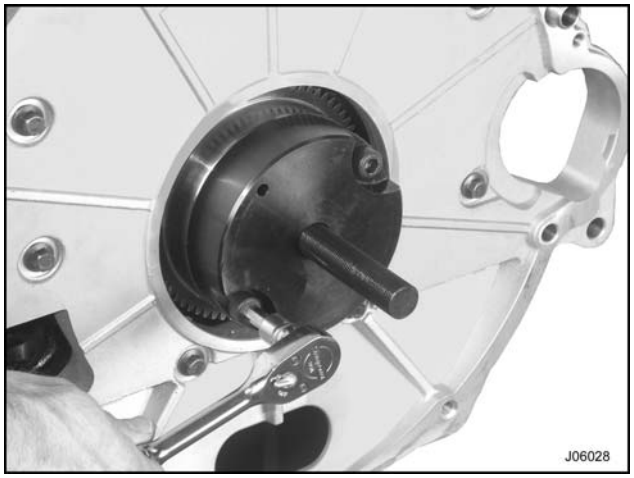

Figure 432 Rear Seal / Wear Sleeve Installer (CityStar™)

3. Bolt Rear Seal / Wear Sleeve installer onto end of crankshaft. Make sure crankshaft dowel fits in installation tool dowel recess hole.

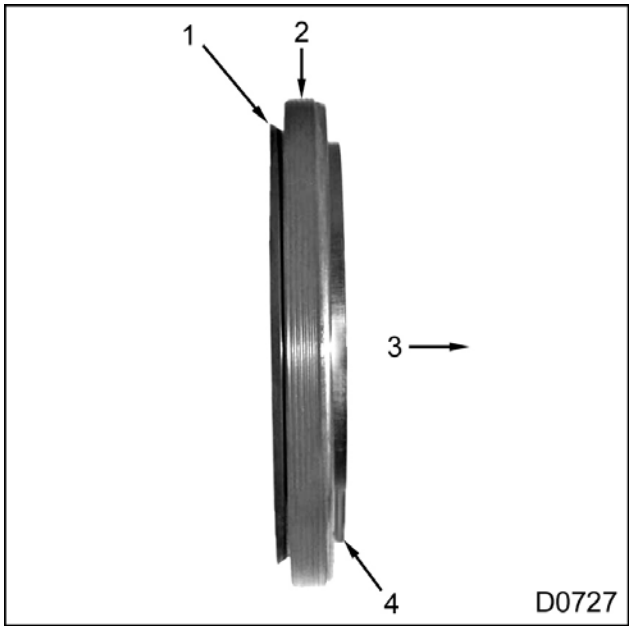

Figure 433 Rear main oil seal and wear sleeve

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

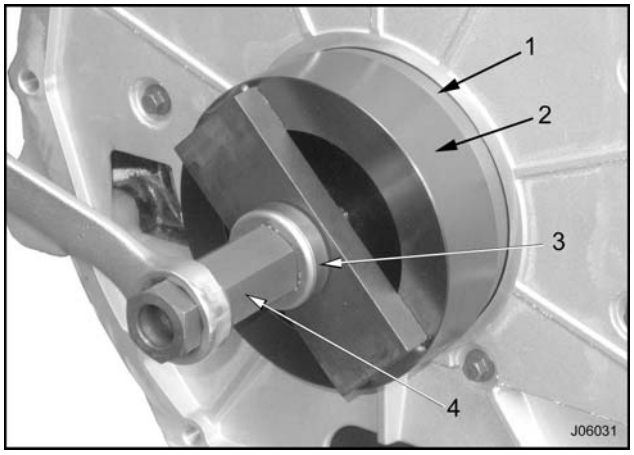

Figure 434 Rear main seal / wear sleeve installation

1. Rear main oil seal
2. Rear Seal / Wear Sleeve Installer
3. Thrust bearing
4. Drive nut

4. Position rear main oil seal and wear sleeve combination on the Rear Seal / Wear Sleeve Installer. Make sure the beveled edge of the wear sleeve is oriented toward the crankshaft.
5. Place thrust bearing and drive nut onto threaded shaft. Tighten nut until rear main oil seal bottoms out onto rear oil seal carrier.
6. Remove the Rear Seal/Wear Sleeve Installer tool.

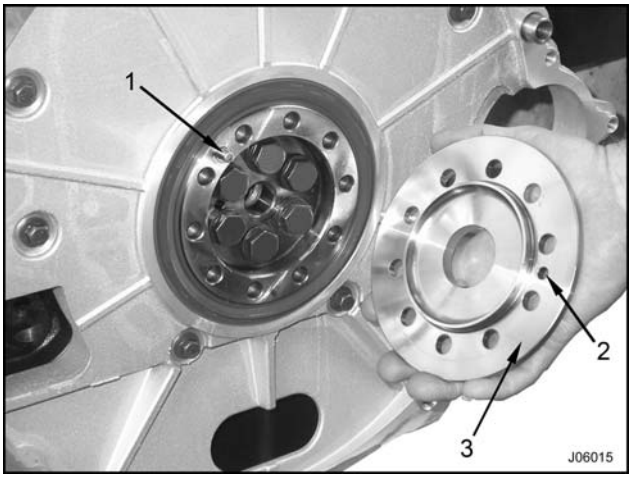

Figure 435 Flywheel adapter (CityStar™)

1. Dowel pin
2. Pin recess
3. Flywheel adapter

CAUTION: To prevent engine damage, do not scratch crankshaft primary flange sealing surface.

7. Place flywheel adaptor onto crankshaft primary flange. Be sure to line up dowel pin. If necessary, carefully tap with hammer to start and seat.

Stripped Chassis Applications

CAUTION: To prevent engine damage, do not separate wear sleeve from oil seal, damage to the seal and engine will result.

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

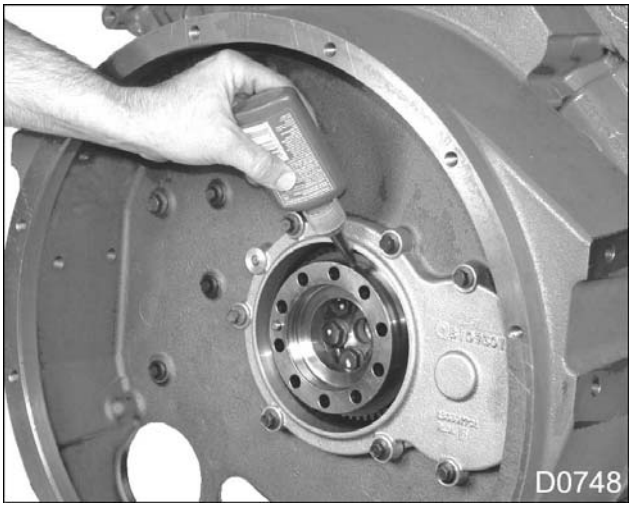

Figure 436 Sealant application to crankshaft secondary flange

1. Place a 360° bead of Loctite® Hydraulic Sealant onto the rear edge of the crankshaft secondary flange prior to wear sleeve and rear main oil seal installation. See Special Service Tools (page 305).

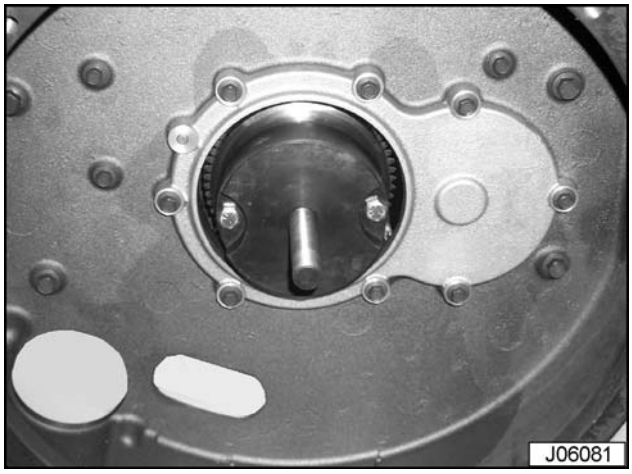

Figure 437 Rear Seal / Wear Sleeve Installer

2. Bolt Rear Seal / Wear Sleeve Installer (page 305) onto the end of secondary crankshaft flange. Make sure crankshaft alignment dowel fits in dowel recess hole.

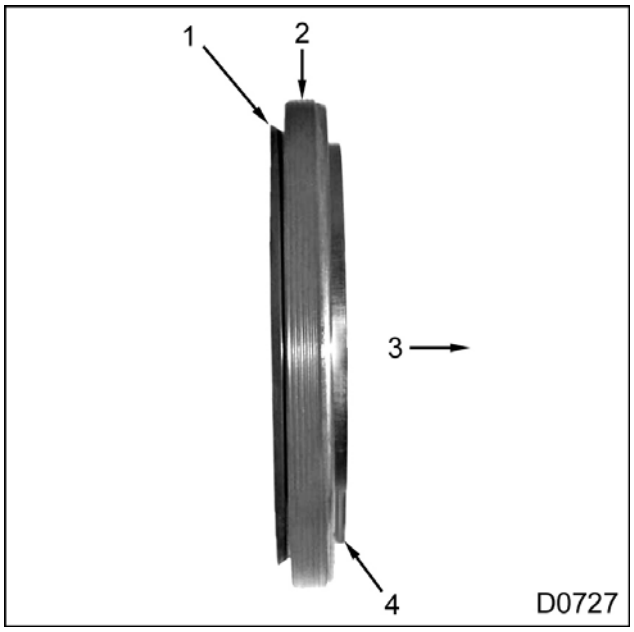

Figure 438 Rear main oil seal and wear sleeve orientation

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

3. Orient seal as shown in (Figure 438) and slide on Rear Seal / Wear Sleeve Installer. Make sure the beveled edge of the wear sleeve is oriented toward the crankshaft.

4. Position rear main oil seal and wear sleeve combination on the Rear Seal / Wear Sleeve Installer.

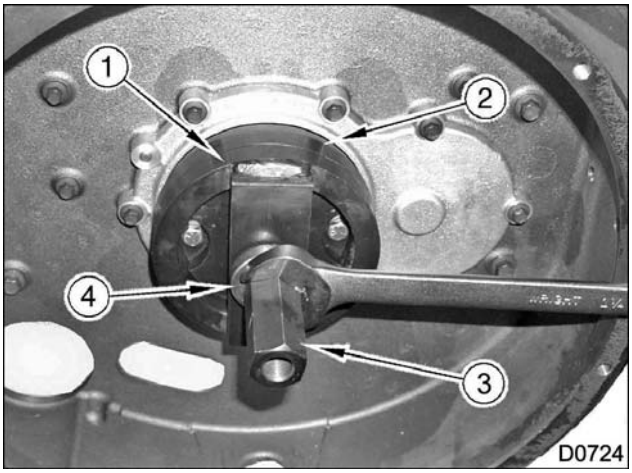

Figure 439 Rear main oil seal and wear sleeve combination

1. Rear Seal / Wear Sleeve Installer
2. Rear main oil seal
3. Drive nut
4. Thrust bearing

5. Place thrust bearing and drive nut onto threaded shaft. Tighten nut until rear main oil seal bottoms out in rear oil seal carrier.

Flywheel

CAUTION: To prevent engine damage, always install new flywheel mounting bolts when installing the flywheel.

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

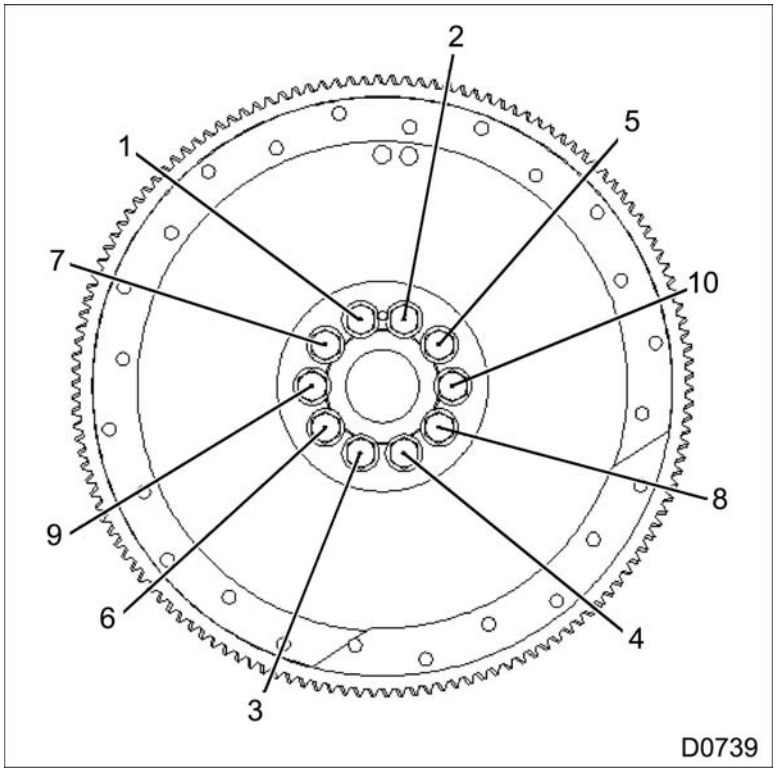

Figure 440 Flywheel torque sequence (typical)

1. Align crankshaft dowel pin with flywheel alignment hole and slide flywheel into place.
2. Install 10 new flywheel bolts.
   - CityStar™ series – M10 x 31
   - Stripped chassis – M10 x 77
3. Evenly tighten all flywheel bolts to special torque (page 305) using the torque sequence illustration (Figure 440).
4. Measure ring gear runout (page 295).
5. Stripped chassis only, place converter housing adaptor onto rear cover assembly and install 12 bolts (M10 x 35). Tighten bolts to standard torque (page 400).

Specifications

Max. flywheel ring gear T.I.R. runout	1.27 mm (0.050 in)
Rear cover face maximum runout	0.51 mm (0.020 in)

Special Torque

Flywheel mounting bolts (all applications) new bolts only	94 N·m (69 lbf·ft) see flywheel torque sequence (Figure 440)

Special Service Tools

Crankshaft Secondary Flange Installation Studs (2)	ZTSE4720
Dial indicator with magnetic base	Obtain locally
Gear Puller (for secondary flange)	ZTSE4520
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Loctite® Hydraulic Sealant	Obtain locally
Rear Seal / Wear Sleeve Installer[1]	ZTSE4515B
Rear Wear Sleeve Remover	ZTSE4518
Slide Hammer	ZTSE4398A

[1] CityStar™ bolts - M10 x 40, Stripped Chassis bolts - M10 x 70

Table of Contents

Exploded View.....309

Removal.....310
Preliminary Checks.....311
Piston Protrusion.....311
Connecting Rod Side Clearance.....312
Connecting Rod and Piston Assembly Removal.....312
Piston Disassembly.....314

Cleaning, Inspection, and Measurement.....315
Pistons.....315
Piston Rings.....317
Connecting Rods.....318
Connecting Rod Bore Out-of-Round and Taper Check.....319
Connecting Rod Bearing Fit Check.....320
Piston Pin Inspection.....321

Installation.....322
Piston Assembly.....322
Connecting Rod and Piston Installation.....324

Specifications.....326

Special Torque.....327

Special Service Tools.....327

Exploded View

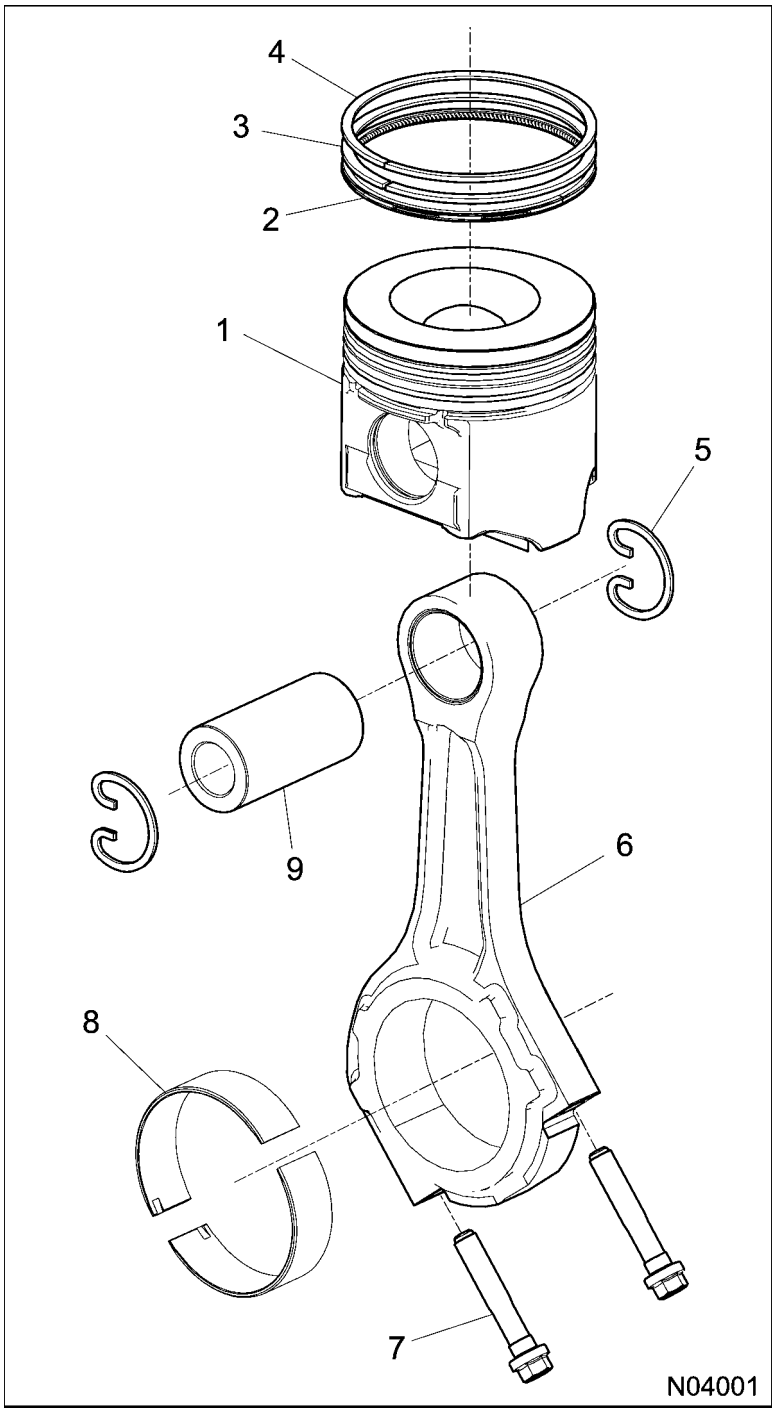

Figure 441 Piston, rings, and connecting rod

1. Piston
2. Oil control ring
3. Intermediate compression ring
4. Top compression ring
5. Retaining ring (2)
6. Connecting rod (with fractured cap mating surfaces)
7. Connecting rod bolt (2)
8. Connecting rod bearing
9. Piston pin

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, allow engine to cool before working with components.

WARNING: To prevent personal injury or death, disconnect ground (-) cable from battery before doing service or diagnostic procedures.

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 and filters according to applicable regulations. Never put engine fluids in the trash, on the ground, in sewers or bodies of water.

CAUTION: To prevent engine damage, do not allow connecting rod or connecting rod cap fractured mating surfaces to contact any surface other then its matched fractured surface. Contacting any other surface could cause misalignment of the mating surface, resulting in connecting rod bearing and engine failure.

Preliminary Checks

Piston Protrusion

NOTE: Before removing any piston and connecting rod assemblies, check piston protrusion and connecting rod side clearance to help identify bent or twisted connecting rods.

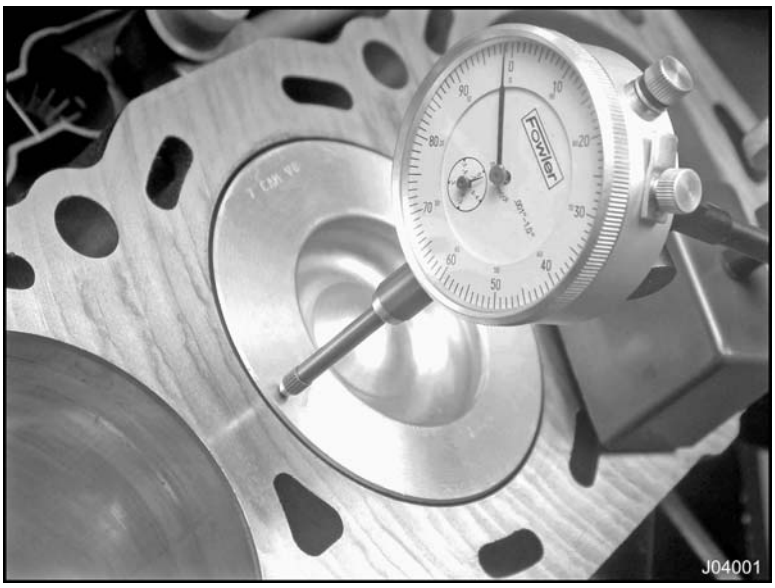

Figure 442 Piston protrusion measurement

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

1. Check piston protrusion above crankcase as follows:
   a. Position a dial indicator with magnetic base (page 327) close to the piston to be measured.
   b. Zero the dial indicator gauge on crankcase deck surface.
   c. Position dial indicator tip over the piston head at the 3 o'clock position.
   d. Bar the crankshaft around in the direction of normal rotation. This will raise the piston to its maximum outward protrusion at cylinder Top Dead Center (TDC). Read this maximum protrusion on dial indicator.
   e. Record reading.
   f. Reposition dial indicator tip on piston head at the 9 o'clock position.
   g. Bar the crankshaft around in the direction of normal rotation to raise the piston to its maximum protrusion. Read the maximum protrusion (piston height above the crankcase) on the dial indicator.
   h. Average the two maximum protrusion readings and compare to Specifications (page 326). Replace piston and piston rod as required.

Connecting Rod Side Clearance

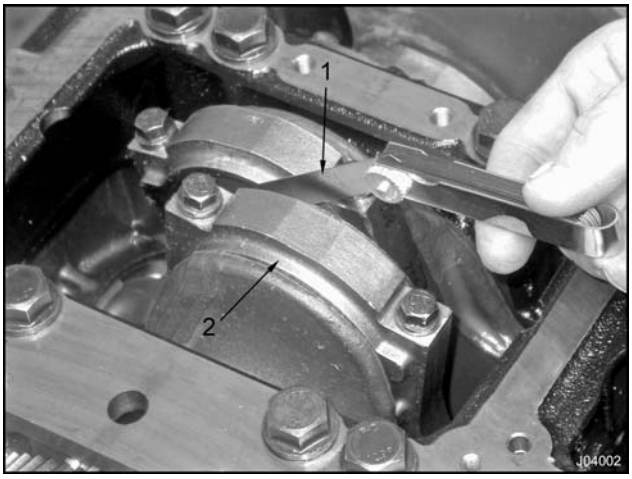

Figure 443 Connecting rod side clearance

1. Feeler gauge
2. Connecting rod

1. Lightly pry apart each pair of connecting rods and insert a feeler gauge (page 327) to check connecting rod side clearance (page 326).

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

Connecting Rod and Piston Assembly Removal

CAUTION: To prevent engine damage, remove carbon ridge, if evident, prior to removing the rod and piston assemblies from the top of the cylinder bore. This reduces the chance of piston ring land damage during removal.

1. Use a razor knife or emery cloth to scrape carbon ridge from top of cylinder bore.
2. Rotate crankshaft to position journals for removal of connecting rod assemblies. Mark connecting rod locations.

CAUTION: To prevent engine damage, check connecting rod bolts for binding. If binding occurs, check thread condition carefully during inspection.

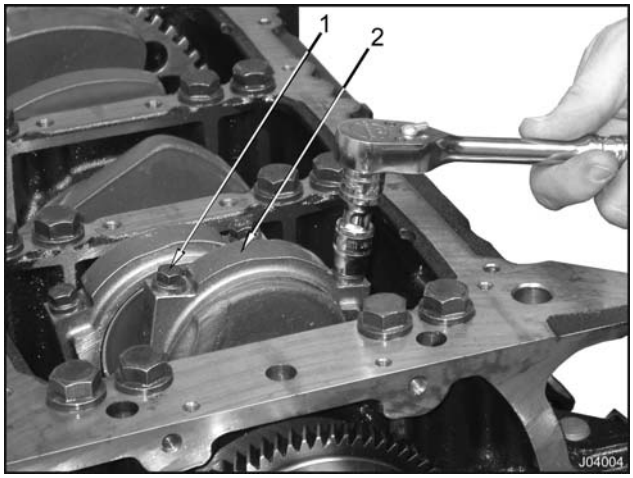

Figure 444 Connecting rod cap

1. Connecting rod bolts (2 per rod cap)
2. Connecting rod cap (6)

3. Remove two connecting rod bolts and connecting rod cap.

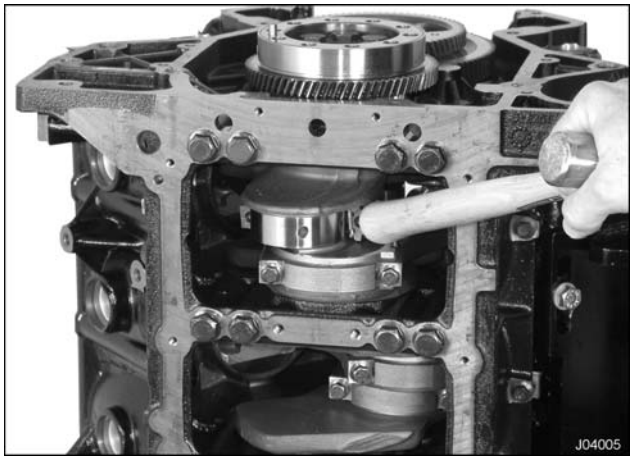

Figure 445 Piston and connecting rod removal

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

4. Remove piston and connecting rod assemblies from crankcase as follows:
   a. Rotate engine to a vertical position.
   b. Use a wooden or plastic handle of a hammer to push the piston and rod assembly from cylinder bore.
   c. Once piston rings are free of cylinder bore, remove piston and connecting rod assembly from top crankcase.

CAUTION: To prevent engine damage, make sure each connecting rod and cap are marked or tagged with the cylinder number. This engine uses fractured connecting rods. Do not alter or damage the fractured mating surfaces of the rod and cap. A cap from one connecting rod is not interchangeable with other connecting rods. The matching connecting rod and cap numbers indicate a matched set.

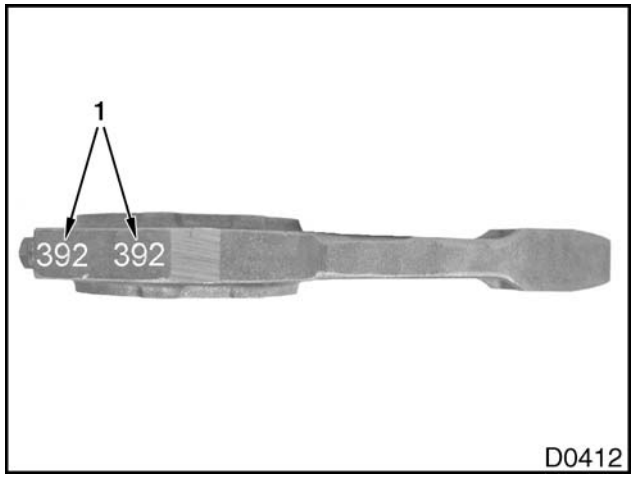

Figure 446 Matching cap and rod numbers

1. Matching numbers

Piston Disassembly

WARNING: To prevent personal injury or death, wear safety glasses with side shields.

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

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, mark each piston with its cylinder number. Each piston must be reinstalled into its original cylinder bore, if the pistons are being reused.

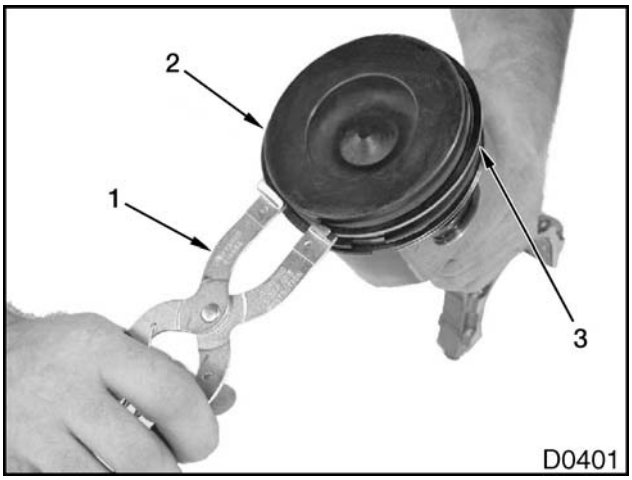

Figure 447 Piston ring removal

1. Piston ring expansion pliers
2. Piston
3. Piston ring

CAUTION: To prevent engine damage, only expand piston rings enough to fit over top of piston.

1. Use Piston Ring Expansion Pliers (page 327) to remove the piston rings. Remove top ring first, intermediate ring, and then finally the oil control ring. Keep rings organized and marked for correct reassembly.

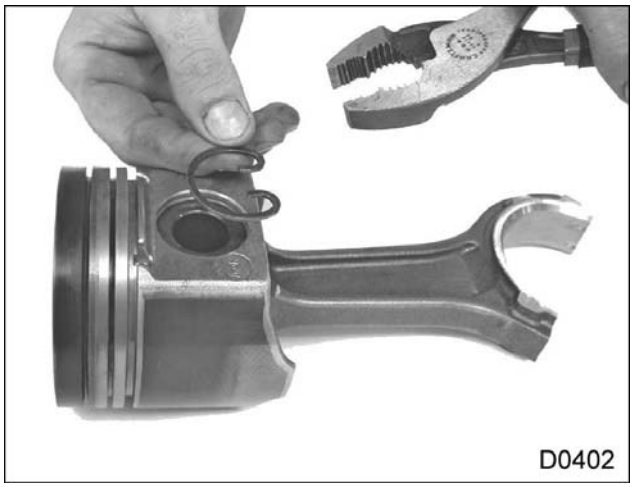

Figure 448 Piston pin retaining ring

2. Separate connecting rod from piston as follows:
   a. Use pliers to remove both piston pin retaining rings.
   b. Remove piston pin from its bore by hand, and then separate connecting rod from piston.

Cleaning, Inspection, and Measurement

NOTE: Do not use a caustic solution or a wire brush for cleaning aluminum pistons. Do not bead blast pistons.

1. Use a soap and water solution to clean aluminum pistons. Soak piston first, and then clean piston with a nonmetallic brush.
2. Clean all piston ring grooves thoroughly.
3. The following disassembled components may be cleaned using a suitable solvent:
   - Piston pins
   - Piston pin retainers
   - Connecting rods
4. Thoroughly clean all 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 any pistons showing such damage.

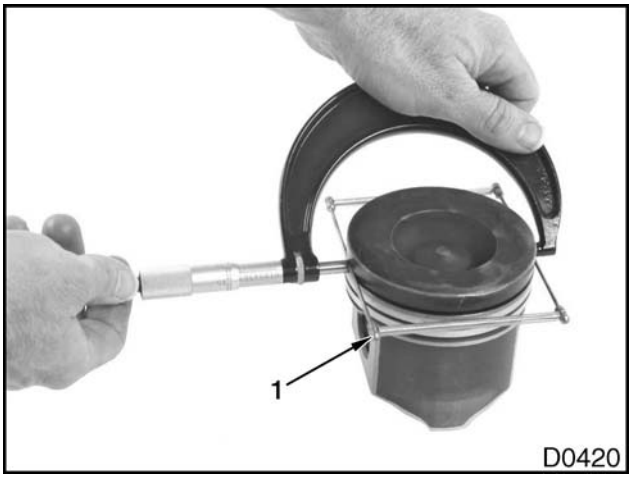

Figure 449 Top compression ring groove measurement

1. Piston gauge pins (0.082 in)

2. Check top compression ring groove for wear as follows:

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

   a. Install the Piston Gauge Pins (0.082 in) in the top ring groove. Piston gauge pins must be parallel. See Special Service Tools (page 327).

   b. Use a 3 - 4 inch outside micrometer to measure diameter over piston gauge pins. See Specifications (page 326).

   c. If measurement over the gauge pin is not within specifications, excessive piston groove wear exists. Replace piston.

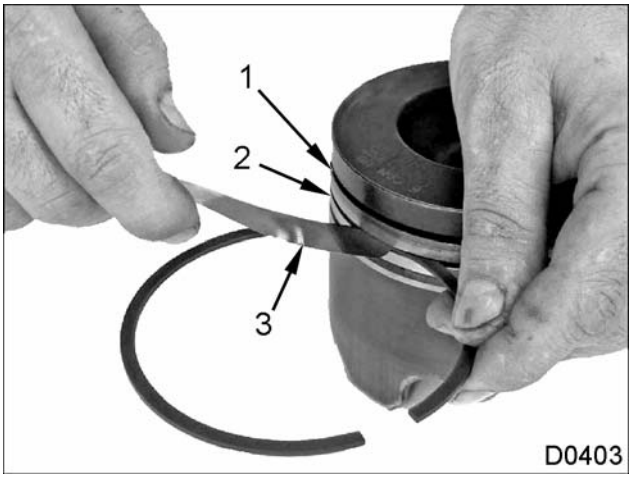

Figure 450 Ring groove clearance measurement (intermediate ring shown)

1. Compression ring groove
2. Intermediate compression ring groove
3. Feeler gauge

3. 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 327) to check side clearance. Excessive side clearance indicates ring groove wear and requires piston replacement. See Specifications (page 326).
4. 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 is able to move freely in groove.
   c. Use a feeler gauge to check side clearance of oil control ring in its respective groove. Excessive side clearance indicates ring groove wear and requires piston replacement. See Specifications (page 326).

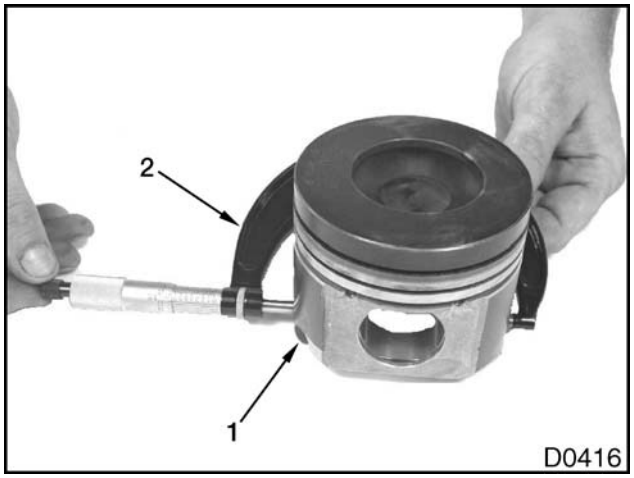

Figure 451 Piston skirt diameter measurement

1. Piston skirt
2. 3-4 inch micrometer

5. Measure piston skirt diameter under conditions indicated in the Specifications (page 326).

   When considering piston replacement, check each cylinder condition and bore out-of-round (page 342). Cylinder boring may be required. Such bore reconditioning will require oversize service pistons.

NOTE: In addition to the 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)

6. 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, de-glaze bore using a glaze breaker brush, then reassemble. See Crankcase and Crankshaft section for the correct de-glazing procedure.

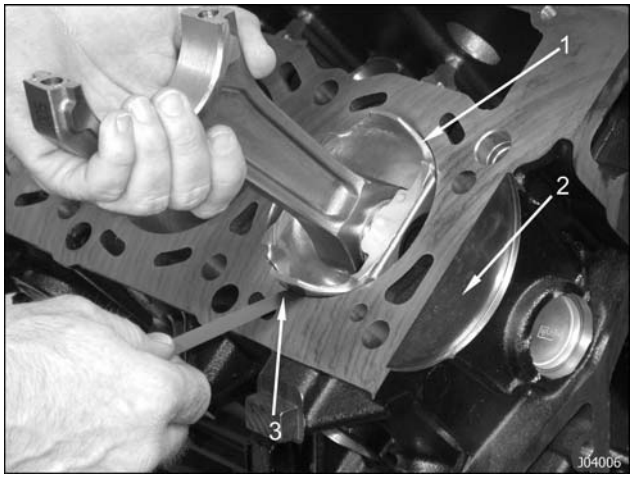

Figure 452 Piston skirt clearance in cylinder bore

1. Piston
2. Crankcase
3. Feeler gauge

7. Check piston skirt clearance (page 326) with a feeler gauge in the cylinder bore. Correct as required.

Piston Rings

NOTE: Faulty rings cannot always be detected by visual inspection. Therefore, whenever a piston is removed from a cylinder, replace the piston rings.

1. Inspect new piston rings for cleanliness.
2. Before installing new piston rings on piston, 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 the top of the piston ring travel).
   b. Use a feeler gauge to measure gap between ends of each piston ring.

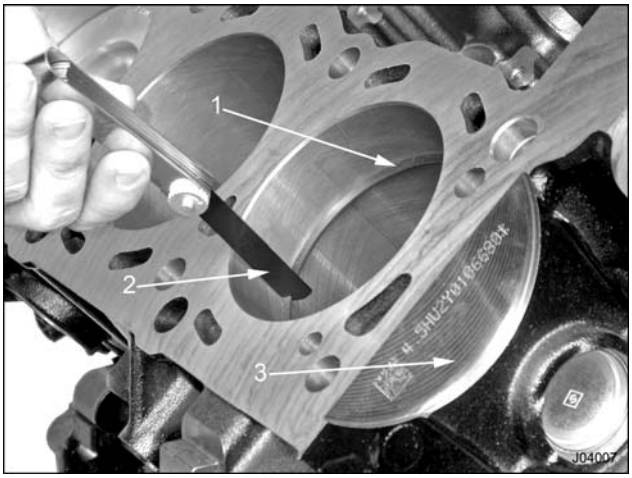

Figure 453 Piston ring end gap clearance in cylinder bore

1. Piston ring
2. Feeler gauge
3. Crankcase

   c. If gap does not meet specifications, select another ring or recheck cylinder bore wear. See Specifications (page 326).

Connecting Rods

CAUTION: To prevent engine damage, the connecting rod cap fractured mating surfaces must be assembled onto the original connecting rod and in the original orientation (matching numbers must be adjacent to each other).

CAUTION: To prevent engine damage, keep the fractured mating surfaces clean and free of debris. Do not allow mating surfaces to rest on any other surface. Do not bump mating surfaces or drop the connecting rod or cap. This could cause wear and chipping of the fractured surface, resulting in improper mating during installation and possible engine damage.

1. Inspect connecting rod bolts 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 as required.

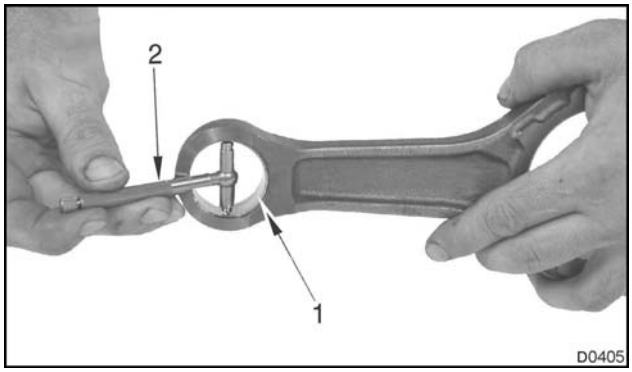

Figure 454 Inside diameter of piston pin bushing

1. Piston pin bushing
2. Telescoping gauge

3. Inspect connecting rod piston pin bushing for wear as follows:
   a. Using a Telescoping Gauge and a 1-2 inch micrometer, measure pin bore at two locations approximately 90° apart. Record the measurements. See Special Service Tools (page 327).
   b. If inside diameter of piston pin bushing exceeds specification, replace connecting rod. See Specifications (page 326).

Connecting Rod Bore Out-of-Round and Taper Check

CAUTION: To prevent engine damage, check connecting rod bolts for binding. They should thread into connecting rod freely when lubricated with clean engine oil. If they do not, the connecting rod must be discarded. Connecting rod threads cannot be re-tapped if binding exists. Check thread condition carefully during inspection.

1. Lubricate connecting rod bolts with clean engine oil. Assemble cap to rod without bearing insert. Tighten bolts to special torque (page 327).

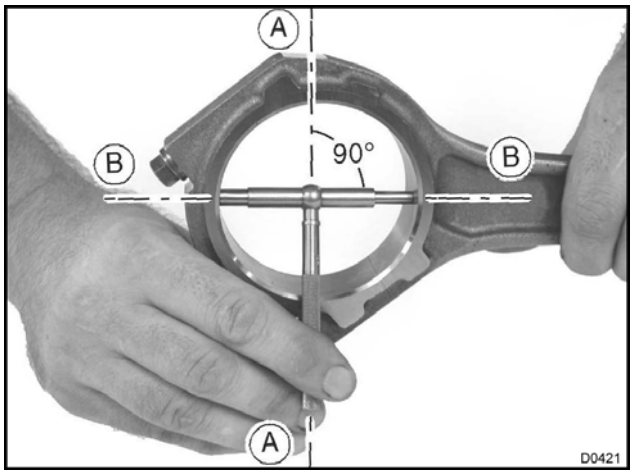

Figure 455 Connecting rod bearing bore out of round measurements

2. Using a Telescoping Gauge, measure connecting rod at two locations, 90° apart. See Special Service Tools (page 327).
3. If the difference between dimension A and B exceeds out-of-round specifications, replace connecting rod. See Specifications (page 326).

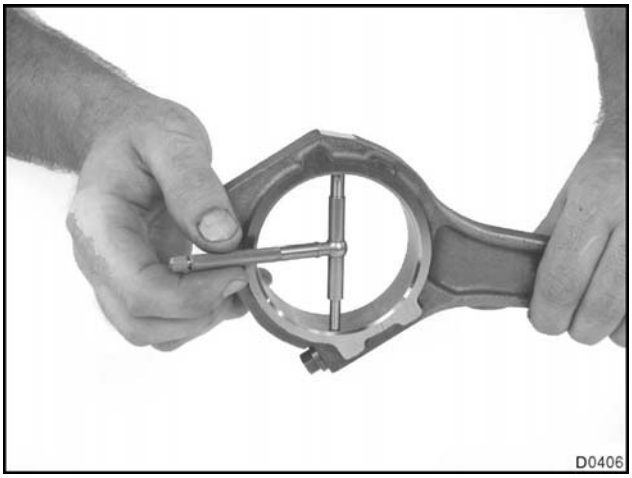

Figure 456 Connecting rod bore taper measurement

4. Measure connecting rod taper as follows:
   a. Insert a Telescoping Gauge near chamfer on either side. Record the readings. See Special Service Tools (page 327).
   b. Measure inner diameter of connecting rod bearing bore near chamfer on other side. Record the readings.

      The difference between the two readings is the connecting rod bore taper. If connecting rod bore taper exceeds specification, replace connecting rod. See Specifications (page 326).
5. 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 the connecting rod and cap, they protrude above the parting line. This protrusion is required to achieve "bearing crush." Therefore connecting rod caps must be wiped clean prior to installation of the bearing shell.

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

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

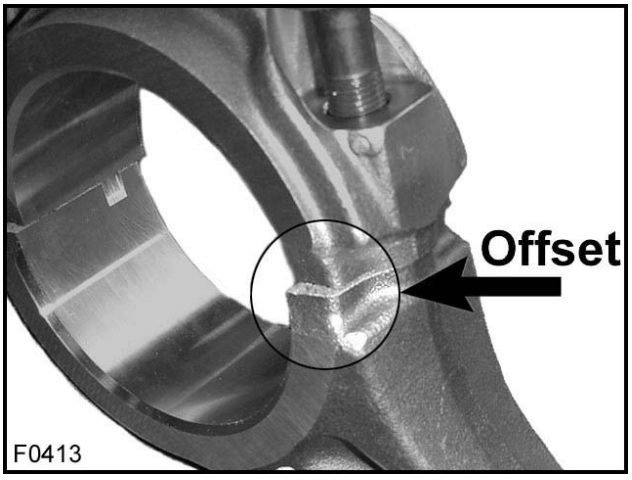

Figure 457 Offset for incorrect rod cap assembly

CAUTION: To prevent engine damage, make sure connecting rods are installed with their caps in the right direction. If a rod cap is reversed during assembly, an obvious offset will be seen at the mating surfaces. If the connecting rod assembly is installed on the crankshaft this way, the connecting rod must be replaced. Also, check crank pin fillets for damage as such damage would require replacement of the crankshaft.

1. Lubricate connecting rod bolts with clean engine oil. Assemble cap to rod with new bearing shells installed. Tighten bolts alternately and evenly to the special torque (page 327).
2. Using a Telescoping Gauge, measure inside diameter of connecting rod bearing at two locations 90° apart. Average the two inside diameters. Record reading. See Special Service Tools (page 327).
3. Using a 2–3 inch micrometer, measure each crankshaft rod journal diameter. Record reading.
4. Subtract the crankshaft rod journal diameter from the respective connecting rod bearing inside diameter to obtain connecting rod bearing running clearance. Repeat for each crankshaft rod journal.
5. If bearing-to-crankshaft running clearances exceed specifications because of wear on crankshaft, replace or grind crankshaft and install undersize precision type bearing shells. See Specifications (page 326).

CAUTION: To prevent engine damage, do not attempt to reduce journal-to-bearing running clearances by reworking bearing cap, bearings, or both. Grind or replace the crankshaft only.

NOTE: Plastigage® may be used as an alternate method of determining running clearance.

Piston Pin Inspection

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

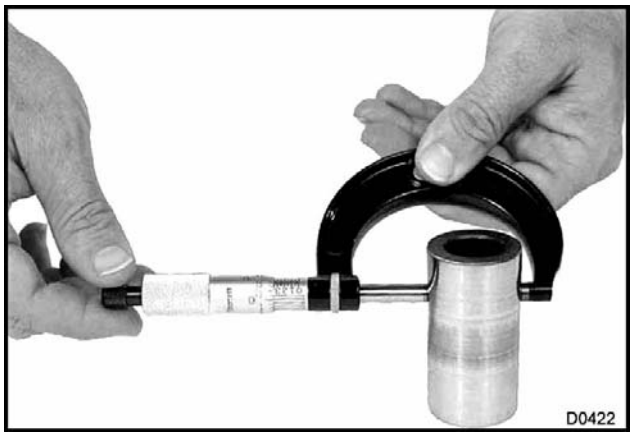

Figure 458 Piston pin measurement

2. Using a 1-2 inch micrometer, measure piston pin outside diameter at two locations 90° apart. Measure each end of the pin. Record the range of readings. If piston pin wear exceeds specifications (page 326), replace piston pin.

Figure 459 Piston pin bore inside diameter measurement

3. Using a 1-2 inch telescoping gauge and micrometer, measure each piston pin bore inside diameter, at two locations 90° apart. Record reading.
4. To check piston pin clearance, subtract piston pin outside diameter from piston pin bore inside diameter measurement. If clearance exceeds specifications, recheck piston pin, piston, and connecting rod bushing measurements. Replace component that is out of Specifications (page 326).

Installation

Piston Assembly

WARNING: To prevent personal injury or death, wear safety glasses with side shields.

CAUTION: To prevent engine damage, make sure the connecting rod and piston are assembled correctly.

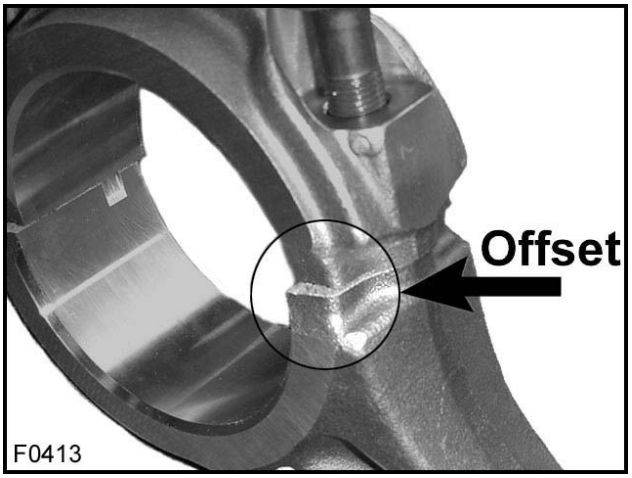

Figure 460 Offset for incorrect rod cap assembly

CAUTION: To prevent engine damage, the rod cap can only be correctly installed on the connecting rod if it is oriented in the correct direction. If the rod cap is reversed during assembly of the connecting rod, an obvious offset will be seen at the mating surfaces. If the connecting rod assembly is installed on the crankshaft in this manner, the connecting rod must be replaced. Also check the crank pin fillets for damage. Such damage will require replacement of the crankshaft.

Assemble the piston rings, piston, and connecting rod as follows:

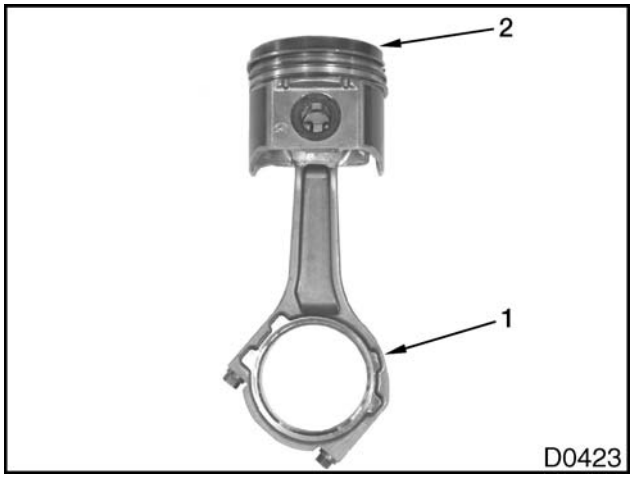

Figure 461 Proper position of installed connecting rod

1. Longer leg of connecting rod (cam side)
2. “CAM V8” stamped 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. Orient the longer leg of the connecting rod with the side of the piston bearing the “CAM V8” stamped in its crown.

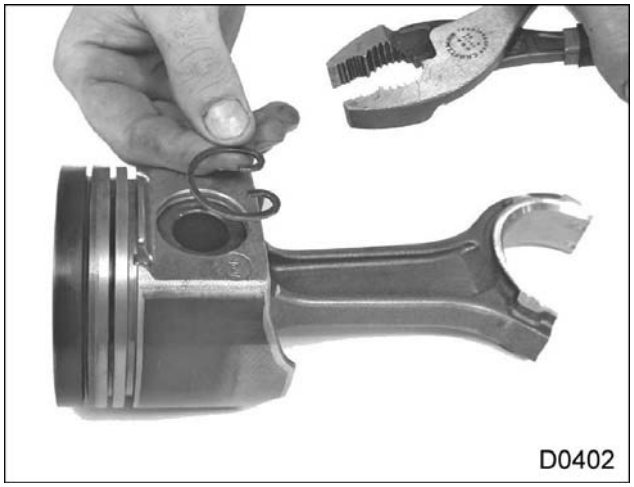

Figure 462 Piston pin retaining ring installation

   c. Using pliers, install retaining ring at one end of piston pin bore.

d. Slide piston pin through bored holes, stopping at installed retaining ring.

e. Install second retaining ring.

f. Check to see if the piston slides easily on piston pin from one snap ring to the other.

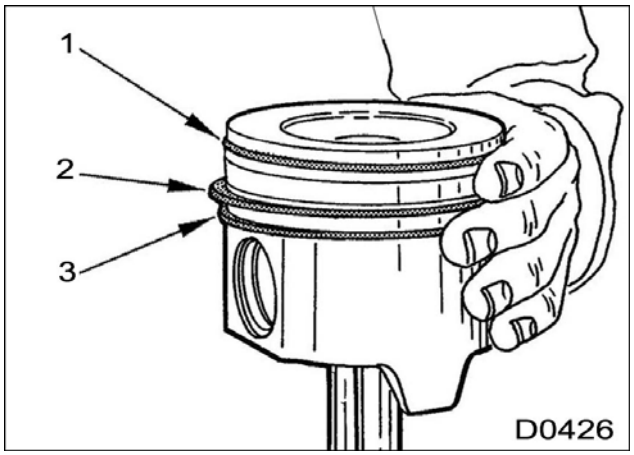

Figure 463 Piston ring locations

1. Top compression ring
2. Intermediate compression ring
3. Oil control ring

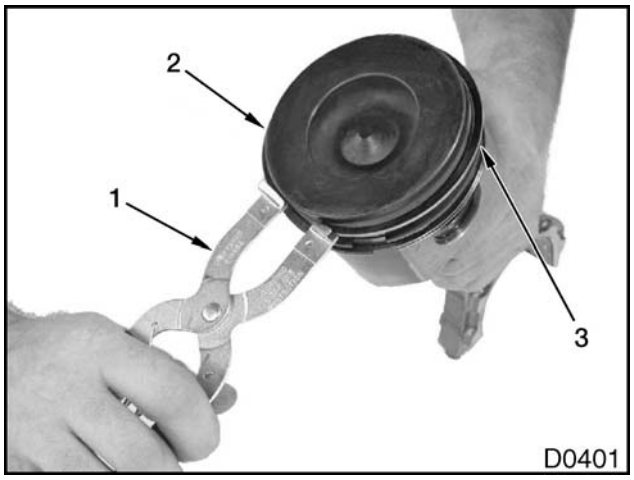

Figure 464 Piston ring installation (typical)

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

2. Using Piston ring expansion pliers (page 327), install piston rings as follows:

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.

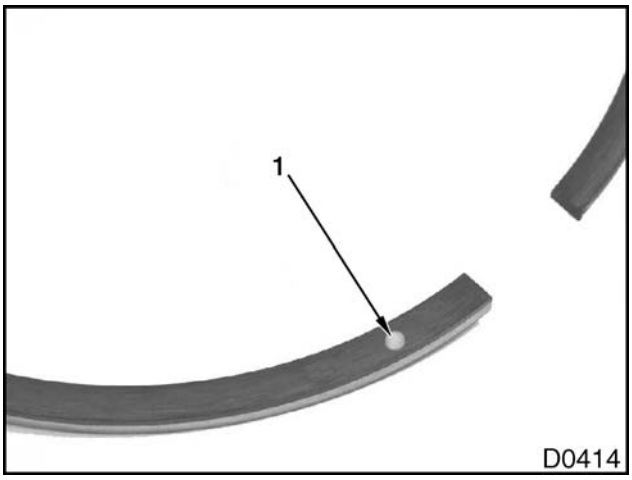

Figure 465 Piston ring identification marks (top ring shown)

1. Identification mark

CAUTION: To prevent engine damage, make sure piston rings are installed correctly. Both intermediate and compression rings have the same identification markings. The intermediate ring has a square cross section. The top compression ring has a keystone cross section.

c. Install intermediate ring (rectangular cross section) into middle piston groove with identification mark facing up. The intermediate ring is identified by one 'O' mark on the top surface of ring.

d. Install compression ring (keystone cross section) into top piston groove with identification mark facing up. The compression ring is identified by the 'O' mark on the top surface of ring.

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

Connecting Rod and Piston Installation

1. Turn crankshaft so that the number 1 connecting rod journal is at the bottom of its stroke.

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

2. Coat piston and piston rings with clean engine oil. Coat cylinder walls, crankshaft journals, and piston cope with clean engine oil.

CAUTION: To prevent engine damage, the "CAM V8" stamped on top of the piston must be oriented towards the camshaft side of the crankcase, toward center of engine.

NOTE: Pistons are interchangeable between the VT 365 and MaxxForce™ 5 diesel engines.

Figure 466 Piston Ring Compressor

3. Place piston in Piston Ring Compressor (cope) to compress rings and ease the installation of piston and connecting rod assembly into the crankcase. See Special Service Tools (page 327).

NOTE: Make certain that connecting rod and cap bearing surfaces have been wiped clean of any oil or residue.

4. Install bearing shells in connecting rod and cap. Coat bearing shell in connecting rod with clean engine oil.

5. Carefully insert connecting rod and start piston into the top end of the cylinder bore until cope is against the top of the cylinder.

CAUTION: To prevent engine damage, use caution not to damage piston cooling tubes when installing connecting rod and piston assemblies.

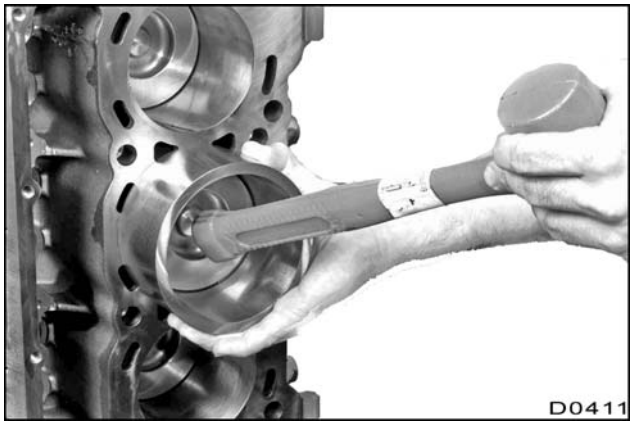

Figure 467 Piston installation into cylinder bore

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

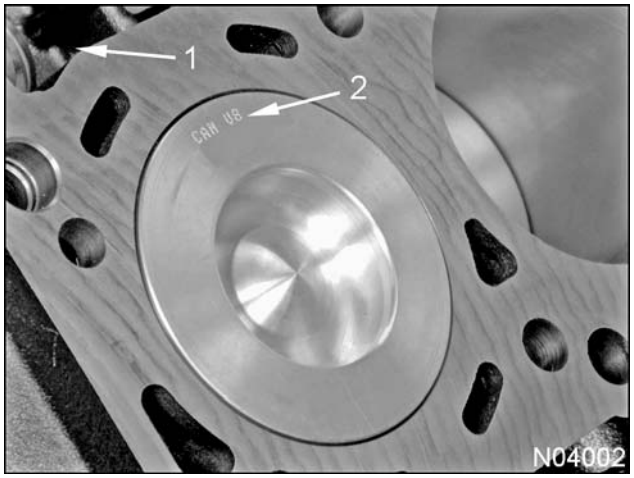

Figure 468 Orientation of piston in cylinder bore

1. Cam follower opening
2. Identification mark, “CAM V8”

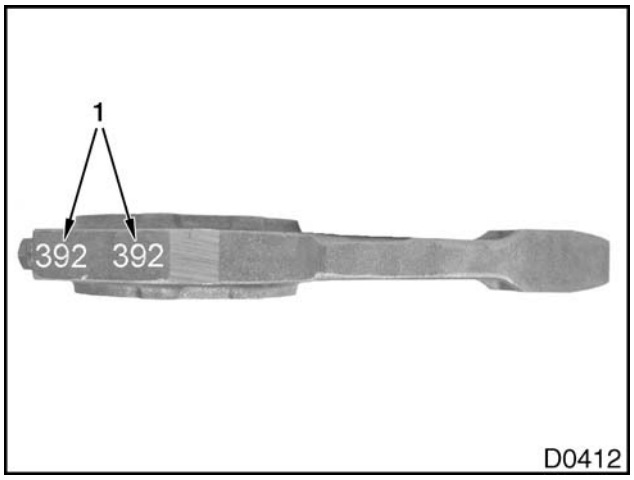

Figure 469 Connecting rod and cap matching identification numbers

1. Matching numbers

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

7. Apply clean engine oil to connecting rod bolt hole threads and bearing shell in cap before installing bolts.
8. Assemble cap to connecting rod with matching identification code on same crankshaft journal from which it was removed. Be certain that the longer leg of the connecting rod and the “CAM V8” stamp on piston crown are oriented towards the camshaft.

CAUTION: To prevent engine damage, do not use air powered tools when installing connecting rod bolts. This may cause seizure of connecting rod bolts.

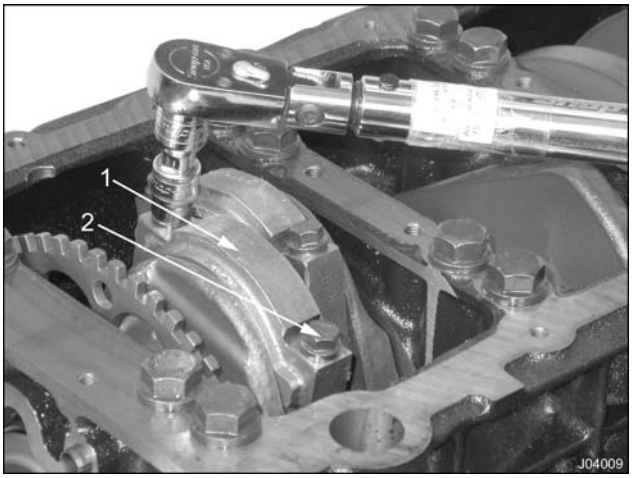

Figure 470 Torquing the connecting rod cap bolts

1. Connecting rod bearing cap
2. Connecting rod bolt

9. Install and tighten connecting rod bolts evenly to the initial and final torque values. See special torque (page 327).
10. Repeat installation procedure for remaining connecting rod and piston assemblies.
11. Check connecting rod side clearance with feeler gauge. See procedure in removal section Piston and Connecting Rod Checks in this section.
12. Complete the engine rebuild and reinstall all safety guards, shields and covers after servicing the engine.
13. Make sure all tools, covers, loose parts and service equipment are removed from the engine area after all work is done.

Specifications

Connecting Rods	
Connecting rod length (center to center)	176 mm (6.929 in)
Bushing bore diameter (pin end)	36.98 to 37.02 mm (1.456 to 1.457 in)
Piston pin bushing inside diameter	34.0140 to 34.0215 mm (1.3391 to 1.3394 in)
Bearing bore diameter (crankshaft end)	72.987 to 73.013 mm (2.8735 to 2.8745 in)
Bearing bore maximum out-of-round	0.013 mm (0.0005 in)
Bearing bore maximum taper per 25 mm (1 inch)	0.013 mm (0.0005 in)
Connecting rod bearing inside diameter	69.027 to 69.077 mm (2.7176 to 2.7196 in)
Connecting rod bearing running clearance (diameter)	0.0203 to 0.0837 mm (0.0008 to 0.0033 in)
Connecting rod side clearance	0.3 to 0.6 mm (0.012 to 0.024 in)
Weight (complete rod without bearing)	1201.5 to 1215.5 g (2.649 to 2.679 lb)
Pistons	
Material	Aluminum Alloy
Skirt diameter [1]	94.9460 to 94.9186 mm (3.737 to 3.738 in)
[1] Measure 14.68 mm (0.578 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	94.9460 to 94.9186 mm (3.737 to 3.738 in)
0.254 mm (0.010 in) oversize	95.1738 to 95.1992 mm (3.747 to 3.748 in)
0.508 mm (0.020 in) oversize	95.4278 to 95.4532 mm (3.757 to 3.758 in)
0.762 mm (0.030 in) oversize	95.6818 to 95.7072 mm (3.767 to 3.768 in)
Top compression ring groove width (measured over 2.08 mm (0.082 in) gauge pins):	
Upper limit	94.469 mm (3.7192 in)
Replacement limit	94.290 mm (3.7122 in)
Piston protrusion above crankcase deck	0.900 mm (0.0354 in)
Piston skirt clearance (1 - 8)	0.0441 to 0.0909 mm (0.0017 to 0.0036 in)

Piston Pins	
Length	65.073 to 65.327 mm (2.5619 to 2.5719 in)
Diameter	33.9975 to 34.0025 mm (1.3385 to 1.3387 in)
Pin fit at room temperature of 19 to 21 °C (66 to 70 °F):	
Clearance in connecting rod (piston pin bushing)	0.0115 to 0.0240 mm (0.00045 to 0.00094 in)
Clearance in piston	0.013 to 0.022 mm (0.0005 to 0.0009 in)
End clearance	0.24 mm (0.009 in)
Piston Rings	
Ring diameter (standard):	95 mm (3.74 in)
Ring groove (side clearance):	
Intermediate compression	0.051 to 0.102 mm (0.0020 to 0.0040 in)
Oil control	0.038 to 0.084 mm (0.0015 to 0.0033 in)
Ring gap in bore:	
Top compression	0.29 to 0.55 mm (0.011 to 0.021 in)
Intermediate compression	1.40 to 1.66 mm (0.055 to 0.065 in)
Oil control	0.24 to 0.50 mm (0.009 to 0.019 in)

Special Torque

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

Special Service Tools

Dial indicator with magnetic base	Obtain locally
Feeler gauge	Obtain locally
Piston Gauge Pins (0.082 in)	ZTSE4513
Piston Ring Compressor (cope)	ZTSE4514
Piston ring expansion pliers	Obtain locally
Telescoping gauge set	Obtain locally

Table of Contents

Removal.....333
- **Preliminary Checks**.....333
- **Lower Crankcase**.....337
- **Crankshaft**.....338
- **Piston Cooling Tubes**.....338
- **Camshaft / Primary Balancer**.....339
- **Camshaft Bushings**.....340
- **Coolant Heater**.....340

Cleaning, Inspection and Testing.....341
- **Crankcase**.....341
- **Crankshaft**.....344
- **Piston Cooling Tubes**.....344
- **Camshaft / Primary Balancer**.....345
- **Camshaft Bushings**.....347
- **Coolant Heater**.....347

Installation.....348
- **Camshaft Bushings**.....348
- **Piston Cooling Tubes**.....349
- **Camshaft / Primary Balancer**.....349
- **Crankshaft and Timing**.....351
- **Lower Crankcase**.....353
- **Crankcase Sensors and Coolant Heater**.....358

Specifications.....359

Special Torque.....361

Special Service Tools.....361

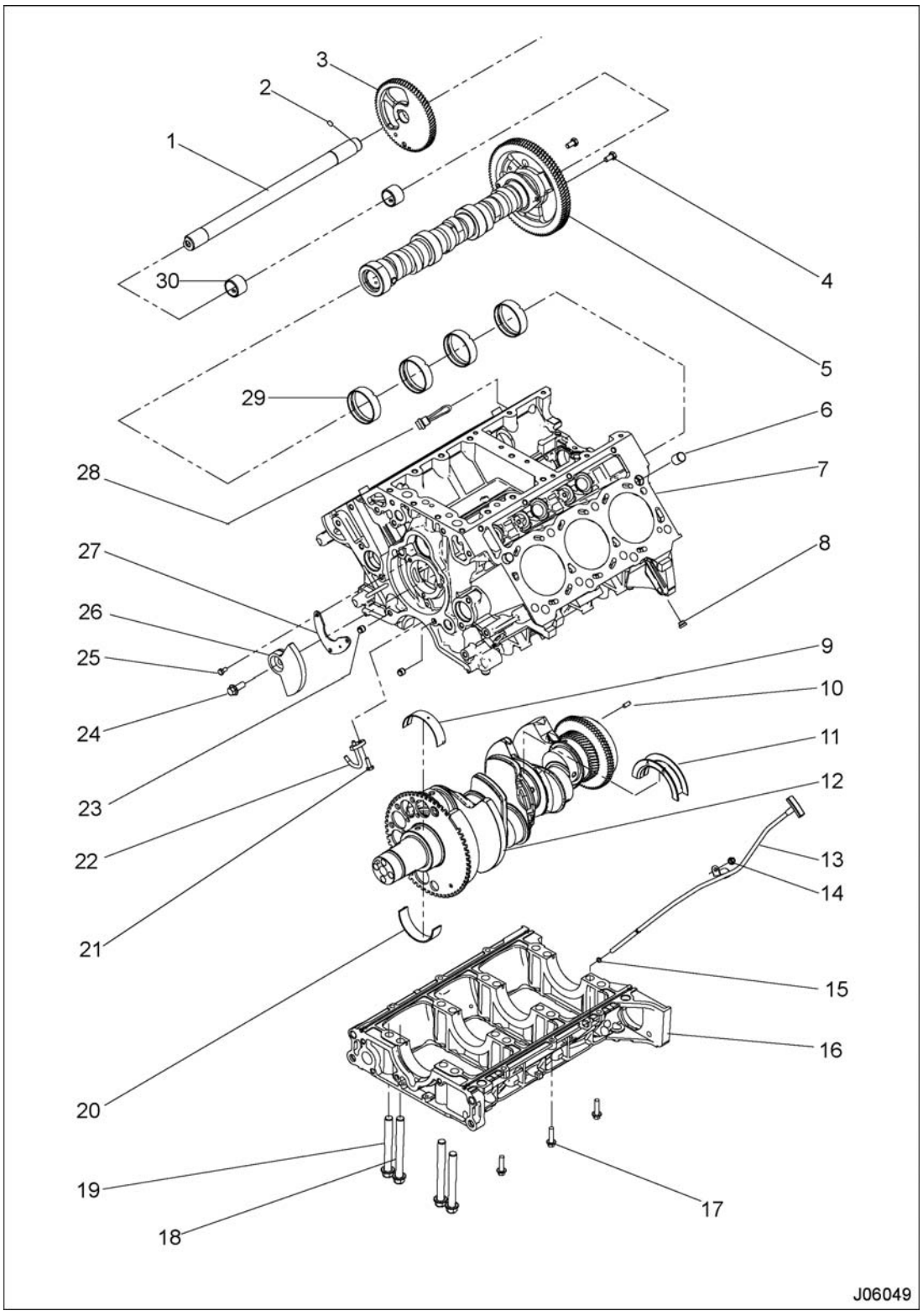

Figure 471 Crankcase, crankshaft, and camshaft

1. Primary balancer shaft
2. Dowel pin
3. Primary balancer gear
4. Bolt, M8 x 16 (2)
5. Camshaft assembly
6. Spring dowel pin (4)
7. Crankcase assembly
8. Plug, M16 (2)
9. Crankshaft upper main bearing (3)
10. Dowel pin
11. Crankshaft upper main thrust bearing (1)
12. Crankshaft assembly
13. Oil level gauge tube assembly
14. Nut, M8
15. Dipstick tube seal
16. Lower crankcase assembly
17. Bolt, M8 x 30 (6)
18. Main bearing bolt, M14 x 127 (8)
19. Main bearing bolt, M14 x 114 (8)
20. Crankshaft lower main bearings (4)
21. Bolt, M8 x 18 (6)
22. Piston cooling tube (6)
23. Dowel pin (2)
24. Bolt, M10 x 25
25. Bolt, M6 x 12 (3)
26. Primary balancer counterweight
27. Primary thrust plate
28. Coolant heater, right side rear (optional)
29. Camshaft bushing (4)
30. Primary balancer bushing (2)

Removal

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

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

WARNING: To prevent personal injury or death, allow engine to cool before working with components.

WARNING: To prevent personal injury or death, disconnect ground (-) cable from battery before doing service or diagnostic procedures.

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

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 and filters according to applicable regulations. Never put engine fluids in the trash, on the ground, in sewers or bodies of water.

CAUTION: To prevent engine damage, do not remove the rear primary crankshaft flange bolts. If the flange is removed and reinstalled, it will result in engine vibration and premature transmission wear.

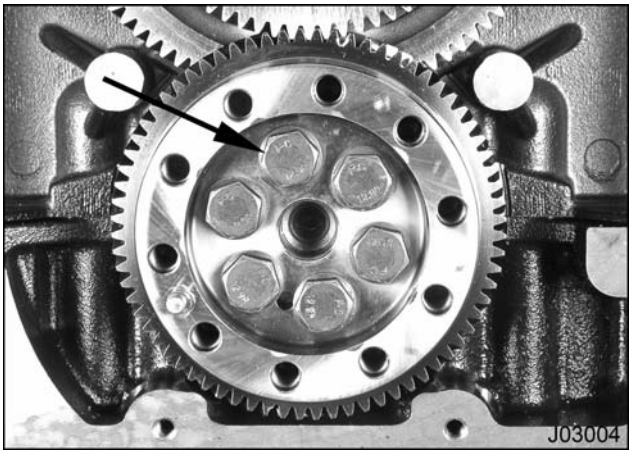

Figure 472 Rear primary crankshaft flange bolts (do not remove)

Preliminary Checks

Measure the following:

- Crankshaft gear to camshaft gear
- Primary balancer gear to crankshaft gear
- Crankshaft end play
- Camshaft end play
- Primary balancer shaft end play

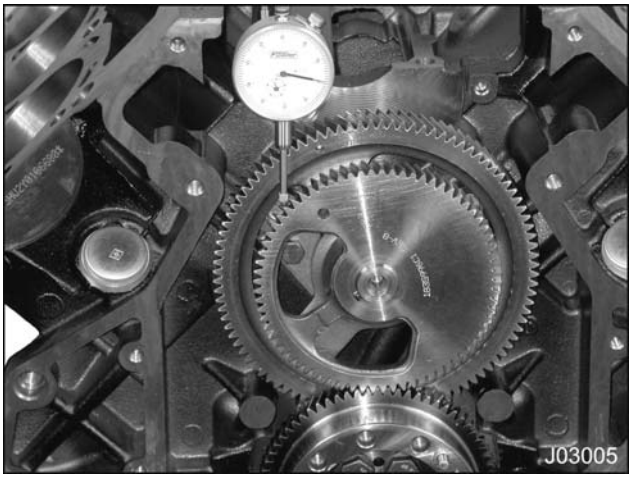

Figure 473 Primary balancer gear-to-crankshaft gear backlash

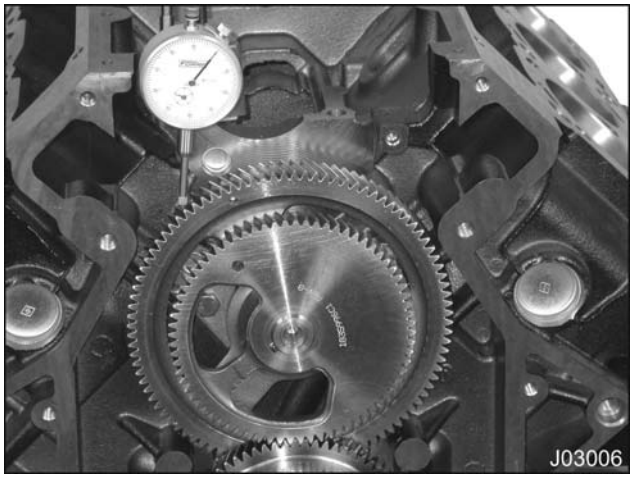

Figure 474 Camshaft-to-crankshaft gear backlash

1. Check and record primary balancer gear-to-crankshaft gear backlash as follows:

   NOTE: Crankshaft gear must be fixed, not allowed to rotate. Only the primary balance gear should be allowed to rotate, otherwise the reading will not be valid.

   a. Mount dial indicator with magnetic base (page 361) onto rear of engine.

   b. Position dial indicator tip onto a primary balancer gear tooth and remove lash.

   c. Zero dial indicator.

   d. Rotate gear by hand and read indicator. Record backlash.

   e. If backlash exceeds Specifications (page 359), replace primary balance gear.

2. Check and record camshaft gear-to-crankshaft gear backlash as follows:

   NOTE: Crankshaft gear must be fixed, not allowed to rotate. Only the camshaft gear should be allowed to rotate, otherwise the reading will not be valid.

   a. Mount dial indicator with magnetic base (page 361) onto rear of engine.

   b. Position dial indicator tip onto a cam gear tooth and remove lash.

   c. Zero dial indicator.

   d. Rotate gear by hand and read indicator. Record backlash.

   e. If backlash exceeds Specifications (page 359), replace camshaft gear.

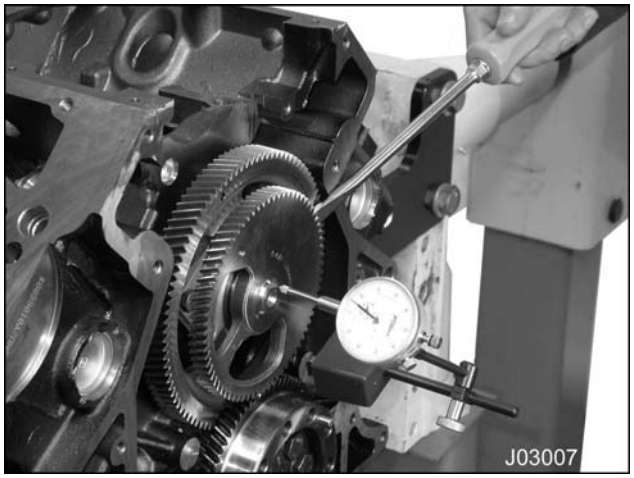

Figure 475 Primary balance shaft end play

3. Check and record primary balance shaft end play as follows:
   a. Reposition dial indicator tip to balance shaft, not gear.
   b. Push camshaft towards the front of the engine.
   c. Zero dial indicator.
   d. Place a small pry bar between the primary balance gear and crankcase. Lightly pry primary balance gear toward indicator. Compare dial indicator reading with Specifications (page 359).

Figure 476 Balance shaft counterweight bolt

4. Remove the balance shaft counterweight bolt (M10 x 25).

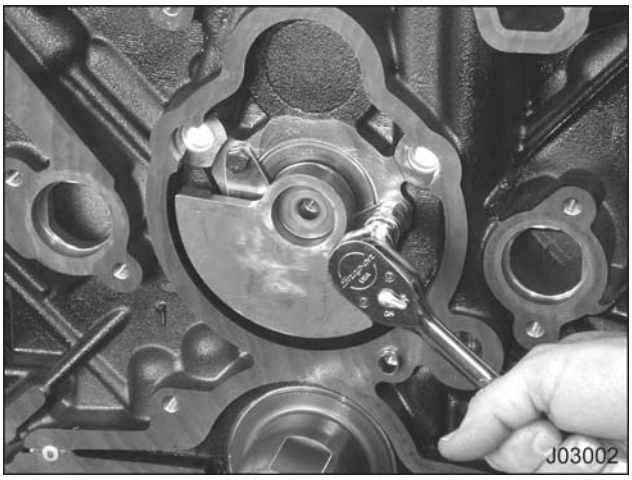

Figure 477 Balance shaft thrust plate bolts

5. Remove three balance shaft thrust plate bolts (M6 x 12).

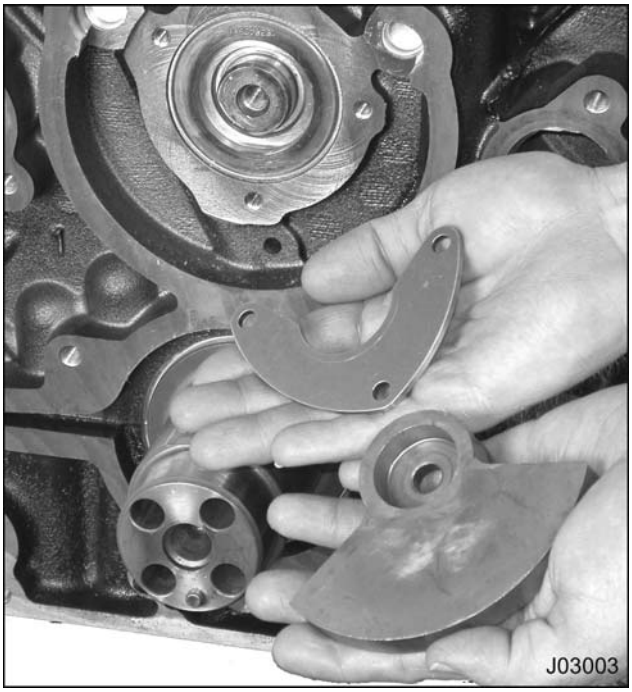

Figure 478 Balance shaft counterweight and thrust plate

6. Remove balance shaft counterweight and thrust plate.

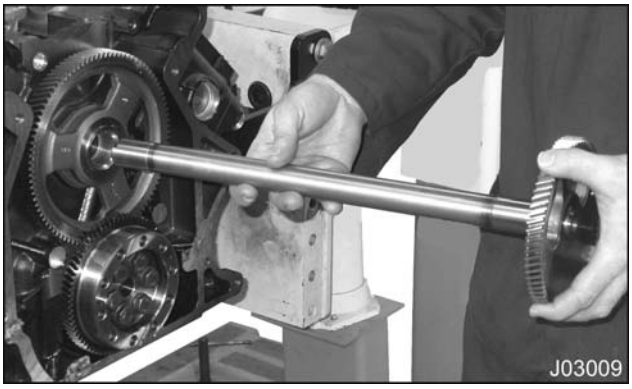

Figure 479 Balance shaft removal

7. Carefully remove balance shaft from the inside of the camshaft.

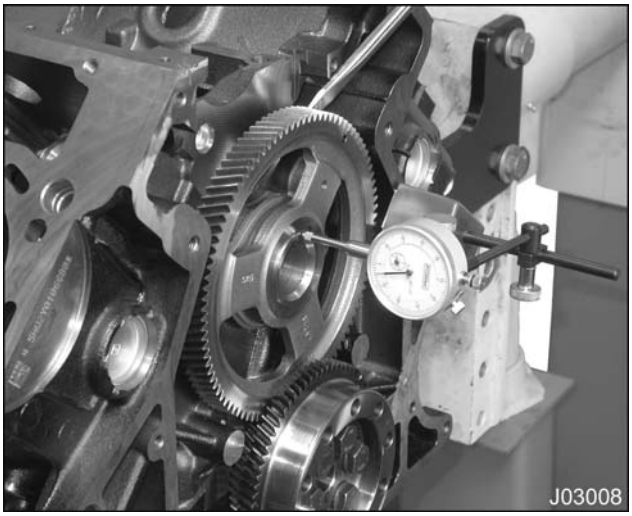

Figure 480 Camshaft end play

NOTE: Check camshaft end play only after the balance shaft has been removed.

8. Check and record camshaft end play as follows:
   a. Reposition dial indicator tip onto camshaft, not gear.
   b. Push camshaft towards the front of the engine.
   c. Zero dial indicator.
   d. Place a small pry bar or screwdriver between the camshaft gear and crankcase. Lightly pry camshaft gear towards indicator. Compare dial indicator measurement with Specifications (page 359).

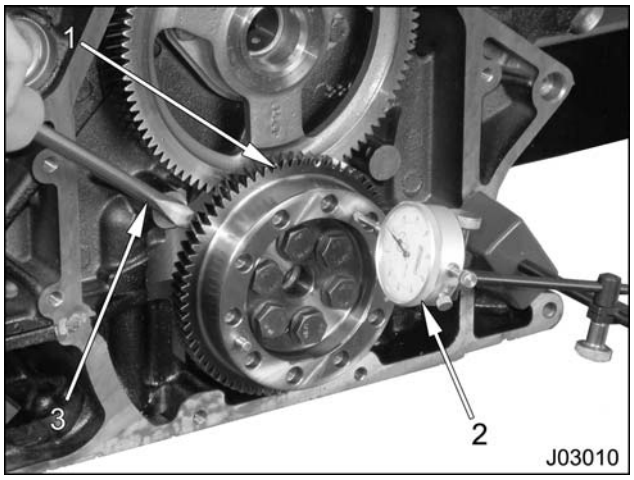

Figure 481 Crankshaft end play

1. Crankshaft gear
2. Dial indicator
3. Pry bar or screwdriver

9. Check crankshaft end play as follows:
   a. Mount dial indicator on crankcase with indicator tip on the end of crankshaft flange as shown.
   b. Pry crankshaft forward with pry bar and zero dial indicator.
   c. Pry crankshaft back and forth while reading dial indicator. Record end play measurement.

Lower Crankcase

1. Remove oil gauge tube assembly if not done so already. Remove dipstick tube seal and discard.
2. Remove retaining bolt (M6 x 14) from CKP sensor installed in the front lower right of the crankcase.

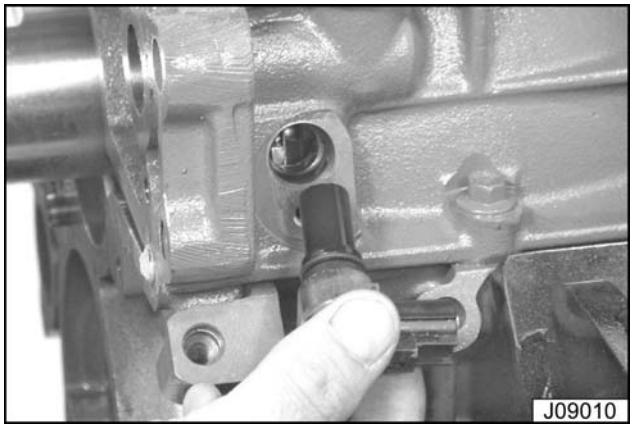

Figure 482 Crankcase Position (CKP) sensor

3. Remove CKP sensor from lower crankcase. Discard O-ring seal.

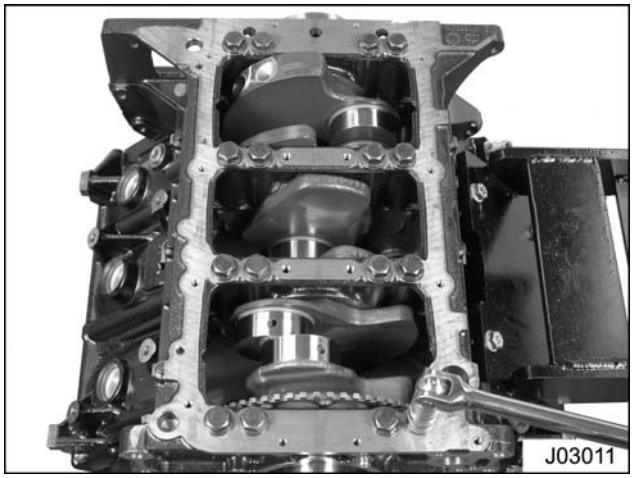

Figure 483 Lower crankcase main bolts

4. Remove all lower crankcase main bearing bolts (inboard and outboard).

NOTE: There are three different bolt sizes supporting the lower crankcase:

- Eight lower crankcase main bearing bolts (M14 x 127 - inboard)
- Eight lower crankcase main bearing bolts (M14 x 114 - outboard)
- Six lower crankcase outer bolts (M8 x 30)

5. Remove six lower crankcase bolts (M8 x 30).

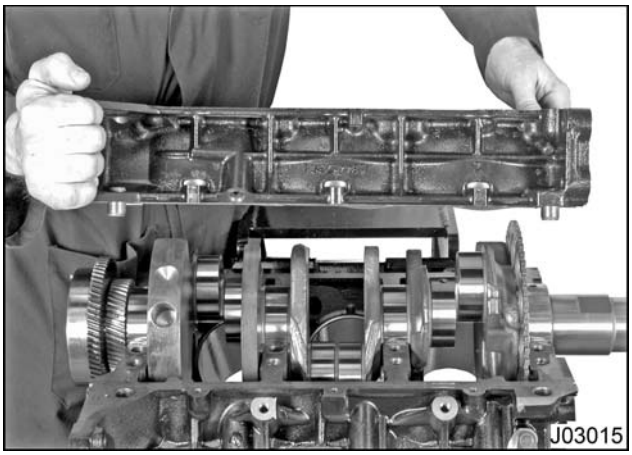

Figure 484 Lower crankcase removal

6. Carefully lift lower crankcase away from crankshaft. Discard seal.

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

7. Remove main bearing shells from lower crankcase by pushing them out of bearing saddles. Mark each lower bearing shell with numbers 1 to 4, beginning from the front.

Crankshaft

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

1. Install a bolt into each end of the crankshaft.

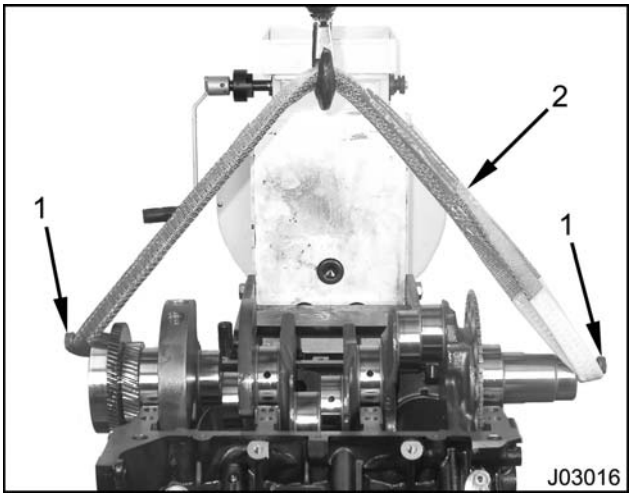

Figure 485 Crankshaft removal from crankcase

1. Bolts threaded into crankshaft
2. Lifting sling

2. Attach lifting sling to crankshaft over bolts installed in crankshaft. Lift crankshaft straight up and out of crankcase.

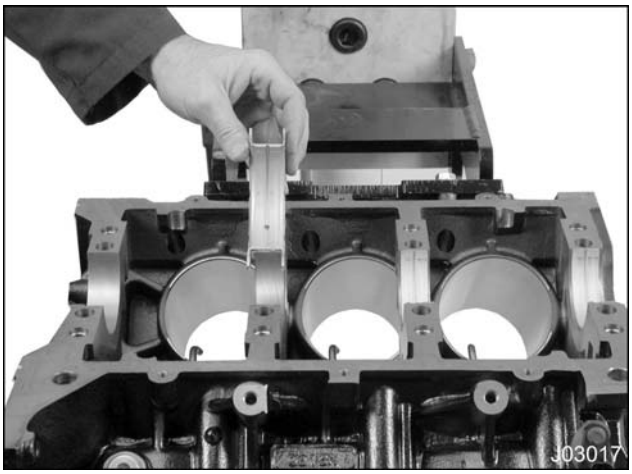

Figure 486 Upper main bearings (thrust bearing shown)

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

3. Remove bearings from upper main bearing saddles by pushing them out. Mark upper bearings and put them with their respective lower bearings for proper inspection.

Piston Cooling Tubes

CAUTION: To prevent engine damage, the piston cooling tubes use a special patch mounting bolt. Do not substitute.

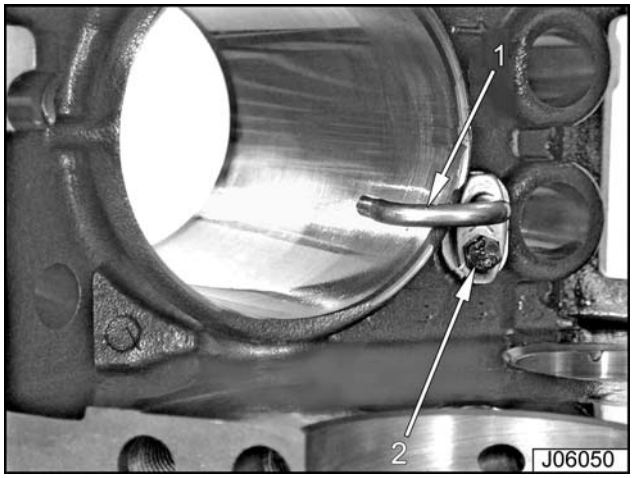

Figure 487 Piston cooling tube

1. Piston cooling tube
2. Piston cooling tube mounting bolt

Remove each piston cooling tube by removing its special patch mounting bolt (M6 x 18). The bolts are reusable, add Loctite® #242 to bolt threads before installation.

Camshaft / Primary Balancer

1. Remove the Camshaft Position (CMP) sensor retaining bolt (M6 x 14) located at front of engine, lower left.

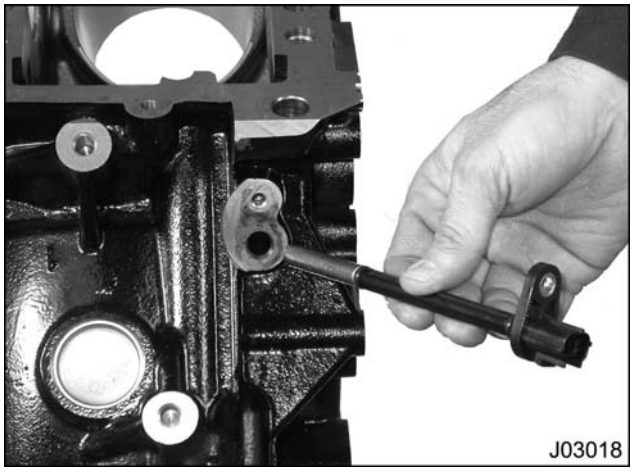

Figure 488 CMP sensor

2. Remove the CMP sensor and discard both sensor O-rings.

Figure 489 Camshaft thrust plate mounting bolts

1. Camshaft thrust plate mounting bolt (2)

3. Remove two camshaft thrust plate mounting bolts (M8 x 16).

NOTE: If the engine is mounted on a revolving stand, rotate engine so rear of engine is facing up (in vertical position). This position allows for easy removal of camshaft assembly.

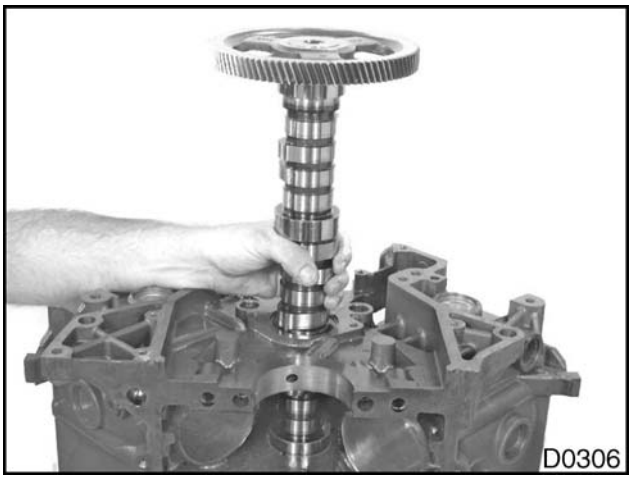

Figure 490 Camshaft assembly

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

NOTE: The camshaft gear is assembled to the camshaft with a shrink fit and can be removed with a hydraulic press if required.

Camshaft Bushings

1. Determine necessity of replacing bushings based on running clearance (Camshaft Bushings, page 347).
2. If bushings require replacement, use existing Camshaft Bushing Kit in conjunction with Camshaft Bushing Remover / Installer (expanding collet) to remove all camshaft bushings. Install Camshaft Bushing Remover / Installer (expanding collet in collapsed state) into camshaft bushing. See Special Service Tools (page 361).

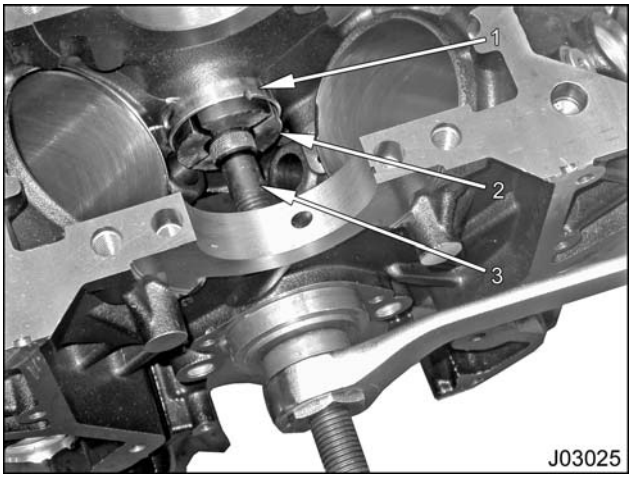

Figure 491 Camshaft bushing removal

1. Camshaft bushing
2. Camshaft Bushing Remover/Installer (expanding collet)
3. Pulling screw (from camshaft bushing kit)

3. Assemble pulling screw in Camshaft Bushing Remover/Installer (expanding collet) and tighten backup nut until collet fits snug 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 thread nut on pulling screw until camshaft bushing is free from crankcase.

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

Coolant Heater

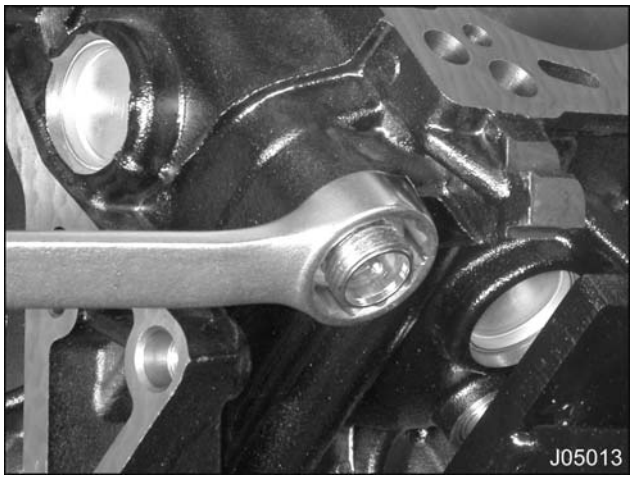

Figure 492 Coolant heater removal

Remove coolant heater from right rear side of engine block and discard O-ring seal.

Cleaning, Inspection and Testing

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

Crankcase

NOTE: The best way to clean the crankcase during an engine overhaul is in a chemical bath or hot tank. This procedure removes all carbonized material and mineral deposits which collect in coolant passages. When a hot tank is not available, use the following procedure:

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

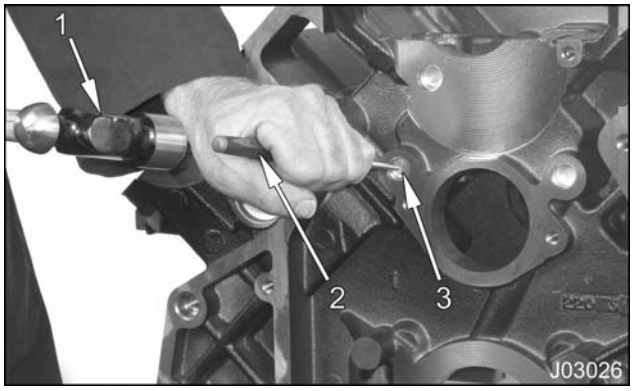

Figure 493 Oil gallery cup plug removal

1. Hammer
2. Punch
3. Oil gallery cup plug (5)

1. To remove main oil gallery cup plug (16 mm) located in rear of crankcase, use a punch and hammer near the edge of the plug and strike with hammer. Remove plug from crankcase and discard.

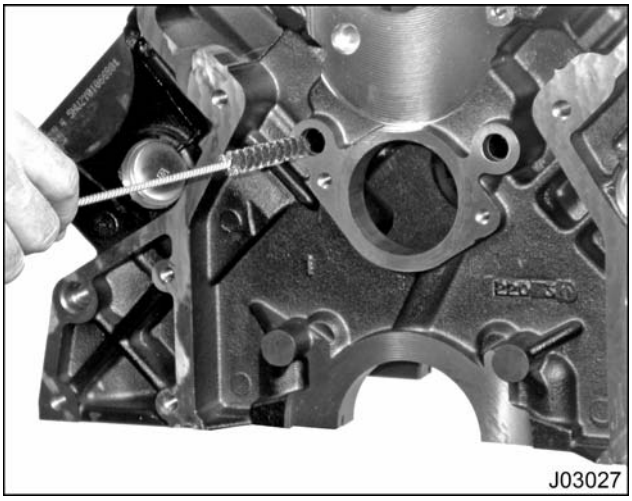

Figure 494 Cleaning the main oil gallery

2. Clean main galleries with an Oil Gallery Cleaning Brush (page 361).
3. Spray or wipe main oil gallery cup plug bores with an appropriate cleaning solvent. The bores must be free of any oily residue for the sealant to adhere and be effective.
4. Coat edges of new oil gallery cup plugs and crankcase joints with Loctite® #620 (page 361) prior to installing cup plugs.
5. Use an Oil Gallery Plug Driver to install new oil gallery cup plugs. It should be flush with the crankcase surface to approximately 1.50 mm (0.060 in) below surface. See Special Service Tools (page 361).
6. Use non-metallic stiff bristle brushes and scrapers to clean gasket material from machined surfaces of crankcase.
7. Clean cylinder bore with soap, water, and a nylon stiff bristle brush.
8. Clean lower crankcase in solvent. Dry with filtered compressed air.

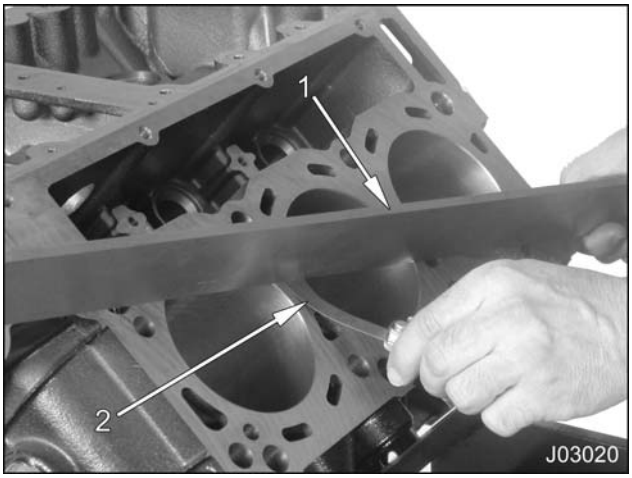

Figure 495 Deck flatness measurement

1. Straightedge
2. Feeler gauge

9. Use a Straightedge (page 361) to check the crankcase top surface for flatness. Insert a Feeler gauge between the Straightedge and crankcase head surface.
   a. Measure the total deck surface, if any gap exceeds Specifications (page 359), the crankcase must be replaced.
   b. Divide the deck surface into areas of approximately 150 mm^2. Measure each area and if any gap exceeds specifications, the crankcase must be replaced. See Specifications (page 359).
   c. Divide the deck surface into areas of approximately 25 mm^2. Measure each area and if any gap exceeds specifications, the crankcase must be replaced. See Specifications (page 359).

CAUTION: Do not resurface the crankcase. Surface defects beyond those listed above cannot be corrected.

CAUTION: To prevent engine damage, threads in the crankcase bolt holes must be clean and blown dry with filtered compressed air. Dirt or oil left in holes may cause binding and a false torque reading during assembly.

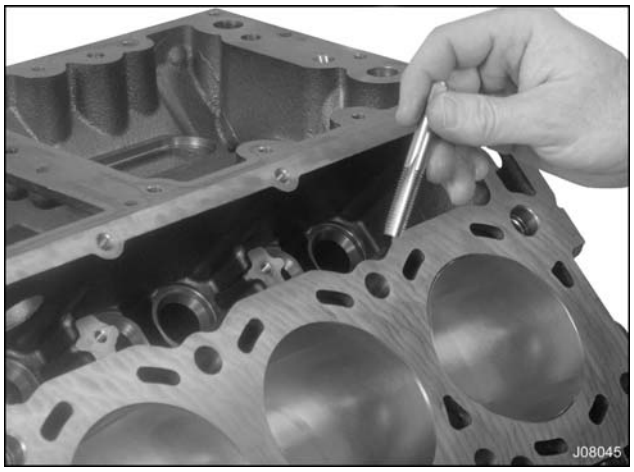

Figure 496 Crankcase head bolt holes

10. Clean all cylinder head bolt holes with Head Bolt Bottoming Tap (page 361). Blow out holes with filtered compressed air.
11. After cleaning, inspect crankcase for cracks, scoring, roughness or wear at cylinder bores.
12. If cylinder walls have minor surface damage, but are otherwise within out-of-round specifications, it may be possible to remove such damage by honing.

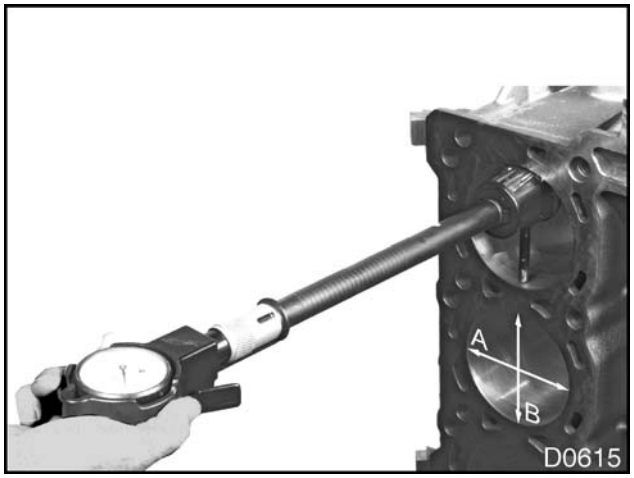

Figure 497 Cylinder bore out-of-round measurement

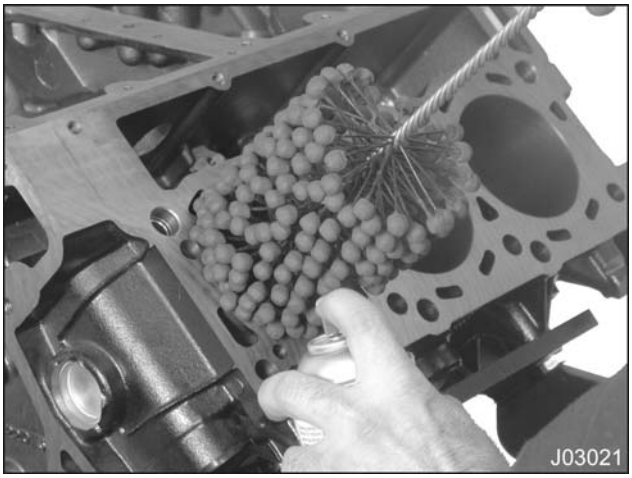

Figure 498 De-glazing hone

13. Use a Cylinder Bore Gauge (page 361) to check cylinder bore for out-of-round.
    a. Measure diameter of cylinder bore at top of piston ring travel. Be sure to measure at a right angle to the center line of crankshaft (dimension A). Record reading.
    b. Measure each bore so gauge reading coincides with center line of crankshaft (dimension B). Record reading.
    c. The difference between dimension A and dimension B is the out-of-round condition at the top of the cylinder bore.
14. Repeat the same procedure at the bottom of ring travel to check for out-of-round condition.

CAUTION: To prevent engine damage, if cylinder bores are deeply scored, out-of-round or exceed specifications, all cylinders must be bored oversize.

15. If cylinder bore is within specifications, standard size pistons and rings may be used. If cylinder bore is suitable for use without reconditioning, de-glaze the cylinder bore before assembling. See Specifications (page 359).

NOTE: If cylinder bores are to be de-glazed, all piston cooling tubes must be removed.

16. Spray both the cylinder to be de-glazed and the de-glazing hone with penetrating fluid or equivalent. This spray contains colloidal graphite and works well for this application.
17. De-glaze cylinder as follows:
    a. Attach a De-glazing hone (page 361) to a variable speed electric or air powered drill.

       NOTE: A speed of approximately 100 to 120 rpm is required. Speed adjustment is required for the procedure to be successful.
    b. De-glaze cylinder wall for about 15 seconds. Stroke bore up and down at a rate of one complete up and down stroke per second.
    c. Withdraw de-glazing hone from cylinder bore while brush is rotating. Wipe portion of cylinder wall and inspect cross hatch pattern.

       NOTE: The cross hatch pattern left by the abrasive tool should be approximately 45°.
    d. If pattern is “flatter” than required, increase up and down stroke speed or slow down drill rotation as required.
    e. Continue de-glazing cylinder bore for 10 to 15 seconds or 20 to 25 strokes.
    f. Wipe cylinder bore clean and inspect bore for proper 45° cross hatch pattern.
18. After de-glazing, thoroughly clean cylinder bores with soft bristle brush, soap and water. Dry with filtered compressed air. Lubricate bore with clean engine oil.

Crankshaft

1. Clean and inspect the crankshaft and main bearings as follows:
   a. Clean crankshaft with a suitable solvent and dry with compressed air.
   b. Use a stiff nylon brush to clean all internal oil passages of crankshaft. Loosen all accumulated dirt, sludge, and deposits. Flush oil passages with a suitable solvent.
   c. Inspect crankshaft journals (main and connecting rod) for scratches, grooves, and scoring.
2. Inspect crankshaft bearings (main and connecting rod) for scratches, grooves, scoring, pitting, and inconsistent coloring.

Figure 499 Crankshafts main journal measurement

NOTE: If crankshaft journals exceed maximum out-of-round or other specifications the crankshaft must be reground or replaced.

3. Measure diameter of each crankshaft main journal at two points 90 degrees from each other using a 3-4 inch micrometer (page 361). Move the micrometer over the entire width of the journal at each measurement point. Measure and record readings for each of the seven main journals.
4. Compare main journal measurements to crankshaft Specifications (page 359).

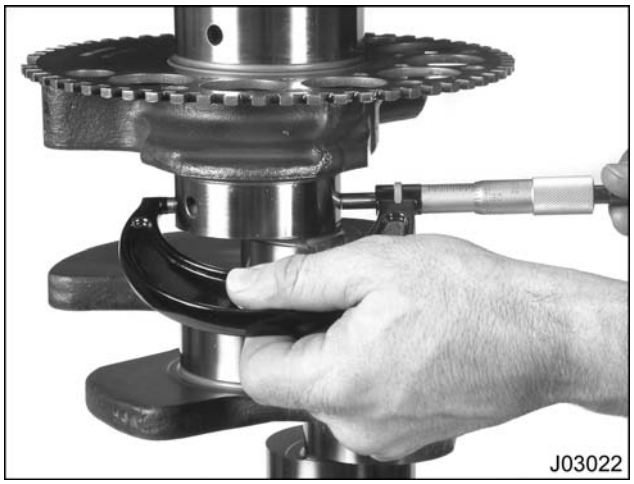

Figure 500 Crankshaft connecting rod journal measurement

5. Measure diameter of each crankshaft connecting rod journal at two points 90 degrees from each other using a 2-3 inch micrometer. Move the micrometer over the entire width of the journal at each measurement point. Measure and record readings for each of the six connecting rod journals.
6. Compare connecting rod journal measurements to crankshaft Specifications (page 359).

Piston Cooling Tubes

1. With the piston cooling tubes removed, run an appropriate size wire through the tube to ensure there is no blockage.
2. Use dry filtered compressed air to blow out any debris that remains from cleaning.
3. Replace any cracked or bent tubes.

Camshaft / Primary Balancer

1. Wash camshaft / primary balancer assembly in cleaning solvent with a soft brush. Dry components with filtered compressed air.
2. Inspect camshaft. If any lobes are scuffed, scored or cracked, replace camshaft.

   NOTE: This engine uses hydraulic valve tappets with roller followers. Roller follower guides are used to maintain proper roller to cam lobe orientation. Normal clearance between the valve tappet and guide allows for slight tracking of the roller across the cam lobe. Typical wear patterns on cam lobes will have tracks from side to side and have wide and narrow areas from the loading and unloading of the follower. The visual wear pattern (tracking) is normal and does not require camshaft replacement.
3. Beyond visual inspection, evaluate camshaft main journal and lobe condition as follows:

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

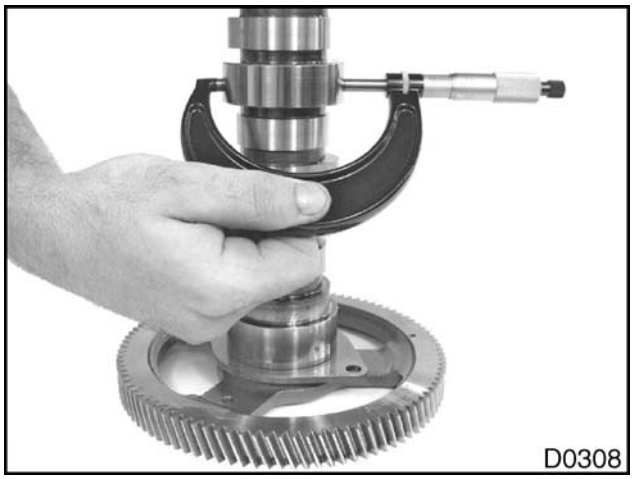

Figure 501 Camshaft main bearing journal measurement

   a. Use a 2-3 inch micrometer (page 361) to measure camshaft main bearing journals and then again at 90°. Record measurements for later use in camshaft bushing inspection. Compare with specifications, and if worn beyond limits replace the camshaft.

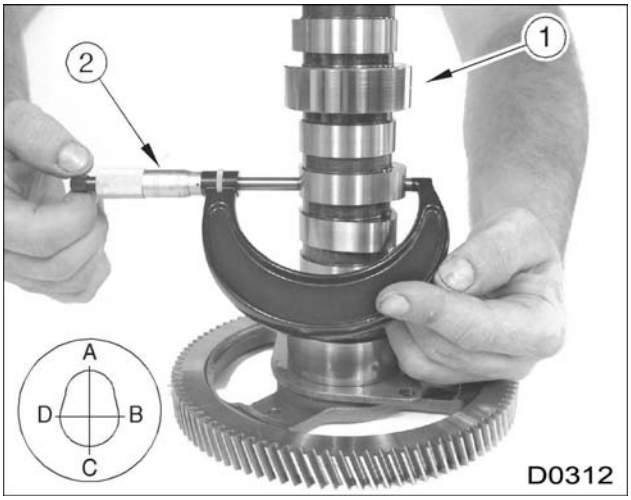

Figure 502 Camshaft intake and exhaust lobe measurement

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. Replace camshaft when cam lobe wear exceeds specifications. See Specifications (page 359).
4. Inspect thrust plate for wear, cracks or distortion. Use a micrometer to measure thrust plate thickness. Replace thrust plate if worn or damaged. See Specifications (page 359).
5. Inspect camshaft drive gear for worn or damaged teeth.

Figure 503 Primary balance shaft bushing inside diameter measurement

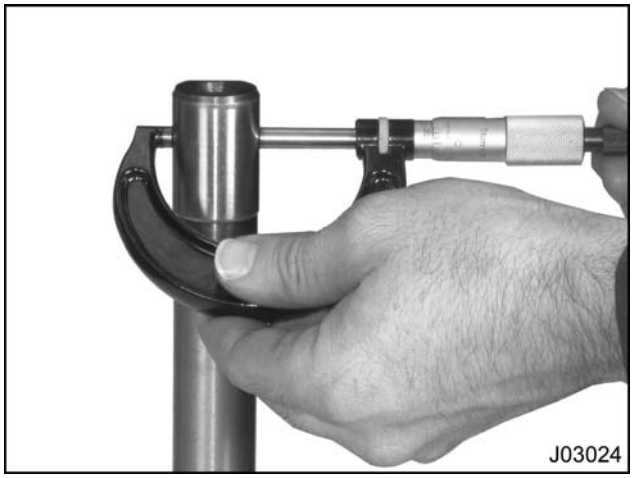

Figure 504 Primary balancer shaft outside diameter measurement

6. Using a telescoping gauge (page 361), measure the primary balance shaft bushing inside diameter in each end of the camshaft.
7. Measure the primary balance shaft outside diameter at each end of shaft (bushing location).
8. Subtract primary balance shaft outside diameter from primary balance shaft bushing inside diameter. This will give the balance shaft bearing clearance. Refer to Specifications (page 359). Replace camshaft as necessary.

Camshaft Bushings

Inspect the four camshaft bushings for wear and proper running clearance as follows:

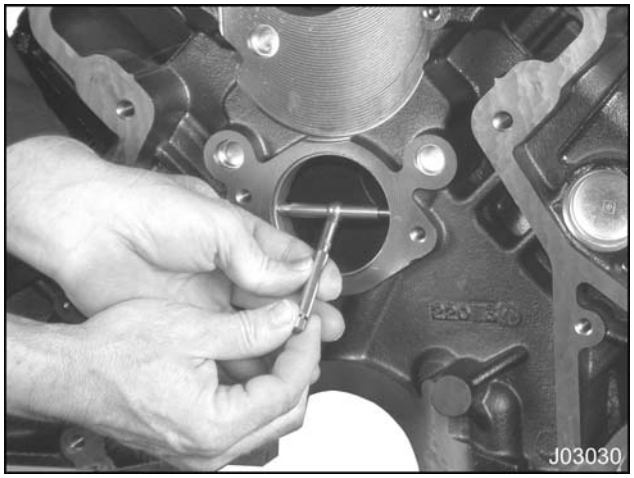

Figure 505 Camshaft bushing measurement

1. Using a telescoping gauge (page 361), measure camshaft bushing inside diameter with bushings installed in crankcase.

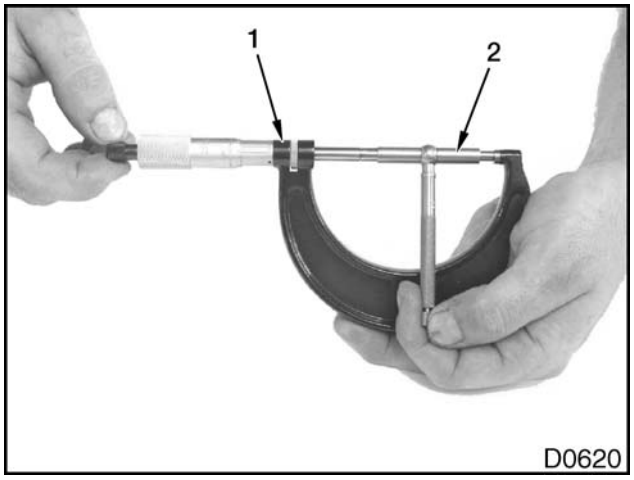

Figure 506 Measurement of telescoping gauge

1. Outside micrometer
2. Telescoping gauge

2. Measure telescoping gauge with a 2-3 inch micrometer and record measurement.
3. To determine running clearance for each bushing and journal, subtract previous camshaft journal diameter reading from camshaft bushing inside diameter reading. See Specifications (page 359).
4. If maximum allowable running clearance is exceeded, replace camshaft bushings. See camshaft bushing removal and installation procedures within this section. Also, see Specifications (page 359).
5. Inspect each bushing bore in crankcase for burrs or debris that could potentially damage new bushings.
6. Remove burrs and clean bores thoroughly before installing new camshaft bushings.

Coolant Heater

1. Using a volt-ohm meter, inspect heater for electrical continuity.
2. Check element sealant around terminals for evidence of cracking.
3. Replace O-ring whenever heater is removed.

Installation

Camshaft Bushings

CAUTION: To prevent engine damage, use the correct Camshaft Bushing Remover / Installer (expanding collet). See Special Service Tools (page 361).

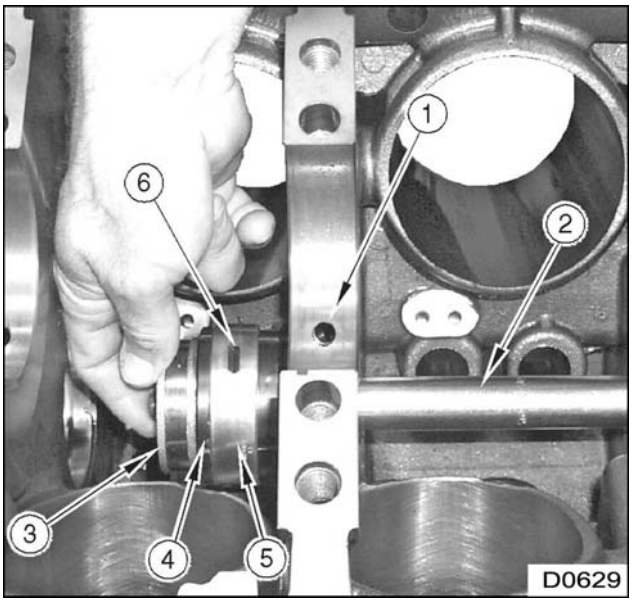

Figure 507 Camshaft bushing installation

1. Oil supply hole
2. Pulling screw
3. Backup nut
4. Camshaft Bushing Remover/Installer (expanding collet)
5. Camshaft bushing
6. Camshaft bushing oil supply slot

CAUTION: To prevent engine damage, and to ensure proper oil circulation through the crankcase, make sure all camshaft bushing oil slots are aligned with corresponding oil supply holes machined in the crankcase.

1. Slide a new bushing onto the Camshaft Bushing Remover / Installer (expanding collet). See Special Service Tools (page 361).
2. Thread pulling screw, backup nut, and Camshaft Bushing Remover / Installer together. Tighten expanding collet by turning backup nut until bushing is held securely on the Camshaft Bushing Remover/Installer.
3. To aid alignment of bushing and crankcase oil holes, use a marker to indicate oil hole location on backup nut of installation tool. Repeat for each camshaft bushing.
4. Install camshaft bushings through rear of crankcase. Pull bushings in place at rear of crankcase by turning pulling nut on pulling screw. Remove Camshaft Bushing Remover/Installer and inspect oil hole alignment.

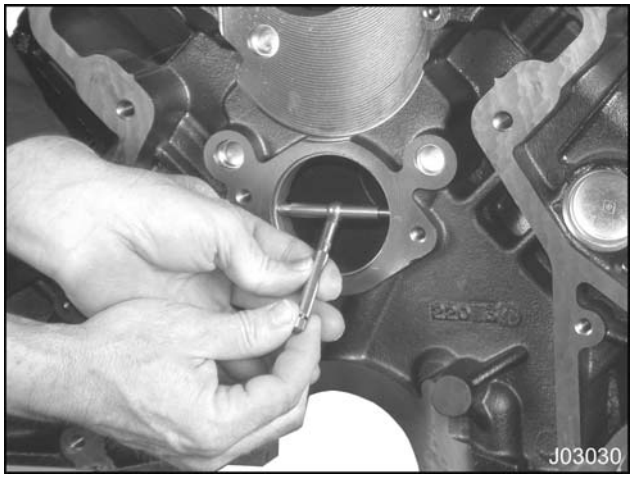

Figure 508 Camshaft bushings measurement

5. Using a telescoping gauge (page 361), measure camshaft bushing inside diameter with bushings installed in crankcase.
6. Measure telescoping gauge with a 2-3 inch micrometer and record measurement.
7. To determine running clearance for each bushing / journal, subtract previous camshaft journal diameter reading from camshaft bushing inside diameter reading. See Specifications (page 359).
8. If maximum allowable running clearance is exceeded, measure cam journal outside diameter and cam bushing inside diameter again and compare with Specifications (page 359). See camshaft bushing removal and installation procedures within this section.
9. Lubricate new camshaft bushings and crankcase bores with clean engine oil.

Piston Cooling Tubes

CAUTION: To prevent engine damage, the piston cooling tubes use a special patch mounting bolt. Do not substitute.

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

1. Place piston cooling tubes on crankcase mounting pad.
2. When installing the piston cooling tube bolts, use either:
   - A new piston cooling tube mounting bolts (patch type)
   - Remove oil residue with a suitable solvent and apply Loctite® #242 to the threads of existing piston cooling tube bolts (patch type). See Special Service Tools (page 361).

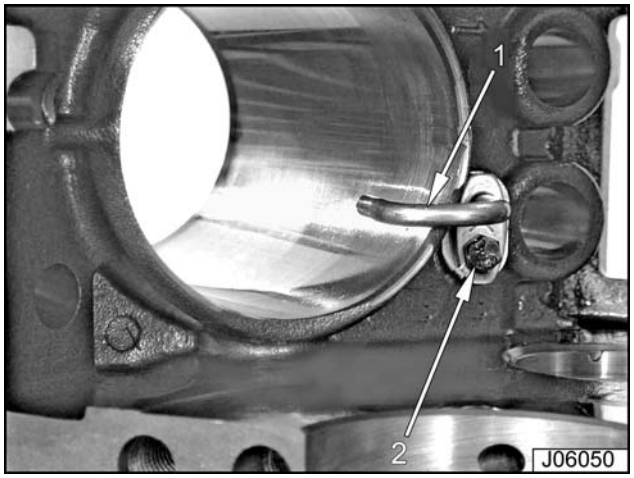

Figure 509 Piston cooling tube

1. Piston cooling tube
2. Piston cooling tube mounting bolt, M6 x 18 (patch type)

3. Install and tighten piston cooling tube bolts (M6 x 18) to the standard torque (page 400).

Camshaft / Primary Balancer

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

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

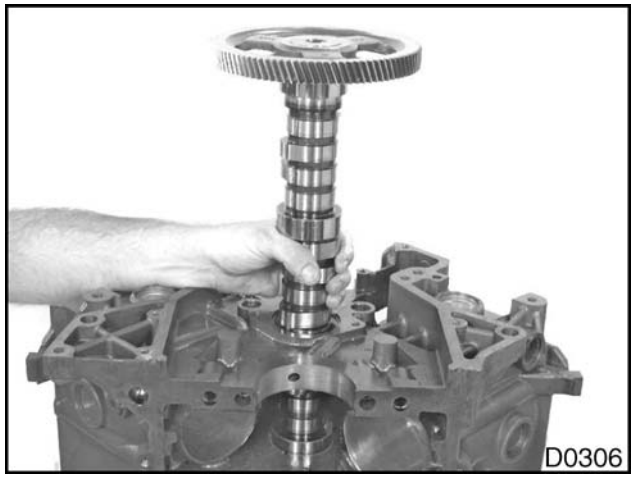

Figure 510 Camshaft assembly installation

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

Figure 511 Camshaft thrust plate mounting bolts

1. Camshaft thrust plate mounting bolts (2)

3. Install two camshaft thrust plate mounting bolts (M8 x 16). Tighten bolts to the standard torque (page 400).

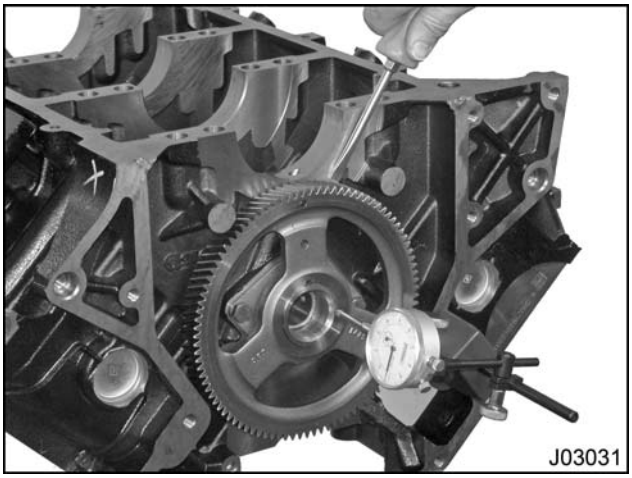

Figure 512 Camshaft end play measurement

4. Verify that camshaft end play is within specifications. See Specifications (page 359).

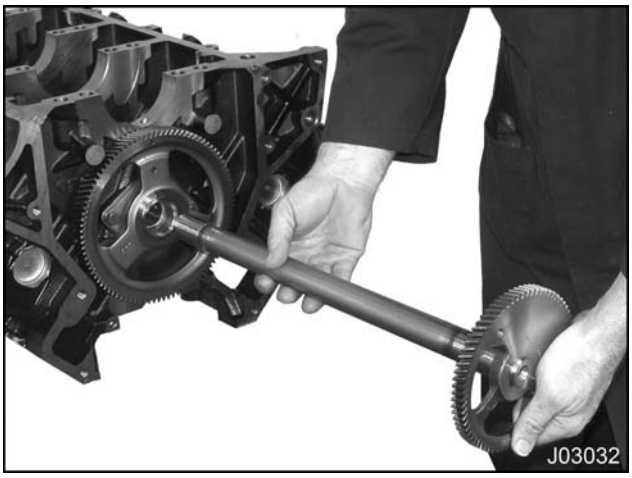

Figure 513 Primary balance shaft installation

5. Coat primary balance shaft with clean engine oil and install inside camshaft.

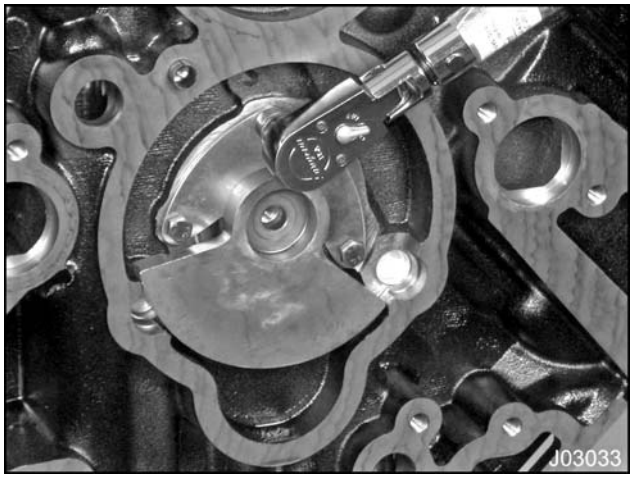

Figure 514 Balance shaft thrust plate bolts

6. Install three balance shaft thrust plate bolts (M6 x 12) and tighten to the standard torque (page 400).

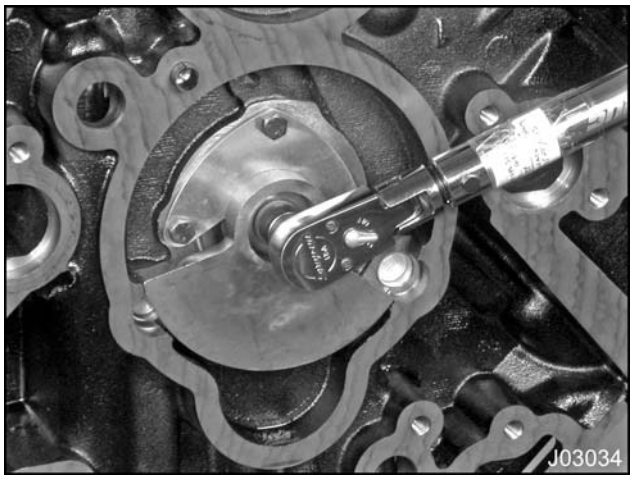

Figure 515 Balance shaft counterweight bolt

7. Install the balance shaft counterweight bolt (M10 x 25) and tighten to the standard torque (page 400).

Crankshaft and Timing

NOTE: Make sure the crankshaft has been inspected per instructions found within this section prior to proceeding.

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

NOTE: When inserting main bearings in the crankcase, be sure that there is no oil between the back side of the bearing and crankcase bearing saddles.

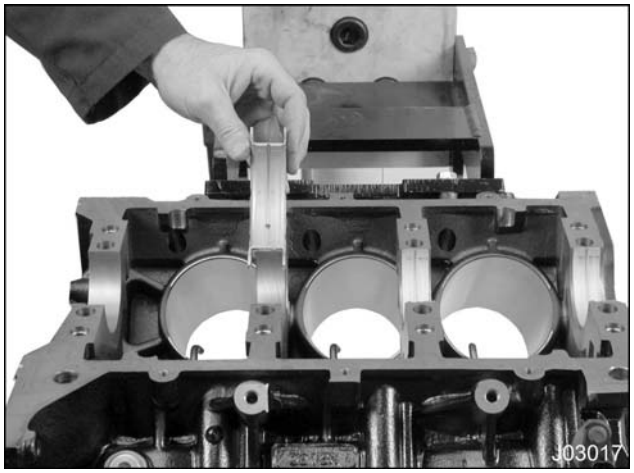

Figure 516 Upper crankshaft main bearings (thrust bearing shown)

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

   NOTE: Crankshaft thrust bearing is installed at the number 3 upper main bearing journal.

4. Lubricate the upper main bearings with clean engine oil.

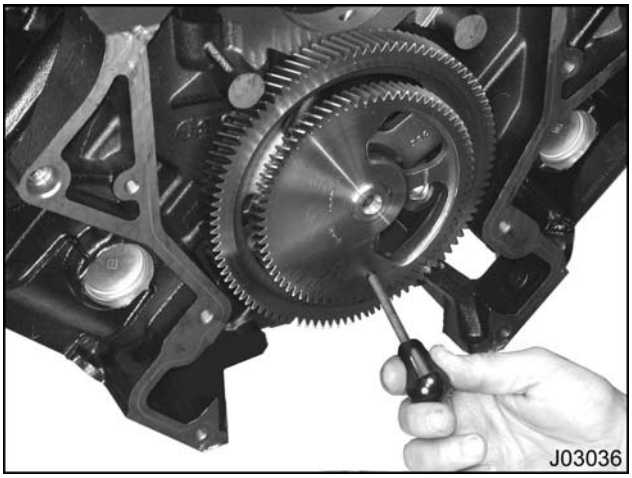

Figure 517 Crankshaft Timing Tool

5. Align index marks on both camshaft gear and primary balancer gear so that they are adjacent to each other. Install Crankshaft Timing Tool through machined holes in both balancer gear and camshaft gear as well as the machined hole in crankcase. See Special Service Tools (page 361).

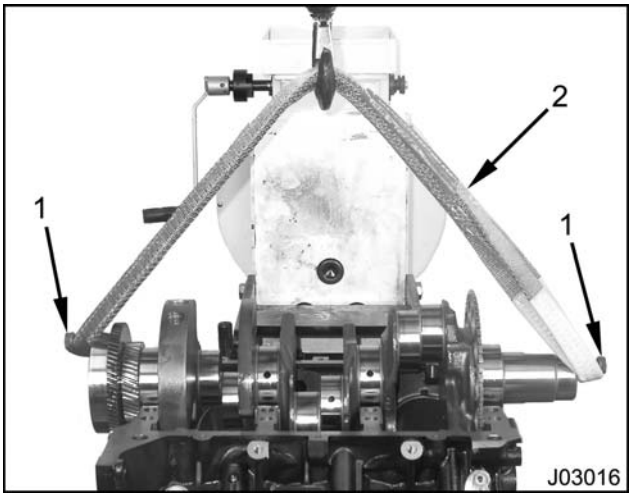

Figure 518 Installing crankshaft into crankcase

1. Bolts threaded into crankshaft
2. Lifting sling

6. Place a bolt in each end of the crankshaft. Attach hoist and lifting sling around crankshaft bolts and carefully lower onto the four main bearings.

WARNING: To prevent personal injury or death, use an appropriately sized lifting sling and hoist equipped with a safety latch on hook.

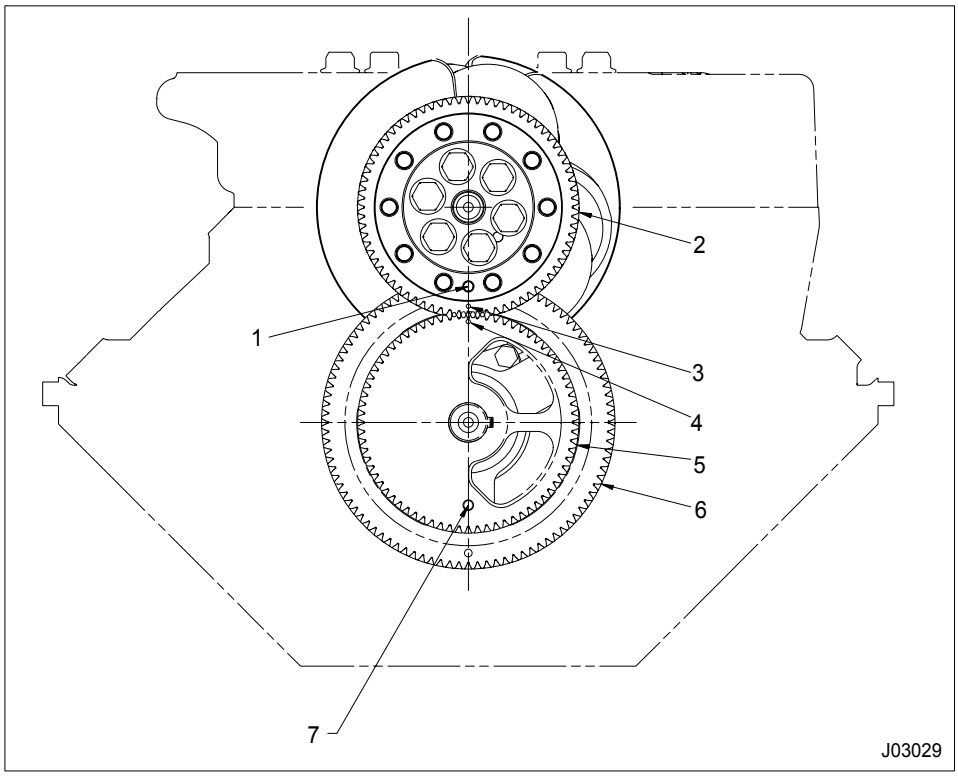

Figure 519 Crankshaft / camshaft / primary balancer timing alignment

1. Flywheel alignment pin
2. Crankshaft gear (1 of 2)
3. Crankshaft gear timing mark
4. Primary balancer gear timing mark
5. Primary balancer gear
6. Camshaft gear
7. Timing tool thru hole

7. Install crankshaft so that index mark aligns with both camshaft and primary balancer index marks.
8. Remove Camshaft Timing Tool.

Lower Crankcase

1. Make sure the lower crankcase sealing recesses are free of any dirt and oil.

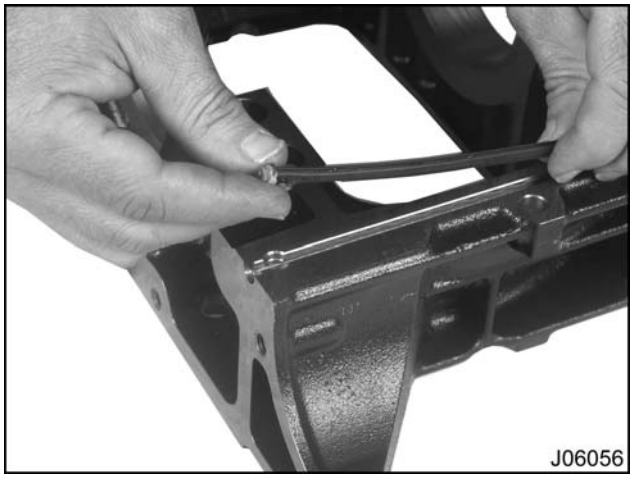

Figure 520 Lower crankcase seal installation

2. Install two new lower crankcase seals.

NOTE: Make certain that the lower crankcase machined bearing surfaces are free of all dirt and oil.

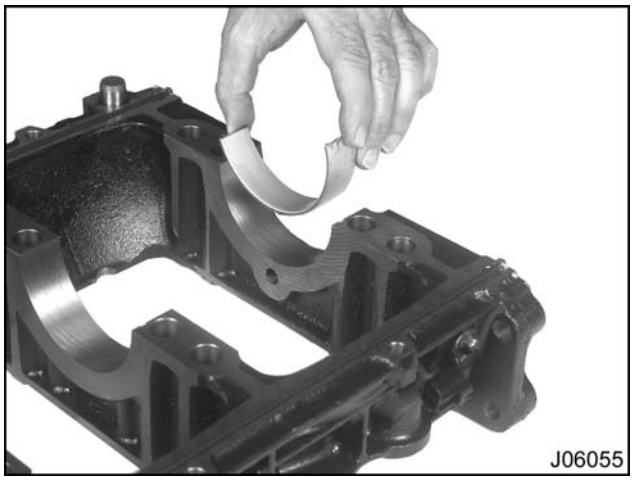

Figure 521 Lower crankcase bearing installation

3. Install bearings into the lower crankcase, making sure bearing alignment tab is fitted into machined notch.
4. Apply clean engine oil to all lower bearing inserts, crankshaft journals and lower crankcase bolts.

CAUTION: To prevent engine damage, make sure the longer main cap bolts (M14 x 127) are installed inboard and the shorter bolts (M14 x 114) are installed outboard.

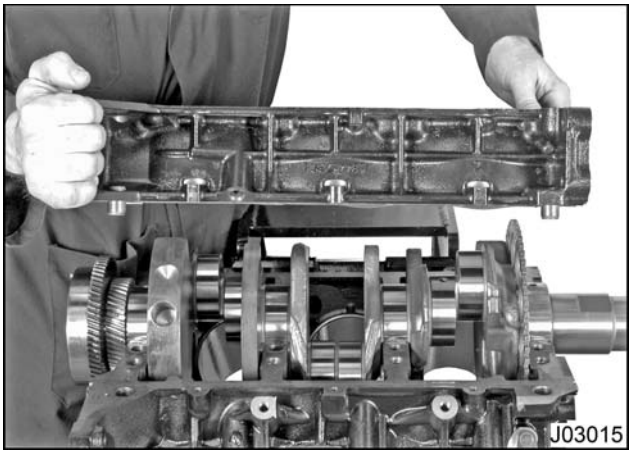

Figure 522 Lower crankcase installation

5. Install the lower crankcase over the crankshaft being careful not to bump crankshaft and knock any bearings out.

Lower Crankcase Torque Sequence

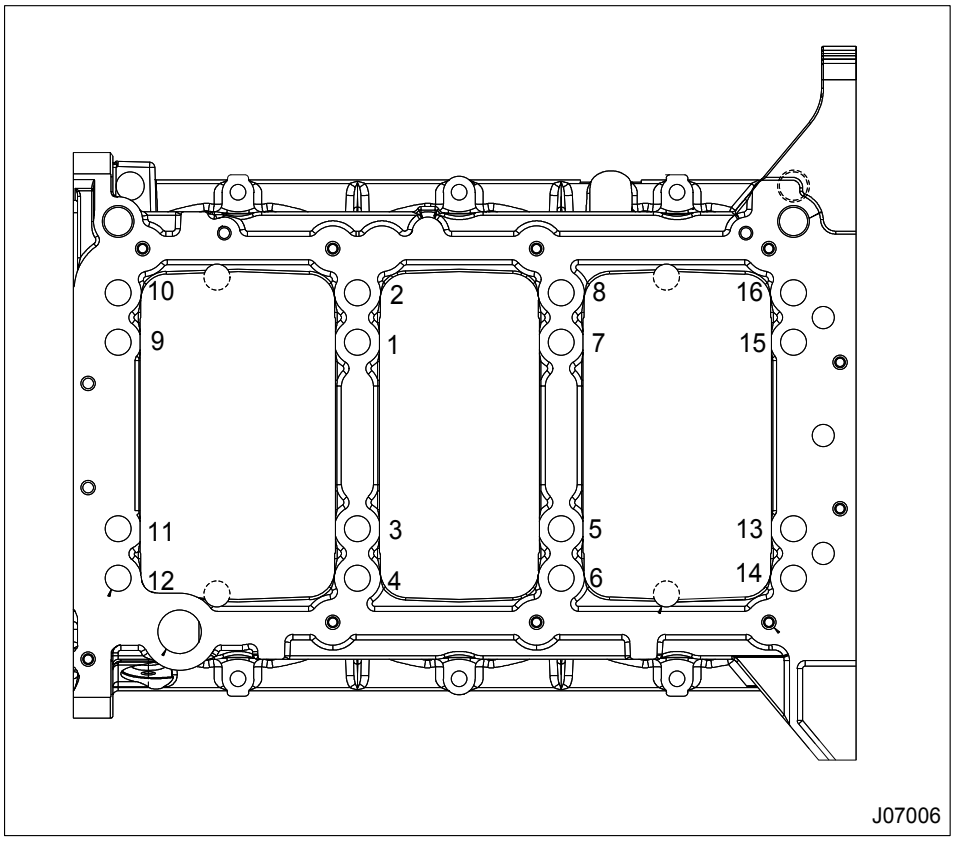

Figure 523 Lower crankcase main bearing bolt torque sequence

6. Install all 16 lower crankcase main bearing mounting bolts. Tighten main cap bolts to the special torque as follows using the sequence shown in the "Lower crankcase main bearing mounting bolt tightening sequence" (Figure 523):
   a. Initially torque bolts to 122 N·m (90 lbf·ft) in the numerical sequence shown in "Lower crankcase main bearing mounting bolt tightening sequence" (Figure 523).
   b. Increase torque for bolts to 163 N·m (120 lbf·ft) in the numerical sequence shown in "Lower crankcase main bearing mounting bolt tightening sequence" (Figure 523).
   c. Increase torque for bolts to a final value of 231 N·m (170 lbf·ft) in the numerical sequence shown in "Lower crankcase main bearing mounting bolt tightening sequence" (Figure 523).

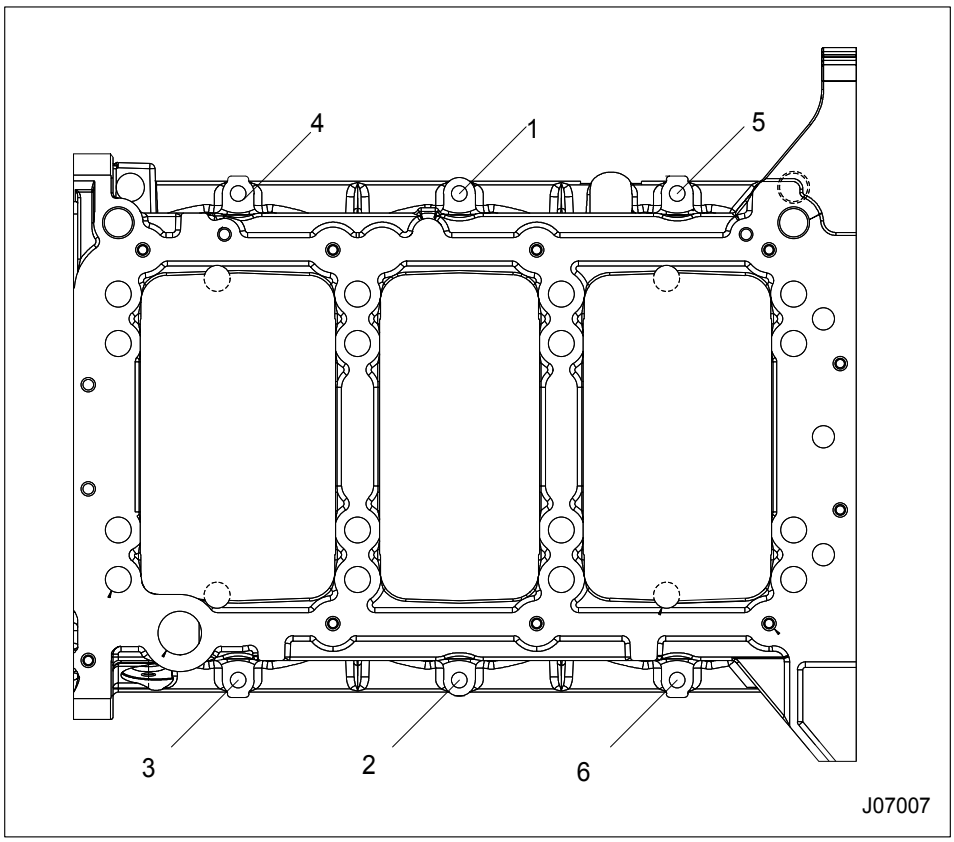

Figure 524 Lower crankcase outer bolt torque sequence

7. Install six bolts (M8 x 30) around outside of lower crankcase. Tighten bolts to the standard torque (page 400) using the sequence shown in "Lower crankcase outer bolt tightening sequence" (Figure 524).

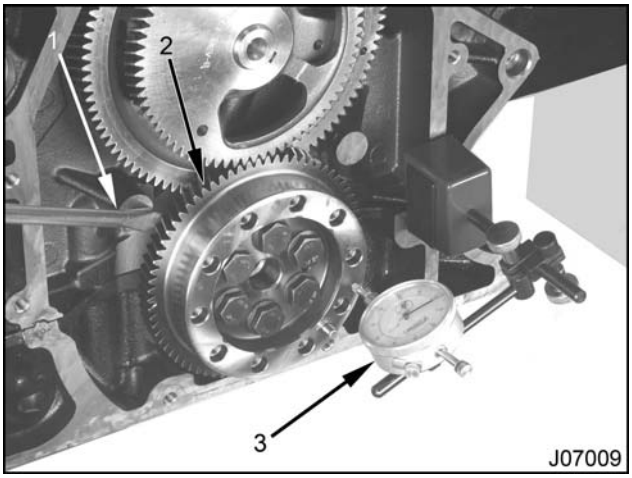

Figure 525 Crankshaft end play measurement

1. Pry bar or screwdriver
2. Crankshaft flange
3. Dial indicator

8. Check crankshaft end play as follows:
   a. Mount dial indicator on crankcase with indicator tip on the end of crankshaft flange as shown.
   b. Pry crankshaft forward with pry bar and zero dial indicator.
   c. Pry crankshaft back and forth while reading dial indicator. Record end play.

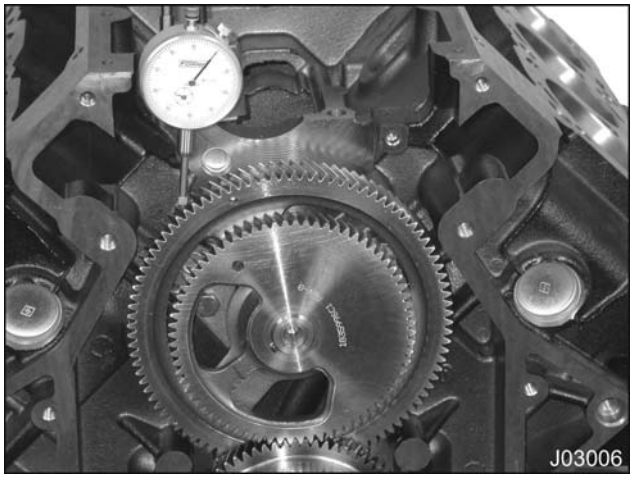

Figure 526 Camshaft-to-crankshaft gear backlash

9. Check and record camshaft gear-to-crankshaft gear backlash as follows:

   NOTE: Crankshaft gear must be fixed, not allowed to rotate, only the camshaft gear should be allowed to rotate, otherwise the reading will be invalid.

   a. Mount Dial Indicator with Magnetic Base onto rear of engine. See Special Service Tools (page 361).
   b. Position dial indicator tip onto a gear tooth and remove any lash.
   c. Zero dial indicator index.
   d. Rotate gear by hand and read indicator. Record backlash.
   e. If backlash exceeds specified limits, replace camshaft gear. See Specifications (page 359).

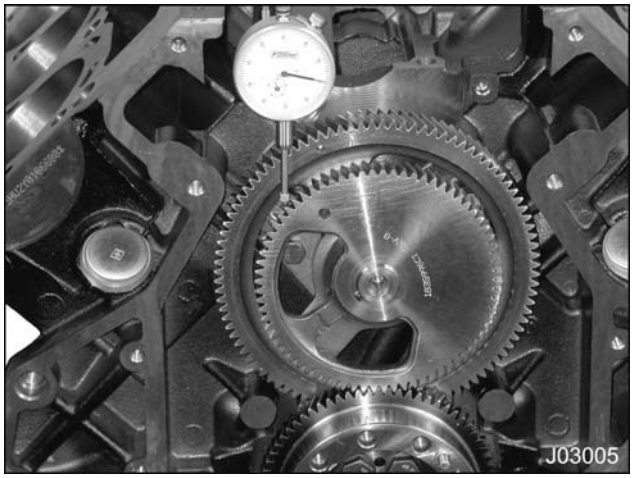

Figure 527 Primary balancer gear-to-crankshaft gear backlash

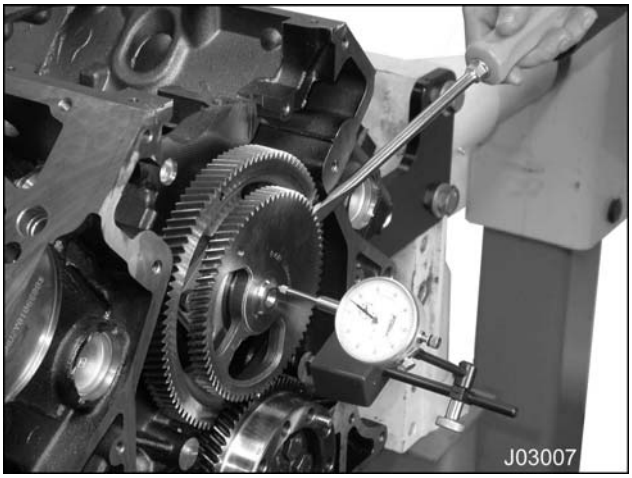

Figure 528 Primary balancer shaft end play

10. Check and record primary balancer gear-to-crankshaft gear backlash as follows:

    NOTE: Crankshaft gear must be fixed, not allowed to rotate, only the primary balancer gear should be allowed to rotate, otherwise the reading will be invalid.

    a. Mount dial indicator with magnetic base (page 361) onto rear of engine.

    b. Position dial indicator tip on primary balancer gear tooth and remove lash.

    c. Zero dial indicator index.

    d. Rotate gear by hand and read indicator. Record backlash.

    e. If backlash exceeds specified limits, replace primary balancer gear. See Specifications (page 359).

11. Check and record the primary balancer shaft end play as follows:

    a. Reposition dial indicator tip to balance shaft, not gear.

    b. Push camshaft to the front of the engine.

    c. Zero dial indicator index.

    d. Place a small pry bar between the primary balance gear and crankcase. Lightly pry primary balancer gear toward indicator. Compare dial indicator reading with specifications. See Specifications (page 359).

12. Slide a new dipstick tube seal onto oil level gauge assembly and install into lower crankcase, making certain that the seal is fully seated within the lower crankcase.

Crankcase Sensors and Coolant Heater

1. Place two new O-rings onto CMP sensor.

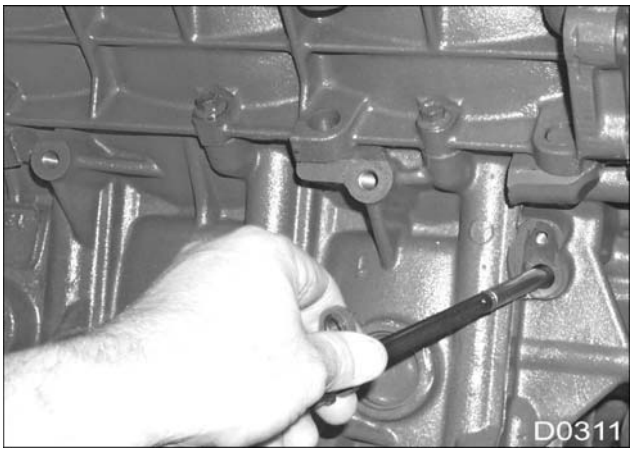

Figure 529 CMP sensor

2. Lubricate sensor O-rings with clean engine oil and install CMP sensor into crankcase.
3. Secure sensor with bolt (M6 x 16) and tighten to the standard torque (page 400).
4. Place a new lubricated O-ring seal onto the crankshaft position sensor.

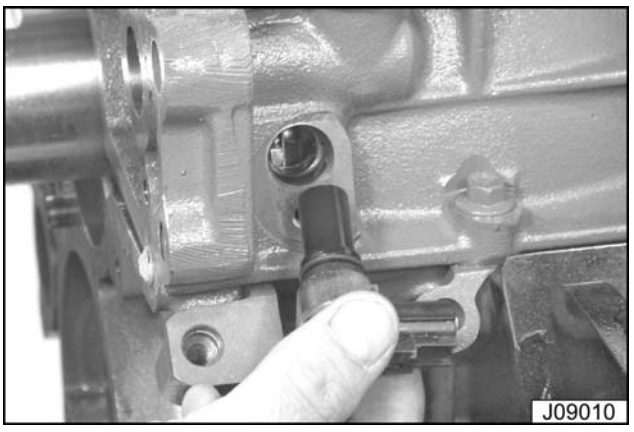

Figure 530 CKP sensor

5. Install CKP sensor into lower crankcase.
6. Install retaining bolt (M6 x 14) to CKP sensor located on the front of the engine, lower right. Tighten bolt to the standard torque (page 400).
7. Lubricate a new O-ring and install onto the coolant heater.

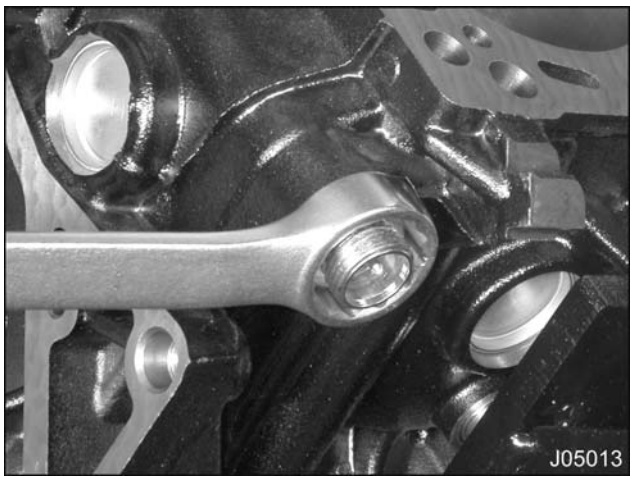

Figure 531 Coolant heater

8. Install coolant heater element into crankcase and tighten to the special torque (page 361).
9. Remove tools, parts and equipment.
   a. Reinstall all safety guards, shields and covers after servicing the engine.
   b. Make sure all tools, loose parts and service equipment are removed from the engine area after all work is done.

Specifications

Crankshaft	
Crankshaft end play (maximum)	0.222 mm (0.0087 in)
Crankshaft gear backlash (maximum)	0.32 mm (0.012 in)
Crankshaft connecting rod journal out-of-round	0.006 mm (0.00024 in)
Crankshaft connecting rod journal taper (maximum per inch)	0.0076 mm (0.0003 in)
Crankshaft main journal out-of-round	0.006 mm (0.00024 in)
Crankshaft main journal taper (maximum per inch)	0.0076 mm (0.0003 in)
Main bearing thrust face maximum runout	0.051 mm (0.002 in)
Oil seal journal maximum runout	0.025 mm (0.001 in)
Vibration damper mounting area maximum runout	0.05 mm (0.002 in)
Flywheel mounting surface maximum runout	0.05 mm (0.002 in)
Main bearing to crankshaft running clearance	0.025 to 0.076 mm (0.001 to 0.003 in)
Main Bearing Journal Diameter	
• Standard size	80.987 to 81.012 mm (3.188 to 3.150 in)
• 0.254 mm (0.010 in) under size	80.733 to 80.758 mm (3.178 to 3.140 in)
• 0.508 mm (0.020 in) under size	80.479 to 80.504 mm (3.168 to 3.130 in)
• 0.762 mm (0.030 in) under size	80.225 to 80.250 mm (3.158 to 3.120 in)
Connecting Rod Journal Diameter	
• Standard size	68.99 to 69.01 mm (2.716 to 2.717 in)
• 0.254 mm (0.010 in) under size	68.73 to 68.75 mm (2.706 to 2.707 in)
• 0.508 mm (0.020 in) under size	68.48 to 68.50 mm (2.696 to 2.697 in)
• 0.762 mm (0.030 in) under size	68.23 to 68.25 mm (2.686 to 2.687 in)

Camshaft and Bushings	
Camshaft bushing inside diameter	62.05 to 62.14 mm (2.443 to 2.446 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)
Camshaft lobe wear (max)	0.51 mm (0.02 in)
Camshaft journal diameter (all journals)	61.987 to 62.013 mm (2.440 to 2.441 in)
Camshaft thrust plate thickness	3.589 to 3.649 mm (0.1413 to 0.1436 in)
Journal and bushing running clearance	0.037 to 0.153 mm (0.0015 to 0.0060 in)
Primary balance shaft bearing clearance (max)	0.123 mm (0.005 in)
Primary balance shaft end play	1.77 mm (0.070 in)
Primary balance gear backlash	0.184 to 0.306 mm (0.007 to 0.012 in)
Camshaft lobe lift (maximum)	
• Intake	5.820 mm (0.2291 in)
• Exhaust	5.906 mm (0.2325 in)
Valve timing no. 1 cylinder (top of lobe)	
• Intake open	16.2° BTDC
• Intake closed	50.4° ABDC
• Exhaust open	47.5° BBDC
• Exhaust closed	14.9° ATDC

Crankcase	
Cylinder block top surface of crankcase flatness	Total deck surface: 0.10 mm (0.004 in)
	150 mm^2 (36 in^2) area: 0.05 mm (0.02 in)
	25 mm^2 (1 in^2) area: 0.025 mm (0.001in)
Crankcase main bearing bore diameter	85.99 to 86.01 mm (3.3854 to 3.3862 in)
Crankcase cam bearing bore diameter	65.98 to 66.02 mm (2.597 to 2.599 in)
Roller follower bore diameter	23.44 to 23.48 mm (0.923 to 0.924 in)
Roller follower outside diameter	23.39 to 23.41 mm (0.921 to 0.923 in)
Cylinder bore diameter	94.991 to 95.001 mm (3.740 to 3.741 in)
Cylinder bore maximum out-of-round	0.008 mm (0.0003 in)
Cylinder stroke	105 mm (4.13 in)

Coolant heater element rating	1,000 watts, 120 volts
Main Bearings	
Material	Steel backed copper/lead
Number of main bearings	4
Thrust bearing location	No. 3 main upper
Lower crankcase	Four bolts per main journal

Special Torque

Lower crankcase main bearing cap bolts	See tightening procedure and sequence (page 354)
Coolant heater element or plug	41 N·m (30 lbf·ft)
Crankcase coolant drain plug / O-ring, M16	20 N·m (15 lbf·ft)

Special Service Tools

Camshaft Bushing Kit	ZTSE2893B
Camshaft Bushing Remover/Installer (expanding collet)	ZTSE4489
Crankshaft Timing Tool	ZTSE4687
Cylinder bore gauge	Obtain locally
De-glazing hone (four-inch)	Obtain locally
Dial indicator with magnetic base	Obtain locally
Feeler gauge	Obtain locally
Freeze Plug Installer	ZTSE4509
Head Bolt Bottoming Tap	ZTSE4508
Loctite® #242 Threadlocker	Obtain locally
Loctite® #620 Compound	Obtain locally
Micrometer, 2-3 in	Obtain locally
Micrometer, 3-4 in	Obtain locally
Oil Gallery Cleaning Brush	ZTSE4511
Oil Gallery Plug Driver	ZTSE4512
Straightedge	Obtain locally
Telescoping gauge set	Obtain locally

Table of Contents

Rocker Arm Replacement.....365

Special Service Tools.....369

Rocker Arm Replacement

Before performing rocker arm replacement, the following components must be removed as outlined elsewhere in this engine service manual:

- Turbocharger inlet air ducting
- Valve cover(s)
- High-pressure oil rail(s)

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, allow engine to cool before working with components.

WARNING: To prevent personal injury or death, disconnect ground (-) cable from battery before doing service or diagnostic procedures.

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

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 and filters according to applicable regulations. Never put engine fluids in the trash, on the ground, in sewers or bodies of water.

CAUTION: To prevent engine damage, position shop towels or rubber hose into each of the cylinder head oil drain holes before fuel injector removal. This will ensure small parts (or broken pieces) will not get into the oil. Potentially damaging components include:

- **⅜" rocker arm pivot balls**
- **Rocker arm pivots and pivot retainers**

Account for all parts (or pieces of) before removing shop towels or rubber hose after rocker arm has been installed.

1. Locate dowel hole in vibration damper. The hole is located between two of the four bolt heads.

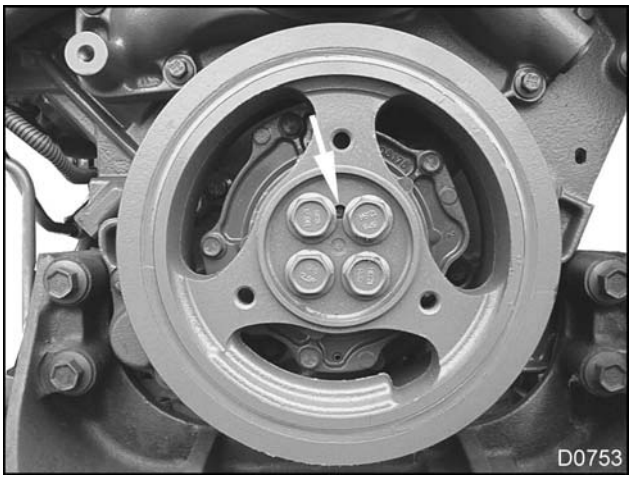

Figure 532 Dowel hole in vibration damper

2. Rotate crankshaft until the dowel hole is at the 12:00 O'clock position.

   Wiggle both rocker arms at the #1 cylinder. If the rockers do not move freely, rotate crankshaft one complete revolution (360°). The #1 cylinder rocker arms should now feel free of valve train loading. Rocker arm replacement can be performed at cylinders 1, 2, and 4.

   Rotate crankshaft one additional revolution (360°) to service both rocker arms for cylinders 3, 5, and 6.

3. Disconnect and remove the fuel injector electrical connection at the rocker arm carrier using the Injector Connector Remover. See Special Service Tools (page 369).

4. Remove the fuel injector hold down clamp assembly using a T45 Torx bit socket (page 369).
5. Place injector into a closable container, cover with oil, and close container.

   CAUTION: To prevent engine damage, place a clean paper towel inside the injector sleeve to prevent entrance of foreign material.

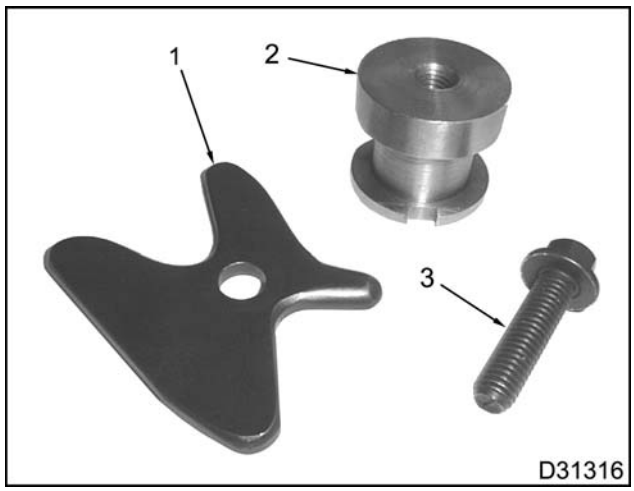

Figure 533 On Engine Valve Spring Compressor Tool

1. Valve Spring Compressor Plate
2. Valve Spring Compressor Base
3. Valve Spring Compressor Bolt

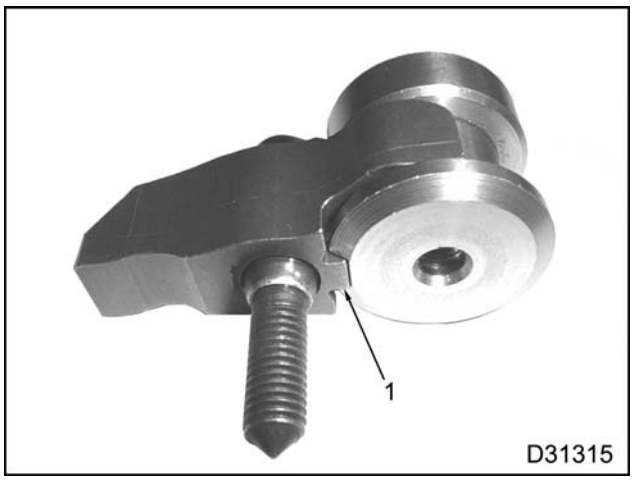

Figure 534 Hold down clamp and base

1. Locating notch / index feature

6. Using the On Engine Valve Spring Compressor Tool, insert the Valve Spring Compressor Base into injector hold down clamp, making sure the notch in the base aligns with index feature on hold down clamp.

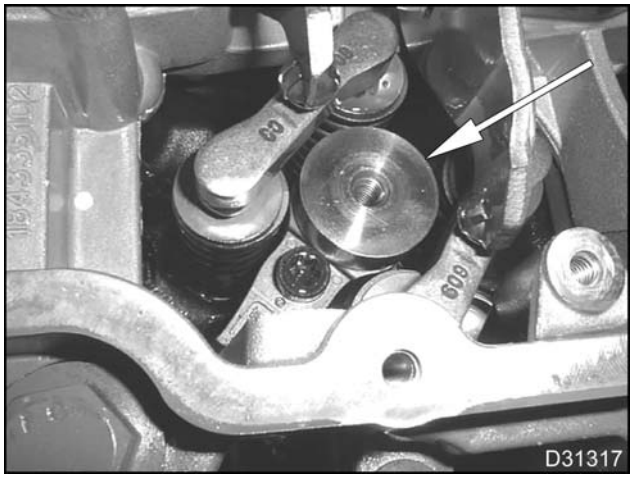

Figure 535 Valve Spring Compressor Base installed

7. Install assembly between valve bridges as if installing an injector. While centering Valve Spring Compressor Base between the two valve bridges, lightly tighten injector hold down clamp bolt, but do not torque.

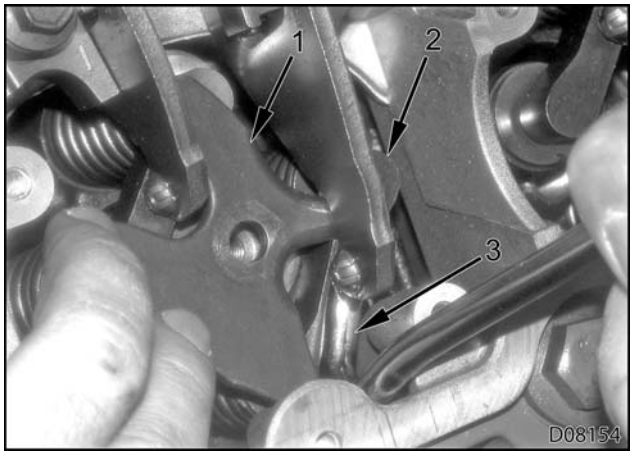

Figure 536 Creating clearance between rocker arm and valve bridge

1. Valve Spring Compressor Plate
2. Valve bridge (2)
3. Small pry bar

8. Install Valve Spring Compressor Plate onto the top of each valve bridge, locating the small point of plate between the exhaust rocker and valve bridge.

   a. If exhaust rocker is severely worn, insert a small pry bar between the exhaust rocker arm and valve bridge. Compressing the valve bridge down and raising the rocker slightly should give enough clearance to rotate the small point of the Valve Spring Compressor Plate between the two components.

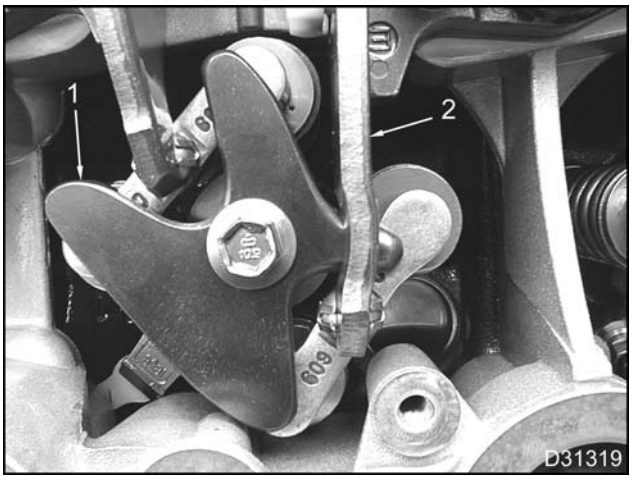

Figure 537 Valve Spring Compressor Plate installed

1. Plate properly positioned on top of valve bridges
2. Exhaust rocker arm

   b. Once the Valve Spring Compressor Plate is in position, install the Valve Spring Compressor Bolt through the Valve Spring Compressor Plate and into Valve Spring Compressor Base.

      CAUTION: To prevent engine damage, do not use power tools.

   c. Using a hand wrench, tighten bolt to compress valve springs until Valve Spring Compressor Plate contacts top of Valve Spring Compressor Base.

9. Disengage rocker arm from push rod while rotating rocker arm and compressing rocker arm clip simultaneously. Repeat procedure for adjacent rocker arm.

   CAUTION: To prevent engine damage, account for the two ⅜" rocker arm pivot balls. If balls fall onto cylinder head, use a magnet to retrieve them.

   CAUTION: To prevent engine damage, account for each rocker arm pivot and pivot retainer. Failure to account for broken pieces would require the removal of the oil pan to retrieve, if shop towels or hoses were not placed within the oil drain holes.

10. With rocker arms removed, back out Valve Spring Compressor Bolt and remove Valve Spring Compressor Plate to gain access to valve bridges.

11. Replace valve bridges as necessary. Compress valves again to enable installation of new rocker arms.

12. Place a dab of wheel bearing grease onto new rocker arm socket (to hold new ⅜" ball in place while installing rocker arm).

13. Position ⅜" ball and rocker arm underneath fulcrum and rotate rocker arm into place making sure push rod is seated within rocker arm.

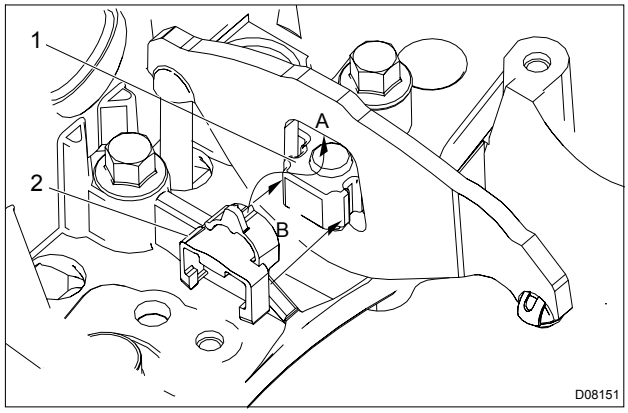

Figure 538 Position "A" in first then slide "B" around fulcrum plate

1. Fulcrum plate
2. Rocker arm retaining clip

14. Install new plastic rocker arm retaining clip (Figure 538) by positioning top of clip to top of rocker arm opening and rotating clip until snapping around fulcrum plate.

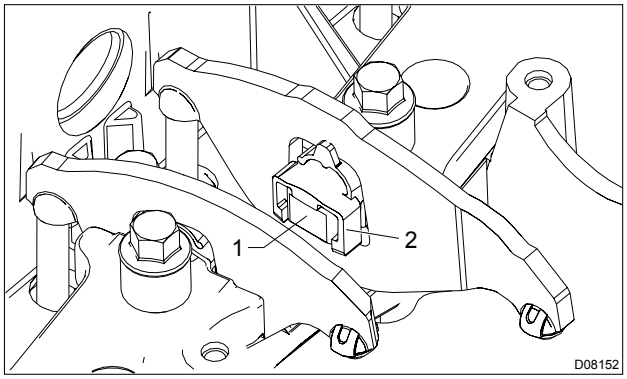

Figure 539 Retaining clip in correct position

1. Fulcrum plate
2. Rocker arm retaining clip

15. Refer to illustration (Figure 539) for correctly installed clip. Repeat procedure with adjacent rocker arm.

16. Remove Valve Spring Compressor Bolt making sure rocker arm remains in place and ⅜" ball has not fallen out. Repeat procedure on remaining cylinders for this crankshaft position session.

17. After all desired rocker arms and valve bridges have been replaced for cylinders 1, 2, and 4, the crankshaft can be rotated one complete revolution (360°) to service rocker arms at cylinders 3, 5 and 6.

18. Install a new O-ring seal kit onto each of the fuel injectors as outlined in Cylinder Head and Valve Train section of this manual.

19. Remove paper towels from injector bores and install injectors.

20. Look for small broken particles (visually and using a magnet) before removing shop towels or rubber hose from oil drain holes.

21. Continue to install the following components as outlined in this engine service manual:

    - High-pressure oil rail(s)
    - Valve cover(s)
    - Turbocharger inlet air ducting

Special Service Tools

T45 Torx bit socket	Obtain locally
Quick Release Tool kit	ZTSE4454
Injector Connector Remover	ZTSE4650
On Engine Valve Spring Compressor Tool	ZTSE4697

Table of Contents

Abbreviations and Acronyms.....373
Abbreviations and Acronyms.....373

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

C – Celsius
CAC – Charge Air Cooler
CAN – Controller Area Network
CAP – Cold Ambient Protection
CARB – California Air Resources Board
cc – Cubic centimeter
CCA – Cold Cranking Ampere
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 Recirculation 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 – Pound force
lb/s – Pounds per second
lbf ft – Pounds of force per foot
lbf in – Pounds of force per inch
lbm – Pound 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.....**379**
Terms.....**379**

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

Specifications.....387
- **Engine Electrical**.....387
- **Dual Stage Turbocharger Assembly**.....387
- **Manifolds and Exhaust Gas Recirculation (EGR)**.....387
- **High-pressure Oil System**.....387
- **Fuel System**.....388
- **Oil Cooler and Filter Housing**.....388
- **Front Cover, Vibration Damper, Oil Pump, and Cooling System**.....389
- **Cylinder Head and Valve Train**.....391
- **Rear Cover**.....392
- **Power Cylinder**.....392
- **Crankcase, Crankshaft, and Camshaft**.....394

Specifications

Engine Electrical

Glow plugs	10.9 V to 11.1 V
Intake Air Heater (IAH)	60 Amps
Camshaft Position (CMP) sensor operating speed	30 rpm to 3000 rpm
Crankshaft Position (CKP) sensor operating actuator speed	15 rpm to 2000 rpm

Dual Stage Turbocharger Assembly

Maximum turbine shaft axial end play (LP turbocharger)	0.091 mm (0.0036 in)
Maximum turbine shaft radial shaft movement (clearance) (LP turbocharger)	0.5 mm (0.02 in)
Maximum turbine shaft axial end play (HP turbocharger)	0.091 mm (0.0036 in)
Maximum turbine shaft radial shaft movement (clearance) (HP turbocharger)	0.5 mm (0.02 in)

Manifolds and Exhaust Gas Recirculation (EGR)

Exhaust Manifolds	
Maximum allowable warpage	0.08 mm (0.003 in)
Intake Manifold	
Maximum allowable warpage	0.08 mm (0.003 in)

High-pressure Oil System

Injection Control Pressure (ICP) sensor operating pressure range	0 to 30 MPa (0 to 4,350 psi)
Injection Pressure Regulator (IPR) valve relief pressure	31 MPa (4,500 psi)
IPR valve maximum pressure	38 MPa (5,500 psi)

Fuel System

Horizontal Fuel Conditioning Module (HFCM)	
Electric heater	150 W
Filter efficiency	10 micron
Rated flow capacity	98 L/hr (26 gph @ 60 psi)
Secondary Fuel Filter	
Filter efficiency	4 micron
Maximum fuel pressure in secondary filter	400 kPa (58 psi @ 35 gph)
Valve unseating pressure	310 ± 28 kPa (45 ± 4 psi)
Injection Pressure Regulator (IPR) valve	
Operating temperature range	-40 °C to 220 °C (-40 °F to 428 °F)
Maximum operating pressure	28 MPa (4,061 psi)

Oil Cooler and Filter Housing

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

Front Cover, Vibration Damper, Oil Pump, and Cooling System

Vibration Damper	
Face runout (maximum)	0.635 mm (0.025 in)
Rubber bulging (maximum)	1.5 mm (0.060 in)
Lubricating Oil Pump and Pressure Regulator	
Type	Gerotor
Drive	Crankshaft
Location	Gerotor oil pump housing (front cover)
Oil Pressure:	
• 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)
Oil pump end clearance (inner and outer rotor to housing)	0.025 to 0.095 mm (0.001 to 0.004 in)
Oil pump radial clearance (between outer rotor and housing)	0.15 to 0.28 mm (0.006 to 0.011 in)
Oil pressure regulator bore	18.81 ± 0.02 mm (0.741 0.001)
Thermostat	
Type	Balanced pressure, wax pellet
Full open temperature, >10 mm (0.394 in) stroke	104 °C (219 °F)

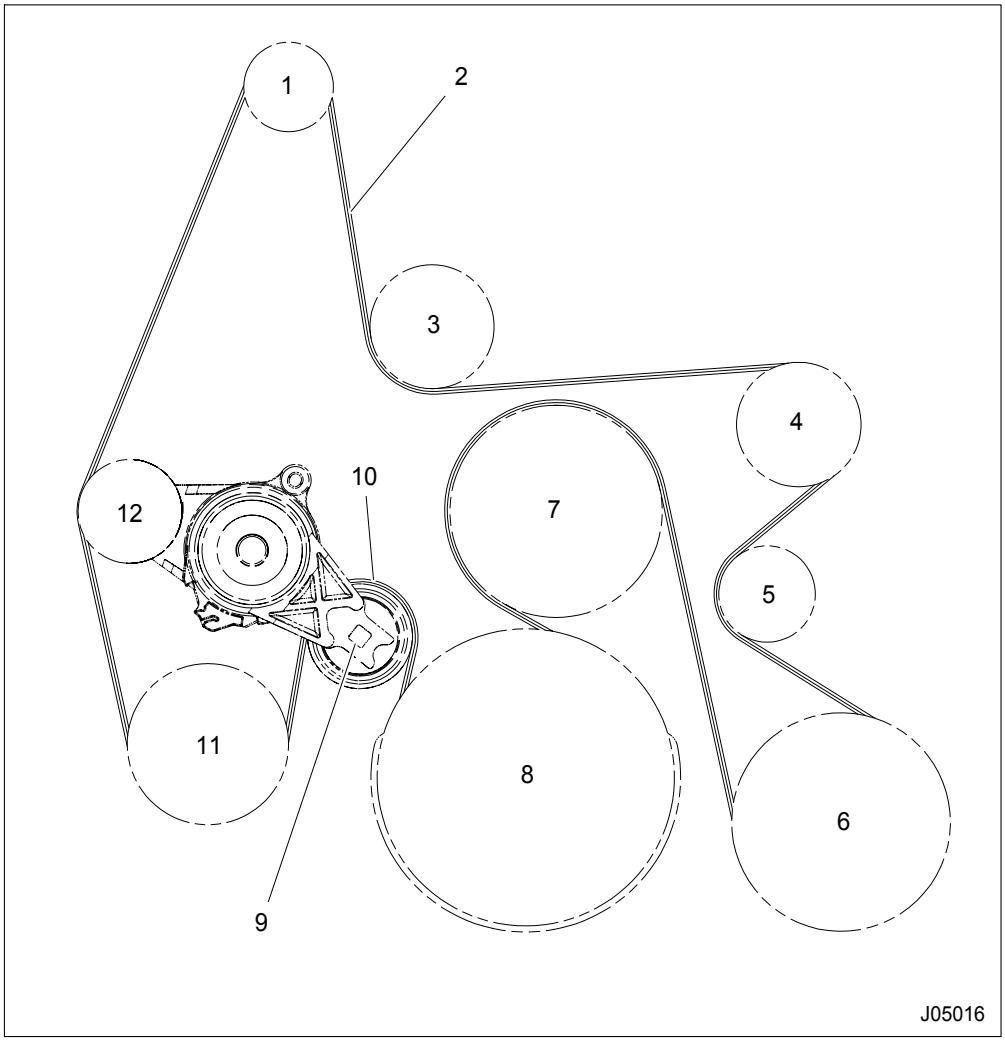

Figure 540 Accessories drive belt routing

1. Alternator
2. Drive belt
3. Flat idler
4. Grooved idler
5. Flat idler
6. Power steering pump
7. Water pump
8. Crankshaft damper
9. Tensioner square
10. Tensioner pulley
11. AC compressor or non AC pulley
12. Grooved idler

Cylinder Head and Valve Train

Valve Specifications	
Face to stem runout (T.I.R. max.)	0.038 mm (0.0015 in)
Stem to guide clearance (max. allowable before replacement)	0.140 mm (0.0055 in)
Valve stem diameter	6.947 to 6.965 mm (0.2735 to 0.2742 in)
Exhaust valve face angle	37.5°
Intake valve face angle	30.0°
Exhaust valve margin (minimum)	1.35 mm (0.053 in)
Intake valve margin (minimum)	1.40 mm (0.055 in)

Valve Spring Specifications	
Free length	51.96 mm (2.045 in)
Compressed* (first test)	46.30 mm @ 340 ± 17 N (1.82 in @ 76.5 ± 3.8 lbf)
Compressed* (second test)	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.

Cylinder Head Specifications	
Valve guide inside diameter	7.003 to 7.029 mm (0.276 to 0.277 in)
Valve guide bore runout	0.05 mm (0.002 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)	30.0°
Valve seat angle (exhaust)	37.5°
Valve seat runout (T.I.R. max.)	0.035 mm (0.0014 in)
Gasket surface flatness (maximum)	0.051 mm (0.002 in) per check point
Overall thickness of cylinder head (deck-to-deck)	95 mm (3.74 in)
Valve head recession relative to deck (surface of cylinder head)	0.32 to 0.68 mm (0.0126 to 0.0268 in)
Push rod runout (maximum)	0.25 mm (0.01 in)

Rear Cover

Max. flywheel ring gear T.I.R. runout	1.27 mm (0.050 in)
Rear cover face maximum runout	0.51 mm (0.020 in)

Power Cylinder

Connecting Rods	
Connecting rod length (center to center)	176 mm (6.929 in)
Bushing bore diameter (pin end)	36.98 to 37.02 mm (1.456 to 1.457 in)
Piston pin bushing inside diameter	34.0140 to 34.0215 mm (1.3391 to 1.3394 in)
Bearing bore diameter (crankshaft end)	72.987 to 73.013 mm (2.8735 to 2.8745 in)
Bearing bore maximum out-of-round	0.013 mm (0.0005 in)
Bearing bore maximum taper per 25 mm (1 inch)	0.013 mm (0.0005 in)
Connecting rod bearing inside diameter	69.027 to 69.077 mm (2.7176 to 2.7196 in)
Connecting rod bearing running clearance (diameter)	0.0203 to 0.0837 mm (0.0008 to 0.0033 in)
Connecting rod side clearance	0.3 to 0.6 mm (0.012 to 0.024 in)
Weight (complete rod without bearing)	1201.5 to 1215.5 g (2.649 to 2.679 lb)
Pistons	
Material	Aluminum Alloy
Skirt diameter [1]	94.9460 to 94.9186 mm (3.737 to 3.738 in)
[1] Measure 14.68 mm (0.578 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	94.9460 to 94.9186 mm (3.737 to 3.738 in)
0.254 mm (0.010 in) oversize	95.1738 to 95.1992 mm (3.747 to 3.748 in)
0.508 mm (0.020 in) oversize	95.4278 to 95.4532 mm (3.757 to 3.758 in)
0.762 mm (0.030 in) oversize	95.6818 to 95.7072 mm (3.767 to 3.768 in)
Top compression ring groove width (measured over 2.08 mm (0.082 in) gauge pins):	
Upper limit	94.469 mm (3.7192 in)
Replacement limit	94.290 mm (3.7122 in)
Piston protrusion above crankcase deck	0.900 mm (0.0354 in)
Piston skirt clearance (1 - 8)	0.0441 to 0.0909 mm (0.0017 to 0.0036 in)

Piston Pins	
Length	65.073 to 65.327 mm (2.5619 to 2.5719 in)
Diameter	33.9975 to 34.0025 mm (1.3385 to 1.3387 in)
Pin fit at room temperature of 19 to 21 °C (66 to 70 °F):	
Clearance in connecting rod (piston pin bushing)	0.0115 to 0.0240 mm (0.00045 to 0.00094 in)
Clearance in piston	0.013 to 0.022 mm (0.0005 to 0.0009 in)
End clearance	0.24 mm (0.009 in)
Piston Rings	
Ring diameter (standard):	95 mm (3.74 in)
Ring groove (side clearance):	
Intermediate compression	0.051 to 0.102 mm (0.0020 to 0.0040 in)
Oil control	0.038 to 0.084 mm (0.0015 to 0.0033 in)
Ring gap in bore:	
Top compression	0.29 to 0.55 mm (0.011 to 0.021 in)
Intermediate compression	1.40 to 1.66 mm (0.055 to 0.065 in)
Oil control	0.24 to 0.50 mm (0.009 to 0.019 in)

Crankcase, Crankshaft, and Camshaft

Crankshaft	
Crankshaft end play (maximum)	0.222 mm (0.0087 in)
Crankshaft gear backlash (maximum)	0.32 mm (0.012 in)
Crankshaft connecting rod out-of-round	0.006 mm (0.00024 in)
Crankshaft connecting rod journal taper (maximum per inch)	0.0076 mm (0.0003 in)
Crankshaft main journal out-of-round	0.006 mm (0.00024 in)
Crankshaft main journal taper (maximum per inch)	0.0076 mm (0.0003 in)
Main bearing thrust face maximum runout	0.051 mm (0.002 in)
Oil seal journal maximum runout	0.025 mm (0.001 in)
Vibration damper mounting area maximum runout	0.05 mm (0.002 in)
Flywheel mounting surface maximum runout	0.05 mm (0.002 in)
Main bearing to crankshaft running clearance	0.025 to 0.076 mm (0.001 to 0.003 in)
Main Bearing Journal Diameter	
• Standard size	80.987 to 81.012 mm (3.188 to 3.150 in)
• 0.254 mm (0.010 in) under size	80.733 to 80.758 mm (3.178 to 3.140 in)
• 0.508 mm (0.020 in) under size	80.479 to 80.504 mm (3.168 to 3.130 in)
• 0.762 mm (0.030 in) under size	80.225 to 80.250 mm (3.158 to 3.120 in)
Connecting Rod Journal Diameter	
• Standard size	68.99 to 69.01 mm (2.716 to 2.717 in)
• 0.254 mm (0.010 in) under size	68.73 to 68.75 mm (2.706 to 2.707 in)
• 0.508 mm (0.020 in) under size	68.48 to 68.50 mm (2.696 to 2.697 in)
• 0.762 mm (0.030 in) under size	68.23 to 68.25 mm (2.686 to 2.687 in)

Camshaft and Bushings	
Camshaft journal diameter (all journals)	61.987 to 62.013 mm (2.440 to 2.441 in)
Bushing inside diameter	62.05 to 62.14 mm (2.443 to 2.446 in)
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)
Balance shaft end play	1.77 mm (0.070 in)
Balance shaft gear backlash	0.184 to 0.306 mm (0.007 to 0.012 in)
Balance shaft bearing clearance	0.123 mm (0.005 in)

Camshaft lobe lift (maximum)	
• Intake	5.820 mm (0.2291 in)
• Exhaust	5.906 mm (0.2325 in)
Valve timing no. 1 cylinder (top of lobe)	
• Intake open	16.2° BTDC
• Intake closed	50.4° ABDC
• Exhaust open	47.5° BBDC
• Exhaust closed	14.9° ATDC

Crankcase	
Cylinder block top surface of crankcase flatness	Total deck surface: 0.10 mm (0.004 in) 150 mm^2 (36 in^2) area: 0.05 mm (0.02 in) 25 mm^2 (1 in^2) area: 0.025 mm (0.001in)
Crankcase main bearing bore diameter	85.99 to 86.01 mm (3.3854 to 3.3862 in)
Crankcase cam bearing bore diameter	65.98 to 66.02 mm (2.597 to 2.599 in)
Roller follower bore diameter	23.44 to 23.48 mm (0.923 to 0.924 in)
Roller follower outside diameter	23.39 to 23.41 mm (0.921 to 0.923 in)
Cylinder bore diameter	94.991 to 95.001 mm (3.740 to 3.741 in)
Cylinder bore maximum out-of-round	0.008 mm (0.0003 in)
Cylinder stroke	105 mm (4.13 in)
Coolant heater element rating	1,000 watts, 120 volts
Main Bearings	
Material	Steel backed copper/lead
Number of main bearings	4
Thrust bearing location	No. 3 main upper
Lower crankcase	Four bolts per main journal

Table of Contents

General Torque.....399
Bolt Identification.....399
General Torque Guidelines.....400
Standard Torque Charts.....400
Using a Torque Wrench Extension.....401

Special Torques.....402
Mounting Engine on Engine Stand.....402
Engine Electrical.....402
Dual Stage Turbocharger Assembly.....402
Manifolds and Exhaust Gas Recirculation (EGR).....403
High-pressure Oil System.....403
Fuel System.....403
Oil Cooler and Filter Housing.....404
Front Cover, Vibration Damper, Oil Pump, and Cooling System.....404
Cylinder Head and Valve Train.....404
Rear Cover and Flywheel.....405
Power Cylinder.....405
Crankcase, Crankshaft and Camshaft.....405

General Torque

Bolt Identification

DESIGNATION		MATERIAL TYPE	THERMAL TREATMENT	HEAD MARKING	
INTERNATIONAL CLASS	ISO R 898 I			PREFERRED	OPTIONAL
5.8	5.8	LOW OR MEDIUM CARBON STEEL	NON REQUIRED		
8.8	8.8	MEDIUM CARBON OR MEDIUM CARBON ALLOY STEEL OR LOW CARBON BORON STEEL	QUENCH AND TEMPERED		
9.8	–				
10.9	10.9				

d31209

Figure 541 Classification and Identification – Metric Fasteners

INTERNATIONAL DESIGNATION	TYPE OF MATERIAL	THERMAL TREATMENT	HEAD MARKING	
CLASS	METRIC FASTENERS		PREFERRED	OPTIONAL
10.9R	MEDIUM CARBON, MEDIUM CARBON ALLOY STEEL	QUENCH AND TEMPERED, ROLL THREADED AFTER HEAT TREATMENT		
12.9	MEDIUM CARBON ALLOY STEEL	QUENCH AND TEMPERED		
12.9R		QUENCH AND TEMPERED, ROLL THREADED AFTER HEAT TREATMENT		

d31210

Figure 542 Classification and Identification – Special Use Fasteners

General Torque Guidelines

CAUTION: To prevent engine damage, do not substitute fasteners. Original equipment standard hardware is defined as Class 10.9 metric or Grade 8 standard coarse thread bolts and nuts and hardened flat washers (Rockwell "C" 38-45), all phosphate coated.

The standard torque charts provide the tightening torque for general purpose applications using original equipment standard hardware as listed in the Parts Catalog for the application involved.

NOTE: Visually inspect parts for cleanliness and obvious defects prior to 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 tension in the fastener (bolt and nut), which in turn develops 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 proper 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 proper bolt tension and clamping load can never be attained if the fastener is dry. The fastener threads must be new condition or have a film of clean lubricant (engine oil) to be considered lubricated.

Standard Torque Charts

Standard Torques – Pipe Thread

Thread Size	Torque
1/8 in NPT	11 N·m (90 lbf·in)
1/4 in NPT	14 N·m (120 lbf·in)
3/8 in NPT	20 N·m (180 lbf·in)
1/2 in NPT	34 N·m (25 lbf·ft)
3/4 in NPT	41 N·m (30 lbf·ft)

Standard Torques – Class 10.9 Metric Bolts and Studs

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

Standard Torques – Class 12.9 Metric Bolts and Studs

Thread Diameter	Thread Pitch (mm/thread)	Torque
6 mm	1	15 N·m (132 lbf·in)
8 mm	1.25	36 N·m (27 lbf·ft)
10 mm	1.5	72 N·m (53 lbf·ft)
12 mm	1.75	126 N·m (93 lbf·ft)
14 mm	2	201 N·m (148 lbf·ft)
15 mm	2	252 N·m (186 lbf·ft)
16 mm	2	311 N·m (230 lbf·ft)
18 mm	2.5	430 N·m (317 lbf·ft)
20 mm	2.5	608 N·m (448 lbf·ft)

Using a Torque Wrench Extension

Occasionally an extension, crowfoot, or other type of 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 faster from what the torque wrench reads. Use the following formula to calculate the correct torque wrench setting to achieve a specific torque value.

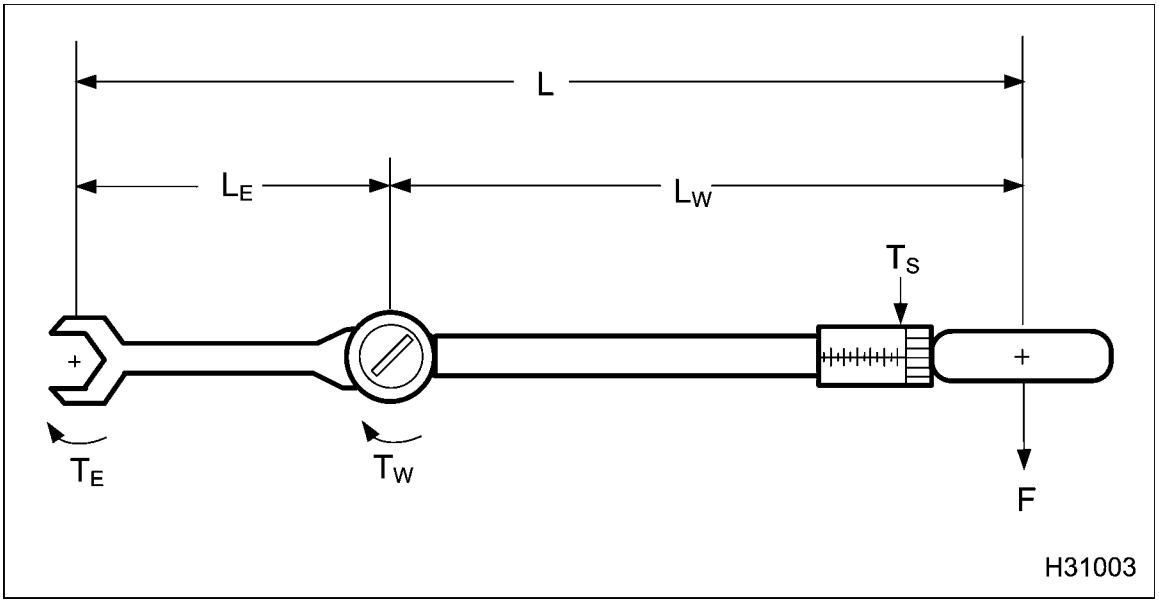

Figure 543 Torque wrench extension

- 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 applied 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 wrench length (L_W) = 12 inches
- Length of extension L_E = 6 inches

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

T_S = 65 lbf·ft (12 in / 18 in)

T_S = 65 lbf·ft (0.666)

T_S = **43.3 lbf·ft**

Special Torques

Mounting Engine on Engine Stand

Oil pan drain plug	44 N·m (32 lbf·ft)
Crankcase coolant drain plug	20 N·m (15 lbf·ft)

Engine Electrical

Alternator M10 x 80 mounting bolts	48 N·m (35 lbf·ft)
Alternator power connector nut	8 N·m (71 lbf·in)
Engine Coolant Temperature (ECT) sensor	17.5 N·m (154 lbf·in)
Engine Oil Pressure (EOP) sensor	14 N·m (124 lbf·in)
Engine Oil Temperature (EOT) sensor	17.5 N·m (154 lbf·in)
Exhaust Back Pressure (EBP) sensor	20 N·m (178 lbf·in)
Engine Fuel Pressure (EFP) switch	14 N·m (124 lbf·in)
Injection Control Pressure (ICP) sensor	17 N·m (150 lbf·in)
Intake Air Heater (IAH) element	61 N·m (45 lbf·ft)
Intake Air Heater (IAH) element M5 cable nut	4 N·m (35 lbf·in)
Intake Air Temperature (IAT) sensor	14 N·m (124 lbf·in)
Manifold Absolute Pressure (MAP) sensor	11.5 N·m (101 lbf·in)
Manifold Air Temperature (MAT) sensor	14 N·m (124 lbf·in)

Dual Stage Turbocharger Assembly

Air inlet duct worm gear clamp	5 N·m (48 lbf·in)
Bango bolt, M12	24 N·m (18 lbf·ft)
Boost Control Solenoid mounting bolt, M6 x 30	9 N·m (79 lbf·in)
Exhaust tubing to exhaust manifold, M8 x 50	See Turbocharger and Exhaust Tube Torque Sequence (page 122).
Low-pressure turbine exhaust outlet studs	22 N·m (16 lbf·ft)
V-band clamp (crossover tube)	7 N·m (62 lbf·in)
V-band clamp (turbine mating)	10 N·m (88 lbf·in)

Manifolds and Exhaust Gas Recirculation (EGR)

Coolant deaeration fitting	10 N·m (90 lbf·in)
EGR cooler mounting bolt assembly, M6 x 25	11 N·m (97 lbf·in)
EGR cooler to manifold stud bolts, M6 x 55 x 20	11 N·m (97 lbf·in)
Exhaust manifold bolts, M8 x 40[1]	See Exhaust Manifolds (page 140) torque sequence
Intake manifold bolts, M6 bolts and stud bolts	11 N·m (97 lbf·in) See intake manifold bolt torque sequence (Figure 171)

[1] Apply anti-seize compound to bolt threads before assembly

High-pressure Oil System

Branch tube adaptor jam nut	72 N·m (53 lbf·ft)
Case-to-head tube and rail port plug	82 N·m (60 lbf·ft)
Injection Pressure Regulator (IPR)	50 N·m (37 lbf·ft)
Prime port plug, M8	8 N·m (71 lbf·in)
High-pressure pump plug, M12	35 N·m (26 lbf·ft)

Fuel System

Banjo bolt, 12 mm (fuel supply tube to each cylinder head)	38 N·m (28 lbf·ft)
Fuel filter cap (secondary)	14 N·m (124 lbf·in)
Secondary fuel filter housing mounting screws, M6 x 25	10 N·m (88 lbf·in)
Fuel injector hold down clamp bolt	35 N·m (26 lbf·ft)
Fuel supply hollow screw, M14	35 N·m (26 lbf·ft)
Engine Fuel Pressure (EFP) switch	14 N·m (124 lbf·in)
Fuel pump mounting screws, self tapping #10	5 N·m (44 lbf·in)
Fuel return fitting, M16	46 N·m (34 lbf·ft)
Fuel return to HFCM tube fitting	25 N·m (19 lbf·ft)
Fuel return tube assembly mounting screws, 8/32 x 3/8	2-3 N·m (20-25 lbf·in)
HFCM cover plate screws	5 N·m (44 lbf·in)
HFCM housing mounting nuts (M8)	15 N·m (132 lbf·in)
Left and right cylinder head supply tube fittings at filter, M12	25 N·m (18 lbf·ft)
Plug assembly, M12 (rear of cylinder head)	36 N·m (27 lbf·ft)
Primary fuel filter cap	25 N·m (18 lbf·ft)

Oil Cooler and Filter Housing

Oil filter base assembly screws (M6 x 25)	10 N·m (85 lbf·in)
Oil filter base assembly bolt (M8 x 45)	11 N·m (97 lbf·in)
Oil filter base assembly screws (M8 x 23)	23 N·m (17 lbf·ft)
Oil bypass / filter inlet guide valve screws (M5 x 18)	7 N·m (62 lbf·in)
Oil filter housing mounting screws (M6 x 25)	15 N·m (132 lbf·in)
Diagnostic port	16 N·m (144 lbf·in)
EGR coolant supply elbow, M6 screw	9.7 N·m (85 lbf·in)
Oil filter cap	25 N·m (18 lbf·ft)

Front Cover, Vibration Damper, Oil Pump, and Cooling System

Water pump / fan drive pulley bolts	36 N·m (26 lbf·ft)
Front cover bolts, M8 x 35	24 N·m (18 lbf·ft)
Nut (heater feed to lifting eye), M10	41 N·m (35 lbf·ft)
Oil pressure regulator end cap	27 N·m (240 lbf·in)
Gerotor oil pump cover bolts, M6 x 25	13 N·m (110 lbf·in)
Thermostat stud bolts, M8 x 30 x 19	22 N·m (200 lbf·in)
Vibration damper mounting bolts, M12 x 59	New bolts only: 68 N·m (50 lbf·ft) + 90° rotation
Water pump mounting bolts	23 N·m (17 lbf·ft)

Cylinder Head and Valve Train

Cylinder head bolt torque and sequence	See Cylinder Head Bolt Torque Sequence(page 277)
Crankcase breather bolts (M6 x 43)	11 N·m (96 lbf·in)
Fuel rail plug, M12	36 N·m (27 lbf·ft)
Glow plugs	18 N·m (159 lbf·in)
Lifting eye, front (M10 x 30)	41 N·m (30 lbf·ft)
Lifting eye, rear (M10 x 35)	41 N·m (30 lbf·ft)
Rocker arm fulcrum plate (M8 x 45)	31 N·m (23 lbf·ft)
Valve cover bolt assemblies (M6)	9 N·m (84 lbf·in)

Rear Cover and Flywheel

Flywheel mounting bolts (all applications) new bolts only	94 N·m (69 lbf·ft) see flywheel torque sequence (Figure 440)

Power Cylinder

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

Crankcase, Crankshaft and Camshaft

Lower crankcase main bearing cap bolts	See tightening procedure and sequence (page 354)
Coolant heater element or plug	41 N·m (30 lbf·ft)
Crankcase coolant drain plug / O-ring, M16	20 N·m (15 lbf·ft)

Table of Contents

Special Service Tools.....409
Mounting Engine on Stand.....409
Engine Electrical.....409
Dual Stage Turbocharger Assembly.....409
Manifolds and Exhaust Gas Recirculation (EGR).....409
High-pressure Oil System.....410
Fuel System.....410
Oil Cooler and Filter Housing.....410
Front Cover, Vibration Damper, and Gerotor Oil Pump.....410
Cylinder Head and Valve Train.....411
Rear Cover.....411
Power Cylinder.....412
Crankcase, Crankshaft and Camshaft.....412
In Chassis Service.....412

Special Tool Photos.....413
Photos of Essential Tools from MaxxForce™ 5 Essential Tool Kit, ZTSE5010.....413
Photos of Essential Tools from VT 365 Essential Tool Kit, ZTSE5000.....415
Photos of Essential Tools from T 444E Essential Tool Kit, ZTSE4350.....418

Special Service Tools

Special tools for the MaxxForce™ 5 engine can be ordered from the SPX Corporation, 1-800-520-2584.

Mounting Engine on Stand

Engine Stand Mounting Bracket	ZTSE4507
Engine Stand	OTC1750A

Engine Electrical

Glow Plug Connector Remover / Installer	ZTSE4670

Dual Stage Turbocharger Assembly

Cap Kit (all)	ZTSE4610
Dial indicator with magnetic base	Obtain locally
Intake Guard	ZTSE4293
Turbo Crossover Tube Seal Remover / Installer	ZTSE4676
Slide Hammer	ZTSE4398A

Manifolds and Exhaust Gas Recirculation (EGR)

Anti-seize compound	Obtain locally
Cap Kit (all)	ZTSE4610
EGR Cooler Pressure Test Plates	ZTSE4707
EGR Valve Puller	ZTSE4669
Feeler gauge	Obtain locally
Intake Manifold Pressure Test Plates	ZTSE4527
Intake Manifold Pressure Test Plug	ZTSE4888
Intake Manifold Pressure Test Cap	ZTSE4682
Magnetic Covers for Cylinder Head Intake Ports	ZTSE4559

High-pressure Oil System

Anti-rotation Handle (branch tube adaptor)	ZTSE4876–1
Branch tube adaptor installation depth gauge	ZTSE4876–2
Case-to-head Tube Removal Tool	ZTSE4694
IPR Removal / Installation Tool	ZTSE4666
Liquid Gasket (RTV, 6 oz. tube)	1830858C1
Crowfoot, flare nut, 15/16 inch, 12-point	Obtain locally

Fuel System

Cap Kit (all)	ZTSE4610
T45 Torx bit socket	Obtain locally
Fuel Injector Tip Cleaning Brush	ZTSE4301
Injector Connector Remover	ZTSE4650
Injector Sleeve Brush Set	ZTSE4304
Turbocharger Inlet Guard	ZTSE4293

Oil Cooler and Filter Housing

Magnetic Covers	ZTSE4557
Oil Cooler Pressure Test Plate	ZTSE4525

Front Cover, Vibration Damper, and Gerotor Oil Pump

Dial indicator with magnetic base	Obtain locally
Fan Hub Wrench (2 inch)	ZTSE43972
Fan Wrench (pulley bolts)	ZTSE4587
Front Seal / Wear Sleeve Installer	ZTSE4680
Front Wear Sleeve Remover	ZTSE4517
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Loctite® Hydraulic Sealant	Obtain locally

Cylinder Head and Valve Train

Cylinder Head Lifting Bracket	ZTSE4661
Cylinder Head Pressure Test Plate	ZTSE4534
Dye Penetrant Kit	PT-7191
Fuel Gallery Cleaning Brush	ZTSE4541
Glow Plug Sleeve Brush (nylon)	ZTSE4533
Glow Plug Sleeve Installer	ZTSE4532
Glow Plug Sleeve Remover (consists of: tap, bolt and adapter)	ZTSE4531
Glow Plug Sleeve Seat Wire Brush	ZTSE4589
Head Bolt Bottoming Tap	ZTSE4508
Injector Sleeve Brush	ZTSE43041
Injector Sleeve Flat Bottom Brush	ZTSE43042
Injector Sleeve Installer	ZTSE4529
Injector Sleeve Remover (consists of: tap and adapter)	ZTSE4528
Intake Port Covers on Heads	ZTSE4559
Loctite® #620	Obtain locally
Slide Hammer Kit	ZTSE4398A
Straightedge	Obtain locally
Valve Guide Gauge Tool	ZTSE4577
Valve Spring Compressor	ZTSE1846
Valve spring tester	Obtain locally

Rear Cover

Crankshaft Secondary Flange Installation Studs (2)	ZTSE4720
Dial indicator with magnetic base	Obtain locally
Gear Puller (secondary flange)	ZTSE4520
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Loctite® Hydraulic Sealant	Obtain locally
Rear Seal / Wear Sleeve Installer[1]	ZTSE4515A
Rear Wear Sleeve Remover	ZTSE4518
Slide Hammer	ZTSE4398A

[1] **CityStar™** bolts - M10 x 40, **Stripped Chassis** bolts - M10 x 70

Power Cylinder

Dial indicator with magnetic base	Obtain locally
Feeler gauge	Obtain locally
Piston Gauge Pins (0.082 in)	ZTSE4513
Piston Ring Compressor (Cope)	ZTSE4514
Piston ring expansion pliers	Obtain locally
Telescoping gauge set	Obtain locally

Crankcase, Crankshaft and Camshaft

Camshaft Bushing Kit	ZTSE2893B
Camshaft Bushing Remover/Installer (expanding collet)	ZTSE4489
Crankshaft Timing Tool	ZTSE4687
Cylinder bore gauge	Obtain locally
De-glazing hone (four-inch)	Obtain locally
Dial indicator with magnetic base	Obtain locally
Feeler Gauge	Obtain locally
Freeze Plug Installer	ZTSE4509
Head Bolt Bottoming Tap	ZTSE4508
Loctite® #242 Threadlocker	Obtain locally
Loctite® #620 Compound	Obtain locally
Micrometer, 2-3 in	Obtain locally
Micrometer, 3-4 in	Obtain locally
Oil Gallery Cleaning Brush	ZTSE4511
Oil Gallery Plug Driver	ZTSE4512
Straightedge	Obtain locally
Telescoping gauge set	Obtain locally

In Chassis Service

T45 Torx bit socket	Obtain locally
Quick Release Tool kit	ZTSE4454
Injector Connector Remover	ZTSE4650
On Engine Valve Spring Compressor Tool	ZTSE4697

Special Tool Photos

Photos of Essential Tools from MaxxForce™ 5 Essential Tool Kit, ZTSE5010

Figure 544 Injector Connector Remover, ZTSE4650

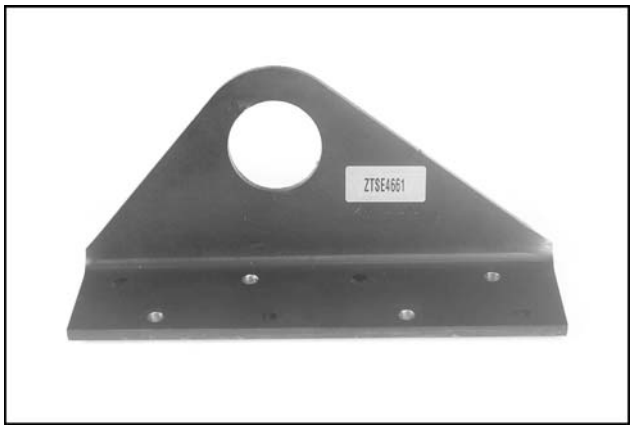

Figure 545 Cylinder Head Lifting Bracket, ZTSE4661

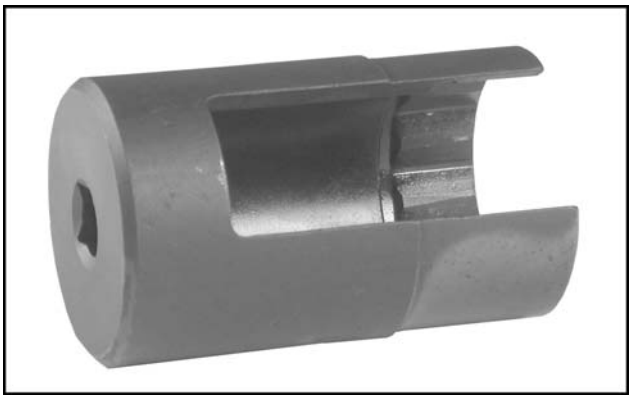

Figure 546 IPR Valve Socket, ZTSE4666

Figure 547 Glow Plug Connector Remover, ZTSE4670

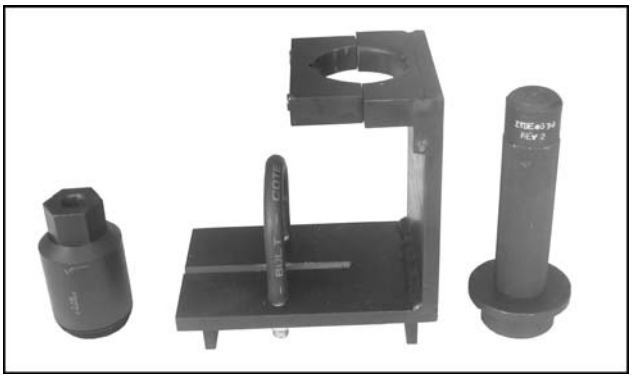

Figure 548 Turbo Crossover Tube Seal Remover and Installer, ZTSE4676

Figure 549 Front Seal Installer / Wear Sleeve Installer, ZTSE4680

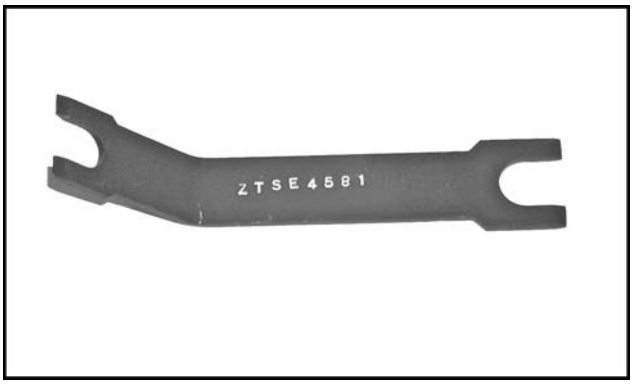

Figure 550 Quick Release Tool (#8 and #10) , ZTSE4581

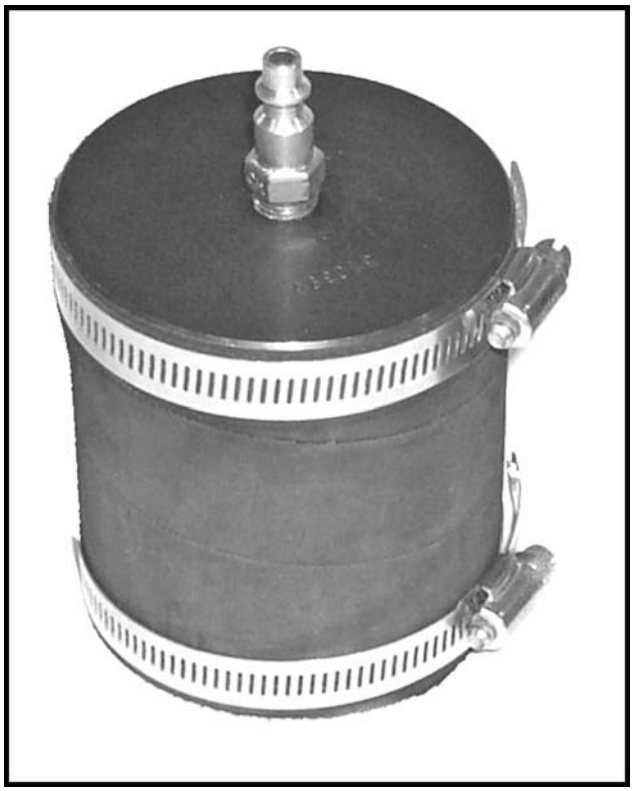

Figure 551 Intake Manifold Pressure Test Cap, ZTSE4682

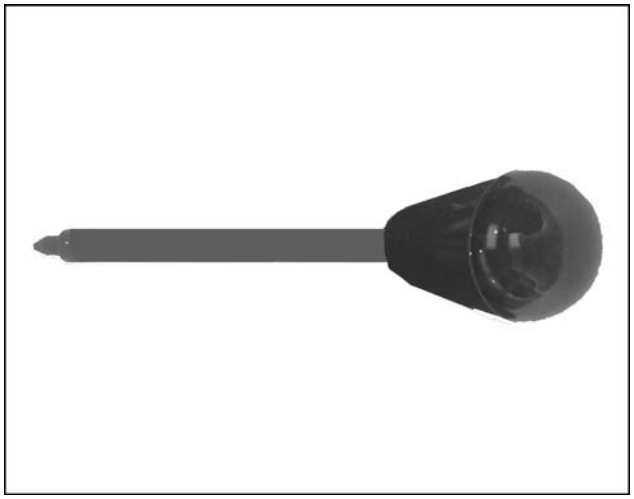

Figure 552 Crankshaft Timing Tool, ZTSE4687

Figure 553 Case-to-head Tube Removal Tool, ZTSE4694

Photos of Essential Tools from VT 365 Essential Tool Kit, ZTSE5000

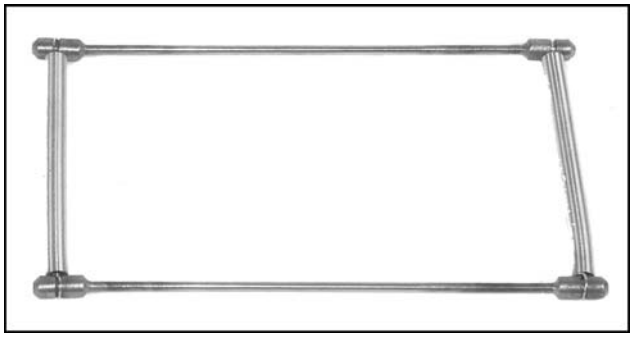

Figure 554 Piston Gauge Pins (0.082 in), ZTSE4513

Figure 555 Crankshaft Rear Seal / Wear Sleeve Installer, ZTSE4515A

Figure 556 Front Wear Sleeve Remover, ZTSE4517

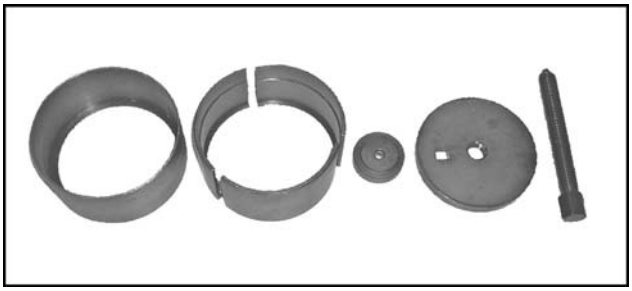

Figure 557 Crankshaft Rear Wear Sleeve Remover, ZTSE4518

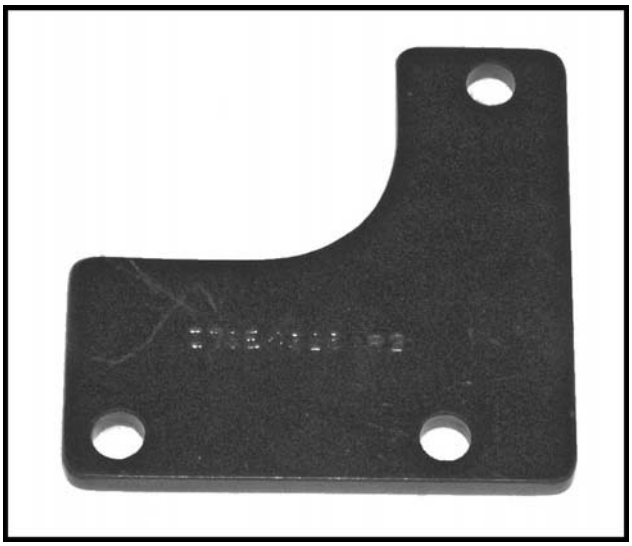

Figure 558 Oil Cooler Test Plate / Pressure Adapter, ZTSE4525

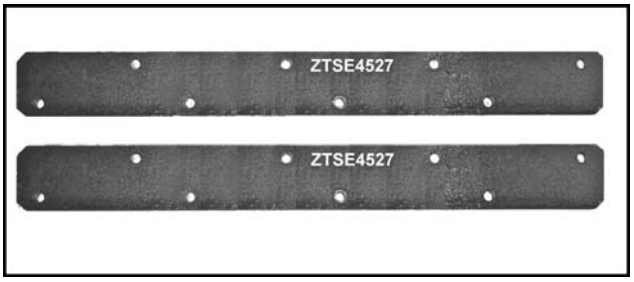

Figure 559 Intake Manifold Test Plates, ZTSE4527

Figure 560 Injector Sleeve Remover, ZTSE4528

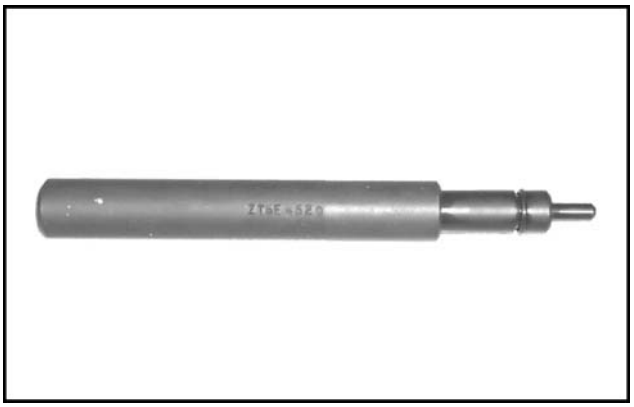

Figure 561 Injector Sleeve Installer, ZTSE4529

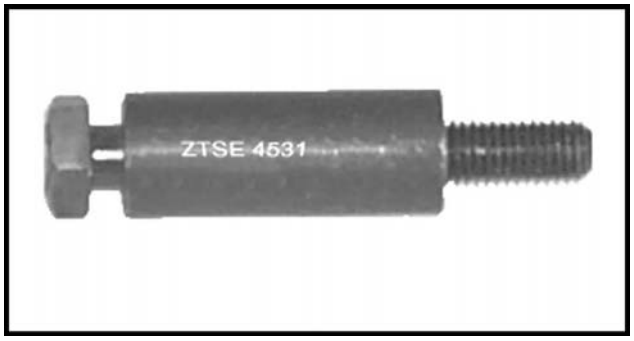

Figure 562 Glow Plug Sleeve Remover, ZTSE4531

Figure 563 Glow Plug Sleeve Installer, ZTSE4532

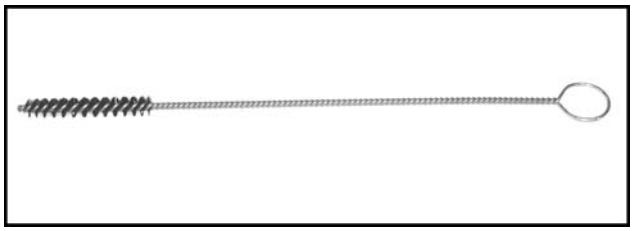

Figure 564 Glow Plug Sleeve Brush (nylon), ZTSE4533

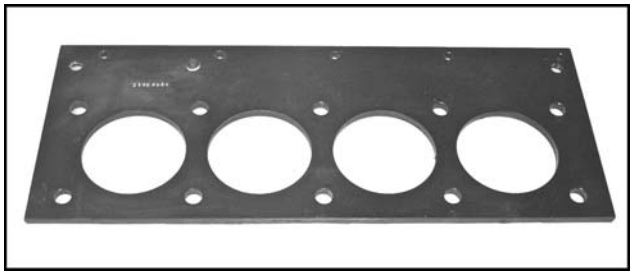

Figure 565 Cylinder Head Pressure Test Plate, ZTSE4534

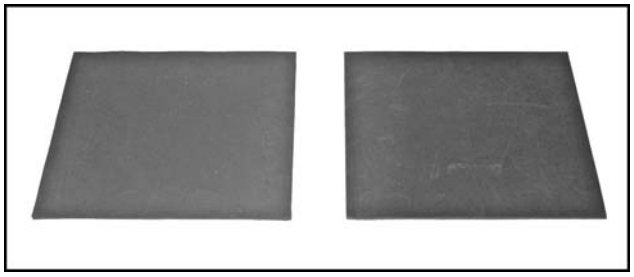

Figure 566 Oil Cooler Reservoir / High-pressure Pump Magnetic Covers, ZTSE4557

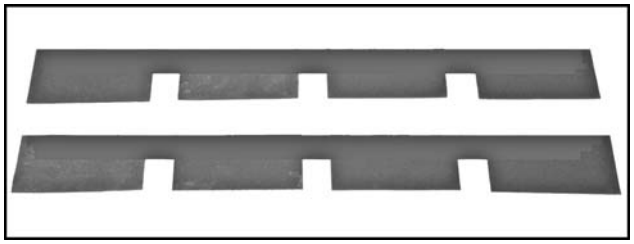

Figure 567 Magnetic Covers for Cylinder Head Intake Ports, ZTSE4559

Figure 568 Fan Wrench (pulley bolts), ZTSE4587

Figure 569 Slide Hammer Kit ⅝ in, ZTSE4398A

Figure 570 V - Engines Supplemental Service Tool Kit, ZTSE4721

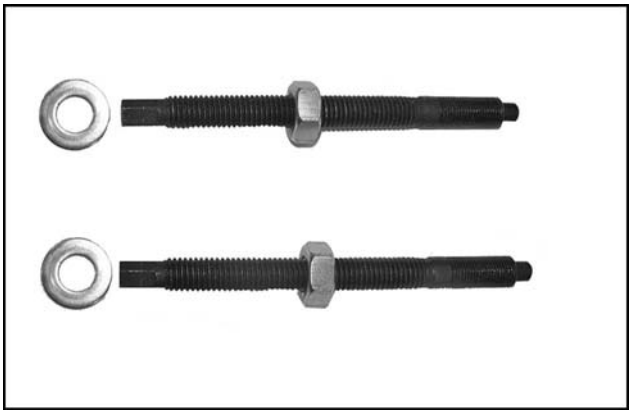

Figure 571 Crankshaft Secondary Flange Installation Studs, ZTSE4720

Figure 572 On Engine Valve Spring Compressor, ZTSE4697

Photos of Essential Tools from T 444E Essential Tool Kit, ZTSE4350

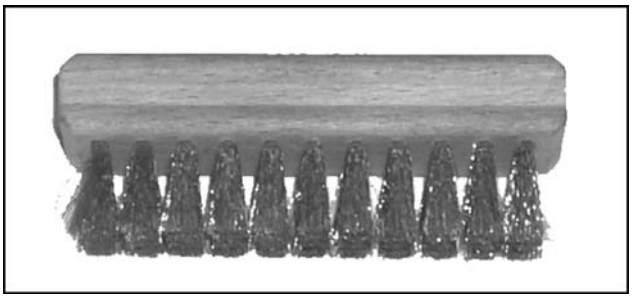

Figure 573 Injector Tip Cleaning Brush, ZTSE4301

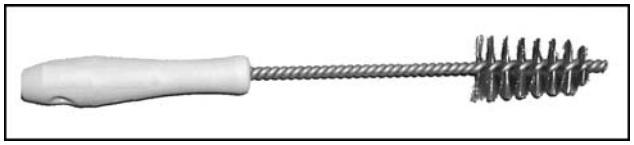

Figure 574 Injector Sleeve Brush, ZTSE43041

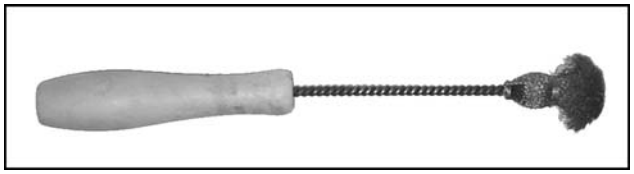

Figure 575 Injector Sleeve Flat Bottom Brush, ZTSE43042

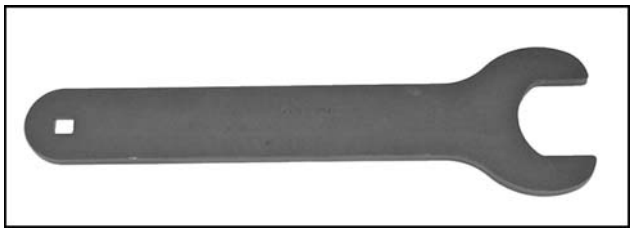

Figure 576 Fan Hub Wrench (2 inch), ZTSE43972

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