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Description

Fuel System Components

Parts Information

The fuel system consists of the following components:

- Fuel tank(s) and fuel level sending device
- Chassis mounted fuel conditioning module consisting of an electric pump, fuel heater, water separator, and primary filter
- Fuel tubing
- Secondary fuel filter and pressure regulator module
- Six fuel injector assemblies

WARNING: To avoid serious personal injury, possible death, or damage to the engine or vehicle, comply with the following when draining fuel:

- **Do not smoke**
- **Keep away from open flames and sparks.**

WARNING: Disconnect both battery ground cables. See "Safety Information (page 3)."

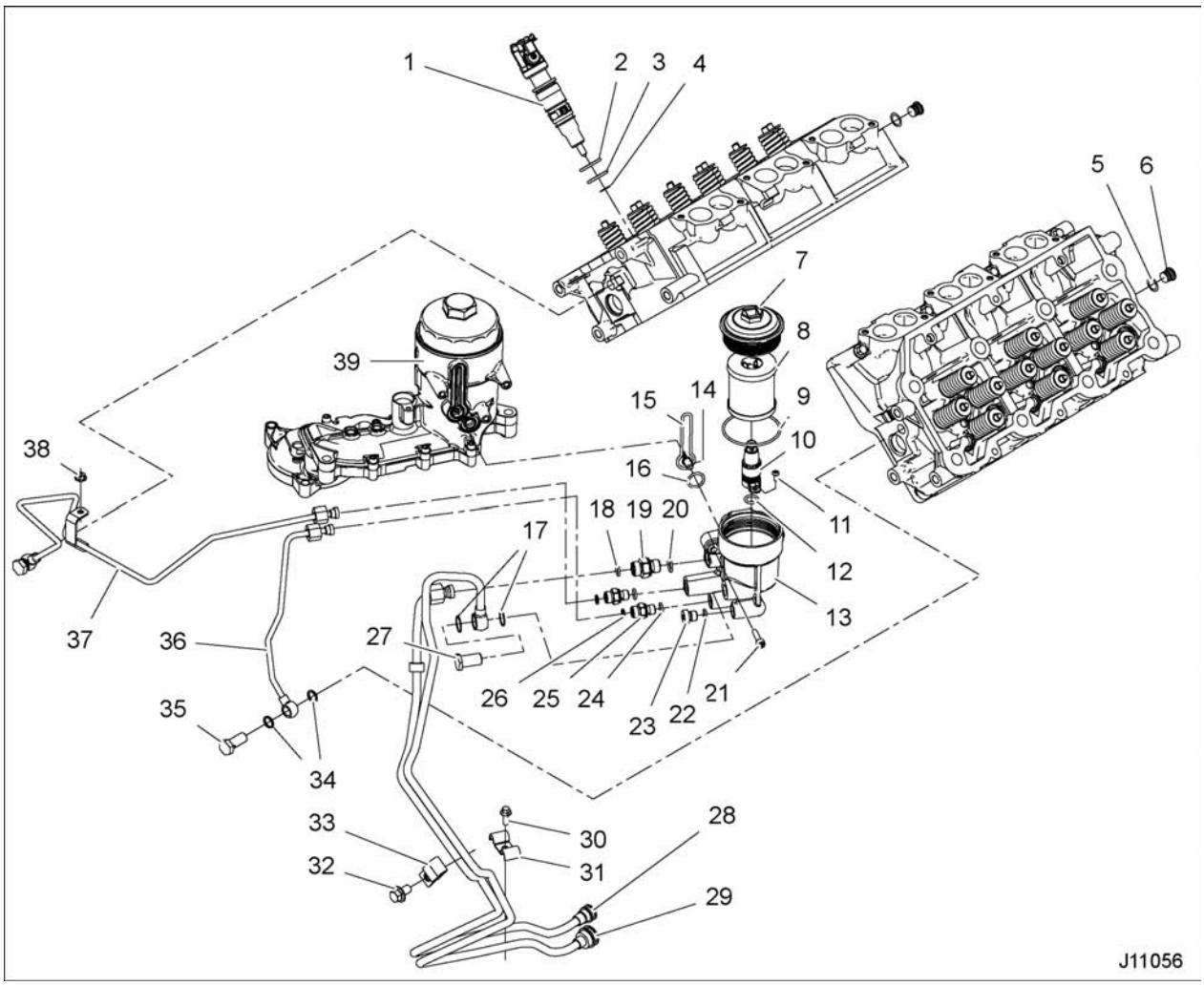

Figure 555 Fuel System Components (engine)

1. Fuel injector assembly (6)
2. Upper fuel seal
3. Lower fuel seal
4. Injector gasket
5. Viton seal (2)
6. Fuel plug, M12 (2)
7. Fuel filter cap
8. Secondary fuel filter element assembly
9. O-ring, size #146
10. Fuel return tube assembly
11. Screw, 8/32 x 3/8 in (2)
12. O-ring, size #112
13. Secondary fuel filter housing assembly
14. Poppet, spring and gasket
15. Pressure regulator cover seal
16. O-ring seal, size #115
17. Fitting gasket (2)
18. O-ring seal, size #012
19. Fuel inlet fitting, M16
20. O-ring seal
21. Screw, M6 x 25 (3)
22. O-ring seal
23. Diagnostic pressure test port plug, M12
24. O-ring seal (2)
25. Fuel outlet fitting, M12 (2)
26. O-ring seal, size #011 (2)
27. Banjo bolt
28. Fuel return to tank tube assembly
29. Fuel supply to filter tube assembly
30. Bolt, M6 x 16
31. Saddle clamp
32. Bolt, M10 x 16
33. Dual tube clamp
34. Copper washers (4)
35. Banjo bolt, M12 with check valve (2)
36. Fuel supply line, left cylinder head
37. Fuel supply line, right cylinder head
38. Nut, M6
39. Oil filter housing assembly

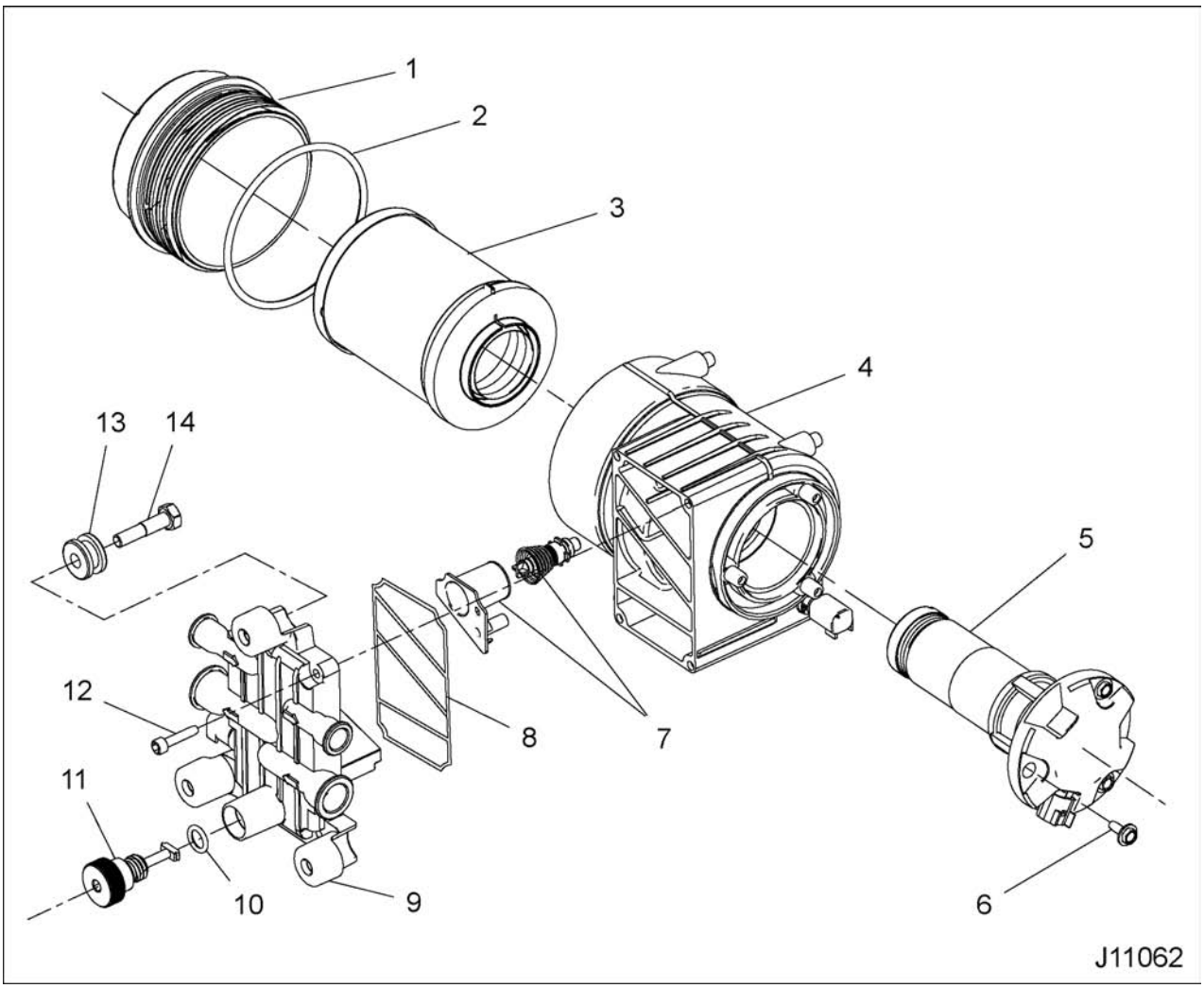

Figure 556 Horizontal Fuel Conditioning Module (HFCM)

1. Primary filter element cap
2. Cap O-ring seal
3. Primary fuel filter element
4. Primary fuel filter housing
5. Electric fuel pump
6. Self-tapping screw, #10 (3)
7. Thermo recirculating valve assembly
8. Cover plate gasket
9. Cover plate
10. O-ring seal
11. Water drain knob
12. Screw, M5 x 23 (4)
13. Mounting grommet (3)
14. Bolt with shoulder, M8 x 40 (3)

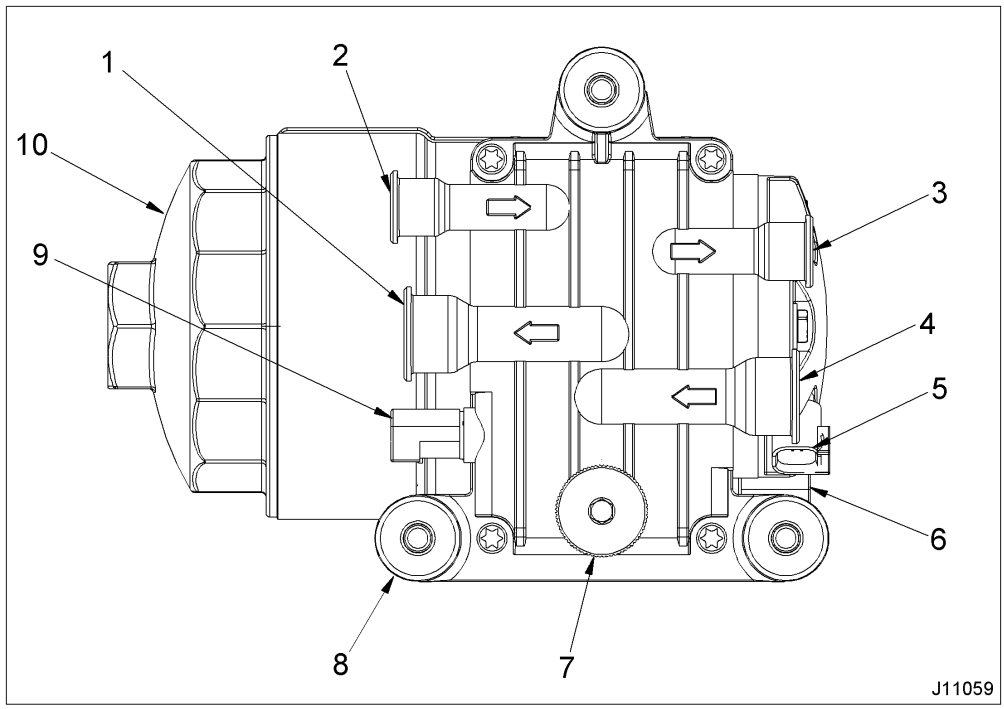

Figure 557 HFCM (chassis mounted)

1. Fuel supply port to engine
2. Fuel return port from engine
3. Fuel return port to tank
4. Fuel supply port to HFCM
5. Electric pump connection
6. Water in fuel electrical connection
7. Water drain knob
8. Mounting grommet (3)
9. Fuel heater electrical connection
10. Primary filter element cap

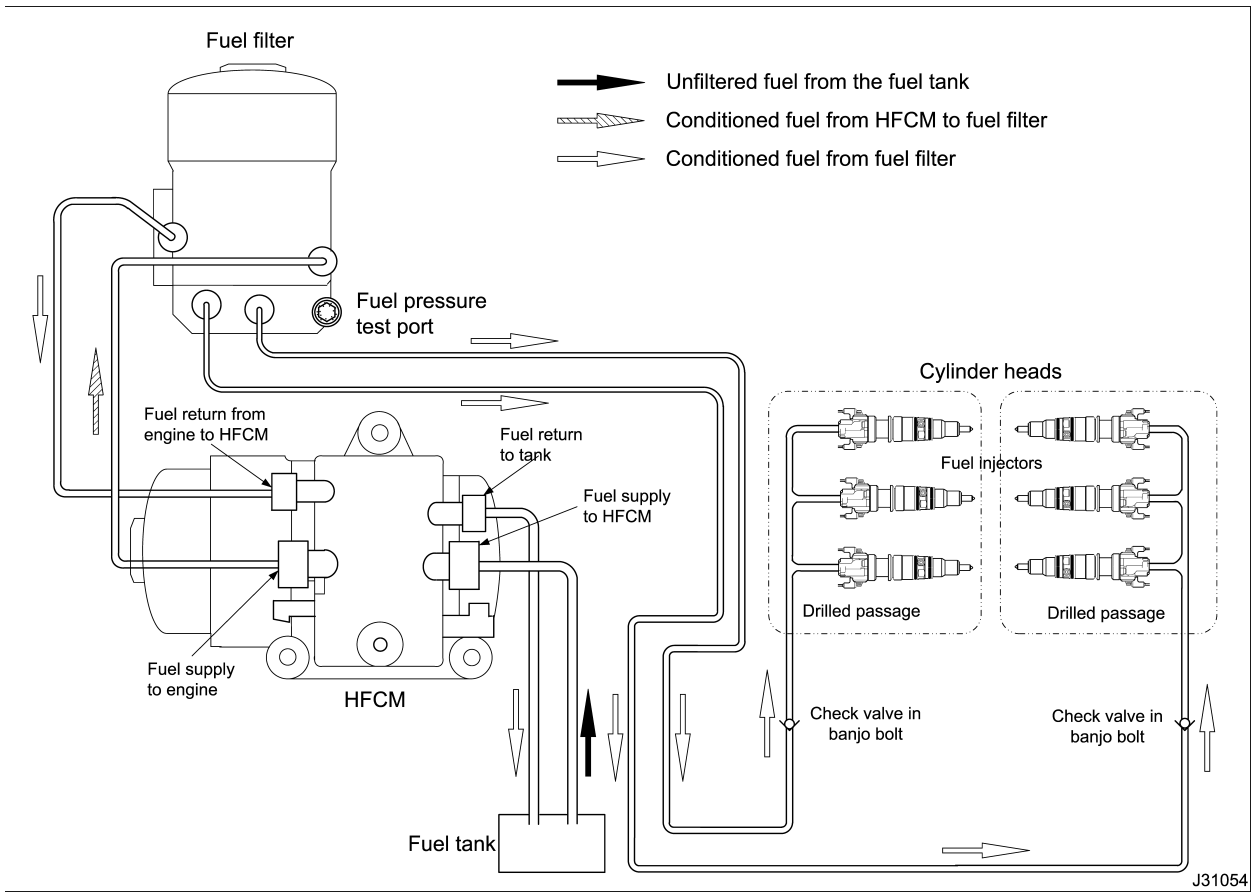

Figure 558 Fuel system schematic

Removal and Disassembly

Intake Air Duct

WARNING: To avoid serious personal injury, possible death, or damage to the engine or vehicle, do not turn "KEY ON" during any phase of disassembly. This engine is equipped with an electric fuel pump. Turning on the ignition key could pump fuel to disconnected tubing, resulting in fire if an ignition source is available.

Figure 559 Intake air duct mounting bolt

1. Remove bolt (M6 x 16) securing intake air duct to intake manifold.
2. Remove intake air duct clamp at turbocharger.
3. Remove air inlet breather hose and intake air duct as an assembly.
4. Install Turbocharger Inlet Guard or protective cap onto turbocharger inlet. See Special Service Tools (page 347).

Secondary Fuel Filter

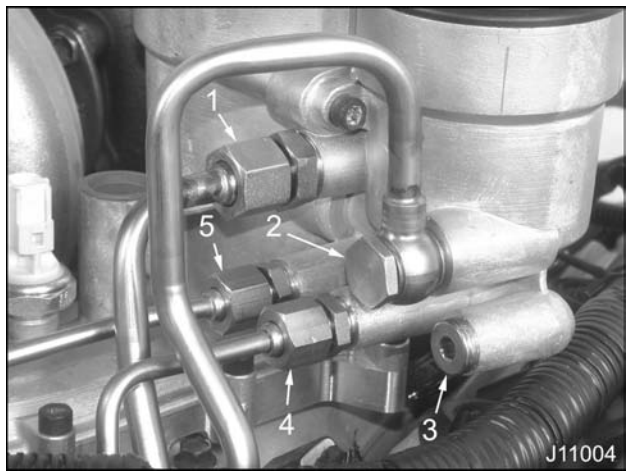

Figure 560 Secondary fuel filtration tubing

1. Fuel return (to tank)
2. Fuel supply (from tank)
3. Diagnostic port plug, M12
4. Fuel supply tube to left cylinder head
5. Fuel supply tube to right cylinder head

1. Drain the fuel filter housing by placing a suitable container beneath the fuel diagnostic port plug. Remove plug, then crack open fuel filter cap to allow air into filter housing. Place plug back into port when filter housing is empty.
2. Remove all tube connections attached to fuel filter assembly as follows:

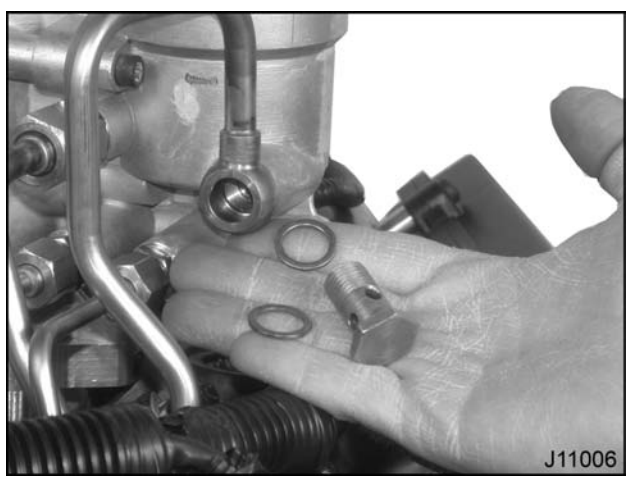

Figure 561 Fuel supply tube and fitting gaskets

a. Remove fuel filter banjo bolt and discard copper washers.

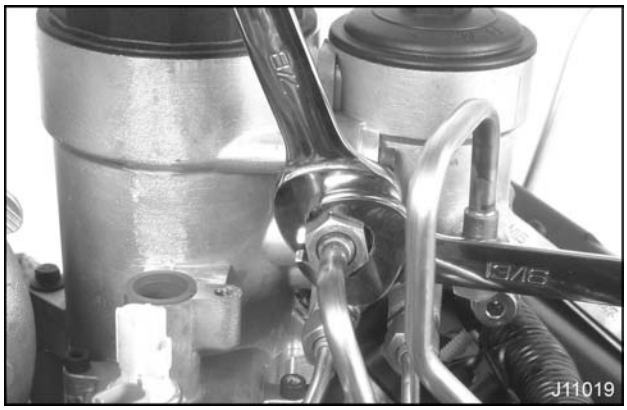

Figure 562 Fuel return tube fitting

b. Using backup wrenches, disconnect fuel return tube fitting and discard O-rings.

c. Using backup wrenches, disconnect left and right cylinder head fuel tubing and discard O-rings.

3. Using the Cap Kit (all), cap all open ports on the secondary fuel filter housing. See Special Service Tools (page 347).

4. Remove secondary fuel filter assembly mounting screws (M6 x 25) for further disassembly and inspection.

5. Remove secondary fuel filter assembly.

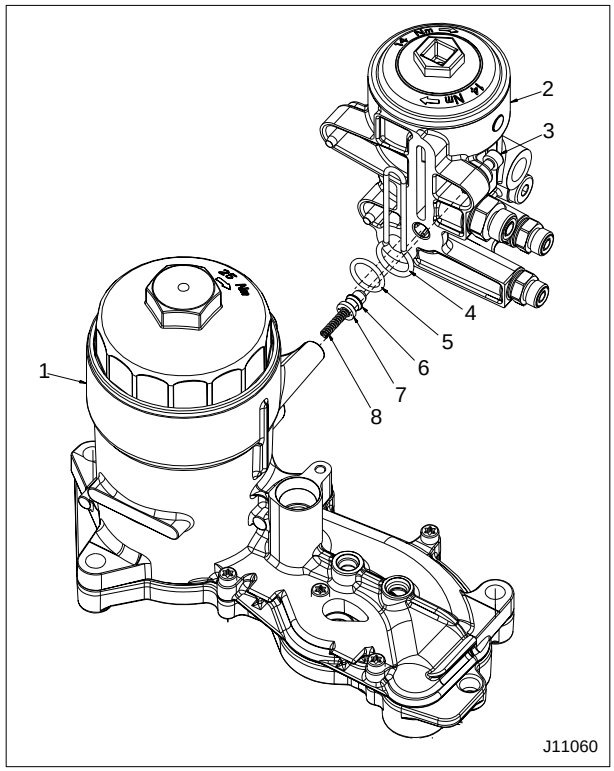

Figure 563 Pressure regulator poppet assembly

1. Oil filter assembly
2. Fuel filter assembly
3. Screw, M6 x 25 (3)
4. Pressure regulator cover gasket
5. Viton O-ring, size #115
6. Poppet gasket seal
7. Brass poppet
8. Pressure regulator valve spring

6. Removing the filter assembly exposes the pressure regulator poppet components. Remove these parts for later inspection.

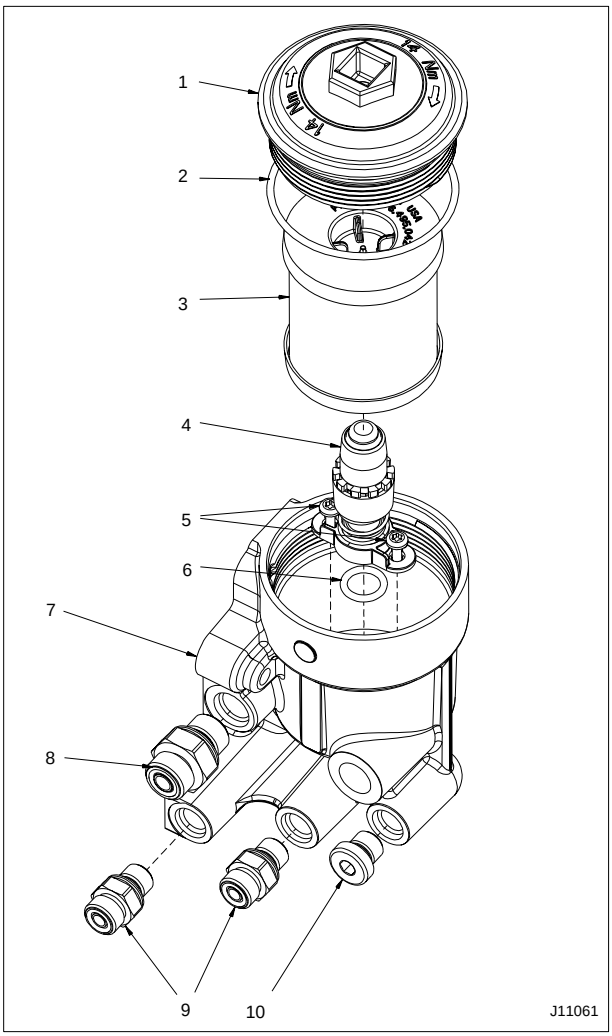

Figure 564 Fuel filter assembly

1. Fuel filter cap
2. O-ring seal
3. Fuel filter element
4. Fuel return tube assembly
5. Screw, 8/32 x 3/8 in (2)
6. Viton O-ring, size #112
7. Fuel filter housing
8. Fuel return fitting, M16
9. Left and right cylinder head fuel tube assembly fitting, M12 (2)
10. Diagnostic pressure test port plug, M12

7. Loosen fuel filter cap and discard O-ring seal.
8. Before removing filter, depress filter to verify spring loaded fuel return tube is free.
9. Lift out secondary fuel filter element and discard.

Fuel System Tubing

1. Remove one bolt (M6 x 16) securing fuel return and supply tubing to oil pan.
2. Remove one bolt (M10 x 16) securing fuel return and supply tubing to left cylinder head.
3. Remove nut (M6) securing right fuel supply tube to intake air elbow.
4. Remove banjo bolt securing each fuel supply tube to its respective cylinder head. Discard copper washers.

Horizontal Fuel Conditioning Module (HFCM)

The HFCM is mounted in different locations for the CF and stripped chassis applications.

The CF application has the HFCM mounted on the vehicle frame rail on the driver's side.

The stripped chassis application has the HFCM mounted on a bracket attached to the transmission housing on the passenger side.

For both applications, see "Horizontal Fuel Conditioning Module (HFCM)" (Figure 556) when doing the following steps:

1. Place a container under HFCM to drain fuel and any accumulated water. Rotate drain knob to release fuel pressure and drain module.
2. Disconnect fuel pump, fuel heater, and water-in-fuel electrical connectors.
3. Press in retaining clips to release fuel hoses from housing.
4. Disconnect fuel hoses and discard fuel hose retaining clips
5. Remove three mounting nuts (M8) and fuel conditioning module from chassis.

Disassembly of the HFCM

1. Remove primary filter cap and discard O-ring seal.
2. Remove primary filter element and discard.
3. Remove four cover plate screws (M5 x 23) and discard cover plate gasket.

4. Remove heater assembly.
5. Remove drain plug assembly.
6. Remove the thermo recirculating valve assembly.
7. Remove three fuel pump screws (#10 self-tapping) and discard O-rings.

Fuel Injectors

NOTE: See the Cylinder Head and Valve Train section for fuel injector removal procedure.

Cleaning and Inspection

1. Inspect fuel lines for misalignment, chaffing or other signs of damage. Replace fuel lines if necessary.
2. Check poppet valve and spring for signs of misalignment. Inspect poppet gasket seal (Figure 563) for signs of uneven seating with the fuel filter housing.
3. Check fuel return tube for broken or cracking pieces.
4. Clean out any accumulated sediment in the bottom of the secondary fuel filter housing and HFCM housing.
5. Wash all fuel filter components in a suitable solvent and dry with filtered compressed air. See "Safety Information (page 3)."
6. Check HFCM fuel heater for open or unusually high resistance if a diagnostic trouble code (DTC) was encountered. Refer to *Engine Diagnostics*.

Assembly and Installation

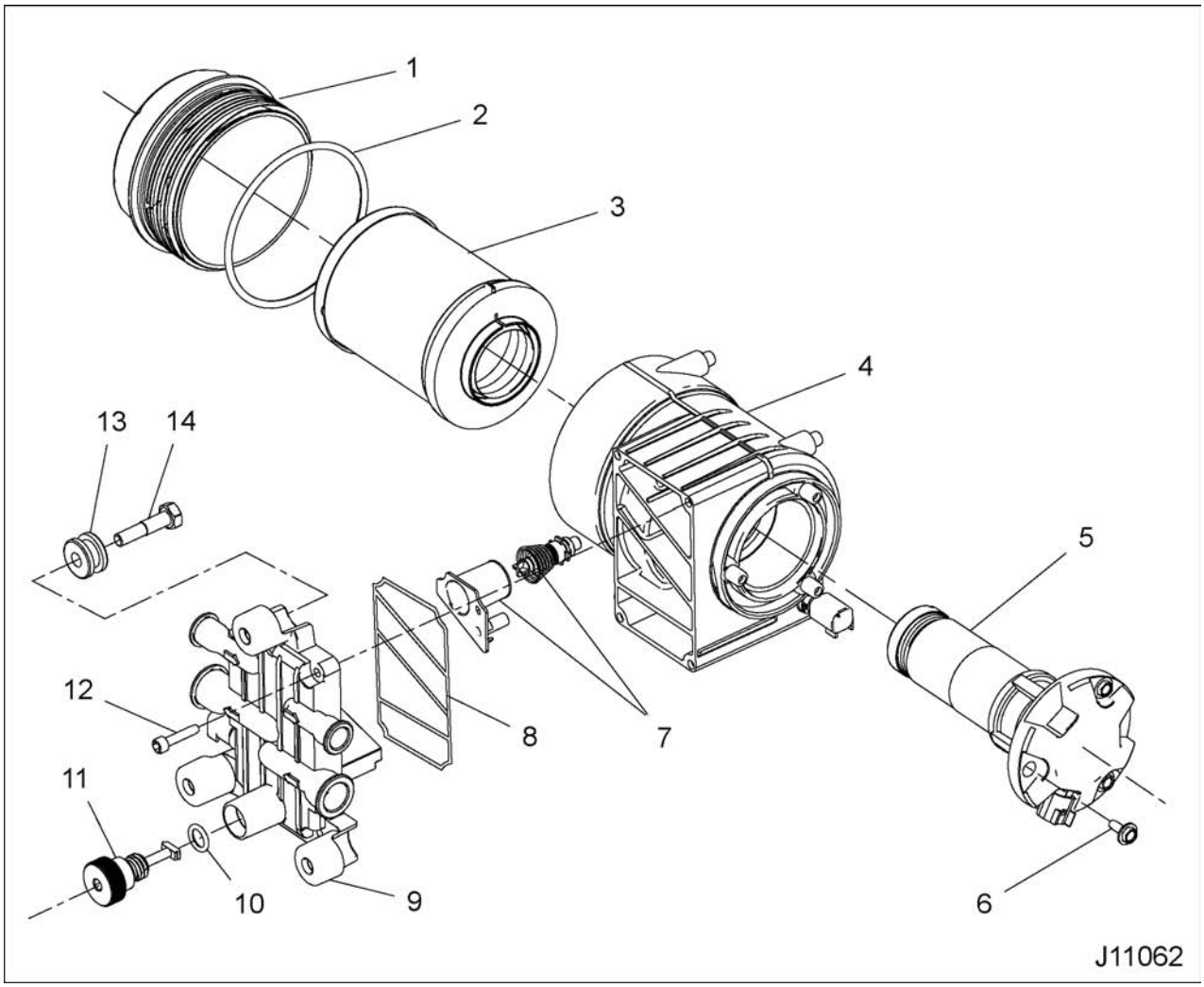

Figure 565 Horizontal Fuel Conditioning Module (HFCM)

1. Primary filter element cap
2. Cap O-ring seal
3. Primary fuel filter element
4. Primary fuel filter housing
5. Electric fuel pump
6. Self-tapping screw, #10 (3)
7. Thermo recirculating valve assembly
8. Cover plate gasket
9. Cover plate
10. O-ring seal
11. Water drain knob
12. Screw, M5 x 23 (4)
13. Mounting grommet (3)
14. Bolt with shoulder, M8 x 40 (3)

Assembly of the HFCM

1. Install the thermo recirculating valve assembly into housing.
2. Install heater assembly.
3. Install drain plug assembly.
4. Place cover plate gasket onto cover plate.
5. Position cover plate onto housing and thread in four screws (M5 x 23). Tighten screws to the Special Torque (page 347).
6. Install new O-rings onto the fuel pump and lubricate with clean fuel.

7. Install fuel pump assembly with three screws (#10 self-tapping). Tighten screws to the Special Torque (page 347).
8. Install primary filter element.
9. Coat a new O-ring gasket seal with fuel and install onto primary filter cap. Thread cap into HFCM housing and tighten to the Special Torque (page 347).

HFCM

1. CF – Install HFCM to chassis rail. Thread three mounting nuts (M8) onto mounting bolts (M8 x 40) and tighten to the Special Torque (page 347).

   Stripped chassis – Install HFCM to transmission housing mounting bracket. Thread three mounting nuts (M8) onto mounting bolts (M8 x 40) and tighten to the Special Torque (page 347).
2. Install new retaining clips onto fuel hoses.
3. Install fuel hoses onto HFCM cover plate.
4. Connect the water-in-fuel, fuel heater, and fuel pump electrical connectors.
5. Close water drain knob assembly.

Secondary Fuel Filter

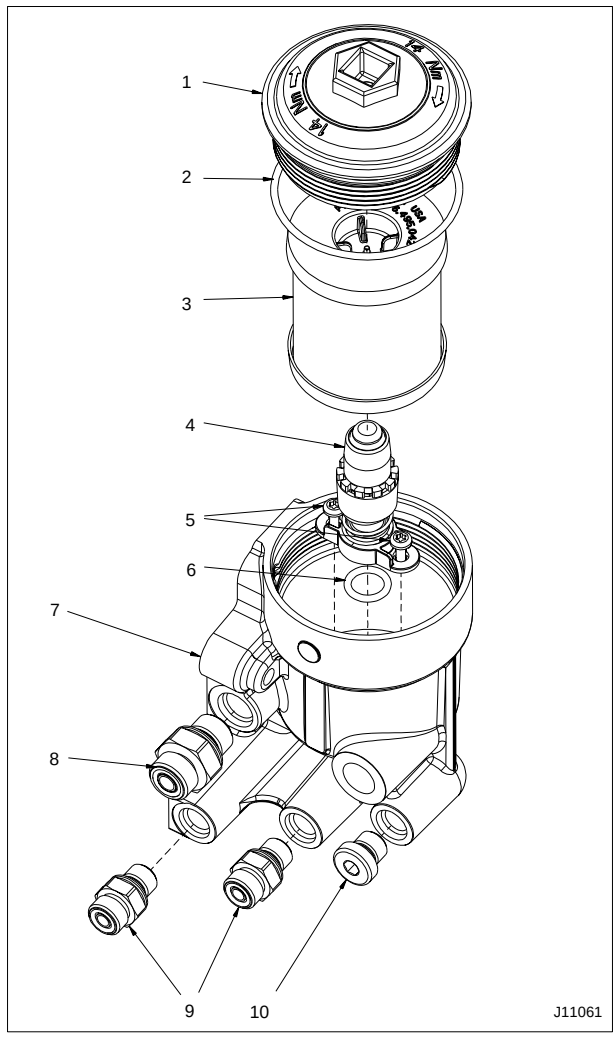

Figure 566 Fuel filter assembly

1. Fuel filter cap
2. O-ring seal
3. Fuel filter element
4. Fuel return tube assembly
5. Screw, 8/32 x 3/8 in (2)
6. Viton O-ring, size #112
7. Fuel filter housing
8. Fuel return fitting assembly, M16
9. Left and right cylinder head fuel tube assembly fitting, M12 (2)
10. Diagnostic pressure test port plug, M12

1. Assemble fuel filter as shown in the preceding illustration:

a. Place a new O-ring gasket into the base of the fuel filter housing.

b. Place return tube assembly over O-ring and secure with two screws (8/32 x 3/8 in). Tighten screws to the Special Torque (page 347).

c. Position fuel filter element over return tube. Rotate element slightly until filter engages teeth and can be moved up and down against spring pressure.

d. Apply a coating of diesel fuel to a new O-ring and install onto fuel filter cap. Thread fuel filter cap onto filter housing and tighten to the Special Torque (page 347).

e. If fuel inlet and outlet fittings have been removed from housing, you must install new O-rings onto fittings. These O-rings are serviceable, however are not included in the preceding illustration. Refer to Fuel System Components (engine) (Figure 555) for additional details.

f. If removed, install fuel inlet and outlet fittings onto filter housing.

CAUTION: To prevent engine damage, tighten fuel cap on fuel filter assembly. The engine will not run without the fuel filter element in place. The fuel filter element is required to open the valve in the fuel return tube assembly, allowing fuel to flow into the filter. This feature protects injectors from contamination if element is not installed.

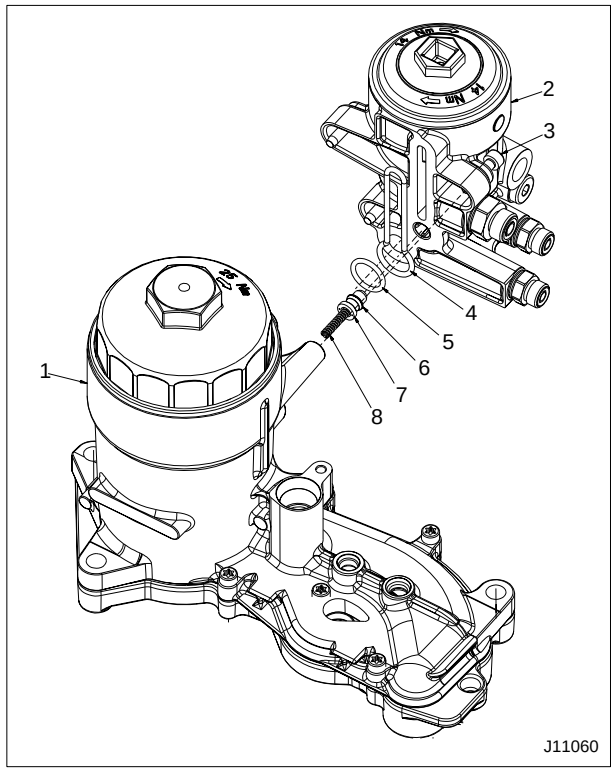

Figure 567 Pressure regulator poppet assembly

1. Oil filter assembly
2. Fuel filter assembly
3. Screw, M6 x 25 (3)
4. Pressure regulator cover gasket
5. Viton O-ring, size #115
6. Poppet gasket seal
7. Brass poppet
8. Pressure regulator valve spring

2. Install fuel filter pressure regulator components as follows:

   a. Place a new pressure regulator cover gasket and new O-ring into their respective recesses within the fuel filter housing.

   b. Make sure brass poppet has a new gasket seal on it before placing assembly into fuel filter housing. Brass poppet goes in first, spring is oriented toward oil filter side.

   c. Place three screws (M6 x 25) through the fuel filter housing and attach them to the oil filter assembly. Thread screws in evenly, watching the alignment of gasket, O-ring and poppet spring.

3. Install the secondary fuel filter assembly onto oil filter assembly.

Fuel System Tubing

1. Uncap all ports on fuel filter housing.
2. Install all tubing connections (hand tight) to fuel filter assembly, cylinder heads, and anchoring points as follows:

   NOTE: Tighten all fittings and anchoring clamps to the respective torque value only after all tubing connections have been hand threaded.

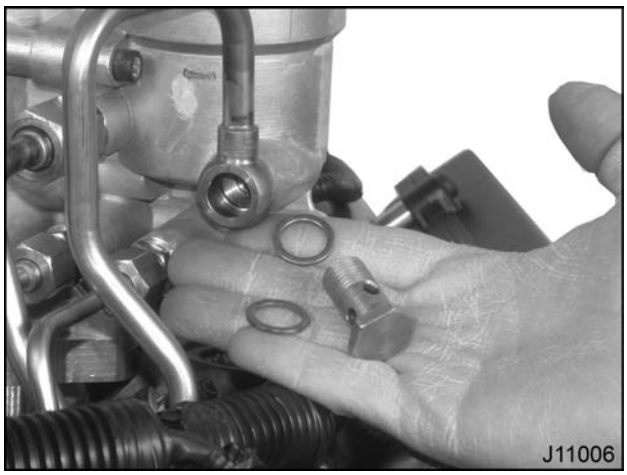

Figure 568 Fuel supply banjo bolt

   a. Install a new copper washer onto banjo bolt. Slide screw and gasket through fuel supply tubing. Place another new copper washer onto banjo bolt and thread tubing into filter housing. Tighten screw to the Special Torque (page 347).
   b. Using backup wrench, connect and tighten fuel return tube fitting to the Special Torque (page 347).

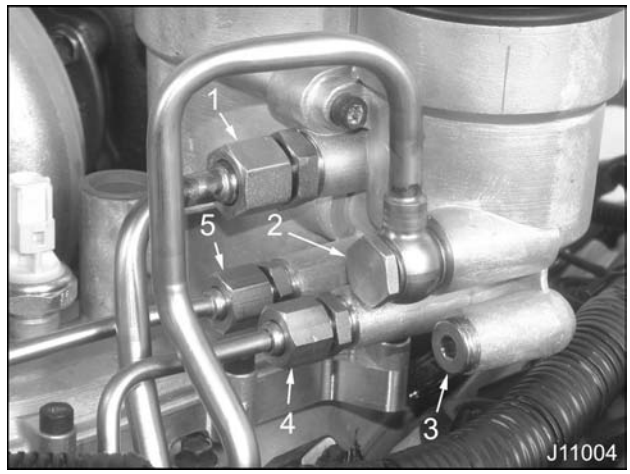

Figure 569 Secondary fuel filtration tubing

1. Fuel return (to tank)
2. Fuel supply (from tank)
3. Diagnostic port plug, M12
4. Fuel supply tube to left cylinder head
5. Fuel supply tube to right cylinder head

   c. Connect left and right cylinder head fuel tubes to fuel filter assembly.
   d. Place a new O-ring seal on diagnostic port plug (M12) and tighten to the Special Torque (page 347).

Figure 570 Fuel return tube

3. Install new copper washers onto left and right banjo bolt fittings.
4. Connect banjo bolt fittings to the left and right cylinder heads. Tighten fittings to the Special Torque (page 347).

5. Anchor right fuel tubing to air inlet elbow stud. Tighten nut (M6) to the Special Torque (page 347).
6. Install one bolt (M10 x 16) to secure fuel return and supply tubing to the left cylinder head. Tighten bolt to the Standard Torque (page 405).
7. Install one bolt (M6 x 16) to secure fuel return and supply tubing to oil pan. Tighten bolt to the Standard Torque (page 405).

Intake Air Duct

1. Remove intake guard or protective cap from turbocharger air inlet.
2. Install air inlet breather hose elbow and intake air duct as an assembly.

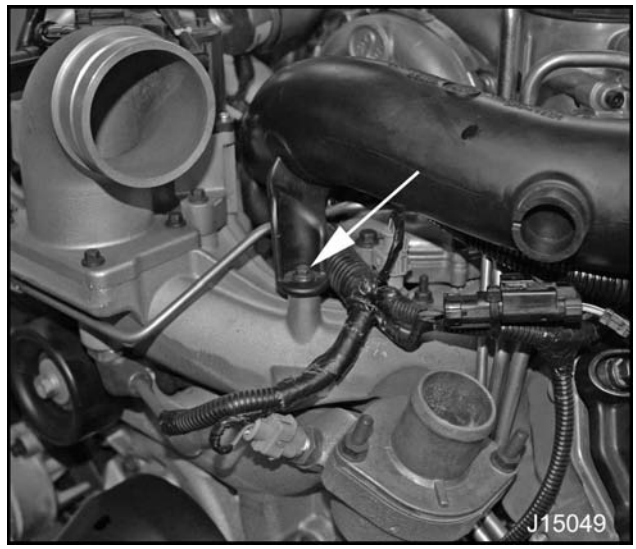

Figure 571 Air inlet duct mounting bolt

3. Install bolt (M6 x 16) to secure air inlet duct to intake manifold. Position clamp at turbocharger air inlet. Tighten bolt and clamp to the Special Torque (page 347).

Fuel Injectors

NOTE: See the Cylinder Head and Valve Train section for fuel injector installation instructions.

Specifications

Fuel System Components	
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)

Special Torque

Fuel System Components	
Banjo bolt, 12 mm	38 N·m (28 lbf·ft)
Diagnostic port plug, M12	4-9 N·m (35-75 lbf·in)
Fuel filter cap (secondary)	14 N·m (124 lbf·in)
Fuel filter housing mounting screws, M6 x 25	10 N·m (88 lbf·in)
Fuel supply hollow screw, M14	35 N·m (26 lbf·ft)
Fuel pump mounting screws	5 N·m (44 lbf·in)
Fuel return tube at filter	25 N·m (19 lbf·ft)
Fuel return tube 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 nuts (M8)	15 N·m (132 lbf·in)
Left and right cylinder head supply tubing at filter	25 N·m (18 lbf·ft)
Oil supply tube bolt, M6 x 20	13 N·m (120 lbf·in)
Plug assembly, M12 (rear of cylinder head)	36 N·m (27 lbf·ft)
Primary filter cap	25 N·m (18 lbf·ft)
Right cylinder head supply tubing anchor at inlet elbow	11 N·m (96 lbf·in)

Special Service Tools

Fuel System Tools	
Description	**Tool Number**
Cap Kit (all)	ZTSE4610
Turbocharger Inlet Guard	ZTSE4293

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Related Components

NOTE: There are two different rear cover assemblies in use depending upon vehicle application.

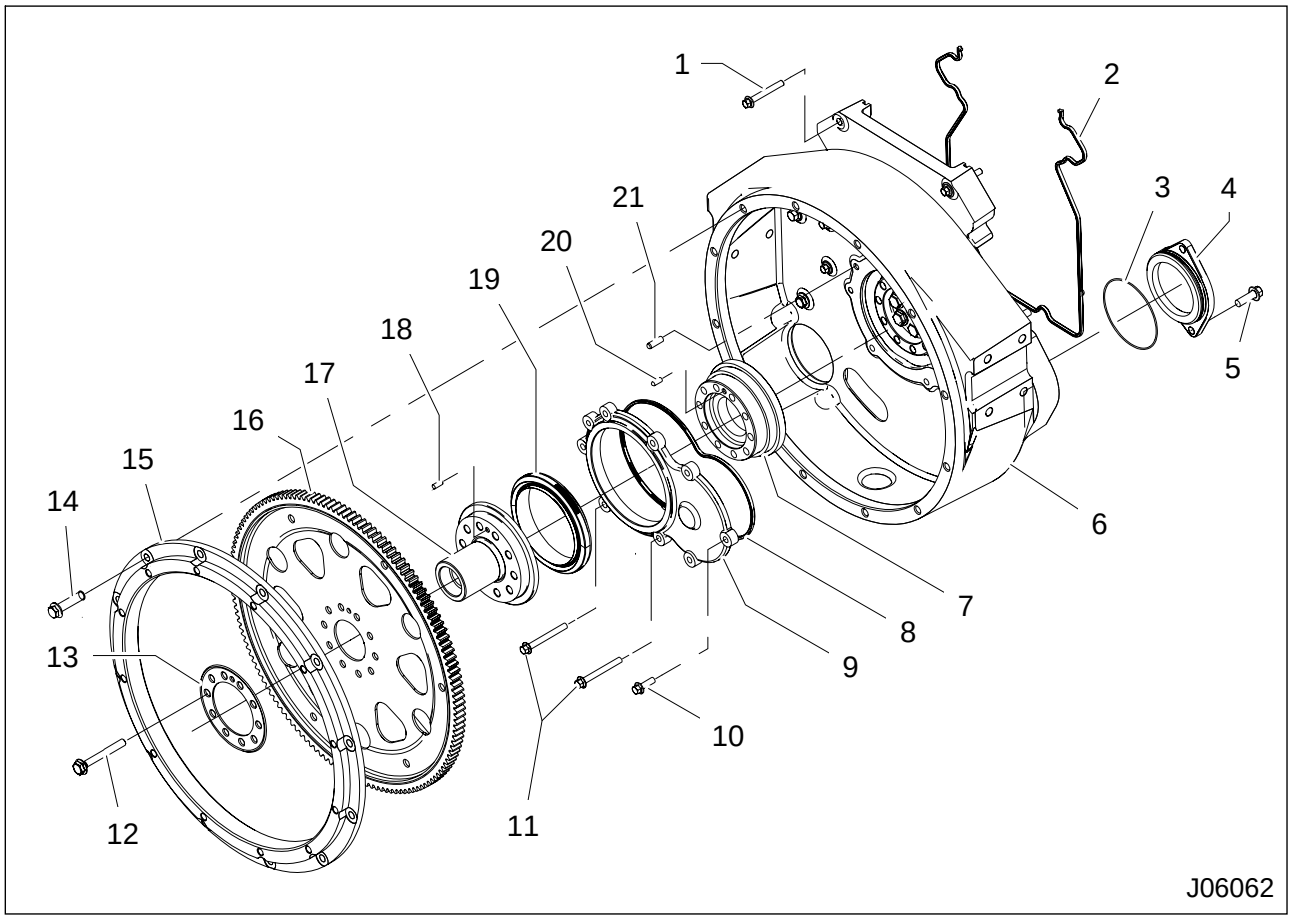

Figure 572 Rear cover and related components (stripped chassis)

1. Bolt, M8 x 55 (5), Refer to (Figure 593)
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

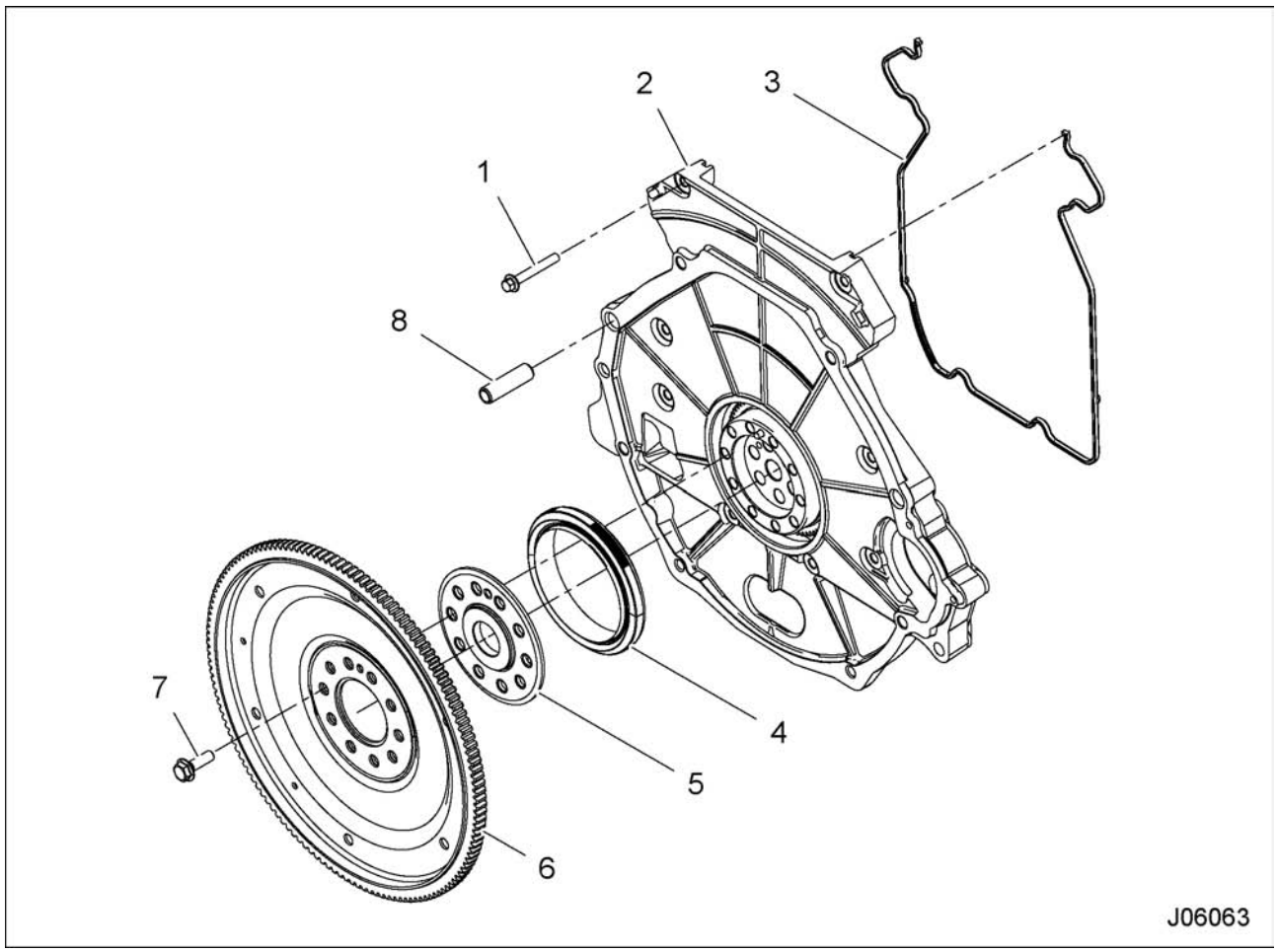

Figure 573 Rear cover and related components (CF chassis)

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

Ring Gear Runout Check

CAUTION: To prevent engine damage, check flywheel surface runout. These checks are performed to ensure proper engine to transmission alignment. Failure to ensure proper bore concentricity and face runout may result in reduced clutch and/or transmission life.

1. Check for ring gear damage associated with the starter pinion. If damage is found, skip ring gear surface run out check. Flywheel should be replaced.

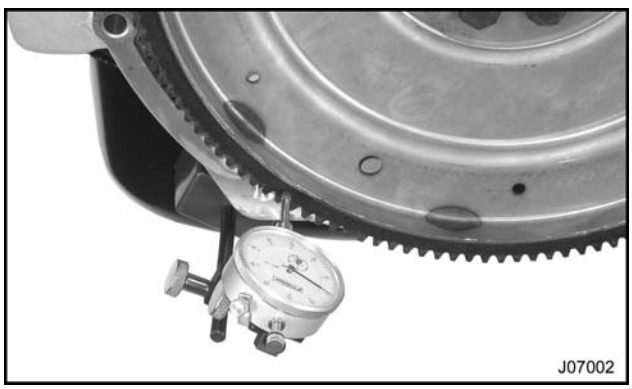

Figure 574 Checking ring gear for a run out condition (typical)

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 onto engine. Place dial indicator tip against surface of ring gear. See Special Service Tools (page 372).

   B. Zero the dial indicator.

   C. Rotate crankshaft slowly (clockwise) and record total indicator runout. See Specifications (page 372).

3. Replace ring gear if total indicator runout has been determined to be out of specifications.

Flywheel

WARNING: To avoid serious personal injury or possible death, do not reuse the flywheel bolts.

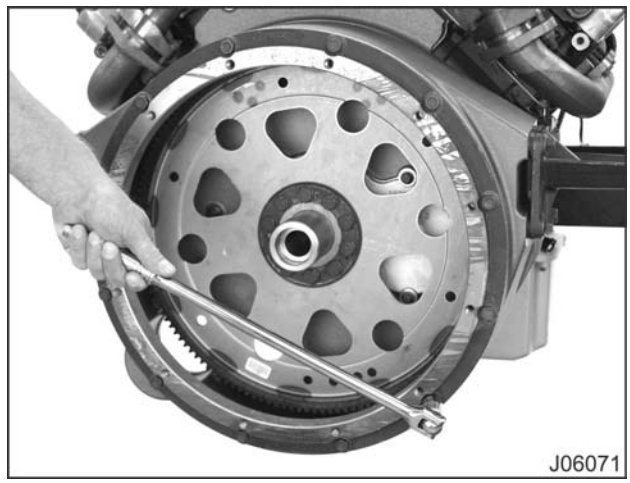

Figure 575 Removing the transmission adapter ring bolts (stripped chassis)

NOTE: Stripped chassis applications only – In order to remove the flywheel assembly, remove all 12 bolts (M10 x 35) securing the transmission adapter ring to the rear cover.

Figure 576 Removing the flywheel bolts (typical)

1. Remove 10 flywheel mounting bolts (M10 x 31 - CF) (M10 x 77 - stripped chassis) and discard bolts.

NOTE: The 10 flywheel mounting bolts are not reusable.

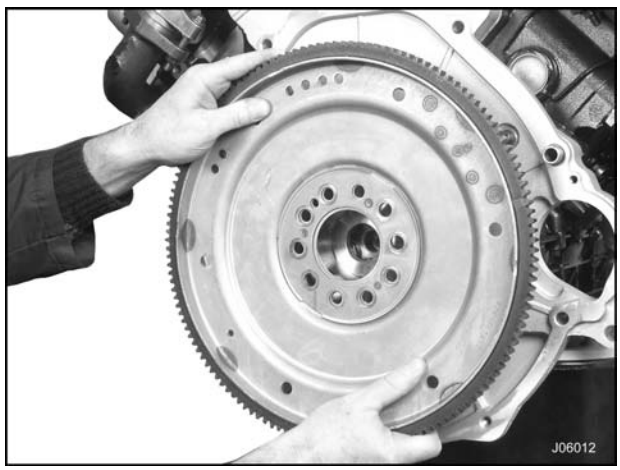

Figure 577 Removing the flywheel (typical)

2. Remove flywheel assembly.

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

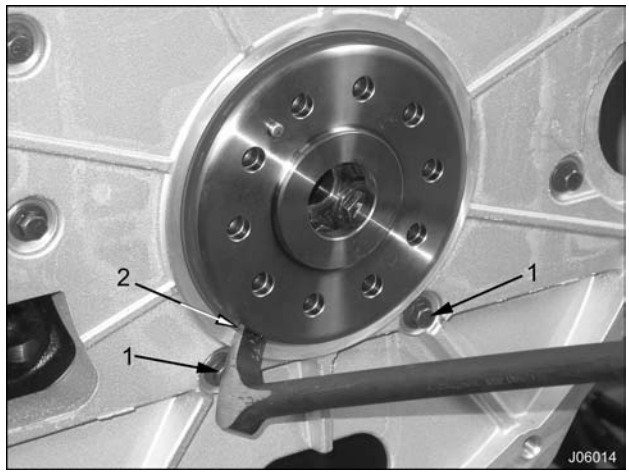

Figure 578 Removing the rear flywheel adapter (CF)

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

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.

3. Use the head of the rear cover bolt for supporting the heel bar to remove the flywheel adapter.
4. Place the heel bar on the head of the rear cover bolt and the hook under the lip of the flywheel adapter.
5. Alternate between the two rear cover head bolts to pry off the flywheel adapter.

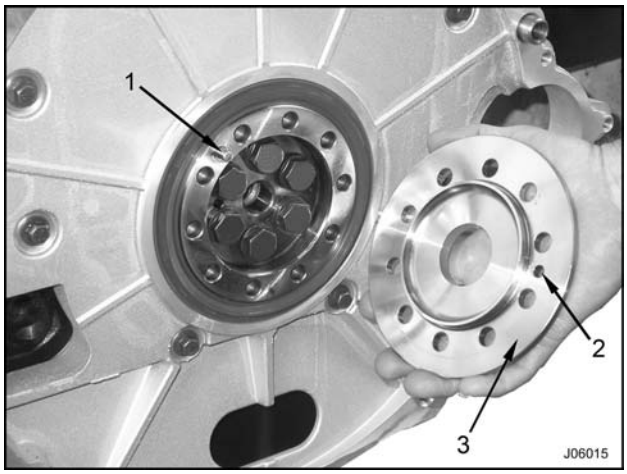

Figure 579 Flywheel adapter removed (CF)

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

6. Remove flywheel adapter or adapter hub.

Rear Main Seal and Wear Sleeve

CF Applications

WARNING: To avoid serious personal injury or possible death, wear safety glasses with side shields when performing the following procedure. See "Safety Information (page 3)."

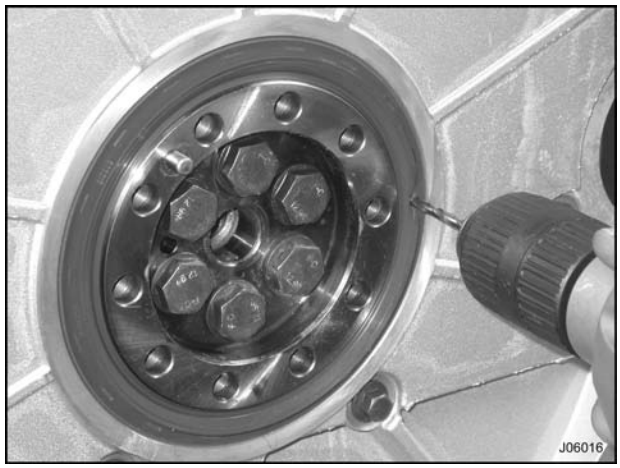

Figure 580 Drilling starter holes (CF)

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

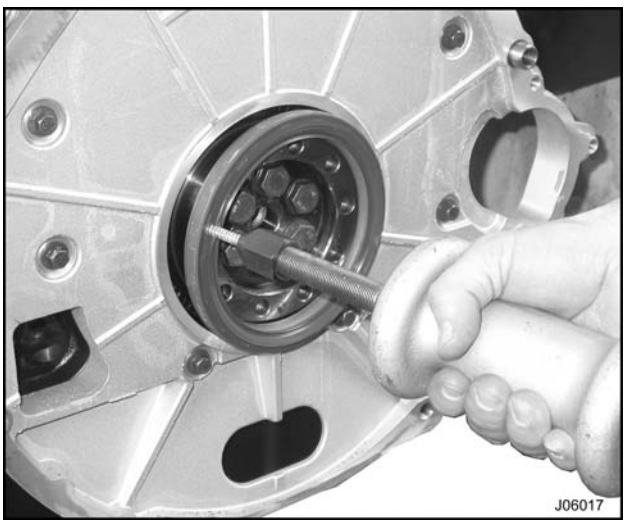

Figure 581 Removing the rear main oil seal (CF)

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 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.

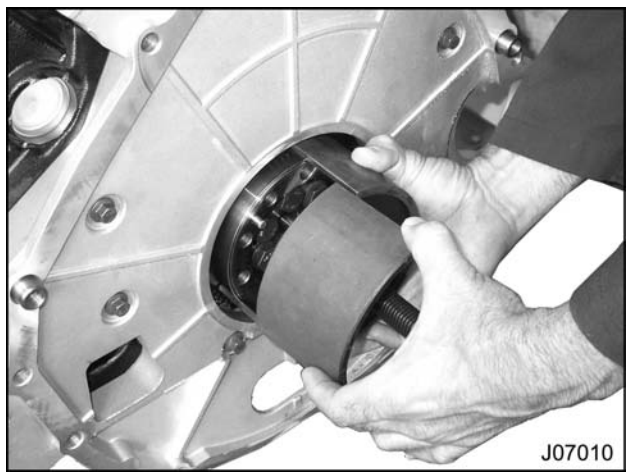

Figure 582 Installing the Rear / Wear Sleeve Removal Tool (CF)

4. Install the Rear / Wear Sleeve Removal Tool (tri-shell components).

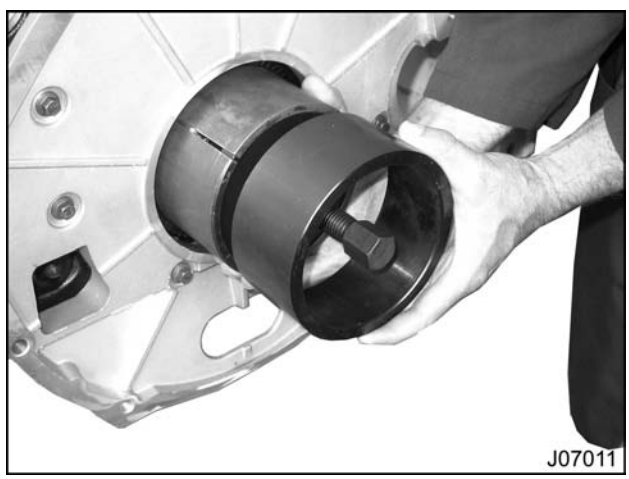

Figure 583 Installing the outer ring (CF)

5. Install the Rear / Wear Sleeve Removal Tool (outer ring component). Make sure wear sleeve removal tool shells are securely in place behind wear sleeve prior to applying any force to threaded shaft.

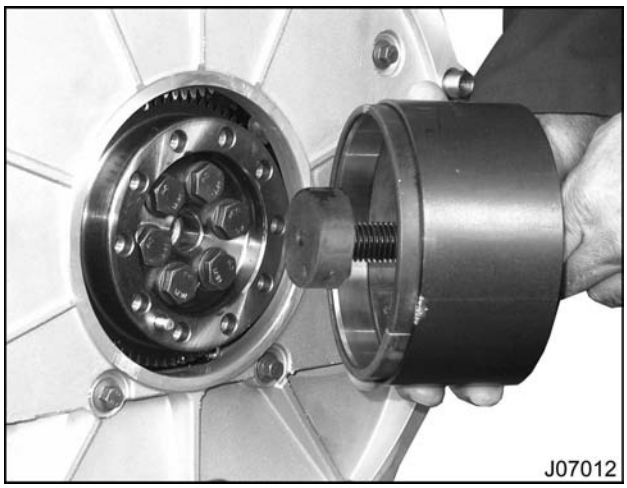

Figure 584 Wear sleeve removed (CF)

6. Thread puller shaft tool in and remove wear sleeve.

Stripped Chassis Applications

WARNING: To avoid serious personal injury or possible death, wear safety glasses with side shields when performing the following procedure. See "Safety Information (page 3)."

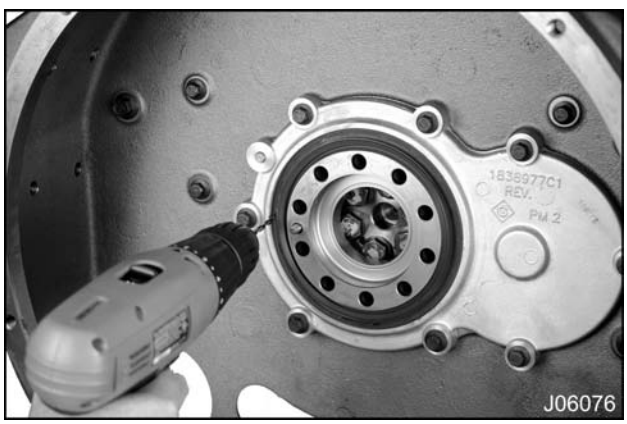

Figure 585 Drilling starter holes (stripped chassis)

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

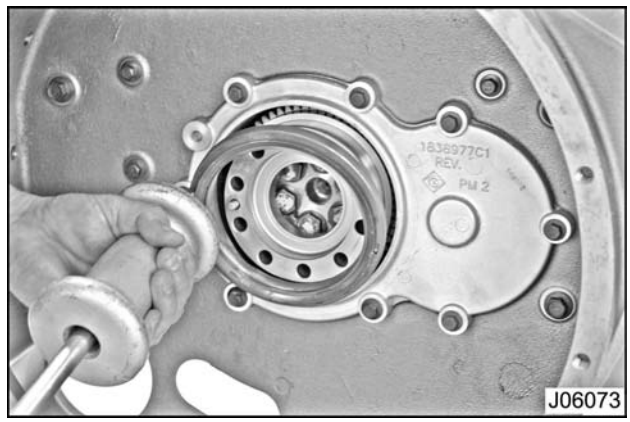

Figure 586 Removing the rear main oil seal (stripped chassis)

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, please 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 the Rear / Wear Sleeve Removal Tool (tri-shell components) around the wear sleeve.

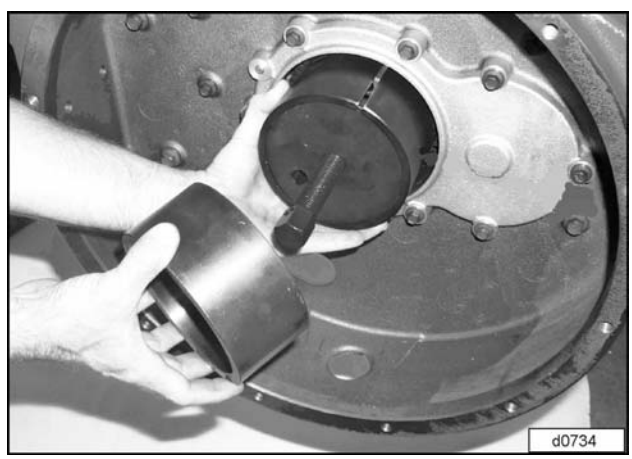

Figure 587 Removing the wear sleeve (stripped chassis)

5. Install the Rear / Wear Sleeve Removal Tool (outer ring component). Make sure wear sleeve removal tool shells are securely in place behind wear sleeve prior to applying any force to threaded shaft.

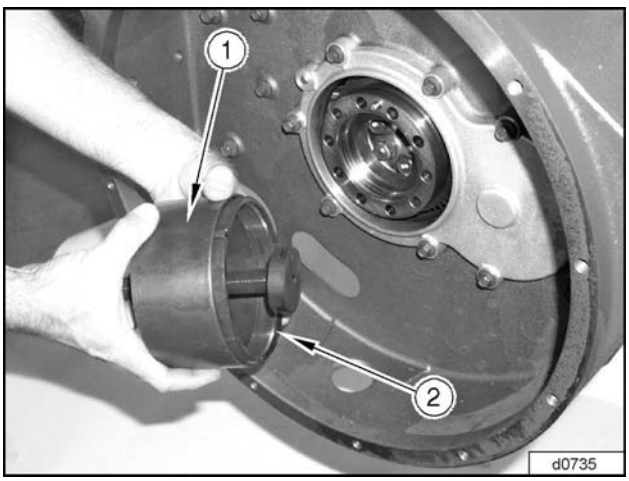

Figure 588 Wear sleeve removed (stripped chassis)

1. Wear sleeve removal tool
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)

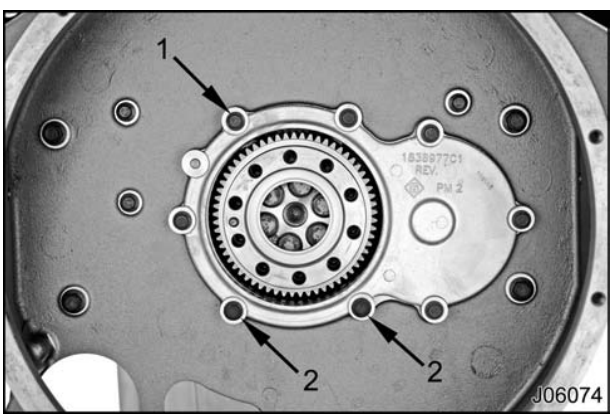

Figure 589 Rear oil seal carrier bolts (stripped chassis)

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

1. Remove eight rear oil seal carrier bolts (M8).

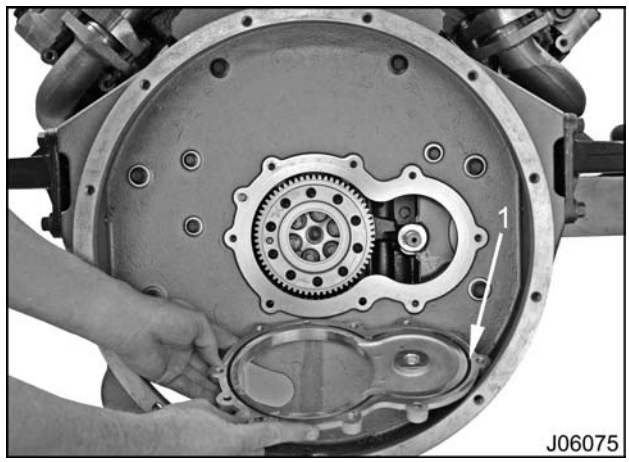

Figure 590 Removing the rear oil seal carrier (stripped chassis)

1. Gasket

2. Remove rear oil seal carrier and discard gasket.

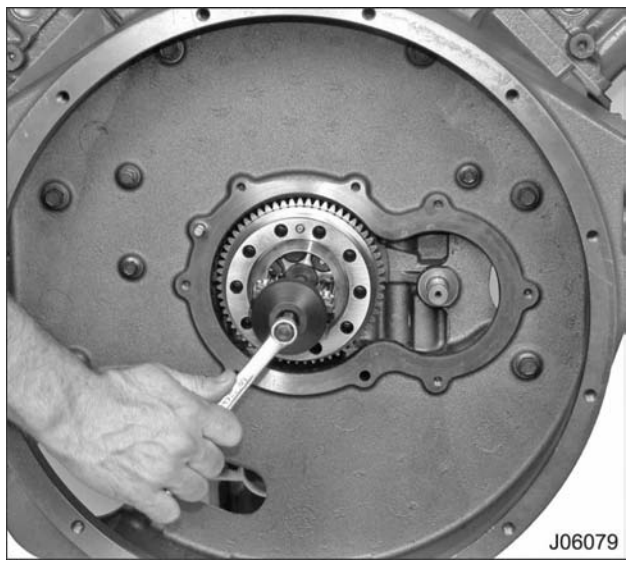

Figure 591 Removing the crankshaft secondary flange (stripped chassis)

3. Use a gear puller to remove the crankshaft secondary flange.

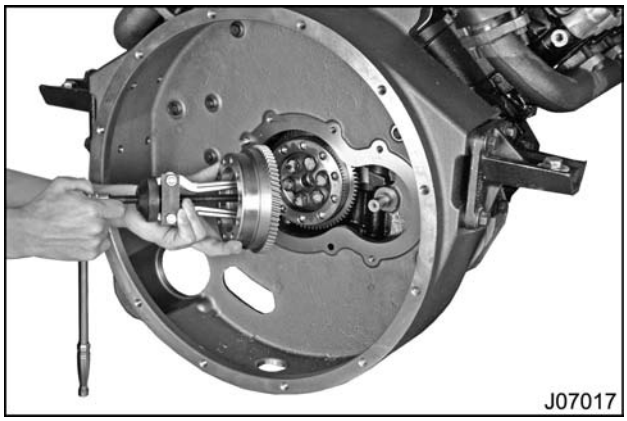

Figure 592 Crankshaft secondary flange removed (stripped chassis)

Rear Cover

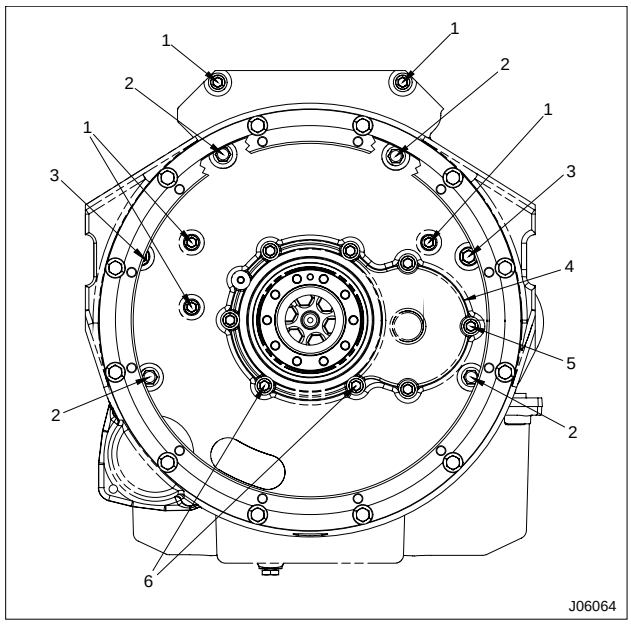

Figure 593 Rear cover bolt arrangement (stripped chassis)

1. Bolt, M8 x 55 (5)
2. Bolt, M10 x 60 (4)
3. Bolt, M10 x 70 (2)
4. Crankshaft rear oil seal carrier
5. Bolt, M8 x 25 (6)
6. Bolt, M8 x 70 (2)

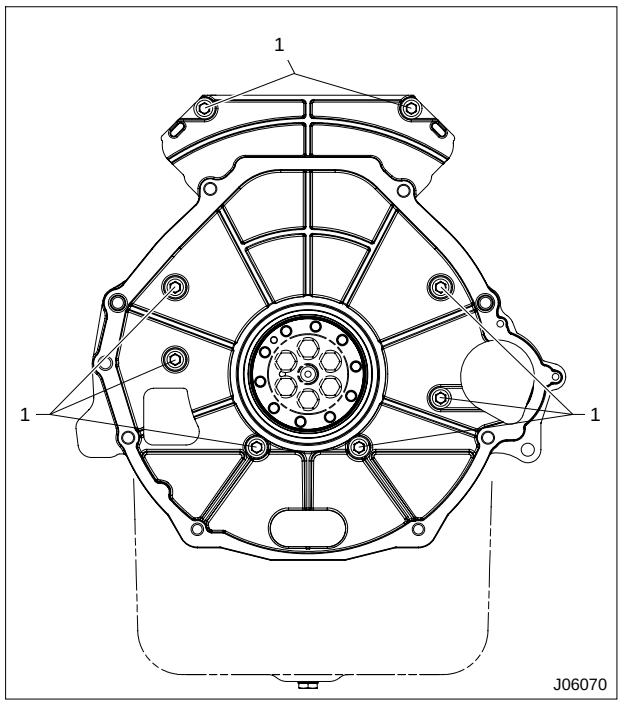

Figure 594 Rear cover bolt arrangement (CF)

1. Bolt, M8 x 35 (8)

1. Stripped Chassis – Remove necessary rear cover mounting bolts. Refer to (Figure 593) for rear cover bolt pattern.

   CF Chassis – Remove eight rear cover mounting bolts (M8 x 35). Refer to (Figure 594) for rear cover bolt pattern.

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 prior to removing rear cover could result in upper and lower crankcase gaskets being pulled out. Complete engine removal and disassembly would be required to replace the lower crankcase gasket.

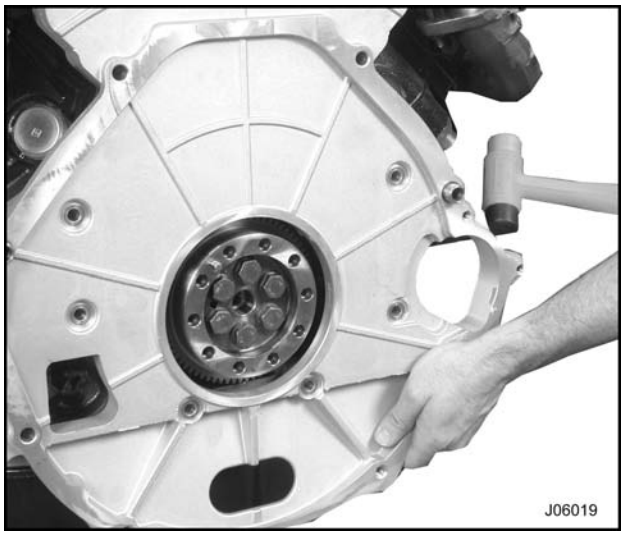

Figure 595 Removing the rear cover with a rubber hammer (typical)

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.

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.

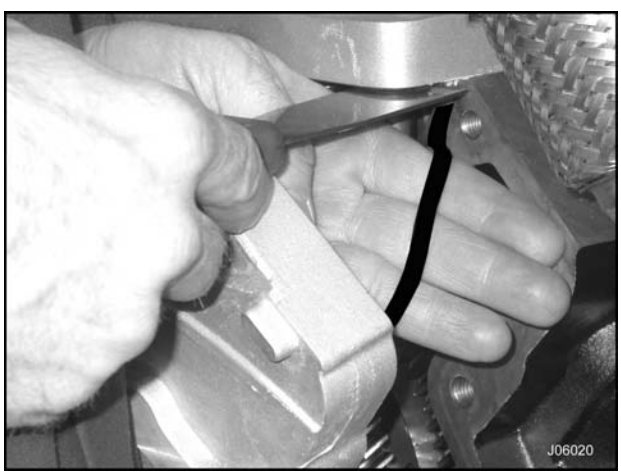

Figure 596 Cutting the rear cover gasket (typical)

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.

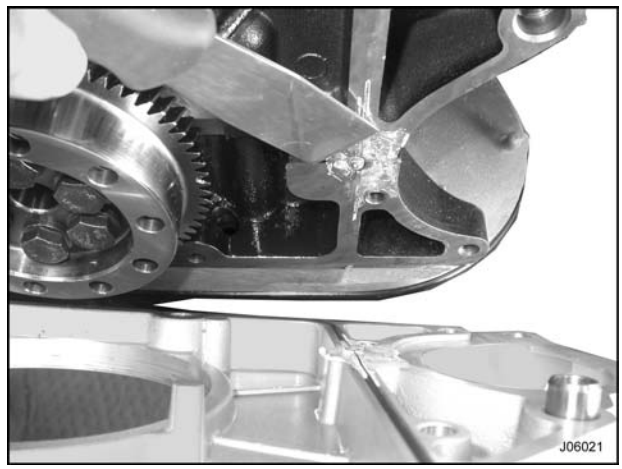

Figure 597 Separating the rear cover from the lower crankcase gasket (typical)

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.

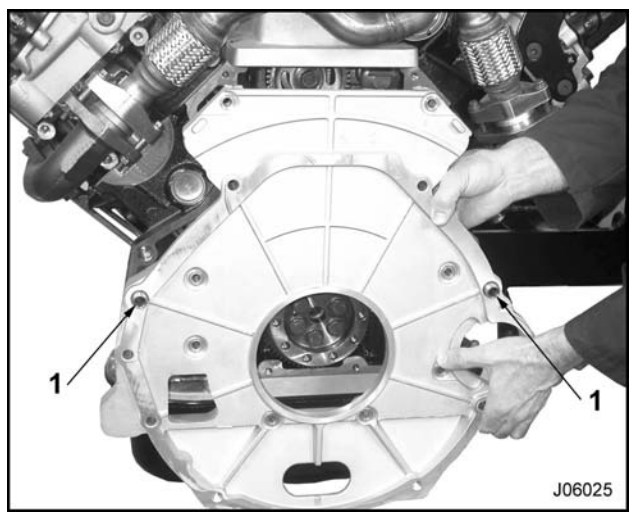

Figure 598 Removing the rear cover assembly (CF)

1. Alignment dowels

6. Remove the rear cover assembly.

WARNING: (Stripped chassis applications only) – To avoid serious personal injury or possible death, have an assistant help with the removal of the rear cover as it is considerably heavier than the CF chassis version. See "Safety Information (page 3)."

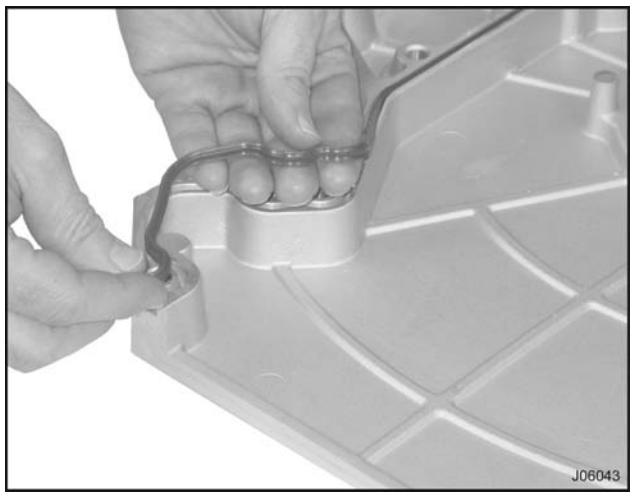

Figure 599 Removing the rear cover gasket (typical)

7. Remove the rear cover gasket and discard.

Cleaning and Inspection

All Components

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.

WARNING: To avoid serious personal injury or possible death, wear safety glasses with side shields when using compressed air for cleaning to reduce the danger from flying debris. Limit the air pressure to 207 kPa (30 psi). See "Safety Information (page 3)."

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 weldment locations. Replace flywheel if any evidence of cracking is found.
6. Inspect all ring gear teeth for evidence of starter pinion damage. Replace flywheel if necessary.

Installation

Rear Cover

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

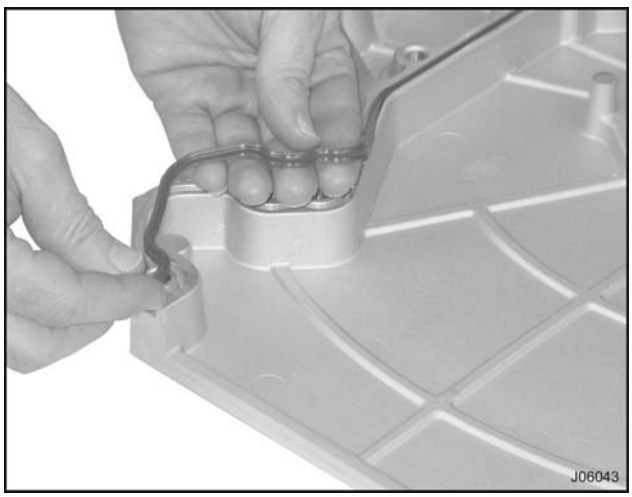

Figure 600 Installing the rear cover gasket (typical)

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

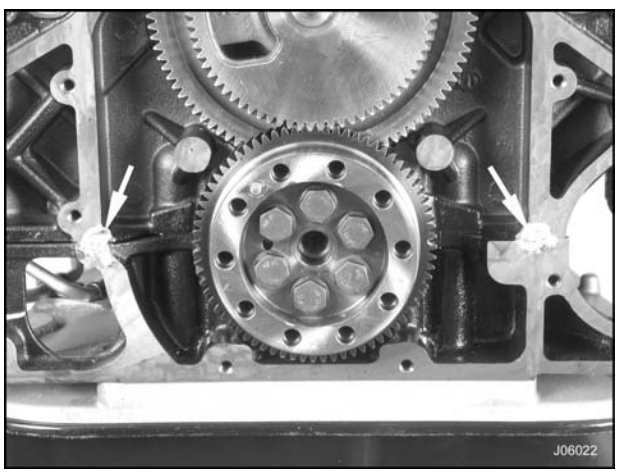

Figure 601 Application of sealant (typical)

2. Apply Liquid Gasket (RTV) at two locations, where the crankcase and lower crankcase join. See Special Service Tools (page 372).

CAUTION: To prevent engine damage, do not allow Liquid Gasket (RTV) to set longer than 10 minutes prior to tightening joint.

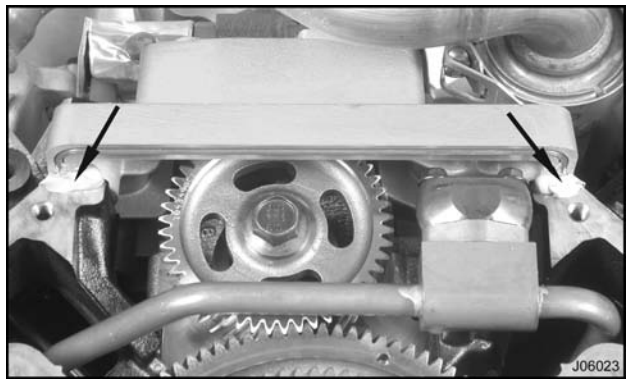

Figure 602 Applying Liquid Gasket (RTV) under the high-pressure pump cover (typical)

3. Apply a small amount of Liquid Gasket (RTV) under the high-pressure pump cover.

CAUTION: To prevent engine damage, do not allow Liquid Gasket (RTV) to set longer than 10 minutes prior to tightening joint.

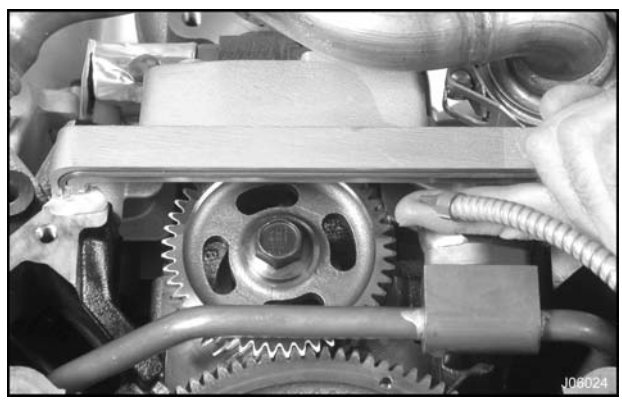

Figure 603 Applying oil to the high-pressure pump cover gasket (typical)

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

WARNING: (Stripped chassis applications only) – To avoid serious personal injury or possible death, have an assistant help with the installation of the rear cover as it is considerably heavier than the CF chassis version. See "Safety Information (page 3)."

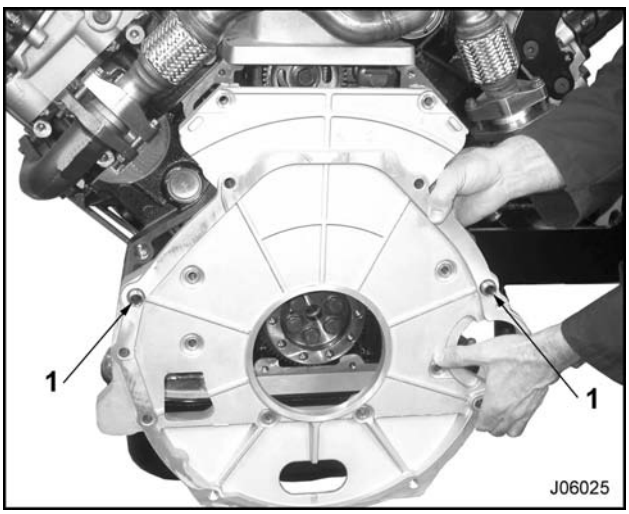

Figure 604 Installing the rear cover (CF)

1. Dowel pins (2)

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

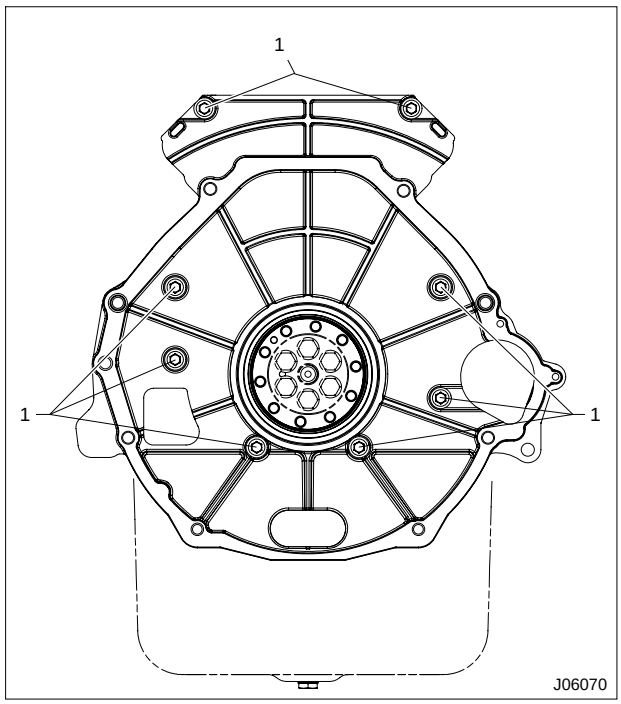

Figure 605 Rear cover bolt arrangement (CF)

1. Bolt, M8 x 35 (8)

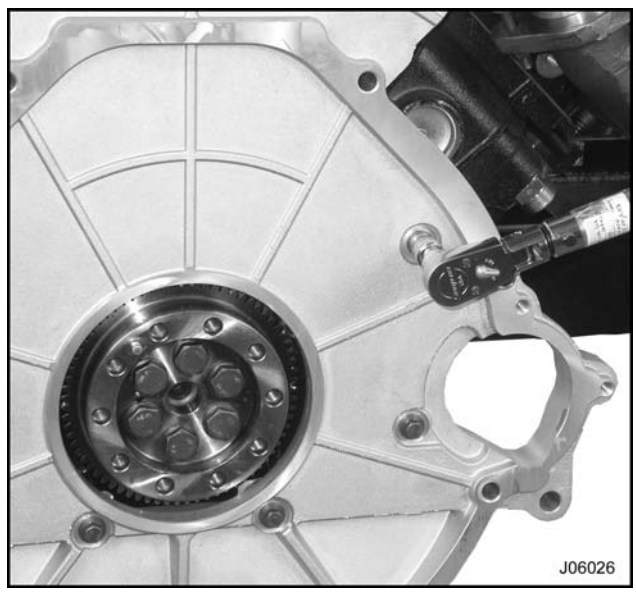

Figure 606 Torquing the rear cover mounting bolts (typical)

6. CF Chassis – Install eight rear cover mounting bolts (M8 x 35) and tighten to the Standard Torque (page 405). Refer to (Figure 605).

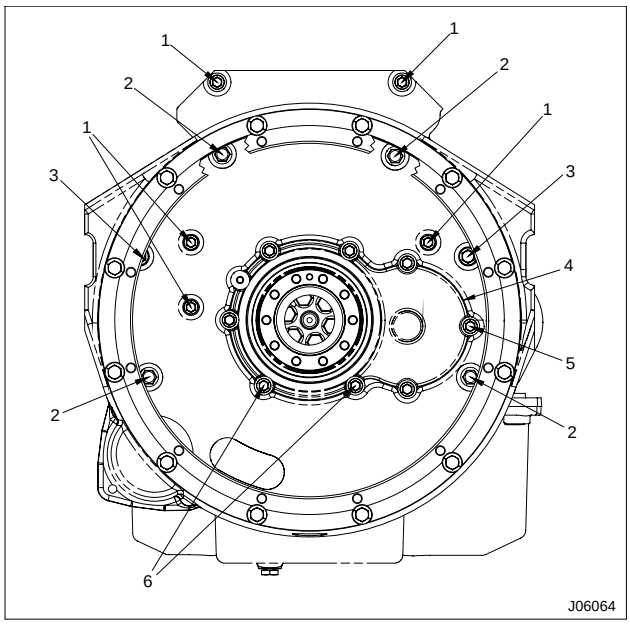

Figure 607 Rear cover bolt arrangement (stripped chassis)

1. Bolt, M8 x 55 (5)
2. Bolt, M10 x 60 (4)
3. Bolt, M10 x 70 (2)
4. Crankshaft rear oil seal carrier
5. Bolt, M8 x 25 (6)
6. Bolt, M8 x 70 (2)

Stripped Chassis – Refer to (Figure 607) for rear cover bolt pattern. Tighten all bolts to the Standard Torque (page 405).

Crankshaft Secondary Flange (Stripped Chassis Only)

Figure 608 Crankshaft secondary flange sealant location

1. Place a 360° bead of Loctite® Hydraulic Sealant onto the forward edge of the crankshaft secondary flange (primary flange mating surface). See Special Service Tools (page 372).
2. Install crankshaft secondary flange by aligning the dowel pin hole with the crankshaft dowel pin.

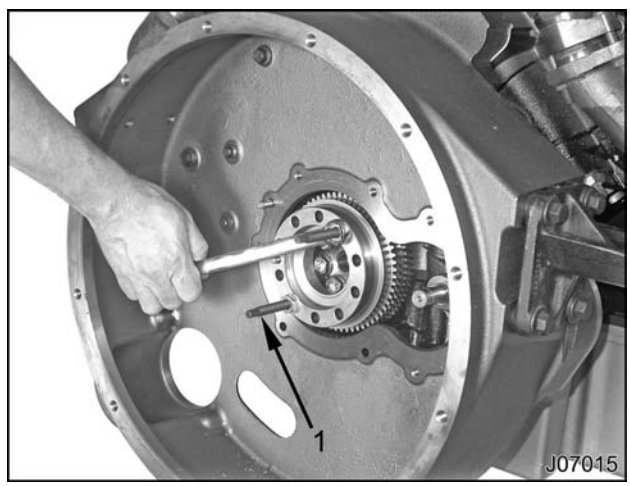

Figure 609 Installing the crankshaft secondary flange

1. Crankshaft Secondary Flange Installation Studs (2)

3. Install two Crankshaft Secondary Installation Studs (page 372) 180° apart through the crankshaft secondary flange and into the

crankshaft primary flange. Make certain the studs are completely threaded into the crankshaft primary flange and tight. Pull crankshaft secondary flange into place by tightening and alternating stud nuts. Remove studs after flange has been thoroughly seated.

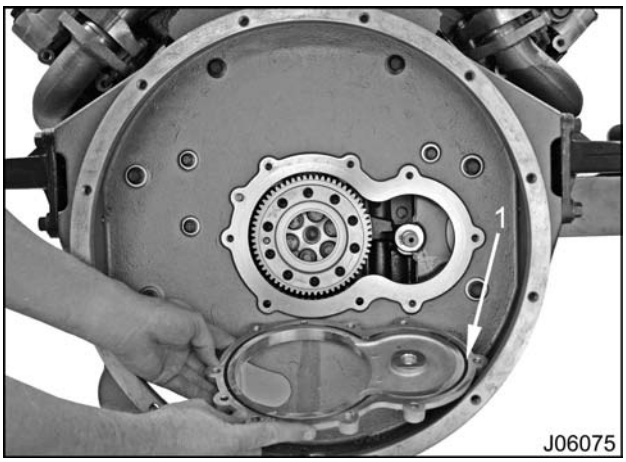

Figure 610 Installing the rear oil seal carrier (stripped chassis)

1. Gasket

4. Place a new gasket onto rear oil seal carrier.

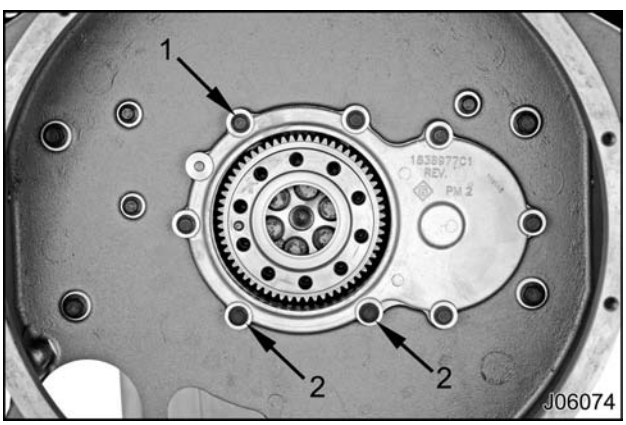

Figure 611 Rear oil seal carrier bolts (stripped chassis)

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

5. Install two rear oil seal carrier bolts (M8 x 70) in lower holes (Figure 611). Install six remaining rear oil seal carrier bolts (M8 x 25) to secure rear oil seal carrier to rear cover. Tighten all bolts to the Standard Torque (page 405).

Rear Main Oil Seal and Wear Sleeve

CF 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.

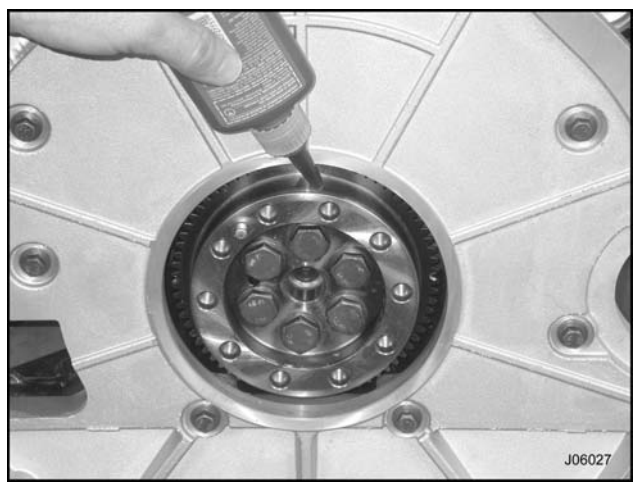

Figure 612 Applying sealant to the crankshaft primary flange (CF)

2. Place a 360° bead of Loctite® Hydraulic Sealant onto the rear edge of the crankshaft primary flange prior to wear sleeve and rear main oil seal installation. See Special Service Tools (page 372).

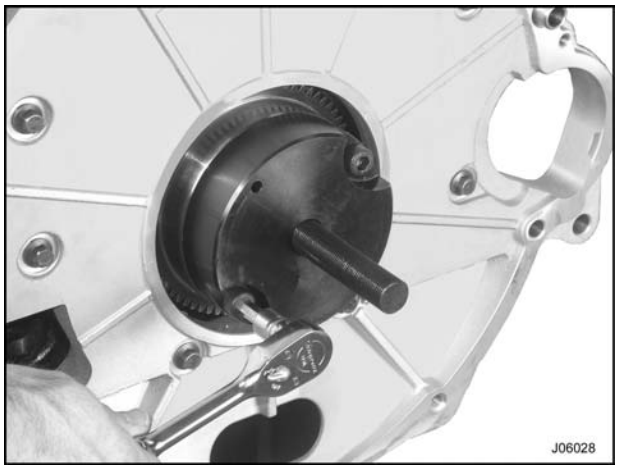

Figure 613 Installing the rear seal / wear sleeve installer (CF)

3. Bolt rear main seal/wear sleeve installation tool onto end of crankshaft. Make sure crankshaft dowel fits in installation tool dowel recess hole.

NOTE: Lubricate outer diameter of rubber seal with a solution of dish washing soap and water (approximately 50/50 mix) prior to assembly. Do not use any other type of lubricant.

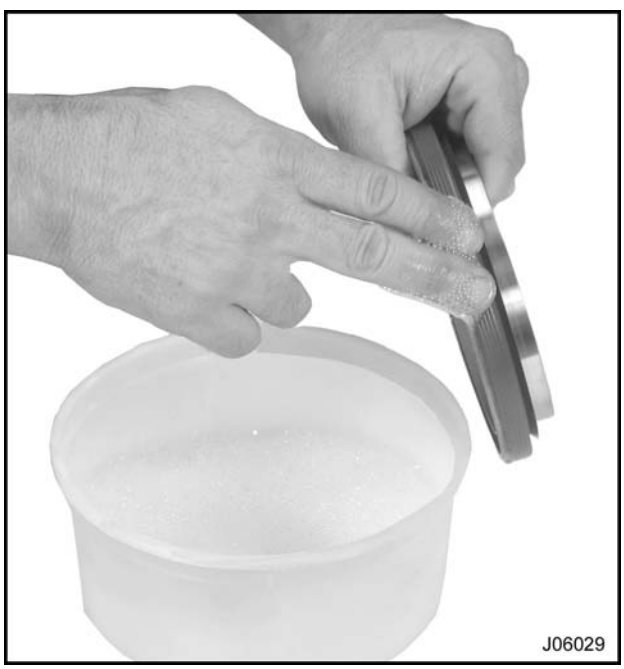

Figure 614 Applying soap to the rear seal

4. Before installing, lubricate the outer diameter of rubber seal with a solution of dish washing soap and water (approximately 50/50 mix) prior to assembly. Do not use any other type of lubricant.

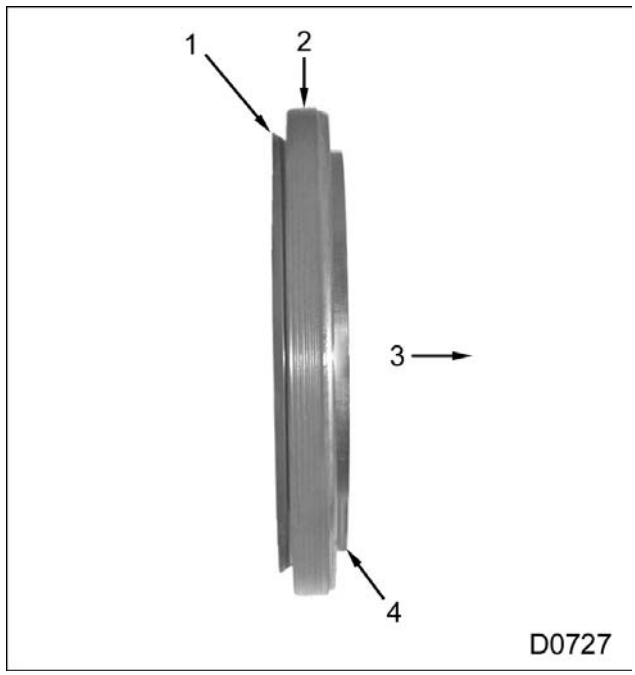

Figure 615 Rear main oil seal and wear sleeve orientation

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

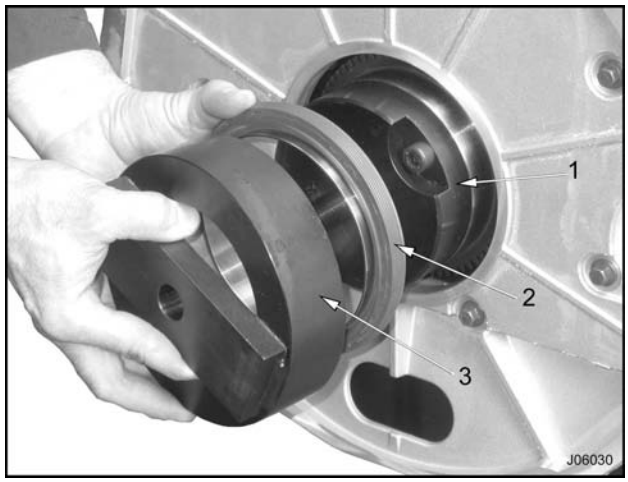

Figure 616 Installing the Rear Seal / Wear Sleeve Installer

1. Base
2. Rear main oil seal and wear sleeve
3. Rear Seal / Wear Sleeve Installer

5. 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.

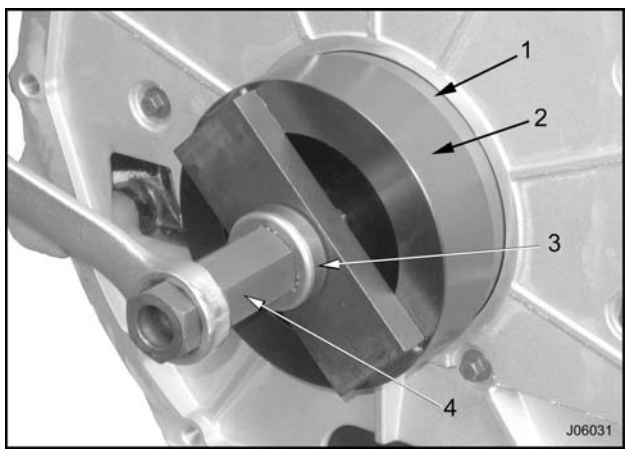

Figure 617 Installing the rear main seal / wear sleeve onto crankshaft

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

6. Place thrust bearing and drive nut onto threaded shaft. Tighten nut until rear main oil seal bottoms out onto rear oil seal carrier.
7. Remove the Rear Seal/Wear Sleeve Installer tool.

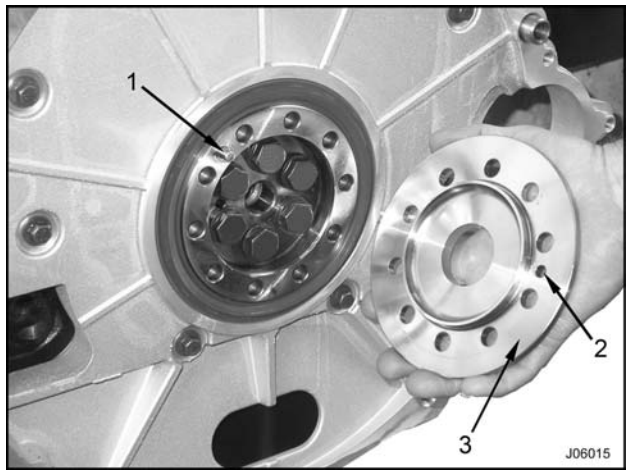

Figure 618 Installing the rear flywheel adapter

1. Dowel pin
2. Pin recess

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

8. Place flywheel adaptor onto crankshaft primary flange. Be sure to line up dowel pin. If necessary, tap with soft 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 to the 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.

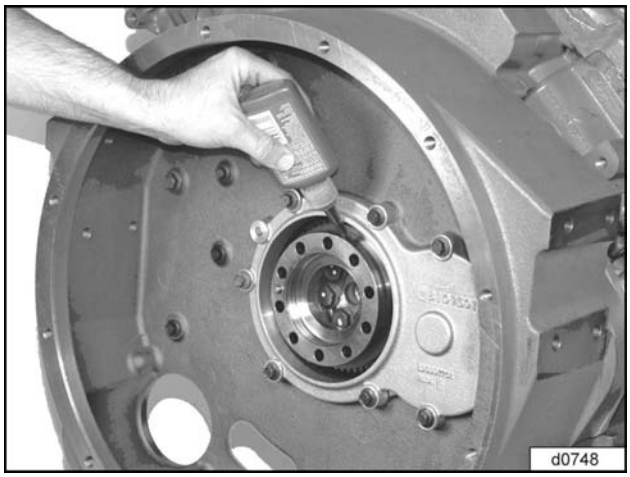

Figure 619 Apply sealant to the crankshaft secondary flange

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 372).

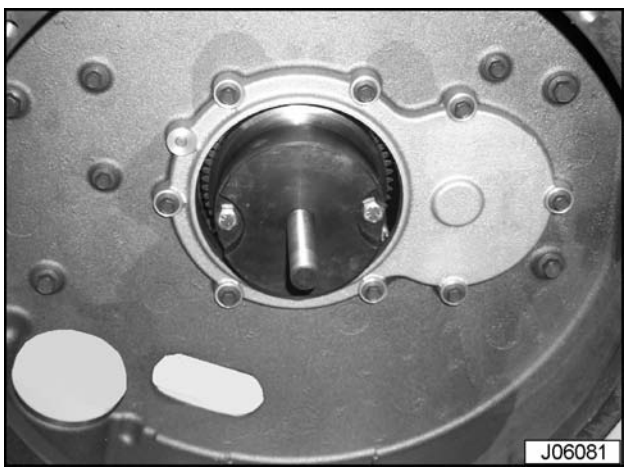

Figure 620 Rear / Wear Sleeve Installer

2. Bolt Rear/Wear Sleeve Installer (page 372) onto end of secondary crankshaft flange. Make sure crankshaft alignment dowel fits in dowel recess hole in the rear/wear sleeve installer.

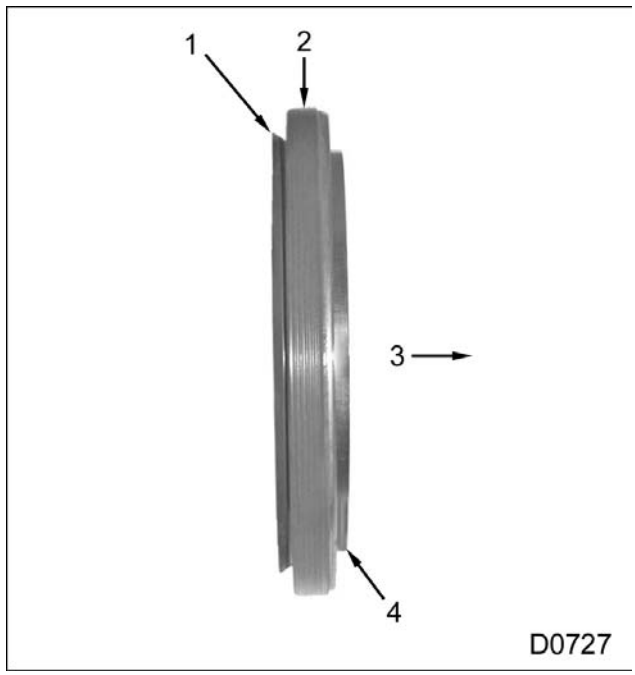

Figure 621 Rear main oil seal and wear sleeve orientation

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 621) and slide on rear/wear sleeve installer. Make sure the beveled edge of the wear sleeve is oriented toward the crankshaft.

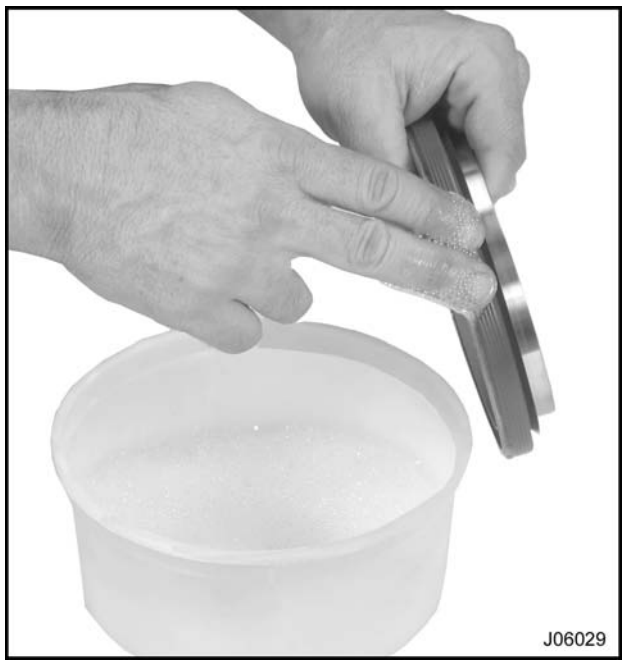

Figure 622 Applying soap to the rear seal

4. Before installing, lubricate the outer diameter of rubber seal with a solution of dish washing soap and water (approximately 50/50 mix) prior to assembly. Do not use any other type of lubricant.

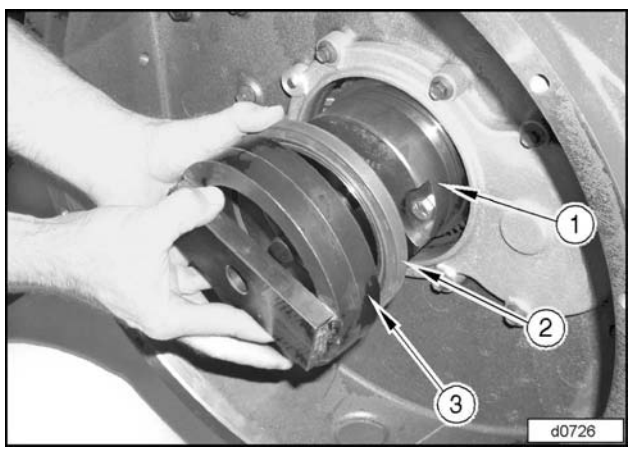

Figure 623 Rear oil seal and wear sleeve installer

1. Base
2. Rear main oil seal and wear sleeve
3. Rear/wear sleeve installer

5. Position rear main oil seal and wear sleeve combination on the rear/wear sleeve installer.

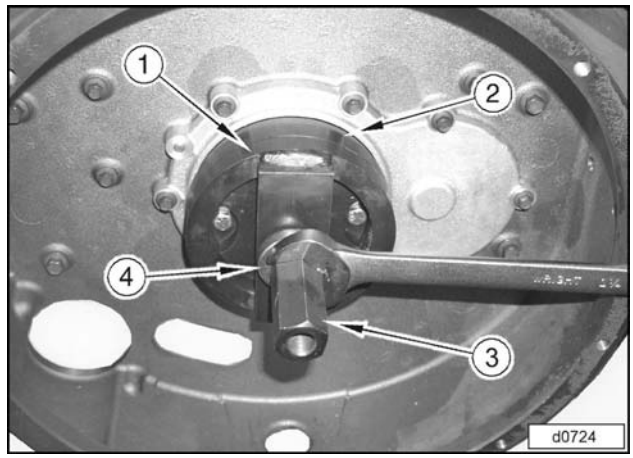

Figure 624 Installing rear main oil seal and wear sleeve combination onto crankshaft

1. Rear/wear sleeve installer
2. Rear main oil seal
3. Drive nut
4. Thrust bearing

6. 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, you must always install new flywheel mounting bolts when installing the flywheel.

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

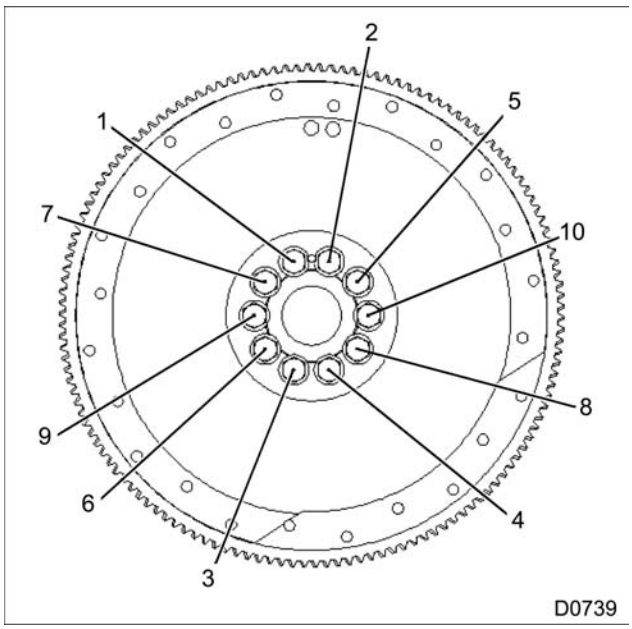

Figure 625 Typical flywheel torque sequence (typical)

1. Align crankshaft dowel pin with flywheel alignment hole.
2. Install 10 new flywheel bolts.
   - CF series – M10 x 31
   - Stripped chassis – M10 x 77

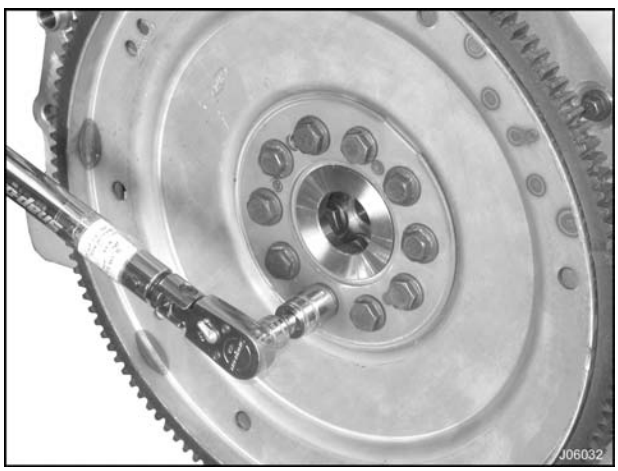

Figure 626 Installing the flywheel (typical)

3. Using an alternating pattern across the center, evenly tighten all flywheel bolts to the Special Torque (page 372) using the torque sequence illustration (Figure 625).

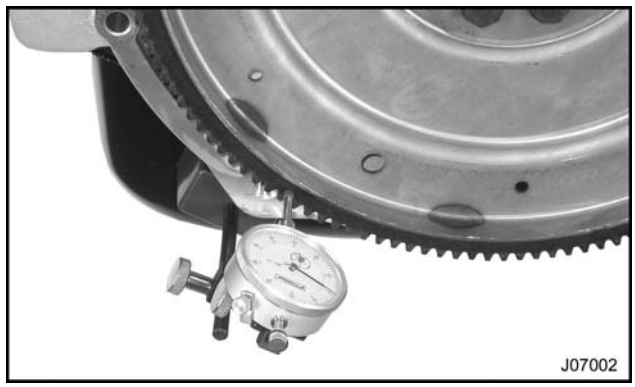

Figure 627 Checking ring gear for a run out condition

4. Inspect flywheel ring gear for run out.

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

   A. Attach Dial Indicator with Magnetic Base onto lower oil pan. Place dial indicator tip against surface of flywheel ring gear. See Special Service Tools (page 372).

   B. Zero the dial indicator.

   C. Rotate crankshaft slowly in a clockwise direction. Compare total dial indicator variation. See Specifications (page 372).

   D. Compare the result to the flywheel surface runout specification. Replace if necessary. See Specifications (page 372).

5. Stripped Chassis Only – Place ring adapter onto rear cover assembly and install 12 bolts (M10 x 35). Tighten bolts to the Standard Torque (page 405).

Specifications

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

Special Torque

Flywheel	
Flywheel mounting bolts (all applications) new bolts only	94 N·m (69 lbf·ft) flywheel torque sequence (Figure 625)

Special Service Tools

Flywheel and Rear Cover	
Description	**Tool Number**
Dial Indicator with Magnetic Base	Obtain locally
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Loctite® Hydraulic Sealant	Obtain locally
Rear Seal/Wear Sleeve Installer[1]	ZTSE4515A
Rear/Wear Sleeve Removal Tool	ZTSE4518
Slide Hammer	ZTSE4398A
Crankshaft Secondary Flange Installation Studs (2)	ZTSE4720
Gear Puller (for secondary flange)	ZTSE4520

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

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Rocker Arm Replacement

Prior to performing any 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 avoid serious personal injury, possible death, or damage to the engine or vehicle, make sure the transmission is in neutral, parking brake is set, and wheels are blocked before doing diagnostic or service procedures on engine or vehicle. Read all safety instructions in the "Safety Information" section of the service manual for this engine.

WARNING: To avoid serious personal injury, possible death, or damage to the engine or vehicle, make sure that the engine has cooled down sufficiently before attempting to remove any engine components.

CAUTION: To prevent engine damage, position clean shop towels (refer to TSI-02-12-16) or rubber hose into each of the holes prior to fuel injector removal. This practice will ensure that small parts (or broken pieces) will not get into the oil supply should they become dislodged. Potentially damaging components include:

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

Be certain to 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.

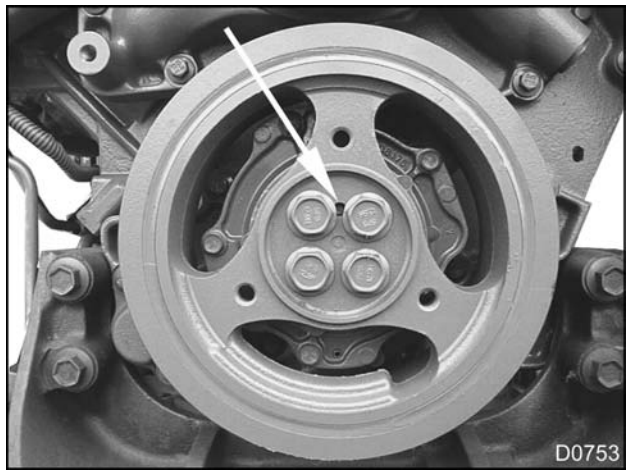

Figure 628 Dowel hole in vibration damper

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 379).
4. Remove the fuel injector hold down clamp assembly using the Fuel Injector Hold Down Wrench. See Special Service Tools (page 379).
5. Place injector into Fuel Injector Rack Holder. See Special Service Tools (page 379).

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

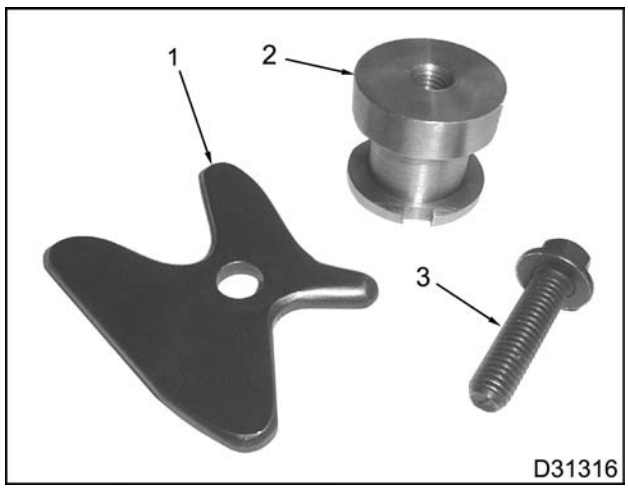

Figure 629 On Engine Valve Spring Compressor Tool

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

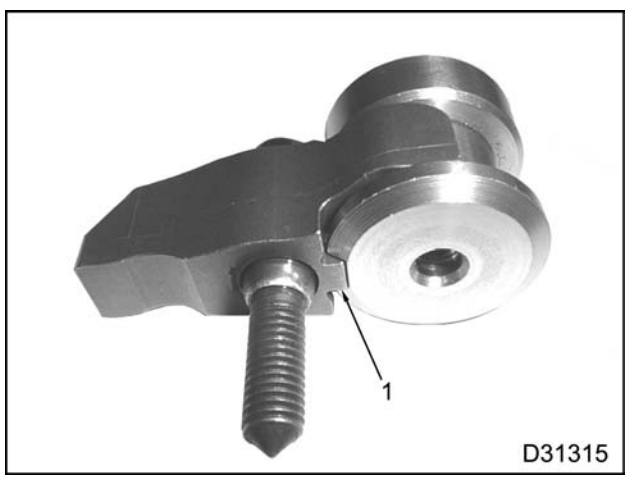

Figure 630 Hold down clamp and base

1. Locating notch / index feature

6. Using the On Engine Valve Spring Compressor Tool, insert the Valve Spring Compressor Base into an injector hold down clamp, making sure the notch in the base aligns with index feature on hold down clamp. Install assembly between the valve bridges as if installing an injector.

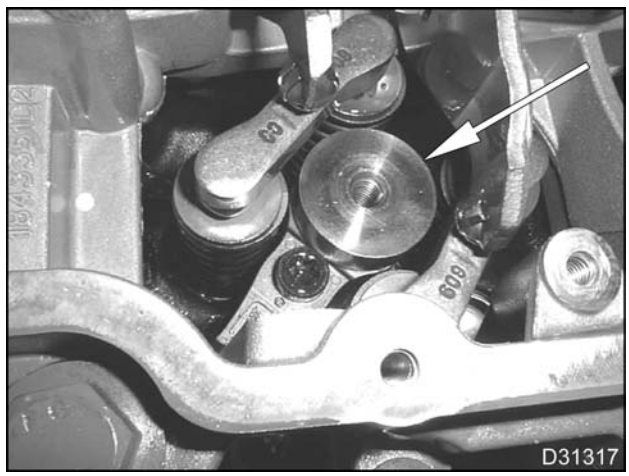

Figure 631 Valve Spring Compressor Base installed

NOTE: While centering Valve Spring Compressor Base between the two valve bridges, lightly tighten hold down bolt, but do not torque.

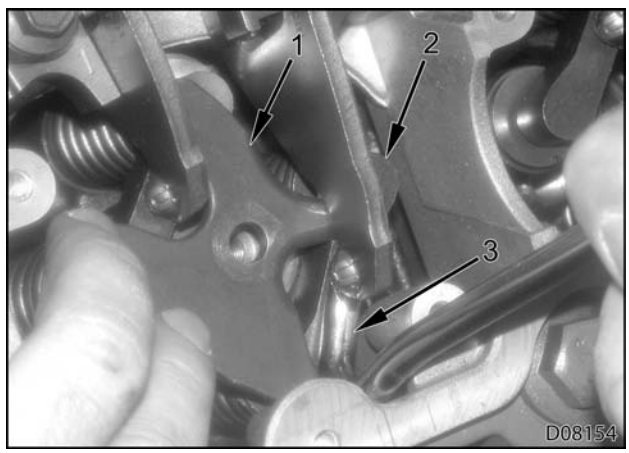

Figure 632 Creating clearance between rocker arm and valve bridge

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

7. 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. By compressing

the valve bridge down and raising the rocker slightly you should gain enough clearance to rotate the small point of the Valve Spring Compressor Plate between the two components.

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.

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

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

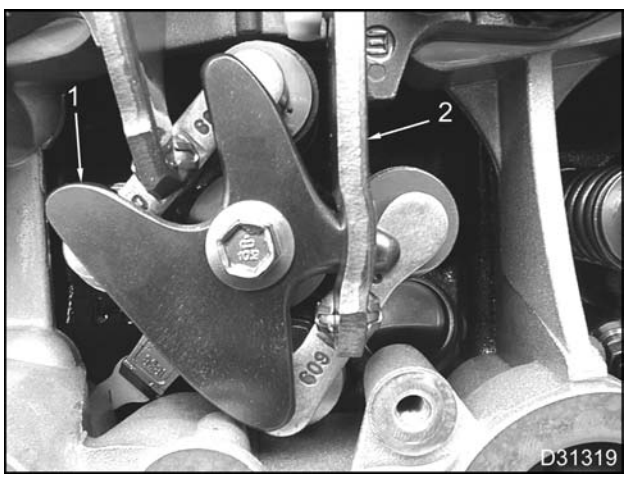

Figure 633 Valve Spring Compressor Plate installed

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

8. 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, make sure you can 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, you must 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.

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

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

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

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

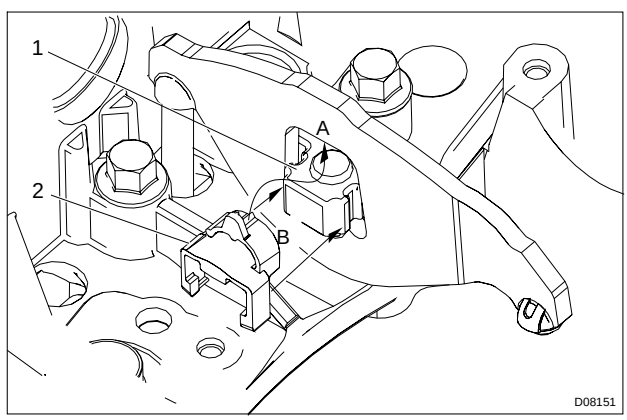

Figure 634 Position "A" in first then slide "B" around fulcrum plate

1. Fulcrum plate
2. Rocker arm retaining clip

13. Install new plastic rocker arm retaining clip (Figure 634) by positioning top of clip to top of rocker arm opening and rotating clip until snapping around fulcrum plate.

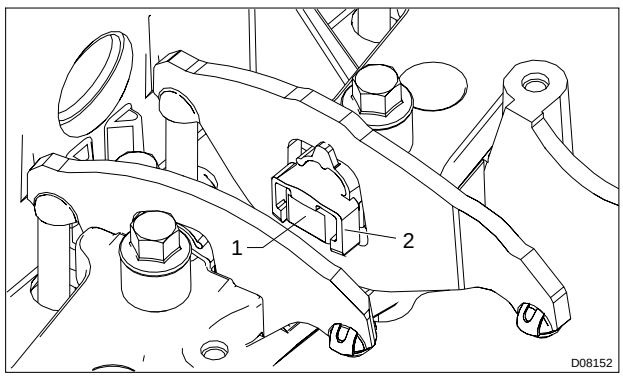

Figure 635 Retaining clip in correct position

1. Fulcrum plate
2. Rocker arm retaining clip

14. Refer to above illustration for correctly installed clip. Repeat procedure with adjacent rocker arm.
15. Remove Valve Spring Compressor Bolt making sure rocker arm remains in place and ⅜" ball have not fallen out. Repeat procedure on remaining cylinders for this crankshaft position session.
16. 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.
17. 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.
18. Remove paper towels from injector bores and install injectors.
19. Look for small broken particles (visually and using a magnet) before removing shop towels or rubber hose from oil drain holes.
20. 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

In Chassis Service	
Description	**Tool Number**
Fuel Injector Hold Down Wrench	ZTSE4524
Quick Release Tool kit	ZTSE4454
Fuel Injector Rack Holder	ZTSE4299B
Injector Connector Remover	ZTSE4650
On Engine Valve Spring Compressor Tool	ZTSE4697

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Terminology

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 (autoignites) at high compression temperature.

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

Output State Test (OST) – An On demand test that forces the processor to activate actuators (High or Low) for additional diagnostics.

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.

Positive On Shaft Excluder (POSE) – A Positive On Shaft Excluder is a separate piece from the rest of the front or rear seal used to keep out dust / debris.

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 Modulation (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.

Read Only Memory (ROM) – Computer memory that stores permanent information for calibration tables and operating strategies. Permanently stored information in ROM cannot be changed or lost by turning the engine off or when ECM power is interrupted.

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.

Sulfur dioxide (SO_2) – Sulfur dioxide is caused by oxidation of sulfur contained in fuel.

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.

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Specifications

Dual Turbocharger and Exhaust Tubing

Turbocharger Shaft	
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)

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)

Cylinder Head and Valve Train

Cylinder Head and Valve Train	
Exhaust Valves	
Stem diameter	6.947 to 6.965 mm (0.2735 to 0.2742 in)
Stem to guide clearance (max. allowable before replacement)	0.140 mm (0.0055 in)
Face to stem runout (T.I.R. max.)	0.038 mm (0.0015 in)
Valve face angle	37.5°
Valve margin (minimum)	1.35 mm (0.053 in)
Valve recession in head	0.50 ± 0.18 mm (0.020 ± 0.007 in)
Intake Valves	
Stem diameter	6.947 to 6.965 mm (0.2735 to 0.2742 in)
Stem to guide clearance (max. allowable before replacement)	0.140 mm (0.0055 in)
Face to stem runout (T.I.R. max.)	0.0038 mm (0.0015 in)
Valve face angle	30.0°
Valve margin (minimum)	1.40 mm (0.055 in)
Valve recession in head	0.50 ± 0.18 mm (0.020 ± 0.007 in)
Cylinder Heads	

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	0.05 mm (0.002 in) **per 51 mm (2 in)** 0.10 mm (0.004 in) **per total surface area**
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)
Valve Spring:	
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.	
Push Rods	
Runout (maximum)	0.25 mm (0.01 in)

Front Cover, Vibration Damper, and Gerotor Oil Pump

Front Cover, Vibration Damper, and Gerotor Oil Pump	
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
• Engine oil pressure, low idle (min. @ 110°C (230°F) oil temp.)	69 kPa (10 psi)
• Engine oil pressure, high idle (min. @ 110°C (230°F) oil temp.)	276 kPa (40 psi)
• Oil pump discharge pressure (2,500 rpm)	483 to 621 kPa (70 to 90 psi)
End clearance (inner and outer rotor to housing)	0.025 to 0.095 mm (0.001 to 0.004 in)
Radial clearance (between outer rotor and housing)	0.15 to 0.28 mm (0.006 to 0.011 in)
Pressure Regulating Valve:	
Plunger bore	18.81 ± 0.02 mm (0.741 0.001)
Thermostat	
Type	Balanced pressure, wax pellet
Normal operating temperature, >10 mm (0.394 in) stroke	104°C (219°F)

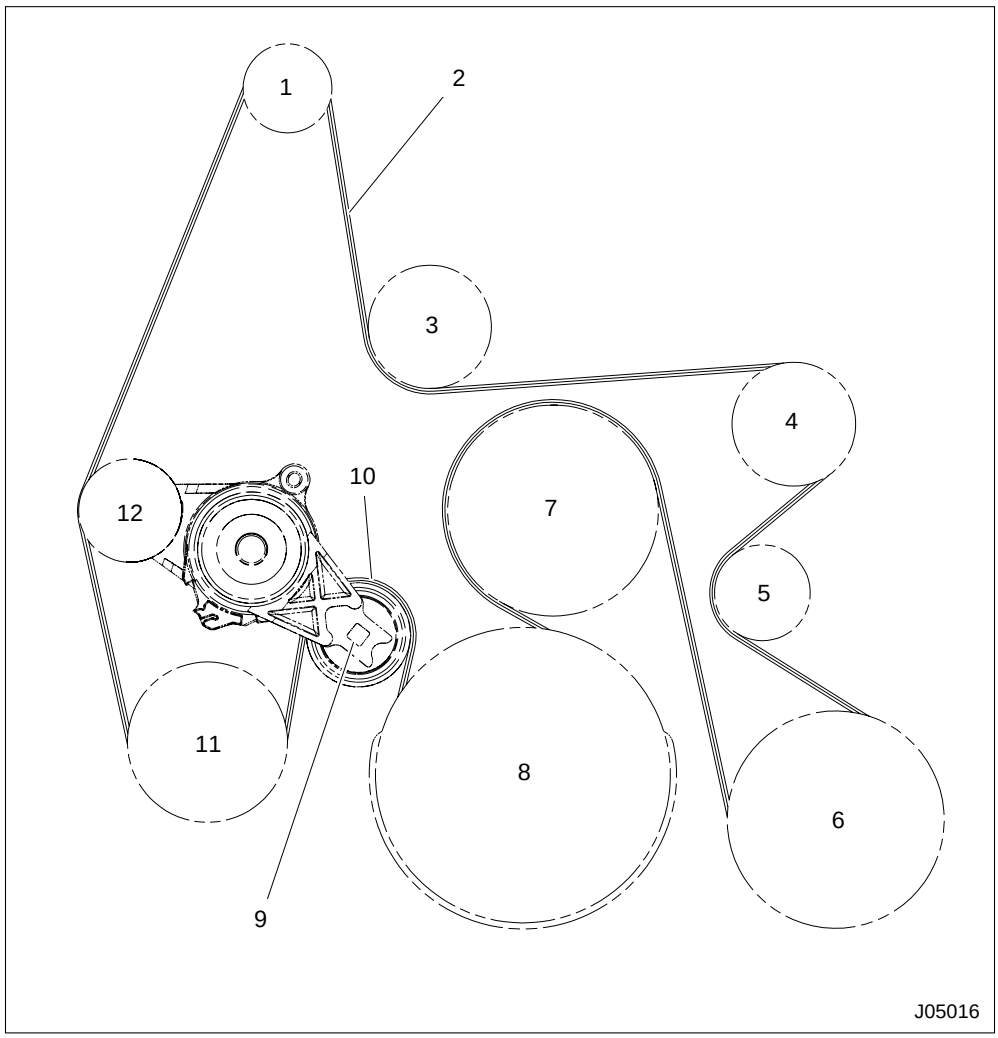

Figure 636 Accessories drive belt routing

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

Power Cylinder

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 height above crankcase deck (protrusion)	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)
Fit in groove (side clearance in bore):	
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 main journal out of round	0.006 mm (0.00024 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 and Main Bearings	
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

Oil Cooler and Filter Housing

Oil Cooler and Oil Filter Assemblies	
Oil Cooler	
Type	Full-flow: 11 fins oil, 11 fins water
Heat transfer	1650 BTU / min / 60° ETD
Location	Engine valley (forward)
Oil Filter	
Type	Cartridge, full flow - disposable
Filtering efficiency	20 microns and larger
Location	Front, oil cooler mounted
Filter bypass location	Oil filter return tube assembly

Engine Electrical Components

Engine Electrical	
Glow Plugs	
Applied voltage	10.9 - 11.1V
Intake Air Heater	
Amperage rating	60 Amps
Camshaft Position (CMP) Sensor	
Operating speed	30 - 3000 rpm
Crankshaft Position (CKP) Sensor	
Operating actuator speed	15 to 2,000 rpm
Operating temperature	-40 to +130°C (-40 to +266°F)
Injection Pressure Regulator (IPR) Valve	
Operating temperature range	-40 to +220°C (-40 to +428°F)
Maximum operating pressure	28 MPa (4,061 psi)

High-pressure Oil Pump

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

Fuel System

Fuel System Components	
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)

Rear Cover

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

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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.

Standard Torques

Standard Torques – Pipe Thread

Thread Size	Torque[1]
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)

1 Tolerances are ±10% of nominal value.

Standard Torques – Class 10.9 Metric Bolts and Studs

Thread Diameter	Thread Pitch (mm/thread)	Torque[1]
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)

1 Tolerances are ±10% of nominal value.

Standard Torques – Class 12.9 Metric Bolts and Studs

Thread Diameter	Thread Pitch (mm/thread)	Torque[1]
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)

1 Tolerances are ±10% of nominal value.

DESIGNATION				HEAD MARKING	
INTERNATIONAL CLASS	ISO R 898 I	MATERIAL TYPE	THERMAL TREATMENT	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				

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Figure 637 Classification and Identification – Metric Fasteners

INTERNATIONAL DESIGNATION	TYPE OF MATERIAL	THERMAL TREATMENT	HEAD MARKING	
			PREFERRED	OPTIONAL
CLASS	METRIC FASTENERS			
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		

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Figure 638 Classification and Identification – Special Use Fasteners

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 due to engine rpm or vibration.

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 the 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 maximum clamping effect is not achieved. This condition can lead to failure of the fastener to maintain component integrity. The proper bolt tension and clamping effect can never be attained if the fastener is dry. The fastener threads must have a film of clean lubricant (engine oil) to be considered lubricated.

Using a Torque Wrench Extension

Occasionally the need will arise to use an extension, crowfoot, or other type of adapter with your torque wrench to torque a bolt or line fitting. Sometimes an extension or adapter is necessary to reach a bolt in a hard to reach location. Adding adapters or extensions will alter the actual clamping force at the faster. By using the following formula you can determine what the torque wrench setting should be to achieve the known standard or special torque value.

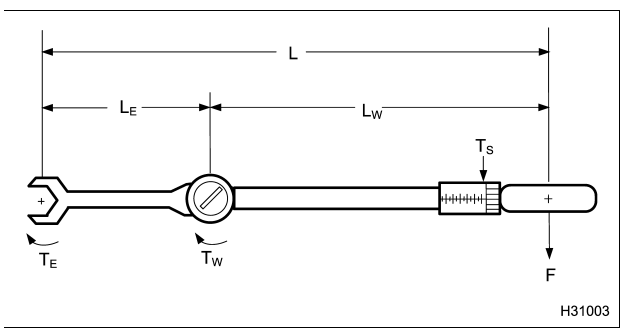

Figure 639 Torque wrench extension

- F – Force applied by service technician
- L – Length through which force is applied to fastener
- L_E – Length of extension
- L_W – Length of torque wrench
- T_E – Torque applied at fastener
- T_W – Torque applied at end of torque wrench
- T_S – Torque wrench setting

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

Example:

A component has a known torque value of 88 N·m (65 lbf·ft) and an extension is required to reach it. What will the torque wrench setting have to be in order to compensate for the additional extension?

- Torque wrench = 12 inches
- Extension = 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 or 58.9 N·m**

Special Torques

Mounting Engine on Stand

Mounting Engine on Stand	
Oil pan drain plug	44 N·m (32 lbf·ft)

Dual Turbocharger and Exhaust Tubing

Turbocharger Related Torque Values	
Air inlet duct hose clamp	4 to 5 N·m (36 to 48 lbf·in)
Boost control solenoid mounting bolt, M6 x 25	9 N·m (79 lbf·in)
Crossover V-band	7 N·m (62 lbf·in)
EGR cooler inlet V-band clamp	12 N·m (106 lbf·in)
Exhaust tubing bolts (at manifold)[1]	27 N·m (20 lbf·ft)
Exhaust tubing bolts (at turbocharger)[2]	49 N·m (36 lbf·ft)
Low-pressure turbine exhaust outlet studs (3)	22 N·m (16 lbf·ft)
Oil drain tubing bolts	23 N·m (17 lbf·ft)
Oil fill extension tube	14 N·m (124 lbf·in)
Oil supply tube (fittings)	17 N·m (150 lbf·in)
V-clamp	10 N·m (88 lbf·in)

1 Apply anti-seize compound to bolt threads prior to assembly

2 Apply anti-seize compound to bolt threads prior to assembly

Manifolds and Exhaust Gas Recirculation (EGR)

Manifolds and Exhaust Gas Recirculation (EGR)	
Intake air heater element (cable nut)	4 N·m (35 lbf·in)
Air intake heater (to manifold)	61 N·m (45 lbf·ft)
Coolant deaeration fitting	10 N·m (90 lbf·in)
EGR cooler mounting bolt assembly, M6	11 N·m (97 lbf·in)
EGR cooler to manifold stud bolts	11 N·m (97 lbf·in)
EGR valve mounting bolts	11 N·m (97 lbf·in)
Exhaust manifold hex flange bolts[1]	See Exhaust Manifold Torque Sequence (page 106)
Intake air elbow, M6 hex flange and stud bolt	11 N·m (97 lbf·in)
Intake manifold bolts, M6 hex flange and stud bolt	11 N·m (97 lbf·in) (Figure 134)

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

Cylinder Head and Valve Train

Cylinder Head and Valve Train	
Case-to-head tube assembly	82 N·m (60 lbf·ft)
Cylinder head bolt torque and sequence	(Cylinder Head Torque Instructions and Tightening Sequence, page 150)
Crankcase breather bolts	11 N·m (96 lbf·in)
Fuel injector hold down bolt	33 N·m (24 lbf·ft)
Glow plugs	18 N·m (159 lbf·in)
Injection Control Pressure (ICP) sensor	12 N·m (105 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)

Front Cover, Vibration Damper, and Gerotor Oil Pump

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

Power Cylinder

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

Crankcase, Crankshaft and Camshaft

Crankcase, Crankshaft and Camshaft	
Lower crankcase main bearing cap bolts	See tightening procedure and sequence (page 242)
Coolant heater element or plug	41 N·m (30 lbf·ft)
Crankcase coolant drain plug / O-ring, M16	20 N·m (15 lbf·ft)

Oil Cooler and Filter Housing

Oil Cooler and Oil Filter Assemblies	
Oil filter base assembly (M6 x 25)	10 N·m (85 lbf·in)
Oil filter base assembly (M8 x 45)	11 N·m (97 lbf·in)
Oil filter base assembly (M8 x 23)	23 N·m (17 lbf·ft)
Oil bypass / filter inlet guide valve (M5 x 18)	7 N·m (62 lbf·in)
Oil cooler mounting bolts (M6 x 25)	15 N·m (132 lbf·in)
Diagnostic valve	16 N·m (144 lbf·in)
Oil filter cap	25 N·m (18 lbf·ft)

Engine Electrical Components

Engine Electrical	
Intake air heater element (cable nut)	4 N·m (35 lbf·in)
Engine Coolant Temperature (ECT) sensor	18 N·m (158 lbf·in)
Engine Oil Temperature (EOT) sensor	19 N·m (168 lbf·in)
Engine Oil Pressure (EOP) switch	14 N·m (123 lbf·in)
Glow plug	19 N·m (14 lbf·ft)
Injection Control Pressure (ICP) sensor	12 N·m (106 lbf·in)
Injection Pressure Regulator (IPR) valve	50 N·m (37 lbf·ft)
Manifold Absolute Pressure (MAP) sensor	12 N·m (108 lbf·in)
Manifold Air Temperature (MAT) sensor	18 N·m (156 lbf·in)

High-pressure Oil Pump

High-pressure System Components	
Case-to-head tube	60 N·m (82 lbf·ft)
Injection Pressure Regulator (IPR)	50 N·m (37 lbf·ft)
Prime port plug	8 N·m (71 lbf·in)
High-pressure pump plug	35 N·m (26 lbf·ft)

Fuel System

Fuel System Components	
Banjo bolt, 12 mm	38 N·m (28 lbf·ft)
Diagnostic port plug, M12	4-9 N·m (35-75 lbf·in)
Fuel filter cap (secondary)	14 N·m (124 lbf·in)
Fuel filter housing mounting screws, M6 x 25	10 N·m (88 lbf·in)
Fuel supply hollow screw, M14	35 N·m (26 lbf·ft)
Fuel pump mounting screws	5 N·m (44 lbf·in)
Fuel return tube at filter	25 N·m (19 lbf·ft)
Fuel return tube 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 nuts (M8)	15 N·m (132 lbf·in)
Left and right cylinder head supply tubing at filter	25 N·m (18 lbf·ft)
Oil supply tube bolt, M6 x 20	13 N·m (120 lbf·in)
Plug assembly, M12 (rear of cylinder head)	36 N·m (27 lbf·ft)
Primary filter cap	25 N·m (18 lbf·ft)
Right cylinder head supply tubing anchor at inlet elbow	11 N·m (96 lbf·in)

Rear Cover

Flywheel	
Flywheel mounting bolts, new bolts only	94 N·m (69 lbf·ft) flywheel torque sequence (Figure 625)

Table of Contents

Special Service Tools

Special tools for the VT 275 engine can be ordered from the SPX Corporation, 1-800-520-2584.

Mounting Engine on Stand

Mounting Engine on Stand	
Description	**TOOL NUMBER**
Engine Stand Mounting Bracket	ZTSE4507
Engine Stand	OTC1750A

Dual Turbocharger and Exhaust Tubing

Turbocharger	
Description	**Tool Number**
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)

Manifolds and Exhaust Gas Recirculation (EGR)	
Description	**Tool Number**
Anti-Seize Compound	Obtain locally
Cap Kit (all)	ZTSE4610
EGR Cooler Pressure Test Plates	ZTSE4545
EGR Valve Puller	ZTSE4669
EGR Valve Puller Arm (offset)	ZTSE4685
Feeler Gauge	Obtain locally
Intake Manifold Pressure Test Plates	ZTSE4527
Intake Manifold Pressure Test Plug	ZTSE4544
Intake Manifold Pressure Test Cap	ZTSE4682
Magnetic Covers for Cylinder Head Intake Ports	ZTSE4559

Cylinder Head and Valve Train

Cylinder Head and Valve Train	
Description	**TOOL NUMBER**
Case-To-Head Tube Removal Tool	ZTSE4694
Cylinder Head Lifting Bracket	ZTSE4661
Cylinder Head Pressure Test Plate	ZTSE4534
Dye Penetrant Kit	PT-7191
Fuel Gallery Cleaning Brush	ZTSE4541
Fuel Injector Hold Down Wrench	ZTSE4524
Fuel Injector Rack Holder	ZTSE4299B
Fuel Injector Tip Cleaning Brush	ZTSE4301
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 Connector Remover	ZTSE4650
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

Front Cover, Vibration Damper, and Gerotor Oil Pump

Front Cover, Vibration Damper, and Gerotor Oil Pump	
Description	**Tool Number**
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

Power Cylinder

Power Cylinder	
Description	**Tool Number**
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

Crankcase, Crankshaft and Camshaft	
Description	**Tool Number**
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
Front Seal/Wear Sleeve Installer	ZTSE4680
Front Wear Sleeve Remover	ZTSE4517
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

Oil Cooler and Filter Housing

Oil Cooler Cover Assembly	
Description	**Tool Number**
Magnetic Covers	ZTSE4557
Oil Cooler Pressure Test Plate	ZTSE4525

Engine Electrical Components

Engine Electrical	
Description	**Tool Number**
Glow Plug Connector Remover / Installer	ZTSE4670
IPR Valve Socket	ZTSE4666

High-pressure Oil Pump

High-pressure System	
Description	**Tool Number**
IPR Valve Socket	ZTSE4666
Liquid Gasket (RTV, 6 oz. tube)	1830858C1
#10 Quick Release Tool	ZTSE4581

Fuel System

Fuel System Tools	
Description	**Tool Number**
Cap Kit (all)	ZTSE4610
Turbocharger Inlet Guard	ZTSE4293

Rear Cover

Flywheel and Rear Cover	
Description	**Tool Number**
Dial Indicator with Magnetic Base	Obtain locally
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Loctite® Hydraulic Sealant	Obtain locally
Rear Seal/Wear Sleeve Installer[1]	ZTSE4515A
Rear/Wear Sleeve Removal Tool	ZTSE4518
Slide Hammer	ZTSE4398A

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

In Chassis Service

In Chassis Service	
Description	**Tool Number**
Fuel Injector Hold Down Wrench	ZTSE4524
Quick Release Tool kit	ZTSE4454
Fuel Injector Rack Holder	ZTSE4299B
Injector Connector Remover	ZTSE4650
On Engine Valve Spring Compressor Tool	ZTSE4697

Special Tool Photos

Photos of Essential Tools from VT 275 Essential Tool Kit, ZTSE5010

Figure 640 Injector Connector Remover, ZTSE4650

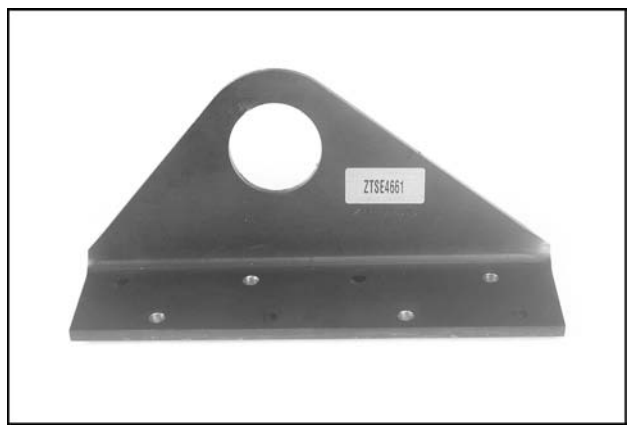

Figure 641 Cylinder Head Lifting Bracket, ZTSE4661

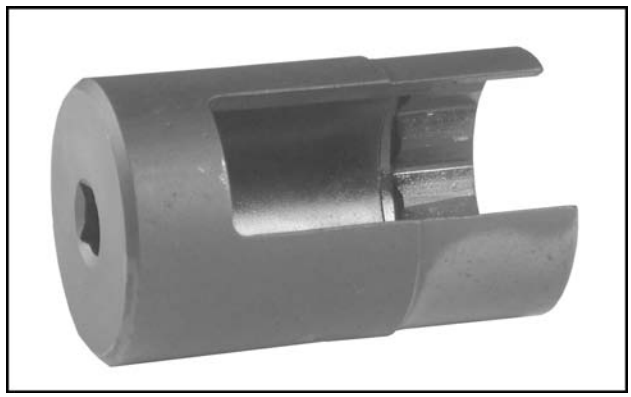

Figure 642 IPR Valve Socket, ZTSE4666

Figure 643 Glow Plug Connector Remover, ZTSE4670

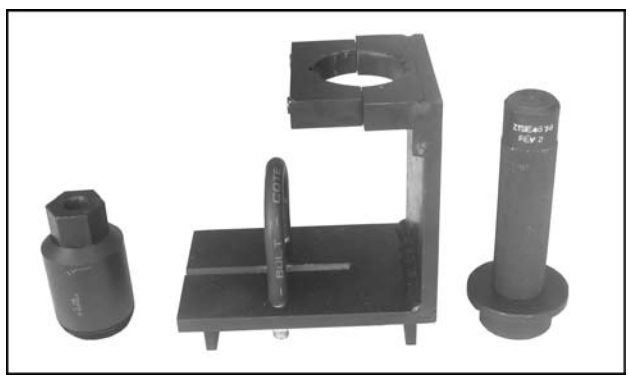

Figure 644 Turbo Crossover Tube Seal Remover and Installer, ZTSE4676

Figure 645 Front Seal Installer / Wear Sleeve Installer, ZTSE4680

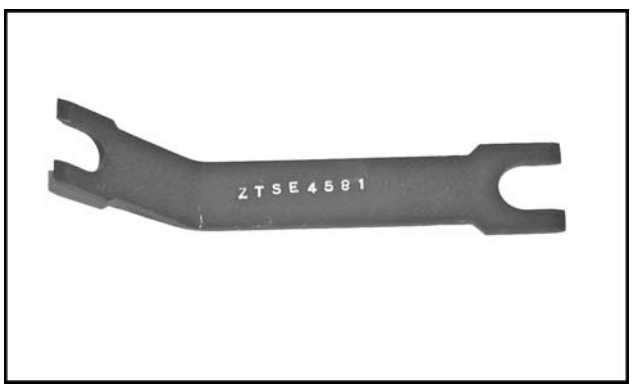

Figure 646 Quick Release Tool (#8 and #10) , ZTSE4581

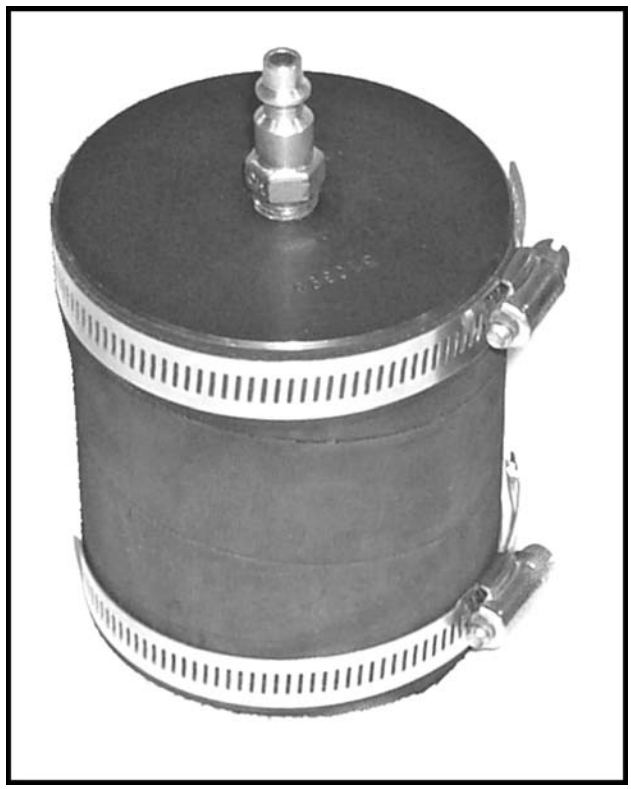

Figure 647 Intake Manifold Pressure Test Cap, ZTSE4682

Figure 648 EGR Valve Puller, ZTSE4685

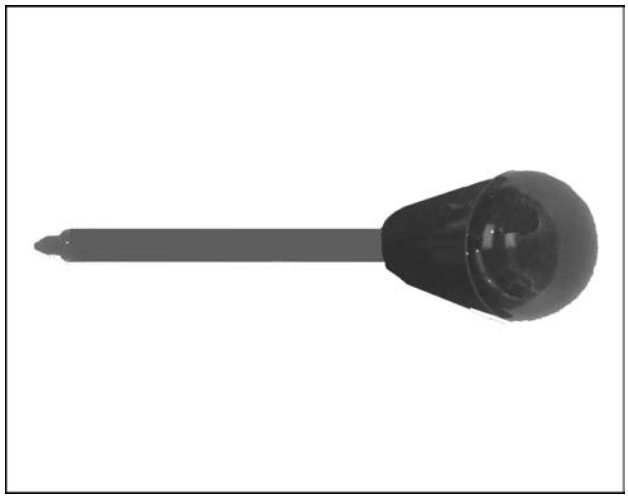

Figure 649 Crankshaft Timing Tool, ZTSE4687

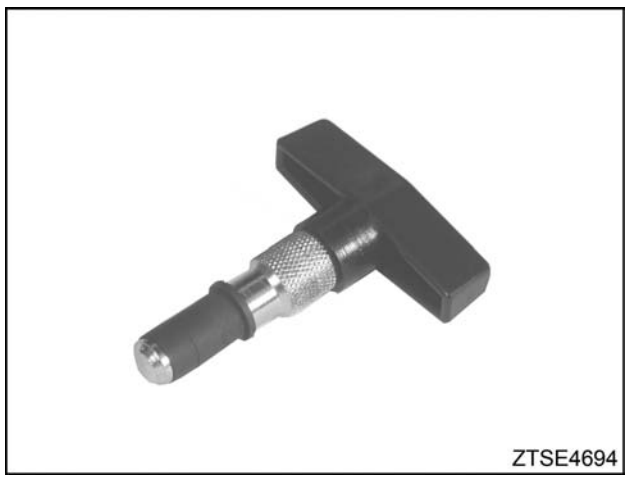

Figure 650 Case-to-Head Tube Removal Tool, ZTSE4694

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

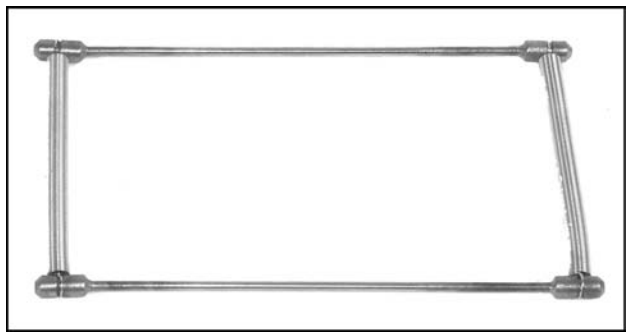

Figure 651 Piston Gauge Pins (0.082 in), ZTSE4513

Figure 652 Crankshaft Rear Seal / Wear Sleeve Installer, ZTSE4515A

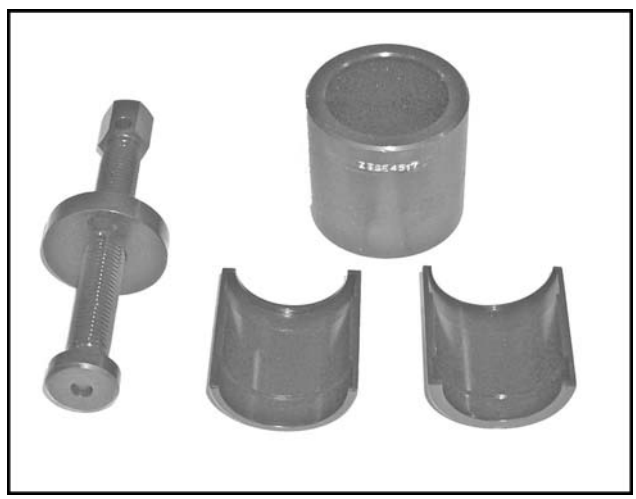

Figure 653 Front Wear Sleeve Remover, ZTSE4517

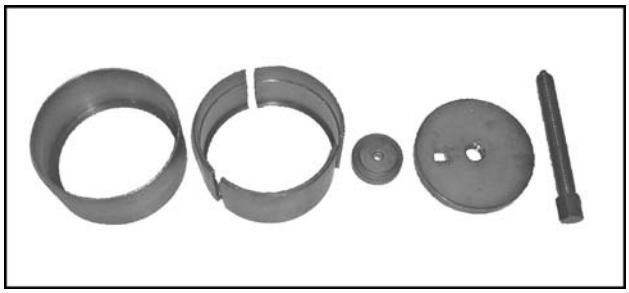

Figure 654 Crankshaft Rear Wear Sleeve Remover, ZTSE4518

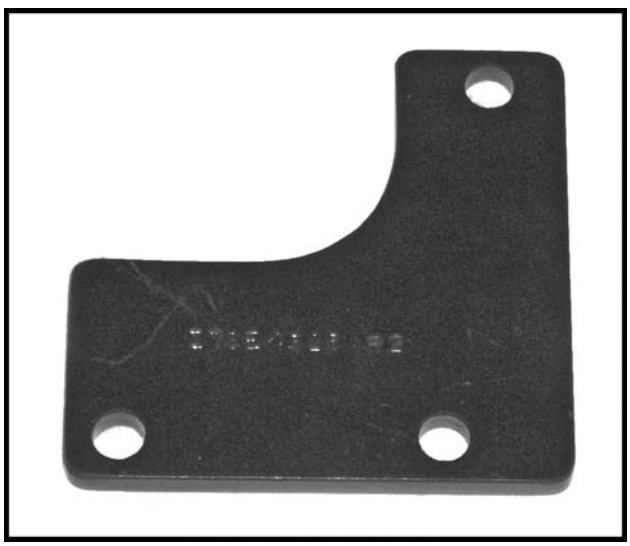

Figure 655 Oil Cooler Test Plate / Pressure Adapter, ZTSE4525

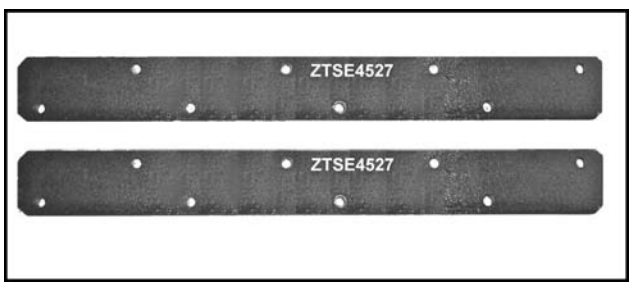

Figure 656 Intake Manifold Test Plates, ZTSE4527

Figure 657 Injector Sleeve Remover, ZTSE4528

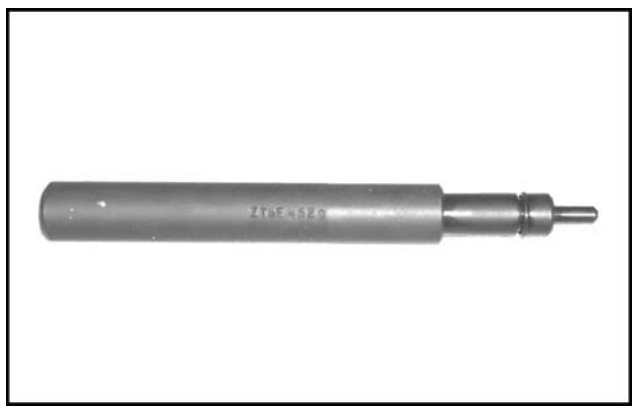

Figure 658 Injector Sleeve Installer, ZTSE4529

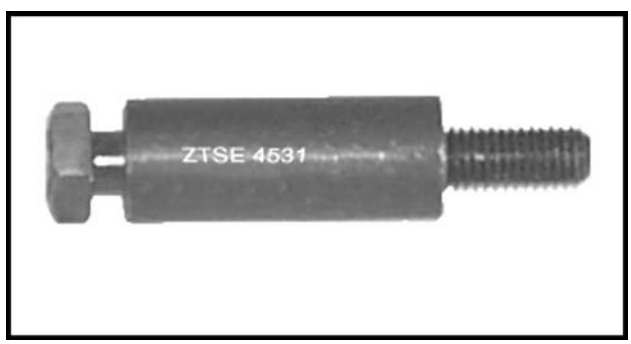

Figure 659 Glow Plug Sleeve Remover, ZTSE4531

Figure 660 Glow Plug Sleeve Installer, ZTSE4532

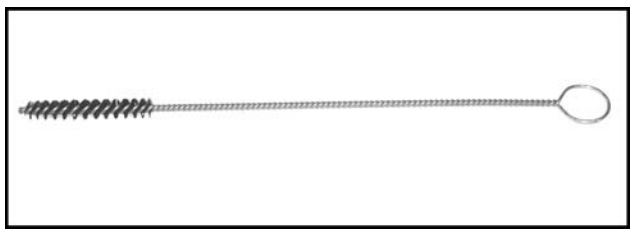

Figure 661 Glow Plug Sleeve Brush (nylon), ZTSE4533

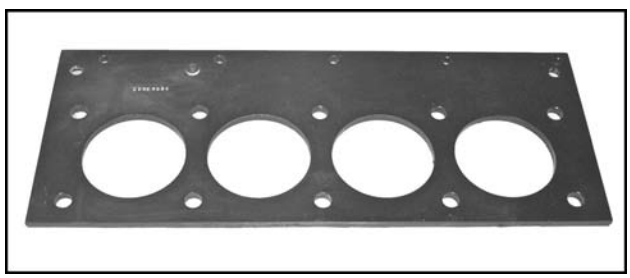

Figure 662 Cylinder Head Pressure Test Plate, ZTSE4534

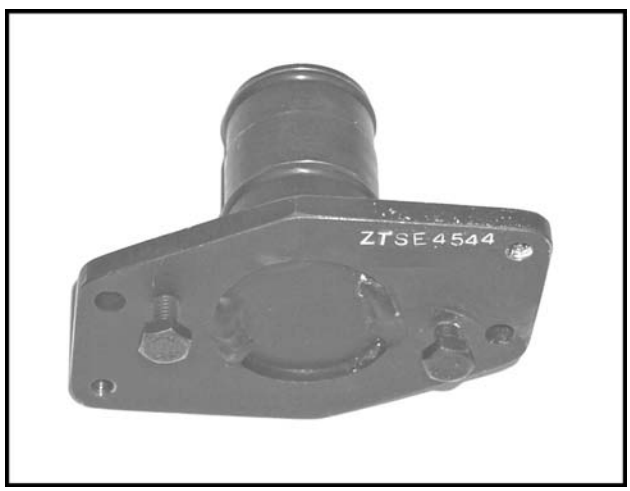

Figure 663 Intake Manifold Pressure Test Plug (EGR Valve), ZTSE4544

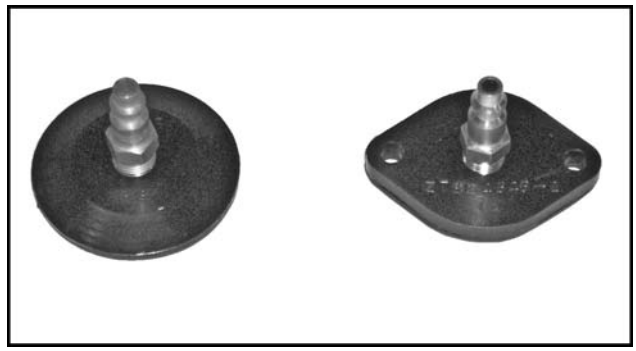

Figure 664 EGR Cooler Test Plates, ZTSE4545

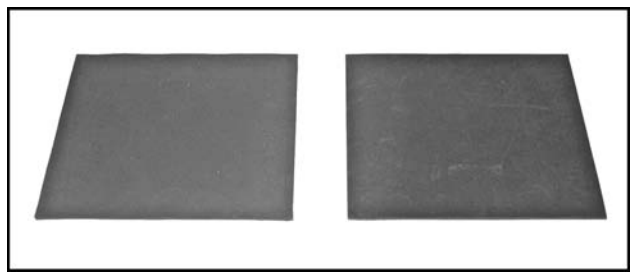

Figure 665 Oil Cooler Reservoir / High-pressure Pump Magnetic Covers, ZTSE4557

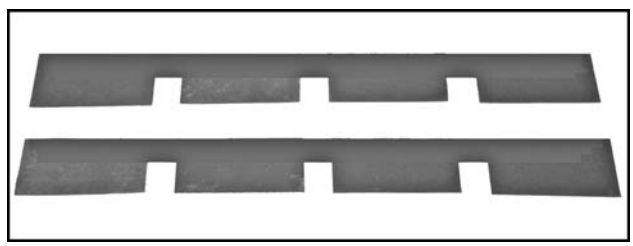

Figure 666 Magnetic Covers for Cylinder Head Intake Ports, ZTSE4559

Figure 667 Fan Wrench (pulley bolts), ZTSE4587

Figure 668 Slide Hammer Kit ⅝ in, ZTSE4398A

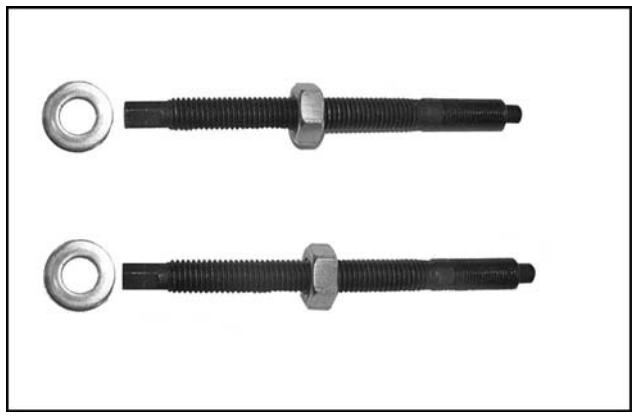

Figure 670 Crankshaft Secondary Flange Installation Studs, ZTSE4720

Figure 669 V - Engines Supplemental Service Tool Kit, ZTSE4721

Figure 671 On Engine Valve Spring Compressor, ZTSE4697

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

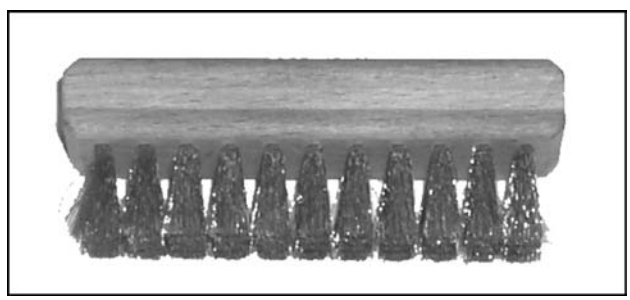

Figure 672 Injector Tip Cleaning Brush, ZTSE4301

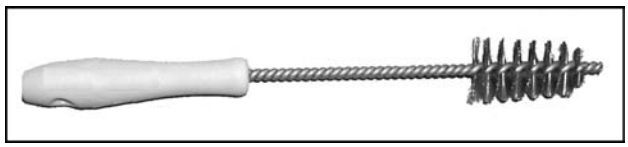

Figure 673 Injector Sleeve Brush, ZTSE43041

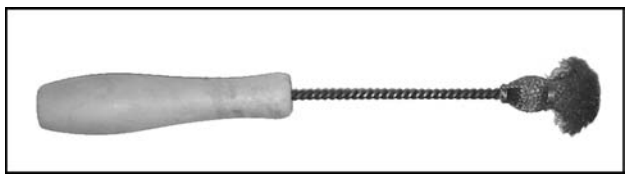

Figure 674 Injector Sleeve Flat Bottom Brush, ZTSE43042

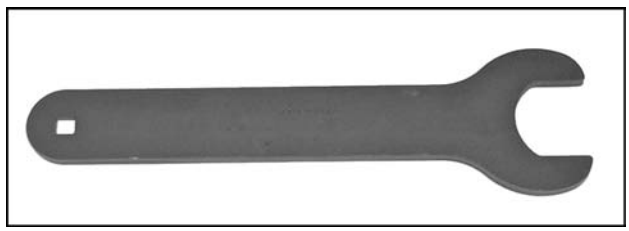

Figure 675 Fan Hub Wrench (2 inch), ZTSE43972

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