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## Description

### CYLINDER HEAD COMPONENTS

**NOTE:** Before removing cylinder heads, remove the following components:

- Fuel filter assembly and lines

  See “Fuel System.”

- VGT assembly

  See “Variable Geometry Turbocharger (VGT) Assembly.”

- Electronic Control Module (ECM), Injector Driver Module (IDM), and mounting bracket

  See “Engine Electrical.”

- Glow plug relay and bracket

  See “Engine Electrical”

- Intake manifold

  See “Manifolds and Exhaust Gas Recirculation (EGR)”

- Flywheel and rear cover (if removing cam followers)

  See “Rear Cover, Flywheel, and Power Steering Gear Drive.”

- Branch tube assembly (if removing cam followers)

  See “High-pressure Oil Pump.”

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

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

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

**NOTE:** Engine fluids (oil, fuel, and coolant) are a threat to the environment. Recycle or dispose of engine fluids according to local regulations. Never put engine fluids in the trash, on the ground, in sewers or other bodies of water.

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

**WARNING: To prevent personal injury or death, disconnect the main battery negative terminal before disconnecting or connecting electrical components.**


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**Figure 105 Cylinder head and related components**

1. Oil fill cap
2. Oil fill extension
3. Oil fill O-ring
4. Valve cover
5. Breather element O-ring
6. Crankcase breather element (left side only)
7. Valve cover gasket
8. Rocker arm carrier
9. Rocker arm carrier gasket
10. Exhaust manifold (left side)
11. Cylinder head (left side)
12. Intake manifold
13. Dowels


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**Figure 106 Cylinder head components**

1. Valve retainer keys (64)
2. Valve spring retainer (32)
3. Valve spring (32)
4. Valve stem oil seal (32)
5. Fuel injector sleeve (8)
6. Push rod (16)
7. Glow plug sleeve (8)
8. Cylinder head (2)
9. Exhaust valves (16)
10. Intake valves (16)
11. Hydraulic cam follower (16)
12. Cam follower guide (4)
13. Valve bridges (16)


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**Figure 107 Rocker arm carrier components**

1. Fulcrum plate (exhaust)
2. Dowel sleeve bushing (end fulcrums only)
3. Rocker arm (exhaust)
4. Rocker arm clip
5. Ball, 3/8 chrome
6. Fulcrum plate (dual)
7. Fulcrum plate (intake)
8. Rocker arm (intake)
9. Fulcrum bolt spacer
10. Rocker arm carrier


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**Figure 108 Rocker arm carrier and cylinder head components**

1. Injector harness connector
2. Crankcase to head tube assembly
3. Intake rocker arm (short)
4. Exhaust rocker arm (long)
5. Injector assembly
6. Valve bridge (2 per cyl)
7. Rocker arm fulcrum

## Component Removal

### Valve Covers and Rear Heat Shield

### Valve Covers

**CAUTION:** To prevent engine damage, do not use air tools when removing and installing valve covers.

**Figure 109 Removal of right valve cover**

1. Stud
2. Bolt

Remove the right valve cover as follows:

1. Remove 11 mounting bolts and valve cover.


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**Figure 110 Removal of left valve cover**

1. Stud
2. Bolt

Remove the left valve cover as follows:

2. Remove 11 mounting bolts and valve cover.

**Crankcase Breather**

**NOTE:** Do not remove the crankcase breather unless necessary.

**Figure 111 Valve cover and breather element**

3. Remove eight nuts that secure crankcase breather element to underside of valve cover.
4. Replace breather element only if necessary.

**Rear Heat Shield**

1. Remove one M10 x 16 bolt from the tubing heat shield from the left side cylinder head.
2. Remove two M6 x 12 bolts from the tubing heat shield rear cover assembly.
3. Remove rear heat shield and place aside for cleaning.
4. Remove cylinder head to filter tubing on each side as required.

**High-pressure Oil Rail System**

**Figure 112 Removal of hose from high-pressure oil rail**

1. Hose
2. Oil rail assembly
3. #10 Quick Release Tool

1. Use a #10 Quick Release Tool (Table 13) to slide release ring back while pulling the oil hose outward from high-pressure oil rail.


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**Figure 113 Removing hose from crankcase-to-head tube assembly**

1. Hose
2. #6 Quick Release Tool

**NOTE:** When releasing the hose with the #6 Quick Release Tool, do not pry release ring off.

2. Use a #6 Quick Release Tool (Table 13) to slide release ring back while lifting oil hose from crankcase-to-head tube assembly.
3. Remove eight M6 x 25 bolts that retain the oil rail assembly to rocker arm carrier.

**Figure 114 Removing high-pressure oil rail assembly**

4. Lift oil rail straight up and away from injectors. Allow oil to drain back to the sump or some other suitable container.

**Figure 115 Removing the crankcase-to-head tube assembly**

5. Remove the crankcase-to-head assembly in upper side of rocker arm carrier. Discard tube assembly and O-ring.

**NOTE:** After removing the crankcase-to-head assembly, do not reattach it to the oil hose without the release ring.


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### High-pressure Oil Rail System Service (if required)

**Figure 116 Oil rail check valve and plug**

1. Oil rail
2. O-ring
3. M14 internal hex plug
4. O-ring
5. Oil rail check valve

6. Remove M14 internal hex plug and discard O-ring.
7. Remove oil rail check valve and discard O-ring.
8. Inspect the plug and check valve for cracks and worn threads. If either are found replace them.
9. Install new O-ring onto check valve and torque to special torque (Table 12).
10. Install new O-ring onto the M14 internal hex plug and torque to special torque (Table 12).

**CAUTION:** To prevent engine damage, do not remove 1-1/4 x 20 UNF oil rail end plugs or the Acoustic Wave Attenuator (AWA) bottom port fitting. Service parts are not available.

### Fuel Injectors

**NOTE:** There is no need to drain the fuel rail if removing an injector in chassis.

**Figure 117 Releasing the injector harness connector**

1. Use a correct sized socket to push the injector connector into the rocker arm carrier.

**CAUTION:** To prevent engine damage, do not use air tools when removing and installing fuel injectors. The snap ring that extracts the injector can dislodge and fall into the oil drain hole.

**Figure 118 Oil drain hole to glow plug**

1. Oil Drain Hole
2. Glow Plug


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**Figure 119 Positioning shop towels into oil drain holes with a screwdriver**

**NOTE:** The shop cloth towels can be positioned without the removal of glow plugs and buss bar.

Repeat this procedure for each injector assembly.

2. Before removing the injector assembly, insert clean shop towels into oil drain holes next to each glow plug (Figure 118). A thin screwdriver at least six inches in length can be used to position shop towels into the oil drain holes (Figure 119). This step will enable the recovery of snap rings or other pieces dislodged during injector removal.

**Figure 120 Fuel injector hold down clamp assembly (typical)**

1. Bolt, M8 X 45
2. Snap ring (earlier design) or Retainer (later design)
3. Clamp alignment index

**Figure 121 Fuel injector hold down clamp assembly**

1. Fuel injector assembly
2. Fuel injector hold down clamp assembly

3. Use the Fuel Injector Hold Down Wrench (Table 13) to remove the fuel injector hold down clamp assembly.

**CAUTION:** To prevent damage to the engine, make sure snap rings or pieces of snaps rings are found and removed.

**Figure 122 Fuel Injector**

1. Fuel injector assembly
2. Fuel injector hold down clamp assembly

**NOTE:** Loosening the injector bolt extracts the injector and clamp simultaneously.


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4. Once the injector assembly has been removed, verify snap ring is in place on each injector hold down bolt (Figure 120).

   **NOTE:** If a snap ring or piece of snap ring is missing from the injector hold down assembly, it must be located before removing any shop towels.

5. Remove fuel injector from cylinder head bore by lifting injector and hold down clamp assembly straight up and out.

6. Place each fuel injector into the Injector Holder Rack (Table 13).

### Rocker Arm Carrier

**CAUTION:** To prevent engine damage, do not remove and replace just one rocker arm or cylinder head bolt. All bolts and the head gasket must be replaced.

**Figure 123 Rocker arm carrier assembly**

1. Rocker arm carrier assembly
2. Cylinder head bolt (10)
3. Rocker arm carrier mounting bolt (8)

1. Remove eight M8 x 70 rocker arm carrier bolts and ten M14 x 193 cylinder head bolts using a circular pattern to loosen. Begin with the outer bolts and loosen bolts moving inward.

**Figure 124 Removing rocker arm carrier**

2. Lift rocker arm carrier assembly from cylinder head and place aside for disassembly, cleaning, inspection, and assembly.

### Valve Bridges and Push Rods

**CAUTION:** To prevent engine damage, do not use paint to identify internal components or their orientation. Use permanent markers only.


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**Figure 125 Valve bridge identification (left cylinder head)**

1. Identify each valve bridge with its respective valve set so they may be installed into their original locations.

   Example: **2 - I**

   - Cylinder number **2** as counted from the front of engine
   - **I** = Intake, **E** = Exhaust

**Figure 126 Removing push rods**

1. Push rod (copper color end goes up)

2. Remove and identify all push rods so that they may be returned to their original positions during installation.


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## Cylinder Heads

**Figure 127 Removal of glow plugs**

1. Remove glow plugs.

**WARNING: To prevent personal injury or death, make sure the cylinder head lifting bracket is mounted on the center of cylinder head. Also make sure the lifting hook has a safety latch.**

2. Remove three middle M8 x 50 bolts – cylinder head to crankcase.

**Figure 129 Cylinder head lifting bracket**

1. M8 x 50 bolt – cylinder head to crankcase
2. Cylinder head lifting bracket
3. Lifting bracket mounting bolt (4)

3. Position lifting bracket on cylinder head and install four lifting bracket mounting bolts.

   **NOTE:** The lifting bracket allows the cylinder head to be removed squarely from the crankcase.

**Figure 130 Cylinder head removal**

4. Attach a lifting hoist hook or suitable lifting sling to lifting bracket.
5. Remove the two remaining M8 x 70 bolts – cylinder head to crankcase.
6. Lift cylinder head from the crankcase.

**CAUTION:** Do not damage cylinder head locating dowel sleeves.

7. Put cylinder head on suitable surface.

**CAUTION:** Do not scratch cylinder head surface.


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8. Remove and discard cylinder head gasket.

### Hydraulic Cam Followers

#### Removal

**NOTE:** If cam followers must be removed, the rear cover and the high-pressure oil pump cover must be removed to gain access to the rear engine tube assembly. See “Rear Cover, Flywheel, and Power Steering gear Drive.”

**CAUTION:** To prevent engine damage, keep cam followers and push rods in the order removed. Install cam followers and push rods to original positions.

**NOTE:** If the valve train operates quietly and hydraulic cam followers function satisfactorily, do not service cam followers.

1. Remove the M6 x 15 bolt with washer securing each roller follower guide to the crankcase.

**NOTE:** Identify orientation of each cam follower and guide during disassembly.

**Figure 131 Cam followers and roller follower guides**

2. Remove cam followers and roller follower, lifting the guide straight up. A hand tool may be required.

**Figure 132 Cam follower removal from roller follower guide**

3. Remove cam followers from roller follower guide.


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## Cleaning and Inspection

### Cylinder Head Components

### Cleaning

1. With valves installed to protect seats, use a scraper and wire brush to remove deposits and gasket material from valve heads and gasket surface. Do not damage gasket surface of cylinder head.
2. Use a suitable solvent to remove dirt, grease, and deposits from removed parts.

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

3. Clean all bolt holes, Make sure gasket surfaces, oil return, and coolant passages are clean. After rinsing thoroughly with hot water, dry with filtered compressed air. (page 3 ).

**CAUTION:** To prevent engine damage, new head bolts and a new cylinder head gasket must be used when installing the cylinder head. Even if one bolt was removed, a new cylinder head gasket and new bolts are required.

4. Clean all bolts (except head bolts) with a suitable solvent and dry thoroughly. New head bolts must be installed.
5. Clean crankcase threads.

**NOTE:** Dirt in threads or damaged threads may cause binding, resulting in a false torque reading.

**Figure 133 Bottoming tap**

6. Use a Bottoming Tap (metric) (Table 13) to clean each tapped hole in crankcase top deck. Remove debris with filtered compressed air. (page 3 )

**CAUTION:** To prevent engine damage, always replace head bolts when installing the cylinder head. Even if you are removing only one bolt, it will be necessary to replace the cylinder head gasket and all cylinder head bolts.

Do not use antiseize compound, grease, or any other lubricant except clean engine oil. Other lubricants have an adverse effect on torque results.

7. Thoroughly clean each push rod using a suitable solvent. Dry using filtered compressed air (page 3 ).

### Cylinder Head Inspection – Valves Installed

**NOTE:** Inspect cylinder head for thickness, warping, cracks, and valve leakage.


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**Figure 134 Measurement of cylinder head thickness**

1. To determine if cylinder head has been resurfaced, use a 3-4 inch micrometer to measure cylinder head deck thickness at four corner locations. If overall cylinder head thickness (deck-to-deck) specification is not met (Table 11), install a new cylinder head.

**Figure 135 Check for gasket surface flatness**

1. Feeler gauge
2. Straightedge

2. Use a Straightedge (Table 13) and Feeler Gauge to check cylinder head gasket surface for flatness. Use the following pattern. Check for flatness horizontally, diagonally, and transversely. If specifications are not met (Table 11), install a new cylinder head.

**Figure 136 Checking valve recession**

1. Straightedge
2. Feeler gauge
3. Valve head

3. Before removing valves, check valve head recession (relative to deck) as follows:
   a. Place a Straightedge (Table 13) across each valve.
   b. Place a feeler gauge between Straightedge (Table 13) and valve head. Record valve recession clearance.
   c. If out of specification (Table 11), replace valve. Do step 2 again and if specifications are still not met, install a new cylinder head.
4. Inspect for cracks in the cylinder head using the following dye penetrant method (Table 13):


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**Figure 137 Cleaner sprayed on cylinder head**

a. Spray cleaner onto lower deck (gasket surface) of cylinder head and wipe dry.

**Figure 138 Spraying dye penetrant onto cylinder head**

b. Spray dye penetrant onto lower deck (gasket surface) of cylinder head. Allow dye to remain on surface from 1-30 minutes.

c. Wipe dye off cylinder head surface.

**NOTE:** Dye will remain in any cracks during this 'wipe off' step.

d. Spray on developer and let dry for 5-15 minutes. Cracks will show up as purple lines against white developer.

**Figure 139 Spraying developer onto cylinder head**

**Figure 140 Cylinder head crack between intake and exhaust valves**

**CAUTION:** To prevent engine damage, replace cylinder head, if cracked.

5. Check for valve leakage using mineral spirits as follows:

   a. Position cylinder head on wooden blocks with gasket surface facing down.


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**Figure 141 Intake and exhaust ports sprayed with mineral spirits**

b. Squirt mineral spirits into intake and exhaust ports.

**Figure 142 Leak inspection**

1. Inspection mirror
2. Reflection of valve
3. Flashlight

c. Wait five minutes. Then use an inspection mirror to inspect valve seat area for leakage of mineral spirits.

**NOTE:** Valve seats must not leak. Valve seat reconditioning is not required, if the cylinder head passes the mineral spirits test. If valve seats leak, recondition the valves. See Removal in this section.

**Removing Valves from Cylinder Head**

**Figure 143 Compressing valve spring**

1. Using a “C” Type Valve Spring Compressor (Table 13), compress valve springs for valve retainer key removal. Remove valve retainer keys. A small magnet is useful for this procedure.

**Figure 144 Removing valve retainer keys**

1. Valve retainer keys
2. “C” Type Valve Spring Compressor


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**Figure 145 Removing valve spring retainer**

2. Remove valve spring retainer.
3. Remove valve spring.

**Figure 146 Removing valve spring**

**Figure 147 Removing valve from cylinder head**

4. Remove valve from cylinder head.

**Figure 148 Removing valve stem oil seal**

5. Remove valve stem oil seal and discard. Valve stem seals are not reusable. Pliers will be necessary to get seal off the end of the valve stem guide.


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**Cylinder Head Inspection – Valves Removed**

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

1. Pressure testing the cylinder head will reveal cracks in ports or sleeve leakage which cannot be observed using dye penetrant. Pressure test the cylinder head as follows:
   a. Remove valves.
   b. Fasten Cylinder Head Pressure Test Plate (Table 13) on gasket side of cylinder head. Secure plate using ten M14 and five M8 mounting bolts.

**Figure 149 Cylinder Head Pressure Test Plate**

1. Mounting bolt (15)
2. Cylinder Head Pressure Test Plate
3. Pressure Test Regulator/Gauge assembly

   c. Install Pressure Test Regulator/Gauge assembly (Table 13) to Cylinder Head Pressure Test Plate (Table 13).
   d. Immerse cylinder head in water. Apply air pressure and adjust to 124-138 kPa (18-20 psi) and inspect for leaks at the following places:
      - Ports
      - Upper cylinder head deck
      - Lower cylinder head deck
      - Nozzle sleeve area
      - Glow plug sleeve area

**CAUTION:** To prevent engine damage, replace cylinder head if leaking.

2. With the valves removed from the cylinder head, clean all valve guides using a nylon brush, soap and water. Blow out any residue with filtered compressed air. See (page 3 ).
3. Position an inspection light at the bottom of the valve guide bores and examine the walls for burning or cracking. Replace the head as necessary.

**Figure 150 Measurement of small hole gauge (valve guide ID)**

4. Measure each valve guide by using a small hole gauge (Table 13) and a 0-1 inch outside micrometer. Record each valve guide inner diameter so valve-to-guide running clearance may be determined. If valve guide inner diameter exceeds specifications (Table 11), replace cylinder head.
5. Using the valve guide inside diameter and the valve stem diameter measurements recorded earlier, determine valve stem-to-guide running clearance. See Specifications (Table 11). Replace valve as required.
6. Clean valve seat area using suitable solvent, before inspection.


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7. Inspect the exhaust valve seats for burned or cracked conditions. If any of these conditions exist, replace cylinder head.

### Cylinder Head Component Inspection

#### Push Rods

1. Inspect each push rod for wear and deposits which may restrict the flow of oil into the rocker arm assemblies. Replace as required.

**Figure 151 Checking for push rod flatness**

2. Check all push rods by rolling them on a straight flat surface. If it is not straight, see Specifications for runout (Table 11). If specifications are exceeded, replace push rod.

#### Valves

1. Remove all carbon from valve stems and valve heads using a wire brush.
2. Inspect each valve, replacing any that show evidence of burn marks, warpage, scuffing, bending, or valve tip spalling.
3. Measure each valve stem for wear using a 0-1 inch micrometer to measure valve stem diameter.

**NOTE:** Measure valves at three locations 90° apart. See Specifications (Table 11). Install new valves that exceed the specification for minimum stem diameter.

**NOTE:** The intake valve has a larger diameter head.

**Figure 152 Measurement of valve face**

4. Measure valve face margin at four locations (90° apart) using a dial caliper.

**CAUTION:** To prevent engine damage, minimum valve face margin must be maintained across the entire valve face. An insufficient margin will not provide correct heat dissipation and will lead to valve warping or breakage. Intake and exhaust valve margins are different. Replace valve, if the margin is less than specified minimum. See Specifications .

**NOTE:** If valves and seats are serviceable, they may be refaced to specified angles .

#### Valve Springs

1. Clean all valve springs in a suitable solvent.
2. Inspect valve springs for rust, pitting, distortion, and cracks. If any of these conditions exist, replace the valve spring.


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**Figure 153 Flatness check of valve spring**

3. Inspect to verify that spring ends are flat and square to prevent lateral loads on valve stem. Replace any springs that do not have flat and square ends.
4. Measure valve spring tension using a Valve Spring Tester (Table 13).

**Figure 154 Measurement of valve spring free length**

a. Measure valve spring free length. See Specifications (Table 11).


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**Figure 155 Measurement of valve spring free length under load**

b. Apply the appropriate test load to each spring and determine whether test length is achieved. See Specifications (Table 11).

### Valve Spring Retainer Keys

1. Clean all valve spring retainer keys with a suitable cleaning solvent.
2. Inspect the inside and outside of the valve spring retainer keys for wear. Install new spring keys, if necessary.

### Fuel Injector Sleeve Removal

**CAUTION:** To prevent engine damage (if replacing injector sleeves in chassis), place a small plug into the bottom of the injector sleeve before cutting removal threads. The plug will prevent small metal chips from entering the combustion chamber.

**Figure 156 Injector Sleeve Remover - tap**

1. Lubricate Injector Sleeve Remover - tap (Table 13) .

   **NOTE:** The injector sleeve remover is made of stainless steel. Lubrication of the Injector Sleeve Remover - tap is required, otherwise excessive force is necessary to get the tap started.

**Figure 157 Cutting threads into fuel injector sleeve**

2. Thread Injector Sleeve Remover - tap into fuel injector sleeve. Cut threads at least 1/2 inch deep to accommodate the injector sleeve removal tool.


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**Figure 158 Injector Sleeve Remover**

3. Install the Injector Sleeve Remover (Table 13) into the threaded sleeve and tighten.
4. Thread the Slide Hammer (Table 13) into the Injector Sleeve Remover.

**Figure 159 Installing Slide Hammer**

**Figure 160 Removing fuel injector sleeve from bore**

1. Fuel injector bore
2. Fuel injector sleeve
3. Injector Sleeve Remover
4. Slide Hammer

5. Use Slide Hammer to remove fuel injector sleeve.

**Figure 161 Cleaning the injector bore**

6. Insert an Injector Sleeve Brush (Table 13) into the fuel injector bore to remove deposits and hardened sealant from bore.
7. Remove fuel rail plug assembly (M12).


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**Figure 162 Cleaning the fuel gallery**

1. Fuel Gallery Cleaning Brush
2. Fuel gallery port

8. Clean the fuel gallery with a Fuel Gallery Cleaning Brush (Table 13).

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

**Figure 163 Blowing out fuel gallery**

9. Use filtered compressed air (page 3 ) to clean out all debris from the fuel gallery port.
10. Install the fuel rail plug assembly and tighten to the special torque (Table 12).

**Fuel Injector Sleeve Installation**

Use the following steps when installing a new fuel injector sleeve:

1. Verify injector bore is completely clean and dry.
2. Place fuel injector sleeve onto tool.

**Figure 164 Application of liquid gasket to fuel injector sleeve**

1. Wall (end)
2. Upper wall (top)

3. Apply Liquid Gasket (RTV) (Table 13) sealant to fuel injector sleeve.

**Figure 165 Installing fuel injector sleeve**

4. Carefully center the sleeve into the injector bore.


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**Figure 166 Installation of fuel injector sleeve into bore**

5. Use a hammer, drive Injector Sleeve Installer (Table 13) with fuel injector sleeve in fuel injector bore until the sleeve bottoms. If liquid gasket gets in the inside of the injector sleeve, it must be cleaned out before it hardens.

### Glow Plug Sleeve Removal

**CAUTION:** To prevent engine damage (if replacing glow plug sleeves in chassis), place a small plug into the bottom of the glow plug sleeve before cutting removal threads. The plug will prevent small metal chips from entering the combustion chamber.

**Figure 167 Glow Plug Sleeve Remover – tap**

1. Lubricate Glow Plug Sleeve Remover – tap (Table 13).

   **NOTE:** The glow plug sleeve is made of stainless steel. Lubrication of the Glow Plug Sleeve Remover – tap is required, otherwise excessive force will be necessary to get the tap started.

2. Install tool to cut threads into the glow plug sleeve. Cut threads at least 1/2 inch deep to accommodate the Glow Plug Sleeve Remover tool.

**Figure 168 Glow Plug Sleeve Remover – tap**

3. Thread the Glow Plug Sleeve Remover (Table 13) into the sleeve.

**Figure 169 Glow Plug Sleeve Remover**


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**Figure 170 Removing glow plug sleeve**

4. Use a wrench to thread tool into sleeve until sleeve is extracted.
5. Remove glow plug sleeve.

**Figure 171 Glow plug sleeve removed**

**Figure 172 Cleaning glow plug bore**

6. Clean glow plug bore with Glow Plug Sleeve Seat Wire Brush (Table 13).

### Glow Plug Sleeve Installation

**NOTE:** Be certain that the glow plug recess was cleaned out with a Glow Plug Sleeve Seat Wire Brush (Table 13), rinsed with a suitable cleaning solution, and blown out with shop air.

**Figure 173 Application of liquid gasket to sleeve**

1. Wall (end)
2. Upper wall (top)

1. Apply Liquid Gasket (RTV) (Table 13) to the two locations on the glow plug sleeve.


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**Figure 174 Installing glow plug sleeve**

1. Glow Plug Sleeve Installer
2. Glow plug sleeve

2. Install glow plug sleeve into cylinder head with the Glow Plug Sleeve Installer (Table 13).

**Figure 175 Installing glow plug sleeve into bore**

1. Glow Plug Sleeve Installer
2. Glow plug sleeve

3. Install glow plug sleeve into recess until it bottoms.
4. Clean glow plug sleeve after installation with a nylon brush and solvent. Make sure Liquid Gasket is cleaned out before it hardens.

**Cylinder Head Reassembly**

Clean valve faces and seats with a suitable cleaning solvent to remove all dirt or foreign material. Blow dry all new and used components using filtered compressed air (page 3 ).

**Installing Valves**

**NOTE:** Guides must be clean. Use a valve guide brush to clean guides.

1. Dry valve guides with filtered compressed air. (page 3 )
2. Lubricate the inside diameter of the new valve stem seal with clean engine oil and install valve seal over valve guide until it stops.

**NOTE:** Valve seal will not seat completely over valve guide by hand. Seals can be seated using a suitable deep socket and a rubber mallet to provide a positive contact with machined base.

**Figure 176 Valve seal, spring, and retainer**

1. Valve seal
2. Valve spring
3. Valve retainer

3. Place valve spring over valve stem seal.


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**Figure 177 Installation of valve retainer key**

1. Valve retainer key
2. “C” Type Valve Spring Compressor

4. Install a valve spring retainer on top of spring.
5. Attach “C” Type Valve Spring Compressor Glow Plug Sleeve Seat Wire Brush (Table 13) and compress the valve spring. Install the retainer keys and release valve spring compression tool.

**CAUTION:** To prevent engine damage, be sure retainer keys are correctly seated in each valve stem.

6. After valve replacement, measure valve head recession relative to deck to confirm reconditioning. See Specifications (Table 11).


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### Rocker Arm Carrier Fulcrum Removal

### Disassembly of Rocker Fulcrums

**Figure 178 Removal of bolts from dual rocker arm fulcrum**

1. Intake fulcrum plate
2. Mounting bolt and spacer (8 each)
3. Dual rocker fulcrum plate (3)
4. Exhaust fulcrum plate

1. Remove eight M8 x 65 bolts and spacers holding rocker arm fulcrums to the rocker arm carrier.
2. Remove – as assemblies – the intake fulcrum plate, three dual rocker fulcrum plates, and exhaust fulcrum plate from the rocker arm carrier. Do steps 3 through 6 to disassemble.

**Figure 179 Separation of rocker arm from fulcrum plate (typical)**

1. Rocker arm
2. Fulcrum plate
3. Rocker arm clip


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3. Put rocker arm and fulcrum plate assembly upside down in your palm.
4. Push up on the rocker arm with palm and forward on the fulcrum plate with thumb of opposite hand.

**Figure 180 Rocker arm separated (typical)**

1. Rocker arm ball
2. Rocker arm
3. Rocker arm clip
4. Fulcrum plate

5. Remove the rocker arm and rocker arm ball.

**Figure 181 Rocker arm clip removed (typical)**

1. Fulcrum plate
2. Rocker arm clip

6. Remove and discard rocker arm clip.

**Figure 182 New rocker arm fulcrum (dual)**

1. Exhaust end
2. intake end

**NOTE:** Earlier rocker arm fulcrums are no longer serviceable; new rocker arm fulcrums and clips are required.

**Cleaning and Inspection**

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

1. Clean all parts with a suitable solvent. Use filtered compressed air to dry parts.
2. Inspect each rocker arm pivot foot and corresponding valve bridge for pitting or scuffing. Inspect each rocker arm ball and socket for scuffing. Replace rocker arms and valve bridges as required.
3. Inspect rocker arm post ball socket for excessive wear. Inspect bolts for thread damage, replace worn components as required.
4. Inspect the valve cover gasket for any evidence of damage or misalignment under compression. Under normal service conditions it is designed to be reused.


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**Reassembly**

**Figure 183 New rocker arm fulcrum (dual underside)**

1. Exhaust end
2. intake end

**NOTE:** Earlier rocker arm fulcrums are no longer serviceable; new rocker arm fulcrums and clips are required.

**Figure 184 Installation of new rocker arm clip (typical)**

1. Fulcrum plate
2. Rocker arm clip

1. Install a new rocker arm clip on new fulcrum plate.

**Figure 185 Installation of rocker arm ball (typical)**

1. Rocker arm ball
2. Rocker arm
3. Rocker arm clip
4. Fulcrum plate

2. Insert rocker arm ball in detent in fulcrum plate.

**Figure 186 Installation of rocker arm (typical)**

1. Rocker arm
2. Fulcrum plate
3. Rocker arm clip

3. Position lower part of rocker arm under rocker arm clip, push up with your palm, and use thumb back


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to pull upper part of rocker arm over rocker arm ball.

4. Check for freedom of movement of rocker arm on fulcrum plate.

**Figure 187 Installation of end fulcrum plate and dowel**

5. Assemble individual intake and exhaust fulcrum plates to each end of the rocker carrier assembly by setting the fulcrum onto the locating dowel and orienting the stamped **E** and **I** to face up. Install an M8 x 65 bolt and spacer onto each fulcrum and tighten to the special torque (Table 12).

**Figure 188 Installation of dual rocker fulcrum plates**

6. Assemble the dual rocker fulcrum plates to carrier assembly by orienting the **E** and **I** facing up and the casting branches towards the camshaft. Install six M8 x 65 bolts and spacers and tighten to the special torque (Table 12).

**Figure 189 Cylinder head to rocker carrier gasket**

7. Replace cylinder head to rocker carrier gasket.


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## Component Reassembly

### Hydraulic Cam Follower

1. Clean hydraulic cam followers and roller follower guide. Use care to maintain roller follower identification and orientation.

**NOTE:** Identify orientation of each cam follower and guide during assembly.

**Figure 190 Installation of cam follower in guide**

2. Lubricate and place each hydraulic cam follower into its respective roller follower guide.

**Figure 191 Installation of cam followers and guide**

3. Lubricate cam followers with clean engine oil and install followers into their respective bores.

**NOTE:** See the “High Pressure Oil Pump” section, for procedure relating to the rear engine tube assembly (branch) which mounts over the rear cam follower guides.

4. Install an M6 x 15 bolt with washer to roller follower guides (front guides only) and torque bolt to the standard value (General Torque Guidelines, page 333).

### Cylinder Heads

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

**CAUTION:** To prevent engine damage, make sure cylinder head and head gasket are clean and free of debris. A contaminated seal between the cylinder head and gasket can lead to oil, coolant, and compression leakage. Do not apply sealer to head gasket surfaces.

**CAUTION:** Threads in crankcase bolt holes must be clean and blown dry with filtered compressed air. Dirt or oil left in holes may cause binding and false torque reading during assembly.


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1. If not done, clean all cylinder head bolt holes with a Head Bolt Bottoming Tap (Table 13) and remove debris with filtered compressed air. (page 3 )

**Figure 192 Old cylinder head (eight tapped M8 holes)**

1. Tapped M8 bolt hole (8)

**Figure 193 New cylinder head (two tapped M8 holes)**

1. Tapped M8 bolt hole (2)

**Figure 194 Cylinder head dowel sleeves**

1. Dowel sleeve (2)

2. Make sure two cylinder head dowel sleeves are installed (one at front and one at rear of crankcase).

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

**CAUTION:** Threads in crankcase bolt holes must be clean and blown dry with filtered compressed air. Dirt or oil left in holes may cause binding or a false torque reading during assembly.

**CAUTION:** To prevent engine damage, make sure cylinder head and head gasket are clean and free of debris. A contaminated seal between the cylinder head and gasket can lead to oil, coolant, and compression leakage. Do not apply sealer to head gasket surfaces.


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**Figure 195 Cylinder head gasket**

**CAUTION:** To prevent engine damage, install a new cylinder head gasket with part number facing up. Make sure the top five bolt holes and head gasket push rod holes line up.

**NOTE:** Use care to avoid scratching blue compound on cylinder head gaskets.

3. Align new cylinder head gasket with spring dowel pins and press to install.

**NOTE:** Cam followers cannot be removed or replaced when cylinder head is bolted to the crankcase. Be sure to complete required work on cam followers, before installing cylinder head.

**Figure 196 Installation cylinder head lifting bracket**

1. Cylinder Head Lifting Bracket
2. Lifting bracket mounting bolt (4)

4. Install Cylinder Head Lifting Bracket (Table 13) in center of cylinder head. Tighten bracket mounting bolts.

**CAUTION:** To prevent engine damage, do not drop or slide cylinder head on head gasket.

**Figure 197 Installing Cylinder Head**

1. Lifting bracket
2. Hoist
3. Cylinder head

5. Attach hoist hook or lifting sling to lifting bracket.
6. Raise cylinder head and position to align with dowel sleeves previously installed in crankcase, and lower onto gasket.

**Figure 198 Installation of cylinder head**

1. M8 x 70 bolt – cylinder head to crankcase (2 of 5)
2. Cylinder head lifting bracket
3. Lifting bracket mounting bolt (4)


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7. Install two outer M8 x 70 bolts – cylinder head to crankcase. Run threads down until finger tight.
8. Remove hoist latch from cylinder head lifting bracket.
9. Remove cylinder head lifting bracket.

**Figure 199 Installation of middle M8 x 70 bolts**

10. Install three middle M8 x 70 bolts – cylinder head to crankcase. Run threads down until finger tight.

### Valve Bridges and Push Rods

**Figure 200 Pushrod**

1. Pushrod

1. Apply clean engine oil to each end of pushrods and install to original locations.
2. Coat the end of each valve stem with clean engine oil.

**Figure 201 Valve bridges**

3. Place each of the previously marked valve bridges onto their respective valve stems.

### Rocker Arm Carrier

**Figure 202 Alignment guides and dowel sleeve bushing in old cylinder head (eight tapped M8 holes)**

1. Alignment guide (2)
2. M8 dowel sleeve bushing (2)


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**Figure 203 Alignment guides and dowel sleeve bushing in new cylinder head (two tapped M8 holes)**

1. Alignment guide (2)
2. M8 dowel sleeve bushing (2)

1. Install dowels in cylinder head.

   **NOTE:** Dowels may still be attached to the cylinder head side of the rocker arm carrier.

2. Install cylinder head/rocker carrier alignment guides (make locally) in position shown before installing rocker arm carrier.

3. Rotate the crankshaft until damper locating dowel hole is in the six o'clock position. This positions all pistons below TDC so the valves do not contact the pistons when tightening the rocker arm assemblies.

4. Apply engine oil to the top center of each valve bridge.

**Figure 204 Old rocker arm carrier**

1. Alignment guide (2)
2. M8 x 50 bolt (8)

**Figure 205 New rocker arm carrier**

1. Alignment guide (2)
2. M8 x 50 bolt (2)

5. Place rocker arm carrier onto guides.

6. Install eight or two bolts in rocker arm carrier and tighten to the standard torque (General Torque Guidelines, page333).

**NOTE:** If installing eight M8 x 50 bolts, pay close attention to rocker carrier alignment dowels when tightening down rocker arm carriers. It may be necessary to tighten the top four bolts first, then the lower bolts, to ensure correct engagement of dowels.


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**CAUTION:** To prevent engine damage use only permanent ink markers to identify bolt torque orientation.

**CAUTION:** To prevent engine damage, check to make sure push rod has seated in the rocker arm pocket.

**CAUTION:** To prevent engine damage, install new M14 x 193 head bolts when installing the cylinder head. Lightly lubricate new bolt threads and mating surfaces of bolt flanges with clean engine oil. Too much oil will cause hydrostatic lock and give incorrect torque reading.

**CAUTION:** Do not use antiseize compounds, grease, or any other lubricant except engine oil. Other lubricants have an adverse effect on torque results.

7. Lightly lubricate new M14 x 193 cylinder head bolts with clean engine oil. Install eight bolts into the open positions finger tight.
8. Remove the two rocker arm carrier alignment guides and replace with the two remaining new oiled bolts finger tight.


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### Cylinder Head Torque Instructions and Tightening Sequence

#### M14 x 193 Bolts

**Figure 206 Torque sequence for cylinder head mounting bolts (typical)**

**NOTE:** All M14 x 193 cylinder head mounting bolts must be torqued first, before torquing M8 x 70 bolts.

1. Torque lubricated bolts in the sequence numbered 1 through 10 to 88 N·m (65 lbf·ft).
2. Torque bolts 1, 3, 5, 7 and 9 in sequence to 116 N·m (85 lbf·ft).
3. Torque all bolts in sequence numbered 1 through 10, clockwise 90°.
4. Torque all bolts in sequence numbered 1 through 10, a second time clockwise 90°.
5. Torque all bolts in sequence numbered 1 through 10, a third time clockwise 90°.
6. M14 x 193 torque sequence complete.

#### M8 x 70 Bolts

**CAUTION:** To prevent engine damage, do not lubricate the M8 x 70 bolts. Too much oil will cause hydrostatic lock and give incorrect torque reading. Lubricants have an adverse effect on torque results.

1. Torque M8 bolts in the sequence numbered 11 through 15 to 24 N·m (18 lbf·ft).
2. Torque all M8 bolts in the sequence numbered 11 through 15 to 31 N·m (23 lbf·ft).
3. M8 x 70 torque sequence complete.


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### Crankcase-to-Head Tube Assemblies and Rear Heat Shield

**Figure 207 Installing crankcase-to-head tube assembly**

1. Install a new crankcase-to-head tube assembly and O-ring into each side of the crankcase. Seat each tube into the rear engine tube assembly and thread to the rocker arm carrier. Torque each tube to the special torque (Table 12).
2. Align rear heat shield with holes in the cylinder head and rear cover.
3. Install one M10 x 16 bolt through the heat shield tubing into the left side cylinder head and two M6 x 12 bolts into the rear cover assembly. Tighten bolts to the special torque (Table 12).

### Fuel Injectors

**CAUTION:** To prevent engine damage, do not use air tools when installing fuel injectors. Do not scratch injector surfaces.

### Replacing Fuel Injector O-rings and Copper Gasket

**CAUTION:** To prevent engine damage, replace external O-rings and copper gasket each time a fuel injector is removed.

1. Remove the old copper gasket with a small hand tool. Wipe injector nozzle with a lint free towel.

**Figure 208 Replacement of copper gasket**

1. Injector (nozzle end)
2. Gasket (copper)
3. Deep socket

2. Install a new copper injector gasket at the tip. Push on with a deep socket to seat gasket.

   **NOTE:** The copper gasket may be installed in either direction.

**Figure 209 Injector oil inlet**

1. Snap ring
2. Ferrule ring
3. D-ring


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**Figure 210 Removal of injector oil inlet D-ring**

1. D-ring
2. Ferrule ring
3. Snap ring

3. Remove the injector oil inlet snap ring, ferrule ring, and D-ring. Use caution not to scratch injector surfaces.
4. Coat seal components with clean engine oil. Install the injector oil inlet D-ring, ferrule ring and snap ring. See (Figure 209) and (Figure 210).
5. Remove the upper and lower O-rings from fuel injector by using a nonmetallic hand tool and discard.
6. Install a new Teflon coated (black) O-ring (larger diameter) into the recess just above the fuel inlet screens. Avoid contact with sharp machined surfaces.

**Figure 211 Fuel injector external O-rings**

1. O-ring, lower (white Teflon coating) (smaller diameter)
2. Fuel inlet screen (3)
3. O-ring, upper (black Teflon coating) (larger diameter)
4. Clamp alignment slot
5. O-ring, harness connector (dark blue)

7. Install a new Teflon coated (white) O-ring (smaller diameter) into the lower recess just below the fuel screens. Avoid contact with sharp machined surfaces.

**Figure 212 Lubrication of fuel injector O-rings**

8. Lubricate upper and lower O-ring with clean engine oil.


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### Installing the Fuel Injector Assembly

**CAUTION:** To prevent engine damage, verify hold down bolt snap ring is in position when installing injector hold down clamp assembly.

9. Align injector assembly clamp alignment slot with hold down clamp alignment index. This will orient the injector correctly within the cylinder head.

**Figure 213 Fuel injector hold down clamp assembly (typical)**

1. Bolt, M8 X 45
2. Snap ring (earlier design) or Retainer (later design)
3. Clamp alignment index

**Figure 214 Installation of injector**

1. Fuel injector
2. Fuel injector hold down clamp assembly

10. Install fuel injector assembly by lowering fuel injector and hold down clamp assembly into injector bore as one unit.

**Figure 215 Fuel Injector Hold Down Wrench**

1. Fuel injector assembly
2. Fuel injector hold down clamp assembly
3. Fuel Injector Hold Down Wrench

11. Use the Fuel Injector Hold Down Wrench (Table 13) to thread the fuel injector hold down clamp assembly into the cylinder head. Do not use air powered tools to remove or install the injector.

12. Tighten hold down clamp to the special torque (Table 12).


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**Figure 216 Installation of injector harness connector**

13. Replace O-ring on connector and install injector harness into carrier by pushing connector straight in until its tabs snap into place. Identification marks should face up.

**Figure 217 Lubricating top D-ring**

14. Lubricate the D-ring in the top of the injector cavity with clean engine oil.

**CAUTION:** To prevent engine damage, be sure injector wiring is clear of all moving parts.

**High-pressure Oil Rail System**

**Figure 218 Oil rail assembly**

1. Align oil rail assembly with oil inlets of each injector.
2. Tilt oil rail assembly toward engine, align oil rail assembly with case-to-head tube assembly, and push down evenly until oil rail assembly is firmly seated.
3. Hand start bolts M6 x 25 oil rail assembly bolts 1, 2, and 3 until finger tight.

**Figure 219 Torque sequence for oil rail bolts**

4. Torque bolts to the special torque (Table 12) following the sequence above.

**NOTE:** When installing the hose make sure release ring is in place, before snapping oil hose into oil supply tube.


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**Figure 220 Hose to crankcase-to-head tube assembly**

1. Hose
2. Crankcase to head tube assembly

5. Install hose to crankcase-to-head tube assembly by pushing down firmly until mechanism locks. Pull up on hose to make sure it is locked.

**Figure 221 Hose to oil rail assembly**

1. Hose
2. Oil rail assembly

6. Install hose to oil rail assembly by pushing down firmly until mechanism locks. Pull up on hose to make sure it is locked.

**Figure 222 Glow plug**

### Installing Glow Plugs

Install the glow plugs and tighten to the special torque (Table 12).

### Valve Covers

**CAUTION:** To prevent engine damage, do not use air powered tools when installing valve covers.

### Right Side Valve Cover

**Figure 223 Valve cover mounting hardware**

1. Valve cover stud bolt
2. Valve cover bolt

1. Install new gasket if necessary. Then place valve cover onto rocker arm carrier. Install valve cover mounting bolts. Place stud bolts in correct locations to accommodate the glow plug relay bracket and other harness routing hardware. Leave finger tight until all bolts are started.


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2. Continue to secure valve cover with remaining eight bolts. Tighten all mounting bolts to the special torque (Table 12).

   **NOTE:** After the right side valve cover has been installed, the following parts can be installed.

   - Glow plug relay bracket. See “Engine Electrical Section” for installation procedure.
   - Tube assembly, filter to right hand cylinder head.

**Left Side Valve Cover**

**Figure 224 Valve cover mounting hardware**

1. Valve cover stud
2. Valve cover bolt

3. Install new gasket if necessary. Then place valve cover onto rocker arm carrier. Install valve cover mounting bolts. Place studs in correct locations to accommodate the ECM/IDM bracket and other harness routing hardware. Leave finger tight until all bolts are started. Tighten all bolts to the special torque (Table 12).
4. Install oil filler extension tube onto valve cover.
5. If removed for any reason, install lifting eyes on the rear of each rocker arm carrier and one on the left front carrier. Tighten bolts to the special torque (Table 12).

**NOTE:** After the left side valve cover has been installed, the following parts can be installed.

- ECM/IDM and bracket
- Breather hose assembly with pitot tube. See VGT Turbocharger.
- Turbocharger air inlet duct. See VGT Turbocharger.
- Tube assembly, filter to left hand cylinder head.


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## Specifications

**Table 11 Cylinder Head and Valve Train**

| | |
|---|---|
| **Exhaust Valves** | |
| Stem diameter | 6.947 - 6.965 mm (0.2735 - 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 (min.) | 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 - 6.965 mm (0.2735 - 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 (min.) | 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 - 7.029 mm (0.276 - 0.277 in) |
| Valve guide bore runout | 0.05 mm (0.002 in) |
| Valve guide taper (max.) | 0.10 mm (0.004 in) |
| Valve seat width (int.) | 1.80 - 2.56 mm (0.071 - 0.101 in) |
| Valve seat width (exh.) | 1.48 - 2.24 mm (0.058 - 0.088 in) |
| Valve seat angle (int.) | 30.0° |
| Valve seat angle (exh.) | 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)<br>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 - 0.68 mm (0.0126 - 0.0268 in) |
| Valve Spring: | |
| Free length | 51.96 mm (2.045 in) |
| Solid height | 36.1 mm (1.42 in) |


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**Table 11 Cylinder Head and Valve Train (cont.)**

| | |
|---|---|
| Compressed* | 46.30 mm @ 340 ± 17 N (1.82 in @ 76.5 ± 3.8 lbf) |
| Compressed* | 38.30 mm @ 850 ± 43 N (1.51 in @ 191.1 ± 9.7 lbf) |
| * Spring must be compressed to a solid height before checking test loads. | |
| **Push Rods** | |
| Runout (max.) | 0.25 mm (0.01 in) |

## Special Torque

**Table 12**

| | |
|---|---|
| Lifting eye, front, (M10 x 30) | 41 ± N·m (30 ± 3 lbf·ft) |
| Lifting eye, rear, flat socket head (M10 x 35) | 41 ± N·m (30 ± 3 lbf·ft) |
| Crankcase breather nuts | 7 N·m (60 lbf·in) |
| Cylinder head bolt torque and sequence | (Cylinder Head Torque Instructions and Tightening Sequence, page125) |
| Fuel injector hold down bolt | 33 N·m (24 lbf·ft) |
| Rocker arm fulcrum plate (M8 x 65) | 31 N·m (23 lbf·ft) |
| Glow plugs | 19 N·m (168 lbf·in) |
| Injection Control Pressure (ICP) sensor | 12 ± 2 N·m (108 ± 18 lbf·in) |
| Oil rail assembly mounting bolts (M6 x 1 x 25) | 13 N·m (120 lbf·in) (Figure 553) |
| Crankcase to head tube assembly (M14 x 1.5) | 45 N·m (33 lbf·ft) |
| Oil rail check valve fitting (M14 x 1.5) | 34 N·m (25 lbf·ft) |
| Plug assembly w/O-ring (oil supply) (M14 x 1.5) | 45 N·m (33 lbf·ft) |
| Oil rail vent plugs (bleed port) (M8 x 1) | 10 N·m (90 lbf·in) |
| Valve cover bolts and studs | 9 +1/-2 N·m (72 ± 12 lbf·in) |
| Oil fill extension | 14 ± 1 N·m (120 - 132 lbf·in) |
| Fuel rail plug assembly (12 mm) | 27 ± 1 N·m (20 ± 1 lbf·ft) |
| Rear heat shield (M10 x 1.5 x 16) | 49 ± 5 N·m (36 ± 4 lbf·ft) |


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## Special Service Tools

**Table 13**

| TOOL NUMBER | DESCRIPTION |
|---|---|
| ZTSE2241 | Valve Spring Tester |
| ZTSE4299B | Fuel Injector Rack Holder |
| ZTSE4398 | Slide Hammer Kit |
| ZTSE4454 | Quick Release Tool Kit |
| ZTSE4508 | Bottoming tap (metric) |
| ZTSE4301 | Fuel Injector Tip Cleaning Brush |
| ZTSE4523 | Fuel Injector Holder Plastic Cups |
| ZTSE4524 | Fuel Injector Hold Down Wrench |
| ZTSE4528 | Injector Sleeve Remover |
| ZTSE4529 | Injector Sleeve Installer |
| ZTSE43041 | Injector Sleeve Brush |
| ZTSE4531 | Glow Plug Sleeve Remover |
| ZTSE4532 | Glow Plug Sleeve Installer |
| ZTSE4533 | Glow Plug Sleeve Brush (nylon) |
| ZTSE4534 | Cylinder Head Pressure Test Plate |
| ZTSE4535 | Cylinder Head Lifting Bracket |
| ZTSE1846 | Valve Spring Compressor |
| ZTSE4541 | Fuel Gallery Cleaning Brush |
| ZTSE4577 | Valve Guide Gauge Tool |
| ZTSE4581 | Quick Release Tool |
| ZTSE4589 | Glow Plug Sleeve Seat Wire Brush |
| PT-7191 | Dye Penetrant Kit |
| Liquid Gasket (RTV) (6 oz. tube) | 1830858C1 |
| Obtain locally | Straightedge |


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## Description

### FRONT COVER COMPONENTS

The front cover includes components for the cooling system, lube oil delivery, and vibration damper.

**Figure 225 Front cover components**

1. Front cover assembly
2. Front cover coolant outlet
3. Thermostat assembly
4. Gerotor oil pump assembly
5. Oil pressure regulating valve
6. Vibration damper
7. Pulley
8. Water pump assembly
9. Front cover coolant inlet


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## Removal

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

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

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

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

**NOTE:** Engine fluids (oil, fuel, and coolant) are a threat to the environment. Recycle or dispose of engine fluids according to local regulations. Never put engine fluids in the trash, on the ground, in sewers or bodies of water.

**Vibration Damper**

**Figure 226 Vibration damper runout**

1. Dial Indicator with Magnetic Base
2. Paint removed, four points (90° apart)

1. Before removing vibration damper, inspect vibration damper for runout as follows:
   a. Remove paint from face of vibration damper at four points 90° apart.
   b. Attach Dial Indicator with Magnetic Base (Table 16) to front of crankcase. Position indicator point on unpainted surface.
   c. Pry crankshaft forward and zero the dial indicator. This becomes the baseline.

      **NOTE:** Pry only in one direction to eliminate possible error induced by crankshaft end play.
   d. Turn crankshaft 90°. Pry crankshaft forward and record reading.
   e. Repeat at each unpainted surface. If run out exceeds specification (Table 14), install new vibration damper.

**WARNING: To prevent personal injury or death, support the vibration damper during mounting bolt removal. The damper can easily slide off the crankshaft.**

**Figure 227 Vibration damper mounting bolts**

1. Mounting bolt (4)
2. Vibration damper

2. Remove four M12 x 59 bolts that secure vibration damper to crankshaft.
3. Remove vibration damper from crankshaft. Discard vibration damper retaining bolts. They are not reusable.


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### Front Oil Seal and Wear Sleeve

**NOTE:** The VT 365 is not equipped with a wear sleeve during factory production. Wear sleeves are available with an oil seal service kit.

**NOTE:** If removing only the seal, do steps 1 through 3. Otherwise, remove seal and wear sleeve by doing steps 1 through 4.

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

**CAUTION:** To prevent engine damage, do not immerse damper in petroleum based solvents. Damage to rubber damping element may result.

**Figure 228 Holes for slide hammer**

1. With an awl and hammer, punch two holes 180° apart into the front oil seal.

**Figure 229 Slide hammer**

2. Thread a slide hammer with an appropriately sized screw into one of the two holes.
3. Slide hammer until one side of the seal begins to pull out the gerotor cover. Move the slide hammer to the other hole and repeat until the front oil seal is removed.

**NOTE:** The following steps are necessary if the engine has a front wear sleeve. Wear sleeves are only available in oil seal service kits.

4. Do the following steps to install the Front Wear Sleeve Remover (Table 16):

**Figure 230 Removal of front wear sleeve**


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**Figure 231 Front wear sleeve removed**

1. Front wear sleeve

a. Install the tools two half shell ridges behind the front wear sleeve.

b. Place the threaded shaft and pulling flange within the two shells while holding the shells together.

c. Thread the shaft up to the crankshaft, and apply tension to the two half shells. Remove the wear sleeve.

### Gerotor Oil Pump

**Figure 232 Gerotor oil pump cover**

1. Gerotor oil pump cover mounting bolt (5)
2. Gerotor oil pump cover

1. Remove five gerotor oil pump cover mounting bolts.

**Figure 233 Gerotor components**

1. Gerotor cover
2. O-ring
3. Dowel
4. Gerotor assembly

2. Carefully remove cover to expose gerotor.

**CAUTION:** To prevent engine damage, do not use paint to identify internal components or their orientation. Use a permanent marker only.

3. Mark the front of each gerotor using a permanent marker for correct reassembly orientation.

4. Remove gerotor gear set from housing.

### Water Pump

**NOTE:** If removing the front cover, the water pump and thermostat do not need to be removed; however, the water pump pulley must be removed.


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**Figure 234 Water pump pulley**

1. Remove four M8 x 12 bolts securing the pulley to the water pump.

**Figure 235 Water pump assembly**

1. Water pump mounting bolt, M8 x 25 (4)
2. Front cover assembly

2. Remove four M8 x 25 bolts that secure water pump assembly to the front cover.
3. Remove and discard water pump O-ring.

**Thermostat**

**Figure 236 Thermostat assembly mounting bolts**

1. Thermostat assembly mounting bolt M8 x 30 (2)
2. Coolant outlet side of front cover

1. Remove two M8 x 30 bolts that secure thermostat assembly to left side of front cover.

**Figure 237 Thermostat assembly**

1. Thermostat assembly
2. O-ring

2. Remove thermostat assembly from front cover.
3. Remove and discard O-ring.


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**Front Cover**

**Figure 238 Front cover retaining bolts**

1. Remove 16 retaining bolts (M8 x 35 hex flanged, dog point) from front cover.

**CAUTION:** To prevent engine damage, when removing the front cover, cut the sealant where the upper and lower crankcase meets.

**Figure 239 Sealant between upper and lower crankcase joint**

2. Use a thin blade scraper to cut sealant where upper and lower crankcase meet.

**Figure 240 Removal of front cover**

3. Remove front cover.
4. Remove front cover gasket and discard.


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## Cleaning, Inspection, and Testing

### Vibration Damper

**CAUTION:** To prevent engine damage, do not immerse damper in petroleum based solvents. Damage to rubber damping element may result.

1. Clean vibration damper with soap, water, and a soft parts brush.

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

2. Dry damper with filtered compressed air. See (page 3 ).
3. Inspect vibration damper rubber compound for cracks, bulging or separation. Replace vibration damper if necessary.

### Gerotor Oil Pump

1. Wash all parts thoroughly in a suitable solvent.

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

2. Dry parts with filtered compressed air. See (page 3 ).
3. Lay front cover assembly on workbench.
4. Inspect gerotors and housing for nicks, burrs or scoring.
5. Replace any damaged components.

   **NOTE:** The inner and outer gerotors are a matched set and cannot be replaced individually.

   **NOTE:** If installing new gerotors, correct orientation is not necessary. If installing old gerotors, correct orientation is necessary.

6. Place inner and outer gerotors into oil pump housing.

**Figure 241 Gerotor inspection**

1. Feeler gauge
2. Front cover assembly
3. Outer gerotor

7. Use a feeler gauge to inspect wear by checking the radial clearance between outer gerotor and oil pump housing.

**Figure 242 End clearance check for oil pump**

1. Straightedge
2. Outer gerotor
3. Inner gerotor
4. Feeler gauge

8. Check oil pump end clearance as follows:


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a. With the gerotors in place in the front cover, place Straightedge (Table 16) across housing.

b. Insert feeler gauge under Straightedge(Table 16) at inner and outer gerotors. Compare end clearance with specifications (Table 14).

c. If measurements are not within specifications, install new gerotors (as a set).

**Figure 243 Oil pressure regulator components**

1. End cap and O-ring
2. Oil pressure bypass spring
3. Piston poppet

9. Use a 12 mm hex head wrench to remove the oil pressure regulator.

10. Inspect oil pressure regulator components and bore for wear.

### Front Cover and Water Pump

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

1. Wash thoroughly in a suitable cleaning solvent.

2. Dry with filtered compressed air. (page 3 )

3. Inspect front cover for cracks.

4. Inspect water pump for leaks, cracks, bearing failure, and problems with bearings or shaft seal. Replace if necessary.

5. Replace front cover if cracked.

### Thermostat

**WARNING: To prevent personal injury or death, wear heat resistant gloves and appropriate eye protection during thermostat operation checks.**

**CAUTION:** To prevent engine damage when servicing thermostat, make sure the thermostat opens fully at the specified temperature to avoid overheating.

**NOTE:** Only genuine International® thermostats ensure correct coolant flow and positive sealing for correct engine cooling.

**Figure 244 Testing thermostat operation**

1. Suspension line
2. Ribbon
3. Thermometer
4. Thermostat
5. Heat source

Check thermostat operation as follows:

1. Manually open the thermostat enough to insert a nylon ribbon under the valve seat. Suspend the thermostat in a container so the thermostat does not touch the bottom of the container.

2. Heat the water filled container to the approximate Start-To-Open temperature of the thermostat, (see specifications for temperature). Observe


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the thermometer and record the temperature as soon as the thermostat drops from the nylon ribbon. This is the Start-To-Open temperature. See specifications for sleeve travel at the start to open temperature (Table 14)

**Figure 245 Thermostat sleeve travel**

1. Thermostat assembly
2. Minimum travel

3. Continue to heat the water to the Full-Open temperature of the thermostat (see Specifications for temperature). Observe the thermometer and movement of the thermostat sleeve.
4. While sleeve is off its seat, remove thermostat from container and inspect seat area for pitting and foreign deposits.
5. If the thermostat is damaged or operates incorrectly, replace thermostat.


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## Installation

### Front Cover

**Figure 246 Front cover crankcase dowels**

1. If removed, install front cover crankcase dowels.

**NOTE:** Dowels may become lodged in front cover. Remove dowels and install in crankcase if necessary.

**Figure 247 Liquid gasket applications**

2. Apply Liquid Gasket (RTV) (Table 16) to joining surfaces of upper and lower crankcase.

**Figure 248 Front cover gasket installed**

3. Position a new front cover gasket onto the crankcase.

**Figure 249 Front cover alignment**

1. Alignment guides

4. Align front cover with crankcase dowels and alignment guides (make locally).


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**Figure 250 Front cover module retaining bolts**

5. Fasten front cover assembly to crankcase with 16 bolts (M8 x 35 hex flanged, dog point).
6. Tighten bolts to the special torque (Table 15).
7. If removed, install water pump on front cover with new O-ring (Water Pump, page147).

### Thermostat

**Figure 251 Thermostat assembly**

1. Thermostat
2. Thermostat O-ring seal

1. Install a new O-ring seal onto the thermostat housing.
2. Install thermostat assembly on front cover coolant outlet.
3. Secure thermostat assembly with two M8 x 30 mounting bolts.
4. Tighten bolts to the standard torque (General Torque Guidelines, page333).

### Water Pump

1. Install a new O-ring onto the front cover assembly. Petroleum jelly can be used to hold O-ring in place.

**Figure 252 Water pump**

1. Water pump mounting bolt (4)
2. Front cover

2. Install water pump assembly onto front cover with new O-ring and secure with four M8 x 25 mounting bolts. Tighten bolts to the standard torque. See General Torque Guidelines (Table 55).
3. Install water pump pulley with four M8 x 12 bolts.
4. Tighten bolts to the special torque (Table 15).


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### Gerotor Oil Pump

**Figure 253 Outer gerotor gear**

1. Gerotor cover
2. O-ring
3. Dowel
4. Gerotor assembly
5. Lithium assembly grease

1. Lubricate inner gear with lithium assembly grease and install onto crankshaft.
2. Lubricate outer gear with lithium assembly grease and mesh with inner gear rotor in oil pump housing. Wipe off excess assembly grease.
3. Align dowel pins and install oil pump cover onto front cover.

**Figure 254 Oil pump housing**

1. Oil pump cover
2. Oil pump cover retaining bolt

4. Install five retaining bolts to oil pump cover and tighten to the standard torque (General Torque Guidelines, page 333).

### Front Oil Seal and Wear Sleeve

**NOTE:** A wear sleeve is not installed during engine production. The wear sleeve is required for rebuild and is supplied with the front oil seal as a service part only.

**Figure 255 Liquid gasket application**


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1. Put a 360° bead of Loctite® hydraulic sealant onto the leading edge of the crankshaft before wear sleeve installation.

**Figure 256 Front oil seal and wear sleeve**

1. Wear sleeve
2. Front oil seal
3. Front Seal/Wear Sleeve Installer

2. Use the Front Seal/Wear Sleeve Installer (Table 16) to drive the oil seal and wear sleeve assembly into the oil pump cover.

### Vibration Damper

1. Align vibration damper with dowel pin located on the front of the crankshaft.

**WARNING: To prevent personal injury or death, install four new bolts to secure the vibration damper.**

**CAUTION:** Do not use antiseize compounds, grease or lubricants. Each has an adverse effect on torque results.

**Figure 257 Vibration damper on crankshaft**

2. Install four new M12 x 59 bolts to secure vibration damper on crankshaft.

**Figure 258 Torque sequence for vibration damper bolts**

3. Vibration damper bolt torque sequence:
   a. Tighten each bolt to the special torque (Table 15) using the sequence shown.
   b. Torque each bolt an additional 90° in the sequence shown.


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## Specifications

**Table 14**

| | |
|---|---|
| **Vibration Damper** | |
| Face runout (max.) | 0.635 mm (0.025 in) |
| Rubber bulging (max.) | 1.5 mm (0.060 in) |
| **Lubricating Oil Pump** | |
| Type | Gerotor |
| Drive | Crankshaft |
| Location | Gerotor oil pump housing |
| Pressure Regulating Valve: | |
| Pressure, low idle (min @ 110 °C (230 °F) oil temp.) | 69 kPa (10 psi) |
| Pressure, high idle (min @ 110 °C (230 °F) oil temp.) | 276 kPa (40 psi) |
| Discharge pressure (2,500 rpm) | 483 - 621 kPa (70 - 90 psi) |
| End clearance (inner and outer rotor to housing) | 0.02 - 0.08 mm (0.001 - 0.003 in) |
| Radial clearance (between outer rotor and housing) | 0.15 - 0.28 mm (0.006 - 0.011 in) |
| **Thermostat** | |
| Type | Balanced pressure, wax pellet |
| Minimum recommended coolant operating temperature | 71 °C (160 °F) |
| Start-to-open temperature, 0.381 mm (0.015 in) stroke | 87 - 91 °C (188 - 196 °F) |
| Full-open temperature, 8 mm (0.315 in) stroke | 104 °C (219 °F) |

## Special Torque

**Table 15**

| | |
|---|---|
| Front cover module bolts | 24 N·m (18 lbf·ft) |
| Water pump mounting bolts | 23 ± 1 N·m (17 ± 1 lbf·ft) |
| Vibration damper mounting bolts | New bolts only: 68 N·m (50 lbf·ft) + 90° rotation. (Figure 258) |


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## Special Service Tools

**Table 16**

| Tool Number | Description |
|---|---|
| Obtain locally | Dial Indicator with Magnetic Base |
| ZTSE4517 | Front Wear Sleeve Remover |
| ZTSE4516 | Front Seal/Wear Sleeve Installer |
| ZTSE4587 | Fan Wrench (pulley bolts) |
| ZTSE43972 | Fan Hub Wrench (2 inch) |
| 1830858C1 | Liquid Gasket (RTV) (6 oz. tube) |
| Obtain locally | Straightedge |


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## Removal

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

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

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

**NOTE:** Engine fluids (oil, fuel, and coolant) are a threat to the environment. Recycle or dispose of engine fluids according to local regulations. Never put engine fluids in the trash, on the ground, in sewers or bodies of water.

**Lower Oil Pan**

**Figure 259 Mounting bolts for lower oil pan**

1. Remove sixteen M6 mounting bolts from lower oil pan.
2. Remove lower oil pan.

**Oil Pickup Tube**

**Figure 260 Oil pickup tube**

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

1. Remove three mounting bolts from oil pickup tube.

**Figure 261 O-ring**

1. Oil pickup tube O-ring

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


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**Upper Oil Pan**

**Figure 262 Mounting bolts for upper oil pan**

1. M8 X 40 (6)
2. M6 X 25 (4)

1. Remove ten mounting bolts from upper oil pan.
2. Remove upper oil pan.
3. Discard gasket.


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## Cleaning and Inspection

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

### Lower Oil Pan

1. Remove old gasket and discard.
2. Clean oil pan with a suitable solvent.
3. Dry with filtered compressed air. See (page 3 ).
4. Inspect bottom of oil pan for metallic particles or engine damage. Look for warps, dents, and cracks. Install new oil pan, if necessary.

### Oil Pickup Tube

1. Clean tube in a suitable solvent.
2. Dry with filtered compressed air. See (page 3 ).
3. Inspect the oil pickup tube and bracket for cracking. Replace if necessary.

### Upper Oil Pan

1. Clean oil pan in a suitable solvent.
2. Dry with filtered compressed air. See (page 3 ).
3. Look for signs of warping or cracking. Replace if necessary.


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## Installation

### Upper Oil Pan

1. Install new gaskets in upper oil pan.

**Figure 263 Mounting bolts for upper oil pan**

1. M8 X 40 (6)
2. M6 X 25 (4)

2. Install upper oil pan and ten mounting bolts.
3. Tighten mounting bolts to the standard torque (General Torque Guidelines, page333).

### Oil Pickup Tube

**Figure 264 New O-ring**

1. Oil pickup tube O-ring

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

**Figure 265 Oil pickup tube**

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

3. Install oil pickup tube and three mounting bolts.
4. Tighten bolts to the standard torque (General Torque Guidelines, page333).


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**Lower Oil Pan**

**Figure 266 Lower oil pan**

1. Place a new gasket onto the upper oil pan (lower surface).
2. Place lower oil pan onto upper oil pan mating surface.

**Figure 267 Oil pan mounting bolts**

3. Install sixteen M6 mounting bolts into lower oil pan.
4. Tighten mounting bolts to the standard torque (General Torque Guidelines, page333).


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## Removal

**NOTE:** Before removing pistons, rings, and connecting rods, remove the following components:

- Fuel Filter and Lines

  See “Fuel System.”

- VGT

  See “VGT Electronically Controlled Turbocharger.”

- Electronic Control Module (ECM), Injector Driver Module (IDM) and Mounting Bracket

  See “Engine Electrical.”

- Glow Plug Relay and Bracket

  See “Engine Electrical.”

- Intake Manifold

  See “Manifolds and Exhaust Gas Recirculation (EGR).”

- Cylinder Heads

  See “Cylinder Head and Valve Train.”

### Connecting Rod and Piston Assembly

**NOTE:** Before removing piston and connecting rod assemblies, piston protrusion should be evaluated. This will help identify bent or twisted connecting rods.

**Figure 268 Checking piston protrusion**

1. Check piston protrusion above crankcase as follows:
   a. Zero Dial Indicator with Magnetic Base (Table 19) on crankcase deck surface.
   b. Position dial indicator tip onto piston head at the 3 or 9 o’clock position.
   c. Bar crankshaft to measure maximum piston protrusion.
   d. Record reading.
   e. Reposition dial indicator tip onto piston head at the 9 o’clock position.
   f. Record reading, then average the two readings.

**Figure 269 Side clearance check for connecting rod**

1. Feeler gauge
2. Connecting rods

2. Use a feeler gauge to check connecting rod side clearance as follows:
   a. Pry apart a pair of connecting rods on a crankshaft rod journal. Insert largest feeler gauge to check clearance.
   b. Repeat for each pair of connecting rods on each crankshaft rod journal and compare with specification (Table 17).

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


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**CAUTION:** To prevent engine damage, check for carbon ridge on top of the cylinder bore, before removing the rod and piston assemblies.

3. Scrape carbon ridge from top of cylinder bore, if necessary.

**Figure 270 Connecting rods**

1. Connecting rod bolt
2. Connecting rod cap
3. Crankshaft

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

**CAUTION:** To prevent engine damage, check connecting rod bolts for binding. If binding exists, check threads carefully.

**Figure 271 Connecting rod cap bolts**

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

5. Remove two connecting rod bolts and connecting rod cap.
6. Remove piston and connecting rod assemblies from crankcase as follows:
   a. Rotate engine into a vertical position.

**Figure 272 Piston and connecting rod assembly**

   b. Use a wooden or plastic handle to push piston and rod assembly from cylinder bore.
   c. Once piston rings are free of cylinder bore, remove piston and connecting rod assembly from crankcase.


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**CAUTION:** To prevent engine damage, make sure each connecting rod and cap is stamped, marked, or tagged as a matched set.

This engine uses fractured connecting rods. Do not alter or damage the fractured mating surfaces of the rod and cap.

**Figure 273 Cap and rod numbers**

1. Matching numbers

7. Make sure matching connecting rod and cap numbers stay together as a set. A cap from one connecting rod is not interchangeable with any other connecting rod.

**Piston Disassembly**

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

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

**CAUTION:** To prevent engine damage, note the engine serial number (stamped on the crankcase pad, left side rear of the crankcase) and piston part number (stamped on the piston crown). Multiple pistons are available for service applications. Do not install pistons having different part numbers.

**CAUTION:** To prevent engine damage, mark pistons with the cylinder number from which each was removed. Each reused piston must be reinstalled into its original cylinder bore.

**Figure 274 Piston ring removal**

1. Piston Ring Expansion Pliers
2. Piston
3. Piston ring

1. Use Piston Ring Expansion Pliers (Table 19) to remove the piston rings. Remove top ring first, then intermediate ring, and finally oil control ring.

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

**Figure 275 Piston pin retaining ring**

2. Separate connecting rod from piston as follows:


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a. Use pliers to remove both piston pin retaining rings.

b. Remove piston pin from its bore by hand, then separate connecting rod from piston.

## Cleaning

**NOTE:** Do not use a caustic solution or a wire brush for cleaning aluminum pistons. Do not use bead blasted material on pistons.

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

## Inspection

### Pistons

1. Inspect pistons for scuffed or scored skirts, cracked or worn ring lands, and cracked or scuffed pin bores. Replace any pistons showing such damage.
2. Check top compression ring groove for wear as follows:

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

   a. Install the Piston Gauge Pins (0.082 in) (Table 19) into the top ring groove. Piston Gauge Pins must be parallel.

**Figure 276 Top compression ring groove**

1. Piston Gauge Pins (0.082 in)

   b. Use a 3 - 4 inch outside micrometer to measure diameter over Piston Gauge Pins.

   c. If measurement over the gauge pin is not within specifications (Table 17), excessive piston groove wear exists. Replace piston.

**Figure 277 Side clearance for intermediate ring groove**

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


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3. Check side clearance of intermediate ring groove as follows:
   a. Place outer edge of new ring in its respective ring groove.
   b. Roll ring entirely around piston in its respective groove. Make sure ring is able to move freely in its groove.
   c. Use a feeler gauge to check side clearance of each ring in its respective groove (Table 17). Excessive side clearance indicates ring groove wear and requires piston replacement.
4. Check side clearance of oil control ring groove as follows:
   a. Place outer edge of new ring in oil control ring groove.
   b. Roll ring entirely around piston in its respective groove. Make sure ring is able to move freely in groove.
   c. Use a feeler gauge to check side clearance of oil control ring in its respective groove. Excessive side clearance indicates ring groove wear and requires piston replacement.
5. When considering piston replacement, check cylinder bore out-of-round specifications. (See Specifications in “Crankcase, Crankshaft and Bearings, Camshaft and Bushings” section.) Cylinder boring may be required. Such bore reconditioning will require oversize service pistons. Verify piston size by measuring skirt diameter under conditions indicated in Specifications (Table 17).

**Figure 278 Piston skirt diameter**

1. Piston skirt
2. 3 - 4 inch micrometer

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

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

6. If cylinder walls have minor surface damage, but are otherwise within specification (out of round), it may be possible to remove such damage by honing.

   If cylinder bore is suitable for use without reconditioning, deglaze bore using a glaze breaker brush, then reassemble. (See Specifications in “Crankcase, Crankshaft and Bearings, Camshaft and Bushings” section for the correct deglazing procedure.)
7. Check piston skirt clearance in the cylinder bore.


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**Figure 279 Piston skirt clearance check in cylinder bore**

1. Piston
2. Feeler gauge
3. Crankcase

**Figure 280 Piston ring end gap clearance in cylinder bore**

1. Piston ring
2. Feeler gauge
3. Crankcase

### Piston Rings

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

1. Inspect new piston rings for cleanliness.
2. Before installing new piston rings on piston, check gap for each ring as follows:
   a. Push piston ring down into cylinder bore. Make sure the piston ring is square with cylinder wall. An inverted piston head can be used to push piston ring to desired location of measurement (usually at the top of the piston stroke).
   b. Use a feeler gauge to measure gap between ends of each piston ring.
   c. If gap does not meet specifications (Table 17), select another ring or recheck cylinder bore wear.

### Connecting Rods

**CAUTION:** To prevent engine damage, if the rod cap is reversed or not installed on its original matching connecting rod, the fractured mating surfaces will be damaged. The entire connecting rod assembly must be replaced.

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

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


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**Figure 281 Inside diameter of piston pin bushing**

1. Piston pin bushing
2. Telescoping Gauge

3. Inspect connecting rod piston pin bushing for wear as follows:
   a. Use a Telescoping Gauge (Table 19) and a 1-2 inch micrometer to measure pin bore at two locations 90° apart. Record the measurements.
   b. If inside diameter of piston pin bushing exceeds minimum specification (Table 17), replace connecting rod.

### Connecting Rod Bore Out-of-Round and Taper Check

**CAUTION:** To prevent engine damage, check connecting rod bolts for binding. Bolts should thread into connecting rod freely, when lubricated with clean engine oil. If not, discard the connecting rod. Connecting rod threads cannot be retapped, if binding. Check thread condition carefully during inspection.

4. Lubricate connecting rod bolts with clean engine oil. Assemble cap to rod without bearing insert. Tighten bolts to special torque (Table 18).

**Figure 282 Measurement for out-of-round of bore of connecting rod bearing**

5. Use a Telescoping Gauge (Table 19) to measure connecting rod at two locations, 90° apart.
6. If the difference between dimension A and B exceeds out-of-round specifications (Table 17), replace connecting rod.

**Figure 283 Measurement for bore taper of connecting rod**

7. Measure connecting rod taper as follows:
   a. Insert a Telescoping Gauge (Table 19) near chamfer on either side. Record readings.
   b. Measure inner diameter of connecting rod bearing bore near chamfer on other side. Record readings.


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The difference between the two readings is the connecting rod bore taper. If connecting rod bore taper exceeds specification (Table 17), replace connecting rod.

8. With connecting rod cap removed, inspect surface finish of connecting rod bearing bore. Bore must be smooth and free of scoring, nicks or burrs. Replace as required.

### Connecting Rod Bearing Fit Check

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

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

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

9. Lubricate connecting rod bolts with clean engine oil. Assemble cap to rod with new bearing shells installed. Tighten bolts alternately and evenly to special torque value (Table 18).
10. Use a Telescoping Gauge (Table 19) to measure inside diameter of connecting rod bearing at two locations 90° apart. Average the two inside diameters.
11. Use a micrometer to measure each crankshaft rod journal diameter.
12. Subtract the crankshaft rod journal diameter from the respective connecting rod bearing inside diameter to obtain bearing-to-crankshaft running clearance. Repeat for each crankshaft rod journal.
13. If bearing-to-crankshaft running clearances exceed specifications because of wear on crankshaft, replace or grind crankshaft and install undersize precision type bearing shells.

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

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

### Piston Pin Inspection

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

**Figure 284 Piston pin wear**

15. Use a 1-2 inch micrometer to measure piston pin outside diameter at two locations 90° apart. Measure each end of the pin. If piston pin wear exceeds specifications (Table 17), replace piston pin.

**Figure 285 Inside diameter measurement of piston pin bore**


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16. Using a 1-2 inch telescoping gauge and micrometer, measure each piston pin bore inside diameter, at two locations 90° apart.
17. To check piston pin clearance, subtract piston pin outside diameter from piston pin bore inside diameter measurement. If clearance exceeds specifications (Table 17), replace piston pin.

## Installation

### Piston and Ring Assembly

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

**CAUTION:** To prevent engine damage, note the engine serial number (stamped on the crankcase pad, left side rear of the crankcase) and piston part number (stamped on the piston crown). Multiple pistons are available for service applications. Do not install pistons having different part numbers.

**CAUTION:** Some engines have pistons with greater mass, depending on engine serial number. Inertia values of the flywheel, flexplate, and vibration damper must compliment the pistons mass. Contact your International dealer for details.

**CAUTION:** To prevent engine damage, make sure the connecting rods and pistons are assembled correctly.

**Figure 286 Correct position of installed connecting rod**

1. Longer leg of connecting rod (cam side)
2. CAM V8 stamp on cam side of piston crown

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

1. Connect piston to connecting rod as follows:
   a. Lubricate connecting rod piston pin bore, piston pin bore, and piston pin with clean engine oil.
   b. Orient the longer leg of the connecting rod with the side of the piston bearing the CAM V8 stamped in its crown.


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**Figure 287 Piston pin retaining ring**

c. Use pliers to install retaining ring at one end of piston pin bore.

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

e. Use pliers to install second retaining ring.

f. Check the piston pin end clearance (Table 17).

2. Use Piston Ring Expansion Pliers (Table 19) to install piston rings onto piston as follows:

**Figure 288 Piston ring locations**

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

**Figure 289 Rings in piston**

1. Piston Ring Expansion Pliers
2. Piston
3. Piston ring (top compression shown)

a. Install expansion spring component of two piece oil control ring into bottom piston groove.

b. Install oil scraper component of two piece oil control ring over expansion spring.

**Figure 290 Piston ring identification marks (top ring shown)**

1. Identification mark

c. Install intermediate ring into middle piston groove. The intermediate ring is identified by


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two 'OO' marks located on the top surface of the ring.

d. Install compression ring into top piston groove. The compression ring is identified by the 'O' mark located on the top surface of the ring. Make sure the ring is installed with the identification mark facing up.

3. Install intermediate and top compression rings with their identification marks facing up (to top of piston). Space ring gaps approximately 120° apart after ring installation.

### Connecting Rod/Piston Assembly

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

**Figure 291 Piston and piston ring lubrication**

2. Coat piston and piston rings with clean engine oil.

**Figure 292 Cylinder wall lubrication**

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

**CAUTION:** To prevent engine damage, CAM V8 stamped on top of the piston, must be oriented towards the camshaft side of the crankcase or up position.

**Figure 293 CAM V8 stamp on piston**

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


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**Figure 294 Piston installed in Piston Ring Compressor (Cope)**

4. Place piston into Piston Ring Compressor (Table 19).
5. Install bearing shells into connecting rod and cap. Coat bearing shell in connecting rod with clean engine oil.
6. Carefully place piston/piston cope combination and connecting rod assembly into crankcase bore.

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

**Figure 295 Installation of piston**

7. Once piston and connecting rod assembly have been inserted into cylinder bore, use the handle of a hammer to tap piston into crankcase bore. Guide connecting rod into place on crankshaft.
8. Apply clean engine oil to connecting rod bolt hole threads and bearing shell in cap before installing bolts.

**Figure 296 Connecting rod and cap**

1. Matching numbers

9. Assemble cap to connecting rod with matching identification code on same crankshaft journal from which it was removed. Make sure the longer leg of the connecting rod and the CAM V8 stamp on piston crown are oriented towards the camshaft.

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

**Figure 297 Connecting rod cap**

1. Connecting rod bearing cap
2. Connecting rod bolt


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10. Install and tighten connecting rod bolts evenly to the initial and final torque values. See Special Torques (Table 18).
11. Repeat installation procedure for remaining connecting rod and piston assemblies.
12. Check connecting rod side clearance with feeler gauge. See procedure in removal section (page 163).


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## Specifications

**Table 17 Connecting Rods and Pistons**

| | |
|---|---|
| **Connecting Rods** | |
| Connecting rod length (center to center) | 176 mm (6.929 in) |
| Bushing bore diameter (pin end) | 36.98 - 37.02 mm (1.456 - 1.457 in) |
| Piston pin bushing inside diameter | 34.0140 - 34.0215 mm (1.3391 - 1.3394 in) |
| Material | I-Beam Section - Powdered |
| Bearing bore diameter (crankshaft end) | 72.987 - 73.013 mm (2.8735 - 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 - 69.077 mm (2.7176 - 2.7196 in) |
| Connecting rod bearing running clearance (diameter) | 0.0203 - 0.0837 mm (0.0008 - 0.0033 in) |
| Connecting rod side clearance | 0.3 - 0.6 mm (0.012 - 0.024 in) |
| Weight (complete rod without bearing) | 1201.5 - 1215.5 g (2.649 - 2.679 lb) |
| **Pistons** | |
| Material | Aluminum Alloy |
| Skirt diameter [1] | 94.9460 - 94.9186 mm (3.737 - 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 - 21 °C (66 - 70 °F). | |
| Service Piston: | |
| Standard size | 94.9460 - 94.9186 mm (3.737 - 3.738 in) |
| 0.254 mm (0.010 in) oversize | 95.1738 - 95.1992 mm (3.747 - 3.748 in) |
| 0.508 mm (0.020 in) oversize | 95.4278 - 95.4532 mm (3.757 - 3.758 in) |
| 0.762 mm (0.030 in) oversize | 95.6818 - 95.7072 mm (3.767 - 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 - 0.0909 mm (0.0017 - 0.0036 in) |
| **Piston Pins** | |
| Length | 65.073 - 65.327 mm (2.5619 - 2.5719 in) |
| Diameter | 33.9975 - 34.0025 mm (1.3385 - 1.3387 in) |
| Pin fit at room temperature of 19 - 21 °C (66 - 70 °F): | |
| Clearance in connecting rod (piston pin bushing) | 0.0115 - 0.0240 mm (0.00045 - 0.00094 in) |


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**Table 17 Connecting Rods and Pistons (cont.)**

| | |
|---|---|
| Clearance in piston | 0.013 - 0.022 mm (0.0005 - 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): | |
| Top compression | 0.165 mm (0.0065 in) |
| Intermediate compression | 0.051 - 0.102 mm (0.0020 - 0.0040 in) |
| Oil control | 0.038 - 0.084 mm (0.0015 - 0.0033 in) |
| Ring gap in bore: | |
| Top compression | 0.29 - 0.55 mm (0.011 - 0.021 in) |
| Intermediate compression | 1.40 - 1.66 mm (0.055 - 0.065 in) |
| Oil control | 0.24 - 0.50 mm (0.009 - 0.019 in) |

## Special Torque

**Table 18**

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

## Special Service Tools

**Table 19**

| Tool Number | Description |
|---|---|
| ZTSE4220 | Piston Ring Expansion Pliers |
| ZTSE4513 | Piston Gauge Pins (0.082 in) |
| ZTSE4514 | Piston Ring Compressor (Cope) |
| Obtain locally | Dial Indicator with Magnetic Base |
| | Telescoping Gauge Set |


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