# ENGINE SERVICE MANUAL

## 2007 MaxxForce® DT, 9, and 10 Engine Service Manual

# Navistar, Inc.

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2007 MaxxForce® DT, 9, and 10 Engine Service Manual
EPA 07 - US, Canada and Mexico

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# TABLE OF CONTENTS

# Foreword

Navistar, Inc. is committed to continuous research and development to improve products and introduce technological advances. Procedures, specifications, and parts defined in published technical service literature may be altered.

This *Service Manual* provides a general sequence of procedures for out-of-chassis engine overhaul (removal, inspection, and installation). For in-chassis service of parts and assemblies, the sequence may vary.

**NOTE:** Photo illustrations identify specific parts or assemblies that support text and procedures; other areas in photo illustrations may not be exact.

See vehicle manuals and Technical Service Information (TSI) bulletins for additional information.

| **Technical Service Literature** | |
|---|---|
| 1171939R3 | MaxxForce® DT, 9, and 10 *Engine Operation and Maintenance Manual* |
| 0000646601 | 2007 MaxxForce® DT, 9, and 10 *Engine Service Manual* |
| 0000002581 (Supersedes EGES-370) | 2007 MaxxForce® DT, 9, and 10 *Engine Diagnostic Manual* |
| EGED-375 | MaxxForce® DT, 9, and 10 Hard Start/ No Start Diagnostic Form |
| EGED-380 | MaxxForce® DT, 9, and 10 Performance Diagnostic Form |
| EGED-385 | MaxxForce® DT, 9, and 10 Electronic Control Systems Form |

Technical Service Literature is revised periodically and mailed automatically to “Revision Service” subscribers. If a technical publication is ordered, the latest revision will be supplied.

**NOTE:** To order technical service literature, contact your Navistar dealer.

## Service Diagnosis

Service diagnosis is an investigative procedure that must be followed to find and correct an engine application problem or an engine problem.

If the problem is engine application, see specific vehicle manuals for further diagnostic information.

If the problem is the engine, see specific *Engine Diagnostic Manual* for further diagnostic information.

**Prerequisites for Effective Diagnosis**

- Availability of gauges and diagnostic test equipment
- Availability of current information for engine application and engine systems
- Knowledge of the principles of operation for engine application and engine systems
- Knowledge to understand and do procedures in diagnostic and service publications

**Technical Service Literature required for Effective Diagnosis**

- *Engine Service Manual*
- *Engine Diagnostic Manual*
- Diagnostics Forms
- Electronic Control Systems Diagnostics Forms
- Service Bulletins

## Safety Information

This manual provides general and specific service procedures essential for reliable engine operation and your safety. Since many variations in procedures, tools, and service parts are involved, advice for all possible safety conditions and hazards cannot be stated.

Read safety instructions before doing any service and test procedures for the engine or vehicle. See related application manuals for more information.

Disregard for Safety Instructions, Warnings, Cautions, and Notes in this manual can lead to injury, death or damage to the engine or vehicle.

### SAFETY TERMINOLOGY

Three terms are used to stress your safety and safe operation of the engine: Warning, Caution, and Note

**Warning**: A warning describes actions necessary to prevent or eliminate conditions, hazards, and unsafe practices that can cause personal injury or death.

**Caution**: A caution describes actions necessary to prevent or eliminate conditions that can cause damage to the engine or vehicle.

**Note**: A note describes actions necessary for correct, efficient engine operation.

### SAFETY INSTRUCTIONS

**Vehicle**

- Make sure the vehicle is in neutral, the parking brake is set, and the wheels are blocked before doing any work or diagnostic procedures on the engine or vehicle.

**Work area**

- Keep work area clean, dry, and organized.
- Keep tools and parts off the floor.
- Make sure the work area is ventilated and well lit.
- Make sure a first aid kit is available.

**Safety equipment**

- Use correct lifting devices.
- Use safety blocks and stands.

**Protective measures**

- Wear protective safety glasses and shoes.
- Wear correct hearing protection.
- Wear cotton work clothing.
- Wear sleeved heat protective gloves.
- Do not wear rings, watches or other jewelry.
- Restrain long hair.

**Fire prevention**

- Make sure charged fire extinguishers are in the work area.

**NOTE:** Check the classification of each fire extinguisher to ensure that the following fire types can be extinguished.

1. Type A — Wood, paper, textiles, and rubbish
2. Type B — Flammable liquids
3. Type C — Electrical equipment

**Batteries**

Batteries produce highly flammable gas during and after charging.

- Always disconnect the main negative battery cable first.
- Always connect the main negative battery cable last.
- Avoid leaning over batteries.
- Protect your eyes.
- Do not expose batteries to open flames or sparks.
- Do not smoke in workplace.

**Compressed air**

- Limit shop air pressure for blow gun to 207 kPa (30 psi).
- Use approved equipment.
- Do not direct air at body or clothing.
- Wear safety glasses or goggles.
- Wear hearing protection.
- Use shielding to protect others in the work area.

**Tools**

- Make sure all tools are in good condition.
- Make sure all standard electrical tools are grounded.
- Check for frayed power cords before using power tools.

**Fluids under pressure**

- Use extreme caution when working on systems under pressure.
- Follow approved procedures only.

**Fuel**

- Do not over fill the fuel tank. Over fill creates a fire hazard.
- Do not smoke in the work area.
- Do not refuel the tank when the engine is running.

**Removal of tools, parts, and equipment**

- Reinstall all safety guards, shields, and covers after servicing the engine.
- Make sure all tools, parts, and service equipment are removed from the engine and vehicle after all work is done.

# Table of Contents

# Engine Identification

### Engine Serial Number

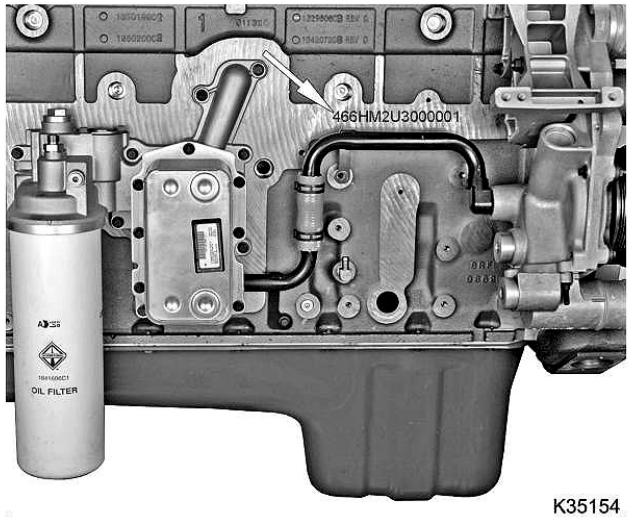


**Figure 1 Engine serial number**

The engine serial number is in two locations:

- Stamped on a crankcase pad on the right side of the crankcase below the cylinder head.
- On the engine emission label on the valve cover.

### Engine Serial Number Examples

International® MaxxForce® DT: 466HM2U3000001

International® MaxxForce® 9 and 10: 570HM2U3000001

### Engine Serial Number Codes

**466 –** Engine displacement
**570 –** Engine displacement
**H –** Diesel, turbocharged, Charge Air Cooler (CAC) and electronically controlled
**M2 –** Motor truck
**U –** United States
**7 digit suffix –** Engine serial number sequence beginning with 3000001

### Engine Emission Label

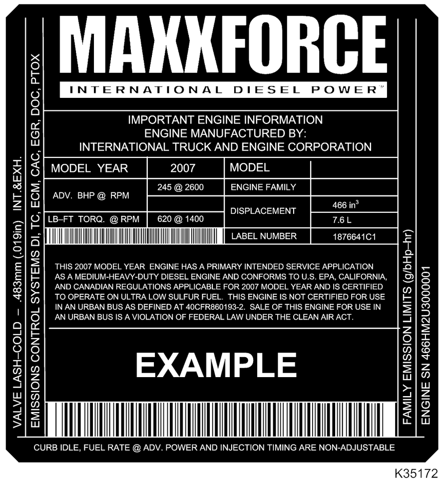


**Figure 2 U.S. Environmental Protection Agency (EPA) exhaust emission label (example)**

The U.S. Environmental Protection Agency (EPA) exhaust emission label is attached on top of the valve cover. The EPA label typically includes the following:

- Model year
- Engine family, model, and displacement
- Advertised brake horsepower and torque rating
- Emission family and control systems
- Valve lash specifications
- Engine serial number
- EPA, EURO, and reserved fields for specific applications

### Engine Accessory Labels

The following engine accessories may have manufacturer's labels or identification plates:

- Air compressor
- Air conditioning compressor
- Alternator
- Cooling fan clutch
- Power steering pump
- Starter motor

### Engine Description

**International® MaxxForce® DT, 9, and 10 Diesel Engines**

| | |
|---|---|
| Engine configuration | 4 stroke, inline six cylinder diesel |
| MaxxForce® DT displacement | 7.6 L (466 $in^3$) |
| MaxxForce® 9 and 10 displacement | 9.3 L (570 $in^3$) |
| Bore (sleeve diameter) | 116.6 mm (4.59 in) |
| Stroke | |
| • MaxxForce® DT | 119 mm (4.68 in) |
| • MaxxForce® 9 and 10 | 146 mm (5.75 in) |
| Compression ratio | |
| • MaxxForce® DT | 16.9 : 1 |
| • MaxxForce® 9 and 10 | 17.2 : 1 |
| Aspiration | VGT turbocharged and Charge Air Cooled (CAC) |
| Rated power @ rpm[1] | |
| • MaxxForce® DT | 245 bhp @ 2600 rpm |
| • MaxxForce® 9 | 310 bhp @ 2200 rpm |
| • MaxxForce® 10 | 310 bhp @ 2200 rpm |
| Peak torque @ rpm[1] | |
| • MaxxForce® DT | 620 lbf·ft @ 1400 rpm |
| • MaxxForce® 9 | 950 lbf·ft @ 1200 rpm |
| • MaxxForce® 10 | 1050 lbf·ft @ 1200 rpm |
| Engine rotation (facing flywheel) | Counterclockwise |
| Combustion system | Direct injection turbocharged |
| Fuel system | Electro-hydraulic injection |
| Total engine weight (oil and accessories) | |
| • MaxxForce® DT | 881 kg (1,943 lbs) |
| • MaxxForce® 9 and 10 | 905 kg (1,995 lbs) |
| Cooling system capacity (engine only) | 12.8 L (13.5 qts US) |
| Lube system capacity (including filter) | 28 L (30 qts US) |
| Lube system capacity (overhaul only, with filter) | 33 L (35 qts US) |
| Firing order | 1-5-3-6-2-4 |

1 Example ratings shown. See Performance Specifications appendix in Diagnostic Manual for additional ratings.

**Standard Features**

MaxxForce® DT, 9, and 10 diesel engines are designed for increased durability, reliability, and ease of maintenance.

The cylinder head has four valves per cylinder with centrally located fuel injectors directing fuel over the pistons. This configuration provides improved performance and reduces emissions.

The camshaft is supported by four insert bushings pressed into the crankcase. The camshaft gear is driven from the front of the engine. A thrust flange is located between the camshaft and the drive gear. The overhead valve train includes mechanical roller lifters, push rods, rocker arms, and dual valves that open using a valve bridge.

MaxxForce® DT engines use one piece aluminum alloy pistons. MaxxForce® 9 and 10 engines use one piece steel pistons. All pistons use an offset piston axis and centered combustion bowls. Crown markings show correct piston orientation in the crankcase.

The one piece crankcase uses replaceable wet cylinder sleeves that are sealed by a single crevice seal. Some applications include a crankcase ladder which is designed to support heavier loads and reduce engine noise.

The crankshaft has seven main bearings with fore and aft thrust controlled at the rear bearing. One fractured cap connecting rod is attached at each crankshaft journal. A piston pin moves freely inside the connecting rod and piston. Piston pin retaining rings secure the piston pin in the piston. The rear oil seal carrier is part of the flywheel housing.

A gerotor lube oil pump is mounted on the front cover and is driven by the crankshaft. Pressurized oil is supplied to engine components and the high-pressure injection system. All MaxxForce® DT, 9, and 10 engines use an engine oil cooler and spin-on engine oil filter.

The water supply housing serves as the mounting bracket for the Freon® compressor. Mounting capabilities for a dual Freon® compressor are available as an option. The pad mounting design of the alternator and Freon® compressor brackets provide easy removal and improved durability.

The low-pressure fuel supply pump draws fuel from the fuel tank through the fuel filter housing. The housing includes a strainer, filter, primer pump, drain valve, Water in Fuel (WIF) sensor, and Engine Fuel Pressure (EFP) sensor. If equipped, an optional fuel heater element is located in the fuel filter housing. Conditioned fuel is pumped through the intake manifold and cylinder head to the fuel injectors.

The WIF sensor detects water in the fuel system. When a programmed value of water is collected in the fuel filter housing, the instrument panel's amber FUEL FILTER lamp will illuminate. The collected water must be removed immediately. The water is drained by using the drain valve located on the fuel filter housing.

The fuel injection system is electro-hydraulic. The system includes an under-valve-cover high-pressure oil manifold, fuel injectors, and a high-pressure oil pump. The injectors are installed in the cylinder head, under the high-pressure oil manifold.

The Variable Geometry Turbocharger (VGT) has actuated vanes in the turbine housing. These vanes modify exhaust gas flow through the VGT. The ECM commands the VGT in response to boost and exhaust back pressure for various engine speeds and load conditions.

The Inlet Air Heater (IAH) system warms the incoming air supply prior to cranking to aid cold engine starting and reduce white smoke during warm-up. The IAH system will initially illuminate the WAIT TO START lamp located on the instrument panel. When the lamp turns off, the engine can be started.

The Exhaust Gas Recirculation (EGR) system circulates cooled exhaust into the intake air stream in the intake manifold. This cools the combustion process and reduces the formation of $NO_X$ engine emissions.

A closed crankcase breather system uses an engine mounted oil separator to return oil to the crankcase and vent crankcase pressure into the intake system.

### Optional Features

Optional features available include the following:

- Air compressor
- Power Takeoff (PTO)
- Engine or exhaust brake

An air compressor is available for applications that require air brakes or air suspension. A hydraulic power steering pump can be used with or without the air compressor.

The front cover has a mounting flange available for PTO accessories. The air compressor drive gear train is used with a spline adapter and provides power for front mounted PTO accessories.

The Diamond Logic® engine brake is available for all engine displacements. The engine brake is a compression release brake system that provides additional braking performance. The operator can control the engine brake for different operating conditions.

The Diamond Logic® exhaust brake system is also available for all engine displacements. The exhaust brake uses the turbocharger to restrict exhaust flow for additional braking. The operator can control the exhaust brake for different operating conditions.

### Optional Cold Climate Features

Optional cold climate features available include the following:

- Oil pan heater
- Coolant heater
- Fuel heater

All three heaters use an electric element to warm engine fluids in cold weather conditions.

The oil pan heater warms engine oil to ensure optimum oil flow.

The coolant heater warms engine coolant surrounding the cylinders. Warmed engine coolant aids in performance and fuel economy during start-up.

The fuel heater is installed in the fuel filter header assembly and warms the supply fuel. Warmed supply fuel prevents waxing, and improves performance and fuel economy during cold weather start-up.

**Chassis Mounted Features**

A Charge Air Cooler (CAC) is an air-to-air heat exchanger which increases the density of the air charge.

The Aftertreatment System, part of the larger Exhaust System, processes engine exhaust to meet tailpipe emission requirements.

- The Diesel Oxidation Catalyst (DOC) burns oxygen and hydrocarbons in the exhaust stream.
- The Diesel Particulate Filter (DPF) captures and burns particulates in the exhaust stream.

### Engine Component Locations

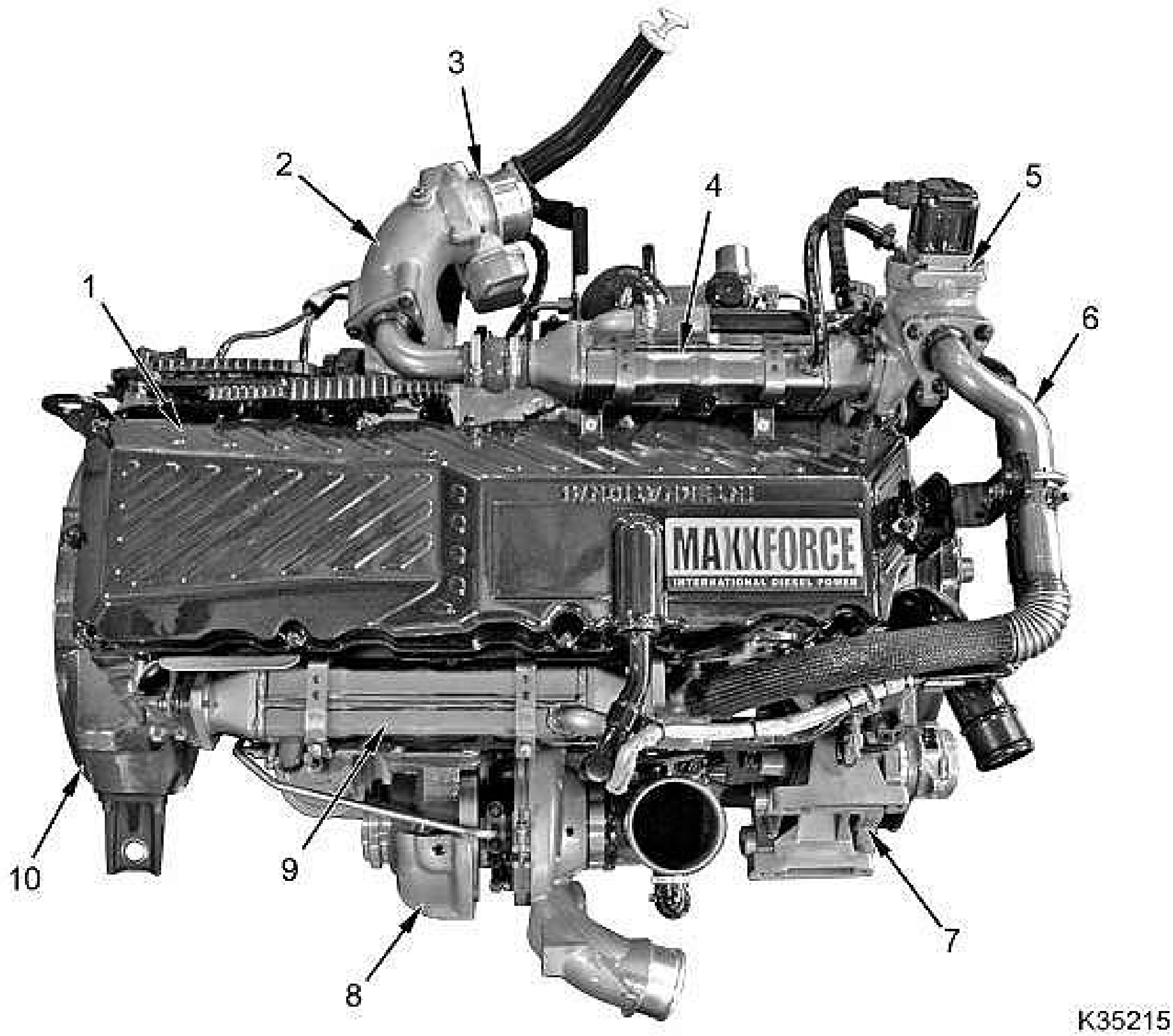


**Figure 3 Component location – top**

1. Valve cover
2. EGR and inlet air mixer duct
3. Intake throttle assembly
4. Intake side EGR cooler
5. EGR valve manifold assembly
6. EGR tube assembly
7. Alternator bracket
8. Variable Geometry Turbocharger (VGT) assembly
9. Exhaust side EGR cooler
10. Flywheel housing

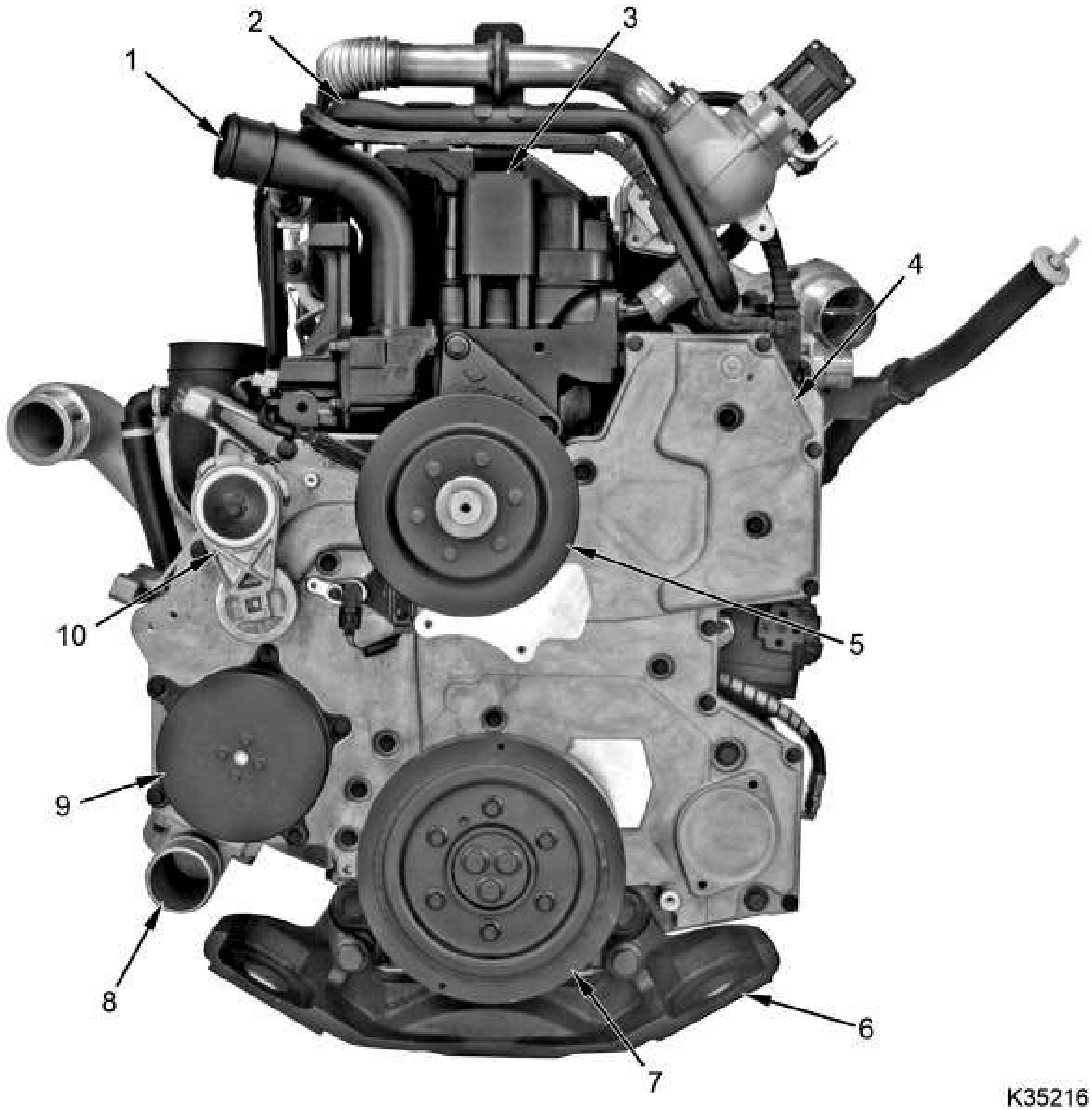


**Figure 4 Component location – front**

1. Water outlet tube assembly
2. Coolant crossover tube assembly (EGR)
3. Tube support
4. Front cover
5. Fan drive pulley
6. Front engine mounting bracket
7. Vibration damper assembly
8. Water inlet elbow
9. Water pump pulley
10. Automatic belt tensioner

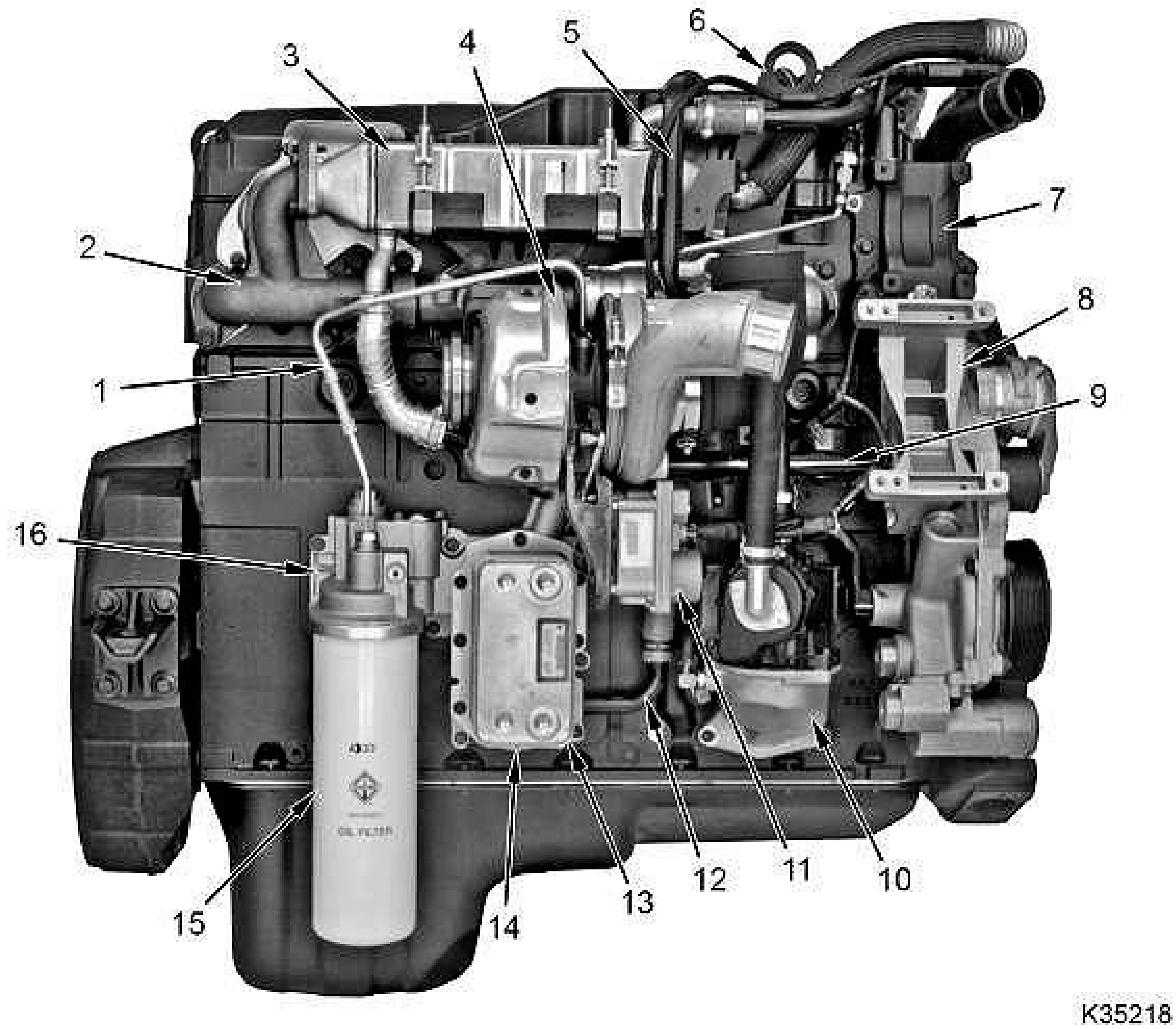


**Figure 5 Component location – right**

1. Turbocharger oil supply tube assembly
2. Exhaust manifold
3. Exhaust side EGR cooler
4. Variable Geometry Turbocharger (VGT) assembly
5. Breather inlet tube assembly
6. Lifting eye
7. Water supply housing (Freon® compressor mount)
8. Alternator bracket
9. EGR coolant supply tube
10. Crankcase breather assembly with turbine
11. VGT actuator
12. Coolant tube (oil system module)
13. Cooler heat exchanger
14. M18 plug assembly (coolant drain)
15. Oil filter
16. Oil system module assembly

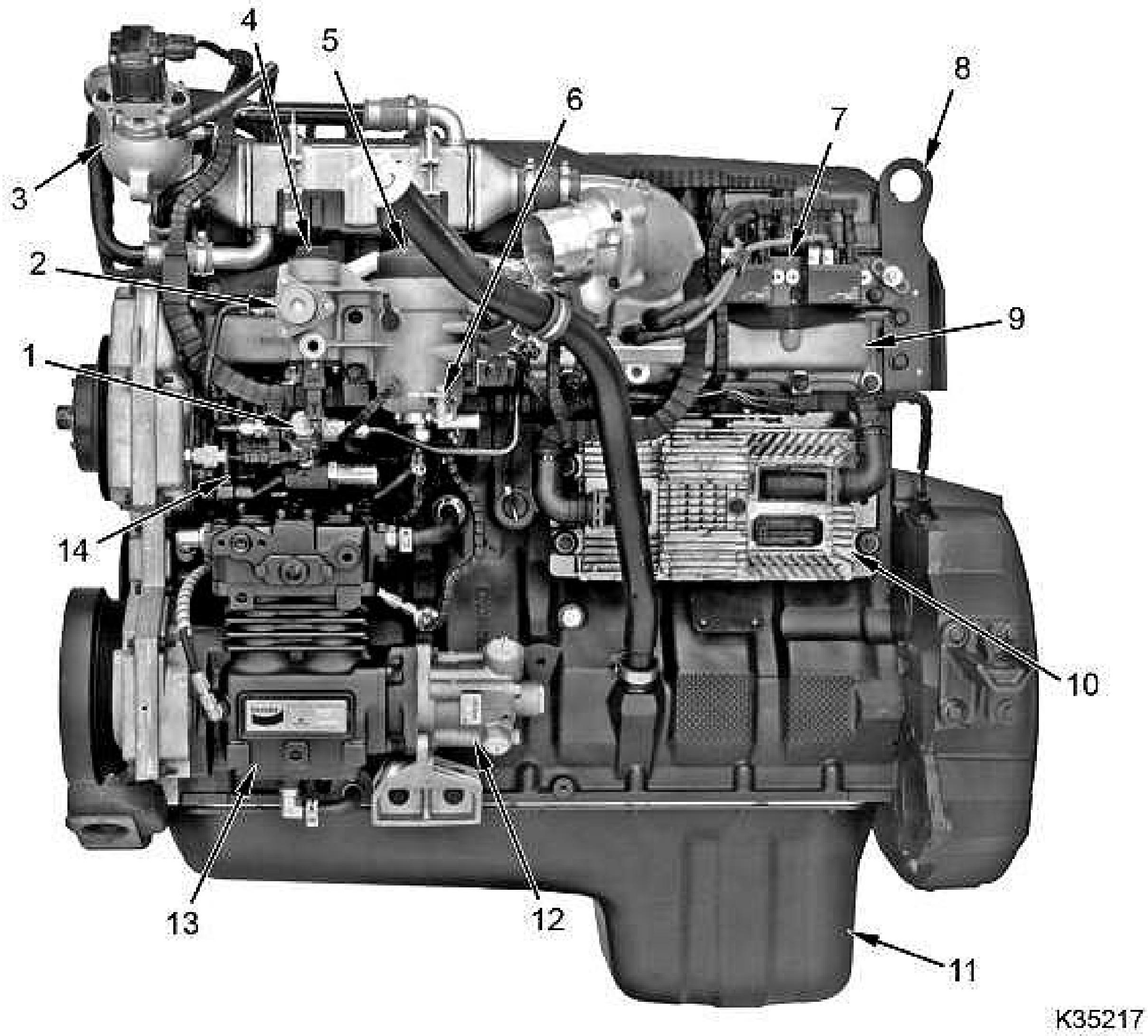


**Figure 6 Component location – left**

1. Low-pressure fuel pump
2. Priming pump (fuel)
3. EGR valve manifold assembly
4. Fuel strainer cap
5. Fuel filter cap
6. Water drain valve
7. Intake Air Heater (IAH) relay assembly
8. Lifting eye
9. Intake manifold
10. ECM
11. Oil pan
12. Power steering pump assembly
13. Air compressor assembly
14. High-pressure oil pump

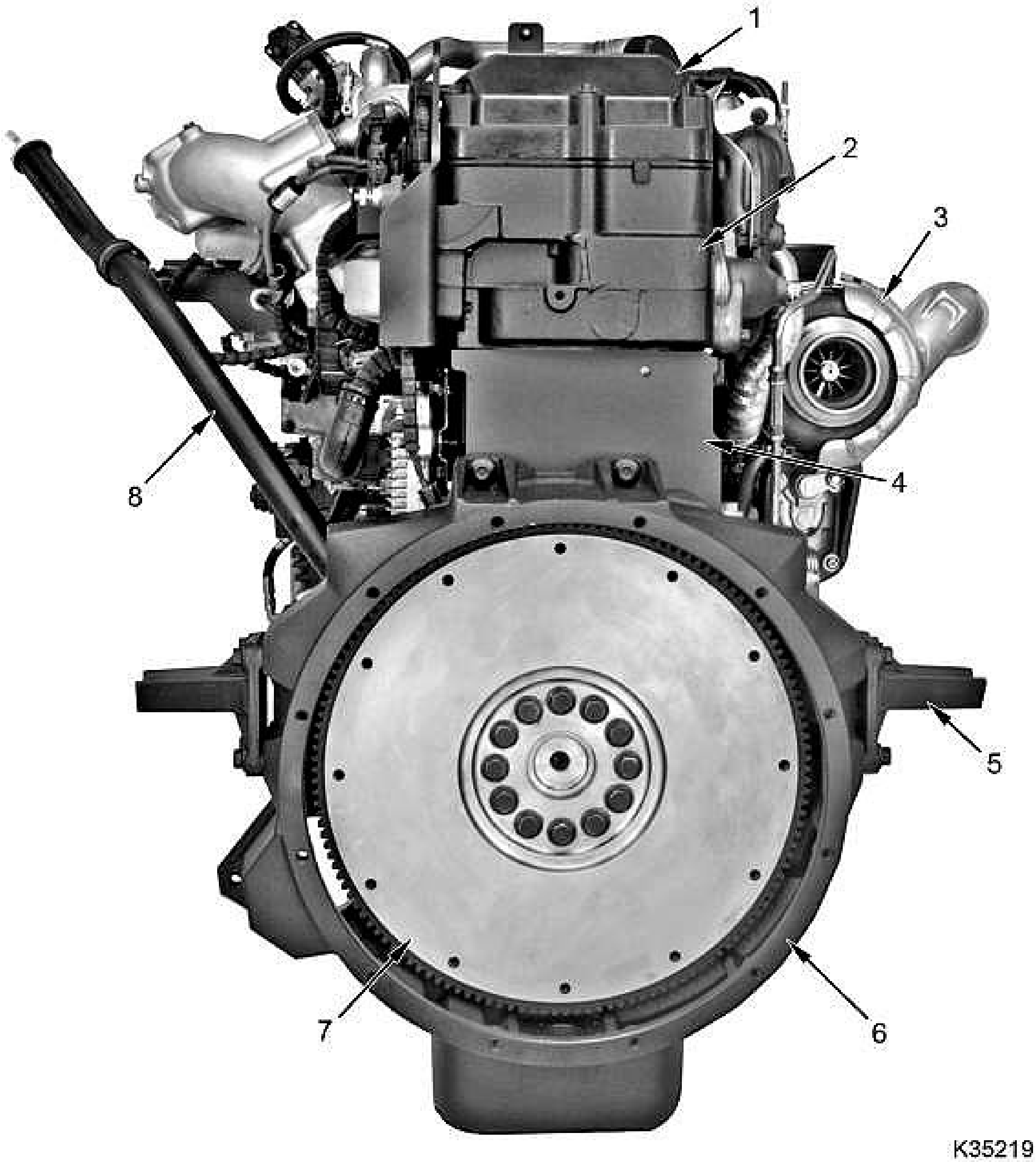


**Figure 7 Component location – rear**

1. Valve cover
2. Cylinder head
3. VGT assembly
4. Crankcase
5. Rear engine mounting bracket (2)
6. Flywheel housing
7. Flywheel
8. Oil filler tube

## Air Management System

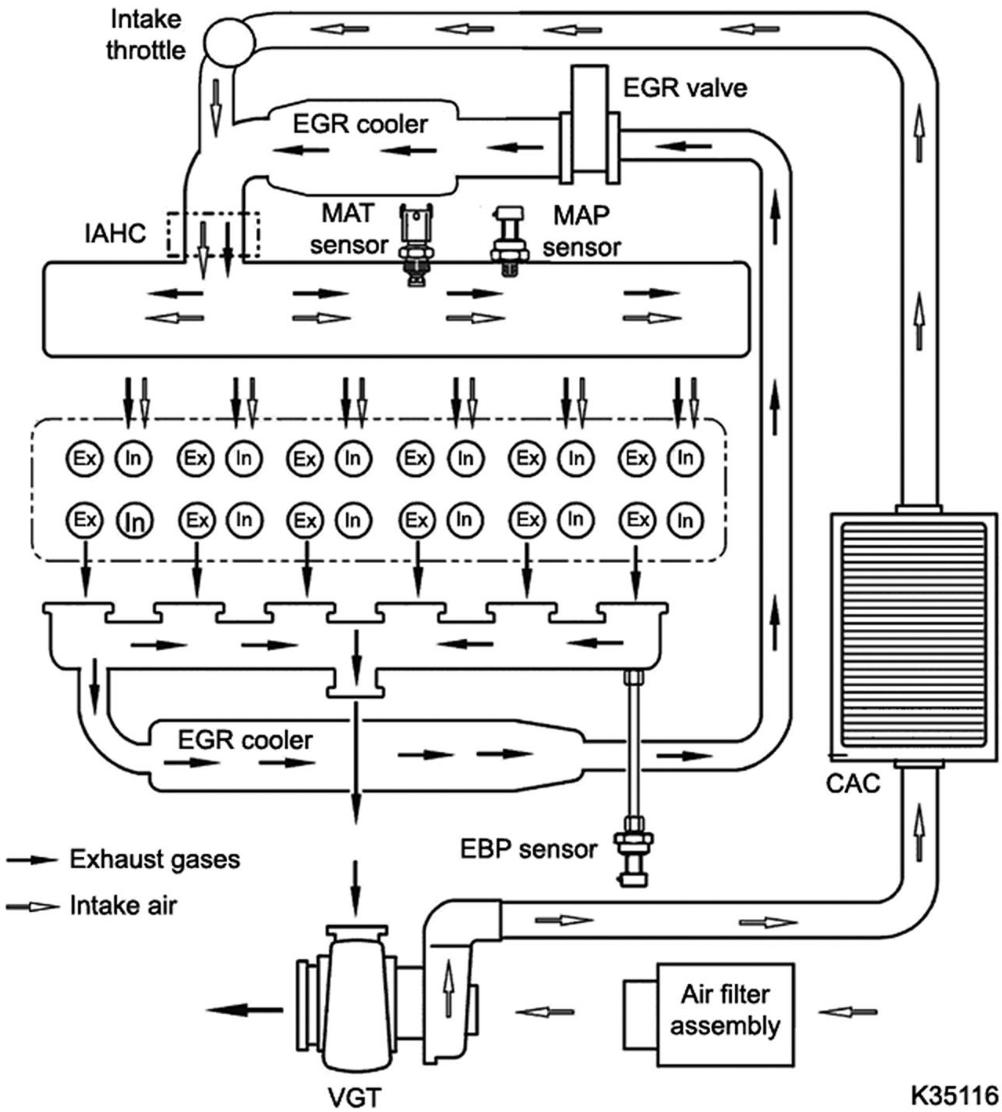


**Figure 8 Air management system**

The Air Management System includes the following:

- Air filter assembly
- Variable Geometry Turbocharger (VGT)
- Charge Air Cooler (CAC)
- Intake throttle valve
- Exhaust Gas Recirculation (EGR)
- Intake manifold and EGR mixer

- Inlet Air Heater Control (IAHC)
- Exhaust and intake valves
- Exhaust system
- Diamond Logic® exhaust and engine brake
- Diesel Particulate Filter (DPF – Aftertreatment System)

### Air Flow

Air flows through the air filter assembly and enters the VGT. The VGT compressor increases the pressure, temperature, and density of the intake air before it enters the CAC. Cooled compressed air flows from the CAC into the inlet throttle valve and EGR mixer duct.

If the EGR control valve is open, exhaust gas will pass through the EGR system and mix with the filtered intake air. This mixture flows through the inlet air heater and into the intake manifold.

If the EGR control valve is closed, only filtered intake air will flow through the inlet air heater and into the intake manifold.

After combustion gases exit through the exhaust valves and ports, the gas is forced through the exhaust manifold to the EGR system and VGT.

Some gas flows through the EGR system, which is controlled by the EGR valve. The remaining gas flows to the VGT turbine.

The turbo vanes control flow and pressure of exhaust gas. This controls the speed of the compressor wheel, which is connected to the turbine wheel by a shaft. The VGT compressor wheel compresses the filtered air.

Exhaust gases exit the turbocharger, flow into the exhaust piping to the aftertreatment system, and are released from the exhaust tail pipe.

### Air Management Components

### Charge Air Cooler (CAC)

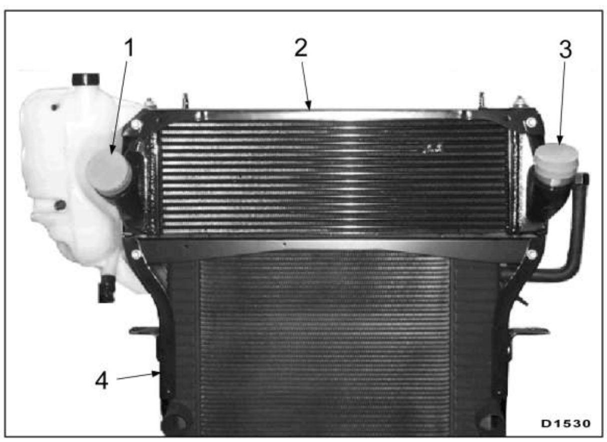


**Figure 9 CAC**

1. Air outlet
2. CAC
3. Air inlet
4. Radiator

The chassis mounted CAC is mounted on top of the radiator. Air from the turbocharger passes through a network of heat exchanger tubes before entering the engine intake system. Outside air flowing over the heat exchanger tube fins cools the charge air. Cooling the charge air increases the density and improves the air to fuel ratio during combustion.

**Exhaust Gas Recirculation (EGR) System**

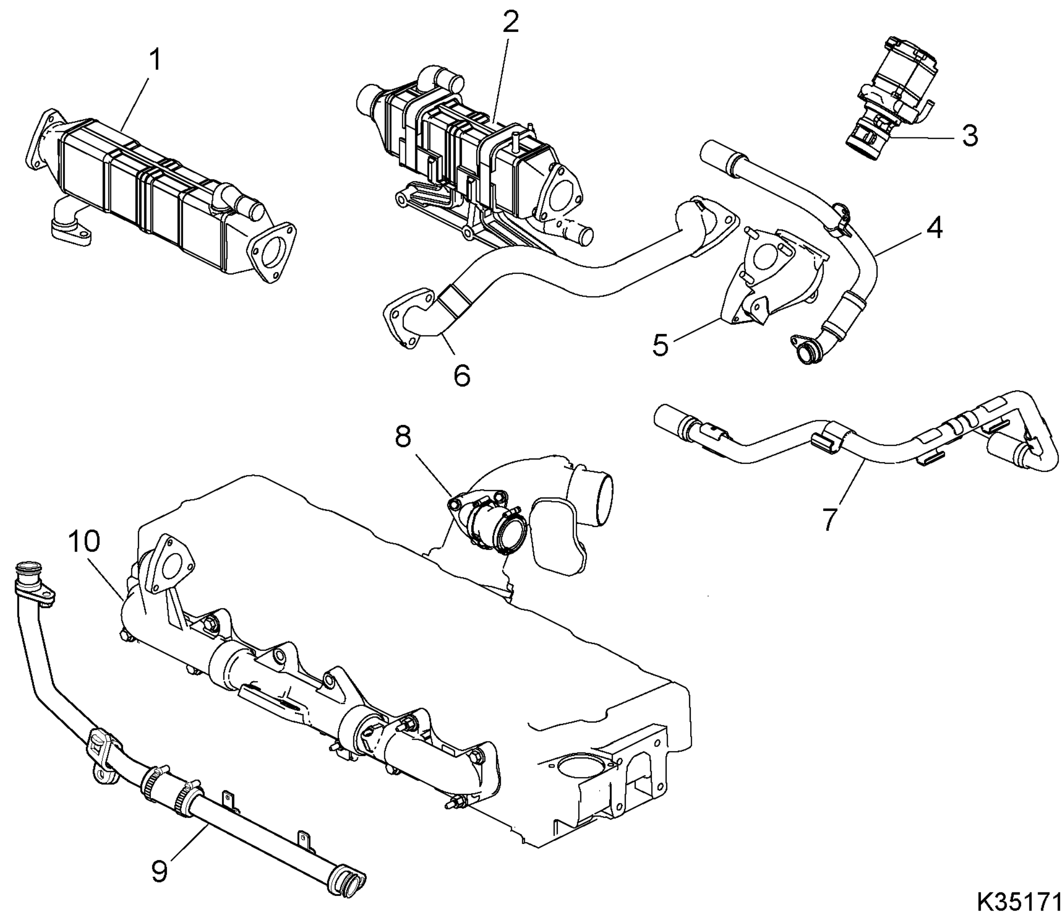


**Figure 10 EGR system**

1. Exhaust side EGR cooler
2. Intake side EGR cooler
3. EGR valve
4. EGR coolant return tube assembly
5. EGR valve manifold
6. EGR tube assembly
7. Coolant crossover tube assembly
8. EGR metering tube
9. EGR coolant supply tube
10. Exhaust manifold

The EGR system includes the following:

- Exhaust manifold
- EGR exhaust side cooler
- Exhaust gas crossover tube
- Electrical control system
- EGR control valve
- EGR intake side cooler

- EGR mixer duct
- Intake manifold

The EGR system reduces Nitrogen Oxide ($NO_x$) engine emissions. $NO_x$ forms during a reaction between nitrogen and oxygen at high temperatures during combustion. Combustion starts when fuel is injected into the compressed combustion chamber.

**EGR Flow**

Metered exhaust gas from the exhaust manifold flows into the exhaust side EGR cooler. Cooled exhaust gas flows through the exhaust tube assembly to the EGR control valve.

When the EGR is commanded, the EGR control valve opens and allows cooled exhaust gas to enter the intake side EGR cooler for further cooling. This exhaust gas is directed into the EGR mixer duct where it is mixed with filtered intake air.

**EGR Control Valve**

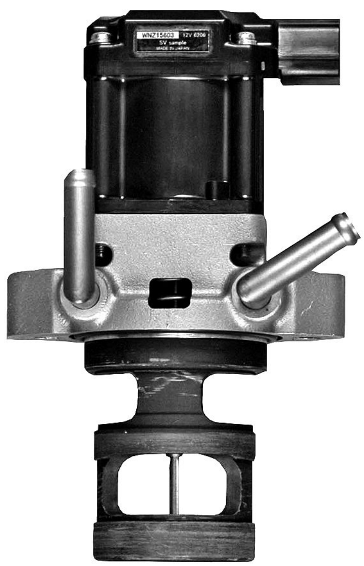

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**Figure 11 EGR control valve**

The EGR valve consists of three major components, a valve, an actuator motor, and an Integrated Circuit (IC).

The EGR valve is installed in the EGR valve manifold on the top front of the engine.

The EGR valve uses a DC motor to control position of the valve assembly. The motor pushes directly on the valve stem to open. The valve is shut by a spring. The valve assembly has two poppet valves on a common shaft.

The IC has three hall effect position sensors to monitor valve movement.

**EGR Closed Loop System**

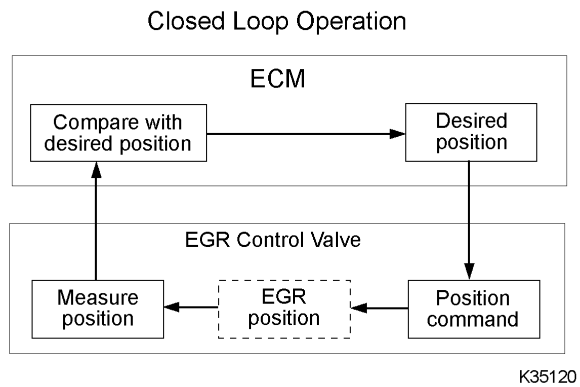


**Figure 12 EGR closed loop system**

The ECM commands the EGR control valve position based on engine speed and load conditions. The EGR control valve provides feedback to the ECM on current valve position.

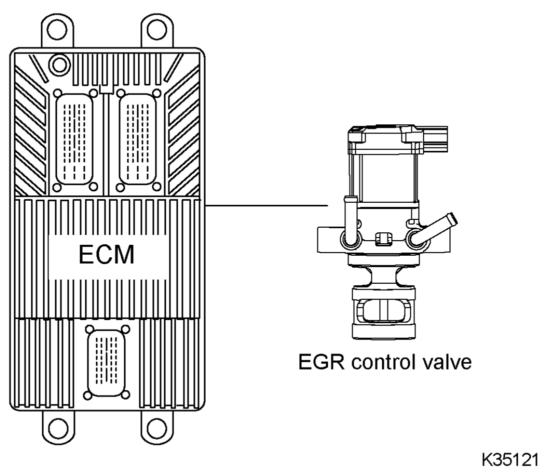


**Figure 13 EGR control**

**Variable Geometry Turbocharger (VGT)**

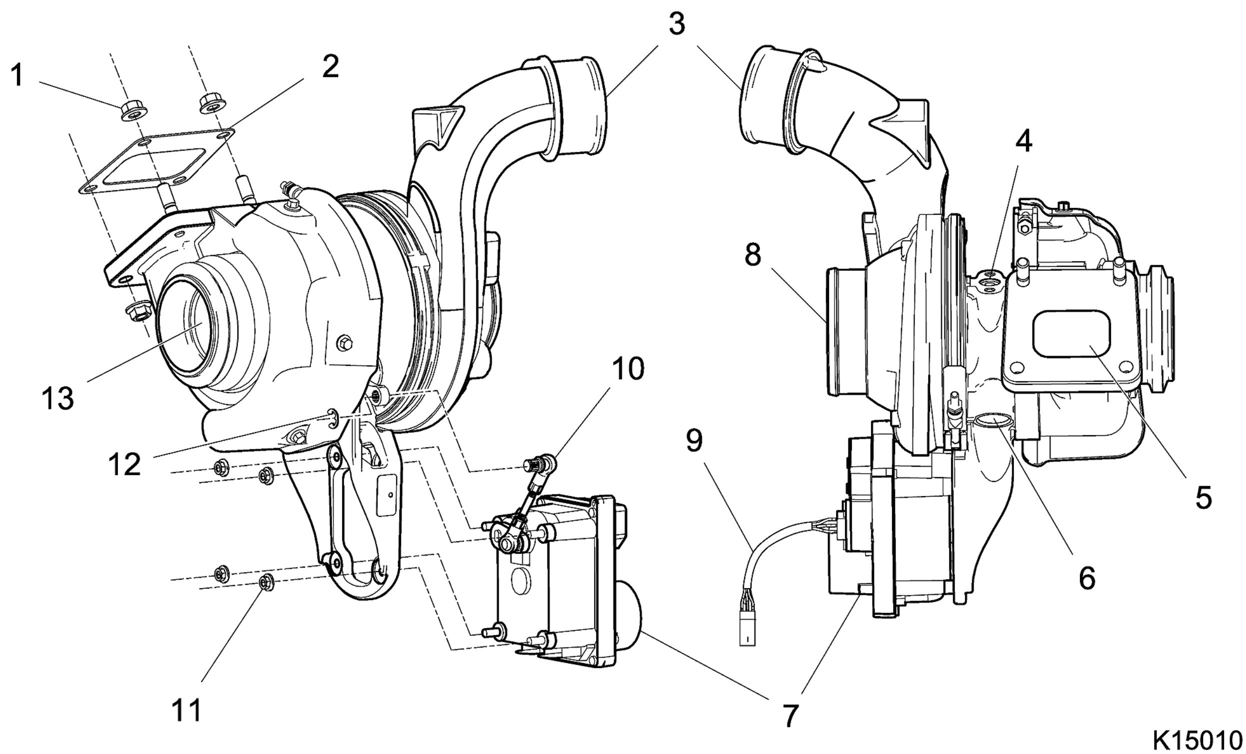


**Figure 14 VGT components**

1. M10 nut (4)
2. Turbo mounting gasket
3. Compressor outlet
4. Oil supply port
5. Turbine inlet
6. Oil drain port
7. VGT actuator
8. Compressor inlet
9. VGT actuator harness
10. VGT actuator linkage
11. M6 serrated lock nut (4)
12. E-clip
13. Turbine outlet

The VGT responds to engine load. During heavy load, an increased flow of exhaust gases turns the turbine wheel faster. The increased speed turns the compressor impeller faster and supplies greater air quantity and boost pressure to the intake manifold. When engine load is light, the flow of exhaust gases decreases which causes reduction in air volume and boost pressure.

The VGT has actuated vanes in the turbine housing. These vanes modify flow characteristics of the exhaust gases through the VGT to further control boost pressures for various engine speeds and load conditions.

**VGT Closed Loop System**

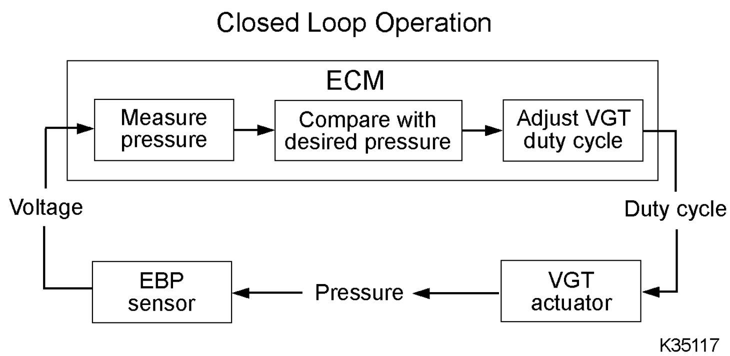


**Figure 15 VGT closed loop system**

The VGT is a closed loop system that uses the EBP sensor to provide feedback to the ECM. The EBP sensor continuously monitors exhaust system back pressure while the ECM adjusts VGT position to match engine requirements.

**VGT Control**

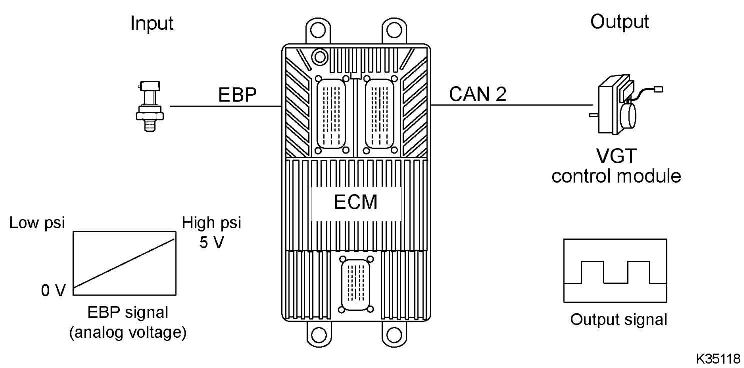


**Figure 16 VGT control**

The VGT actuator is a control module located below the turbocharger. The internal microchip controls a DC motor which rotates a crank lever that adjusts vane position in the turbine housing. The position of the vanes is based on the VGT signal sent from the ECM.

Moveable vanes are mounted around the inside circumference of the turbine housing. A unison ring links all the vanes together. When the unison ring moves, all vanes will move to the same position. Unison ring movement occurs when the crank lever in the VGT actuator moves.

Exhaust gas flow can be regulated, depending on required exhaust system back-pressure, to match engine speed and load. As demand for exhaust system back-pressure increases, the ECM increases the VGT signal to the VGT actuator. When exhaust system back-pressure demand is reduced, the ECM decreases the VGT signal to the VGT actuator.

### Aftertreatment (AFT) System

The AFT System, part of the larger exhaust system, processes engine exhaust to meet emissions requirements. The AFT system traps particulate matter (soot) and prevents it from leaving the tailpipe.

### AFT Control System

The control system performs the following functions:

- Monitors exhaust gases, the aftertreatment system, and controls engine operating parameters for emission processing and failure recognition
- Cancels regeneration in the event of catalyst or sensor failure
- Monitors the level of soot accumulation in the Diesel Particulate Filter (DPF) and adapts engine operating characteristics to compensate for increased back pressure
- Controls engine operating parameters to make regeneration automatic.
- Maintains vehicle and engine performance during regeneration

### Sensors

Sensors produce an electronic signal based on temperature and pressure. It is used by the control system to regulate the aftertreatment function.

The sensors measure the temperature and pressure at the center of the exhaust flow.

### Diesel Oxidation Catalyst (DOC)

The DOC does the following:

- Oxidizes hydrocarbons and carbon monoxide (CO) in exhaust stream
- Provides heat for exhaust system warm-up
- Aids in system temperature management for the DPF
- Oxidizes NO into $NO_2$ for passive DPF regeneration

### Diesel Particulate Filter (DPF)

The DPF does the following:

- Captures and temporarily stores carbon-based particulates in a filter
- Allows for oxidation (regeneration) of stored particulates once loading gets to a particular level (pressure drop)
- Provides the required exhaust back pressure drop for engine performance
- Stores noncombustible ash

### AFT Conditions and Responses

The operator is alerted audibly or with instrument panel indicators of system status. Automatic or manual regeneration is required when levels of soot exceed acceptable limits. For additional information see the applicable vehicle *Operator's Manual* and the vehicle visor placard.

# Fuel Management System

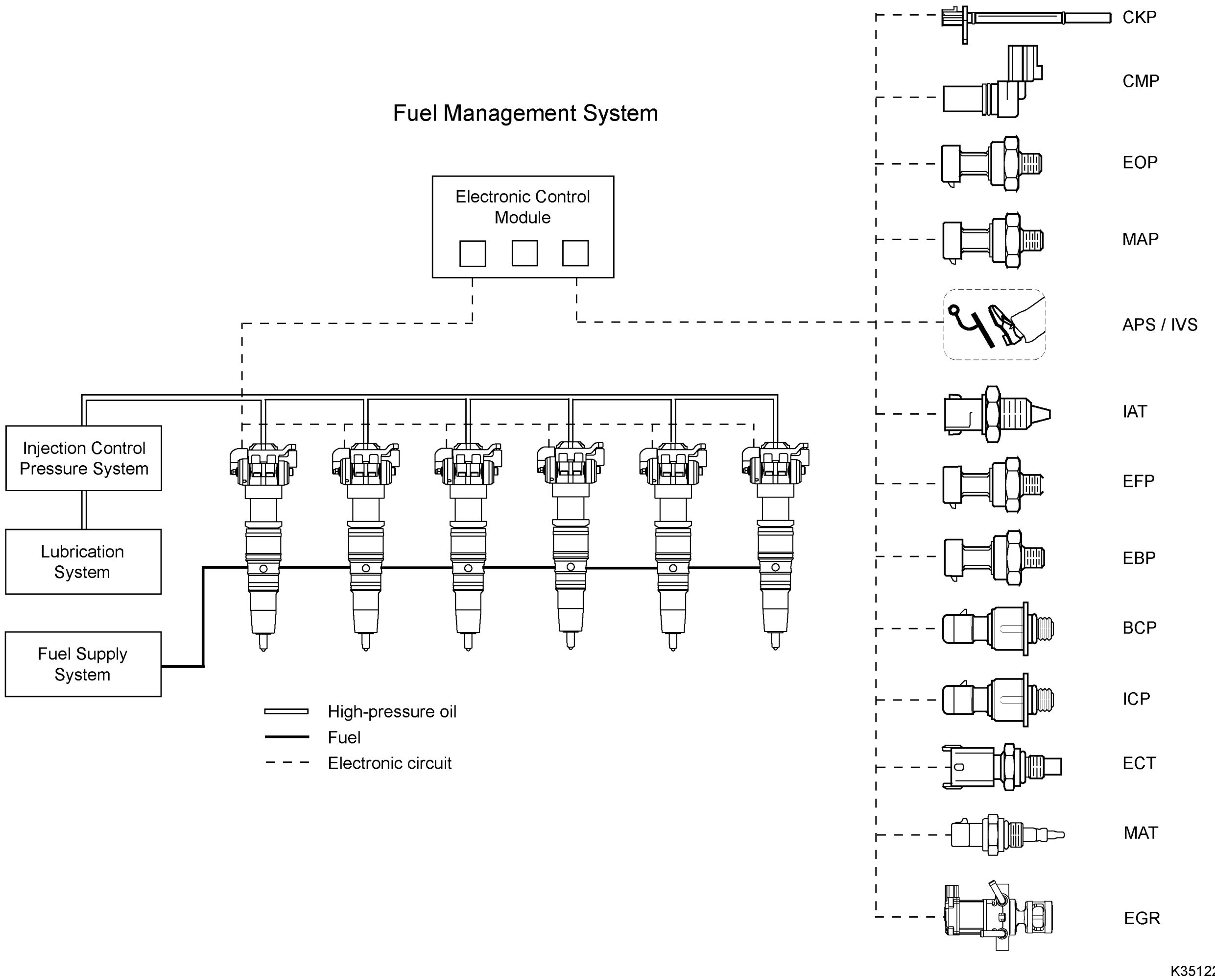


**Figure 17 Fuel management system**

The fuel management system includes the following:

- Lubrication system
- Injection Control Pressure (ICP) system
- Diamond Logic® engine brake
- Fuel supply system
- Fuel injectors
- Electronic control system

### ICP System

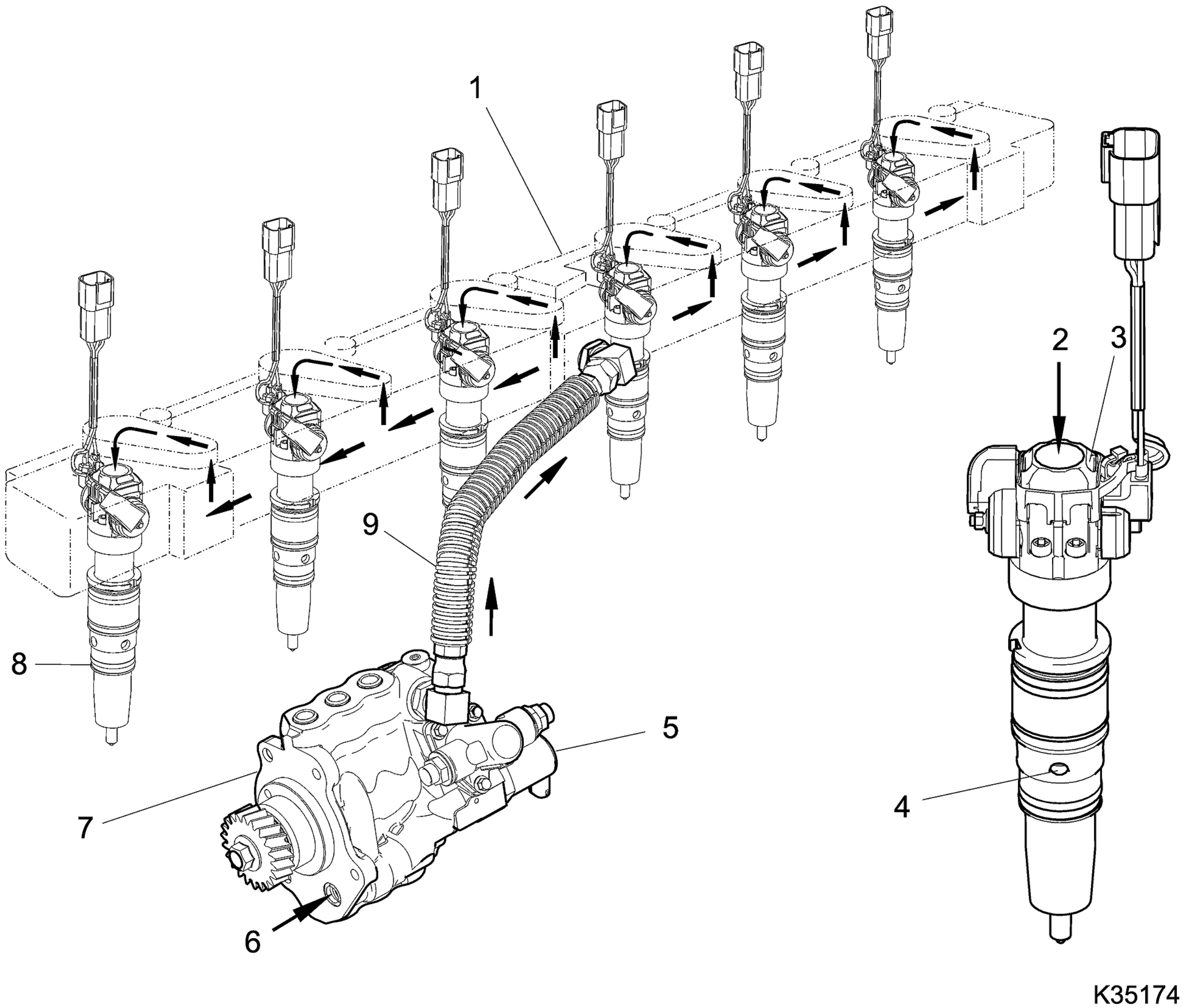


**Figure 18 ICP system**

1. High-pressure oil manifold
2. Injector oil inlet from high-pressure oil manifold
3. Oil outlet (2)
4. Fuel inlet port (4)
5. Injection Pressure Regulator (IPR) valve
6. Oil inlet from front cover reservoir
7. High-pressure oil pump assembly
8. Fuel injector assembly (6)
9. High-pressure oil hose

### High-Pressure Oil Flow

The lubrication system constantly refills the oil reservoir located in the front cover. The reservoir provides oil for the high-pressure oil pump. The pump is mounted on the backside of the front cover and gear driven from the front of the engine.

High-pressure oil is directed to the high-pressure oil hose, cylinder head passage, and high-pressure oil manifold, which is located beneath the valve cover.

High-pressure oil is used by the fuel injectors to inject, pressurize, and atomize fuel in the cylinders. This occurs when the OPEN coil for each fuel injector is energized.

Excess high-pressure oil is directed to the crankcase sump by the Injection Pressure Regulator (IPR) valve. The IPR valve is controlled by the Engine Control Module (ECM) to maintain a desired injection control pressure.

If equipped with the optional engine brake, some high-pressure oil is directed internally to the engine brake pistons when the brake is activated.

**ICP Closed Loop System**

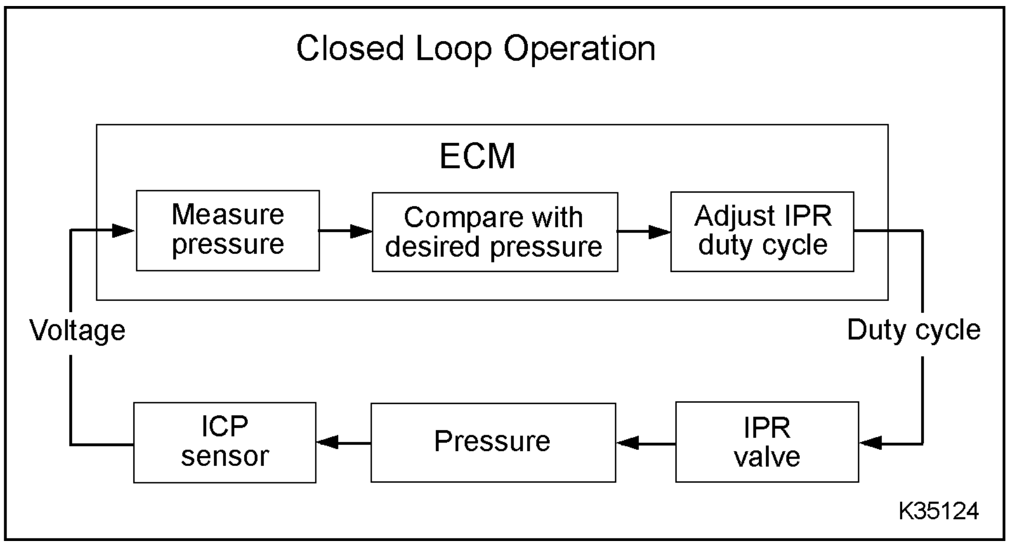


**Figure 19 ICP closed loop system**

The ICP system is a closed loop system that uses the ICP sensor to continuously provide injection control pressure feedback to the ECM. The ECM commands the IPR duty cycle to adjust ICP pressure to match engine requirements.

### ICP Control System

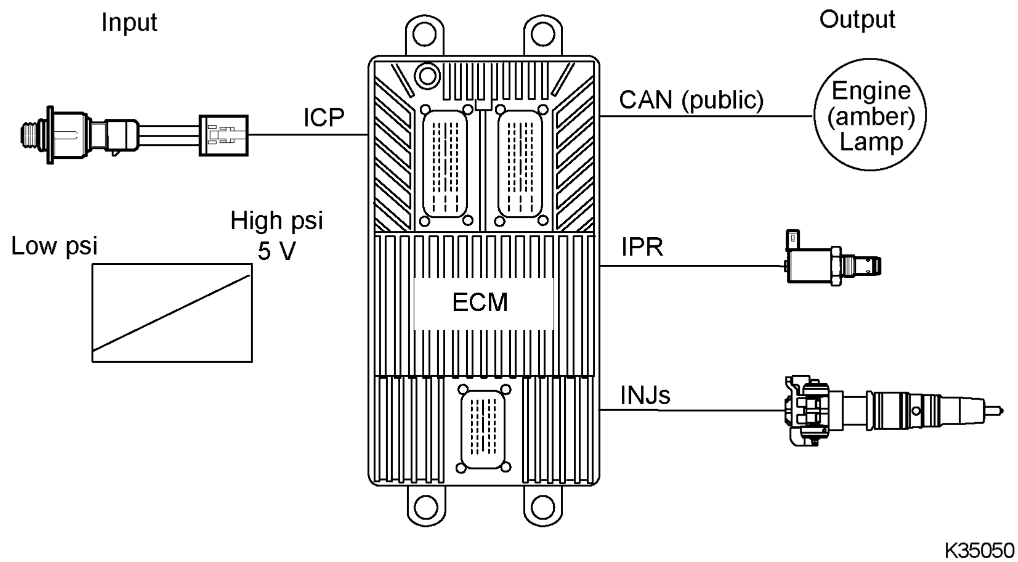


**Figure 20 ICP sensor control system**

The IPR solenoid receives a pulse-width modulated signal from the ECM. This indicates the on and off time the IPR control valve is energized. The pulse is calibrated to control ICP pressure which ranges from 5 MPa (725 psi) up to 32 MPa (4,650 psi).

The IPR valve is mounted in the body of the high-pressure pump. The IPR valve maintains desired injection control pressure by dumping excess oil back to the crankcase sump.

As demand for injection control pressure increases, the ECM increases the pulse-width modulation to the IPR solenoid. When demand for injection control pressure decreases, the duty cycle to the IPR solenoid decreases and more oil is allowed to flow to the drain orifice.

When the injection control pressure electrical signal is out-of-range, the ECM sets a Diagnostic Trouble Code (DTC). The ECM will not set DTCs if an injection control pressure signal corresponds to an in-range valve for injection control pressure for a given operating condition.

When ICP signals that are out-of-range, the ECM ignores out-of-range signals and go into open loop operation. The IPR valve will operate from programmed default values.

The ICP sensor is installed in the high-pressure oil manifold under the valve cover.

### Fuel Injector

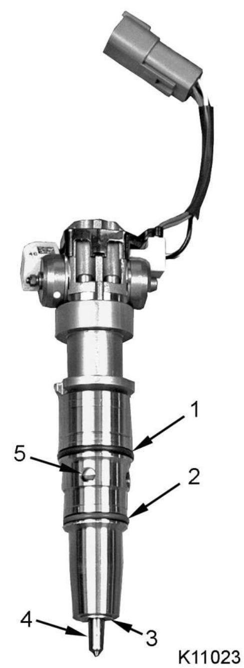


**Figure 21 Fuel injector**

1. Upper O-ring
2. Lower O-ring
3. Nozzle gasket
4. Injector nozzle
5. Fuel inlet port

### Fuel Injector Features

Two 48 volt, 20 amp coils control a spool valve that directs oil flow in and out of the injector. The injector coils are turned on for approximately 800 μs (microseconds). Each injector has a single four pin connector that couples to the valve cover gasket assembly.

### Injector Coils and Spool Valve

An OPEN coil and a CLOSE coil on the injector move the spool valve from side to side using magnetic force. The spool has two positions:

- When the spool valve is open, oil flows into the injector from the high-pressure oil manifold.

- When the spool valve is closed, oil exits from the top of the fuel injector and drains back to the crankcase.

**Intensifier Piston and Plunger**

When the spool valve is open, high-pressure oil enters the injector pushing down the intensifier piston and plunger. Since the intensifier piston is 7.1 times greater in surface area than the plunger, the injection pressure is also 7.1 times greater than injection control pressure on the plunger.

**Plunger and Barrel**

Fuel pressure builds at the base of the plunger in the barrel. When the intensifier piston pushes the plunger down, the plunger increases fuel pressure in the barrel 7.1 times greater than injection control pressure. The plunger has a hardened coating to resist scuffing.

**Injector Needle**

The injector needle opens inward when fuel pressure overcomes the Valve Opening Pressure (VOP) of 28 MPa (4,075 psi). Fuel is atomized at high-pressure through the nozzle tip.

### Fuel Injector Operation

The injector operation has three stages:

- Fill stage
- Injection
- End of injection

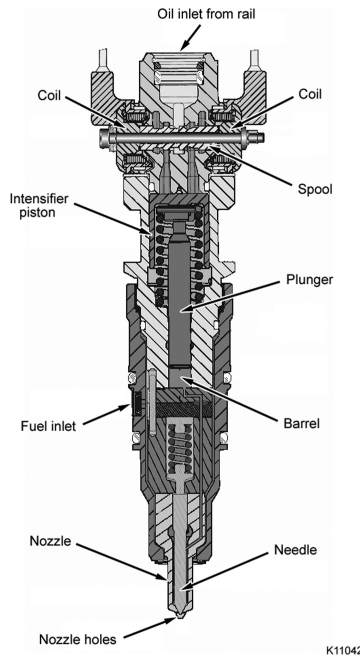


**Figure 22 Fuel injector cross section**

### Fill Stage

During the fill stage both coils are de-energized and the spool valve is closed. High-pressure oil from the high-pressure oil manifold is stopped at the spool valve.

Low-pressure fuel fills the four ports and enters through the edge filter on its way to the chamber beneath the plunger. The needle control spring holds the needle onto its seat to prevent fuel from entering the combustion chamber.

### Injection

1. A pulse-width controlled current energizes the OPEN coil. Magnetic force moves the spool valve open. High-pressure oil flows past the spool valve and onto the top of the intensifier piston. Oil pressure overcomes the force of the intensifier piston spring and the intensifier starts to move down. An increase in fuel pressure under the plunger seats the fuel inlet check ball, and fuel pressure starts to build on the needle.
2. The pulse-width controlled current to the OPEN coil is shut off, but the spool valve remains open. High-pressure oil from high-pressure oil manifold continues to flow past the spool valve. The intensifier piston and plunger continue to move and fuel pressure increases in the barrel. When fuel pressure rises above the VOP, the needle lifts off its seat and injection begins.

**End of Injection**

1. When the ECM determines that the correct injector on-time has been reached (the correct amount of fuel has been delivered), the ECM sends a pulse-width controlled current to the CLOSE coil of the injector. The current energizes the CLOSE coil and magnetic force closes the spool valve. High-pressure oil is stopped against the spool valve.
2. The pulse-width controlled current to close the coil is shut off, but the spool valve remains closed. Oil above the intensifier piston flows past the spool valve through the exhaust ports. The intensifier piston and plunger return to their initial positions. Fuel pressure decreases until the needle control spring forces the needle back onto its seat.

# Fuel Supply System

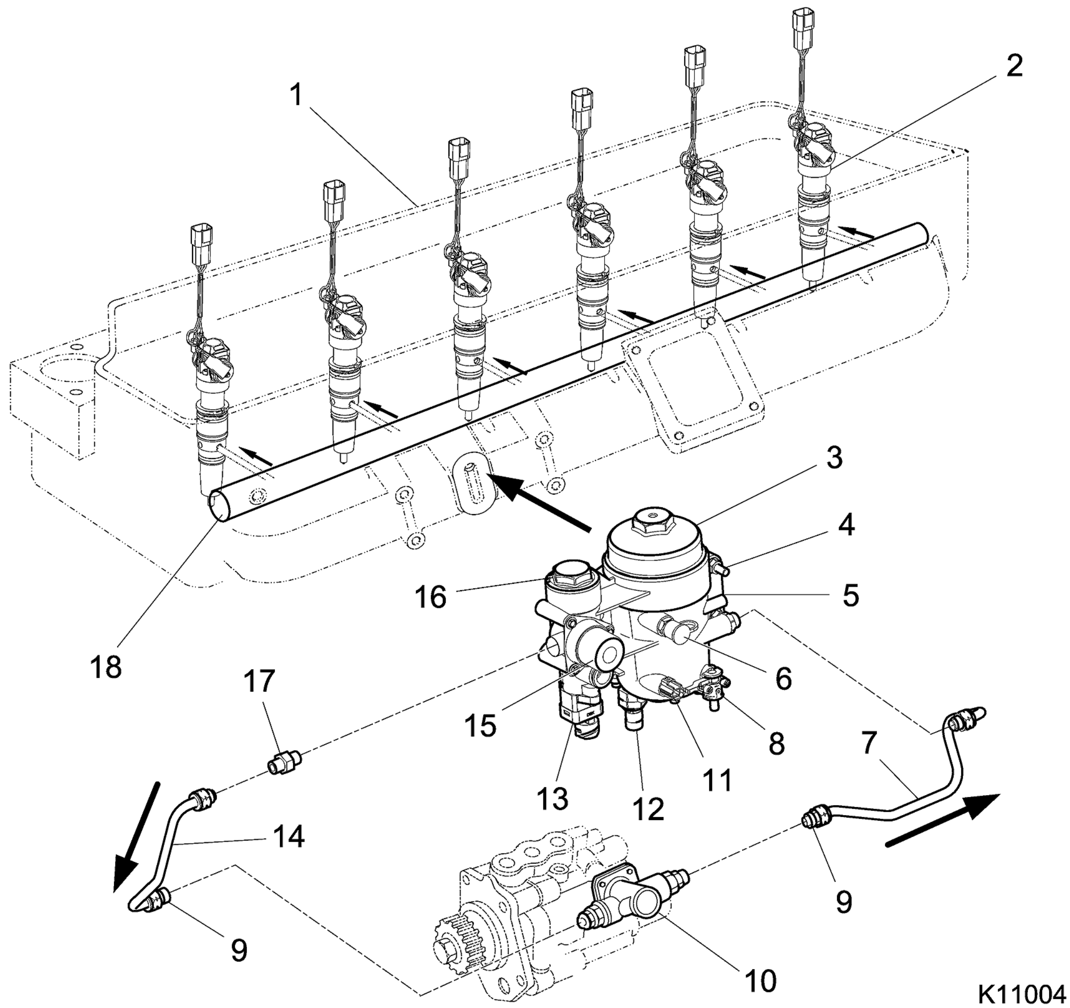


**Figure 23 Low-pressure fuel system**

1. Cylinder head
2. Fuel injector assembly (6)
3. Fuel filter cap
4. M8 x 75 stud bolt
5. Fuel filter header assembly
6. Diagnostic coupling assembly and dust cap
7. Transfer pump outlet tube assembly
8. Water drain valve
9. 3/8 tube sleeve (2 each tube)
10. Low-pressure fuel pump
11. Water In Fuel (WIF) sensor
12. Engine Fuel Pressure (EFP) sensor
13. Fuel heater (optional)
14. Transfer pump inlet tube assembly
15. Primer pump
16. Fuel strainer cap
17. Fitting assembly with check valve
18. Low-pressure fuel rail (cast in intake manifold)

### Fuel Supply System Flow

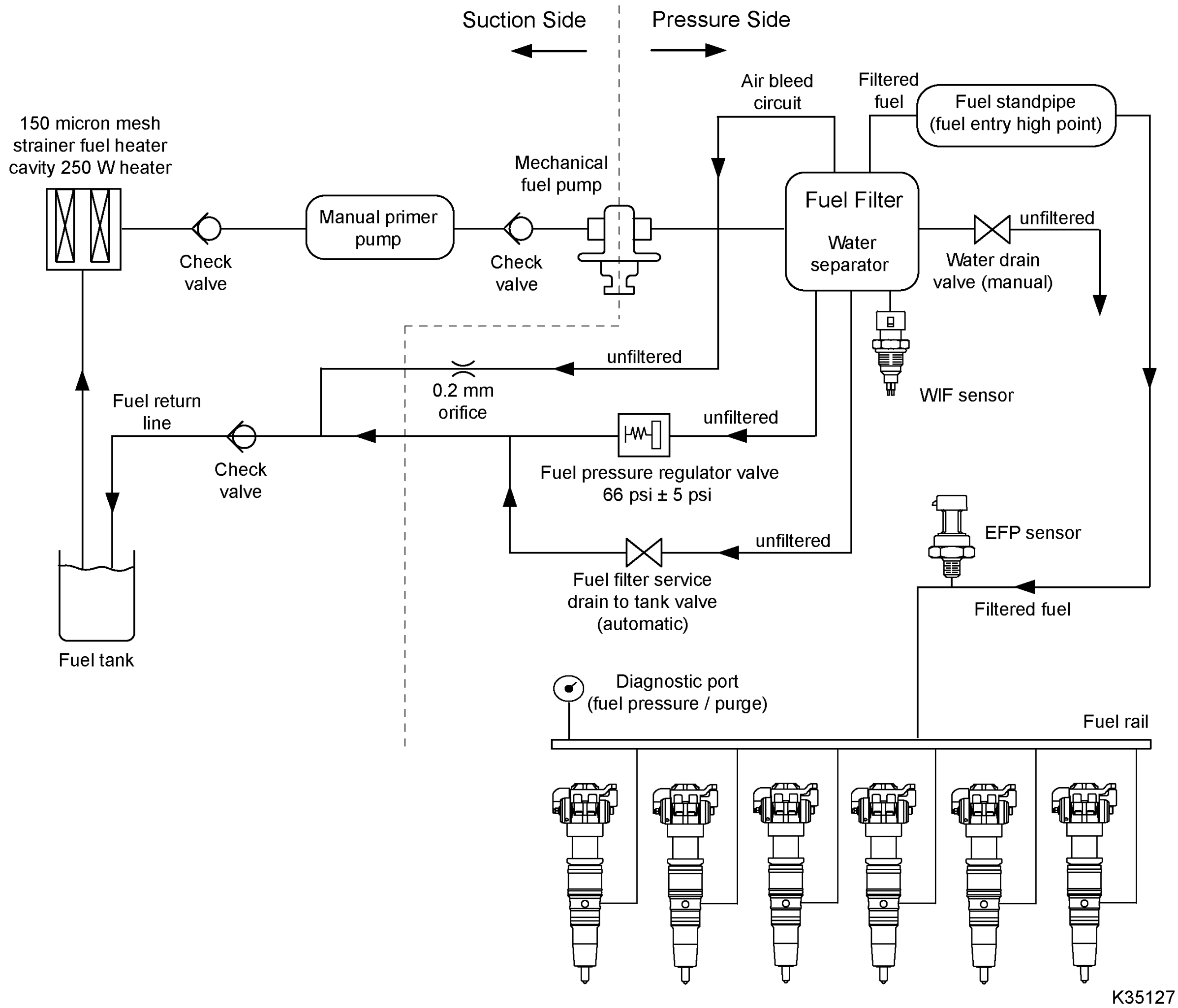


**Figure 24 Fuel flow**

The low-pressure fuel pump draws fuel through the fuel lines from the fuel tank. Fuel enters the fuel filter header assembly and passes through the 150 micron strainer.

An optional 250 watt electric heating element is available to warm incoming fuel to prevent waxing and improve cold weather performance. The heater is located in the base of the fuel strainer.

Fuel flows from the strainer through the low-pressure fuel pump to the fuel filter for further conditioning.

Fuel flows through the filter element and the standpipe. The filter element removes debris from the fuel. The standpipe prevents fuel from draining from the fuel rail during service.

If water is in the fuel, the fuel filter element repels the water. The water is collected at the bottom of the main filter element cavity in the fuel filter assembly.

When the maximum amount of water is collected in the element cavity, the WIF sensor sends a signal to the Engine Control Module (ECM). The ECM will turn on the amber FUEL FILTER lamp located on the instrument panel.

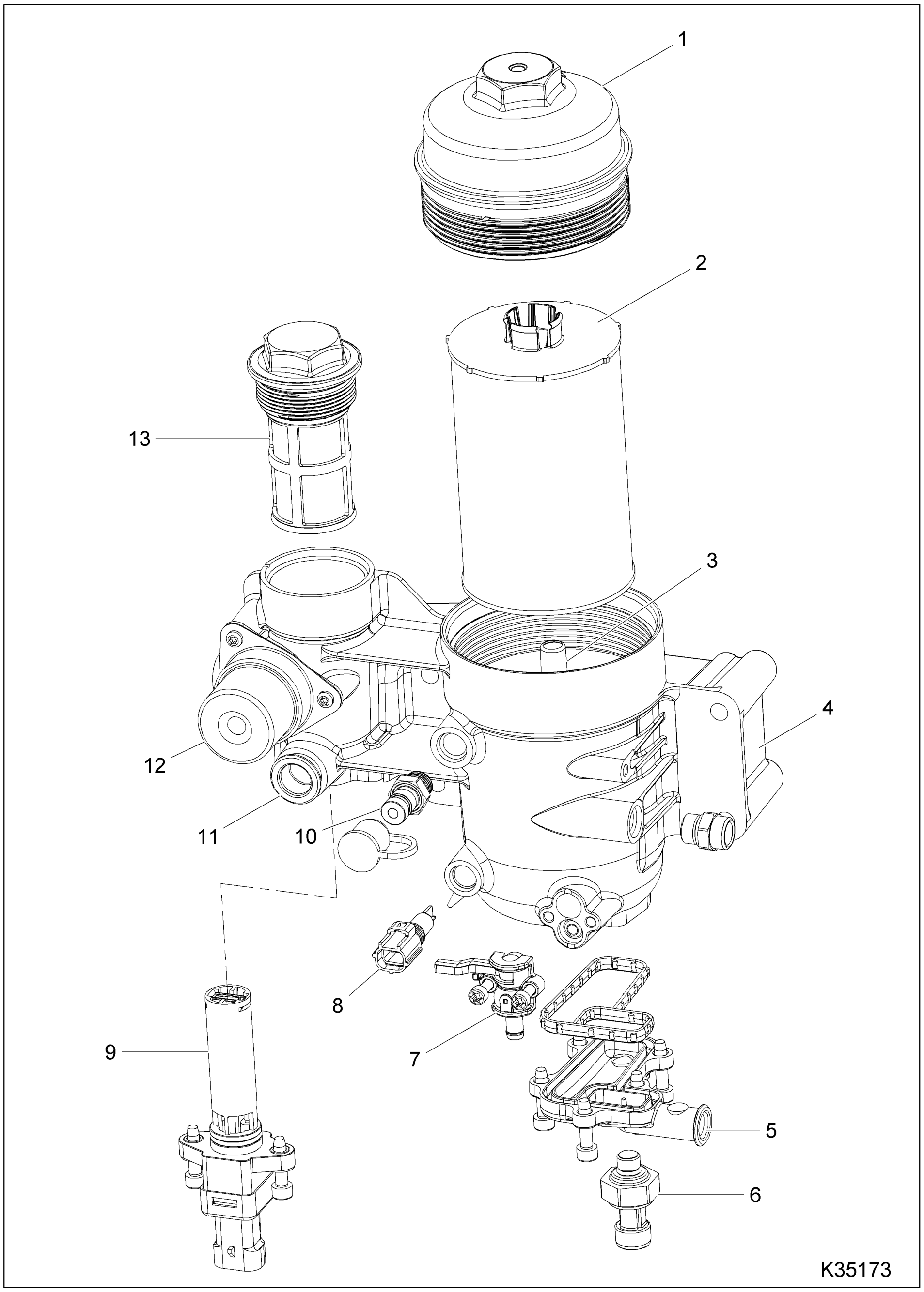


**Figure 25 Fuel filter header assembly**

1. Fuel filter cap
2. Fuel filter element
3. Standpipe
4. Filter assembly housing
5. Fuel outlet with check valve
6. Engine Fuel Pressure (EFP) sensor
7. Water drain valve assembly
8. Water In Fuel (WIF) sensor
9. 250 Watt fuel heater assembly (optional)
10. Diagnostic coupling assembly
11. Fuel inlet
12. Fuel primer
13. Fuel strainer element

A water drain valve is located on the fuel filter assembly and can be opened to drain contaminants (usually water) from the assembly.

A fuel pressure regulator valve is built into the fuel filter header assembly. The regulator valve is calibrated to open at 455 kPa ± 34 kPa (66 psi ± 5 psi) to regulate and relieve excessive fuel pressure. Excess fuel is sent through a fuel return line back to the fuel tank. Return fuel is not filtered.

Fuel continuously flows from the top of the filter element cavity, through a 0.2 mm air bleed orifice (filter center tube feature), and into the return fuel line. This aids in removing trapped air from the element cavity as a result of servicing.

When the fuel filter is removed, an automatic drain-to-tank valve is opened. Fuel present in the filter housing then drains out and back to the tank to provide improved cleanliness during servicing.

The Engine Fuel Pressure (EFP) sensor detects low fuel pressure caused by a fuel restriction or dirty fuel filter. The EFP sensor sends a signal to the ECM when pressure is below programmed values for various engine conditions and the ECM will turn on the amber FUEL FILTER lamp located on the instrument panel.

Filtered fuel flows from the fuel filter header assembly into the fuel rail. The fuel rail is an integral part of the intake manifold. The fuel flows into six cylinder head passages to each fuel injector.

When the fuel injectors are activated, fuel flows from the fuel passages through the injector inlet ports and inside the fuel injectors.

# Engine Lubrication System

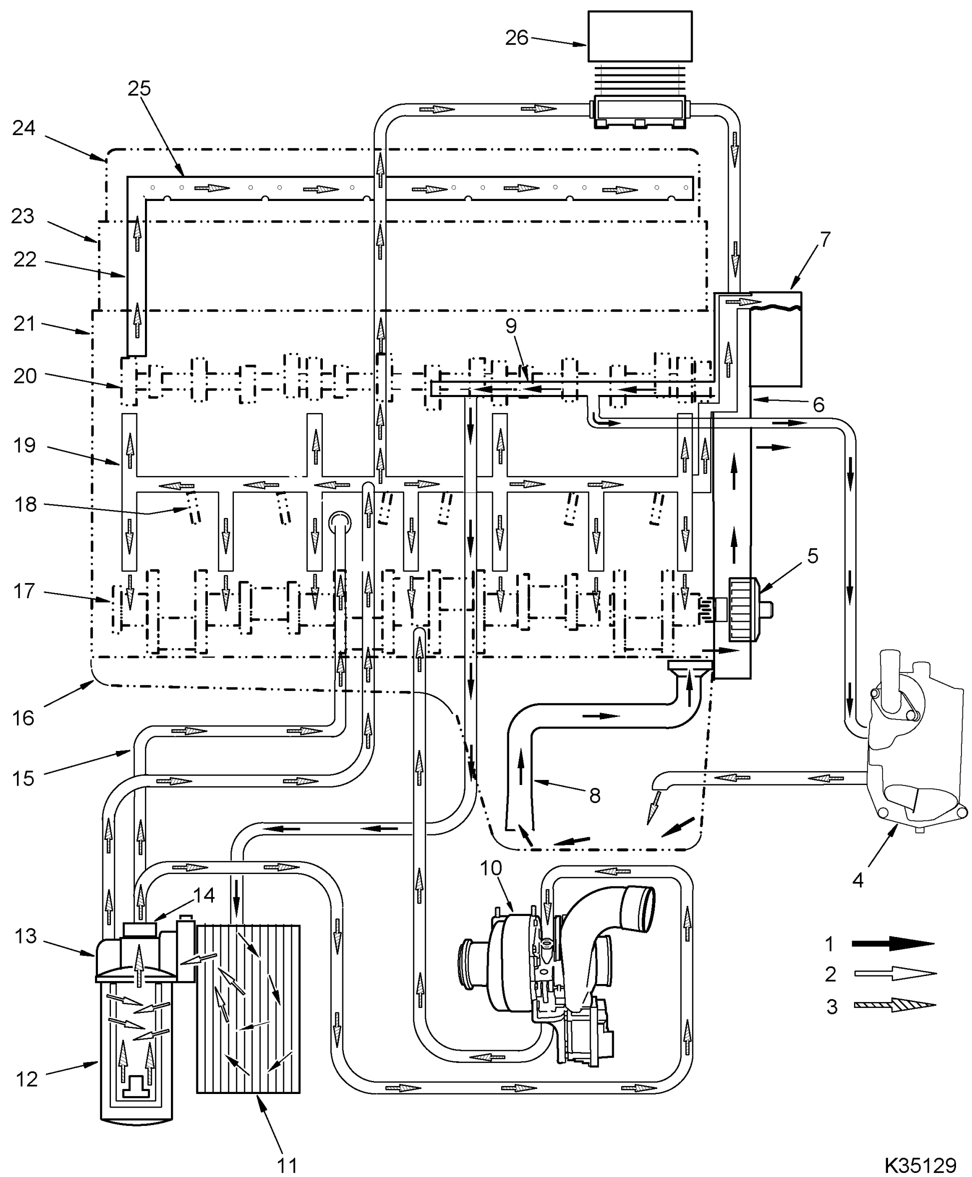


**Figure 26 Lubrication system**

1. Unfiltered oil
2. Cooled unfiltered oil
3. Filtered oil
4. Crankcase breather assembly
5. Gerotor oil pump
6. Front cover
7. Reservoir for high-pressure oil pump
8. Pick-up tube
9. Unfiltered oil gallery
10. Variable Geometry Turbocharger (VGT)
11. Oil cooler
12. Oil filter
13. Oil system module assembly
14. Oil pressure regulator relief valve
15. Regulator relief valve drain to crankcase
16. Oil pan assembly
17. Crankshaft
18. Piston cooling tube (6)
19. Main filtered oil gallery
20. Camshaft
21. Crankcase
22. Vertical gallery
23. Cylinder head
24. Valve cover
25. Rocker arm assembly
26. Air compressor (optional)

**Oil Flow**

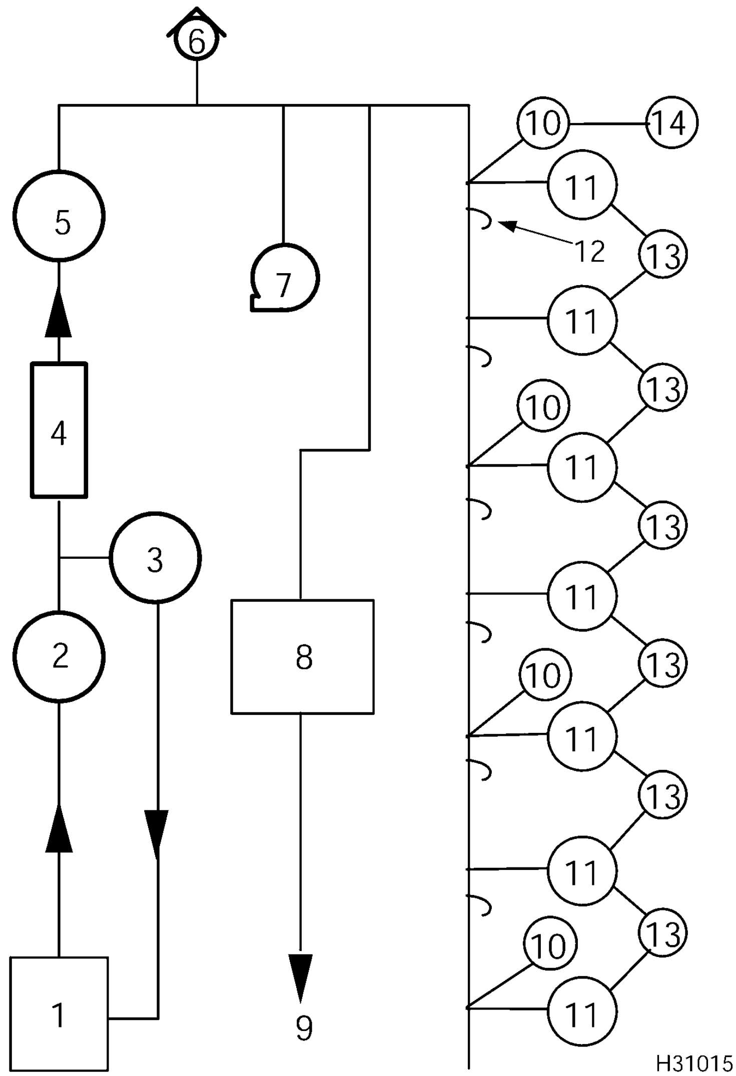


**Figure 27 Lubrication system**

1. Sump
2. Oil pump
3. Crankcase breather assembly
4. Oil cooler
5. Oil filter
6. Oil pressure regulator valve
7. Variable Geometry Turbocharger (VGT)
8. Oil reservoir for high-pressure pump
9. To high-pressure oil system
10. Cam bearing
11. Main bearings
12. Piston cooling tube (6)
13. Connecting rods
14. Rocker arm shaft

Unfiltered oil is drawn from the oil pan through the pickup tube and front cover passage by the crankshaft driven oil pump. Pressurized oil is forced through a front cover passage, into the crankcase gallery, and to the oil system module assembly. Oil flow at the oil system module assembly is controlled by the oil thermal valve assembly.

The thermal valve assembly allows unfiltered oil to bypass the oil cooler when the oil temperature is cold, and flow directly to the oil filter. As the oil temperature begins to warm, the thermal valve assembly begins to open. This allows unfiltered oil to flow into the oil cooler and oil filter.

When the oil temperature is hot, the thermal valve assembly allows unfiltered oil to flow through the oil cooler before entering the oil filter.

Unfiltered oil moves through plates in the oil cooler heat exchanger. Engine coolant flows around the plates to cool the surrounding oil.

Oil that exits or bypasses the oil cooler mixes and enters the spin-on oil filter. Oil flows from outside the filter element towards the inside to remove debris. When the filter is restricted, the oil filter bypass (located in the oil system module assembly) opens and allows oil to bypass the filter to maintain engine lubrication. The filter bypass valve opens when pressure reaches 345 kPa (50 psi).

After passing through the filter, the oil travels past the oil pressure regulator. The regulator directs excess oil back to the oil pan to maintain oil pressure at a maximum of 379 kPa (55 psi).

Clean regulated oil enters the main oil gallery of the engine to lubricate the crankshaft, camshaft, and tappets. The crankshaft has cross-drillings that direct oil to the connecting rods.

Oil is also provided to the high-pressure reservoir through a passage in the front cover.

Piston cooling jets continuously direct cooled oil to the bottom of the piston crowns.

Oil from the main oil gallery exits upwards through a passage at the rear of the crankcase. Oil flows through a passage in the cylinder head and enters the hollow rocker shaft which lubricates the rocker arms.

The crankcase breather assembly is driven by unfiltered oil pressure taken from the right side of the crankcase. Oil flows from the crankcase into the breather assembly. Passages direct the oil through a pressed brass nozzle that controls oil flow into a drive wheel. Oil drains into the base and mixes with waste oil from the breather system. The collected oil drains into the crankcase and then into the oil pan.

The turbocharger is lubricated with filtered oil from a supply tube assembly that connects the oil system module assembly to the center housing of the turbocharger. Oil drains back to the oil pan through a drain tube connected to the crankcase.

The optional air compressor is lubricated with filtered engine oil through a flexible hose. The hose is connected to a tee on the left side of the crankcase near the Engine Oil Pressure (EOP) sensor. Oil drains into the front cover and to the oil pan. Oil can also drain from the bottom of the air compressor through a tube into the crankcase.

The front gear train is splash lubricated with oil that drains from the high-pressure reservoir and the optional air compressor.

## Engine Cooling System

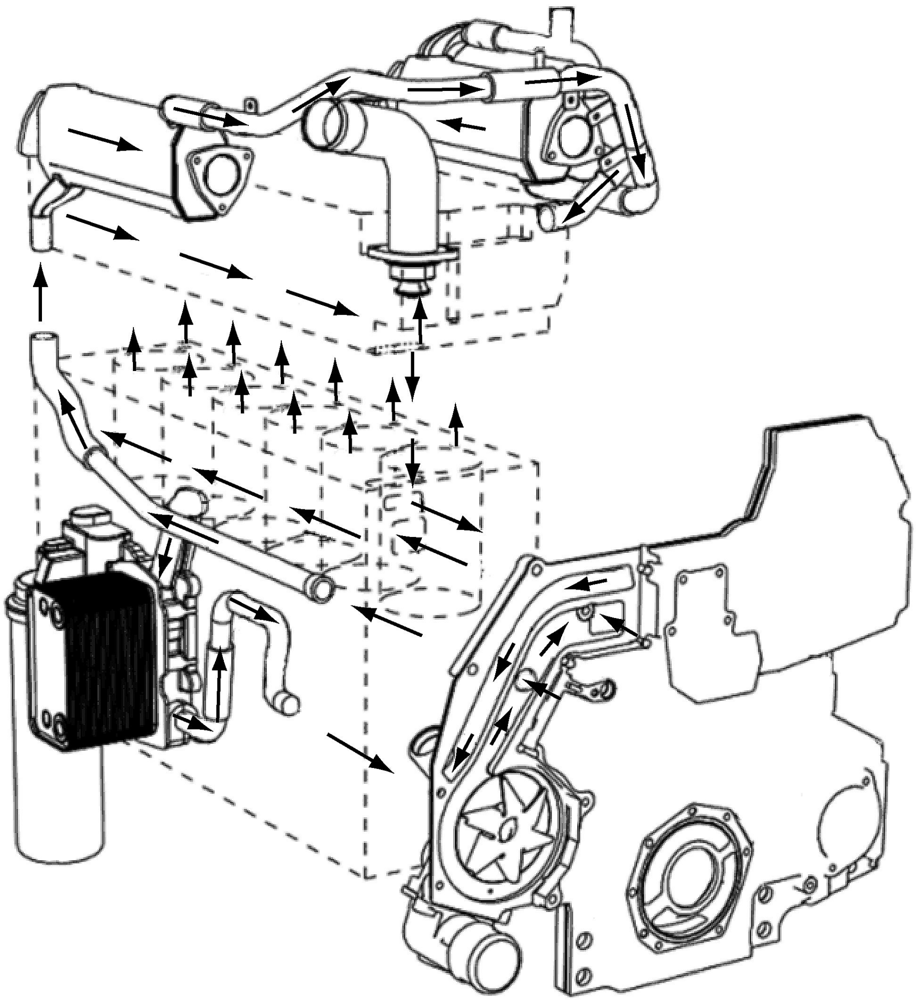


**Figure 28 Cooling system components and flow**

The engine cooling system includes the following:

- Chassis mounted radiator
- Fan
- Water inlet elbow
- Front engine covers
- Water pump
- Crankcase
- Cylinder sleeves

- Cylinder head
- Oil system module assembly
- Air compressor
- Thermostat
- Dual EGR coolers
- EGR control valve
- Surge tank
- Coolant heater

**Cooling System Flow**

Coolant is drawn from the radiator through an inlet elbow and front cover by the water pump. The water pump pushes coolant into two passages in the front cover.

Coolant flows to the crankcase and through the water jackets from front to rear. This coolant flows around the cylinder liners to absorb heat from combustion. The coolant may also pass by the optional engine coolant heater.

Swirling coolant flow in the cylinder liner jackets directs coolant through passages in the head gasket and upwards into the cylinder head.

Coolant flows through the cylinder head water jackets towards the thermostat cavity at the front of the cylinder head. Depending on coolant temperature, the thermostat can direct in two directions to exit the cylinder head.

When the thermostat is closed, coolant is directed through the bypass port, crankcase, front cover, and into the water pump.

When the thermostat is open, the bypass port is blocked, and coolant is directed from the engine into the radiator.

Coolant passes through the radiator and is cooled by moving air from the coolant fan. The coolant will return to the engine through the inlet elbow.

The air compressor is cooled with engine coolant supplied by a hose from the left side of the crankcase. Coolant passes through the air compressor cylinder head and returns through a hose back into the crankcase.

The oil system module assembly receives coolant from a passage in the crankcase. Coolant passes between the oil cooler plates and returns through a tube leading back to the water pump suction passage located in the front cover.

The exhaust side EGR cooler receives coolant from the water pump through a supply tube. Coolant passes between the EGR cooler plates, travels parallel to the exhaust flow, and exits into another coolant tube. Coolant is supplied to the intake side EGR cooler from this tube. Coolant passes between the EGR cooler plates, parallel to the exhaust flow, and exits into the coolant return tube which connects to the cylinder head water jacket. The deaeration port on the top of the intake side EGR cooler directs coolant and trapped air through the EGR valve and towards the coolant surge tank.

### Cooling System Components

#### Coolant Heater (optional)

An optional coolant heater is available to warm engine coolant in cold weather. The coolant heater warms the coolant surrounding the cylinders. Warmed engine coolant aids in performance and fuel economy during start-up. The coolant heater is located on the left side of the crankcase, in front of the Electronic Control Module (ECM).

### Thermostat Operation

The thermostat has two outlets. One directs coolant to the radiator when the engine is at operating temperature. The other directs coolant to the water pump until the engine reaches operating temperature. The thermostat begins to open at 88 °C (190 °F) and is fully open at 96 °C (205 °F).

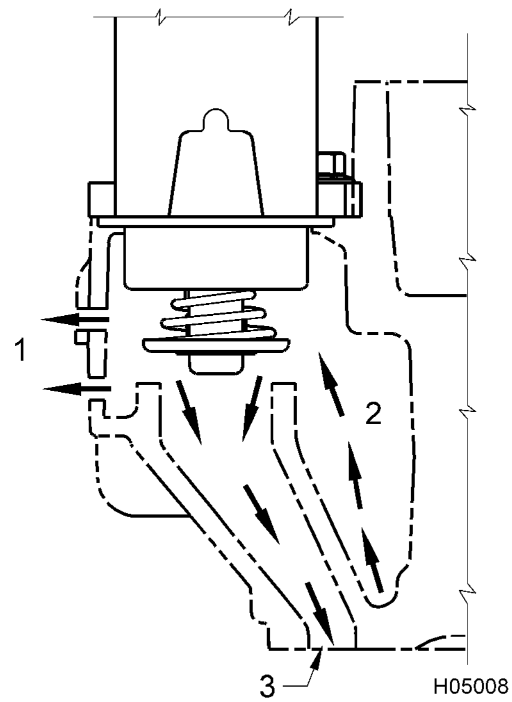


**Figure 29 Thermostat closed**

1. Coolant flow to heater port
2. Coolant in from engine
3. Bypass to water pump

When engine coolant is below the 88 °C (190 °F) the thermostat is closed, blocking flow to the radiator. Coolant is forced to flow through a bypass port back to the water pump.

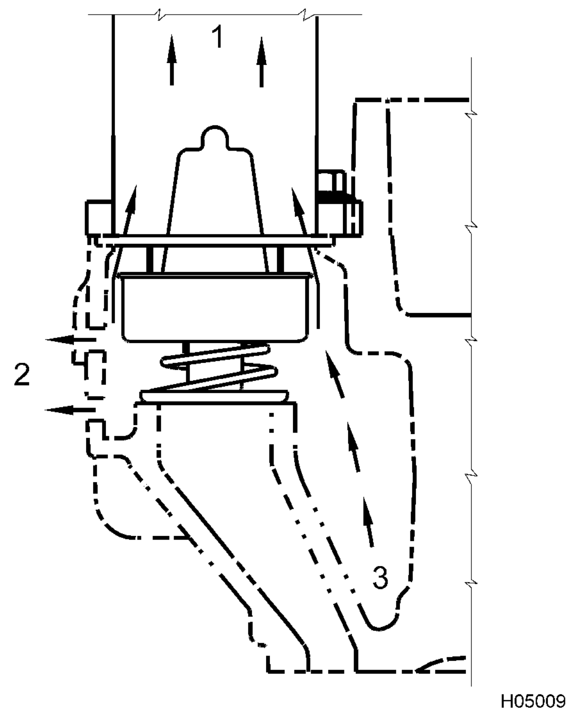


**Figure 30 Thermostat open**

1. Coolant out to radiator
2. Coolant flow to heater port
3. Coolant in from engine

When coolant temperature reaches the nominal opening temperature (88 °C [190 °F]) the thermostat opens allowing some coolant to flow to the radiator. When coolant temperature exceeds 96 °C (205 °F), the lower seat blocks the bypass port directing full coolant flow to the radiator.

# Electronic Control System

### Electronic Control System Components

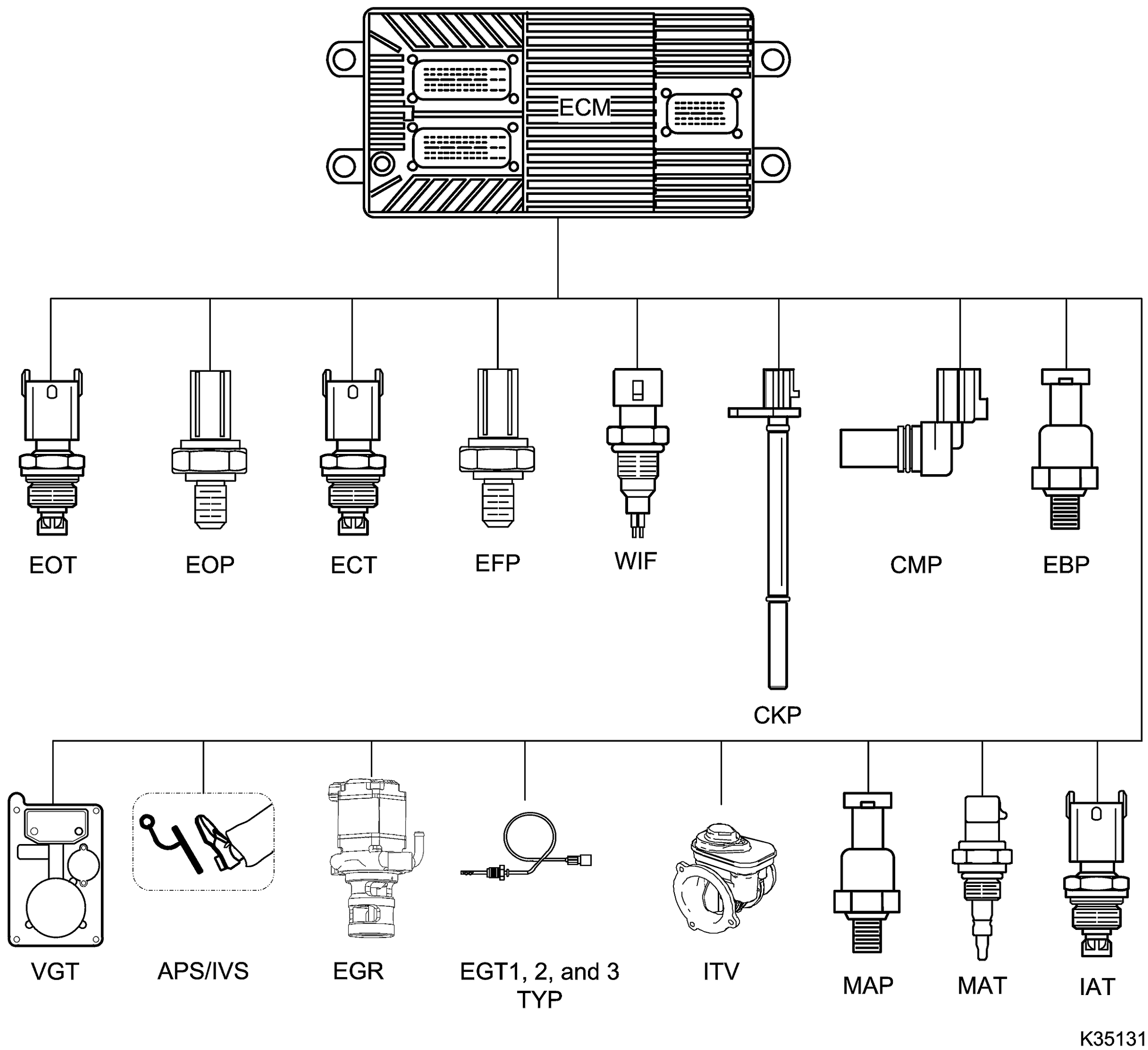


**Figure 31 Electronic Control System**

### Operation and Function

The Electronic Control Module (ECM) monitors and controls engine performance to ensure maximum performance and adherence to emissions standards. The ECM performs the following functions:

- Provide Reference Voltage (VREF)
- Condition input signals
- Process and stores control strategies
- Control actuators

### Reference Voltage (VREF)

The ECM supplies a 5 volt VREF signal to input sensors in the electronic control system. By comparing the 5 volt VREF signal sent to the sensors with their respective returned signals, the ECM determines pressures, positions, and other variables important to engine and vehicle functions.

The ECM supplies three independent circuits for VREF:

- VREF supplies 5 volts to engine sensors
- VREF supplies 5 volts to vehicle aftertreatment
- VREF supplies 5 volts to fuel injector control

### Signal Conditioner

The signal conditioner in the internal microprocessor converts analog signals to digital signals, squares up sine wave signals, or amplifies low intensity signals to a level that the ECM microprocessor can process.

### Microprocessor

The ECM microprocessor stores operating instructions (control strategies) and value tables (calibration parameters). The ECM compares stored instructions and values with conditioned input values to determine the correct strategy for all engine operations.

Continuous calculations in the ECM occur at two different levels or speeds: Foreground and Background.

- Foreground calculations are faster than background calculations and are normally more critical for engine operation. Engine speed control is an example.
- Background calculations are normally variables that change at slower rates. Engine temperature is an example.

Diagnostic Trouble Codes (DTCs) are set by the microprocessor, if inputs or conditions do not comply with expected values.

Diagnostic strategies are also programmed into the ECM. Some strategies monitor inputs continuously and command the necessary outputs for correct performance of the engine.

### Microprocessor Memory

The ECM microprocessor includes Read Only Memory (ROM) and Random Access Memory (RAM).

### ROM

ROM stores permanent information for calibration tables and operating strategies. Permanently stored information cannot be changed or lost by turning the ignition switch OFF or when ECM power is interrupted. ROM includes the following:

- Vehicle configuration, modes of operation, and options
- Engine Family Rating Code (EFRC)
- Engine warning and protection modes

**RAM**

RAM stores temporary information for current engine conditions. Temporary information in RAM is lost when the ignition switch is turned to OFF or when ECM power is interrupted. RAM information includes the following:

- Engine temperature
- Engine rpm
- Accelerator pedal position

### Actuator Control

The ECM controls the actuators by applying a low level signal (low side driver) or a high level signal (high side driver). When switched on, both drivers complete a ground or power circuit to an actuator.

Actuators are controlled in one of the following ways, depending upon type of actuator:

- Duty cycle (percent time on/off)
- Switched on or off
- CAN messages

### Actuators

The ECM controls engine operation with the following:

- Exhaust Gas Recirculation (EGR) valve
- Intake Air Heater (IAH) relay
- Intake throttle control and throttle position
- Turbo actuator

### EGR Valve

The EGR valve controls the flow of exhaust gases to the intake manifold.

The EGR valve receives the desired valve position from the ECM for exhaust gas recirculation. The EGR valve provides feedback to the ECM on the valve position.

The EGR valve constantly monitors the valve position and temperature. When an EGR control error is detected, the EGR valve sends a message to the ECM and a DTC is set.

### IAH Relays

The IAH system warms the incoming air supply prior to cranking to aid cold engine starting.

The ECM is programmed to energize the IAH elements through the IAH relays while monitoring certain programmed conditions for engine coolant temperature, engine oil temperature, and atmospheric pressure.

The ECM activates the IAH relay. The relay delivers VBAT to the heater elements for a set time, depending on engine coolant temperature and altitude. The ground circuit is supplied directly from the battery ground at all times.

### Intake Throttle Actuator and Position Sensor

The intake throttle valve controls the flow of inlet air to regulate operating temperature for exhaust aftertreatment.

The integral intake throttle actuator controls the intake throttle valve.

The intake throttle actuator receives the desired intake throttle valve position from the ECM to activate the throttle valve. The throttle position sensor provides feedback to the ECM on the throttle valve position.

## Engine and Vehicle Sensors

### Thermistor Sensors

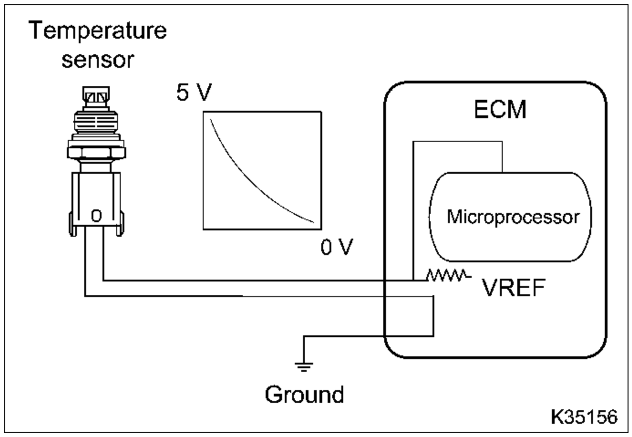


**Figure 32 Thermistor**

A thermistor sensor varies electrical resistance with changes in temperature. Resistance in the thermistor decreases as temperature increases, and increases as temperature decreases. Thermistors have a resistor that limits current in the ECM to a voltage signal matched with a temperature value.

The top half of the voltage divider is the current limiting resistor inside the ECM. A thermistor sensor has two electrical connectors, signal return and ground. The output of a thermistor sensor is a nonlinear analog signal.

Thermistor type sensors include the following:

- Aftertreatment temperature sensors
- Engine Coolant Temperature (ECT) sensor
- Engine Oil Temperature (EOT) sensor
- Inlet Air Temperature (IAT) sensor
- Manifold Air Temperature (MAT) sensor

**Aftertreatment Sensors**

Three Aftertreatment System sensors:

- Exhaust Gas Temperature (EGT) 1 sensor
- EGT 2 sensor
- EGT 3 sensor

The EGT 1 sensor provides a feedback signal to the ECM indicating Diesel Oxidation Catalyst (DOC) inlet temperature. The EGT 1 sensor is the first temperature sensor installed past the turbocharger and just before the DOC.

The EGT 2 sensor provides a feedback signal to the ECM indicating Diesel Particulate Filter (DPF) inlet temperature. The EGT 2 sensor is the second temperature sensor installed past the turbocharger and just after the DOC.

The EGT 3 sensor provides a feedback signal to the ECM indicating DPF outlet temperature. The EGT 3 sensor is the third temperature sensor installed past the turbocharger and just after the DPF.

During a catalyst regeneration, the ECM will monitor all three sensors along with the Exhaust Gas Recirculation (EGR) System and Intake Throttle Valve (ITV).

### ECT Sensor

The ECM monitors the ECT signal and uses this information for the instrument panel temperature gauge, coolant compensation, Engine Warning Protection System (EWPS), and IAH operation. The ECT is a backup, if the EOT is out-of-range. The ECT sensor is installed in the water supply housing (Freon® compressor bracket), to the right of the flat idler pulley assembly.

### EOT Sensor

The ECM monitors the EOT signal and uses this information to control fuel quantity and timing when operating the engine. The EOT signal allows the ECM to compensate for differences in oil viscosity for temperature changes. The EOT sensor is located in the rear of the front cover, to the left of the high-pressure pump assembly.

### IAT Sensor

The ECM monitors the IAT signal to control injector timing and fuel rate during cold starts. The ECM also uses the IAT signal to control EGR position and intake throttle control. The IAT sensor is installed in the air filter housing.

### MAT Sensor

The ECM monitors the MAT signal for EGR operation. The MAT sensor is located in the intake manifold, to the right of the MAP sensor.

### Variable Capacitance Sensors

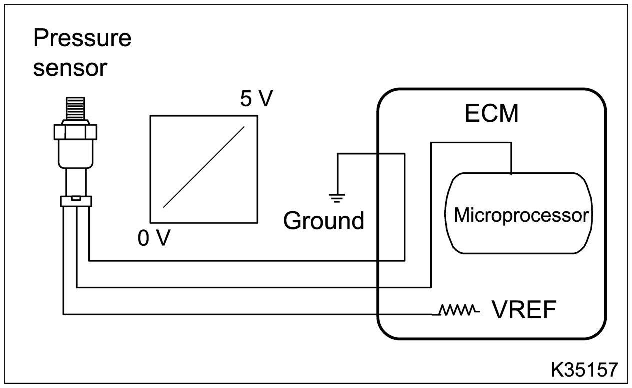


**Figure 33 Variable capacitance sensor**

Variable capacitance sensors measure pressure. The pressure measured is applied to a ceramic material. The pressure forces the ceramic material closer to a thin metal disk. This action changes the capacitance of the sensor.

The sensor is connected to the ECM by the VREF, signal, and signal ground wires.

The sensor receives the VREF and returns an analog signal voltage to the ECM. The ECM compares the voltage with pre-programmed values to determine pressure.

The operational range of a variable capacitance sensor is linked to the thickness of the ceramic disk. The thicker the ceramic disk the more pressure the sensor can measure.

Variable capacitance sensors include the following:

- Exhaust Gas Differential Pressure (EGDP) sensor
- Engine Fuel Pressure (EFP) sensor
- Engine Oil Pressure (EOP) sensor
- Exhaust Back Pressure (EBP) sensor
- Manifold Air Pressure (MAP) sensor

#### EGDP Sensor

The EGDP sensor provides a feedback signal to the ECM indicating the pressure difference between the inlet and outlet of the particulate filter. During a catalyst regeneration, the ECM will monitor this sensor along with three Aftertreatment System thermistor sensors, the EGR System, and the Intake Throttle Valve (ITV).

The EGDP sensor is a differential pressure sensor with two tap-offs installed past the turbocharger. A tap-off is located before and after the DPF.

#### EFP Sensor

The ECM uses the EFP sensor signal to monitor engine fuel pressure and give an indication when the fuel filter needs to be changed. The EFP sensor is installed in the fuel filter housing on the left side of the crankcase.

### EOP Sensor

The ECM monitors the EOP signal, and uses this information for the instrument panel pressure gauge and EWPS. The EOP sensor is installed in the left side of the crankcase, below the left side of the fuel filter housing.

### EBP Sensor

The ECM monitors the exhaust pressure so that the ECM can control the VGT, EGR, and intake throttle systems. The sensor provides feedback to the ECM for closed loop control of the Variable Geometry Turbocharger (VGT). The EBP sensor is installed in a bracket mounted on the water supply housing (Freon® compressor bracket).

### MAP Sensor

The ECM monitors the MAP signal to determine intake manifold pressure (boost). This information is used to control the turbocharger boost. The MAP sensor is installed in the intake manifold, left of the MAT sensor.

### Magnetic Pickup Sensors

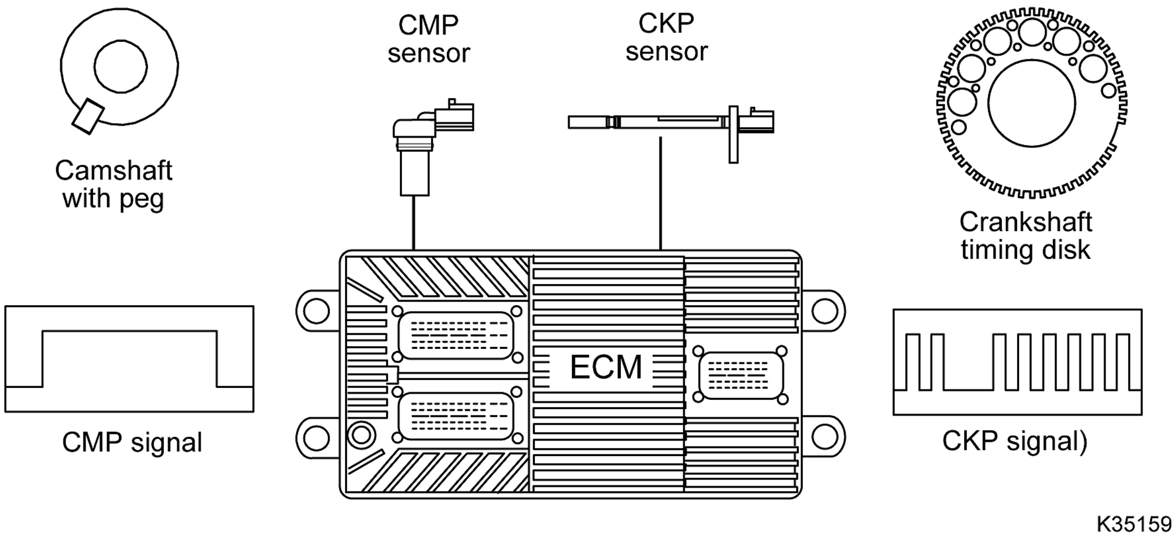


**Figure 34 Magnetic pickup sensors**

A magnetic pickup sensor contains a permanent magnet core that is surrounded by a coil of wire. The sensor generates a voltage signal through the collapse of a magnetic field that is created by a moving metal trigger. The movement of the trigger then creates an AC voltage in the sensor coil.

Magnetic pickup sensors used include the following:

- Crankshaft Position (CKP) sensor
- Camshaft Position (CMP) sensor
- Vehicle Speed Sensor (VSS)

### CKP Sensor

The CKP sensor provides the ECM with a signal that indicates crankshaft speed and position. As the crankshaft turns, the CKP sensor detects a 60 tooth timing disk on the crankshaft. Teeth 59 and 60 are missing. By comparing the CKP signal with the CMP signal, the ECM calculates engine rpm and timing requirements. The CKP sensor is installed in the top left side of the flywheel housing.

### CMP Sensor

The CMP sensor provides the ECM with a signal that indicates camshaft position. As the cam rotates, the sensor identifies the position of the cam by locating a peg on the cam. The CMP sensor is installed in the front cover, above and to the right of the water pump pulley.

### VSS

The VSS provides the ECM with transmission tail shaft speed by sensing the rotation of a 16 tooth gear on the rear of the transmission. The detected sine wave signal (AC), received by the ECM, is used with tire size and axle ratio to calculate vehicle speed. The VSS is on the left side of the transmission.

### Micro Strain Gauge (MSG) Sensors

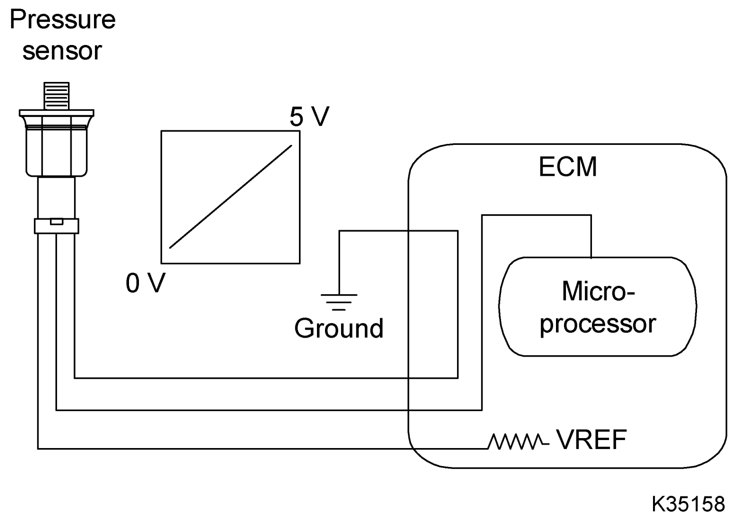


**Figure 35 MSG sensor**

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

The sensor is connected to the ECM by the VREF, signal, and signal ground wires.

The sensor is powered by VREF received from the ECM and is grounded through the ECM to a common sensor ground. The ECM compares the voltage with pre-programmed values to determine pressure.

Inline six engine micro strain gauge type sensors include the following:

- Brake Control Pressure (BCP)
- Injection Control Pressure (ICP)

**BCP**

The ECM monitors the BCP signal to determine the oil pressure in the brake gallery of the high-pressure oil manifold. The BCP sensor is under the valve cover, forward of the No. 2 fuel injector in the high-pressure oil manifold.

**ICP**

The ECM monitors the ICP signal to determine injection control pressure for engine operation. The ICP signal is used to control the IPR valve. The ICP sensor provides feedback to the ECM for Closed Loop IPR control. The ICP sensor is under the valve cover, forward of the No. 6 fuel injector in the high-pressure oil manifold.

**Potentiometer**

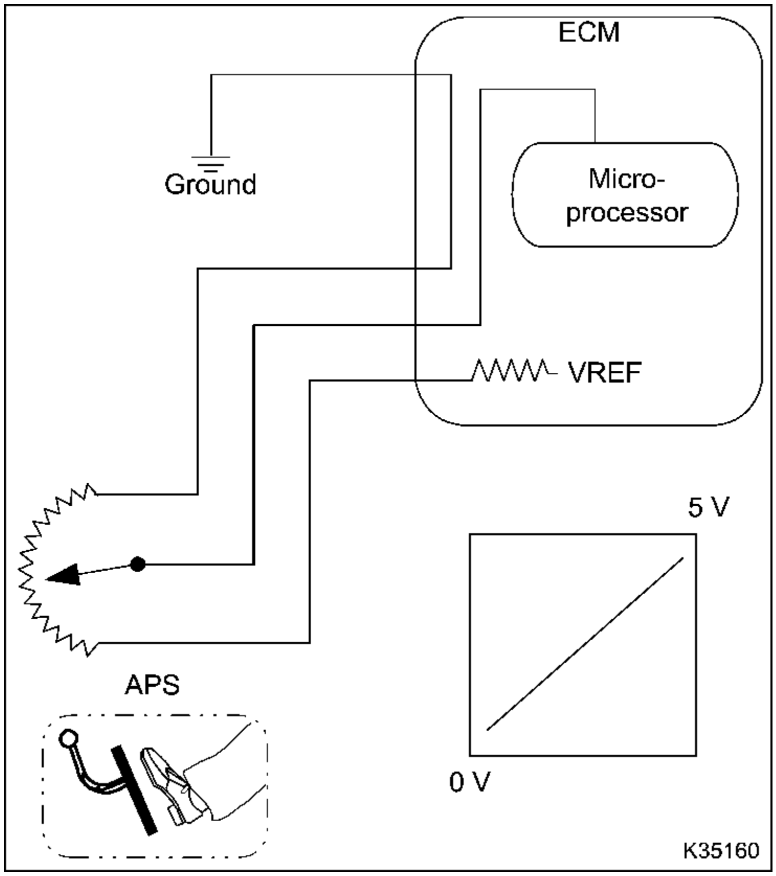


**Figure 36 Potentiometer**

A potentiometer is a variable voltage divider that senses the position of a mechanical component. A reference voltage is applied to one end of the potentiometer. Mechanical rotary or linear motion moves the wiper along the resistance material, changing voltage at each point along the resistive material. Voltage is proportional to the amount of mechanical movement.

The engine has one potentiometer, the Accelerator Position Sensor (APS).

**APS**

The APS provides the ECM with a feedback signal (linear analog voltage) that indicates the operator's demand for power. The APS is installed in the cab on the accelerator pedal.

**Switches**

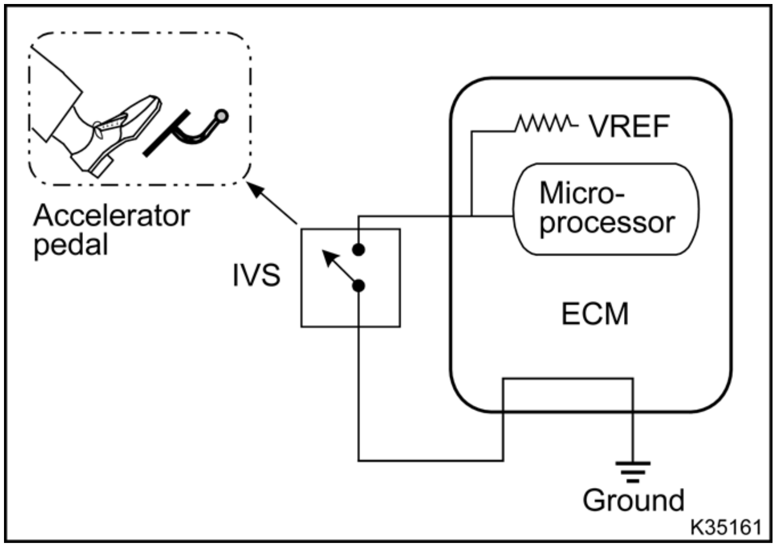


**Figure 37 Switch**

Switch sensors indicate position, level, or status. They operate open or closed, regulating the flow of current. A switch sensor can be a voltage input switch or a grounding switch. A voltage input switch supplies the ECM with a voltage when it is closed. A grounding switch grounds the circuit when closed, causing a zero voltage signal. Grounding switches are usually installed in series with a current limiting resistor.

Switches include the following:

- Driveline Disengagement Switch (DDS)
- Engine Coolant Level (ECL)
- Idle Validation Switch (IVS)
- Water In Fuel (WIF)

**DDS**

The DDS determines if a vehicle is in gear. For manual transmissions, the clutch switch serves as the DDS. For automatic transmissions, the neutral indicator switch or datalink communication functions as the DDS.

**ECL**

ECL is part of the Engine Warning Protection System (EWPS). The ECL switch is used in plastic deaeration tanks. When a magnetic switch is open, the tank is full.

If engine coolant is low, the switch closes and the red ENGINE lamp on the instrument panel is illuminated.

**IVS**

The IVS is a redundant switch that provides the ECM with a signal that verifies when the APS is in the idle position.

### WIF

A Water In Fuel (WIF) sensor in the element cavity of the fuel filter housing detects water. When enough water accumulates in the element cavity, the WIF sensor signal changes to the Electronic Control Module (ECM). The ECM sends a message to illuminate the amber water and fuel lamp, alerting the operator. The WIF is installed in the base of the fuel filter housing.

**Intake Throttle Valve**

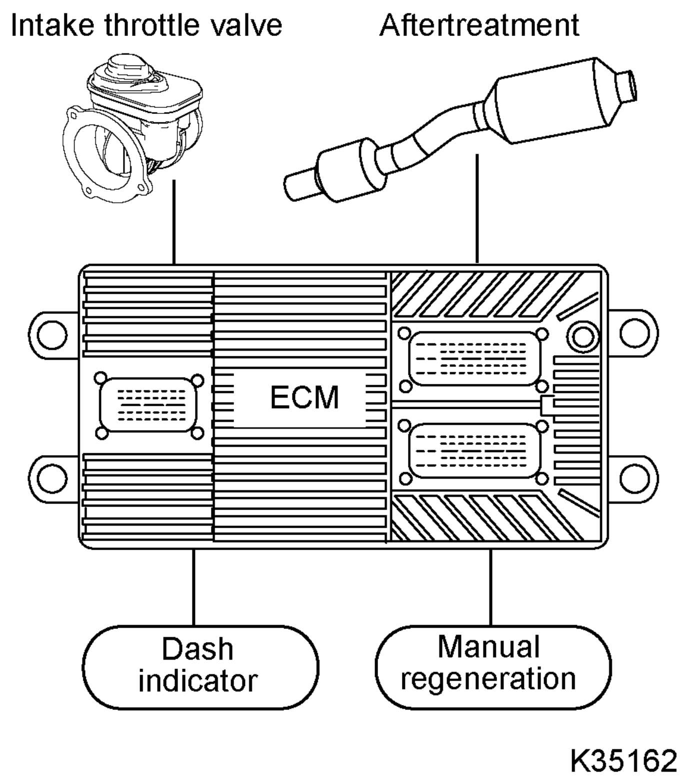


**Figure 38 Intake throttle control system**

The intake throttle valve is controlled to limit inlet air to the intake manifold. Reducing the air flow to the intake manifold increases fuel in the exhaust. The increased fuel in the exhaust is used for regeneration in the aftertreatment system.

The aftertreatment control system controls engine operating parameters to automate regeneration. It manages aftertreatment system temperatures, and monitors and controls the intake throttle valve to control the Air/Fuel ratio of the exhaust stream. It also maintains vehicle and engine performance during regenerations.

## Diamond Logic® Brake System

The Diamond Logic® brake system is available for all engine displacements.

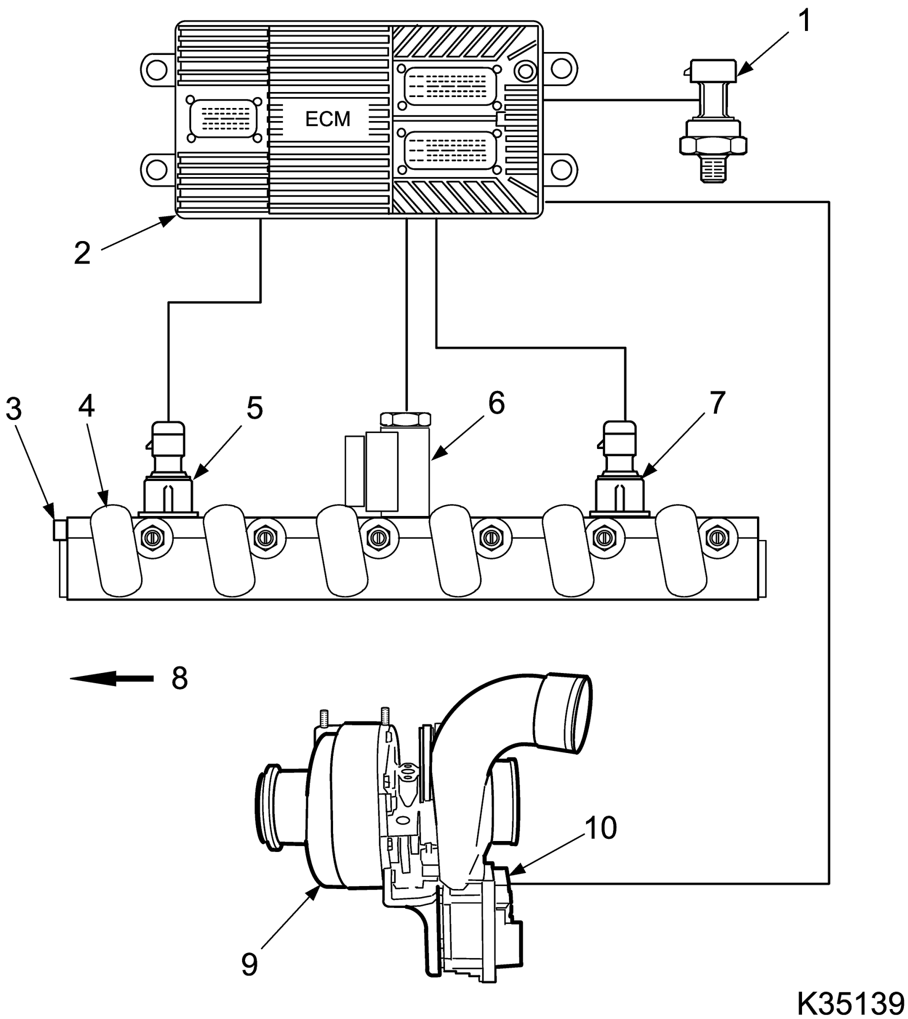


**Figure 39 Diamond Logic® brake system**

1. Exhaust Back Pressure (EBP) sensor
2. Electronic Control Module (ECM)
3. Brake pressure relief valve
4. High-pressure oil manifold
5. Brake Control Pressure (BCP) sensor
6. Brake Shut-off Valve (BSV) assembly
7. Injection Control Pressure (ICP) sensor
8. Front of engine
9. Variable Geometry Turbocharger (VGT)
10. VGT control module

### BCP

The BCP sensor provides a feedback signal to the ECM indicating brake control pressure. The ECM monitors the BCP signal during engine normal and braking operation to determine if the engine brake system is working without fault. The BCP sensor is installed in the high-pressure oil manifold, under the valve cover.

### BSV

The BSV controls pressure entering the brake oil gallery from the high-pressure oil manifold gallery. This activates the brake actuator pistons and opens the exhaust valves. The BSV is located in the center of the high-pressure oil manifold.

### Brake Pressure Relief Valve

The brake pressure relief valve vents excess pressure under the valve cover. The ECM deactivates the engine brake by shutting off power to the BSV. Residual brake gallery pressure initially bleeds from the actuator bore. When brake gallery pressure reaches a set point, the brake pressure relief valve opens and oil drains back to the sump.

### EBP

The EBP sensor measures exhaust back pressure. The ECM monitors the exhaust back pressure signal and commands the VGT and EGR systems to open or close to most restrictive position.

### High-Pressure Oil Manifold

The high-pressure oil manifold has two internal separated oil galleries. The manifold supplies high-pressure oil to each fuel injector during normal operation. High-pressure oil is directed to the brake pistons during engine brake operation.

### VGT

The ECM commands the VGT vanes to the closed (most restrictive) position during exhaust and engine brake operation. This exhaust restriction increases exhaust back pressure.

## Brake Operation Modes

The Diamond Logic® brake system offers three modes of operation based on terrain, driving conditions, or driver preference.

### Coast Mode

When the coast mode is selected the brake system will activate when the driver applies the vehicle service brake. The coast mode allows the vehicle to coast without automatic brake system activation.

### Latched Mode

When the latched mode is selected the brake system will activate when the driver releases the accelerator pedal. The brake system will deactivate when the drivers depresses the accelerator or clutch pedals. The brake system will also deactivate when the engine speed is below a set rpm.

### Cruise Mode

When the cruise mode is selected the brake system performs similar to latch mode under normal driving conditions. When cruise control is used the brake system will activate when the vehicle travels down a grade. The brake system helps the cruise control system maintain the set vehicle speed.

## Exhaust Brake System

The exhaust brake is an exhaust back pressure brake system that provides improved braking performance.

The operator can enable the brake function by toggling a dash mounted switch to ON or OFF.

The exhaust brake replaces the older style mechanical brake that was added into the exhaust system. No additional parts or wiring are required. The system uses the existing VGT and ECM programming to enable this feature.

**Operation**

The exhaust brake system retards vehicle speed during deceleration or braking. During operation, the ECM commands the VGT vanes to the most restrictive position and increases exhaust back pressure. The exhaust restriction absorbs vehicle momentum. When the brake is disabled the VGT vane position opens and engine operation returns to normal.

### Engine Brake System

The engine brake is a compression release brake system that provides enhanced braking performance. The exhaust brake is an integrated engine brake system component. However, the exhaust brake can not be used independently.

The operator can enable the brake function by toggling a dash mounted switch to ON or OFF and selecting a desired level. There are three brake level choices that accommodate terrain, driving conditions, or driver preference.

**Operation**

The engine brake system retards vehicle speed during deceleration or braking. During engine brake operation, high-pressure oil is used to force the exhaust valves partially open. An integrated high-pressure oil manifold and brake shut-off valve distribute high-pressure oil to each brake piston. These brake pistons hold the exhaust valves open.

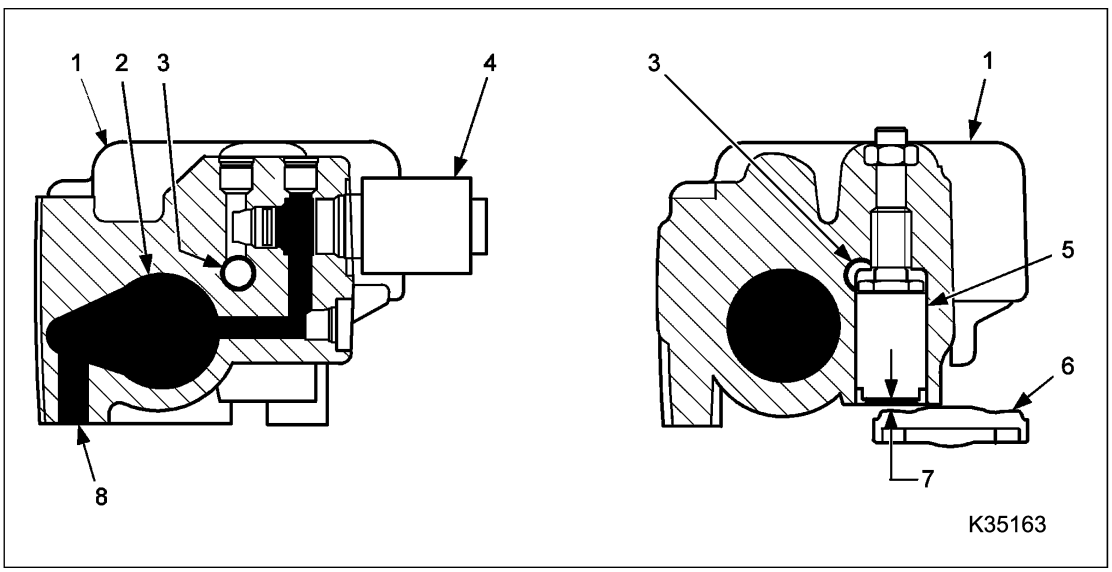


**Figure 40 Brake shut-off valve and brake actuator– OFF**

1. High-pressure oil manifold
2. Injector oil gallery
3. Brake oil gallery
4. Brake shut-off valve assembly
5. Brake actuator piston assembly
6. Exhaust valve bridge
7. Valve lash (actuator retracted)
8. Oil inlet

During normal engine operation, oil in the high-pressure manifold goes to the fuel injectors only. A brake shut-off valve, mounted in the high-pressure oil manifold, is closed to prevent oil from entering the brake gallery.

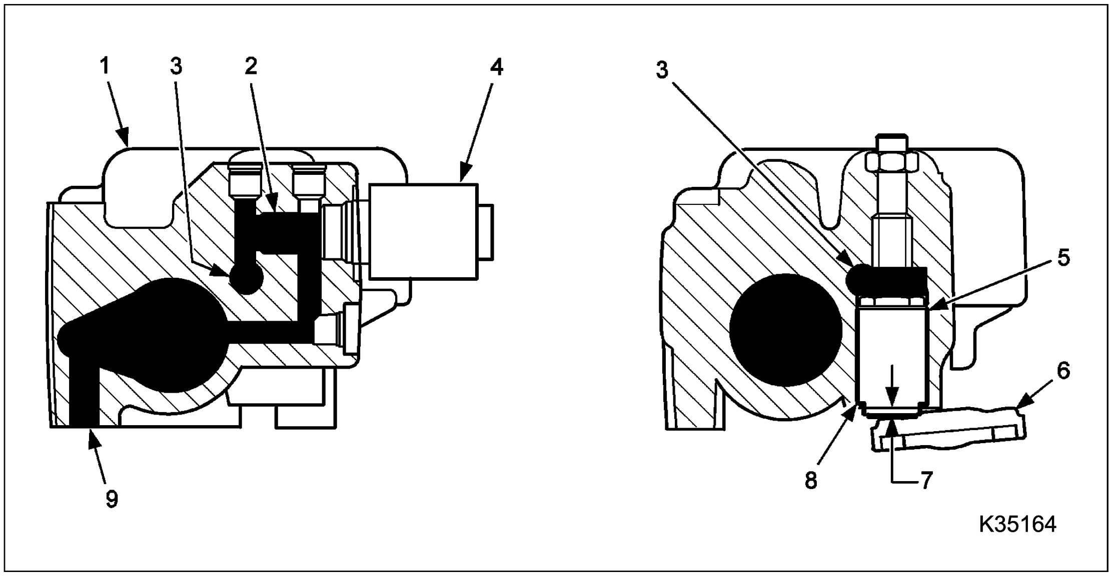


**Figure 41 Brake shut-off valve and brake actuator– ON**

1. High-pressure oil manifold
2. High-pressure oil flow to brake oil gallery
3. Brake oil gallery
4. Brake shut-off valve assembly
5. Brake actuator piston assembly
6. Exhaust valve bridge
7. Valve lash (actuator deployed)
8. Normal oil seepage
9. Oil inlet

The ECM monitors the following criteria to make sure certain conditions are met.

- ABS (inactive)
- RPM (greater than 1200)
- APS (less than 5%)
- Idle validation
- EOT (greater than or equal to 60 °C [140 °F])
- Operator input switches (On/Off) (power selection – Low, Med, High)

If On is selected, and the preceding criteria is met, the engine brake will activate.

When the engine brake is activated, the ECM provides the power to activate the brake shut-off valve to allow oil from the injector oil gallery to flow to the brake oil gallery. High oil pressure activates the brake actuator pistons to open the exhaust valves.

The VGT vanes also move to restrict exhaust air flow. The combination of the compression release and exhaust restriction absorbs vehicle momentum.

During an ABS event, the engine brake is deactivated. The engine brake is reactivated once the ABS event is over.

The ECM removes the power source from the brake shut-off valve to deactivate the engine brake. Residual brake gallery pressure initially bleeds from the actuator bore. When brake gallery pressure bleeds down to 6895 kPa (1000 psi), the brake pressure relief valve opens, and oil drains back to sump.

# Table of Contents

## Engine Preparation

**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, wear safety glasses with side shields. Limit compressed air pressure to 207 kPa (30 psi).**

**WARNING:**

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

**WARNING:**

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

**WARNING:**

**To prevent personal injury or death, inspect turbocharger with engine off, and turbocharger not spinning. Turbocharger components may be extremely hot. Turbocharger wheels are very sharp and spin at high speeds.**

**WARNING:**

**To prevent personal injury or death, support turbocharger assembly during removal and installation.**

**WARNING:**

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

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

**Clean Engine**

1. Disconnect the negative battery cable.
2. Cap all engine openings to prevent water and degreasing agents from entering engine.
3. Cover exposed electrical connectors and the ECM using plastic and duct tape.
4. Use an appropriate detergent mixed in the correct ratio and apply to engine using a hot pressure washer or similar cleaning equipment.

**Drain Coolant**

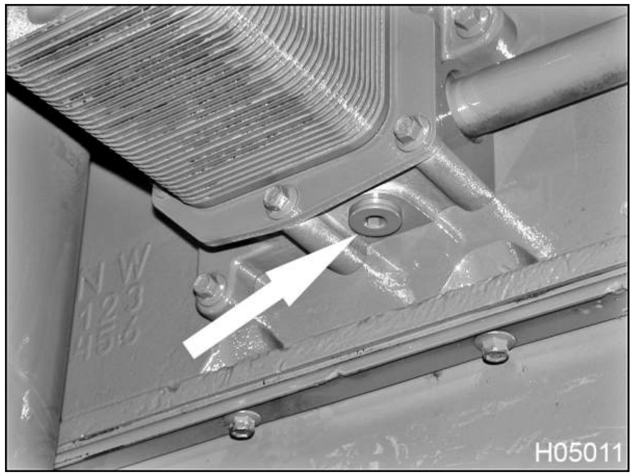


**Figure 42 Coolant drain plug**

1. Place a coolant drain pan under the oil system module.
2. Remove M18 coolant drain plug from the bottom of the oil system module. Open radiator cap to allow system to drain quicker.
3. Remove and discard coolant drain plug O-ring.
4. Install a new O-ring on the coolant drain plug.
5. After coolant has drained, install coolant drain plug in the oil system module.
6. Tighten coolant drain plug to special torque (page 90).
7. Recycle or dispose of coolant according to applicable regulations.

**Drain Oil**

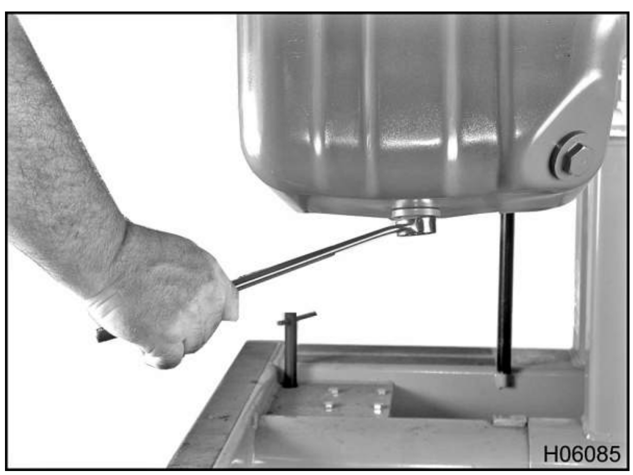


**Figure 43 Oil drain plug removal**

1. Place an oil drain pan beneath the oil drain plug.
2. Remove the M25 oil pan drain plug and discard O-ring.
3. Inspect drain plug and replace if necessary.
4. Install a new O-ring on the oil drain plug.
5. After oil has drained, install oil drain plug in the oil pan.
6. Tighten oil drain plug to special torque (page 90).
7. Recycle or dispose of oil according to applicable regulations.

## Removal

**Variable Geometry Turbocharger (VGT)**

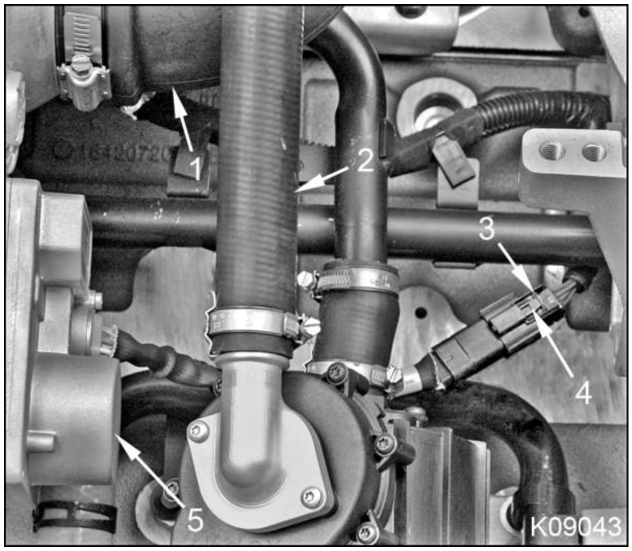


**Figure 44 VGT actuator connector and turbocharger air intake duct**

1. Turbocharger air intake duct
2. Breather tube
3. Lock tab (up to unlock)
4. Release tab (push to release)
5. VGT actuator

1. Loosen worm gear clamps on the turbocharger air intake duct and breather tube. Pull turbocharger air intake duct assembly off the VGT and crankcase breather.
2. Push lock tab up to unlock VGT actuator connector.
3. Press the release tab and pull sensor harness connector out of the VGT actuator connector.

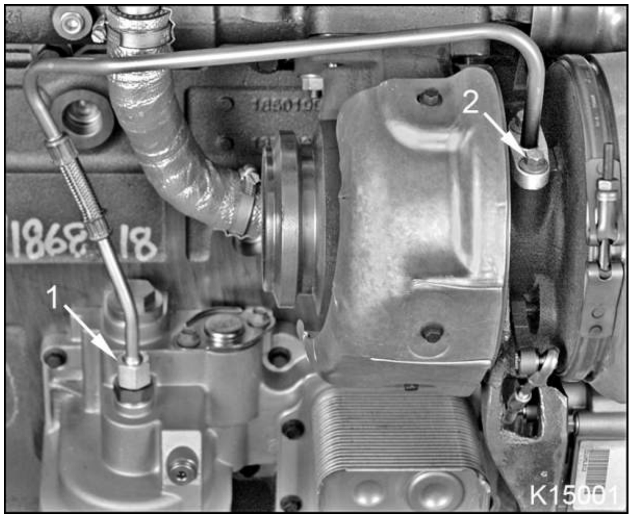


**Figure 45 Turbocharger oil supply tube assembly**

1. Turbocharger oil supply tube nut
2. M8 x 25 bolt (2)

4. Remove the turbocharger oil supply tube nut from the fitting on top of the oil filter header.
5. Remove two M8 x 25 bolts connecting the turbocharger oil supply tube assembly to the VGT oil supply port and remove the tube assembly.


**Figure 46 VGT oil drain tube, bracket, and bolt**

1. M8 x 16 bolt
2. Oil drain tube bracket
3. Oil drain tube

6. Remove M8 x 16 bolt from VGT oil drain tube bracket and remove bracket.
7. Pull oil drain tube out of crankcase.

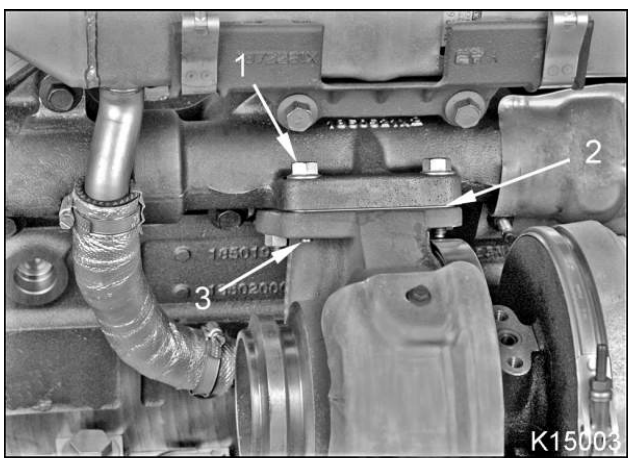


**Figure 47 VGT mounting**

1. M10 VGT mounting nut (4)
2. Turbocharger mounting gasket
3. VGT mounting stud

**NOTE:** To aid removal of the turbocharger, loosen four M10 nuts ¼ turn then tap each nut using a socket or flat punch and hammer. This will knock the “peaks” of the threads down, allowing the nuts to unthread easily.

**WARNING:**

**To prevent personal injury or death, support the turbocharger assembly during removal and installation.**

8. Remove three of four M10 mounting nuts holding the VGT assembly to the exhaust manifold.
9. Support the VGT assembly and remove the fourth M10 nut holding the VGT to the exhaust manifold.
10. Remove the VGT assembly and oil drain tube.
11. Cap openings on turbocharger assembly. If plastic caps are not available, use duct tape to cover openings.

### EGR Coolant Supply Tube

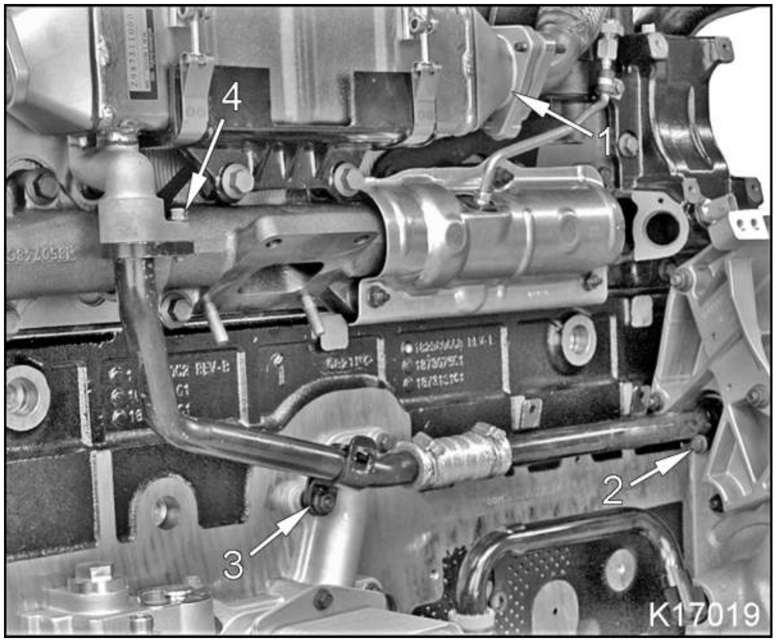


**Figure 48 EGR coolant supply tube**

1. Exhaust side EGR cooler assembly
2. M8 x 25 bolt (front cover EGR coolant supply port)
3. M8 nut, 2-piece tube support, and flat washer
4. M8 x 25 bolt

1. Remove M8 nut and 2-piece tube support.
2. Remove M8 x 25 bolt from front cover EGR coolant supply port.
3. Remove M8 x 25 bolt from the exhaust side EGR cooler.
4. Pull EGR coolant supply tube down and out of the exhaust side EGR cooler.
5. Pull EGR coolant supply tube back and out of the front cover.

### Oil Filter

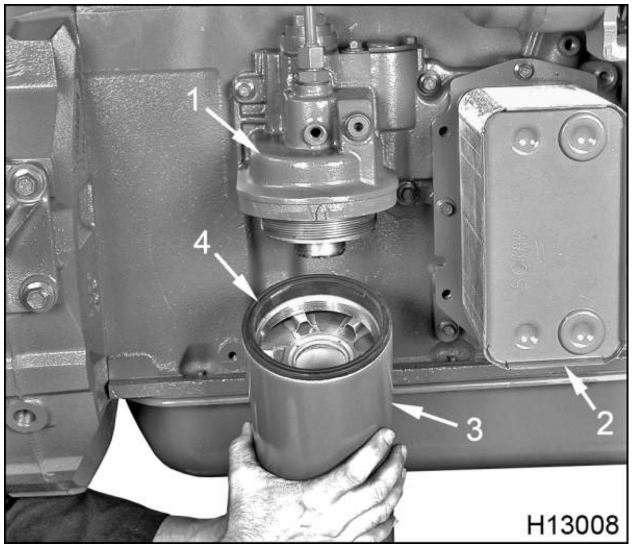


**Figure 49 Oil filter**

1. Oil filter header
2. Heat exchanger
3. Oil filter (spin-on)
4. Oil filter gasket

1. Place an oil drain pan under the oil filter.
2. Rotate oil filter counterclockwise with an oil filter wrench (page 90) and remove oil filter.
3. Remove oil filter gasket if stuck to the oil filter header.
4. Recycle or dispose of oil and filter according to applicable regulations.

**Oil System Module Assembly**


**Figure 50 Oil system module and coolant tube**

1. Turbocharger oil supply tube fitting
2. M8 x 30 stud bolt
3. M8 x 30 bolt (7)
4. M8 x 30 coolant tube bolt
5. M8 x 20 stud bolt

1. Place a drain pan under the oil system module.
2. Remove seven M8 x 30 bolts and one M8 x 30 stud bolt holding the oil system module to the crankcase. Remove oil system module from the crankcase.
3. Remove M8 x 30 coolant tube bolt and M8 x 20 stud bolt.
4. Pull coolant tube out of front cover.
5. Recycle or dispose of oil and coolant according to applicable regulations.

## Mounting Engine Stand Bracket and Engine

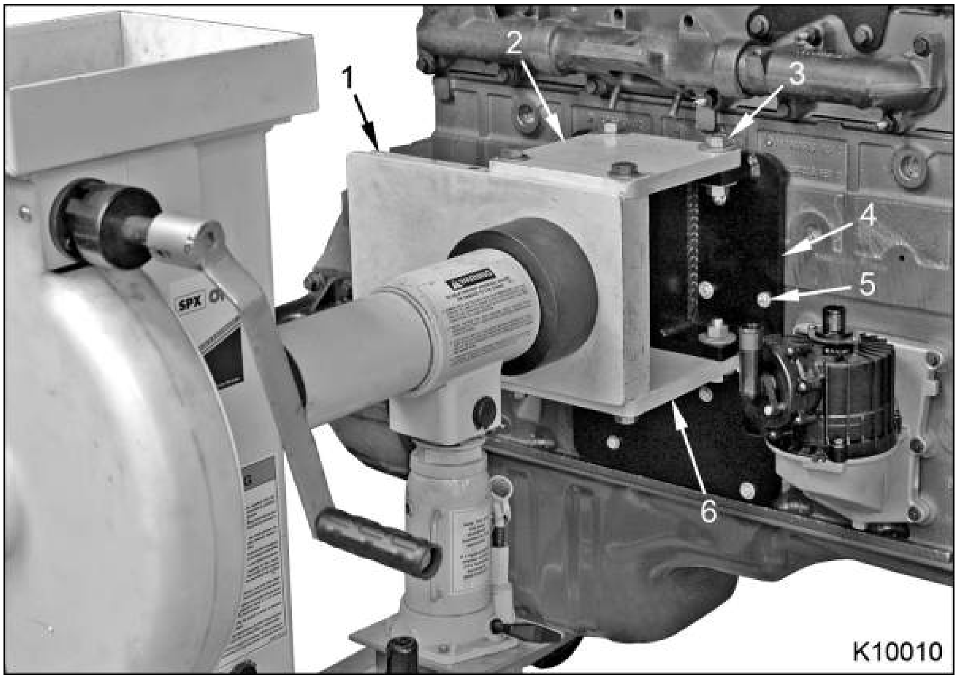


**Figure 51 Engine Stand and Engine Stand Bracket**

1. Engine Stand
2. Square plate (top)
3. M16 bolt (8)
4. Engine Stand Bracket
5. Class 10.9 M8 bolt (9)
6. Square plate (bottom)

**WARNING:**

**To prevent personal injury or death, use a minimum three ton rated chain hoist, equipped with safety hooks to lift the engine from factory installed lifting eyes.**

**WARNING:**

**To prevent personal injury or death, use metric Class 10.9 or SAE grade 8 bolts when mounting the Engine Mounting Bracket to the engine and Engine Stand. See instructions included with Engine Stand and Engine Mounting Bracket.**

1. Remove engine from vehicle. Lift engine from factory installed lifting eyes using a minimum three ton rated chain hoist equipped with safety hooks.
2. Install the bottom square plate on the Engine Stand (page 90) and tighten two grade 8 M16 bolts to standard torque (page 683).
3. Match Engine Stand Bracket (page 90) holes with bolt holes in the exhaust side of the crankcase and install nine Class 10.9 M8 bolts.
4. Tighten nine M8 bolts to standard torque.
5. Raise or lower the engine to the approximate height of the Engine Stand (page 90).

6. Install two grade 8 M16 bolts through the bottom square plate and Engine Stand Bracket. Install two M16 nuts on bolts and finger tighten.
7. Install the top square plate on the Engine Stand and loosely install two grade 8 M16 bolts.
8. Install two grade 8 M16 bolts thought the top square plate and Engine Stand Bracket. Install two M16 nuts on bolts and finger tighten.
9. Tighten eight M16 bolts to standard torque.
10. Slowly release tension from engine hoist.
11. Remove hoist safety chain hooks from engine lifting eyes.

## Special Torque

| | |
|---|---|
| Coolant drain plug, M18 | 24 N·m (18 lbf·ft) |
| Oil pan drain plug, M25 | 68 N·m (50 lbf·ft) |

## Special Service Tools

| | |
|---|---|
| Engine Stand Bracket | ZTSE4649 |
| Engine Stand | OTC1750A |
| Oil filter wrench | Obtain locally |

# Table of Contents

# Illustrations

### Electronic Components – Top

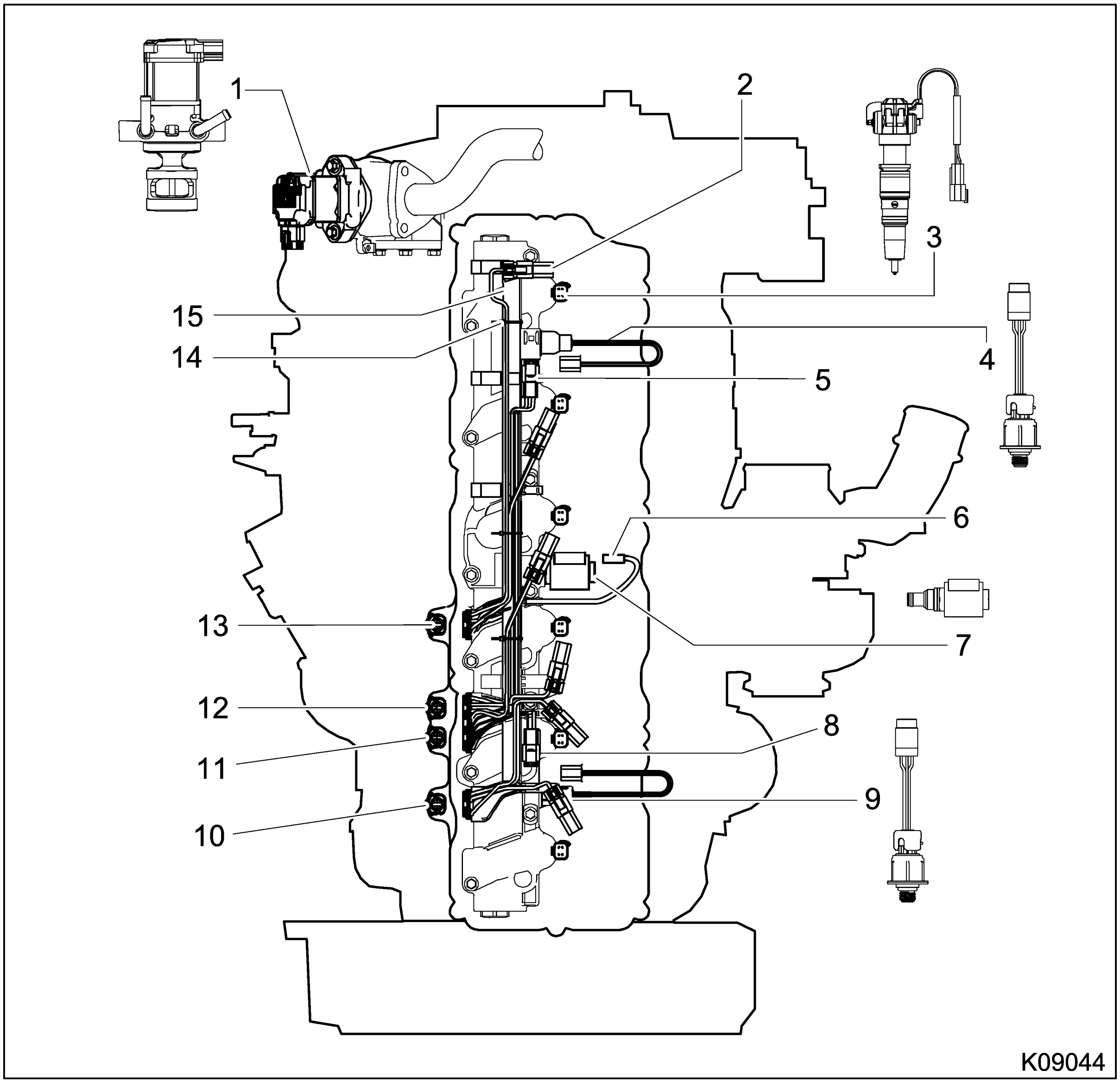


**Figure 52 Electronic components – top**

1. Exhaust Gas Recirculation (EGR) valve
2. Injector connector (6)
3. Injector assembly (6)
4. Brake Control Pressure (BCP) sensor (optional)
5. Brake Control Pressure (BCP) connector (optional)
6. Brake shut-off valve connector (optional)
7. Brake shut-off valve (optional)
8. Injection Control Pressure (ICP) sensor connector
9. Injection Control Pressure (ICP) sensor
10. Under Valve Cover (UVC) electrical terminal, injectors 5, 6
11. UVC electrical terminal, ICP, BCP
12. UVC electrical terminal, injectors 3, 4
13. UVC electrical terminal, injectors 1, 2
14. Wire tie (3)
15. Harness channel

### Electronic Components – Front

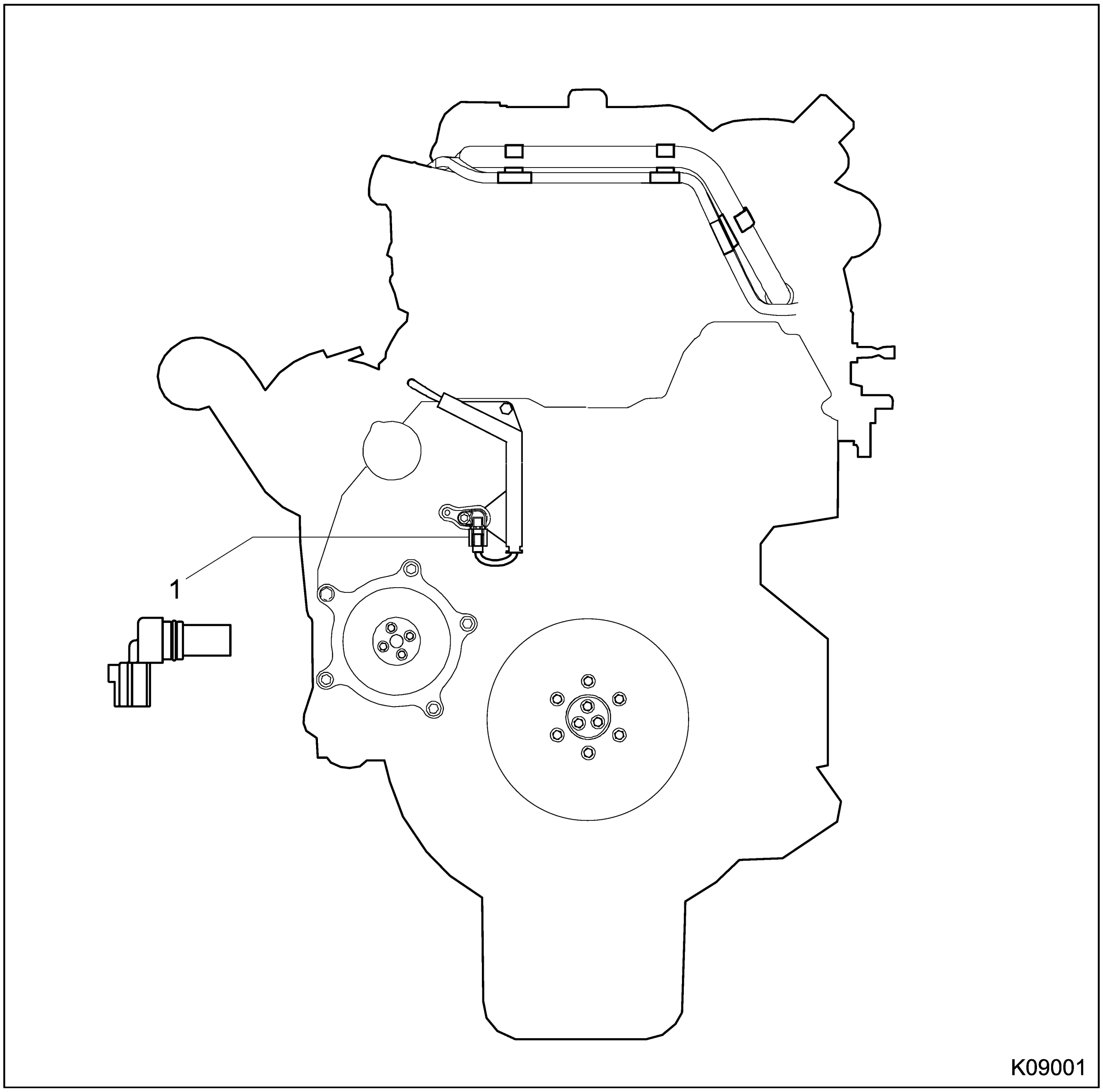


**Figure 53 Electronic components – front**

1. Camshaft Position (CMP) sensor

### Electronic Components – Intake Side

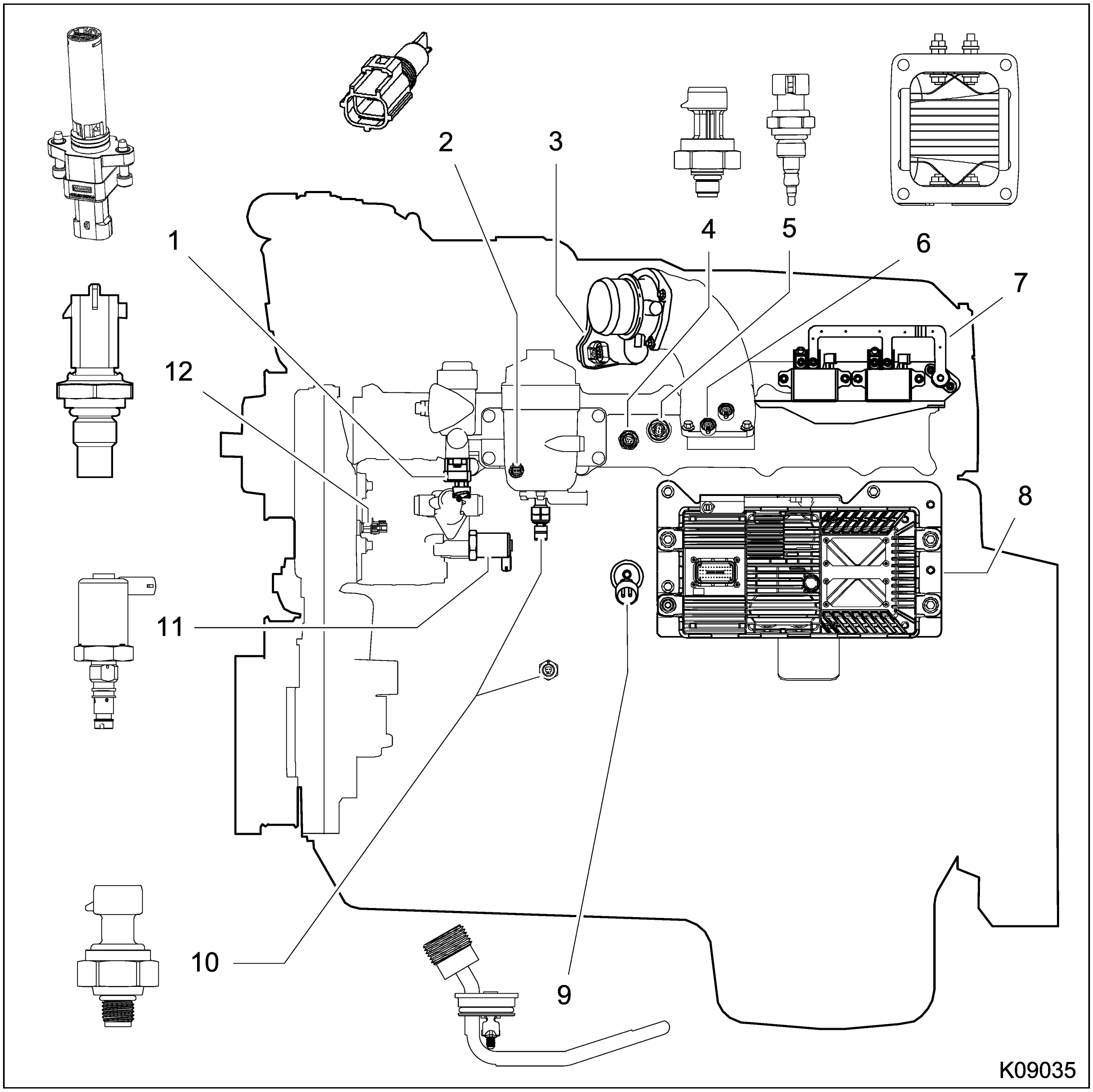


**Figure 54 Electronic components – intake side**

1. Fuel heater (optional)
2. Water In Fuel (WIF) sensor
3. Intake throttle assembly
4. Manifold Absolute Pressure (MAP) sensor
5. Manifold Air Temperature (MAT) sensor
6. Intake air heater grid
7. Intake Air Heater (IAH) relay assembly
8. Electronic Control Module (ECM)
9. Coolant heater
10. Engine Oil Pressure (EOP) and Engine Fuel Pressure (EFP) sensors
11. Injection Pressure Regulator (IPR) valve
12. Engine Oil Temperature (EOT) sensor

### Electronic Components – Exhaust Side

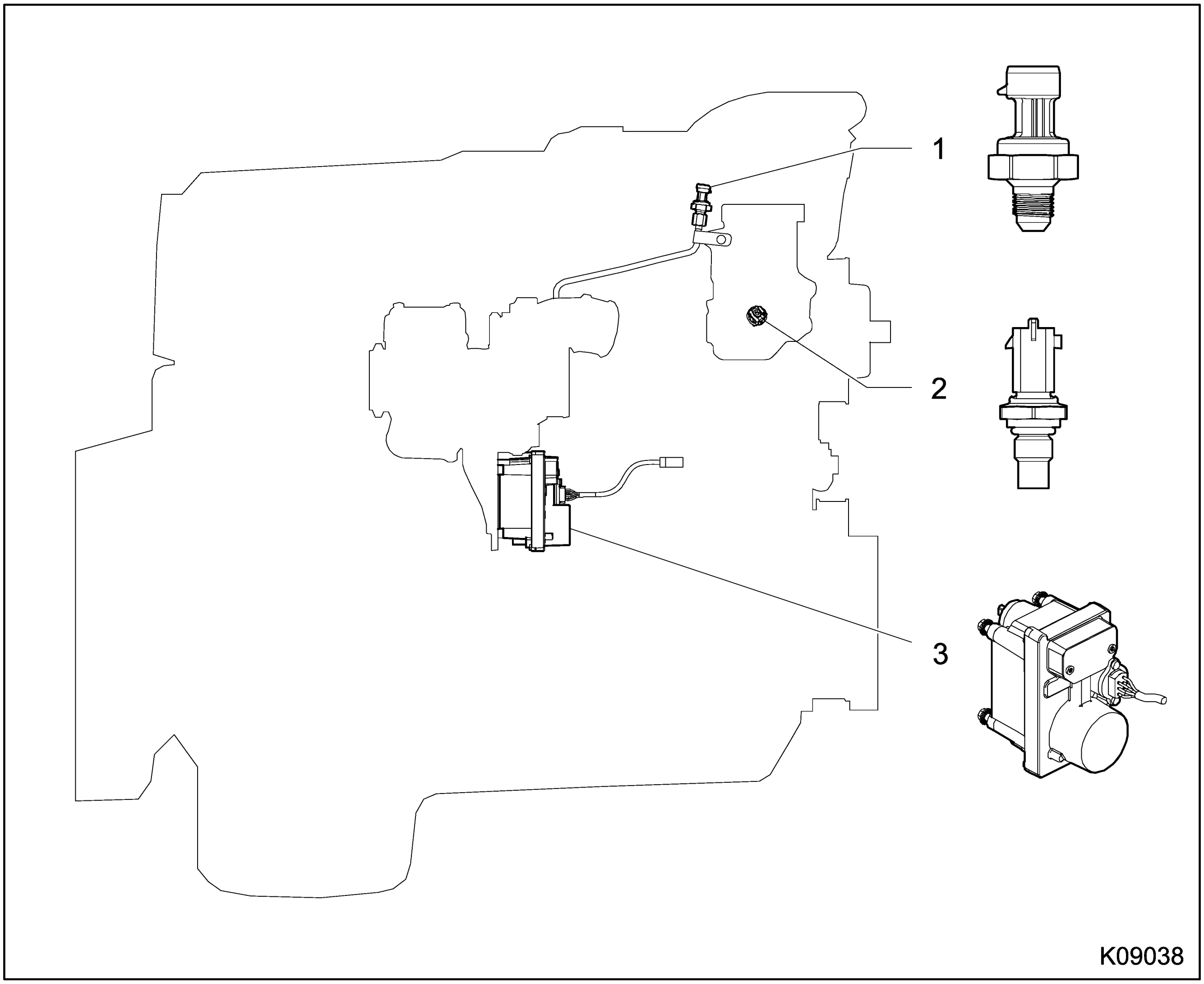


**Figure 55 Electronic components – exhaust side**

1. Exhaust Back Pressure (EBP) sensor
2. Engine Coolant Temperature (ECT) sensor
3. Variable Geometry Turbocharger (VGT) actuator

**Electronic Components – Rear**

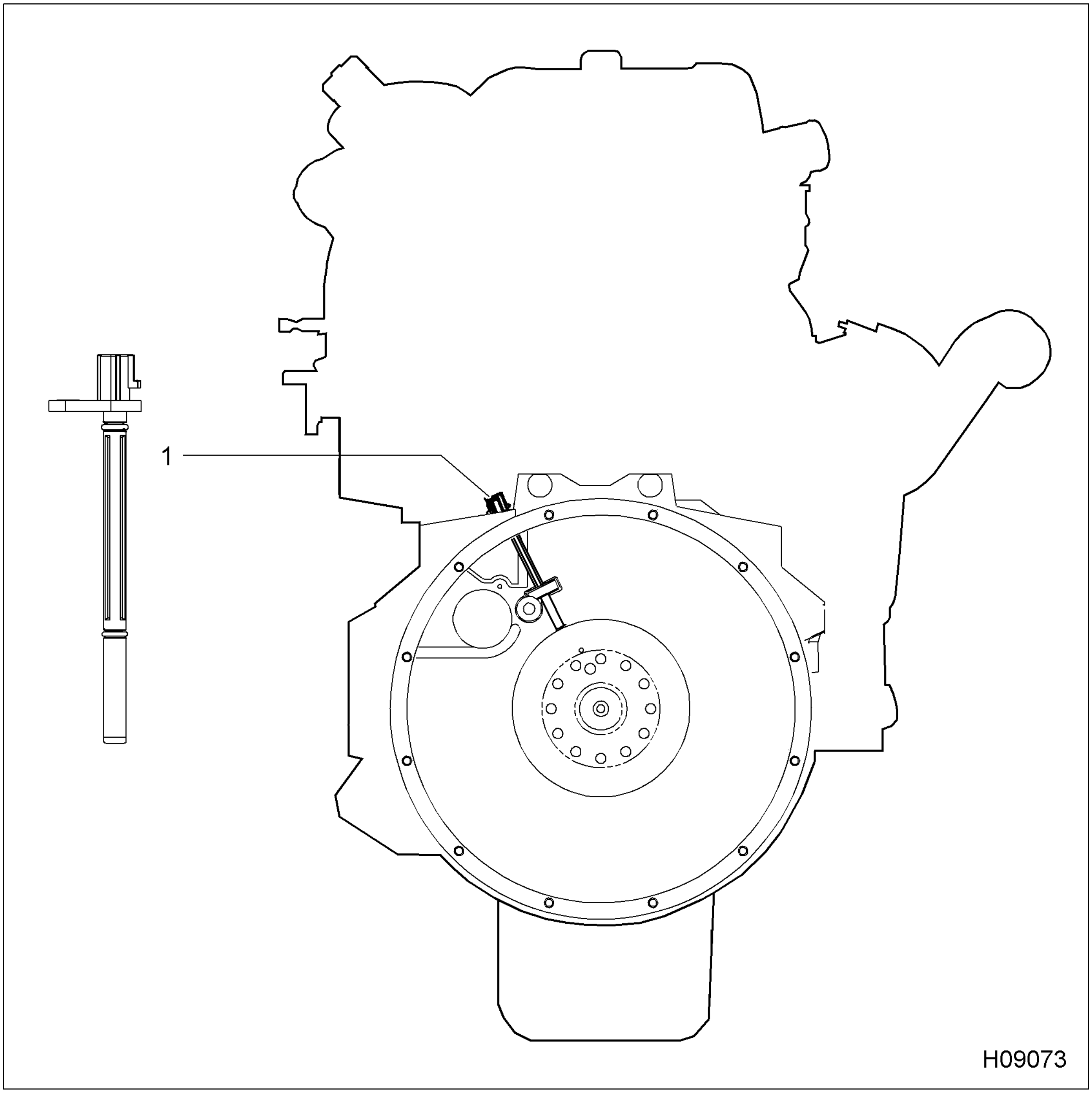


**Figure 56 Electronic components – rear**

1. Crankshaft Position (CKP) sensor

# Description of Engine Sensors, Valves, and Actuators

See Electronic Control System (page 50) for additional details.

**NOTE:** For information on diagnostics and troubleshooting, see the following publications:

- EGES-370-1 MaxxForce® DT, 9, and 10 *Engine Diagnostic Manual*
- EGED-375 MaxxForce® DT, 9, and 10 Hard Start/No Start Diagnostic Form
- EGED-380 MaxxForce® DT, 9, and 10 Engine Performance Diagnostic Form
- EGED-385 MaxxForce® DT, 9, and 10 Electronic Control System Diagnostic Form

**Crankshaft Position (CKP) Sensor**


**Figure 57 CKP sensor**

The CKP sensor, a magnetic pickup sensor, indicates crankshaft speed and position.

The CKP sensor sends a pulsed signal to the ECM as the crankshaft turns. The CKP sensor reacts to a 60 tooth timing disk rotating on the crankshaft. For crankshaft position reference, teeth 59 and 60 are missing. By comparing the CKP signal with the CMP signal, the ECM calculates engine rpm and timing requirements.

The CKP is installed in the top left of the flywheel housing.

**NOTE:** The long CKP sensor, used with International® MaxxForce® DT, 9, and 10 diesel engines, is the Camshaft Position (CMP) sensor used with other Navistar diesel engines.

**Camshaft Position (CMP) Sensor**

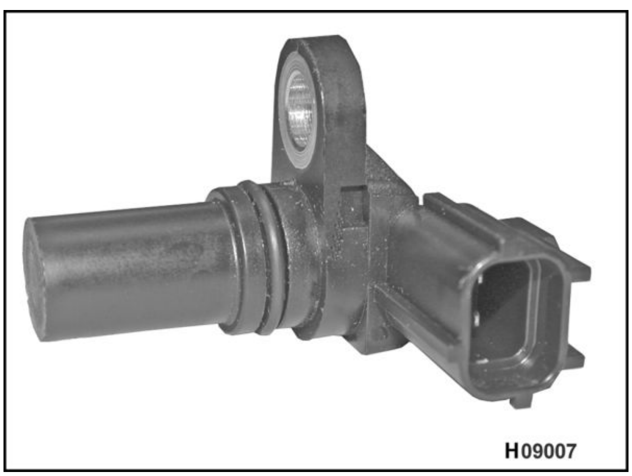


**Figure 58 CMP sensor**

The CMP sensor, a magnetic pickup sensor, indicates camshaft speed and position.

The CMP sensor sends a pulsed signal to the ECM when a single peg on the camshaft rotates past the CMP sensor once during each revolution of the camshaft. The ECM calculates camshaft speed and position from CMP signal frequency.

The CMP sensor is installed in the front cover, to the right of the water pump pulley.

**NOTE:** The short CMP sensor, used with International® MaxxForce® DT, 9, and 10 diesel engines, is the Crankshaft Position (CKP) sensor used with other Navistar diesel engines.

**Exhaust Back Pressure (EBP) Sensor**

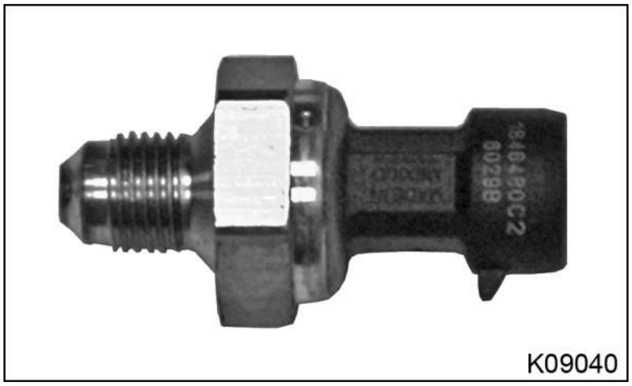


**Figure 59 EBP sensor**

The EBP sensor, a variable capacitance sensor, measures exhaust back pressure before the turbocharger.

The EBP sensor provides feedback to the ECM for closed loop control of the VGT and for EGR rate calculations.

The EBP sensor is installed in a tube plumbed to the exhaust manifold.

**Engine Coolant Temperature (ECT) Sensor**

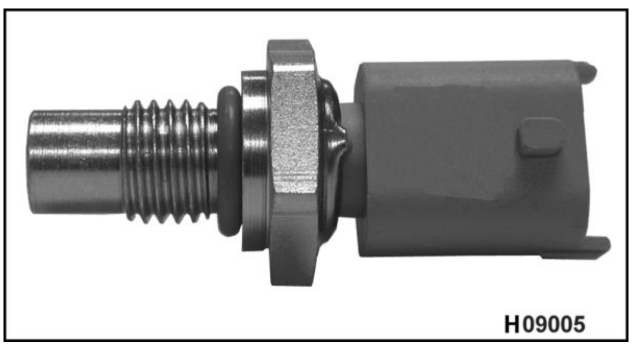


**Figure 60 ECT sensor**

The ECT sensor, a thermistor sensor, detects engine coolant temperature.

The ECT signal is monitored by the ECM for operation of the instrument panel temperature gauge, coolant temperature compensation, optional Engine Warning Protection System (EWPS), and the wait to start lamp. The ECM will use ECT sensor input as a backup, if EOT sensor values are out of range.

The ECT sensor is installed in the water supply housing (Freon® compressor bracket).

**Engine Oil Temperature (EOT) Sensor**

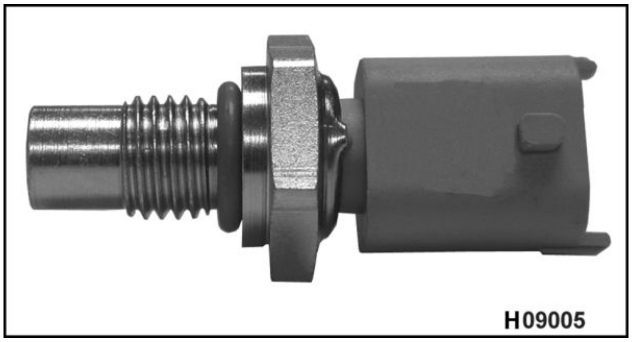


**Figure 61 EOT sensor**

The EOT sensor, a thermistor sensor, detects engine oil temperature.

The EOT signal is monitored by the ECM for EGR valve, VGT, and for engine fueling calculations. The EOT signal allows the ECM to compensate for differences in oil viscosity, due to temperature changes.

The EOT sensor is installed in the rear of the front cover, on the intake side of the engine.

**Engine Oil Pressure (EOP) Sensor**

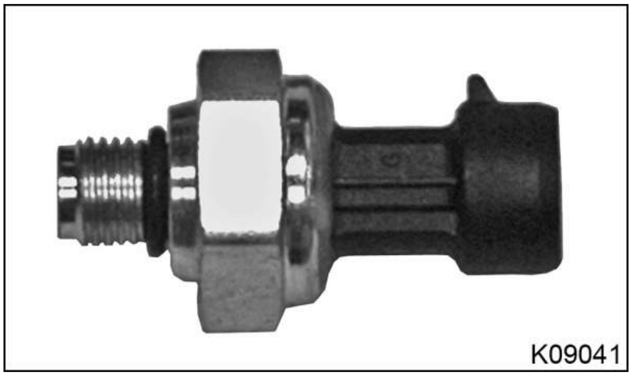


**Figure 62 EOP sensor**

The EOP sensor, a variable capacitance sensor, detects engine oil pressure.

The EOP signal is monitored by the ECM for operation of the instrument panel pressure gauge and optional EWPS.

The EOP sensor is installed in the intake side of the crankcase below the fuel filter header.

**Engine Fuel Pressure (EFP) Sensor**

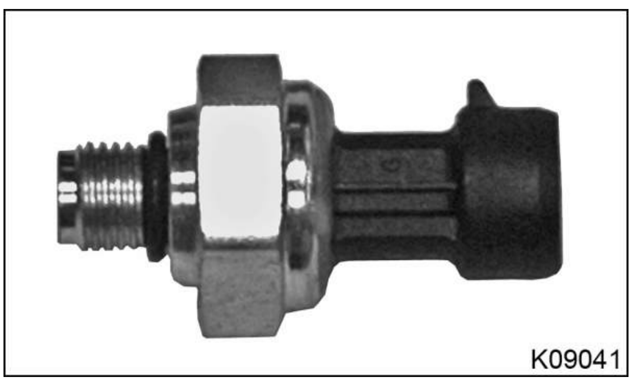


**Figure 63 EFP sensor**

The EFP sensor, a variable capacitance sensor, measures fuel supply pressure.

The EFP sensor provides feedback to the ECM which indicates when the fuel filter needs to be changed.

The EFP sensor is installed in the bottom of the fuel filter header on the intake side of the engine.

**NOTE:** EOP and EFP sensors are identical and share the same part number.

**Water In Fuel (WIF) Sensor**

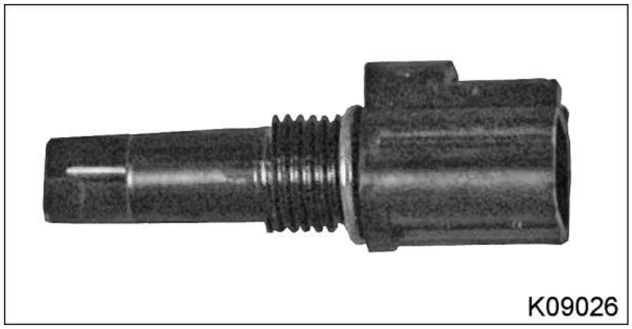


**Figure 64 WIF sensor**

The WIF sensor, a switch sensor, detects water in the fuel filter header.

The WIF sensor signal is monitored by the ECM for operation of the amber water in fuel lamp.

The WIF sensor is installed in the side of the fuel filter header on the intake side of the engine.

**250 Watt Fuel Heater**

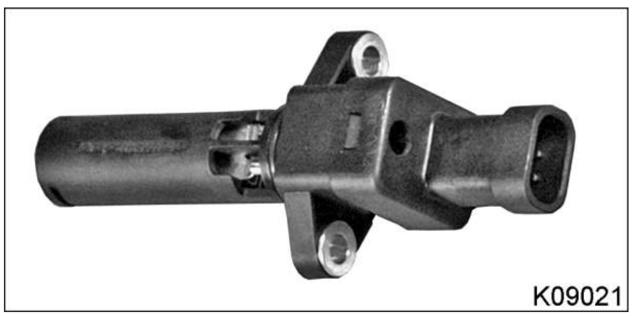


**Figure 65 Fuel heater (optional)**

The fuel heater heats incoming fuel to prevent fuel “waxing” during cold temperatures.

The fuel heater is thermostatically controlled and turns on at approximately 7 °C (44.6 °F) and turns off at approximately 21 °C (69.8 °F).

The fuel heater is installed in the bottom front of the fuel filter header on the intake side of the engine.

**Manifold Absolute Temperature (MAT) Sensor**

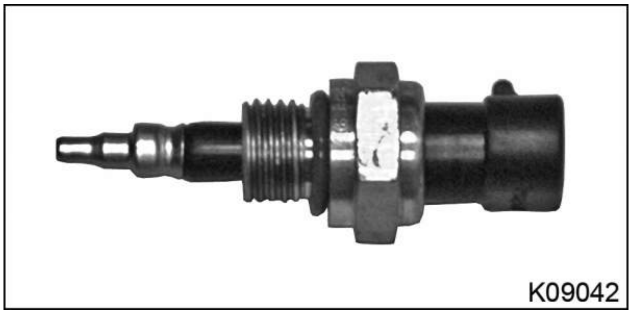


**Figure 66 MAT sensor**

The MAT sensor, a thermistor sensor, detects intake manifold air temperature.

The MAT signal is monitored by the ECM for EGR operation.

The MAT sensor is installed in the intake manifold, to the right of the MAP sensor.

**Manifold Absolute Pressure (MAP) Sensor**

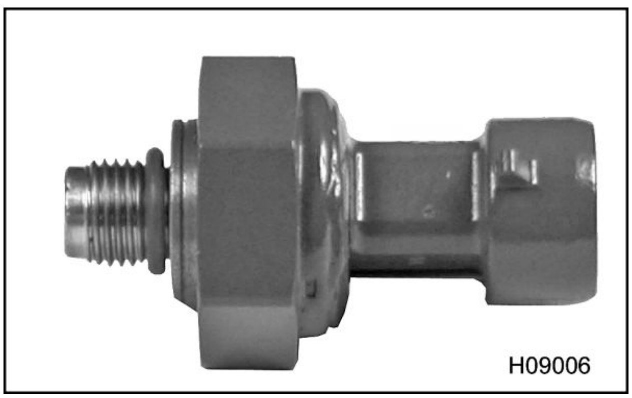


**Figure 67 MAP sensor**

The MAP sensor, a variable capacitance sensor, detects intake manifold boost pressure.

The MAP signal is monitored by the ECM for EGR valve, VGT, and engine fueling calculations.

The MAP sensor is installed in the intake manifold left of the MAT sensor.

**Intake Throttle Assembly**

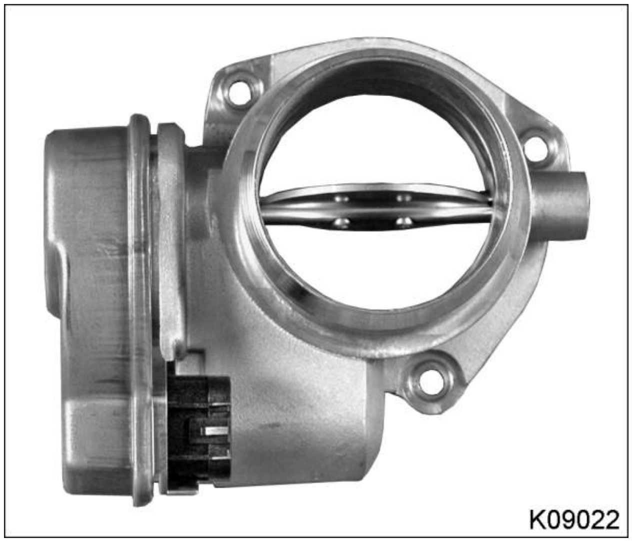


**Figure 68 Intake throttle assembly**

The intake throttle assembly, a variable position actuator, restricts intake air flow to help heat the exhaust during aftertreatment regeneration. The intake throttle also restricts air flow for key-on engine shut down.

The intake throttle assembly changes valve position in response to Pulse Width Modulated (PWM) signals from the ECM.

The intake throttle assembly is mounted on the EGR and inlet air mixer duct on the intake side of the engine.

**Injection Pressure Regulator (IPR) Valve**

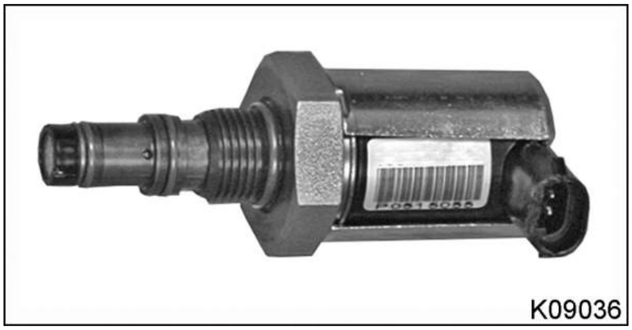


**Figure 69 IPR valve**

The IPR valve, a variable position Pulse Width Modulated (PWM) valve, regulates injection control pressure.

The IPR valve is controlled by a ground circuit in the ECM in response to ICP sensor input. Voltage is supplied through the ignition switch. The IPR valve includes a high-pressure relief valve which releases excessive injection control pressure.

The IPR valve is installed in the rear of the high-pressure oil pump on the intake side of the engine.

**Injection Control Pressure (ICP) Sensor**

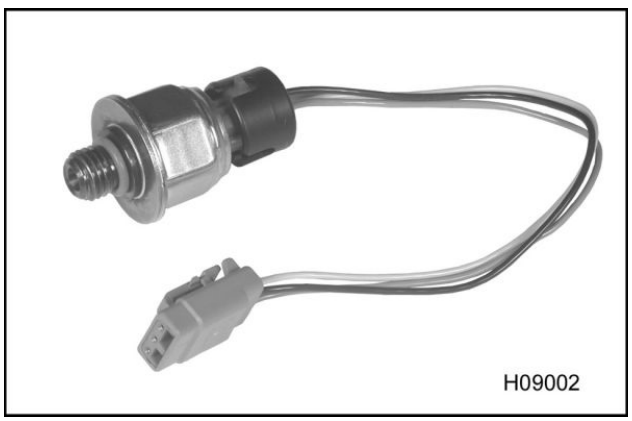


**Figure 70 ICP sensor**

The ICP sensor, a micro-strain gauge sensor, measures injection control pressure.

The ICP signal is monitored by the ECM for closed loop control of the IPR valve and engine fueling calculations.

The ICP sensor is installed in the high-pressure oil manifold, to the rear of cylinder 5 fuel injector.

**Brake Control Pressure (BCP) Sensor**

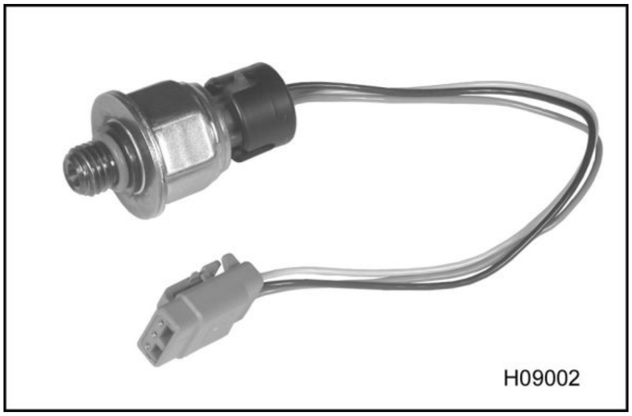


**Figure 71 BCP sensor**

The BCP sensor, a micro-strain gauge sensor, measures brake gallery pressure.

The BCP signal is monitored by the ECM for engine brake-on brake-off fault detection.

The BCP sensor is installed in the high-pressure oil manifold, forward of cylinder 2 fuel injector.

**NOTE:** ICP and BCP sensors are identical and share the same part number.

See Diamond Logic® Brake System (page 70) for BSV description.

**Exhaust Gas Recirculation (EGR) Valve**

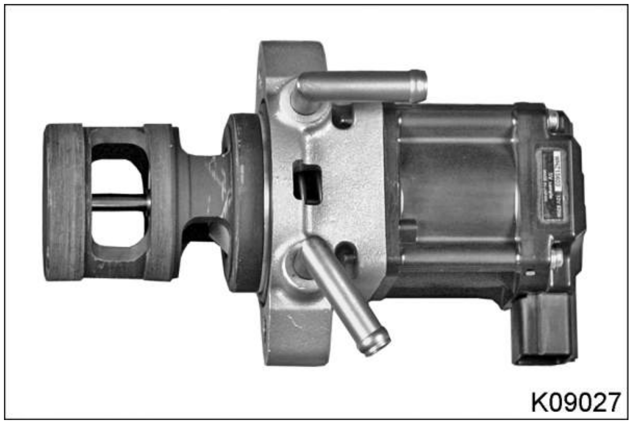


**Figure 72 EGR Valve**

The EGR valve, a variable position electromechanical valve, recirculates cooled exhaust gases into the intake air stream to reduce NOx emissions by reducing combustion temperatures.

The EGR valve changes valve position in response to private Controller Area Network (CAN) digital signals from the ECM.

The EGR valve has three major components: a dual poppet valve assembly, a DC motor, and an Integrated Circuit (IC). The IC has three Hall effect position sensors that monitor valve movement.

The EGR valve is installed in the EGR manifold on the top front of the engine.

**Variable Geometry Turbocharger (VGT) Actuator**

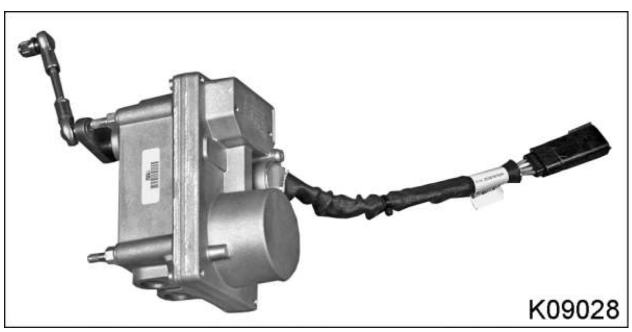


**Figure 73 VGT actuator**

The VGT actuator, a variable position actuator, controls turbocharger vane position.

The VGT actuator is controlled by private CAN digital signals from the ECM in response to engine speed, required fuel quantity, boost, exhaust back pressure, and altitude. The VGT actuator controls movement of vanes linked by a unison ring in the turbine housing. Turbine exhaust gas flow and VGT boost are modified by vane position.

The VGT actuator is installed on the bottom of the VGT mounting bracket on the exhaust side of the engine.

## Removal

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

**CAUTION:**

**To prevent engine damage, do not tug on wiring harnesses; if resistance is felt, find the problem and free connectors or clips.**

**WARNING:**

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

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

### Camshaft Position (CMP) Sensor

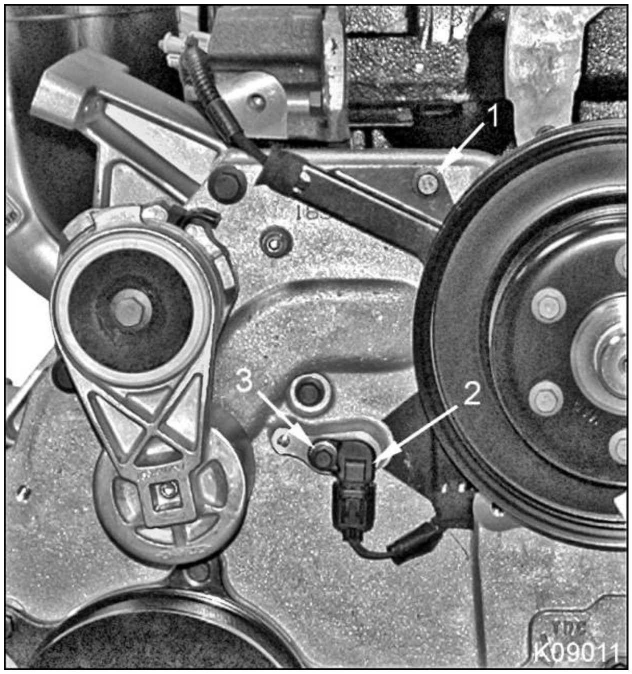


**Figure 74 CMP sensor**

1. M8 x 16 bolt
2. CMP sensor
3. M6 x 16 sensor retaining bolt

1. Disconnect 2-pin sensor harness connector from CMP sensor installed in the front cover.
2. Remove M6 x 16 sensor retaining bolt.
3. Pull out and remove CMP sensor.
4. Discard sensor O-ring.

### Engine Coolant Temperature (ECT) Sensor


**Figure 75 ECT sensor**

1. Place a coolant drain pan under the engine.
2. Pull lock tab up to unlock connector.
3. Press the release tab and disconnect 2-pin sensor harness connector from the ECT sensor, installed in the water supply housing (Freon® compressor bracket).
4. Remove ECT sensor.
5. Discard sensor O-ring.
6. Recycle or dispose of coolant according to applicable regulations.

### VGT Actuator Connector

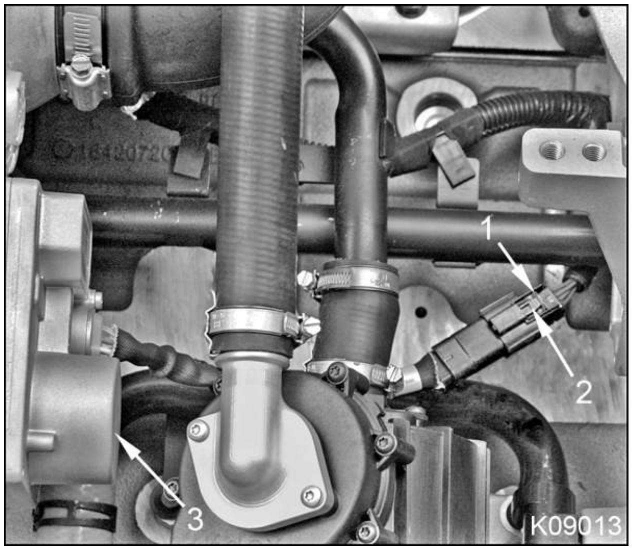


**Figure 76 VGT actuator connector**

1. Lock tab (up to unlock)
2. Release tab
3. VGT actuator

1. Push lock tab up to unlock VGT actuator connector.
2. Press the release tab and pull sensor harness connector out of VGT actuator connector.

### Exhaust Back Pressure (EBP) Sensor

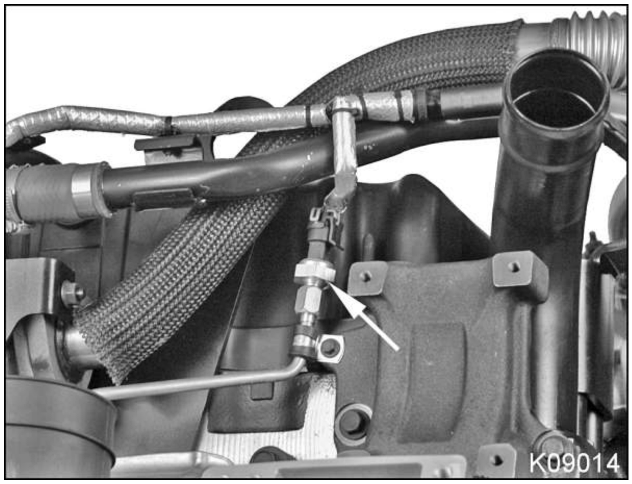


**Figure 77 EBP sensor**

1. Disconnect 3-pin sensor harness connector from the EBP sensor, installed in a tube mounted on the water supply housing (Freon® compressor bracket).
2. Remove EBP sensor.

### Water In Fuel (WIF) Sensor, Engine Fuel Pressure (EFP) Sensor, and Fuel Heater Connectors

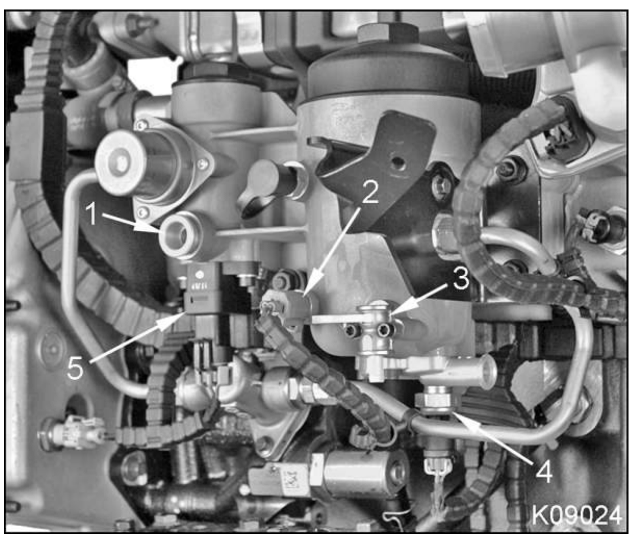


**Figure 78 Fuel filter header assembly**

1. Fuel inlet (from tank)
2. WIF sensor
3. Water drain valve
4. EFP sensor
5. Fuel heater (optional)

1. Disconnect sensor harness connector from fuel heater.
2. Disconnect sensor harness connector from the WIF sensor.
3. Disconnect 3-pin sensor harness connector from the EFP sensor.
4. See Water In Fuel (WIF) sensor, Engine Fuel Pressure (EFP) Sensor, and Fuel Heater removal (page 232) for fuel system sensor and heater removal.

### Exhaust Gas Recirculation (EGR) Valve Connector

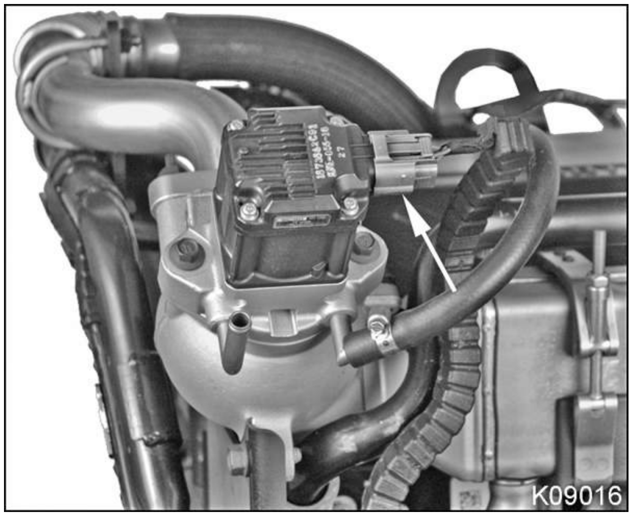


**Figure 79 EGR valve**

1. Disconnect sensor harness connector from the EGR valve, installed in the EGR valve manifold on the top left of the engine.
2. See EGR Valve Manifold Assembly (page 181) for removal.

### Engine Oil Pressure (EOP) Sensor

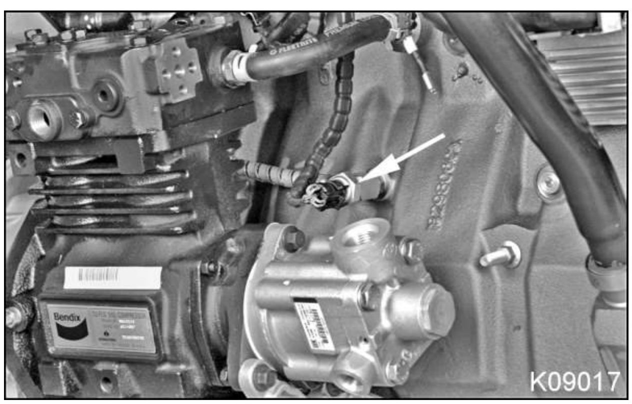


**Figure 80 EOP sensor**

1. Disconnect 3-pin sensor harness connector from the EOP sensor, installed in the intake side of the crankcase.
2. Remove EOP sensor.
3. Discard EOP sensor O-ring.

**Engine Oil Temperature (EOT) Sensor**

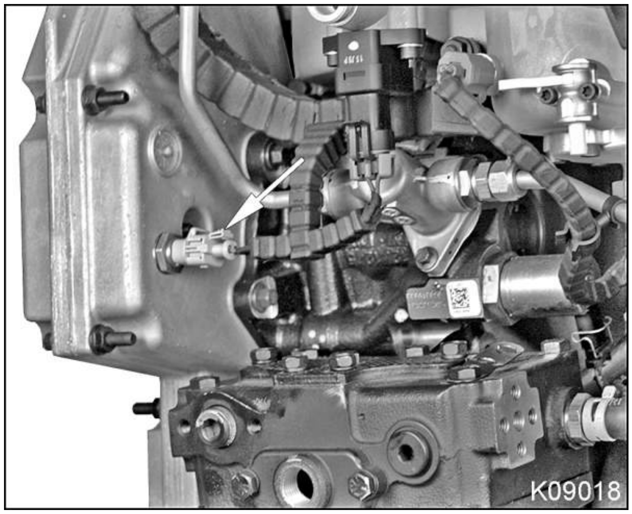


**Figure 81 EOT sensor**

1. Pull lock tab out to unlock connector.
2. Press the release tab and disconnect 2-pin sensor harness connector from the EOT sensor, installed in the rear of the front cover assembly on the intake side of the engine.
3. Remove EOT sensor.
4. Discard EOT sensor O-ring.

**Manifold Absolute Pressure (MAP) and Manifold Air Temperature (MAT) Sensors**

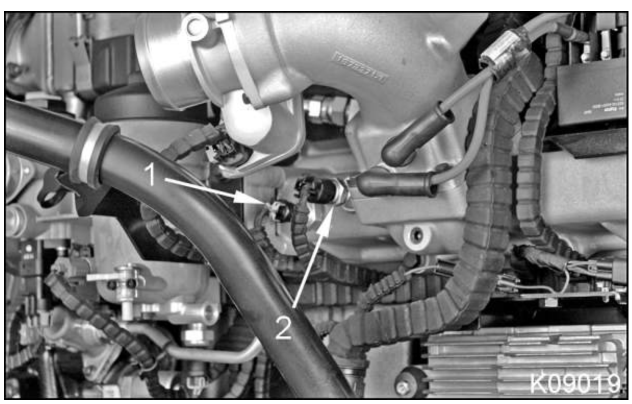


**Figure 82 MAP and MAT sensors**

1. MAP sensor
2. MAT sensor

1. Pull up MAT sensor locking tab.

2. Push release tab and disconnect 3-pin sensor harness connector from MAP sensor and 2-pin sensor harness connector from MAT sensor. Both sensors are installed in the intake manifold.
3. Remove MAP and MAT sensors.
4. Discard MAP and MAT sensor O-rings.

### Intake Throttle Assembly Connector


**Figure 83 Intake throttle assembly**

1. Intake throttle assembly
2. Locking tab
3. Sensor harness connector

1. Pull up locking tab.
2. Push release tab and disconnect sensor harness connector from the intake throttle assembly, installed on the intake side of the engine.
3. See Intake Throttle Assembly (page 207) for removal.

### Injection Pressure Regulator (IPR) Valve Connector

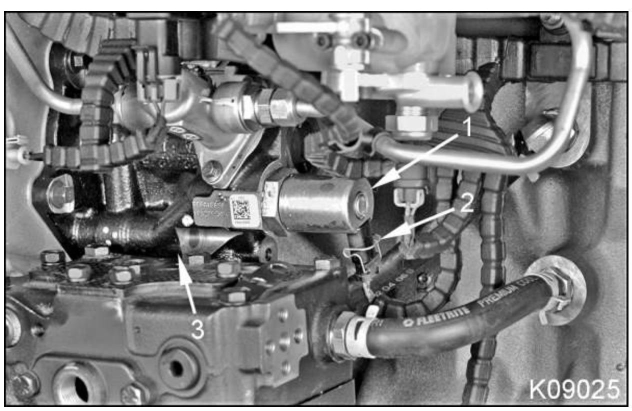


**Figure 84 IPR valve**

1. IPR valve
2. Wire clip lock
3. High-pressure oil pump

1. Disconnect IPR valve connector wire clip lock.
2. Disconnect 2-pin sensor harness connector from the IPR valve, installed in the rear of the high-pressure oil pump on the intake side of the engine.
3. For IPR valve removal, see High-pressure Oil Pump and IPR Valve removal (page 238).

### Crankshaft Position (CKP) Sensor

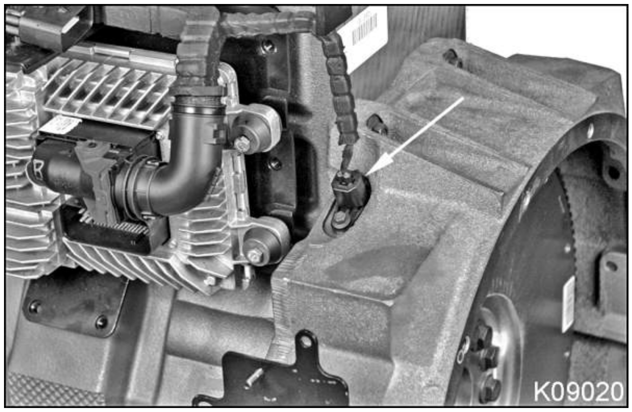


**Figure 85 CKP sensor**

1. Disconnect 2-pin sensor harness connector from CKP sensor installed in the top left of the flywheel housing.
2. Remove M6 x 16 sensor retaining bolt.
3. Pull up and remove CKP sensor.
4. Discard sensor O-rings.

### Engine Sensor Wiring Harness

1. Disconnect the battery ground (-) cable.
2. Disconnect CMP sensor and remove M8 x 16 bolt (page 110) securing the harness routing channel to the front cover. Loosen or remove fan pulley, if required.
3. Disconnect the ECT sensor (page 111), VGT actuator, and EBP sensor (page 113) connectors.

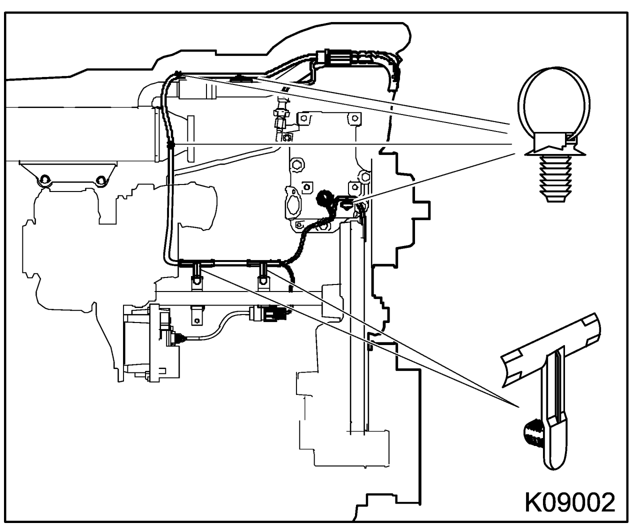


**Figure 86 Sensor wiring harness connection points – exhaust side**

4. Disconnect sensor wiring harness from connection points on the exhaust side of the engine.
5. Disconnect the EFP sensor, fuel heater, and WIF sensor connectors (page 114).
6. Remove the Fuel Filter Header Assembly (page 234).
7. Disconnect the EGR valve (page 115), IPR valve (page 119), EOT sensor (page 116), EOP sensor (page 115), MAP, and MAT sensor (page 116) connectors.
8. Disconnect the intake throttle assembly connector (page 118).
9. Disconnect the CKP sensor connector (page 120).

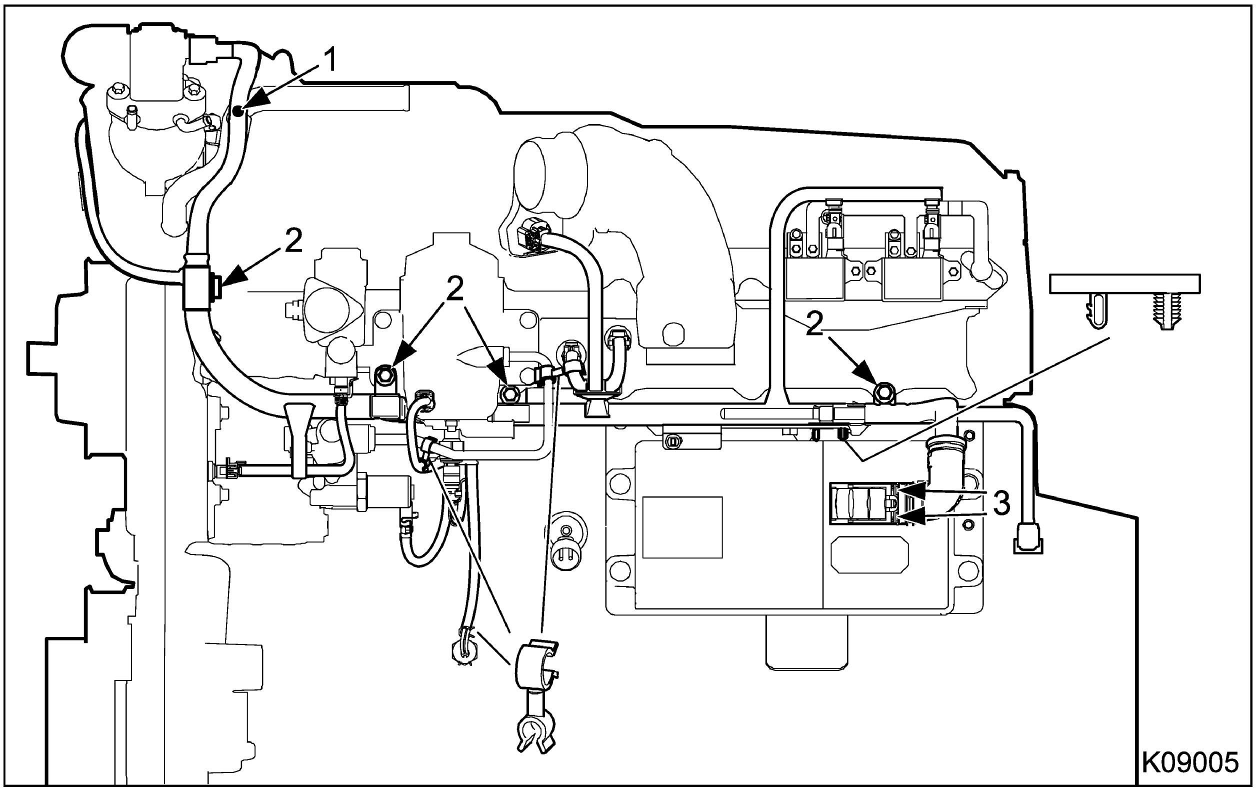


**Figure 87 Sensor wiring harness connection points – intake side**

1. Push in sensor harness connection
2. Sensor harness retaining nut (4)
3. 76-pin sensor harness connector lever release tabs (2)

10. Press two 76-pin sensor harness connector lever release tabs and carefully pull open the connector lever.
11. Pull out and disconnect the 76-pin sensor harness connector from the ECM.
12. Disconnect two 2-pin sensor wiring harness connectors to the intake air heater relays.
13. Remove four sensor harness retaining nuts.
14. Disconnect wiring harness from connection points on the intake side of the engine and remove harness from engine.

### Injector Wiring Harness

**WARNING:**

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

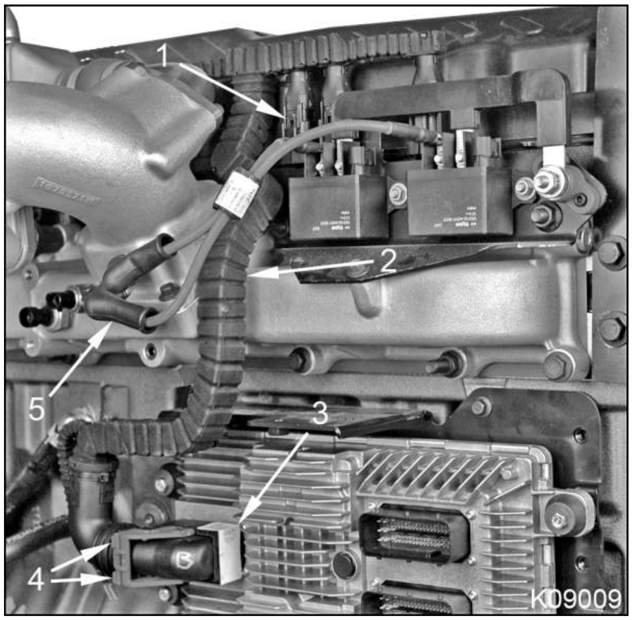


**Figure 88 Injector wiring harness**

1. Injector harness connector to UVC connector (4)
2. Injector wiring harness
3. 36-pin injector harness connector to ECM
4. Injector harness connector lever release tabs (2)
5. Intake air heater cable(s)

1. Remove two M6 nuts connecting the intake air heater cables to the intake air heater grids.
2. Press two injector harness connector lever release tabs and carefully pull open the connector lever.

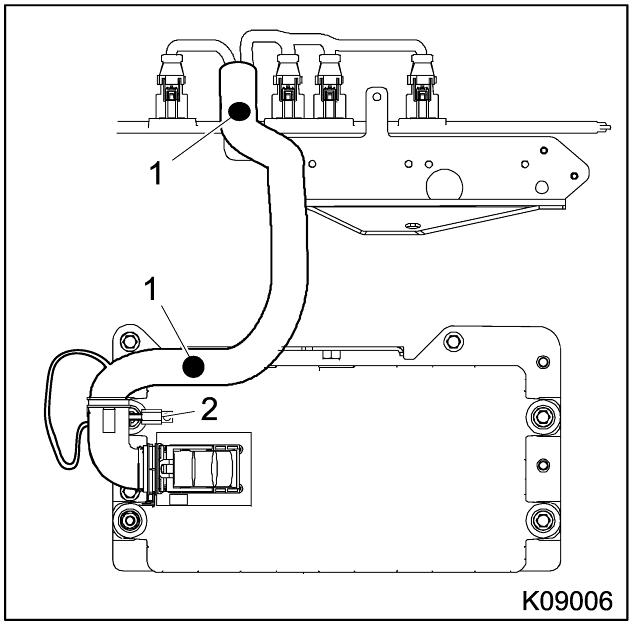


**Figure 89 Injector wiring harness**

1. Push in injector harness connection (2)
2. Injector harness ground connection

3. Disconnect the 36-pin injector harness connector and one-wire ground connection from the ECM.
4. Disconnect injector harness from connection points on the ECM bracket and the intake air heater bracket.
5. Disconnect four injector harness connectors from Under Valve Cover (UVC) harness connectors and remove injector wiring harness.

**Intake Air Heater (IAH) Relay Assembly**

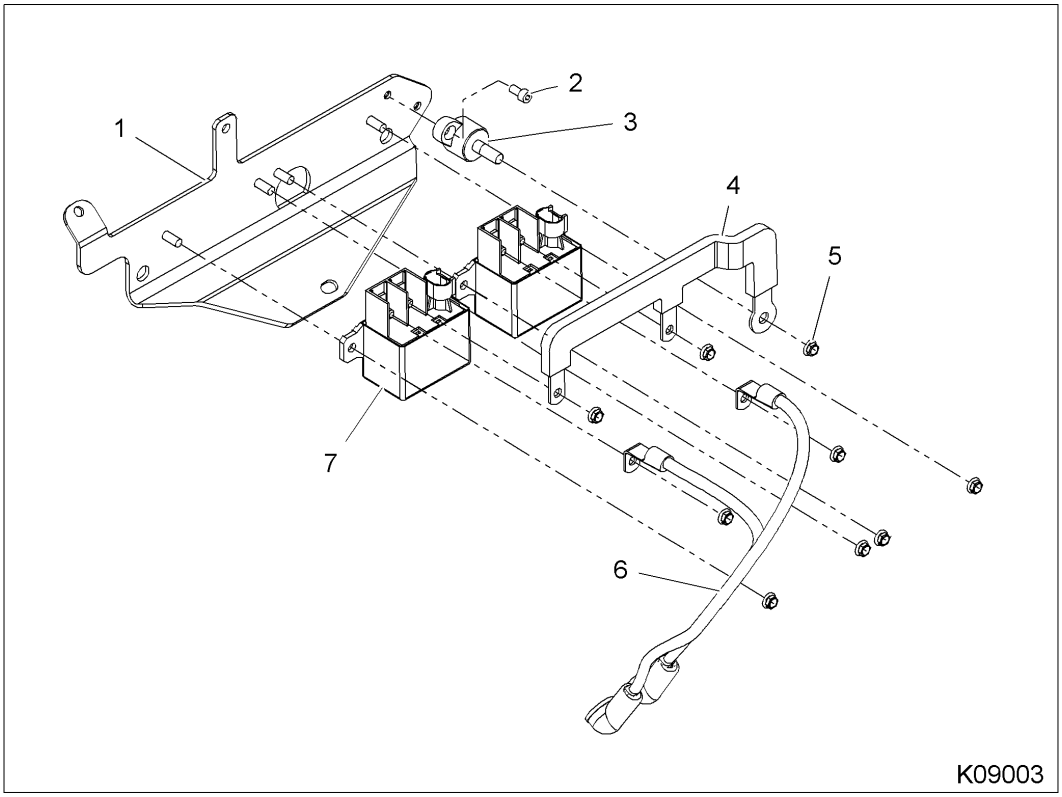


**Figure 90 IAH relay assembly – exploded view**

1. Mounting bracket
2. M5 x 10 socket screw
3. Junction block
4. Buss bar
5. M6 nut (9)
6. Intake air heater cable (2)
7. High current relay (2)

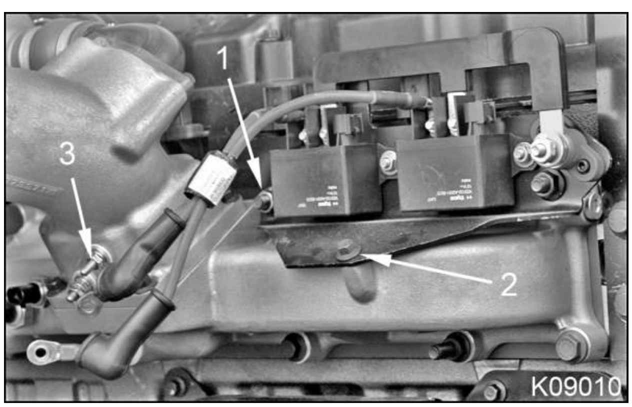


**Figure 91 IAH relay assembly**

1. M10 nut (2)
2. M8 x 20 bolt
3. Intake air heater grid stud (2)

1. Disconnect negative battery cable.
2. Remove positive battery cable from IAH relay assembly
3. Remove two M6 nuts connecting intake air heater cables to intake air heater grid studs.
4. Remove M8 x 20 bolt and two M10 nuts holding IAH relay assembly to engine.
5. Remove IAH relay assembly.

**ECM and Mounting Bracket**

1. Disconnect ground (-) cable from battery.

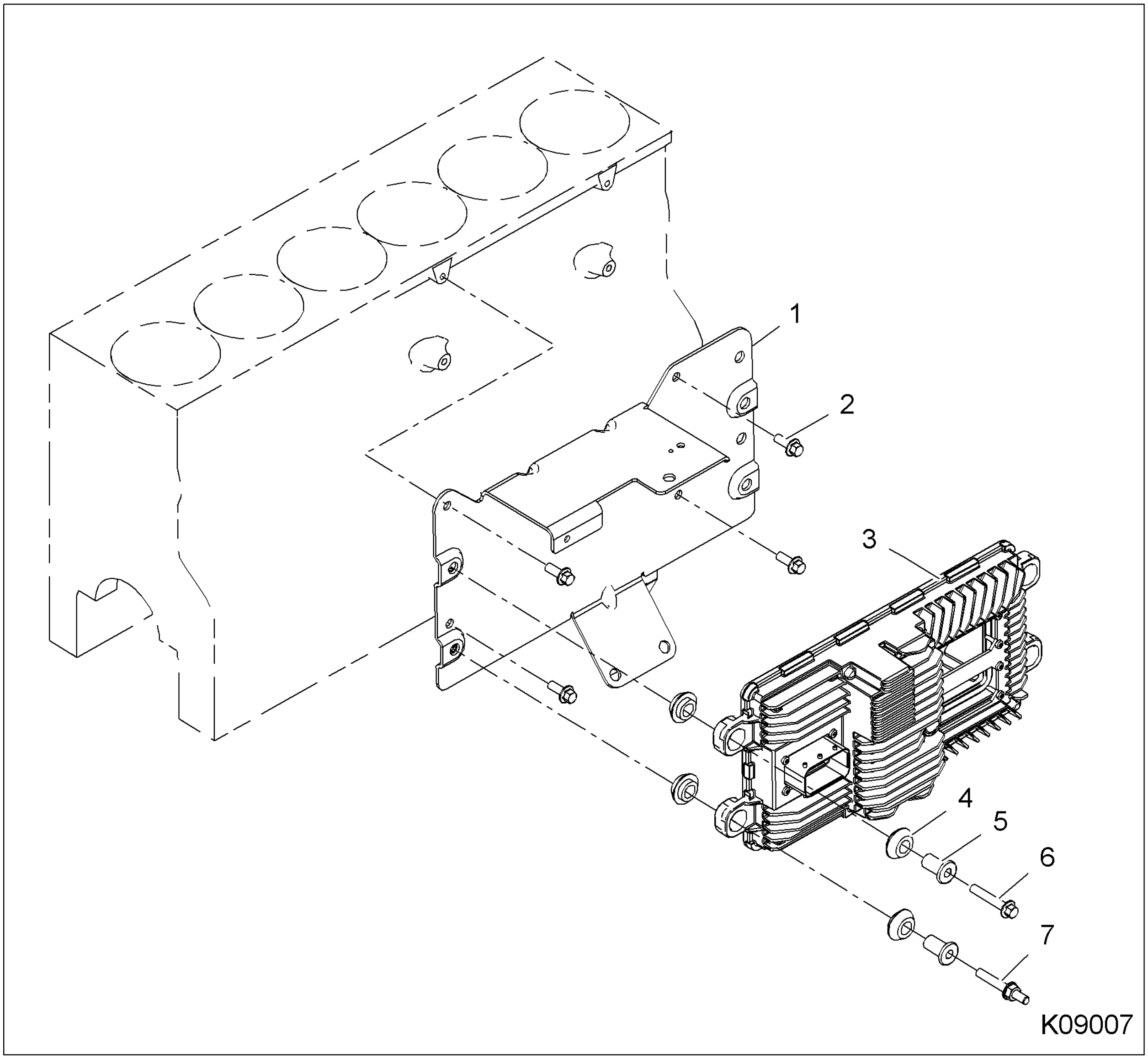


**Figure 92 ECM and mounting bracket**

1. ECM mounting bracket
2. M8 x 20 bolt (4)
3. ECM module assembly
4. Vibration isolator grommet (8)
5. Vibration isolator bushing (4)
6. M8 x 45 bolt (3)
7. M8 x 40 stud bolt

2. Disconnect engine sensor harness, injector harness, and chassis harness connectors from ECM.
3. Remove four M8 x 45 bolts holding ECM to mounting bracket.
4. Remove vibration isolator bushings, isolator grommets, and ECM assembly.
5. Remove four M8 x 20 bolts holding ECM bracket to crankcase and remove bracket assembly.

**Injection Control Pressure (ICP) Sensor**

1. Remove valve cover (page 427).

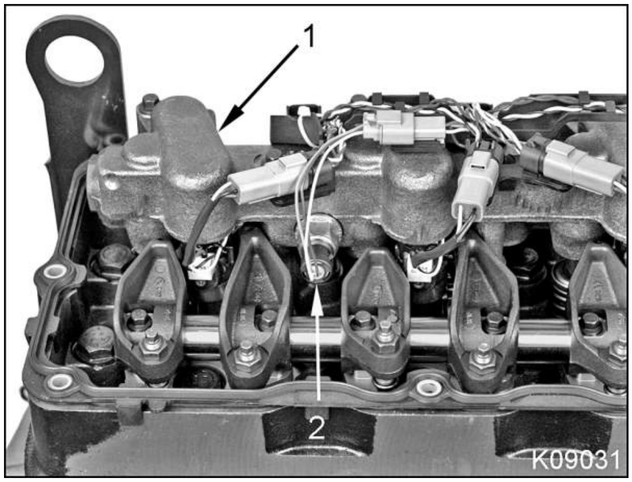


**Figure 93 ICP sensor**

1. High-pressure oil manifold
2. ICP sensor

2. Disconnect 3-pin UVC harness connector from the ICP sensor, installed in the high-pressure oil manifold rear of cylinder 5 fuel injector.
3. Remove ICP sensor.
4. Discard sensor O-ring.

**Brake Control Pressure (BCP) Sensor**


**Figure 94 BCP sensor (optional)**

1. Disconnect 3-pin harness connector from BCP sensor, installed in the high-pressure oil manifold forward of cylinder 2 fuel injector.
2. Remove BCP sensor.
3. Discard sensor O-ring.

**Brake Shut-off Valve (BSV) Connector**

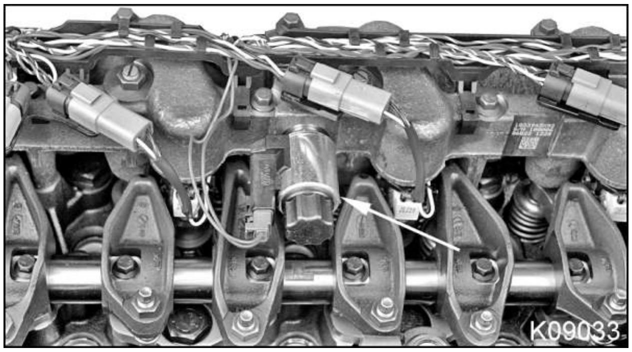


**Figure 95 BSV assembly (optional)**

1. Disconnect harness connector from BSV.
2. See Brake shut-off valve (BSV) assembly (page 272) for BSV valve removal.

**Under Valve Cover (UVC) Harness Valve Cover Gasket Assembly**

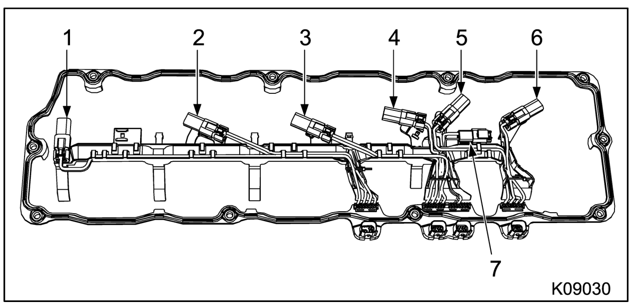


**Figure 96 UVC harness assembly (non-brake)**

1. Injector 1 harness connector
2. Injector 2 harness connector
3. Injector 3 harness connector
4. Injector 4 harness connector
5. Injector 5 harness connector
6. Injector 6 harness connector
7. ICP sensor harness connector

1. Disconnect six injectors, ICP sensor, optional BSV assembly, and BCP sensor harness connectors.
2. Starting at one side, lightly pry up and open each of the six wire channel retainers while gently pulling up to remove UVC harness from engine.

**NOTE:** For engines with engine brake, see UVC harness (page 274) from more details.

## Inspection

**Inspect Wiring Harness, Connectors, and Electrical Components**

1. Inspect each wiring harness for corrosion (green, gray, or white deposits), female connector sleeves that are spread open, and terminal pins that are pushed back relative to the other terminals in the same connector. Clean, repair, or replace connectors and terminals if necessary.
2. Inspect each wiring harness for wear and heat damage to wiring and connectors. Repair or replace if necessary.
3. Replace any broken harness connection points and zip ties.
4. Inspect connector pins on all electrical components. If any pins are bent or pushed in, repair or replace component.
5. Inspect electrical sensors, actuators, and valves for cracks and damage. Replace damaged components if necessary.

**NOTE:** See EGES-370-1 *Engine Diagnostic Manual* for further inspection and repair of engine electrical components and systems.

## Installation

**WARNING:**

**To prevent personal injury or death, disconnect main negative battery terminal before removing or installing electrical components.**

#### Injection Control Pressure (ICP) Sensor

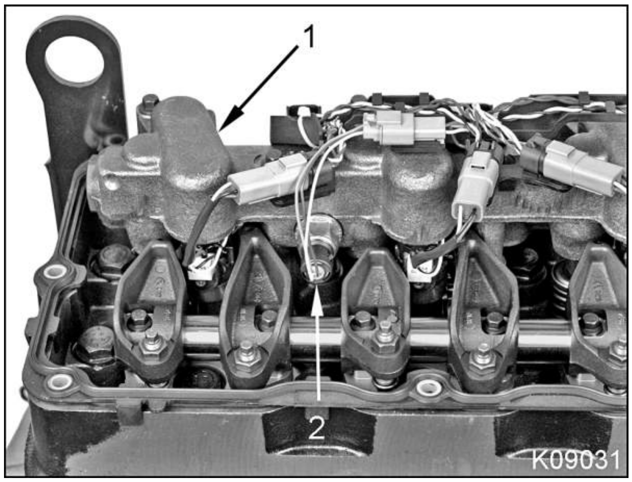


**Figure 97 ICP sensor**

1. High-pressure oil manifold
2. ICP sensor

1. Install a new O-ring on the ICP sensor and lubricate O-ring with clean engine oil.
2. Install ICP sensor into high-pressure oil manifold, to the rear of cylinder 5 fuel injector, and tighten to special torque (page 152).
3. Connect UVC harness connector to the ICP sensor.

**Brake Control Pressure (BCP) Sensor**


**Figure 98 BCP sensor (optional)**

1. Install a new O-ring on the BCP sensor and lubricate O-ring with clean engine oil.
2. Install BCP sensor into the high-pressure oil manifold, forward of cylinder 2 fuel injector, and tighten to special torque (page 152).
3. Connect UVC harness connector to the BCP sensor.

### Brake Shut-off Valve (BSV) Connector

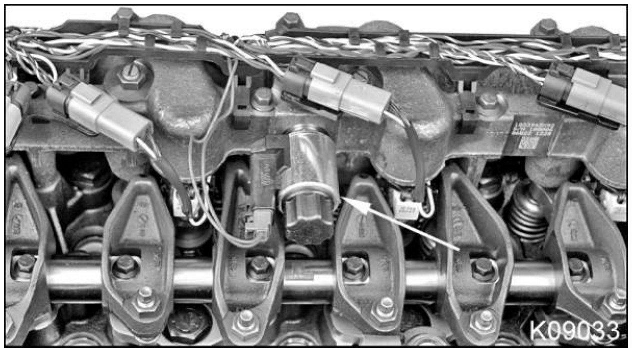


**Figure 99 BSV assembly (optional)**

**CAUTION:**

**To prevent engine damage, BSV harness connector must be positioned to give proper clearance for rocker arm movement.**

1. See Brake Shut-off Valve (BSV) Assembly (page 285) for brake BSV installation.
2. Connect UVC harness connector to the BSV.

### Under Valve Cover (UVC) Harness Valve Cover Gasket Assembly

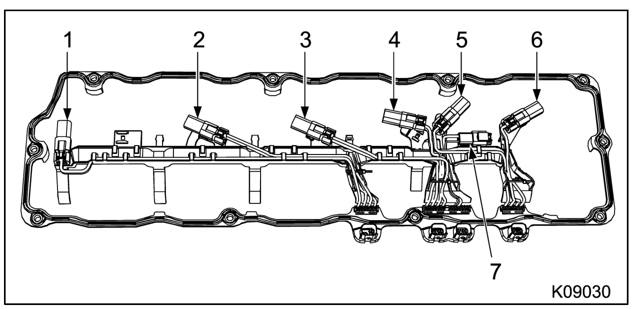


**Figure 100 UVC harness assembly (non-brake)**

1. Injector 1 harness connector
2. Injector 2 harness connector
3. Injector 3 harness connector
4. Injector 4 harness connector
5. Injector 5 harness connector
6. Injector 6 harness connector
7. ICP sensor harness connector

1. Position UVC harness on the cylinder head and carefully push down each of the six wire channel retainers to snap harness onto high-pressure oil manifold.
2. Connect six injectors, ICP sensor, and optional BSV, and BCP sensor harness connectors.

**NOTE:** For engines with engine brake, see UVC harness (page 284) from more details.

**ECM and Mounting Bracket**

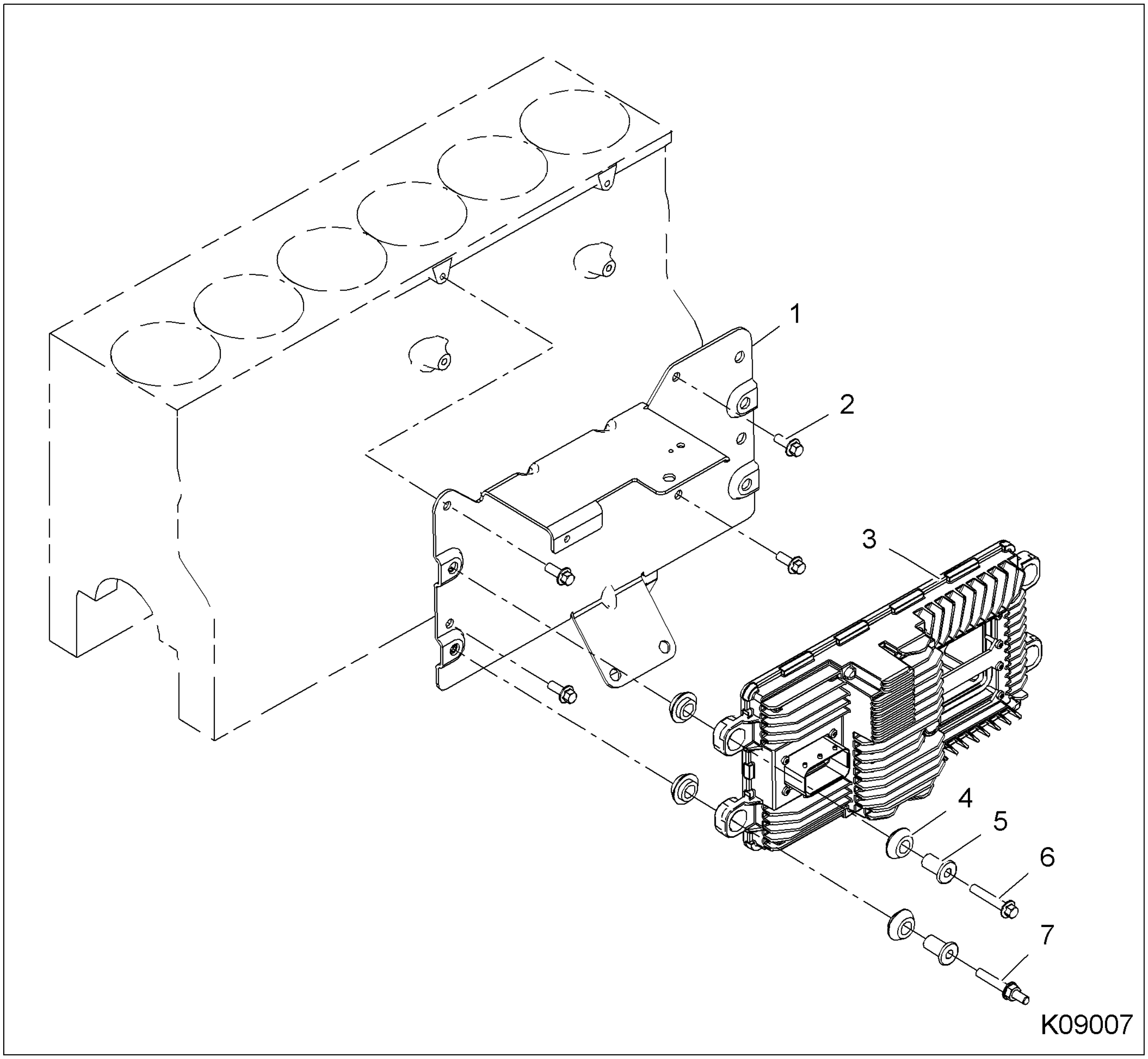


**Figure 101 ECM and mounting bracket**

1. Bracket assembly
2. M8 x 20 bolt (4)
3. ECM module assembly
4. Vibration isolator grommet (8)
5. Vibration isolator bushing (4)
6. M8 x 45 bolt (3)
7. M8 x 45 stud bolt

1. Install four M8 x 20 bolts holding the ECM bracket to the crankcase and tighten bolts to standard torque (page 683).
2. Install eight vibration isolator grommets and four isolator bushings on ECM.

3. Install M8 x 45 stud bolt and three M8 x 45 bolts holding the ECM to the mounting bracket and tighten to special torque (page 152).
4. Connect engine sensor harness, injector harness, and chassis harness connectors to the ECM.

### Crankshaft Position (CKP) Sensor

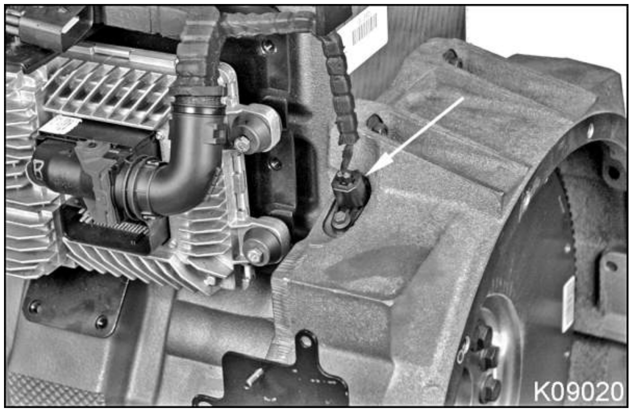


**Figure 102 CKP sensor**

1. Install new O-rings on the CKP sensor.
2. Install CKP sensor into the flywheel housing.
3. Install M6 x 16 retaining bolt and tighten to standard torque (page 683).
4. Connect sensor harness connector to CKP sensor.

### Injection Pressure Regulator (IPR) Valve Connector

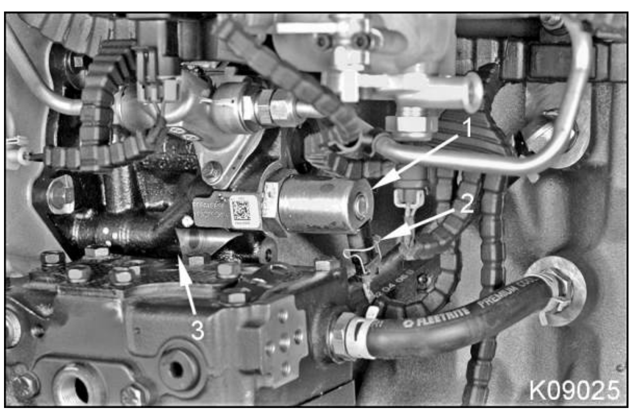


**Figure 103 IPR valve on high-pressure oil pump**

1. IPR valve
2. Wire clip lock
3. High-pressure oil pump

1. For IPR valve installation, see High-pressure Oil Pump and IPR Valve installation (page 253).
2. Connect 2-pin sensor harness connector to IPR valve.
3. Connect sensor harness wire clip lock.

### Intake Throttle Assembly Connector


**Figure 104 Intake throttle assembly**

1. Intake throttle assembly
2. Locking tab
3. Sensor harness connector

1. See Intake Throttle Assembly (page 216) for throttle assembly installation.
2. Connect sensor harness connector to the intake throttle assembly.
3. Push down locking tab to lock sensor harness connector.

### Manifold Absolute Pressure (MAP) and Manifold Air Temperature (MAT) Sensors

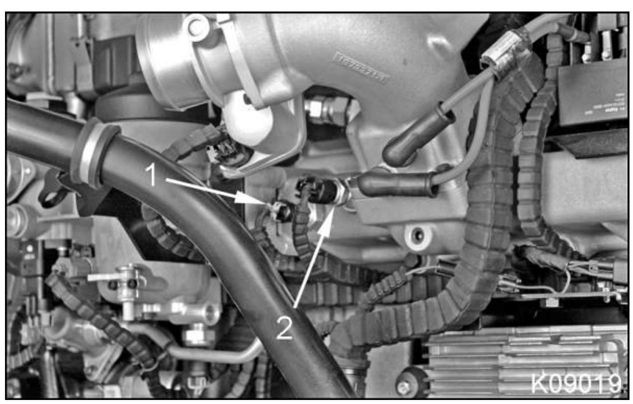


**Figure 105 MAP and MAT sensors**

1. MAP sensor
2. MAT sensor

1. Install a new O-ring on the MAP sensor and MAT sensor.

2. Install MAP and MAT sensors into the intake manifold and tighten to special torque (page 152).
3. Connect sensor harness connectors to the MAP and MAT sensors.
4. Push down MAT sensor locking tab to lock sensor harness connector.

**Engine Oil Pressure (EOP) Sensor**

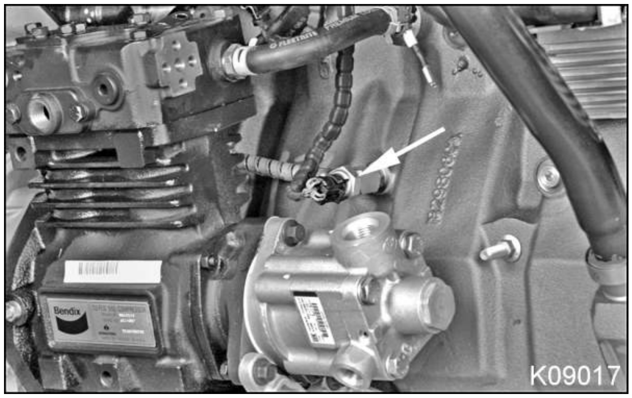


**Figure 106 EOP sensor**

1. Install a new O-ring on EOP sensor and lubricate with clean engine oil.
2. Install EOP sensor into the intake side of the crankcase and tighten to special torque (page 152).
3. Connect sensor harness connector to EOP sensor.

**Engine Oil Temperature (EOT) Sensor**

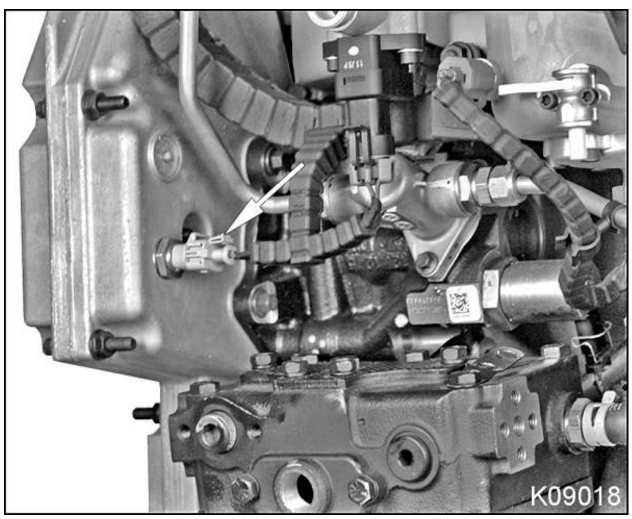


**Figure 107 EOT sensor**

1. Install a new O-ring on EOT sensor and lubricate with clean engine oil.
2. Install EOT sensor into the back of the front cover and tighten to special torque (page 152).
3. Connect sensor harness connector to the EOT sensor.
4. Push lock tab down to lock connector.

### Exhaust Gas Recirculation (EGR) Valve Connector

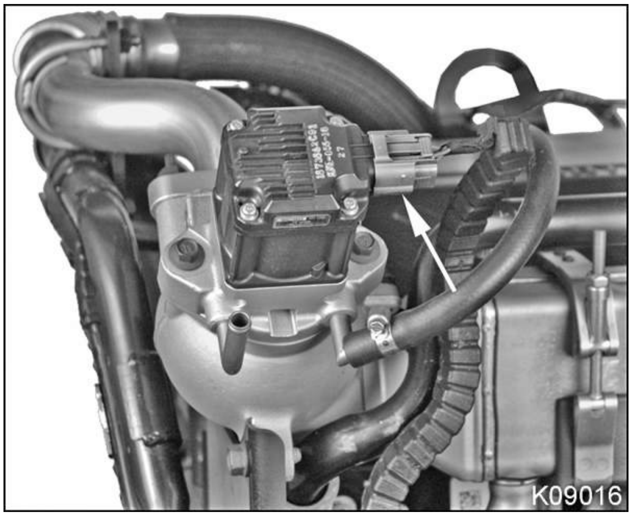


**Figure 108 EGR valve connector**

1. See EGR Valve Manifold Assembly (page 189) for EGR valve installation.
2. Connect sensor harness connector to the EGR valve, installed in the EGR valve manifold.

### Water In Fuel (WIF) Sensor, Engine Fuel Pressure (EFP) Sensor, and Fuel Heater Connectors

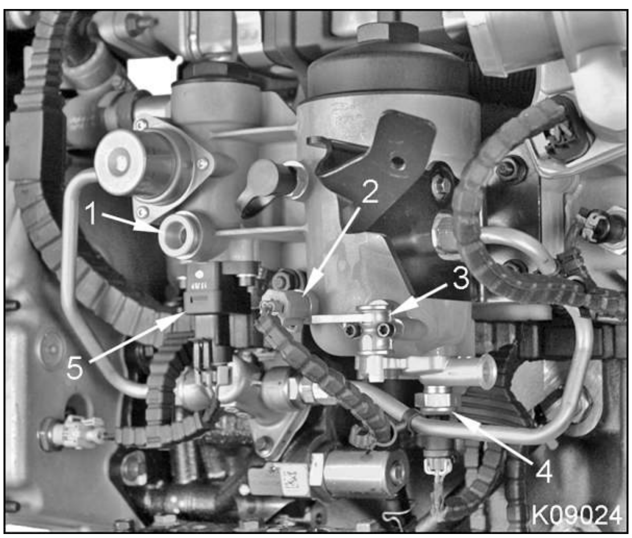


**Figure 109 Fuel filter header assembly**

1. Fuel inlet (from tank)
2. WIF sensor
3. Water drain valve
4. EFP sensor
5. Fuel heater (optional)

1. See Water In Fuel (WIF) sensor, Engine Fuel Pressure (EFP) Sensor, and Fuel Heater (page 261) for fuel sensor and heater installation.
2. Connect sensor harness connector to the fuel heater.
3. Connect sensor harness connector to the WIF sensor.
4. Connect 3-pin sensor harness connector to the EFP sensor.

**Exhaust Back Pressure (EBP) Sensor**

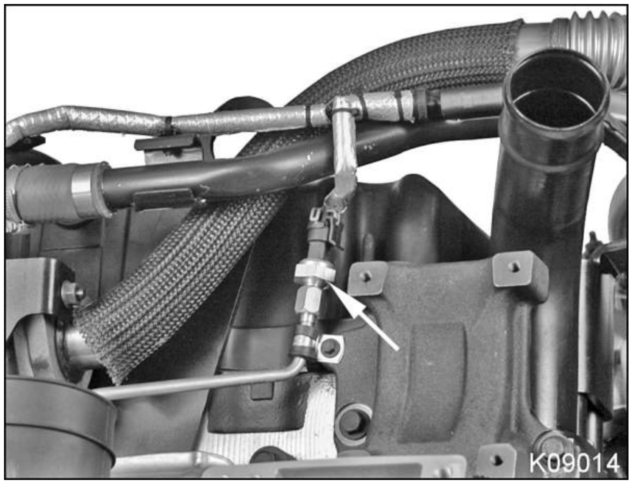


**Figure 110 EBP sensor**

1. Install EBP sensor into tube mounted on the water supply housing (Freon® compressor bracket).
2. Tighten EBP sensor to special torque (page 152).
3. Connect sensor harness connector to EBP sensor.

**VGT Actuator Connector**

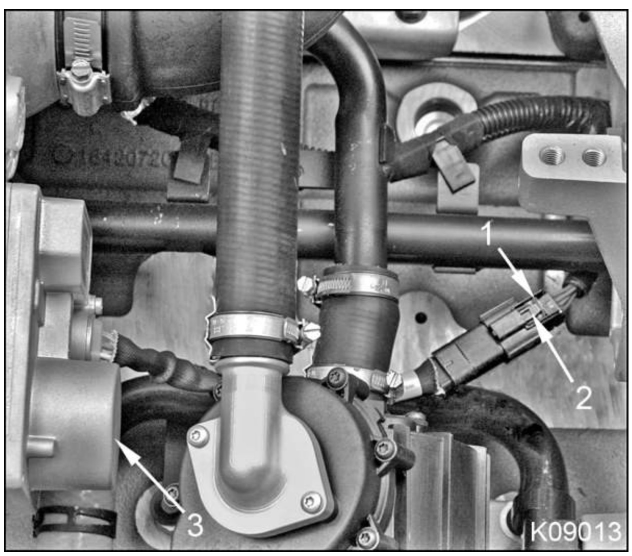


**Figure 111 VGT actuator connector**

1. Lock tab (down to lock)
2. Release tab
3. VGT actuator

1. Connect VGT actuator connector to engine sensor harness connector.
2. Push lock tab down to lock VGT actuator connector.

### Engine Coolant Temperature (ECT) Sensor

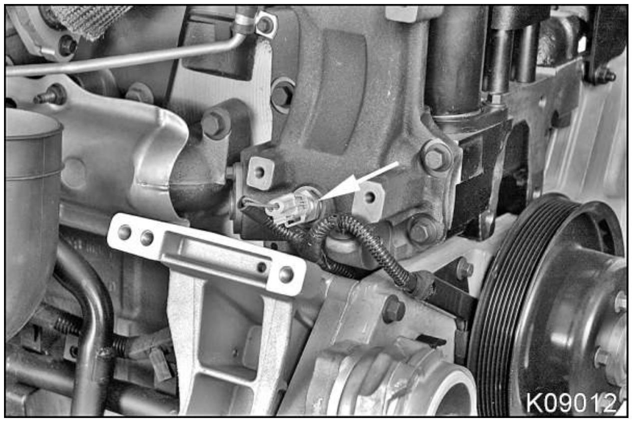


**Figure 112 ECT sensor**

1. Install a new O-ring on ECT sensor.
2. Install ECT sensor into the water supply housing (Freon® compressor bracket) and tighten to special torque (page 152).
3. Connect sensor harness connector to ECT sensor.
4. Push lock tab down to lock connector.

**Camshaft Position (CMP) Sensor**

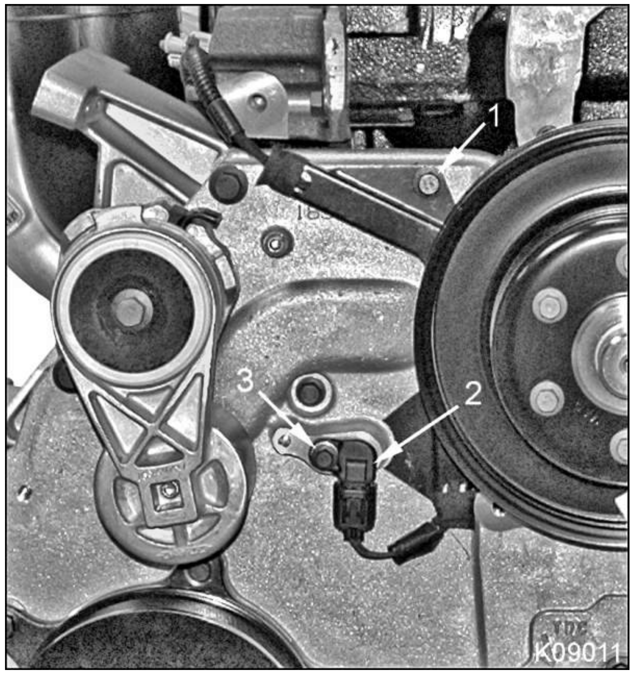


**Figure 113 CMP sensor**

1. M8 x 16 bolt
2. CMP sensor
3. M6 x 16 sensor retaining bolt

1. Install a new O-ring on the CMP sensor.
2. Install CMP sensor into front cover.
3. Install M6 x 16 sensor retaining bolt and tighten to standard torque (page 683).
4. Connect sensor harness connector to the CMP sensor.

**Engine Sensor Wiring Harness**

1. Connect CMP sensor and install M8 x 16 bolt (page 145) securing the harness routing channel to the front cover.
2. Tighten M8 x 16 harness routing channel bolt to standard torque (page 683).
3. Connect the ECT sensor (page 144), VGT actuator connector (page 143), and EBP sensor.

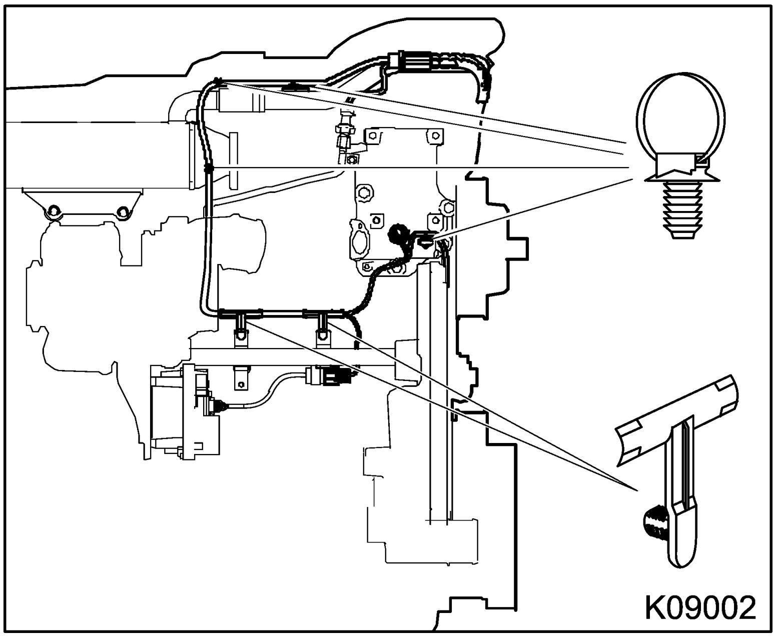


**Figure 114 Sensor harness connection points – exhaust side**

4. Replace any broken harness connection points and zip ties.
5. Connect sensor harness to connection points on the exhaust side of the engine.
6. Connect sensor harness to connection points on the EGR coolant crossover tube assembly.

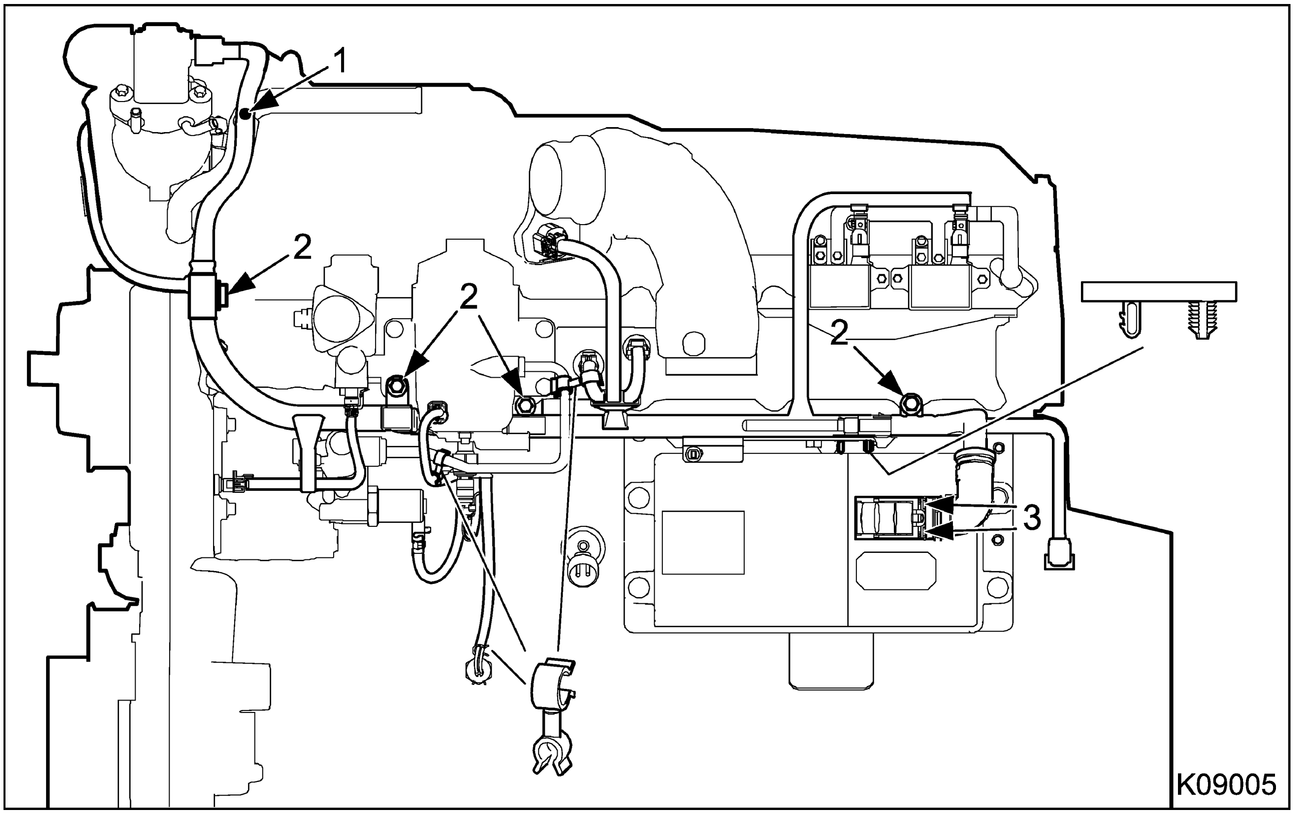


**Figure 115 Sensor harness connection points – intake side**

1. Push in sensor harness connection
2. Sensor harness retaining nut (4)
3. 76-pin sensor harness connector lever release tabs (2)

7. Connect the EGR valve connector (page 140), IPR valve (page 136), EOT sensor (page 139), EOP sensor, MAP, and MAT sensor (page 137).
8. Connect sensor harness connector to the intake throttle assembly connector (page 137).
9. Connect sensor harness connector to the ECM (page 134).
10. Connect the CKP sensor (page 135).
11. Plug in two connectors to the intake air heater relays.
12. Install the Fuel Filter Header Assembly (page 258) and connect the fuel heater, WIF sensor, and EFP sensor harness connectors.
13. Connect sensor harness to connection points on the intake side of the engine.
14. Install four sensor harness retaining nuts and tighten to standard torque (page 683).

### Injector Wiring Harness

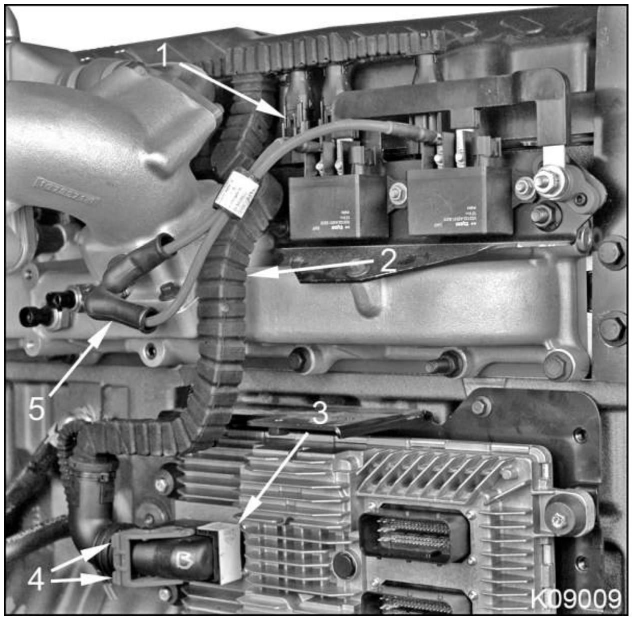


**Figure 116 Injector wiring harness**

1. Injector harness connector to UVC connector (4)
2. Injector wiring harness
3. 36-pin injector harness connector to ECM
4. Injector harness connector lever release tabs (2)
5. Intake air heater cable(s)

1. Connect four injector harness connectors to UVC harness connectors.
2. Install the 36-pin injector harness connector into the ECM and close the connector lever until it locks in place.

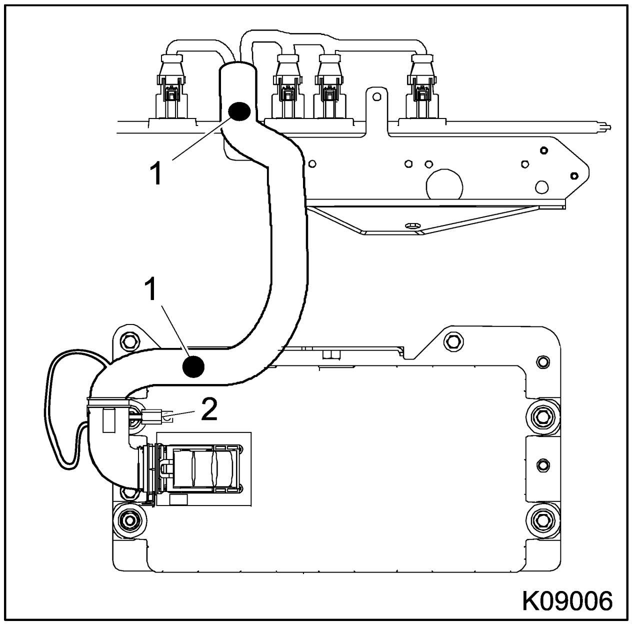


**Figure 117 Injector wiring harness connection points**

1. Push in injector harness connection (2)
2. Injector harness ground connection

3. Connect injector harness to connection points on the ECM bracket and the intake air heater bracket.
4. Connect the one-wire injector harness ground connection to the ECM.

**Intake Air Heater (IAH) Relay Assembly**

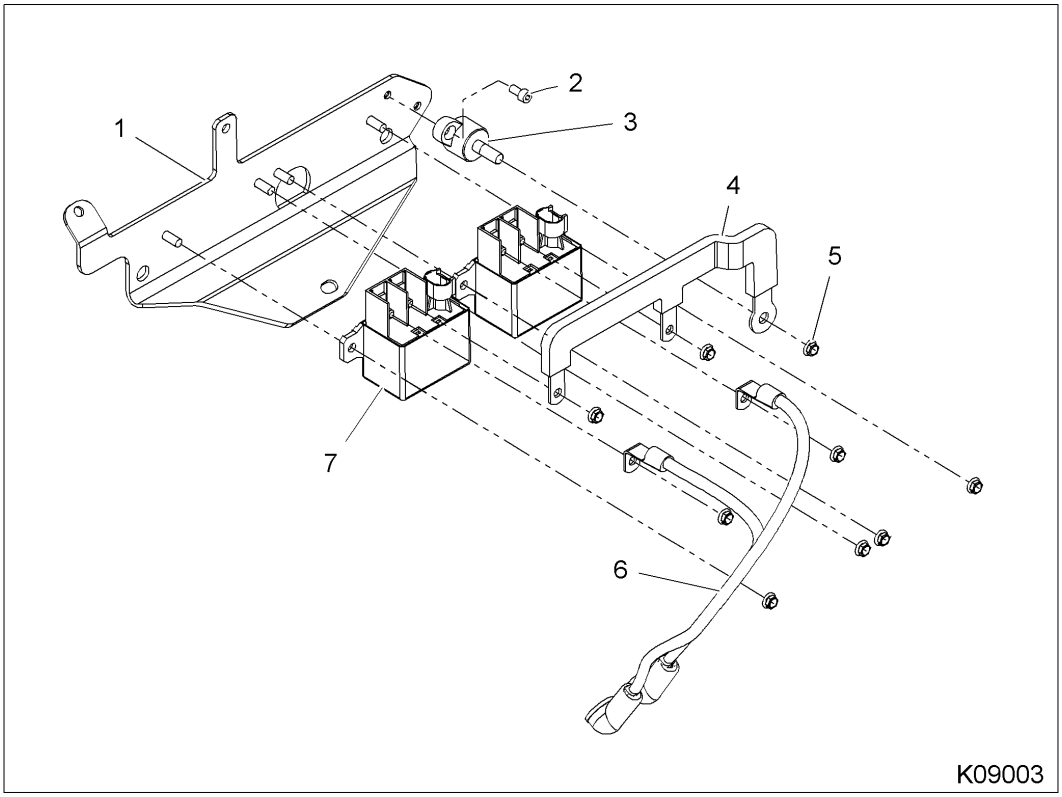


**Figure 118 IAH relay assembly – exploded view**

1. Mounting bracket
2. M5 x 10 socket screw
3. Junction block
4. Buss bar
5. M6 nut (9)
6. Intake heater cable (2)
7. High current relay (2)

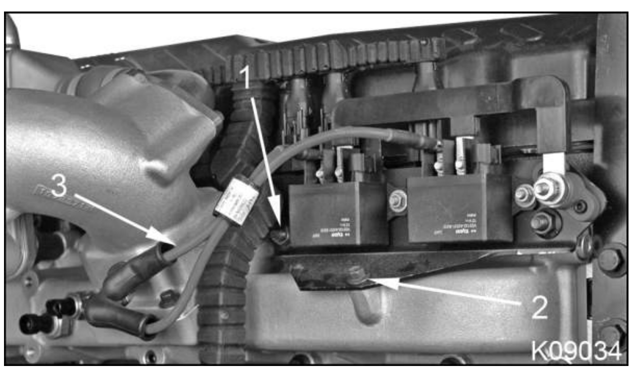


**Figure 119 IAH relay assembly**

1. M10 nut (2)
2. M8 x 20 bolt
3. Intake air heater cable (2)

1. Install IAH relay assembly on engine and install M8 x 20 heater relay bracket bolt finger tight.
2. Install two M10 intake air heater mounting nuts finger tight.
3. Tighten M8 x 20 bolt and two M10 nuts to standard torque (page 683).
4. Install two M6 nuts attaching the intake air heater cables to the intake air heater grid studs and tighten to special torque (page 152).

## Special Torque

| | |
|---|---|
| ECM mounting bolts, M8 | 20 N·m (180 lbf·in) |
| Engine coolant temperature (ECT) sensor | 18 N·m (156 lbf·in) |
| Engine oil pressure (EOP) sensor | 12 N·m (102 lbf·in) |
| Engine oil temperature (EOT) sensor | 18 N·m (156 lbf·in) |
| Exhaust Back Pressure (EBP) sensor | 20 N·m (178 lbf·in) |
| Injection control pressure (ICP) sensor and Brake Control (BCP) sensor | 18 N·m (162 lbf·in) |
| Intake air heater cable to heater grid M6 nut | 4 N·m (35 lbf·in) |
| Intake Manifold Air Pressure (MAP) sensor | 12 N·m (102 lbf·in) |
| Intake Manifold Air Temperature (MAT) sensor | 18 N·m (154 lbf·in) |

# Table of Contents

## Illustration and Description

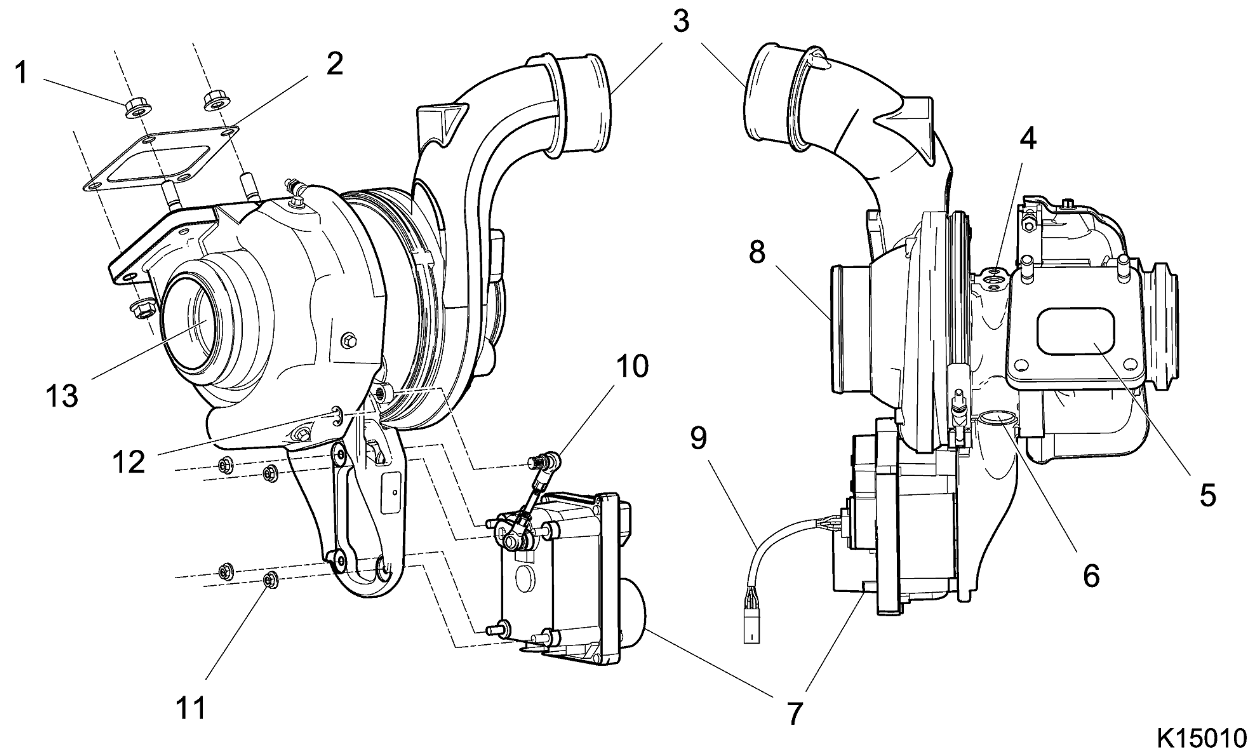


**Figure 120 Variable Geometry Turbocharger (VGT) components**

1. M10 Spiralock® nut (4)
2. Turbocharger mounting gasket
3. Compressor outlet
4. Oil supply port
5. Turbine inlet
6. Oil drain port
7. VGT actuator
8. Compressor inlet
9. VGT actuator harness
10. VGT actuator linkage
11. M6 serrated lock nut (4)
12. E-clip
13. Turbine outlet

The VGT uses actuated vanes mounted on a unison ring inside the turbine housing to modify exhaust gas flow to control intake boost pressure for various engine speed and load conditions.

The VGT is part of a closed loop system which uses the Exhaust Back Pressure (EBP) sensor to continuously provide exhaust pressure feedback to the ECM.

The Electronic Control Module (ECM) commands the VGT actuator with a digital signal over the CAN 2 link. A DC motor in the VGT actuator moves linkage connected to the unison ring to control vane position and turbocharger boost.

See Variable Geometry Turbocharger (VGT) (page 26) for additional details.

## Removal

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

**WARNING:**

**To prevent personal injury or death, inspect turbocharger with engine off, and turbocharger not spinning. Turbocharger components may be extremely hot. Turbocharger wheels are very sharp and spin at high speeds.**

**WARNING:**

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

**WARNING:**

**To prevent personal injury or death, support turbocharger assembly during removal and installation.**

**WARNING:**

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

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

### VGT Actuator Connector

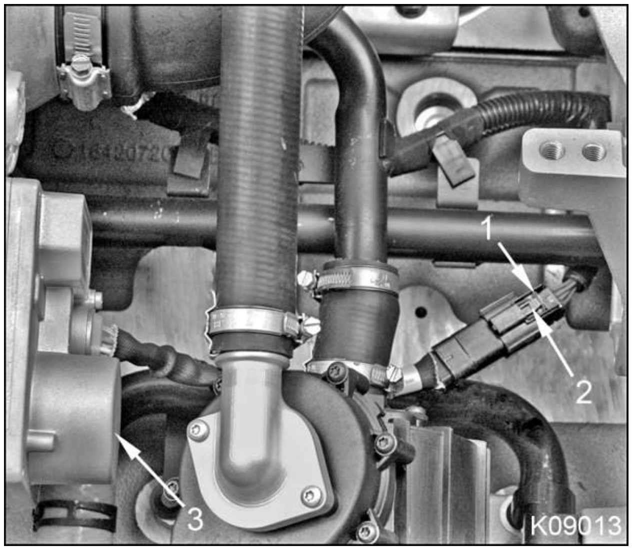


**Figure 121 VGT actuator connector**

1. Lock tab (up to unlock)
2. Release tab (push to release)
3. VGT actuator

1. Push lock tab up to unlock VGT actuator connector.
2. Press the release tab and pull sensor harness connector out of VGT actuator connector.

### Turbocharger Oil Supply Tube Assembly

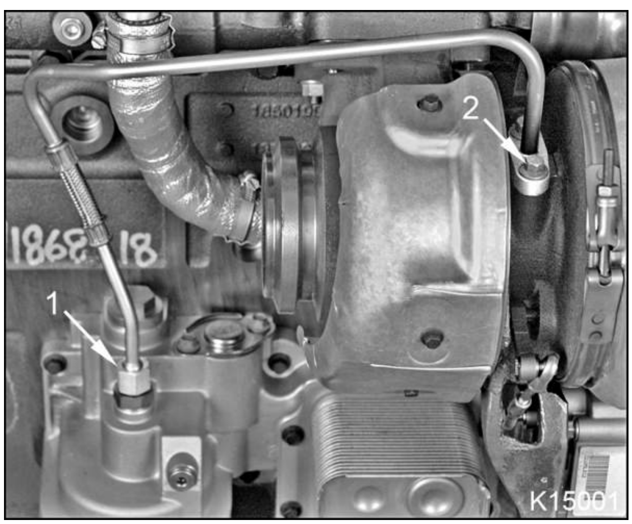


**Figure 122 Turbocharger oil supply tube assembly**

1. Turbocharger oil supply tube nut
2. M8 x 25 bolt (2)

1. Remove turbocharger oil supply tube nut from fitting on top of oil filter header.
2. Remove two M8 x 25 bolts connecting the turbocharger oil supply tube assembly to the VGT oil supply port and remove tube assembly.
3. Remove and discard O-ring.

**Variable Geometry Turbocharger (VGT) Assembly and Turbocharger Oil Drain Tube**

1. Loosen worm gear clamps on turbocharger air intake duct and breather tube. Pull turbocharger air intake duct off the VGT and crankcase breather assemblies.
2. Loosen exhaust clamp and remove down pipe from VGT exhaust flange.


**Figure 123 Turbocharger oil drain tube, bracket, and bolt**

1. M8 x 16 bolt
2. Tube bracket (oil drain)
3. Turbocharger oil drain tube

3. Remove M8 x 16 bolt from tube bracket and remove bracket.
4. Pull oil drain tube out of crankcase.

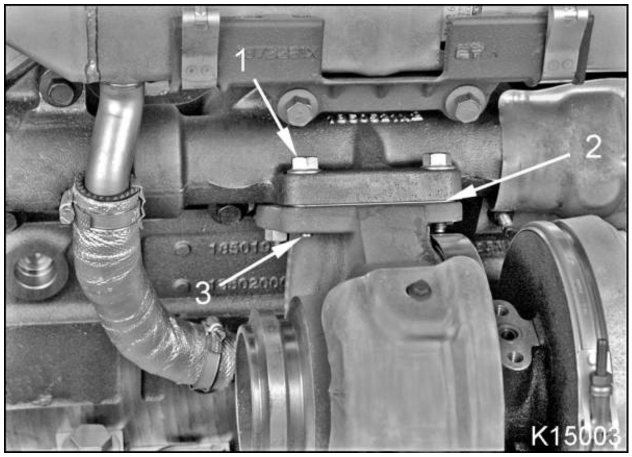


**Figure 124 VGT mounting**

1. M10 Spiralock® nut (4)
2. Turbocharger mounting gasket
3. VGT mounting stud

**NOTE:** To aid removal of the turbocharger, loosen four M10 nuts ¼ turn then tap each nut using a socket or flat punch and a hammer. This will knock the "peaks" of the threads down, allowing the nuts to unthread easily.

**WARNING:**

**To prevent personal injury or death, support turbocharger assembly during removal and installation.**

5. Remove three of four M10 Spiralock® nuts holding the VGT assembly to the exhaust manifold.
6. Support the VGT assembly and remove the fourth M10 nut. Remove the VGT assembly and oil drain tube.
7. Remove and discard the turbocharger mounting gasket and oil drain tube O-rings.
8. Discard used M10 Spiralock® nuts.

## Cleaning, Inspection, and Testing

**WARNING:**

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

### Clean VGT and Related Parts

1. Clean piping between the VGT and air cleaner assembly with soap and water. Dry piping with filtered compressed air.
2. Clean air inlet piping and connecting hoses and dry with filtered compressed air.
3. Clean turbocharger oil supply tube and oil drain tube with suitable solvent and a nylon brush. Dry tubes with filtered compressed air. Replace any damaged tubes.
4. Clean the turbine housing and exhaust manifold mounting surfaces.

### Inspect Turbine and Compressor

**NOTE:** This inspection can be done with the VGT assembly mounted on or off the engine.

1. Inspect VGT assembly for cracks and leaks. Replace VGT if necessary.

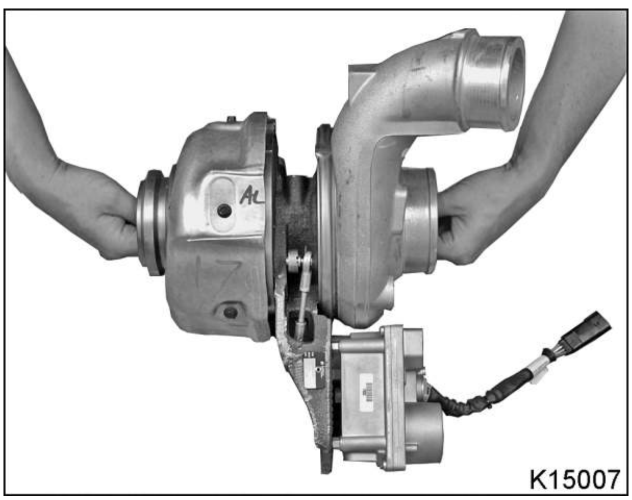


**Figure 125 Inspect turbine shaft rotation**

2. Turn turbine shaft by hand and check for wheel rub in each housing.

   Shaft wheels must rotate freely. If there is any rubbing or interference, replace the VGT assembly.

**NOTE:** Do not attempt to straighten bent blades.

3. Inspect compressor impeller and turbine wheels. If any blades are bent, broken, or eroded, replace the VGT assembly.

## Installation

**VGT Assembly and Oil Drain Tube**

1. Install a new O-ring on each end of the turbocharger oil drain tube and lubricate with clean engine oil.

**CAUTION:**

**To prevent engine damage, use care to not damage oil drain tube O-rings.**

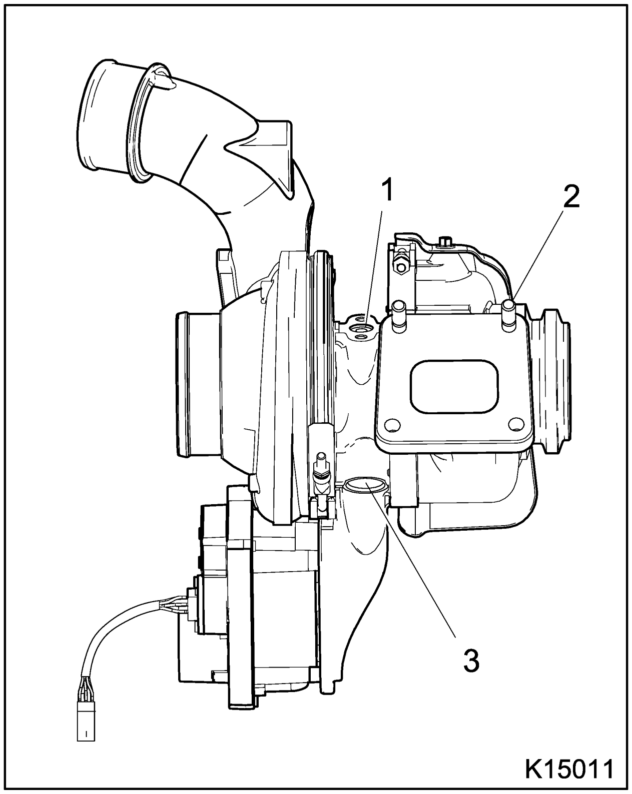


**Figure 126 VGT assembly rear view**

1. Oil supply port
2. VGT mounting stud
3. Oil drain port

2. Install one end of the oil drain tube into the VGT oil drain port.
3. Place a new turbocharger mounting gasket over VGT mounting studs.

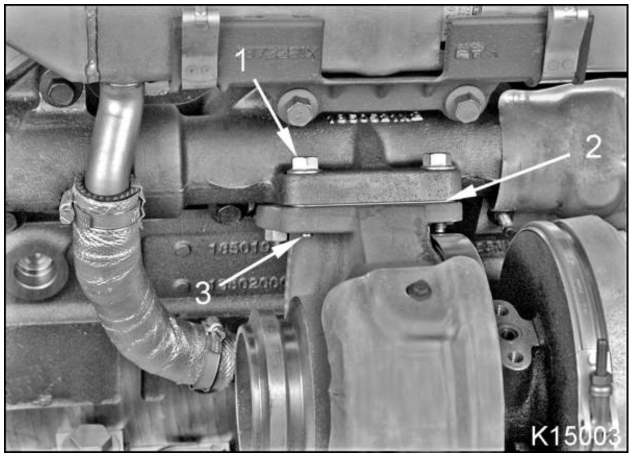


**Figure 127 VGT mounting**

1. M10 Spiralock® nut (4)
2. Turbocharger mounting gasket
3. VGT mounting stud

**WARNING:**

**To prevent personal injury or death, support turbocharger assembly during removal and installation.**

4. Lift VGT assembly onto engine and insert VGT mounting studs into the exhaust manifold and install two new M10 Spiralock® nuts on the VGT mounting studs.
5. Pre-lube the VGT assembly by adding oil to the oil supply port while rotating the turbine shaft. Continue to add oil until oil comes out the oil drain tube.
6. Install the oil drain tube into the crankcase.
7. Install two new M10 Spiralock® nuts on the exhaust manifold studs.
8. Verify the oil drain tube is seated in the crankcase oil drain port.
9. Tighten four M10 nuts to special torque (page 168).


**Figure 128 Turbocharger oil drain tube, bracket, and bolt**

1. M8 x 16 bolt
2. Tube bracket (oil drain)
3. Turbocharger oil drain tube

10. Align oil drain tube then install tube bracket and M8 x 16 bolt.
11. Tighten M8 x 16 bolt to standard torque (page 683).
12. Install turbocharger air intake duct on the VGT and crankcase breather assemblies. Tighten worm gear clamps on turbocharger air intake duct and breather tube.

### Turbocharger Oil Supply Tube Assembly

1. Install a new turbocharger oil supply O-ring on the VGT oil supply flange located on top of the VGT central housing.

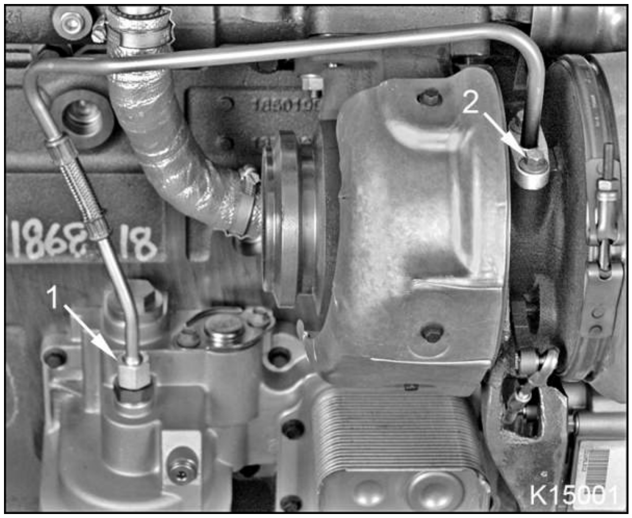


**Figure 129 Turbocharger oil supply tube assembly**

1. Turbocharger oil supply tube nut
2. M8 x 25 bolt (2)

2. Install two M8 x 25 bolts attaching the turbocharger oil supply tube to the VGT oil supply port.
3. Install turbocharger oil supply tube nut onto fitting on top of the oil filter header.
4. Tighten two M8 x 25 bolts to standard torque (page 683).
5. Tighten turbocharger oil supply tube nut to special torque (page 168).

### Variable Geometry Turbocharger (VGT) Actuator Connector

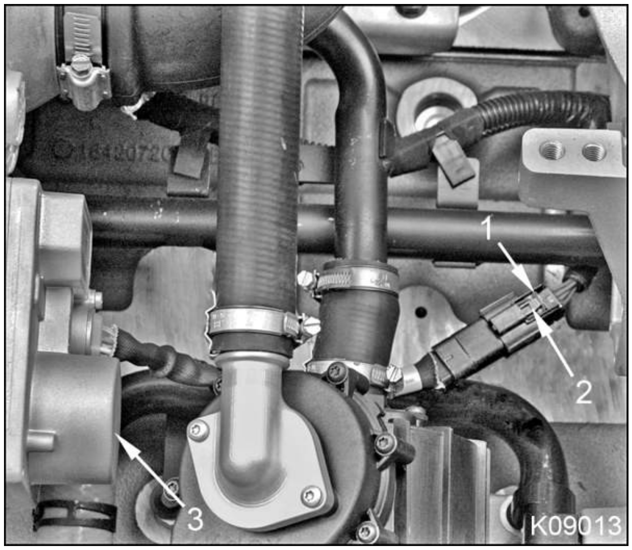


**Figure 130 VGT actuator connector**

1. Lock tab (down to lock)
2. Release tab (push to release)
3. VGT actuator

1. Connect VGT actuator connector to engine sensor harness connector.
2. Push lock tab down to lock VGT actuator connector.

## Specifications

| | |
|---|---|
| VGT axial linkage shaft | Must strike open and closed stops in actuator, 90° rotation |

## Special Torque

| | |
|---|---|
| Turbocharger oil supply tube nut | 25 N·m (18 lbf·ft) |
| VGT Spiralock® nuts (M10) | 71 N·m (52 lbf·ft) |
| V-band clamp | 12.5 N·m (111 lbf·in) |
| M6 VGT actuator serrated lock nuts | 14 N·m (120 lbf·in) |
| M6 x 10 VGT heat shield bolts | 19 N·m (14 lbf·ft) |

## Special Service Tools

| | |
|---|---|
| Dial indicator set | Obtain locally |
| Turbocharger Intake Shield | ZTSE4752 |

# Table of Contents

## Exploded View

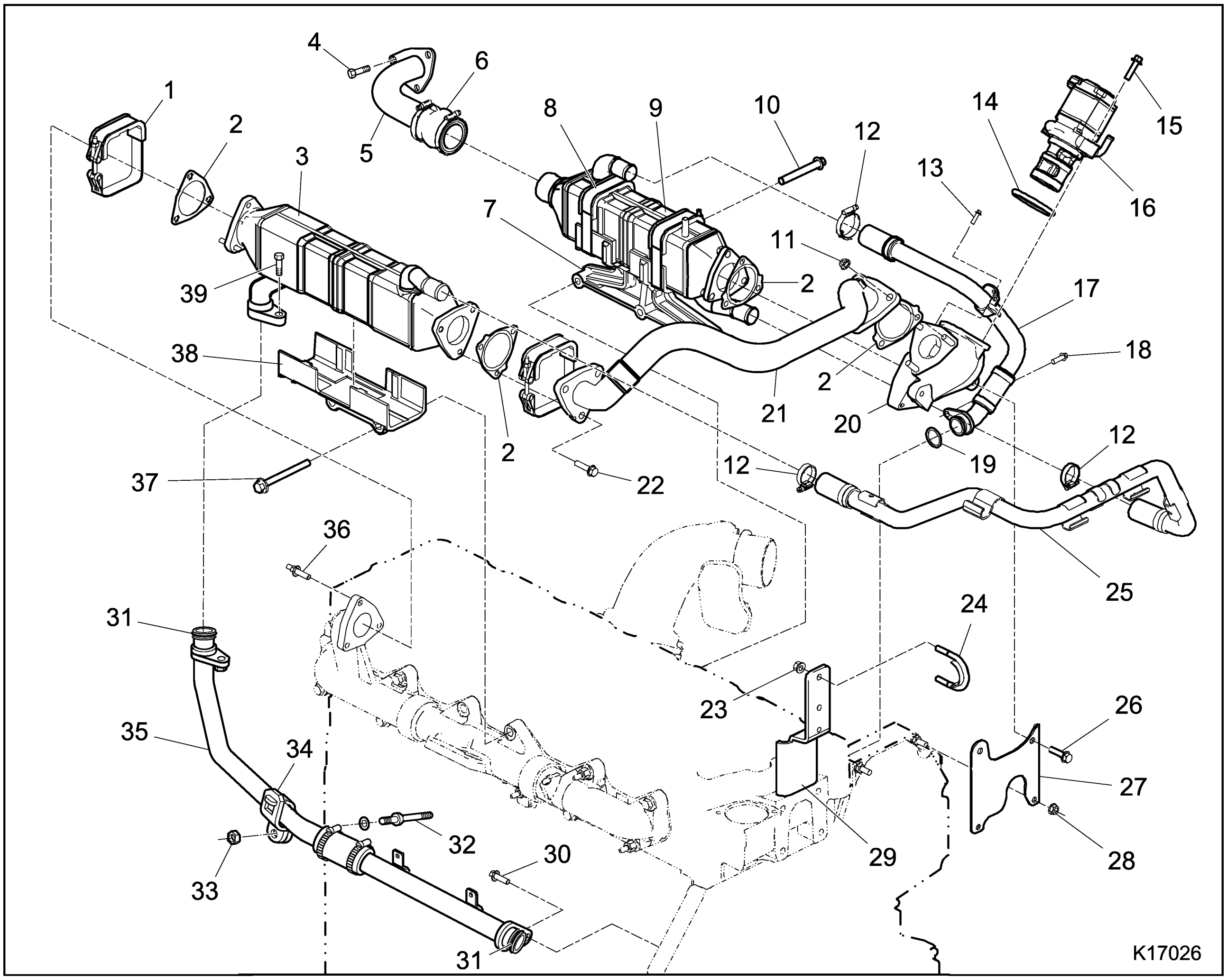


**Figure 131 EGR system components**

1. EGR cooler clamp (2)
2. Exhaust tube gasket (4)
3. Exhaust side EGR cooler
4. M8 x 30 bolt (3)
5. EGR distribution tube
6. EGR cooler to duct hose
7. Intake side EGR cooler bracket
8. EGR cooler clamp (2)
9. Intake side EGR cooler
10. M10 x 70 bolt (3)
11. M8 nut (3)
12. Hose clamp
13. M6 x 12 bolt
14. EGR valve seal
15. M8 x 40 bolt (2)
16. EGR valve
17. EGR coolant return tube
18. M8 x 16 bolt
19. EGR coolant return tube O-ring
20. EGR valve manifold
21. EGR tube assembly
22. M8 x 26 bolt (See EGR Tube Assembly (page 174))
23. M8 nut (2)
24. U-Bolt
25. Coolant crossover tube assembly
26. M8 x 26 bolt (2)
27. EGR valve manifold support
28. M8 nut (2)
29. Tube support
30. M8 x 25 bolt
31. O-ring
32. M8 x 30 stud bolt and 5/16 ID flat washer
33. M8 nut
34. 2-piece tube support
35. EGR coolant supply tube
36. M8 x 30 stud bolt (See EGR Cooler and Bracket - Exhaust Side (page 178))
37. M12 x 70 bolt (2)
38. Exhaust side EGR cooler bracket
39. M8 x 25 bolt

## Removal

**CAUTION:**

**To prevent engine damage, do not use air tools to remove EGR system nuts and bolts. EGR system nuts and bolts will be damaged if removed too quickly.**

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

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

See Exhaust Gas Recirculation (EGR) System (page 23) for description.

**EGR Coolant Supply Tube**

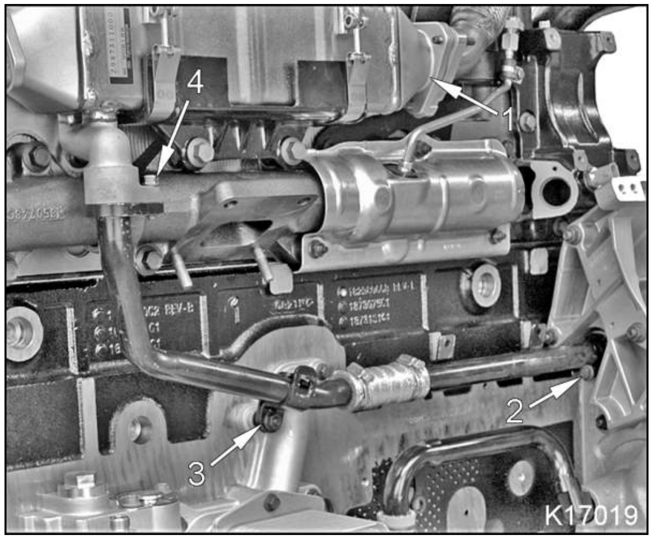


**Figure 132 EGR coolant supply tube**

1. Exhaust side EGR cooler assembly
2. M8 x 25 bolt (front cover EGR coolant supply port)
3. M8 nut, 2-piece tube support, and flat washer
4. M8 x 25 bolt

1. Remove M8 nut, 2-piece tube support, and flat washer.
2. Remove M8 x 25 bolt from the front cover EGR coolant supply port.
3. Remove M8 x 25 bolt from the exhaust side EGR cooler.
4. Pull EGR coolant supply tube down and out of the exhaust side EGR cooler.
5. Pull EGR coolant supply tube back and out of the front cover.
6. Discard two coolant supply tube O-rings.

### EGR Tube Assembly

1. Remove crankcase ventilation inlet tube (page 595).


**Figure 133 EGR tube assembly – exhaust side**

1. M8 x 30 stud bolt
2. M8 x 26 bolt (2)
3. Exhaust tube gasket

2. Remove M8 x 30 stud bolt and two M8 x 26 bolts from the EGR tube assembly at the exhaust side EGR cooler outlet.

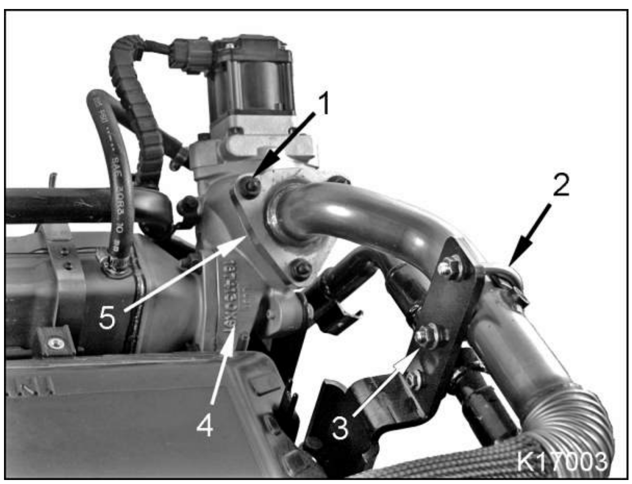


**Figure 134 EGR tube assembly – intake side**

1. M8 nut (3)
2. U-bolt
3. M8 nut (2)
4. EGR valve manifold assembly
5. Exhaust tube gasket

3. Remove three M8 nuts from the EGR tube assembly at the EGR valve manifold.
4. Remove two M8 nuts from U-bolt and remove U-bolt.
5. Pull EGR tube assembly off engine.
6. Remove and discard exhaust tube gaskets.

**Coolant Crossover Tube and Support Bracket**

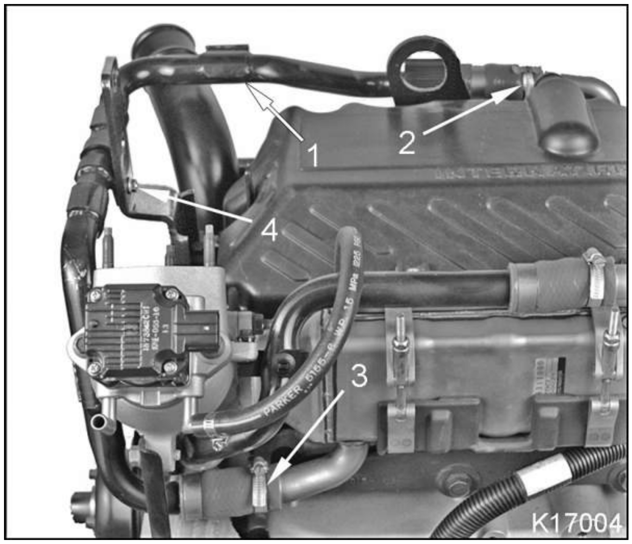


**Figure 135 Coolant crossover tube assembly**

1. Coolant crossover tube
2. Hose clamp (exhaust side)
3. Hose clamp (intake side)
4. M6 nut

1. Loosen hose clamps on ends of coolant crossover tube assembly.
2. Remove M6 nut on tube support bracket.
3. Pull coolant crossover hoses off each EGR cooler.
4. Pull crossover tube assembly forward and remove from engine.


**Figure 136 Tube support bracket**

1. M10 x 100 bolt (2)
2. Tube support bracket

5. Remove two M10 x 100 bolts and remove tube support bracket.

**EGR Cooler and Bracket – Exhaust Side**

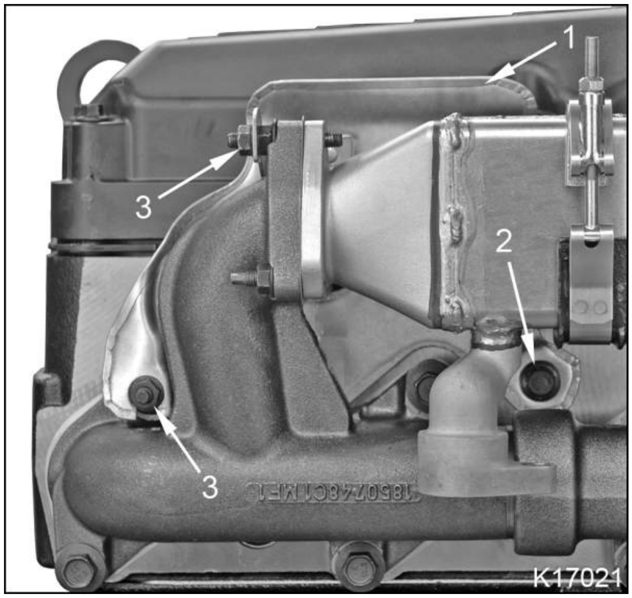


**Figure 137 Rear heat shield, exhaust side EGR cooler**

1. Heat shield
2. M10 x 20 bolt
3. M8 nut (2)

1. Remove M10 x 20 bolt.
2. Remove two M8 nuts from exhaust manifold stud bolts.
3. Pull up and wiggle heat shield to remove.

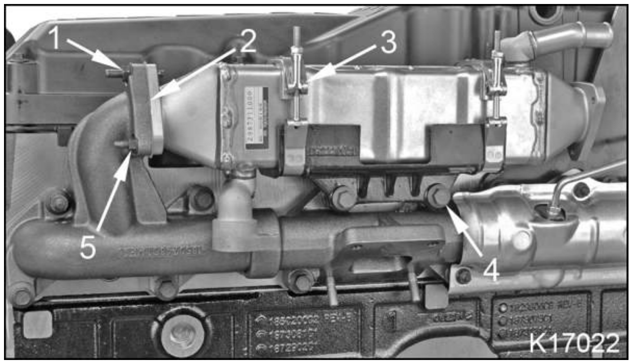


**Figure 138 Exhaust side EGR cooler and bracket**

1. M8 x 30 stud bolt
2. Exhaust tube gasket
3. EGR cooler clamp (2)
4. M12 x 70 bolt (2)
5. M8 nut (2)

4. Remove M8 x 30 stud bolt and two M8 nuts connecting the exhaust side EGR cooler to the exhaust manifold.
5. Remove two M12 x 70 EGR cooler bracket bolts and remove EGR cooler assembly from engine.
6. Discard exhaust tube gasket.
7. Remove and discard EGR cooler clamps.

### EGR Coolant Return Tube

1. Disconnect sensor harness connector from the EGR valve.

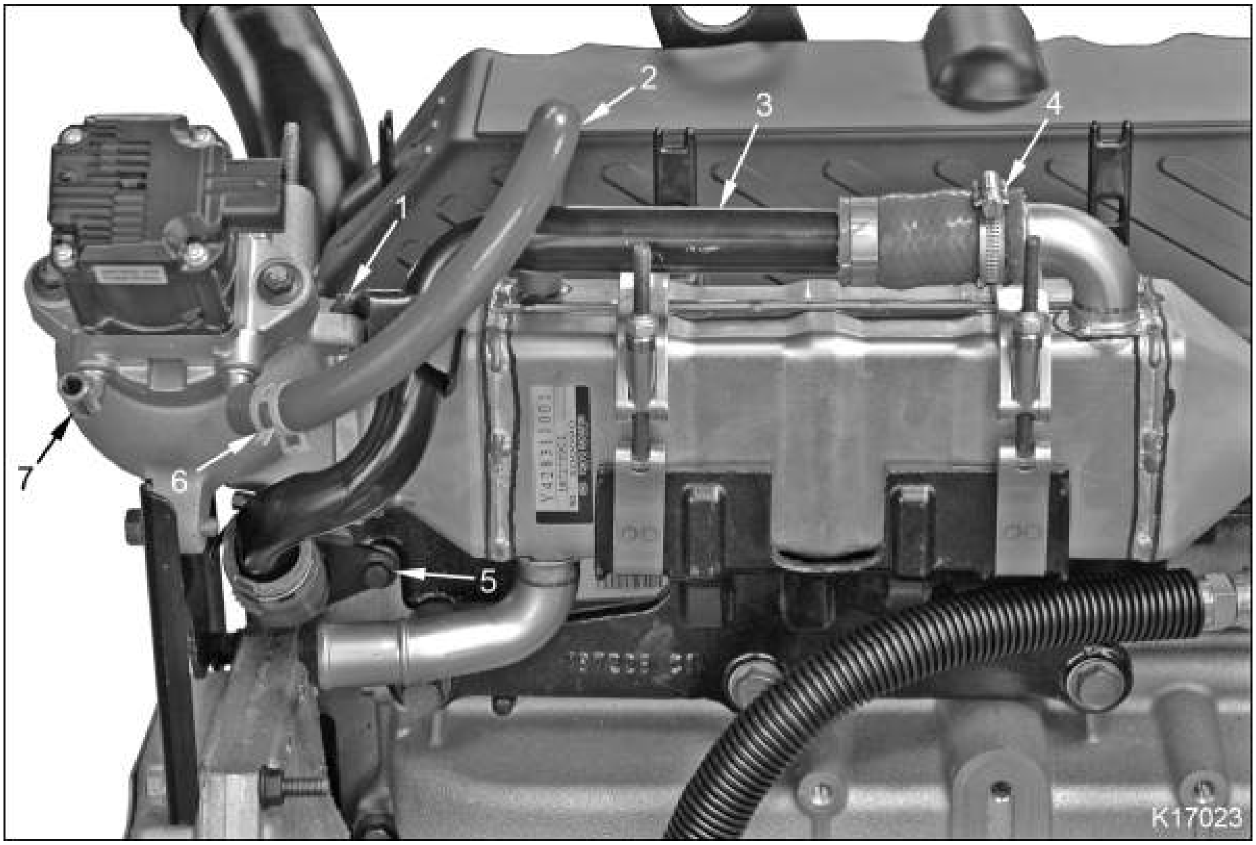


**Figure 139 EGR coolant return tube and intake side EGR cooler**

1. M6 x 12 bolt
2. EGR valve coolant hose
3. EGR coolant return tube
4. Hose clamp
5. M8 x 16 bolt
6. Spring hose clamp (2)
7. Coolant overflow hose fitting

2. Loosen hose clamp and remove coolant overflow hose from EGR valve.
3. Loosen two spring hose clamps and pull EGR valve coolant hose off the intake side EGR cooler and EGR valve.
4. Remove M6 x 12 bolt supporting the EGR coolant return tube.
5. Loosen hose clamp connecting the EGR coolant return tube hose to the intake side EGR cooler.
6. Remove M8 x 16 bolt holding the EGR coolant return tube to the cylinder head.
7. Pull EGR coolant return tube out of cylinder head and then pull off of intake side EGR cooler.
8. Remove and discard coolant return tube O-ring.

**EGR Valve Manifold Assembly**

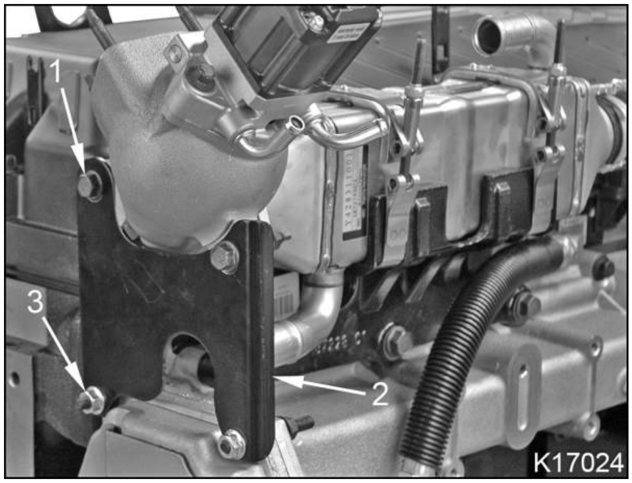


**Figure 140 EGR valve manifold support**

1. M8 x 26 bolt (2)
2. EGR valve manifold support
3. M8 nut (2)

1. Remove two M8 nuts connecting the EGR manifold support to the front cover.
2. Remove two M8 x 25 bolts and remove EGR manifold support.

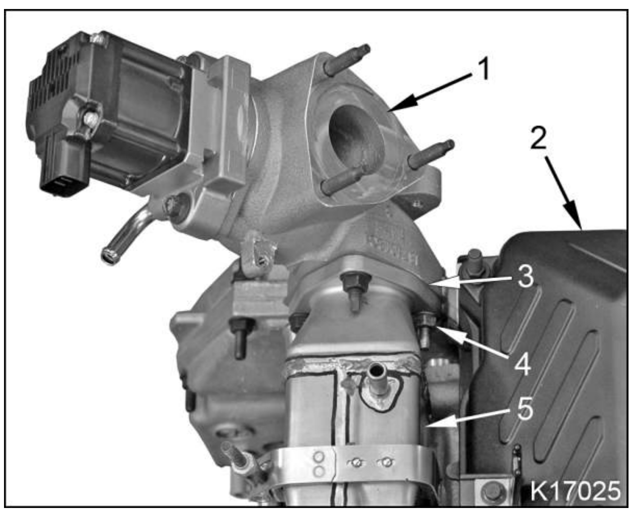


**Figure 141 EGR valve manifold assembly (top view)**

1. EGR valve manifold assembly
2. Valve cover
3. Exhaust tube gasket
4. M8 nut (3)
5. Intake side EGR cooler

3. Remove three M8 nuts securing the EGR valve manifold assembly to the intake side EGR cooler and slide assembly off EGR cooler. If required to access the inner M8 nut, remove the valve cover (page 427) or the intake side EGR cooler (page 184).
4. Discard exhaust tube gasket.

### EGR Distribution Tube Assembly

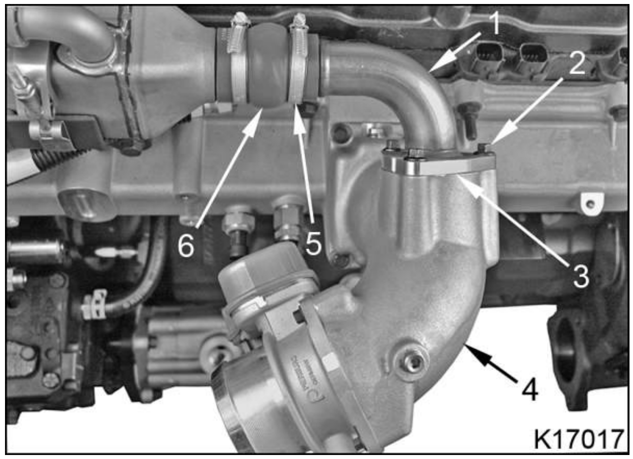


**Figure 142 EGR distribution tube (top view)**

1. EGR distribution tube
2. M8 x 30 bolt (3)
3. Exhaust tube gasket
4. EGR and inlet air mixer duct
5. Hose clamp
6. EGR cooler to duct hose

1. Loosen hose clamps holding the EGR distribution tube to the EGR cooler to duct hose.
2. Remove three M8 x 30 bolts holding distribution tube to the EGR and inlet air mixer duct.
3. Remove EGR distribution tube and discard exhaust tube gasket.

### EGR Cooler and Bracket – Intake Side

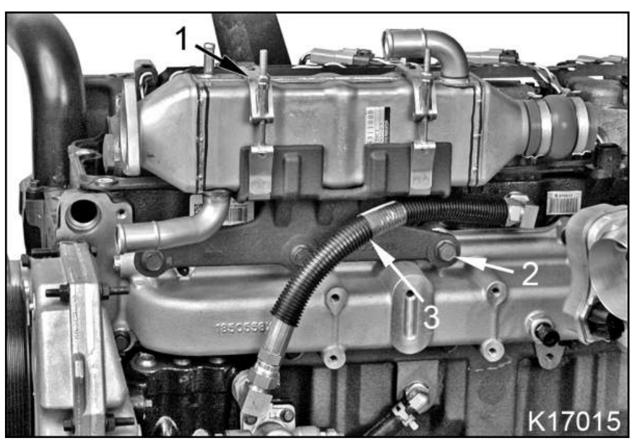


**Figure 143 Intake side EGR cooler assembly and high-pressure oil hose**

1. EGR cooler clamp (2)
2. M10 x 70 bolt (3)
3. High-pressure oil hose

1. Remove conduit cover (plastic cover) from the high-pressure oil hose.
2. Loosen center EGR cooler bracket M10 x 70 bolt all the way.
3. Remove two M10 x 70 bolts from the ends of the intake side EGR cooler bracket.
4. Slide the center M10 x 70 bolt out, rotate EGR cooler assembly, and carefully remove cooler assembly from the engine with out disturbing the high-pressure oil hose.
5. Remove and discard EGR cooler clamps.

## Cleaning, Inspection, and Testing

**WARNING:**

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

### Clean and Inspect EGR System Components

1. Clean gasket material and carbon deposits off exhaust side EGR cooler and exhaust manifold mating surfaces.
2. Clean gasket mating surfaces of EGR tube, intake side EGR cooler, EGR distribution tube, and EGR and inlet air mixer duct.
3. Clean gasket mating surfaces of EGR valve manifold assembly and remove carbon deposits.
4. Clean corrosion from ends of all EGR system coolant pipes and hoses.
5. Clean EGR coolant supply port in the back of the front cover assembly and clean coolant return port in the intake side of the cylinder head.
6. Inspect all EGR system components for cracks, leaks, and damage. Replace damaged parts.

### Pressure Test EGR Coolers

1. Follow direction included in EGR Leak Detection Kit.

## Installation

**CAUTION:**

**To prevent engine damage, do not use air tools to install EGR system nuts and bolts. EGR system nuts and bolts will be damaged if installed too quickly.**

**NOTE:** Apply a light coat of clean engine oil on bolt threads and under bolt head when installing used nuts and bolts.

**EGR Cooler and Bracket – Intake Side**

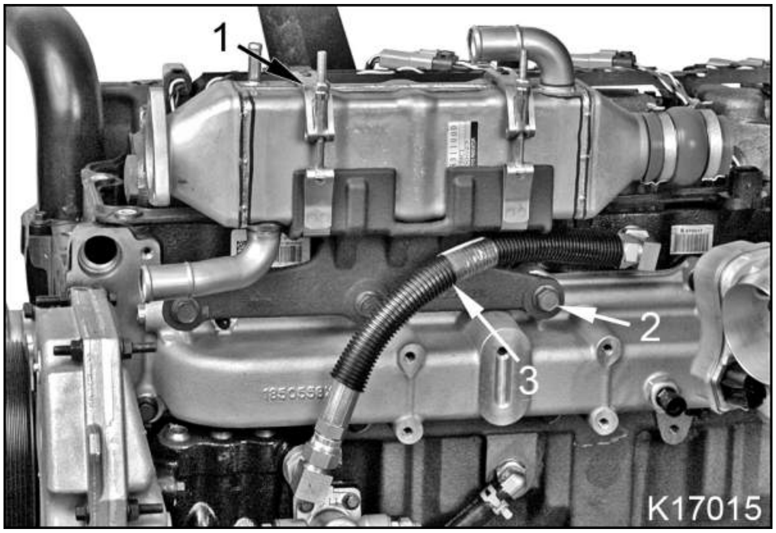


**Figure 144 Intake side EGR cooler assembly and high-pressure oil hose**

1. EGR cooler clamp (2)
2. M10 x 70 bolt (3)
3. High-pressure oil hose

1. Loosely assemble the intake side EGR cooler, cooler bracket, and two new EGR cooler clamps.
2. Install the center M10 x 70 bolt in the EGR cooler bracket.
3. Install the intake side EGR cooler assembly on the engine while not disturbing the high-pressure oil hose.
4. Install two M10 x 70 bolts in the ends of the EGR cooler bracket.
5. If the intake manifold was removed, torque intake manifold bolts to standard torque (page 683) in proper sequence (page 214).
6. Tighten three M10 x 70 bolts to standard torque.
7. Install high-pressure oil hose conduit cover.

**CAUTION:**

**To prevent engine damage, install all EGR system components before tightening the EGR cooler clamps.**

8. Pre-tighten EGR cooler clamp nuts to 8 N·m (71 lbf·in).

9. Loosen both EGR clamp nuts two turns (720 degrees).
10. Tighten EGR cooler clamp nuts to a final torque of 7 N·m (60 lbf·in).

### EGR Distribution Tube Assembly

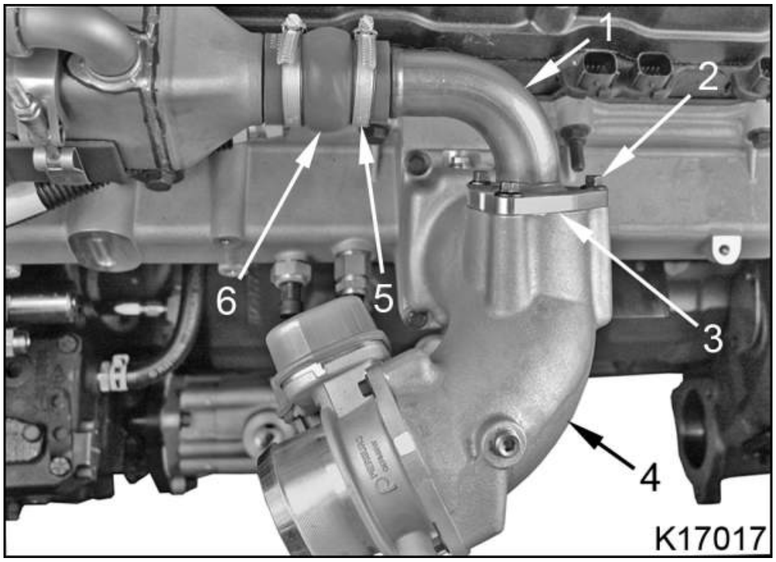


**Figure 145 EGR distribution tube**

1. EGR distribution tube
2. M8 x 30 bolt (3)
3. Exhaust tube gasket
4. EGR and inlet air mixer duct
5. Hose clamp
6. EGR cooler to duct hose

1. Push EGR distribution tube end into the EGR cooler to duct hose.
2. Install a new exhaust tube gasket on the EGR distribution tube flange and install into the EGR and inlet air mixer duct.
3. Install three M8 x 30 bolts and tighten to special torque (page 199).
4. Tighten hose clamps securing the EGR distribution tube to the EGR cooler to duct hose.

### EGR Valve Manifold Assembly

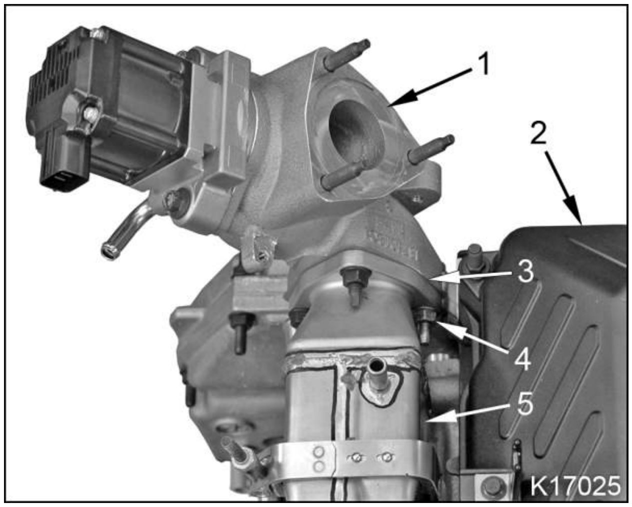


**Figure 146 EGR valve manifold and intake side EGR cooler**

1. EGR valve manifold assembly
2. Valve cover
3. Exhaust tube gasket
4. M8 nut (3)
5. Intake side EGR cooler

1. Install a new exhaust tube gasket on the EGR valve manifold assembly and slide the assembly on the intake side EGR cooler.
2. Install three M8 nuts and tighten to standard torque (page 683).
3. Install valve cover (page 482), if removed.

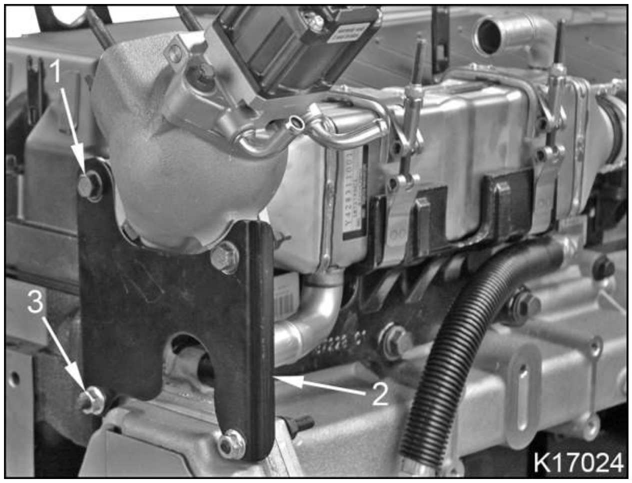


**Figure 147 EGR valve manifold support**

1. M8 x 26 bolt (2)
2. EGR valve manifold support
3. M8 nut (2)

4. Install EGR manifold support on EGR valve manifold and front cover.
5. Install two M8 x 26 bolts and two M8 nuts finger tight.
6. Tighten two M8 x 26 bolts and two M8 nuts to standard torque (page 683).

### EGR Coolant Return Tube

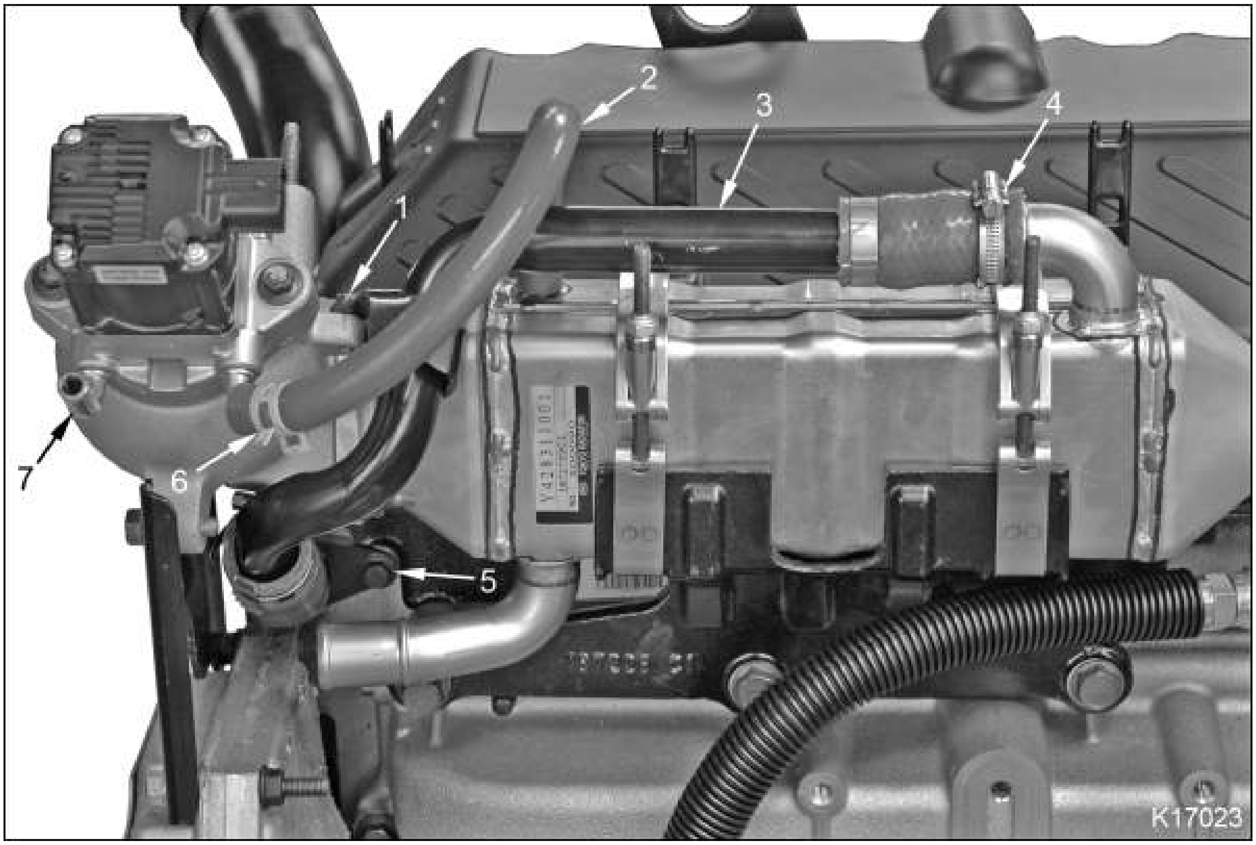


**Figure 148 EGR coolant return tube and intake side EGR cooler**

1. M6 x 12 bolt
2. EGR valve coolant hose
3. EGR coolant return tube
4. Hose clamp
5. M8 x 16 bolt
6. Spring hose clamp (2)
7. Coolant overflow hose fitting

1. Install a new O-ring on the EGR coolant return tube.
2. Push EGR coolant return tube hose onto intake side EGR cooler fitting.
3. Push coolant return tube into coolant port in the cylinder head while aligning tube retaining bracket with its mount on the EGR manifold.
4. Install M8 x 16 bolt and finger tighten.
5. Install M6 x 12 bolt and finger tighten.
6. Tighten M8 x 16 bolt to standard torque (page 683).
7. Tighten M6 x 12 bolt to standard torque.
8. Tighten hose clamps on EGR coolant return tube hoses.
9. Push EGR valve coolant hose ends onto hose fitting of the intake side EGR cooler and EGR valve. Install hose clamps.
10. Install coolant overflow hose on EGR valve and tighten hose clamp.

### EGR Cooler and Bracket – Exhaust Side

1. If the exhaust manifold was removed, torque exhaust manifold bolts to special torque in proper sequence (page 213).
2. Install two M8 x 11.5 studs into the exhaust side EGR cooler inlet flange lower two bolt holes. Torque studs to 14 N·m (120 lbf·in).
3. Loosely assemble the exhaust side EGR cooler, cooler bracket, and two new EGR cooler clamps.
4. Install a new exhaust tube gasket on the exhaust side EGR cooler inlet flange studs.

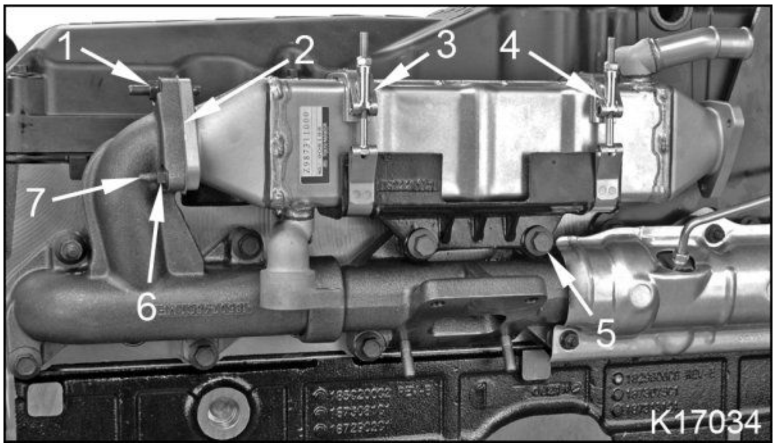


**Figure 149 Exhaust side EGR cooler and bracket**

1. M8 x 30 stud bolt
2. Exhaust tube gasket (inlet flange)
3. EGR cooler clamp (inlet)
4. EGR cooler clamp (outlet)
5. M12 x 70 bolt (2)
6. M8 nut (2)
7. M8 x 11.5 stud (2)

5. Install exhaust side EGR cooler assembly on the exhaust manifold and install two M12 x 70 bolts finger tight.

**CAUTION:**

**To prevent EGR cooler and engine damage, tighten EGR cooler clamps and bolts as follows.**

6. Install M8 x 30 stud bolt and two M8 nuts and tighten to standard torque (page 683).
7. Pre-tighten EGR cooler clamp (inlet) nut to 5.4 N·m (48 lbf·in).
8. Loosen EGR clamp (inlet) nut two turns (720 degrees).
9. Tighten EGR cooler clamp (inlet) nut to a final torque of 6.8 N·m (60 lbf·in).
10. Pre-tighten EGR cooler clamp (outlet) nut to 5.4 N·m (48 lbf·in).
11. Loosen EGR clamp (outlet) nut two turns (720 degrees).
12. Tighten EGR cooler clamp (outlet) nut to a final torque of 6.8 N·m (60 lbf·in).

13. Tighten two M12 x 70 bolts to special torque (page 199).

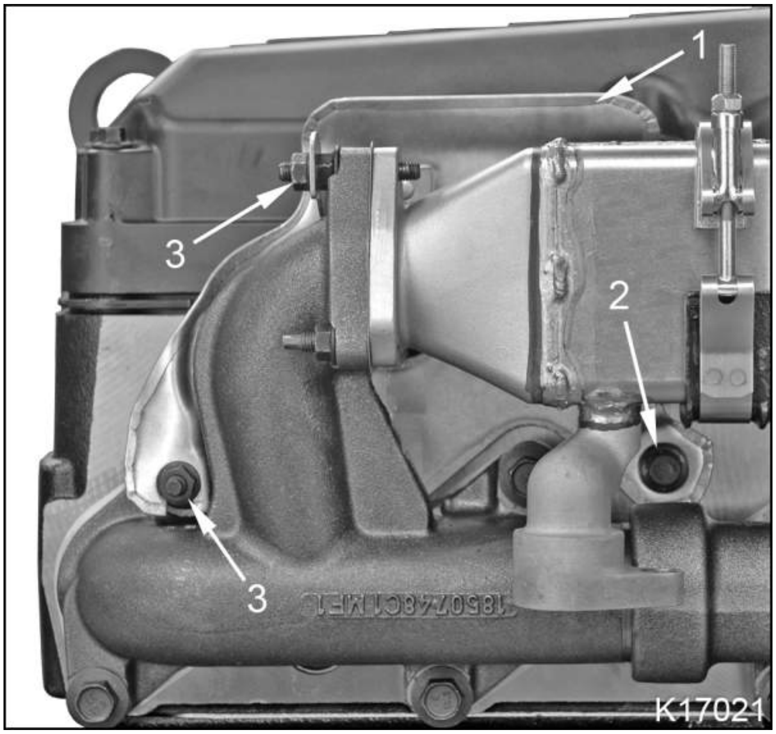


**Figure 150 Rear heat shield, exhaust side EGR cooler**

1. Heat shield
2. M10 x 20 bolt
3. M8 nut (2)

14. Position heat shield for installation and push down to fit in place.
15. Install heat shield slots over exhaust manifold stud bolts.
16. Install M10 x 20 bolt and tighten to standard torque (page 683).
17. Install two M8 heat shield nuts on exhaust manifold stud bolts and tighten to special torque (page 199).

**Coolant Crossover Tube and Support Bracket**


**Figure 151 Tube support bracket**

1. M10 x 100 bolt (2)
2. Tube support bracket

1. Install tube support bracket onto cylinder head and finger tighten two M10 x 100 bolts.
2. Tighten two M10 x 100 bolts to standard torque (page 683).

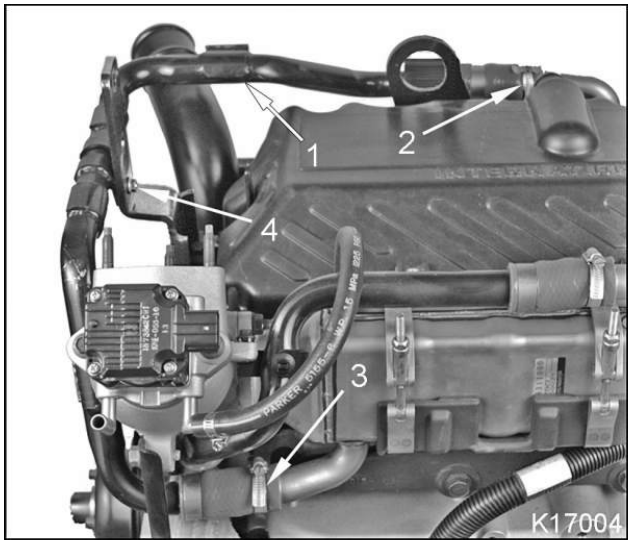


**Figure 152 Coolant crossover tube assembly**

1. Coolant crossover tube
2. Hose and hose clamp (exhaust side)
3. Hose and hose clamp (intake side)
4. M6 nut

3. Position the coolant crossover tube assembly on the engine and align the intake and exhaust side hoses onto the intake and exhaust side EGR cooler coolant fittings.
4. Push each coolant crossover tube assembly hose onto its EGR cooler fitting while aligning and installing the coolant crossover tube retaining stud into the tube support bracket lower hole.
5. Install coolant crossover tube M6 nut and tighten to special torque (page 199).
6. Tighten the intake and exhaust side coolant crossover tube hose clamps.

### EGR Tube Assembly

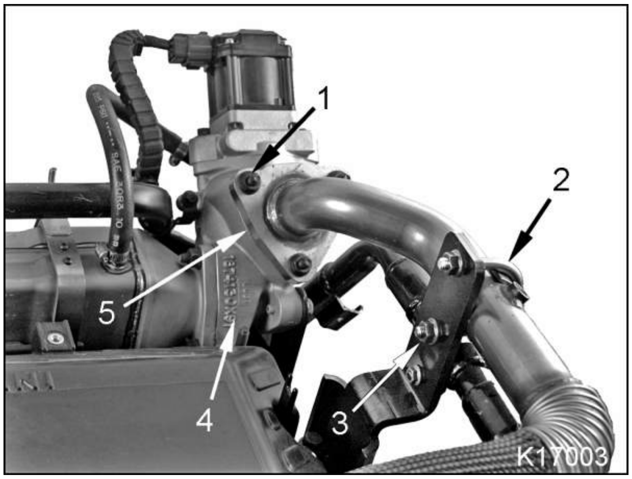


**Figure 153 EGR tube assembly – intake side**

1. M8 nut (3)
2. U-bolt
3. M8 nut (2)
4. EGR valve manifold assembly
5. Exhaust tube gasket

1. Install a new exhaust tube gasket on the EGR valve manifold studs and install EGR tube assembly.


**Figure 154 EGR tube assembly – exhaust side**

1. M8 x 30 stud bolt
2. M8 x 26 bolt (2)
3. Exhaust tube gasket

2. Install a new exhaust tube gasket, M8 x 30 stud bolt, and two M8 x 26 bolts connecting the EGR tube assembly to the exhaust side EGR cooler outlet.

3. Install three M8 nuts securing the EGR tube to the EGR valve manifold.
4. Install threaded ends of U-bolt over the EGR tube and into the support bracket. Install two M8 nuts onto the U-bolt ends and finger tighten nuts to equal positions.
5. Lightly tighten all EGR tube nuts and bolts while ensuring flanges are properly aligned.
6. Tighten M8 x 30 stud bolt and two M8 x 26 bolts to standard torque (page 683).
7. Tighten three M8 nuts securing the EGR tube to the EGR valve manifold to standard torque.

**CAUTION:**

**To prevent engine damage, do not crush EGR tube when torquing U-bolt M8 nuts.**

8. Evenly tighten two M8 nuts securing the U-bolt on the support bracket to special torque (page 199). Do not crush EGR tube when torquing nuts.

### EGR Coolant Supply Tube

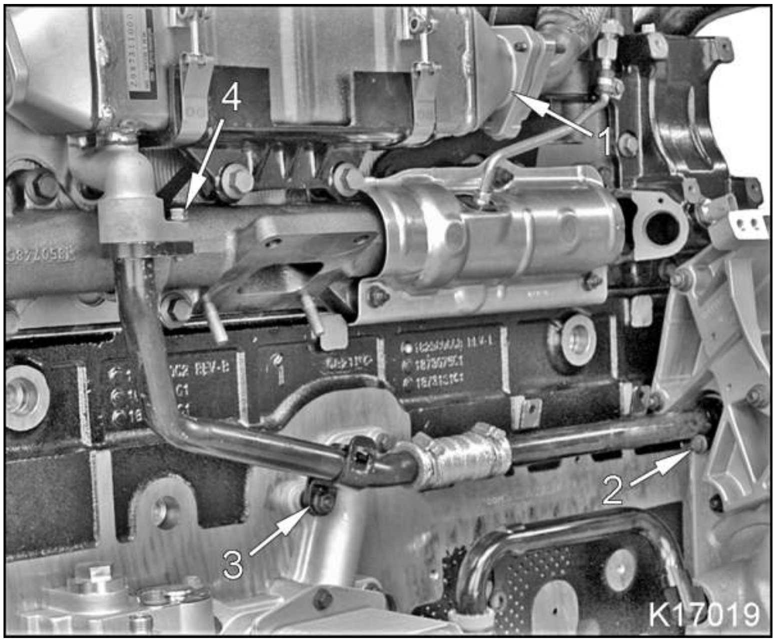


**Figure 155 EGR coolant supply tube**

1. Exhaust side EGR cooler assembly
2. M8 x 25 bolt (front cover EGR coolant supply port)
3. M8 nut, 2-piece tube support, and flat washer
4. M8 x 25 bolt

1. Install new O-rings on the EGR coolant supply tube ends.
2. Push EGR coolant supply tube end into coolant port on the back of front cover.
3. Push other coolant supply tube end onto the exhaust side EGR cooler fitting.
4. Install flat washer on oil system module stud bolt.
5. Install and position 2-piece tube support bracket on the EGR coolant supply tube
6. Install 2-piece tube support and M8 nut on the oil system module stud bolt and finger tighten M8 nut.
7. Install M8 x 25 bolt securing the EGR coolant supply tube to the front cover and tighten to standard torque (page 683).
8. Install M8 x 25 bolt securing the EGR coolant supply tube to the exhaust side EGR cooler fitting and tighten to standard torque.
9. Tighten M8 nut to special torque (page 199).

## Special Torque

| | |
|---|---|
| Coolant crossover tube M6 nut | 5 N·m (41 lbf·in) |
| EGR coolant supply tube retaining M8 nut | 26 N·m (19 lbf·ft) |
| EGR cooler clamp nut | See EGR Cooler – Intake Side (page 186) and Exhaust Side (page 192) installation. |
| EGR distribution tube M8 x 30 bolt | 26 N·m (19 lbf·ft) |
| EGR tube assembly U-bolt M8 nut | Lightly tighten nuts to equal positions, then evenly torque nuts to 15 N·m (132 lbf·in) (do not crush EGR tube) |
| EGR valve manifold and EGR cooler studs | 14 N·m (120 lbf·in) |
| Exhaust side EGR cooler bracket M12 x 70 bolt | 105 N·m (77 lbf·ft) |
| Exhaust side EGR cooler inlet heat shield M8 nuts | 26 N·m (19 lbf·ft) |

## Special Service Tools

| |
|---|
| EGR Leak Detection Kit |

# Table of Contents

## Exploded View

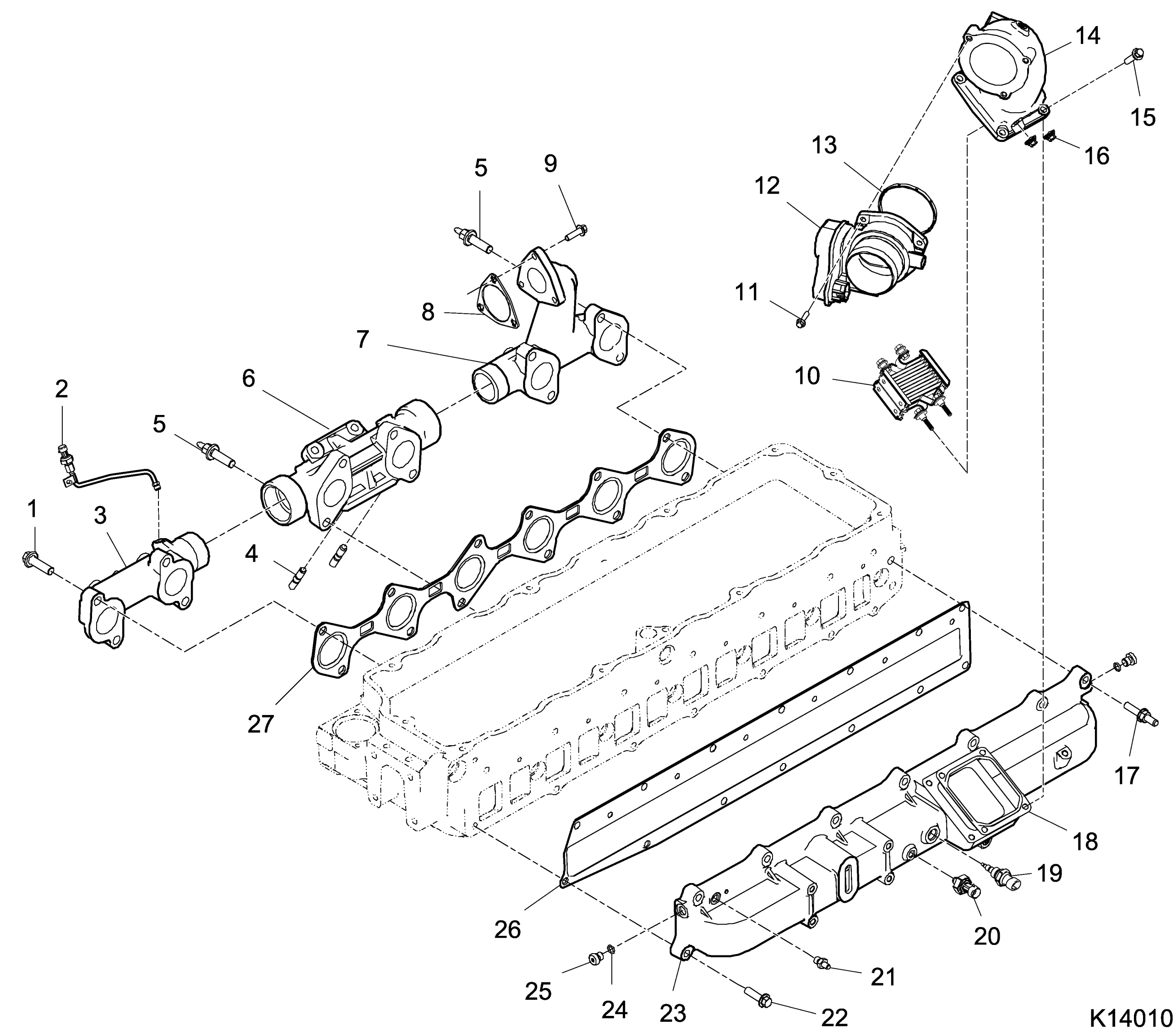


**Figure 156 Intake manifold, EGR and inlet air mixer, and exhaust manifold assemblies**

1. M12 x 40 bolt (5)
2. Exhaust Back Pressure (EBP) sensor assembly
3. Exhaust manifold front section
4. Turbocharger adaptor stud (2)
5. M12 x 40 stud bolt (5)
6. Exhaust manifold center section
7. Exhaust manifold rear section
8. Exhaust gasket
9. M8 x 30 stud bolt
10. Inlet Air Heater (IAH) grid
11. M6 x 25 bolt (3)
12. Intake throttle assembly
13. Inlet throttle gasket
14. EGR and inlet air mixer duct assembly
15. M8 x 30 bolt (4)
16. M6 nut (2)
17. M10 x 35 stud bolt (4)
18. Inlet duct to intake manifold gasket
19. Intake Manifold Air Temperature (MAT) sensor
20. Intake Manifold Absolute Pressure (MAP) sensor
21. Fuel valve assembly (Schrader)
22. M10 x 35 bolt (6)
23. Air inlet (intake) manifold assembly
24. O-ring seal (2)
25. M12 plug, fuel rail (2)
26. Intake manifold gasket
27. Exhaust manifold gasket

## Removal

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

**WARNING:**

**To prevent personal injury or death, do not smoke and keep fuel away from flames and sparks.**

**WARNING:**

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

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

**Exhaust Manifold**

1. Remove VGT assembly (page 159).
2. Remove crankcase breather inlet tube assembly (page 595).
3. Remove exhaust side EGR cooler and bracket (page 178).
4. Disconnect EBP sensor connector.

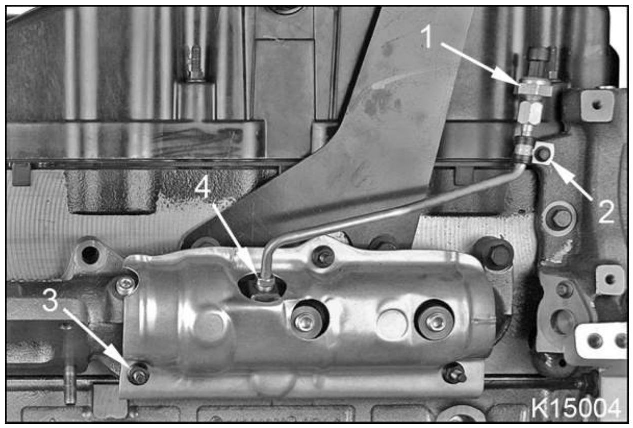


**Figure 157 EBP tube assembly and front exhaust manifold heat shield**

1. Exhaust Back Pressure (EBP) sensor
2. M6 x 12 bolt
3. M8 nut (3)
4. EBP tube nut

5. Remove M6 x 12 bolt from the EBP tube assembly clamp.
6. Remove EBP tubing nut from the exhaust manifold and remove EBP tube assembly.
7. Remove three M8 nuts and remove exhaust manifold heat shield.

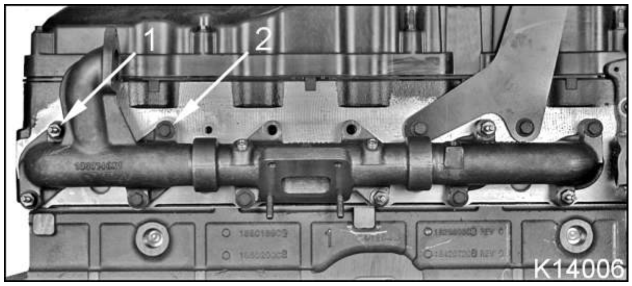


**Figure 158 Exhaust manifold assembly**

1. M12 x 40 stud bolt (5)
2. M12 x 40 bolt (5)

8. Remove five M12 x 40 bolts holding the three-piece exhaust manifold to the cylinder head.
9. Support exhaust manifold and remove five M12 x 40 stud bolts.
10. Remove exhaust manifold assembly from engine and discard exhaust manifold gasket.

### Intake Throttle Assembly

1. Disconnect sensor harness connector from the intake throttle assembly.

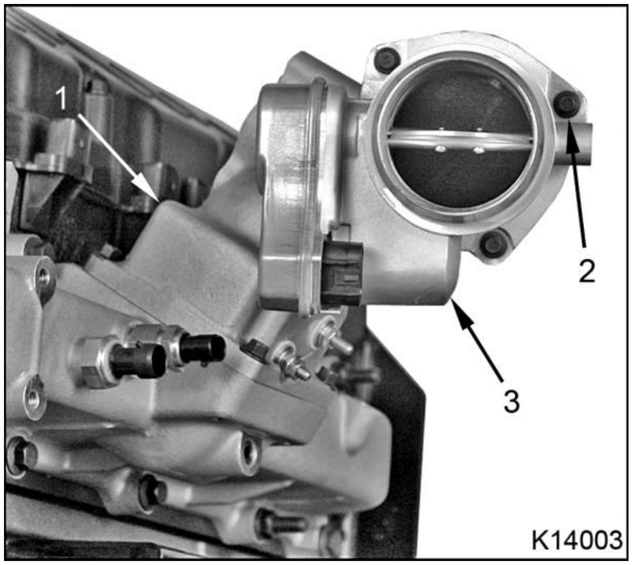


**Figure 159 Intake throttle assembly**

1. EGR and inlet air mixer duct assembly
2. M6 x 25 bolt (3)
3. Intake throttle assembly

2. Remove three M6 x 25 bolts holding the intake throttle assembly to the EGR and inlet air mixer duct and remove throttle assembly.

### EGR and Inlet Air Mixer Duct Assembly

1. Remove the EGR Distribution Tube Assembly (page 183).
2. Disconnect Intake Air Heater (IAH) cables (page 125) from the EGR and inlet air mixer duct.

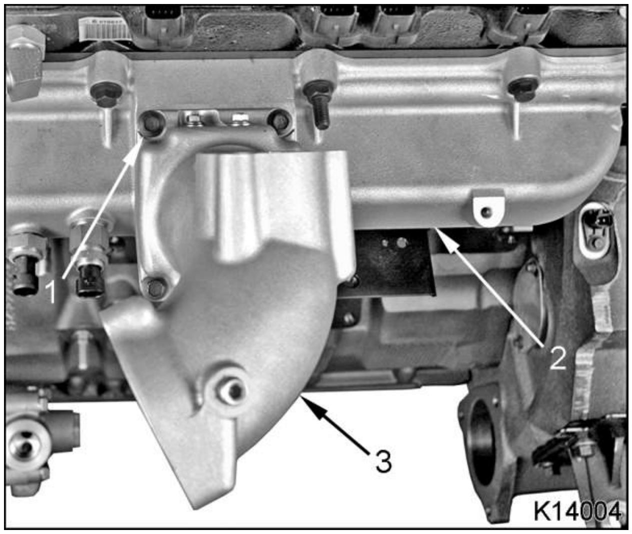


**Figure 160 EGR and inlet air mixer duct**

1. M8 x 30 bolt (4)
2. Intake manifold
3. EGR and inlet air mixer duct

3. Remove four M8 x 30 bolts securing the EGR and inlet air mixer duct to the intake manifold.
4. Remove the EGR and inlet air mixer duct and discard the inlet duct to intake manifold gasket.

**Intake Manifold, Fuel Valve, and Fuel Rail Plugs**

1. Remove the intake side EGR cooler and bracket (page 184).
2. Remove the fuel filter header assembly (page 234).
3. Remove the (IAH) relay assembly (page 125).

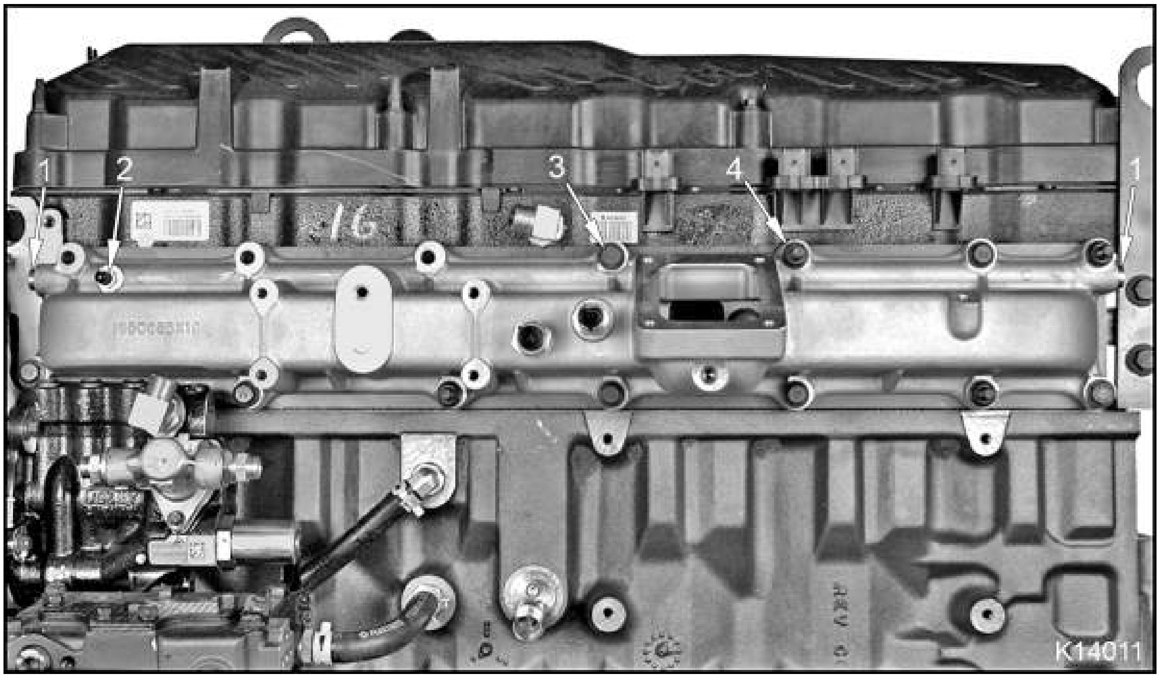


**Figure 161 Intake manifold**

1. M12 Fuel rail plug (2)
2. Fuel valve assembly
3. M10 x 35 bolt (7)
4. M10 x 35 stud bolt (4)

**WARNING:**

**To prevent personal injury or death, do not smoke and keep fuel away from flames and sparks.**

**NOTE:** Removal of the rear engine lifting eye may be required to access the rear fuel rail plug with the intake manifold on engine.

4. Remove M12 fuel rail plugs and drain fuel into a correct container marked DIESEL FUEL.
5. Remove seven M10 x 35 bolts and four M10 x 35 stud bolts securing the intake manifold to the cylinder head.
6. Remove the intake manifold and gasket from the engine. Drain remaining fuel from the intake manifold and discard the intake manifold gasket.
7. Remove and discard O-rings from fuel rail plugs.
8. If required, remove the fuel valve assembly (air bleed and pressure test port) and discard O-ring.

## Cleaning, Inspection, and Measurement

**WARNING:**

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

**Exhaust Manifold**

1. Scrape excess scale and rust from exhaust manifold surfaces.
2. Inspect manifold for cracks and damage. Replace if necessary.
3. Install exhaust manifold (page 212) without gasket onto cleaned cylinder head mating surface.
4. Torque exhaust manifold mounting bolts to special torque in proper sequence (page 213).

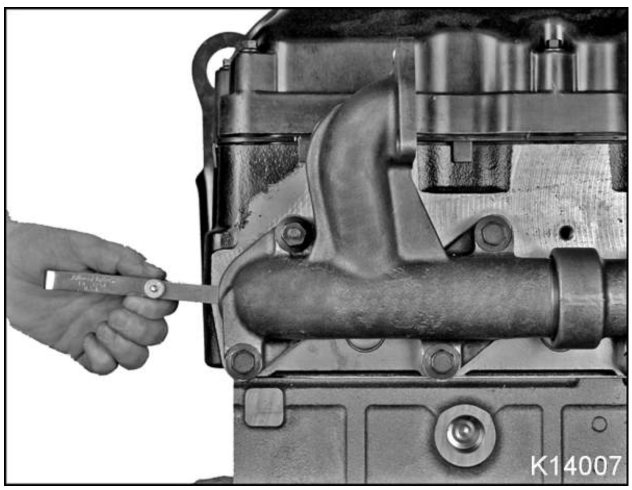


**Figure 162 Exhaust manifold warpage measurement**

5. Measure the gap between the cylinder head and exhaust manifold mating surfaces using a 0.12 mm (0.005 in) feeler gauge (page 217). If the feeler gauge passes through the gap, replace the manifold.

### Intake Manifold

**CAUTION:**

**To prevent engine damage, do not grind or machine intake manifold to compensate for warpage.**

1. Clean intake manifold thoroughly with a suitable non-caustic solvent.
2. Blow manifold dry using filtered compressed air.
3. Inspect intake manifold for cracks and damage. Replace if necessary.

### EGR and Inlet Air Mixer Duct and Intake Throttle Assembly

1. Inspect EGR and inlet air mixer duct and intake throttle assembly for cracks or damage. Replace if necessary.
2. Inspect electrical connections of grid heaters and sensor harness connectors for corrosion or damage. Replace if necessary.

## Installation

**NOTE:** Apply a light coat of clean engine oil on bolt threads and under bolt head when installing used nuts and bolts.

### Exhaust Manifold

1. Assemble exhaust manifold by inserting front and rear exhaust manifold sections into the exhaust manifold center section.
2. Place exhaust manifold gasket on assembled exhaust manifold and insert one exhaust manifold bolt in each end of the assembly. This will help align the exhaust manifold and gasket during installation.

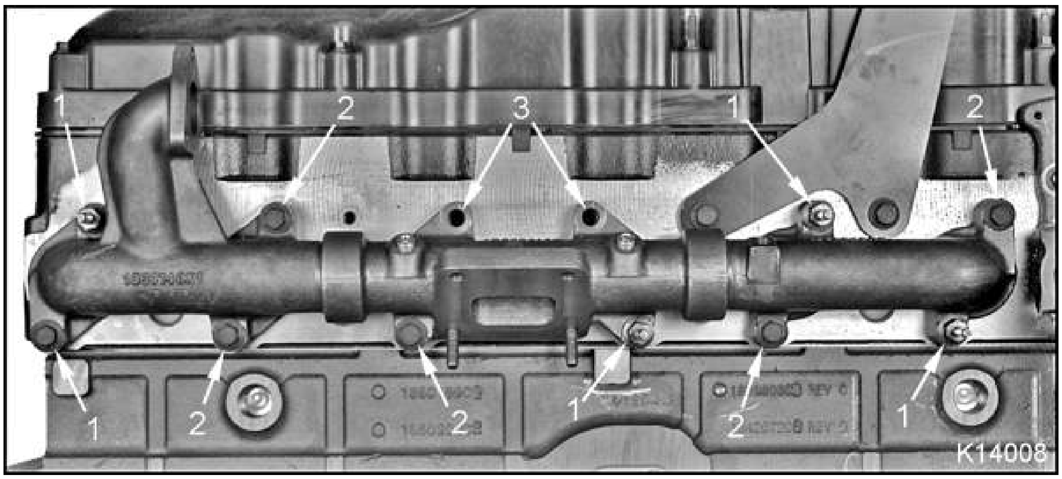


**Figure 163 Exhaust manifold**

1. M12 x 40 stud bolt (5)
2. M12 x 40 bolt (5)
3. M12 x 70 EGR cooler bracket bolt holes

3. Install assembled exhaust manifold and gasket onto cylinder head.
4. Install five M12 x 40 stud bolts and five M12 x 40 bolts finger tight.
5. Install exhaust side EGR cooler bracket and two M12 x 70 bolts (page 192).

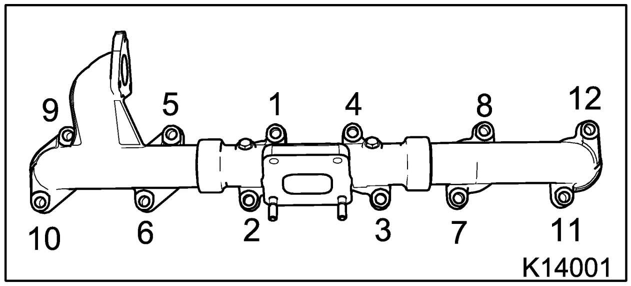


**Figure 164 Exhaust manifold torque sequence**

6. Torque 12 exhaust manifold bolts in the following three step sequence.
   a. Tighten bolts in sequence 1 through 12 to 27 N·m (20 lbf·ft).
   b. Tighten bolts in sequence 1 through 12 to 54 N·m (40 lbf·ft).
   c. Tighten bolts in sequence 1 through 12 to 105 N·m (77 lbf·ft).

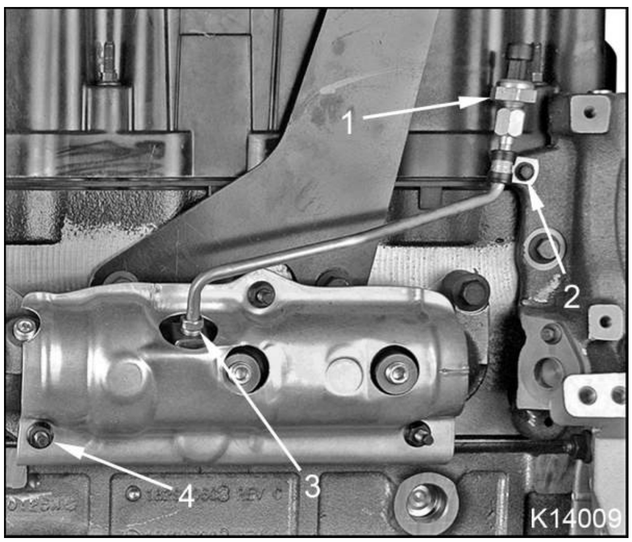


**Figure 165 EBP tube assembly and front exhaust manifold heat shield**

1. EBP sensor
2. M6 x 12 bolt
3. EBP tube nut
4. M8 nut (3)

7. Install front exhaust manifold heat shield on exhaust manifold studs and install three M8 nuts.
8. Tighten three M8 nuts to standard torque (page 683).
9. Install EBP tube nut into exhaust manifold and finger tighten.
10. Install M6 x 12 bolt through the EBP tube clamp and finger tighten.
11. Tighten EBP tube nut.
12. Tighten M6 x 12 bolt to standard torque (page 683).

### Intake Manifold, Fuel Valve, and Fuel Rail Plugs

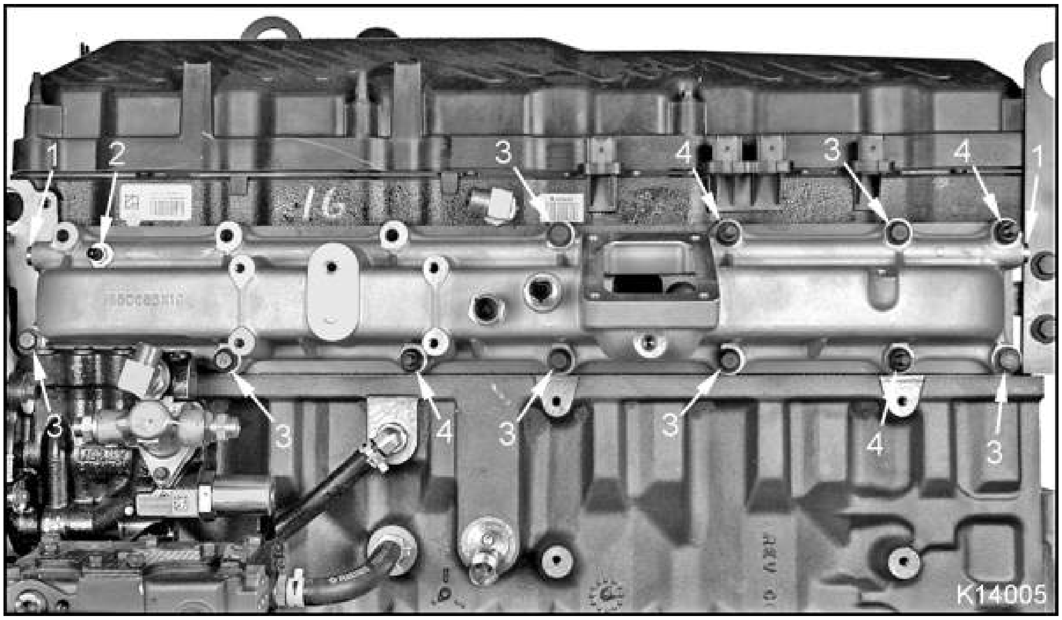


**Figure 166 Intake manifold**

1. M12 fuel rail plug (2)
2. Fuel valve assembly
3. M10 x 35 bolt (7)
4. M10 x 35 stud bolt (4)

1. Install new O-rings on M12 fuel rail plugs and install plugs into ends of intake manifold.
2. Tighten fuel rail plugs to special torque (page 217).
3. Install new O-ring on fuel valve assembly and install valve assembly into intake manifold.
4. Tighten fuel valve assembly to special torque.
5. Place intake manifold gasket on intake manifold and insert one intake manifold bolt in each end of the assembly. This will help align the intake manifold and gasket during installation.
6. Install intake manifold and gasket onto cylinder head.
7. Install four M10 x 35 stud bolts and seven M10 x 35 bolts finger tight.
8. Install intake side EGR cooler bracket and three M10 x 70 bolts (page 186).

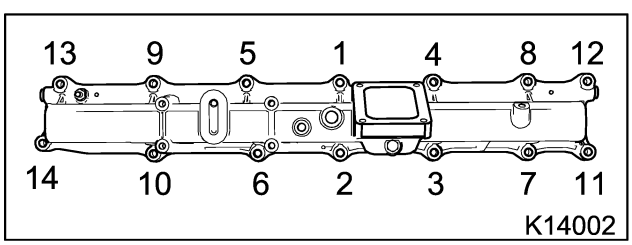


**Figure 167 Intake manifold torque sequence**

9. Tighten intake manifold bolts to standard torque (page 683) in sequence 1 to 14.

### EGR and Inlet Air Mixer Duct Assembly

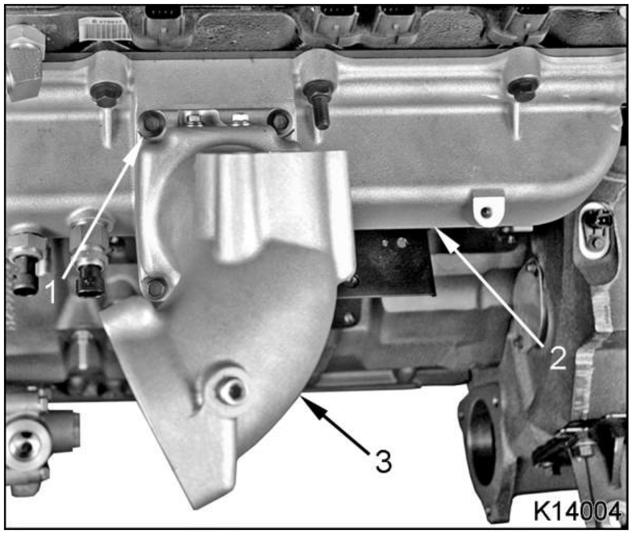


**Figure 168 EGR and inlet air mixer duct**

1. M8 x 30 bolt (4)
2. Intake manifold
3. EGR and inlet air mixer duct

1. Install the EGR and inlet air mixer duct with a new inlet duct to intake manifold gasket on the intake manifold and finger tighten four M8 x 30 bolts.
2. Tighten four M8 x 30 bolts to standard torque (page 683).

### Intake Throttle Assembly

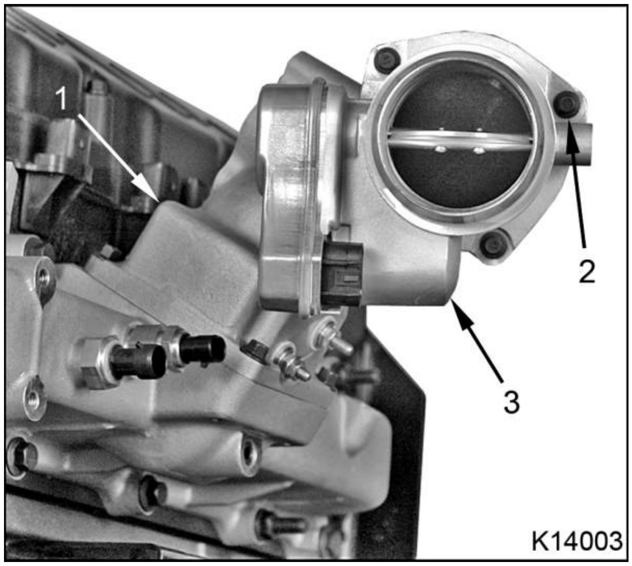


**Figure 169 Intake throttle assembly**

1. EGR and inlet air mixer duct
2. M6 x 25 bolt (3)
3. Intake throttle assembly

1. Install intake throttle assembly on the EGR and inlet air mixer duct and finger tighten three M6 x 25 bolts.
2. Tighten three M6 x 25 throttle assembly bolts to special torque (page 217).

## Special Torque

| | |
|---|---|
| Exhaust manifold mounting bolts | See Exhaust manifold installation for torque and sequence (page 213). |
| Fuel valve assembly (Schrader) | 15 N·m (132 lbf·in) |
| Intake throttle assembly M6 x 25 mounting bolts | 12 N·m (9 lbf·ft) |
| M12 Fuel rail plug | 25 N·m (18 lbf·ft) |

## Special Service Tools

| | |
|---|---|
| Feeler gauge | Obtain locally |

# Table of Contents

# Illustrations and Description

### Low-pressure Fuel System

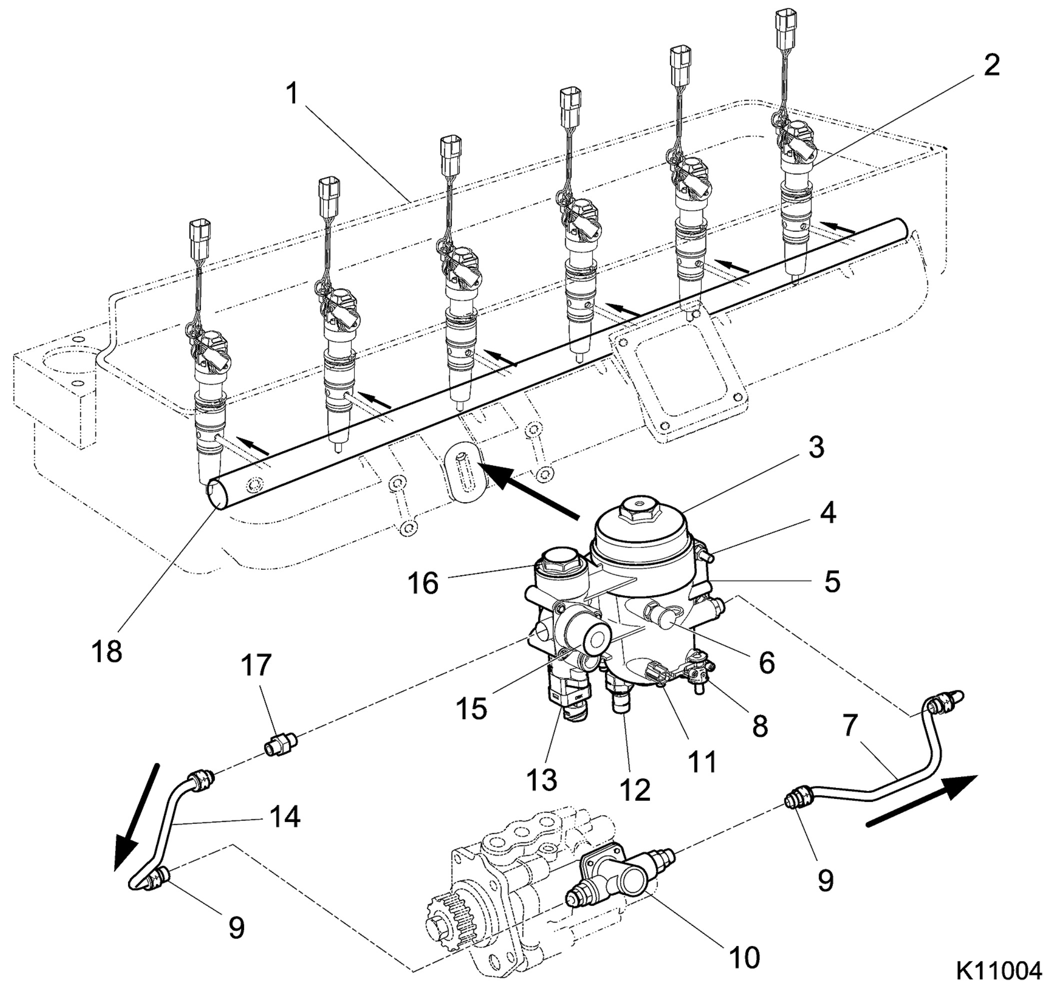


**Figure 170 Low-pressure fuel system**

1. Cylinder head
2. Fuel injector assembly (6)
3. Fuel filter cap
4. M8 x 75 stud bolt
5. Fuel filter header assembly
6. Diagnostic coupling assembly and dust cap
7. Low-pressure fuel pump outlet tube assembly
8. Water drain valve
9. 3/8 tube sleeve (2 each tube)
10. Low-pressure fuel pump
11. Water In Fuel (WIF) sensor
12. Engine Fuel Pressure (EFP) sensor
13. Fuel heater (optional)
14. Low-pressure fuel pump inlet tube assembly
15. Primer pump
16. Fuel strainer cap
17. Fitting assembly with check valve
18. Low-pressure fuel rail (cast in intake manifold)

The low-pressure fuel system draws fuel from the fuel tank with a low-pressure fuel pump. Fuel first enters the fuel filter header, is heated by the optional fuel heater (if necessary) and passes through the fuel strainer. Fuel then passes through the low-pressure fuel pump, tubing, and through the fuel filter. Fuel finally passes through the intake manifold and cylinder head and is delivered to each fuel injector.

### Fuel Filter Header Assembly

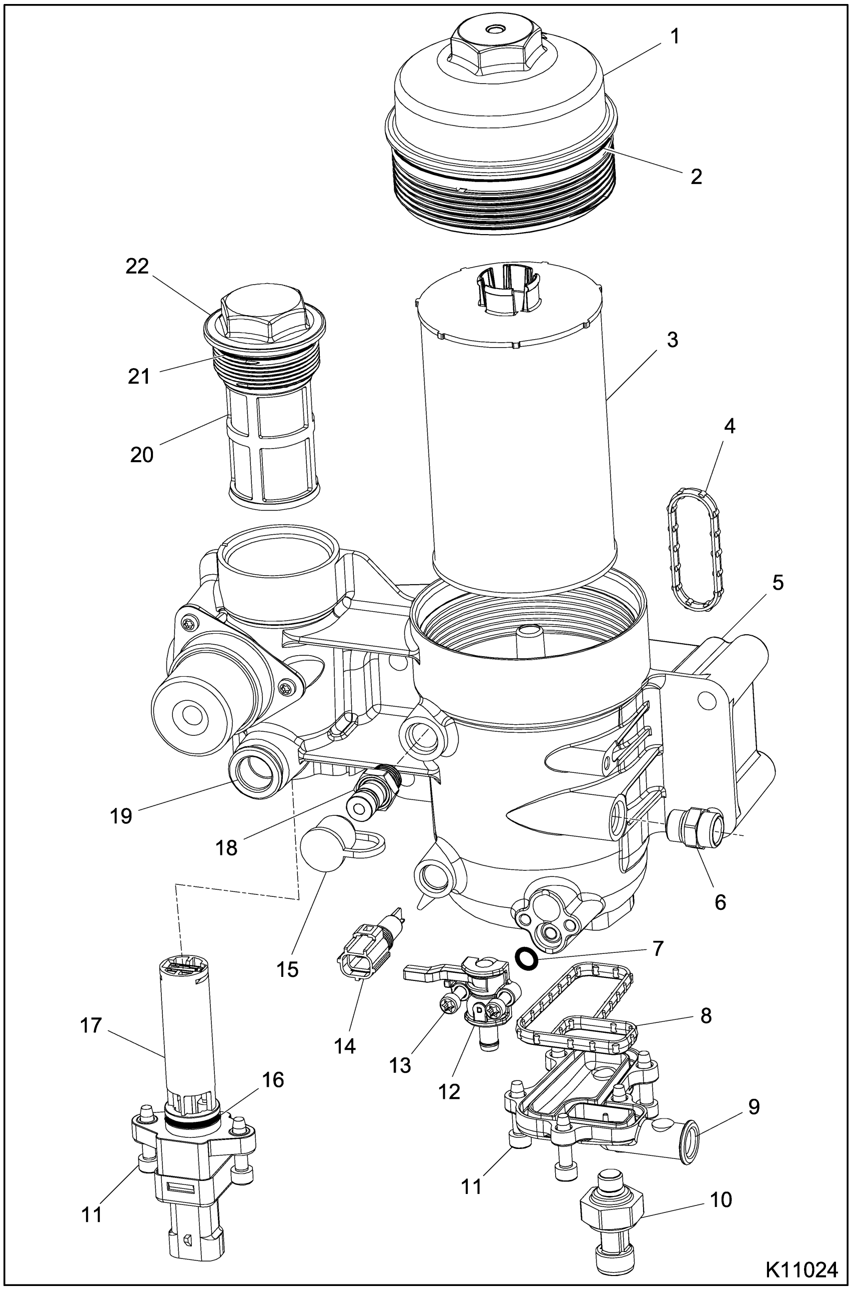


**Figure 171 Fuel filter header assembly**

1. Fuel filter cap
2. O-ring gasket
3. Fuel filter element
4. Irregular molded gasket
5. Filter assembly housing
6. Tube fitting assembly
7. O-ring
8. Cover plate seal
9. Fuel outlet fitting (return to tank)
10. Engine Fuel Pressure (EFP) sensor
11. M6 x 25 bolt
12. Water drain valve assembly
13. M5 screw (2)
14. Water In Fuel (WIF) sensor
15. Dust cap
16. Heater O-ring gasket
17. 250 Watt fuel heater assembly (optional)
18. Diagnostic coupling assembly
19. Fuel inlet fitting (from tank)
20. Fuel strainer element
21. O-ring gasket
22. Strainer lid

### High-pressure Oil System

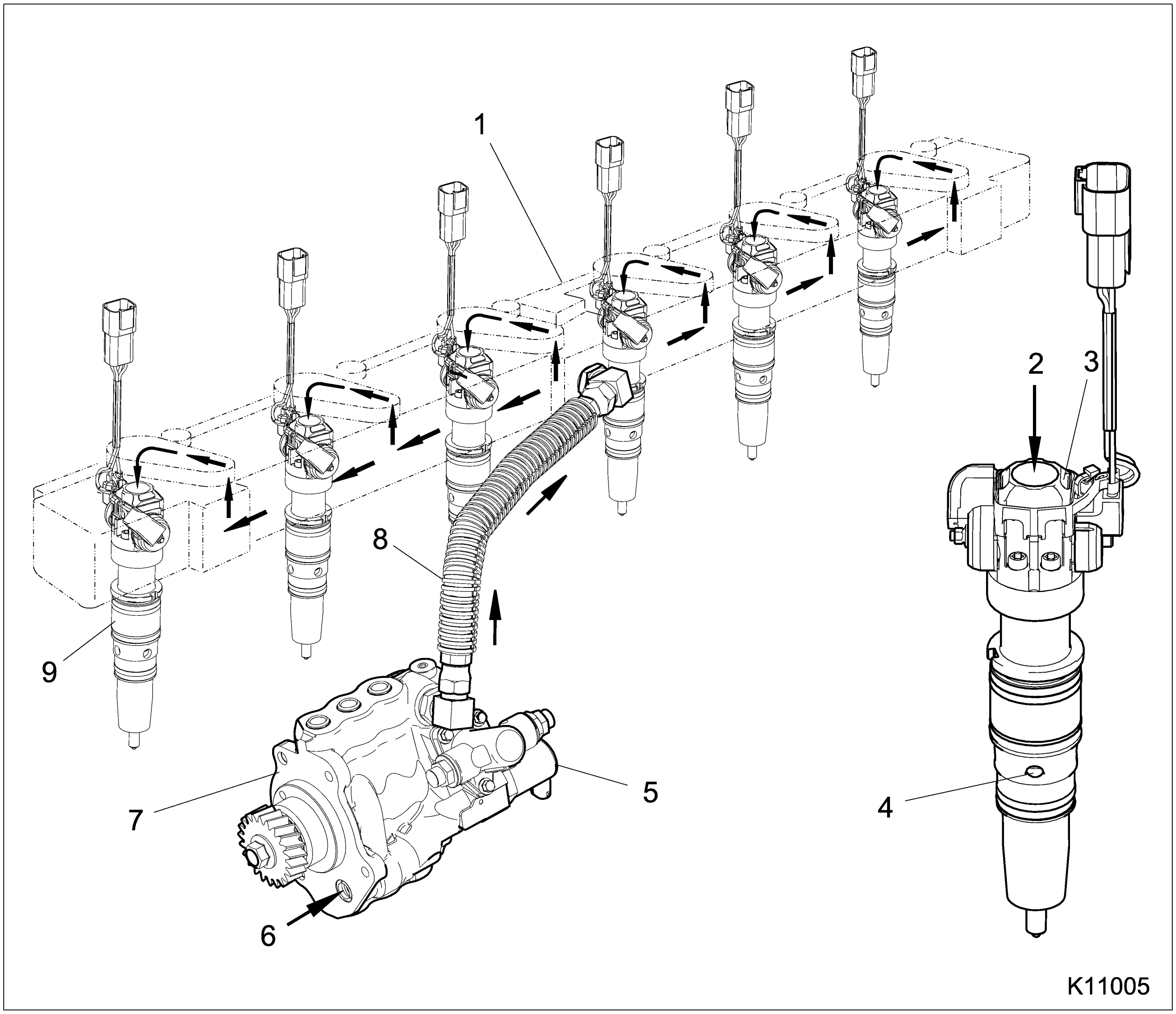


**Figure 172 Injection Control Pressure (ICP) system**

1. High-pressure oil manifold
2. Injector oil inlet from high-pressure oil manifold
3. Oil outlet (2)
4. Fuel inlet port (4)
5. Injection Pressure Regulator (IPR) valve
6. Oil inlet from front cover reservoir
7. High-pressure oil pump assembly
8. High-pressure hose
9. Fuel injector assembly (6)

The high-pressure oil system draws oil from the front cover reservoir into the high-pressure oil pump. The high-pressure oil pump pressurizes this oil which is forced through the high-pressure hose, high-pressure oil manifold, and sent to the oil inlet on top of each fuel injector. High-pressure oil increases fuel pressure inside the injectors, which deliver high-pressure fuel to each cylinder.

**High-pressure Oil and Low-pressure Fuel Pumps**

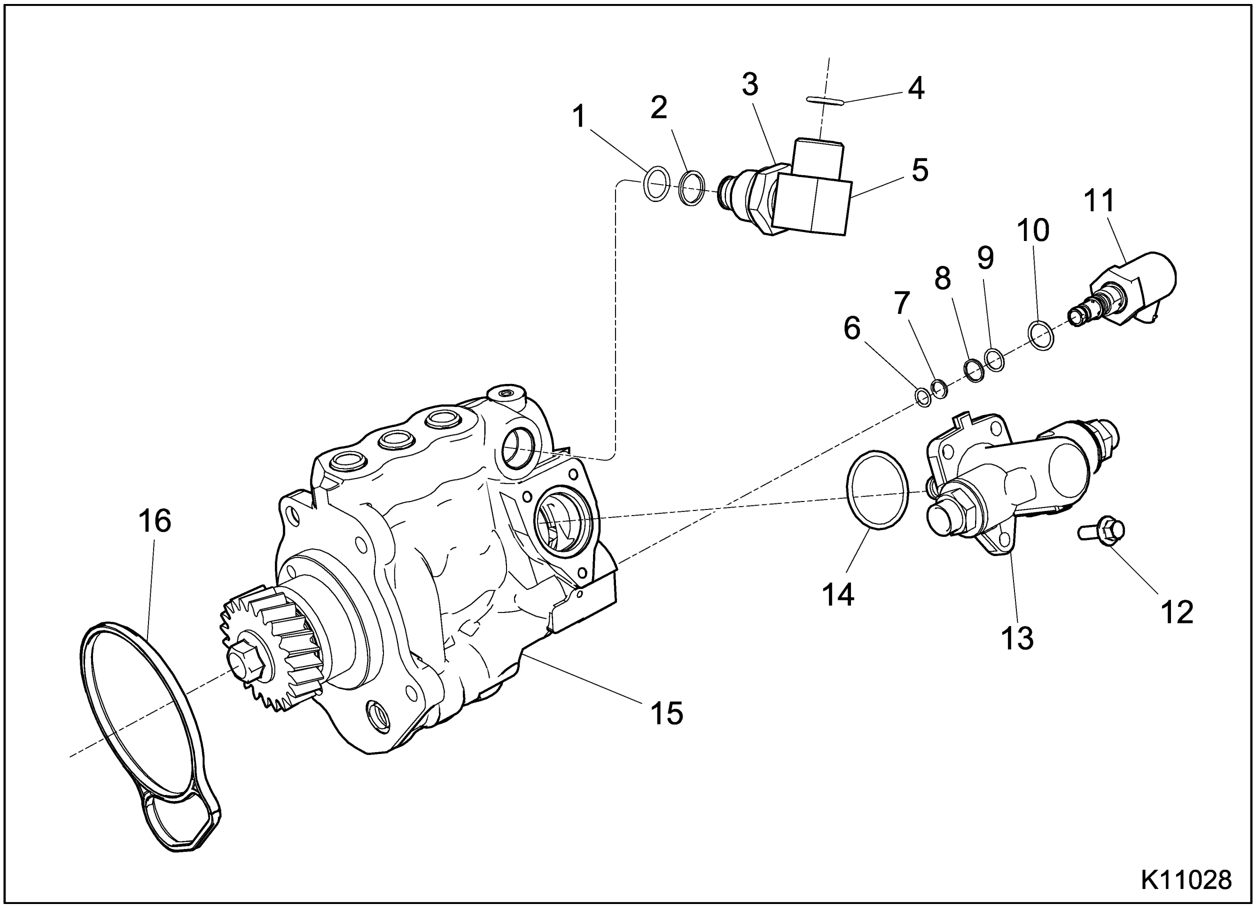


**Figure 173 High-pressure oil and low-pressure fuel pumps**

1. O-ring seal (#14)
2. Back-up O-ring
3. Jam nut
4. O-ring seal (#14)
5. 90 degree elbow
6. O-ring seal
7. Back-up ring seal
8. Middle back-up ring seal
9. O-ring seal (#14)
10. O-ring seal
11. Injection Pressure Regulator (IPR) valve
12. M6 x 16 bolt (3)
13. Low-pressure fuel pump assembly
14. O-ring gasket
15. High-pressure oil pump assembly
16. High-pressure pump gasket

See Fuel Management System (page 29) for additional details.

## Periodic Service

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

**WARNING:**

**To prevent personal injury or death, do not smoke and keep fuel away from flames and sparks.**

**GOVERNMENT REGULATION: Dispose of fuel according to applicable regulations in a correct container clearly marked DIESEL FUEL.**

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

**Fuel Strainer**

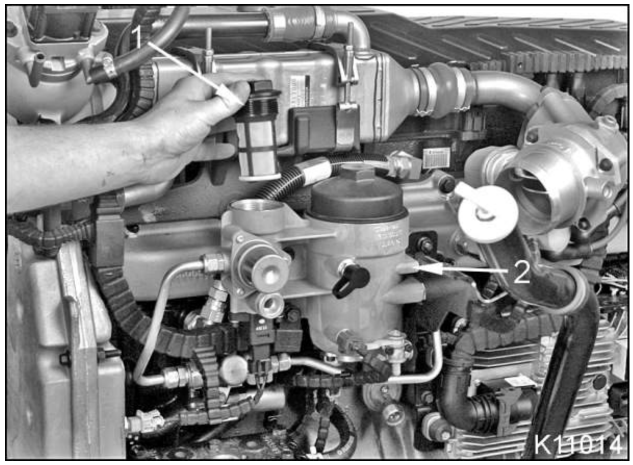


**Figure 174 Fuel strainer**

1. Fuel strainer
2. Fuel filter header assembly

1. Remove fuel strainer cap from fuel filter header.
2. Remove and discard strainer cap O-ring.
3. Clean or replace fuel strainer.
4. Clean out debris from inside fuel filter header.
5. Clean seal areas and install a new O-ring on the fuel strainer cap.
6. Coat fuel strainer cap threads and new O-ring with clean diesel fuel.
7. Install new or cleaned fuel strainer into fuel filter header.
8. Tighten fuel strainer cap to special torque (page 262).
9. Start engine and check for fuel leaks. If fuel is leaking turn off engine and repair leaks.

**Fuel Filter**


**Figure 175 Fuel filter and water drain valve**

1. Fuel filter element
2. Water drain valve (closed position)

**WARNING:**

**To prevent personal injury or death, do not smoke and keep fuel away from flames and sparks.**

1. Remove fuel filter cap from fuel filter header.
2. Remove and discard fuel filter cap O-ring.
3. Pull fuel filter up and out of fuel filter header and dispose of filter element properly.
4. Clean seal areas and install a new O-ring on fuel filter cap.
5. Clean out debris from inside the fuel filter header.
6. Install a new fuel filter element in fuel filter header assembly.
7. Lubricate fuel filter cap threads and new O-ring with clean diesel fuel.
8. Tighten fuel filter cap to special torque (page 262).
9. Prime fuel system (page 230), if required.
10. Start engine and check for fuel leaks. If fuel is leaking turn off engine and repair leaks.

**Drain Water In Fuel**

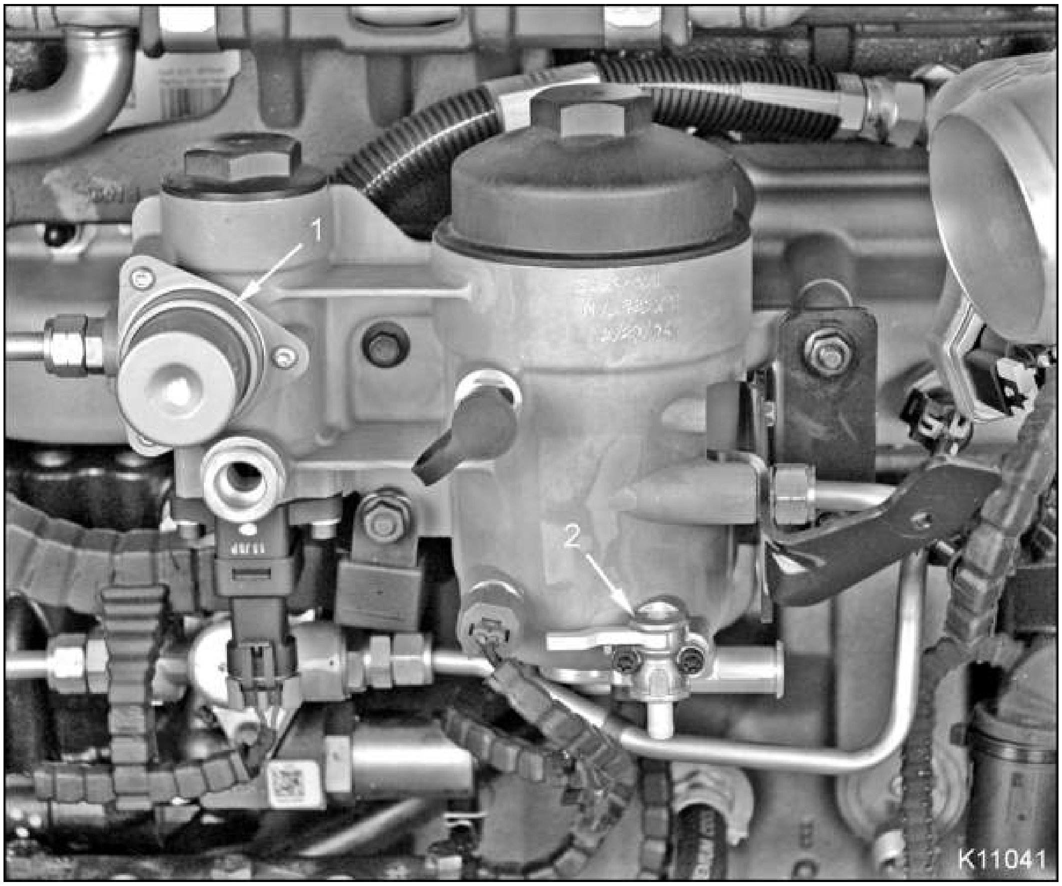


**Figure 176 Water drain valve and priming pump**

1. Priming pump assembly
2. Water drain valve assembly (closed position)

**WARNING:**

**To prevent personal injury or death, do not smoke and keep fuel away from flames and sparks.**

**NOTE:** A hose can be connected to the water drain valve to aid fuel and water draining.

If the amber Water In Fuel (WIF) light is lit, do the following:

1. Open water drain valve and drain water and fuel into a correct container clearly marked DIESEL FUEL.
2. Push fuel primer pump until a water free stream of fuel comes out the water drain valve.
3. Close water drain valve and dispose of fuel and water properly.
4. Start engine and check for fuel leaks. If fuel is leaking turn off engine and repair leaks.

**Priming Fuel System**

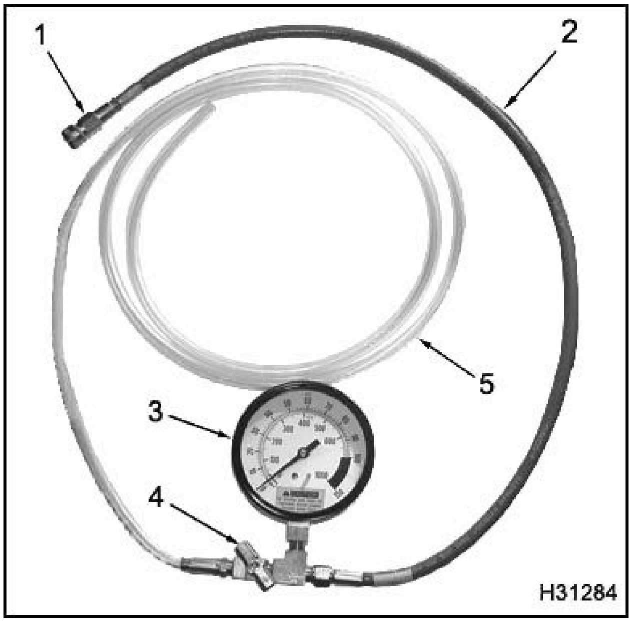


**Figure 177 Fuel Pressure Gauge assembly**

1. Quick disconnect check valve
2. Fuel test line
3. Fuel Pressure Gauge
4. Inline shut-off valve
5. Clear test line

**WARNING:**

**To prevent personal injury or death, do not smoke and keep fuel away from flames and sparks.**

If engine runs out of fuel or the fuel filter header has been drained, do the following:

1. Collect fuel in a correct container clearly marked DIESEL FUEL. Install Fuel Pressure Gauge assembly (page 263) quick disconnect check valve on engine Fuel Schrader® valve.
2. Open gauge assembly inline shut-off valve.

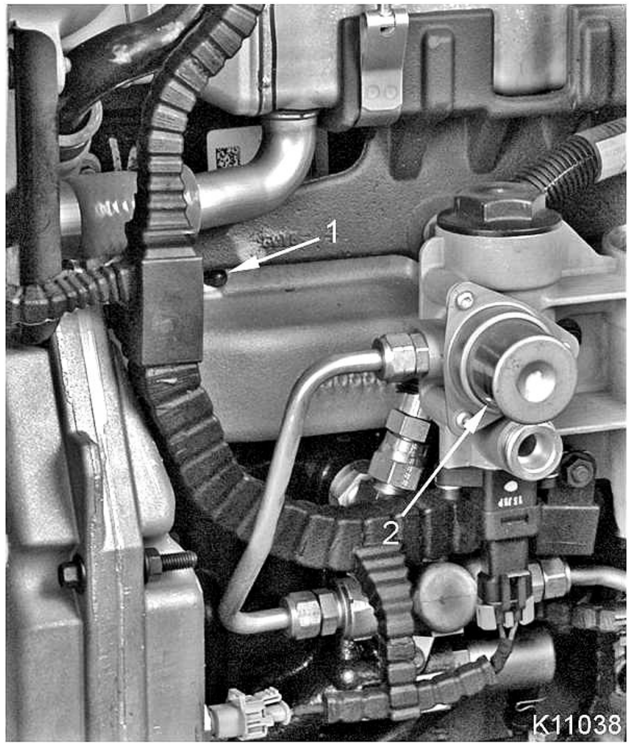


**Figure 178 Fuel Schrader® valve and priming pump**

1. Fuel Schrader® valve (fuel pressure test port and air bleed)
2. Fuel priming pump

3. Push fuel primer pump until an air free stream of fuel comes out the clear test line.
4. Close the gauge assembly inline shut-off valve.
5. Start engine and check for fuel leaks. If fuel is leaking, turn off engine and repair leaks. Refer to specific engine starting procedures in the *Engine Operation and Maintenance Manual*.
6. Turn off engine, remove Fuel Pressure Gauge assembly, and dispose of fuel according to applicable regulations.

## Removal

**Water In Fuel (WIF) Sensor, Engine Fuel Pressure (EFP) Sensor, and Fuel Heater**

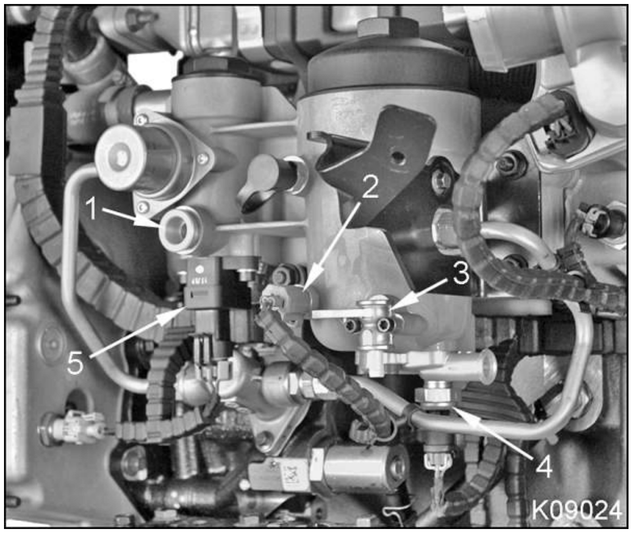


**Figure 179 Fuel filter header assembly**

1. Fuel inlet fitting (from tank)
2. WIF sensor
3. Water drain valve assembly
4. EFP sensor
5. Fuel heater (optional)

1. Disconnect sensor harness connector from fuel heater.
2. Disconnect sensor harness connector from the WIF sensor.
3. Disconnect 3-pin sensor harness connector from the EFP sensor.

**WARNING:**

**To prevent personal injury or death, do not smoke and keep fuel away from flames and sparks.**

4. Open water drain valve and drain fuel into a correct container clearly marked DIESEL FUEL.
5. Remove WIF sensor.
6. Discard WIF sensor O-ring.
7. Remove EFP sensor.
8. Discard EFP sensor O-ring.
9. Disconnect fuel inlet line and drain fuel into a correct container clearly marked DIESEL FUEL.
10. Remove two M6 fuel heater retaining bolts with a T30 Torx bit (page 263).
11. Pull fuel heater down to remove and discard O-ring.

**Water Drain Valve Assembly**

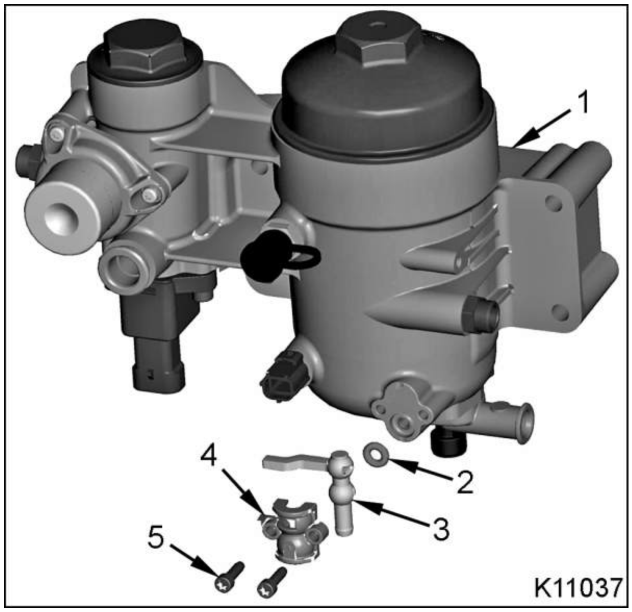


**Figure 180 Water drain valve assembly and fuel filter header**

1. Fuel filter header assembly
2. O-ring
3. Drain stem
4. Drain retainer
5. M5 screws (2)

1. Open water drain valve and drain fuel into a correct container clearly marked DIESEL FUEL.
2. Remove two M5 screws using a T27 Torx bit.
3. Remove drain retainer, drain stem, and O-ring from the fuel filter header housing.
4. Discard O-ring.

**Fuel Filter Header Assembly**

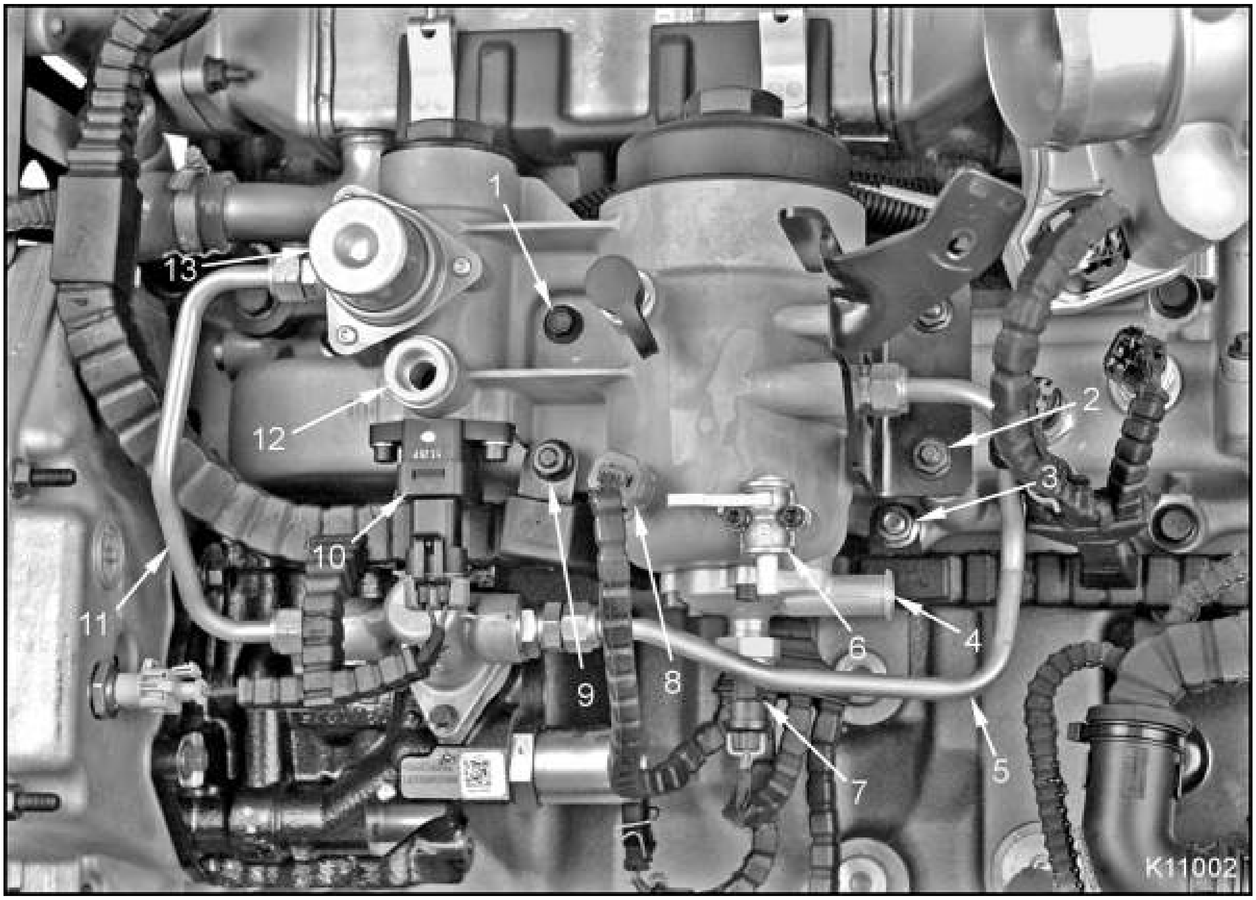


**Figure 181 Fuel filter header**

1. M8 x 75 bolt
2. M8 oil filler tube support nut (2)
3. M10 sensor harness retaining nut
4. Fuel outlet fitting (return to tank)
5. Low-pressure fuel pump outlet tube assembly
6. Water drain valve
7. Engine Fuel Pressure (EFP) sensor
8. Water In Fuel (WIF) sensor
9. M8 sensor harness retaining nut
10. Fuel heater (optional)
11. Low-pressure fuel pump inlet tube assembly
12. Fuel inlet fitting (from tank)
13. Priming pump assembly

**WARNING:**

**To prevent personal injury or death, do not smoke and keep fuel away from flames and sparks.**

1. Open water drain valve and drain fuel into a correct container clearly marked DIESEL FUEL.
2. Disconnect the fuel inlet and return lines.
3. Remove the oil filler tube (page 596).
4. Disconnect the WIF sensor, fuel heater, and EFP sensor harness connectors.

5. Loosen coupling nuts on ends of low-pressure fuel pump inlet tube assembly and remove inlet tube assembly.
6. Loosen coupling nuts on ends of low-pressure fuel pump outlet tube assembly and remove outlet tube assembly.
7. Remove and discard 3/8 tube sleeves from ends of low-pressure fuel pump inlet and outlet tube assemblies.
8. Cover openings to fuel filter header and low-pressure fuel pump to prevent dirt entry.
9. Remove two M8 nuts and one M6 x 16 bolt holding the oil filler tube support to the fuel filter header.
10. Remove M10 nut holding sensor harness to intake manifold stud bolt under the fuel filter header (Item 3).
11. Remove M8 nut holding sensor harness to the fuel filter header stud bolt. Remove flat washer under the sensor harness retainer.
12. Remove three M8 x 75 stud bolts and one M8 x 75 bolt holding the fuel filter header to the intake manifold and remove the fuel filter header.
13. Remove and discard the irregular molded gasket from between the fuel filter header and intake manifold.

### High-pressure Oil Hose and Elbows

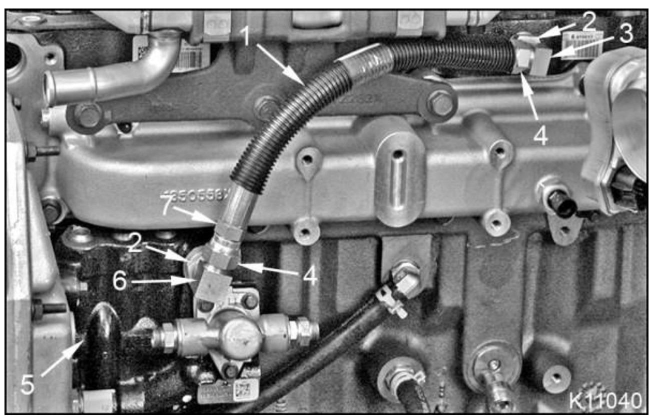


**Figure 182 High-pressure oil hose**

1. High-pressure oil hose
2. Elbow jam nut (2)
3. 70 degree elbow
4. Swivel nut
5. High-pressure oil pump
6. 90 degree elbow
7. High-pressure oil hose nut (2)

1. Remove high-pressure oil hose swivel nuts from 70 and 90 degree elbows. Use one wrench to hold the high-pressure oil hose nut in place while loosening its corresponding swivel nut using another wrench. Remove the high-pressure hose.

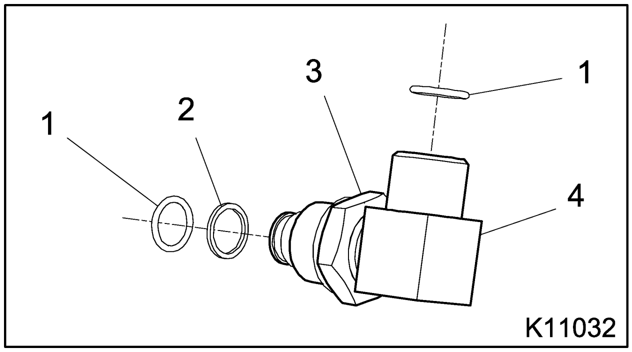


**Figure 183 High-pressure oil elbow (typical)**

1. O-ring seal (#14)
2. Back-up ring
3. Elbow jam nut
4. Elbow

2. Loosen jam nuts on each elbow.
3. Remove 70 and 90 degree elbows.
4. Remove and discard each elbow back-up ring and O-rings.

**NOTE:** See Intake Manifold, Fuel Valve, and Fuel Rail Plugs (page 209) for fuel valve and fuel rail plug removal.

**Low-pressure Fuel Pump**

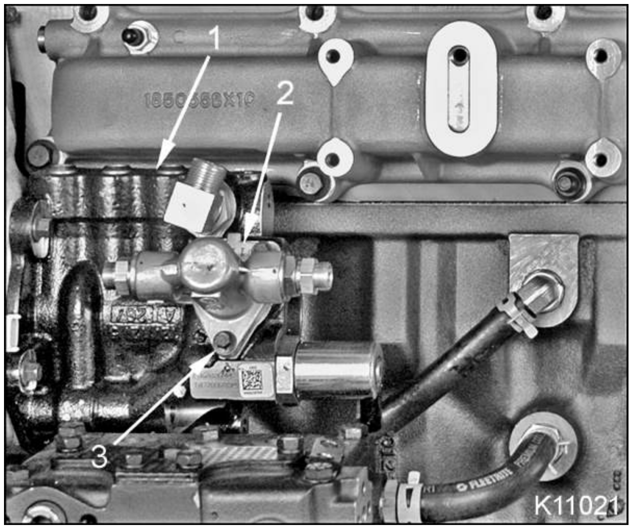


**Figure 184 Low-pressure fuel pump**

1. High-pressure oil pump
2. Low-pressure fuel pump
3. M6 x 16 bolt (3)

1. Remove three M6 x 16 bolts holding the low-pressure fuel pump to the high-pressure oil pump.
2. Remove and discard fuel pump O-ring gasket.

**High-pressure Oil Pump and Injection Pressure Regulator (IPR) Valve**

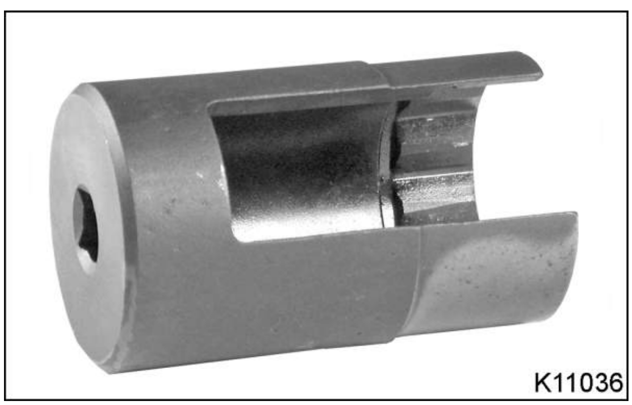


**Figure 185 IPR Removal / Installation Tool**

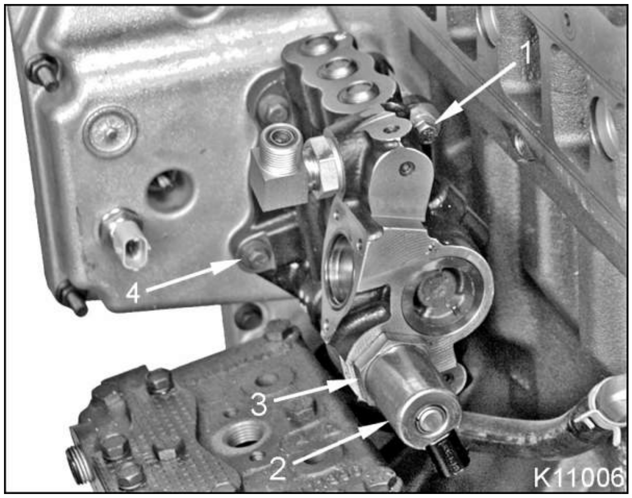


**Figure 186 High-pressure oil pump**

1. M8 x 100 bolt (2)
2. IPR valve magnetic coil
3. IPR valve
4. M8 x 30 bolt (2)

**NOTE:** IPR valve magnetic coil rotates separately from the IPR valve.

1. Remove IPR valve as follows:
   - If the high-pressure oil pump and air compressor are installed, hold the IPR valve magnetic coil stationary while turning the IPR valve to remove from the high-pressure oil pump.
   - If the high-pressure oil pump or air compressor are not installed, use the IPR Removal / Installation Tool (page 263) to remove IPR valve from the high-pressure oil pump.
2. Remove and discard IPR valve O-rings and back-up rings.
3. Remove two M8 x 100 and two M8 x 30 bolts holding the high-pressure oil pump to the front cover.
4. Remove the high-pressure oil pump and discard the high-pressure pump gasket.

**High-pressure Oil Manifold**

1. Remove valve cover (page 427).

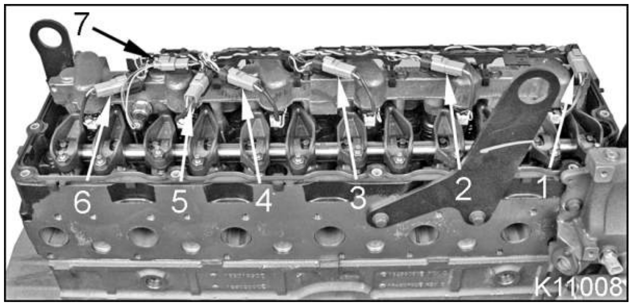


**Figure 187 Under Valve Cover (UVC) harness (non-brake)**

1. Injector 1 connector
2. Injector 2 connector
3. Injector 3 connector
4. Injector 4 connector
5. Injector 5 connector
6. Injector 6 connector
7. Injection Control Pressure (ICP) sensor connector

2. Disconnect six injector connectors and ICP sensor connector.
3. Disconnect optional BCP sensor (page 128) and brake shut-off valve connector (page 129).
4. Remove UVC harness. Starting at one side, lightly pry up and open each of the six wire channel retainers while gently pulling up to remove harness from engine.

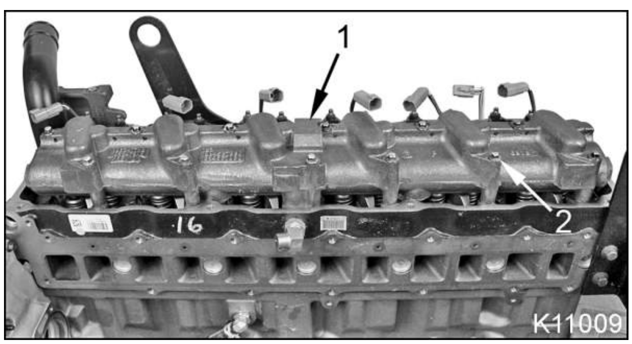


**Figure 188 High-pressure oil manifold (non-brake)**

1. High-pressure oil manifold
2. M8 x 90 bolt (12)

5. Remove 12 M8 x 90 bolts holding the high-pressure oil manifold to the cylinder head.

**WARNING:**

**To prevent personal injury or death, get assistance to remove and install the high-pressure oil manifold assembly.**

6. Lift high-pressure oil manifold up just enough to drain oil out of manifold before lifting it away from the cylinder head.
7. Lift up and remove high-pressure oil manifold from engine.
8. Remove and discard injector oil inlet adaptor seals and backup rings.
9. Remove and discard oil inlet O-ring (Figure 199).

### Injector Oil Inlet Adaptor (Puck) Assembly

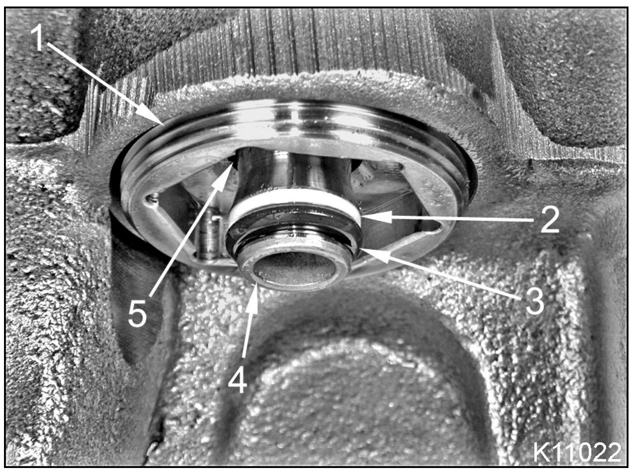


**Figure 189 Injector oil inlet installed in high-pressure oil manifold**

1. Injector oil inlet adaptor
2. Backup ring
3. Injector oil inlet seal
4. Oil inlet tube
5. Internal O-ring (not serviceable)

Remove any damaged injector oil inlet adaptor assemblies using Injector Adaptor Removal Tool (page 263).

**Fuel Injector Assemblies**

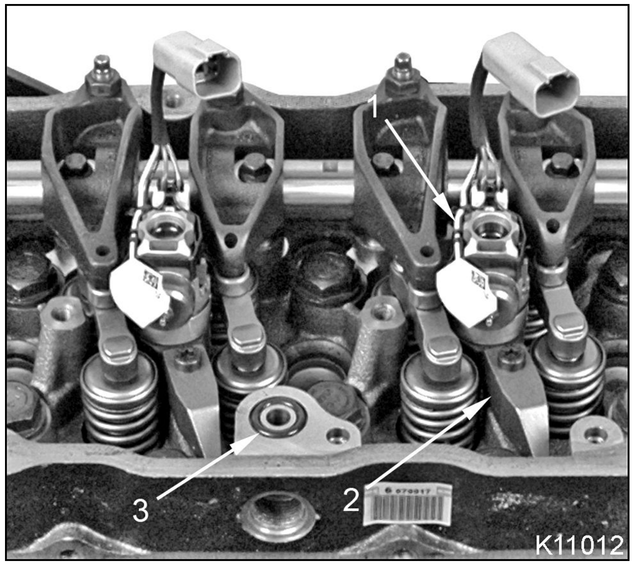


**Figure 190 Fuel injector assemblies and oil inlet O-ring**

1. Fuel injector (6)
2. Injector hold down clamp assembly (6)
3. Oil inlet O-ring (high-pressure)

1. Remove six injector hold down clamps and injectors by backing out injector clamp bolt with a T40 Torx bit (Fuel Injector Remover Tool) (page 263).

**NOTE:** Fuel injectors are self extracting and come out of injector bores as injector hold down clamp bolt is loosened.

**CAUTION:**

**To prevent engine damage, do not clean injectors with parts solvent or other chemicals.**

2. Remove and discard injector upper and lower O-rings and nozzle gasket with a non-metalic hand tool.

**NOTE:** If nozzle gasket is missing from any injector removed, look for gasket at the bottom of its injector bore. Remove and discard all nozzle gaskets.

**CAUTION:**

**To prevent engine damage, when injectors are removed from the engine, place injectors in a closeable container, cover with clean engine oil, and close container.**

3. Remove each fuel injector assembly, place in a closeable container, cover with clean engine oil, and close container.

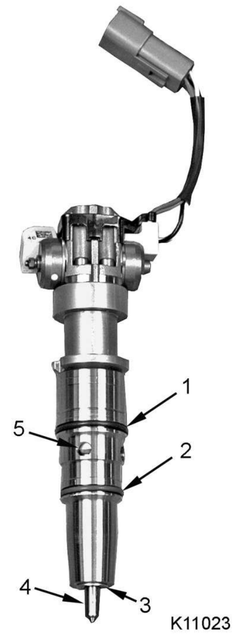


**Figure 191 Fuel injector assembly**

1. Upper O-ring
2. Lower O-ring
3. Nozzle gasket
4. Injector nozzle
5. Fuel inlet port

## Cleaning and Inspection

**WARNING:**

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

#### Low-pressure Fuel and High-pressure Oil System Components

1. Clean high-pressure oil pump, high-pressure oil manifold, IPR valve, and low-pressure fuel pump with a suitable non-caustic solvent.
2. Blow parts dry using filtered compressed air.
3. Inspect high-pressure oil pump, high-pressure oil hose, and high-pressure oil manifold for cracks and leaks. Replace cracked or leaking parts.

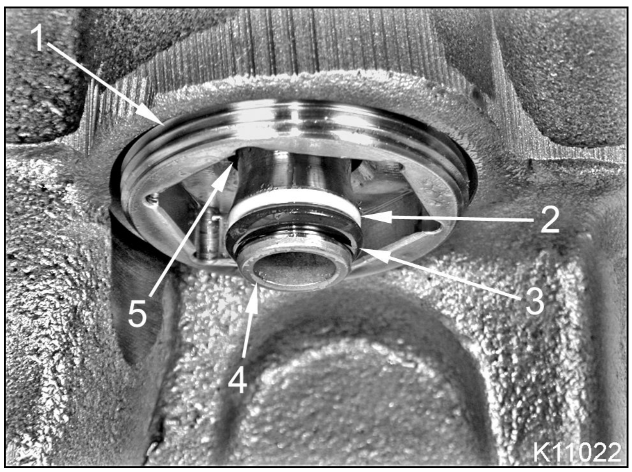


**Figure 192 Injector oil inlet adaptor installed in high-pressure oil manifold**

1. Injector oil inlet adaptor
2. Backup ring
3. Injector oil inlet seal
4. Oil outlet tube
5. Internal O-ring (not serviceable)

4. Verify six injector oil inlet adaptor oil inlet tubes move and are not frozen. Inspect injector oil inlet adaptors for internal O-ring extrusion and high-pressure oil leak paths. Replace any adaptor which has an extruded internal O-ring, frozen oil inlet tube, or high-pressure oil leak path.

5. Check IPR valve inlet screen for restrictions. Clean or replace valve if necessary.

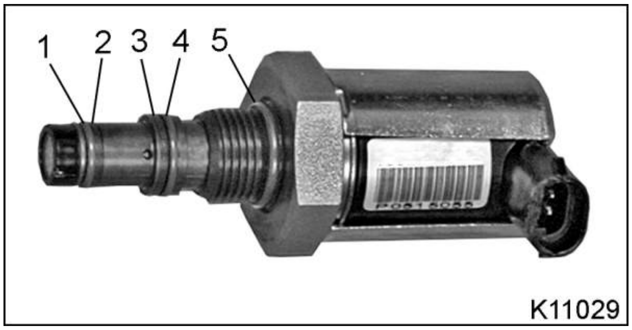


**Figure 193 IPR valve O-rings and back-up rings**

1. O-ring seal
2. Back-up ring seal
3. Middle back-up ring seal
4. O-ring seal (#14)
5. O-ring seal

6. Check IPR valve middle back-up ring seal area for erosion or other damage. Replace IPR valve if eroded or damaged.
7. Inspect intake manifold and fuel injectors for cracks and leaks. Replace cracked or leaking parts.
8. Inspect all fuel lines for kinks, obstructions, or other damage. Replace fuel lines if necessary.
9. Inspect low-pressure fuel pump tappet for cracks, burrs, and straightness. Replace pump if necessary.

**Fuel Filter Header Assembly Service Recommendations**

**NOTE:** See Fuel Filter Header Assembly (Figure 180) and Low-pressure Fuel System (Figure 170) illustrations.

Disassembly of the fuel filter header is not normally recommended beyond the following servicing:

- Fuel filter element replacement
- Fuel strainer cleaning or replacement
- Sensor or fuel heater assembly replacement
- Diagnostic coupling assembly cleaning or replacement
- Water drain valve assembly cleaning or replacement
- Fitting assembly with check valve cleaning or replacement

Disassemble or replace the fuel filter header to correct the following problems:

- Contaminated fuel in the engine
- Fuel or air leaks of the priming pump assembly

1. Clean fuel filter header assembly with a suitable non-caustic solvent.
2. Inspect fuel filter header assembly for cracks and leaks. Replace cracked or leaking parts if necessary.

# Installation

### Fuel Injector Assemblies

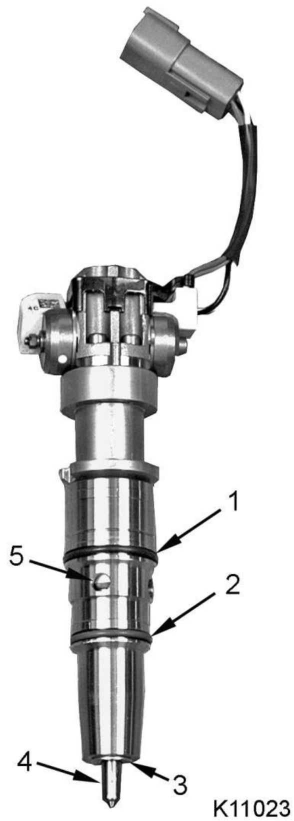


**Figure 194 Fuel Injector assembly**

1. Upper O-ring
2. Lower O-ring
3. Nozzle gasket
4. Fuel nozzle
5. Fuel inlet port

**CAUTION:**

**To prevent engine damage, replace upper and lower injector O-rings and nozzle gasket each time an injector is removed.**

1. Lubricate new injector upper O-ring with clean engine oil and slide in the recess just above the fuel inlet ports.
2. Lubricate new lower O-ring with clean engine oil and slide in the recess just below the fuel inlet ports.

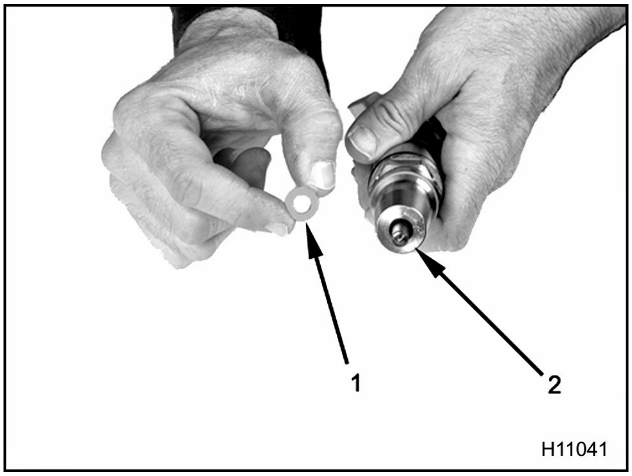


**Figure 195 Injector nozzle gasket**

1. Injector nozzle gasket
2. Injector nozzle

**CAUTION:**

**To prevent engine damage, do not nick or scratch injector nozzle gasket.**

3. Push a new injector nozzle gasket on injector nozzle using a deep socket to support the nozzle gasket. Nozzle gasket can go on either way.

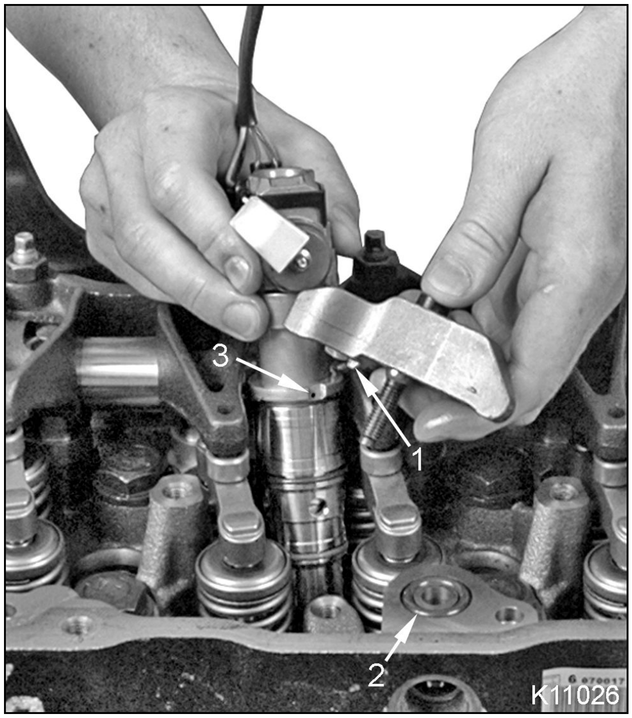


**Figure 196 Injector assembly installation**

1. Injector hold down clamp notch
2. Oil inlet O-ring (high-pressure)
3. Injector assembly slot

4. Align each injector assembly slot with hold down clamp notch and install assembly in cylinder head.

**CAUTION:**

**To prevent engine damage, do not use air tools to install fuel injectors.**

5. Tighten injector hold down clamp bolts using a T40 Torx bit (Fuel Injector Remover Tool) (page 263). Make sure injector and hold down clamp are installed squarely as the bolt is tightened.
6. Tighten six injector hold down clamp bolts to special torque (page 262). Injector will be placed at the correct depth.

### Injector Oil Inlet Adaptor (Puck) Assembly

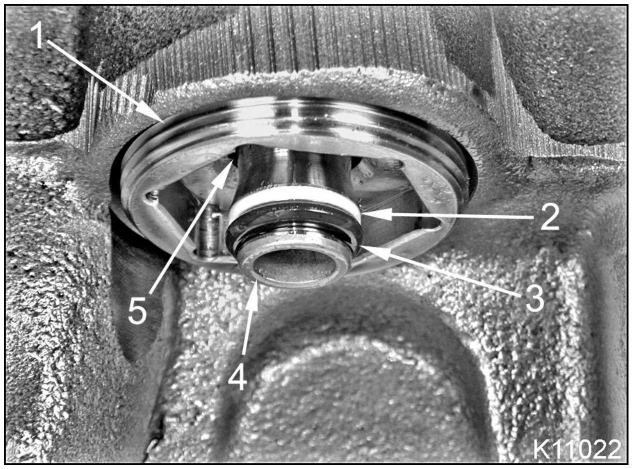


**Figure 197 Injector oil inlet adapter installed in high-pressure oil manifold**

1. Injector oil inlet adaptor
2. Backup ring
3. Injector oil inlet seal
4. Oil inlet tube
5. Internal O-ring (not serviceable)

1. Install injector oil inlet adaptors using Injector Adaptor Removal Tool (page 263).
2. Tighten injector oil inlet adaptors to special torque (page 262).

### High-pressure Oil Manifold

1. Install valve bridges (page 480).
2. Verify six injector oil inlet adaptor oil inlet tubes move and are not frozen. Inspect injector oil inlet adaptors for internal O-ring extrusion and high-pressure oil leak paths. Replace any adaptor which has an extruded internal O-ring, frozen oil inlet tube, or high-pressure oil leak path.
3. Install new backup rings and injector oil inlet seals on all oil inlet adaptors that were not replaced with new.
4. Coat backup rings and injector oil inlet seals with clean engine oil.
5. Coat a new oil inlet O-ring (Figure 206) with clean engine oil and install in cylinder head recess.

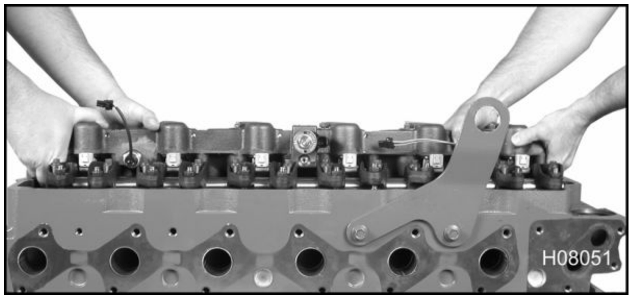


**Figure 198 High-pressure oil manifold installation**

**WARNING:**

**To prevent personal injury or death, get assistance to remove and install the high-pressure oil manifold assembly.**

6. With help from an assistant, lift the high-pressure oil manifold up and carefully place on engine.

**CAUTION:**

**To prevent engine damage, carefully align six injector oil inlet ports with six injector oil inlet adaptors of the high-pressure oil manifold before tightening oil manifold bolts.**

7. Carefully align six injector oil inlet ports with six injector oil inlet adapters of the high-pressure oil manifold and firmly push down to “snap” manifold in place.

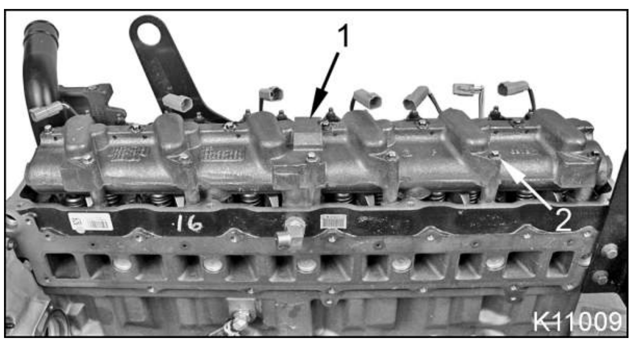


**Figure 199 High-pressure oil manifold (non-brake)**

1. High-pressure oil manifold
2. M8 x 90 bolt (12)

8. Install and finger tighten twelve M8 x 90 bolts securing the high-pressure oil manifold to the cylinder head.

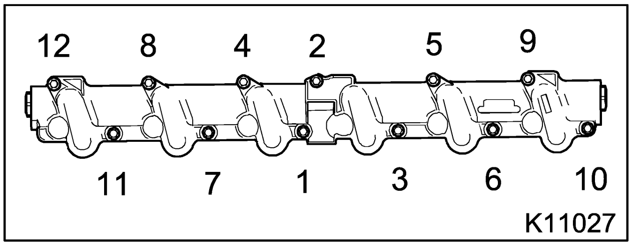


**Figure 200 High-pressure oil manifold bolt torque sequence**

9. Tighten twelve M8 x 90 bolts to 30 N·m (22 lbf·ft) in the proper torque sequence.

**NOTE:** Air trapped in the high-pressure oil manifold will be purged automatically during cranking and start up.

### High-pressure Oil Pump and Injection Pressure Regulator (IPR) Valve

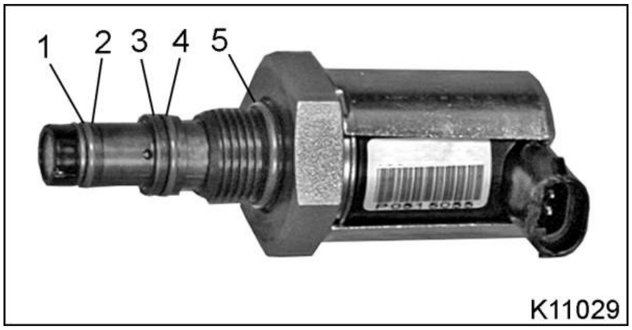


**Figure 201 IPR valve O-rings and back-up rings**

1. O-ring seal
2. Back-up ring seal
3. Middle back-up ring seal
4. O-ring seal (#14)
5. O-ring seal

1. Install new O-rings and back-up rings on the IPR valve assembly.
2. Lubricate IPR valve O-rings with clean engine oil.

**NOTE:** IPR valve can be installed in the high-pressure oil pump with IPR Removal / Installation Tool (page 263), before the high-pressure oil pump or air compressor is installed.

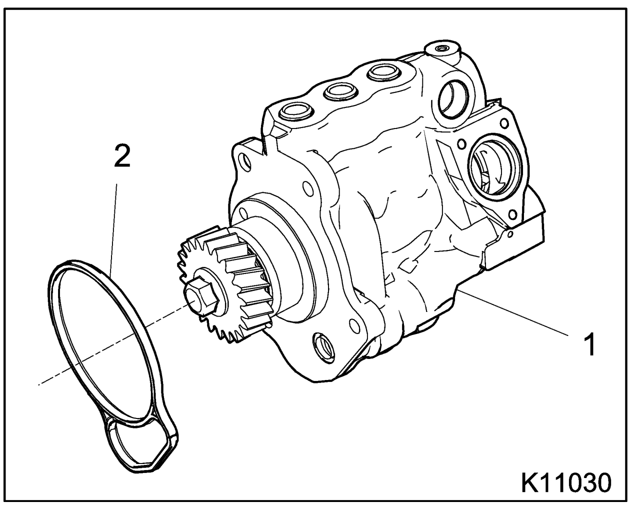


**Figure 202 High-pressure oil pump and gasket**

1. High-pressure oil pump
2. High-pressure pump gasket

3. Install a new high-pressure pump gasket on the rear of the front cover assembly.
4. Install high-pressure oil pump into the front cover, making sure pump gear meshes with upper idler gear.

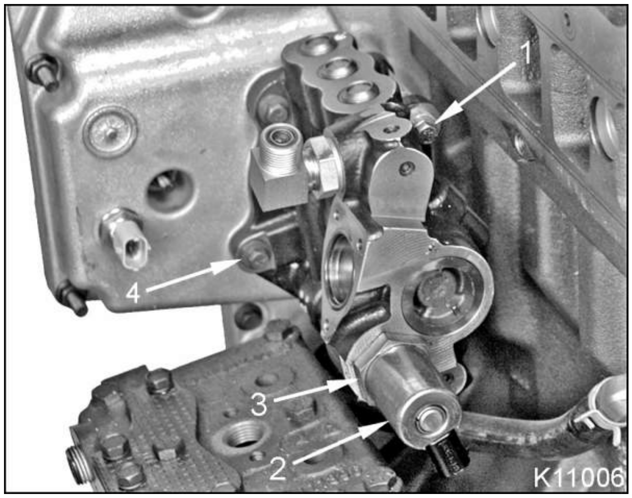


**Figure 203 High-pressure oil pump**

1. M8 x 100 bolt (2)
2. IPR valve magnetic coil
3. IPR valve
4. M8 x 30 bolt (2)

5. Install two M8 x 100 and two M8 x 30 bolts connecting the high-pressure oil pump to the front cover.
6. Tighten two M8 x 100 and two M8 x 30 bolts to special torque (page 262).

**NOTE:** IPR valve magnetic coil rotates separately from the IPR valve.

7. Install the (IPR) valve as follows:
   - If the high-pressure oil pump and air compressor are installed, hold the IPR valve magnetic coil stationary while turning IPR valve to install in the high-pressure oil pump.
   - If high-pressure oil pump or air compressor are not installed, use IPR Removal / Installation Tool (page 263) to install IPR valve in the high-pressure oil pump.
8. Tighten IPR valve to special torque (page 262).

**Low-pressure Fuel Pump**

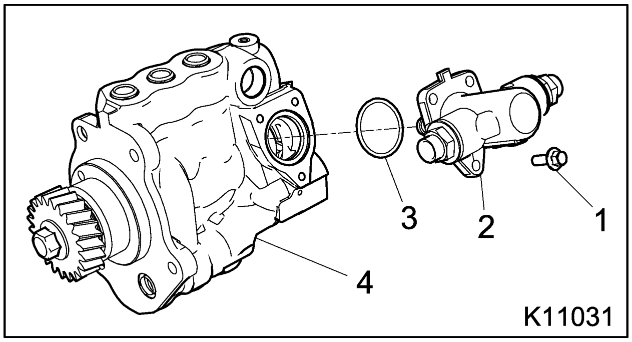


**Figure 204 Low-pressure fuel pump**

1. M6 x 16 bolt (3)
2. Low-pressure fuel pump
3. O-ring gasket
4. High-pressure oil pump

1. Install new O-ring gasket on the high-pressure oil pump assembly and lubricate with clean engine oil.
2. Install low-pressure fuel pump onto high-pressure oil pump.
3. Install three M6 x 16 bolts and tighten to special torque (page 262).

**High-pressure Oil Hose and Elbows**

See TSI 08–12–22 for high-pressure oil system design change and part information.

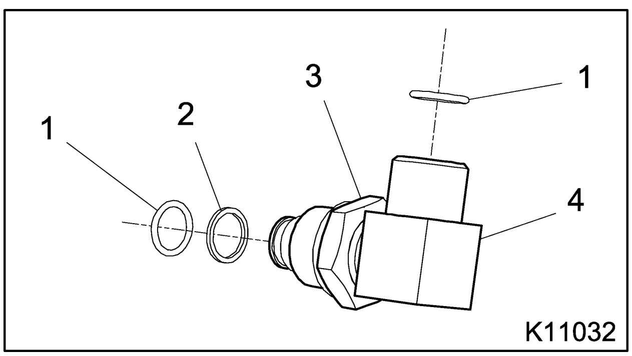


**Figure 205 High-pressure oil elbow (typical)**

1. O-ring seal (#14)
2. Back-up ring
3. Elbow jam nut
4. Elbow

1. Rotate both elbow jam nuts all the way to the base of the elbows.
2. Install new O-rings and back-up ring on the 70 and 90 degree elbows.

3. Lubricate new O-rings with clean engine oil.

**CAUTION:**

**To prevent engine damage, make all adjustments to the high-pressure oil elbows within 15 minutes of applying Loctite®.**

4. Apply two beads of Loctite® 246 Threadlocker (page 263) to the threads of both high-pressure oil elbows.

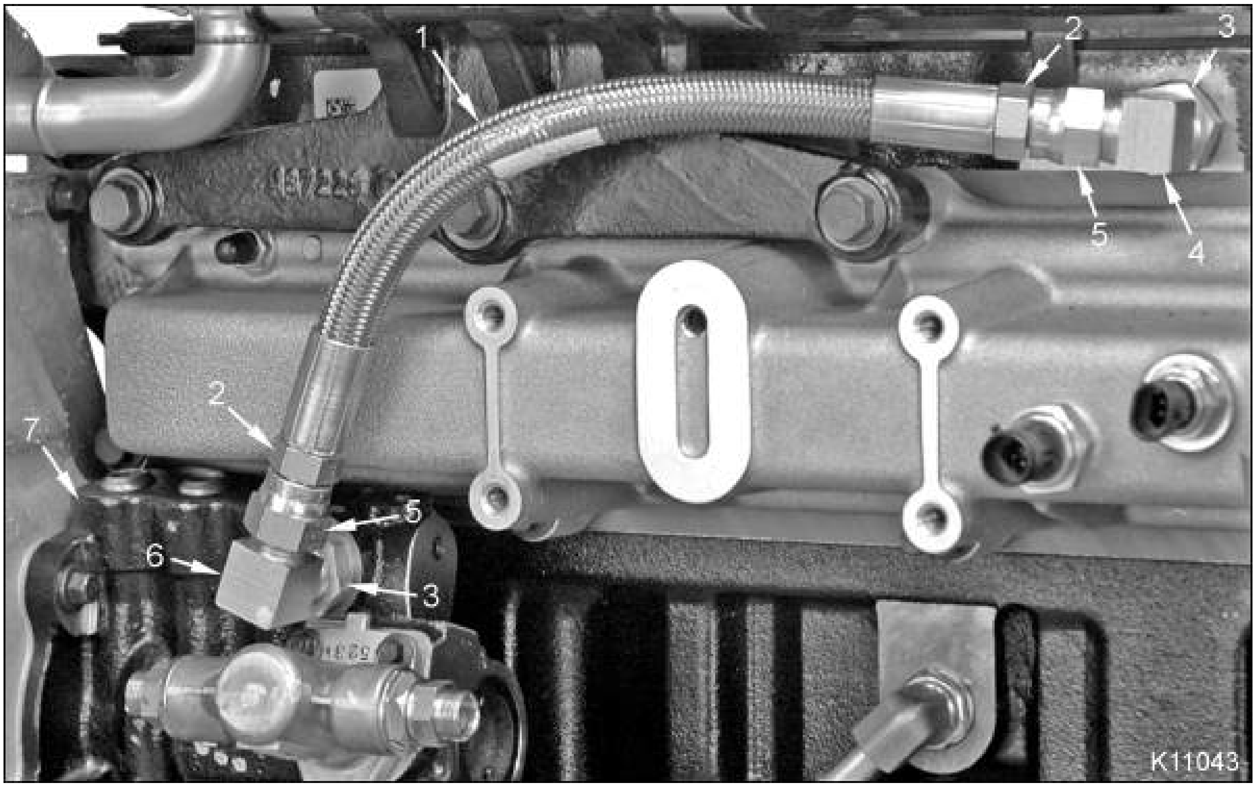


**Figure 206 High-pressure oil hose and elbows (flexible conduit cover removed)**

1. High-pressure oil hose
2. High-pressure oil hose nut (2)
3. Elbow jam nut
4. 70 degree elbow
5. Swivel nut
6. 90 degree elbow
7. High-pressure oil pump

5. Install 70 degree elbow into high-pressure oil port on intake side of the cylinder head. Run fitting all the way in finger tight and then back fitting off (less than one full turn) to orient fitting toward the front of the engine.
6. Install 90 degree elbow into high-pressure oil pump. Run fitting all the way in finger tight and then back fitting off (less than one full turn) to orient fitting.
7. Remove the flexible conduit cover from the high-pressure oil hose.
8. Install the high-pressure oil hose on the 70 and 90 degree elbows and finger tighten swivel nuts.

**CAUTION:**

**To prevent engine damage, orient the high-pressure oil hose so the hose is not under any excess tension, the hose bends in a smooth arc, is not twisted, and does not touch other engine components.**

9. Orient the high-pressure oil hose so the hose is not under any excess tension and is not twisted. Use one wrench to hold the high-pressure hose nut in place while tightening its corresponding swivel nut to special torque (page 262) using another wrench.

10. Orient the high-pressure oil hose so the hose is not under any excess tension and the hose bends in a smooth arc. Use one wrench to hold each elbow in place while tightening its elbow jam nut to special torque (page 262) using another wrench.
11. Install the flexible conduit cover on the high-pressure oil hose.

**Fuel Filter Header Assembly**

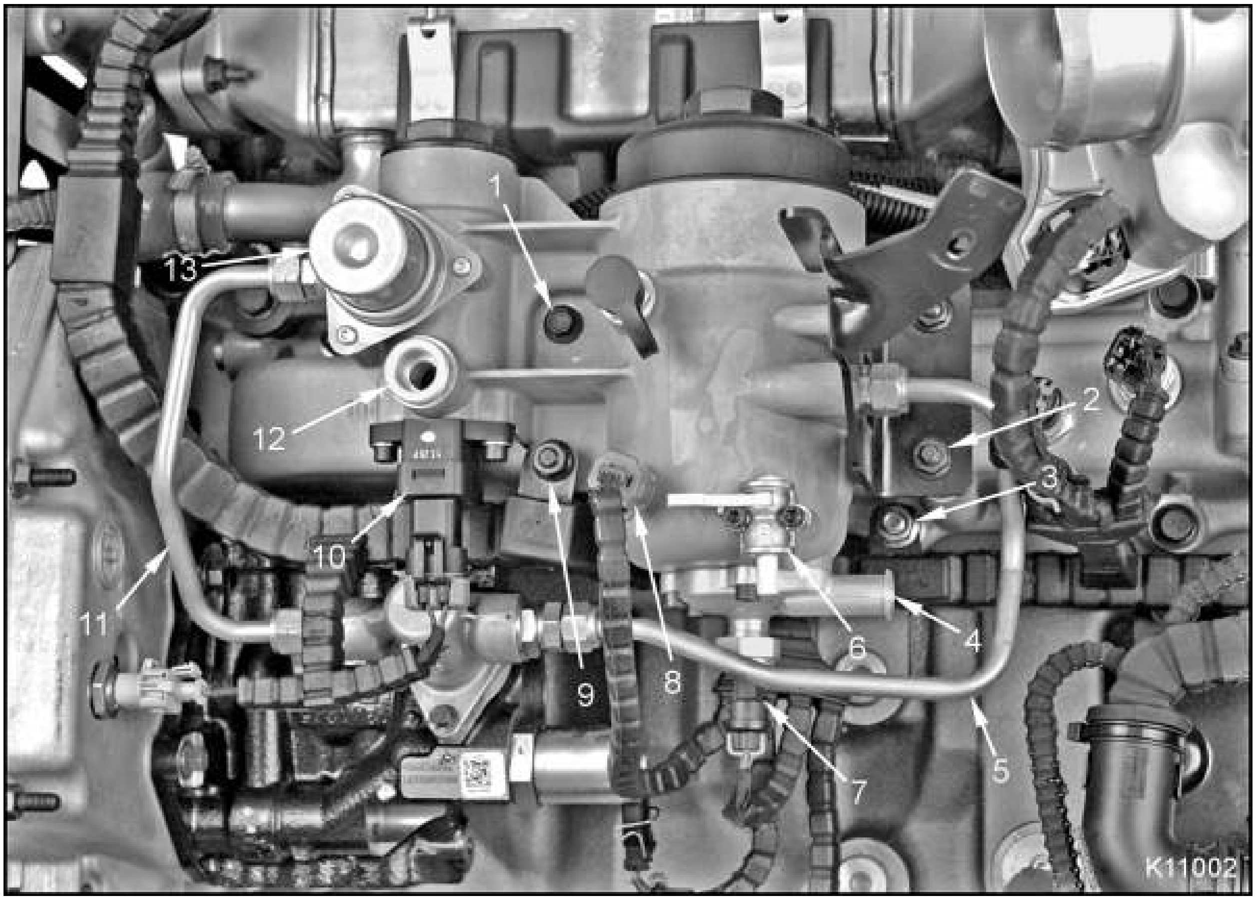


**Figure 207 Fuel filter header**

1. M8 x 75 bolt
2. M8 oil filler tube support nut (2)
3. M10 sensor harness retaining nut
4. Fuel outlet fitting (return to tank)
5. Low-pressure fuel pump outlet tube assembly
6. Water drain valve
7. Engine Fuel Pressure (EFP) sensor
8. Water In Fuel (WIF) sensor
9. M8 sensor harness retaining nut
10. Fuel heater (optional)
11. Low-pressure fuel pump inlet tube assembly
12. Fuel inlet fitting (from tank)
13. Priming pump assembly

1. Install a new irregular molded gasket between the fuel filter header and intake manifold. Position fuel filter header assembly on the intake manifold.
2. Install three M8 x 75 stud bolts and one M8 x 75 bolt holding fuel filter header to the intake manifold and tighten bolts to special torque (page 262).
3. Install flat washer, sensor harness, and M8 nut on lower front M8 x 75 stud bolt (Item 9).

4. Install M10 nut holding sensor harness to the intake manifold stud bolt under the fuel filter header (Item 3).
5. Tighten M8 and M10 sensor harness retaining nuts to standard torque (page 683).
6. Install oil filler tube support, two M8 nuts, and one M6 x 16 bolt holding the oil filler tube support to the fuel filter header.
7. Tighten M6 x 16 bolt to special torque (page 644).
8. Tighten two M8 nuts to special torque (page 644).

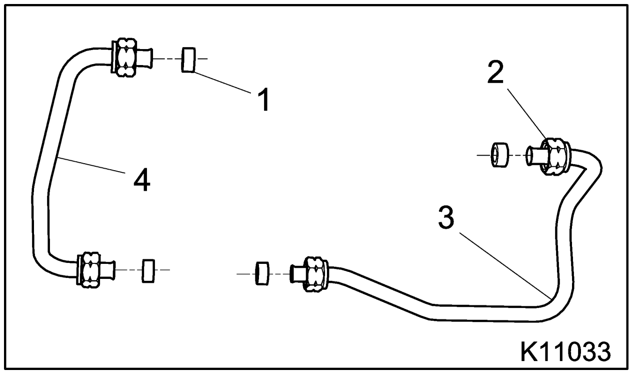


**Figure 208 Low-pressure fuel pump inlet and outlet tube assemblies**

1. 3/8 tube sleeve (4)
2. Coupling nut (4)
3. Low-pressure fuel pump outlet tube assembly
4. Low-pressure fuel pump inlet tube assembly

9. Install two new 3/8 tube sleeves onto ends of both the low-pressure fuel pump inlet and outlet tube assemblies.
10. Install low-pressure fuel pump inlet tube assembly ends into the fuel filter header and low-pressure fuel pump and tighten coupling nuts to special torque (page 262).
11. Install low-pressure fuel pump outlet tube assembly ends into the fuel filter header and low-pressure fuel pump and tighten nuts to special torque.
12. Connect the fuel return and inlet lines.
13. Install the Oil Level Gauge Assembly (page 636).
14. Connect the IPR valve, fuel heater, WIF sensor, and EFP sensor harness connectors.
15. See Priming Fuel System (page 230) to purge air out of fuel system to start engine.

### Water Drain Valve Assembly

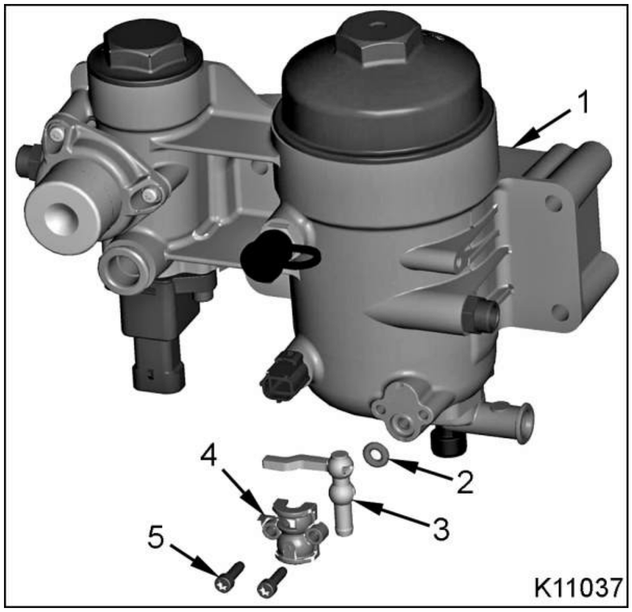


**Figure 209 Water drain valve assembly and fuel filter header**

1. Fuel filter header assembly
2. O-ring
3. Drain stem
4. Drain retainer
5. M5 screws (2)

1. Install a new water drain valve O-ring into the fuel filter header housing.
2. Install drain stem, drain retainer, and finger tighten two M5 screws.
3. Tighten two M5 screws using a T27 Torx bit (page 263) and a torque wrench to special torque (page 262).
4. See Priming Fuel System (page 230) to purge air out of fuel system to start engine.

**Water In Fuel (WIF) Sensor, Engine Fuel Pressure (EFP) Sensor, and Fuel Heater**

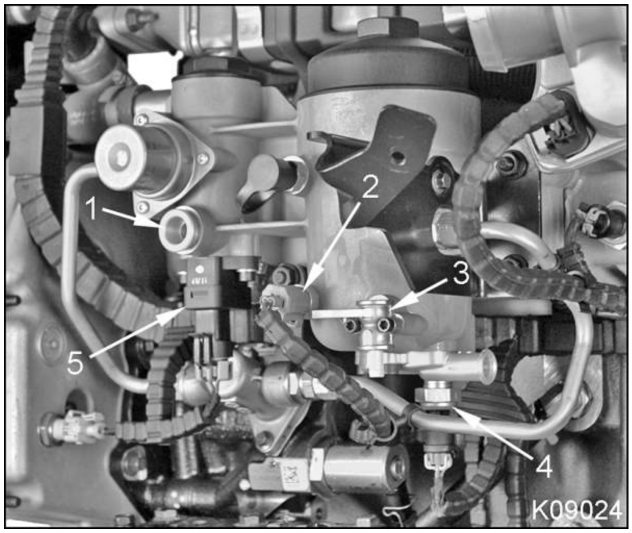


**Figure 210 Fuel filter header assembly**

1. Fuel inlet port
2. WIF sensor
3. Water drain valve assembly
4. EFP sensor
5. Fuel heater (optional)

1. Install a new O-ring on the fuel heater and lubricate O-ring with clean diesel fuel.
2. Install fuel heater into fuel filter header and finger tighten two M6 x 25 retaining bolts.
3. Tighten two M6 x 25 fuel heater retaining bolts to special torque (page 262).
4. Install a new O-ring on WIF sensor and lubricate O-ring with clean diesel fuel.
5. Install WIF sensor into fuel filter header and tighten to special torque (page 262) or until O-ring contacts fuel filter header and then turn sensor an additional 1/16 of a turn.
6. Install a new O-ring on the EFP sensor and lubricate O-ring with clean diesel fuel.
7. Install EFP sensor into the bottom of the fuel filter header and tighten to special torque (page 262).
8. Connect engine sensor harness connectors to the fuel heater, WIF sensor, and EFP sensor.

## Specifications

| | |
|---|---|
| Fuel heater switching points | On: 7 °C (44.6 °F) |
| | Off: 21 °C (69.8 °F) |
| Fuel pressure regulator assembly opening pressure | 420 to 490 kPa (61 to 71 psi) |
| Fuel strainer | 150 micron |
| High-pressure oil manifold pressure range | 5 to 32 MPa (725 to 4,650 psi) |
| High-pressure oil pump end play | 0.127 to 0.457 mm (0.005 to 0.018 in) |

## Special Torque

| | |
|---|---|
| Diagnostic coupling assembly | 17 N·m (145 lbf·in) |
| Elbow jam nut, 70 and 90 degree | 102 N·m (75 lbf·ft) |
| Engine Fuel Pressure (EFP) sensor | 11 N·m (100 lbf·in) |
| Fitting assembly with check valve | 18 N·m (155 lbf·in) |
| Fuel filter cap | 30 N·m (22 lbf·ft) |
| Fuel filter header mounting bolt and stud bolts, M8 x 75 | 27 N·m (20 lbf·ft) |
| Fuel heater and cover plate bolts, M6 x 25 | 10 N·m (85 lbf·in) |
| Fuel rail plug assembly, (intake manifold fuel rail) | 25 N·m (18 lbf·ft) |
| Fuel strainer cap | 18 N·m (155 lbf·in) |
| Fuel valve assembly (air bleed and pressure test port) | 15 N·m (132 lbf·in) |
| High-pressure oil hose (swivel nuts) Small diameter hose | 48 N·m (35 lbf·ft) |
| High-pressure oil hose (swivel nuts) Large diameter hose | 65 N·m (48 lbf·ft) |
| High-pressure oil manifold bolts, M8 x 90 | See High-pressure Oil Manifold (page 252) |
| High-pressure oil pump assembly bolts, M8 x 30 and M8 x 100 | 30 N·m (22 lbf·ft) |
| High-pressure oil pump assembly (gear) | 240 N·m (176 lbf·ft) |
| Injector hold down clamp bolt | 41 N·m (30 lbf·ft) |
| Injector oil inlet adaptor (puck) assembly | 204 N·m (150 lbf·ft) |
| IPR valve assembly | 50 N·m (37 lbf·ft) |
| Low-pressure fuel pump bolts, M6 x 16 | 16 N·m (140 lbf·in) |
| Low-pressure fuel pump tube coupling nuts | 18 N·m (155 lbf·in) |
| Oil rail plug assembly (bottom) | 204 N·m (150 lbf·ft) |
| Plug assembly, M12 and M10 | 12 N·m (108 lbf·in) |
| Rail end plug assembly | 204 N·m (150 lbf·ft) |
| Tube fitting assembly | 18 N·m (155 lbf·in) |

| | |
|---|---|
| Water drain valve M5 screw | 6 N·m (50 lbf·in) |
| Water In Fuel (WIF) sensor | 2 N·m (15 lbf·in) |

## Special Service Tools

| | |
|---|---|
| Injector Oil Inlet Plugs | ZTSE4660 |
| Fuel Injector Remover Tool (T40) | ZTSE4524 |
| Fuel Pressure Gauge | ZTSE4681 |
| Injector Adaptor Removal Tool | ZTSE4725 |
| IPR Removal / Installation Tool | ZTSE4666 |
| Loctite® 246 Threadlocker | Obtain locally |
| T27 Torx bit | Obtain locally |
| T30 Torx bit | Obtain locally |

# Table of Contents

## Exploded View and Description

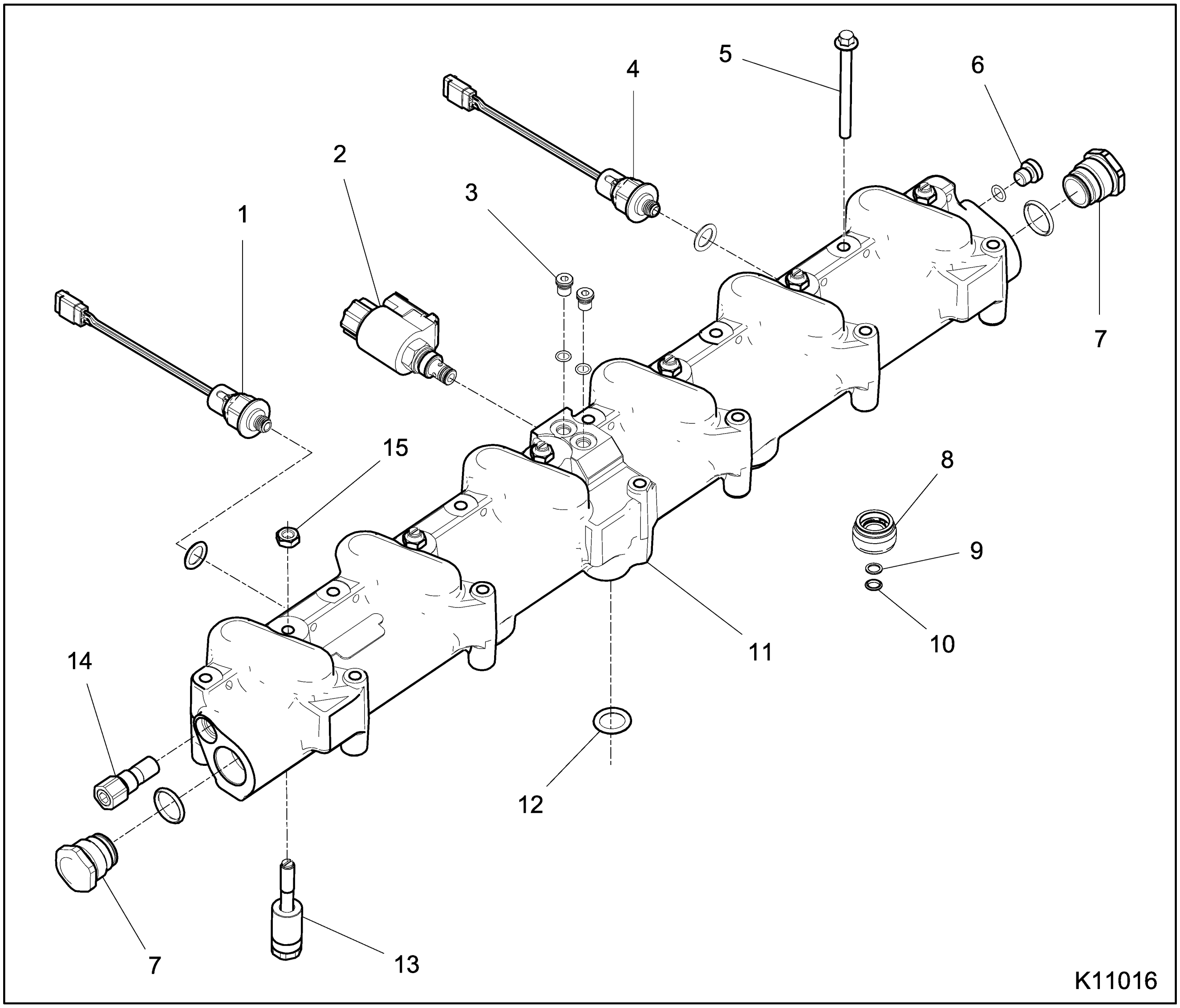


**Figure 211 High-pressure oil manifold (brake)**

1. Brake Control Pressure (BCP) sensor
2. Brake Shut-off Valve (BSV) assembly
3. M10 plug
4. Injection Control Pressure (ICP) sensor
5. M8 x 90 bolt (12)
6. M12 plug
7. Rail end plug assembly (2)
8. Injector oil inlet adaptor (6)
9. Back-up ring (6)
10. Injector oil inlet seal (6)
11. High-pressure oil manifold (brake)
12. Oil inlet O-ring
13. Brake actuator piston (6)
14. Oil pressure relief valve
15. Brake actuator piston lock nut (6)

The engine brake system uses high-pressure oil in the high-pressure oil manifold, controlled by a brake shut-off valve, to force six brake actuator pistons down onto the valve bridges to partially open one exhaust valve for each cylinder. The release of combustion chamber compression on the power stroke increases engine braking. See Diamond Logic® Brake System (page 70) for additional details.

## Periodic Service

**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, wear safety glasses with side shields. Limit compressed air pressure to 207 kPa (30 psi).**

**WARNING:**

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

**WARNING:**

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

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

**NOTE:** If the valve cover is removed for any reason, verify six brake piston locknuts are tight. If loose, verify and reset brake lash.

### Engine Brake Lash Adjustment

Crankshaft is rotated twice during brake lash adjustment procedure.

- Three brake actuator pistons are adjusted when piston 1 is at Top Dead Center (TDC) compression.
- Three brake actuator pistons are adjusted when piston 6 is at Top Dead Center (TDC) compression.

Corresponding intake and exhaust valve lash can be adjusted (page 423) when piston 1 and 6 are at TDC compression.

**NOTE:** Valve lash adjustments are not required when adjusting engine brake lash.

1. Remove the valve cover (page 427) and EGR tube support bracket (page 176).
2. Turn the crankshaft in the direction of engine rotation to remove gear lash. Position piston 1 at TDC compression by observing cylinder 6 rocker arms in overlap as the vibration damper timing mark approaches the TDC mark on the front cover. Cylinder 6 exhaust valve will be closing (coming up) and the intake valve will be starting to open (going down).
3. If piston 1 is at TDC compression, see Chart 1 (page 270) and do steps 4, 5, and 6 for cylinders 1, 3, and 5.

**Chart 1**

| Brake and valve lash adjustments (inches) with piston 1 at TDC compression (Chart 1) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cylinder 1 | | Cylinder 2 | | Cylinder 3 | | Cylinder 4 | | Cylinder 5 | | Cylinder 6 | |
| intake 1 | exhaust 2 | intake 3 | exhaust 4 | intake 5 | exhaust 6 | intake 7 | exhaust 8 | intake 9 | exhaust 10 | intake 11 | exhaust 12 |
| 0.019 | 0.019 | 0.019 | | | 0.019 | 0.019 | | | 0.019 | | |
| Brake 0.019 | | | | Brake 0.019 | | | | Brake 0.019 | | | |

**Brake and valve lash adjustments with piston 1 at TDC compression**

**Chart 2**

| Brake and valve lash adjustments (inches) with piston 6 at TDC compression (Chart 2) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cylinder 1 | | Cylinder 2 | | Cylinder 3 | | Cylinder 4 | | Cylinder 5 | | Cylinder 6 | |
| intake 1 | exhaust 2 | intake 3 | exhaust 4 | intake 5 | exhaust 6 | intake 7 | exhaust 8 | intake 9 | exhaust 10 | intake 11 | exhaust 12 |
| | | | 0.019 | 0.019 | | | 0.019 | 0.019 | | 0.019 | 0.019 |
| | | Brake 0.019 | | | | Brake 0.019 | | | | Brake 0.019 | |

**Brake and valve lash adjustments with piston 6 at TDC compression**

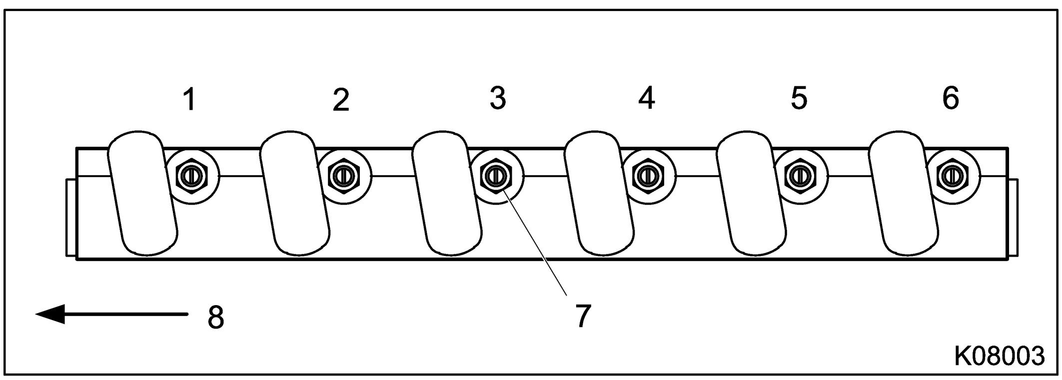


**Figure 212 High-pressure oil manifold (brake)**

1. Cylinder 1
2. Cylinder 2
3. Cylinder 3
4. Cylinder 4
5. Cylinder 5
6. Cylinder 6
7. Brake actuator piston locknut (6)
8. Front of engine

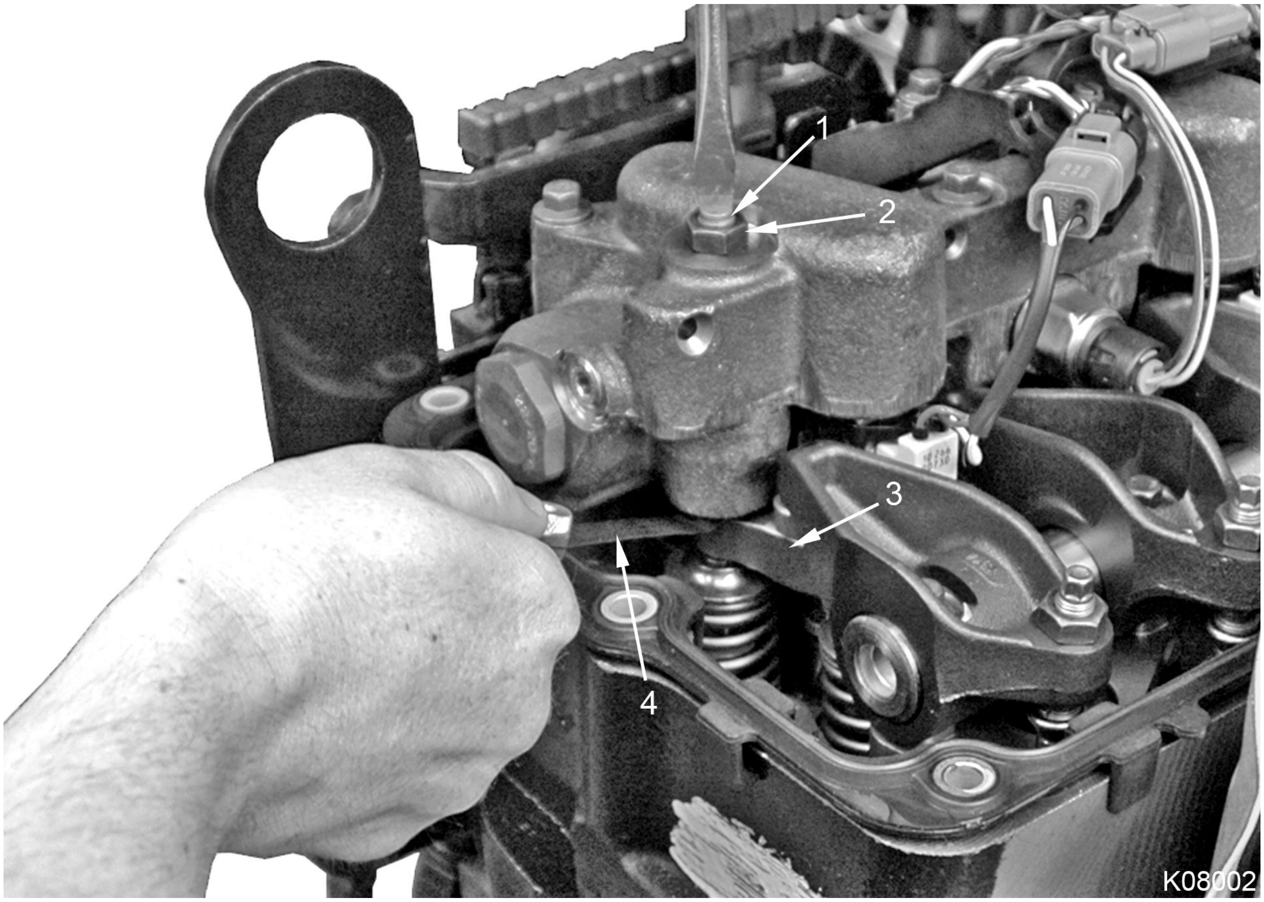


**Figure 213 Brake lash measurement**

1. Brake actuator piston screw
2. Brake actuator piston locknut
3. Valve bridge
4. Feeler gauge

4. Measure brake lash when engine is cold. Put a 0.48 mm (0.019 in) feeler gauge (page 287) between the brake actuator piston and valve bridge, a light drag on the feeler gauge should be felt. If adjustment is required, loosen actuator piston locknut and turn actuator piston screw.
5. Once brake lash is set, tighten actuator piston locknut to special torque (page 287) and remove feeler gauge. Recheck lash with a light drag on feeler gauge. If drag is too tight or loose, repeat steps 4 and 5.

   Corresponding valve lash can be adjusted before rotating crankshaft.
6. Turn the crankshaft 360° in the direction of engine rotation to remove gear lash. Position piston 6 at TDC compression by observing cylinder 1 rocker arms in overlap as the vibration damper timing mark approaches the TDC mark on the front cover.
7. If piston 6 is at TDC compression, see Chart 2 (page 270) and do steps 4, 5, and 6 for cylinders 2, 4, and 6.

## Removal

**NOTE:** If the valve cover is removed for any reason, verify six brake piston locknuts are tight. If loose, verify and reset brake lash (page 269).

**Brake Shut-off Valve (BSV) Assembly**

1. Remove valve cover (page 427).

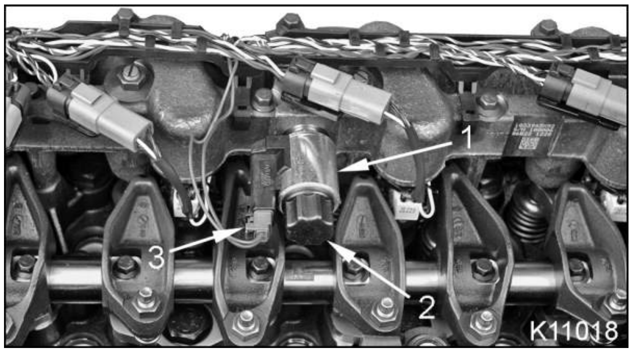


**Figure 214 BSV assembly**

1. Solenoid
2. Solenoid nut
3. Harness connector

2. Disconnect UVC harness connector from BSV assembly.
3. Remove solenoid nut and solenoid from brake shut-off valve.

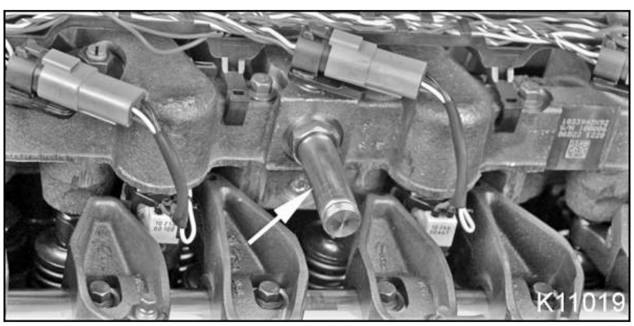


**Figure 215 Brake shut-off valve**

4. Remove brake shut-off valve from high-pressure oil manifold.
5. Remove and discard brake shut-off valve O-rings and back-up rings.

**Brake Control Pressure (BCP) Sensor**


**Figure 216 BCP sensor**

1. Disconnect 3-pin harness connector from BCP sensor, installed in the high-pressure oil manifold forward of cylinder 2 fuel injector.
2. Remove BCP sensor.
3. Discard sensor O-ring.

**Under Valve Cover (UVC) Harness Valve Cover Gasket Assembly (Brake)**

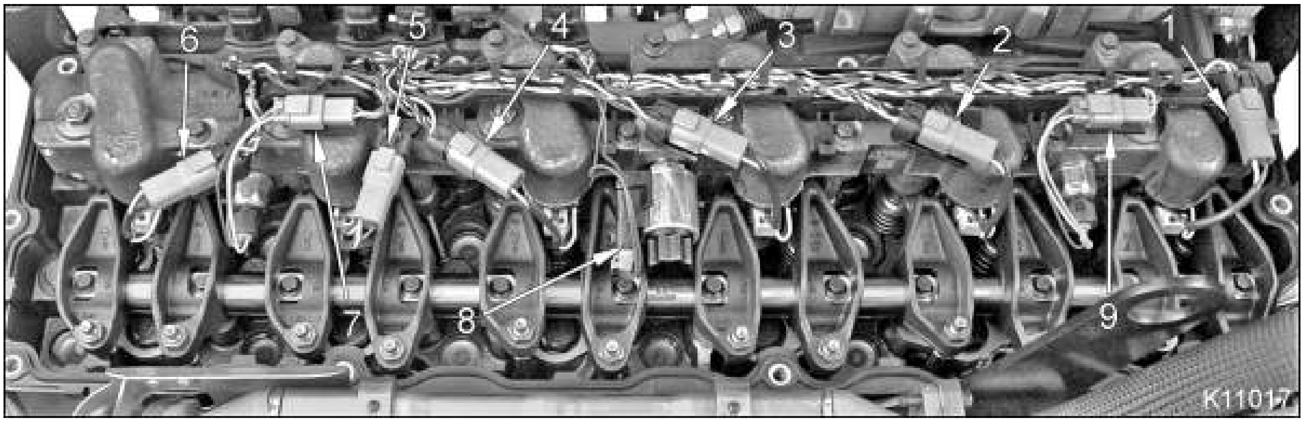


**Figure 217 UVC harness assembly (brake)**

1. Injector 1 connector (front of engine)
2. Injector 2 connector
3. Injector 3 connector
4. Injector 4 connector
5. Injector 5 connector
6. Injector 6 connector
7. Injection Control Pressure (ICP) sensor connector
8. Brake Shut-off Valve (BSV) connector
9. Brake Control Pressure (BCP) sensor connector

1. Disconnect four injector wiring harness (page 122) connectors from the UVC harness assembly.

**NOTE:** ICP and BCP sensors are identical and share the same part number.

2. Disconnect six injector connectors, ICP, and BCP sensor connectors.
3. Disconnect BSV connector.
4. Starting at one side, lightly pry up and open each of the six wire channel retainers while gently pulling up to remove UVC harness from engine.

**High-pressure Oil Manifold (Brake)**

1. Remove 12 M8 x 90 bolts holding high-pressure oil manifold to the cylinder head.

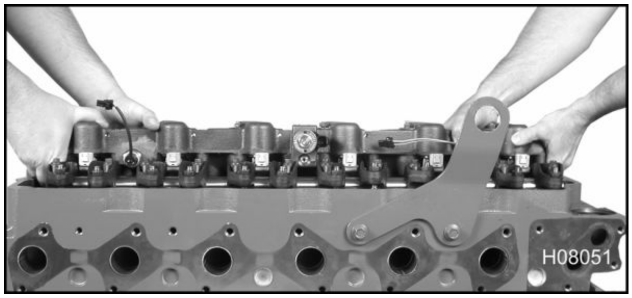


**Figure 218 High-pressure oil manifold removal**

**WARNING:**

**To prevent personal injury or death, get assistance to remove or install the high-pressure oil manifold assembly.**

2. Lift high-pressure oil manifold straight up just enough to drain oil out of manifold before lifting it away from cylinder head.
3. Lift up and remove high-pressure oil manifold from engine.

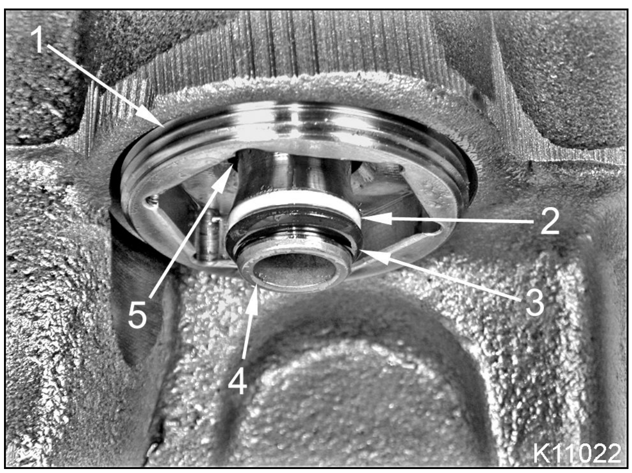


**Figure 219 Injector oil inlet adaptor installed in high-pressure oil manifold**

1. Injector oil inlet adaptor
2. Backup ring
3. Injector oil inlet seal
4. Oil inlet tube
5. Internal O-ring (not serviceable)

4. Remove and discard injector oil inlet adaptor seals and backup rings.
5. Remove any damaged injector oil inlet adaptor assemblies using Injector Adaptor Removal Tool (page 287).

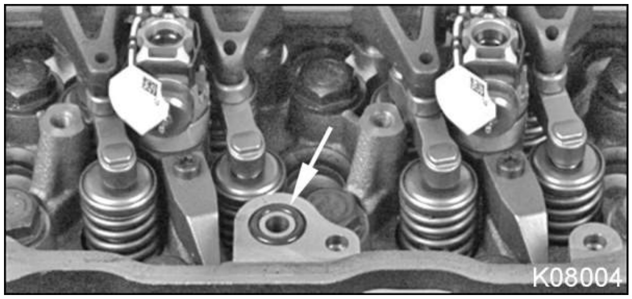


**Figure 220 Oil inlet O-ring**

6. Discard oil inlet O-ring

**Oil Pressure Relief Valve**

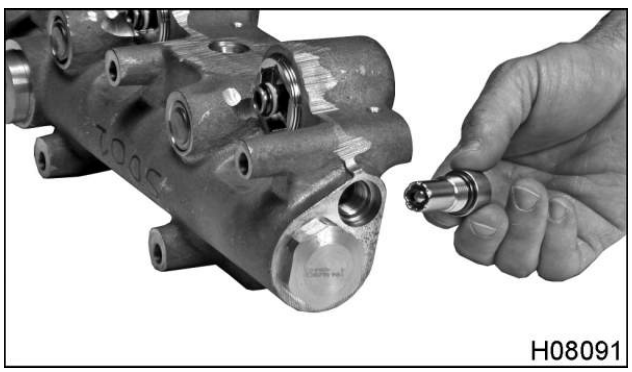


**Figure 221 Oil pressure relief valve**

1. Remove oil pressure relief valve from high-pressure oil manifold.
2. Discard valve O-ring.

**Brake Actuator Piston Assembly**

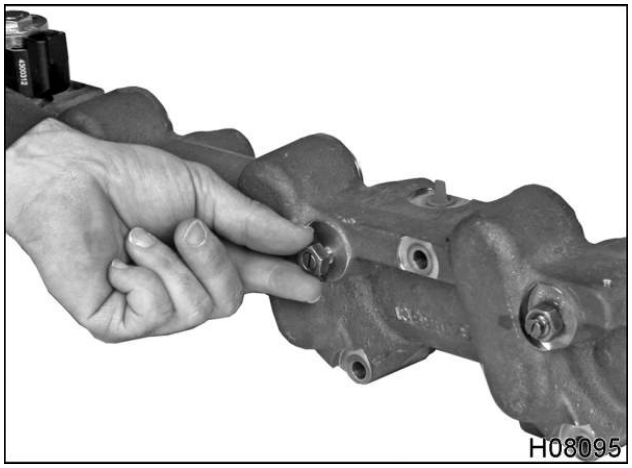


**Figure 222 Brake actuator piston locknut**

1. Remove brake actuator piston locknut.

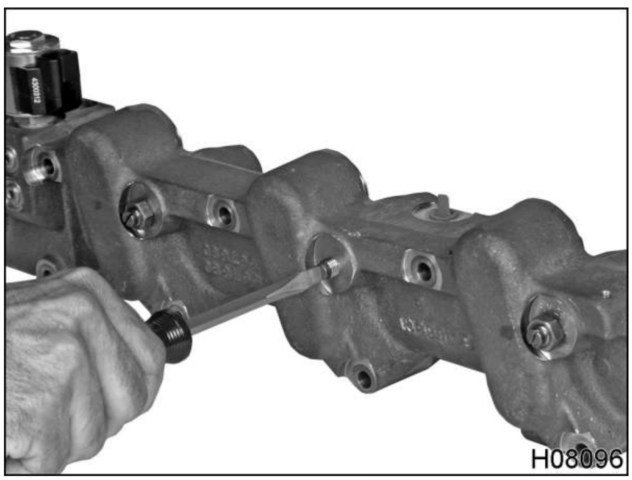


**Figure 223 Brake actuator piston removal**

2. Remove brake actuator piston assembly from the high-pressure oil manifold.

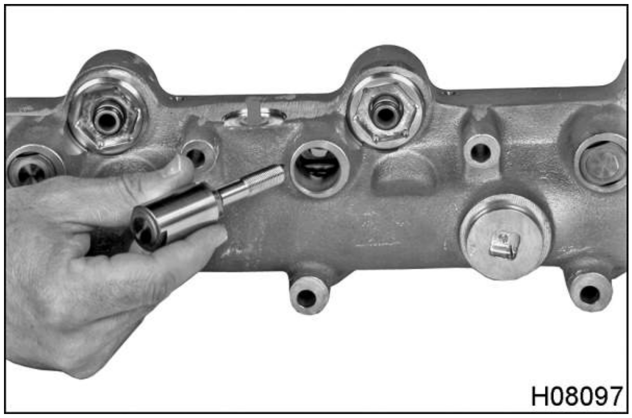


**Figure 224 Brake actuator piston assembly**

3. Remove brake actuator piston.

**NOTE:** There are no seals associated with the brake actuator piston assembly.

## Cleaning and Inspection

**WARNING:**

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

1. Clean high-pressure oil manifold, brake actuator pistons, valve bridges, oil pressure relief valve, oil manifold plugs, brake shut-off valve, and brake control pressure sensor with a suitable non-caustic solvent.
2. Blow parts dry using filtered compressed air.
3. Inspect high-pressure oil manifold, oil pressure relief valve, and oil manifold plugs for cracks and leaks. Replace cracked or leaking parts.

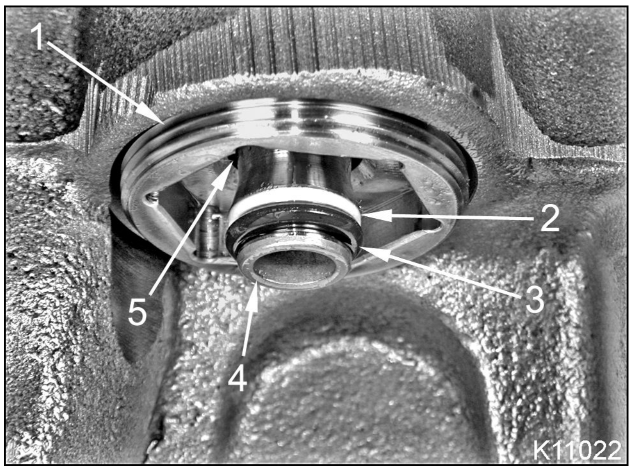


**Figure 225 Injector oil inlet adaptor installed in high-pressure oil manifold**

1. Injector oil inlet adaptor
2. Backup ring
3. Injector oil inlet seal
4. Oil inlet tube
5. Internal O-ring (not serviceable)

4. Verify six injector oil inlet adaptor oil inlet tubes move and are not frozen. Inspect injector oil inlet adaptors for internal O-ring extrusion and high-pressure oil leak paths. Replace any adaptor which has an extruded internal O-ring, frozen oil inlet tube, or high-pressure oil leak path.
5. Inspect all brake actuator pistons and valve bridge contact surfaces. Look for pitting and material transfer deformation. Replace pitted or deformed parts if necessary. Polished surfaces are acceptable.
6. Inspect the brake shut-off valve and brake control pressure sensor for cracks and leaks. Replace cracked or leaking parts.

# Installation

### Brake Actuator Piston Assembly

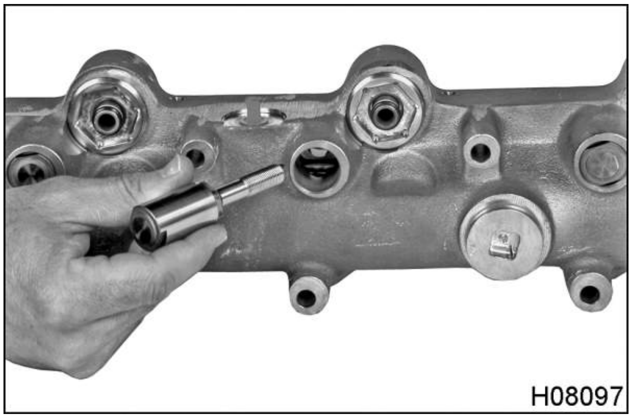


**Figure 226 Brake actuator piston assembly**

1. Lubricate brake actuator piston and high-pressure oil manifold bore with clean engine oil.
2. Install brake actuator piston in high-pressure oil manifold. Install used brake actuator pistons in the same location as removed.

**NOTE:** There are no seals associated with the brake actuator piston assembly.

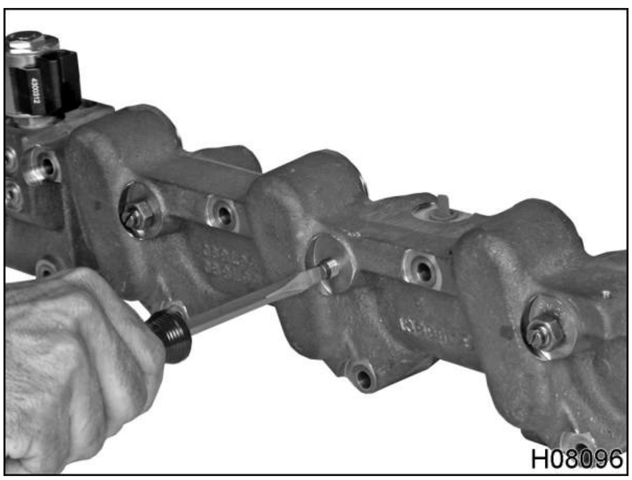


**Figure 227 Brake actuator piston installation**

3. Screw brake actuator piston assembly into high-pressure oil manifold.

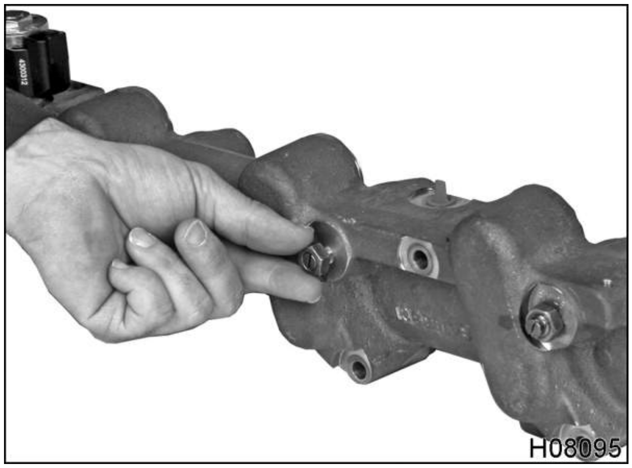


**Figure 228 Brake actuator piston locknut**

4. Install brake actuator piston locknut.
5. Final brake lash adjustments will be made after high-pressure oil manifold is installed on the cylinder head.

**Oil Pressure Relief Valve**

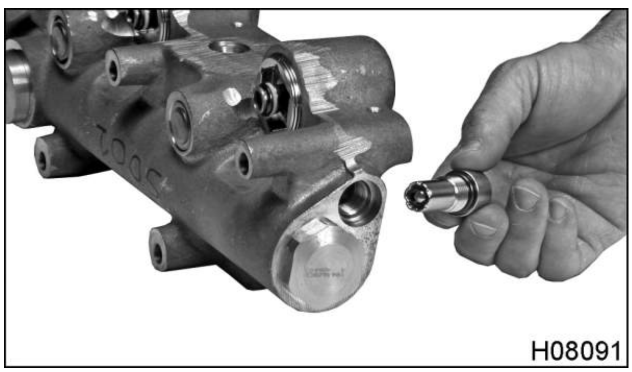


**Figure 229 Oil pressure relief valve**

1. Install new O-ring on oil pressure relief valve.
2. Install oil pressure relief valve and tighten to special torque (page 287).

**High-pressure Oil Manifold (Brake)**

1. Back off all brake actuator piston lash adjustments, for correct high-pressure oil manifold bolt torque during high-pressure oil manifold installation.

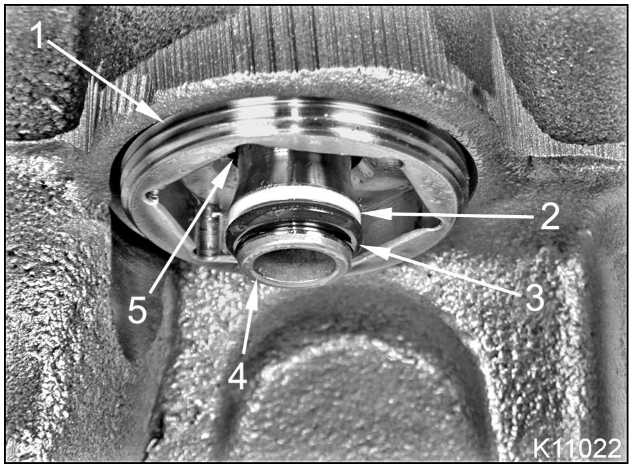


**Figure 230 Injector oil inlet adaptor installed in high-pressure oil manifold**

1. Injector oil inlet adaptor
2. Backup ring
3. Injector oil inlet seal
4. Oil inlet tube
5. Internal O-ring (not serviceable)

2. Verify that six injector oil inlet adaptor oil outlet tubes move and are not frozen. Inspect injector oil inlet adaptors for internal O-ring extrusion and high-pressure oil leak paths. Replace any adaptor which has an extruded internal O-ring, frozen oil outlet tube, or high-pressure oil leak path.
3. Install injector oil inlet adaptors with Injector Adaptor Removal Tool (page 287). Tighten injector oil inlet adaptors to special torque (page 287).
4. Install new backup rings and injector oil inlet seals on all oil inlet adaptors that were not replaced.
5. Coat backup rings and injector oil inlet seals with clean engine oil.

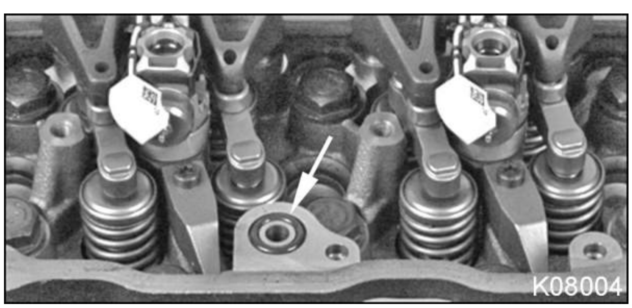


**Figure 231 Oil inlet O-ring**

6. Coat new oil inlet O-ring with clean engine oil and install in cylinder head recess.
7. Install valve bridges (page 480).

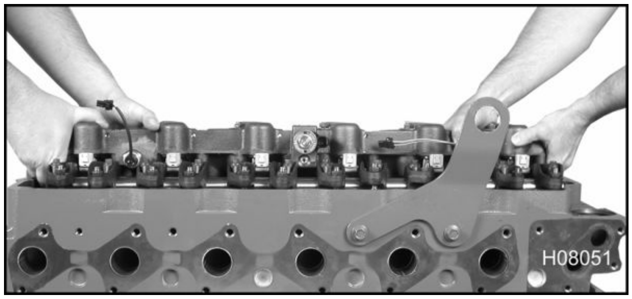


**Figure 232 High-pressure oil manifold installation**

**WARNING:**

**To prevent personal injury or death, get assistance to remove and install the high-pressure oil manifold assembly.**

8. With help from an assistant, lift the high-pressure oil manifold up and carefully place on engine.

**CAUTION:**

**To prevent engine damage, carefully align six injector oil inlet ports with six injector oil inlet adaptors of the high-pressure oil manifold before tightening oil manifold bolts.**

9. Carefully align six injector oil inlet ports with six injector oil inlet adapters of the high-pressure oil manifold and firmly push down to “snap” manifold in place.
10. Install and finger tighten 12 M8 x 90 bolts securing high-pressure oil manifold to the cylinder head.

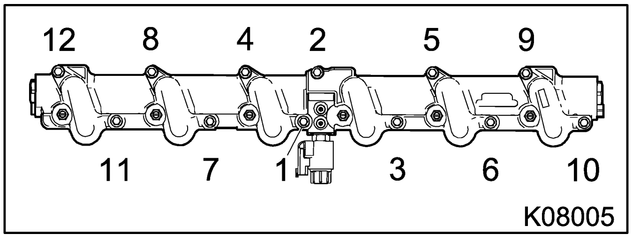


**Figure 233 High-pressure oil manifold bolt torque sequence**

11. Tighten 12 high-pressure oil manifold M8 x 90 bolts to in the proper torque sequence to 30 N·m (22 lbf·ft).
12. Adjust Engine Brake Lash (page 269) for all cylinders.

**NOTE:** Air trapped in the high-pressure oil manifold will be purged automatically during cranking and start up.

**Under Valve Cover (UVC) Harness Valve Cover Gasket Assembly (Brake)**

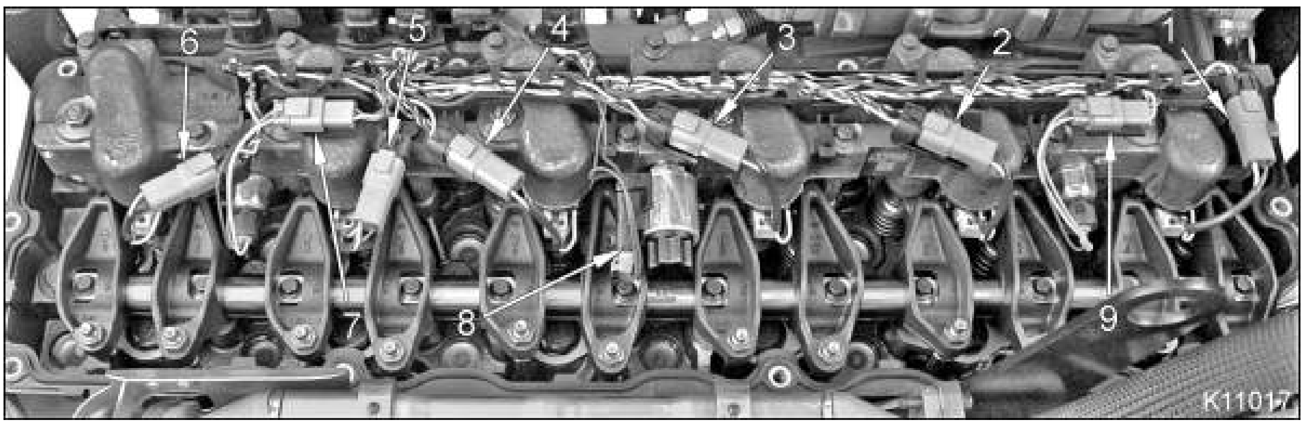


**Figure 234 UVC harness assembly (brake)**

1. Injector 1 connector (front of engine)
2. Injector 2 connector
3. Injector 3 connector
4. Injector 4 connector
5. Injector 5 connector
6. Injector 6 connector
7. Injection Control Pressure (ICP) sensor connector
8. Brake Shut-off Valve (BSV) connector
9. Brake Control Pressure (BCP) sensor connector

**NOTE:** ICP and BCP sensors are identical and share the same part number.

1. Position UVC harness on cylinder head and carefully push down each of the six wire channel retainers to snap harness onto high-pressure oil manifold.
2. Connect six injectors, ICP sensor, BCP sensor, and BSV harness connectors.

### Brake Control Pressure (BCP) Sensor


**Figure 235 BCP sensor**

1. Install new O-ring on BCP sensor and lubricate with clean engine oil.
2. Install BCP sensor into high-pressure oil manifold, forward of cylinder 2 fuel injector, and tighten to special torque (page 287).
3. Connect UVC harness connector to BCP sensor.

### Brake Shut-off Valve (BSV) Assembly

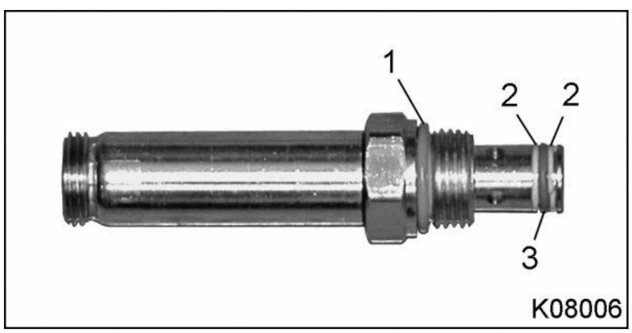


**Figure 236 Brake Shut-off Valve seals**

1. O-ring
2. Back-up ring (2)
3. O-ring

1. Install new O-rings and back-up rings on brake shut-off valve.
2. Lubricate O-rings with clean engine oil.

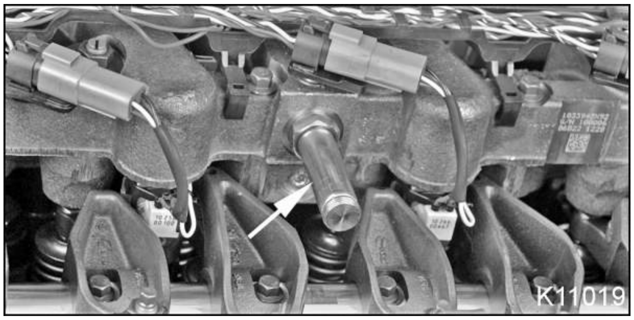


**Figure 237 Brake shut-off valve**

3. Install brake shut-off valve in high-pressure oil manifold.
4. Tighten brake shut-off valve to special torque.

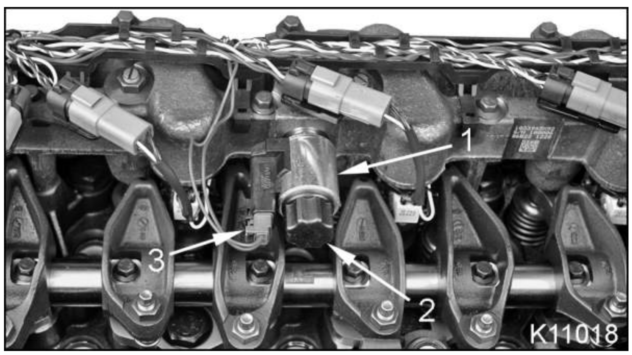


**Figure 238 BSV assembly**

1. Solenoid
2. Solenoid nut
3. Harness connector

5. Install solenoid over the brake shut-off valve.

**CAUTION:**

**To prevent engine damage, position BSV solenoid harness connector to give proper clearance for rocker arm movement.**

6. Install solenoid nut and position BSV solenoid harness connector to give proper clearance for rocker arm movement.
7. Tighten solenoid nut to special torque.
8. Connect UVC harness connector to BSV assembly

## Specifications

| | |
|---|---|
| Brake actuator lash (cold) | 0.48 mm (0.019 in) |

## Special Torque

| | |
|---|---|
| Brake Control Pressure (BCP) sensor and Injection Control Pressure (ICP) sensor | 18 N·m (162 lbf·in) |
| Brake actuator piston locknut | 25 N·m (19 lbf·ft) |
| Brake shut-off valve solenoid nut | 5 N·m (45 lbf·in) |
| Brake shut-off valve | 27 N·m (20 lbf·ft) |
| High-pressure oil manifold bolts M8 x 90 | See High-pressure Oil Manifold (Brake) (page 284). |
| Injector oil inlet adaptor assembly | 204 N·m (150 lbf·ft) |
| Oil pressure relief valve | 45 N·m (33 lbf·ft) |
| Plug assembly, M12 | 12 N·m (108 lbf·in) |
| Plug assembly, M10 | 12 N·m (108 lbf·in) |
| Rail end plug assembly | 204 N·m (150 lbf·ft) |

## Special Service Tools

| | |
|---|---|
| Feeler gauge | Obtain locally |
| Injector Adaptor Removal Tool | ZTSE4725 |

# Table of Contents

# Illustrations

### Air Compressor

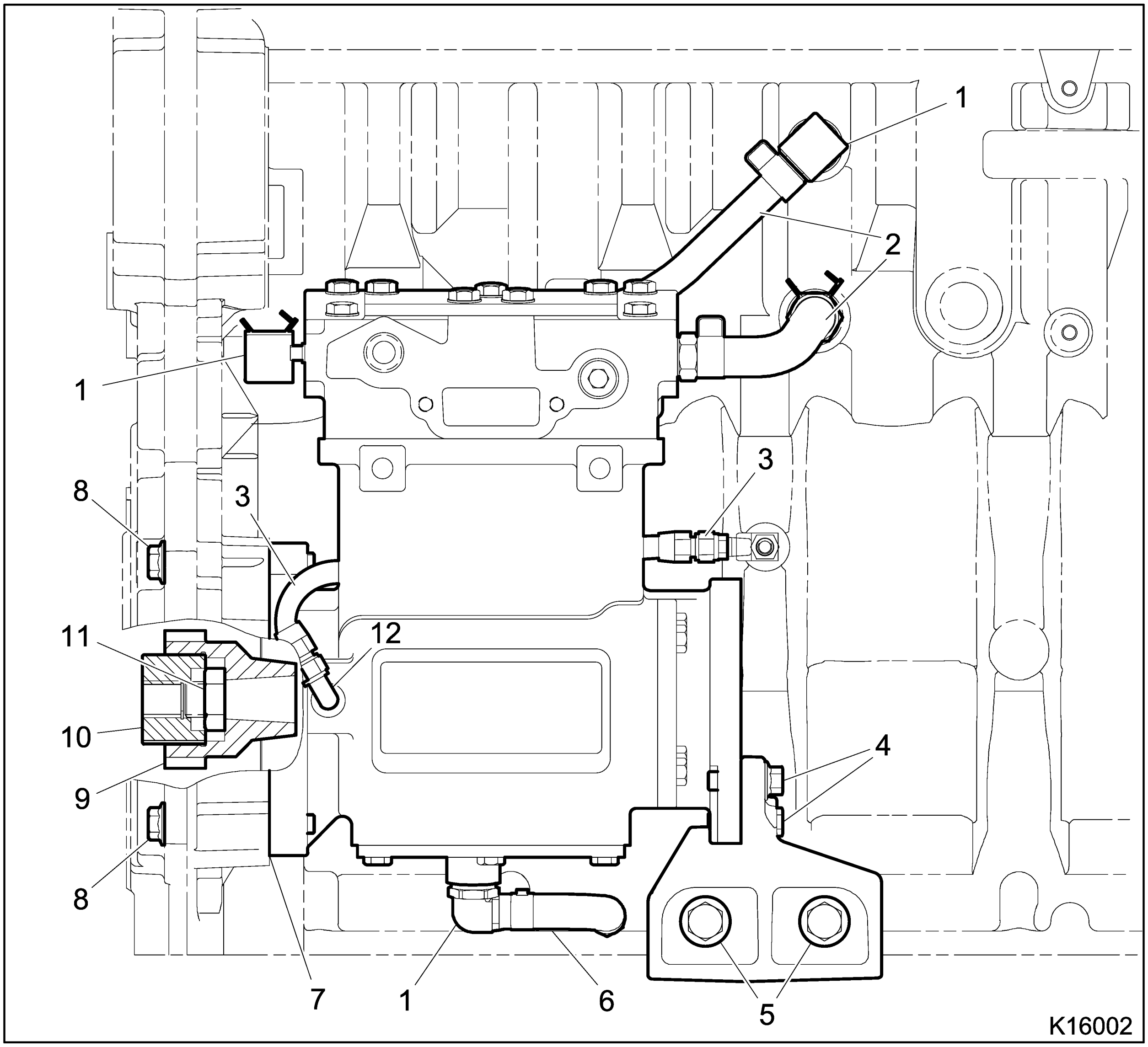


**Figure 239 Air compressor mounting and connections**

1. M18 elbow assembly (3)
2. Hose (coolant) .50 ID (2)
3. Air compressor (oil supply) hose assembly
4. M10 x 30 bolt (2)
5. M12 x 50 bolt (2)
6. Drain hose (oil)
7. Gasket
8. M12 x 80 bolt (2)
9. Air compressor gear
10. PTO spline adaptor assembly
11. Air compressor gear nut
12. M10 elbow assembly

**Power Steering Pump**

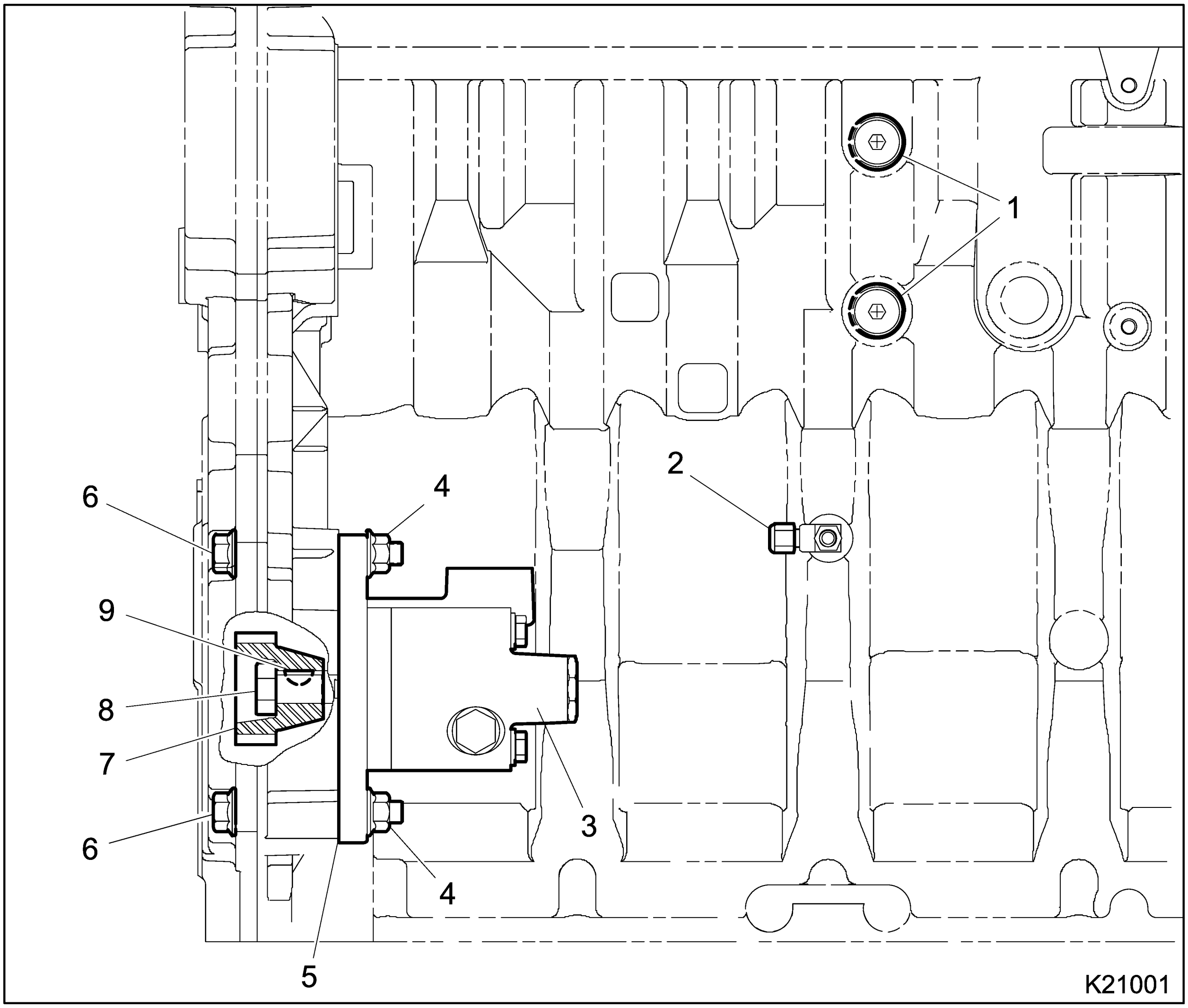


**Figure 240 Power steering pump without air compressor**

1. M18 plug assembly (coolant)
2. Cap (oil)
3. Power steering pump assembly
4. M12 nut (2)
5. Gasket
6. M12 x 90 bolt (2)
7. Drive gear
8. Power steering pump gear nut
9. Shaft key

## Description

The optional air compressor is gear driven from the lower idler gear located in the engine front cover.

Lubrication oil for the air compressor is provided through a hose connected to the engine oil pressure sensor tee. Oil drains back to the crankcase through a hose on the bottom of the compressor.

Filtered air for the air compressor is drawn through an air hose connected to the air cleaner assembly. Air is compressed and delivered to an air tank. When the air tank is full, excess compressed air is vented to the atmosphere.

Coolant for the air compressor is supplied and returned through two hoses connected to the intake side of the crankcase.

The optional power steering pump assembly is mounted in one of two configurations:

- Without an air compressor, the power steering pump is mounted on the front cover and driven by the lower idler gear.
- With an air compressor, the power steering pump is mounted to the air compressor. The compressor is driven by the lower idler gear and torque is transferred to the power steering pump through the compressor crankshaft.

**NOTE:** For individual component service procedures other than removal and installation refer to the International Service Information Solutions - ISIS® web site and then select the “Suppliers” link.

## Removal

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

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

**NOTE:** Air compressor and power steering pump may be removed together as an assembly or separately depending on service requirements.

**Power Steering Pump**

1. Place a drain pan under the power steering pump assembly.
2. Disconnect high-pressure power steering hose at power steering pump.
3. Disconnect low-pressure power steering hose at power steering pump.
4. Cap oil lines to keep dirt out and reduce fluid spills.

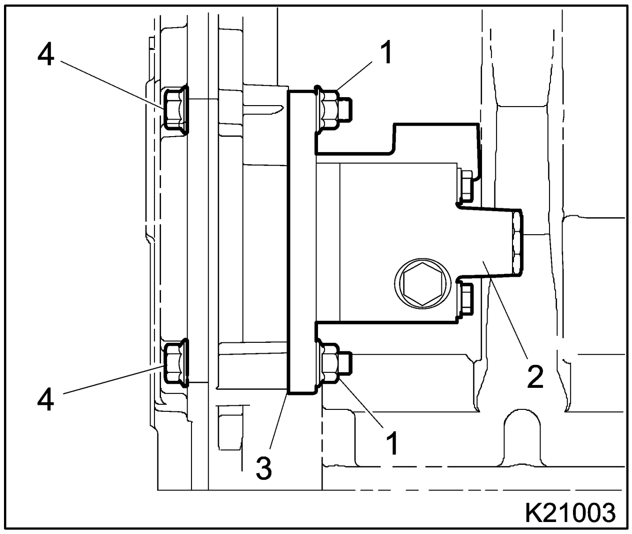


**Figure 241 Power steering pump without air compressor**

1. M12 nut (2)
2. Power steering pump assembly
3. Gasket
4. M12 x 90 bolt (2)

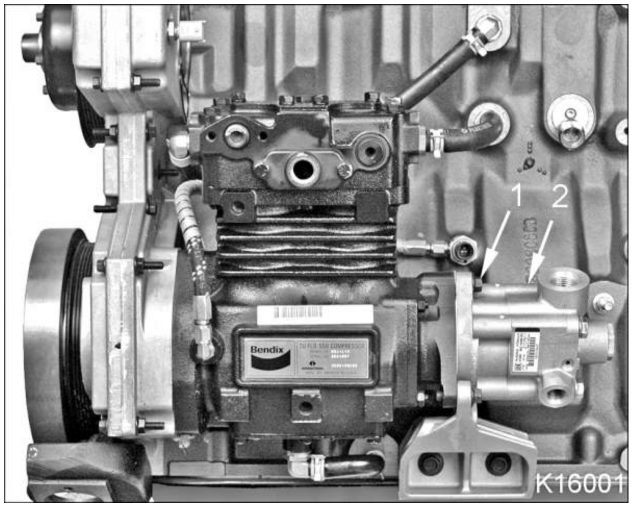


**Figure 242 Power steering pump with air compressor**

1. M10 x 35 bolt (2)
2. Power steering pump assembly

5. Depending on application, do one of the following:
   - For power steering pump without air compressor, remove two M12 x 90 bolts and M12 nuts.
   - For power steering pump with air compressor, remove two M10 x 35 bolts.
6. Remove power steering pump and discard gasket.

**Air Compressor**

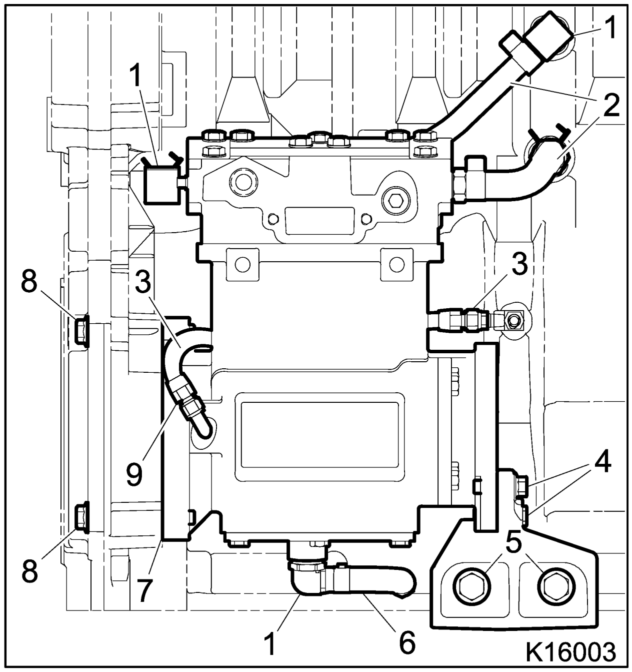


**Figure 243 Air compressor mounting and connections**

1. M18 elbow assembly (3)
2. Hose (coolant) .50 ID (2)
3. Air compressor (oil supply) hose assembly
4. M10 x 30 bolt (2)
5. M12 x 50 bolt (2)
6. Drain hose (oil)
7. Air compressor gasket
8. M12 x 80 bolt (2)
9. M10 elbow assembly

1. Place a drain pan under the air compressor assembly.
2. Clamp off coolant hoses so engine coolant does not drain out.
3. Loosen coolant hose clamps and remove two coolant hoses from air compressor.
4. Remove air compressor (oil supply) hose assembly.
5. Loosen oil drain hose clamps and remove drain hose.
6. Cap oil and coolant lines to keep dirt out and reduce fluid spills.
7. Remove two M12 x 80 bolts holding air compressor to the front cover.

**WARNING:**

**To prevent personal injury or death, get assistance to remove and install the air compressor and power steering pump assembly.**

8. Support weight of air compressor and remove two M12 x 50 bolts holding the air compressor and support bracket to the crankcase. Remove air compressor and bracket assembly from engine.
9. Remove two M10 x 30 bolts connecting the air compressor bracket to the air compressor.
10. Remove and discard air compressor gasket, mounted between the air compressor and front cover.

## Cleaning and Inspection

1. Clean the power steering pump, air compressor, and lines with a rag or brush and a suitable solvent.
2. Check power steering pump and air compressor for cracks and leaks. Replace if required.
3. Check hoses and lines for cracks and leaks. Replace cracked or leaking lines and hoses.

# Installation

### Air Compressor

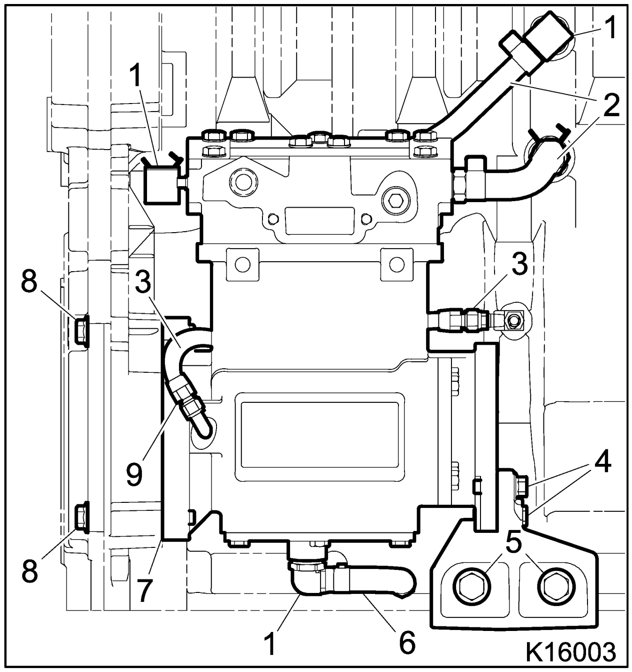


**Figure 244 Air compressor mounting and connections**

1. M18 elbow assembly (3)
2. Hose (coolant) .50 ID (2)
3. Air compressor (oil supply) hose assembly
4. M10 x 30 bolt (2)
5. M12 x 50 bolt (2)
6. Drain hose (oil)
7. Air compressor gasket
8. M12 x 80 bolt (2)
9. M10 elbow assembly

1. Install two M10 x 30 bolts connecting the air compressor bracket to the air compressor and finger tighten.
2. Install a new air compressor gasket on the front cover.

**WARNING:**

**To prevent personal injury or death, get assistance to remove and install the air compressor and power steering pump assembly.**

3. With help from an assistant, install air compressor assembly into front cover while aligning air compressor gear with the lower idler gear. Install two M12 x 50 bolts through air compressor bracket into crankcase and finger tighten.
4. Align air compressor bolt holes with the front cover bolt holes and install two M12 x 80 bolts finger tight.

**CAUTION:**

**To prevent engine damage, do not over torque air compressor mounting bolts. Over tightening bolts will result in a fractured front cover.**

5. Tighten two M12 x 80 bolts connecting the air compressor to the front cover to special torque (page 304).
6. Tighten two M10 x 30 bolts connecting the air compressor to the air compressor bracket to special torque (page 304).
7. Push up on rear of air compressor and tighten two M12 x 50 bolts connecting the air compressor bracket to the crankcase to special torque (page 304).
8. Install all elbow assemblies and hose connector assemblies removed from the crankcase and air compressor.
9. Orient elbow assemblies to reduce hose stress. Tighten elbow assemblies and hose connector assemblies to special torque (page 304).
10. Install air compressor (oil supply) hose assembly on M10 elbow assembly. Finger tighten hose nut and then turn nut 1/2 to 2 additional turns until tight.
11. Install oil drain hose and tighten hose clamps.

### Power Steering Pump Without Air Compressor

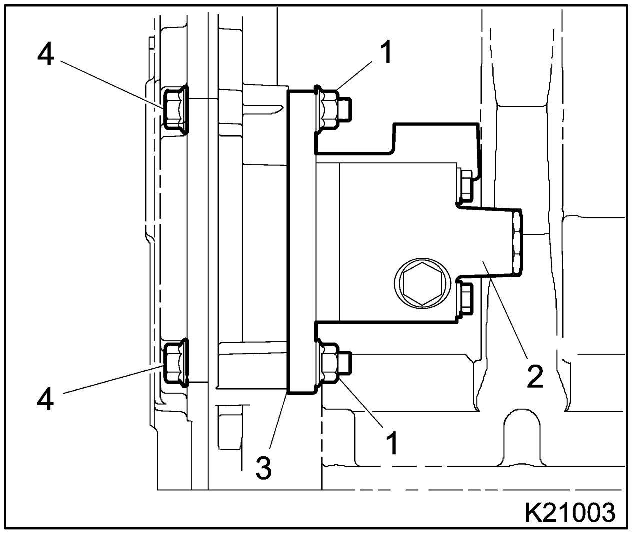


**Figure 245 Power steering pump without air compressor**

1. M12 nut (2)
2. Power steering pump assembly
3. Gasket
4. M12 x 90 bolt (2)

1. Install a new power steering pump gasket on the back of the front cover.
2. Install power steering pump on the front cover and install two M12 x 90 bolts and two M12 nuts.
3. Tighten two M12 x 90 bolts and two M12 nuts to standard torque (page 683).
4. Install low-pressure power steering hose.
5. Install high-pressure power steering hose.
6. Fill power steering reservoir to full mark.
7. Start engine and turn steering wheel lock-to-lock several times.
8. Turn engine off.
9. Check for leaks and fill engine power steering reservoir to full mark.

**Power Steering Pump With Air Compressor**

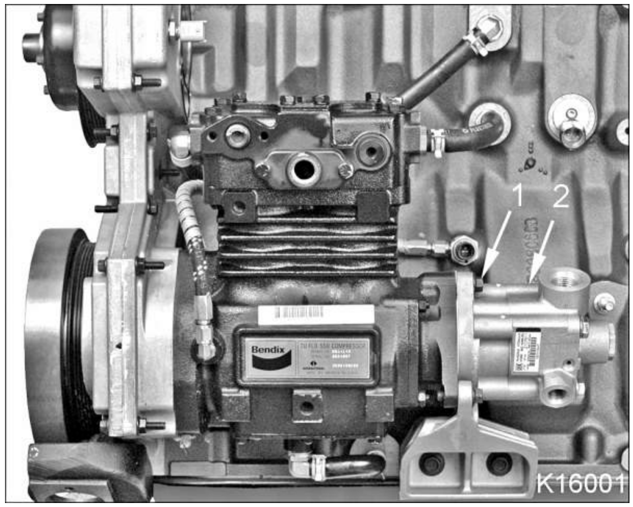


**Figure 246 Power steering pump with air compressor**

1. M10 x 35 bolt (2)
2. Power steering pump assembly

1. Install a new power steering pump gasket on the back of the air compressor.
2. Install power steering pump on the back of the air compressor and secure with two M10 x 35 bolts.
3. Tighten two M10 x 35 bolts to special torque (page 304).
4. Install low-pressure power steering hose.
5. Install high-pressure power steering hose.
6. Fill power steering reservoir to full mark.
7. Start engine and turn steering wheel lock-to-lock several times.
8. Turn engine off.
9. Check for leaks and fill engine power steering reservoir to full mark.

## Specifications

| | |
|---|---|
| Lower idler gear to air compressor gear backlash | 0.508 mm (0.020 in) |

## Special Torque

| | |
|---|---|
| Air compressor gear nut | 150 N·m (110 lbf·ft) |
| Air compressor M12 x 80 bolts | 83 N·m (61 lbf·ft) |
| Bracket to air compressor M10 x 30 bolts | 67 N·m (49 lbf·ft) |
| Compressor bracket to crankcase M12 x 50 bolts | 115 N·m (85 lbf·ft) |
| Elbow assembly, M10 | 16 N·m (138 lbf·in) |
| Elbow assembly, M18 | 48 N·m (35 lbf·ft) |
| Hose connector assembly, M18 | 48 N·m (35 lbf·ft) |
| Power steering pump mounting bolts, M10 x 35 | 57 N·m (42 lbf·ft) |
| Power steering pump drive nut | 90 N·m (66 lbf·ft) |

# Table of Contents

## Exploded View and Description

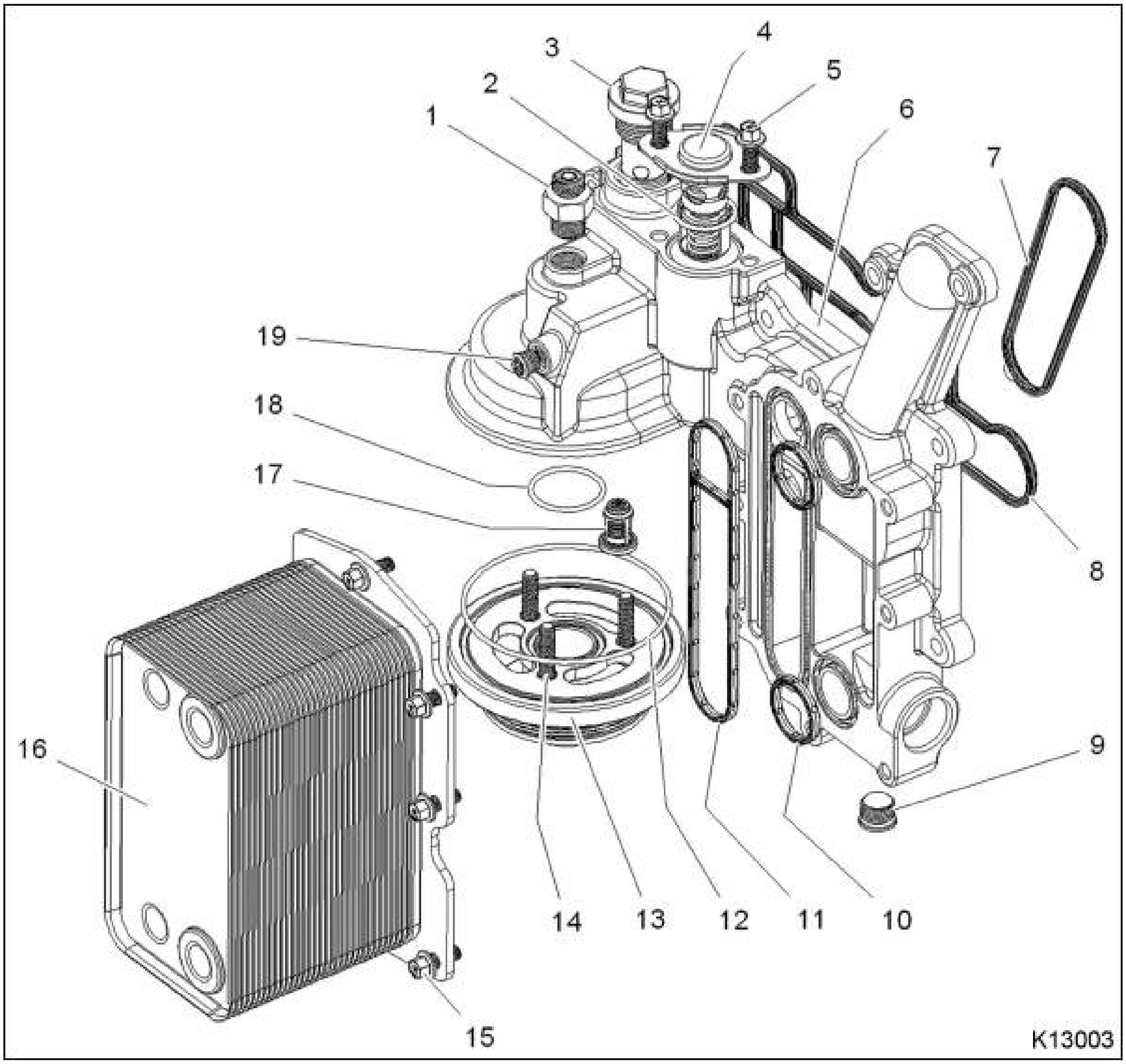


**Figure 247 Oil system module assembly**

1. Turbocharger oil supply tube fitting and O-ring
2. O-ring
3. Regulator valve assembly (oil pressure)
4. Thermal valve assembly (oil)
5. M8 x 20 bolt (2)
6. Oil cooler housing
7. Coolant seal
8. Irregular gasket (oil)
9. M18 plug assembly (coolant drain)
10. Coolant seal (2)
11. Oil seal
12. O-ring
13. Lube filter adapter
14. M8 x 25 bolt (3)
15. M8 x 20 bolt (8)
16. Cooler heat exchanger (23 or 33 plates)
17. Filter bypass valve
18. O-ring
19. M12 plug assembly (oil priming)

The oil system module assembly uses engine coolant, a heat exchanger, and a thermal oil valve to cool engine oil. An oil pressure regulator valve dumps excess oil to the oil pan to regulate oil pressure and an oil filter filters engine oil. See Engine Lubrication System (page 42) for additional lubrication system details.

## Removal

**WARNING:**

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

**WARNING:**

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

**WARNING:**

**To prevent personal injury or death, allow engine to cool before removing components.**

**WARNING:**

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

**WARNING:**

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

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

**Drain Coolant**

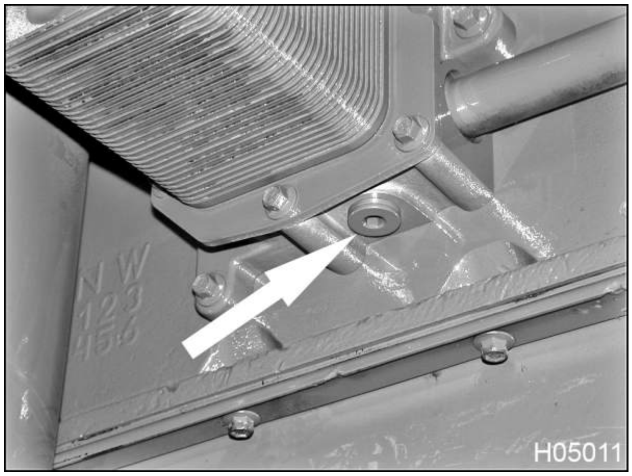


**Figure 248 Coolant drain plug**

1. Place a coolant drain pan under the oil system module.
2. Remove M18 coolant drain plug from the bottom of the oil system module. Open radiator cap to allow system to drain quicker.
3. Remove and discard coolant drain plug O-ring.
4. Install a new O-ring on the coolant drain plug.
5. After coolant has drained, install coolant drain plug in the oil system module.
6. Tighten coolant drain plug to special torque (page 332).
7. Recycle or dispose of coolant according to applicable regulations.

### Coolant Tube


**Figure 249 Oil system module and coolant tube**

1. Turbocharger oil supply tube fitting
2. M8 x 30 stud bolt
3. M8 x 30 bolt (7)
4. M8 x 30 coolant tube bolt
5. M8 x 16 stud bolt

1. Remove M8 x 16 stud bolt and M8 x 30 coolant tube bolt from coolant tube brackets.
2. Pull coolant tube out of oil system module and front cover.
3. Discard coolant tube O-rings.

### Oil System Module Assembly

1. Place an oil drain pan under the oil filter.
2. Rotate oil filter counterclockwise with an oil filter wrench and remove oil filter.
3. Remove the turbocharger oil supply tube (page 159) from the oil system module.
4. Cap the open end of the turbocharger oil supply tube and fitting.
5. Discard turbocharger oil supply tube O-ring.
6. Remove seven M8 x 30 bolts and one M8 x 30 stud bolt holding the oil system module to the crankcase.
7. Remove oil system module from the crankcase.

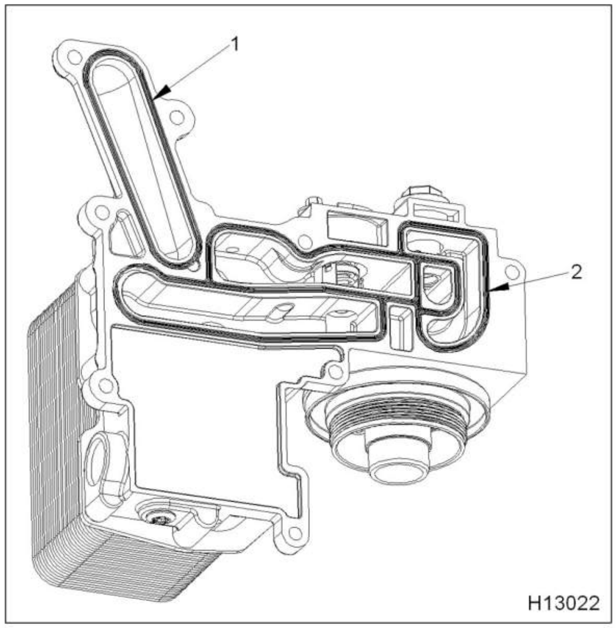


**Figure 250 Oil system module oil and coolant seals**

1. Coolant seal
2. Irregular gasket (oil)

8. Remove and discard coolant seal and irregular gasket.

## Disassemble

**NOTE:** Only disassemble oil system module if a component fails or is leaking.

**Regulator Valve (Oil Pressure)**


**Figure 251 Regulator valve removal**

1. Remove regulator valve from the oil cooler housing, using a 24 mm or 15/16 in wrench.
2. Remove and discard two O-rings

**Thermal Valve (Oil)**

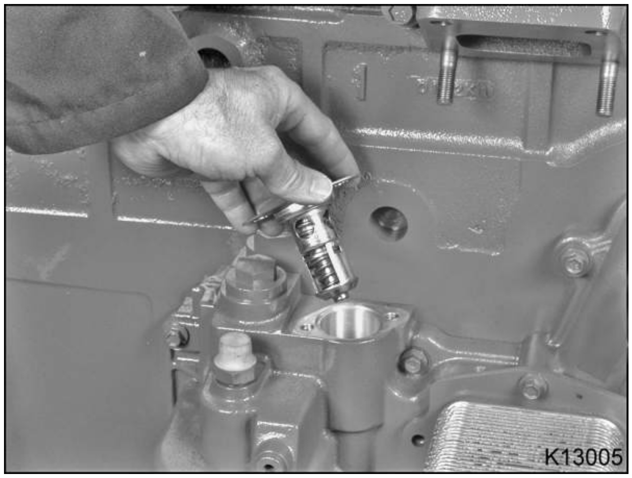


**Figure 252 Thermal valve removal**

1. Remove two M8 x 20 bolts.
2. Remove thermal valve from oil cooler housing.
3. Remove and discard O-ring.

### Cooler Heat Exchanger

**NOTE:** It is not necessary to remove the oil system module assembly from the engine to remove the cooler heat exchanger.

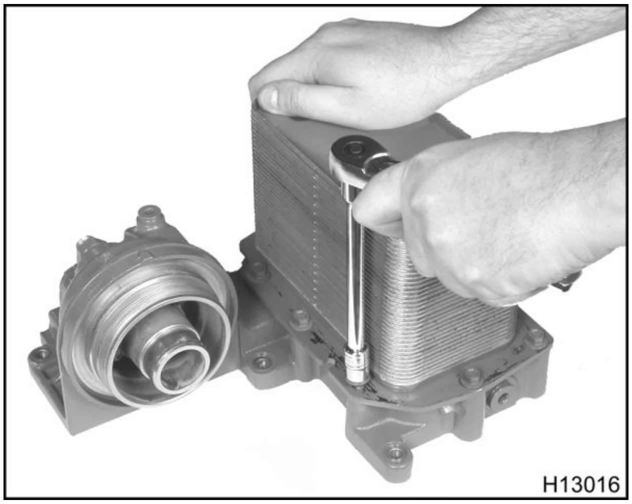


**Figure 253 Heat exchanger removal**

1. Remove and discard eight M8 x 20 bolts connecting the heat exchanger to the oil cooler housing.

**CAUTION:**

**To prevent engine damage, do not use excessive force against aluminum cooler plate to separate heat exchanger from oil cooler housing. Do not apply any force to heat exchanger fins.**

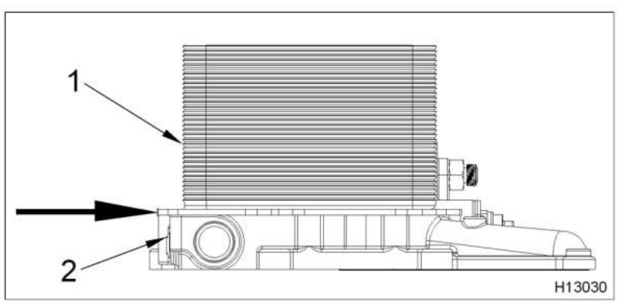


**Figure 254 Heat exchanger separation point**

1. Cooler heat exchanger
2. Oil cooler housing

2. Separate heat exchanger from the oil cooler housing by applying just enough force (at large arrow) for separation.

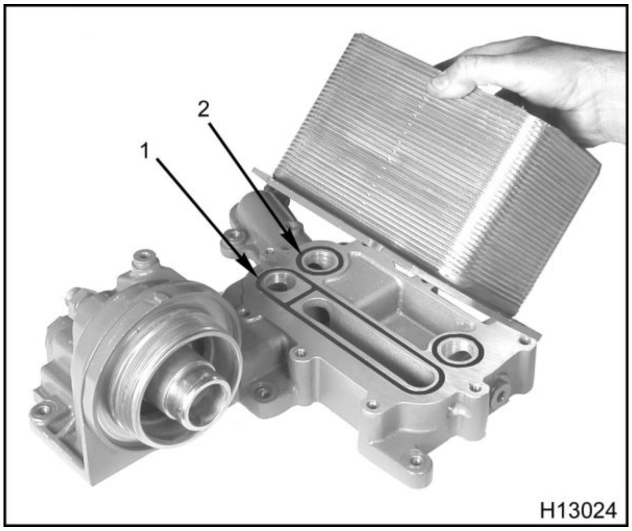


**Figure 255 Heat exchanger seals**

1. Oil seal
2. Coolant seal (2)

3. Remove and discard two coolant seals and one oil seal.
4. Drain oil and coolant out of heat exchanger.

**Lube Filter Adapter Assembly**

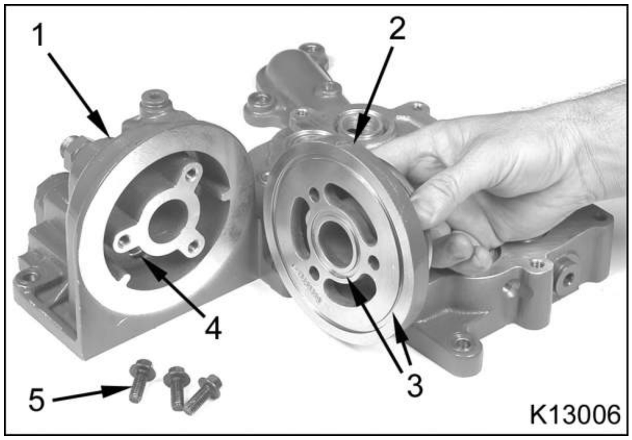


**Figure 256 Lube filter adapter assembly and oil cooler housing**

1. Oil cooler housing
2. Lube filter adapter
3. O-ring recess (2)
4. Filter bypass valve
5. M8 x 25 bolt (3)

1. Remove three M8 x 25 bolts holding lube filter adapter to the oil cooler housing.

   **NOTE:** Bolts are thread-forming fasteners. These bolts may be removed and reinstalled, or may be replaced with standard bolts.

2. Remove lube filter adapter from oil cooler housing.
3. Remove and discard two O-rings.

**Oil Filter Bypass Valve**

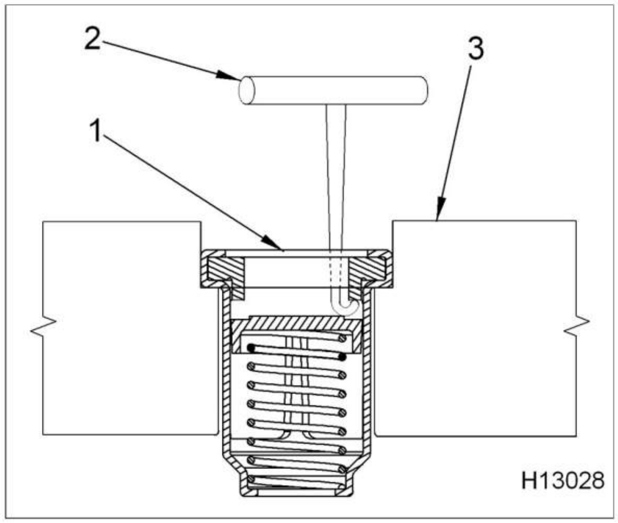


**Figure 257 Filter bypass valve removal**

1. Filter bypass valve
2. Hooked shaped tool (tool size shown not to scale)
3. Oil cooler housing

1. Remove lube filter adapter for access to the filter bypass valve, which is pressed in the oil cooler housing.
2. Remove oil bypass valve (only if defective) by inserting a hook shaped tool (obtain locally) and depressing the check valve, while catching valve seat. As an alternative method, use a slide hammer threaded through valve.

## Cleaning, Inspection, and Testing

**WARNING:**

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

### Clean Oil System Module

**CAUTION:**

**To prevent engine damage, replace the cooler heat exchanger if an engine bearing fails. Bearing debris can not be removed from the heat exchanger.**

**CAUTION:**

**To prevent engine damage, do not clean the assembled oil system module in solvent. Solvent will be trapped in the heat exchanger, regulator valve assembly, and oil thermal valve assembly.**

Remove the following components from the oil cooler housing before cleaning with solvent:

- Heat exchanger
- Regulator valve assembly
- Thermal valve assembly

The oil cooler housing and lube filter adapter can be cleaned in solvent and blown dry with filtered compressed air.

1. Clean the disassembled oil cooler housing and lube adapter in a suitable solvent.
2. Flush and drain oil cooler housing and lube filter adapter to remove any residue. Dry components with filtered compressed air.
3. Check oil cooler housing for blocked orifices and damaged threads. Replace housing if required.
4. Remove any debris blocking the filter bypass valve.
5. Remove turbocharger oil supply tube fitting on top of the oil filter header and discard O-ring.

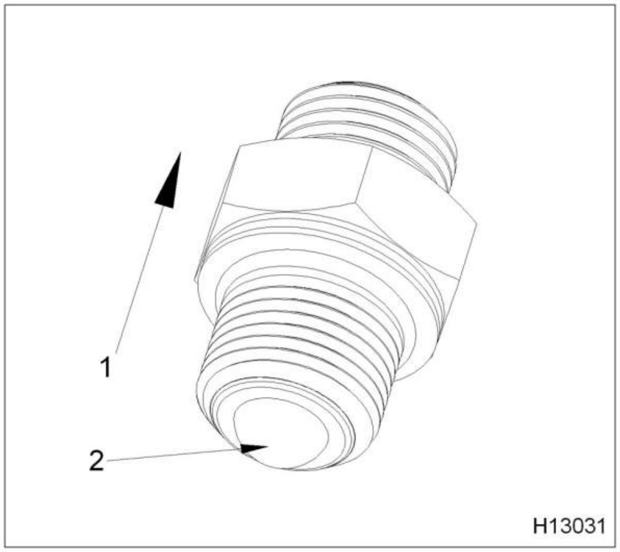


**Figure 258 Turbocharger oil supply tube fitting**

1. Direction of oil flow
2. Wire mesh screen

6. Inspect wire mesh screen for damage or particle obstruction. Clean or replace turbocharger oil supply tube fitting if necessary.
7. Install a new O-ring on tube fitting.
8. Install turbocharger oil supply tube fitting into oil cooler housing and finger tighten.
9. Tighten turbocharger oil supply tube fitting to special torque (page 332).

### Test Cooler Heat Exchanger for Leaks

### External

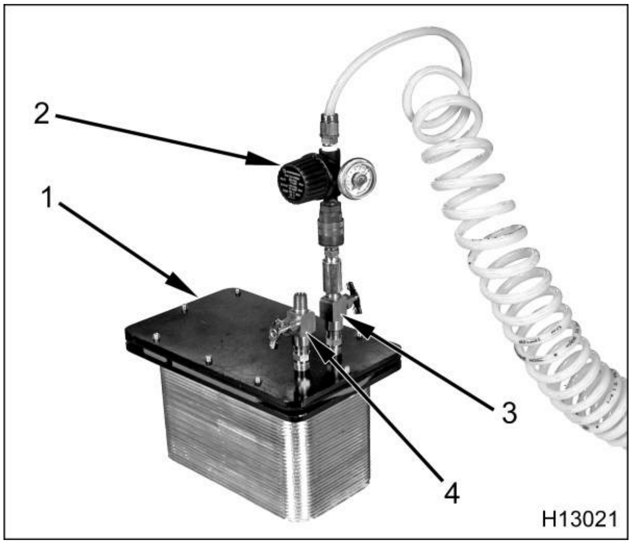


**Figure 259 Heat exchanger coolant passage leak test**

1. Test plate set
2. Air pressure regulator
3. Coolant port valve (with air hose)
4. Oil port valve (closed)

1. Attach Oil Cooler Pressure Test Plate (page 332) to heat exchanger and torque eight M8 x 20 bolts to special torque (page 332).
2. Close oil port valve.
3. Connect air pressure regulator (page 332) between test plate coolant port and shop air supply.
4. Immerse heat exchanger and test plate in a large container of clean water.
5. Open coolant port valve and allow air to fill coolant side of heat exchanger.
6. Apply 172 to 276 kPa (25 to 40 psi) of air pressure while assembly is under water.
7. Inspect heat exchanger and test plate for leaks. If test plate fittings leak, tighten fittings and continue looking for leaks. Air bubbles at any location on the heat exchanger indicate a coolant passage leak. Replace heat exchanger if leaking.

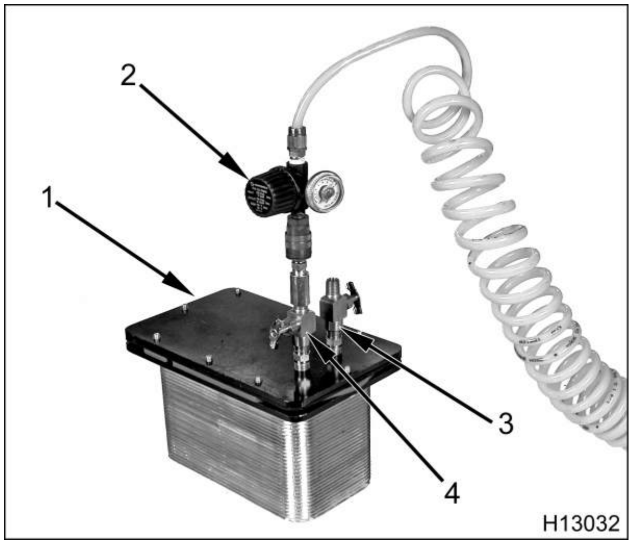


**Figure 260 Heat exchanger oil passage leak test**

1. Test plate set
2. Air pressure regulator
3. Coolant port valve (closed)
4. Oil port valve (with air hose)

8. Remove assembly from water.
9. Connect air pressure regulator between the test plate oil port and the shop air supply.
10. Close coolant port valve.
11. Immerse heat exchanger and test plate in a large container of clean water.
12. Open oil port valve and allow air to fill oil side of heat exchanger.
13. Apply 172 to 276 kPa (25 to 40 psi) of air pressure while assembly is under water.
14. Inspect heat exchanger and test plate for leaks. If test plate fittings leak, tighten fittings and continue looking for leaks. Air bubbles at any location on the heat exchanger indicate an oil passage leak. Replace heat exchanger if leaking.

### Internal

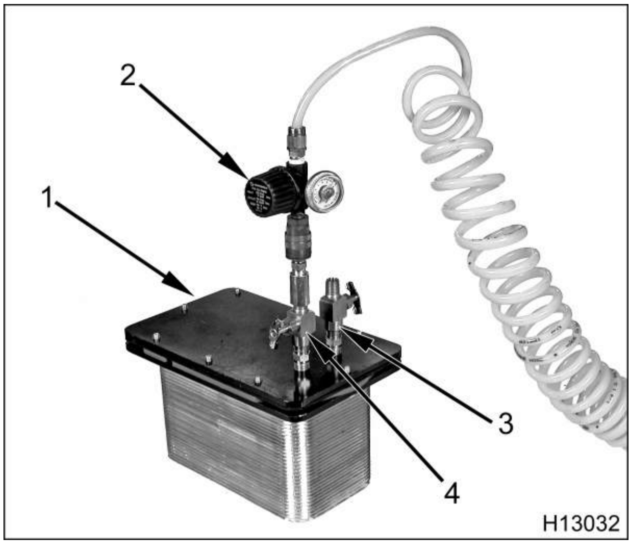


**Figure 261 Heat exchanger internal leak test**

1. Test plate set
2. Air pressure regulator
3. Coolant port valve (open)
4. Oil port valve (with air hose)

1. Connect air pressure regulator (page 332) between the test plate oil port and shop air supply.
2. Open coolant port valve to allow water to fill the coolant side of the heat exchanger.
3. Immerse heat exchanger and test plate in a large container of clean water.
4. Apply 172 to 276 kPa (25 to 40 psi) of air pressure while the assembly is under water.
5. Inspect coolant port valve for air bubbles. Bubbles coming out of the coolant port indicate an internal leak between oil and coolant passages. Replace heat exchanger if leaking.
6. Remove Oil Cooler Pressure Test Plate and drain any water, coolant, and oil out of heat exchanger.
7. Blow heat exchanger oil passages dry using filtered compressed air.

# Assemble

### Oil Filter Bypass Valve

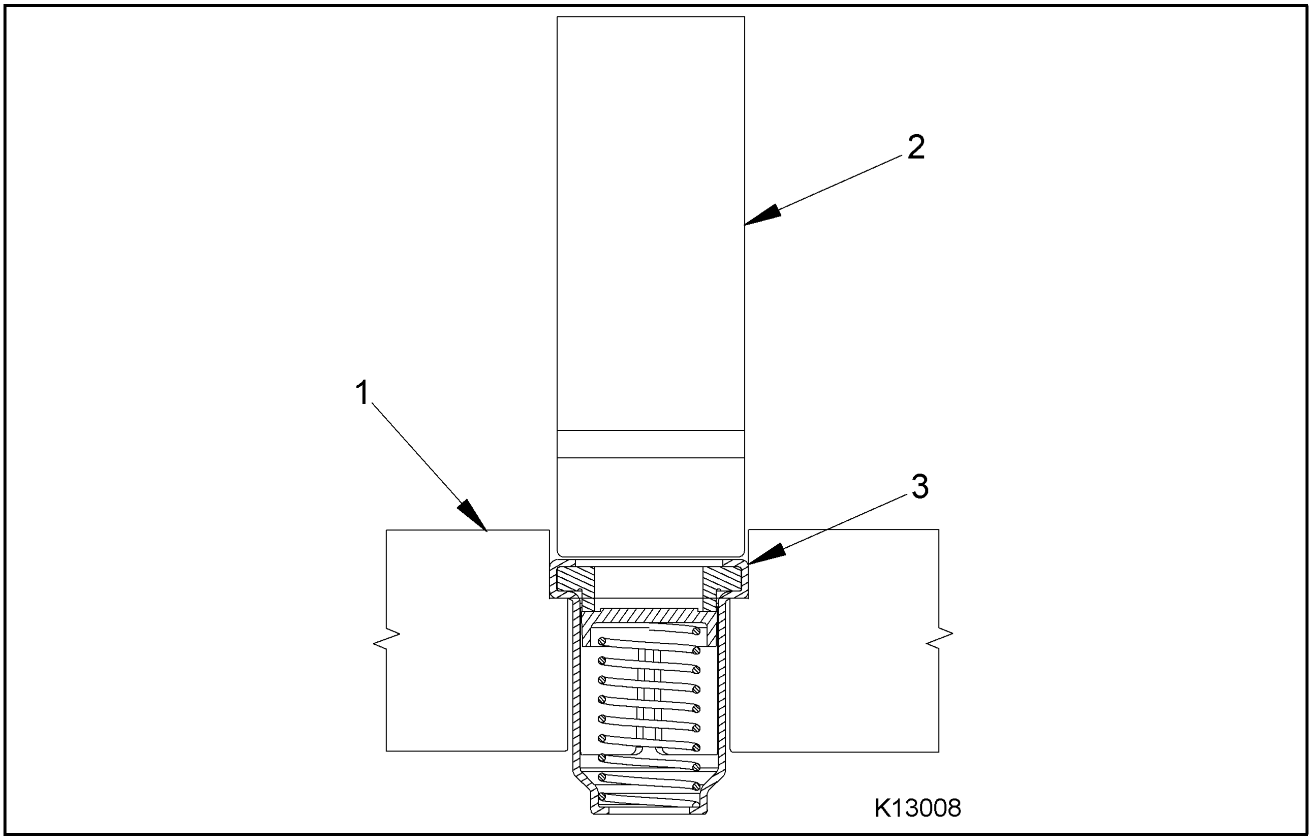


**Figure 262 Filter bypass valve installation**

1. Oil cooler housing
2. Deep socket
3. Filter bypass valve

**NOTE:** Measure socket outside diameter. Do not rely on bolt head size stamped on socket.

1. Place filter bypass valve and a deep socket with an outside diameter less than 20 mm (0.787 in) but greater than 16 mm (0.630 in) in position on the oil cooler housing.
2. Carefully tap or press socket and bypass valve into oil cooler housing until valve is seated.

### Lube Filter Adaptor Assembly

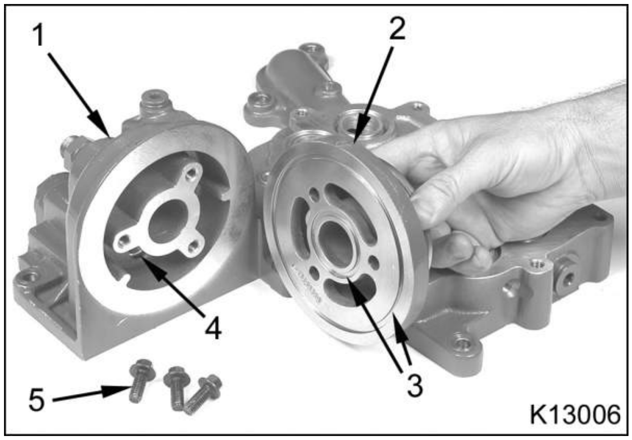


**Figure 263 Lube filter adapter assembly and oil cooler housing**

1. Oil cooler housing
2. Lube filter adaptor
3. O-ring recess (2)
4. Filter bypass valve
5. M8 x 25 bolt (3)

1. Install new small and large diameter O-rings in recesses of the lube adapter.
2. Attach lube filter adapter to the oil cooler housing with three M8 x 25 bolts and finger tighten.
3. Tighten three M8 x 25 bolts to special torque (page 332).

**Thermal Valve (Oil)**

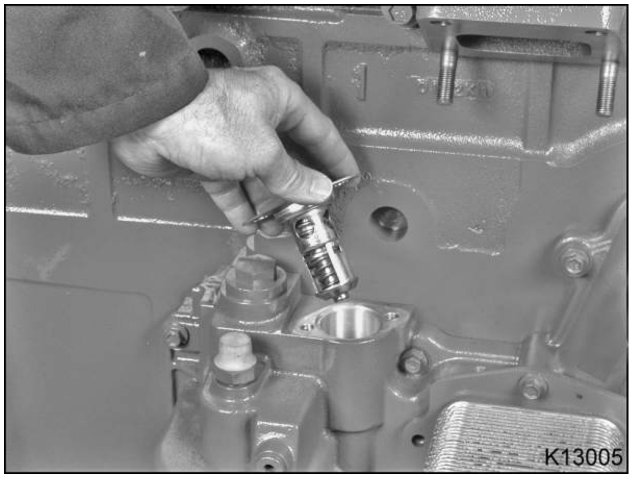


**Figure 264 Thermal valve installation**

1. Install oil thermal valve assembly into oil cooler housing with new O-ring.
2. Tighten two M8 x 20 bolts to special torque (page 332).

**Regulator Valve (Oil Pressure)**


**Figure 265 Regulator valve installation**

1. Install two new O-rings on oil pressure regulator valve. Lubricate only bottom O-ring with clean engine oil.
2. Install oil pressure regulator valve in the oil cooler housing and tighten to special torque (page 332).

### Cooler Heat Exchanger

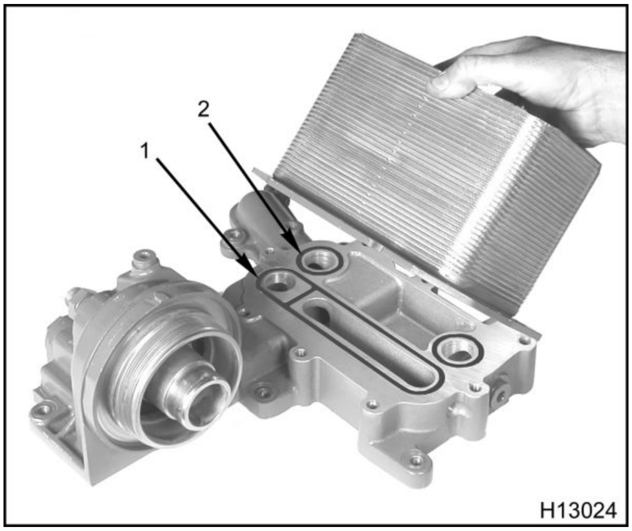


**Figure 266 Heat exchanger seals**

1. Oil seal
2. Coolant seal (2)

1. Install new oil seal and two new coolant seals in the oil cooler housing recesses.

**CAUTION:**

**To prevent engine damage, do not use pneumatic tools to install heat exchanger bolts.**

2. Install heat exchanger on the oil cooler housing and finger tighten eight new M8 x 20 bolts.
3. Tighten eight M8 x 20 bolts in a star pattern to 10 N·m (84 lbf·in)
4. Tighten eight M8 x 20 bolts in a star pattern to 19 N·m (168 lbf·in)
5. Tighten eight M8 x 20 bolts in a star pattern to a final torque of 29 N·m (21 lbf·ft).

# Installation

### Oil System Module

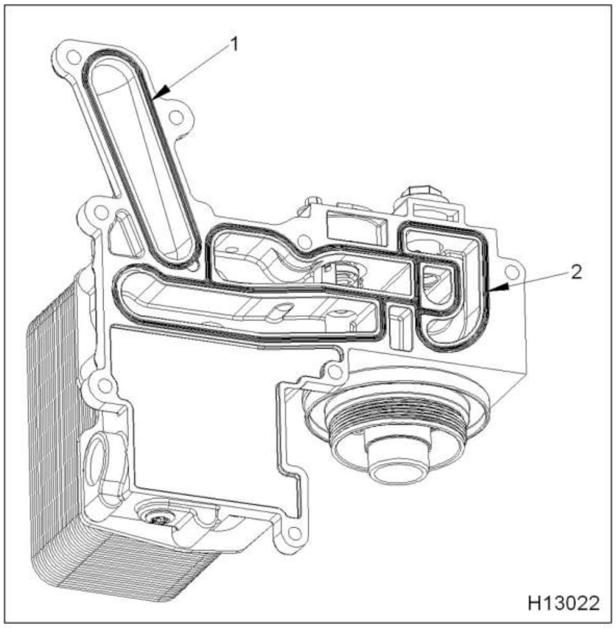


**Figure 267 Oil system module oil and coolant seals**

1. Coolant seal
2. Irregular gasket (oil)

1. Install oil and coolant seals in the oil cooler housing recesses.
2. Clean crankcase oil system module mating surface.


**Figure 268 Oil system module and coolant tube**

1. Turbocharger oil supply tube fitting
2. M8 x 30 stud bolt
3. M8 x 30 bolt (7)
4. M8 x 30 coolant tube bolt
5. M8 x 16 stud bolt

3. Install oil system module on crankcase and finger tighten seven M8 x 30 bolts and one M8 x 30 stud bolt.
4. Tighten seven M8 x 30 bolts and one M8 x 30 stud bolt to special torque (page 332).
5. Install turbocharger oil supply tube fitting into the oil filter header and tighten to special torque (page 332).
6. Install the turbocharger oil supply tube (page 166).

**Coolant Tube**

1. Install two new O-rings on coolant tube ends.
2. Install coolant tube into oil system module and front cover.
3. Install crankcase breather assembly, if removed. See Crankcase, Crankshaft, and Camshaft.
4. Install and finger tighten M8 x 30 coolant tube bolt and M8 x 16 stud bolt into coolant tube retaining brackets.
5. Tighten M8 x 30 bolt and M8 x 16 stud bolt to special torque (page 332).
6. Refill cooling system and check for leaks.

### Oil Filter

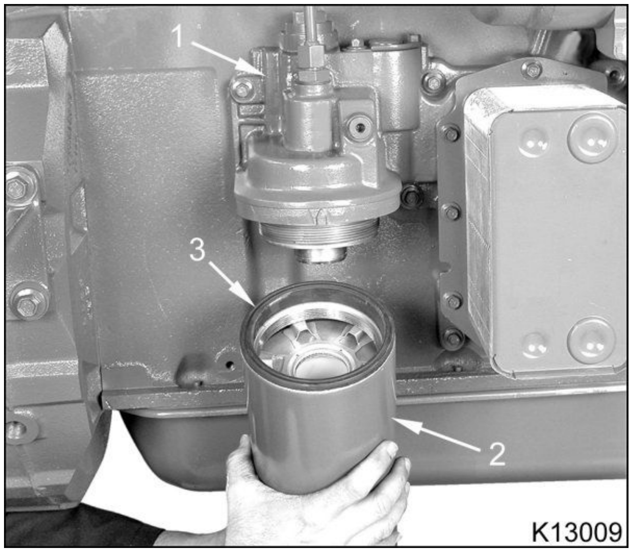


**Figure 269 Oil filter installation**

1. Oil System Module
2. Oil filter (spin-on)
3. Oil filter gasket

1. Fill oil filter with the proper grade and viscosity of engine oil. See *Engine Operation and Maintenance Manual*.
2. Lubricate new oil filter gasket with clean engine oil.

**CAUTION:**

**To prevent engine damage, do not overtighten oil filter.**

3. Spin oil filter on oil system module until filter gasket initially makes contact. Using an oil filter wrench with a band width of 38 mm (1.5 in) or greater, tighten filter an additional turn.

**Prime Lubrication System**

**CAUTION:**

**To prevent engine damage, after engine or lubrication system service, prime engine with oil before starting engine. This will lubricate internal engine components during the critical initial startup phase.**

**NOTE:** After a complete engine rebuild, a dry engine should be filled with 35 quarts of engine oil (total). After running engine, recheck oil level and fill to the full mark.

**Pressurization Method (Preferred)**

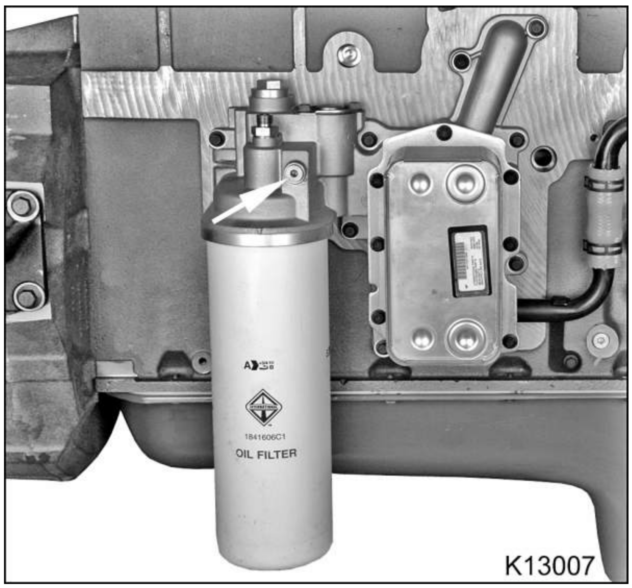


**Figure 270 M12 plug assembly**

1. Remove M12 plug assembly and pressurize lubrication system with sufficient engine oil to fill the oil filter and charge the entire lubrication system. See *Engine Operation and Maintenance Manual* for proper grade and viscosity of engine oil.

2. Install M12 plug assembly and tighten to special torque (page 332).
3. Finish fill to engine oil specifications (page 346) remembering to subtract oil added during lubrication system pressurization and oil added directly to the oil filter.
4. Start engine and check for oil leaks. If oil is leaking, turn off engine and repair leaks.
5. Turn off engine. Wait 15 minutes. Check oil level and fill to the full mark.

**Cranking Method (Alternate)**

**CAUTION:**

**To prevent engine damage, use the Pressurization method to prime lubrication system after an engine overhaul.**

1. Fill engine with the proper grade, viscosity, and quantity of engine oil. See *Engine Operation and Maintenance Manual*. Do not exceed total oil fill specifications (page 346).
2. Disconnect CMP sensor connector.
3. Crank engine until the oil pressure gauge shows sufficient oil pressure.
4. After oil pressure is evident in the lubrication system, reconnect CMP sensor connector and start engine.
5. Start engine and check for oil leaks. If oil is leaking turn off engine and repair leaks.
6. Turn off engine and clear CMP fault code. See EGES-370-1 *Engine Diagnostic Manual*.
7. Check oil level and fill to the full mark.

## Specifications

| | |
|---|---|
| Heat exchanger, all engines with front drive axle | 33 plates |
| Heat exchanger, MaxxForce® DT | 23 plates |
| Heat exchanger, MaxxForce® 9 and 10 | 33 plates |
| Oil filter bypass valve, opening pressure | 345 kPa (50 psi) |
| Oil pressure regulator valve, opening pressure | 380 kPa (55 psi) @ 38 °C (100 °F) |
| Oil thermal valve, opening temperature | 111 °C (232 °F) |

## Special Torque

| | |
|---|---|
| Coolant drain plug, M18 | 24 N·m (18 lbf·ft) |
| Coolant tube bracket bolts, M8 | 26 N·m (19 lbf·ft) |
| Heat exchanger bolts, M8 x 20 | See Cooler Heat Exchanger (page 326) |
| Lube filter adapter bolts, M8 x 25 | 29 N·m (21 lbf·ft) |
| Oil pressure regulator valve | 68 N·m (50 lbf·ft) |
| Oil system module M8 mounting bolts | 27 N·m (20 lbf·ft) |
| Oil thermal valve bolts, M8 x 20 | 29 N·m (21 lbf·ft) |
| Plug assembly, M12 | 5 N·m (46 lbf·in) |
| Turbocharger oil supply tube fitting | 25 N·m (18 lbf·ft) |

## Special Service Tools

| | |
|---|---|
| Air pressure regulator | Obtain locally |
| Oil Cooler Pressure Test Plate | ZTSE4654 |

# Table of Contents

# Exploded Views

### Front Sump

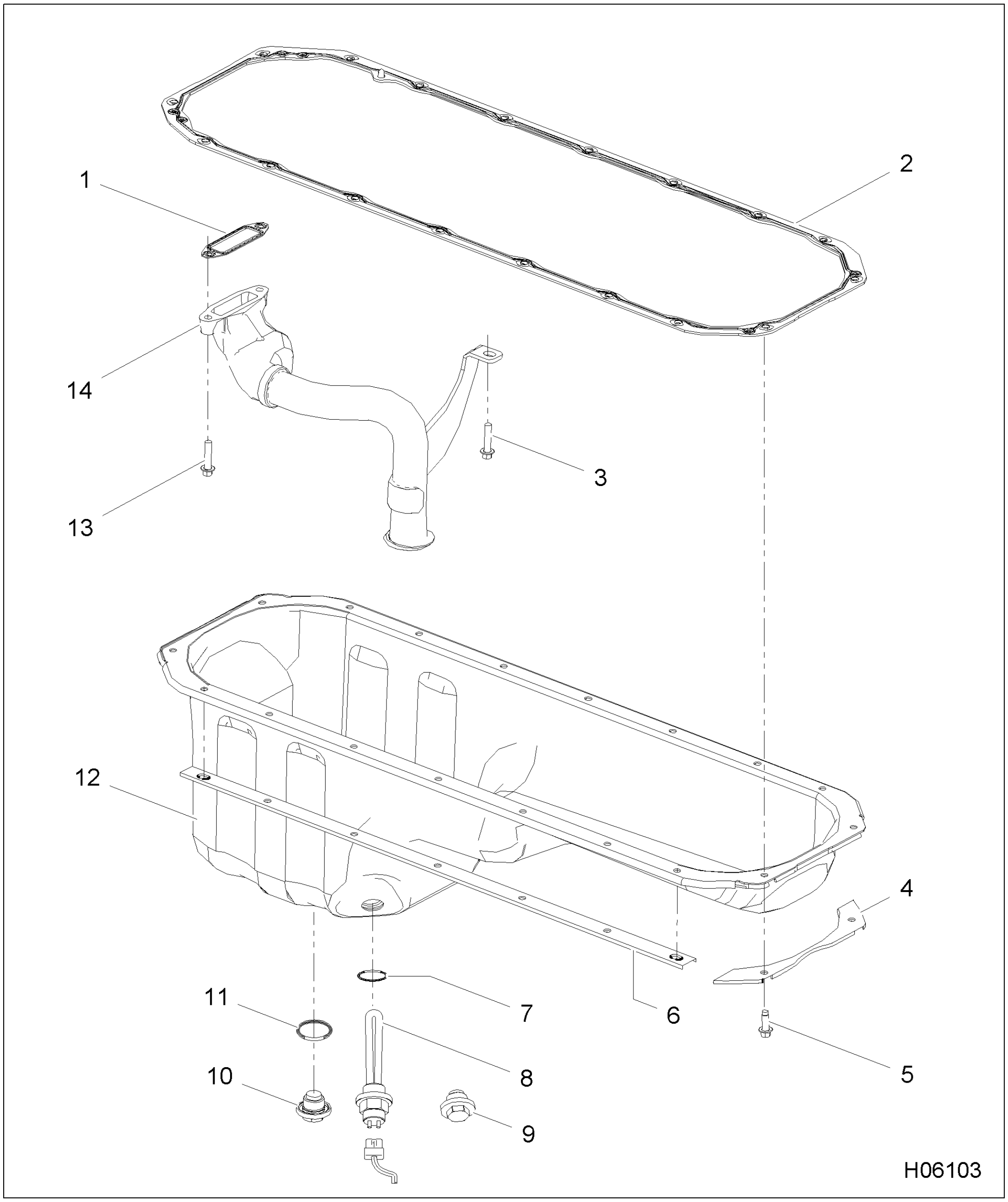


**Figure 271 Oil pan and oil suction tube (front sump)**

1. Oil suction tube gasket
2. Oil pan gasket
3. M10 x 25 bolt
4. Oil pan end rail stiffener (2)
5. M8 x 24 bolt (18)
6. Oil pan rail stiffener (2)
7. Heater element gasket
8. Heater element (optional)
9. Plug (without oil pan heater)
10. Oil drain plug
11. Oil drain plug O-ring
12. Oil pan (front sump)
13. M8 x 35 bolt (2)
14. Oil suction tube assembly (front sump)

### Rear Sump

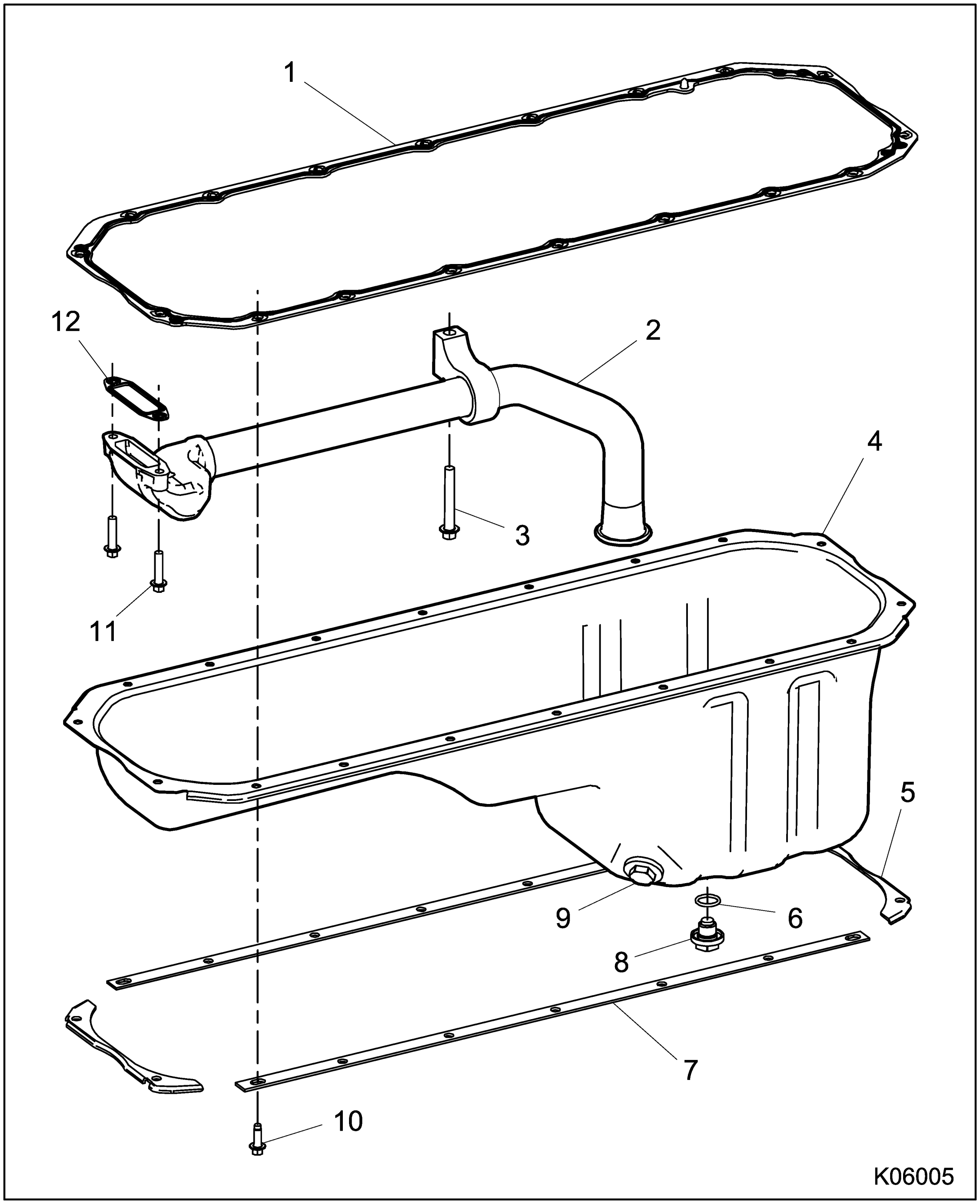


**Figure 272 Oil pan and oil suction tube (rear sump)**

1. Oil pan gasket
2. Suction tube assembly (rear sump)
3. M10 x 70 bolt
4. Oil pan (rear sump)
5. Oil pan rail end stiffener (2)
6. Oil drain plug O-ring
7. Oil pan rail stiffener (2)
8. Oil drain plug
9. Plug (without oil pan heater)
10. M8 x 24 bolt (18)
11. M8 x 35 bolt (2)
12. Oil suction tube gasket

## Removal

**WARNING:**

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

**WARNING:**

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

**WARNING:**

**To prevent personal injury or death, allow engine to cool before removing components.**

**WARNING:**

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

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

### Drain Engine Oil

1. Place an oil drain pan under the engine oil pan.
2. Remove oil drain plug mounted in the bottom of the oil pan.
3. Discard oil drain plug O-ring.
4. Inspect drain plug and replace if necessary.
5. Install a new O-ring on the oil drain plug.
6. After oil has drained, install oil drain plug in the bottom of the oil pan and tighten to special torque (page 346).
7. Recycle or dispose of oil according to applicable regulations.

### Oil Pan and Gasket

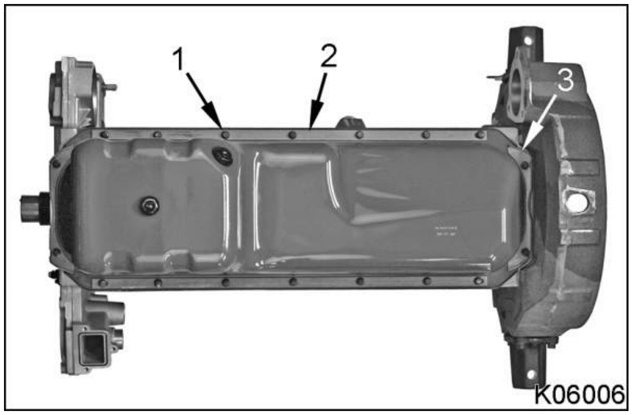


**Figure 273 Oil pan bolts and rail stiffeners**

1. M8 x 24 bolt (18)
2. Oil pan rail stiffener (2)
3. Oil pan end rail stiffener (2)

1. Remove 18 M8 x 24 oil pan mounting bolts.
2. Remove two oil pan end rail stiffeners and two oil pan rail stiffeners.
3. Separate oil pan from the oil pan gasket and remove oil pan from engine.

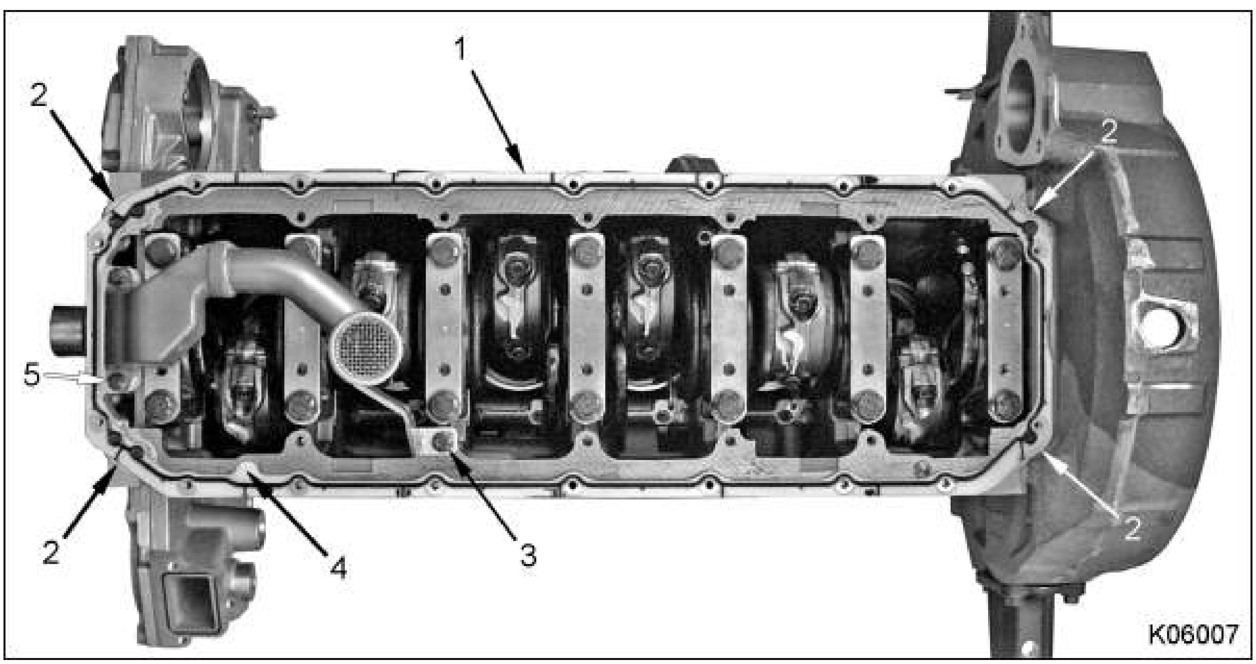


**Figure 274 Oil pan gasket, RTV sealant locations, and suction tube assembly (front sump)**

1. Oil pan gasket
2. RTV sealant locations
3. M10 x 25 bolt (front sump)
4. Oil pan gasket dowel (into crankcase)
5. M8 x 35 bolt (2)

**NOTE:** The oil pan gasket is reusable if it is not cracked and the sealing surface is in good condition.

4. Remove the oil pan gasket from the front cover, flywheel housing, and crankcase.
5. Cut through RTV sealant under the oil pan gasket at locations on the oil pan mounting surface using a flat gasket scraper or similar tool. Cut parallel to the gasket path.

**Oil Suction Tube Assembly**

1. Remove two M8 x 35 bolts connecting the oil suction tube assembly to the front cover.
2. Remove M10 bolt holding the oil suction tube bracket to the crankcase.
3. Remove the oil suction tube assembly and discard gasket.

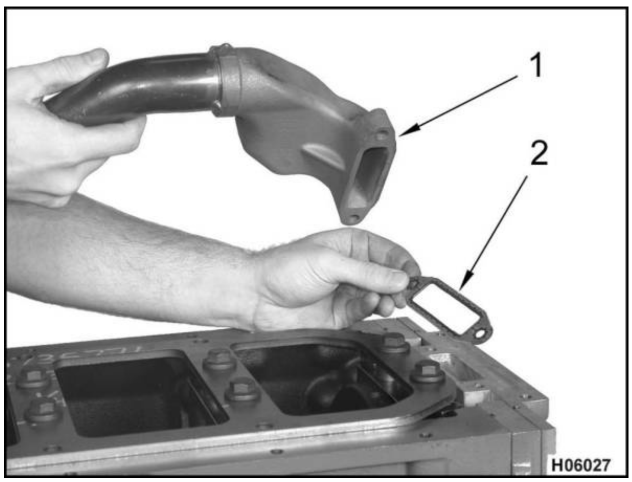


**Figure 275 Oil suction tube assembly and gasket**

1. Oil suction tube assembly
2. Oil suction tube gasket

## Cleaning and Inspection

1. Remove RTV sealant from the crankcase, oil pan, front cover, and flywheel housing mating surfaces with a flat scraper. Scrape parallel to the gasket path.
2. Clean the oil pan, front cover, flywheel housing, oil suction tube assembly, and crankcase mating surfaces thoroughly with a suitable solvent.
3. Clean and inspect the oil pan gasket. Discard the oil pan gasket if it is cracked or the sealing surfaces are damaged.
4. Clean and inspect the oil suction tube assembly. Make sure the oil suction tube is free of obstructions.
5. Check the oil pan and oil suction tube assembly for cracks and damage. Replace components if necessary.

## Installation

**Oil Suction Tube Assembly**

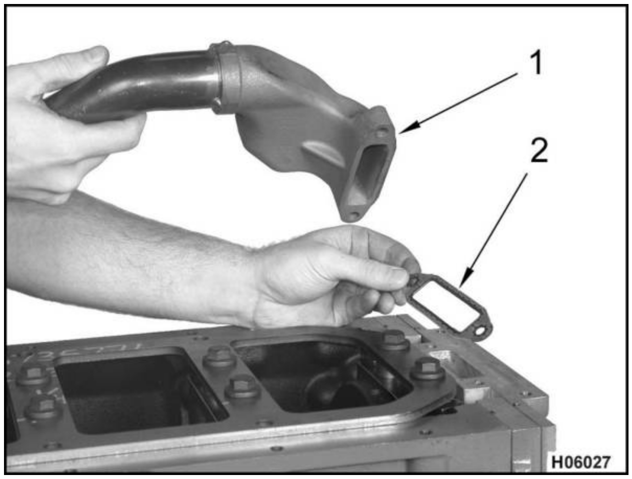


**Figure 276 Oil suction tube assembly and gasket**

1. Oil suction tube assembly
2. Oil suction tube gasket

1. Install oil suction tube assembly and a new gasket on the front cover and finger tighten two M8 x 35 bolts.

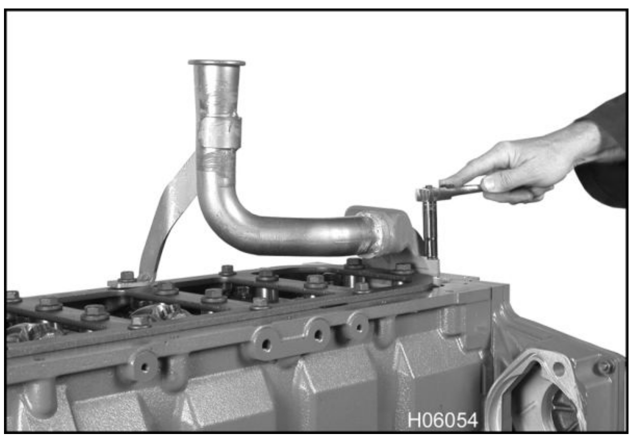


**Figure 277 Oil suction tube assembly installation (typical)**

2. Install one M10 bolt connecting the oil suction tube mounting bracket to the crankcase and finger tighten.
3. Tighten two M8 x 35 bolts to special torque (page 346).
4. Tighten M10 bolt to standard torque (page 683).

**Oil Pan and Gasket**

1. Install flywheel housing (page 510).
2. Install front cover (page 380).

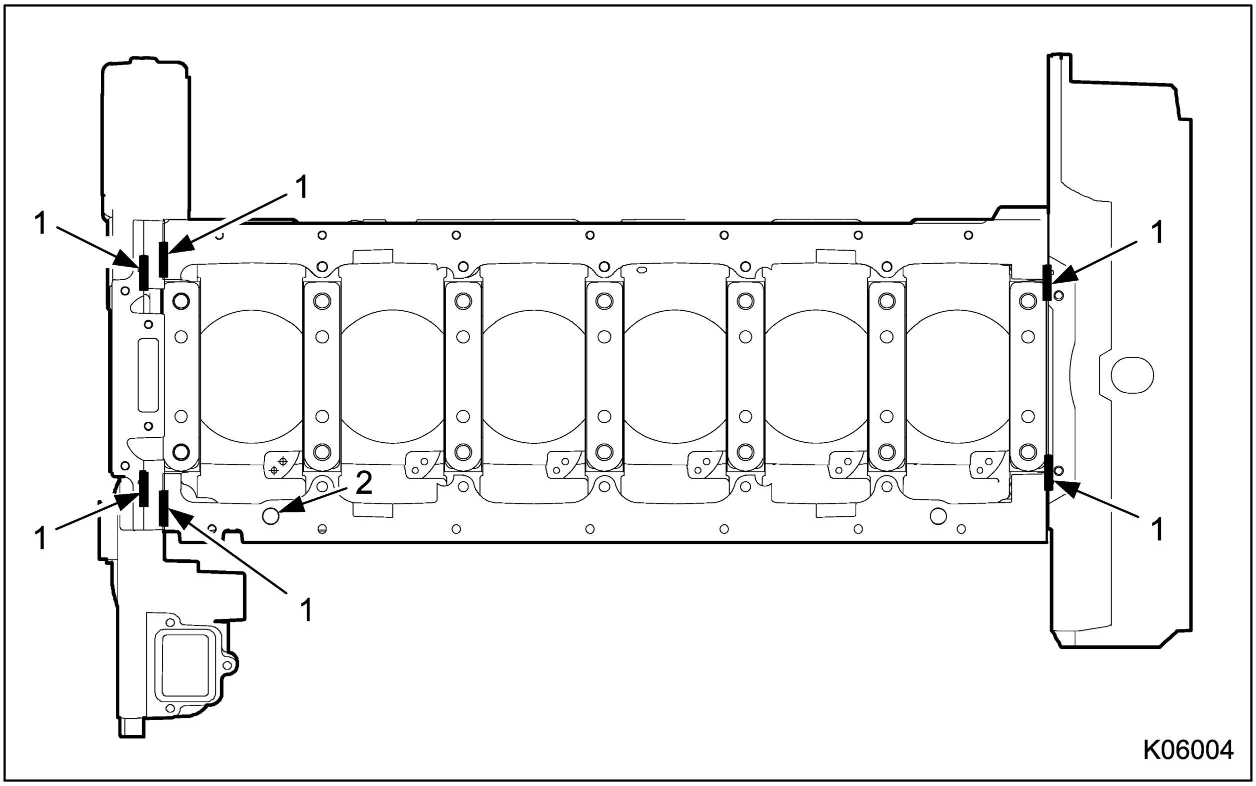


**Figure 278 Oil pan gasket mounting surface**

1. RTV sealant locations
2. Oil pan gasket dowel hole

3. Apply a 6 mm (0.25 in) bead of Wacker T – 442 RTV sealant (page 346) to the six locations on the oil pan mounting surface. These locations coincide with gasket joints between the front cover halves, crankcase, and flywheel housing.

4. Before the RTV sealant dries, install a clean oil pan gasket on the crankcase mounting surface. Make sure the oil pan gasket dowel is aligned with the hole in the crankcase mounting surface.
5. Install the oil pan on the crankcase.

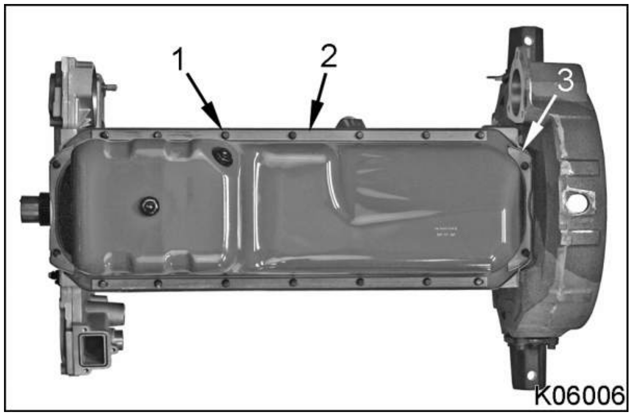


**Figure 279 Oil pan, bolts, and rail stiffeners**

1. M8 x 24 bolt (18)
2. Oil pan rail stiffener (2)
3. Oil pan end rail stiffener (2)

6. Install two oil pan end rail stiffeners and two oil pan rail stiffeners on the oil pan.
7. Install 18 M8 x 24 oil pan mounting bolts finger tight.
8. Tighten M8 x 24 bolts to special torque (page 346).

### Fill Engine with Oil

**CAUTION:**

**To prevent engine damage, after engine or lubrication system service, prime engine with oil (page 330) before starting engine. This will lubricate internal engine components during the critical initial startup phase.**

1. Fill engine with the proper grade, viscosity, and quantity of engine oil. See *Engine Operation and Maintenance Manual*. Do not exceed engine oil fill specifications (page 346).
2. Start engine and check for oil leaks. If oil is leaking, turn off engine and repair leaks.
3. Turn off engine.
4. Wait 15 minutes. Check oil level and fill to the full mark.

## Specifications

| | |
|---|---|
| Engine oil dry (after rebuild and new filter) | 33 L (35 quarts US) |
| Engine oil wet (after oil drain and filter change) | 28 L (30 quarts US) |

## Special Torque

| | |
|---|---|
| Oil pan drain plug | 68 N·m (50 lbf·ft) |
| Oil pan heater plug | 68 N·m (50 lbf·ft) |
| Oil pan mounting bolts, M8 x 24 | 32 N·m (24 lbf·ft) |
| Oil suction tube bolts, M8 x 35 | 27 N·m (20 lbf·ft) |

## Special Service Tools

| | |
|---|---|
| Wacker T – 442 RTV sealant | Obtain locally |

# Table of Contents

## Exploded View and Description

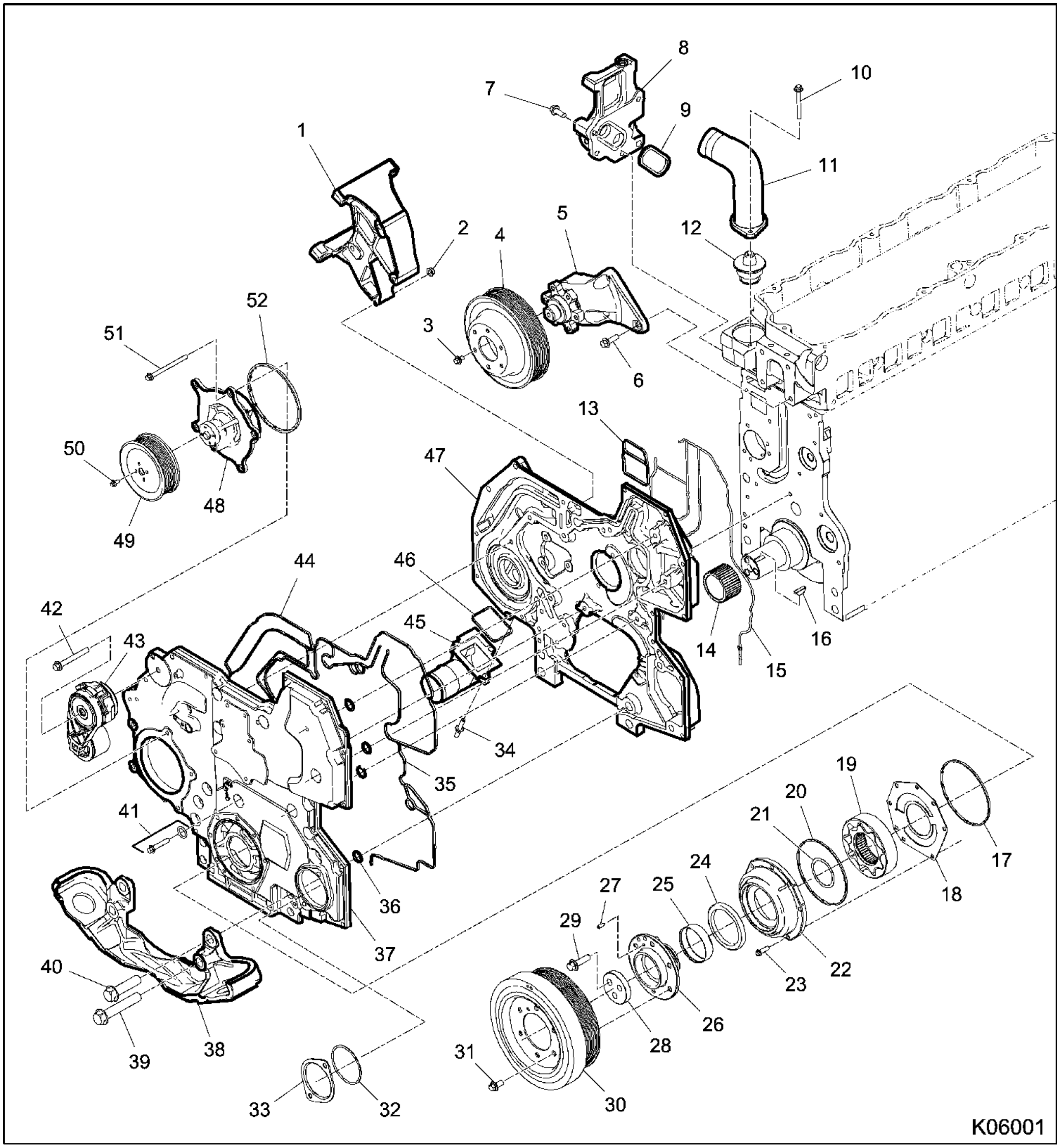


**Figure 280 Front cover and related components, less gear train (typical)**

1. Alternator bracket
2. M8 nut
3. M8 x 20 bolt (6)
4. Fan drive pulley
5. Fan housing assembly
6. M10 x 30 bolt (3)
7. M10 x 25 bolt (4)
8. Water supply housing (Freon® compressor mount)
9. Coolant port seal
10. M8 x 25 bolt (2)
11. Water outlet tube assembly
12. Thermostat assembly
13. Front cover rear half (coolant) gasket
14. Oil pump spline drive
15. Front cover rear half (oil) gasket
16. Vibration damper key
17. Oil pump (housing plate) seal
18. Oil pump housing plate
19. Rotor assembly
20. Oil pump (housing) seal
21. Washer, seal
22. Oil pump and rotor housing
23. M8 x 25 bolt (See Oil Pump Assembly (page 365))
24. Front oil seal
25. Wear sleeve
26. Damper hub
27. Dowel pin
28. Damper retainer
29. M12 x 40 damper bolt, 12 point (3)
30. Vibration damper assembly
31. M10 x 16 bolt (6)
32. O-ring seal, #235 (PTO equipped only)
33. PTO adapter cover (PTO equipped only)
34. M8 stud bolt (3)
35. Front cover front half (oil) gasket
36. O-ring (4)
37. Front cover (front half)
38. Front engine mounting bracket
39. M18 x 100 bolt, lower (2)
40. M18 x 70 bolt, upper (2)
41. Seal assembly
42. M10 x 90 bolt
43. Automatic belt tensioner
44. Front cover front half (coolant) gasket
45. Water inlet elbow
46. Water inlet gasket
47. Front cover (rear half)
48. Water pump assembly
49. Water pump pulley
50. M6 x 12 bolt (4)
51. M8 x 100 bolt (See Water Pump Assembly (page 358))
52. Water pump housing seal

MaxxForce® DT, 9, and 10 engines are available in various front cover and cooling system configurations. Engines are available with or without a power takeoff (PTO) adaptor attachment on the front cover. Numerous spin-on and Horton DriveMaster® fan drive configurations are available. Engines can be equipped with one, two, or no Freon® compressor. Several water outlet tubes are also used. See Engine Cooling System (page 45) for additional details.

See TSI 08–12–21 for front cover design and part number variations.

## 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 engine has cooled before removing components.**

**WARNING:**

**To prevent personal injury or death, do not open pressurized Freon® lines.**

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

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

**NOTE:** Valve train failures from broken or bent push rods, valves, rocker arms, and worn valve retainers and rotators can be caused by improper gear train timing. Depending on valve lash setting, if the camshaft gear is improperly timed by one tooth, the pistons will strike the intake or exhaust valves.

**Drive Belt**

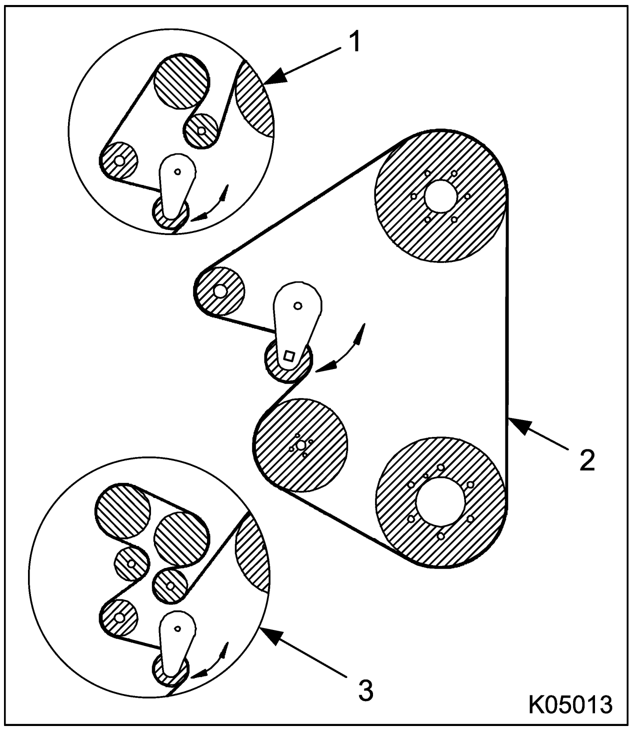


**Figure 281 Drive belt routing**

1. Single Freon® compressor and single idler pulley
2. Without Freon® compressor
3. Dual Freon® compressors and dual idler pulleys

1. Insert 1/2 inch square drive ratchet or breaker bar into belt tensioner square hole.
2. Rotate belt tensioner clockwise to release belt tension.
3. Remove drive belt and release belt tensioner.

**Alternator Bracket, Automatic Belt Tensioner, and Single Idler Pulley**

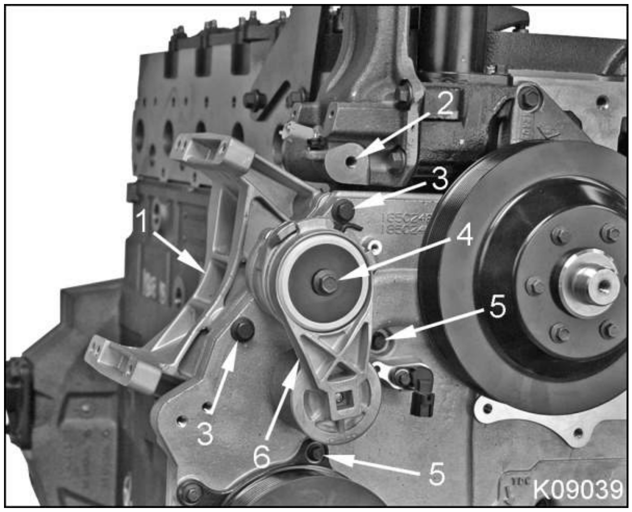


**Figure 282 Alternator bracket, belt tensioner, and single idler pulley bolt locations**

1. Alternator bracket
2. M10 x 90 bolt hole (single idler pulley)
3. M10 x 120 bolt (2)
4. M10 x 90 bolt (belt tensioner)
5. M8 x 100 bolt (2)
6. Automatic belt tensioner

1. Remove two M8 x 100 bolts and nuts.
2. Remove two M10 x 120 bolts and nuts.
3. Remove alternator bracket.
4. If equipped, remove single idler pulley M10 x 90 bolt and remove pulley from the water supply housing (pulley not shown).
5. Remove automatic belt tensioner M10 x 90 bolt and remove assembly from the front cover.

### Secondary Compressor Support, Dual Idler Pulleys, and Idler Mounting Plate

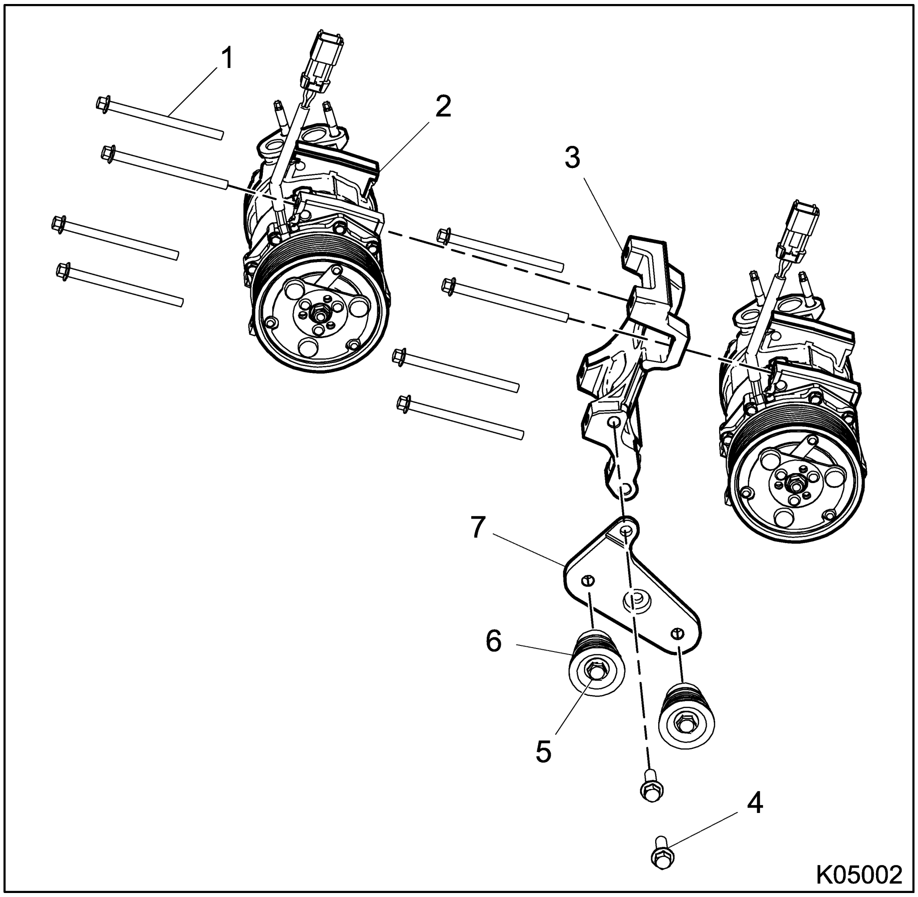


**Figure 283 Dual Freon® compressor mounting**

1. M8 x 110 bolt (8)
2. A/C (Freon®) compressor (2)
3. Secondary Freon® compressor support
4. M10 x 30 bolt (2)
5. M10 x 60 bolt (2)
6. Flat idler pulley assembly (2)
7. Idler mounting plate

**WARNING:**

**To prevent personal injury or death, do not open pressurized Freon® lines.**

**NOTE:** The following procedure only applies to engines equipped with dual A/C (Freon®) compressors.

1. Remove four M8 x 110 bolts holding the outer Freon® compressor to the secondary Freon® compressor support.
2. Do not remove or disconnect pressurized Freon® lines. Move outer Freon® compressor out of the way and secure with a strap or remove from engine.

3. If required, remove two M10 x 60 bolts and remove two flat idler pulley assemblies.
4. If required, remove two M10 x 30 bolts and remove the idler mounting plate from the secondary Freon® compressor support.
5. Remove four M8 x 110 bolts holding the secondary Freon® compressor support and inner Freon® compressor to the cylinder head.

**Water Supply Housing (Freon® Compressor Mount)**

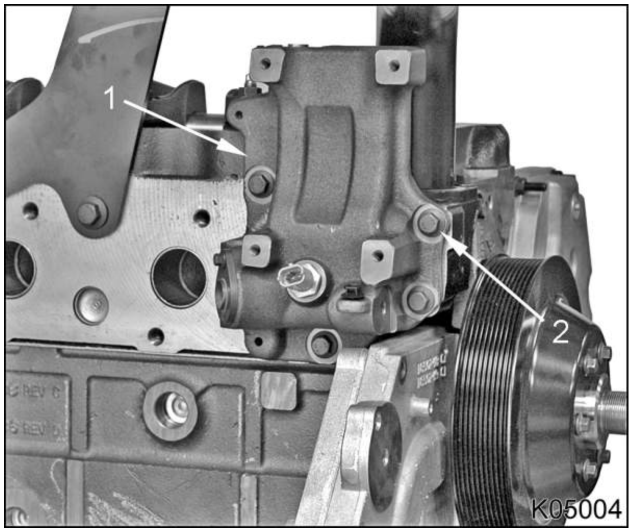


**Figure 284 Water supply housing**

1. Water supply housing (Freon® compressor mount)
2. M10 x 25 bolt (4)

1. Remove four M10 x 25 bolts and remove water supply housing.

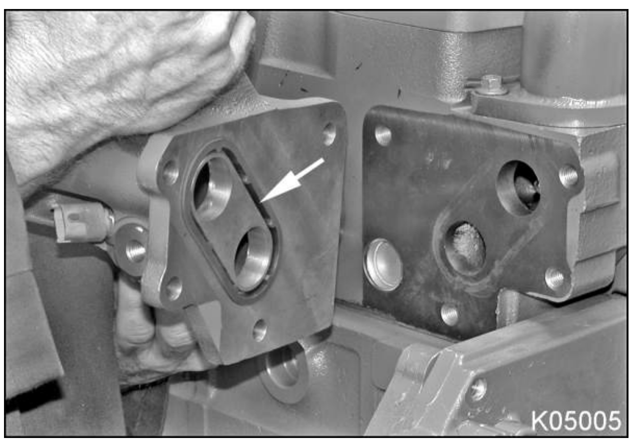


**Figure 285 Water supply housing coolant port seal**

2. Remove and discard coolant port seal.

**Water Outlet Tube, and Thermostat**

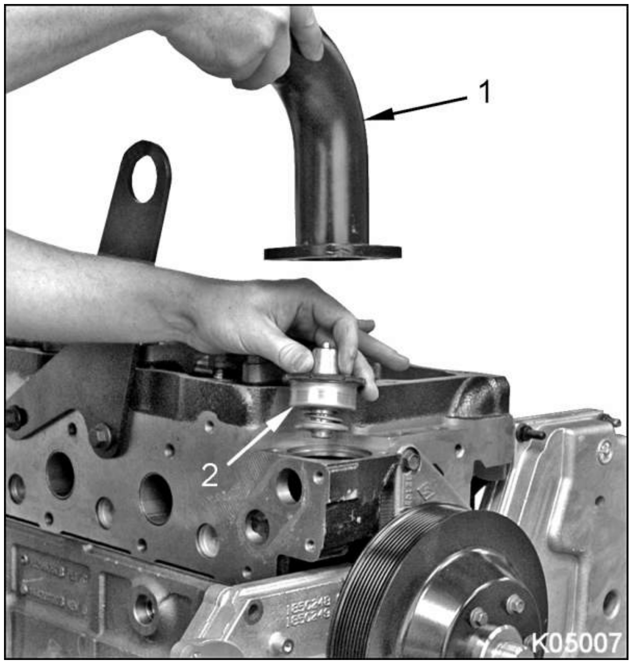


**Figure 286 Water outlet tube and thermostat**

1. Water outlet tube (typical)
2. Thermostat assembly

**NOTE:** Water outlet tube configurations use either two M8 x 25 bolts or two M8 x 115 bolts to hold the water outlet tube to the cylinder head.

1. Remove two M8 bolts holding the water outlet tube to the cylinder head.
2. Remove water outlet tube and thermostat.
3. If equipped, remove the thermostat bypass housing and discard gasket.

### Water Pump Assembly

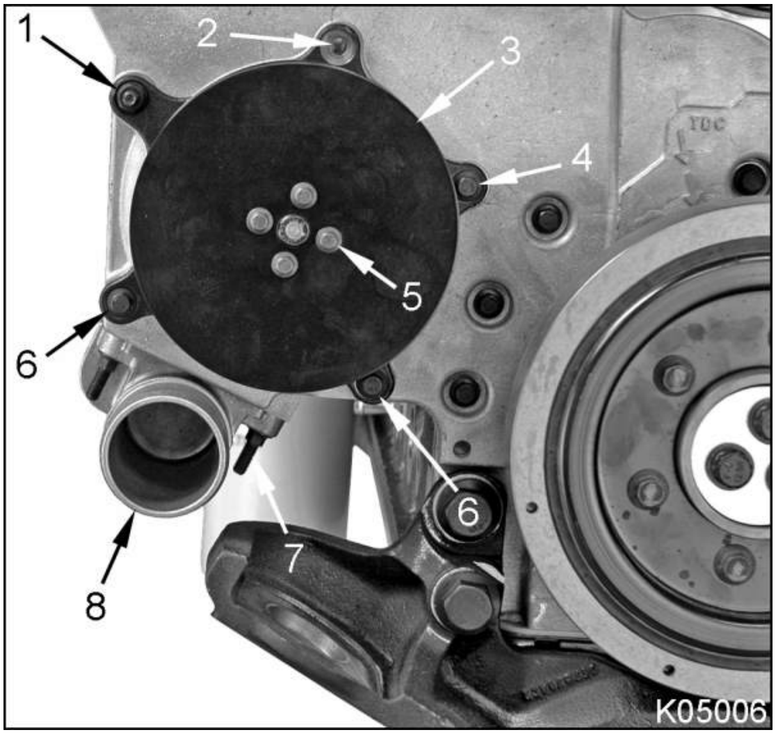


**Figure 287 Water pump and inlet elbow (typical)**

1. M8 x 55 bolt (nut on front)
2. M8 x 100 bolt (nut on back)
3. Water pump pulley (typical)
4. M8 x 16 bolt
5. M6 x 12 bolt (4)
6. M8 x 45 bolt (2)
7. M8 stud bolt (3)
8. Water inlet elbow

1. Remove four M6 x 12 pulley bolts and remove water pump pulley.
2. Remove M8 x 100 bolt (nut on back).
3. Remove M8 x 55 bolt (nut on front).
4. Remove M8 x 16 bolt.
5. Remove two M8 x 45 bolts.
6. Remove water pump assembly and discard water pump housing seal.

### Water Inlet Elbow

**NOTE:** Water inlet elbow configurations use either three M8 stud bolts or three M8 x 30 bolts to hold the water inlet elbow to the front cover.

1. Remove three M8 bolts holding the water inlet elbow to the front cover.
2. Remove water inlet elbow and discard gasket.

**Fan Drive**

**Spin-on Fan Drive**

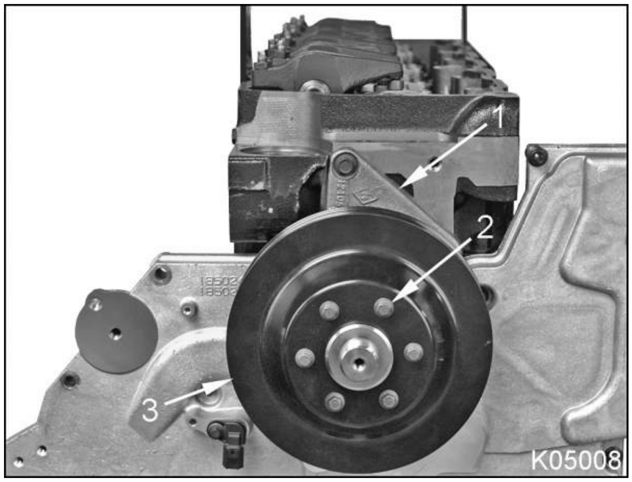


**Figure 288 Fan drive pulley, spin-on**

1. Fan housing assembly (typical)
2. M8 x 20 bolt (6)
3. Fan drive pulley

1. Remove six M8 x 20 bolts and remove the fan drive pulley.

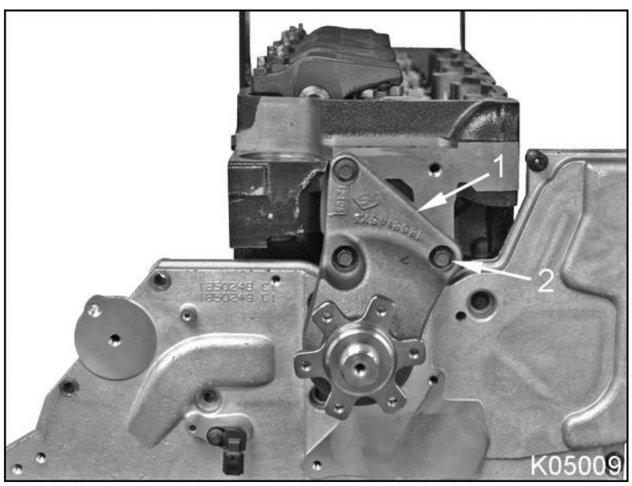


**Figure 289 Fan housing assembly, spin-on (typical)**

1. Fan housing assembly (typical)
2. M10 x 30 bolt (3)

**NOTE:** Fan drive configurations use either three or four M10 x 30 bolts to hold the fan housing assembly to the cylinder head.

2. Remove M10 x 30 bolts and remove the fan housing assembly.

**Horton DriveMaster® Fan Drive**

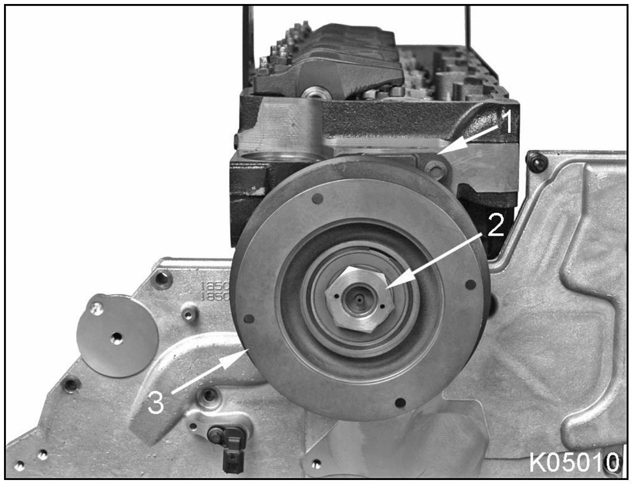


**Figure 290 Fan pulley, DriveMaster®**

1. Fan mounting bracket (typical)
2. Nut assembly
3. Fan pulley

1. Remove nut assembly from fan mounting bracket, using a Fan Hub Wrench (2 inch) (page 415).

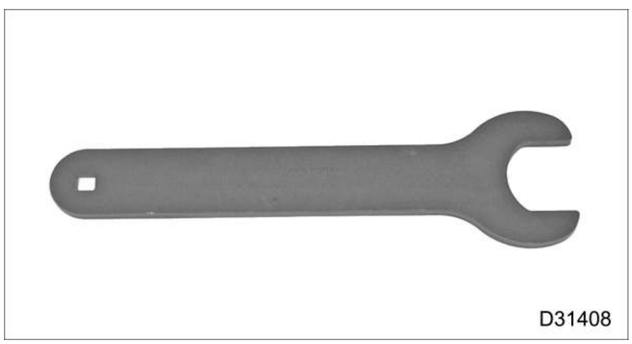


**Figure 291 Fan hub wrench**

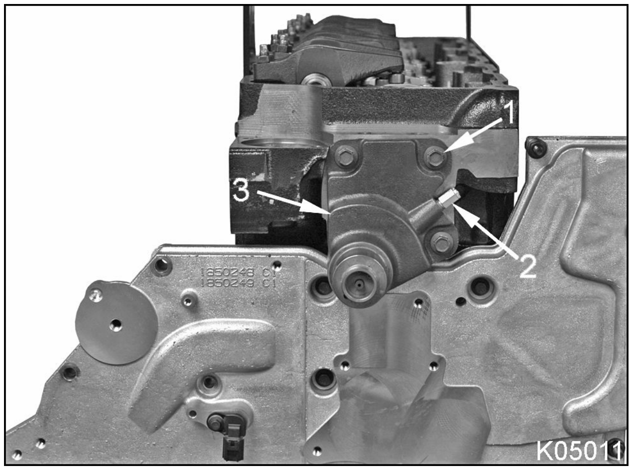


**Figure 292 Fan mounting bracket, DriveMaster® (typical)**

1. M10 x 30 bolt (3)
2. Fan clutch air supply fitting (typical)
3. Fan mounting bracket (typical)

**NOTE:** Fan drive configurations use either three or four M10 x 30 bolts to hold the fan mounting bracket to the cylinder head.

2. Remove M10 x 30 bolts and remove the fan mounting bracket.

### Vibration Damper, Hub, and Wear Sleeve

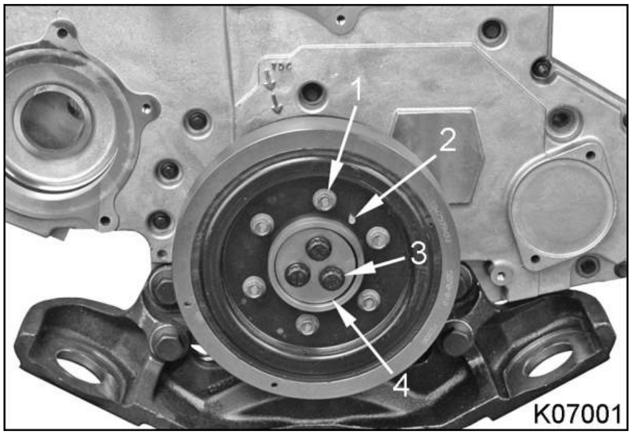


**Figure 293 Vibration damper assembly**

1. M10 x 16 bolt (6)
2. Dowel pin
3. M12 x 40 (12 point) damper bolt (3)
4. Damper retainer

**NOTE:** The dowel pin for MaxxForce® 9 and 10 vibration dampers is almost flush with the damper front surface. The dowel pin for MaxxForce® DT vibration dampers protrudes out approximately 6 mm (0.24 in).

1. Remove six M10 x 16 bolts holding the vibration damper to the damper hub and remove vibration damper.
2. Remove three M12 x 40 (12 point) damper bolts and remove the damper retainer.

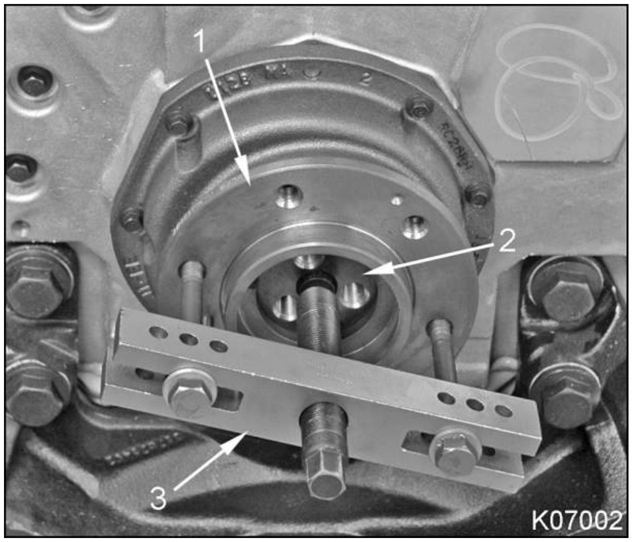


**Figure 294 Damper hub and H-bar puller**

1. Damper hub
2. Crankshaft
3. H-bar puller

3. Install two M10 x 80 bolts and washers through H-bar puller (page 415) and into the damper hub. Install M10 x 80 bolt heads at equal lengths from the vibration damper mounting surface.
4. Tighten H-bar center shaft to pull damper hub off of crankshaft and remove damper hub.

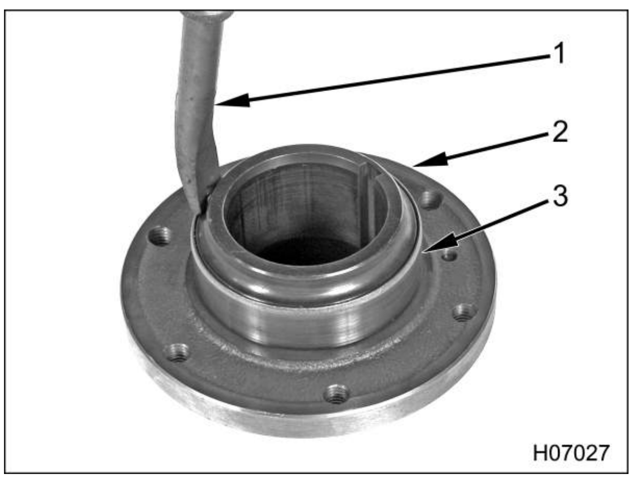


**Figure 295 Damper hub and wear sleeve**

1. Muffler chisel
2. Damper hub
3. Wear sleeve

**CAUTION:**

**To prevent engine damage, do not damage or distort damper hub while removing wear sleeve.**

5. Carefully split wear sleeve with a muffler chisel (page 415) and remove sleeve from the damper hub. Be careful not to damage the damper hub.

**Oil Pump Assembly**

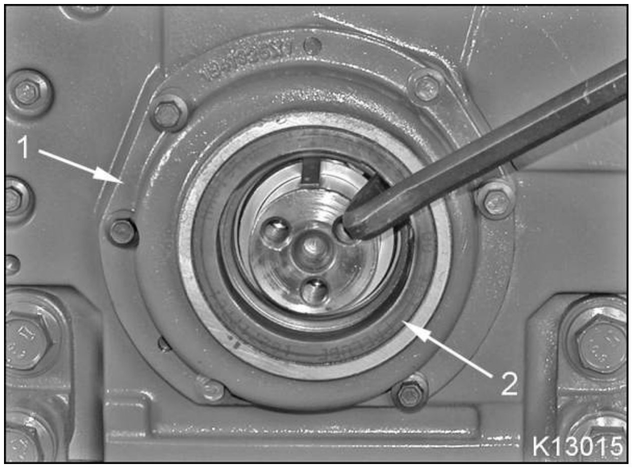


**Figure 296 Front oil seal removal**

1. Oil pump and rotor housing
2. Front oil seal

**NOTE:** Be careful not to damage the crankshaft or front oil seal mounting surface while removing the front oil seal.

1. Remove the front oil seal with a heel bar (page 415) or seal puller, while the oil pump and rotor housing assembly is attached to the front cover.
2. Discard front oil seal.

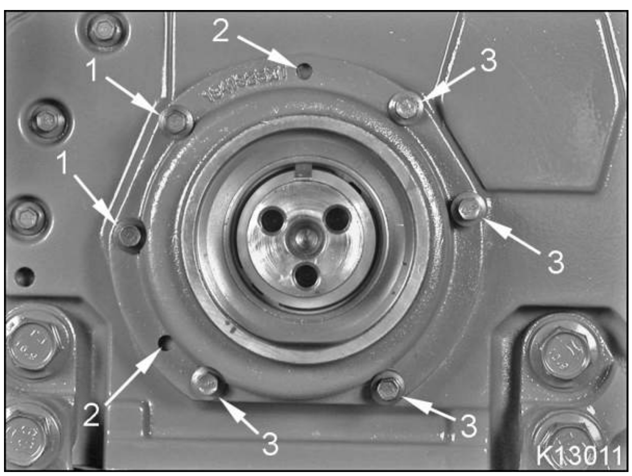


**Figure 297 Oil pump and rotor housing assembly**

1. M8 x 60 bolt (2)
2. Dowel (2)
3. M8 x 25 bolt (4)

3. Remove two M8 x 60 bolts holding the oil pump and rotor housing to the front cover.

4. Remove four M8 x 25 bolts.

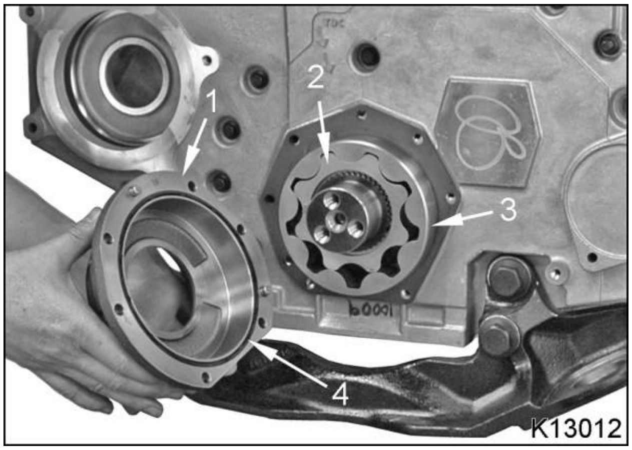


**Figure 298 Oil pump housing and rotor assembly**

1. Oil pump and rotor housing
2. Inner rotor
3. Outer rotor
4. Oil pump (housing) seal

5. Remove the oil pump and rotor housing and discard oil pump (housing) seal.

**CAUTION:**

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

6. Mark inner and outer rotors with a permanent marker, if oil pump is to be reused. Mark will indicate rotor turning direction and orientation to front cover.
7. Remove outer rotor.

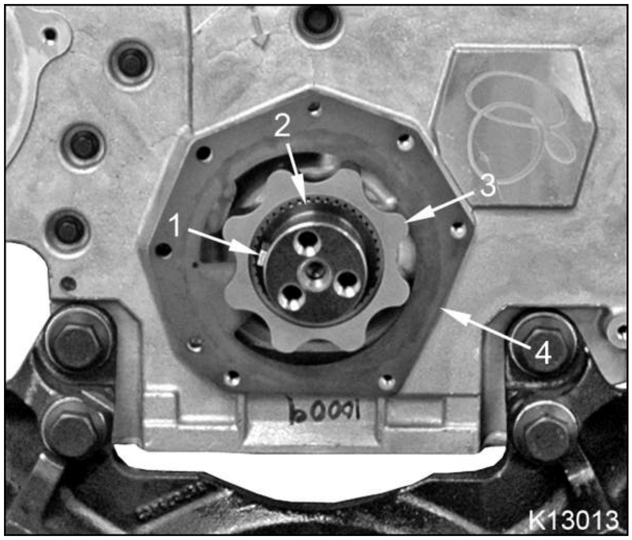


**Figure 299 Vibration damper key, inner rotor, and oil pump housing plate**

1. Vibration damper key
2. Washer seal
3. Inner rotor
4. Oil pump housing plate

**CAUTION:**

**To prevent engine damage, do not damage or distort the crankshaft keyway groove during vibration damper key removal.**

8. Carefully tap the vibration damper key out of the crankshaft with a hammer and chisel.
9. Remove washer seal and inner rotor from crankshaft.
10. Remove oil pump housing plate.
11. Remove oil pump housing seal from front cover and discard.

**NOTE:** To remove the oil pump spline drive. See Oil Pump Spline Drive removal (page 603).

**Front Engine Mounting Bracket**

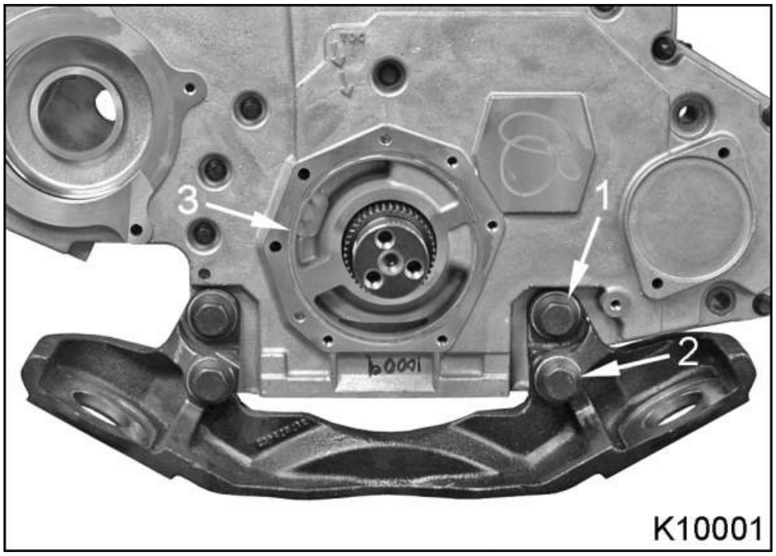


**Figure 300 Front engine mount**

1. M18 x 70 bolt (2)
2. M18 x 100 bolt (2)
3. Oil pump housing seal groove

**WARNING:**

**To prevent personal injury or death, support engine (if in chassis) before removing any bolts from engine mounts.**

1. Properly support the engine.
2. Remove two upper M18 x 70 bolts.
3. Support front engine mount and remove two lower M18 x 100 bolts.
4. Remove front engine mounting bracket.

### Front Cover (Front Half)

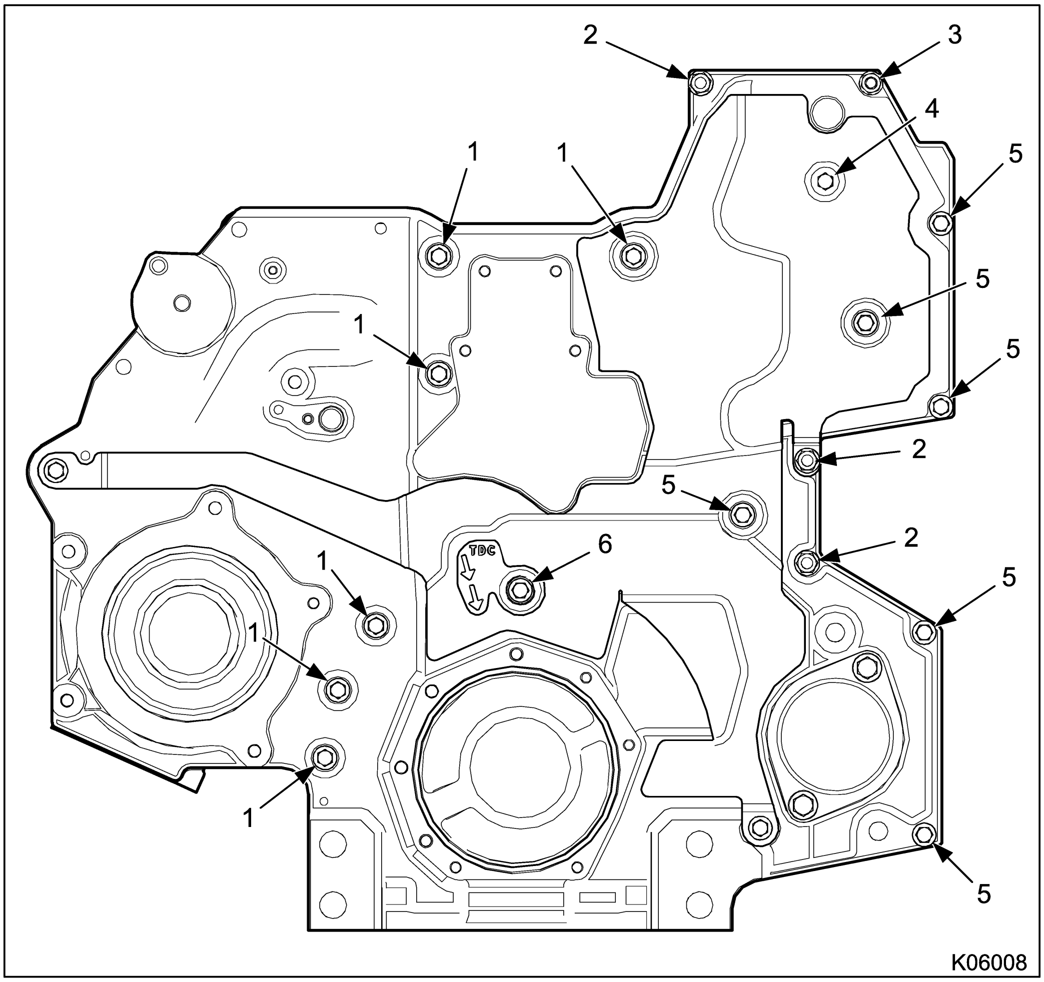


**Figure 301 Front cover (front half) – front side**

1. M8 x 45 bolt (6)
2. M8 x 50 bolt (nut on front) (3)
3. M8 x 73 stud bolt (nut on back)
4. M8 x 75 bolt (nut on back)
5. M8 x 50 bolt (nut on back) (6)
6. Seal assembly, M8 x 50 bolt and seal washer

**NOTE:** The oil pan and oil suction tube assembly must be removed before the front cover can be removed.

1. Remove the oil pan (page 338) and oil suction tube assembly (page 339).
2. Remove six M8 x 45 bolts holding the front cover to the crankcase.
3. Remove seven M8 x 50 bolts (nut on back).
4. Remove two M8 x 50 bolts (nut on front).
5. Remove M8 x 73 stud bolt (nut on back).
6. Remove and discard seal assembly M8 x 50 bolt and seal washer.
7. Remove M8 x 75 bolt (nut on back).

8. Remove front cover (front half) by sliding cover forward and off two dowel pins.
9. Remove and discard oil and coolant gaskets and O-ring seals from the front cover (front half) – back side.

### Idler Gears

**NOTE:** Measure lower idler, upper idler, and camshaft gear backlash (page 374) before removing any gears from the gear train.

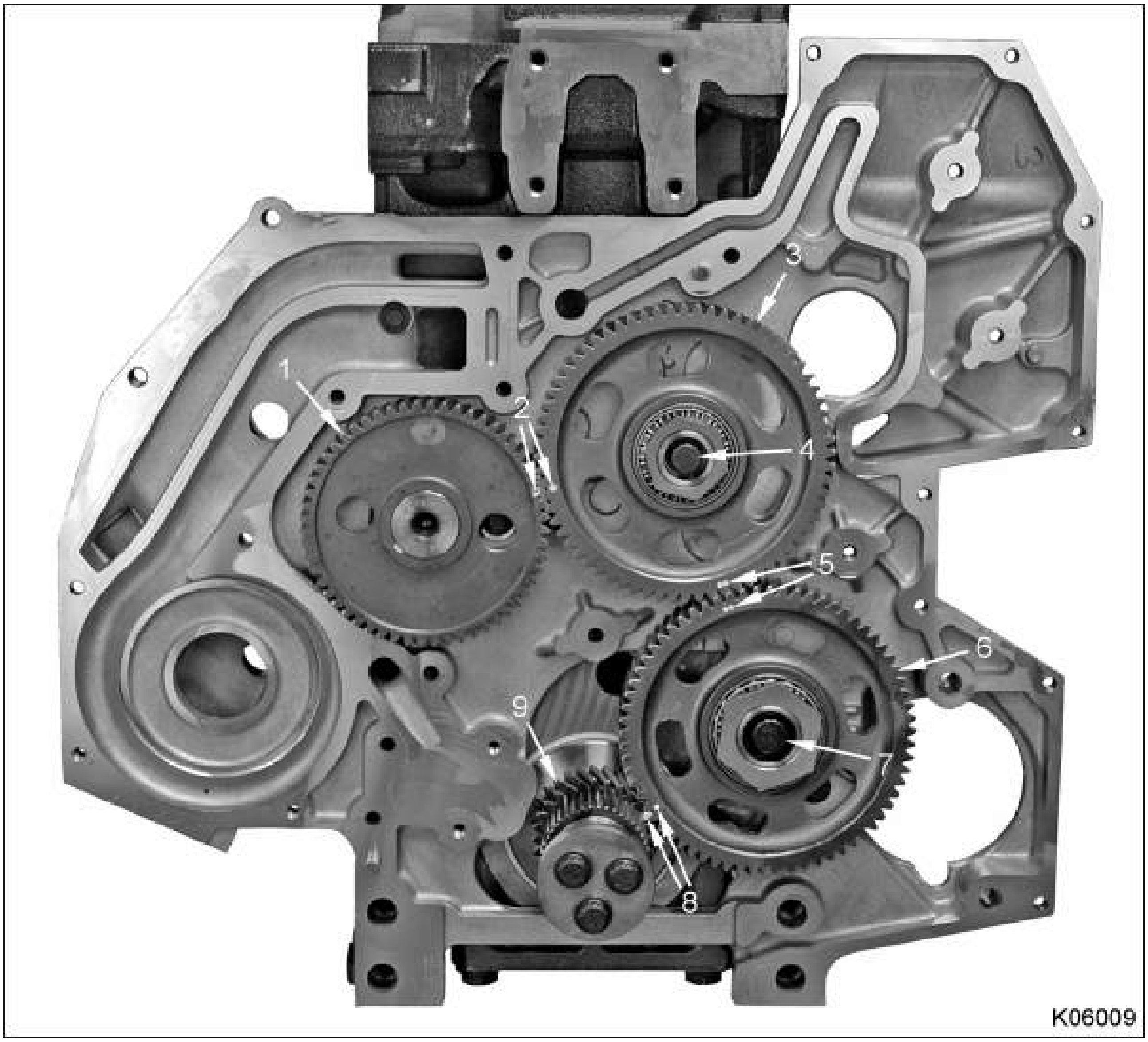


**Figure 302 Gear train**

1. Camshaft gear
2. Camshaft to upper idler gear timing marks (single dimple)
3. Upper idler gear
4. M16 x 65 bolt
5. Upper idler to lower idler gear timing marks (double dimple)
6. Lower idler gear
7. M20 x 70 bolt
8. Lower idler to crankshaft gear timing marks
9. Crankshaft gear

**NOTE:** Once timing marks are aligned, the crankshaft will require 34 revolutions to align timing marks again.

1. Rotate crankshaft until camshaft, upper idler, lower idler, and crankshaft gears timing marks are aligned.
2. If required, remove camshaft gear (page 604) from the camshaft.

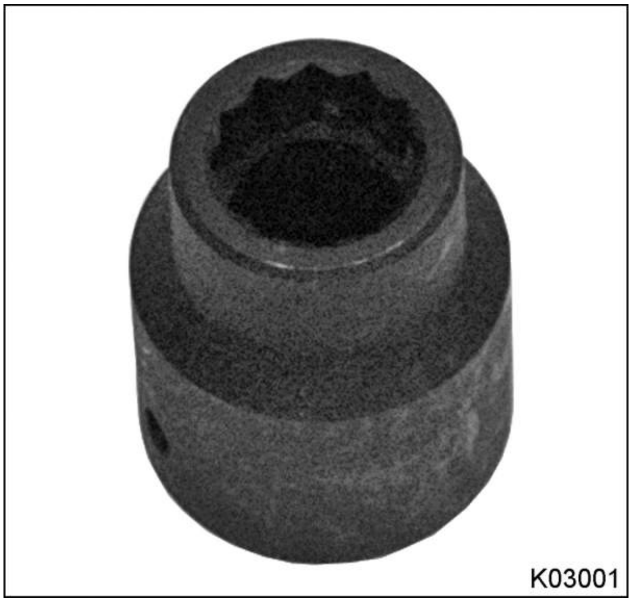


**Figure 303 Lower Idler Gear Socket**

3. Remove M20 x 70 bolt using Lower Idler Gear Socket (page 415) and a 3/4 inch drive breaker bar.
4. Remove lower idler gear.
5. Remove and discard M16 x 65 bolt using a 16 mm 12 point impact socket (page 415) and a 1/2 inch drive breaker bar.
6. Remove upper idler gear.

**NOTE:** If required, Measure Camshaft End Play (page 614) after removing the upper idler gear.

### Front Cover (Rear Half)

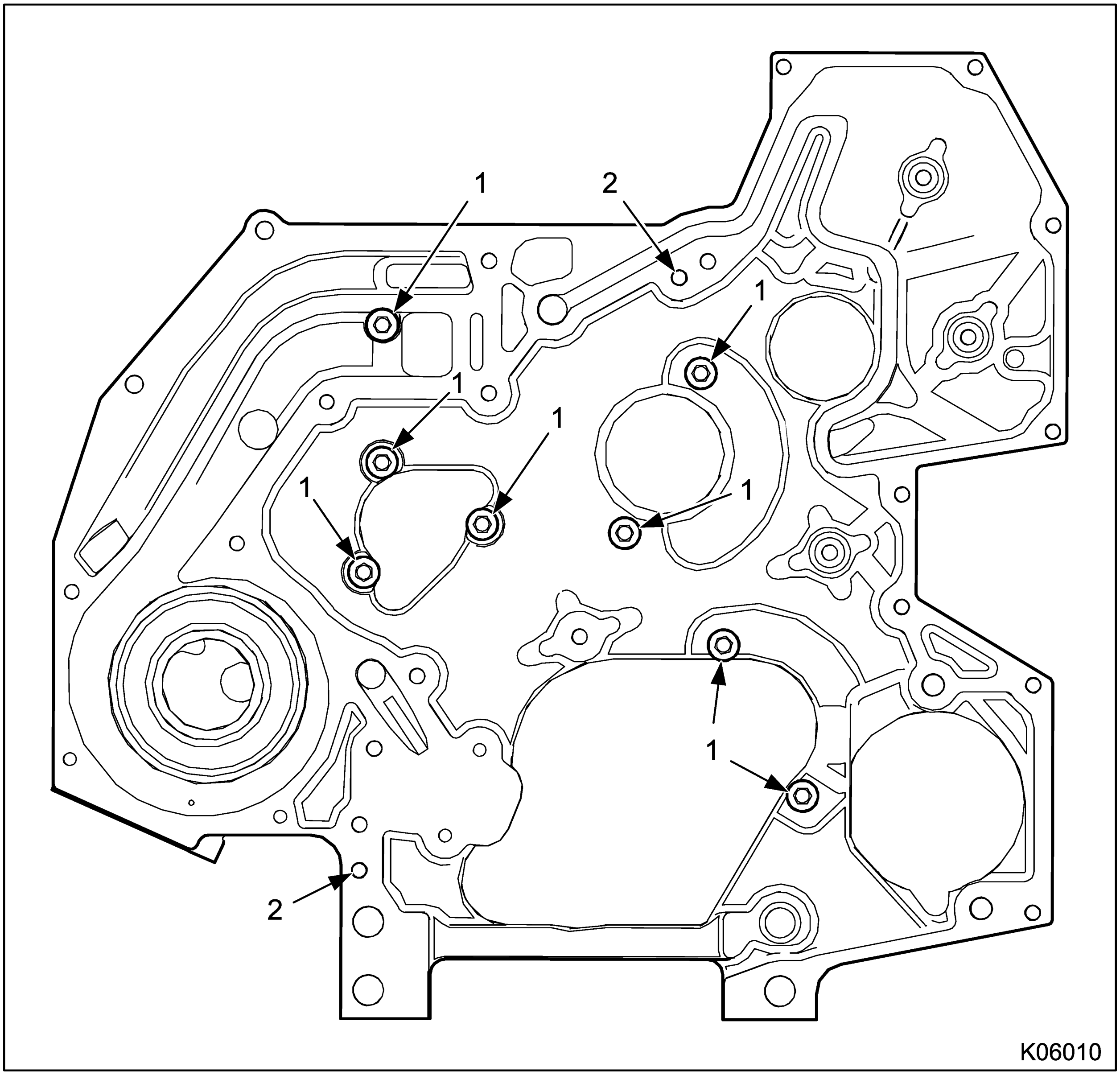


**Figure 304 Front cover (rear half) – front side**

1. Special hex flange bolt, M8 x 20 (8)
2. Dowel pins

1. Remove Camshaft Gear (page 604) or remove Camshaft Assembly (page 605).
2. Remove eight special M8 x 20 bolts holding the front cover (rear half) to the crankcase.
3. Pull cover outward to slide dowel pins out of crankcase and remove cover from engine.
4. Remove and discard oil and coolant gaskets from the front cover (rear half) – crankcase side.

## Cleaning, Inspection, and Measurement

**WARNING:**

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

### Clean and Inspect

1. Clean water supply housing, water pump, water inlet elbow, water outlet tube, oil pump housing, front engine mount, and front cover with a suitable non-caustic solvent.
2. Blow parts dry using filtered compressed air.
3. Clean coolant and oil seal mating surfaces on the cylinder head, water supply housing, water pump, water inlet elbow, water outlet tube, oil pump housing, and front cover.
4. Inspect alternator bracket, secondary Freon® compressor support, water supply housing, water inlet elbow, vibration damper assembly, oil pump and rotor housing, oil pump inner and outer rotors, front cover, and idler gears for cracks, damage, or excessive wear. Replace parts if required.
5. Inspect drive belt for excessive cracks and wear. Replace if necessary.
6. Inspect automatic belt tensioner and pulley to make sure tensioner arm and pulley are properly in line with the fan drive belt and not coming apart. Make sure tensioner arm is not binding and pulley bearing is not loose. Replace belt tensioner if required.
7. Inspect thermostat and gasket. If thermostat is stuck open, damaged, cracked, or not opening properly replace thermostat and gasket.
8. Inspect fan drive bearing by wiggling fan pulley. If bearing has excess play, replace fan housing or mounting bracket.
9. Inspect water pump. Wiggle water pump pulley. If water pump bearing has excess play, replace water pump. Inspect water pump housing for coolant leaks. Replace water pump if leaking.

### Measure Gear Backlash

**NOTE:** Remove rocker arm assembly (page 428) to release pressure exerted by valve train.

**Lower Idler Gear Backlash**

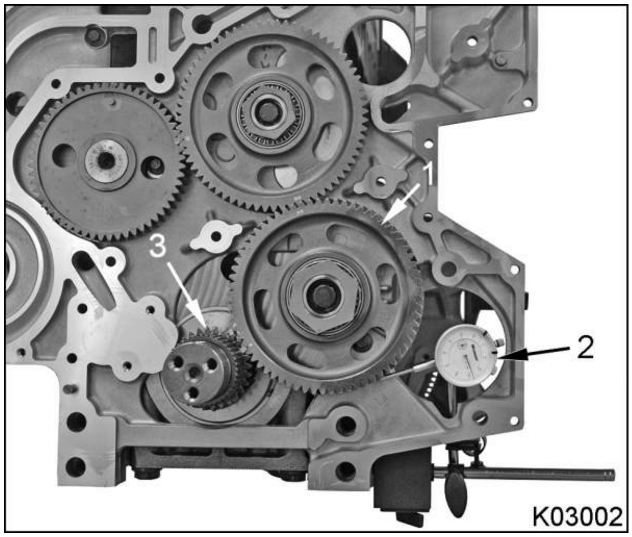


**Figure 305 Lower idler gear and dial indicator**

1. Lower idler gear
2. Dial indicator
3. Crankshaft gear

1. Mount a dial indicator set (page 415) on a level engine surface.
2. Place dial indicator tip on one of the lower idler gear teeth. Position dial indicator tangent (90 degrees relative to the plane of the gear tooth).
3. Rotate lower idler gear by hand in one direction, without moving the crankshaft gear, and zero the dial indicator.
4. Rock the lower idler gear back and forth without moving the crankshaft gear. If lower idler gear to crankshaft gear backlash exceeds Specifications (page 412), replace the lower idler gear.

### Upper Idler Gear Backlash

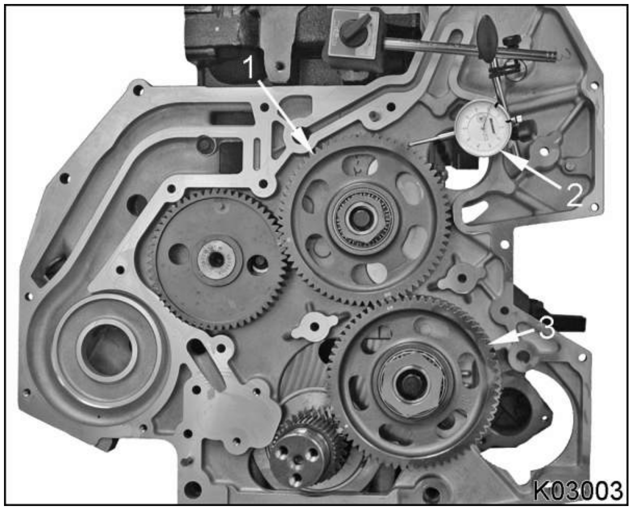


**Figure 306 Upper idler gear and dial indicator**

1. Upper idler gear
2. Dial indicator
3. Lower idler gear

1. Mount a dial indicator set (page 415) on a level engine surface.
2. Place dial indicator tip on one of the upper idler gear teeth. Position dial indicator tangent (90 degrees relative to the plane of the gear tooth).
3. Rotate upper idler gear by hand in one direction while holding the lower idler gear stationary with a gear locking tool or screwdriver. Zero the dial indicator.
4. Rock the upper idler gear back and forth without moving the lower idler gear. If upper idler gear to lower idler gear backlash exceeds Specifications (page 412), replace upper idler gear.

### Camshaft Gear Backlash

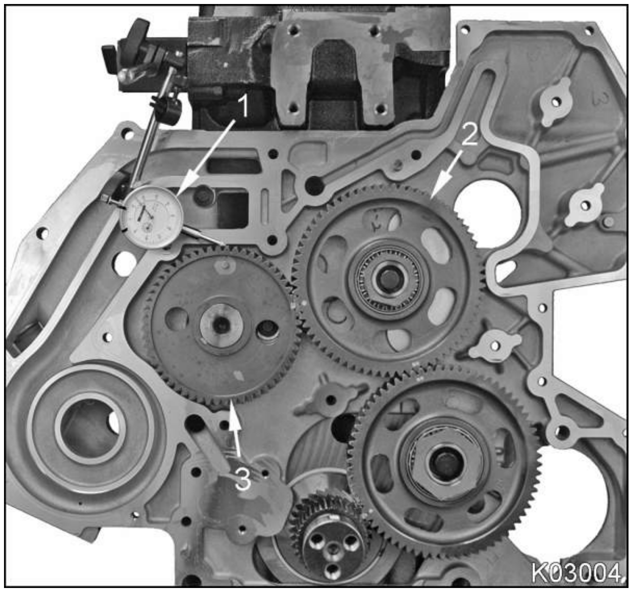


**Figure 307 Camshaft gear and dial indicator**

1. Dial indicator
2. Upper idler gear
3. Camshaft gear

1. Mount a dial indicator set (page 415) on a level engine surface.
2. Place dial indicator tip on one of the camshaft gear teeth. Position dial indicator tangent (90 degrees relative to the plane of the gear tooth).
3. Rotate camshaft gear by hand in one direction while holding the upper idler gear stationary with a gear locking tool or screwdriver. Zero the dial indicator.
4. Rock the camshaft gear back and forth without moving the upper idler gear. If camshaft gear to upper idler gear backlash exceeds Specifications (page 412), replace camshaft gear.

**Measure Oil Pump Side Clearance**

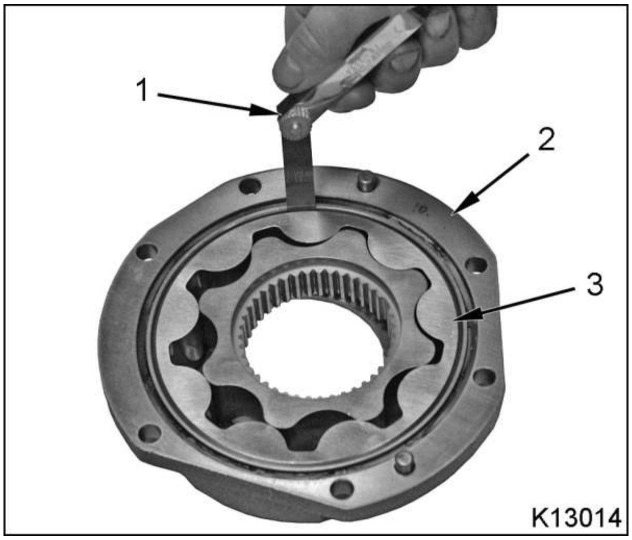


**Figure 308 Oil pump side clearance measurement**

1. Feeler gauge
2. Oil pump and rotor housing
3. Outer rotor

1. Coat outer rotor with oil and install rotor in oil pump and rotor housing.
2. Check oil pump side clearance Specification (page 412) and choose the appropriate thickness feeler gauge (page 415).
3. Insert feeler gauge between the oil pump and rotor housing and outer rotor.
4. Replace oil pump and rotor assembly if not within specification.

**Measure Oil Pump End Clearance**

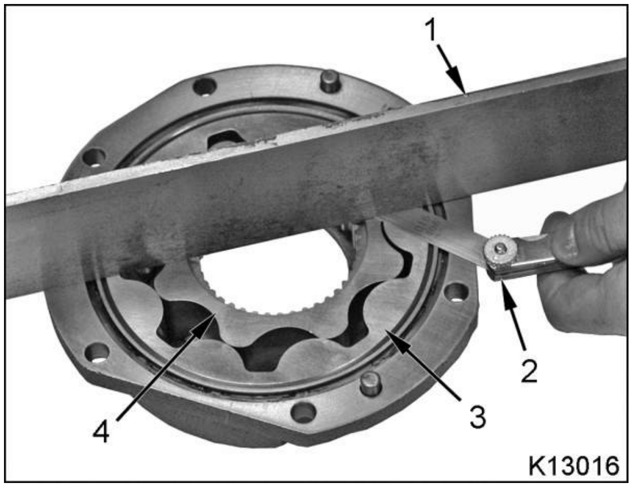


**Figure 309 Oil pump end clearance measurement**

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

1. Place a straightedge (page 415) across the oil pump mounting surface.
2. Check oil pump end clearance Specification (page 412) and choose the appropriate thickness feeler gauge (page 415).
3. Slide feeler gauge between the straightedge and the oil pump inner and outer rotors.
4. Replace oil pump and rotor assembly if not within specification.

## Installation

Install the crankshaft gear and oil pump drive spline (page 623).

### Front Cover (Rear Half)

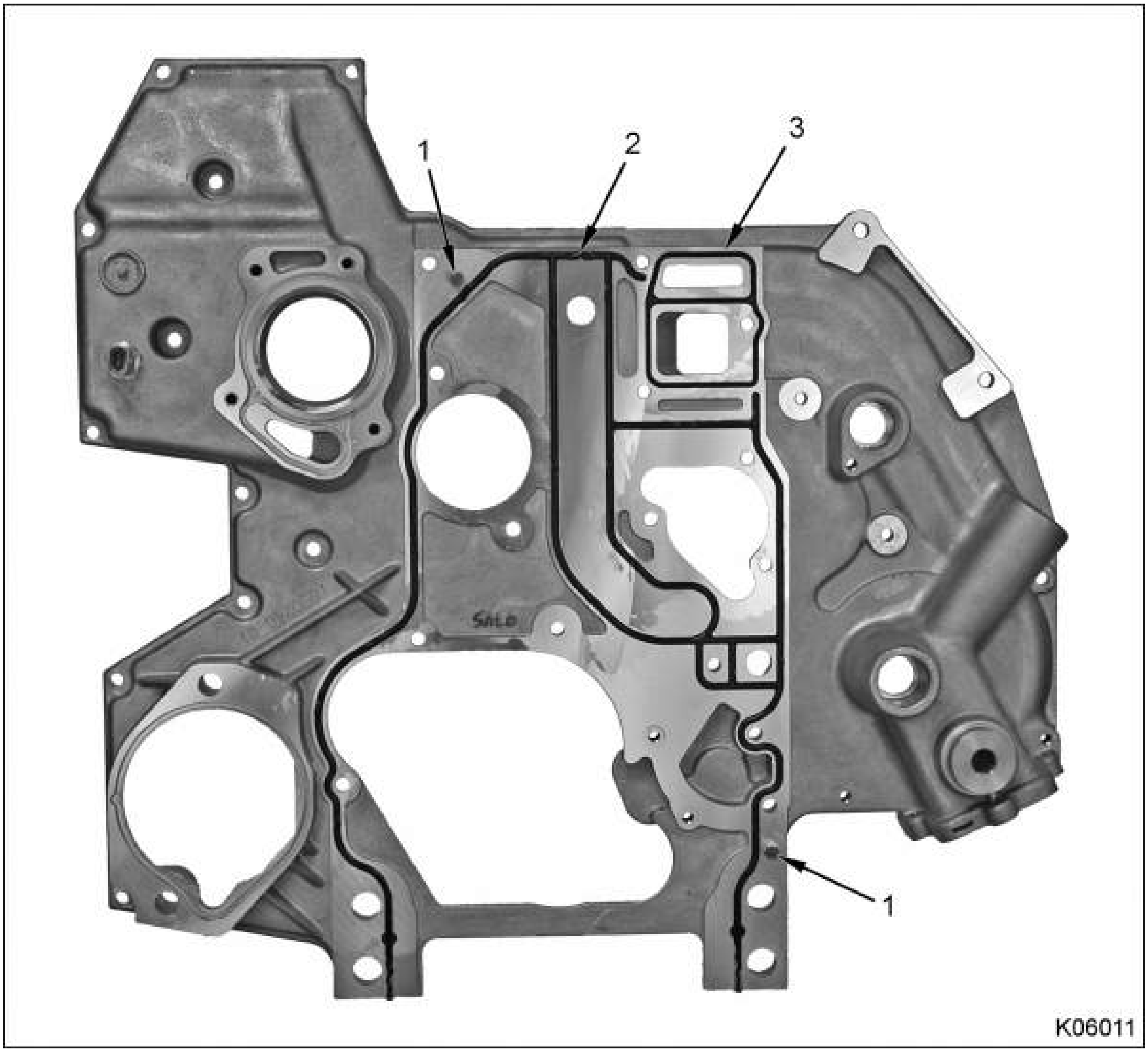


**Figure 310 Front cover (rear half) – crankcase side**

1. Dowel pin (2)
2. Front cover rear half (oil) gasket
3. Front cover rear half (coolant) gasket

1. Install new oil and coolant gaskets on the front cover (rear half) – crankcase side.
2. Align front cover dowel pins with crankcase dowel holes and install front cover (rear half) on the crankcase.

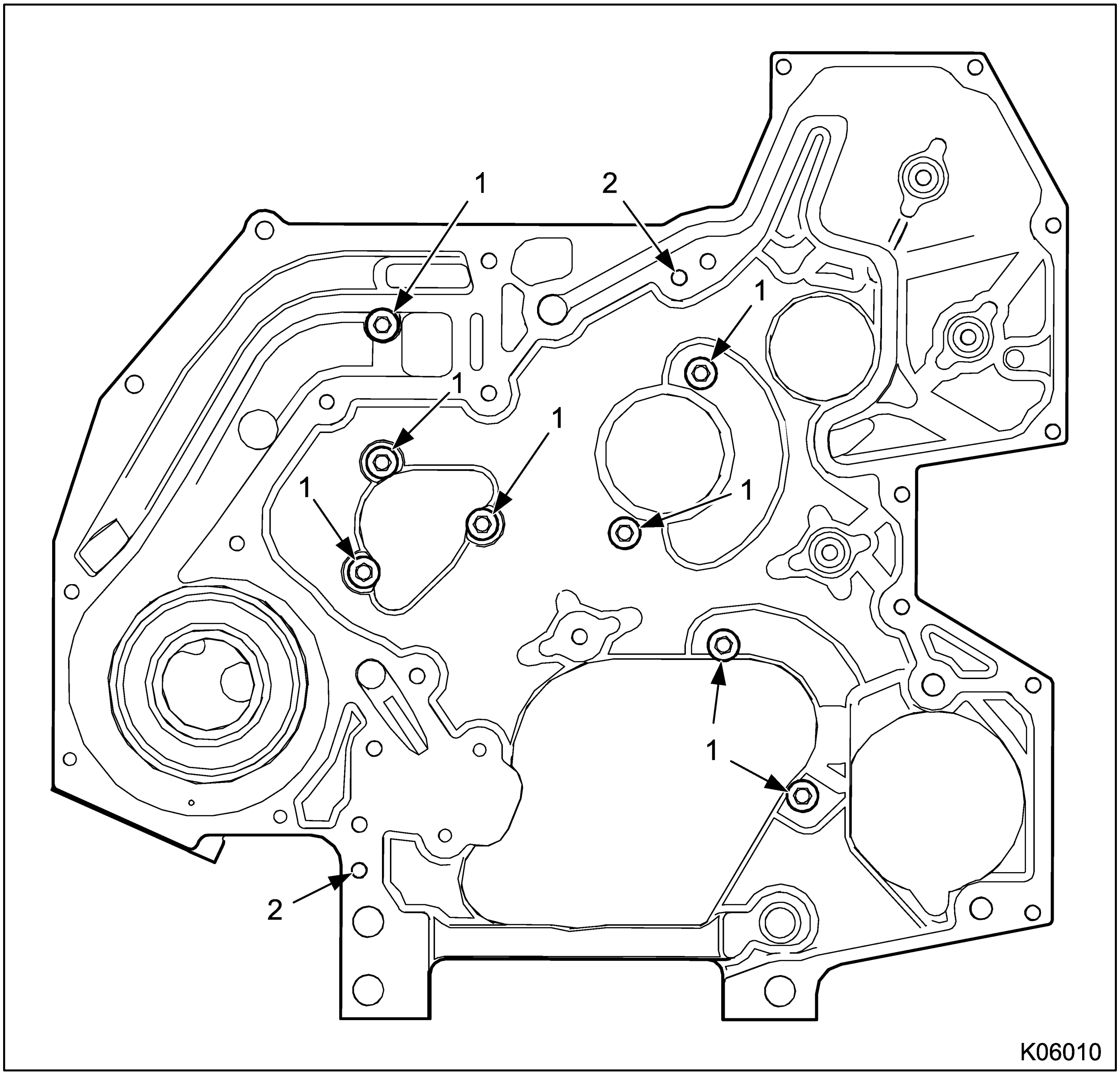


**Figure 311 Front cover (rear half) – front side**

1. Special hex flange bolt, M8 x 20 (8)
2. Dowel pins

3. Install eight special M8 x 20 mounting bolts finger tight.
4. Tighten eight special M8 x 20 mounting bolts to standard torque (page 683).
5. Install Camshaft Assembly (page 620) or Camshaft Gear (page 622).

### Idler Gears

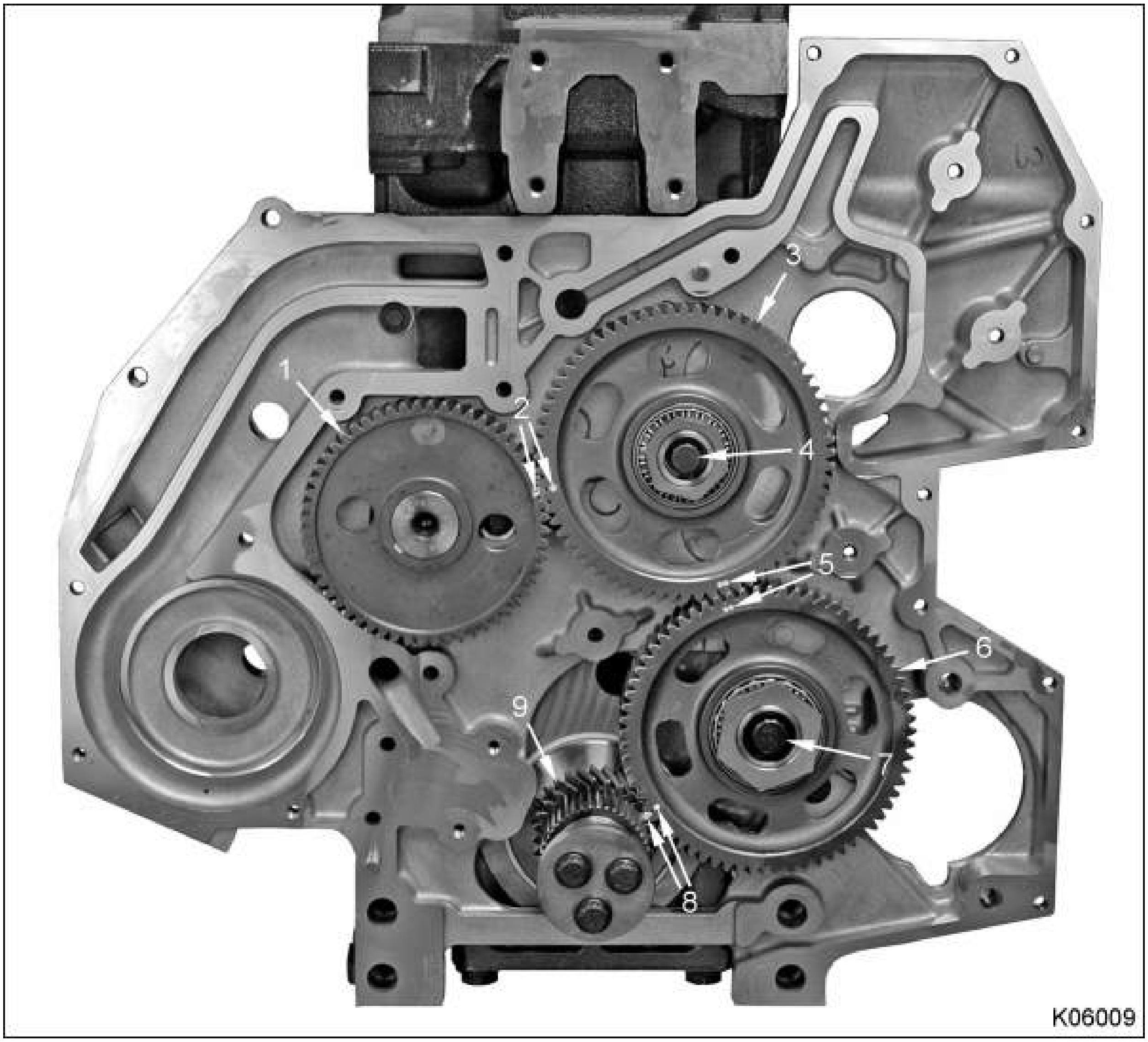


**Figure 312 Gear train**

1. Camshaft gear
2. Camshaft to upper idler gear timing marks (single dimple)
3. Upper idler gear
4. M16 x 65 bolt (12 point)
5. Upper idler to lower idler gear timing marks (double dimple)
6. Lower idler gear
7. M20 x 70 bolt (12 point)
8. Lower idler to crankshaft gear timing marks
9. Crankshaft gear

**NOTE:** Gear train gears should be assembled and installed with the timing marks facing out as shown.

1. Install lower idler gear on the crankcase and align lower idler gear timing mark with crankshaft gear timing mark. If upper idler gear is installed align lower idler gear (double dimple) timing mark with upper idler gear (double dimple) timing mark.

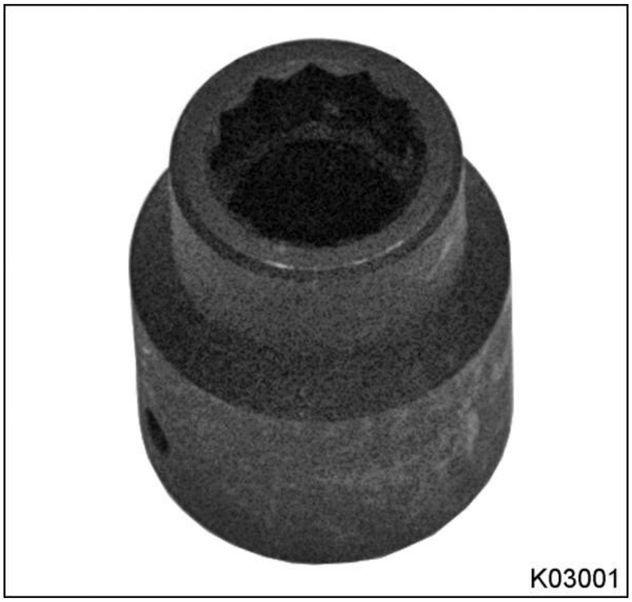


**Figure 313 Lower Idler Gear Socket**

2. Install lower idler gear M20 x 70 bolt and tighten to special torque (page 415) using Lower Idler Gear Socket (page 415).

3. Install upper idler gear on the crankcase and align upper idler gear (double dimple) timing mark with lower idler gear (double dimple) timing mark. Align upper idler gear (single dimple) timing mark with camshaft gear (single dimple) timing mark.

**NOTE:** New upper idler gear bolt must be used with each installation of upper idler gear. There is pre-applied sealant on new mounting bolt.

4. Install new upper idler gear M16 x 65 bolt and tighten to special torque (page 415) using a 16 mm 12 point impact socket (page 415).

**NOTE:** Once timing marks are aligned, the crankshaft will require 34 revolutions to align timing marks again.

5. Measure lower idler, upper idler, and camshaft gears backlash (page 374).
6. Install the high-pressure oil pump (page 253) and measure gear backlash between the upper idler gear and the high-pressure oil pump gear. See Specifications (page 412).
7. Measure high-pressure oil pump end play. See Specifications (page 412).

**Front Cover (Front Half)**

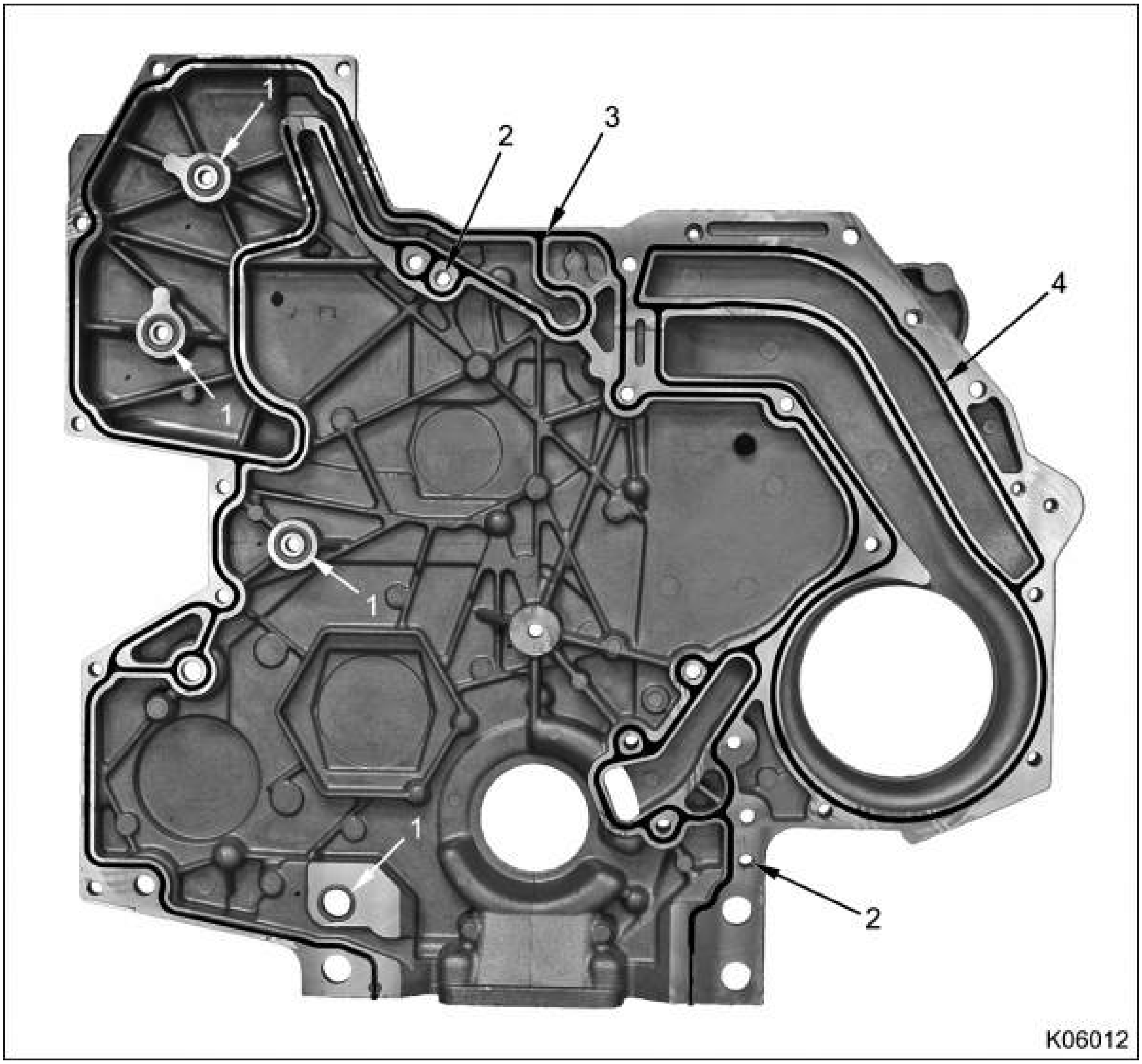


**Figure 314 Front cover (front half) – back side**

1. O-ring (4)
2. Dowel hole (2)
3. Front cover front half (oil) gasket
4. Front cover front half (coolant) gasket

1. Install a new oil gasket, coolant gasket, and four O-rings on the front cover (front half) – back side.
2. Install the front cover (front half) on the front cover (rear half) and align front half dowel holes with rear half dowel pins.

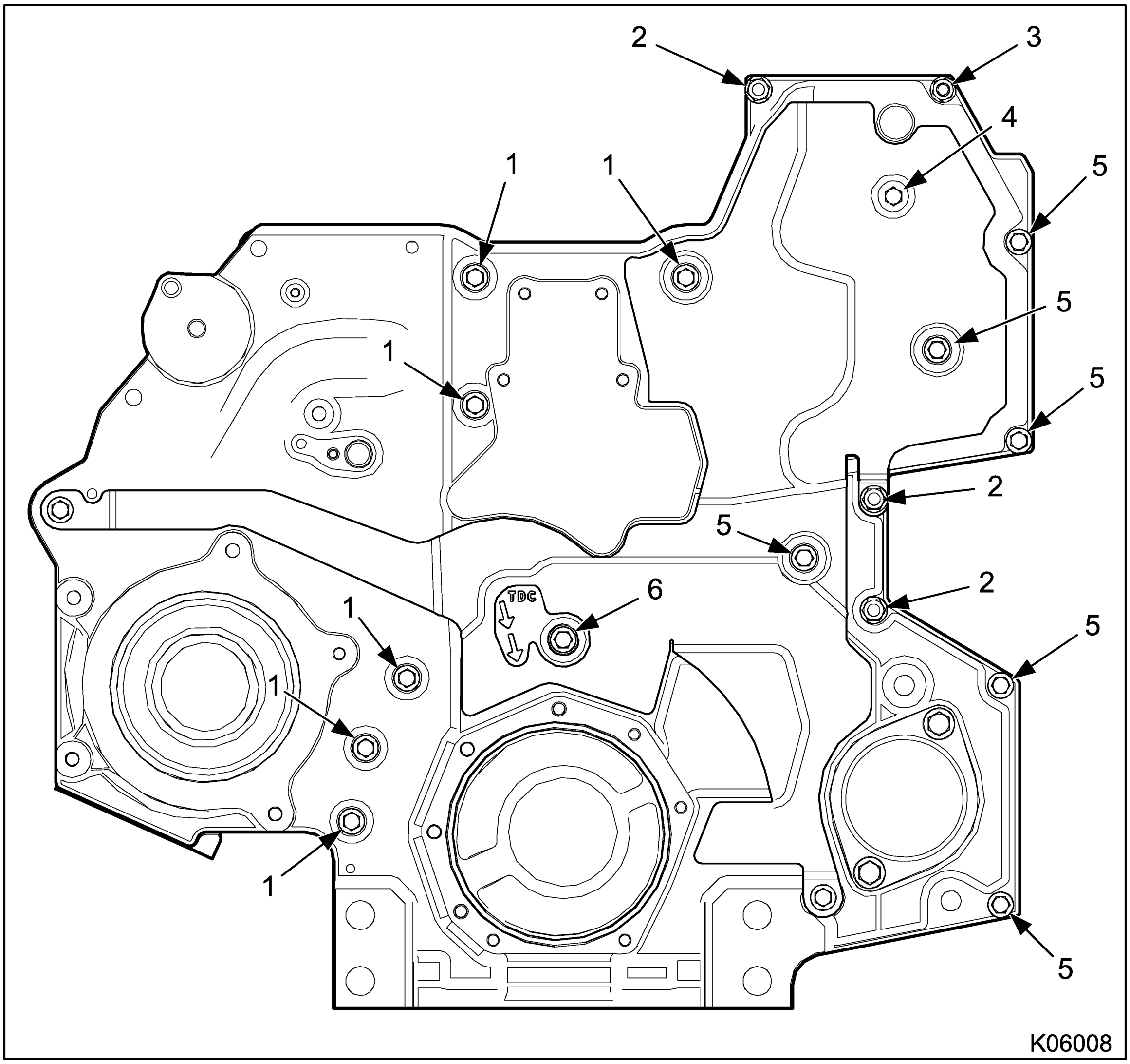


**Figure 315 Front cover (front half) – front side**

1. M8 x 45 bolt (6)
2. M8 x 50 bolt (nut on front) (3)
3. M8 x 73 stud bolt (nut on back)
4. M8 x 75 bolt (nut on back)
5. M8 x 50 bolt (nut on back) (6)
6. Seal assembly, M8 x 50 bolt and seal washer

3. Install M8 x 75 bolt (nut on back) finger tight.

**CAUTION:**

**To prevent engine damage, do not substitute seal assembly M8 x 50 bolt and seal washer with any other bolt.**

4. Install a new seal assembly M8 x 50 bolt and seal washer finger tight.
5. Install M8 x 73 stud bolt (nut on back) finger tight.
6. Install two M8 x 50 bolts (nut on front) finger tight.

7. Install seven M8 x 50 bolts (nut on back) finger tight.
8. Install six M8 x 45 bolts finger tight.
9. Tighten 18 M8 front cover (front half) mounting bolts to standard torque .

**Front Engine Mounting Bracket**

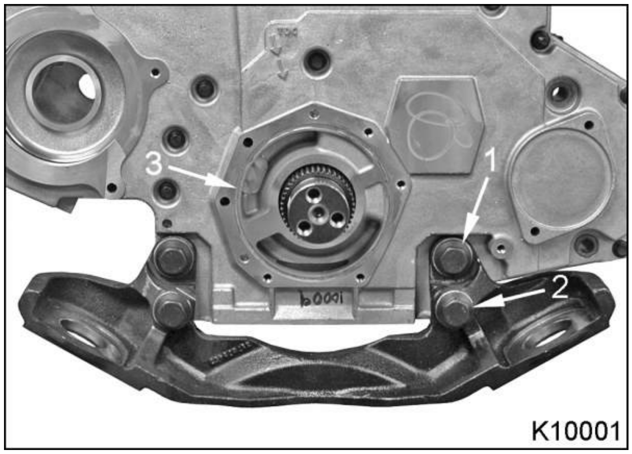


**Figure 316 Front engine mount**

1. M18 x 70 bolt (2)
2. M18 x 100 bolt (2)
3. Oil pump housing seal groove

1. Position front engine mount on front cover and install two M18 x 100 bolts finger tight.
2. Install two M18 x 70 bolts finger tight.
3. Tighten two M18 x 100 and two M18 x 70 bolts to special torque (page 415).

**Oil Pump Assembly**

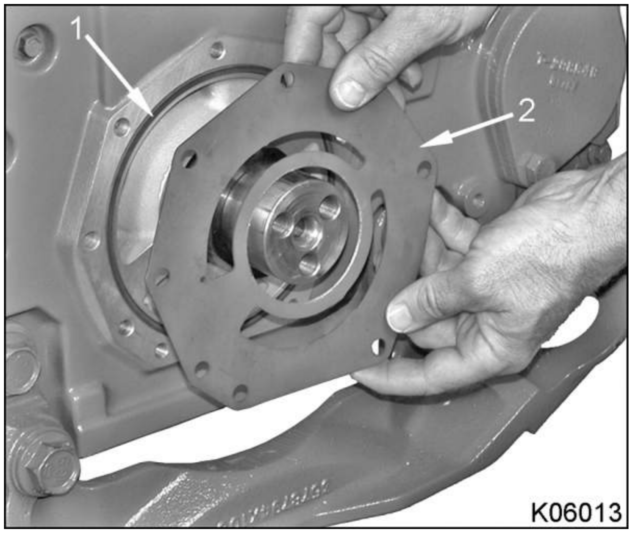


**Figure 317 Oil pump housing plate and seal**

1. Oil pump (housing plate) seal
2. Oil pump housing plate

1. Install a new oil pump housing seal in the front cover and install the oil pump housing plate.

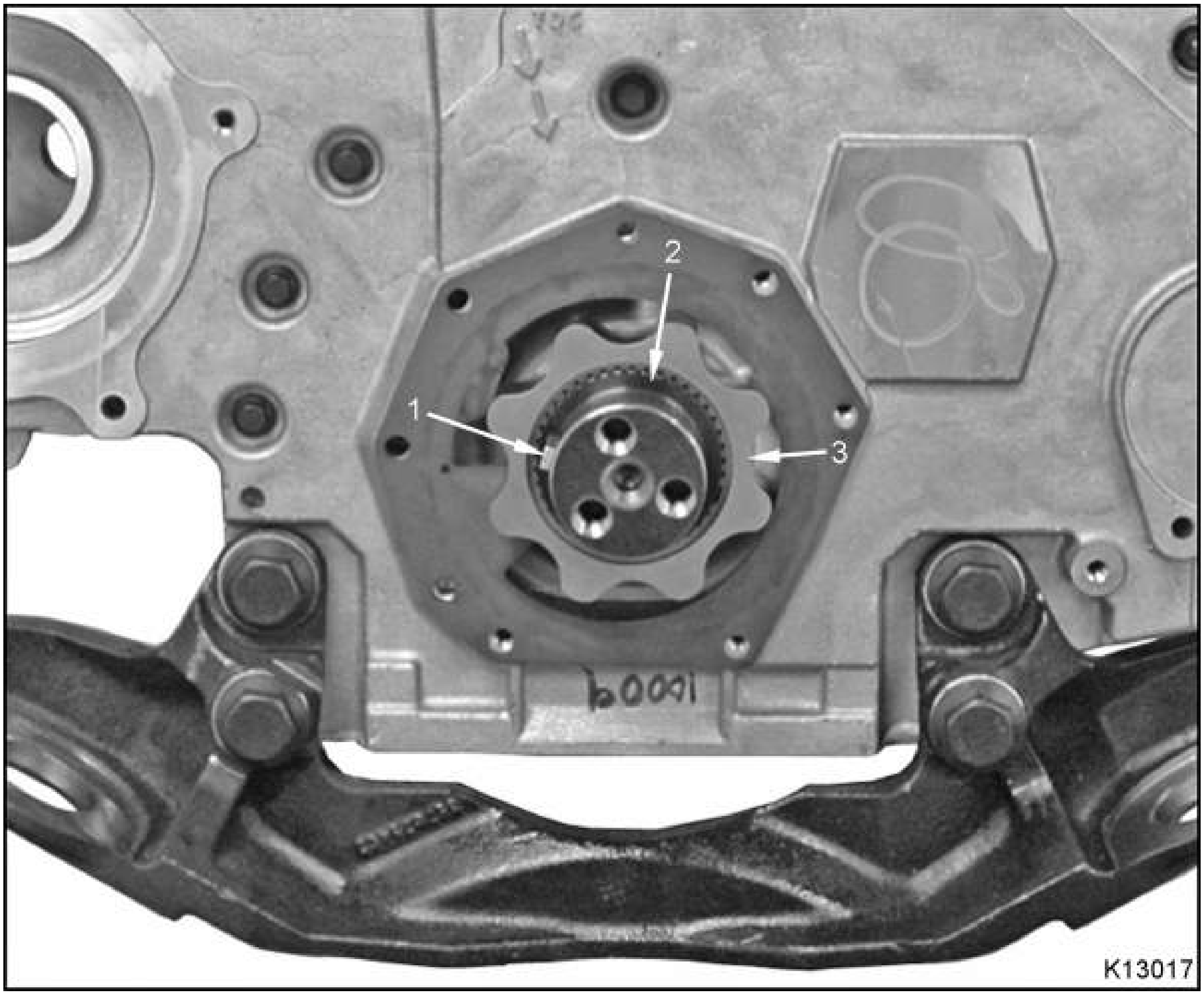


**Figure 318 Vibration damper key, inner rotor, and washer seal**

1. Vibration damper key
2. Washer seal
3. Inner rotor

**CAUTION:**

**To prevent engine damage, make sure used oil pump inner and outer rotors rotate in the same direction as before removal. See marks added during removal for proper rotor orientation.**

2. Slide oil pump inner rotor on the crankshaft oil pump spline drive.
3. Install washer seal with angled outer edge pointing out toward the front of the engine.

**CAUTION:**

**To prevent engine damage, do not mark or distort the crankshaft keyway groove during vibration damper key installation.**

4. Carefully tap the vibration damper key into the crankshaft keyway groove with a hammer.

**NOTE:** MaxxForce® 9 and 10 engines use a front oil seal with a POSE dust seal mounted on the damper hub wear sleeve. MaxxForce® DT engines use a front oil seal without a dust seal.

**CAUTION:**

**To prevent engine damage, for MaxxForce® 9 and 10 engines, replace the POSE dust seal and front oil seal as a set. For MaxxForce® DT engines, only use a front oil seal designed to not use a matching dust seal.**


**Figure 319 Hydraulic sealant and front oil seal**

5. Apply Loctite 569 Hydraulic sealant to the outside edge of the front oil seal.

**CAUTION:**

**To prevent engine damage, wipe excess hydraulic sealant and other contaminates off the front oil seal inside sealing edge.**

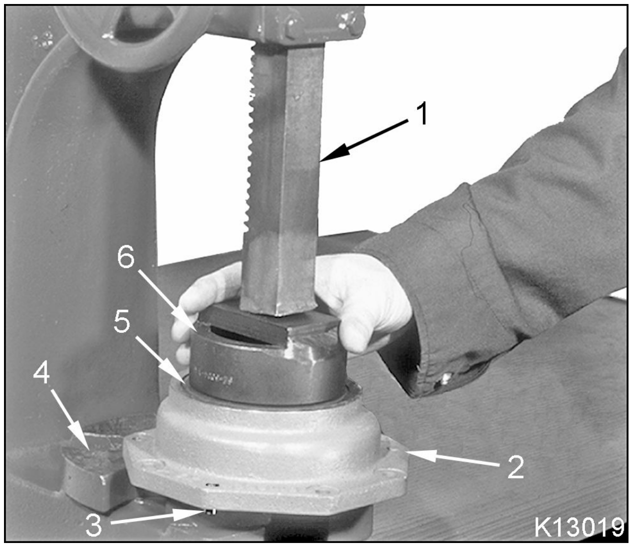


**Figure 320 Front oil seal installation**

1. Press ram
2. Oil pump and rotor housing
3. Dowel pin (2)
4. Press table
5. Front oil seal
6. Front Seal and Wear Sleeve Installer

6. Place oil pump and rotor housing, new front oil seal, and Front Seal and Wear Sleeve Installer (page 415) on press table.
7. Position oil pump housing on press table so housing mating surface is level and supported. Dowel pins should be recessed in press table openings.
8. Position press ram on the center of the Front Seal and Wear Sleeve Installer and carefully press the front oil seal into the oil pump housing until seal is fully seated.

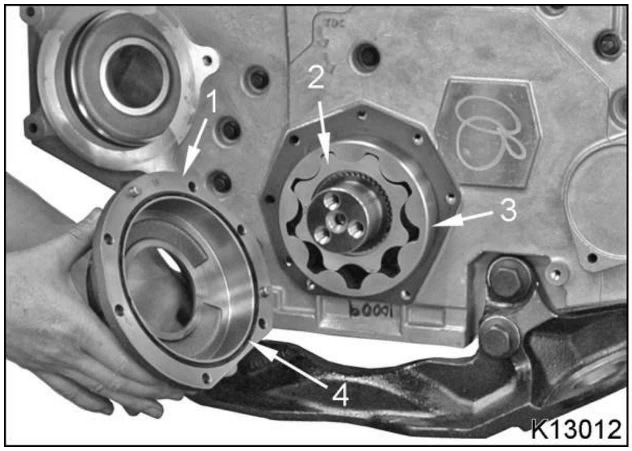


**Figure 321 Oil pump housing and rotor assembly**

1. Oil pump and rotor housing
2. Inner rotor
3. Outer rotor
4. Oil pump seal

9. Install a new oil pump seal in the oil pump and rotor housing groove.
10. Coat the outer rotor with clean engine oil.

**CAUTION:**

**To prevent engine damage, make sure used oil pump inner and outer rotors rotate in the same direction as before removal. See marks added during removal for proper rotor orientation.**

11. Install the outer rotor on the inner rotor.
12. Lightly coat the front oil seal inside sealing surface with clean engine oil.
13. Align two oil pump and rotor housing dowels with two front cover dowel holes and install oil pump and rotor housing.

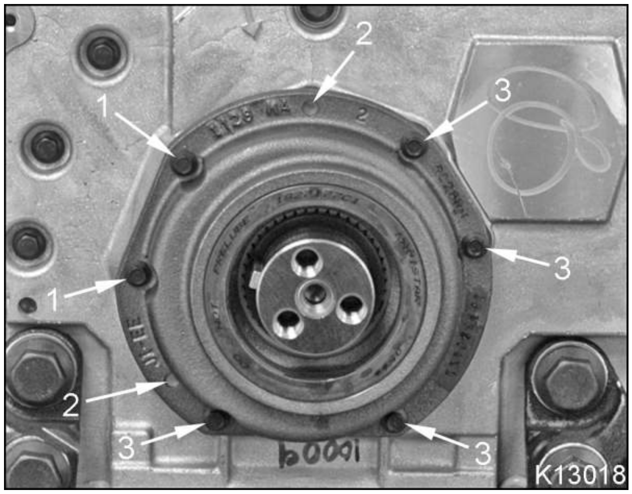


**Figure 322 Oil pump and rotor housing assembly**

1. M8 x 60 bolt (2)
2. Dowel (2)
3. M8 x 25 bolt (4)

14. Install four M8 x 25 bolts finger tight.
15. Install two M8 x 60 bolts finger tight.
16. Tighten four M8 x 25 bolts and two M8 x 60 bolts to special torque (page 415).

### Vibration Damper, Hub, and Wear Sleeve

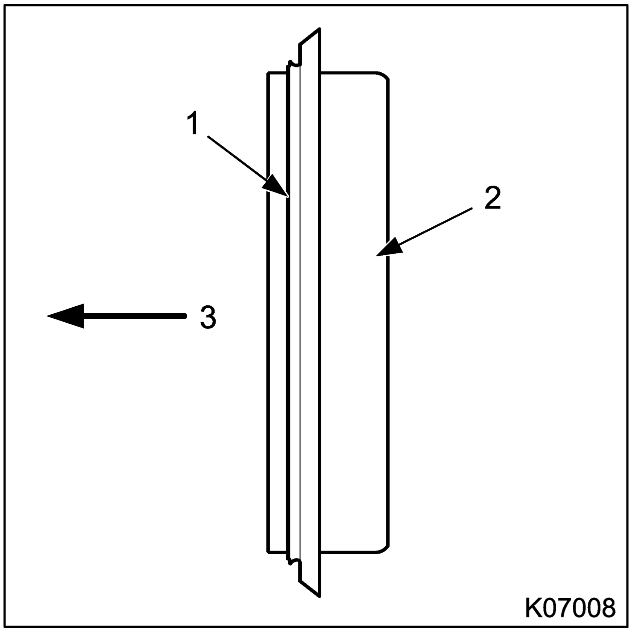


**Figure 323 POSE seal (MaxxForce® 9 and 10 only) and wear sleeve orientation**

1. POSE seal (MaxxForce® 9 and 10 only)
2. Wear sleeve
3. Front of engine

**NOTE:** If service kit contains more than one wear sleeve, use sleeve that has the same width as the current wear sleeve.

**NOTE:** MaxxForce® 9 and 10 engines have a POSE dust seal attached to the wear sleeve. A dust seal is not used on MaxxForce® DT engines.

**CAUTION:**

**To prevent engine damage, for MaxxForce® 9 and 10 engines, replace the POSE dust seal and front oil seal as a set. For MaxxForce® DT engines, only use a front oil seal designed without a matching dust seal.**

**NOTE:** The chamfer (rounded edge) of the wear sleeve outside diameter must face in, toward the engine.

1. Apply Loctite® 569 Hydraulic Sealant (page 415) to the inside diameter of a new wear sleeve.

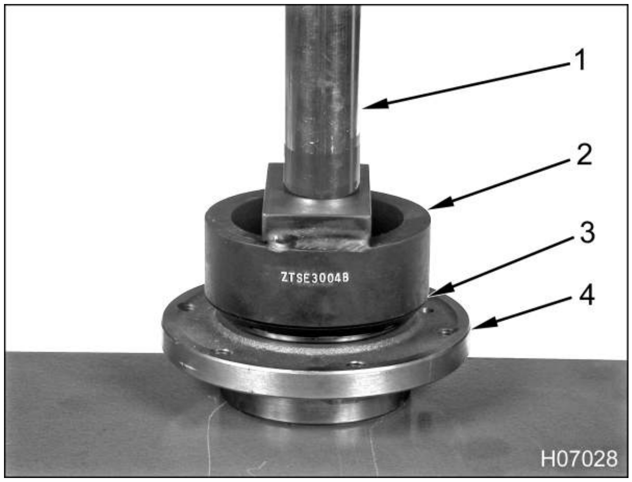


**Figure 324 Front seal and wear sleeve installation**

1. Press ram
2. Front Seal and Wear Sleeve Installer
3. POSE dust seal (MaxxForce® 9 and 10 engines only )
4. Damper hub

2. Center the damper hub, new wear sleeve, and Front Seal and Wear Sleeve Installer (page 415) under press ram.
3. Carefully press the new wear sleeve on the damper hub until sleeve is fully seated.
4. Wipe any excess sealant off the outside diameter of the wear sleeve.

5. Mark damper hub with 100 °C (212 °F) Thermo-melt crayon (page 415).


**Figure 325 Damper hub and hot plate**

**CAUTION:**

**To prevent engine damage, do not heat damper hub assembly above 100 °C (212 °F).**

6. Heat damper hub on a hot plate or other controlled heat source until Thermo-melt crayon mark melts.


**Figure 326 Damper hub installation**

**WARNING:**

**To prevent personal injury or death, wear heat insulated gloves when handling heated components.**

7. Install damper hub on crankshaft while wearing heat insulated gloves. Make sure keyway groove on damper hub aligns with keyway in crankshaft.

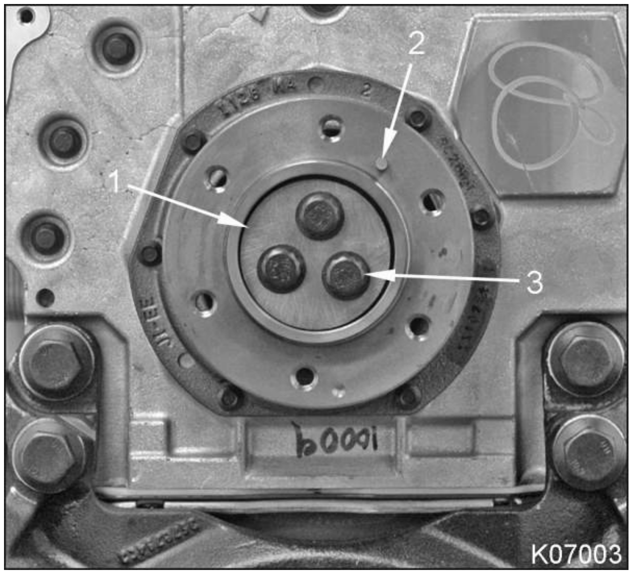


**Figure 327 Damper hub**

1. Damper retainer
2. Dowel pin
3. M12 x 40 (12 point) damper bolt (3)

**WARNING:**

**To prevent personal injury or death, damper hub must be completely seated on the crankshaft.**

**CAUTION:**

**To prevent engine damage, only use 15.2 mm (0.60) in thick damper retainer and Class 12.9 damper bolts.**

8. Install damper retainer and three M12 x 40 damper bolts. Verify damper retainer is 15.2 mm (0.60) in thick and damper bolts are Class 12.9.
9. Tighten three M12 x 40 damper bolts to special torque (page 415).
10. Retighten three M12 x 40 damper bolts in sequence to special torque (page 415) several times until each bolt has no movement.

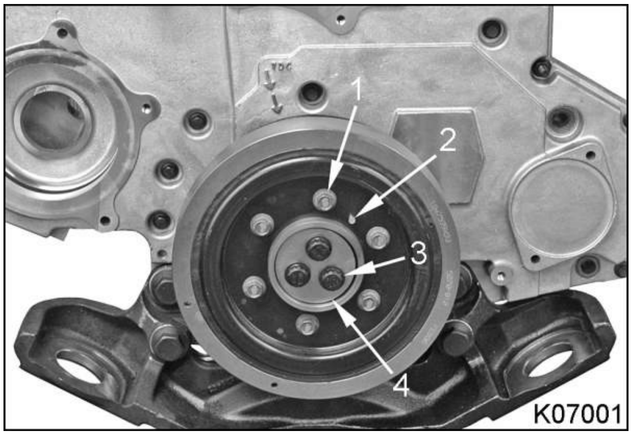


**Figure 328 Vibration damper assembly**

1. M10 x 16 bolt (6)
2. Dowel pin
3. M12 x 40 (12 point) damper bolt (3)
4. Damper retainer

**CAUTION:**

**To prevent engine damage, verify damper hub dowel pin is aligned with dowel hole of the vibration damper assembly.**

11. Install vibration damper assembly on damper hub and align dowel hole in damper with dowel pin on damper hub.
12. Install six M10 x 16 bolts finger tight.
13. Tighten six M10 x 16 bolts to special torque (page 415).

### Fan Drive

#### Spin-on Fan Drive

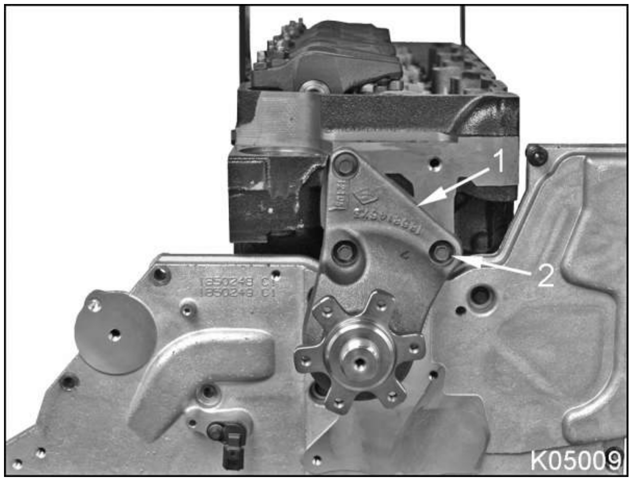


**Figure 329 Fan housing assembly, spin-on (typical)**

1. Fan housing assembly (typical)
2. M10 x 30 bolt (3)

**NOTE:** Fan drive configurations use either three or four M10 x 30 bolts to hold the fan housing assembly to the cylinder head.

1. Install fan housing assembly on cylinder head and install M10 x 30 bolts finger tight.
2. Tighten M10 x 30 bolts to standard torque (page 683).

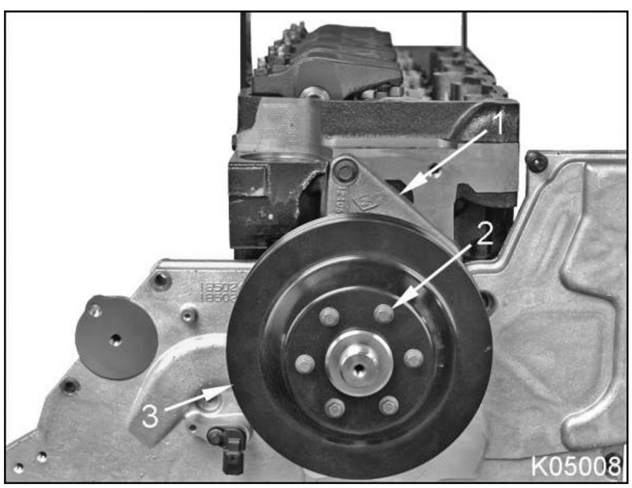


**Figure 330 Fan pulley, spin-on**

1. Fan housing assembly (typical)
2. M8 x 20 bolt (6)
3. Fan drive pulley

3. Install fan drive pulley on fan housing assembly and install six M8 x 20 bolts finger tight.

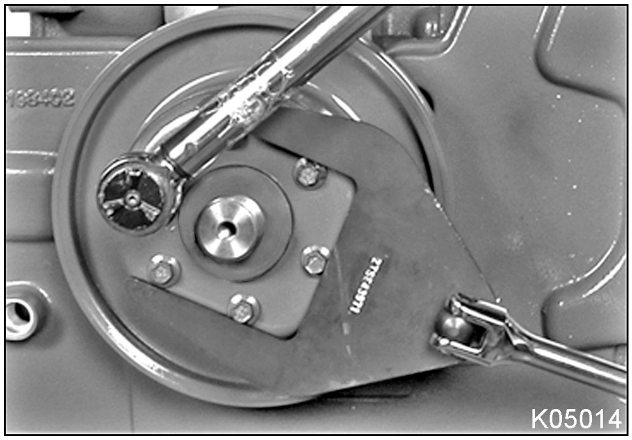


**Figure 331 Fan Wrench and fan drive pulley**

4. Hold the fan drive pulley stationary with a Fan Wrench (page 415).
5. Tighten six M8 x 20 bolts to standard torque (page 683).

**Horton DriveMaster® Fan Drive**

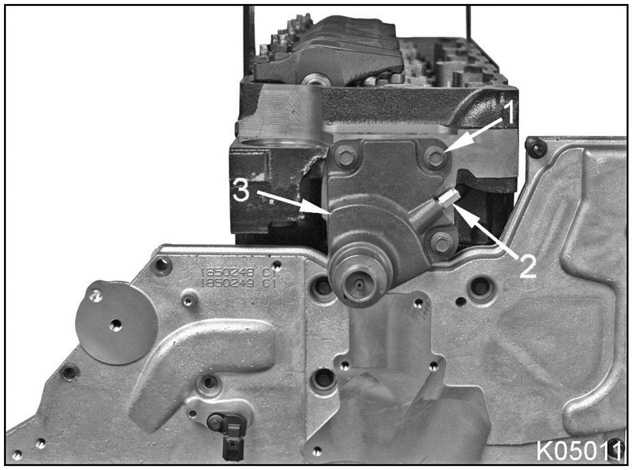


**Figure 332 Fan mounting bracket, DriveMaster® (typical)**

1. M10 x 30 bolt (3)
2. Fan clutch air supply fitting (typical)
3. Fan mounting bracket (typical)

**NOTE:** Fan drive configurations use either three or four M10 x 30 bolts to hold the fan mounting bracket to the cylinder head.

1. Install M10 x 30 bolts holding the fan mounting bracket to the cylinder head.
2. Tighten M10 x 30 bolts to standard torque (page 683).

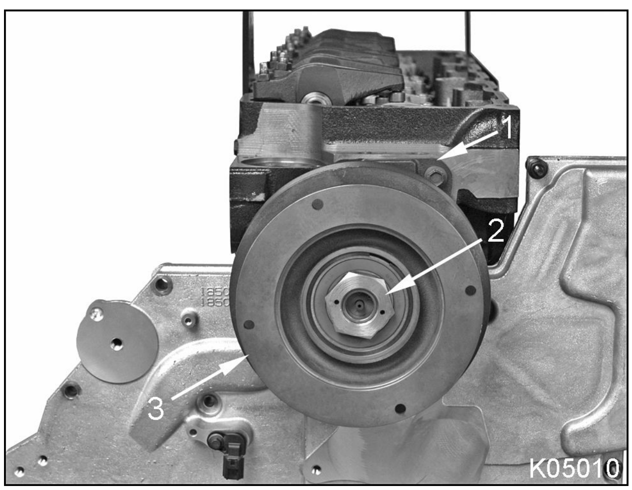


**Figure 333 Fan pulley, DriveMaster®**

1. Fan mounting bracket (typical)
2. Nut assembly
3. Fan Pulley

3. Slide fan pulley on fan mounting bracket.

**CAUTION:**

**To prevent engine damage, install nut assembly with collar toward engine.**

4. Install nut assembly (collar toward engine) on the fan mounting bracket and finger tighten.

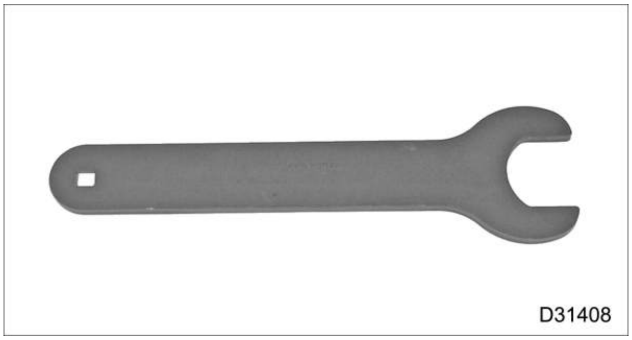


**Figure 334 Fan Hub Wrench**

5. Tighten nut assembly to special torque (page 415) using a Fan Hub Wrench (2 inch) (page 415) and a torque wrench. See Using a Torque Wrench Extension (page 684) to calculate the correct torque wrench setting.

**Water Outlet Tube, and Thermostat**

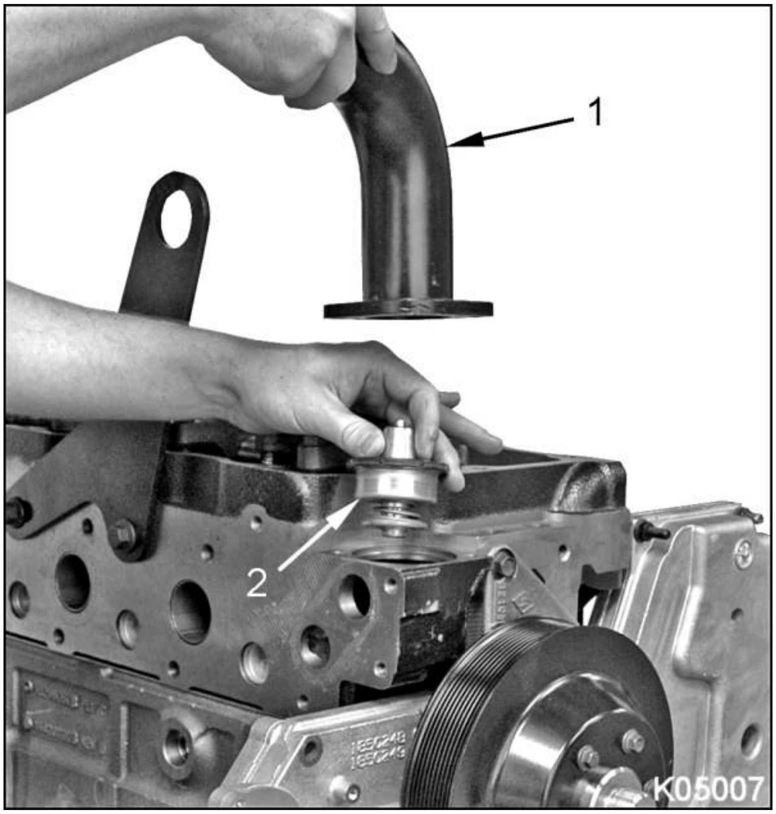


**Figure 335 Water outlet tube and thermostat**

1. Water outlet tube (typical)
2. Thermostat assembly

1. If equipped with a thermostat bypass, install a new thermostat seal and then install the thermostat bypass housing on the cylinder head.
2. Install thermostat assembly in the cylinder head or thermostat bypass.

**NOTE:** Water outlet tube configurations use either two M8 x 25 bolts to hold the water outlet tube to the cylinder head or two M8 x 115 bolts to hold the water outlet tube and thermostat bypass housing to the cylinder head.

3. Install water outlet tube and finger tighten two M8 bolts.
4. Tighten two M8 bolts to standard torque (page 683).

#### Water Pump Assembly

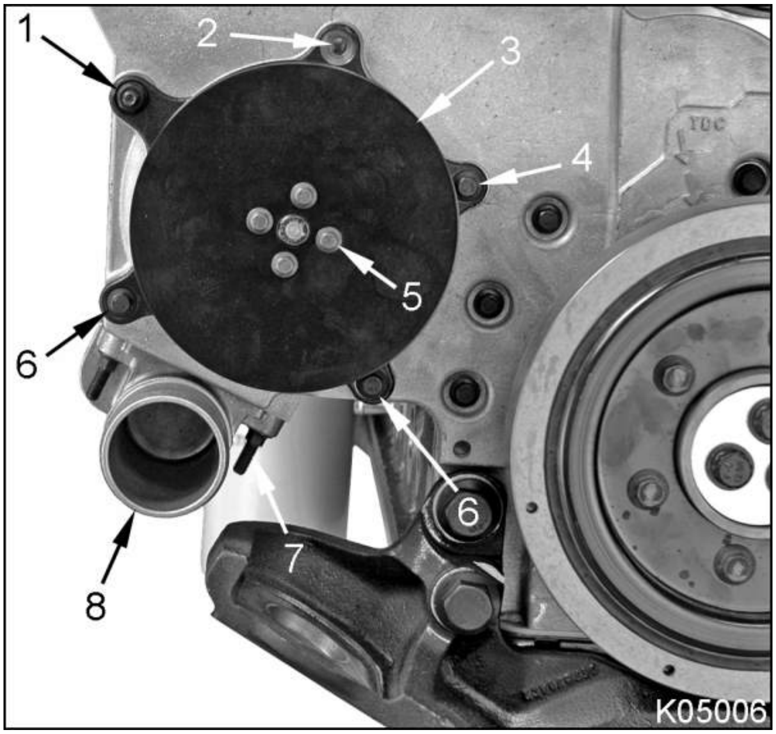


**Figure 336 Water pump and inlet elbow**

1. M8 x 55 bolt (nut on front)
2. M8 x 100 bolt (nut on back)
3. Water pump pulley (typical)
4. M8 x 16 bolt
5. M6 x 12 bolt (4)
6. M8 x 45 bolt (2)
7. M8 stud bolt (3)
8. Water inlet elbow

1. Install a new water pump housing seal in the water pump assembly.
2. Install water pump assembly on the front cover and install two M8 x 45 bolts.
3. Install M8 x 100 bolt (nut on back), M8 x 55 bolt (nut on front), and M8 x 16 bolt finger tight.
4. Tighten five M8 water pump bolts to standard torque (page 683).
5. Install the water pump pulley on the water pump and install four M6 x 12 pulley bolts finger tight.
6. Tighten four M6 x 12 pulley bolts to standard torque (page 683).

#### Water Inlet Elbow

**NOTE:** Water inlet elbow configurations use either three M8 stud bolts or three M8 x 30 bolts to hold the water inlet elbow to the front cover.

1. Install water inlet elbow on the front cover with a new water inlet gasket.
2. Install three M8 water inlet elbow bolts finger tight.
3. Tighten three M8 bolts to standard torque (page 683).

**Water Supply Housing (Freon® Compressor Mount)**

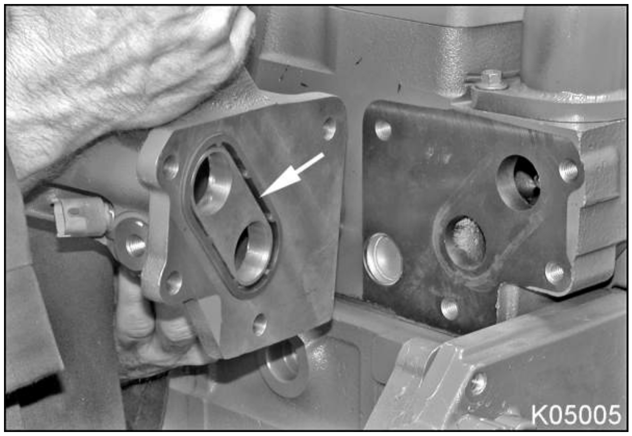


**Figure 337 Water supply housing coolant port seal**

1. Install a new coolant port seal in the water supply housing.

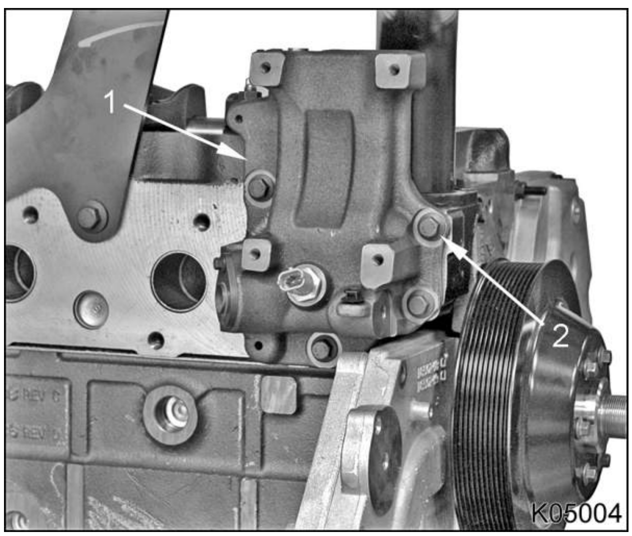


**Figure 338 Water supply housing**

1. Water supply housing (Freon® compressor mount)
2. M10 x 25 bolt (4)

2. Install water supply housing on the cylinder head and install four M10 x 25 bolts finger tight.
3. Tighten four M10 x 25 bolts to standard torque (page 683).

### Alternator Bracket and Automatic Belt Tensioner

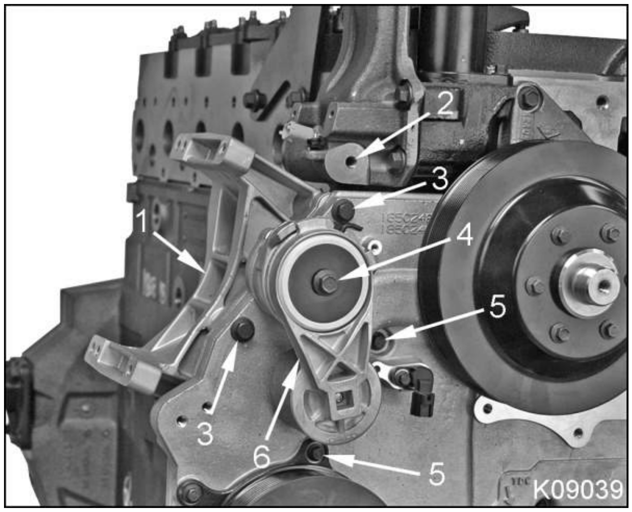


**Figure 339 Alternator bracket, belt tensioner, and single idler pulley location**

1. Alternator bracket
2. M10 x 90 bolt hole (single idler pulley)
3. M10 x 120 bolt (2)
4. M10 x 90 bolt (belt tensioner)
5. M8 x 100 bolt (2)
6. Automatic belt tensioner

1. Position alternator bracket on the back of the front cover.
2. Install two M10 x 120 bolts through the front cover and alternator bracket. Install M10 nuts on back of bolts.
3. Install two M8 x 100 bolts through the front cover and alternator bracket. Install M8 nuts on back bolts.
4. Tighten two M10 x 120 bolts and two M8 x 100 bolts to standard torque (page 683).
5. Install automatic belt tensioner and M10 x 90 bolt on front cover and tighten bolt to special torque (page 415).
6. If required, install single idler pulley on cylinder head and tighten M10 x 90 bolt to standard torque (page 683). (for applications with single Freon® compressor only)

**Secondary Compressor Support, Dual Idler Pulleys, and Idler Mounting Plate**

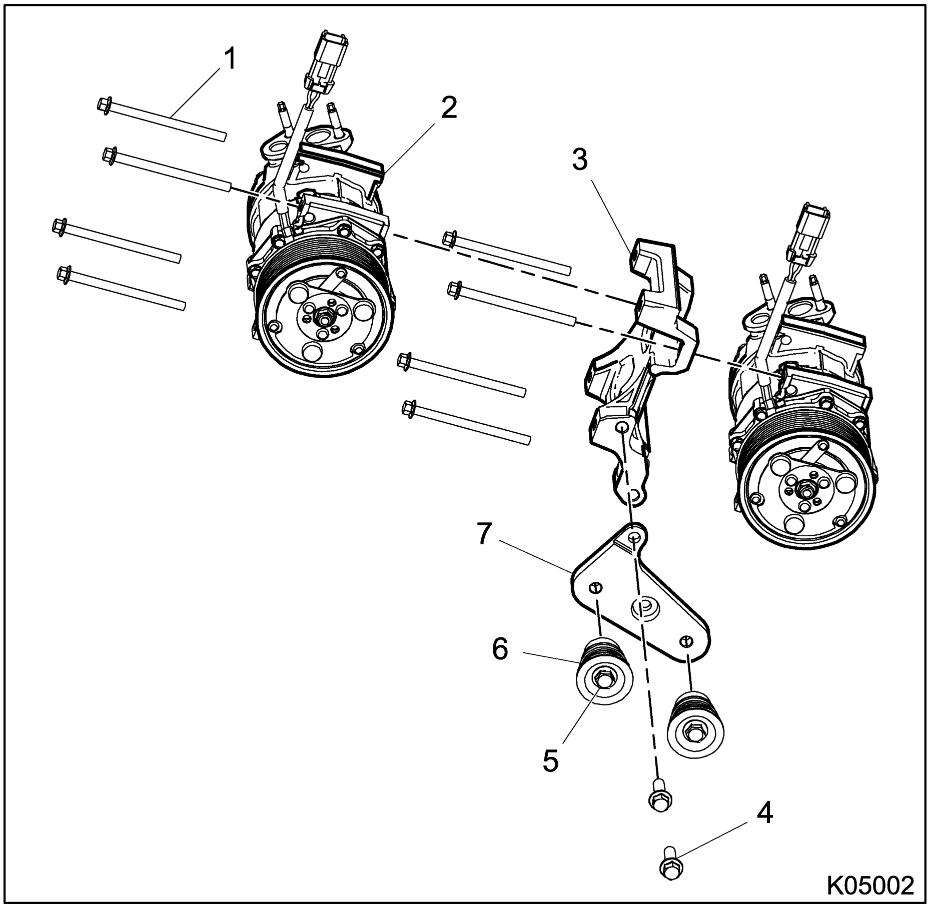


**Figure 340 Dual Freon® compressor mounting**

1. M8 x 110 bolt (8)
2. A/C (Freon®) compressor (2)
3. Secondary Freon® compressor support
4. M10 x 30 bolt (2)
5. M10 x 60 bolt (2)
6. Flat idler pulley assembly (2)
7. Idler mounting plate

**WARNING:**

**To prevent personal injury or death, do not open pressurized Freon® lines.**

**NOTE:** The following procedure only applies to engines equipped with dual A/C (Freon®) compressors.

1. Position inner Freon® compressor on the water supply housing (Freon® compressor mount).
2. Install the secondary Freon® compressor support and four M8 x 110 bolts.
3. Tighten four M8 x 110 bolts to special torque (page 415).
4. Install the idler mounting plate and two M10 x 30 bolts on the secondary Freon® compressor support.
5. Tighten two M10 x 30 bolts to standard torque (page 683).
6. Install two flat idler pulley assemblies on the idler mounting plate and tighten two M10 x 60 bolts to standard torque (page 683).

7. Install outer Freon® compressor and four M8 x 110 bolts.
8. Tighten four M8 x 110 bolts to special torque (page 415).

**Drive Belt**

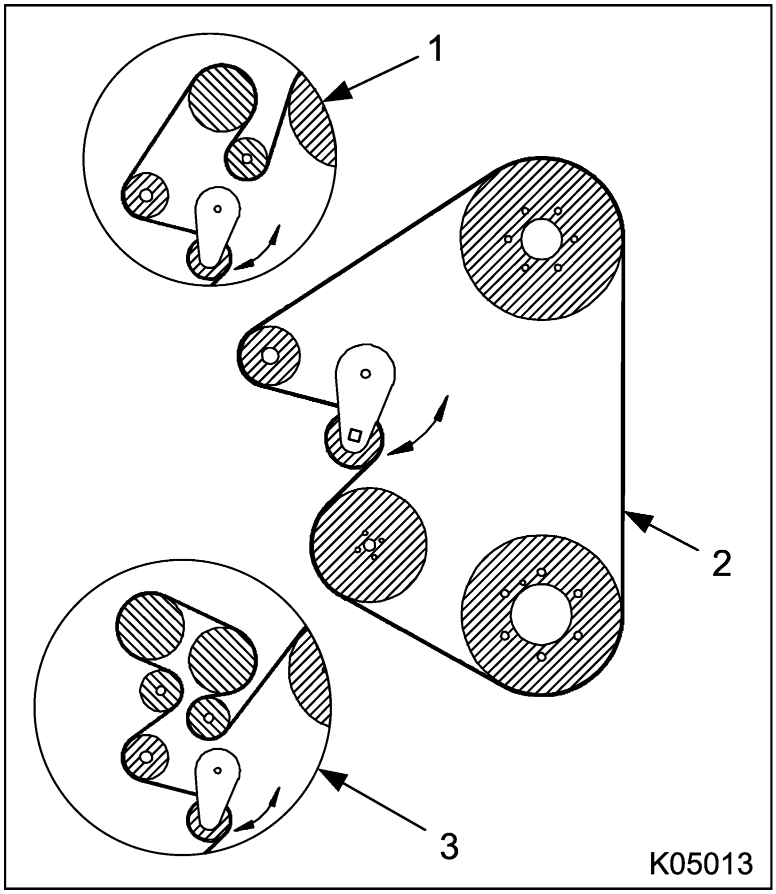


**Figure 341 Drive belt routing**

1. Single Freon® compressor and single idler pulley
2. Without Freon® compressor
3. Dual Freon® compressors and dual idler pulleys

1. Install drive belt on all engine pulleys, except one.
2. Insert 1/2 inch square drive ratchet or breaker bar into belt tensioner square hole.
3. Rotate belt tensioner clockwise.
4. Fit drive belt on last pulley and slowly release belt tensioner.
5. Inspect each pulley to verify drive belt is properly seated.

## Specifications

| | |
|---|---|
| Camshaft gear to upper idler gear backlash | 0.35 mm (0.014 in) |
| High-pressure oil pump end play | 0.127 to 0.457 mm (0.005 to 0.018 in) |
| Lower idler gear to air compressor gear backlash | 0.508 mm (0.020 in) |
| Lower idler gear to crankshaft gear backlash | 0.31 mm (0.012 in) |
| Oil pump end clearance | 0.05 to 0.13 mm (0.002 to 0.005 in) |
| Oil pump side clearance | 0.48 to 0.62 mm (0.019 to 0.024 in) |
| Upper idler gear to high-pressure oil pump gear backlash | 0.48 mm (0.019 in) |
| Upper idler gear to lower idler gear backlash | 0.37 mm (0.015 in) |
| Vibration damper face runout (maximum) | 1.52 mm (0.060 in) |

**Water Pump Pulley Diameters and Spin Ratios**

| Engine | Pulley Diameter | Spin Ratio |
|---|---|---|
| MaxxForce® DT 210 – 230 BHP | 15.54 cm (6.12 in) | 1.39: 1 |
| MaxxForce® DT 245 – 255 BHP | 13.93 cm (5.48 in) | 1.55: 1 |
| MaxxForce® DT 260 – 300 BHP | 12.54 cm (4.94 in) | 1.73: 1 |
| MaxxForce® 9 and 10 | 11.54 cm (4.55 in) | 1.87: 1 |

**Fan Drive Configurations Diameters and Ratios (Spin-on)**

| | | Fan Center Line (CL) | | | |
|---|---|---|---|---|---|
| **Fan Drive Configuration** | **Engine** | **Vertical Above Crank** | **Lateral Offset (toward turbo)** | **Pulley Diameter** | **Fan Drive Ratio** |
| Spin-on 13” fan center | MaxxForce® DT | 330.2 mm (13 in) | 25.4 mm (1 in) | 21.95 cm (8.64 in) | 0.99 : 1 |
| Spin-on 13” fan center | MaxxForce® DT | 330.2 mm (13 in) | 25.4 mm (1 in) | 20.12 cm (7.92 in) | 1.08 : 1 |
| Spin-on 15” fan center | MaxxForce® DT | 381 mm (15 in) | 25.4 mm (1 in) | 21.95 cm (8.64 in) | 0.99 : 1 |
| Spin-on 15” fan center | MaxxForce® 9 and 10 | 381 mm (15 in) | 25.4 mm (1 in) | 18.14 cm (7.14 in) | 1.2 : 1 |
| Spin-on 16.2” fan center | MaxxForce® DT | 411.5 mm (16.2 in) | 95.3 mm (3.75 in) | 21.95 cm (8.64 in) | 0.99 : 1 |
| Spin-on 16.2” fan center | MaxxForce® DT | 411.5 mm (16.2 in) | 95.3 mm (3.75 in) | 20.12 cm (7.92 in) | 1.08 : 1 |
| Spin-on 20” fan center | MaxxForce® DT | 508 mm (20 in) | none | 24.28 cm (9.56 in) | 0.894 : 1 |
| Spin-on 20” fan center | MaxxForce® DT | 508 mm (20 in) | none | 21.95 cm (8.64 in) | 0.99 : 1 |
| Spin-on 20” fan center | MaxxForce® 9 and 10 | 508 mm (20 in) | none | 20.12 cm (7.92 in) | 1.08 : 1 |
| Spin-on 20 ” fan center | MaxxForce® 9 and 10 | 508 mm (20 in) | none | 18.14 cm (7.14 in) | 1.2 : 1 |

**Fan Drive Configurations Diameters and Ratios (DriveMaster®)**

| | | Fan Center Line (CL) | | | |
|---|---|---|---|---|---|
| **Fan Drive Configuration** | **Engine** | **Vertical Above Crank** | **Lateral Offset (toward turbo)** | **Pulley Diameter** | **Fan Drive Ratio** |
| Horton DriveMaster® 13” fan center | MaxxForce® DT | 330.2 mm (13 in) | 25.4 mm (1 in) | 21.95 cm (8.64 in) | 0.99 : 1 |
| Horton DriveMaster® 13” fan center | MaxxForce® DT | 330.2 mm (13 in) | 25.4 mm (1 in) | 20.12 cm (7.92 in) | 1.08 : 1 |
| Horton DriveMaster® 15” fan center | MaxxForce® DT | 381 mm (15 in) | 25.4 mm (1 in) | 21.95 cm (8.64 in) | 0.99 : 1 |
| Horton DriveMaster® 15” fan center | MaxxForce® 9 and 10 | 381 mm (15 in) | 25.4 mm (1 in) | 18.14 cm (7.14 in) | 1.2 : 1 |
| Horton DriveMaster® 16.2” fan center | MaxxForce® DT | 411.5 mm (16.2 in) | 95.3 mm (3.75 in) | 21.95 cm (8.64 in) | 0.99 : 1 |
| Horton DriveMaster® 16.2” fan center | MaxxForce® DT | 411.5 mm (16.2 in) | 95.3 mm (3.75 in) | 20.12 cm (7.92 in) | 1.08 : 1 |
| Horton DriveMaster® 20” fan center | MaxxForce® DT | 508 mm (20 in) | none | 24.28 cm (9.56 in) | 0.894 : 1 |
| Horton DriveMaster® 20” fan center | MaxxForce® DT | 508 mm (20 in) | none | 21.95 cm (8.64 in) | 0.99 : 1 |
| Horton DriveMaster® 20” fan center | MaxxForce® 9 and 10 | 508 mm (20 in) | none | 20.12 cm (7.92 in) | 1.08 : 1 |
| Horton DriveMaster® 20” fan center | MaxxForce® 9 and 10 | 508 mm (20 in) | none | 18.14 cm (7.14 in) | 1.2 : 1 |

## Special Torque

| | |
|---|---|
| Automatic belt tensioner M10 x 90 bolt | 50 N·m (37 lbf·ft) |
| Damper (hub) bolts, M12 x 40 | 163 N·m (120 lbf·ft) Retorque all bolts until no movement |
| Freon® compressor M8 x 110 mounting bolts | 27 N·m (20 lbf·ft) |
| Front engine mounting bracket M18 bolts | 386 N·m (284 lbf·ft) |
| Horton DriveMaster® nut assembly (2 inch) | 177 N·m (130 lbf·ft) |
| Lower idler gear M20 x 70 bolt | 639 N·m (470 lbf·ft) |
| Oil pump and rotor housing M8 bolts | 25 N·m (18 lbf·ft) |
| PTO adapter cover, M10 x 25 bolts (PTO equipped engines only) | 61 N·m (45 lbf·ft) |
| Upper idler gear M16 x 65 bolt | 326 N·m (240 lbf·ft) |
| Vibration damper assembly M10 x 16 mounting bolts | 58 N·m (43 lbf·ft) |

## Special Service Tools

| | |
|---|---|
| Dial indicator set | Obtain locally |
| Fan Wrench (for spin-on fan pulley) | ZTSE43971 |
| Fan Hub Wrench, 2 inch (for DriveMaster nut assembly) | ZTSE43972 |
| Feeler gauge | Obtain locally |
| Front Seal and Wear Sleeve Installer | ZTSE3004B |
| H-bar puller | Obtain locally |
| Heat insulated gloves | Obtain locally |
| Heel bar | Obtain locally |
| Hot plate | Obtain locally |
| Loctite® 569 Hydraulic Sealant | Obtain locally |
| Lower Idler Gear Socket | ZTSE4383 |
| Muffler chisel | Obtain locally |
| Straightedge | Obtain locally |
| Thermo-melt crayon, 100 °C (212 °F) | Obtain locally |
| 16 mm 12 point impact socket | Obtain locally |

# Table of Contents

## Illustrations and Description

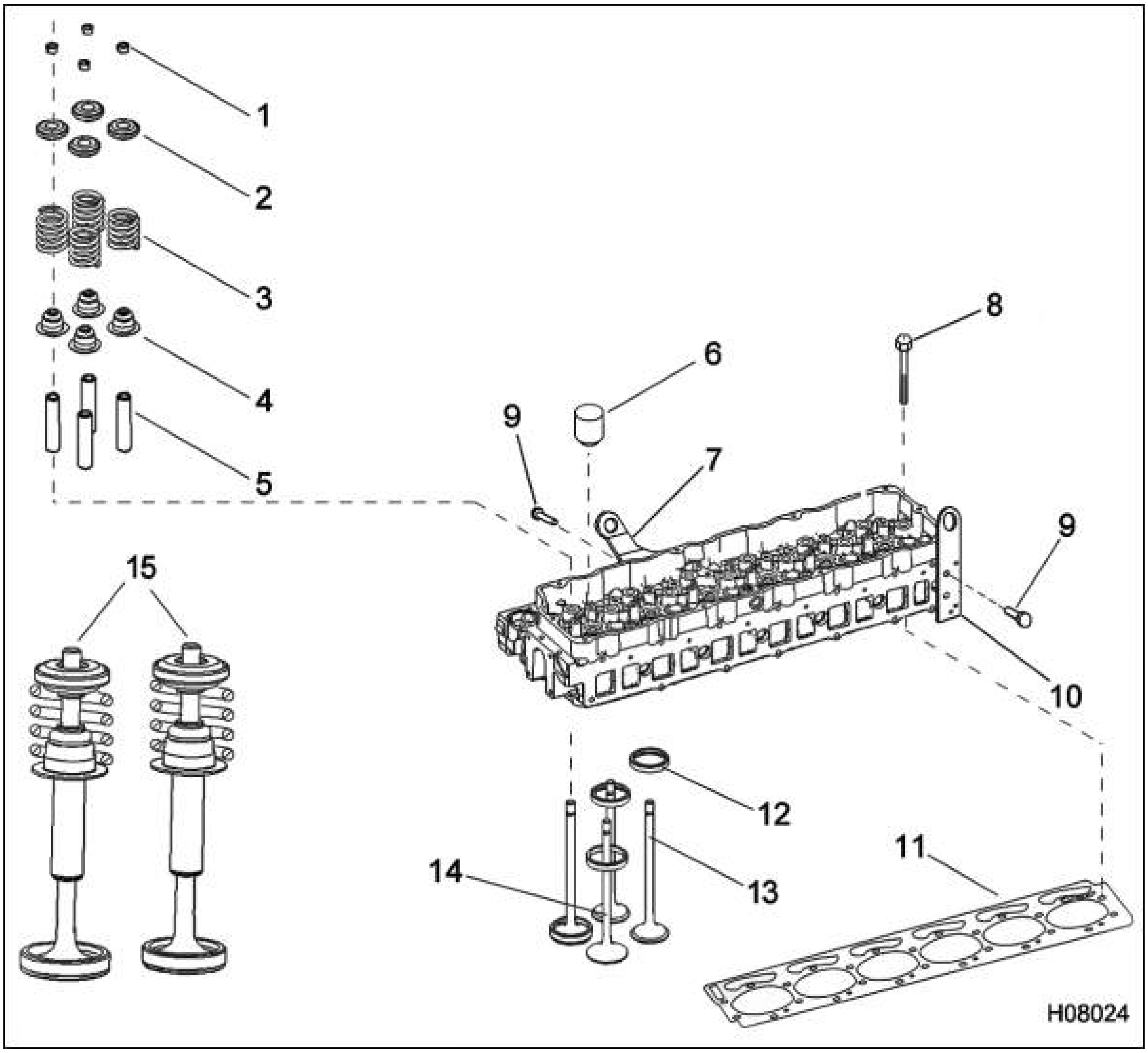


**Figure 342 Cylinder head and valve train components**

1. Valve spring retainer keys (24)
2. Valve rotators or retainers
3. Valve springs (24)
4. Valve stem seals (24)
5. Valve guide inserts (24)
6. Fuel injector sleeve (6)
7. Front lifting eye
8. Cylinder head bolt, (26)
9. M12 x 25 bolt (4)
10. Rear lifting eye
11. Cylinder head gasket
12. Valve seat insert (24)
13. Exhaust valve (12)
14. Intake valve (12)
15. Valve assemblies (24)

MaxxForce® DT, 9, and 10 cylinder heads are cast grey iron and feature four valves per cylinder. A single roller tappet camshaft transfers lifting force through a push rod, rocker arm, and onto a valve bridge where both intake or exhaust valves are opened and closed simultaneously. Four valves per cylinder allows greater air volume to flow into and out of each cylinder than comparably sized engines using only two valves per cylinder.

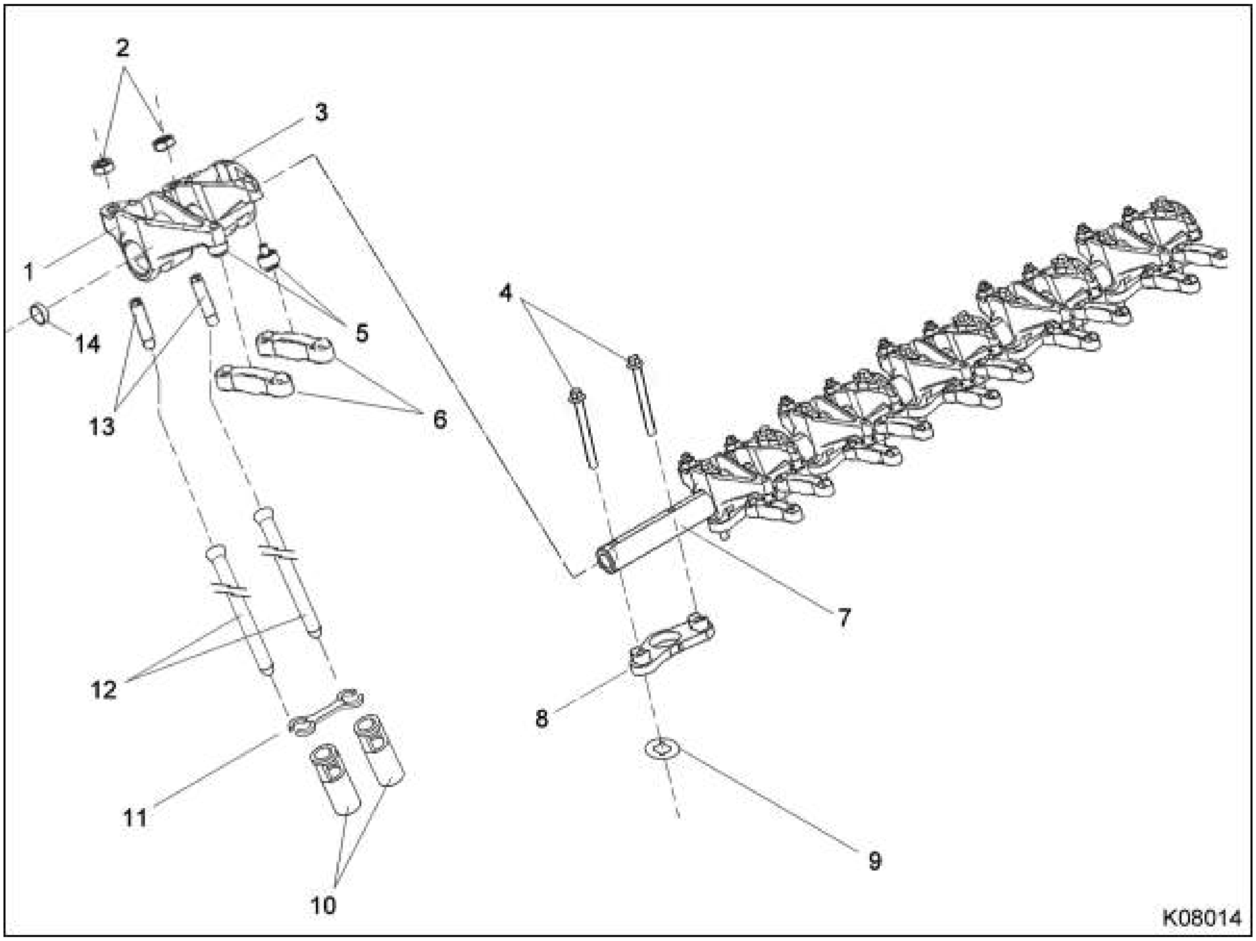


**Figure 343 Valve train components**

1. Intake rocker arm (6)
2. Valve adjusting screw lock nut, M10 (12)
3. Exhaust rocker arm (6)
4. M8 x 60 shaft bolt (12)
5. Pivot foot assembly (12)
6. Valve bridge (12)
7. Rocker arm shaft
8. Rocker shaft support (6)
9. Support washer (assembly aid) (6)
10. Roller tappets (12)
11. Roller tappet guide (6)
12. Push rods (12)
13. Valve lash adjuster screw, M10 (12)
14. Rocker shaft plug (2)

Valve bridges, guides, springs, retainer keys, and valve stem seals are common between the intake and exhaust sides of the cylinder head. Rotators are always used on intake valves and can be used on exhaust valves. Some low horsepower engines have retainers on the exhaust valves.

New valve bridges can be installed on the intake or exhaust valves in either direction, and are also part of compression brake operation.

Valve guides and valve seats are replaceable.

Valve rotators allow valves to rotate for increased valve face life.

Valve stem seals are one piece and have a hardened washer for valve spring seating.

Phosphate coating is used on rocker arms for initial break-in and to extend life.

Pressurized oil is fed from the crankcase through the cylinder head at the cylinder 6 exhaust lower support. Oil then enters the rocker shaft and is distributed to the rocker arms.

## Periodic Service

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

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

### Valve Lash Adjustment

The crankshaft is rotated twice during valve lash adjustment procedure.

- Six valves are adjusted when piston 1 is at Top Dead Center (TDC) compression.
- Six valves are adjusted when piston 6 is at Top Dead Center (TDC) compression.

If engine is equipped with a Diamond Logic® engine brake, corresponding engine brake actuator lash can be adjusted when piston 1 and 6 are at TDC compression.

**NOTE:** Engine brake lash adjustments are not required when adjusting valve lash.

1. Remove the valve cover (page 427) and EGR tube support bracket (page 176).
2. Turn the crankshaft in the direction of engine rotation to remove gear lash. Position piston 1 at TDC compression by observing cylinder 6 rocker arms in overlap as the vibration damper timing mark approaches the TDC mark on the front cover. Cylinder 6 exhaust valve will be closing (coming up) and the intake valve will be starting to open (going down).
3. If piston 1 is at TDC compression, see Chart 3 (page 424) and do steps 4, 5, and 6.

**Chart 3**

| Valve and brake lash adjustments (inches) with piston 1 at TDC compression (Chart 3) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cylinder 1 | | Cylinder 2 | | Cylinder 3 | | Cylinder 4 | | Cylinder 5 | | Cylinder 6 | |
| intake 1 | exhaust 2 | intake 3 | exhaust 4 | intake 5 | exhaust 6 | intake 7 | exhaust 8 | intake 9 | exhaust 10 | intake 11 | exhaust 12 |
| 0.019 | 0.019 | 0.019 | | | 0.019 | 0.019 | | | 0.019 | | |
| Brake 0.019 | | | | Brake 0.019 | | | | Brake 0.019 | | | |

**Valve and brake lash adjustments with piston 1 at TDC compression**

**Chart 4**

| Valve and brake lash adjustments (inches) with piston 6 at TDC compression (Chart 4) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cylinder 1 | | Cylinder 2 | | Cylinder 3 | | Cylinder 4 | | Cylinder 5 | | Cylinder 6 | |
| intake 1 | exhaust 2 | intake 3 | exhaust 4 | intake 5 | exhaust 6 | intake 7 | exhaust 8 | intake 9 | exhaust 10 | intake 11 | exhaust 12 |
| | | | 0.019 | 0.019 | | | 0.019 | 0.019 | | 0.019 | 0.019 |
| | | Brake 0.019 | | | | Brake 0.019 | | | | Brake 0.019 | |

**Valve and brake lash adjustments with piston 6 at TDC compression**

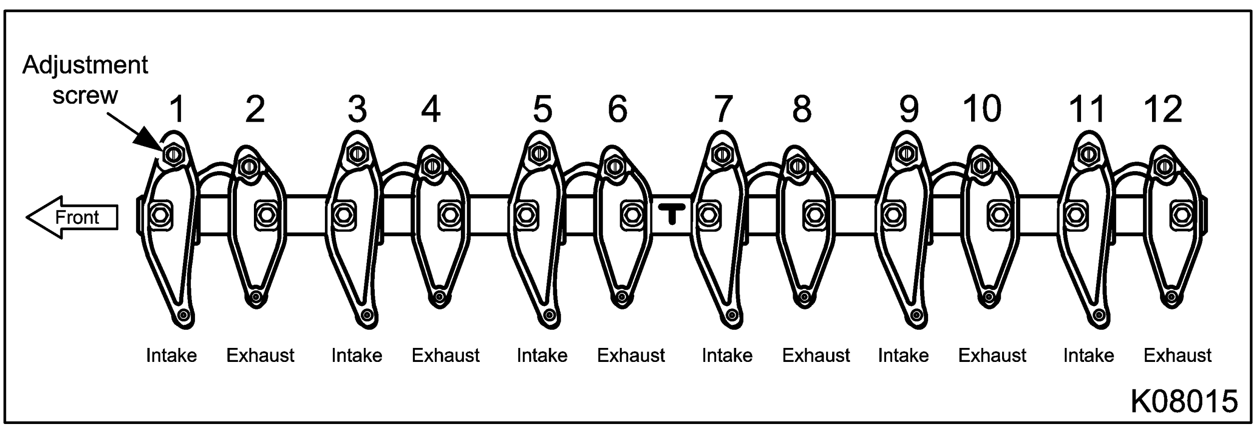


**Figure 344 Valve lash adjustment**

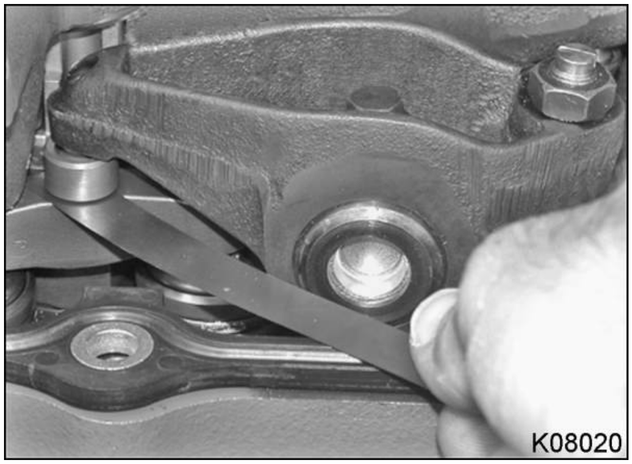


**Figure 345 Valve lash measurement**

4. Measure valve lash when the engine is cold. Put a 0.48 mm (0.019 in) feeler gauge (page 485) between the rocker arm pivot foot and the valve bridge. A light drag should be felt on the feeler gauge. If adjustment is required, loosen lock nut and turn valve adjustment screw until a light drag is felt.

5. Once valve lash is set, tighten valve adjustment screw lock nut to special torque (page 485) and remove feeler gauge. Recheck lash, a light drag should be felt on the feeler gauge. If drag is too tight or loose, repeat steps 4 and 5.

   If engine is equipped with a Diamond Logic® engine brake, corresponding brake actuator lash can be adjusted before rotating crankshaft.

6. Turn crankshaft 360° in the direction of engine rotation to remove gear lash. Position piston 6 at TDC compression by observing cylinder 1 rocker arms in overlap as the vibration damper timing mark approaches the TDC mark on the front cover.

7. If piston 6 is at TDC compression, see Chart 4 (page 424) and do steps 4, 5, and 6.

# Removal

**Valve Cover**

**NOTE:** If the valve cover is removed for any reason and engine is equipped with a Diamond Logic® engine brake, verify six brake piston locknuts are tight. If loose, check brake lash (page 269).

1. Disconnect the crankcase ventilation breather inlet tube (page 595) from the valve cover.

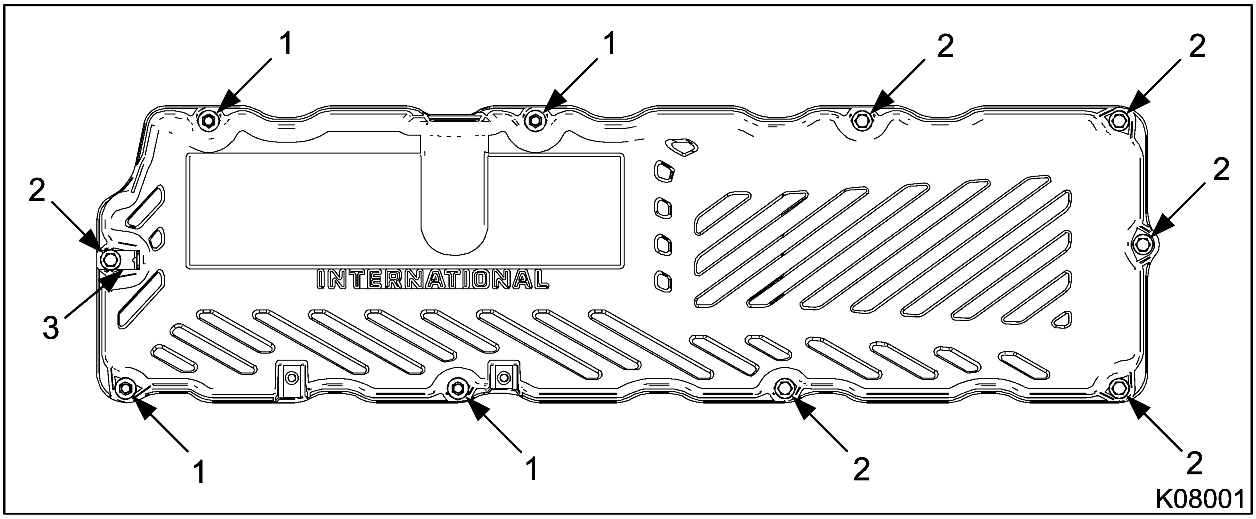


**Figure 346 Valve cover**

1. M8 x 80 stud bolt (4)
2. M8 x 80 bolt (6)
3. Harness mounting bracket

2. Remove four M8 x 80 stud bolts.
3. Remove six M8 x 80 bolts and harness mounting bracket.
4. Lift valve cover off of cylinder head.

**Rocker Arm Assembly**

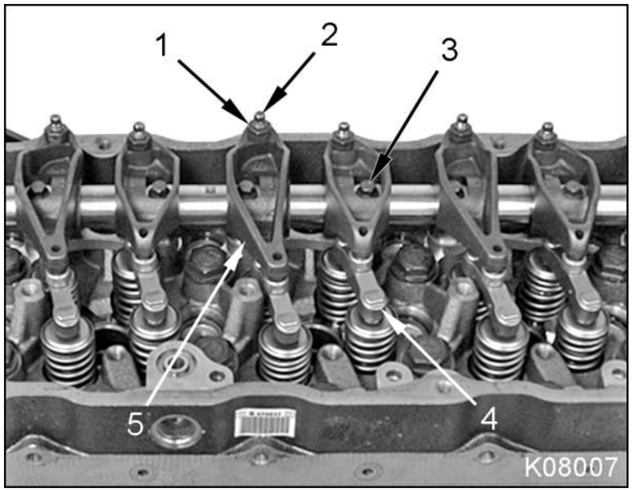


**Figure 347 Valve train components**

1. Valve adjusting screw lock nut (12)
2. Adjuster screw (12)
3. Rocker shaft bolt (12)
4. Valve bridge (12)
5. Rocker arm (12)

1. Loosen 12 adjuster screws and lock nuts. This will help prevent valve train damage and false torque readings during installation.
2. Loosen, but do not remove, 12 rocker shaft bolts.
3. Push down on rocker shaft bolts. This will latch support washers onto shaft bolts and keep rocker shaft supports from falling off.
4. Lift rocker arm shaft assembly up and off cylinder head.

   **NOTE:** There are six support washers, one for each rocker shaft support, for assembly.


**Figure 348 Valve bridge removal**

**CAUTION:**

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

5. Mark all valve bridges for installation in original location and orientation.
6. Remove valve bridges.

**NOTE:** If required, measure camshaft lobe lift (page 434) before removing push rods or cylinder head.

### Rocker Arms

**CAUTION:**

**To prevent engine damage, mark rocker arms and rocker shaft supports for installation in original locations.**

1. Mark each rocker arm for installation in original location.
2. Remove 12 rocker shaft bolts.

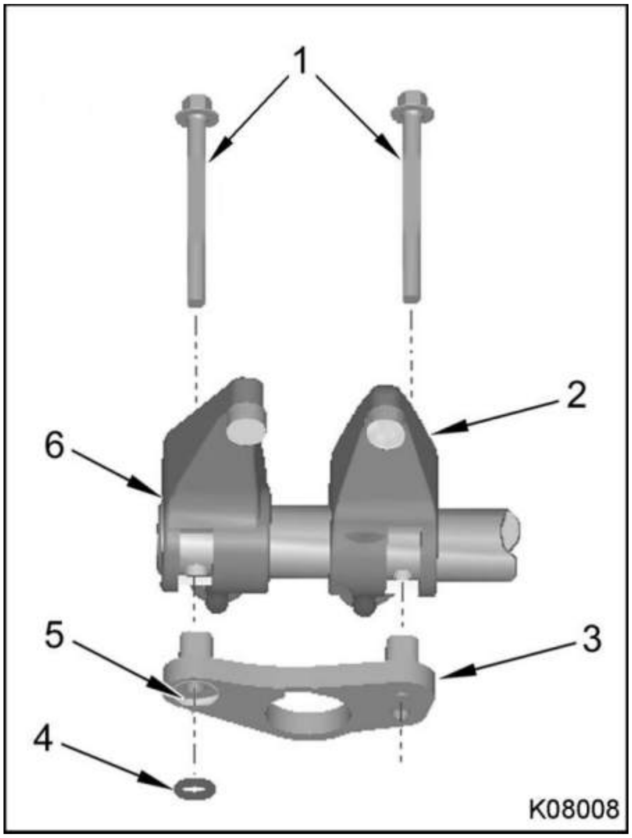


**Figure 349 Rocker arm components**

1. M8 x 60 shaft bolt
2. Exhaust rocker arm
3. Rocker arm shaft support
4. Support washer (assembly aid)
5. Machined recess
6. Intake rocker arm

3. Slide rocker arms off rocker arm shaft.
4. Remove and tag each push rod with cylinder number and valve association (intake or exhaust).

### Cylinder Head

**NOTE:** If required, measure camshaft lobe lift (page 434) before removing push rods or cylinder head.

1. Drain engine coolant (page 79).
2. Remove the oil level gauge (page 596) and crankcase breather inlet tube (page 595).
3. Remove the fuel filter header assembly (page 234).
4. Remove the engine sensor wiring harness (page 120), injector wiring harness (page 122), intake air heater relay assembly (page 125), and UVC harness (page 129).
5. Remove the turbocharger oil supply tube (page 159) and VGT assembly (page 160).
6. Remove the EGR coolant supply tube (page 173), EGR tube assembly (page 174), coolant crossover tube and support bracket (page 176), exhaust side EGR cooler and bracket (page 178), EGR coolant return tube (page 180), EGR valve manifold assembly (page 181), EGR distribution tube (page 183), and intake side EGR cooler and bracket.
7. Remove the exhaust manifold (page 205), intake throttle assembly (page 207), EGR and inlet air mixer duct, and intake manifold (page 209).

**CAUTION:**

**To prevent engine damage, remove fuel injectors before removing the cylinder head.**

8. Remove the high-pressure oil hose (page 235), high-pressure oil manifold (page 239), and fuel injectors (page 241).
9. Remove the water supply housing (page 356), water outlet tube, and fan drive assembly (page 359).

10. Remove 26 M15 x 180 cylinder head mounting bolts.

**WARNING:**

**To prevent personal injury or death, use a hoist rated for the weight of the cylinder head and follow the manufacturer's operation and safety instructions. Attach safety lifting hooks to the cylinder head lifting eyes.**

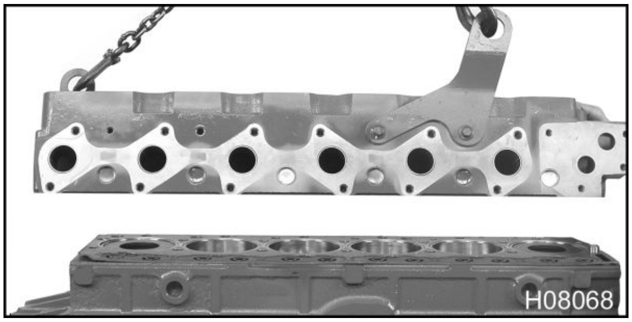


**Figure 350 Cylinder head and crankcase**

11. Attach appropriate hoist and lifting hooks to cylinder head lifting eyes.
12. Carefully lift cylinder head off crankcase.

**NOTE:** Place cylinder head on wood blocks to protect valves and bottom deck surface.

13. Place cylinder head on a workbench.
14. Remove four M12 x 25 bolts and both lifting eyes from cylinder head.


**Figure 351 Cylinder head gasket**

15. Remove cylinder head gasket from crankcase and discard.

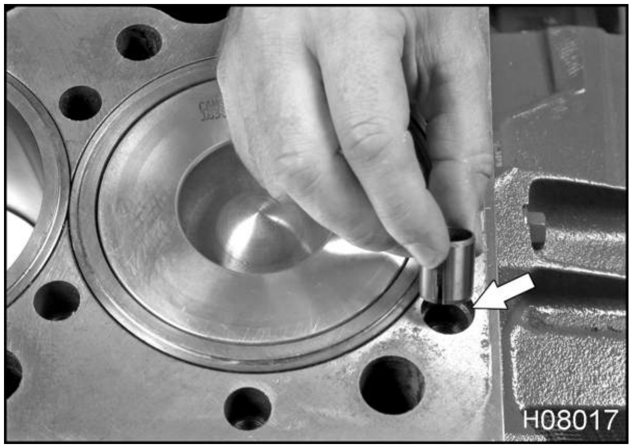


**Figure 352 Cylinder head alignment dowels**

16. Remove two cylinder head alignment dowels from the top of crankcase, if required.

**Roller Tappets**

**Figure 353 Roller tappets and guide**

Remove each roller tappet and guide from tappet bore and mark with cylinder number, valve association (intake or exhaust), and roller orientation.

## Cleaning, Inspection, Measurement, and Testing

**WARNING:**

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

### Measure Camshaft Lobe Lift

**NOTE:** If a complete engine overhaul is scheduled, camshaft wear can be accurately determined by measuring with a micrometer after the camshaft is removed. See Measure Camshaft Lobes and Journals (page 615). If this is not a complete engine overhaul, camshaft lobe lift can be measured using the following procedure.

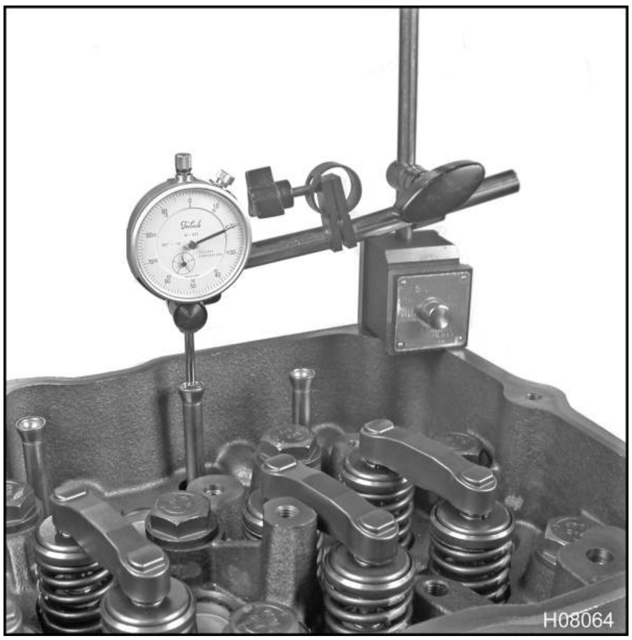


**Figure 354 Dial indicator with magnetic base**

1. Mount a dial indicator set (page 485) on the cylinder head.
2. Place dial indicator tip on top of push rod and rotate engine until push rod is at its lowest point of travel (base circle), then “zero” indicator.
3. Rotate the crankshaft and bring push rod to its highest point of travel. Record readings.
4. Repeat steps 2 and 3 for all twelve camshaft lobes.
5. Compare readings to camshaft lobe lift Specifications (page 483).

**Clean Cylinder Head**

**CAUTION:**

**To prevent engine damage, leave valves installed in cylinder head to protect valve seats during cleaning.**

1. Remove deposits and gasket material from the cylinder head gasket surface using a rotary wire brush or sanding block with mineral spirits.
2. Clean all cylinder head mounting bolt holes using an appropriately sized brush.

**CAUTION:**

**To prevent engine damage, clean or repair dirty or damaged bolt threads which may cause binding and false torque readings.**

3. Clean threads of all cylinder head mounting bolts.
4. Wash rocker arm assemblies, roller tappets, and push rods in a suitable solvent and dry thoroughly. Replace any bolts that have damaged threads.

**CAUTION:**

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

**Clean and Inspect Push Rods**

1. Clean push rods using a suitable solvent and dry using filtered compressed air.
2. Inspect push rods for wear at both ends. Replace if required.

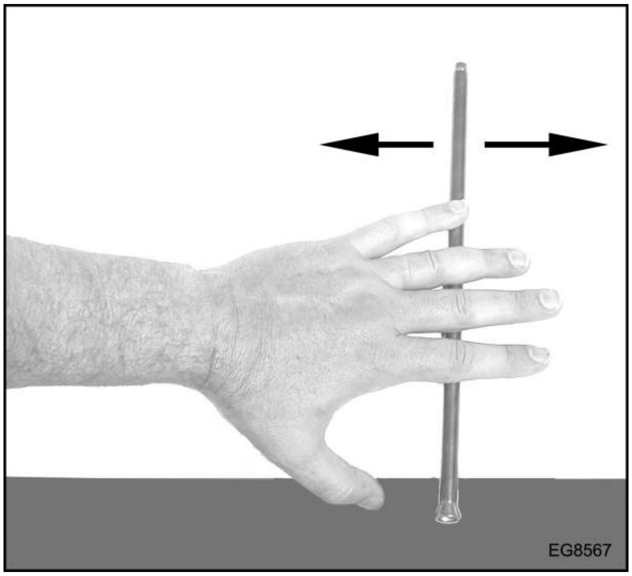


**Figure 355 Inspect push rods for straightness**

3. Inspect push rods for straightness by rolling on a flat surface with the cup end hanging over an edge.
4. Measure push rod runout with a feeler gauge (page 485) between the flat surface and push rod.
5. If Specifications (page 483) are exceeded, replace push rod.

**Measure Rocker Shaft**

**CAUTION:**

**To prevent engine damage, if replacing the rocker arm shaft, all rocker arms must be replaced. Reusing rocker arms on a new shaft will not allow proper break-in, causing premature failure.**

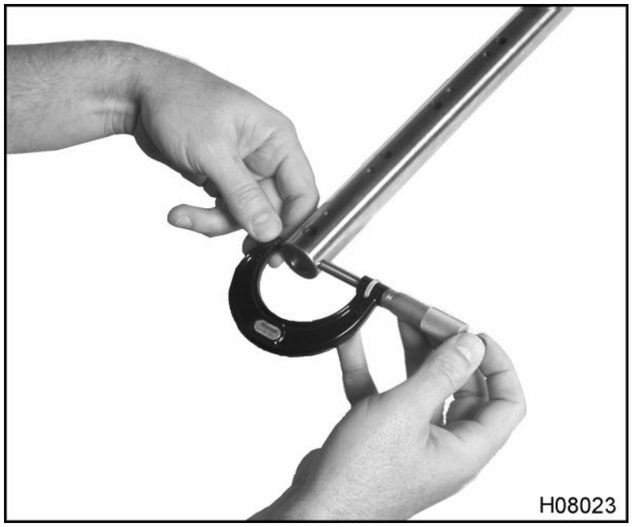


**Figure 356 Rocker arm shaft measurement**

1. Inspect rocker shaft for scoring, pitting, and wear. Replace rocker arm shaft and all of the rocker arms if required.

**NOTE:** It is normal to see slight polishing at rocker arm contact areas.

2. Measure a non-contact area of the rocker arm shaft using an outside micrometer (page 485). This dimension will be used as a baseline for shaft diameter.
3. Measure each of the 12 rocker arm contact areas of the rocker arm shaft with a micrometer. If the difference between the baseline measurement and any of the contact area measurements is greater than 0.03 mm (0.001 in), replace the rocker shaft and all rocker arms.
4. Clean oil supply holes with a small wire or another suitable tool.
5. Inspect cup plugs at each end of the rocker arm shaft. Do not disturb the cup plugs unless they are damaged. If replacement is required, pry out plugs and press in new plugs.

### Inspect and Measure Rocker Arms

1. Inspect rocker arms for scoring, pitting, or signs of excessive wear. If the bore has visible damage, replace the rocker arm. Inspect the lower half of the rocker arm, significant wear can occur at this location. If the phosphate coating is worn off the rocker arms, they may only be reused on the original rocker arm shaft in their original locations.

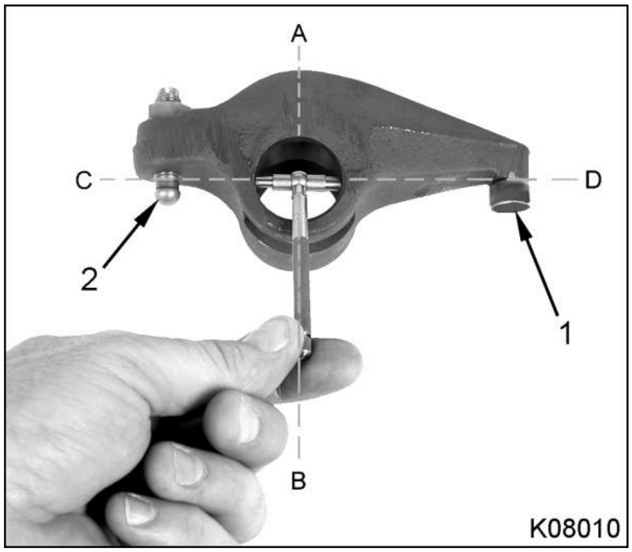


**Figure 357 Rocker arm bore**

1. Pivot foot assembly
2. Valve lash adjuster screw

**NOTE:** The black phosphate coating on rocker arms provides break-in lubricant between the rocker shaft and rocker arm bore. It is normal for the black phosphate coatings to wear off the bottom of the lever arm in the shaft and bore contact area. Rocker arms must be labeled and installed in their original locations to maintain proper wear patterns.

2. Use a telescoping gauge and outside micrometer (page 485) to measure rocker arm bore diameter at two locations. Measure diameter at A-B and C-D. If difference between diameters is greater than or equal to 0.03 mm (0.001 in), replace rocker arm.

3. Inspect twelve rocker arm pivot foot assemblies for scoring, pitting, or signs of excessive wear. Replace rocker arms if necessary.
4. Inspect valve lash adjuster screw for wear. Replace adjuster screw if excessively worn.

**Measure Cylinder Head Warpage**

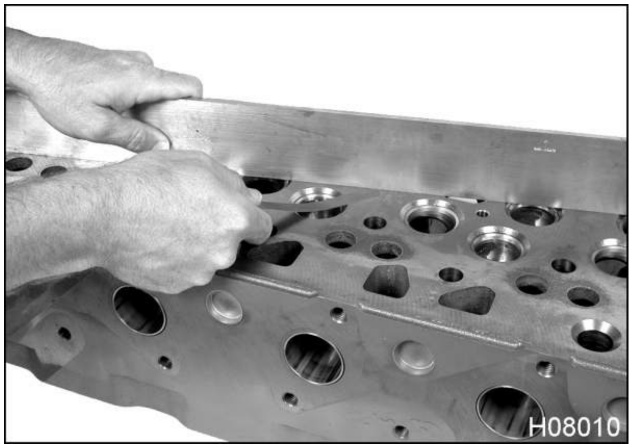


**Figure 358 Cylinder head warpage measurement**

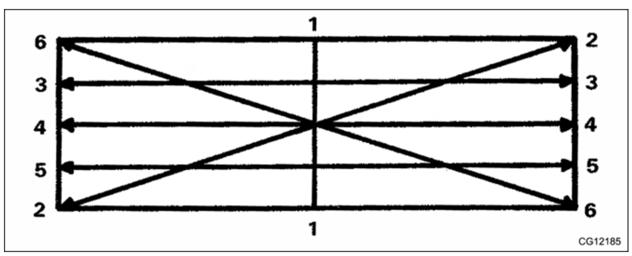


**Figure 359 Cylinder head warpage measurement pattern**

Use a straightedge and feeler gauge (page 485) to measure cylinder head gasket surface for warpage. If warpage exceeds cylinder head gasket surface flatness Specifications (page 483), measure cylinder head thickness.

### Measure Cylinder Head Thickness

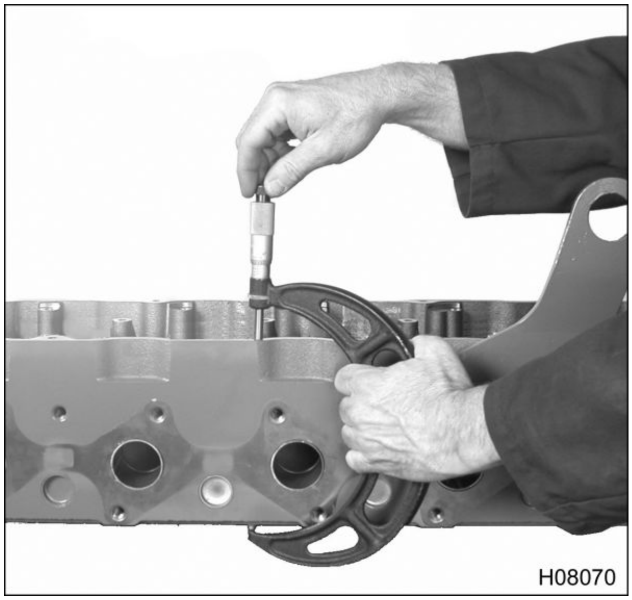


**Figure 360 Cylinder head thickness measurement**

Use a 6 to 7 inch micrometer to measure cylinder head thickness at six locations (four corners and two center points). All Cylinder head thickness measurements must equal or exceed minimum Specification (page 483) after resurfacing. Replace cylinder head if under minimum specification.

### Measure Valve Seat Leakage

**NOTE:** This test does not check condition of valve guides or valve stem-to-guide clearance.

1. Position cylinder head on wood blocks with gasket surface facing down.
2. Squirt mineral spirits in the intake and exhaust valve ports and wait 5 minutes.
3. Use an inspection mirror to inspect valve seat area for leakage of mineral spirits past valve seats.

   **NOTE:** If leakage occurs, valves must be reconditioned.

**Inspect Cylinder Head for Cracks**

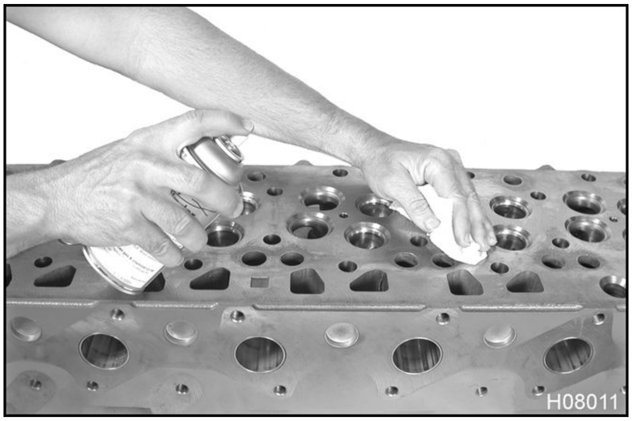


**Figure 361 Spray cleaner on cylinder head**

**NOTE:** Cylinder head crack inspection can be performed with or without valves installed.

1. Spray cleaner, from dye penetrant kit (page 485), on cylinder head gasket surface and wipe dry.

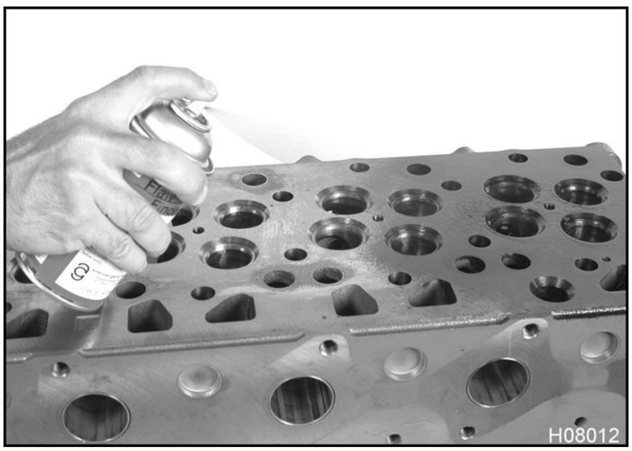


**Figure 362 Spray dye penetrant on cylinder head**

2. Spray dye penetrant, from dye penetrant kit, on cylinder head gasket surface. Leave dye penetrant on for 1 to 10 minutes.

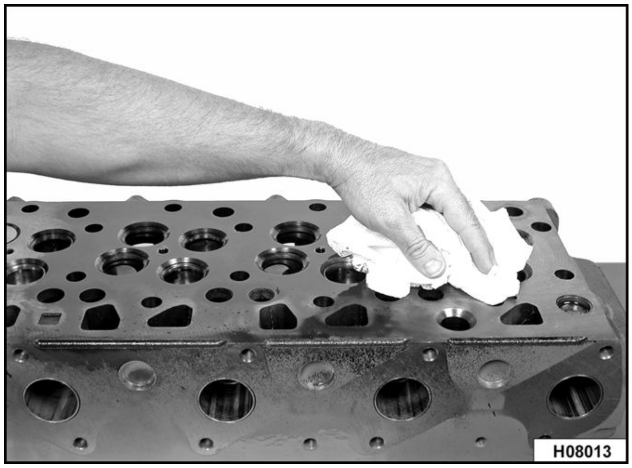


**Figure 363 Wipe dye penetrant off cylinder head**

3. Wipe off dye penetrant after 1 to 10 minutes. Dye will remain in any cracks in the cylinder head.

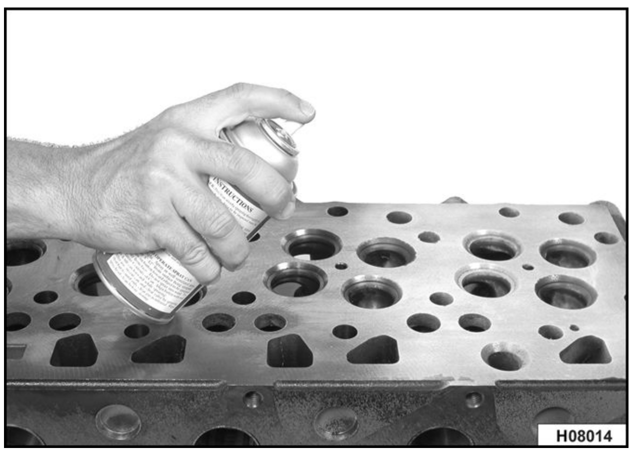


**Figure 364 Spray developer on cylinder head**

4. Spray developer, from dye penetrant kit, on cylinder head gasket surface. Allow developer to dry for 5 to 15 minutes.

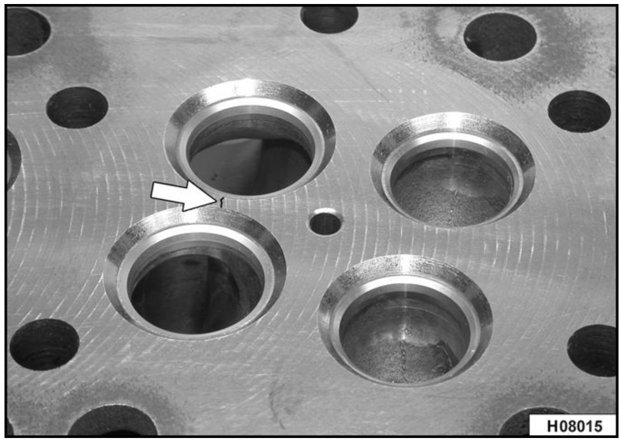


**Figure 365 Crack in cylinder head**

**NOTE:** Any cracks will show up as purple lines against the white developer. If any cracks are present, replace cylinder head.

### Cylinder Head Pressure Test

**NOTE:** Pressure testing the cylinder head will reveal cracks in ports or sleeve leakage which can not be seen using dye penetrant.

1. Remove valves from cylinder head (page 446).
2. Install fuel injectors (page 247) in cylinder head injector bores.

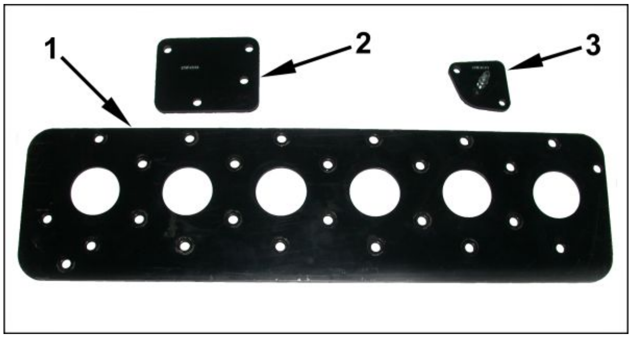


**Figure 366 Cylinder head pressure test tools**

1. Cylinder Head Test Plate
2. Water Supply Housing Pressure Adapter
3. Thermostat Opening Pressure Adapter

3. Pressure test cylinder head using Cylinder Head Test Plate, Water Supply Housing Pressure Adapter, Thermostat Opening Pressure Adapter, and a pressure regulator (page 485).

4. Attach Cylinder Head Test Plate to cylinder head gasket surface using mounting bolts and nuts supplied with kit.
5. Attach Water Supply Housing Pressure Adaptor to cylinder head and secure with mounting bolts.
6. Remove thermostat and fill cylinder head with hot water.
7. Attach Thermostat Opening Pressure Adapter to cylinder head and secure with mounting bolts.
8. Attach compressed air hose and pressure regulator to hose fitting on Thermostat Opening Pressure Adapter.
9. Apply 124 to 138 kPa (18 to 20 psi) air pressure and inspect cylinder head for leaks. Check the following:
    - Fuel injector nozzle sleeve areas
    - Valve ports
    - Upper deck
    - Lower deck

If leakage is observed from any fuel injector nozzle sleeves, replace injector sleeves and pressure test cylinder head again. If cylinder head leakage is observed replace the cylinder head.

# Reconditioning

### Remove Valves from Cylinder Head

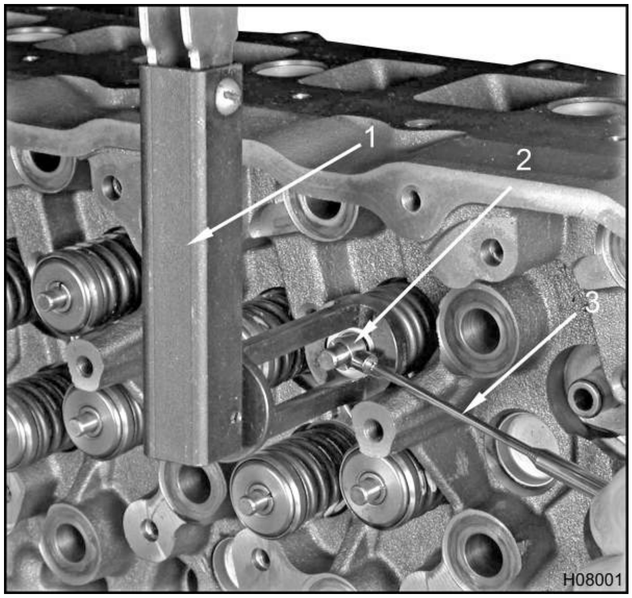


**Figure 367 Valve spring retainer key removal**

1. Valve Spring Compressor
2. Valve spring retainer key
3. Magnet

**WARNING:**

**To prevent personal injury or death, wear safety glasses when removing valves or valve spring retainer keys.**

1. Install a Valve Spring Compressor (page 485) over the valve and compress the valve spring.
2. Use a magnet to remove valve spring retainer keys.

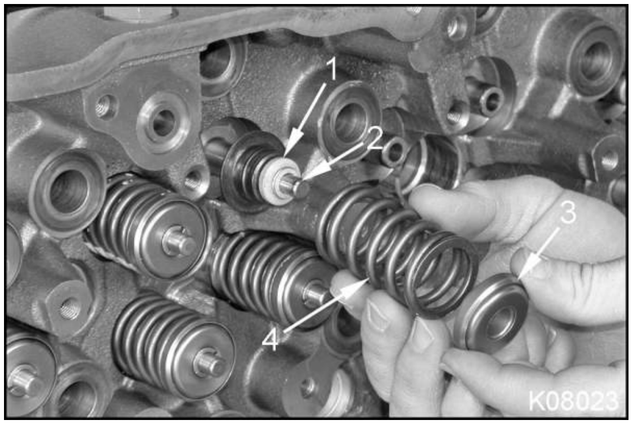


**Figure 368 Valve rotator, spring, and valve stem seal**

1. Valve stem seal
2. Valve stem
3. Valve rotator or retainer (typical)
4. Valve spring

3. Release Valve Spring Compressor and remove valve rotator or retainer and valve spring.
4. Remove and discard valve stem seal.
5. Remove valve from the cylinder head.
6. Repeat steps 1 through 5 for all 24 valves.

### Inspect and Measure Valve Guides

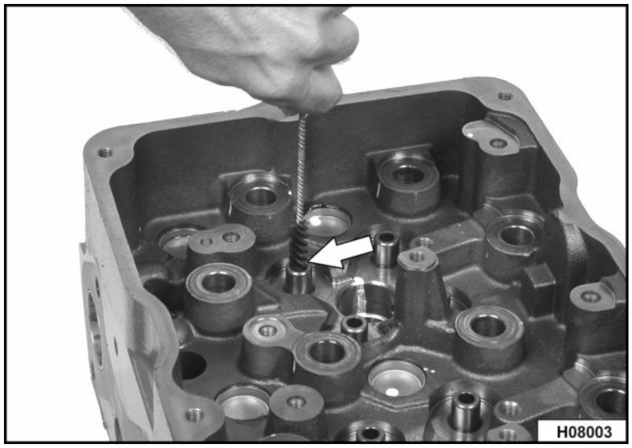


**Figure 369 Clean valve guides**

1. Clean valve guides with soap, water, and a nylon brush.
2. Position an inspection light at the bottom of valve guide bores. Inspect bores for burning or cracks. Replace any damaged valve guides.


**Figure 370 Measure valve guide with ball gauge**


**Figure 371 Measure Ball gauge with micrometer**

3. Measure inside diameter of each valve guide with a ball gauge or small hole gauge set and an outside micrometer (page 485).

   If valve guide bore, taper, or out of round exceeds Specifications (page 483), replace the valve guide.

4. Measure valve guides within 0.64 mm (0.025 in) of each end and 90 degrees from crankshaft center line. Record measurements. Determine valve stem-to-guide running clearance after doing “Inspect and Measure Valves” procedure (page 451).

**Replace Valve Guides**

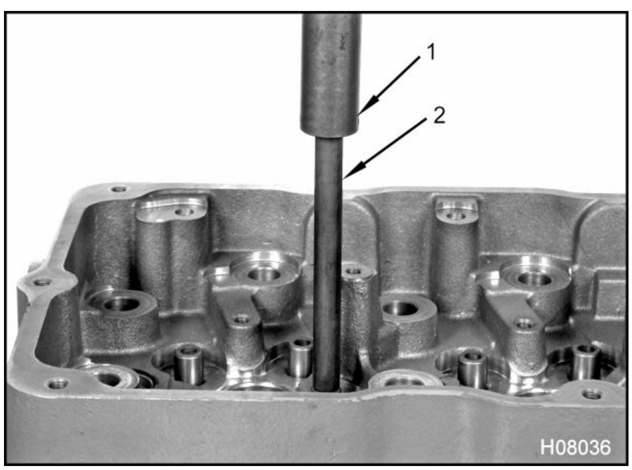


**Figure 372 Press out valve guide insert**

1. Press ram
2. Valve Guide Remover

**NOTE:** Replace Valve guides if damaged or out of specifications.

**CAUTION:**

**To prevent engine damage, do not use a hammer or other improper tool to remove or install valve guides.**

1. Secure cylinder head on a press table with the gasket surface down.
2. Insert Valve Guide Remover (page 485) in the valve guide from the top side of the cylinder head.
3. Align Valve Guide Remover and valve guide to be replaced with center of press ram and press out valve guide insert.

**NOTE:** Chilling valve guide inserts may help installation.

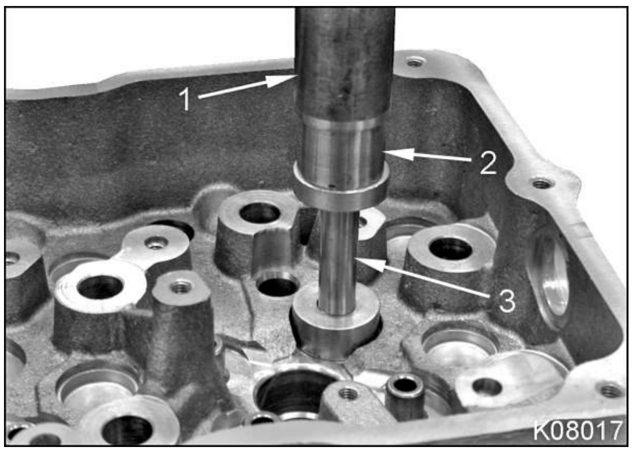


**Figure 373 Press in valve guide insert**

1. Press ram
2. Valve Guide Installer
3. Valve guide insert

4. Lubricate each new valve guide insert with clean engine oil.
5. Center valve guide insert and Valve Guide Installer (page 485) under press ram and install valve guide insert until installer bottoms out against cylinder head.

**NOTE:** Do not ream inside diameter of valve guide after installation. Service valve guides are finish reamed.

6. After installing valve guide insert, debur valve guide with Valve Guide Deburring Tool (page 485).

### Inspect and Measure Valves

1. Remove carbon deposits from valve stems and valve heads.
2. Inspect each valve for burn marks, warpage, scuffing, and bending. Replace any damaged valves.
3. Inspect valve stem tip for scoring, pitting, or signs of excessive wear. Reface valve stem tip (page 455) or replace valve if required.

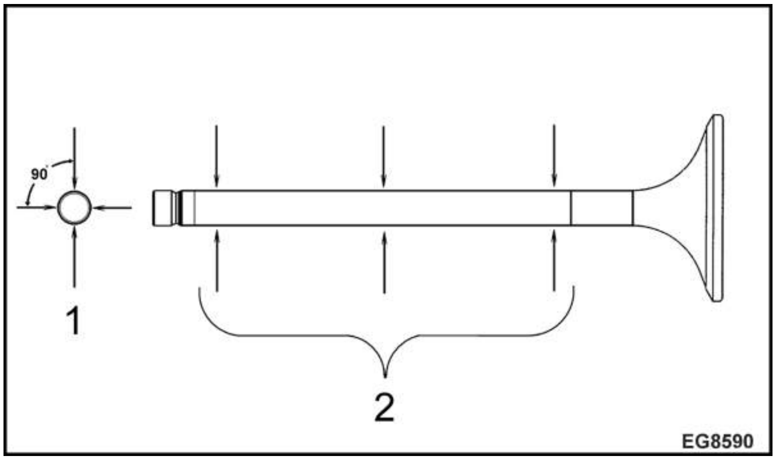


**Figure 374 Valve stem measurement points**

1. Two measurements 90 degrees apart
2. Three valve stem diameter measurement locations

4. Measure valve stem diameter with a micrometer (page 485) at three locations. At each location, take two measurements 90 degrees apart. Average the two measurements from each location.

   If the average of measurements at any of the three locations is not within valve stem diameter Specification (page 483), replace that valve.
5. Determine valve stem-to-guide running clearance using the valve stem diameter measurements above and valve guide inside diameter measurements (page 448). Subtract the average valve stem diameter from the average valve guide inside diameter.

**NOTE:** Valve Stem-to-guide Running Clearance = Valve Guide Inside Diameter – Valve Stem Diameter

6. Replace valve or valve guide if not within Specifications (page 483).

**Reface Valves**

**Valve Face**

**NOTE:** If valves are in good condition and within specifications, they may be refaced to specified angles.

**CAUTION:**

**To prevent engine damage, maintain minimum valve face margin across the entire valve face. An insufficient valve face margin will not allow proper heat dissipation, causing that valve to warp or break.**


**Figure 375 Grind valve face**

**NOTE:** Make sure there is sufficient coolant in the valve grinding machine reservoir. Turn coolant pump on before grinding.

1. Dress the grinder cutting stone using the dressing stud attachment.

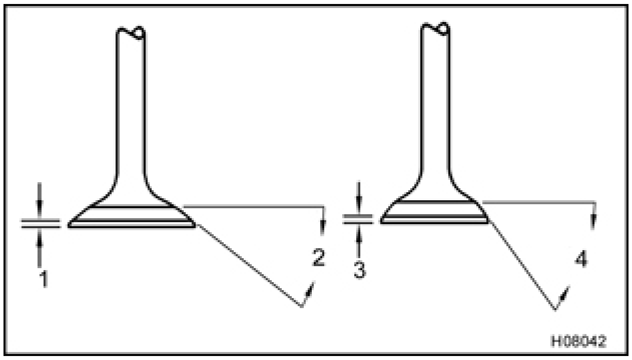


**Figure 376 Valve face angles**

1. Intake margin
2. Intake valve angle
3. Exhaust margin
4. Exhaust valve angle

**NOTE:** Intake valves and exhaust valves have different valve face margins.

2. Install valve in grinder and set grinder to specified intake or exhaust valve face angle (page 483).
3. Turn on coolant and grinder.

**NOTE:** Removal of too much material may reduce valve face margin below minimum specifications.

4. Grind valve face. Only remove the minimum amount of material necessary.

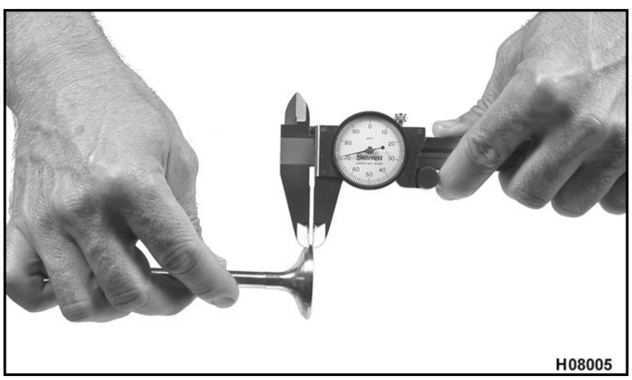


**Figure 377 Valve face margin measurement**

5. Measure valve face margin at four locations with a vernier caliper (page 485). If any measurements are less than minimum Specification (page 483), replace valve.

**Reface Valve Stem Tip**

**CAUTION:**

**To prevent engine damage, leave sufficient material on the tip of the valve stem so the valve bridge does not contact the valve retainer keys or valve rotator during operation. Maintain a minimum of 1.524 mm (0.060 in) gap between the valve bridge and valve spring retainer keys.**

1. Dress the cutting stone using the dressing stud attachment on the grinder.

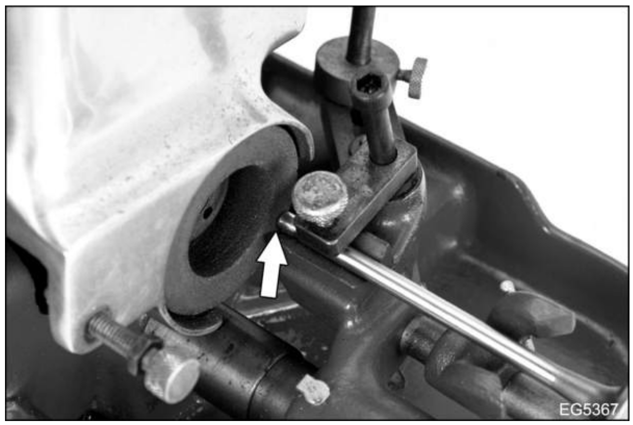


**Figure 378 Valve stem grinding**

2. Install valve in grinder so the tip of the valve stem is close to the grinding stone.
3. Briefly touch the tip of the valve stem to the grinding stone. Only remove the minimum amount of material necessary.

**Inspect Valve Face-to-seat Contact**

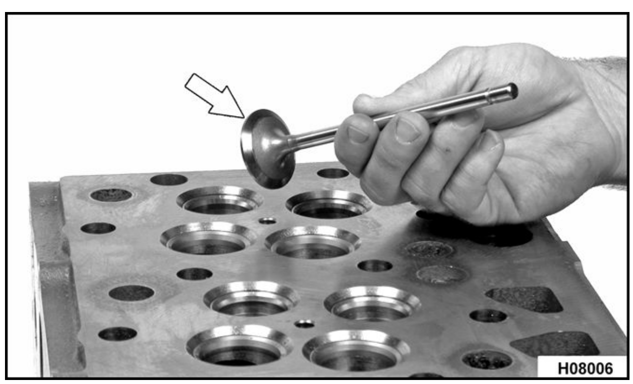


**Figure 379 Apply marker paste to valve face**

1. After refacing a valve, spread a thin film of marker paste (Prussian Blue™ or equivalent) on the valve face and insert the valve in the valve guide.


**Figure 380 Turn valve on valve seat**

2. Apply pressure to the center of the valve head while turning valve 90 degrees on the valve seat.
3. Remove valve from cylinder head. Inspect impression on valve seat and valve face. Marker paste should appear around entire contact surface of valve seat and valve face.
4. Perform impression inspection several times to rule out any errors.
   - If marker paste contact impression is good, continue to Inspect Valve Springs (page 463).
   - If marker paste contact impression is not good, verify correct valve face angles and then continue to Resurface Valve Seats (page 457).

**Resurface Valve Seats**

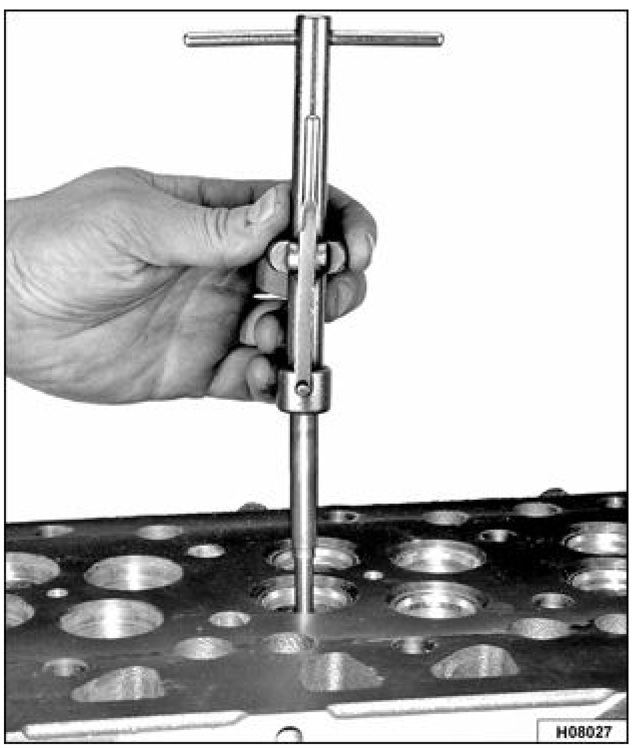


**Figure 381 Valve guide pilot**

1. Lightly lubricate correct size grinding pilot from Valve Seat Grinder (page 485). Install grinding pilot in valve guide.
2. Choose correct angle valve seat grinding stone (page 485) and dress stone. See Specifications (page 483) for correct valve seat angle.
3. Install grinding stone over pilot.

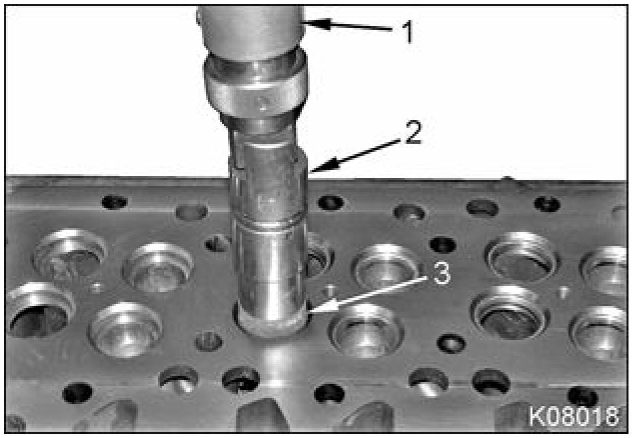


**Figure 382 Grind valve seat**

1. Motor and drive
2. Holder
3. Grindstone

4. Turn on grinding motor and gently apply pressure to the grindstone. Raise grinding stone frequently to prevent overheating. Grind valve seat to a smooth even finish, paying attention to achieving uniform width.


**Figure 383 Valve seat width measurement**

5. Measure valve seat width using a vernier caliper (page 485). If valve seat width exceeds Specifications (page 483), the valve seat may be corrected by grinding with a 15 degree or smaller angle stone.

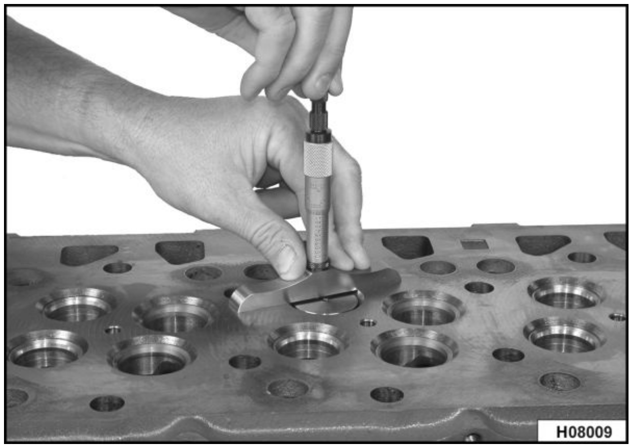


**Figure 384 Measure valve recession**

6. Install each valve in its valve guide. Use a depth micrometer (page 485) to measure valve recession and check Specification (page 483).
   - If valve recedes too far into head, install a new valve or replace valve seat. Reinspect valve face-to-seat contact (page 455).
   - If valve protrudes above cylinder head surface, regrind valve seat. After regrinding valve seat, check valve seat width again. Reinspect valve face-to-seat contact (page 455).

**Replace Valve Seats**

**Remove**

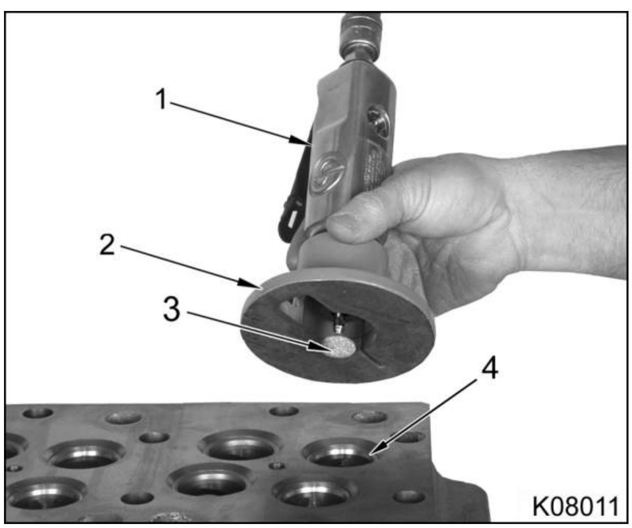


**Figure 385 Valve seat groove grinder**

1. Air motor
2. Grinding base
3. Grinding wheel
4. Valve seat insert

**NOTE:** Replace Valve seats if damaged or out of specifications.

1. Carefully grind a groove in valve seat insert using Valve Seat Extractor Kit (Universal) (page 485). Do not grind into cylinder head.

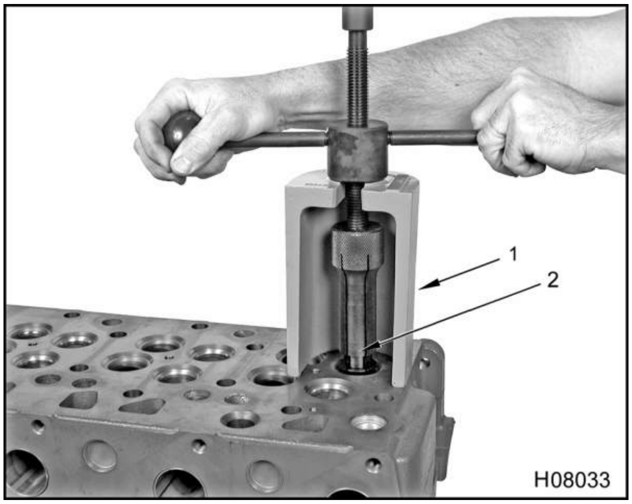


**Figure 386 Remove valve seat insert**

1. Lifting bridge
2. Valve Seat Remover (collet)

2. Position appropriate size Valve Seat Remover (collet) (page 485) in valve seat.
3. Expand collet by threading shaft into valve seat remover until tight inside valve seat. Turn T-handle on shaft to pull valve seat insert out of cylinder head.

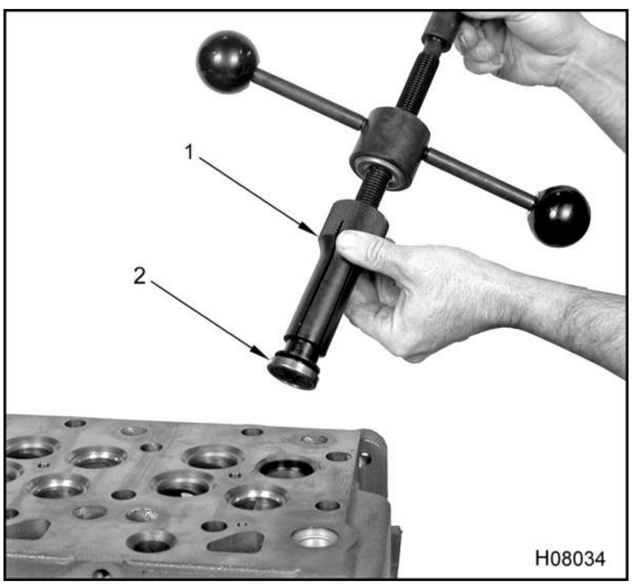


**Figure 387 Remove valve seat insert**

1. Collet
2. Valve seat insert

4. Unlock collet by loosening threaded shaft and discard valve seat insert.

### Install

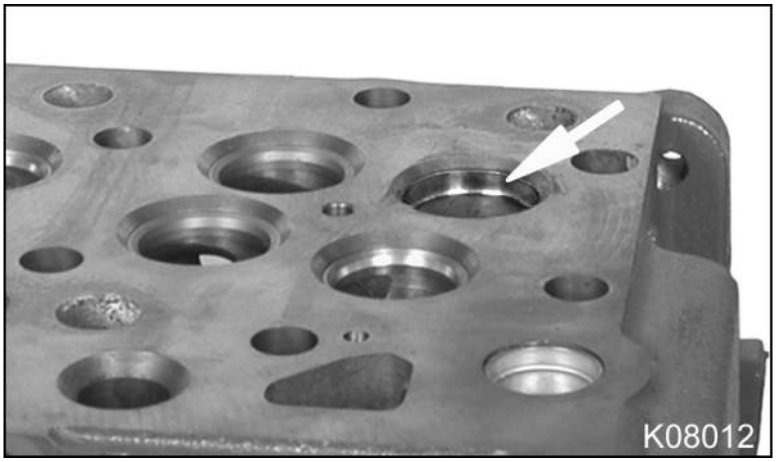


**Figure 388 Valve seat counterbore**

1. Measure valve seat counterbore diameter at two locations 90° apart, using an inside micrometer (page 485). Average the two measurements to determine the appropriate size valve seat insert to install.

**CAUTION:**

**To prevent engine damage, maintain proper diametral interference between valve seat insert outside diameter and valve seat counterbore diameter.**

**Valve Seat Insert Selection Chart**

| **Available inserts (Intake and Exhaust)** | **Intake counterbore average diameter** | **Exhaust counterbore average diameter** |
|---|---|---|
| Standard | 40.120 to 40.170 mm (1.5795 to 1.5815 in) | 37.478 to 37.528 mm (1.4755 to 1.4775 in) |
| Oversize - 0.05 mm (0.002 in) | 40.170 to 40.221 mm (1.5815 to 1.5835 in) | 37.529 to 37.579 mm (1.4775 to 1.4795 in) |

2. Chill valve seat insert in a freezer for 30 minutes. This will slightly shrink insert and prevent the outer layer of metal from being shaved off during installation.

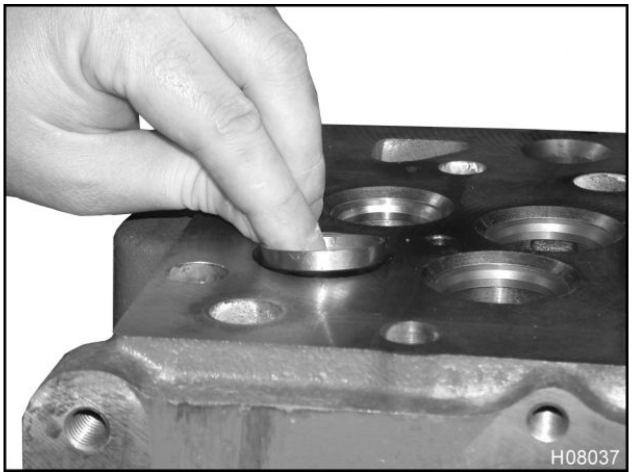


**Figure 389 Valve seat insert**

3. Align chilled valve seat insert over counterbore.

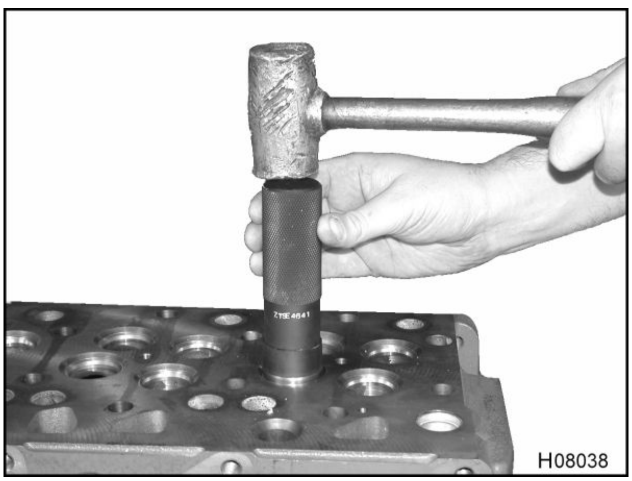


**Figure 390 Valve seat insert installation**

4. Carefully drive valve seat into place, until fully seated, using a hammer and Valve Seat Installer (page 485).
5. Grind new valve seats to Specified angles and widths (page 483).

**Inspect Valve Springs**

**CAUTION:**

**To prevent engine damage, do not grind valve springs or use a wire brush for cleaning. Disruption of spring surface may cause fatigue cracks and spring failure.**

1. Clean valve springs in a suitable solvent.
2. Inspect valve springs for rust, cracks, and pitting. Replace any damaged valve springs.

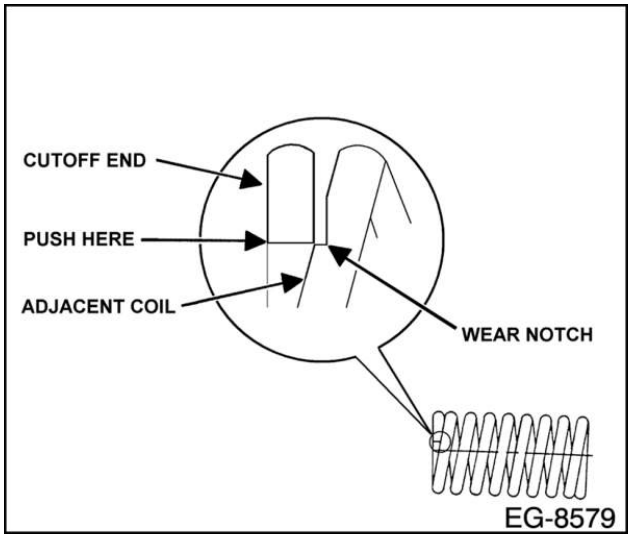


**Figure 391 Inspect valve spring**

3. Inspect both ends of each valve spring at contact points between the cutoff end of the last coil and the adjacent coil. If the cutoff end has worn a notch in the adjacent coil, replace the spring.

   **NOTE:** Valve spring wear notches can also be detected by compressing the spring and listening for a clicking sound.

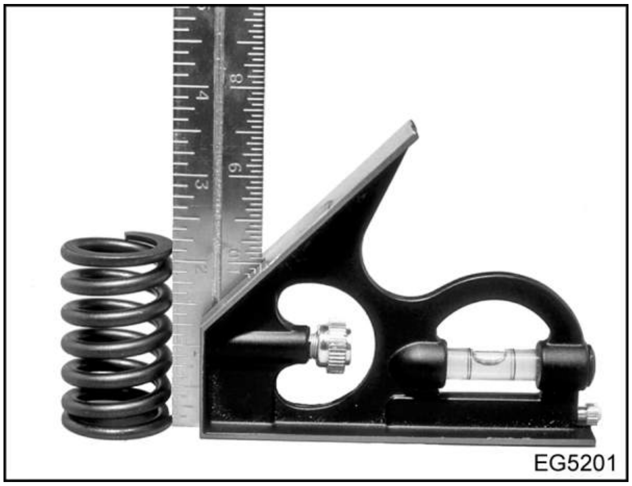


**Figure 392 Measure perpendicularity and flatness of valve spring**

**NOTE:** Valve springs that are not perpendicular to a flat surface put an unequal load on the valve stem, causing premature valve and valve guide wear.

4. Use a square to check flatness and perpendicularity of spring ends. If the end of any valve spring is not flat and square, replace spring.


**Figure 393 Measure valve spring tension**

5. Use a Valve and Clutch Spring Tester (page 485) to measure valve spring tension. Measure the maximum and minimum lengths of the spring at appropriate test loads (valve closed and valve open). Replace any valve spring that does not meet Specifications (page 483).

### Inspect Valve Rotators and Retainers

1. Clean all valve rotators and retainers in a suitable solvent.

**CAUTION:**

**To prevent engine damage, install rotators on intake valves.**

**NOTE:** Some low horse power engines have retainers on the exhaust valves. Rotators must be used on intake valves and can be used on exhaust valves to extend valve life.

2. Inspect valve retainers and rotators for wear, deformation, cracking, or corrosion. Replace if damaged.

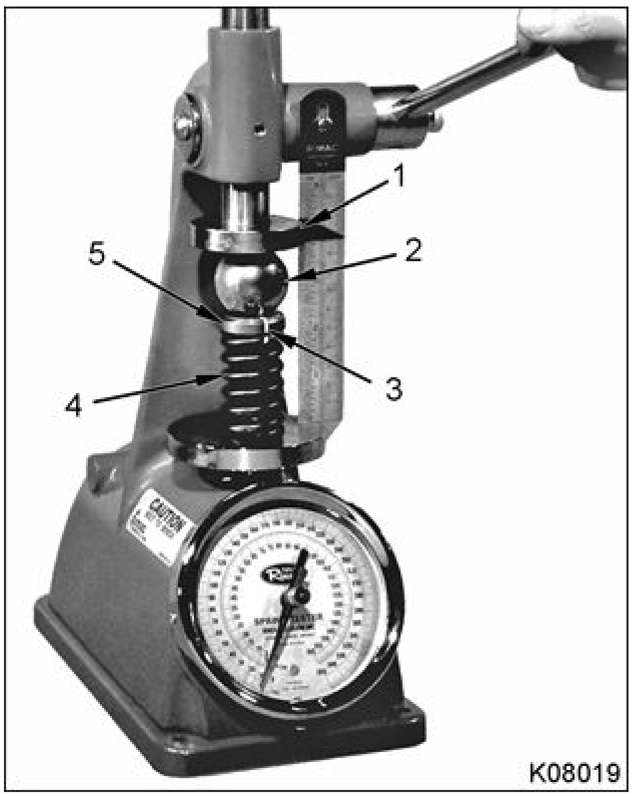


**Figure 394 Inspect valve rotator**

1. Ram
2. Steel ball bearing
3. Paint reference line
4. Spring
5. Valve rotator

**CAUTION:**

**To prevent engine damage, suitable protection must be placed between rotator and ram of Valve and Clutch Spring Tester.**

3. Lubricate valve rotator with clean engine oil. Place valve spring and rotator in Valve and Clutch Spring Tester (page 485).
4. Place a ball bearing between the valve rotator and ram of the spring tester. The ball bearing must be large enough to prevent the ram from touching any part of the rotator.
5. Paint a reference line on the valve rotator and spring.
6. Compress valve spring rapidly with even pressure and observe the valve rotator as it turns. Replace any valve rotator that does not turn.

### Inspect Valve Spring Retainer Keys

1. Clean all valve spring retainer keys with a suitable solvent.
2. Check the inside and outside of the valve spring retainer keys for wear. Replace any worn retainer keys.

### Replace Fuel Injector Sleeves

#### Remove

**NOTE:** Replace injector sleeves if damaged or excessively worn.

**NOTE:** If removing fuel injector sleeves with engine in-chassis, place a cup plug in injector bore before sleeve removal to prevent debris from entering cylinder.

1. Lubricate thread tap, part of Injector Sleeve Remover (page 485).
2. Insert thread tap in fuel injector sleeve.
3. Screw thread tap into fuel injector sleeve. Cut threads at least ¾ inch deep to accommodate fuel injector sleeve puller.

**NOTE:** Ensure fuel injector sleeve puller threads sufficiently into fuel injector sleeve.

4. Insert fuel injector sleeve puller (part of Injector Sleeve Remover) into fuel injector sleeve and tighten. Make sure puller tool is threaded all the way into fuel injector sleeve.

5. Install a slide hammer on puller tool and remove fuel injector sleeve from injector bore.

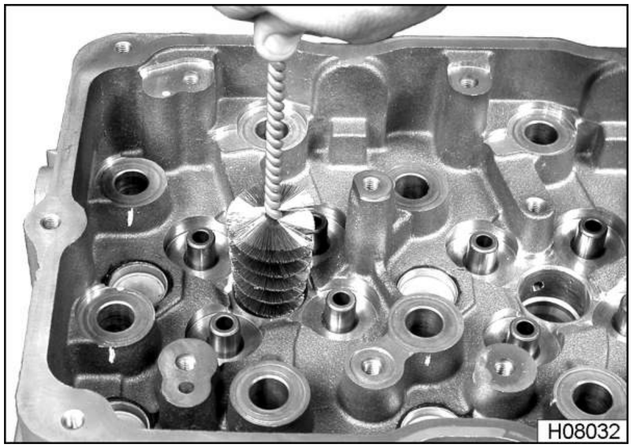


**Figure 395 Clean fuel injector bore**

6. Use a stiff wire brush from the Injector Sleeve Brush Set (set of 2) (page 485), clean deposits and hardened sealant from the fuel injector bore.
7. Insert a small stiff nylon brush tool into oil gallery for cleaning.

**WARNING:**

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

8. Use compressed air to clean out all fuel and oil galleries.

**Install**

1. Use an Injector Sleeve Installer (page 485) that does not have a bent pilot shaft or any nicks where the sleeve will seat.
2. Install a new fuel injector sleeve on the end of the Injector Sleeve Installer.

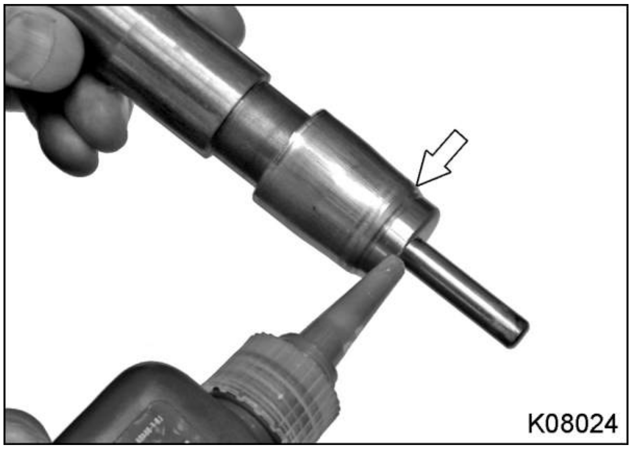


**Figure 396 Apply sealant to fuel injector sleeve**

3. Apply Loctite® 620 Retaining Compound (page 485) around outside bottom of injector sleeve and around beginning of taper at middle of sleeve.

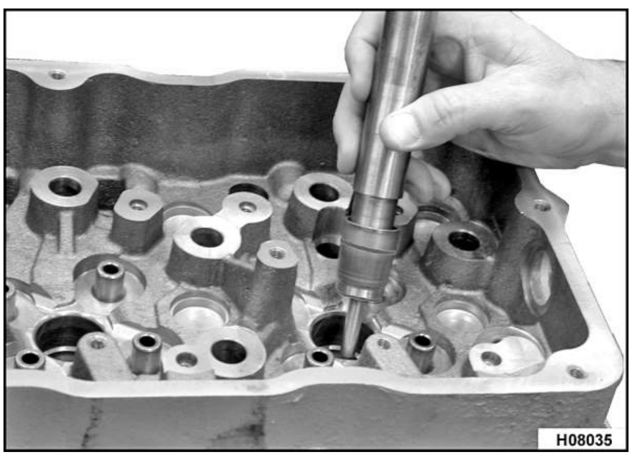


**Figure 397 Fuel injector sleeve and injector bore**

4. Insert fuel injector sleeve and Injector Sleeve Installer into injector bore.

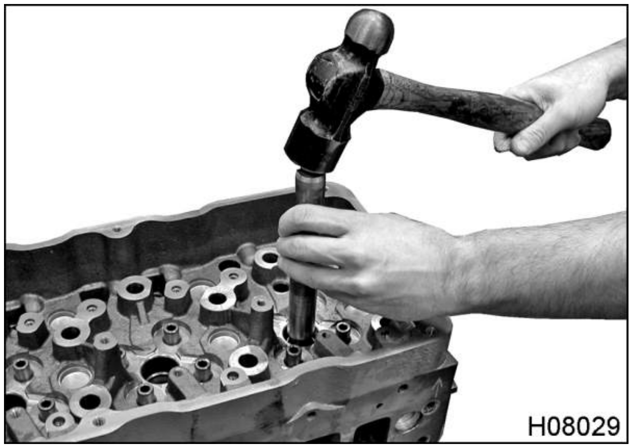


**Figure 398 Install fuel injector sleeve**

5. Carefully drive fuel injector sleeve into injector bore with a hammer.
6. Clean fuel injector sleeve with a soft nylon brush.
7. Inspect inside surfaces of installed fuel injector sleeve. If nicked or scratched, replace sleeve again. Make sure Injector Sleeve Installer is not causing damage. Use a different Injector Sleeve Installer, if necessary.

### Install Valves

#### Clean

**WARNING:**

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

1. Clean valve faces and seats with a suitable solvent. Dry all components using filtered compressed air.
2. To clean valve guides, coat a brush with soap and water. Insert brush into each valve guide bore and rotate in one direction with an up and down motion. Dry valve guide bores using filtered compressed air.
3. Insert a large nylon brush in the rear of the fuel rail gallery to loosen dirt and deposits. Blow out debris using filtered compressed air.

#### Assemble

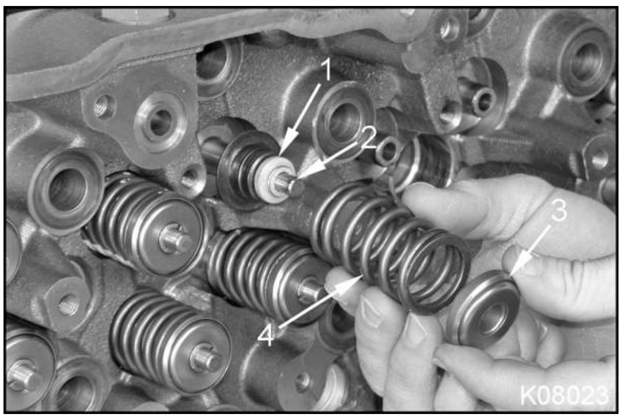


**Figure 399 Valve stem seal, spring, and rotator**

1. Valve stem seal
2. Valve stem
3. Valve rotator or retainer (typical)
4. Valve spring

1. Lubricate valve stem with clean engine oil and insert valve in valve guide.

2. Lubricate inside diameter of new valve stem seals with clean engine oil. Install seals over valve stems and valve guides. Make sure seals are completely seated against cylinder head spring pockets.
3. Install valve springs over valve stem seals.

**CAUTION:**

**To prevent engine damage, rotators must be installed on intake valves.**

4. Install valve rotators on top of intake valve springs. Install valve rotators or retainers on top of exhaust valve springs.

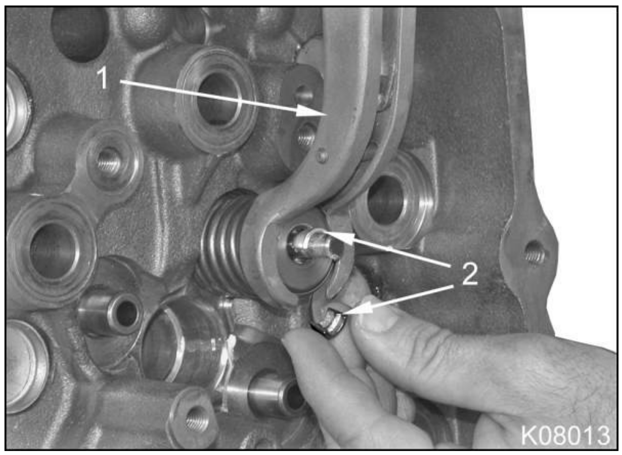


**Figure 400 Valve Spring Compressor and retainer keys**

1. Valve Spring Compressor
2. Valve spring retainer keys

**WARNING:**

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

5. Install Valve Spring Compressor (page 485) over valve and compress valve spring.
6. Install valve spring retainer keys and release spring compressor.

# Installation

### Roller Tappets

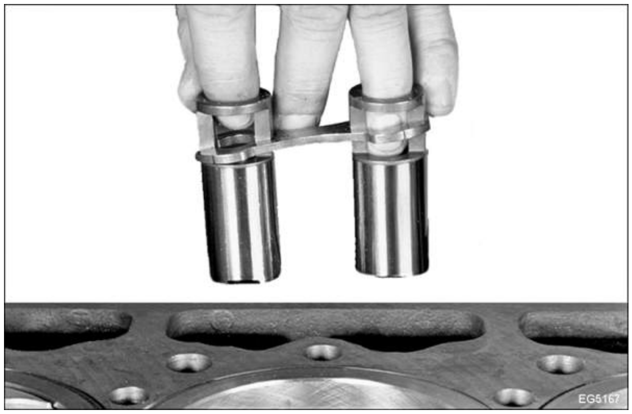


**Figure 401 Roller tappets and guide**

1. Lubricate roller tappets with clean engine oil.
2. Install each roller tappet and guide into tappet bore. Install used roller tappets in their original locations, revolving in the same direction as before removal.

### Cylinder Head

**CAUTION:**

**To prevent engine damage, Measure Cylinder Sleeve Protrusion (page 559) before installing cylinder head.**

1. Install two lifting eyes with four M12 x 25 bolts onto cylinder head. Tighten bolts to standard torque (page 683).
2. Clean head bolt holes in crankcase with correct size tap. Clean and dry cylinder head gasket surfaces.

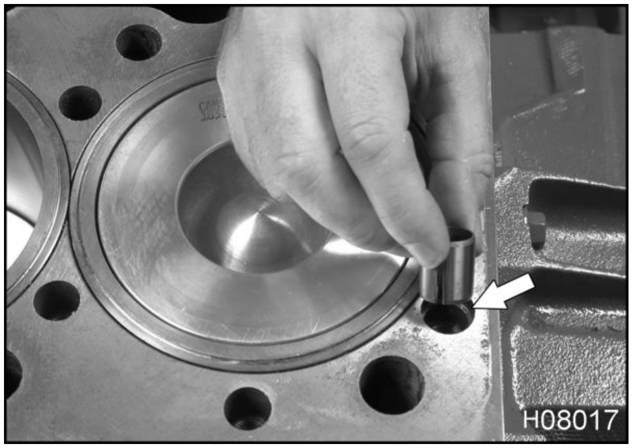


**Figure 402 Cylinder head alignment dowel**

3. Install or verify two alignment dowels are correctly installed in top of crankcase.

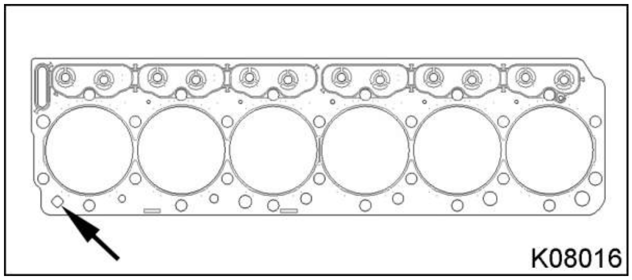


**Figure 403 Cylinder head gasket diamond shape hole**

**NOTE:** MaxxForce® DT, 9, and 10 cylinder head gaskets have a diamond shaped hole which identify them from earlier model year gaskets.


**Figure 404 Cylinder head gasket and alignment dowels**

4. Install a new cylinder head gasket on crankcase, over alignment dowels.

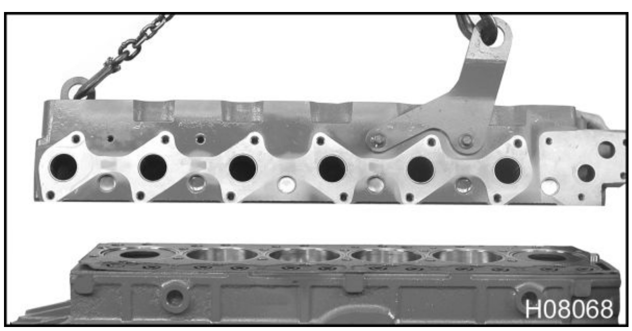


**Figure 405 Cylinder head and crankcase**

**WARNING:**

**To prevent personal injury or death, use a hoist rated for the weight of the cylinder head and follow the manufacturer's operation and safety instructions. Attach safety lifting hooks to the cylinder head lifting eyes.**

5. Attach an appropriate hoist and lifting hooks to cylinder head lifting eyes.

**CAUTION:**

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

6. Carefully lower cylinder head onto crankcase and align cylinder head alignment dowels in the crankcase with dowel holes in the cylinder head.

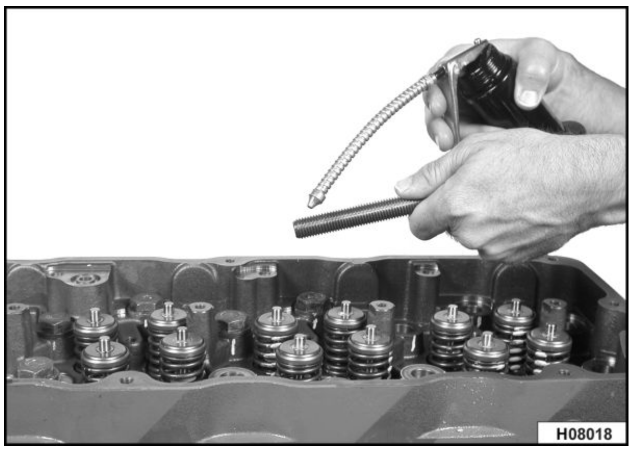


**Figure 406 Cylinder head bolts**

**CAUTION:**

**To prevent engine damage, do not reuse cylinder head bolt.**

**NOTE:** Do not use chlorinated solvents on cylinder head bolts. Parts should be clean, dry, and free of chemicals other than engine oil.

7. Lightly lubricate threads and bolt flange of all cylinder head bolts with clean engine oil.
8. Install all cylinder head bolts finger tight.

### Torque-to-Yield Procedure for Cylinder Head Bolts

**CAUTION:**

**To prevent engine damage, do not reuse cylinder head bolts; install new bolts.**

**NOTE:** Do not use chlorinated solvents on cylinder head bolts. Parts should be clean, dry, and free of chemicals other than engine oil.

1. Lightly lubricate threads and bolt flange of new 26 cylinder head bolts with clean engine oil.
2. Install all new cylinder head bolts finger tight.

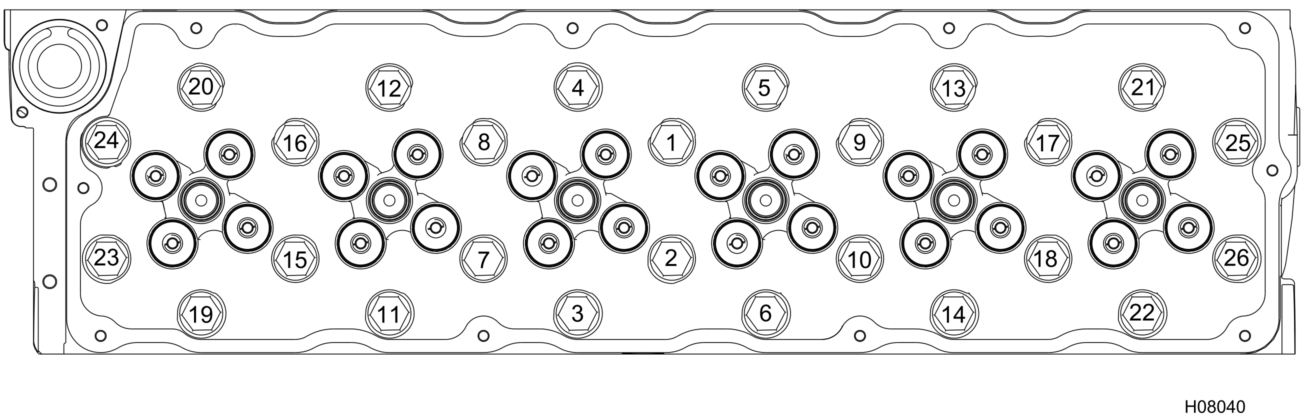


**Figure 407 Torque sequence A for cylinder head bolts**

3. Tighten each cylinder head bolt to 150 N·m (110 lbf·ft) in cylinder head torque sequence A.

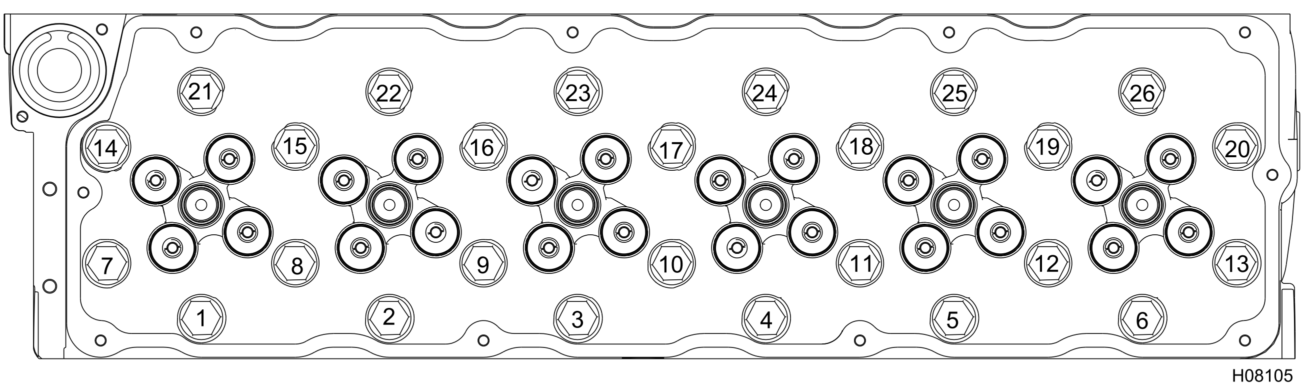


**Figure 408 Torque sequence B for cylinder head bolts**

4. Tighten each cylinder head bolt to 204 N·m (150 lbf·ft) in cylinder head torque sequence B.

**NOTE:** It is necessary to tighten cylinder head bolts in both sequence A and B to obtain uniform head bolt torque.

**CAUTION:**

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

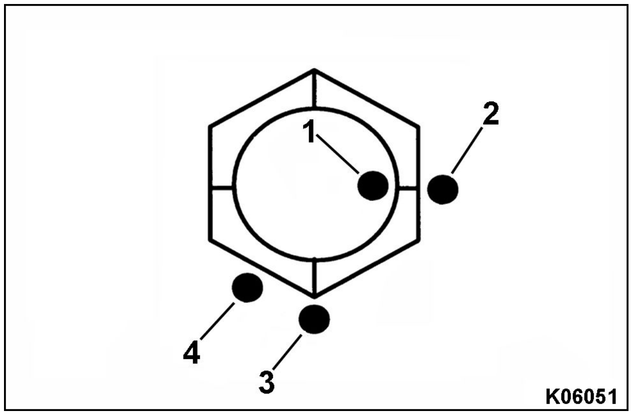


**Figure 409 Cylinder head and head bolt torque markings**

1. Mark on cylinder head bolt
2. Mark on cylinder head surface next to head bolt mark
3. Mark on cylinder head surface 90° CW from head bolt mark
4. Mark on cylinder head surface 120° CW from head bolt mark

5. Using permanent marker, place a mark on each head bolt and put another mark on the head bolt socket (page 485) directly in line with the mark on each head bolt. Put another mark on the cylinder head surface next to the head bolt mark (Items 1 and 2).
6. Place a mark on the cylinder head surface 90 degrees clockwise (CW) from each head bolt mark (Item 3).
7. Place a mark on the cylinder head surface 120 degrees (two hex flats) CW from each head bolt mark (Item 4).
8. Install head bolt socket on head bolt to be torqued (Cylinder head bolt torque sequence A) and align mark on socket with the mark on the head bolt.

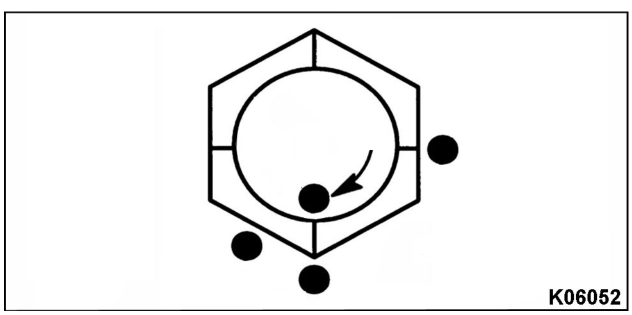


**Figure 410 Head bolt rotated 90° CW**

9. Rotate cylinder head bolt 90 degrees CW (1/4 turn). The marks on the head bolt socket, head bolt, and cylinder head surface should align.

10. Repeat steps 8 and 9 for each cylinder head bolt in cylinder head bolt torque sequence A.

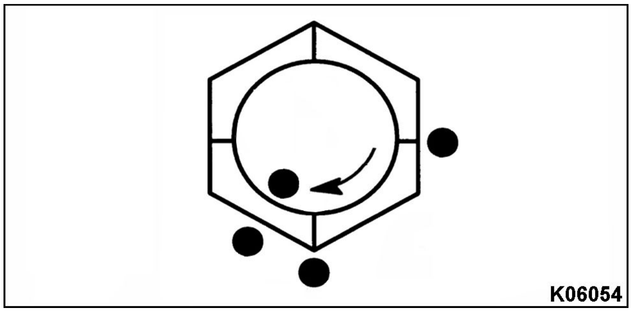


**Figure 411 Head bolt rotated 120° CW**

11. Rotate each cylinder head bolt an additional 30 degrees CW in cylinder head bolt torque sequence A for a total of 120 degrees (two hex flats). The marks on the head bolt socket, head bolt, and cylinder head surface should align.

**Rocker Arms**

**NOTE:** See Fuel System chapter for fuel injector installation (page 247).

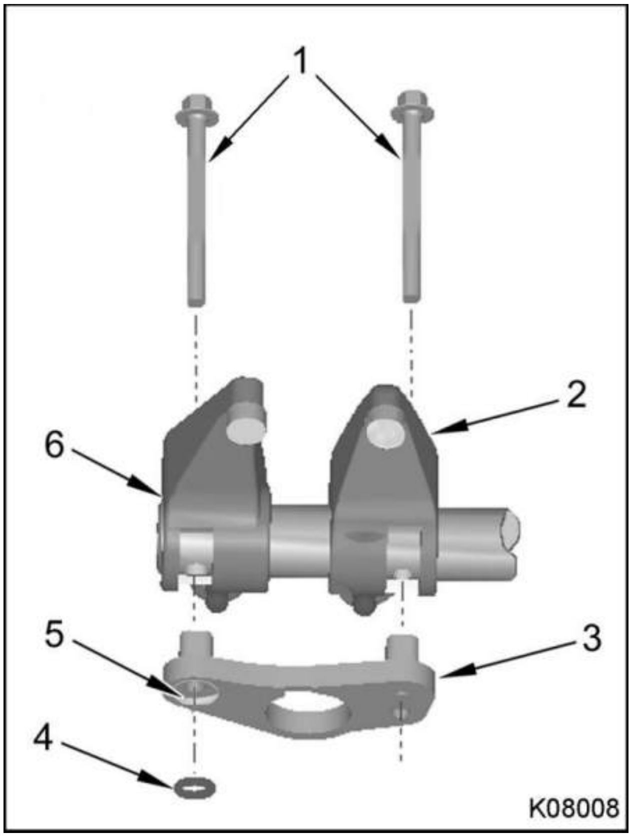


**Figure 412 Rocker arm configuration**

1. M8 x 60 shaft bolt
2. Exhaust rocker arm
3. Rocker arm shaft support
4. Support washer (assembly aid)
5. Machined recess
6. Intake rocker arm

1. Slide 12 rocker arms onto rocker shaft in order removed (rocker arms should have been marked during removal procedure).

**NOTE:** Ensure rocker arm shaft has big “T” stamp facing up (Figure 414).

2. Install twelve shaft bolts through rocker arm shaft and into rocker arm shaft supports.
3. Install a support washer (assembly aid) onto each intake rocker arm shaft bolt (recessed side of shaft support only).

### Rocker Arm Assembly


**Figure 413 Valve bridge installation**

1. Install valve bridges on each set of intake and exhaust valve stems. Used valve bridges must be reinstalled in their original location and orientation. (See marks from removal)

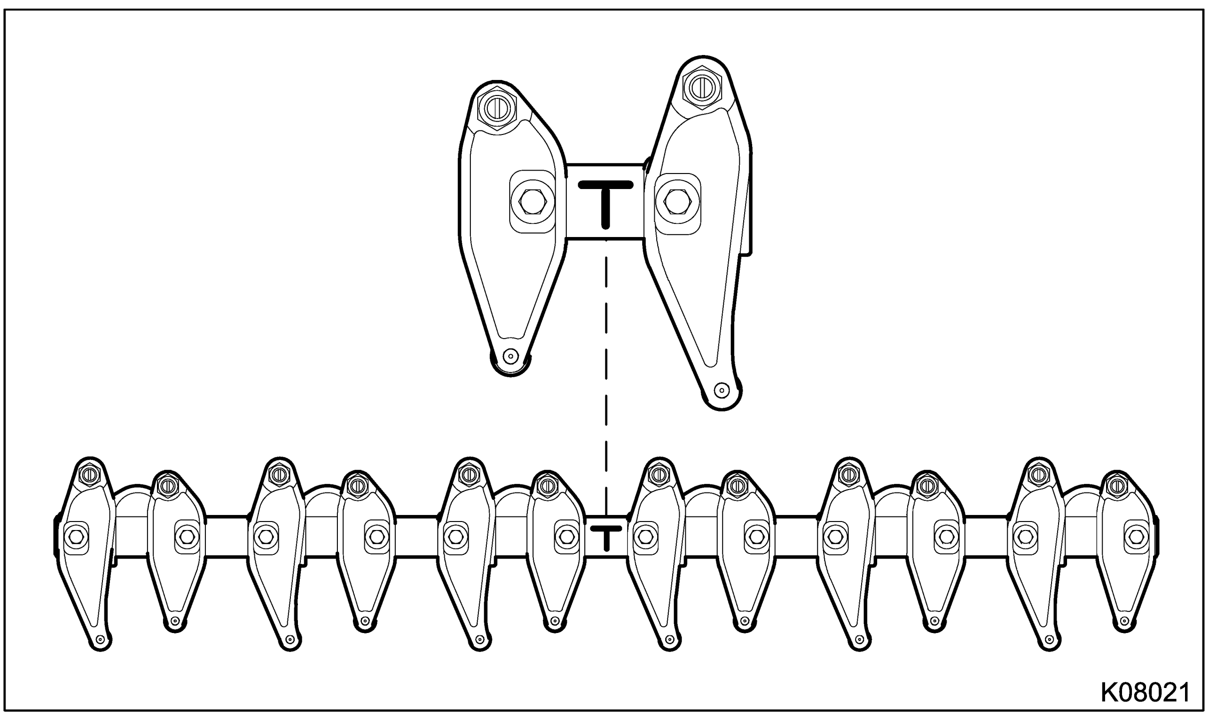


**Figure 414 Rocker arm orientation and big "T" stamp**

2. Install rocker arm shaft assembly with 12 shaft bolts and six shaft supports, onto cylinder head.
3. Align shaft bolts with cylinder head bolt holes and finger tighten bolts.

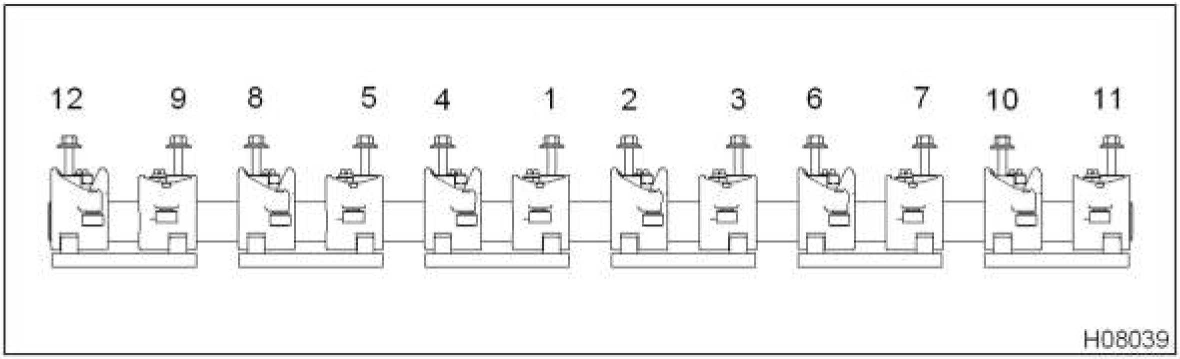


**Figure 415 Rocker arm torque sequence**

4. Tighten shaft bolts in two steps using rocker arm torque sequence (Figure 415).
   a. Torque rocker arm shaft bolts in sequence to 27 N·m (20 lbf·ft).
   b. Torque rocker arm shaft bolts in sequence to 37 N·m (27 lbf·ft).
5. Adjust valve lash (page 423) for all 12 rocker arms.

**Valve Cover**

1. Install UVC harness valve cover gasket assembly (page 133) on the cylinder head.
2. Connect all sensor and injector connectors to the UVC harness valve cover gasket assembly.
3. Install valve cover onto cylinder head.

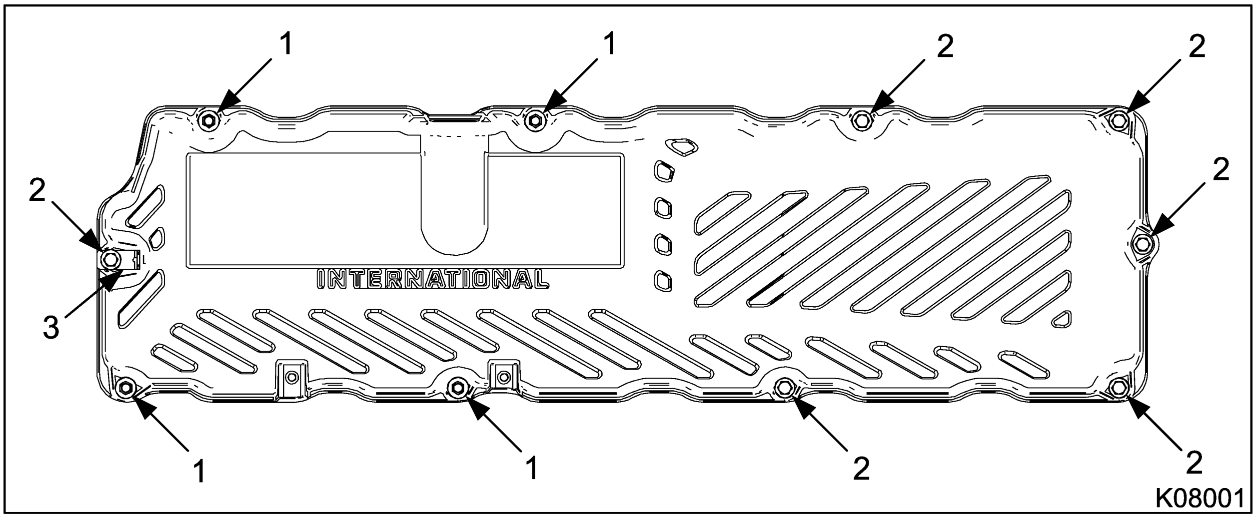


**Figure 416 Valve cover assembly**

1. M8 x 80 stud bolt (4)
2. M8 x 80 bolt (6)
3. Harness mounting bracket

4. Install any harness mounting brackets removed to appropriate bolts.
5. Install four M8 x 80 stud bolts finger tight.
6. Install six M8 x 80 bolts finger tight.
7. Tighten four bolts and six stud bolts to standard torque (page 683).

## Specifications

### Valve Specifications

| | |
|---|---|
| Camshaft lobe lift | Intake:<br>6.68 mm (0.263 in)<br>0.254 mm (0.010 in) maximum wear limit<br>Exhaust:<br>6.91 mm (0.272 in)<br>0.254 mm (0.010 in) maximum wear limit |
| Valve face angle | Intake:<br>59.75 to 60.00°<br>Exhaust:<br>44.75 to 45.00° |
| Valve face margin (minimum) | Intake:<br>1.32 mm (0.052 in)<br>Exhaust:<br>1.16 mm (0.046 in) |
| Valve face-to-valve stem runout (maximum) | 0.038 mm (0.0015 in) |
| Valve lash (cold), intake and exhaust | 0.48 mm (0.019 in) |
| Valve stem diameter (new condition) | Intake:<br>7.92861 ± 0.0089 mm (0.31215 ± 0.00035 in)<br>Exhaust:<br>7.9083 ± 0.0089 mm (0.31135 ± 0.00035 in) |
| Valve stem straightness (maximum) | 0.010 mm (0.0004 in) |
| Valve stem-to-guide running clearance (maximum) | Intake:<br>0.10 mm (0.004 in)<br>Exhaust:<br>0.11 mm (0.005 in) |
| Intake valve head diameter | 39.73 ± 0.13 mm (1.564 ± 0.005 in) |
| Exhaust valve head diameter | 36.55 ± 0.13 mm (1.439 ± 0.005 in) |

**Valve Spring Specifications**

| Intake and Exhaust Valve Springs | |
|---|---|
| Free length | 52.35 mm (2.061 in) |
| Solid height (maximum) | 27.46 mm (1.081 in) |
| Valve closed test length @ 410.1 ± 24.5 N (92.2 ± 5.5 lbf) test load | 40 mm (1.575 in) |
| Valve closed test length @ 764.2 ± 48.9 N (171.8 ± 11.0 lbf) test load | 29.3 mm (1.155 in) |

**Cylinder Head and Valve Train Specifications**

| | |
|---|---|
| Cylinder head gasket surface flatness | 0.10 mm (0.004 in.) per 229 mm (9.0 in) |
| Cylinder head thickness | New: 160.48 mm (6.318 in) |
| | Minimum: 159.97 mm (6.298 in) |
| Cylinder head valve guide bore diameter | 14.308 ± 0.017 mm (0.5633 ± 0.0007 in) |
| Exhaust valve seat counterbore diameter | Standard: 37.503 ± 0.025 mm (1.4765 ± 0.0010 in) |
| | Oversize: 0.05 mm (0.002 in): 37.55 ± 0.03 mm (1.478 ± 0.001 in) |
| Exhaust valve seat insert outside diameter | Standard: 37.57 ± 0.01 mm (1.479 ± 0.0005 in) |
| | Oversize: 0.05 mm (0.002 in): 37.62 ± 0.01 mm (1.481 ± 0.0005 in) |
| Intake valve seat counterbore diameter | Standard: 40.145 ± 0.025 mm (1.5805 ± 0.0010 in) |
| | Oversize 0.05 mm (0.002 in): 40.195 ± 0.025 mm (1.5825 ± 0.0010 in) |
| Intake valve seat insert outside diameter | Standard: 40.21 ± 0.01 mm (1.583 ± 0.0005 in) |
| | Oversize 0.05 mm (0.002 in): 40.26 ± 0.01 mm (1.585 ± 0.0005 in) |
| Valve seat insert OD to valve seat counterbore diametral interference | 0.025 to 0.102 mm (0.001 to 0.004 in) |
| Valve guide bore out-of-round (maximum) | 0.005 mm (0.0002 in) |
| Valve guide bore taper (maximum) | 0.013 mm (0.0005 in) |
| Valve guide height from cylinder head spring pocket | 16.54 ± 0.25 mm (0.651 ± 0.010 in) |
| Valve guide inside diameter (installed) | 7.98 to 8.00 mm (0.314 to 0.315 in) |
| Valve guide inside diameter (installed), maximum wear limit | Intake: 0.102 mm (0.004 in) |
| | Exhaust: 0.127 mm (0.005 in) |
| Valve guide interference fit dimension | 0.043 mm (0.0017 in) |
| Valve guide outside diameter | 14.351 ± 0.010 mm (0.5650 ± 0.0004 in) |
| Valve guide length (overall) | 65.71 mm (2.587 in) |

**Cylinder Head and Valve Train Specifications (cont.)**

| | |
|---|---|
| Valve recession | Intake: |
| | 1.02 ± 0.13 mm (0.040 ± 0.005 in) |
| | Exhaust: |
| | 1.40 ± 0.13 mm (0.055 ± 0.005 in) |
| Valve seat angles | Intake: |
| | 59.75 - 60° |
| | Exhaust: |
| | 44.75 - 45° |
| Valve seat to valve guide bore concentricity (maximum) | 0.076 mm (0.003 in) |
| Valve seat width | 1.91 to 2.16 mm (0.075 to 0.085 in) |
| Push rod runout (maximum) | 0.508 mm (0.020 in) |

## Special Torque

| | |
|---|---|
| Cylinder head mounting bolts torque and sequence | (page 476) |
| Rocker arm bolts torque and sequence | (page 480) |
| Valve adjustment screw lock nut | 27 N·m (20 lbf·ft) |

## Special Service Tools

| | |
|---|---|
| Ball gauge | Obtain locally |
| Cylinder Head Test Plate | ZTSE4289A |
| Depth micrometer | Obtain locally |
| Dial indicator set | Obtain locally |
| Dye penetrant kit | Obtain locally |
| Feeler gauge | Obtain locally |
| Head bolt socket | Obtain locally |
| Head Bolt Bottoming Tap | ZTSE4671 |
| Injector Sleeve Brush Set (set of 2) | ZTSE4304 |
| Injector Sleeve Installer | ZTSE4642 |
| Injector Sleeve Remover | ZTSE4643-1A |
| Inside micrometer | Obtain locally |
| Loctite® 620 Retaining Compound | Obtain locally |
| Outside micrometer | Obtain locally |

| | |
|---|---|
| Pressure regulator | Obtain locally |
| Slide Hammer Puller Set | ZTSE1879 |
| Small hole gauge set | Obtain locally |
| Square | Obtain locally |
| Straightedge | Obtain locally |
| Telescoping gauge | Obtain locally |
| Thermostat Opening Pressure Adapter | ZTSE4647 |
| Valve and Clutch Spring Tester | ZTSE2241 |
| Valve Guide Deburring Tool | ZTSE4393 |
| Valve Guide Installer | ZTSE1943 |
| Valve Guide Remover | ZTSE4377 |
| Valve Seat Extractor Kit (Universal) | ZTSE1951C |
| Valve Seat Grinder | ZTSE1631A |
| Valve seat grinding stones 45° (exhaust) | Obtain locally |
| Valve seat grinding stones 60° (intake) | Obtain locally |
| Valve Seat Installer | ZTSE4641 |
| Valve Seat Remover (collet) | ZTSE4640 |
| Valve Spring Compressor | ZTSE1846 |
| Valve Spring Compressor Jaws | ZTSE4652 |
| Vernier caliper | Obtain locally |
| Water Supply Housing Pressure Adapter | ZTSE4648 |

# Table of Contents

## Exploded View and Description

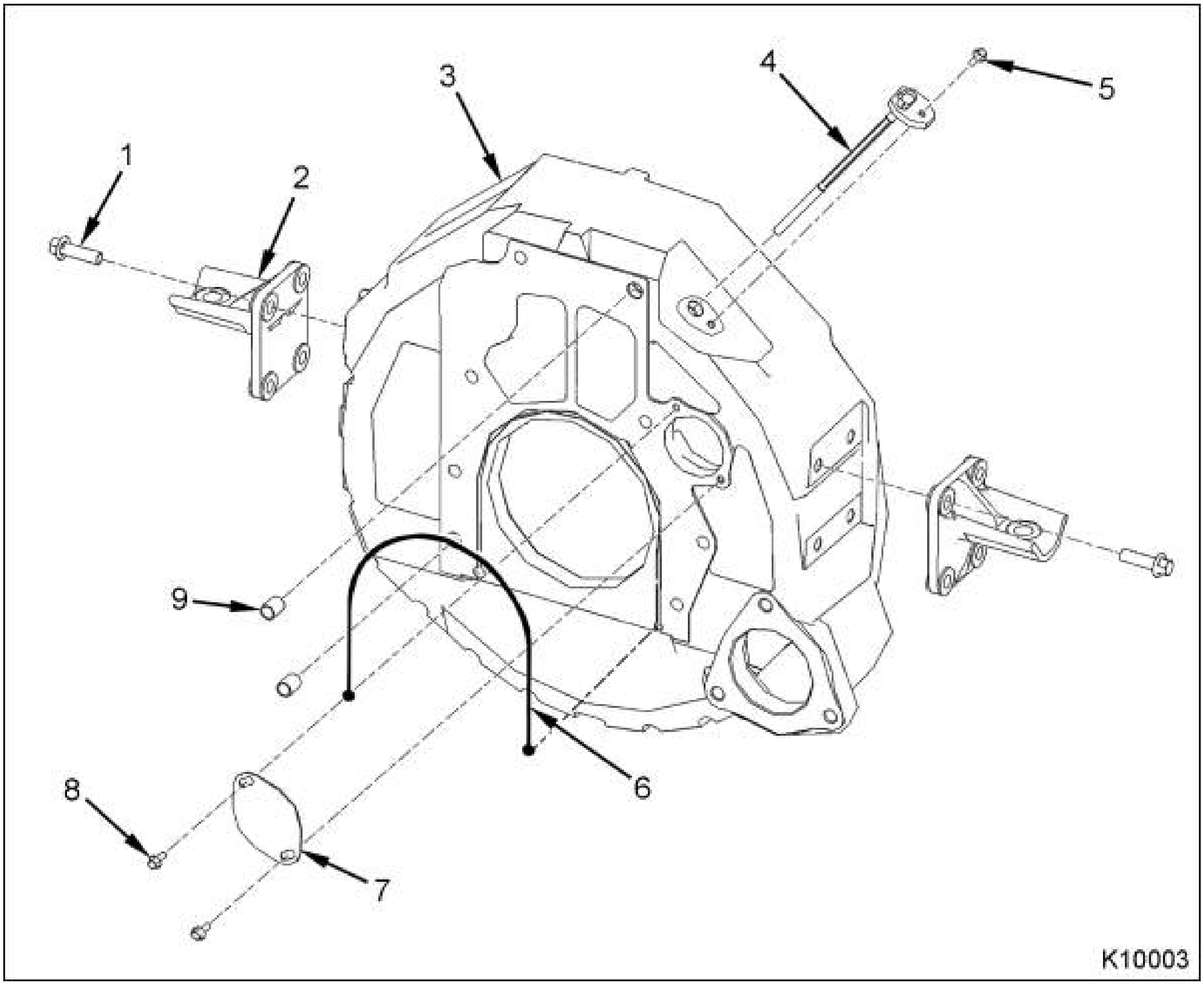


**Figure 417 Flywheel housing and related parts (typical)**

1. M12 x 40 bolt (8)
2. Rear engine mounting bracket (2)
3. Flywheel housing
4. Crankshaft Position sensor (CKP)
5. M6 x 16 bolt
6. Flywheel housing seal
7. Cover plate
8. M6 x 16 bolt (2)
9. Hollow dowel (2)

The flywheel housing assembly is bolted to the back of the crankcase and supports the transmission, starter motor, rear engine mounting brackets, and crankshaft position sensor. A flywheel and clutch assembly (manual transmission) or a flexplate and torque converter assembly (automatic transmission) are housed inside the flywheel housing to transfer engine power to the transmission. Several flywheel housing, flywheel, and flexplate options are available to fit different applications.

All transmission applications are designed to attach to one of the following four flywheel housing assembly configurations:

Flywheel housing SAE #1

- Houses a flywheel or flexplate with a 148 tooth ring gear.
- SAE #1 transmission opening.
- SAE #1 starter motor location (will only work with a 148 tooth ring gear).
- Standard SAE #2 side mount locations.

Flywheel housing SAE #1A

- Houses a flywheel or flexplate with a 138 tooth ring gear.
- SAE #1 transmission opening.
- SAE #2 starter motor location (will only work with a 138 tooth ring gear).
- Standard SAE #2 side mount locations.

Flywheel housing SAE #2

- Houses a flywheel or flexplate with a 138 tooth ring gear.
- SAE #2 transmission opening.
- SAE #2 starter motor location (will only work with a 138 tooth ring gear).
- Standard SAE #2 side mount locations.

Flywheel housing (Bus) SAE #2

- Houses a flywheel or flexplate with a 138 tooth ring gear.
- SAE #2 starter motor location (will only work with a 138 tooth ring gear).
- High side mounts for bus.

## Flywheel and Flexplate Applications

**Manual Transmissions**

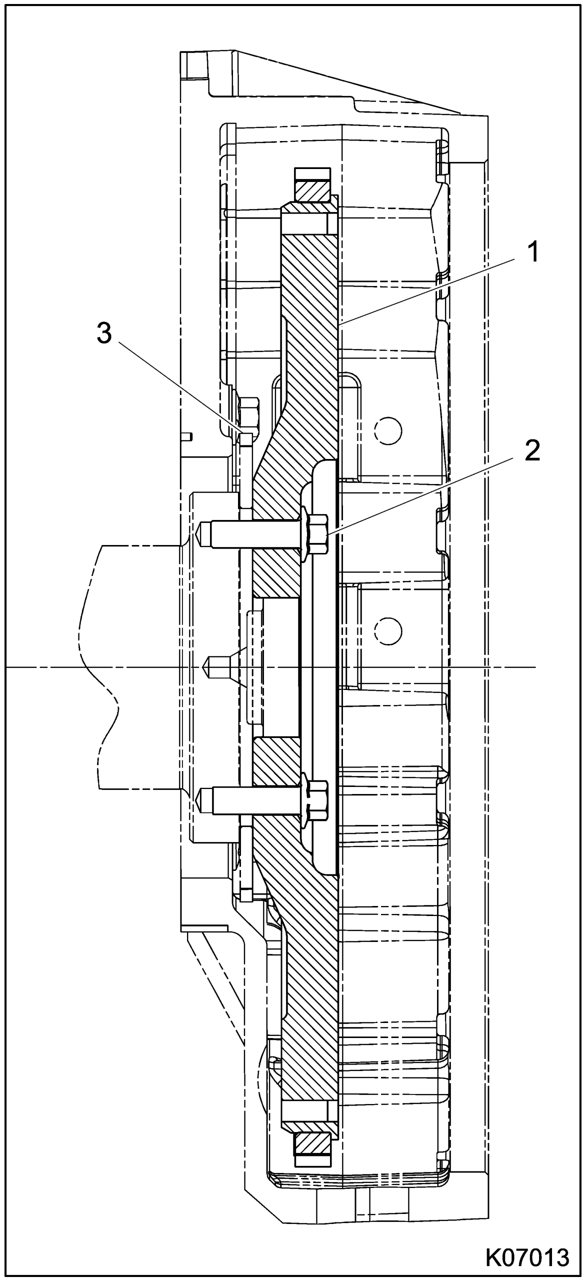


**Figure 418 14 inch flywheel - for multiple plate clutch applications (800 lbf·ft and below)**

1. Flywheel assembly
2. M12 x 40 bolt (12)
3. Crankshaft timing disk

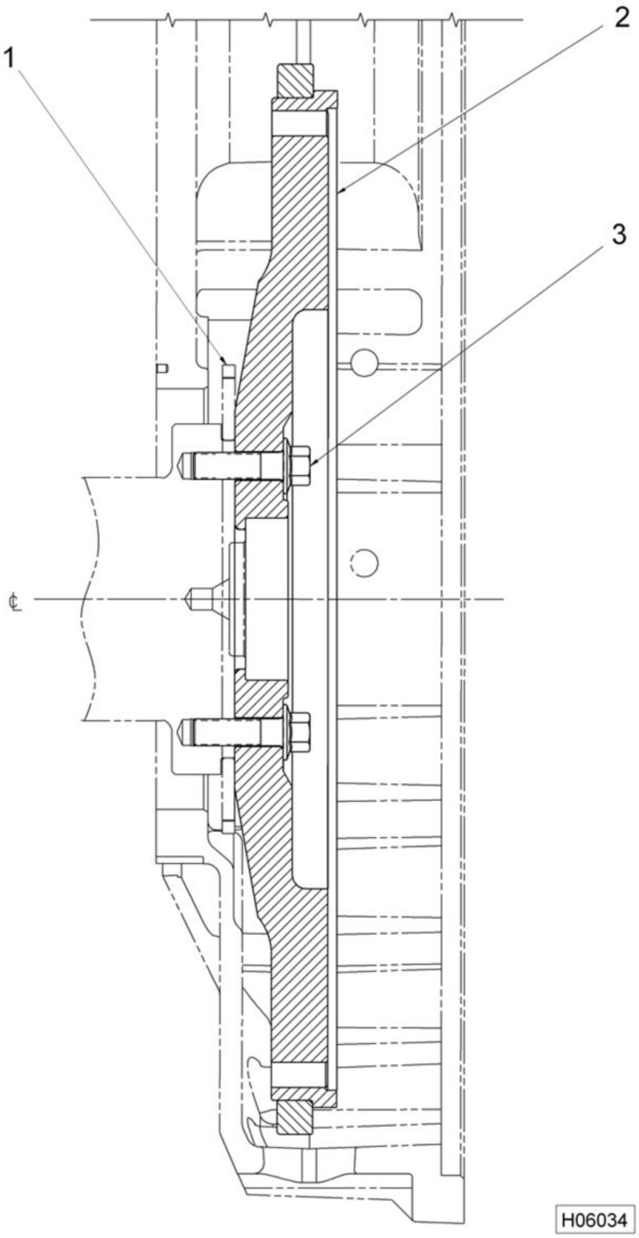


**Figure 419 15.5 inch flywheel - for multiple plate clutch applications (800 lbf·ft and above)**

1. Crankshaft timing disk
2. Flywheel assembly
3. M12 x 40 bolt (12)

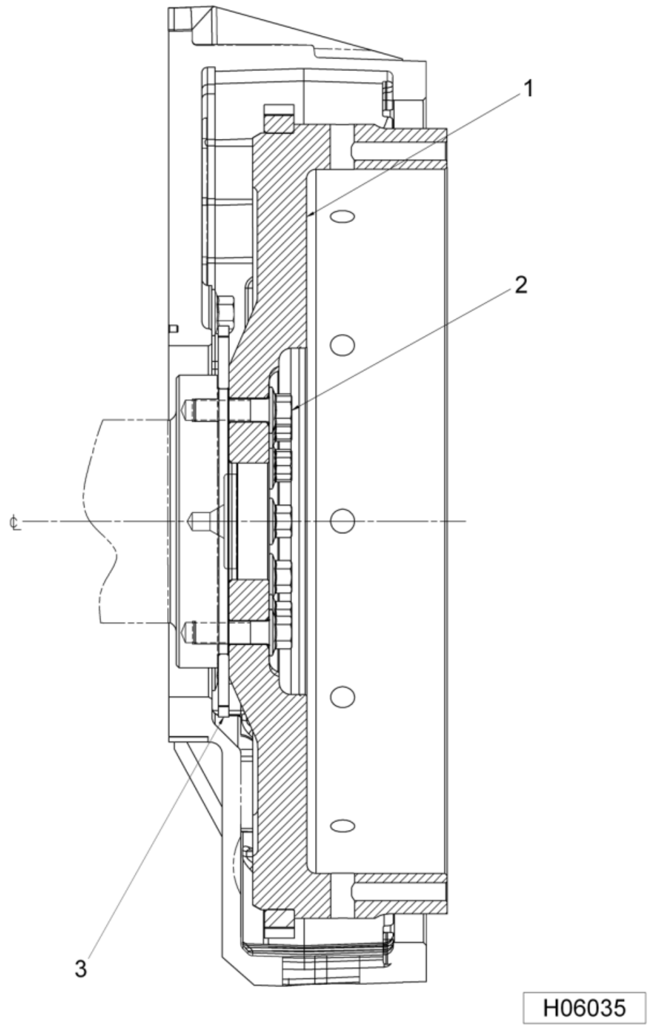


**Figure 420 Pot type flywheel - for multiple plate clutch applications (800 lbf·ft and above)**

1. Flywheel assembly
2. M12 x 40 bolt (12)
3. Crankshaft timing disk

**Automatic Transmissions**

**NOTE:** Side of reinforcement ring stamped with the part number or logo must face outward.

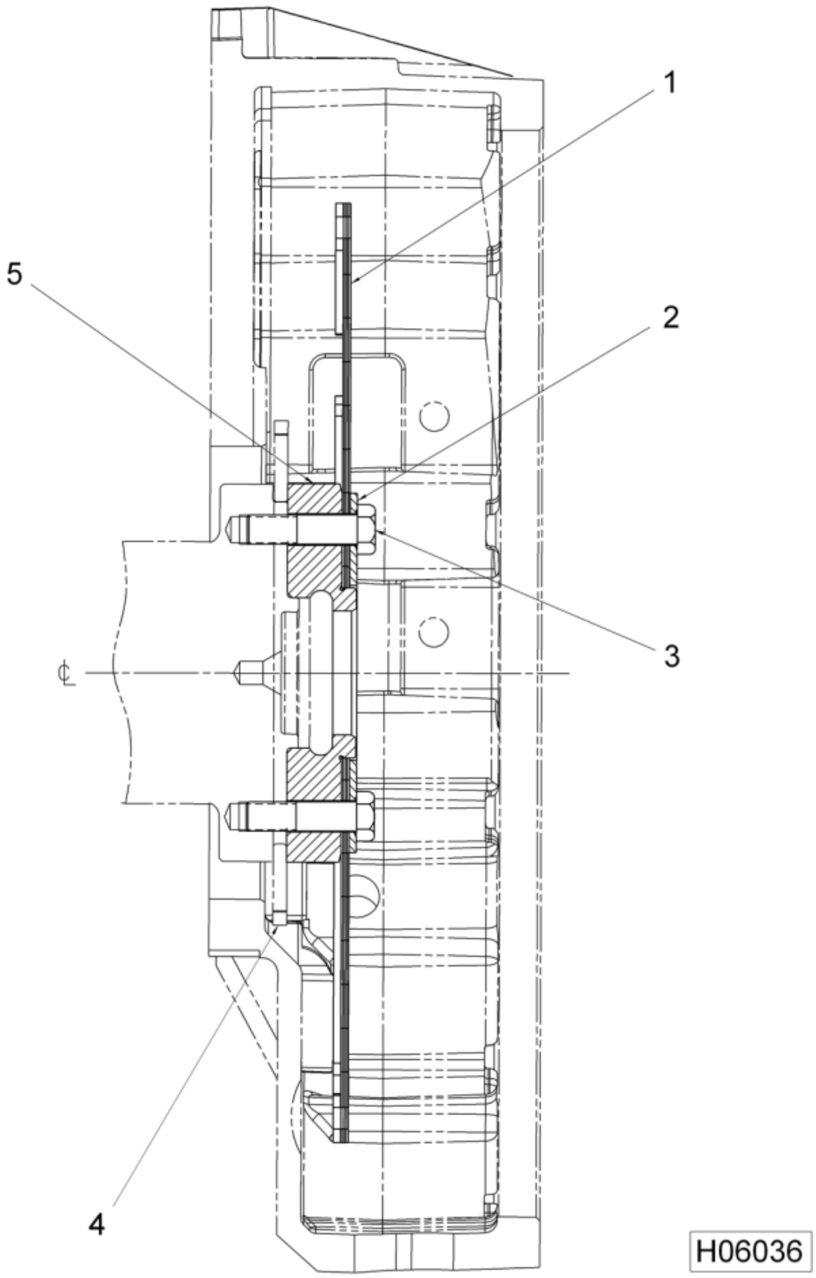


**Figure 421 Application for Allison World Transmissions - MD-3060, MD-3560**

1. Flexplate assembly
2. Reinforcement ring (Allison transmissions only)
3. M12 x 45 bolt (12)
4. Crankshaft timing disk
5. Hub crankshaft adaptor

**NOTE:** Side of reinforcement ring stamped with the part number or logo must face outward.

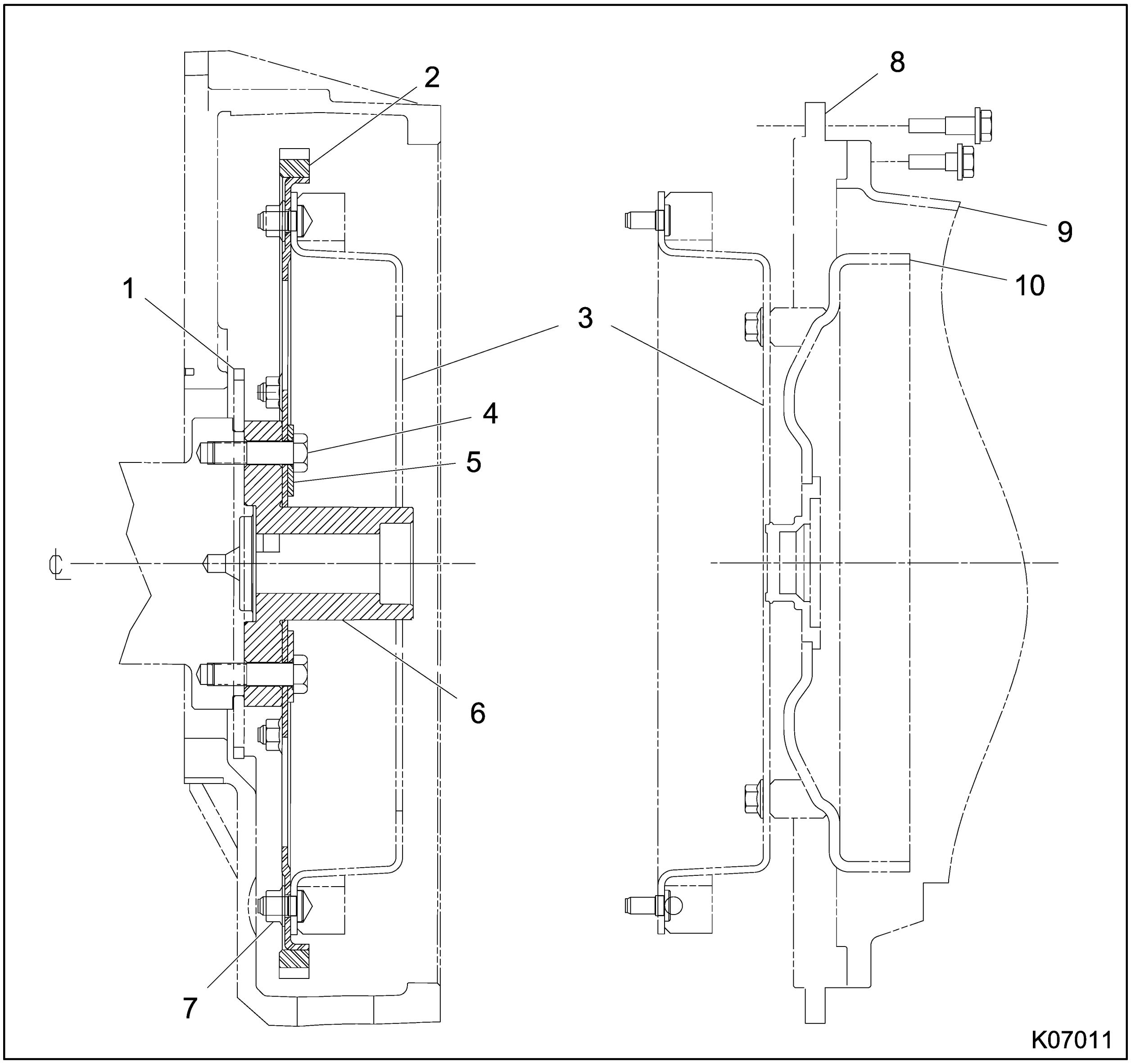


**Figure 422 Application for Allison transmissions**

1. Crankshaft timing disk
2. Ring gear & flex plate assembly
3. Plate assembly, Allison AT transmissions
4. M12 x 43 bolt (12)
5. Reinforcement ring
6. Adapter hub, AT
7. M10 x 1.5 nut
8. Converter adapter ring (SAE #2 to SAE #3 ring)
9. Transmission case
10. Torque converter assembly

## Removal

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

**Flywheel Assembly**

1. Disconnect the negative (ground) cable from the battery.
2. Disconnect the electrical cable and wires from the starter motor.
3. Remove bolts holding the starter motor to the flywheel housing and remove the starter.
4. Remove the transmission and clutch assembly. (See transmission manufacturers service publications.)

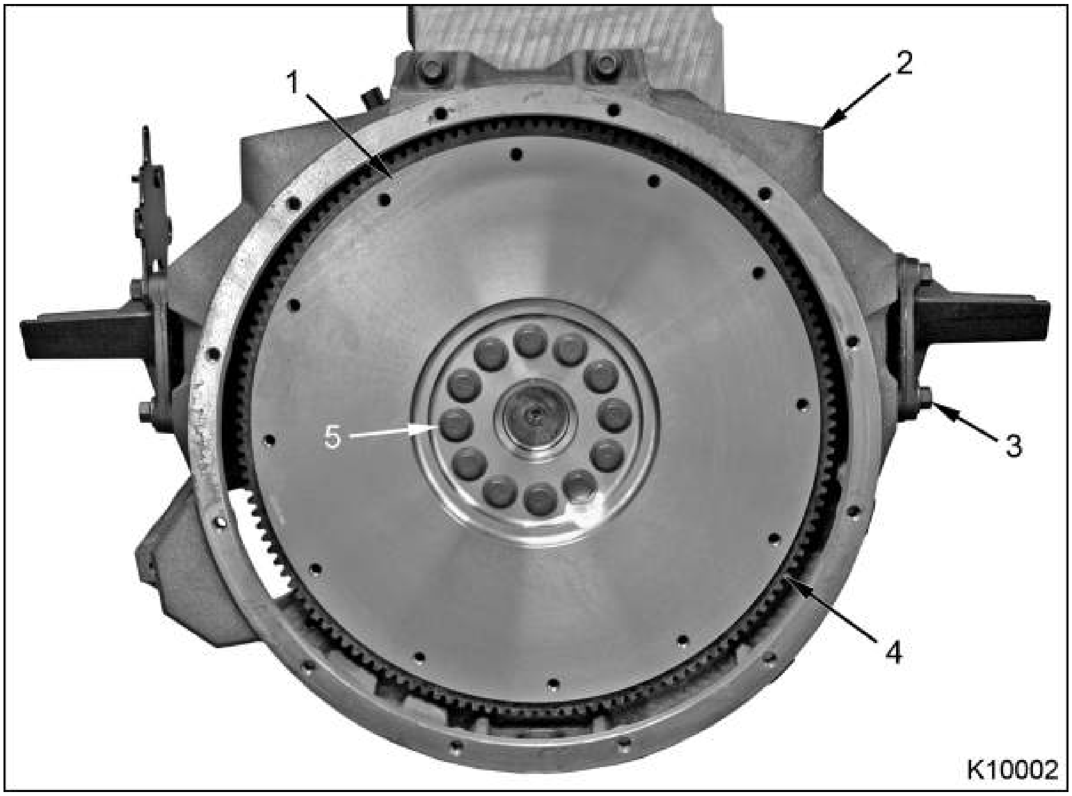


**Figure 423 Flywheel and flywheel housing (typical)**

1. Flywheel assembly (typical)
2. Flywheel housing assembly (typical)
3. M12 x 40 rear engine mount bolt (8)
4. Ring gear
5. M12 x 40 flywheel bolt (12)

**NOTE:** There are two flywheel options for manual transmissions: 138-tooth ring gear and 148-tooth ring gear. For 148-tooth flywheels, loosen the two lowest, rear most M12 x 40 rear engine mount bolts to provide clearance for flywheel removal.

5. Remove two M12 x 40 flywheel bolts, 180° from each other.
6. Install two guide pins (made locally) in place of the two flywheel bolts.
7. Remove remaining ten M12 x 40 flywheel bolts.
8. Carefully slide flywheel out of flywheel housing and off guide pins.
9. Remove guide pins.

**Flexplate (Automatic Transmissions)**

**NOTE:** Flexplate assemblies are available as fully assembled service part assemblies. Typically, there will be no need to disassemble flexplate assemblies.

**Allison 2000 Series Transmissions**

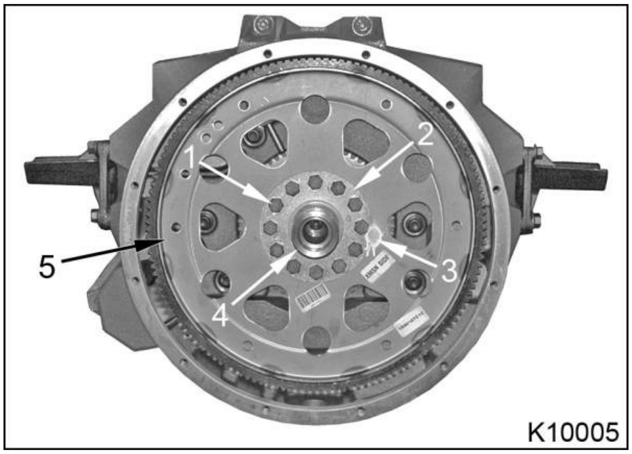


**Figure 424 Flexplate, reinforcement ring, and adaptor hub**

1. M12 x 43 flexplate bolt (12)
2. Reinforcement ring
3. Paint marking index
4. AT adapter hub
5. Flexplate assembly

1. Remove transmission and torque converter assembly. (See transmission manufacturers service publications.)
2. Put a paint mark on the exposed face of the reinforcement ring and flexplate for proper installation orientation.
3. Remove two M12 x 43 flexplate bolts, 180° from each other.
4. Install two guide pins (made locally) in place of two flexplate bolts.
5. Remove remaining ten M12 x 43 bolts.
6. Slide reinforcement ring, flexplate, and adapter hub off guide pins.
7. Remove guide pins.

**MD-3000 Series Transmissions**

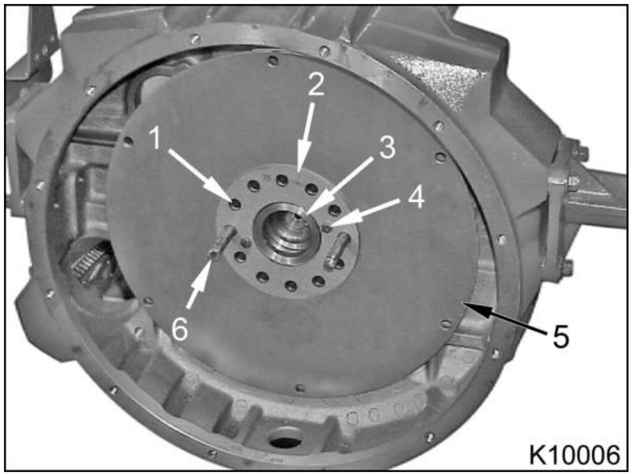


**Figure 425 Flexplate, reinforcement ring, and guide pins**

1. M12 x 45 flexplate bolt hole (12)
2. Reinforcement ring
3. Crankshaft hub adapter
4. M6 flexplate assembly bolt (2)
5. Flexplate assembly
6. Guide pin (2)

1. Remove transmission and torque converter assembly. (See transmission manufacturers service publications.)

**CAUTION:**

**To prevent engine or vehicle damage, do not remove two M6 flexplate assembly bolts.**

2. Remove two M12 x 45 flexplate bolts, 180° from each other.
3. Install two guide pins (made locally) in place of two flexplate bolts.
4. Remove remaining ten M12 x 45 flexplate bolts.
5. Slide flexplate assembly off guide pins.
6. Remove guide pins.

**Crankshaft Timing Disk**

**CAUTION:**

**To prevent engine damage, do not contact the rear oil seal with bolts threaded into the crankshaft timing disk for disk removal. Damage to the rear oil seal could occur resulting in oil leaks.**

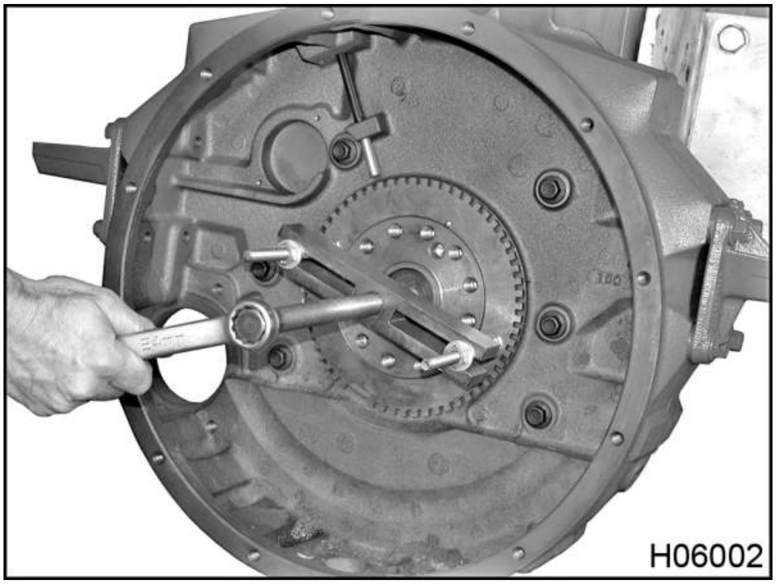


**Figure 426 Crankshaft timing disk removal**

1. Install two bolts and washers through H-bar puller (page 523) and into the crankshaft timing disk. Install bolt heads at equal lengths from the timing disk.
2. Tighten H-bar puller center shaft to pull timing disk off of the crankshaft.

### Rear Oil Seal Assembly

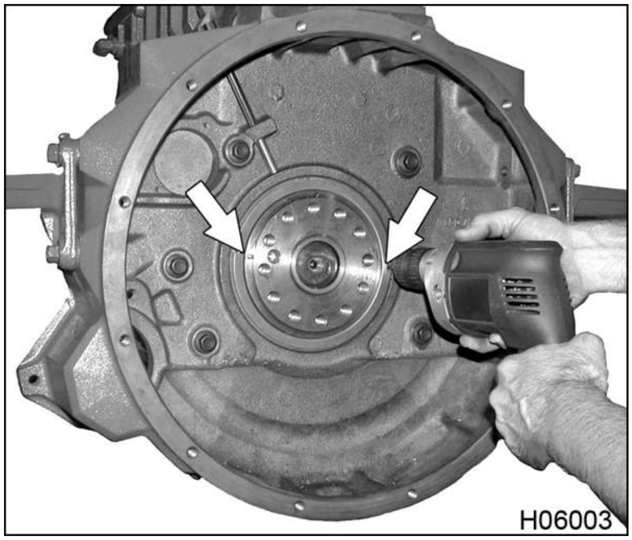


**Figure 427 Drill holes in rear oil seal assembly**

**NOTE:** Use an appropriate size drill bit to fit Slide Hammer Puller screw.

1. Carefully drill two holes approximately 180° from each other in the rear oil seal assembly.

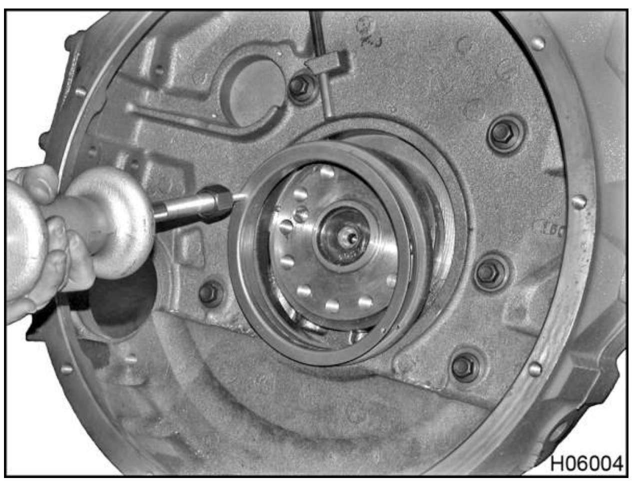


**Figure 428 Rear oil seal assembly and slide hammer**

2. Screw Slide Hammer Puller Set (page 523) screw into holes drilled in the rear oil seal assembly.
3. Alternately pull each side of the rear oil seal out.
4. Remove and discard rear oil seal and wear sleeve.

### Flywheel Housing

1. Remove the oil pan (page 338).

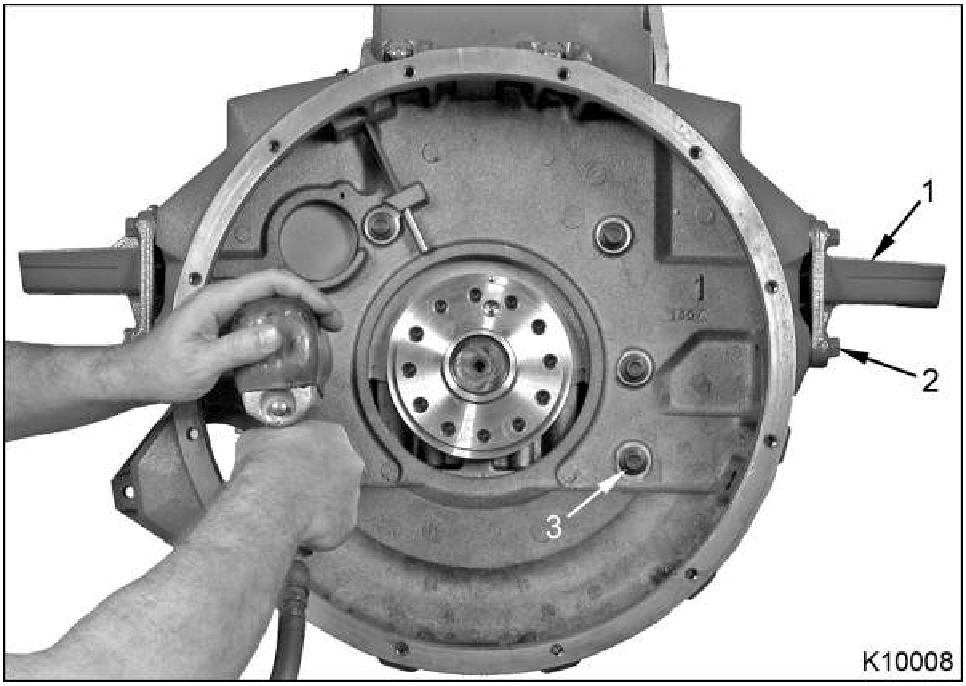


**Figure 429 Flywheel housing removal**

1. Rear engine mounting bracket (2)
2. M12 x 40 rear engine mount bolt (8)
3. M12 x 50 flywheel housing mounting bolt (8)

**WARNING:**

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

2. Properly support the engine and remove eight M12 x 40 rear engine mount bolts and two rear engine mounts.

**WARNING:**

**To prevent personal injury or death, get assistance to remove or install the flywheel housing.**

3. Remove seven M12 x 50 flywheel housing mounting bolts.
4. Support the flywheel housing with help from an assistant.
5. Remove the final M12 x 50 flywheel housing bolt and remove flywheel housing from the crankcase.

## Clean, Inspect, and Measure

**WARNING:**

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

### Clean and Inspect

1. Clean flywheel or flexplate, flywheel housing, and rear engine mounting brackets with a non-caustic solvent and dry with filtered compressed air.
2. Inspect flywheel housing and rear engine mounting brackets for cracks and damage. Replace if required.
3. If equipped, inspect flexplate for cracks, damage, and warpage. Replace if required.
4. If equipped, inspect flywheel for cracks, heat checks, and extensive scoring. Replace or resurface as required.
5. Inspect ring gear for worn, chipped, or cracked teeth. If teeth are damaged, replace the ring gear.
6. Clean and inspect crankshaft and crankcase where flywheel and flywheel housing mount.

### Measure Flywheel Housing Face Runout

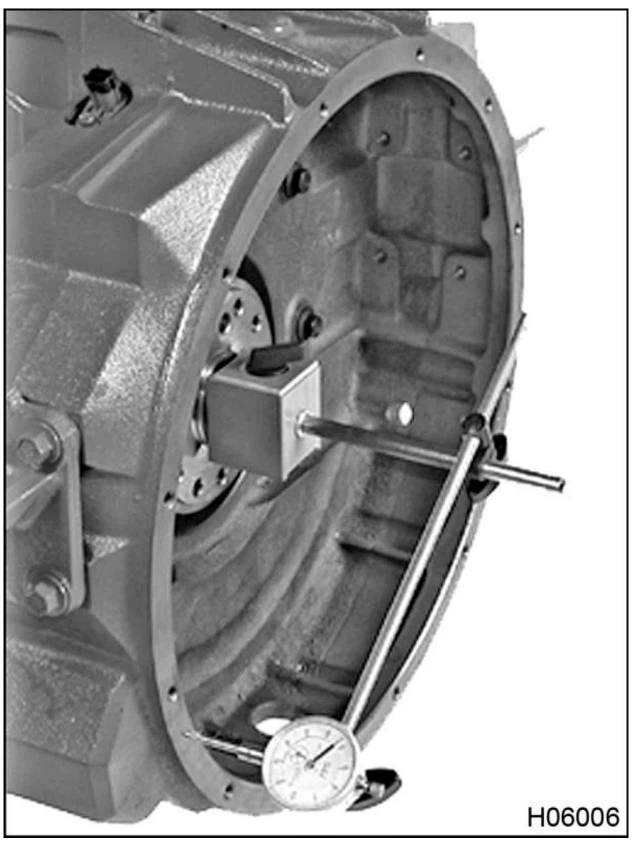


**Figure 430 Flywheel housing face runout measurement**

1. Push the crankshaft in by hand to bring crankshaft end play to zero.
2. Center the magnetic base of a dial indicator set (page 523) on the end of the crankshaft.
3. Place the dial indicator tip against the face of the flywheel housing.
4. Zero dial indicator.
5. Slowly rotate crankshaft 360 degrees while keeping crankshaft end play at zero and observe dial indicator measurements.
6. Compare the total dial indicator variation (highest – lowest reading) to flywheel housing face runout Specifications (page 522).

**Measure Flywheel Housing Bore Concentricity**

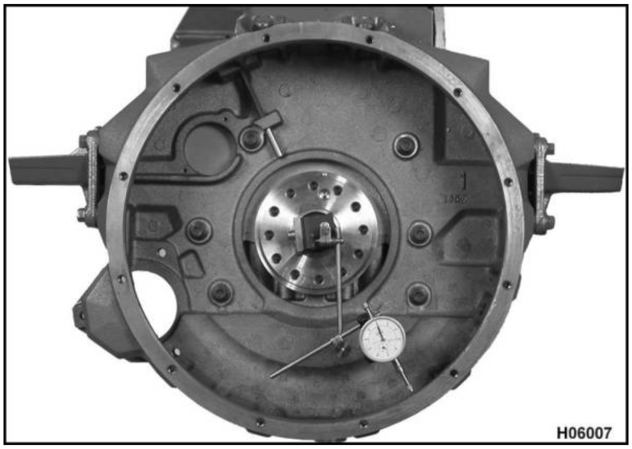


**Figure 431 Flywheel housing bore concentricity measurement**

1. Attach the magnetic base of a dial indicator set (page 523) on the end of the crankshaft.
2. Place the tip of the dial indicator against the flywheel housing bore.
3. Zero the dial indicator.
4. Slowly rotate the crankshaft 360 degrees and observe dial indicator measurements.
5. Compare the total dial indicator variation (highest – lowest reading) to flywheel housing bore concentricity Specification (page 522).

### Measure Crankshaft Pilot Concentricity

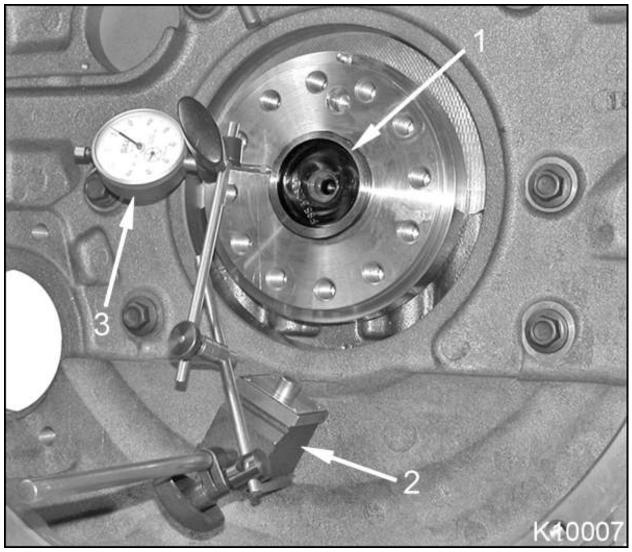


**Figure 432 Crankshaft pilot concentricity measurement**

1. Crankshaft pilot
2. Magnetic base
3. Dial indicator

1. Attach the magnetic base of a dial indicator set (page 523) to the flywheel housing.
2. Place dial indicator tip against the crankshaft pilot outer edge.
3. Zero the dial indicator.
4. Slowly rotate the crankshaft 360 degrees and observe dial indicator measurements.
5. Compare the total dial indicator variation (highest – lowest reading) to crankshaft pilot concentricity Specification (page 522).

**Measure Flywheel Surface Runout**


**Figure 433 Flywheel surface runout measurement**

1. Attach the magnetic base of a dial indicator set (page 523) to the face of the flywheel housing.
2. Place dial indicator tip against the face of the flywheel near the pressure plate mounting holes.
3. Zero the dial indicator.
4. Slowly rotate the crankshaft 360 degrees and observe dial indicator measurements.
5. Compare the total dial indicator variation (highest – lowest reading) to flywheel surface runout Specification (page 522).

## Recondition

### Resurface Flywheel

**NOTE:** Flywheels used with manual transmissions may be resurfaced to correct minor wear and scoring if flywheel is not cracked or damaged and meets minimum thickness specification (page 522).

**WARNING:**

**To prevent personal injury or death, do not machine flywheel beyond minimum thickness specified for flywheel resurfacing.**

**NOTE:** Flywheel resurfacing information is provided for guidance only. International Truck and Engine Corporation assumes no responsibility either for the results of any work performed in accordance with this information or for the ability of service personnel to detect cracks.

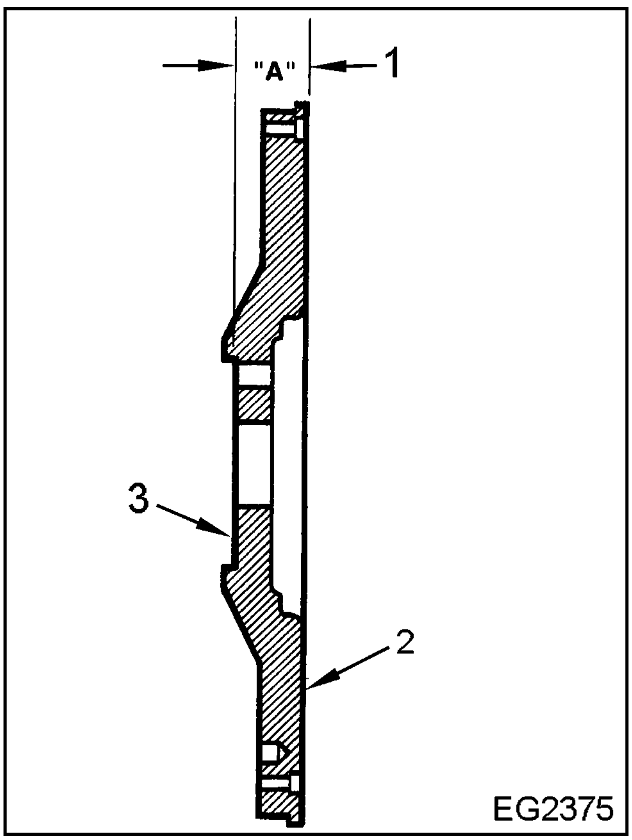


**Figure 434 Flywheel surface dimension (typical)**

1. Flywheel thickness (dimension “A”)
2. Clutch disc mounting face
3. Crankshaft flange mounting face

**WARNING:**

**To prevent personal injury or death, carefully examine flywheel for any cracks or heat checks before and after resurfacing. Cracks in the flywheel can cause it to separate. If there are any questions, do not reuse the flywheel.**

1. Check flywheel for cracks and damage. Replace flywheel if required.
2. Measure flywheel thickness and compare to minimum required thickness Specification (page 522). Discard flywheel if below minimum thickness specification or if flywheel will be below minimum thickness after resurfacing.
3. Resurface flywheel. See flywheel resurfacing machine operators manual for instructions on flywheel resurfacing procedure.
4. Check flywheel for cracks and damage after resurfacing. Replace flywheel if required.
5. Measure flywheel thickness after resurfacing and compare to minimum required thickness Specification. Discard flywheel if below minimum thickness specification.

**Replace Flywheel Ring Gear**

**WARNING:**

**To prevent personal injury or death, wear heat resistant gloves when handling heated components.**

**CAUTION:**

**To prevent engine damage, do not heat ring gear higher than 278 °C (500 °F). Heating beyond this temperature will adversely affect the ring gear hardness.**

1. Evenly heat ring gear with a torch to expand the gear for removal.

**CAUTION:**

**To prevent engine damage, do not hit the flywheel when knocking the ring gear off the flywheel.**

2. After the ring gear is heated, carefully knock the ring gear off the flywheel. Do not hit the flywheel when removing the ring gear.
3. Heat the new ring gear evenly until gear expands enough to slip onto the flywheel.
4. Make sure ring gear is properly seated against flywheel shoulder along the entire radius of the flywheel.

# Installation

**Flywheel Housing and Rear Engine Mounting Brackets**

1. Install a new camshaft rear seal in the back of the crankcase.
2. Install a new flywheel housing seal in the crankcase side of the flywheel housing.

**NOTE:** Verify two hollow dowels are installed in the crankcase side of the flywheel housing before installing the housing.

**WARNING:**

**To prevent personal injury or death, get assistance to remove or install the flywheel housing.**

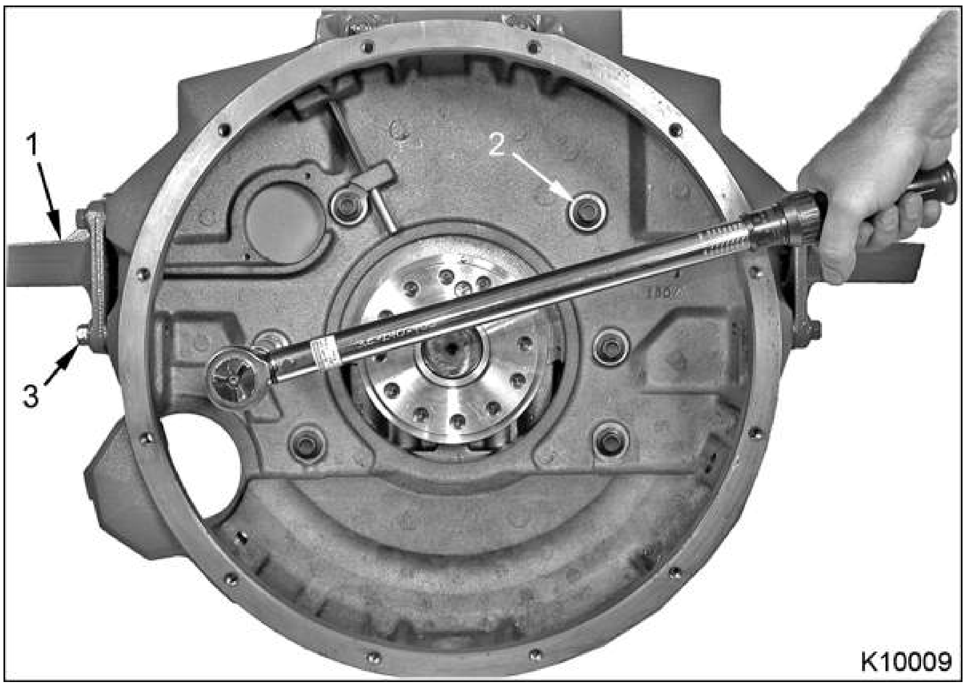


**Figure 435 Flywheel housing installation**

1. Rear engine mounting bracket (2)
2. M12 x 50 flywheel housing bolt (8)
3. M12 x 40 rear engine mount bolt (8)

3. With help from an assistant, lift the flywheel housing into position and align two hollow dowels of the flywheel housing with dowel holes in the crankcase and install one M12 x 50 flywheel housing bolt finger tight.
4. Install seven remaining M12 x 50 flywheel housing bolts finger tight.
5. Tighten eight M12 x 50 flywheel housing bolts to standard torque .

**NOTE:** On engines with a 148-tooth ring gear, leave the lowest, rear most M12 x 40 mounting bracket bolt loose (2 or 3 threads) on each side of the flywheel housing (SAE #1A). This will provide clearance for installation of the flywheel and ring gear assembly.

6. Install two rear engine mounting brackets and finger tighten eight M12 x 40 bolts.

7. Tighten eight M12 x 40 bracket bolts to standard torque.

**Rear Oil Seal**

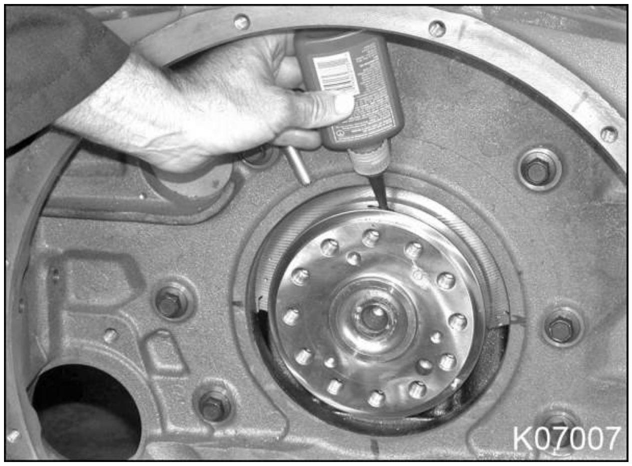


**Figure 436 Application of sealant to crankshaft wear sleeve area**

1. Apply a 360° bead of Loctite® 569 Hydraulic Sealant (page 523) to the crankshaft where the rear oil seal wear sleeve will be positioned.

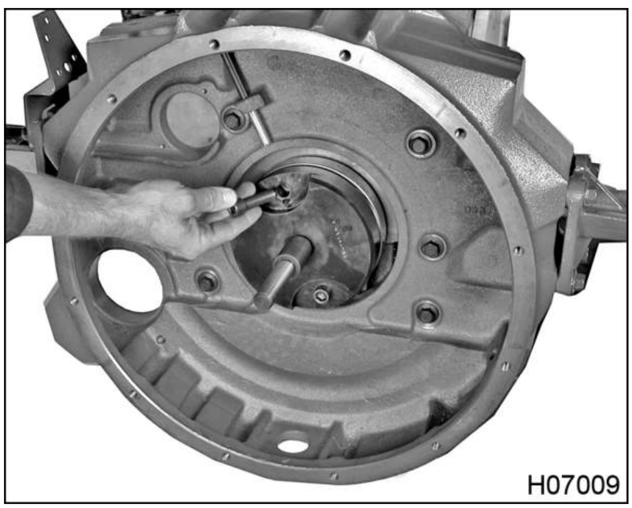


**Figure 437 Rear Seal Installer base**

2. Install base of Rear Seal Installer (page 523) on the crankshaft and tighten two bolts.

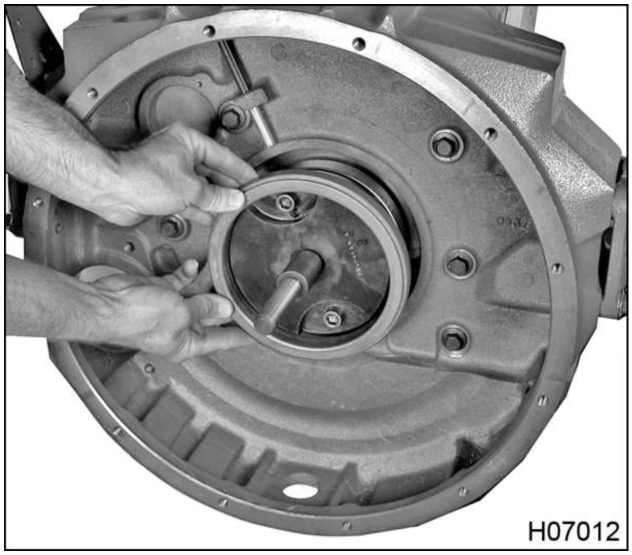


**Figure 438 Rear oil seal installation on base**

3. Turn steel face of rear oil seal outward (towards transmission) and install seal assembly on the Rear Seal Installer base.

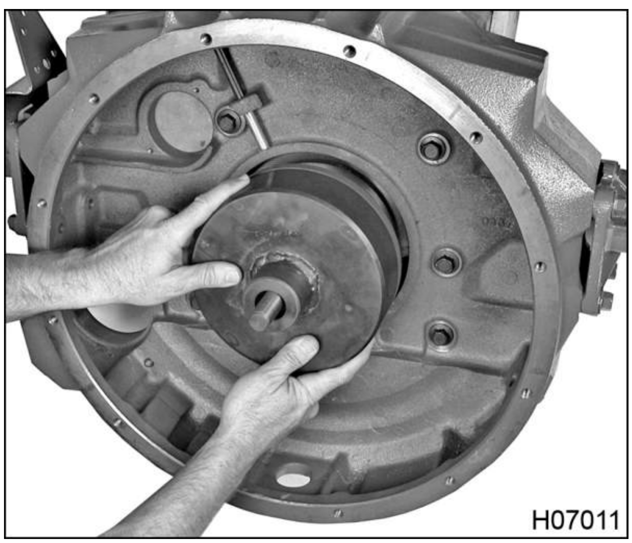


**Figure 439 Rear Seal Installer installation onto base**

4. Install Rear Seal Installer against steel face of rear oil seal and gently push into flywheel housing as far as possible, by hand.

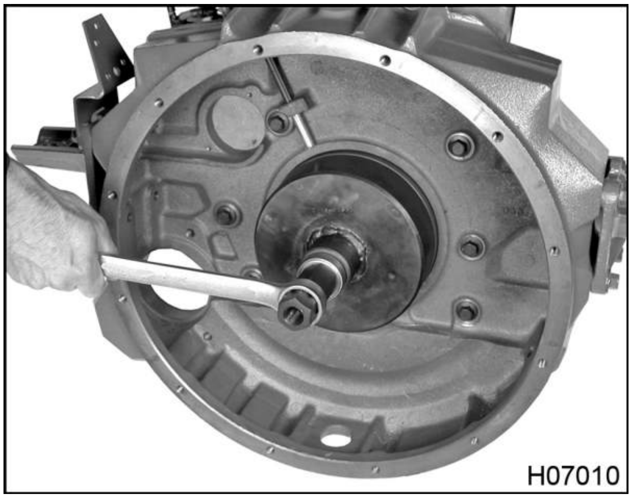

**Figure 440 Rear oil seal installation**

5. Install bearing, washer, and forcing nut on installer shaft.

**CAUTION:**

**To prevent engine damage, do not use air tools to tighten Rear Seal Installer nut.**

6. Tighten forcing nut until rear oil seal installer bottoms out. Rear oil seal assembly will be placed at the correct depth.

**Crankshaft Timing Disk**

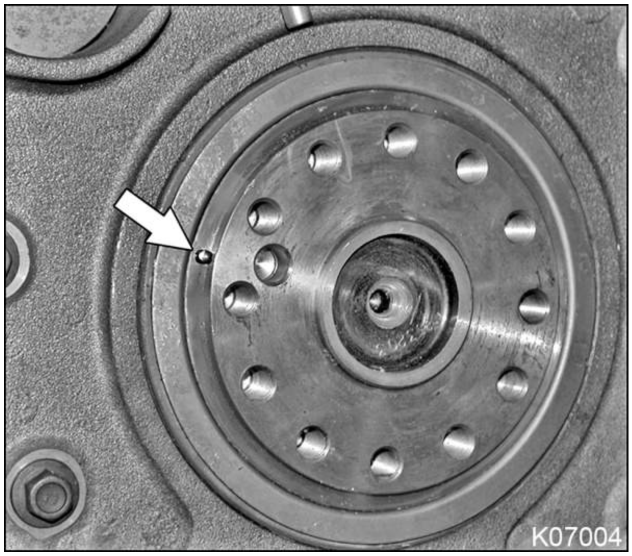


**Figure 441 Crankshaft timing disk alignment spring pin**

**CAUTION:**

**To prevent engine damage, timing disk alignment spring pin must protrude out of the crankshaft.**

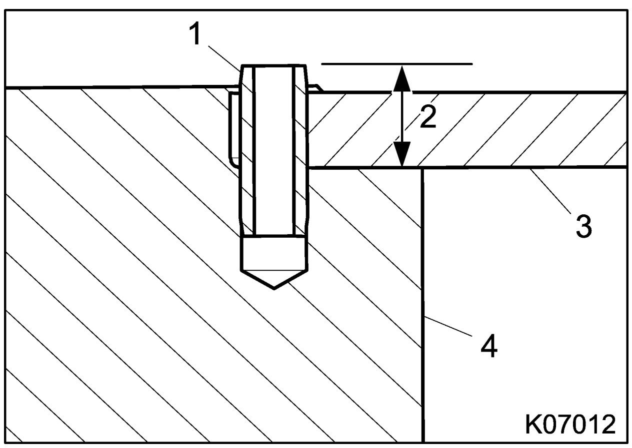


**Figure 442 Crankshaft timing disk alignment spring pin (cut-away)**

1. Slotted spring pin
2. 7.6 mm (0.30 in)
3. Crankshaft timing disk
4. Crankshaft

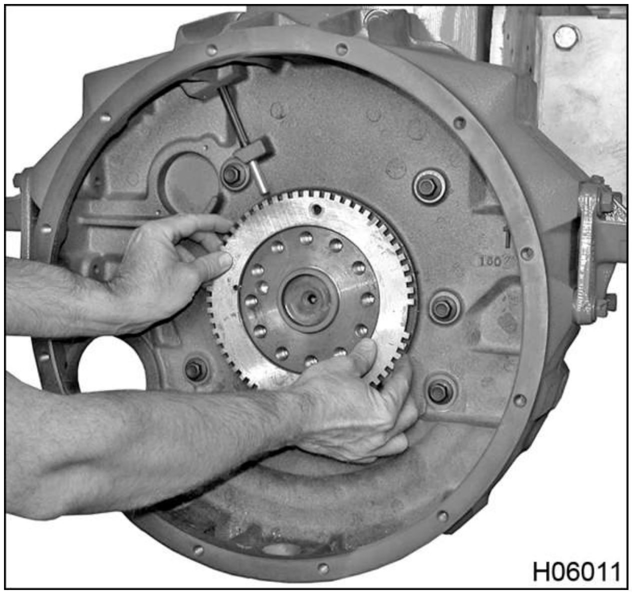


**Figure 443 Crankshaft timing disk installation**

**NOTE:** Crankshaft timing disk can be installed with either side out.

1. Align index notch of the crankshaft timing disk with crankshaft timing disk alignment pin.
2. Use a rubber mallet to carefully tap the crankshaft timing disk onto the crankshaft. Tap evenly around the crankshaft timing disk to ensure a flush fit against the end of the crankshaft.

**NOTE:** Rear Seal Installer (page 523) can be used to press the crankshaft timing disk onto the crankshaft.

**Flywheel Assembly**

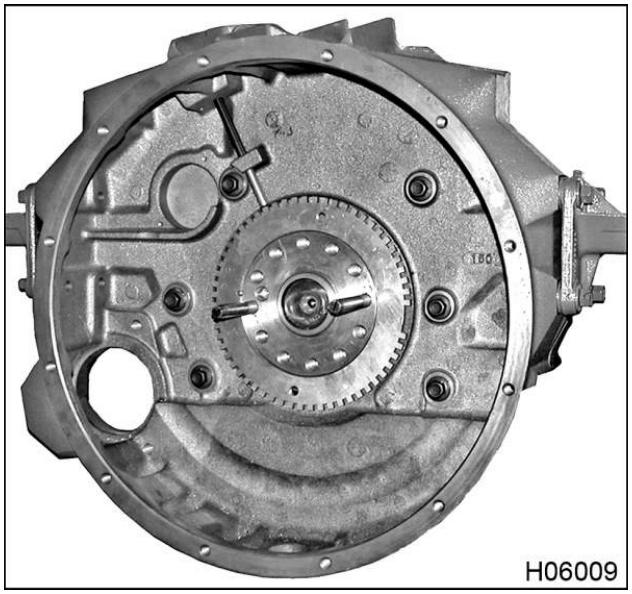


**Figure 444 Guide pins for flywheel installation**

1. Install two guide pins (made locally) in the flywheel mounting bolt holes, 180° from each other.
2. Install flywheel over the guide pins.
3. Install ten M12 x 40 flywheel mounting bolts finger tight.
4. Remove two guide pins and install remaining two M12 x 40 flywheel mounting bolts finger tight.

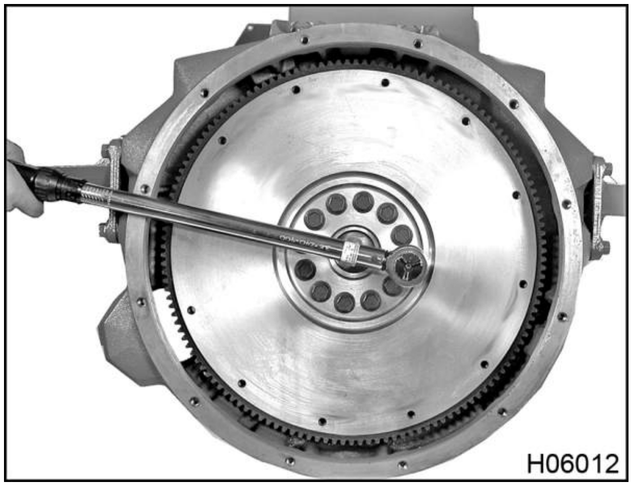


**Figure 445 Flywheel mounting bolts (typical)**

5. Tighten flywheel mounting bolts to special torque (page 523).
6. Tighten two remaining rear engine mounting bracket bolts on manual transmission applications with 148-tooth ring gears to standard torque .
7. Measure Flywheel Surface Runout (page 507).

**Flexplate (Automatic Transmissions)**

**Allison 2000 Series Transmissions**

**CAUTION:**

**To prevent engine damage, if the vehicle is being re-configured with an Allison 2000 Series transmission, make sure the correct flywheel housing is installed on the engine. Otherwise, there will be interference between the flexplate studs and the flywheel housing that will only be evident after the transmission has been installed.**

1. Install two guide pins (made locally) in flexplate mounting bolt holes, 180° from each other.

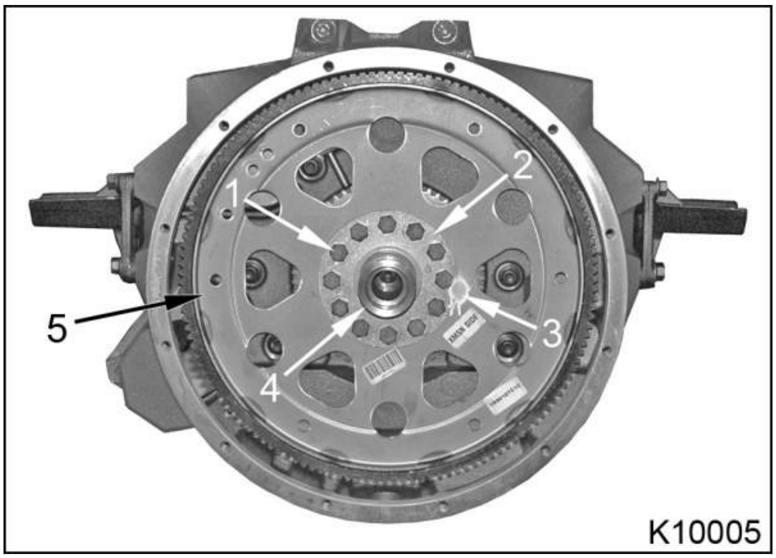


**Figure 446 Adaptor hub, flexplate, and reinforcement ring**

1. M12 x 43 flexplate bolt (12)
2. Reinforcement ring
3. Paint marking index
4. AT adapter hub
5. Flexplate assembly

2. Install AT adapter hub on guide pins.

**NOTE:** When installed correctly, the ring gear of the flexplate is offset (not centered) toward the transmission.

3. Install flexplate assembly on the guide pins.

**CAUTION:**

**To prevent engine damage, make sure the reinforcement ring is installed with the paint mark or XMSN SIDE facing outward (towards the transmission), otherwise, premature flexplate failure may occur.**

4. Install reinforcement ring on the guide pins with paint mark (or XMSN SIDE) facing outward.
5. Install ten M12 x 43 flexplate bolts finger tight.
6. Remove guide pins and install remaining two M12 x 43 flexplate bolts finger tight.

7. Tighten twelve M12 x 43 flexplate bolts to special torque (page 523).

### MD-3000 Series World Transmissions

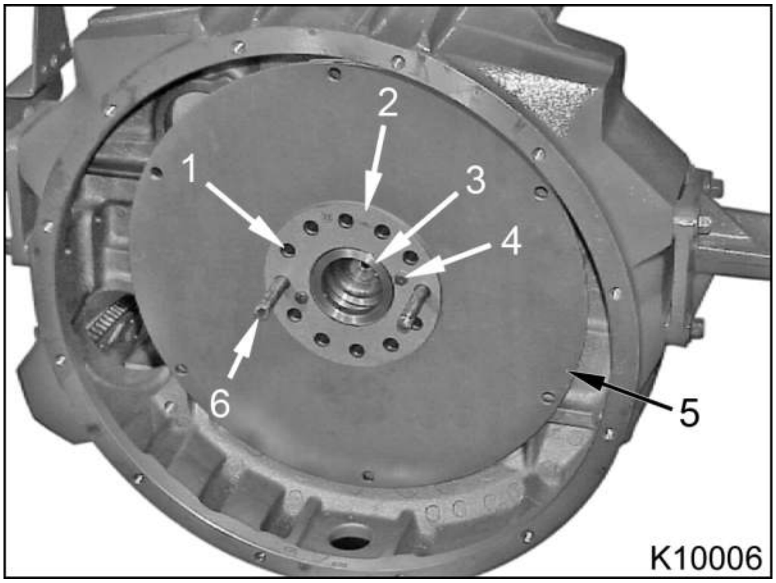


**Figure 447 Flexplate assembly**

1. M12 x 45 flexplate bolt hole (12)
2. Reinforcement ring
3. Crankshaft hub adapter
4. M6 flexplate assembly bolt (2)
5. Flexplate assembly
6. Guide pin (2)

1. Install two guide pins (made locally) in flexplate mounting bolt holes, 180° from each other.

**CAUTION:**

**To prevent engine damage, make sure the paint mark, part number, or XMSN SIDE on the flexplate is facing outward (towards the transmission).**

**NOTE:** The flexplate assembly is available as a complete assembled service part.

2. Install flexplate assembly over the guide pins.

**NOTE:** The following step applies to MD transmissions only.

3. Install reinforcement ring with part number or logo facing out (towards the transmission).
4. Install ten M12 x 45 flexplate bolts finger tight.
5. Remove guide pins and install remaining two M12 x 45 flexplate bolts finger tight.
6. Tighten M12 x 45 flexplate bolts to special torque (page 523).

**NOTE:** Flywheel and ring gear are part of the torque converter assembly.

## Specifications

**WARNING:**

**To prevent personal injury or death, do not machine flywheel beyond minimum thickness specified for flywheel resurfacing.**

**WARNING:**

**To prevent personal injury or death, carefully examine flywheel for any cracks or heat checks after resurfacing. Any cracks or heat checks in the flywheel could cause it to separate. If there are any questions, do not reuse the flywheel.**

**NOTE:** Flywheel resurfacing information is provided for guidance only. International Truck and Engine Corporation assumes no responsibility either for the results of any work performed in accordance with this information or for the ability of service personnel to detect cracks.

| | |
|---|---|
| **Flywheel housing:** | |
| Flywheel housing bore concentricity | SAE # 1 = 0.30 mm (0.012 in) |
| | SAE # 2 = 0.28 mm (0.011 in) |
| Flywheel housing face runout | SAE # 1 = 0.30 mm (0.012 in) |
| | SAE # 2 = 0.28 mm (0.011 in) |
| **Crankshaft pilot:** | |
| Crankshaft pilot concentricity | 0.13 mm (0.005 in) |
| **Flywheel:** | |
| Flat flywheel surface runout maximum (measure at 17.8 cm (7 in) from center) | 0.20 mm (0.008 in) |
| Pot flywheel surface runout maximum (measure at 16.5 cm (6.5 in) from center) | 0.20 mm (0.008 in) |
| Pot flywheel clutch mounting surface runout maximum | 0.30 mm (0.012 in) |

**Flywheel Resurfacing Specifications**

| | |
|---|---|
| Flat flywheel minimum thickness after resurfacing | 36.32 mm (1.430 in) |
| Pot flywheel minimum thickness after resurfacing | 39.37 mm (1.550 in) |

**NOTE:** Requires measurement from crankshaft mounting surface of flywheel to clutch surface of flywheel.

## Special Torque

| | |
|---|---|
| M12 flexplate mounting bolts | 136 N·m (100 lbf·ft) |
| M12 flywheel mounting bolts | 136 N·m (100 lbf·ft) |

## Special Service Tools

| | |
|---|---|
| Dial indicator set | Obtain locally |
| Guide pins | Obtain locally |
| H-bar puller | Obtain locally |
| Loctite® 569 Hydraulic Sealant | Obtain locally |
| Rear Seal Installer | ZTSE4637 |
| Slide Hammer Puller Set | ZTSE1879 |

# Table of Contents

## Exploded View and Description

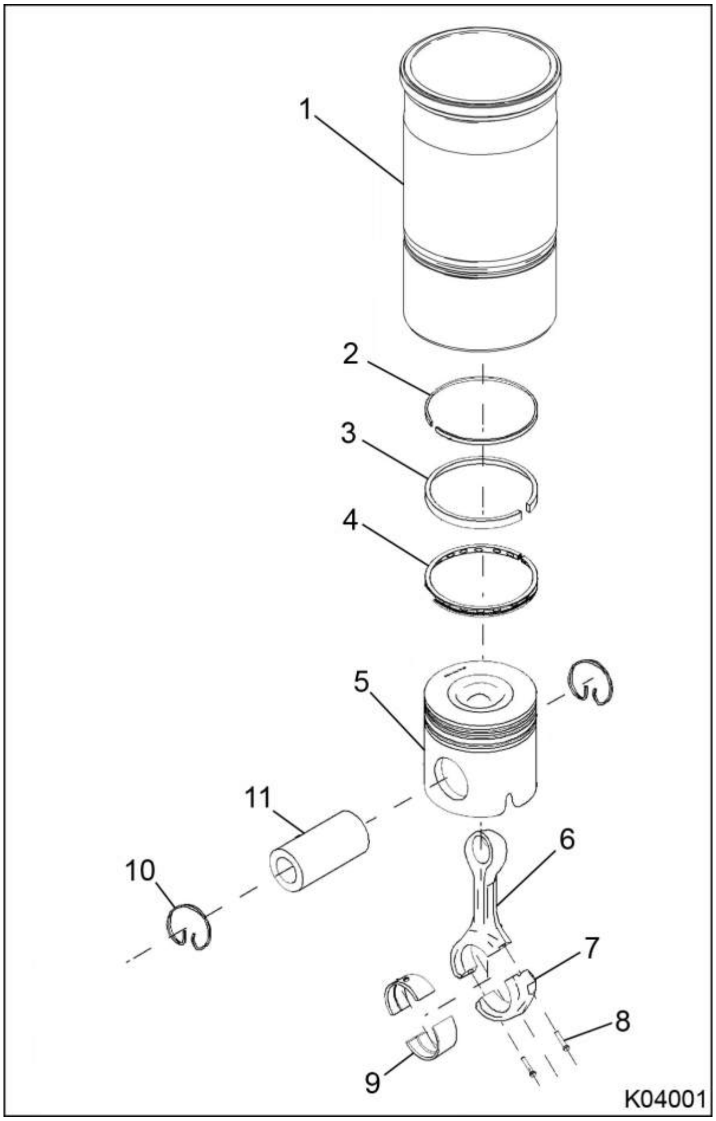


**Figure 448 Cylinder, piston, rings, and connecting rod (typical)**

1. Cylinder sleeve
2. Top compression ring
3. Intermediate compression ring
4. Oil control ring
5. Piston
6. Connecting rod
7. Connecting rod cap
8. Connecting rod bolt (2)
9. Connecting rod bearing (2)
10. Retaining ring (2)
11. Piston pin

Six removable cylinder sleeves are installed in the crankcase.

Pistons are one-piece cast aluminum or one-piece forged steel and use floating piston pins.

Piston cooling tubes spray oil on the bottom of the pistons for cooling and lubrication.

Three rings are installed on each piston to seal the combustion chamber and to control oil on the cylinder walls.

Connecting rods have a fractured surface at the connecting rod cap bolted joint (big end). These are matched mated surfaces and are not interchangeable.

## Removal

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

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

**CAUTION:**

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

**Piston Cooling Tubes**

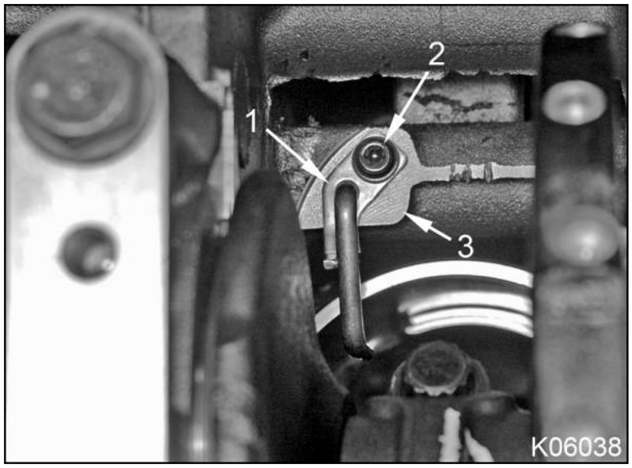


**Figure 449 Piston cooling tube**

1. Piston cooling tube (6)
2. M6 x 12 bolt (6)
3. Crankcase piston cooling tube mounting pad (6)

**NOTE:** The crankshaft may need to be rotated to access some piston cooling tubes.

1. Remove and discard six M6 x 12 bolts, securing the piston cooling tubes to the crankcase.
2. Remove piston cooling tubes and discard O-rings.

**Piston and Connecting Rod Assembly**

**CAUTION:**

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

**NOTE:** If a carbon ridge has developed on the top of the cylinder sleeve, remove the cylinder sleeve and piston as an assembly and then remove the piston from the bottom of the cylinder sleeve.

1. Measure Piston Protrusion (page 539).

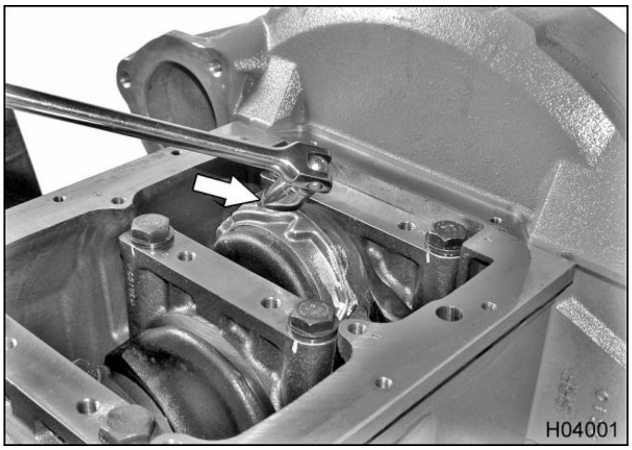


**Figure 450 Connecting rod bolt removal**

2. Loosen both connecting rod bolts. Leave bolts attached to the connecting rod.
3. Push connecting rod bolts down to separate connecting rod from crankshaft journal.

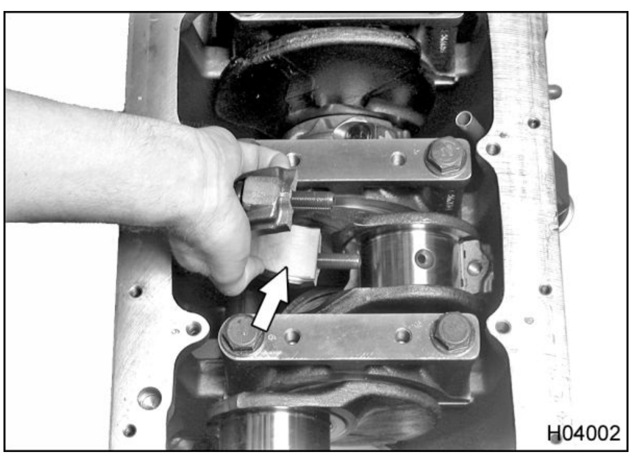


**Figure 451 Connecting rod cap and bolts removal**

4. Remove connecting rod cap and bolts.

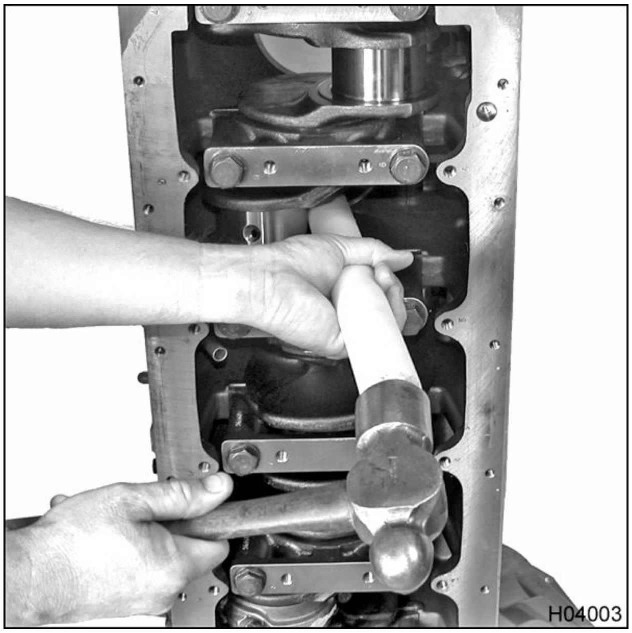


**Figure 452 Piston and connecting rod assembly removal**

**CAUTION:**

**To prevent engine damage, do not push on the connecting rod fractured surface.**

5. Push the piston out of the cylinder sleeve using a hammer with a plastic or wooden handle or a non-marring punch. Do not push on the connecting rod fractured surface.

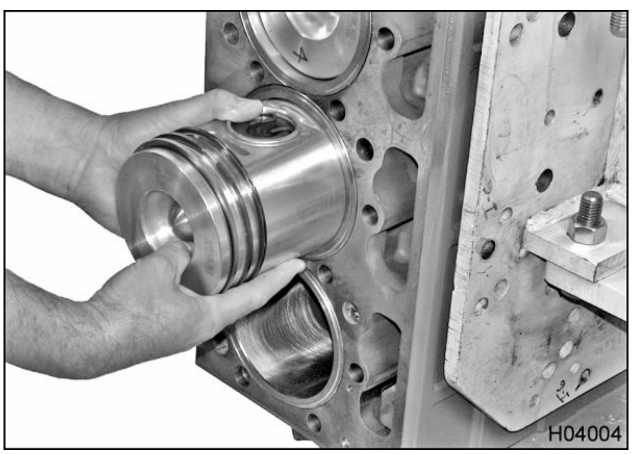


**Figure 453 Piston and connecting rod assembly removal (typical)**

6. When the piston rings are free of the cylinder sleeve, remove the assembly from the top of the crankcase.

**CAUTION:**

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

7. Mark each piston, connecting rod, and cap with its cylinder number. Also mark the front of each piston as it was installed in the engine.
8. Install each connecting rod cap on its matched connecting rod and finger tighten connecting rod cap bolts to protect connecting rod fractured surface.

**NOTE:** Each piston, connecting rod, and cylinder sleeve can be removed together without removing the piston from the cylinder sleeve. Remove the cylinder head and connecting rod cap and then carefully drive the cylinder sleeve straight out using a wood block and a hammer. Be careful not to damage the piston cooling tubes.

### Piston Pin and Rings


**Figure 454 Piston pin retaining ring removal (typical)**

**WARNING:**

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

1. Use pliers to contract the piston pin retaining rings. Remove two piston pin retaining rings.

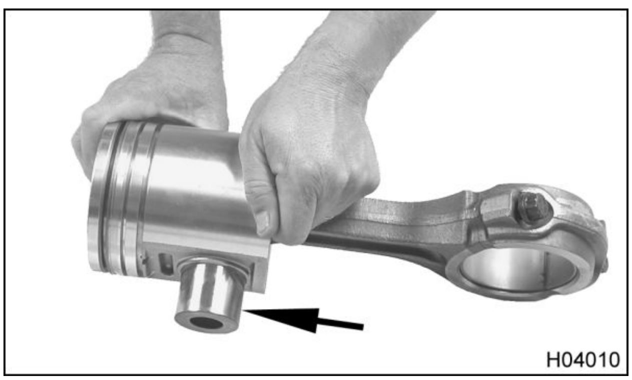


**Figure 455 Remove piston pin (typical)**

2. Push the piston pin out of the piston and connecting rod, by hand.
3. Separate the piston from the connecting rod. Mark the front of the piston pin with its cylinder number.


**Figure 456 Piston ring removal (typical)**

4. Use a Piston Ring Expander (page 587) to expand each piston ring and remove rings from the pistons.

**Cylinder Sleeve**

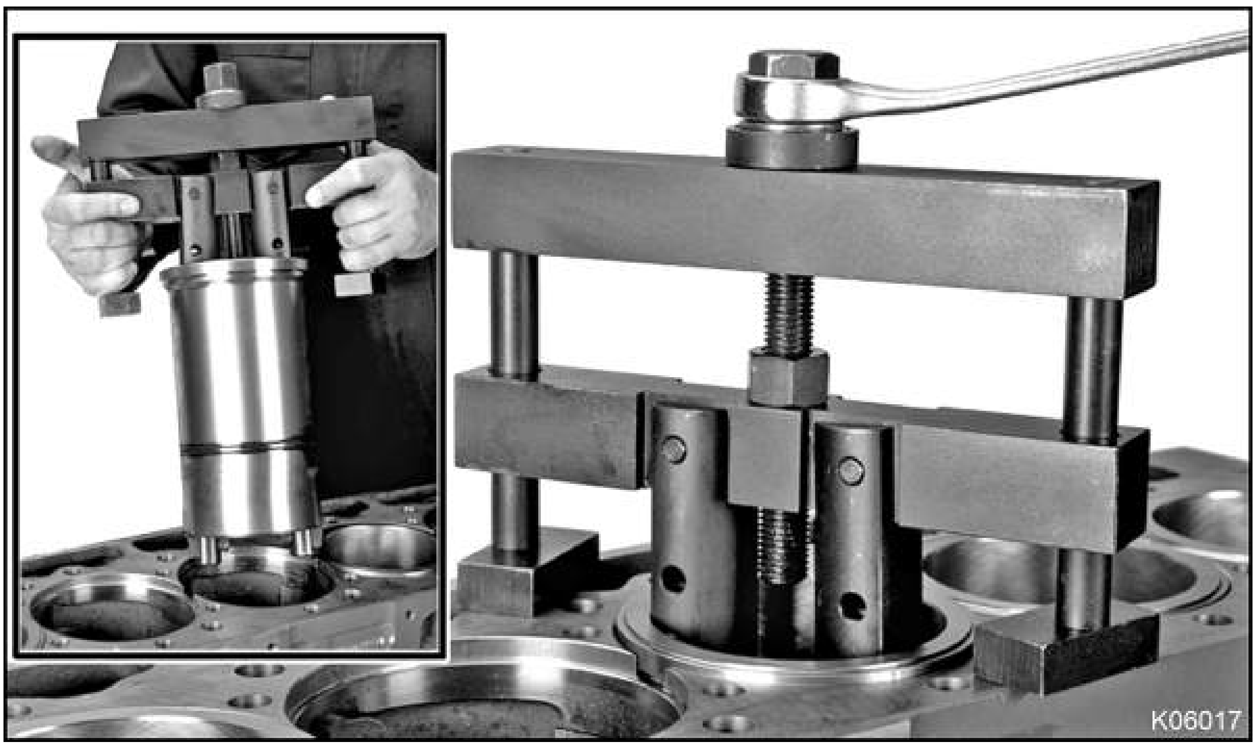


**Figure 457 Cylinder sleeve removal**

**CAUTION:**

**To prevent engine damage, before installing the Cylinder Sleeve Puller in each cylinder, rotate the crankshaft so the crankshaft journal is at the bottom (low point) of its travel. This can prevent damage to the journal during puller installation.**

**CAUTION:**

**To prevent engine damage, be careful not to damage the piston cooling tubes when installing or removing the Cylinder Sleeve Puller.**

**NOTE:** When removing the sleeve from the puller, mark the sleeve with its cylinder number. Also mark the sleeve position in the crankcase for inspection and assembly.

1. Position the Cylinder Sleeve Puller (page 587) in the cylinder sleeve and spread the lifting jaws so the tangs grip the bottom of the sleeve.
2. With the Cylinder Sleeve Puller lifting bridge squarely on the crankcase deck surface, turn the center shaft bolt to pull the cylinder sleeve out of the crankcase.
3. Lift sleeve and puller out of the crankcase.
4. Use a pick to remove the crevice seal at the lower counterbore area of each cylinder sleeve. Discard crevice seal.

## Cleaning, Inspection, and Measurement

### Clean and Inspect

**CAUTION:**

**To prevent engine damage, do not use caustic solvent, wire brushes, or media blasting to clean pistons.**

1. Soak pistons in a soap and water solution and clean with a non-metallic brush.
2. Scrub piston ring grooves thoroughly. Make sure the oil drain holes in the oil ring grooves are not blocked.
3. Inspect pistons for cracks, excessive wear, and worn ring lands. Replace damaged pistons if required.

**CAUTION:**

**To prevent engine damage, do not clean the fractured mating surfaces of connecting rods.**

4. Use a suitable solvent and a non-metallic brush to clean the connecting rods and caps, piston rings, pins, and cylinder sleeves.
5. Inspect piston pins for damage, nicks, and excessive wear. Replace piston pins if required.

**CAUTION:**

**To prevent engine damage, do not mix connecting rods with M12 bolts (Figure 494) and connecting rods with M11 bolts (Figure 495) in the same engine. If one or more connecting rods must be replaced make sure all connecting rods in each engine are the same type.**

6. Clean the connecting rod bolt holes and threads. Do not tap the connecting rod bolt holes. Inspect the finished surface of the connecting rod bearing bore for nicks, burrs, and scoring. Replace the connecting rod if required.
7. Inspect cylinder sleeves for excessive wear, scoring, and cracks. Replace damaged cylinder sleeves if required.
8. Clean crankcase crevice seal bore area of any scale, deposits, or sealant.

### Piston Protrusion Measurement

**NOTE:** Install cylinder Sleeve Protrusion Hold Down Clamps with 10.9 or higher grade bolts finger tight.

1. Tighten cylinder sleeve holding adaptor bolts to 55 N·m (40 lbf·ft).
2. Tighten cylinder sleeve holding adaptor bolts to 110 N·m (80 lbf·ft).
3. Place Cylinder Liner Height Gauge on the crankcase deck.
4. Place Cylinder Liner Height Gauge indicator tip on the crankcase deck and zero the dial indicator.
5. Bring piston to be measured to TDC.
6. Depress indicator plunger and slide Cylinder Liner Height Gauge to allow indicator tip to rest on piston top flat surface as close to area above the wrist pin as possible.

7. Hold Cylinder Liner Height Gauge and slightly bar engine fore and aft to measure maximum piston protrusion above crankcase deck.

### Measure Pistons

#### Measure Top Compression Ring Grooves

**Piston Ring Gauge Pin Selection Table**

| Engine Rating | Ring / Groove Type | Gauge Pin Diameter |
|---|---|---|
| All MaxxForce® DT series engines | Top / keystone cross section | 2.885 mm (0.1136 in) |
| All MaxxForce® 9 and 10 series engines | Top / keystone cross section | 2.70 mm (0.1063 in) |


**Figure 458 Piston ring groove measurement (top / keystone cross section)**

1. Install Piston Gauge Pins (page 587) in the top compression ring groove. Make sure the gauge pins are parallel.
2. With pistons at room temperature 20 °C (68 °F) measure the diameter of the piston over the gauge pins using an outside micrometer (page 587).
3. If the top compression ring groove measurement exceeds Specifications (page 584) replace the piston.

**Measure Intermediate and Oil Control Ring Groove**


**Figure 459 Measure ring groove (typical)**

1. Place the edge of a new intermediate compression ring in the middle piston ring groove. Roll the intermediate compression ring all the way around the piston ring groove to ensure the ring is free in its groove.
2. With the edge of the intermediate compression ring in the piston intermediate compression ring groove, use a feeler gauge (page 587) to measure clearance between the ring and groove.

   If the intermediate compression ring clearance exceeds Specification (page 584), replace the piston.
3. Place the edge of a new oil control ring in the oil control ring groove. Roll the oil control ring all the way around the piston to ensure the ring is free in its groove.
4. With the edge of the oil control ring in the piston oil ring groove, use a feeler gauge (page 587) to measure clearance between the ring and groove.

   If the oil control ring clearance exceeds Specification (page 584), replace the piston.

### Measure Piston-to-Cylinder Sleeve Running Clearance


**Figure 460 Measure piston skirt diameter (typical)**

1. With pistons at room temperature 20 °C (68 °F), use an outside micrometer (page 587) to measure piston skirt diameter. Place micrometer 90 degrees from the piston pin bore.
   - For MaxxForce® DT aluminum pistons take skirt diameter measurement 28 mm (1.1 in) from the bottom of the piston skirt.
   - For MaxxForce® 9 and 10 steel pistons take skirt diameter measurement 12 mm (0.47 in) from the bottom of the piston skirt.
2. Subtract the piston skirt diameter from the inside diameter of the cylinder sleeve. See Measure Cylinder Sleeves (page 553). The result is the running clearance between the piston and the cylinder sleeve.

   **NOTE:** Piston to Cylinder Sleeve Running Clearance = Cylinder Sleeve Inside Diameter – Piston Skirt Diameter
3. If piston to cylinder sleeve running clearance is not within Specification (page 584) recheck piston and cylinder sleeve measurements and specifications and replace the part that is out of specification.

**Measure Piston Rings**

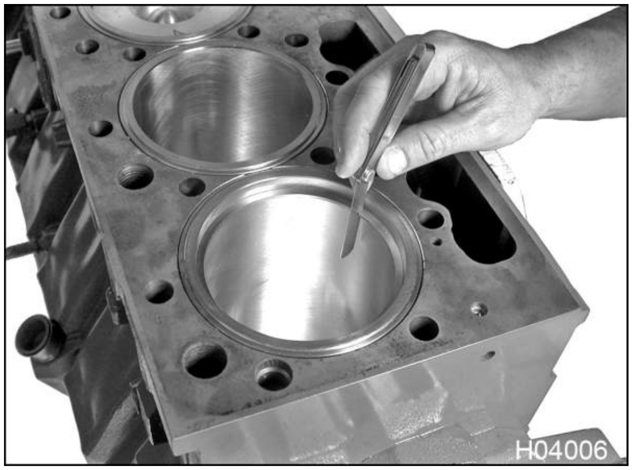


**Figure 461 Piston ring end gap measurement**

**NOTE:** The top of a piston can be used to push piston ring down in the cylinder sleeve to insure ring is squarely positioned in the sleeve.

1. Install each piston ring into its cylinder bore. Make sure the ring is perpendicular to the cylinder wall. If measuring used rings, install ring just below the top of piston ring travel.
2. Use a feeler gauge (page 587) to measure the end gap between the ends of each piston ring.

   Discard any piston ring that does not meet Specifications (page 584).

**NOTE:** If any piston ring is replaced, replace all piston rings and the cylinder sleeve for that cylinder.

**Measure Piston Pins**


**Figure 462 Piston pin measurement**

1. Use an outside micrometer (page 587) to measure the diameter of the each piston pin at two locations.
2. If the diameter of any piston pin is less than minimum Specification (page 584), replace the piston pin.
3. Measure each piston pin bore.

4. Calculate piston pin clearance. Subtract the diameter of the piston pin from the inside diameter of the piston pin bore.

   **NOTE:** Piston Pin Clearance = Piston Pin Bore Inside Diameter – Piston Pin Diameter

5. If piston pin clearance in piston exceeds Specifications (page 584), replace the connecting rod.

### Measure and Inspect Connecting Rods

**CAUTION:**

**To prevent engine damage, do not mix connecting rods with M12 bolts (Figure 494) and connecting rods with M11 bolts (Figure 495) in the same engine. If one or more connecting rods must be replaced make sure all connecting rods in each engine are the same type.**

### Measure Piston Pin Bushing


**Figure 463 Piston pin bushing measurement**

1. Measure the inside diameter of the piston pin bushing at two locations, 90 degrees apart, using a telescoping gauge (page 587).
2. Measure telescoping gauge measurements with an outside micrometer and compare to piston pin bushing inside diameter Specification (page 584).
3. Replace connecting rod if piston pin bushing is out of specification.

**Inspect Connecting Rod Bolt Holes**

1. Lubricate threads of connecting rod bolts with clean engine oil. Match serial numbers on the connecting rod and rod cap (on same side of fractured rod).
2. Install the connecting rod cap on the connecting rod, without the connecting rod bearings, and install new connecting rod cap bolts by hand. If you feel resistance, reclean the bolt holes in the connecting rod. If bolts do not turn in freely, replace the connecting rod. The threads in the bolt holes cannot be tapped.

### Measure Connecting Rod Bearing Bore (Big End)

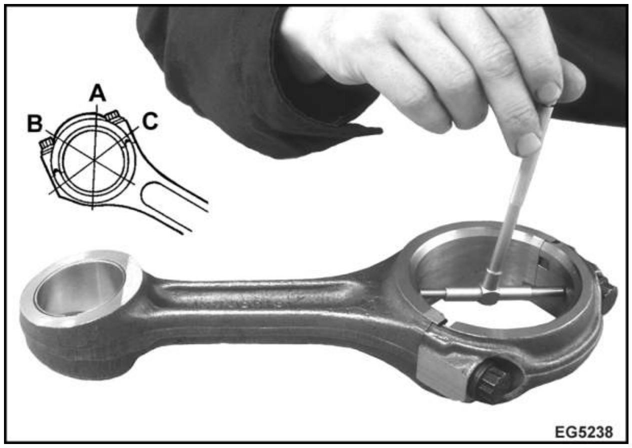


**Figure 464 Connecting rod bearing bore out-of-round measurement**

1. Measure the inside diameter of each connecting rod bearing bore at three locations 60 degrees apart, using an inside micrometer (page 587).

   If the difference between measurement B and the average of measurements A and C exceeds out-of-round Specification (page 584), replace the connecting rod.


**Figure 465 Connecting rod bearing bore taper measurement**

2. Use a telescoping gauge and an outside micrometer (page 587), measure the inside diameter of the connecting rod bearing bore at the edge of each side of the bore.

   If the difference between the two measurements exceeds bore taper Specification (page 584), replace the connecting rod assembly.

### Connecting Rod Bend and Twist

Engine component wear patterns can often be identified and used to diagnose problems. Some common examples of connecting rod wear patterns include:

- A shiny surface on the edge of the piston pin bore usually indicates that a connecting rod is bent or a piston pin hole is not positioned properly in relation to the piston skirt and piston ring grooves.
- Abnormal wear on the connecting rod bearing may indicate that a connecting rod is bent or the bearing bore is excessively tapered.
- A twisted connecting rod will not create an easily identifiable wear pattern, although severely twisted connecting rods will disturb the action of the entire piston and connecting rod assembly and may be the cause of excessive oil consumption.

If any of these conditions exist, use a suitable alignment fixture to check the connecting rod for bends and twists. Follow the instructions of the alignment fixture manufacturer. If bend or twist exceeds Specification (page 584), replace the connecting rod.

### Bearing Fitting Procedures

**CAUTION:**

**To prevent engine damage, do not attempt to reduce journal-to-bearing running clearance by reworking the connecting rod bearing cap or the bearings. Grind the crankshaft to the next available under size or replace the crankshaft.**

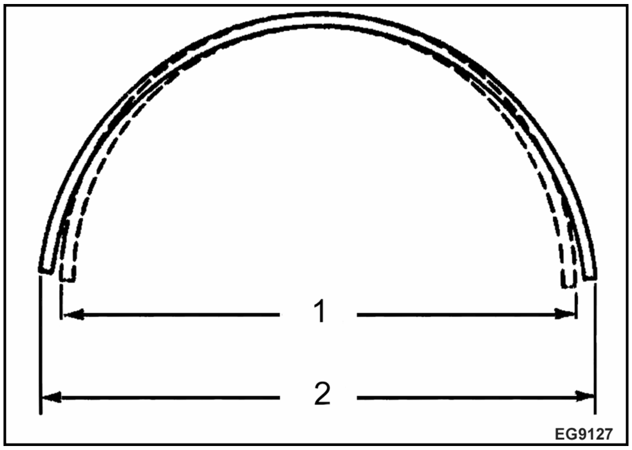


**Figure 466 Effects of bearing crush**

1. Diameter at open ends after bearing crush load
2. Diameter at open ends before bearing crush load

**NOTE:** Connecting rod bearings must fit tightly in the connecting rod bore. When bearings are inserted in the connecting rod and cap, they protrude slightly above the parting surface. This protrusion is required to achieve bearing crush. Bearing crush forces the ends inward at the parting line when a 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 connecting rod bearing is installed and the connecting rod cap bolts are tightened, the bearing is compressed, ensuring a positive contact between the backside of the bearing and the machined surface of the connecting rod bore.

**Measure Bearing Running Clearance**

1. Install new bearings in the connecting rod and cap.

**CAUTION:**

**To prevent engine damage, correct mating of connecting rod and cap are required to prevent damage to connecting rod fractured surface.**

**CAUTION:**

**To prevent engine damage, do not torque-to-yield connecting rod cap bolts while doing this measurement procedure.**

**CAUTION:**

**To prevent engine damage, when torquing connecting rod bolts use a torque wrench that is known to be accurate. Correct torque of connecting rod cap bolts is important.**

2. Match serial numbers on the connecting rod and rod cap (on same side of fractured rod) and install the connecting rod and cap on the crankshaft. See Piston and Connecting Rod Assembly (page 572).
3. Remove the connecting rod cap. Wipe the oil from the face of the bearings in the cap and the exposed portion of the crankshaft.
4. Place a piece of undamaged Plastigage® across the full width of the connecting rod bearing, about 6 mm (0.25 in) from the center of the connecting rod cap.
5. Install the connecting rod cap and tighten the bolts to 109 N·m (80 lbf·ft).

**NOTE:** Do not turn the crankshaft. This will smear the Plastigage® making it unusable.

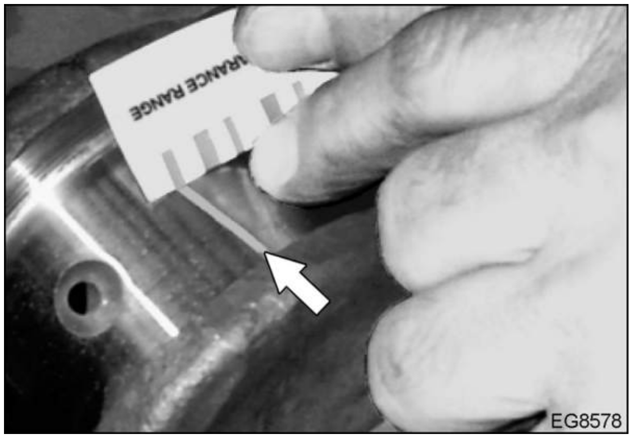


**Figure 467 Plastigage® Measurement**

6. Remove the connecting rod cap. The Plastigage® material will adhere to either the connecting rod bearing or the crankshaft. Do not remove the Plastigage®.
7. Use the Plastigage® paper scale to measure the widest point of the flattened material. The numbers in the graduated marks on the wrapper scale indicate the running clearance in thousandths of an inch or millimeters.
8. Compare Plastigage® measurements with connecting rod bearing running clearance Specifications (page 584).

**NOTE:** If running clearance is not within specifications grinding the crankshaft and using undersized bearings may be necessary. Remeasure running clearance before condemning the crankshaft.

9. Remove the Plastigage® material. Repeat the test for each connecting rod bearing.

### Measure Connecting Rod Side Clearance

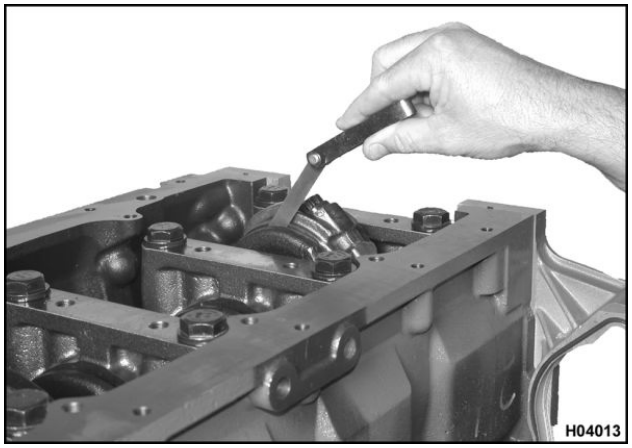


**Figure 468 Connecting rod side clearance measurement**

1. Insert a feeler gauge (page 587) between the connecting rod and crankshaft journal.
2. If the connecting rod side clearance is not in Specification (page 584), replace the connecting rod.

**NOTE:** If there is too little side clearance, the connecting rod may be damaged or the bearing may be out of position. If there is too much clearance, the connecting rod or crankshaft may be damaged.

### Measure Cylinder Sleeves

**NOTE:** If replacement of the cylinder sleeve is required, replace the cylinder sleeve and piston rings as a set.

Measure cylinder sleeve wear (taper), using one of the following methods:

### Telescoping Gauge Method

1. Measure the inside diameter of each cylinder sleeve at two locations 90 degrees apart just below the top of piston ring travel and again below the area of piston ring travel using a telescoping gauge (page 587) and an outside micrometer (page 587).

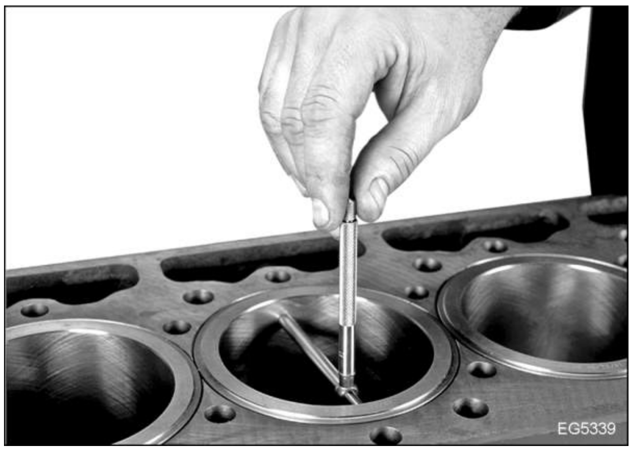


**Figure 469 Cylinder sleeve taper measurement**

2. Install telescoping gauge plungers perpendicular to the cylinder sleeve center line. Unlock and fit plungers to the cylinder sleeve. Lock and then rotate gauge out of cylinder sleeve.


**Figure 470 Telescoping gauge measurement**

3. Measure the telescoping gauge with an outside micrometer (page 587).
4. Calculate cylinder sleeve taper by subtracting the average of the lower reading from the average of the higher reading.
5. If cylinder sleeve taper exceeds Specification (page 584), replace the cylinder sleeve and piston rings.
6. Repeat steps 1 through 5 for all six cylinder sleeves.

**Dial Bore Gauge Method**


**Figure 471 Cylinder sleeve taper measurement**

1. Measure the inside diameter of each cylinder sleeve at two locations 90 degrees apart just below the top of piston ring travel and again below the area of piston ring travel using a cylinder bore gauge (page 587).
2. Calculate cylinder sleeve taper by subtracting the average of the lower reading from the average of the higher reading.
3. If cylinder sleeve taper exceeds Specification (page 584), replace the cylinder sleeve and piston rings.

**Feeler Gauge Method**

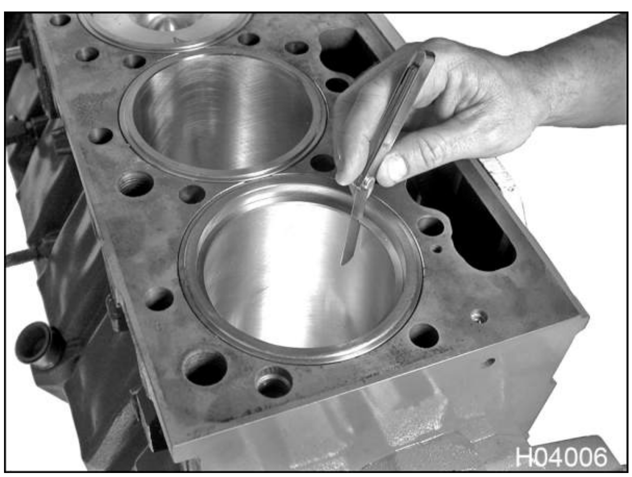


**Figure 472 Measure cylinder sleeve piston ring end gap**

1. Install the top compression ring squarely into its cylinder bore just below the top of piston ring travel. Make sure the ring is perpendicular to the cylinder wall.
2. Use a feeler gauge (page 587) to measure the ring end gap.
3. Move the top compression ring squarely on the bottom of the piston ring travel area.
4. Measure piston ring end gap using a feeler gauge.

**NOTE:** Every increase of 0.07 mm (0.003 in) between the measurements equals a 0.0223 mm (0.0009 in) increase in cylinder sleeve inside diameter.

5. If the cylinder sleeve is worn beyond Specification (page 584), replace the cylinder sleeve and piston rings.

### Measure Counterbore Depth

**NOTE:** Remove any existing shims and clean counterbore surface before measuring counterbore depth. Inspect each crankcase counterbore for cracks.

Use one of the following methods to measure depth of each crankcase counterbore:

### Cylinder Liner Height Gauge Method

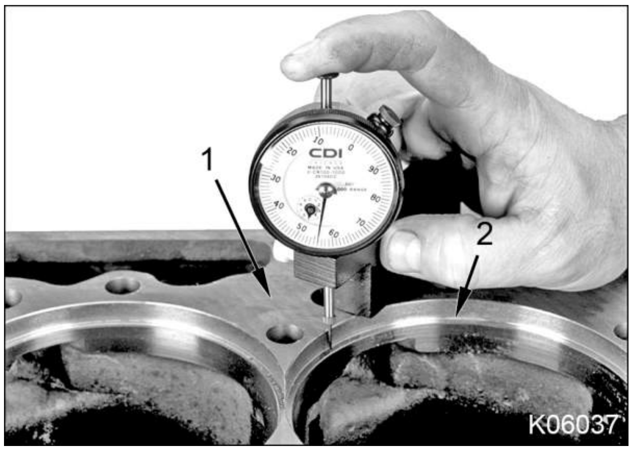


**Figure 473 Counterbore depth measurement**

1. Crankcase deck surface
2. Counterbore ledge

1. Place the indicator tip of a Cylinder Liner Height Gauge (page 587) on the crankcase deck surface and zero the dial indicator.
2. Move the gauge indicator tip to the counterbore ledge and measure the counterbore depth.
3. Measure counterbore depth at four evenly spaced locations around each counterbore ledge.
4. If the maximum variation between the four measurements exceeds Specification (page 584), resurface the counterbore.

### Depth Micrometer Method


**Figure 474 Counterbore depth measurement**

1. Place a depth micrometer (page 587) on the crankcase deck surface and measure the distance to the counterbore ledge (counterbore depth).
2. Measure counterbore depth at four evenly spaced locations around the counterbore ledge.
3. If the maximum variation between the four measurements exceeds Specification (page 584), resurface the counterbore.

### Measure Cylinder Sleeve Protrusion

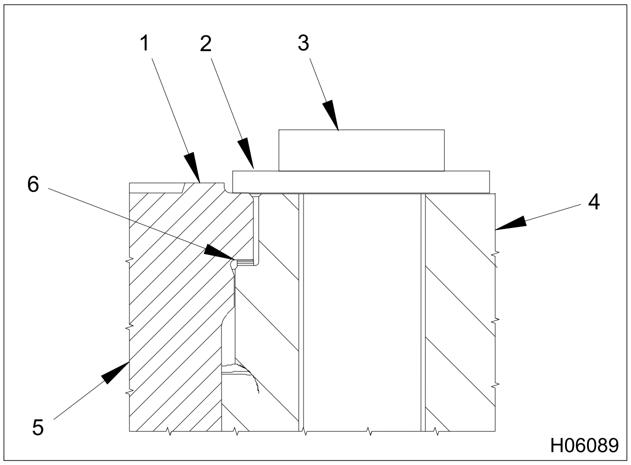


**Figure 475 Cylinder sleeve clamping (cut-away)**

1. Cylinder sleeve fire dam (highest point on cylinder sleeve)
2. Cylinder Sleeve Holding Adaptor
3. Cylinder sleeve holding adaptor bolt
4. Crankcase
5. Cylinder sleeve
6. Shim pack

**CAUTION:**

**To prevent engine damage, do not apply holding adapters to the "fire dam" ridge of the cylinder sleeve. Clamping forces should not be applied to this ridge as internal cracking could develop adjacent to the shim land.**

1. Clean the cylinder sleeve, cylinder sleeve crevice bore, and crankcase counterbore surfaces.
2. Install the cylinder sleeve in the cylinder bore without the crevice seal.

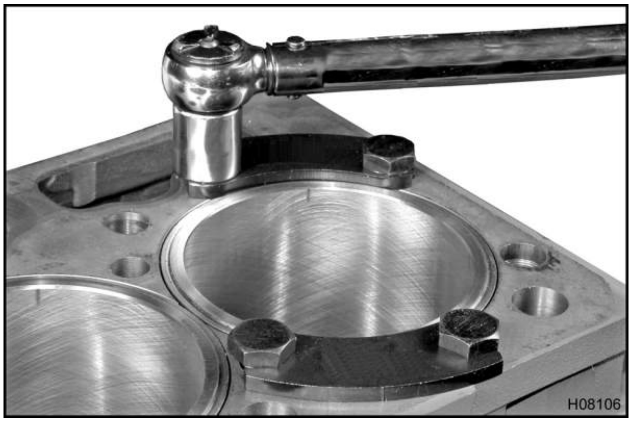


**Figure 476 Cylinder Sleeve Holding Adaptor installation**

3. Install cylinder Sleeve Protrusion Hold Down Clamps (page 587) with 10.9 or higher grade bolts and finger tighten.

**CAUTION:**

**To prevent engine damage, do not “Torque-to-yield” Cylinder Sleeve Holding Adapter bolts.**

4. Tighten Cylinder Sleeve Holding Adaptor bolts to 55 N·m (40 lbf·ft).
5. Tighten Cylinder Sleeve Holding Adaptor bolts to 110 N·m (80 lbf·ft).

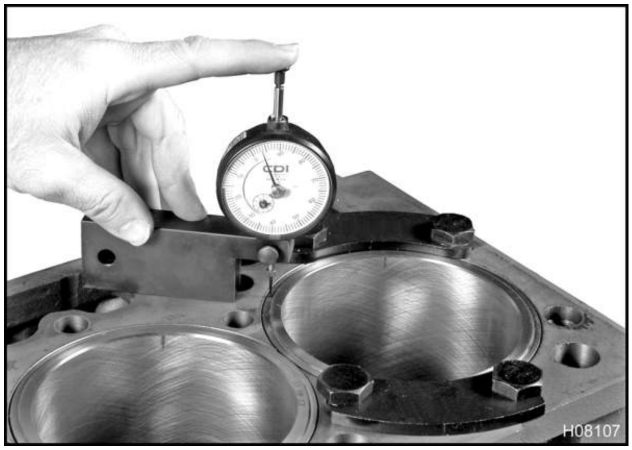


**Figure 477 Cylinder sleeve protrusion measurement**

6. Place the indicator tip of a Cylinder Liner Height Gauge (page 587) on the cylinder sleeve flange and zero the dial indicator.
7. Move the Cylinder Liner Height Gauge until the indicator tip slides off the flange to the surface of the crankcase.

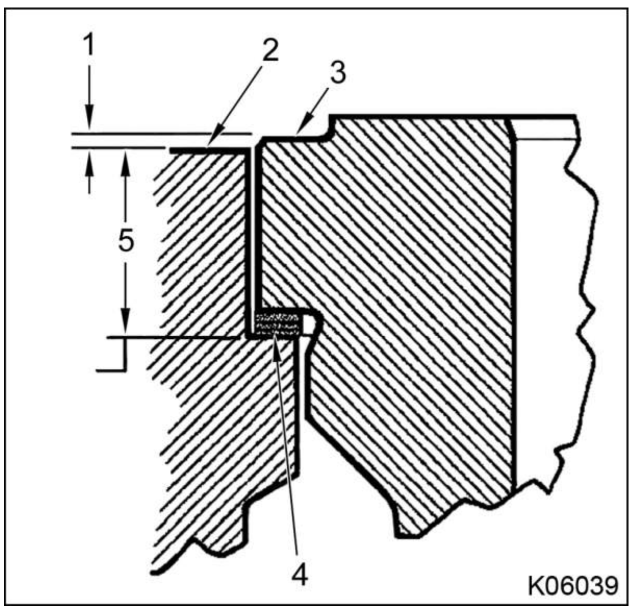


**Figure 478 Cylinder sleeve protrusion (cut-away)**

1. Cylinder sleeve protrusion
2. Top surface of crankcase
3. Cylinder sleeve flange
4. Shim
5. Counterbore depth

8. Measure cylinder sleeve protrusion at four locations evenly spaced around the cylinder sleeve. Average the four readings to determine cylinder sleeve protrusion.

If cylinder sleeve protrusion does not meet Specification (page 584), determine shim thickness necessary to meet the cylinder sleeve protrusion specification.

9. Remove the cylinder sleeve and install the necessary cylinder sleeve shims.
10. Install the cylinder sleeve and re-measure cylinder sleeve protrusion.
11. If the difference in cylinder sleeve protrusion between all six sleeves is greater then 0.03 mm (0.001 in) remove the highest cylinder sleeve and install the correct shim or resurface counterbore. Remeasure cylinder sleeve protrusion.

# Reconditioning

**Resurface Counterbore**

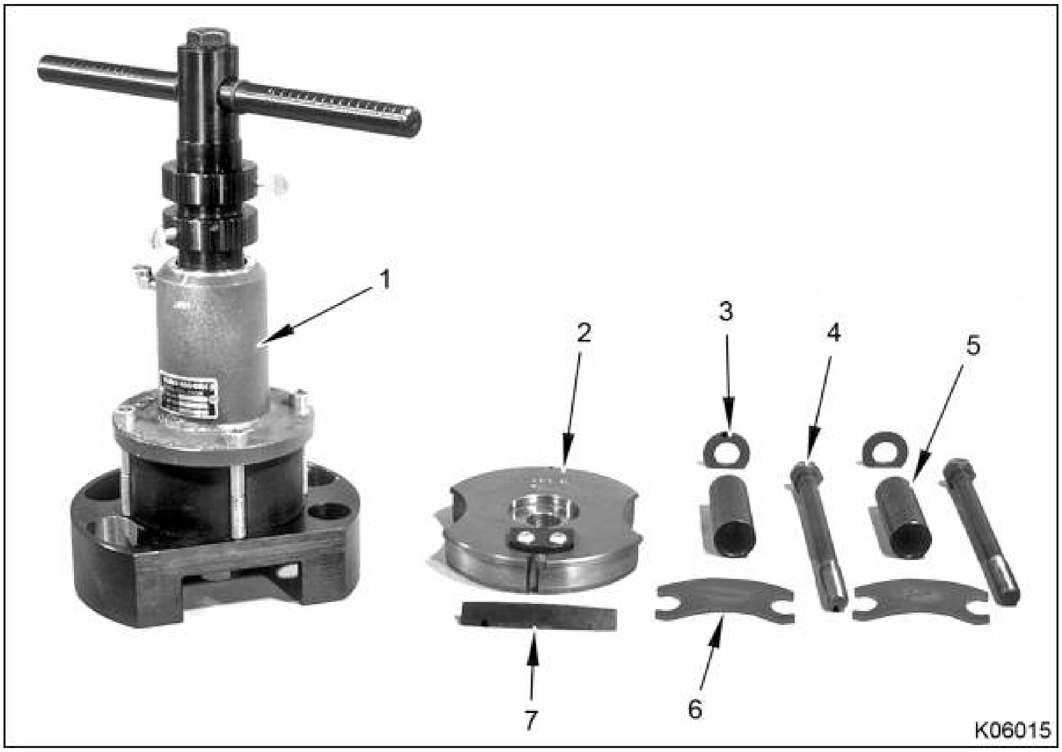


**Figure 479 Cylinder Sleeve Counterbore Tool Kit**

1. Driver unit and adapter plate
2. Counterbore cutting head
3. Washer (2)
4. Mounting bolt (2)
5. Spacer (2)
6. Locking plate (2)
7. Feeler gauge

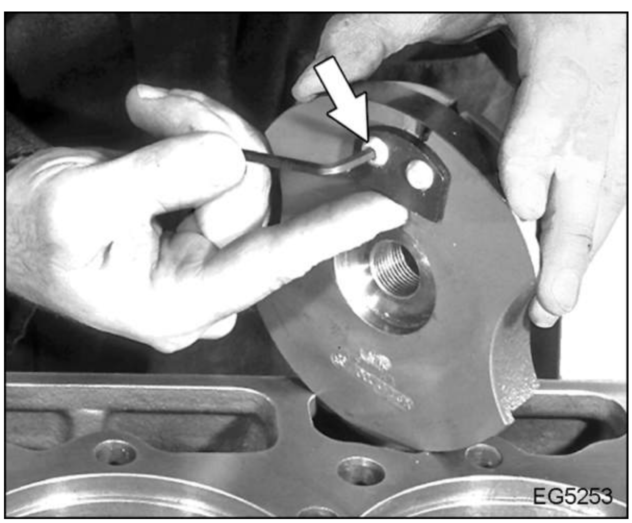


**Figure 480 Counterbore cutting head tool bit**

1. Set the counterbore cutting head tool bit. Place a 0.20 to 0.25 mm (0.008 to 0.010 in) feeler gauge (page 587) on the outside diameter of the cutting head. Push the tool bit out until it touches the feeler gauge. Use a hex head wrench to lock the tool bit in place.
2. Install the cutting head on the driver unit and adapter plate of the counterbore tool.

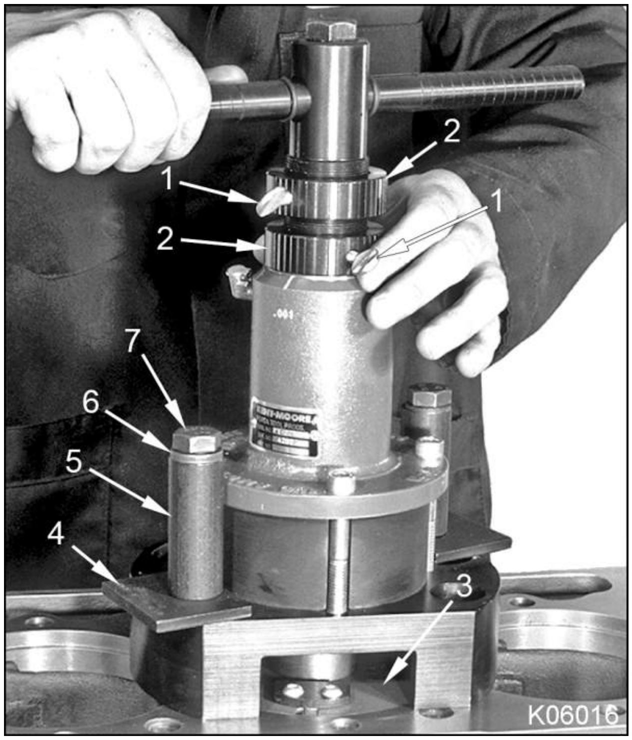


**Figure 481 Counterbore tool**

1. Locking screws
2. Turn knuckles
3. Counterbore cutting head
4. Locking plate (2)
5. Spacer (2)
6. Washer (2)
7. Mounting bolt (2)

3. Pull the plunger and lift up on the handle to raise the cutting head. Mount the counterbore tool on the crankcase. Install the washers and mounting bolts finger tight, and then tighten the bolts to 45 N·m (33 lbf·ft).

4. Loosen the locking screws and the turn knuckles, lower the cutting head. Pull the plunger up to the desired height. Tighten the turn knuckles and locking screws.

**NOTE:** Do not remove more than 0.05 mm (0.002 in) of material at any one attempt.

5. Set the depth of the cut:

   Graduated Marks on Tool

   a. Loosen the locking screw and turn the adjusting nut counterclockwise until it contacts the housing of the driver unit.
   b. Back off the adjusting nut by the amount of the desired cut. Each graduated mark equals 0.03 mm (0.001 in).
   c. Tighten the locking screw.

   Feeler Gauge

   a. Loosen the locking screw on the upper turn knuckle and insert the correct size feeler gauge between the turn knuckles.
   b. Rotate the upper turn knuckle until the feeler gauge is barely held between the turn knuckles.
   c. Tighten the locking screw and remove the feeler gauge.

**CAUTION:**

**To prevent engine or tool damage, do not rotate counterbore tool handle counterclockwise when the tool bit is in contact with the counterbore ledge.**

6. To cut the counterbore, rotate the handle smoothly in a clockwise direction until the driver unit turns freely and is bottomed out between the adjusting nut and the top of the driver unit housing.
7. Remove the counterbore tool and clean the counterbore area. Measure Counterbore Depth (page 557).

## Installation

### Cylinder Sleeve

**CAUTION:**

**To prevent engine damage, if any piston ring or cylinder sleeve is replaced, replace that cylinder sleeve and piston rings as a set.**

**NOTE:** If required, install appropriate shim(s) in each crankcase counterbore based on counterbore depth measurements (page 557).

1. If required, install shim(s) in each crankcase counterbore to bring cylinder sleeve protrusion within Specifications (page 584).

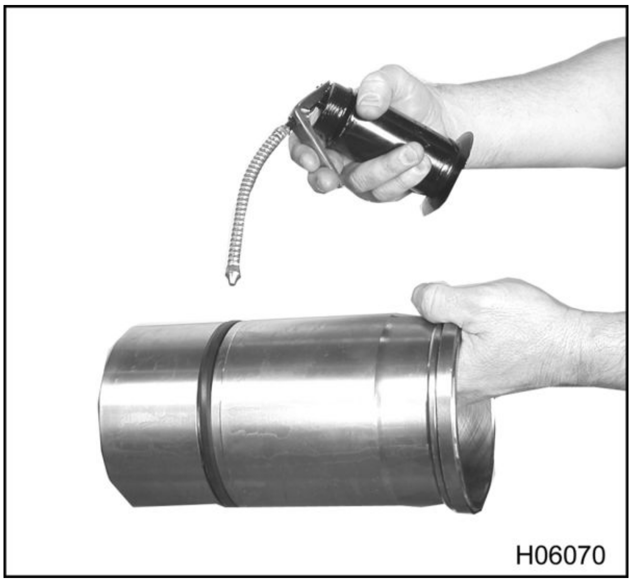


**Figure 482 Cylinder sleeve and crevice seal**

**NOTE:** Each cylinder sleeve has one crevice seal.

2. Lightly lubricate crevice seal with clean engine oil and install in cylinder sleeve groove. Make sure crevice seal is properly aligned in the cylinder sleeve groove.
3. Apply clean engine oil to the lower crankcase counterbore and crevice seal bore.


**Figure 483 Cylinder sleeve installation**

4. Carefully install each cylinder sleeve in its crankcase counterbore.
5. After installation, Measure Cylinder Sleeve Protrusion (page 559).
6. Measure cylinder sleeve protrusion at four locations evenly spaced around each cylinder sleeve. If the difference of the four measurements for any one cylinder is greater then (0.001 in) check for an improperly aligned crevice seal and re-measure protrusion.

   Average the four measurements and check cylinder sleeve protrusion Specification (page 584). If required, determine shim thickness necessary to meet the cylinder sleeve protrusion specification.

### Piston Rings

**CAUTION:**

**To prevent engine damage, if any piston ring or cylinder sleeve is replaced, replace that cylinder sleeve and piston rings as a set.**

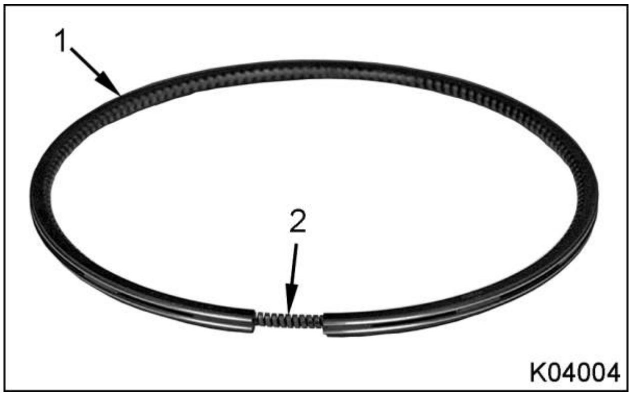


**Figure 484 Oil control ring**

1. Oil control ring
2. Ring expander coil, paint stripe

**NOTE:** The orange paint stripe on the ring expander coil must align and show through the oil ring gap.


**Figure 485 Piston rings installation (typical)**

**NOTE:** Make sure the top side of both compression rings (marked with a dot) are facing up. The oil control ring may be installed with either side facing up, if new.

1. Install rings on each piston using a piston ring expander (page 587). Expand the oil control ring enough to fit it over the piston crown and install in the lower ring groove of the piston.
2. Expand the intermediate compression ring and install in the middle piston ring groove.
3. Expand the top compression ring and install in the top piston ring groove.

**Piston Pin**

**CAUTION:**

**To prevent engine damage, do not mix connecting rods with M12 bolts (Figure 494) and connecting rods with M11 bolts (Figure 495) in the same engine. If one or more connecting rods must be replaced make sure all connecting rods in each engine are the same type.**

**NOTE:** Pistons are installed with arrow on piston crown pointing to the front the of engine and "camside" stamp toward the camside of the crankcase. Align connecting rod cap marks in the same direction as the “front of engine” arrow on the piston crown. The open end of the connecting rod will face the cam side of the crankcase.

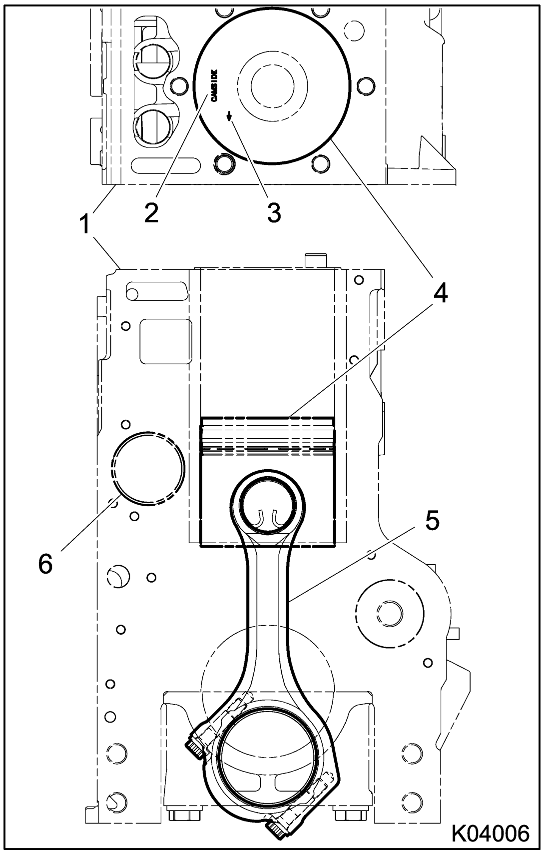


**Figure 486 Piston and connecting rod orientation**

1. Crankcase
2. “Camside” mark on piston
3. Arrow pointing to front of engine
4. Piston
5. Connecting rod
6. Camshaft bore


**Figure 487 Piston pin installation (typical)**

1. Lubricate each piston pin and piston pin bore with clean engine oil.
2. Align the bores in the connecting rod and piston and install the piston pin.


**Figure 488 Piston pin retaining ring installation (typical)**

**WARNING:**

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

3. Contract piston retaining ring using pliers and install one piston pin retaining ring in each end of the piston pin bore.

**Piston and Connecting Rod Assembly**

**CAUTION:**

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

**NOTE:** Turn crankshaft so connecting rod journals 1 and 6 are at Bottom Dead Center (BDC). Install piston and connecting rod assemblies 1 and 6 first. Then repeat the procedure for piston and connecting rod assemblies 2 and 5. Finish with piston and connecting rod assemblies 3 and 4.

1. Install connecting rod bearings into connecting rods and connecting rod caps dry (without oil).
2. Lubricate piston rings with clean engine oil. Stagger piston ring gaps approximately 120 degrees from each other.
3. Lubricate inside diameter of the cylinder sleeve with clean engine oil.

**CAUTION:**

**To prevent engine damage, install each piston with the arrow to the front of the engine and the “camside” mark toward the cam side of the engine.**

4. Carefully install the piston and connecting rod assembly into the cylinder sleeve with the arrow on the piston crown pointing to the front of the engine.

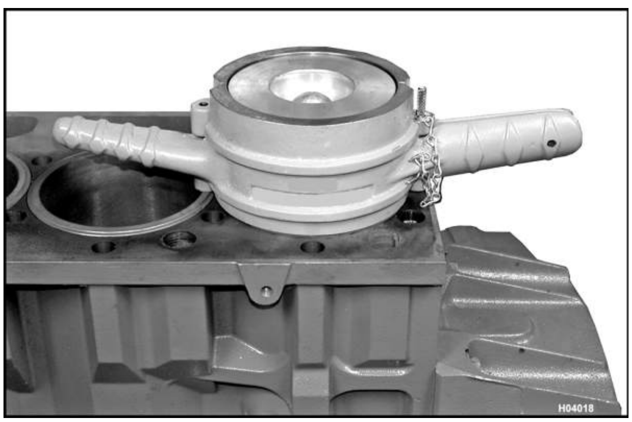


**Figure 489 Piston Ring Compressor Tool**

5. Install a Piston Ring Compressor Tool (page 587) over the piston rings.

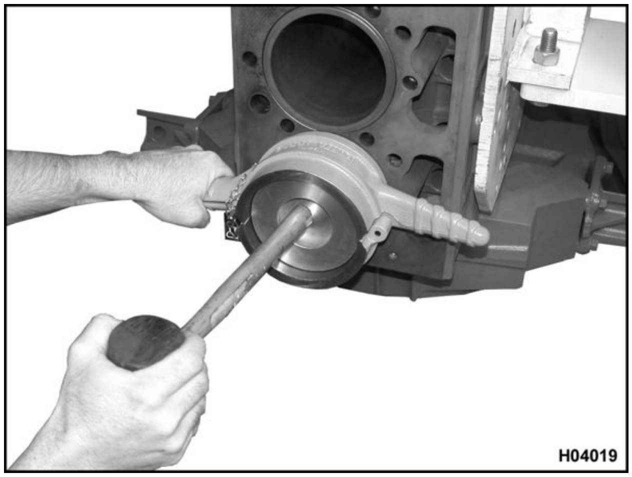


**Figure 490 Piston and connecting rod assembly installation**

6. Push the piston and connecting rod assembly into the cylinder sleeve using a wooden or plastic handle. Carefully guide the connecting rod over the crankshaft connecting rod journal. Do not touch the crankshaft journal with the fractured mating surface of the connecting rod.

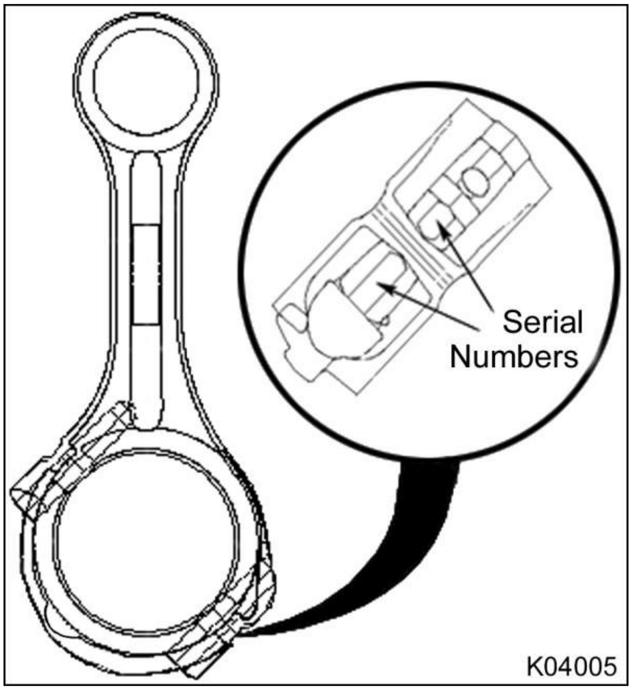


**Figure 491 Connecting rod and cap serial number locations**

**CAUTION:**

**To prevent engine damage, each connecting rod cap serial number must be assembled on the same side as its connecting rod serial number (they must match). If the rod cap is reversed when assembled on the connecting rod or a rod cap is not installed on its original matching connecting rod, the fractured mating surfaces will be ruined. The entire connecting rod assembly must then be replaced.**

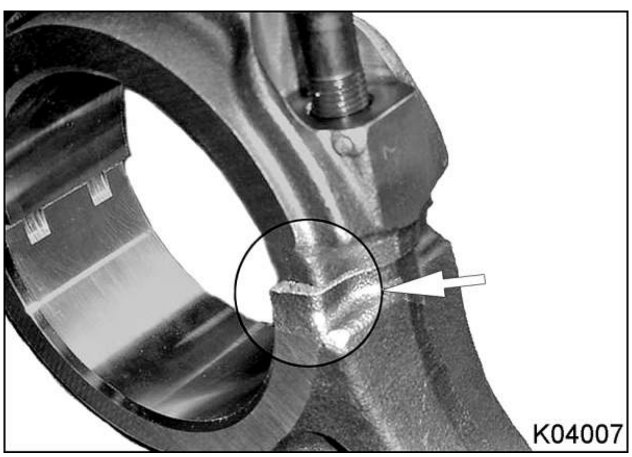


**Figure 492 Incorrect connecting rod cap orientation**

**NOTE:** If the connecting rod cap is reversed during assembly, an obvious offset will be seen at the rod mating surfaces. If the connecting rod cap is installed in the reverse orientation, the connecting rod must be replaced. Also check the crankshaft journal for damage.

**NOTE:** Each connecting rod cap mark must point toward the front of the engine.

7. Lubricate the connecting rod bearing inside diameter with clean engine oil.

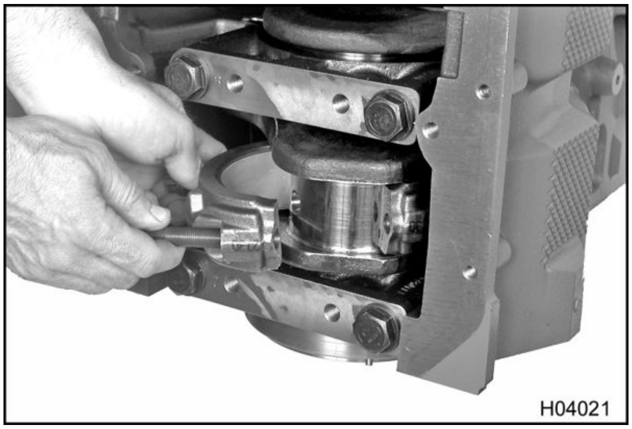


**Figure 493 Connecting rod cap installation**

**CAUTION:**

**To prevent engine damage, install new connecting rod bolts.**

8. Carefully install connecting rod cap and two new rod bolts over the crankshaft journal and finger tighten rod bolts into connecting rod.
9. Inspect connecting rod caps and determine if engine has connecting rods with M12 bolts (Figure 494) or connecting rods with M11 bolts (Figure 495) . Follow the appropriate torque procedure for the connecting rods installed in engine.

### Torque Procedure for Connecting Rods with M12 Bolts

**CAUTION:**

**To prevent engine damage, follow the connecting rod torque procedure for the specific connecting rods in the engine.**

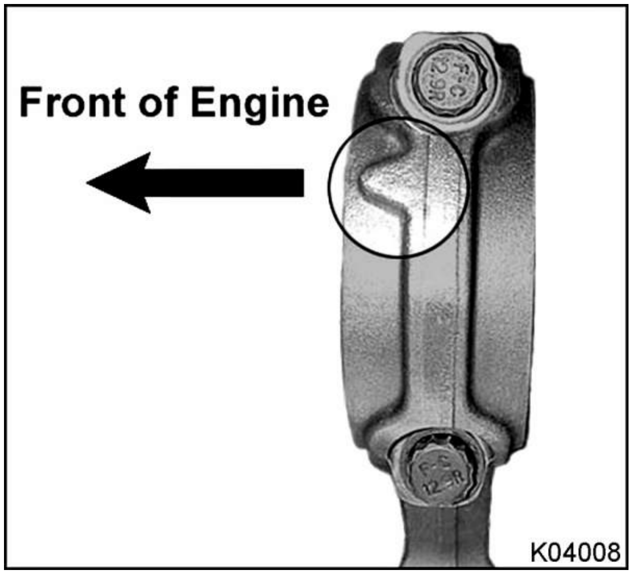


**Figure 494 Connecting rod with M12 bolts (mark pointing to front of engine)**

**NOTE:** If performing bearing fit procedure, tighten connecting rod cap bolts to 109 N·m (80 lbf·ft).

Tighten two new M12 connecting rod cap bolts to 163 N·m (120 lbf·ft).

### Torque-to-yield Procedure for Connecting Rods with M11 Bolts

**CAUTION:**

**To prevent engine damage, follow the connecting rod torque procedure for the specific connecting rods in the engine.**

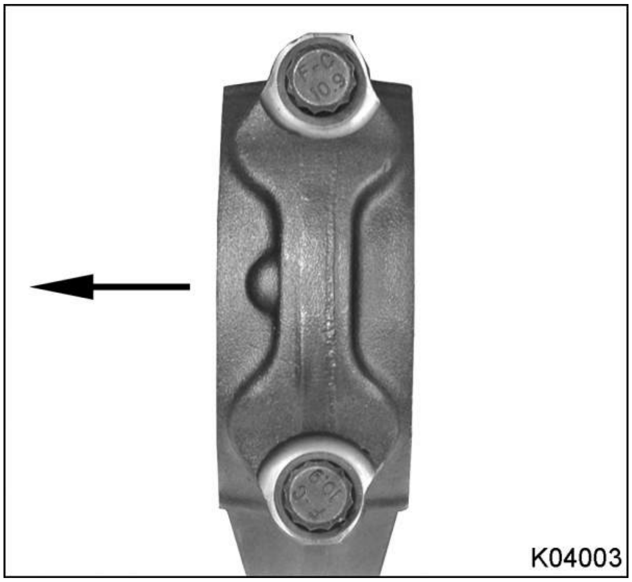


**Figure 495 Connecting rod with M11 bolts (mark pointing to front of engine)**

**NOTE:** If performing bearing fit procedure do not torque-to-yield connecting rod cap bolts. Tighten connecting rod cap bolts to 109 N·m (80 lbf·ft).

1. Tighten two new M11 connecting rod bolts to 41 N·m (30 lbf·ft).

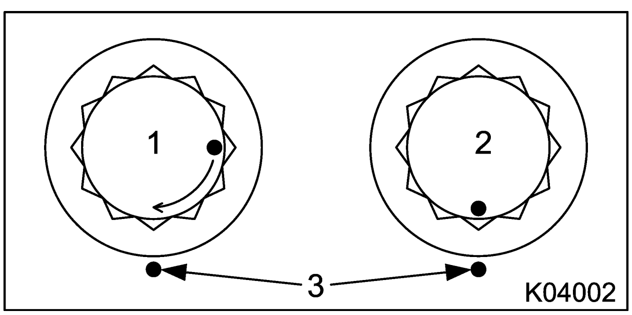


**Figure 496 M11 Connecting rod bolt torque-to-yield markings**

1. Connecting rod bolt with permanent marker spot (before torque-to-yield)
2. Connecting rod bolt with permanent marker spot (after torque-to-yield)
3. Permanent marker spot on connecting rod cap

**CAUTION:**

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

2. Using a permanent marker, place a mark on each connecting rod bolt and put another mark on a 15 mm 12 point socket (page 587) directly in line with the mark on each rod bolt.
3. Put a mark on the connecting rod cap surface 90° clockwise from each rod bolt mark.
4. Install the socket on the rod bolt to be torqued and align mark on socket with the mark on the rod bolt.
5. Torque-to-yield each M11 rod bolt by rotating bolt exactly 90 degrees clockwise (1/4 turn). The marks on the socket, rod bolt, and connecting rod cap surface should be aligned when finished.

### Piston Cooling Tubes

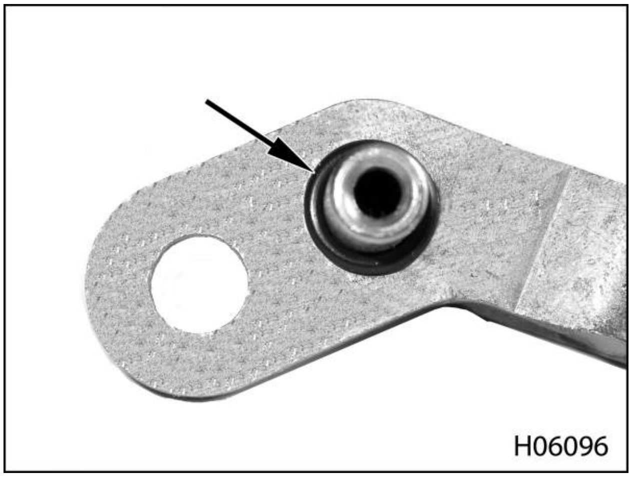


**Figure 497 O-ring on underside of piston cooling tube**

**NOTE:** Be sure O-rings are attached to the piston cooling tubes before installing tubes in the crankcase.

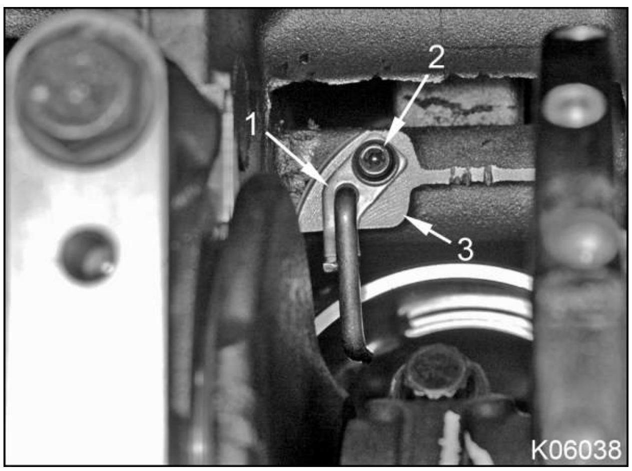


**Figure 498 Piston cooling tube**

1. Piston cooling tube (6)
2. M6 x 12 bolt (6)
3. Crankcase piston cooling tube mounting pad (6)

**CAUTION:**

**To prevent engine damage, verify the correct piston cooling jets are installed. Piston cooling jets with knurling are used in MaxxForce® 9 and 10 engines. Piston cooling jets without knurling are used in MaxxForce® DT engines.**

**CAUTION:**

**To prevent engine damage, piston cooling tubes use a special mounting bolt. Do not substitute.**

**NOTE:** The crankshaft may need to be rotated to access some piston cooling tubes.

**NOTE:** Piston cooling tubes are self aligning.

1. Install six piston cooling tubes with new O-rings and six new M6 x 12 mounting bolts into the crankcase mounting pads.
2. Tighten new piston cooling tube mounting bolts to special torque (page 587).

## Engine Run-in (Break-in) Procedure

**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.**

If new pistons, piston rings, or cylinder sleeves have been installed, use the following engine run-in procedure:

1. Start engine and run at low idle with no load for 5 minutes. Check for leaks in the cooling, oil, fuel, and air induction systems.
2. Check the turbocharger for all of the following conditions:
   - Unusual noise
   - Oil leaks
   - Air leaks
   - Excessive exhaust smoke
   - Excessive vibration
   - Loose mounting

3. Turn engine off and correct any of these conditions to prevent engine or turbocharger damage.
4. Start engine and drive vehicle (unloaded) for 25 minutes in city mode, then drive vehicle (unloaded) for an additional 15 minutes in highway mode.
5. Return to idle and check for leaks.

# Specifications

### Connecting Rod Specifications

| | |
|---|---|
| Bend (maximum) | 0.051 mm (0.002 in) |
| Center-to-center distance between connecting rod bearing bore and piston pin bushing bore | 219.4 to 219.5 mm (8.638 to 8.642 in) |
| Connecting rod bearing bore inside diameter | 85.130 to 85.156 mm (3.3516 to 3.3526 in) |
| Connecting rod bearing inside diameter (installed) | 80.05 to 80.10 mm (3.1518 to 3.1536 in) |
| Connecting rod bearing bore out-of-round (maximum) | 0.02 mm (0.00078 in) |
| Connecting rod bearing bore taper (maximum) | 0.02 mm (0.00078 in) |
| Connecting rod bearing running clearance | 0.030 to 0.107 mm (0.0012 to 0.0042 in) |
| Connecting rod to crankshaft side clearance | 0.190 to 0.419 mm (0.0075 to 0.0165 in) |
| Piston pin bushing inside diameter | 46.393 to 46.401 mm (1.8265 to 1.8268 in) |
| Twist (maximum) | 0.051 mm (0.002 in) |

**Piston Specifications**

| | |
|---|---|
| **MaxxForce® DT** | |
| Piston | One-piece aluminum |
| Piston rings | Top ring - keystone cross section |
| | Intermediate - rectangular cross section |
| **MaxxForce® 9 and 10** | |
| Piston | One-piece steel |
| Piston rings | Top ring - keystone cross section |
| | Intermediate - rectangular cross section |
| Running clearance between piston and cylinder sleeve | MaxxForce® DT piston: 0.085 to 0.133 mm (0.00335 to 0.00524 in) |
| | MaxxForce® 9 and 10 piston: 0.042 to 0.102 mm (0.00165 to 0.00402 in) |
| Skirt diameter | MaxxForce® DT piston: 116.467 to 116.485 mm (4.5853 to 4.5860 in) |
| | MaxxForce® 9 and 10 piston: 116.498 to 116.528 mm (4.5865 to 4.5877 in) |
| Top compression ring groove width, MaxxForce®DT measure over 2.885 mm (0.1135 in) gauge pins | 117.348 to 117.568 mm (4.620 to 4.6287 in) |
| Top compression ring groove width, MaxxForce® 9 and 10 measure over 2.70 mm (0.1063 in) gauge pins | 116.104 to 116.304 mm (4.5710 to 4.5866 in) |
| Intermediate compression ring side clearance, MaxxForce®DT | 0.05 to 0.10 mm (0.002 to 0.0039 in) |
| Intermediate compression ring side clearance, MaxxForce® 9 and 10 | 0.07 to 0.12 mm (0.0028 to 0.0047 in) |
| Oil control ring, side clearance | 0.03 to 0.08 mm (0.0012 to 0.00315 in) |
| Piston protrusion above crankcase top deck | 0.660 to 0.813 mm (0.026 to 0.032 in) |
| Piston cooling tube diameter (spray hole) MaxxForce® DT | 2.18 mm (0.086 in) |
| Piston cooling tube diameter (spray hole) MaxxForce® 9 and 10 | 2.59 mm (0.102 in) |

**Piston Ring Specifications**

| | |
|---|---|
| Top compression ring end gap | 0.35 to 0.50 mm (0.014 to 0.0197 in) |
| Intermediate compression ring end gap | 1.20 to 1.45 mm (0.0472 to 0.0571 in) |
| Oil control ring end gap | 0.35 to 0.65 mm (0.014 to 0.0256 in) |

**Piston Pin Specifications**

| | |
|---|---|
| Clearance in piston | MaxxForce® DT piston: 0.011 to 0.021 mm (0.00043 to 0.00083 in) |
| | MaxxForce® 9 and 10 piston: 0.083 to 0.103 mm (0.00327 to 0.00406 in) |
| Diameter | 46.352 to 46.357 mm (1.8249 to 1.8251 in) |
| Length | MaxxForce® DT piston: 96.57 to 96.82 mm (3.802 to 3.812 in) |
| | MaxxForce® 9 and 10 piston: 77.88 to 78.13 mm (3.066 to 3.076 in) |

**Cylinder Sleeve Specifications**

| | |
|---|---|
| Counterbore depth allowable variation between four points (maximum) | 0.03 mm (0.001 in) |
| Counterbore depth before adding shims (maximum) | 10.49 mm (0.413 in) |
| Counterbore depth (including shims - if any) | 8.84 to 8.89 mm (0.348 to 0.350 in) |
| Cylinder sleeve protrusion | 0.05 to 0.13 mm (0.002 to 0.005 in) |
| Cylinder sleeve protrusion difference (maximum) | 0.03 mm (0.001 in) |
| Cylinder sleeve taper (bore wear step, at top of ring travel (maximum)) | 0.10 mm (0.004 in) |
| Flange thickness | 8.94 to 8.96 mm (0.352 to 0.353 in) |
| Inside diameter | 116.57 to 116.60 mm (4.5895 to 4.5905 in) |

## Special Torque

| | |
|---|---|
| Connecting rod bolts (verify connecting rod type) | See Torque Procedures for Connecting Rod with M12 Bolts (page 577) or M11 Bolts (page 578). |
| Piston cooling tube mounting bolts, M6 x 12 | 13 N·m (114 lbf·in) |

## Special Service Tools

| | |
|---|---|
| Counterbore Cutting Head | ZTSE25144A |
| Cylinder bore gauge | Obtain locally |
| Cylinder Liner Height Gauge | ZTSE2515A |
| Cylinder Sleeve Counterbore Tool Kit | ZTSE2514 |
| Cylinder Sleeve Puller | ZTSE2536 |
| Depth micrometer | Obtain locally |
| Dial indicator set | Obtain locally |
| Feeler gauge | Obtain locally |
| Inside micrometer | Obtain locally |
| Outside micrometer | Obtain locally |
| Piston Ring Compressor Tool | ZTSE4396 |
| Piston ring expander | Obtain locally |
| Piston Gauge Pins (set of 3) | ZTSE4653 |
| Sleeve Protrusion Hold Down Clamps | ZTSE4672 |
| Telescoping gauge set | Obtain locally |
| 15 mm 12 point socket | Obtain locally |

# Table of Contents

## Exploded Views and Description

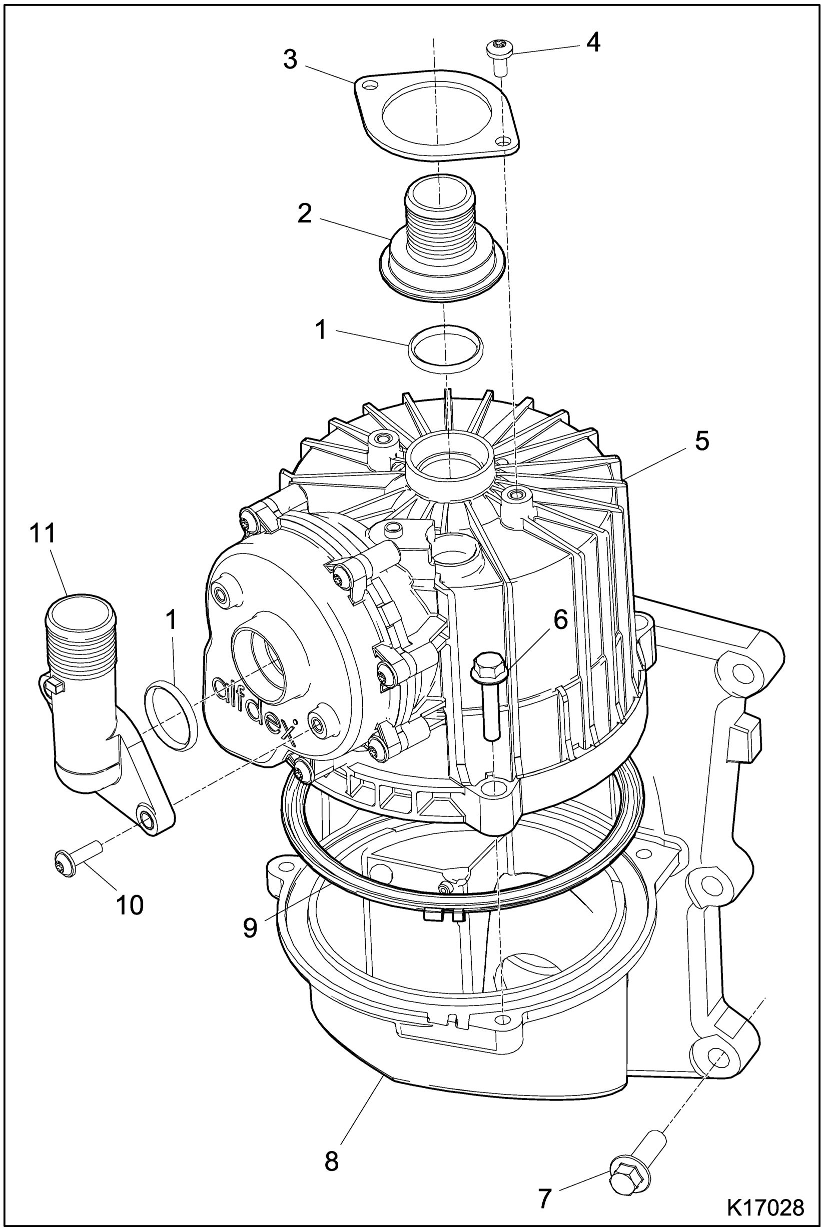


**Figure 499 Crankcase breather assembly with turbine**

1. Breather fittings seal (2)
2. Breather inlet fitting
3. Breather inlet flange
4. M5 x 10 bolt (2)
5. Breather housing assembly
6. M6 x 30 bolt (3)
7. M8 x 25 bolt (5)
8. Turbine housing
9. Breather to turbine housing seal
10. M5 x 16 bolt (2)
11. Breather outlet fitting

The closed crankcase ventilation system separates oil from crankcase gases and returns crankcase gases to the engine intake air and oil to the oil pan.

A turbine in the breather housing assembly is driven by engine oil pressure.

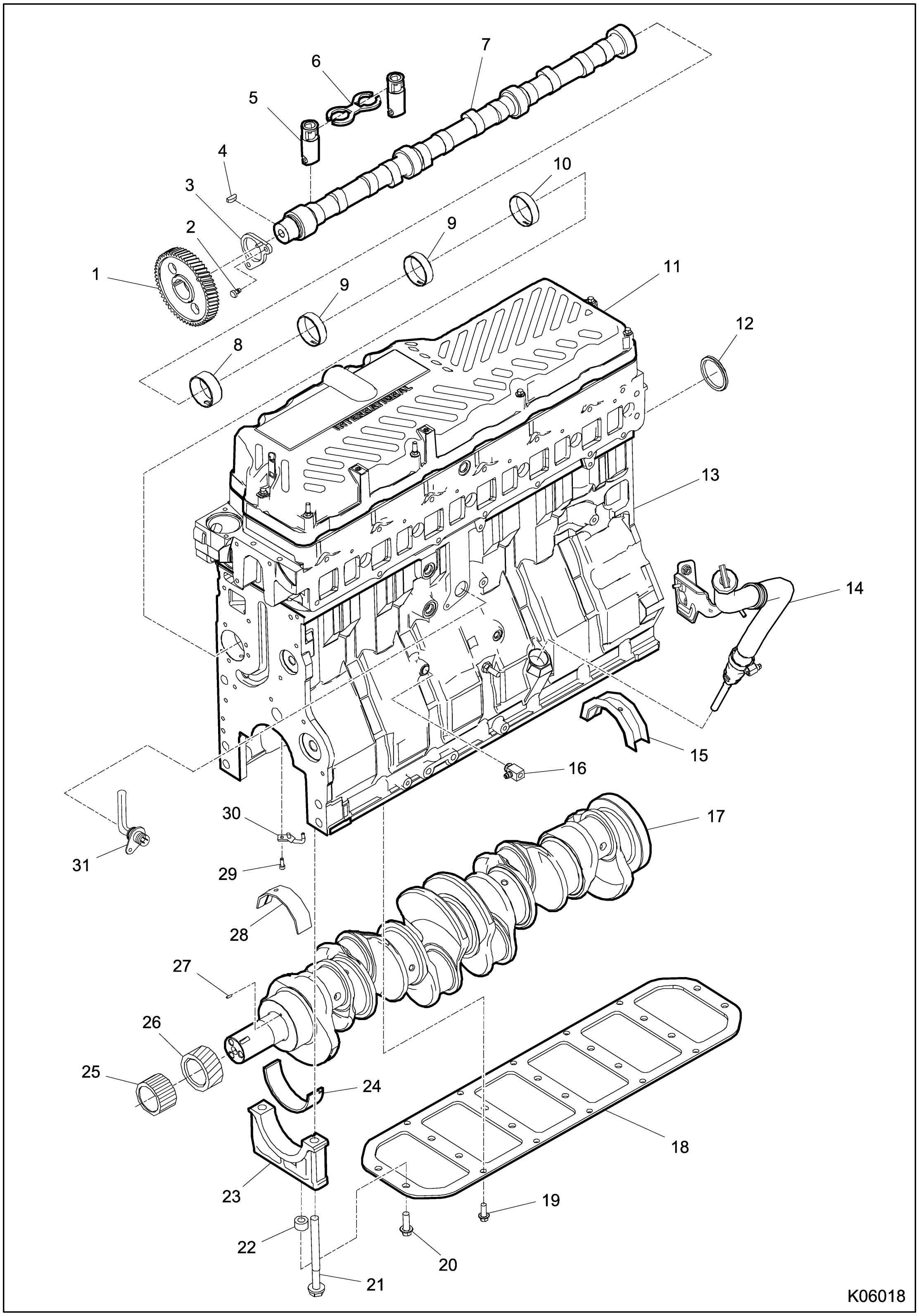


**Figure 500 Crankcase, Crankshaft, and Camshaft**

1. Camshaft gear assembly
2. M8 x 20 bolt (2)
3. Camshaft thrust plate
4. Woodruff key, ¼ x ¾
5. Roller tappet assembly (12)
6. Roller tappet guide (6)
7. Camshaft
8. Front #1 bearing (camshaft)
9. Intermediate #2 and #3 bearing (camshaft) (2)
10. Rear #4 bearing (camshaft)
11. Valve cover
12. Camshaft seal, ring (rear)
13. Crankcase assembly
14. Oil level gauge assembly
15. Thrust main bearing (#7 upper )
16. M12 Tee assembly
17. Crankshaft
18. Crankcase ladder
19. M10 x 25 bolt (10)
20. M12 x 35 bolt (14)
21. M15 x 162 bearing cap bolt (14)
22. Spacer (14)
23. Main bearing cap (7)
24. Lower main bearing (7)
25. Oil pump spline drive
26. Crankshaft gear
27. Slotted spring pin, 5/32 x 5/16
28. Front & intermediate upper main bearing (6)
29. Piston cooling tube bolt, M6 x 12 (6)
30. Piston cooling tube assembly (6)
31. Coolant heater assembly (optional)

The one piece cast grey iron crankcase has removable cylinder sleeves and seven main bearing caps with 2 bolts per main cap.

The forged steel crankshaft has one journal for each connecting rod and thrust is taken by # 7 upper main bearing.

The single roller tappet camshaft is gear driven by the upper idler gear.

## Removal

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

**WARNING:**

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

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

### Crankcase Ventilation System

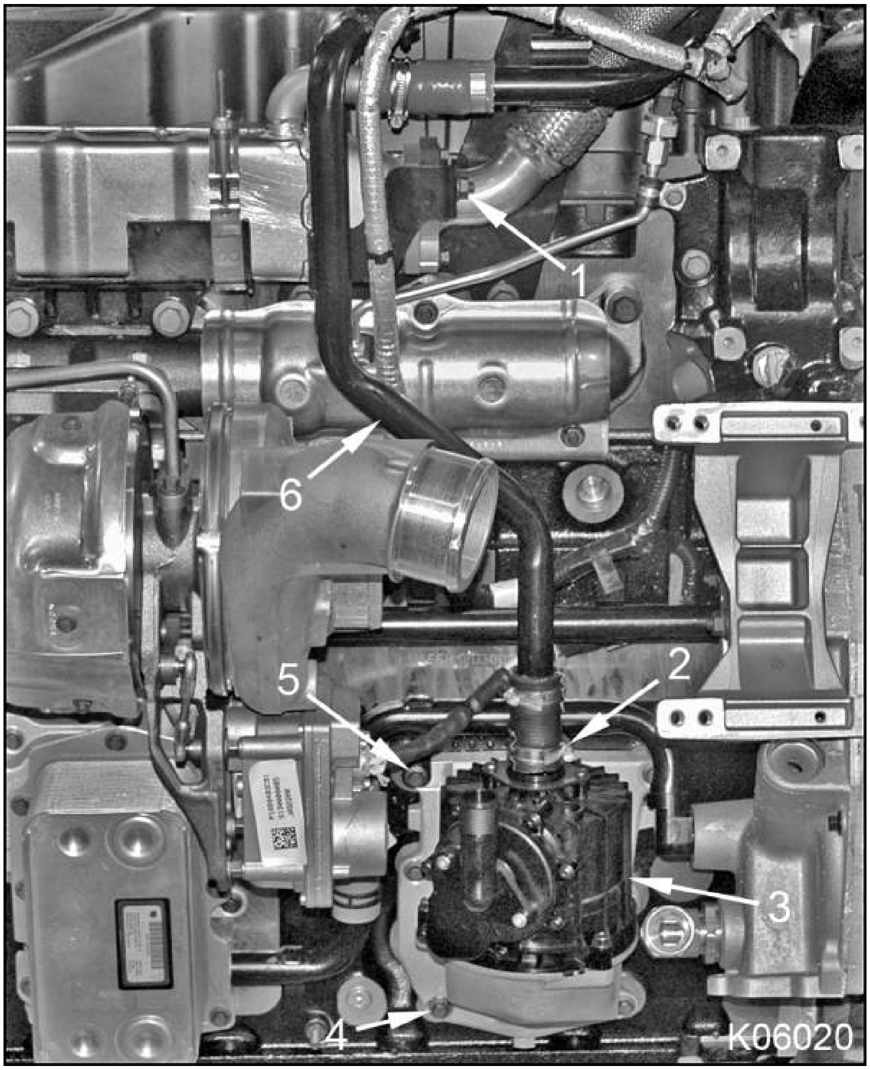


**Figure 501 Crankcase breather assembly and inlet tube**

1. M8 nut
2. Hose clamp (2)
3. Breather assembly with turbine
4. M8 x 25 bolt (5)
5. M8 x 30 bolt
6. Breather inlet tube assembly

1. Remove M8 nut securing the crankcase breather inlet tube assembly to the exhaust side EGR cooler outlet.
2. Loosen hose clamp connecting the breather inlet tube hose to the breather assembly inlet fitting.
3. Pull breather inlet tube assembly out of valve cover and off of breather assembly.
4. Remove five M8 x 25 bolts and one M8 x 30 bolt holding the crankcase breather assembly to the crankcase.
5. Rotate breather assembly out from behind oil system module coolant supply tube retaining bracket and remove from engine.
6. Remove and discard crankcase breather assembly O-ring seals.

**Oil Level Gauge Assembly**

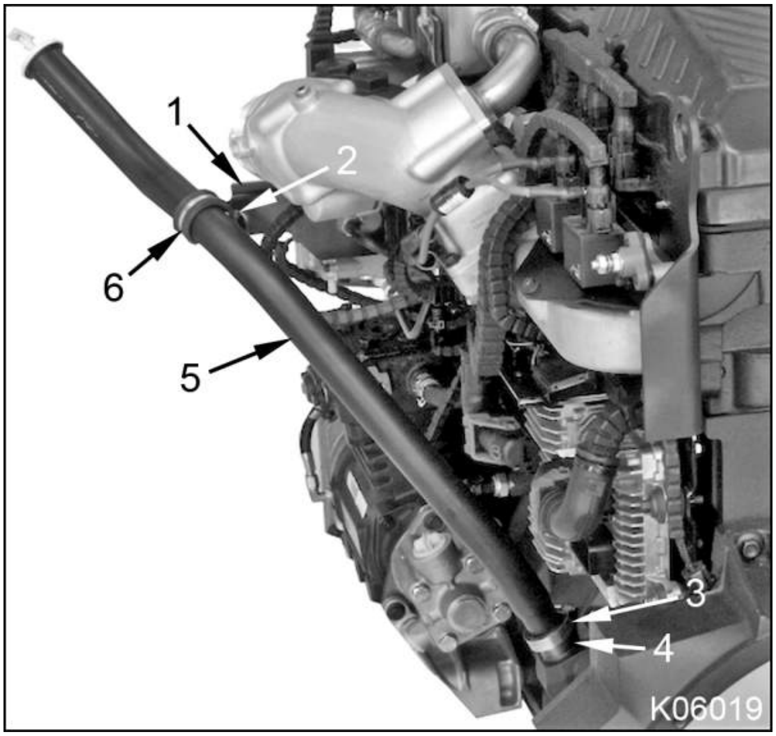


**Figure 502 Oil level gauge assembly**

1. Oil filler tube support
2. M6 x 40 bolt and M6 nut
3. Tube clamp
4. Oil level gauge tube
5. Oil filler tube
6. Cushioned clamp

1. Remove M6 x 40 bolt and M6 nut securing the oil filler tube to the oil filler tube support.
2. Loosen tube clamp and remove the oil filler tube assembly from the oil level gauge tube.
3. If required, remove the oil filler tube support. Remove two M8 nuts and one M6 x 16 bolt holding the oil filler tube support to the fuel filter header and remove the low-pressure fuel pump outlet tube assembly (page 234).

4. If required, remove the oil level gauge tube by driving the tube up and out of the crankcase using a brass punch and hammer.

### Coolant Heater Assembly (Optional)

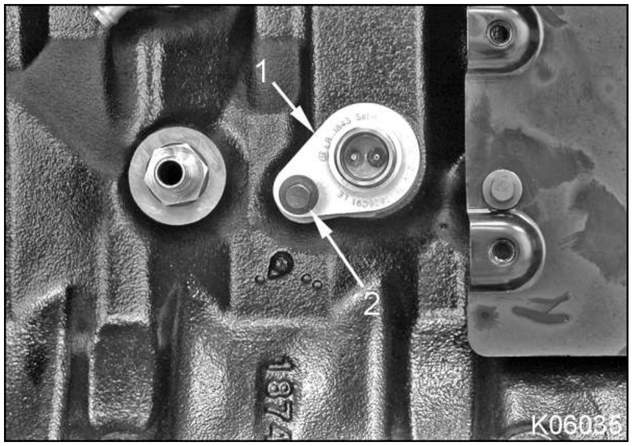


**Figure 503 Coolant heater (intake side of crankcase)**

1. Coolant heater mounting flange
2. M8 x 20 bolt

1. Drain engine coolant to a level below the coolant heater. Dispose of engine coolant according to applicable regulations.
2. Remove M8 x 20 bolt.
3. Pull out and remove coolant heater assembly from crankcase.
4. Discard O-ring.

### Crankcase Ladder Assembly

1. Drain engine oil, remove the oil pan (page 338), and oil suction tube assembly (page 339).

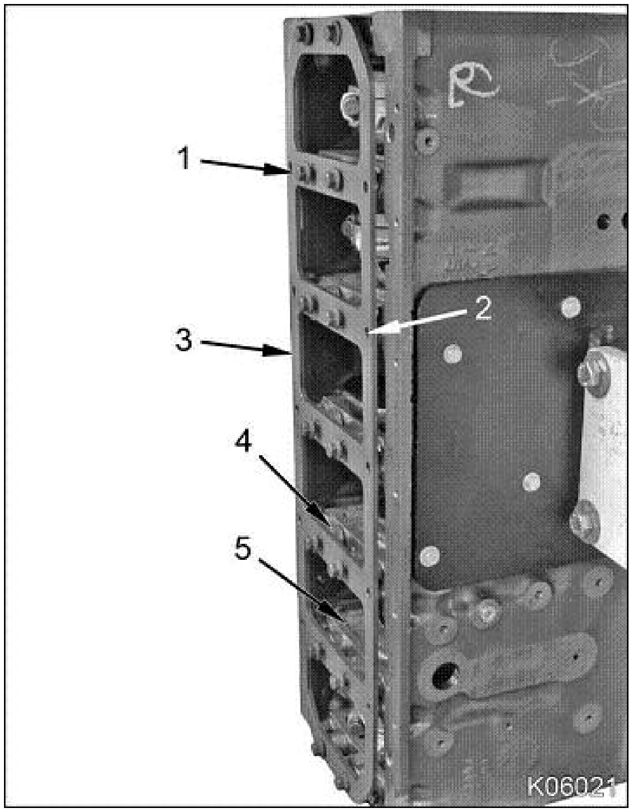


**Figure 504 Crankcase ladder assembly**

1. M12 x 35 bolt (14)
2. M10 x 25 bolt hole (10)
3. Crankcase ladder
4. Spacer (14)
5. Main bearing cap (7)

2. Remove ten M10 x 25 bolts securing the crankcase ladder to the crankcase.
3. Loosen fourteen M12 x 35 bolts securing the crankcase ladder to the main bearing caps and remove crankcase ladder assembly from the engine.

**Main Bearing Caps, Crankshaft, and Main Bearings**

1. Disconnect the connecting rod assemblies. See Remove Piston and Connecting Rod Assembly (page 532).

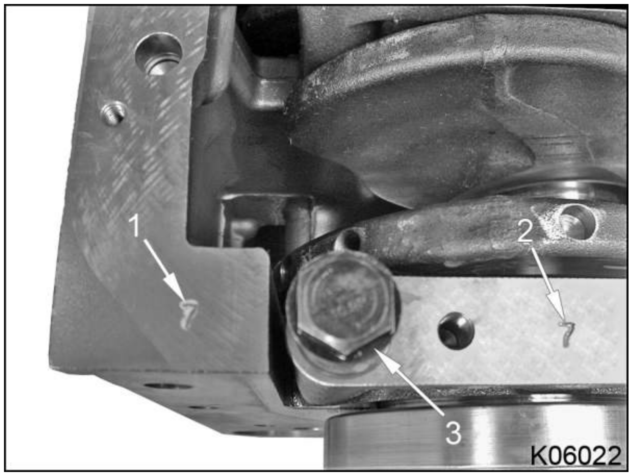


**Figure 505 Main bearing cap and crankcase stamps**

1. Crankcase stamp for #7 main bearing
2. Main bearing cap stamp on #7 main bearing cap
3. M15 x 162 main bearing cap bolt (14)

**NOTE:** Crankcase and main bearing caps may need to be cleaned to see stamped numbers.

2. Verify main bearing caps and crankcase have corresponding numbers stamped in each.
3. Loosen fourteen M15 x 162 main bearing cap bolts.

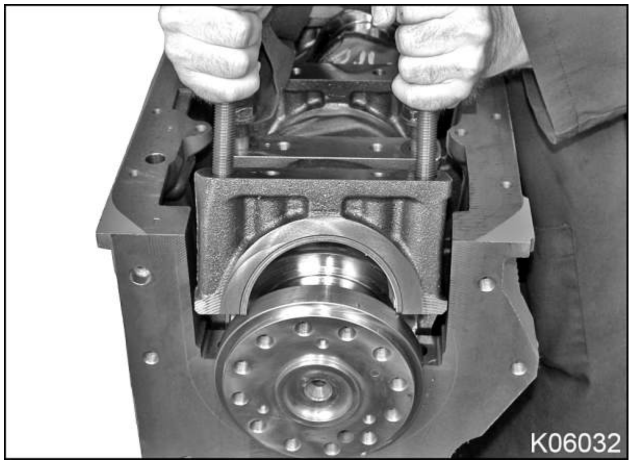


**Figure 506 Main bearing cap removal**

4. Lift up both bolts of each main bearing cap so about half the threads are exposed.
5. Rock each main bearing cap free from the crankcase using both main bearing cap bolts.
6. Remove each main bearing cap and discard main bearing cap bolts.

**NOTE:** Main bearing cap bolts are not reusable, due to permanent deformation caused when bolts are tightened to the yield point (torque-to-yield).

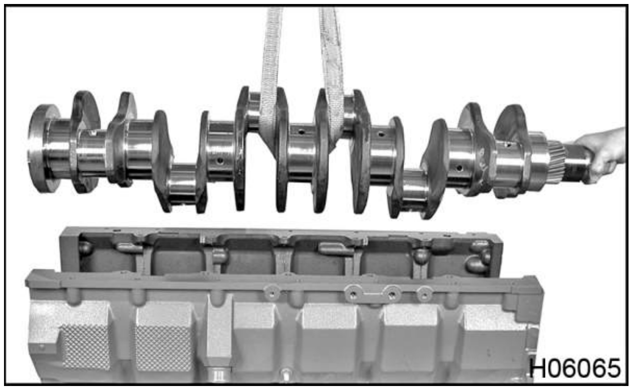


**Figure 507 Crankshaft assembly removal**

**CAUTION:**

**To prevent engine or vehicle damage, do not drop, gouge, or bend the crankshaft.**

7. Place an appropriate sling around the middle of the crankshaft and attach the sling to a hoist or crane.
8. Carefully lift the crankshaft out of the crankcase.

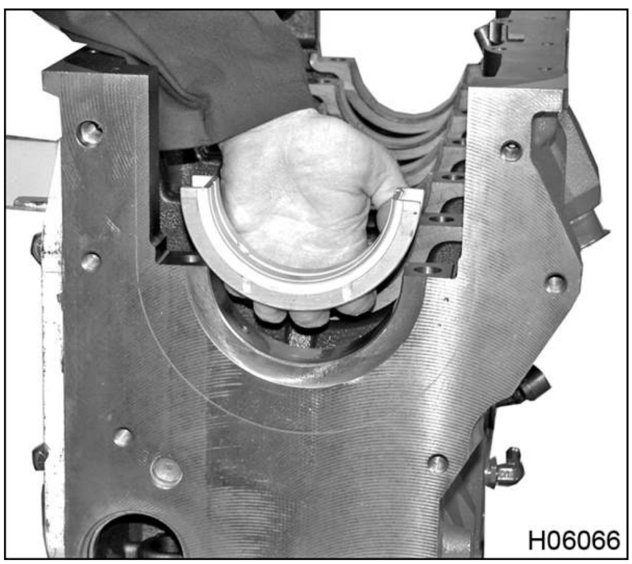


**Figure 508 Thrust main bearing removal**

9. Push thrust main bearing and six other upper main bearings out of the crankcase main bearing saddles by hand. Mark each upper main bearing with its bearing number and orientation. Set each upper main bearing with its corresponding lower main bearing for later inspection and measurements.

### Oil Pump Spline Drive

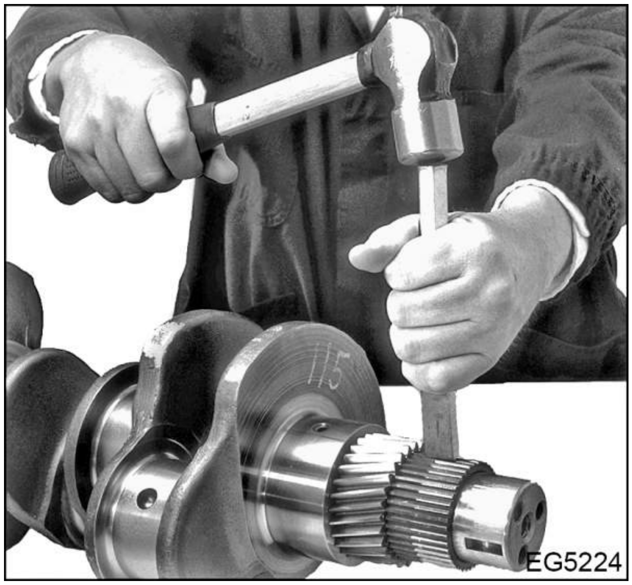


**Figure 509 Oil pump spline drive removal**

**CAUTION:**

**To prevent engine damage, during oil pump spline drive removal, strike chisel carefully to prevent damage to the crankshaft.**

1. Place a chisel between the oil pump spline drive teeth and carefully strike chisel with a hammer to split the spline drive.
2. Remove the oil pump spline drive from the crankshaft.

### Camshaft Gear

**NOTE:** If required, Measure Camshaft End Play (page 614).

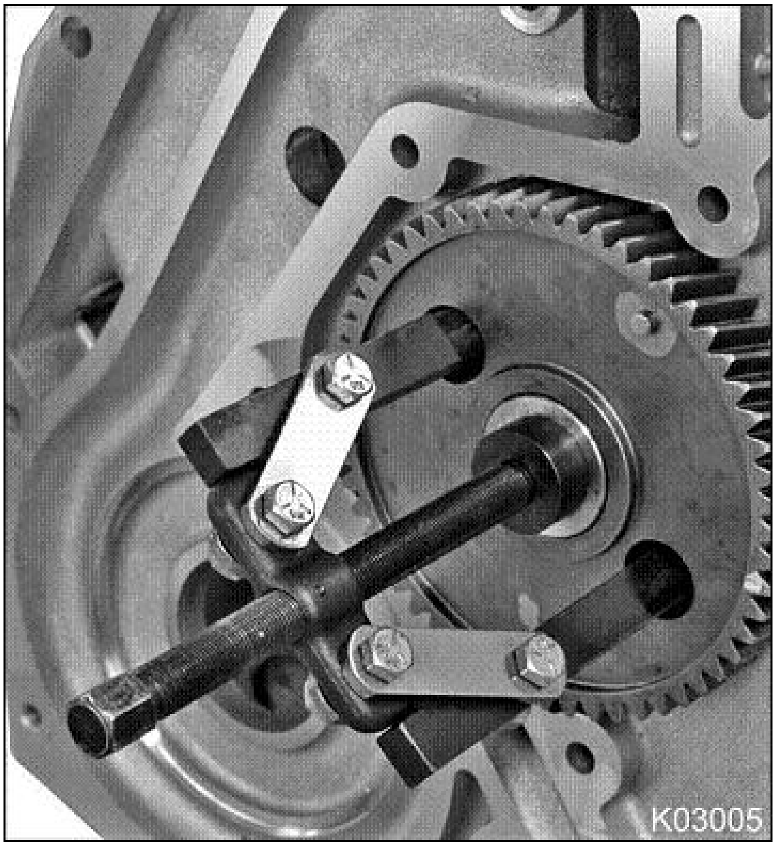


**Figure 510 Camshaft gear and Cam Gear Puller**

**NOTE:** For easier camshaft gear removal, remove the camshaft gear before removing the camshaft assembly, upper idler, or lower idler gears.

1. Install two claws of the Cam Gear Puller (page 644) into two holes of the camshaft gear.
2. Center the gear puller threaded shaft on the center of the camshaft and tighten shaft while firmly attaching puller claws on the camshaft gear.

**NOTE:** Keep the Cam Gear Puller center shaft in line with the camshaft center line while removing the cam gear.

3. Remove the camshaft gear by rotating the gear puller center shaft in a continuous motion using a breaker bar, while holding the camshaft gear and Cam Gear Puller from rotating.

### Camshaft Assembly

**NOTE:** If required, Measure Camshaft End Play (page 614).

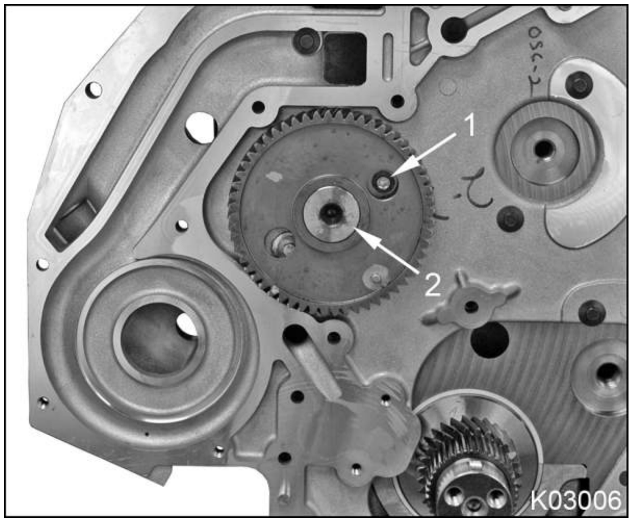


**Figure 511 Camshaft thrust plate bolts**

1. M8 x 20 bolt (2)
2. Camshaft

1. Remove two M8 x 20 camshaft thrust plate bolts.


**Figure 512 Camshaft assembly removal**

2. Rotate engine on stand so camshaft can be pulled straight up.
3. Carefully pull camshaft assembly up and out of crankcase.

### Camshaft Bushings

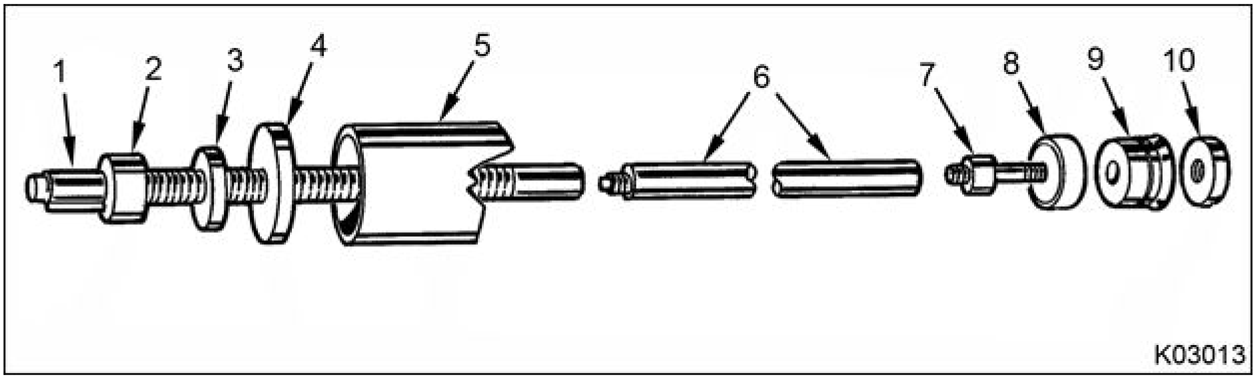


**Figure 513 Camshaft Bushing Puller (installer)**

1. Puller screw
2. Pulling nut
3. Thrust bearing
4. Pulling plate
5. Pulling spacer
6. Extension tube
7. Puller screw extension
8. Camshaft bearing (not part of tool)
9. Expanding collet
10. Backup nut

**NOTE:** Although the inside diameter of each camshaft bushing is the same, the outside diameters and widths are different depending on bushing location. See crankcase and camshaft bushing Specifications (page 640).

Use Camshaft Bushing Puller (page 644) to remove camshaft bushings. Remove the front and rear camshaft bushings first. Remove the camshaft seal ring and rear camshaft bushing from the rear of the crankcase.

1. Assemble the correct expanding collet and backup nut on the puller screw extension. See camshaft bushing Specifications (page 640).

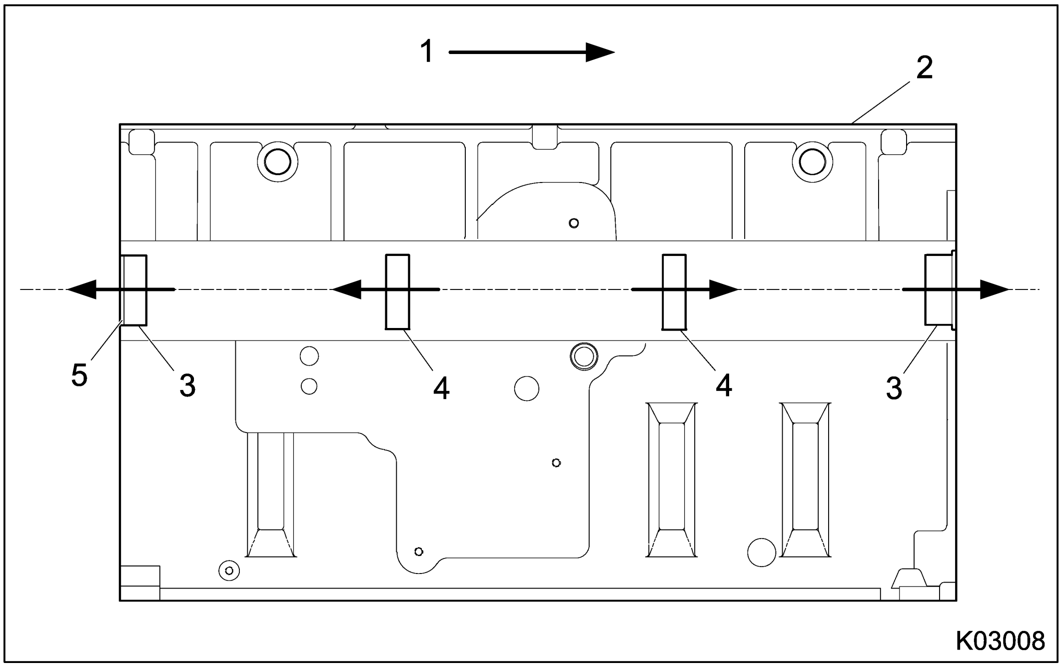


**Figure 514 Camshaft bushing removal pull direction (partial crankcase cut-away)**

1. Front of engine
2. Crankcase assembly
3. Front and rear camshaft bushings
4. Intermediate camshaft bushings
5. Camshaft seal ring

2. Remove the camshaft seal ring from the back of the crankcase.
3. With the expanding collet collapsed, install the collet assembly in the camshaft bushing and tighten backup nut until the collet fits the camshaft bushing.
4. Assemble the Camshaft Bushing Puller and install extension tube on the puller screw extension.

**NOTE:** Make sure pulling spacer is squarely mounted on the crankcase before tightening pulling nut.

5. Hold the end of the puller screw with a wrench and tighten the pulling nut against the thrust bearing and pulling plate until the camshaft bushing is removed.
6. Remove the front and rear camshaft bushings and then remove the two intermediate bushings.

## Cleaning, Inspection, and Measurement

**WARNING:**

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

**Camshaft Assembly**

1. Use a soft bristle brush and a suitable solvent to clean the camshaft assembly and camshaft gear.
2. Inspect the camshaft gear for worn and damaged teeth. Replace gear if necessary.
3. Inspect camshaft for scuffed, scored, and cracked lobes. Replace camshaft if necessary.
4. Inspect the camshaft thrust plate for wear, cracks, and distortion. Replace thrust plate if necessary.
5. Measure camshaft thrust plate thickness using an outside micrometer. Replace thrust plate if not within Specifications (page 640).

**Crankcase Breather Assembly**

1. Clean all tubing, hoses, and crankcase breather assembly.
2. Dry parts with filtered compressed air.
3. Inspect tubing, hoses, and crankcase breather assembly for leaks or cracks. Replace cracked or leaking parts.

### Crankcase, Cup Plugs, and Piston Cooling Tubes

**NOTE:** The best way to clean the crankcase during an engine overhaul is in a chemical bath or "hot tank". If hot tank cleaning is not available, use the following cleaning procedure.

1. Remove deposits and gasket material from gasket surfaces using a rotary wire brush or sanding block with mineral spirits.

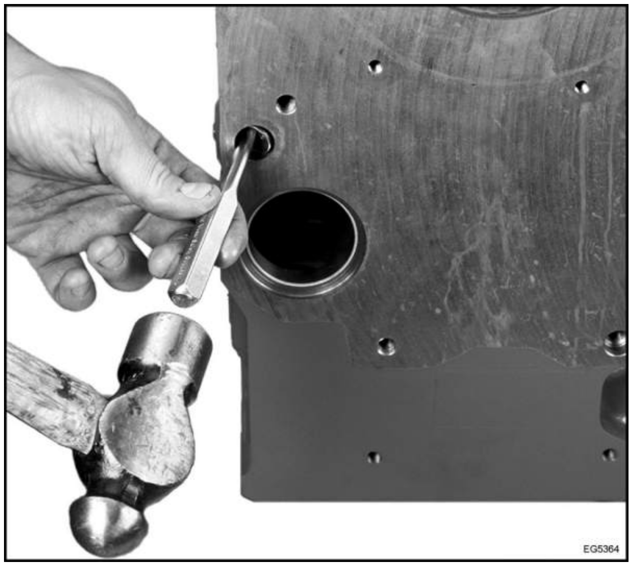


**Figure 515 Crankcase cup (freeze) plug removal**

2. Remove the main oil gallery cup plug, located in the rear of the crankcase. Carefully knock out cup plugs with a hammer and chisel.
3. Clean oil galleries in the crankcase using a Stiff Nylon Brush (page 644) with soap and water.
4. Clean cross drillings in the crankcase using a Nylon Brush with soap and water.
5. Blow out oil galleries and cross drillings with filtered compressed air.
6. Clean all cylinder head bolt holes with Head Bolt Bottoming Tap (page 644).
7. Clean all crankcase threaded holes using an appropriate sized tap from Tap Set (page 644).
8. Clean crankcase mating surfaces for cup plugs.
9. Apply Loctite® 262 (page 644) to the outside edge of cup plugs.
10. Drive cup plug into the crankcase using a punch approximately 6 mm (0.25 in) smaller in diameter than the plug being installed.
11. Recess cup plugs 2.3 mm (0.09 in) below machined surface.
12. Inspect both ends of each piston cooling tube. Verify the flanged end is intact and the orifice end protruding from the crankcase is not broken. Replace any cooling tubes that are damaged.
13. Hold each piston cooling tube under running water. Water should stream out of tube end. Clear blocked piston cooling tubes using filtered compressed air. Replace piston cooling tube if blockage can not be cleared.
14. Clean engine block heater port in the intake side of the crankcase.

15. Inspect each crankcase counterbore for cracks.

**Crankshaft and Main Bearings**

1. Inspect crankshaft gear for chips or excessive wear. Replace gear if required.
2. Clean each main bearing and cap in solvent and dry with filtered compressed air. Do not scrape gum or varnish deposits from main bearings.
3. Clean internal oil passages of the crankshaft using a Stiff Nylon Brush (page 644). Flush oil passages with a suitable non-caustic solvent.
4. Blow crankshaft oil passages dry with filtered compressed air.
5. Inspect crankshaft journals (main and rod) for scratches, grooves, and scoring. Use dye penetrant kit (page 644) to check for cracks.
6. Inspect all upper and lower main bearings. Replace bearings that are scored, chipped, or excessively worn.

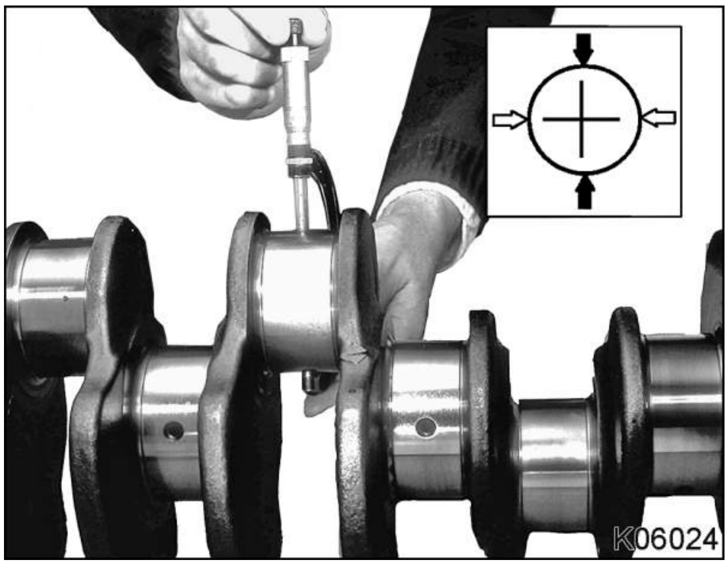


**Figure 516 Crankshaft journal measurement**

7. Measure diameter of each crankshaft journal at two points 90 degrees from each other using an outside micrometer (page 644). Move the micrometer over the entire width of the journal at each measurement point.
8. Compare measurements to crankshaft Specifications (page 640).

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

The crankshaft can be ground to the following undersizes:

- 0.25 mm (0.010 in)
- 0.51 mm (0.020 in)
- 0.76 mm (0.030 in)

### Measure Camshaft End Play

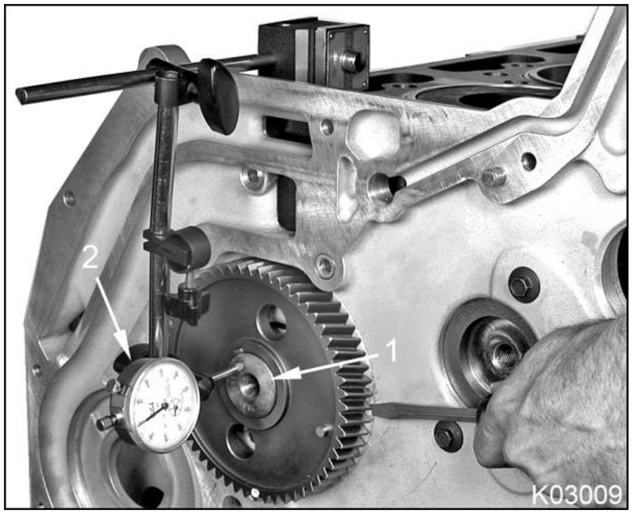


**Figure 517 Camshaft end play measurement**

1. Camshaft
2. Dial indicator set

1. Mount magnetic base of a dial indicator set (page 644) on a flat engine surface.
2. Push camshaft toward the engine and put tip of dial indicator on the camshaft end.
3. Zero dial indicator.
4. Lightly pry camshaft toward the dial indicator and then push away.
5. See camshaft end play Specification (page 640).
   - If camshaft end play exceeds maximum specification, remove the camshaft gear, pull camshaft forward, and reinstall camshaft gear making sure gear is seated all the way on the camshaft. Repeat steps 2, 3, and 4.
   - If camshaft end play is less then minimum specification correct camshaft thrust plate or mating surface problems.

### Measure Camshaft Lobes and Journals

**NOTE:** See Measure Camshaft Lobe Lift (page 434) to measure camshaft lift without removing the camshaft or cylinder head.

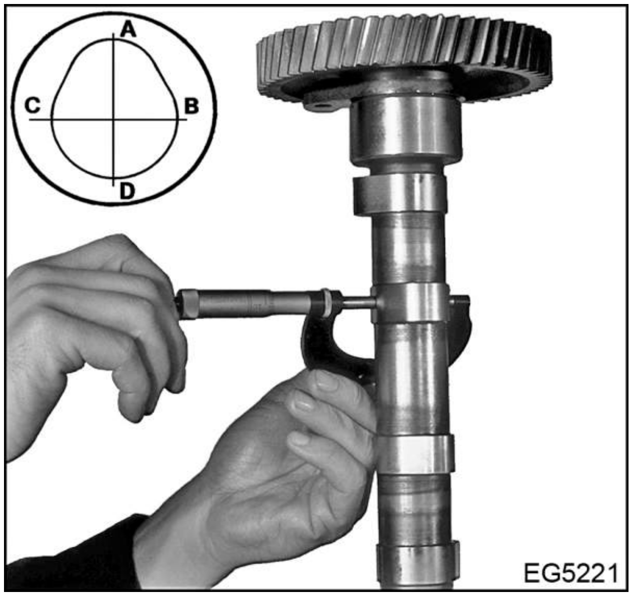


**Figure 518 Camshaft lobe and journal measurement**

1. Measure across each camshaft lobe from points A-D and B-C using an outside micrometer (page 644).
2. Subtract measurement B-C from measurement A-D. This is lobe lift.
3. If any camshaft lobe lift measurement is 0.25 mm (0.010 in) or more below Specification (page 640), replace camshaft.
4. Measure the diameter of each camshaft journal using an outside micrometer.
5. If any journal measurement is below specification, replace the camshaft.

**Measure Crankshaft End Play**

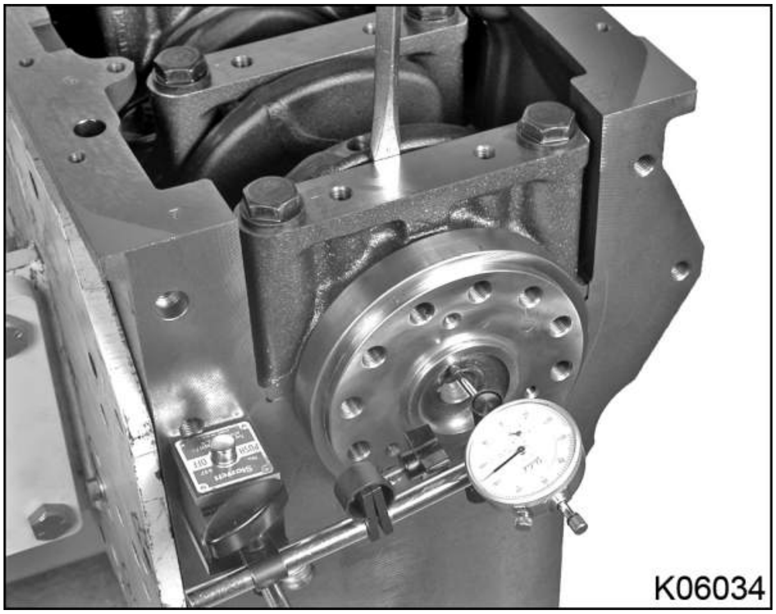


**Figure 519 Crankshaft end play measurement**

1. Mount magnetic base of a dial indicator set (page 644) on a flat engine surface.
2. Push crankshaft toward the rear of the engine and put tip of dial indicator on the crankshaft end.
3. Zero dial indicator.
4. Lightly pry crankshaft toward the front of the engine and then away. Pry between the crankshaft counter weight and crankcase main bearing caps.

**CAUTION:**

**To prevent engine damage, use new main bearing cap bolts whenever main bearing cap bolts are removed.**

5. See crankshaft end play Specification (page 640).
    - If crankshaft end play exceeds maximum specification, replace thrust main bearing (# 7 upper). Install and torque new main bearing cap bolts (page 631). Repeat steps 1 through 4.
    - If crankshaft end play is less than minimum specification, loosen main bearing caps and reposition bearings. Install and torque new main bearing cap bolts. Repeat steps 1 through 4.

# Installation

**Camshaft Bushings**

1. Identify each camshaft bushing according to its outside diameter. See camshaft bushing Specifications (page 640).

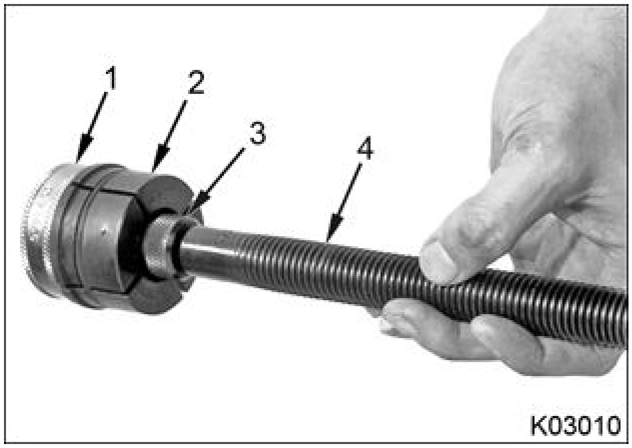


**Figure 520 Camshaft Bushing Puller (installer)**

1. Backup nut
2. Expanding collet
3. Puller screw extension
4. Puller shaft

2. Install a new camshaft bushing on the Camshaft Bushing Puller (page 644) expanding collet.
3. Tighten expanding collet by turning backup nut until camshaft bushing is held securely.


**Figure 521 Camshaft bearing oil hole location mark**

4. Mark each camshaft bushing oil hole location on the backup nut of the Camshaft Bushing Puller to help align bushing oil hole with the crankcase oil hole.

**CAUTION:**

**To prevent engine damage, if the crankcase does not have an annulus in intermediate cam bores, camshaft bushing oil holes must align with crankcase oil holes.**

**CAUTION:**

**To prevent engine damage, camshaft bushings must be installed in the proper order due to different outside diameters. Both intermediate camshaft bushings have an outer diameter slightly smaller than bushings used in the front and rear.**

**NOTE:** If crankcase has an annulus groove in crankcase intermediate cam bores 2 and 3, see Instruction sheet 1171892R1 “Camshaft Bearing Kit”.

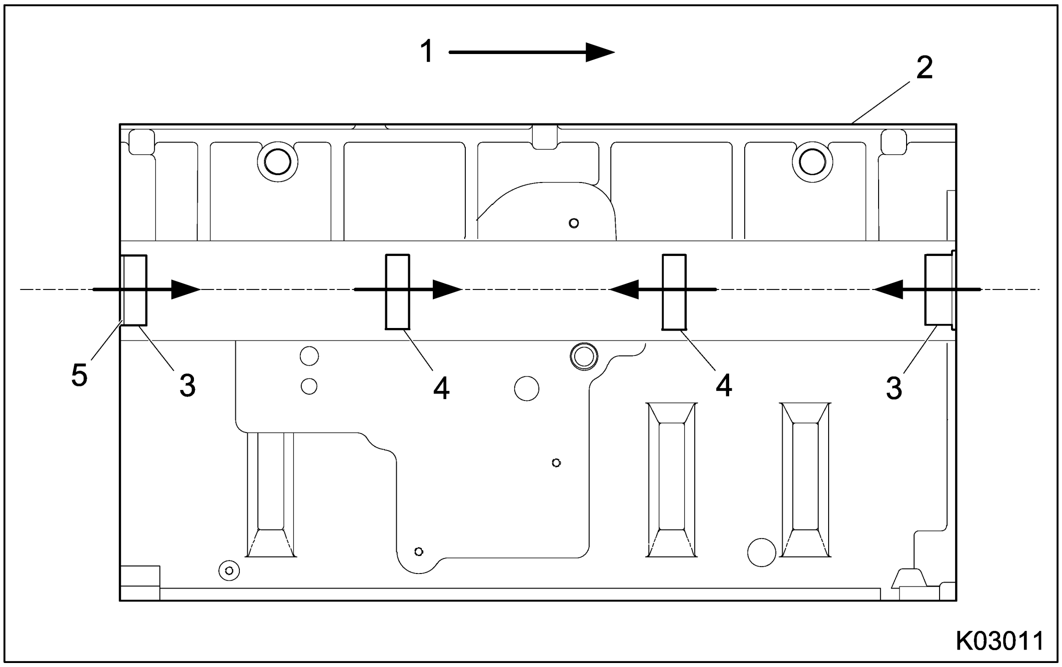


**Figure 522 Camshaft bushing installation pull direction (partial crankcase cut-away)**

1. Front of engine
2. Crankcase assembly
3. Front and rear camshaft bushings
4. Intermediate camshaft bushings
5. Camshaft seal ring

5. Install rear intermediate bushing through the rear of the crankcase.
6. Pull bushing in place from the front of the crankcase by turning the pulling nut on the puller screw.
7. Remove the Camshaft Bushing Puller and inspect camshaft bushing oil hole to crankcase oil hole alignment.
8. Install the front intermediate bushing through the front of the crankcase.
9. Pull bushing in place from the rear of the crankcase by turning the pulling nut on the puller screw.
10. Remove the Camshaft Bushing Puller and inspect camshaft bushing oil hole to crankcase oil hole alignment.

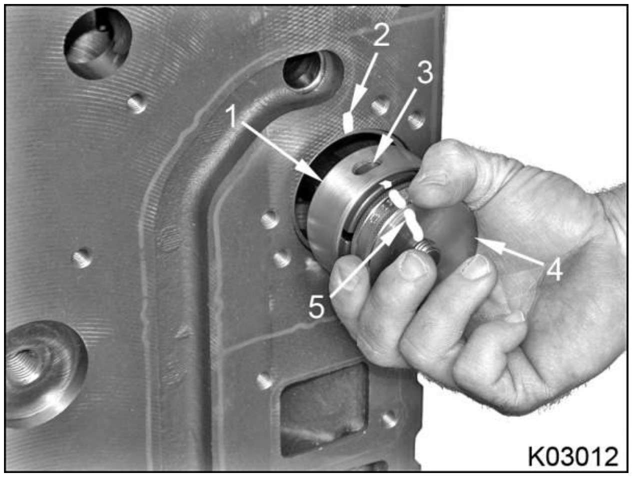


**Figure 523 Front camshaft bushing installation**

1. Front camshaft bushing
2. Crankcase oil hole alignment mark
3. Camshaft bushing oil hole
4. Camshaft Bushing Puller (installer)
5. Camshaft bushing oil hole alignment mark

11. Install the front camshaft bushing through the front of the crankcase.
12. Pull bushing in place from the rear of the crankcase by turning the pulling nut on the puller screw.
13. Remove the Camshaft Bushing Puller and inspect camshaft bushing oil hole to crankcase oil hole alignment.
14. Install the rear bushing through the rear of the crankcase.
15. Pull the bushing in place from the front of the crankcase by turning the pulling nut on the puller screw.
16. Remove the Camshaft Bushing Puller and inspect camshaft bushing oil hole to crankcase oil hole alignment.
17. Install camshaft seal ring in rear of crankcase.

**Camshaft Assembly**


**Figure 524 Camshaft assembly installation**

1. Rotate crankcase to a vertical position.
2. Lubricate all camshaft journals and bushings with clean engine oil.
3. Carefully install camshaft assembly into crankcase. Do not scratch or damage camshaft journals or bushings during installation.

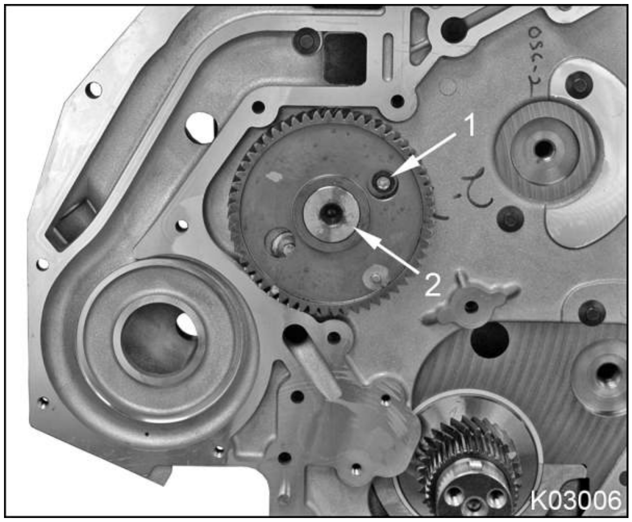


**Figure 525 Camshaft thrust plate bolts**

1. M8 x 20 bolt (2)
2. Camshaft

4. Install two M8 x 20 camshaft thrust plate bolts and tighten to standard torque (page 683).
5. Measure Camshaft End Play (page 614).

**Camshaft Gear**


**Figure 526 Camshaft gear and hot plate**

**WARNING:**

**To prevent personal injury or death, wear heat insulated gloves when handling heated components.**

1. Heat camshaft gear on a hot plate (page 644) or other controlled heat source to 191 to 202 °C (375 to 395 °F).

**CAUTION:**

**To prevent engine damage, do not heat cam gear above 202 °C (395 °F).**

2. Pull camshaft assembly forward prior to sliding heated camshaft gear on the camshaft.

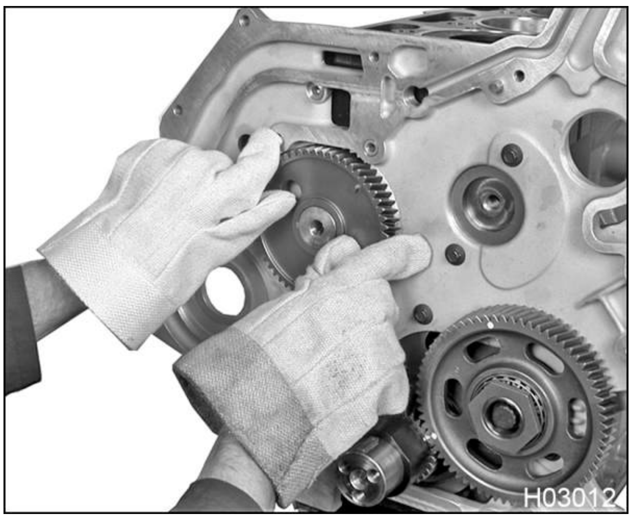


**Figure 527 Camshaft gear installation**

**CAUTION:**

**To prevent engine damage, do not tap or hammer camshaft gear onto camshaft.**

**NOTE:** Heated gear should easily slide on camshaft. If gear does not slide easily, inspect camshaft gear mounting surface and repeat steps 1 and 2.

3. Install heated camshaft gear on the camshaft while wearing heat insulated gloves. Make sure woodruff key groove on gear aligns with key in camshaft. Camshaft gear should slide on the camshaft with only slight hand pressure. Hold the camshaft gear (while thoroughly seated) until it cools on the camshaft (approximately 30 seconds).

**NOTE:** The camshaft should stick out of the camshaft gear slightly when the camshaft gear is properly installed.

4. Measure Camshaft End Play (page 614).

### Crankshaft Gear and Oil Pump Spline Drive

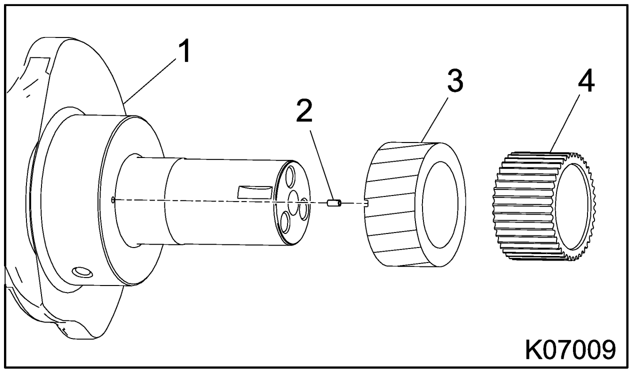


**Figure 528 Crankshaft gear and oil pump spline drive**

1. Crankshaft
2. Slotted spring pin, 3.967 x 7.938 mm (5/32 x 5/16 in)
3. Crankshaft gear
4. Oil pump spline drive

1. Carefully tap slotted spring pin into hole in the crankshaft.

**WARNING:**

**To prevent personal injury or death, wear heat insulated gloves when handling heated components.**

2. Heat crankshaft gear and oil pump spline drive on a hot plate (page 644) or other controlled heat source to 188 to 202 °C (370 to 395 °F).
3. Install heated crankshaft gear while wearing heat insulated gloves. Align the slotted spring pin in the crankshaft with corresponding slot in the crankshaft gear. Press crankshaft gear against the crankshaft shoulder and hold until gear cools (approximately 30 seconds).
4. Install heated oil pump spline drive on the crankshaft against the crankshaft gear while wearing heat insulated gloves. Hold spline drive against the crank gear until spline cools (no orientation required).

**Upper Main Bearings and Crankshaft Assembly**

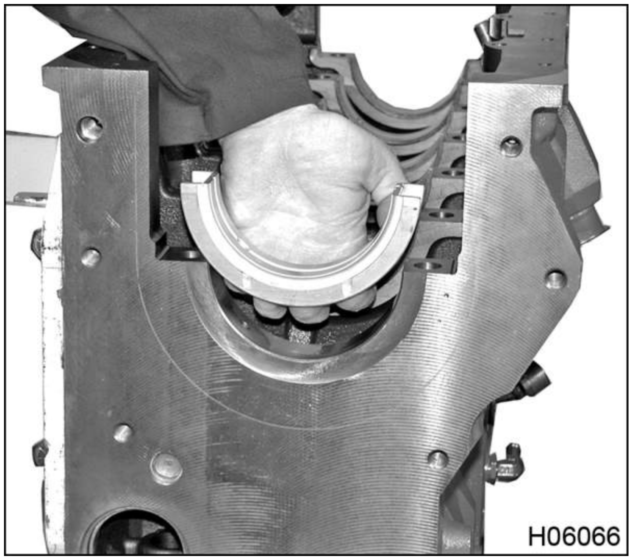


**Figure 529 Thrust bearing installation**

1. Rotate crankcase so main bearing saddles are facing up.
2. Clean oil off crankcase main bearing saddles with a lint-free cloth. Do not lubricate the back side of main bearings.
3. Install thrust main bearing in the rear #7 upper main bearing saddle. Make sure locking tab on bearing aligns with notch in the crankcase.
4. Install the remaining six upper main bearings in their corresponding saddles. Make sure locking tab on each bearing aligns with notch in the crankcase.
5. Apply marker paste (Prussian Blue® (page 644) or equivalent) on the crankshaft main bearing journals.

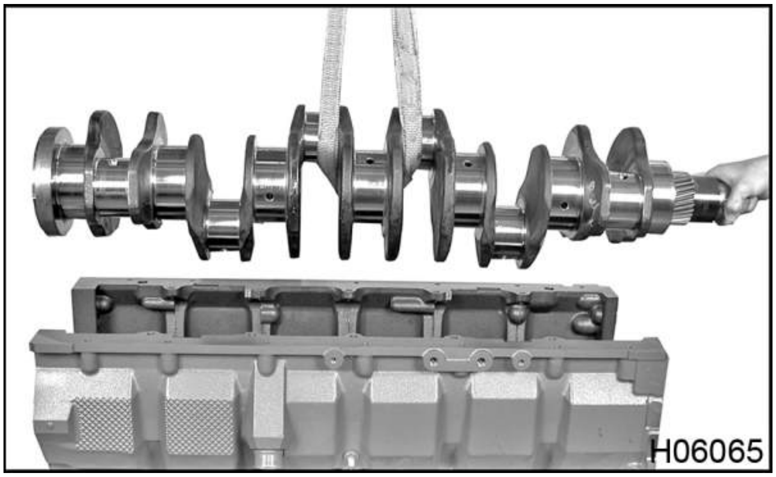


**Figure 530 Crankshaft assembly installation**

**CAUTION:**

**To prevent engine or vehicle damage, do not drop, bend, or gouge crankshaft.**

6. Install and center an appropriate lifting sling on the crankshaft, supported by two connecting rod journals.
7. Carefully lift and lower the crankshaft onto the upper main bearings in the crankcase.

**NOTE:** Do not install the main bearing caps at this time.

8. Rotate the crankshaft 180 degrees (½ turn).
9. Carefully remove the crankshaft and inspect the upper bearings for an even transfer of bluing agent from the journals to the bearings.
   - If voids appear in the blueing agent transfer, inspect and measure the crankcase and crankshaft. Correct any problems and then repeat steps 7 through 13.
   - If the bluing agent transfer is even and normal and the crankcase and crankshaft are not damaged then proceed to step 10.

10. Clean all marker paste off bearings and crankshaft journals.
11. Lubricate upper main bearings with clean engine oil.
12. Install and center an appropriate lifting sling on the crankshaft, supported by two connecting rod journals.
13. Carefully lift and lower the crankshaft onto the main bearings in the crankcase.

**Main Bearing Fit Procedure**

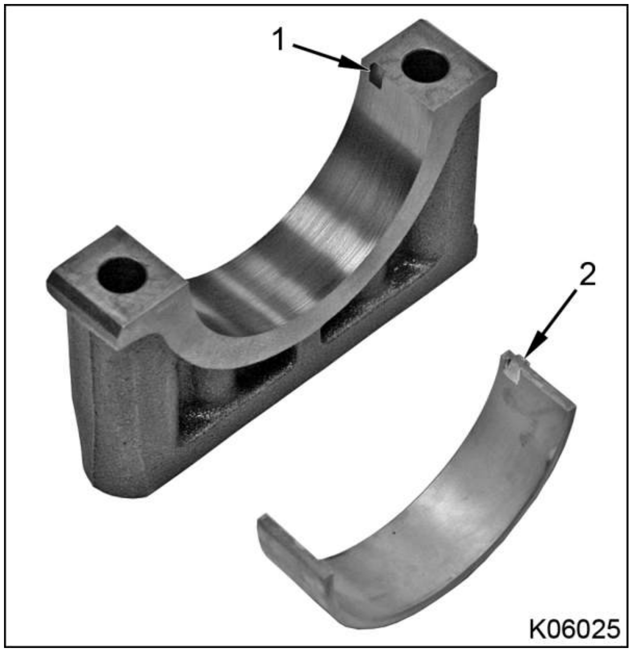


**Figure 531 Main bearing cap and lower main bearing**

1. Main bearing cap notch
2. Bearing alignment tab

**NOTE:** Main bearing caps and the back of main bearing surfaces must be free of oil and dirt. Do not lubricate the backside of main bearings.

1. Install lower main bearing in each main bearing cap. Make sure bearing alignment tabs snap in each bearing cap notch.

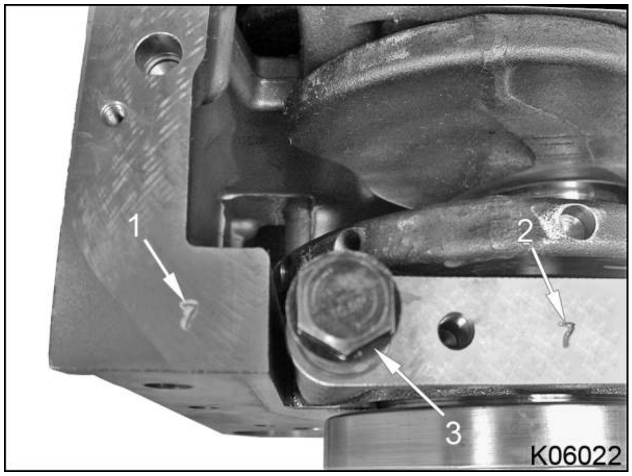


**Figure 532 Main bearing cap and crankcase stamps**

1. Crankcase stamp for #7 main bearing
2. Main bearing cap stamp on #7 main bearing cap
3. M15 x 162 main bearing cap bolt (14)

2. Orient each main bearing cap with its matching crankcase stamp.
3. Clean each lower main bearing surface and the exposed half of the crankshaft journal. These surfaces must be free of oil.
4. Install each main bearing cap assembly. Lightly oil threads of new main bearing bolts with clean engine oil.

**NOTE:** Bearing clearance measurement checks bearing fit and will not permanently stretch main bearing bolts. Do not torque-to-yield main bearing bolts until final assembly.

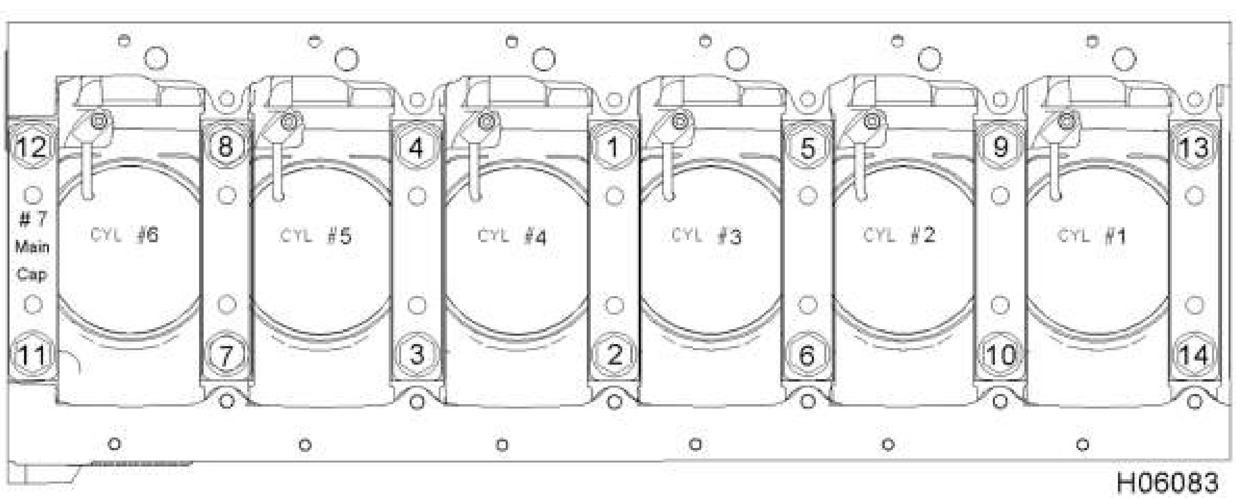


**Figure 533 Main bearing cap bolt torque sequence**

5. Tighten each main bearing cap bolt to 136 N·m (100 lbf·ft) using “Main bearing cap bolt torque sequence”.
6. Tighten each main bearing bolt to 177 N·m (130 lbf·ft) using “Main bearing cap bolt torque sequence”.

7. Remove one main bearing cap assembly at a time. Leave other caps tight.
8. Wipe oil from all contact surfaces of the exposed crankshaft journal and main bearing.

**NOTE:** For in chassis service only: the crankshaft must be supported and held against the upper main bearing halves to get a correct Plastigage® (page 644) reading. Use a jack to support the crankshaft at the counterweight nearest each main bearing being checked. Failure to support the crankshaft will result in inaccurate readings.

**NOTE:** Do not rotate the crankshaft.

9. Place a piece of Plastigage® across the full width of the bearing surface on the crankshaft journal (or bearing insert) approximately 6 mm (0.25 in) off center. Install the bearing cap and tighten main bearing cap bolts to 177 N·m (130 lbf·ft).
10. Remove main bearing cap assembly. Do not disturb the Plastigage®.

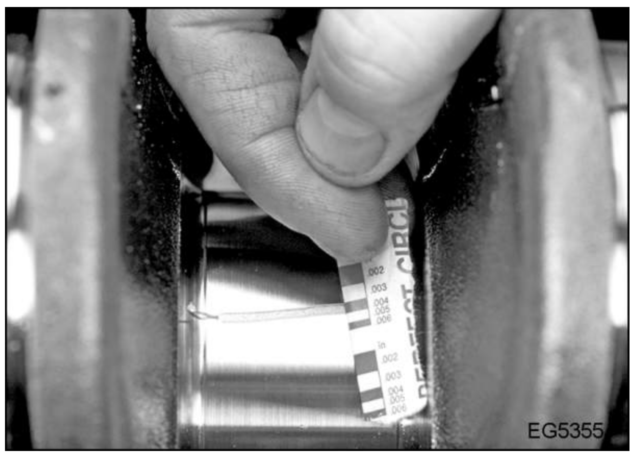


**Figure 534 Plastigage® Measurement**

11. Measure Plastigage® using the scale on the Plastigage® envelope. Measure the widest point of the flattened Plastigage®. This reading indicates the bearing clearance in thousandths of an inch or millimeters.
12. Remove Plastigage®, install main bearing cap assembly, and tighten main bearing bolts to 177 N·m (130 lbf·ft). Repeat steps 7 through 11 for all seven main bearings.
13. If main bearing to crankshaft running clearances are not within Specifications (page 640), replace the crankshaft or resurface the crankshaft and install oversize main bearings.

**Main Bearings and Caps**

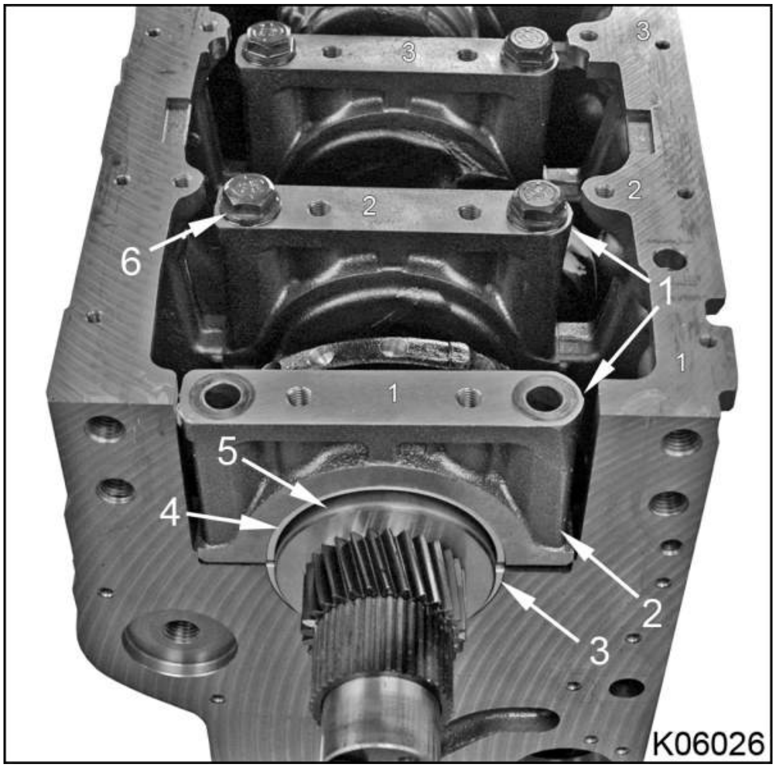


**Figure 535 Main bearings and caps**

1. Rounded end of main bearing caps
2. Main bearing cap #1 (front of engine)
3. Upper main bearing
4. Lower main bearing
5. Crankshaft #1 main bearing journal
6. M15 x 162 main bearing cap bolt (14)

**CAUTION:**

**To prevent engine damage, use new main bearing cap bolts whenever main bearing cap bolts that have been torqued to yield are removed.**

**NOTE:** Thrust main bearing is only located on the crankcase # 7 upper main bearing saddle. All seven lower bearings are the same part number.

1. Clean all Plastigage® and marker paste from main bearing and crankshaft journal surfaces.
2. Coat all main bearing journal surfaces with clean engine oil.
3. Lightly coat new main bearing cap bolts with clean engine oil (coat threads and under bolt head).

**NOTE:** Main bearing cap rounded ends go toward the cam or exhaust side of the crankcase. Match the upper and lower main bearing tabs on the cam side of the engine.

**CAUTION:**

**To prevent engine damage, match and orient each main bearing cap with its corresponding number stamped in the crankcase. Install #1 main bearing cap on the front main bearing journal and install remaining main bearing caps numbered from the front of the engine to the rear (# 7).**

4. Install seven main bearing cap assemblies in their corresponding crankcase saddles. Make sure number on each bearing cap is correctly oriented and matches its corresponding number stamped in the crankcase.
5. Install fourteen new M15 x 162 main bearing cap bolts and finger tighten. See Torque Procedure for Torque-to-yield Main Bearing Cap Bolts (page 631).

### Torque Procedure for Torque-to-yield Main Bearing Cap Bolts

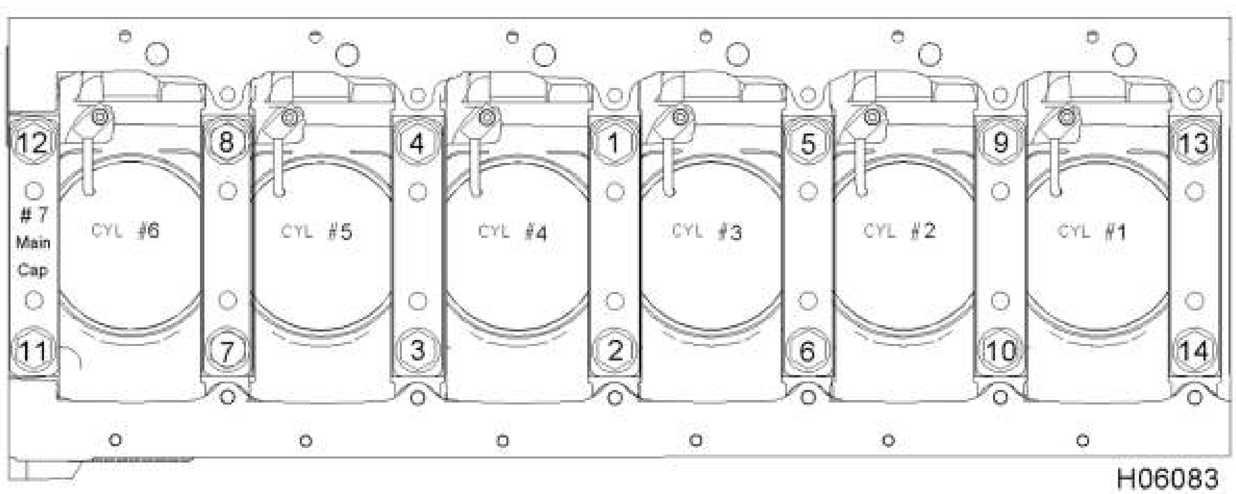


**Figure 536 Main bearing cap bolt torque sequence**

1. Tighten each main bearing cap bolt to 136 N·m (100 lbf·ft) using “Main bearing cap bolt torque sequence”.
2. Measure Crankshaft End Play (page 616). Do not proceed to the next step in this procedure until end play is within Specification (page 640).
3. Tighten each main bearing cap bolt to 177 N·m (130 lbf·ft) using “Main bearing cap bolt torque sequence”.

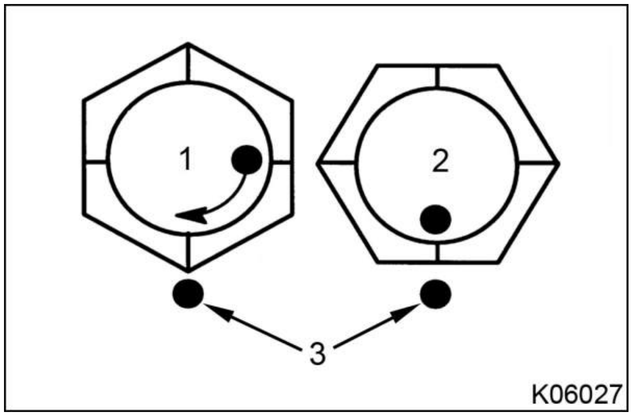


**Figure 537 Main bearing cap bolt torque-to-yield marking**

1. Head of main bearing cap bolt before Torque-to-yield
2. Head of main bearing cap bolt after Torque-to-yield
3. Mark on main bearing cap surface

**CAUTION:**

**To prevent engine damage, use new main bearing cap bolts whenever main bearing cap bolts that have been torqued to yield are removed.**

**CAUTION:**

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

4. Using a permanent marker, place a mark on each new main bearing cap bolt and put another mark on the socket directly in line with the mark on each new main bearing cap bolt.
5. Put a mark on the main bearing cap surface 90° clockwise from each main bearing cap bolt mark.
6. Install socket on main bearing cap bolt to be torqued and align mark on socket with the mark on the main bearing cap bolt.
7. Torque-to-yield each main bearing cap bolt by rotating each bolt 90 degrees clockwise (1/4 turn) in “Main bearing cap bolt torque sequence”. The marks on the socket, main bearing cap bolt, and main bearing cap surface should be aligned.

**Crankcase Ladder Assembly**

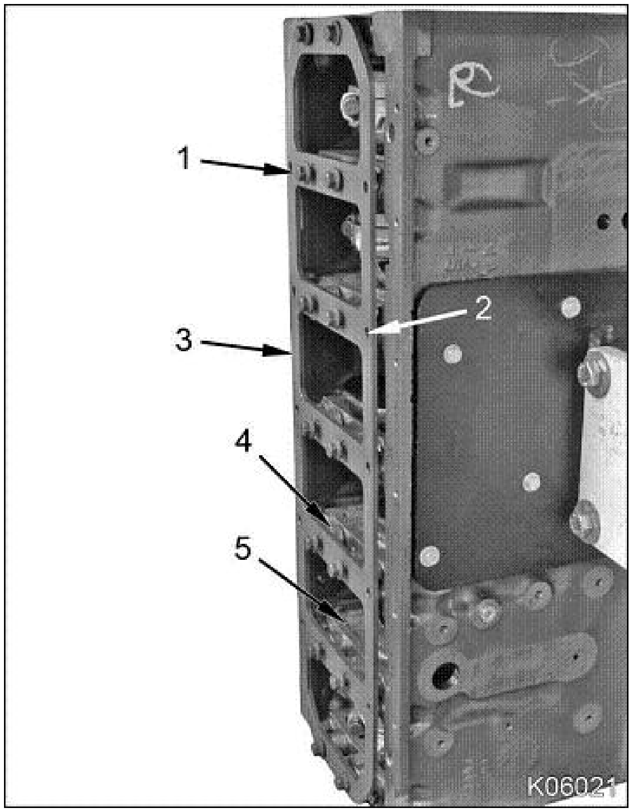


**Figure 538 Crankcase ladder assembly**

1. M12 x 35 bolt (14)
2. M10 x 25 bolt hole (10)
3. Crankcase ladder
4. Spacer (14)
5. Main bearing cap (7)

**NOTE:** The crankcase ladder is symmetrical and can be mounted either way.

**NOTE:** Plastic washers are used as an assembly aid to hold each bolt and spacer to the crankcase ladder. Plastic washers are not required.

1. Position crankcase ladder assembly on the crankcase. Install fourteen spacers and fourteen M12 x 35 bolts on the main bearing cap bolt holes.
2. Install ten M10 x 25 bolts into the crankcase and finger tighten.

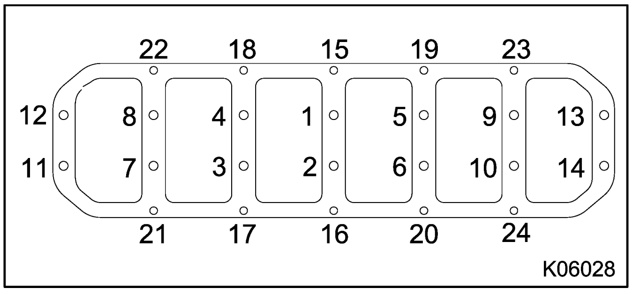


**Figure 539 Crankcase ladder torque sequence**

3. Tighten fourteen M12 x 35 bolts to special torque (page 644) using “crankcase ladder torque sequence” steps 1 through 14.
4. Tighten ten M10 x 25 bolts to special torque using “crankcase ladder torque sequence” steps 15 through 24.

**Coolant Heater Assembly (Optional)**

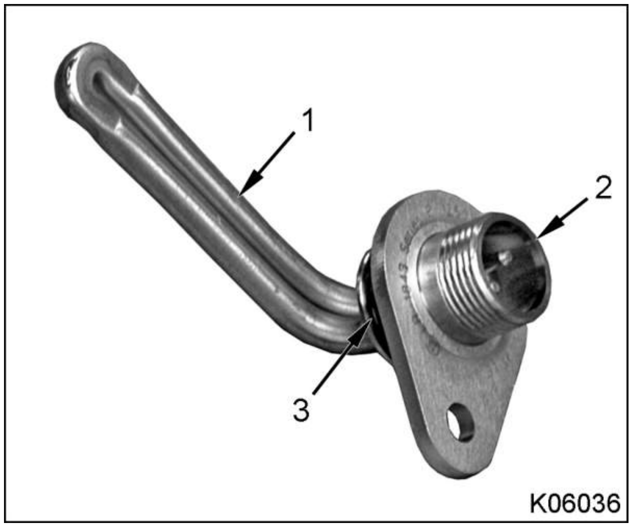


**Figure 540 Coolant heater assembly**

1. Heater element
2. Cord adaptor
3. O-ring

1. Install a new O-ring on the coolant heater assembly.

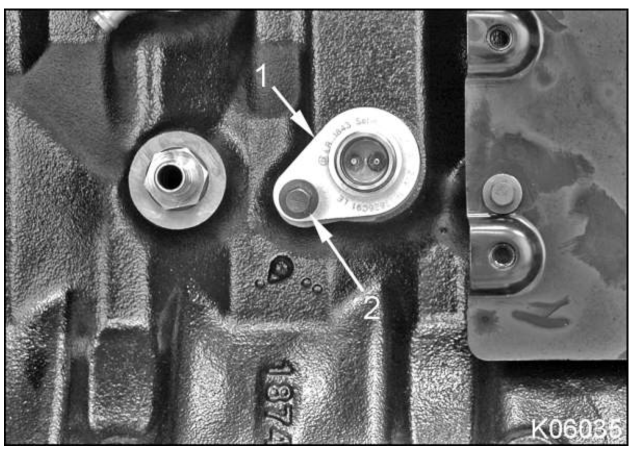


**Figure 541 Coolant heater (intake side of crankcase)**

1. Coolant heater mounting flange
2. M8 x 20 bolt

2. Install coolant heater element into the crankcase. Press coolant heater mounting flange flush with crankcase mounting surface.
3. Tighten M8 x 20 bolt to standard torque (page 683).
4. Refill cooling system and check for leaks.

**Oil Level Gauge Assembly**


**Figure 542 Oil level gauge tube**

1. If removed, install oil level gauge tube in crankcase. Apply Loctite® 277™ (page 644) around entire outside circumference of tube. Drive oil level gauge tube into crankcase until bead of tube is seated in chamfer of crankcase boss (tube orientation is not required).

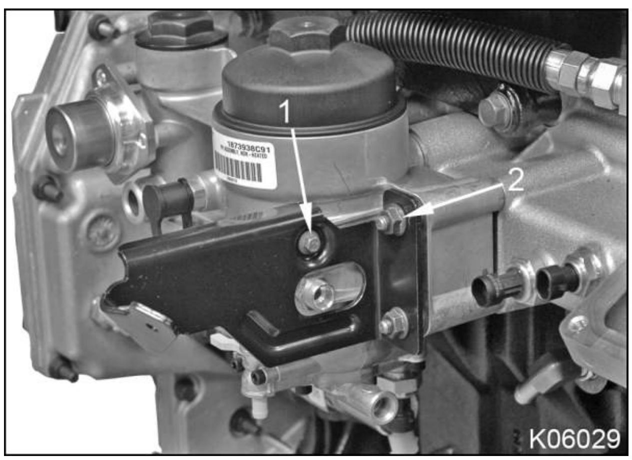


**Figure 543 Oil filler tube support**

1. M6 x 16 bolt
2. M8 nut (2)

2. Install oil filler tube support and two M8 nuts on the fuel filter header assembly mounting studs.
3. Install M6 x 16 bolt and tighten to special torque (page 644).
4. Tighten two M8 nuts to special torque.

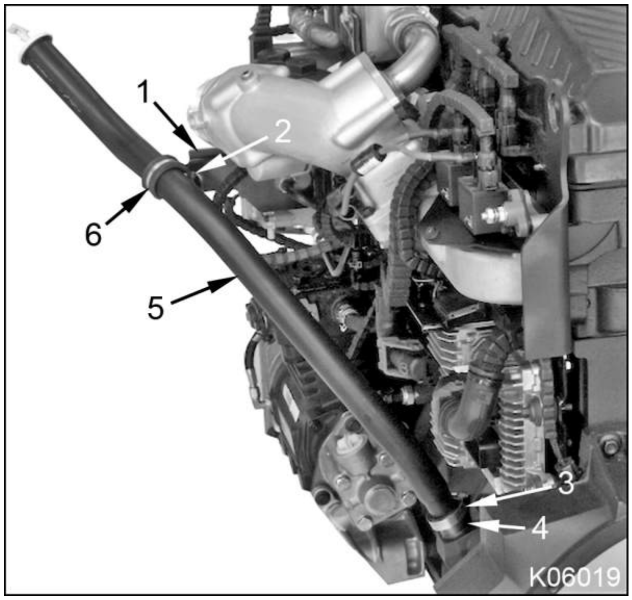


**Figure 544 Oil level gauge assembly**

1. Oil filler tube support
2. M6 x 40 bolt and M6 nut
3. Tube clamp
4. Oil level gauge tube
5. Oil filler tube
6. Cushioned clamp

5. Install oil filler tube and tube clamp on the oil level gauge tube.
6. Install cushioned clamp on the oil filler tube and install the M6 x 40 bolt through the cushioned clamp and oil filler tube support. Install M6 nut on M6 x 40 bolt
7. Tighten tube clamp.
8. Tighten M6 x 40 bolt and nut to special torque (page 644).

**Crankcase Ventilation System**

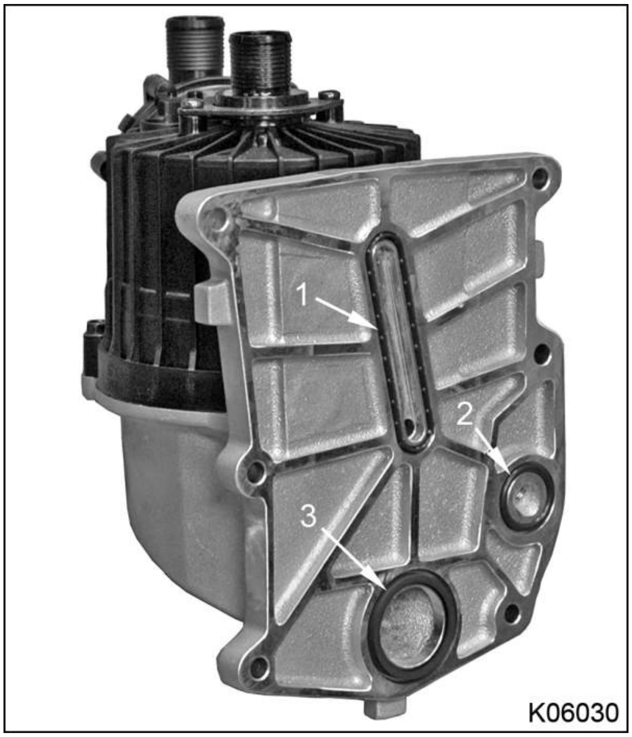


**Figure 545 Crankcase breather assembly with turbine**

1. Breather plate seal (inlet drive oil)
2. O-ring seal (ventilation hole)
3. Breather plate out seal (oil drain)

1. Install a new breather plate seal, breather plate out seal, and O-ring seal in the back of the crankcase breather assembly.
2. Install breather assembly with turbine on the exhaust side of the crankcase and finger tighten five M8 x 25 bolts.

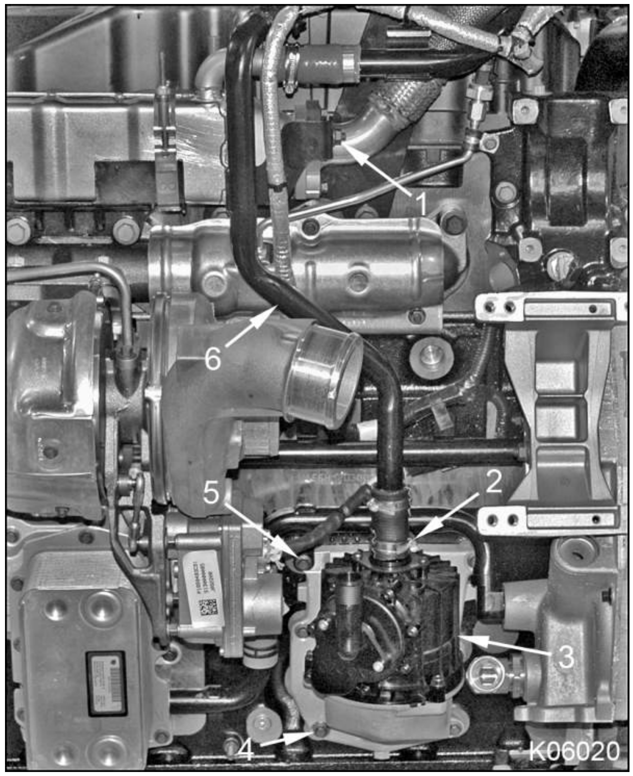


**Figure 546 Crankcase breather assembly and inlet tube**

1. M8 lock nut
2. Hose clamp (2)
3. Breather assembly with turbine
4. M8 x 25 bolt (5)
5. M8 x 30 bolt
6. Breather inlet tube assembly

3. Install oil system module coolant tube (page 328) and M8 x 30 bolt.
4. Tighten M8 x 30 bolt and five M8 x 25 bolts to special torque (page 644).
5. Install hose of breather inlet tube assembly on the breather assembly inlet fitting.
6. Install end of breather inlet tube onto the valve cover breather hole.
7. Align breather inlet tube retaining bracket on the exhaust side EGR cooler outlet stud bolt and tighten M8 nut to special torque.
8. Tighten hose clamps on the breather inlet tube assembly.

# Specifications

**Crankcase Specifications**

| | |
|---|---|
| Main cap attachment | 2 bolts per main cap |
| Main bearing type | Precision replaceable |
| Main bearing material | Steel-backed copper, lead, tin |
| Thrust taken by | Rear upper main bearing #7 |
| Engine block heater rating | 1250 W, 120 V |
| | |
| Center line of main bearing bore to head deck | 368.3 ± 0.05 mm (14.50 ± 0.002 in) |
| Counterbore depth allowable variation between four points (maximum) | 0.025 mm (0.001 in) |
| Counterbore depth in crankcase | 8.865 ± 0.025 mm (0.349 ± 0.001 in) |
| Counterbore diameter in crankcase | 136.14 + 0.381 – 0.127 mm (5.360 + 0.015 – 0.005 in) |
| Counterbore maximum allowable depth | 9.25 mm (0.364 in) |
| Crankcase deck flatness | 0.076 mm (0.003 in) |
| Crankcase main bearing bore diameter | 116.421 ± 0.027 mm (4.4583 ± 0.0005 in) |
| Piston cooling tube diameter (spray hole) MaxxForce® DT | 2.18 mm (0.086 in) |
| Piston cooling tube diameter (spray hole) MaxxForce® 9 and 10 | 2.59 mm (0.102 in) |
| Roller tappet outside diameter | 28.435 to 28.448 mm (1.1195 to 1.1200 in) |
| Sleeve protrusion above crankcase | 0.051 to 0.127 mm (0.002 to 0.005 in) |
| Tappet bore diameter | 28.5306 ± 0.01905 mm (1.12325 ± 0.00075 in) |
| | |
| Camshaft Bushing Bore Diameter in Crankcase: | |
| Front | 63.5521 ± 0.01905 mm (2.50205 ± 0.00075 in) |
| Intermediate (2) | 63.0238 ± 0.01905 mm (2.48125 ± 0.00075 in) |
| Rear | 63.5521 ± 0.01905 mm (2.50205 ± 0.00075 in) |

**Camshaft Specifications**

| | |
|---|---|
| Camshaft bushing inner diameter (ID) (installed) | 58.04 to 58.12 mm (2.285 to 2.288 in) |
| Cam lobe lift, exhaust | 6.91 mm (0.272 in) |
| Cam lobe lift, intake | 6.68 mm (0.263 in) |
| Camshaft end play | 0.18 to 0.33 mm (0.007 to 0.013 in) |
| Camshaft journal diameter | 57.96 to 57.99 mm (2.282 to 2.283 in) |
| Camshaft journal to bearing radial clearance | 0.025 to 0.076 mm (0.001 to 0.003 in) |
| Maximum permissible cam lobe wear | 0.25 mm (0.010 in) |
| Service bushings furnished to size | Yes |
| Thrust plate thickness (new) | 6.96 to 7.01 mm (0.274 to 0.276 in) |

**Camshaft Bushing Specifications**

| Bushing Location | Outside Diameter (nominal) | Width (nominal) |
|---|---|---|
| Front | 63.5 mm (2.50 in) | 25.4 mm (1.00 in) |
| Rear | 63.5 mm (2.50 in) | 17.8 mm (0.70 in) |
| Intermediate | 63.0 mm (2.48 in) | 26.7 mm (1.05 in) |

**Crankshaft Specifications**

| | |
|---|---|
| Crankshaft | Forged steel, induction hardened, grindable |
| Number of main bearings | 7 |
| Thrust taken by | # 7 rear upper main bearing |
| **Main bearing journal diameter:** | |
| Standard size | 107.95 ± 0.015 mm (4.250 ± 0.0006 in) |
| 0.254 mm (0.010 in) undersized | 107.70 ± 0.015 mm (4.240 ± 0.0006 in) |
| 0.508 mm (0.020 in) undersized | 107.44 ± 0.015 mm (4.230 ± 0.0006 in) |
| 0.762 mm (0.030 in) undersized | 107.19 ± 0.015 mm (4.220 ± 0.0006 in) |
| Crankshaft journal waviness (maximum) | 0.00381 mm (0.00015 in) |
| Crankshaft journal surface finish | 0.00015 mm (0.000006 in) |

**NOTE:** Grind all crankshaft journals against operating rotation (when looking at front end of crankshaft, operating rotation is clockwise). Lap all Journals with operating rotation, not more than 0.0127 mm (0.0005 in) stock to be removed by lapping.

| | |
|---|---|
| **Thrust Bearing Journal Length:** | |
| Standard size to 0.76 mm (0.030 in) undersized | 34.404 ± 0.546 mm (1.3545 ± 0.0215 in) |
| **Connecting rod journal diameter:** | |
| Standard size | 80.010 ± 0.015 mm (3.1500 ± 0.0006 in) |
| 0.0254 mm (0.010 in) undersized | 79.756 ± 0.015 mm (3.1400 ± 0.0006 in) |
| 0.508 mm (0.020 in) undersized | 79.502 ± 0.015 mm (3.1300 ± 0.0006 in) |
| 0.762 mm (0.030 in) undersized | 79.248 ± 0.015 mm (3.1200 ± 0.0006 in) |

**Crankshaft Specifications (continued)**

| | |
|---|---|
| Connecting rod bearing to crankshaft running clearance | 0.030 to 0.107 mm (0.0012 to 0.0042 in) |
| Connecting rod bearing width | 39.99 mm (1.5745 in) |
| Connecting rod journal maximum out-of-round | 0.0064 mm (0.00025 in) |
| Connecting rod journal taper (maximum per inch) | 0.0051 mm (0.0002 in) |
| Connecting rod to crankshaft side clearance | 0.190 to 0.419 mm (0.0075 to 0.0165 in) |
| Crankshaft end play | 0.152 to 0.305 mm (0.006 to 0.012 in) |
| Crankshaft end play maximum wear limit | 0.51 mm (0.020 in) |
| Crankshaft flange outside diameter | 155.58 mm (6.125 in) |
| Damper mounting surface runout (maximum) | 0.0127 mm (0.0005 in) |
| Flywheel mounting surface runout (maximum) | 0.05 mm (0.002 in) |
| Main bearing journal maximum out-of-round | 0.00635 mm (0.00025 in) |
| Main bearing journal taper (maximum per inch) | 0.0051 mm (0.0002 in) |
| Main bearing thrust face runout (TIR maximum) | 0.026 mm (0.001 in) |
| Main bearing to crankshaft running clearance | 0.046 to 0.127 mm (0.0018 to 0.0050 in) |
| Main bearing width (except rear thrust) | 34.19 ± 0.13 mm (1.346 ± 0.005 in) |
| Rear oil seal journal runout (maximum) | 0.08 mm (0.003 in) |

## Special Torque

| | |
|---|---|
| Breather inlet tube M8 retaining nut | 26 N·m (19 lbf·ft) |
| Crankcase breather to crankcase M8 bolts | 27 N·m (20 lbf·ft) |
| Crankcase breather fitting M5 bolts | 5 N·m (46 lbf·in) |
| Crankcase breather to turbine M6 x 30 bolts | 9 N·m (79 lbf·in) |
| Crankcase ladder, M12 x 35 | 122 N·m (90 lbf·ft) |
| Crankcase ladder, M10 x 25 | 63 N·m (46 lbf·ft) |
| Main bearing cap bolt torque and sequence | See Torque Procedure for Torque-to-yield Main Bearing Cap Bolts (page 631) |
| Oil filler tube support bolt, M6 x 16 | 14 N·m (120 lbf·in) |
| Oil filler tube support, M8 nuts | 34 N·m (25 lbf·ft) |
| Oil filler tube support, M6 x 40 bolt and M6 nut | 14 N·m (120 lbf·in) |

## Special Service Tools

| | |
|---|---|
| Cam Gear Puller | ZTSE4411 |
| Camshaft Bushing Puller | ZTSE2893B |
| Dial indicator set | Obtain locally |
| Dye penetrant kit | Obtain locally |
| Head Bolt Bottoming Tap | ZTSE4671 |
| Hot plate | Obtain locally |
| Loctite® 262 | Obtain locally |
| Loctite®277™ | Obtain locally |
| Nylon Brush | ZTSE4389 |
| Outside micrometer | Obtain locally |
| Plastigage®. | Obtain locally |
| Prussian Blue® | Obtain locally |
| Stiff Nylon Brush | ZTSE4392 |
| Tap Set | ZTSE4386 |

# Table of Contents

## Abbreviations and Acronyms

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

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

**C –** Celsius
**CAC –** Charge Air Cooler
**CAN –** Controller Area Network
**CAP –** Cold Ambient Protection
**CARB –** California Air Resources Board
**cc –** Cubic centimeter
**CCA –** Cold Cranking Ampere
**CID –** Cubic Inch Displacement
**cfm –** Cubic feet per minute
**cfs –** Cubic feet per second
**CKP –** Crankshaft Position
**CKPO –** Crankshaft Position Out
**cm –** Centimeter
**CMP –** Camshaft Position

**CMPO –** Camshaft Position Out
**CO –** Carbon Monoxide
**COO –** Cruise On / Off switch
**CPU –** Central Processing Unit
**CTC –** Coolant Temperature Compensation
**Cyl –** Cylinder

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

**EBP –** Exhaust Back Pressure
**EBPD –** Exhaust Back Pressure Desired
**ECI –** Engine Crank inhibit
**ECL –** Engine Coolant Level
**ECM –** Electronic Control Module
**ECM PWR –** Electronic Control Module Power
**ECT –** Engine Coolant Temperature
**EFP –** Engine Fuel Pressure
**EFRC –** Engine Family Rating Code
**EFT –** Engine Fuel Temperature
**EG –** Ethylene Glycol
**EGC –** Electronic Gauge Cluster
**EGDP –** Exhaust Gas Differential Pressure
**EGR –** Exhaust Gas Recirculating
**EGRH –** Exhaust Gas Recirculation High control
**EGRL –** Exhaust Gas Recirculation Low control
**EGRP –** Exhaust Gas Recirculating Position
**EGT1 –** Exhaust Gas Temperature 1
**EGT2 –** Exhaust Gas Temperature 2
**EGT3 –** Exhaust Gas Temperature 3
**EMI –** Electromagnetic Interference
**EOP –** Engine Oil Pressure
**EOT –** Engine Oil Temperature
**EPA –** Environmental Protection Agency
**EPR –** Engine Pressure Regulator
**ESC –** Electronic System Controller
**ESN –** Engine Serial Number
**EST –** Electronic Service Tool
**EWPS –** Engine Warning Protection System

**F –** Fahrenheit
**FCV –** Fuel Coolant Valve
**FEL –** Family Emissions Limit

**fhp –** Friction horsepower
**FMI –** Failure Mode Indicator
**FPC –** Fuel Pump Control
**FPCV –** Fuel Pressure Control Valve
**fpm –** Feet per minute
**fps –** Feet per second
**FRP –** Fuel Rail Pressure
**ft –** Feet
**FVCV –** Fuel Volume Control Valve

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

**$H_2O$ –** Water
**HC –** Hydrocarbons
**HFCM –** Horizontal Fuel Conditioning Module
**Hg –** Mercury
**hp –** Horsepower
**HPFP –** High-Pressure Fuel Pump
**hr –** Hour
**Hyd –** Hydraulic

**IAT –** Intake Air Temperature
**IAHC –** Inlet Air Heater Control
**IAHD –** Inlet Air Heater Diagnostic
**IAHR –** Inlet Air heater Relay
**IC –** Integrated Circuit
**ICP –** Injector Control Pressure
**ID –** Inside Diameter
**IDM –** Injector Drive Module
**IGN –** Ignition
**ILO –** Injector Leak Off
**in –** Inch
**inHg –** Inch of mercury
**in$H_2O$ –** Inch of water
**INJ –** Injector
**IPR –** Injection Pressure Regulator
**ISIS –** International® Service Information System
**IST –** Idle Shutdown Timer
**ITP –** Internal Transfer Pump
**ITV –** Intake Throttle Valve
**ITVH –** Intake Throttle Valve High control
**ITVL –** Intake Throttle Valve Low control
**ITVP –** Intake Throttle Valve Position
**IVS –** Idle Validation Switch

**JCT –** Junction (electrical)

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

**L –** Liter
**L/h –** Liters per hour
**L/m –** Liters per minute
**L/s –** Liters per second
**lb –** Pound
**lbf –** Pounds of force
**lb/s –** Pounds per second
**lbf ft –** Pounds of force per foot
**lbf in –** Pounds of force per inch
**lbm –** Pounds of mass
**LSD –** Low Sulfur Diesel

**m –** Meter
**m/s –** Meters per second
**MAF –** Mass Air Flow
**MAG –** Magnetic
**MAP –** Manifold Absolute Pressure
**MAT –** Manifold Air Temperature
**mep –** Mean effective pressure
**mi –** Mile
**mm –** Millimeter
**mpg –** Miles per gallon
**mph –** Miles per hour
**MPR –** Main Power Relay
**MSDS –** Material Safety Data Sheet
**MSG –** Micro Strain Gauge
**MSM –** Multiplex System Module
**MY –** Model Year

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

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

**PID –** Parameter Identifier
**P/N –** Part Number
**ppm –** Parts per million
**PROM –** Programmable Read Only Memory
**psi –** Pounds per square inch
**psia –** Pounds per square inch absolute
**psig –** Pounds per square inch gauge
**pt –** Pint
**PTO –** Power Takeoff
**PWM –** Pulse Width Modulate
**PWR –** Power (voltage)

**qt –** Quart

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

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

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

**ULSD –** Ultra Low Sulfur Diesel
**UVC –** Under Valve Cover

**V –** Volt
**VBAT or B+ –** Battery Voltage
**VC –** Volume Control
**VEPS –** Vehicle Electronics Programming System
**VGT –** Variable Geometry Turbocharger
**VIGN –** Ignition Voltage
**VIN –** Vehicle Identification Number
**VOP –** Valve Opening Pressure
**VRE –** Vehicle Retarder Enable

**VREF –** Reference Voltage
**VSO –** Vehicle Speed Output
**VSS –** Vehicle Speed Sensor

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

**XMSN –** Transmission

# Table of Contents

# Terminology

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

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

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

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

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

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

**Analog –** A continuously variable voltage.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

**Engine RUNNING tests –** Tests done with the engine running.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

**Hydrocarbons –** Unburned or partially burned fuel molecules.

**Idle speed –**

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

**Piezometer –** An instrument for measuring fluid pressure.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

**Substrate –** Material that supports the washcoating or catalytic materials.

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

**Tachometer output signal –** Engine speed signal for remote tachometers.

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

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

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

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

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

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

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

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

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

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

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

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

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

**Voltage –** Electrical potential expressed in volts.

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

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

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

# Table of Contents

# Specifications

### Engine Electrical

| |
|---|
| No specifications required for this section. |

### Variable Geometry Turbocharger (VGT)

| | |
|---|---|
| VGT axial linkage shaft | Must strike open and closed stops in actuator, 90° rotation |

### Exhaust Gas Recirculation (EGR) System

| |
|---|
| No specifications required for this section. |

### Intake, Inlet, and Exhaust Manifolds

| |
|---|
| No specifications required for this section. |

### Fuel and High-pressure Oil Systems

| | |
|---|---|
| Fuel heater switching points | On: 7 °C (44.6 °F) |
| | Off: 21 °C (69.8 °F) |
| Fuel pressure regulator assembly opening pressure | 420 to 490 kPa (61 to 71 psi) |
| Fuel strainer | 150 micron |
| High-pressure oil manifold pressure range | 5 to 32 MPa (725 to 4,650 psi) |
| High-pressure oil pump end play | 0.127 to 0.457 mm (0.005 to 0.018 in) |

### Diamond Logic® Engine Brake

| | |
|---|---|
| Brake actuator lash (cold) | 0.48 mm (0.019 in) |

### Air Compressor and Power Steering Pump

| | |
|---|---|
| Lower idler gear to air compressor gear backlash | 0.508 mm (0.020 in) |

**Oil System Module Assembly**

| | |
|---|---|
| Heat exchanger, all engines with front drive axle | 33 plates |
| Heat exchanger, MaxxForce® DT | 23 plates |
| Heat exchanger, MaxxForce® 9 and 10 | 33 plates |
| Oil filter bypass valve, opening pressure | 345 kPa (50 psi) |
| Oil pressure regulator valve, opening pressure | 380 kPa (55 psi) @ 38 °C (100 °F) |
| Oil thermal valve, opening temperature | 111 °C (232 °F) |

**Oil Pan and Oil Suction Tube**

| | |
|---|---|
| Engine oil dry (after rebuild and new filter) | 33 L (35 quarts US) |
| Engine oil wet (after oil drain and filter change) | 28 L (30 quarts US) |

**Front Cover, Cooling System, and Related Components**

| | |
|---|---|
| Camshaft gear to upper idler gear backlash | 0.35 mm (0.014 in) |
| High-pressure oil pump end play | 0.127 to 0.457 mm (0.005 to 0.018 in) |
| Lower idler gear to air compressor gear backlash | 0.508 mm (0.020 in) |
| Lower idler gear to crankshaft gear backlash | 0.31 mm (0.012 in) |
| Oil pump end clearance | 0.05 to 0.13 mm (0.002 to 0.005 in) |
| Oil pump side clearance | 0.48 to 0.62 mm (0.019 to 0.024 in) |
| Upper idler gear to high-pressure oil pump gear backlash | 0.48 mm (0.019 in) |
| Upper idler gear to lower idler gear backlash | 0.37 mm (0.015 in) |
| Vibration damper face runout (maximum) | 1.52 mm (0.060 in) |

**Water Pump Pulley Diameters and Spin Ratios**

| Engine | Pulley Diameter | Spin Ratio |
|---|---|---|
| MaxxForce® DT 210 – 230 BHP | 15.54 cm (6.12 in) | 1.39: 1 |
| MaxxForce® DT 245 – 255 BHP | 13.93 cm (5.48 in) | 1.55: 1 |
| MaxxForce® DT 260 – 300 BHP | 12.54 cm (4.94 in) | 1.73: 1 |
| MaxxForce® 9 and 10 | 11.54 cm (4.55 in) | 1.87: 1 |

**Fan Drive Configurations Diameters and Ratios (Spin-on)**

| | | Fan Center Line (CL) | | | |
|---|---|---|---|---|---|
| **Fan Drive Configuration** | **Engine** | **Vertical Above Crank** | **Lateral Offset (toward turbo)** | **Pulley Diameter** | **Fan Drive Ratio** |
| Spin-on 13” fan center | MaxxForce® DT | 330.2 mm (13 in) | 25.4 mm (1 in) | 21.95 cm (8.64 in) | 0.99 : 1 |
| Spin-on 13” fan center | MaxxForce® DT | 330.2 mm (13 in) | 25.4 mm (1 in) | 20.12 cm (7.92 in) | 1.08 : 1 |
| Spin-on 15” fan center | MaxxForce® DT | 381 mm (15 in) | 25.4 mm (1 in) | 21.95 cm (8.64 in) | 0.99 : 1 |
| Spin-on 15” fan center | MaxxForce® 9 and 10 | 381 mm (15 in) | 25.4 mm (1 in) | 18.14 cm (7.14 in) | 1.2 : 1 |
| Spin-on 16.2” fan center | MaxxForce® DT | 411.5 mm (16.2 in) | 95.3 mm (3.75 in) | 21.95 cm (8.64 in) | 0.99 : 1 |
| Spin-on 16.2” fan center | MaxxForce® DT | 411.5 mm (16.2 in) | 95.3 mm (3.75 in) | 20.12 cm (7.92 in) | 1.08 : 1 |
| Spin-on 20” fan center | MaxxForce® DT | 508 mm (20 in) | none | 24.28 cm (9.56 in) | 0.894 : 1 |
| Spin-on 20” fan center | MaxxForce® DT | 508 mm (20 in) | none | 21.95 cm (8.64 in) | 0.99 : 1 |
| Spin-on 20” fan center | MaxxForce® 9 and 10 | 508 mm (20 in) | none | 20.12 cm (7.92 in) | 1.08 : 1 |
| Spin-on 20 ” fan center | MaxxForce® 9 and 10 | 508 mm (20 in) | none | 18.14 cm (7.14 in) | 1.2 : 1 |

**Fan Drive Configurations Diameters and Ratios (DriveMaster®)**

| | | Fan Center Line (CL) | | | |
|---|---|---|---|---|---|
| **Fan Drive Configuration** | **Engine** | **Vertical Above Crank** | **Lateral Offset (toward turbo)** | **Pulley Diameter** | **Fan Drive Ratio** |
| Horton DriveMaster® 13” fan center | MaxxForce® DT | 330.2 mm (13 in) | 25.4 mm (1 in) | 21.95 cm (8.64 in) | 0.99 : 1 |
| Horton DriveMaster® 13” fan center | MaxxForce® DT | 330.2 mm (13 in) | 25.4 mm (1 in) | 20.12 cm (7.92 in) | 1.08 : 1 |
| Horton DriveMaster® 15” fan center | MaxxForce® DT | 381 mm (15 in) | 25.4 mm (1 in) | 21.95 cm (8.64 in) | 0.99 : 1 |
| Horton DriveMaster® 15” fan center | MaxxForce® 9 and 10 | 381 mm (15 in) | 25.4 mm (1 in) | 18.14 cm (7.14 in) | 1.2 : 1 |
| Horton DriveMaster® 16.2” fan center | MaxxForce® DT | 411.5 mm (16.2 in) | 95.3 mm (3.75 in) | 21.95 cm (8.64 in) | 0.99 : 1 |
| Horton DriveMaster® 16.2” fan center | MaxxForce® DT | 411.5 mm (16.2 in) | 95.3 mm (3.75 in) | 20.12 cm (7.92 in) | 1.08 : 1 |
| Horton DriveMaster® 20” fan center | MaxxForce® DT | 508 mm (20 in) | none | 24.28 cm (9.56 in) | 0.894 : 1 |
| Horton DriveMaster® 20” fan center | MaxxForce® DT | 508 mm (20 in) | none | 21.95 cm (8.64 in) | 0.99 : 1 |
| Horton DriveMaster® 20” fan center | MaxxForce® 9 and 10 | 508 mm (20 in) | none | 20.12 cm (7.92 in) | 1.08 : 1 |
| Horton DriveMaster® 20” fan center | MaxxForce® 9 and 10 | 508 mm (20 in) | none | 18.14 cm (7.14 in) | 1.2 : 1 |

## Cylinder Head and Valve Train

### Valve Specifications

| | |
|---|---|
| Camshaft lobe lift | Intake: |
| | 6.68 mm (0.263 in) |
| | 0.254 mm (0.010 in) maximum wear limit |
| | Exhaust: |
| | 6.91 mm (0.272 in) |
| | 0.254 mm (0.010 in) maximum wear limit |
| Valve face angle | Intake: |
| | 59.75 to 60.00° |
| | Exhaust: |
| | 44.75 to 45.00° |
| Valve face margin (minimum) | Intake: |
| | 1.32 mm (0.052 in) |
| | Exhaust: |
| | 1.16 mm (0.046 in) |
| Valve face-to-valve stem runout (maximum) | 0.038 mm (0.0015 in) |
| Valve lash (cold), intake and exhaust | 0.48 mm (0.019 in) |
| Valve stem diameter (new condition) | Intake: |
| | 7.92861 ± 0.0089 mm (0.31215 ± 0.00035 in) |
| | Exhaust: |
| | 7.9083 ± 0.0089 mm (0.31135 ± 0.00035 in) |
| Valve stem straightness (maximum) | 0.010 mm (0.0004 in) |
| Valve stem-to-guide running clearance (maximum) | Intake: |
| | 0.10 mm (0.004 in) |
| | Exhaust: |
| | 0.11 mm (0.005 in) |
| Intake valve head diameter | 39.73 ± 0.13 mm (1.564 ± 0.005 in) |
| Exhaust valve head diameter | 36.55 ± 0.13 mm (1.439 ± 0.005 in) |

**Valve Spring Specifications**

| Intake and Exhaust Valve Springs | |
|---|---|
| Free length | 52.35 mm (2.061 in) |
| Solid height (maximum) | 27.46 mm (1.081 in) |
| Valve closed test length @ 410.1 ± 24.5 N (92.2 ± 5.5 lbf) test load | 40 mm (1.575 in) |
| Valve closed test length @ 764.2 ± 48.9 N (171.8 ± 11.0 lbf) test load | 29.3 mm (1.155 in) |

**Cylinder Head and Valve Train Specifications**

| | |
|---|---|
| Cylinder head gasket surface flatness | 0.10 mm (0.004 in.) per 229 mm (9.0 in) |
| Cylinder head thickness | New: 160.48 mm (6.318 in) |
| | Minimum: 159.97 mm (6.298 in) |
| Cylinder head valve guide bore diameter | 14.308 ± 0.017 mm (0.5633 ± 0.0007 in) |
| Exhaust valve seat counterbore diameter | Standard: 37.503 ± 0.025 mm (1.4765 ± 0.0010 in) |
| | Oversize: 0.05 mm (0.002 in): 37.55 ± 0.03 mm (1.478 ± 0.001 in) |
| Exhaust valve seat insert outside diameter | Standard: 37.57 ± 0.01 mm (1.479 ± 0.0005 in) |
| | Oversize: 0.05 mm (0.002 in): 37.62 ± 0.01 mm (1.481 ± 0.0005 in) |
| Intake valve seat counterbore diameter | Standard: 40.145 ± 0.025 mm (1.5805 ± 0.0010 in) |
| | Oversize 0.05 mm (0.002 in): 40.195 ± 0.025 mm (1.5825 ± 0.0010 in) |
| Intake valve seat insert outside diameter | Standard: 40.21 ± 0.01 mm (1.583 ± 0.0005 in) |
| | Oversize 0.05 mm (0.002 in): 40.26 ± 0.01 mm (1.585 ± 0.0005 in) |
| Valve seat insert OD to valve seat counterbore diametral interference | 0.025 to 0.102 mm (0.001 to 0.004 in) |
| Valve guide bore out-of-round (maximum) | 0.005 mm (0.0002 in) |
| Valve guide bore taper (maximum) | 0.013 mm (0.0005 in) |
| Valve guide height from cylinder head spring pocket | 16.54 ± 0.25 mm (0.651 ± 0.010 in) |
| Valve guide inside diameter (installed) | 7.98 to 8.00 mm (0.314 to 0.315 in) |
| Valve guide inside diameter (installed), maximum wear limit | Intake: 0.102 mm (0.004 in) |
| | Exhaust: 0.127 mm (0.005 in) |
| Valve guide interference fit dimension | 0.043 mm (0.0017 in) |
| Valve guide outside diameter | 14.351 ± 0.010 mm (0.5650 ± 0.0004 in) |
| Valve guide length (overall) | 65.71 mm (2.587 in) |

**Cylinder Head and Valve Train Specifications (cont.)**

| | |
|---|---|
| Valve recession | Intake: |
| | 1.02 ± 0.13 mm (0.040 ± 0.005 in) |
| | Exhaust: |
| | 1.40 ± 0.13 mm (0.055 ± 0.005 in) |
| Valve seat angles | Intake: |
| | 59.75 - 60° |
| | Exhaust: |
| | 44.75 - 45° |
| Valve seat to valve guide bore concentricity (maximum) | 0.076 mm (0.003 in) |
| Valve seat width | 1.91 to 2.16 mm (0.075 to 0.085 in) |
| Push rod runout (maximum) | 0.508 mm (0.020 in) |

**Flywheel and Flywheel Housing**

**WARNING:**

**To prevent personal injury or death, do not machine flywheel beyond minimum thickness specified for flywheel resurfacing.**

**WARNING:**

**To prevent personal injury or death, carefully examine flywheel for any cracks or heat checks after resurfacing. Any cracks or heat checks in the flywheel could cause it to separate. If there are any questions, do not reuse the flywheel.**

**NOTE:** Flywheel resurfacing information is provided for guidance only. Navistar, Inc. assumes no responsibility either for the results of any work performed in accordance with this information or for the ability of service personnel to detect cracks.

| | |
|---|---|
| **Flywheel housing:** | |
| Flywheel housing bore concentricity | SAE # 1 = 0.30 mm (0.012 in) |
| | SAE # 2 = 0.28 mm (0.011 in) |
| Flywheel housing face runout | SAE # 1 = 0.30 mm (0.012 in) |
| | SAE # 2 = 0.28 mm (0.011 in) |
| **Crankshaft pilot:** | |
| Crankshaft pilot concentricity | 0.13 mm (0.005 in) |
| **Flywheel:** | |
| Flat flywheel surface runout maximum (measure at 17.8 cm (7 in) from center) | 0.20 mm (0.008 in) |

| | |
|---|---|
| Pot flywheel surface runout maximum (measure at 16.5 cm (6.5 in) from center) | 0.20 mm (0.008 in) |
| Pot flywheel clutch mounting surface runout maximum | 0.30 mm (0.012 in) |

**Flywheel Resurfacing Specifications**

| | |
|---|---|
| Flat flywheel minimum thickness after resurfacing | 36.32 mm (1.430 in) |
| Pot flywheel minimum thickness after resurfacing | 39.37 mm (1.550 in) |
| **NOTE:** Requires measurement from crankshaft mounting surface of flywheel to clutch surface of flywheel. | |

## Power Cylinders

**Connecting Rod Specifications**

| | |
|---|---|
| Bend (maximum) | 0.051 mm (0.002 in) |
| Center-to-center distance between connecting rod bearing bore and piston pin bushing bore | 219.4 to 219.5 mm (8.638 to 8.642 in) |
| Connecting rod bearing bore inside diameter | 85.130 to 85.156 mm (3.3516 to 3.3526 in) |
| Connecting rod bearing inside diameter (installed) | 80.05 to 80.10 mm (3.1518 to 3.1536 in) |
| Connecting rod bearing bore out-of-round (maximum) | 0.02 mm (0.00078 in) |
| Connecting rod bearing bore taper (maximum) | 0.02 mm (0.00078 in) |
| Connecting rod bearing running clearance | 0.030 to 0.107 mm (0.0012 to 0.0042 in) |
| Connecting rod to crankshaft side clearance | 0.190 to 0.419 mm (0.0075 to 0.0165 in) |
| Piston pin bushing inside diameter | 46.393 to 46.401 mm (1.8265 to 1.8268 in) |
| Twist (maximum) | 0.051 mm (0.002 in) |

**Piston Specifications**

| | |
|---|---|
| **MaxxForce® DT** | |
| Piston | One-piece aluminum |
| Piston rings | Top ring - keystone cross section |
| | Intermediate - rectangular cross section |
| **MaxxForce® 9 and 10** | |
| Piston | One-piece steel |
| Piston rings | Top ring - keystone cross section |
| | Intermediate - rectangular cross section |
| Running clearance between piston and cylinder sleeve | MaxxForce® DT piston: 0.085 to 0.133 mm (0.00335 to 0.00524 in) |
| | MaxxForce® 9 and 10 piston: 0.042 to 0.102 mm (0.00165 to 0.00402 in) |
| Skirt diameter | MaxxForce® DT piston: 116.467 to 116.485 mm (4.5853 to 4.5860 in) |
| | MaxxForce® 9 and 10 piston: 116.498 to 116.528 mm (4.5865 to 4.5877 in) |
| Top compression ring groove width, MaxxForce®DT measure over 2.885 mm (0.1135 in) gauge pins | 117.348 to 117.568 mm (4.620 to 4.6287 in) |
| Top compression ring groove width, MaxxForce® 9 and 10 measure over 2.70 mm (0.1063 in) gauge pins | 116.104 to 116.304 mm (4.5710 to 4.5866 in) |
| Intermediate compression ring side clearance, MaxxForce®DT | 0.05 to 0.10 mm (0.002 to 0.0039 in) |
| Intermediate compression ring side clearance, MaxxForce® 9 and 10 | 0.07 to 0.12 mm (0.0028 to 0.0047 in) |
| Oil control ring, side clearance | 0.03 to 0.08 mm (0.0012 to 0.00315 in) |
| Piston protrusion above crankcase top deck | 0.660 to 0.813 mm (0.026 to 0.032 in) |
| Piston cooling tube diameter (spray hole) MaxxForce® DT | 2.18 mm (0.086 in) |
| Piston cooling tube diameter (spray hole) MaxxForce® 9 and 10 | 2.59 mm (0.102 in) |

**Piston Ring Specifications**

| | |
|---|---|
| Top compression ring end gap | 0.35 to 0.50 mm (0.014 to 0.0197 in) |
| Intermediate compression ring end gap | 1.20 to 1.45 mm (0.0472 to 0.0571 in) |
| Oil control ring end gap | 0.35 to 0.65 mm (0.014 to 0.0256 in) |

**Piston Pin Specifications**

| | |
|---|---|
| Clearance in piston | MaxxForce® DT piston: 0.011 to 0.021 mm (0.00043 to 0.00083 in) |
| | MaxxForce® 9 and 10 piston: 0.083 to 0.103 mm (0.00327 to 0.00406 in) |
| Diameter | 46.352 to 46.357 mm (1.8249 to 1.8251 in) |
| Length | MaxxForce® DT piston: 96.57 to 96.82 mm (3.802 to 3.812 in) |
| | MaxxForce® 9 and 10 piston: 77.88 to 78.13 mm (3.066 to 3.076 in) |

**Cylinder Sleeve Specifications**

| | |
|---|---|
| Counterbore depth allowable variation between four points (maximum) | 0.03 mm (0.001 in) |
| Counterbore depth before adding shims (maximum) | 10.49 mm (0.413 in) |
| Counterbore depth (including shims - if any) | 8.84 to 8.89 mm (0.348 to 0.350 in) |
| Cylinder sleeve protrusion | 0.05 to 0.13 mm (0.002 to 0.005 in) |
| Cylinder sleeve protrusion difference (maximum) | 0.03 mm (0.001 in) |
| Cylinder sleeve taper (bore wear step, at top of ring travel (maximum)) | 0.10 mm (0.004 in) |
| Flange thickness | 8.94 to 8.96 mm (0.352 to 0.353 in) |
| Inside diameter | 116.57 to 116.60 mm (4.5895 to 4.5905 in) |

### Crankcase, Crankshaft, and Camshaft

**Crankcase Specifications**

| | |
|---|---|
| Main cap attachment | 2 bolts per main cap |
| Main bearing type | Precision replaceable |
| Main bearing material | Steel-backed copper, lead, tin |
| Thrust taken by | Rear upper main bearing #7 |
| Engine block heater rating | 1250 W, 120 V |
| | |
| Center line of main bearing bore to head deck | 368.3 ± 0.05 mm (14.50 ± 0.002 in) |
| Counterbore depth allowable variation between four points (maximum) | 0.025 mm (0.001 in) |
| Counterbore depth in crankcase | 8.865 ± 0.025 mm (0.349 ± 0.001 in) |
| Counterbore diameter in crankcase | 136.14 + 0.381 – 0.127 mm (5.360 + 0.015 – 0.005 in) |
| Counterbore maximum allowable depth | 9.25 mm (0.364 in) |
| Crankcase deck flatness | 0.076 mm (0.003 in) |
| Crankcase main bearing bore diameter | 116.421 ± 0.027 mm (4.4583 ± 0.0005 in) |
| Piston cooling tube diameter (spray hole) MaxxForce® DT | 2.18 mm (0.086 in) |
| Piston cooling tube diameter (spray hole) MaxxForce® 9 and 10 | 2.59 mm (0.102 in) |
| Roller tappet outside diameter | 28.435 to 28.448 mm (1.1195 to 1.1200 in) |
| Sleeve protrusion above crankcase | 0.051 to 0.127 mm (0.002 to 0.005 in) |
| Tappet bore diameter | 28.5306 ± 0.01905 mm (1.12325 ± 0.00075 in) |
| | |
| Camshaft Bushing Bore Diameter in Crankcase: | |
| Front | 63.5521 ± 0.01905 mm (2.50205 ± 0.00075 in) |
| Intermediate (2) | 63.0238 ± 0.01905 mm (2.48125 ± 0.00075 in) |
| Rear | 63.5521 ± 0.01905 mm (2.50205 ± 0.00075 in) |

**Camshaft Specifications**

| | |
|---|---|
| Camshaft bushing inner diameter (ID) (installed) | 58.04 to 58.12 mm (2.285 to 2.288 in) |
| Cam lobe lift, exhaust | 6.91 mm (0.272 in) |
| Cam lobe lift, intake | 6.68 mm (0.263 in) |
| Camshaft end play | 0.18 to 0.33 mm (0.007 to 0.013 in) |
| Camshaft journal diameter | 57.96 to 57.99 mm (2.282 to 2.283 in) |
| Camshaft journal to bearing radial clearance | 0.025 to 0.076 mm (0.001 to 0.003 in) |
| Maximum permissible cam lobe wear | 0.25 mm (0.010 in) |
| Service bushings furnished to size | Yes |
| Thrust plate thickness (new) | 6.96 to 7.01 mm (0.274 to 0.276 in) |

**Camshaft Bushing Specifications**

| Bushing Location | Outside Diameter (nominal) | Width (nominal) |
|---|---|---|
| Front | 63.5 mm (2.50 in) | 25.4 mm (1.00 in) |
| Rear | 63.5 mm (2.50 in) | 17.8 mm (0.70 in) |
| Intermediate | 63.0 mm (2.48 in) | 26.7 mm (1.05 in) |

**Crankshaft Specifications**

| | |
|---|---|
| Crankshaft | Forged steel, induction hardened, grindable |
| Number of main bearings | 7 |
| Thrust taken by | # 7 rear upper main bearing |
| **Main bearing journal diameter:** | |
| Standard size | 107.95 ± 0.015 mm (4.250 ± 0.0006 in) |
| 0.254 mm (0.010 in) undersized | 107.70 ± 0.015 mm (4.240 ± 0.0006 in) |
| 0.508 mm (0.020 in) undersized | 107.44 ± 0.015 mm (4.230 ± 0.0006 in) |
| 0.762 mm (0.030 in) undersized | 107.19 ± 0.015 mm (4.220 ± 0.0006 in) |
| Crankshaft journal waviness (maximum) | 0.00381 mm (0.00015 in) |
| Crankshaft journal surface finish | 0.00015 mm (0.000006 in) |

**NOTE:** Grind all crankshaft journals against operating rotation (when looking at front end of crankshaft, operating rotation is clockwise). Lap all Journals with operating rotation, not more than 0.0127 mm (0.0005 in) stock to be removed by lapping.

| | |
|---|---|
| **Thrust Bearing Journal Length:** | |
| Standard size to 0.76 mm (0.030 in) undersized | 34.404 ± 0.546 mm (1.3545 ± 0.0215 in) |
| **Connecting rod journal diameter:** | |
| Standard size | 80.010 ± 0.015 mm (3.1500 ± 0.0006 in) |
| 0.0254 mm (0.010 in) undersized | 79.756 ± 0.015 mm (3.1400 ± 0.0006 in) |
| 0.508 mm (0.020 in) undersized | 79.502 ± 0.015 mm (3.1300 ± 0.0006 in) |
| 0.762 mm (0.030 in) undersized | 79.248 ± 0.015 mm (3.1200 ± 0.0006 in) |

**Crankshaft Specifications (continued)**

| | |
|---|---|
| Connecting rod bearing to crankshaft running clearance | 0.030 to 0.107 mm (0.0012 to 0.0042 in) |
| Connecting rod bearing width | 39.99 mm (1.5745 in) |
| Connecting rod journal maximum out-of-round | 0.0064 mm (0.00025 in) |
| Connecting rod journal taper (maximum per inch) | 0.0051 mm (0.0002 in) |
| Connecting rod to crankshaft side clearance | 0.190 to 0.419 mm (0.0075 to 0.0165 in) |
| Crankshaft end play | 0.152 to 0.305 mm (0.006 to 0.012 in) |
| Crankshaft end play maximum wear limit | 0.51 mm (0.020 in) |
| Crankshaft flange outside diameter | 155.58 mm (6.125 in) |
| Damper mounting surface runout (maximum) | 0.0127 mm (0.0005 in) |
| Flywheel mounting surface runout (maximum) | 0.05 mm (0.002 in) |
| Main bearing journal maximum out-of-round | 0.00635 mm (0.00025 in) |
| Main bearing journal taper (maximum per inch) | 0.0051 mm (0.0002 in) |
| Main bearing thrust face runout (TIR maximum) | 0.026 mm (0.001 in) |
| Main bearing to crankshaft running clearance | 0.046 to 0.127 mm (0.0018 to 0.0050 in) |
| Main bearing width (except rear thrust) | 34.19 ± 0.13 mm (1.346 ± 0.005 in) |
| Rear oil seal journal runout (maximum) | 0.08 mm (0.003 in) |

# Table of Contents

# General Torque

**Bolt Identification**

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

M03100

**Figure 547 Metric fasteners – Classification and identification**

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

M03101

**Figure 548 Special fasteners – Classification and identification**

**General Torque Guidelines**

**CAUTION:**

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

**NOTE:** Inspect parts for cleanliness and defects before assembly.

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

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

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

### Standard Torque Chart

**CAUTION:**

**To prevent engine damage, do not use this standard torque chart with other Navistar, Inc. brand engines or engines made by other manufacturers.**

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

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

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

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

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

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

### Using a Torque Wrench Extension

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

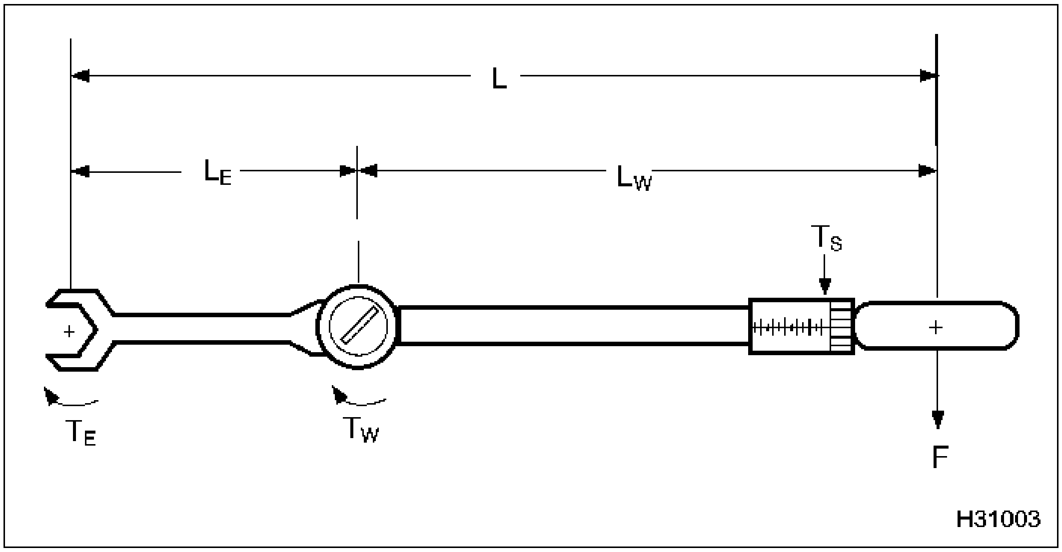


**Figure 549 Torque wrench and extension**

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

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

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

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

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

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

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

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

$T_S$ = 65 lbf·ft (0.666)

$T_S$ = 43.33 lbf·ft

## Special Torque

### Mounting Engine on Engine Stand

| | |
|---|---|
| Coolant drain plug, M18 | 24 N·m (18 lbf·ft) |
| Oil pan drain plug, M25 | 68 N·m (50 lbf·ft) |

### Engine Electrical

| | |
|---|---|
| ECM mounting bolts, M8 | 20 N·m (180 lbf·in) |
| Engine coolant temperature (ECT) sensor | 18 N·m (156 lbf·in) |
| Engine oil pressure (EOP) sensor | 12 N·m (102 lbf·in) |
| Engine oil temperature (EOT) sensor | 18 N·m (156 lbf·in) |
| Exhaust Back Pressure (EBP) sensor | 20 N·m (178 lbf·in) |
| Injection control pressure (ICP) sensor and Brake Control (BCP) sensor | 18 N·m (162 lbf·in) |
| Intake air heater cable to heater grid M6 nut | 4 N·m (35 lbf·in) |
| Intake Manifold Air Pressure (MAP) sensor | 12 N·m (102 lbf·in) |
| Intake Manifold Air Temperature (MAT) sensor | 18 N·m (154 lbf·in) |

### Variable Geometry Turbocharger (VGT)

| | |
|---|---|
| Turbocharger oil supply tube nut | 25 N·m (18 lbf·ft) |
| VGT Spiralock® nuts (M10) | 71 N·m (52 lbf·ft) |
| V-band clamp | 12.5 N·m (111 lbf·in) |
| M6 VGT actuator serrated lock nuts | 14 N·m (120 lbf·in) |
| M6 x 10 VGT heat shield bolts | 19 N·m (14 lbf·ft) |

**Exhaust Gas Recirculation (EGR) System**

| | |
|---|---|
| Coolant crossover tube M6 nut | 5 N·m (41 lbf·in) |
| EGR coolant supply tube retaining M8 nut | 26 N·m (19 lbf·ft) |
| EGR cooler clamp nut | See EGR Cooler – Intake Side (page 186) and Exhaust Side (page 192) installation. |
| EGR distribution tube M8 x 30 bolt | 26 N·m (19 lbf·ft) |
| EGR tube assembly U-bolt M8 nut | Lightly tighten nuts to equal positions, then evenly torque nuts to 15 N·m (132 lbf·in) (do not crush EGR tube) |
| EGR valve manifold and EGR cooler studs | 14 N·m (120 lbf·in) |
| Exhaust side EGR cooler bracket M12 x 70 bolt | 105 N·m (77 lbf·ft) |
| Exhaust side EGR cooler inlet heat shield M8 nuts | 26 N·m (19 lbf·ft) |

**Intake, Inlet, and Exhaust Manifolds**

| | |
|---|---|
| Exhaust manifold mounting bolts | See Exhaust manifold installation for torque and sequence (page 213). |
| Fuel valve assembly (Schrader) | 15 N·m (132 lbf·in) |
| Intake throttle assembly M6 x 25 mounting bolts | 12 N·m (9 lbf·ft) |
| M12 Fuel rail plug | 25 N·m (18 lbf·ft) |

**Fuel and High-pressure Oil Systems**

| | |
|---|---|
| Diagnostic coupling assembly | 17 N·m (145 lbf·in) |
| Elbow jam nut, 70 and 90 degree | 102 N·m (75 lbf·ft) |
| Engine Fuel Pressure (EFP) sensor | 11 N·m (100 lbf·in) |
| Fitting assembly with check valve | 18 N·m (155 lbf·in) |
| Fuel filter cap | 30 N·m (22 lbf·ft) |
| Fuel filter header mounting bolt and stud bolts, M8 x 75 | 27 N·m (20 lbf·ft) |
| Fuel heater and cover plate bolts, M6 x 25 | 10 N·m (85 lbf·in) |
| Fuel rail plug assembly, (intake manifold fuel rail) | 25 N·m (18 lbf·ft) |
| Fuel strainer cap | 18 N·m (155 lbf·in) |
| Fuel valve assembly (air bleed and pressure test port) | 15 N·m (132 lbf·in) |
| High-pressure oil hose (swivel nuts) Small diameter hose | 48 N·m (35 lbf·ft) |
| High-pressure oil hose (swivel nuts) Large diameter hose | 65 N·m (48 lbf·ft) |
| High-pressure oil manifold bolts, M8 x 90 | See High-pressure Oil Manifold (page 252) |
| High-pressure oil pump assembly bolts, M8 x 30 and M8 x 100 | 30 N·m (22 lbf·ft) |
| High-pressure oil pump assembly (gear) | 240 N·m (176 lbf·ft) |
| Injector hold down clamp bolt | 41 N·m (30 lbf·ft) |
| Injector oil inlet adaptor (puck) assembly | 204 N·m (150 lbf·ft) |
| IPR valve assembly | 50 N·m (37 lbf·ft) |
| Low-pressure fuel pump bolts, M6 x 16 | 16 N·m (140 lbf·in) |
| Low-pressure fuel pump tube coupling nuts | 18 N·m (155 lbf·in) |
| Oil rail plug assembly (bottom) | 204 N·m (150 lbf·ft) |
| Plug assembly, M12 and M10 | 12 N·m (108 lbf·in) |
| Rail end plug assembly | 204 N·m (150 lbf·ft) |
| Tube fitting assembly | 18 N·m (155 lbf·in) |
| Water drain valve M5 screw | 6 N·m (50 lbf·in) |
| Water In Fuel (WIF) sensor | 2 N·m (15 lbf·in) |

**Diamond Logic® Engine Brake**

| | |
|---|---|
| Brake Control Pressure (BCP) sensor and Injection Control Pressure (ICP) sensor | 18 N·m (162 lbf·in) |
| Brake actuator piston locknut | 25 N·m (19 lbf·ft) |
| Brake shut-off valve solenoid nut | 5 N·m (45 lbf·in) |
| Brake shut-off valve | 27 N·m (20 lbf·ft) |
| High-pressure oil manifold bolts M8 x 90 | See High-pressure Oil Manifold (Brake) (page 284). |
| Injector oil inlet adaptor assembly | 204 N·m (150 lbf·ft) |
| Oil pressure relief valve | 45 N·m (33 lbf·ft) |
| Plug assembly, M12 | 12 N·m (108 lbf·in) |
| Plug assembly, M10 | 12 N·m (108 lbf·in) |
| Rail end plug assembly | 204 N·m (150 lbf·ft) |

**Air Compressor and Power Steering Pump**

| | |
|---|---|
| Air compressor gear nut | 150 N·m (110 lbf·ft) |
| Air compressor M12 x 80 bolts | 83 N·m (61 lbf·ft) |
| Bracket to air compressor M10 x 30 bolts | 67 N·m (49 lbf·ft) |
| Compressor bracket to crankcase M12 x 50 bolts | 115 N·m (85 lbf·ft) |
| Elbow assembly, M10 | 16 N·m (138 lbf·in) |
| Elbow assembly, M18 | 48 N·m (35 lbf·ft) |
| Hose connector assembly, M18 | 48 N·m (35 lbf·ft) |
| Power steering pump mounting bolts, M10 x 35 | 57 N·m (42 lbf·ft) |
| Power steering pump drive nut | 90 N·m (66 lbf·ft) |

**Oil System Module Assembly**

| | |
|---|---|
| Coolant drain plug, M18 | 24 N·m (18 lbf·ft) |
| Coolant tube bracket bolts, M8 | 26 N·m (19 lbf·ft) |
| Heat exchanger bolts, M8 x 20 | See Cooler Heat Exchanger (page 326) |
| Lube filter adapter bolts, M8 x 25 | 29 N·m (21 lbf·ft) |
| Oil pressure regulator valve | 68 N·m (50 lbf·ft) |
| Oil system module M8 mounting bolts | 27 N·m (20 lbf·ft) |
| Oil thermal valve bolts, M8 x 20 | 29 N·m (21 lbf·ft) |
| Plug assembly, M12 | 5 N·m (46 lbf·in) |
| Turbocharger oil supply tube fitting | 25 N·m (18 lbf·ft) |

**Oil Pan and Oil Suction Tube**

| | |
|---|---|
| Oil pan drain plug | 68 N·m (50 lbf·ft) |
| Oil pan heater plug | 68 N·m (50 lbf·ft) |
| Oil pan mounting bolts, M8 x 24 | 32 N·m (24 lbf·ft) |
| Oil suction tube bolts, M8 x 35 | 27 N·m (20 lbf·ft) |

**Front Cover, Cooling System, and Related Components**

| | |
|---|---|
| Automatic belt tensioner M10 x 90 bolt | 50 N·m (37 lbf·ft) |
| Damper (hub) bolts, M12 x 40 | 163 N·m (120 lbf·ft) Retorque all bolts until no movement |
| Freon® compressor M8 x 110 mounting bolts | 27 N·m (20 lbf·ft) |
| Front engine mounting bracket M18 bolts | 386 N·m (284 lbf·ft) |
| Horton DriveMaster® nut assembly (2 inch) | 177 N·m (130 lbf·ft) |
| Lower idler gear M20 x 70 bolt | 639 N·m (470 lbf·ft) |
| Oil pump and rotor housing M8 bolts | 25 N·m (18 lbf·ft) |
| PTO adapter cover, M10 x 25 bolts (PTO equipped engines only) | 61 N·m (45 lbf·ft) |
| Upper idler gear M16 x 65 bolt | 326 N·m (240 lbf·ft) |
| Vibration damper assembly M10 x 16 mounting bolts | 58 N·m (43 lbf·ft) |

**Cylinder Head and Valve Train**

| | |
|---|---|
| Cylinder head mounting bolts torque and sequence | (page 476) |
| Rocker arm bolts torque and sequence | (page 480) |
| Valve adjustment screw lock nut | 27 N·m (20 lbf·ft) |

**Flywheel and Flywheel Housing**

| | |
|---|---|
| M12 flexplate mounting bolts | 136 N·m (100 lbf·ft) |
| M12 flywheel mounting bolts | 136 N·m (100 lbf·ft) |

**Power Cylinders**

| | |
|---|---|
| Connecting rod bolts (verify connecting rod type) | See Torque Procedures for Connecting Rod with M12 Bolts (page 577) or M11 Bolts (page 578). |
| Piston cooling tube mounting bolts, M6 x 12 | 13 N·m (114 lbf·in) |

**Crankcase, Crankshaft, and Camshaft**

| | |
|---|---|
| Breather inlet tube M8 retaining nut | 26 N·m (19 lbf·ft) |
| Crankcase breather to crankcase M8 bolts | 27 N·m (20 lbf·ft) |
| Crankcase breather fitting M5 bolts | 5 N·m (46 lbf·in) |
| Crankcase breather to turbine M6 x 30 bolts | 9 N·m (79 lbf·in) |
| Crankcase ladder, M12 x 35 | 122 N·m (90 lbf·ft) |
| Crankcase ladder, M10 x 25 | 63 N·m (46 lbf·ft) |
| Main bearing cap bolt torque and sequence | See Torque Procedure for Torque-to-yield Main Bearing Cap Bolts (page 631) |
| Oil filler tube support bolt, M6 x 16 | 14 N·m (120 lbf·in) |
| Oil filler tube support, M8 nuts | 34 N·m (25 lbf·ft) |
| Oil filler tube support, M6 x 40 bolt and M6 nut | 14 N·m (120 lbf·in) |

# Table of Contents

## Tool Ordering Information

Special service tools for MaxxForce® DT, 9, and 10 series engines can be ordered from the SPX Corporation, 1-800-520-2584.

## Special Tools

### Mounting Engine on Engine Stand

| | |
|---|---|
| Engine Stand Bracket | ZTSE4649 |
| Engine Stand | OTC1750A |
| Oil filter wrench | Obtain locally |

### Engine Electrical

| |
|---|
| No special tools |

### Variable Geometry Turbocharger (VGT)

| | |
|---|---|
| Dial indicator set | Obtain locally |
| Turbocharger Intake Shield | ZTSE4752 |

### Exhaust Gas Recirculation (EGR) System

| |
|---|
| EGR Leak Detection Kit |

### Intake, Inlet, and Exhaust Manifolds

| | |
|---|---|
| Feeler gauge | Obtain locally |

### Fuel and High-pressure Oil Systems

| | |
|---|---|
| Injector Oil Inlet Plugs | ZTSE4660 |
| Fuel Injector Remover Tool (T40) | ZTSE4524 |
| Fuel Pressure Gauge | ZTSE4681 |
| Injector Adaptor Removal Tool | ZTSE4725 |
| IPR Removal / Installation Tool | ZTSE4666 |
| Loctite® 246 Threadlocker | Obtain locally |
| T27 Torx bit | Obtain locally |
| T30 Torx bit | Obtain locally |

**Diamond Logic® Engine Brake**

| | |
|---|---|
| Feeler gauge | Obtain locally |
| Injector Adaptor Removal Tool | ZTSE4725 |

**Air Compressor and Power Steering Pump**

No special service tools required for this section.

**Oil System Module Assembly**

| | |
|---|---|
| Air pressure regulator | Obtain locally |
| Oil Cooler Pressure Test Plate | ZTSE4654 |

**Oil Pan and Oil Suction Tube**

| | |
|---|---|
| Wacker T – 442 RTV sealant | Obtain locally |

**Front Cover, Cooling System, and Related Components**

| | |
|---|---|
| Dial indicator set | Obtain locally |
| Fan Wrench (for spin-on fan pulley) | ZTSE43971 |
| Fan Hub Wrench, 2 inch (for DriveMaster nut assembly) | ZTSE43972 |
| Feeler gauge | Obtain locally |
| Front Seal and Wear Sleeve Installer | ZTSE3004B |
| H-bar puller | Obtain locally |
| Heat insulated gloves | Obtain locally |
| Heel bar | Obtain locally |
| Hot plate | Obtain locally |
| Loctite® 569 Hydraulic Sealant | Obtain locally |
| Lower Idler Gear Socket | ZTSE4383 |
| Muffler chisel | Obtain locally |
| Straightedge | Obtain locally |
| Thermo-melt crayon, 100 °C (212 °F) | Obtain locally |
| 16 mm 12 point impact socket | Obtain locally |

**Cylinder Head and Valve Train**

| | |
|---|---|
| Ball gauge | Obtain locally |
| Cylinder Head Test Plate | ZTSE4289A |
| Depth micrometer | Obtain locally |
| Dial indicator set | Obtain locally |
| Dye penetrant kit | Obtain locally |
| Feeler gauge | Obtain locally |
| Head bolt socket | Obtain locally |
| Head Bolt Bottoming Tap | ZTSE4671 |
| Injector Sleeve Brush Set (set of 2) | ZTSE4304 |
| Injector Sleeve Installer | ZTSE4642 |
| Injector Sleeve Remover | ZTSE4643-1A |
| Inside micrometer | Obtain locally |
| Loctite® 620 Retaining Compound | Obtain locally |
| Outside micrometer | Obtain locally |
| Pressure regulator | Obtain locally |
| Slide Hammer Puller Set | ZTSE1879 |
| Small hole gauge set | Obtain locally |
| Square | Obtain locally |
| Straightedge | Obtain locally |
| Telescoping gauge | Obtain locally |
| Thermostat Opening Pressure Adapter | ZTSE4647 |
| Valve and Clutch Spring Tester | ZTSE2241 |
| Valve Guide Deburring Tool | ZTSE4393 |
| Valve Guide Installer | ZTSE1943 |
| Valve Guide Remover | ZTSE4377 |
| Valve Seat Extractor Kit (Universal) | ZTSE1951C |
| Valve Seat Grinder | ZTSE1631A |
| Valve seat grinding stones 45° (exhaust) | Obtain locally |
| Valve seat grinding stones 60° (intake) | Obtain locally |
| Valve Seat Installer | ZTSE4641 |
| Valve Seat Remover (collet) | ZTSE4640 |
| Valve Spring Compressor | ZTSE1846 |
| Valve Spring Compressor Jaws | ZTSE4652 |

| | |
|---|---|
| Vernier caliper | Obtain locally |
| Water Supply Housing Pressure Adapter | ZTSE4648 |

**Flywheel and Flywheel Housing**

| | |
|---|---|
| Dial indicator set | Obtain locally |
| Guide pins | Obtain locally |
| H-bar puller | Obtain locally |
| Loctite® 569 Hydraulic Sealant | Obtain locally |
| Rear Seal Installer | ZTSE4637 |
| Slide Hammer Puller Set | ZTSE1879 |

**Power Cylinders**

| | |
|---|---|
| Counterbore Cutting Head | ZTSE25144A |
| Cylinder bore gauge | Obtain locally |
| Cylinder Liner Height Gauge | ZTSE2515A |
| Cylinder Sleeve Counterbore Tool Kit | ZTSE2514 |
| Cylinder Sleeve Puller | ZTSE2536 |
| Depth micrometer | Obtain locally |
| Dial indicator set | Obtain locally |
| Feeler gauge | Obtain locally |
| Inside micrometer | Obtain locally |
| Outside micrometer | Obtain locally |
| Piston Ring Compressor Tool | ZTSE4396 |
| Piston ring expander | Obtain locally |
| Piston Gauge Pins (set of 3) | ZTSE4653 |
| Sleeve Protrusion Hold Down Clamps | ZTSE4672 |
| Telescoping gauge set | Obtain locally |
| 15 mm 12 point socket | Obtain locally |

**Crankcase, Crankshaft, and Camshaft**

| | |
|---|---|
| Cam Gear Puller | ZTSE4411 |
| Camshaft Bushing Puller | ZTSE2893B |
| Dial indicator set | Obtain locally |
| Dye penetrant kit | Obtain locally |
| Head Bolt Bottoming Tap | ZTSE4671 |
| Hot plate | Obtain locally |
| Loctite® 262 | Obtain locally |
| Loctite® 277™ | Obtain locally |
| Nylon Brush | ZTSE4389 |
| Outside micrometer | Obtain locally |
| Plastigage®. | Obtain locally |
| Prussian Blue® | Obtain locally |
| Stiff Nylon Brush | ZTSE4392 |
| Tap Set | ZTSE4386 |

## Photos of Essential Tools

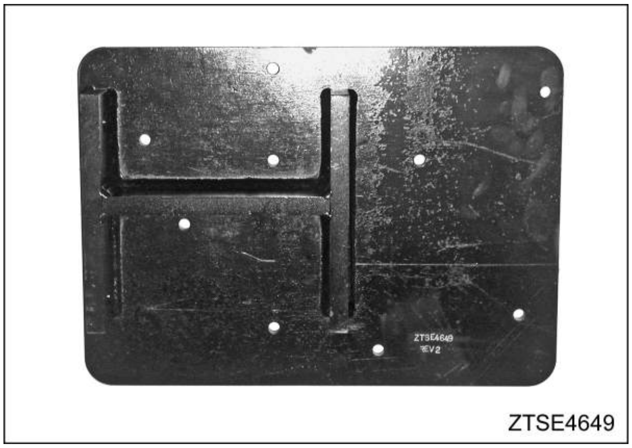


**Figure 550 Engine Stand Bracket, ZTSE4649**

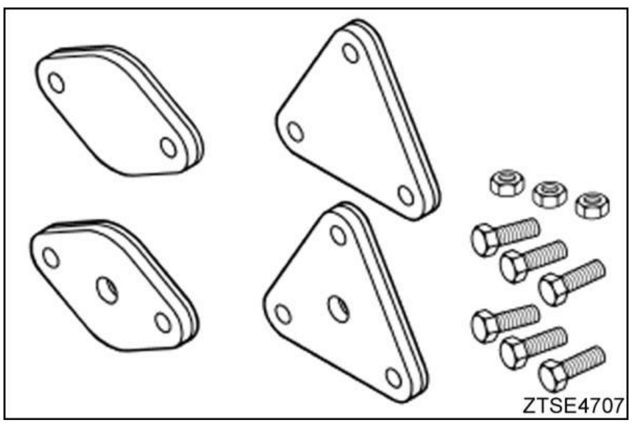


**Figure 551 EGR Cooler Pressure Test Plates, ZTSE4707**

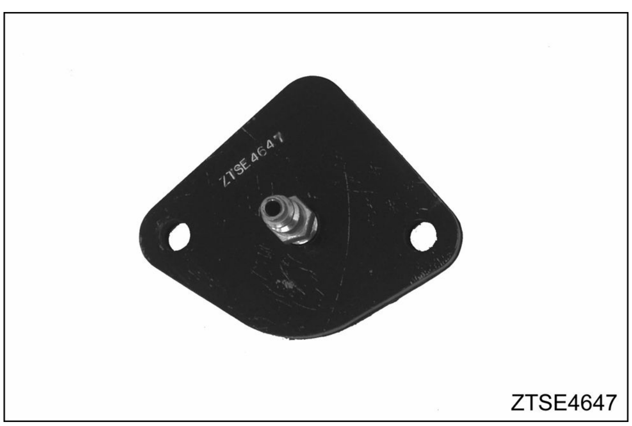


**Figure 552 Thermostat Opening Pressure Adapter - cylinder head, ZTSE4647**

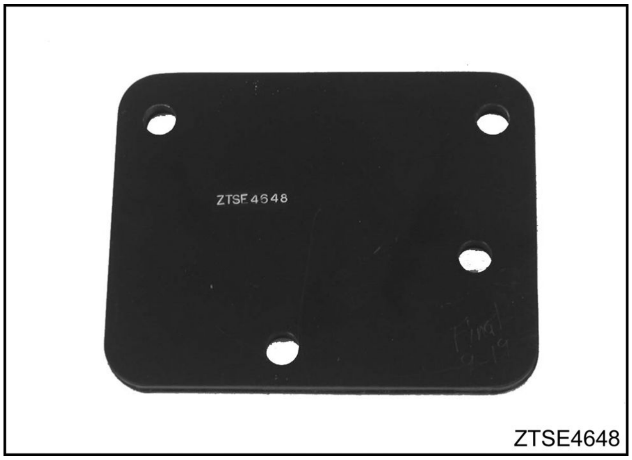


**Figure 553 Water Supply Housing Pressure Adapter - cylinder head, ZTSE4648**

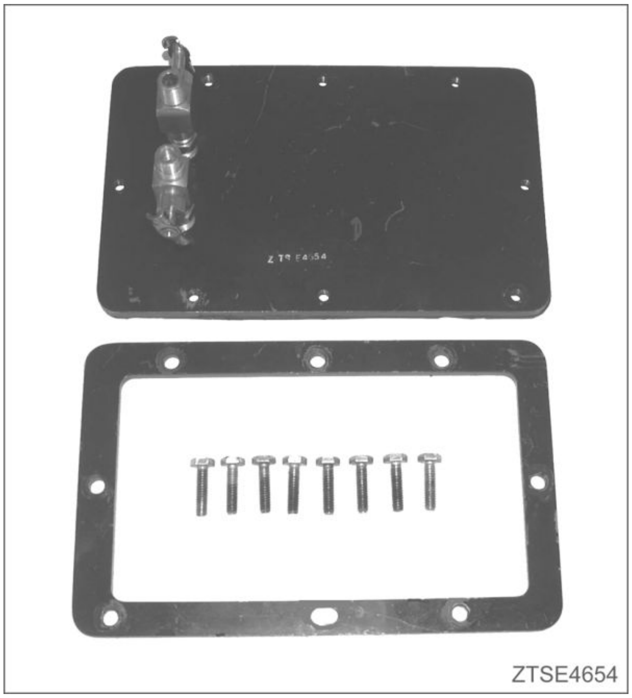


**Figure 554 Oil Cooler Pressure Test Plate, ZTSE4654**

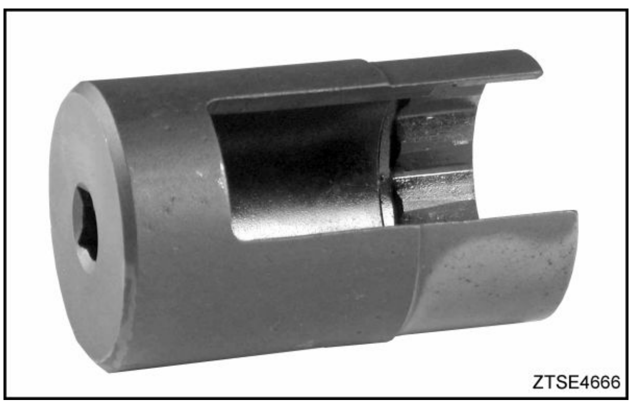


**Figure 555 IPR valve removal and installation tool, ZTSE4666**

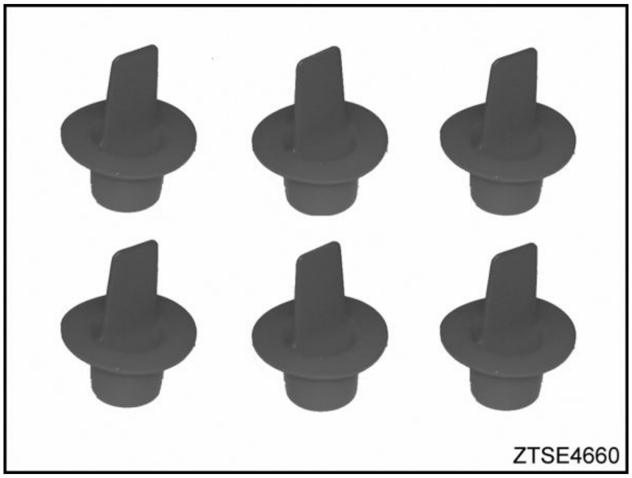


**Figure 556 Injector Oil Inlet Plugs, ZTSE4660**

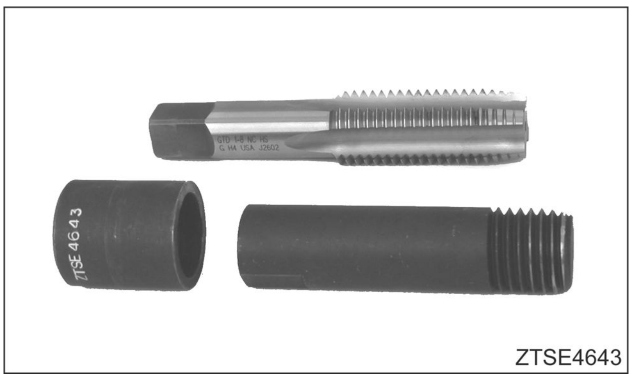


**Figure 557 Injector Sleeve Remover, ZTSE4643-1A**


**Figure 558 Injector Sleeve Installer, ZTSE4642**


ZTSE4652

**Figure 559 Valve Spring Compressor Jaws, ZTSE4652**


ZTSE4640

**Figure 560 Valve Seat Remover (collet), ZTSE4640**


ZTSE4641

**Figure 561 Valve Seat Installer, ZTSE4641**


**Figure 562 Head Bolt Bottoming Tap, ZTSE4671**


**Figure 563 Head/Main Bolt Thread Gauge, ZTSE4667**

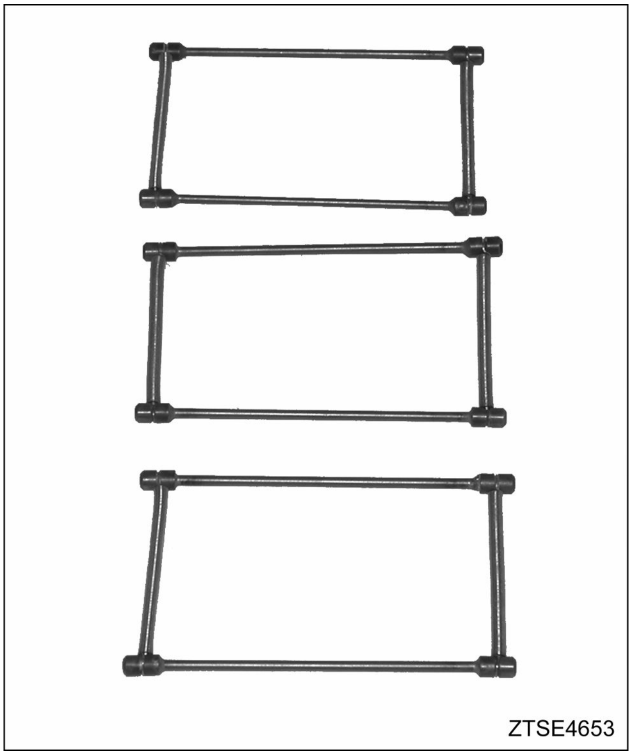


**Figure 564 Piston Gauge Pins (set of three), ZTSE4653**


**Figure 565 Sleeve Protrusion Hold Down Clamps, ZTSE4672**

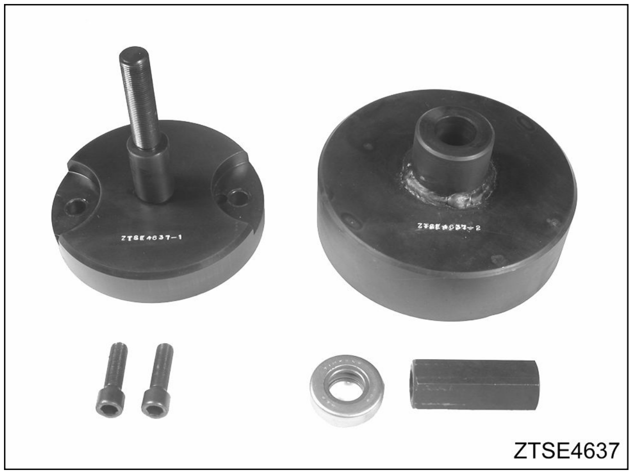


**Figure 566 Rear Seal Installer, ZTSE4637**