ENGINE SERVICE MANUAL
2007 MaxxForce® 7
EPA 10 - US, Canada, Mexico

ENGINE SERVICE MANUAL

2007 MaxxForce® 7

Navistar, Inc.

2701 Navistar Drive, Lisle, IL 60532 USA

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Highlights

Table 1 Summary of Changes

Location	Change
Technical Service Literature	Updated documentation part numbers
Figure 301, 310, 342	Updated graphics to show 2–bolt Auxiliary Accessory Mounting Bracket replaced with 3–bolt bracket.

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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 *Engine 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 a photo illustration may not be exact.

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

Technical Service Literature

1171941R4	International® MaxxForce® 7 *Engine Operation and Maintenance Manual*
EGES-345-1	International® MaxxForce® 7 *Engine Service Manual*
EGES-350-2	International® MaxxForce® 7 *Engine Diagnostic Manual*
EGED-355-2	International® MaxxForce® 7 Hard Start and No Start and Performance Diagnostics Form
EGED-365	International® MaxxForce® 7 Electronic Control Systems Diagnostic 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 International 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 glasses and safety shoes.
- Wear appropriate hearing protection.
- Wear correct work clothing.
- 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.

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Engine Identification

Engine Serial Number

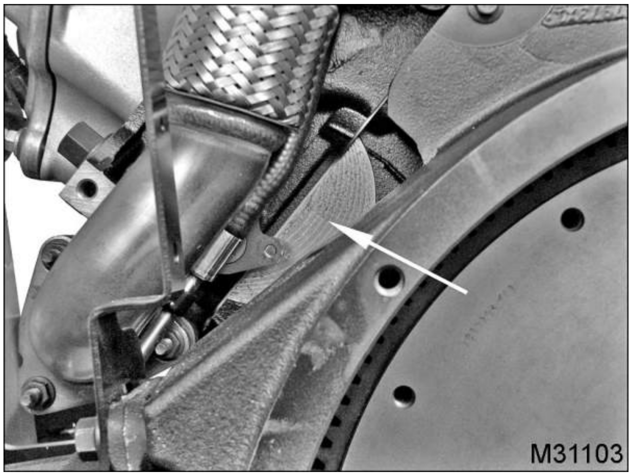

Figure 1 Engine serial number

The engine serial number is stamped on the crankcase pad, on the rear left side below the cylinder head.

Engine Serial Number Example

6.4HM2YXXXXXXX

6.4 – Engine displacement (liters)
H – Diesel, turbocharged, air intercooled and electronically controlled
M2 – Motor truck
Y – United States, Huntsville
7 digit suffix – Sequence number

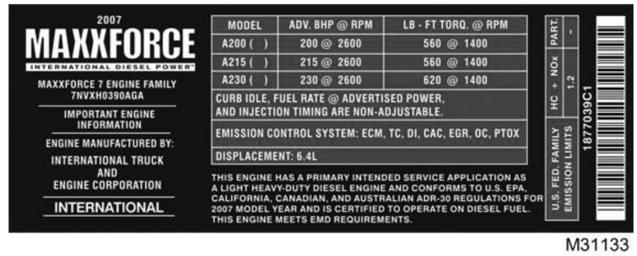

Figure 2 U.S. Environmental Protection Agency (EPA) exhaust emission label (example)

The U.S. Environmental Protection Agency (EPA) exhaust emission label is on top of the rear of the right valve cover, under the EBP sensor mounting bracket. The label includes the following:

- Advertised brake horsepower ratings
- Engine model code
- Service applications
- Emission family and control systems
- Year the engine was certified to meet EPA emission standards

Engine Accessories

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

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

Labels or identification plates include information and specifications helpful to vehicle operators and technicians.

Engine Description

International® MaxxForce® 7 Features and Specifications

Engine configuration	4 stroke, V8 diesel
Displacement	6.4 liters (389 in^3)
Bore (sleeve diameter)	98.2 mm (3.87 in.)
Stroke	105 mm (4.134 in.)
Compression ratio	17.5:1
Aspiration	Variable Geometry Turbocharger (VGT) and Charge Air Cooled (CAC)
Rated power @ rpm	230 hp @ 2300 rpm[1]
Peak torque @ rpm	620 ft·lbs @ 1500 rpm[1]
Engine rotation (facing flywheel)	Counterclockwise
Combustion system	Direct injection, turbocharged
Fuel system	Direct injection common rail
Cooling system capacity (engine only)	10.23 liters (10.8 quarts US)
Lube system capacity (including filter)	17 liters (18 quarts US)
Lube system capacity (overhaul only, with filter)	18.9 liters (19 quarts US)
Firing order	1-2-7-3-4-5-6-8

1 Initial rating at the time of manual printing, ratings are subject to change for various application. See EPA emission label for the exact rating for a particular engine.

Standard Features

The International® MaxxForce® 7 is a V8 engine with a displacement of 6.4 liters (389 cubic inches).

The electronic governor controls the engine's rpm within a safe and stable operating range for ideal performance. Low idle governor prevents the engine rpm from dropping below a stable speed to prevent stalling when various loads are demanded on the engine. High idle governor prevents the engine rpm from going above a safe speed that would cause internal damage to the engine.

The cylinder heads have four valves per cylinder. Each fuel injector is centrally located between the four valves and directs fuel over the piston bowl for improved performance and reduced emissions.

The camshaft is supported by four bushings pressed into the crankcase. The camshaft is crankshaft driven and thrust is controlled by a plate mounted behind the fourth cam journal.

The overhead valve train includes hydraulic roller cam followers, push rods, rocker arms, and valve bridges to open the dual intake and exhaust valves.

The crankcase is comprised of two major matching components. The upper crankcase half houses the cylinders, main bearing saddles, with oil and coolant passages either cast or machined. The lower crankcase consists of a structural plate with the main bearing caps machined into it for improved load retention and alignment.

The crankshaft is supported by five main bearings with fore and aft thrust controlled at the upper half of the second main bearing. Two connecting rods are attached to each crankshaft rod journal and are offset to minimize vibration. Piston pins are free floating, allowing the pins free lateral movement within the connecting rod as well as the piston. Piston pins are held in place with retaining rings.

One piece aluminum-alloy pistons are fitted with one keystone ring, one rectangular intermediate compression ring, and a two piece oil control ring. The combustion bowl is located in the piston crown to reduce emissions. All pistons are mated to fractured cap joint connecting rods.

The Crankshaft Position (CKP) sensor and Camshaft Position (CMP) sensor are used by the Electronic Control Module (ECM) to calculate rpm, fuel timing, fuel quantity, and duration of fuel injection.

The Exhaust Gas Recirculation (EGR) system includes an EGR valve and an intake throttle valve. The EGR valve is mounted in an EGR mixer elbow that is part of the EGR valve elbow housing. The intake throttle valve is mounted on the other side of the EGR valve elbow housing in the air stream from the CAC.

A gerotor lube oil pump is mounted in the front cover and is driven by the crankshaft. Pressurized oil is supplied to engine components. All MaxxForce® 7 engines use an engine oil cooler and engine oil filter.

A closed crankcase breather system draws crankcase vapors through a breather element. The breather element separates the vapor and sends it to the air intake and returns the oil to the crankcase.

The low-pressure fuel pump draws fuel from the fuel tank(s) through the primary fuel filter. The primary fuel filter assembly includes a Water in Fuel (WIF) sensor and an optional fuel heater. Water and solids are separated from the fuel and the water is collected in the water separator bowl. The instrument panel WIF lamp is illuminated when water needs to be drained. A drain valve in the water separator bowl drains water out. Fuel is discharged to the secondary fuel filter. The secondary fuel filter assembly is pressure regulated and incorporates an air bleed orifice allowing air to be automatically purged if it has been introduced to the system.

The high-pressure fuel system includes a High-pressure Fuel Pump (HPFP), high-pressure common rails, and fuel injectors. The ECM electronically controls the injectors allowing multiple injections and more precise fuel delivery to improve combustion, emissions, and cold start performance.

A hand operated primer pump is mounted on the right valve cover. The manual priming pump draws fuel from the fuel tank(s) through the primary filter after filter replacement or when system has run out of fuel. This primes the fuel system to minimize the amount of air injected into the system on initial startup.

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 to control boost pressure for various engine speeds and load conditions.

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.

Diamond Logic® engine control is a single electronic control unit that monitors and controls the engine and chassis components.

The glow plug relay controls the eight glow plugs, one for each cylinder. The glow plugs warm the cylinders during start-up.

Optional Features

An air compressor is available for applications that require air brakes or air suspension.

A coolant heater is available to raise the temperature of the coolant surrounding the cylinders for improved performance during cold weather startups.

A fuel heater is available and installed in the primary fuel filter 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 processes engine exhaust so that it meets emissions requirements at the tailpipe.

- The oxidation catalyst burns oxygen and hydrocarbons in the exhaust stream.
- The DPF captures and burns particulates in the exhaust stream.

Engine Component Locations

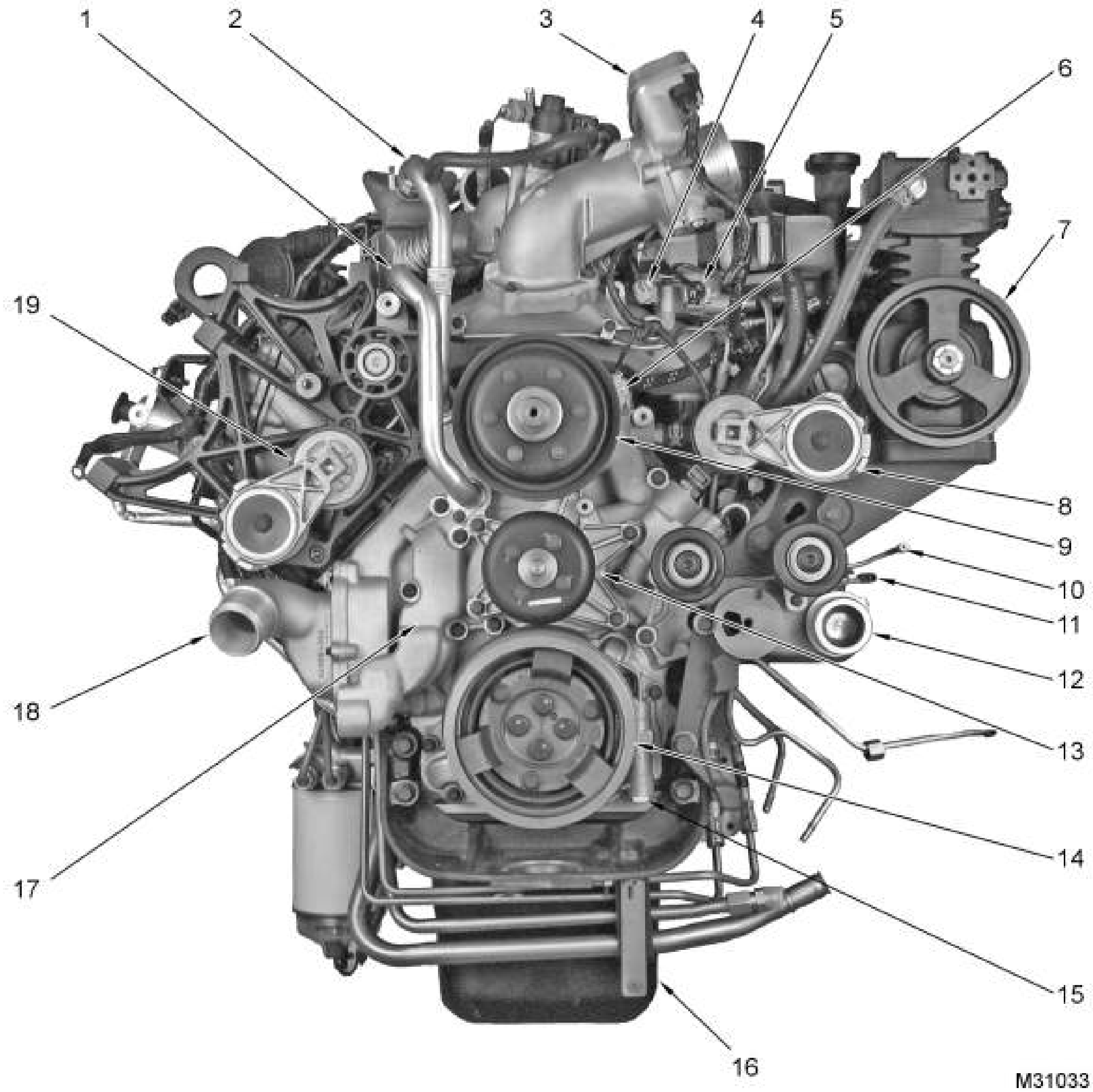

Figure 3 Front

1. EGR coolant supply tube (cooler)
2. EGR coolant return tube (cooler)
3. Intake throttle housing assembly (ITV)
4. Engine Fuel Pressure (EFP) sensor
5. Engine Fuel Temperature (EFT) sensor
6. Engine Coolant Temperature (ECT) sensor
7. Air compressor pulley
8. Air compressor belt tensioner
9. Fan pulley
10. Coolant to secondary radiator
11. Coolant to fuel cooler
12. Coolant inlet
13. Water pump pulley
14. Vibration damper/engine oil pump
15. Oil pressure regulator
16. Lower oil pan
17. Front crankcase cover
18. Thermostat housing (coolant outlet)
19. Belt tensioner

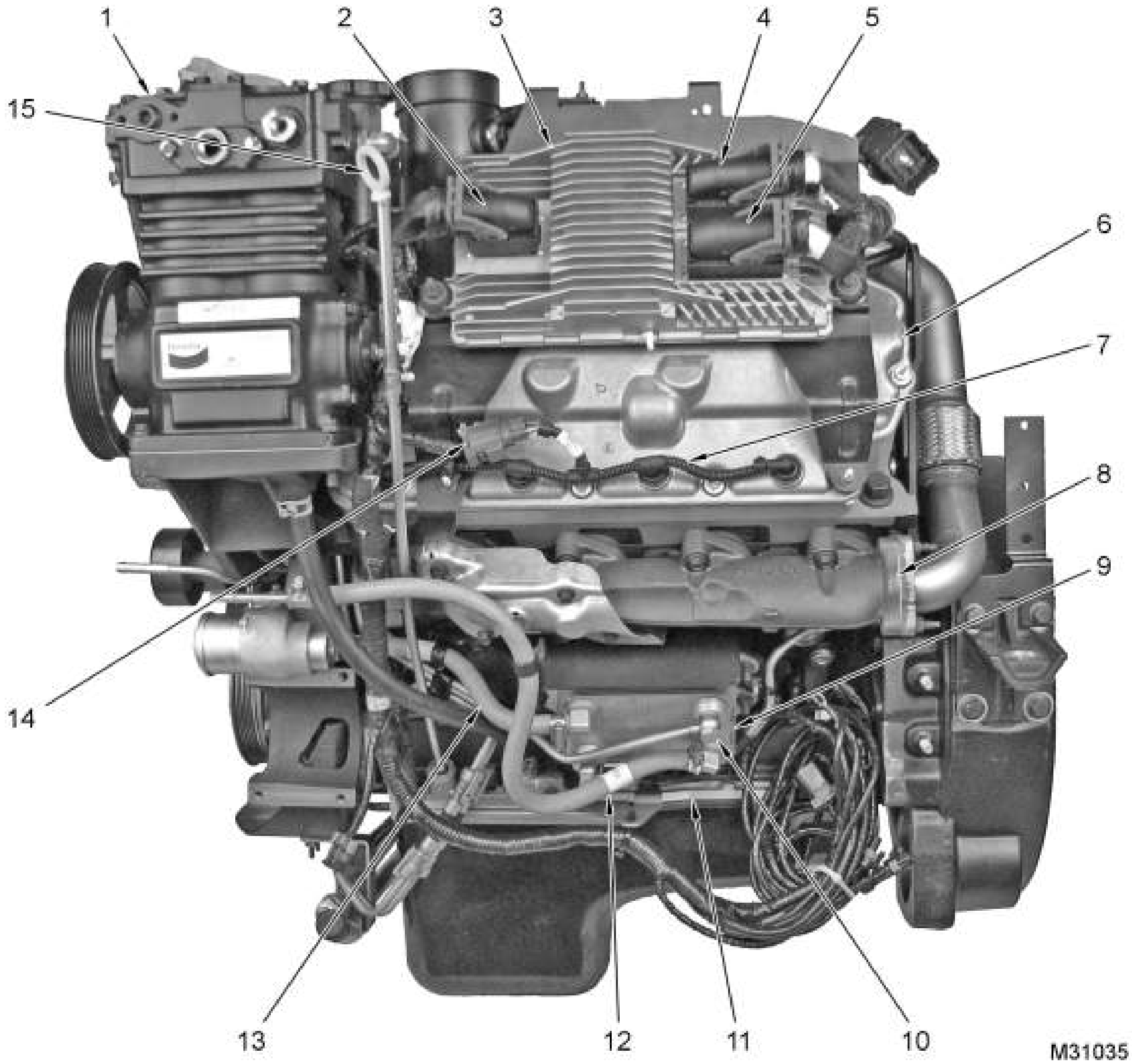

Figure 4 Left

1. Air compressor
2. Injector harness
3. Engine Control Module (ECM)
4. Engine 76-pin harness
5. Vehicle 76-pin harness
6. Valve cover (left)
7. Glow plug harness assembly (left)
8. Exhaust manifold (left)
9. Fuel cooler assembly
10. Fuel cooler to filter tube assembly (secondary fuel filter)
11. Upper oil pan
12. Coolant-in hose (Coolant supply to fuel cooler)
13. Coolant-out from fuel cooler hose
14. Glow plug harness assembly connector (left)
15. Oil level gauge tube assembly

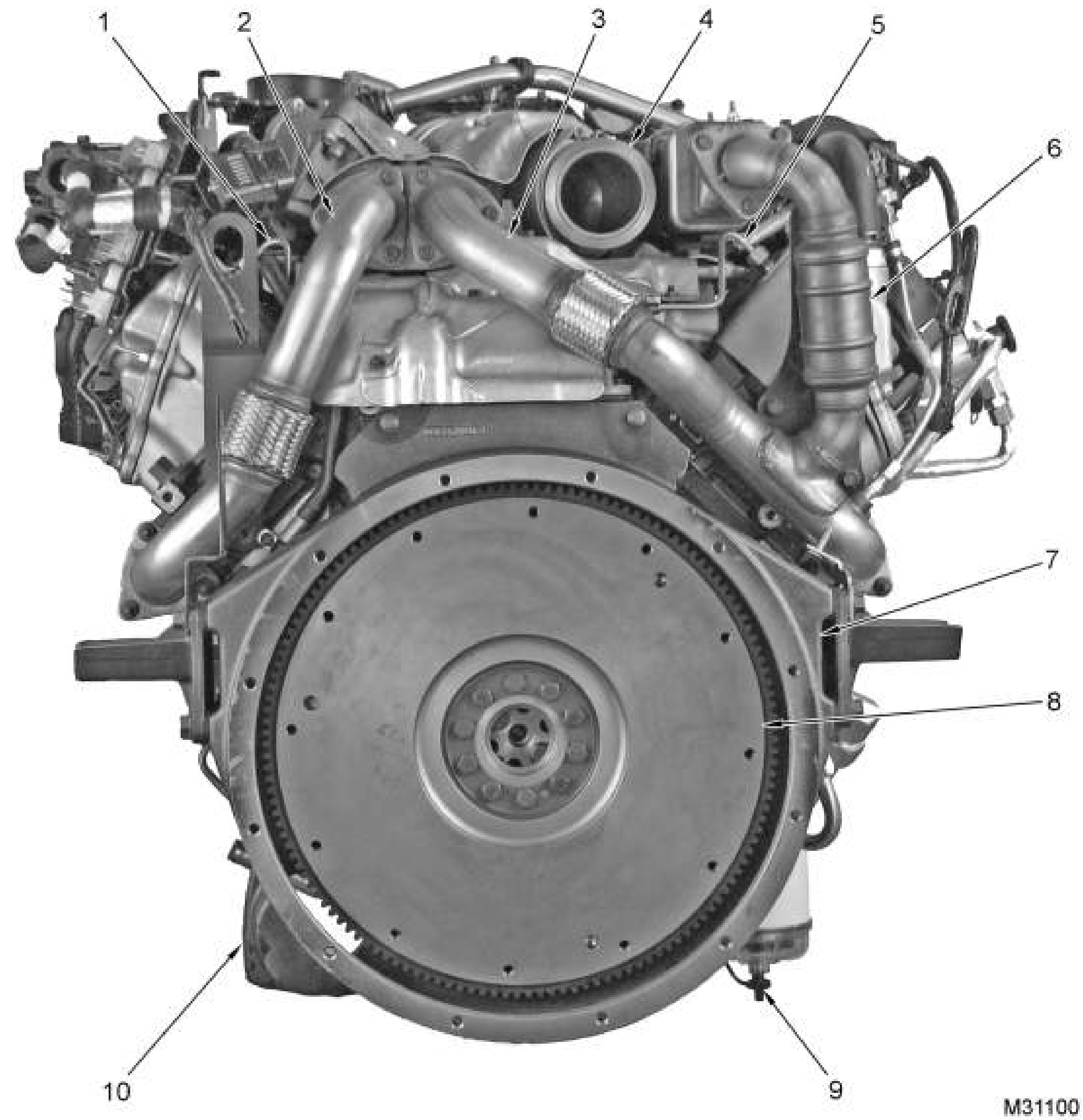

Figure 5 Rear

1. Pump left tube assembly (high-pressure fuel to left fuel rail)
2. Left exhaust tube assembly
3. Right exhaust tube assembly
4. Exhaust outlet
5. Pump right tube assembly (high-pressure fuel to right fuel rail)
6. EGR cooler Diesel Oxidation Catalyst (DOC)
7. Crankcase rear cover
8. Flywheel assembly
9. Fuel drain valve (water and sediment drain for fuel filter)
10. Starter mount (rear cover)

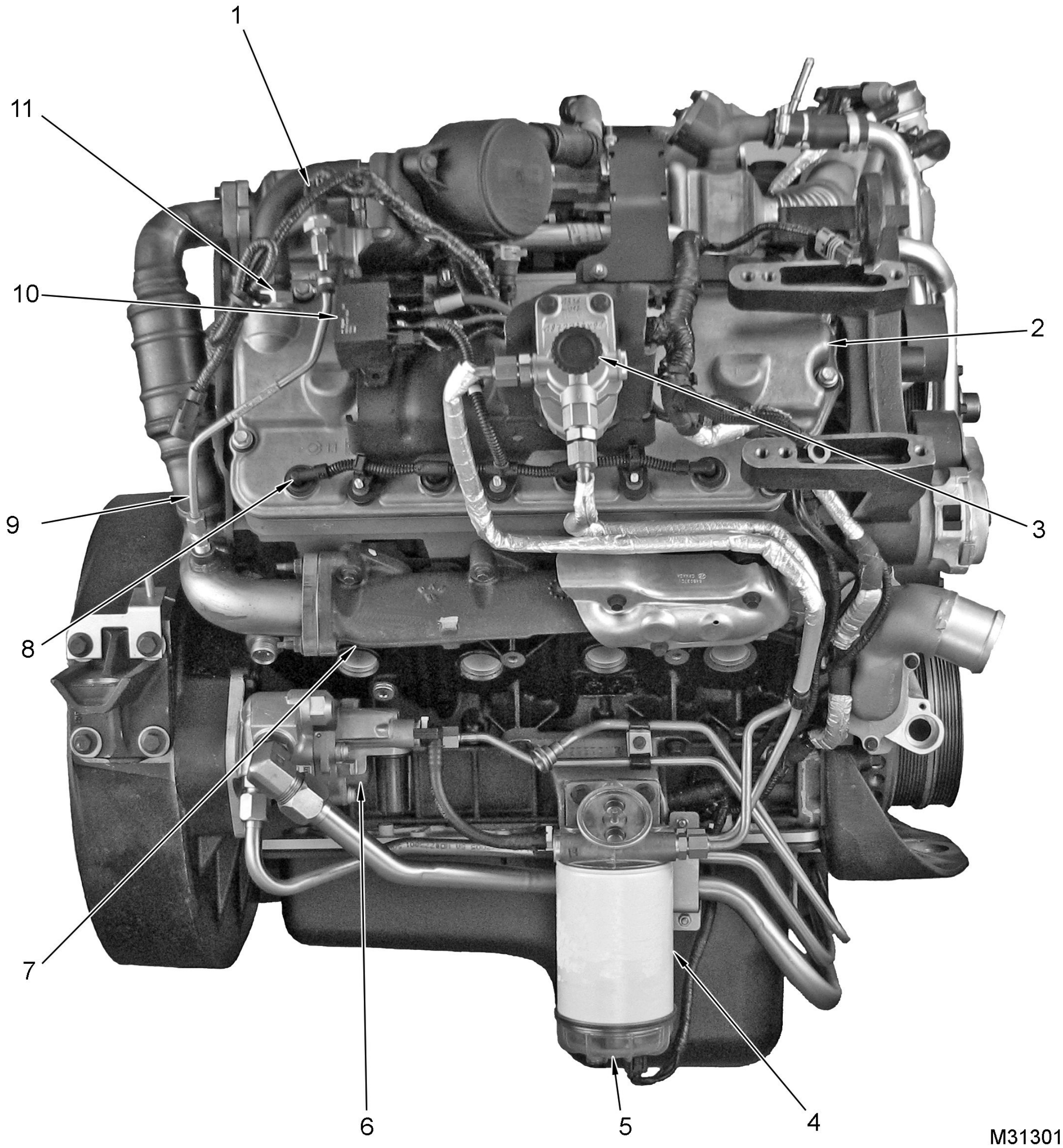

Figure 6 Right

1. Exhaust Back Pressure (EBP) sensor
2. Valve cover (right)
3. Fuel primer pump assembly
4. Primary fuel filter assembly
5. Bowl assembly with fuel heater/probe
6. Gear driven fuel pump assembly (low-pressure fuel pump)
7. Exhaust manifold (right)
8. Glow plug harness assembly (right)
9. EBP tube
10. Glow plug relay
11. Breather inlet adapter (crankcase vent)

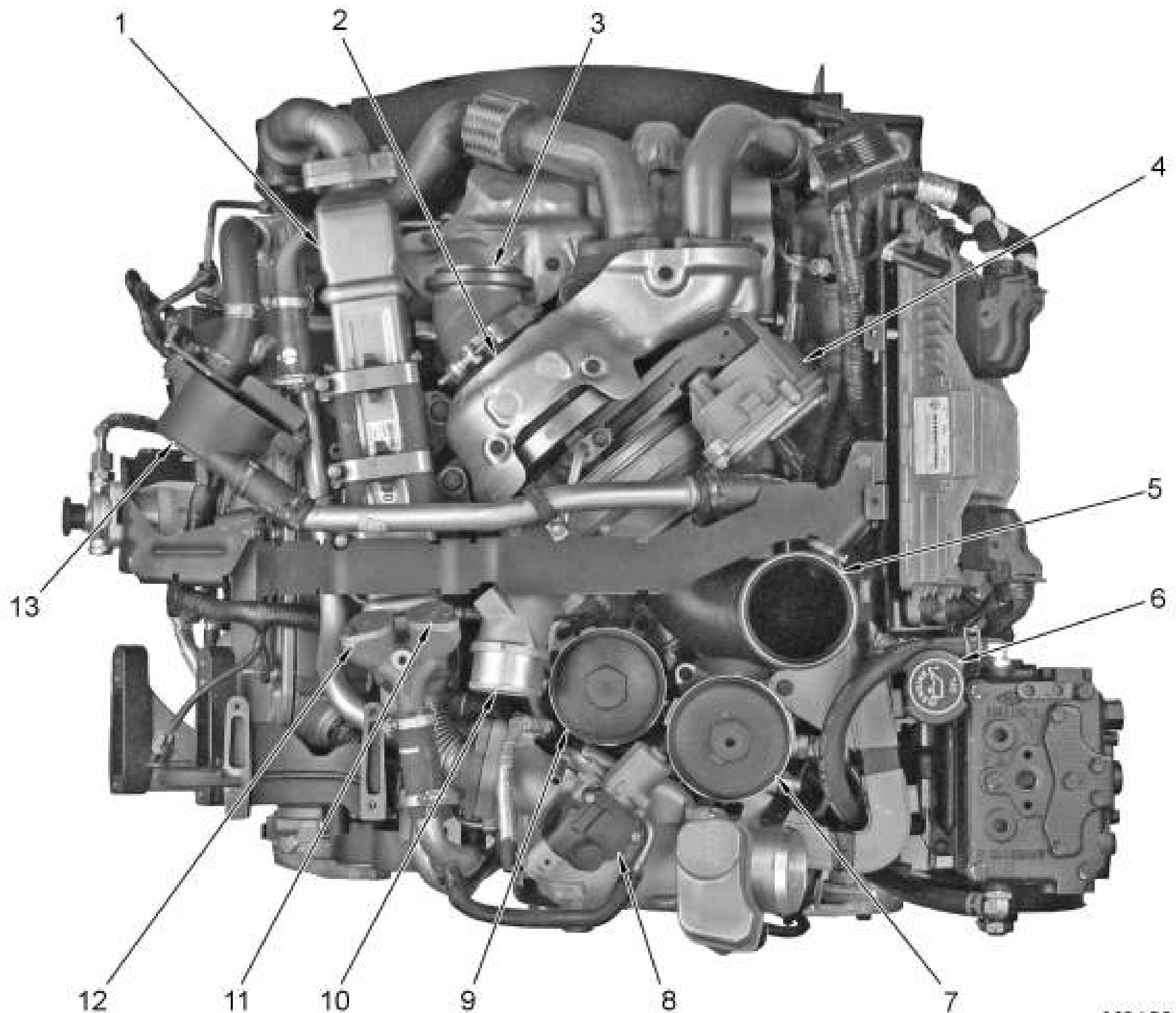

Figure 7 Top

1. Exhaust Gas Recirculation (EGR) cooler
2. Turbocharger assembly
3. Exhaust outlet (Turbocharger)
4. VGT actuator
5. Turbocharger air inlet duct
6. Oil fill cap
7. Secondary fuel filter assembly
8. EGR valve assembly
9. Oil filter
10. Turbocharger air outlet
11. Coolant to chassis heater
12. Coolant to chassis heater (dual for bus applications)
13. Breather assembly (crankcase pressure)

Air Management System

Air Management Components and Air Flow

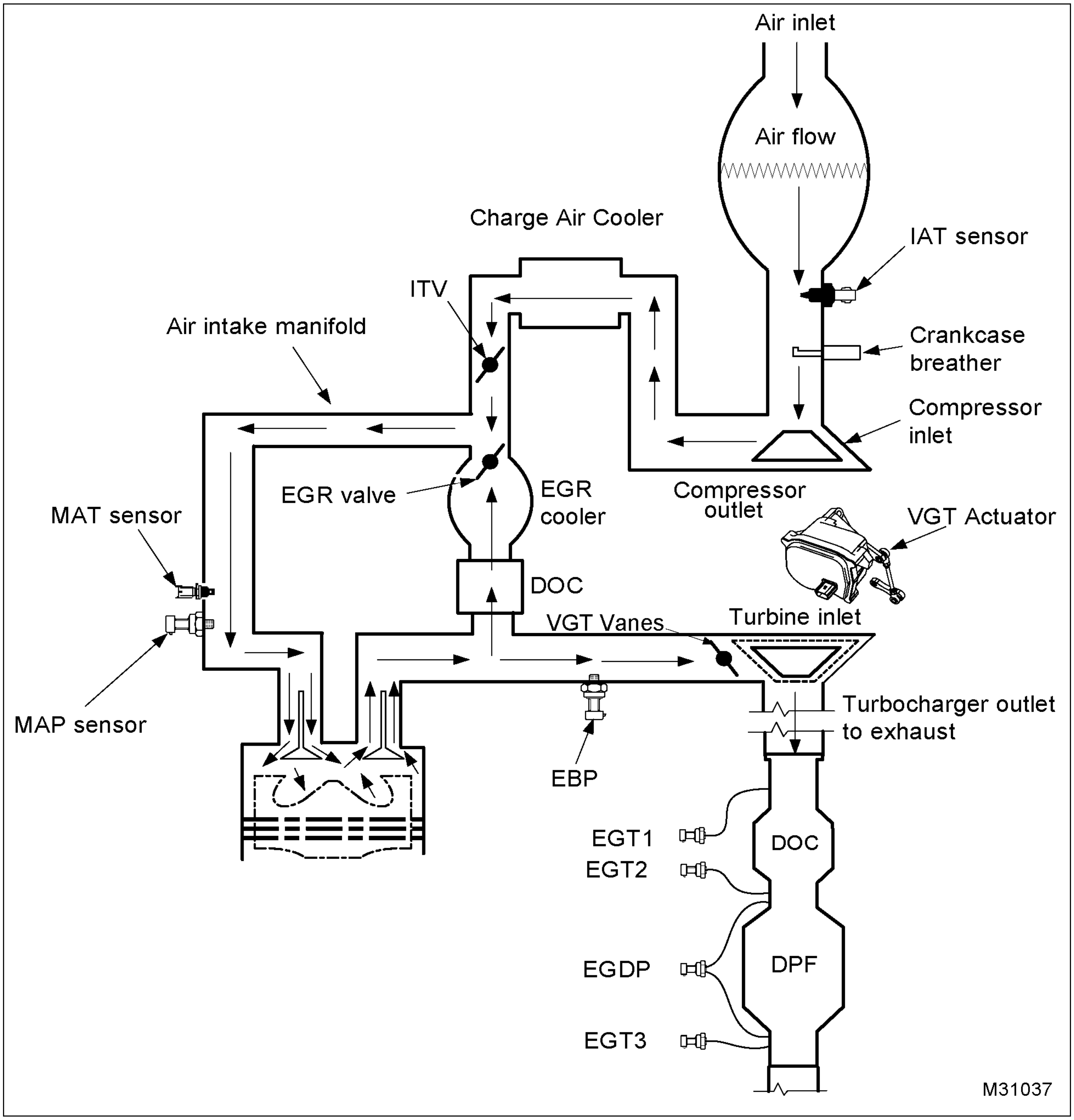

Figure 8 Air Management System (AMS)

The Air Management System (AMS) includes the following:

Air filter assembly
Intake Air Temperature (IAT) sensor
Variable Geometry Turbocharger (VGT) assembly
Charge Air Cooler (CAC)
Intake Throttle Valve (ITV)
Manifold Air Temperature (MAT) sensor
Manifold Absolute Pressure (MAP) sensor
Intake manifold
Intake valves
Exhaust Gas Recirculation (EGR) system (EGR valve, EGR cooler, and EGR cooler DOC)
Exhaust valves
Exhaust manifolds
Exhaust Back Pressure (EBP) sensor
Exhaust tubes
Diesel Oxidation Catalyst (DOC)
Diesel Particulate Filter (DPF)

Air Flow

Air flows through the air filter assembly and enters the Variable Geometry Turbocharger (VGT). The compressor in the VGT increases the pressure, temperature, and density of the intake air before it enters the Charge Air Cooler (CAC). Cooled compressed air flows from the CAC into the EGR valve elbow housing.

If the EGR control valve is open, exhaust gas will mix with filtered intake air and flow into the intake manifold. If the EGR control valve is closed, only filtered air will flow into the intake manifold.

After combustion, exhaust gas is forced through the exhaust manifold to the EGR cooler and VGT. Some exhaust gas is cooled in the EGR cooler and flows through the EGR valve to the EGR valve elbow housing. When exhaust gas mixes with filtered air and fuel during the combustion process, this cools the combustion process and reduces the formation of NO_X engine emissions. The rest of the exhaust gas flows to the VGT when it spins and expands through the turbine wheel, varying boost pressure. The VGT compressor wheel is on the same shaft as the turbine wheel and compresses the mixture of filtered air.

The VGT responds directly to engine loads. During heavy load, increased temperature of exhaust turns the turbine wheel faster. This increased speed turns the compressor impeller faster and supplies more air or greater boost to the intake manifold. Conversely, when engine load is light, the temperature of exhaust decreases and less air is directed into the intake manifold.

Charge Air Cooler (CAC)

The CAC is mounted on top of the radiator. Air from the turbocharger passes through a network of heat exchanger tubes before entering the EGR valve elbow housing. Outside air flowing over the CAC cools the charged air. Charged air is cooler and denser than the air that is not cooled and improves the fuel-to-air ratio during combustion. This results in improved emission control and power output.

Variable Geometry Turbocharger (VGT) Assembly

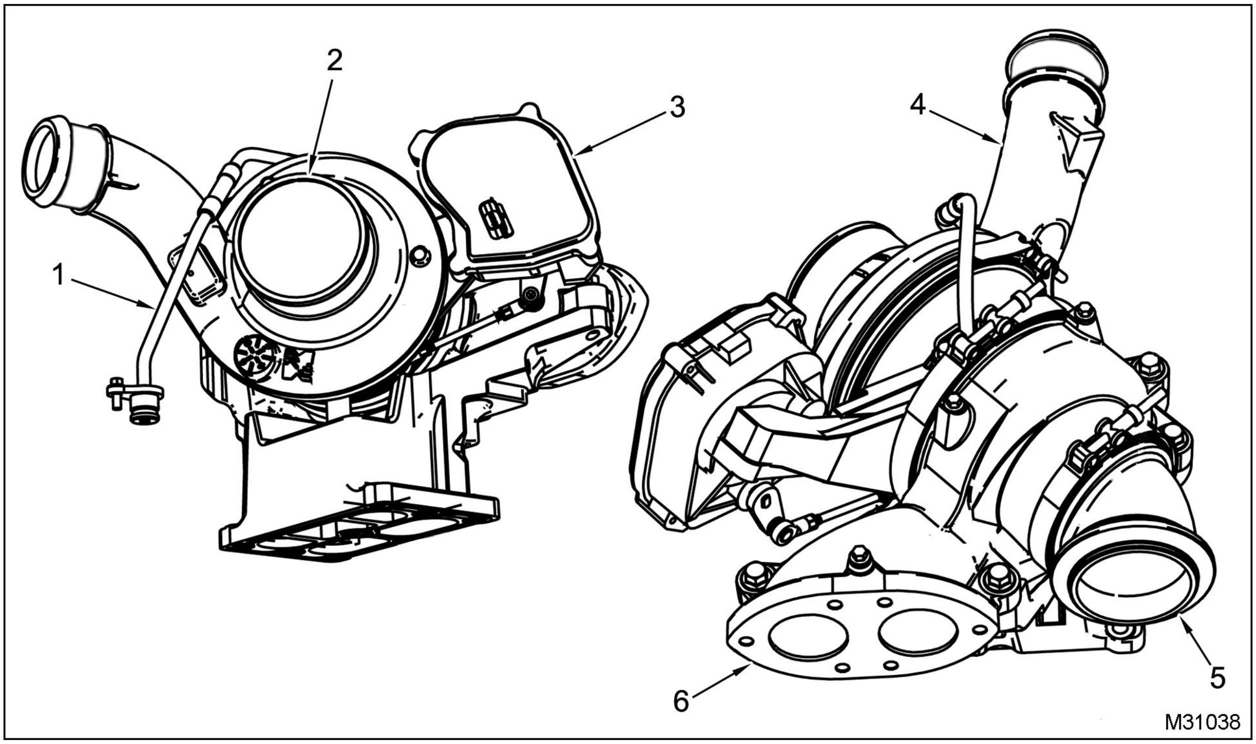

Figure 9 Turbocharger

1. Turbocharger oil supply tube
2. Air inlet
3. VGT actuator
4. Compressor outlet
5. Exhaust outlet
6. Exhaust inlet

The VGT has actuated vanes in its turbine housing. The vanes modify flow characteristics of exhaust gases through the turbine housing. The benefit is the ability to control boost pressure for various engine speeds and load conditions. An additional benefit is lower emissions.

VGT closed loop system

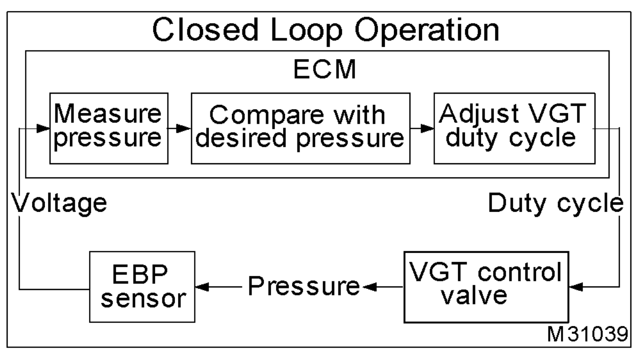

Figure 10 VGT closed loop system

The VGT is a closed loop system that uses the Exhaust Back Pressure (EBP) sensor to provide feedback to the ECM. The ECM uses the EBP sensor to continuously monitor EBP and adjust the duty cycle to the VGT to match engine requirements.

VGT control

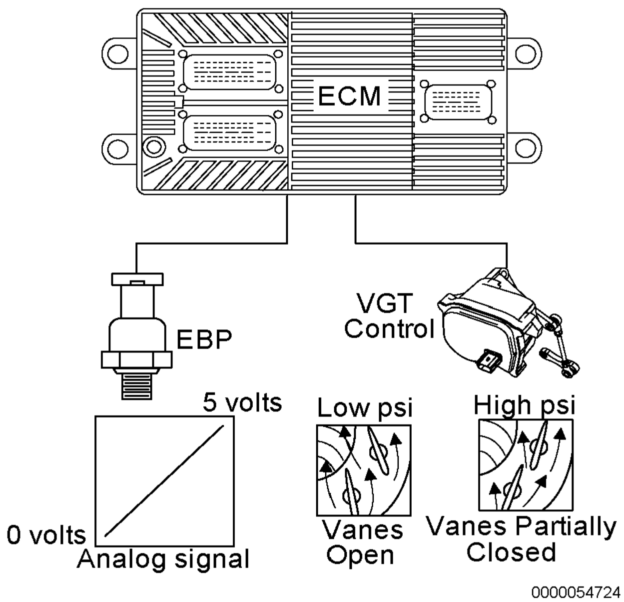

Figure 11 VGT control

Actuator vanes are mounted around the inside circumference of the turbine housing. An adjusting ring links all the vanes. When the adjusting ring moves, all vanes move to the same position. The adjusting ring is connected to the VGT actuator through a vane operating lever. The actuator receives a signal from the ECM. The actuator moves the valve operating lever that moves the unison ring based on the increase or decrease of the exhaust back pressure.

Exhaust gas flow can be regulated depending on required exhaust back pressure for engine speed and load.

Exhaust Gas Recirculation (EGR) System

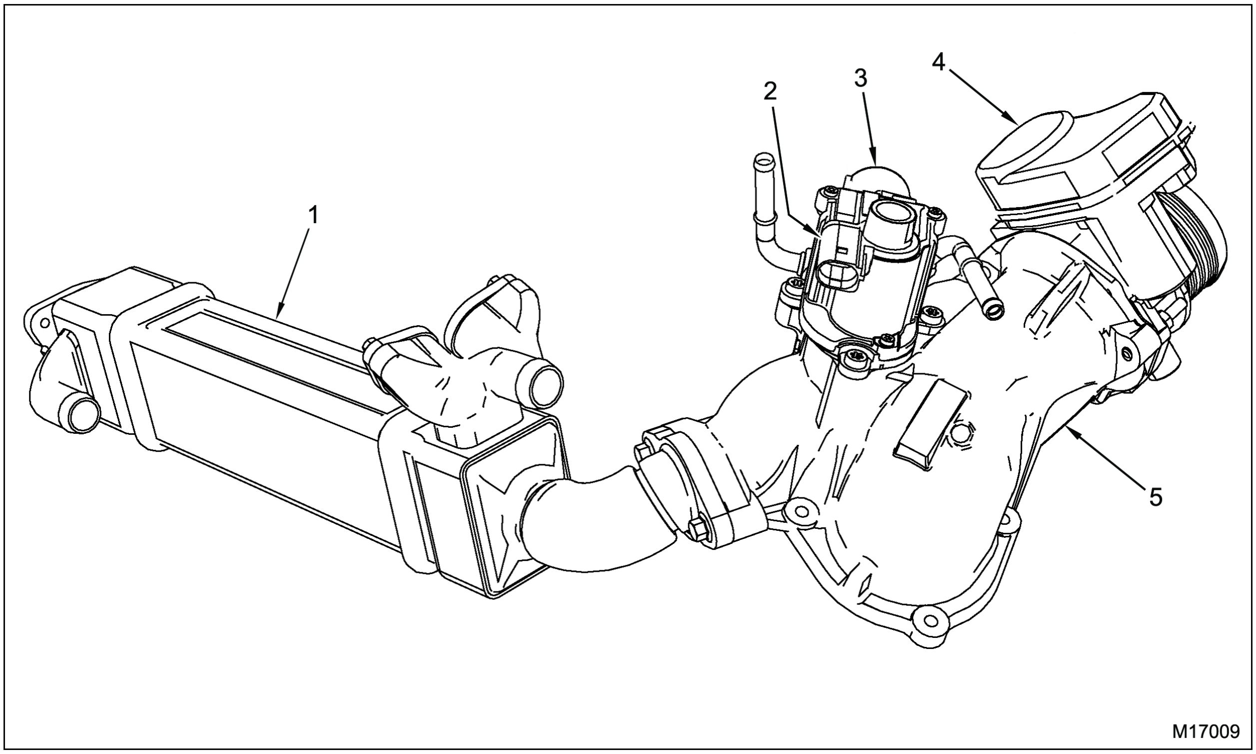

Figure 12 EGR system

1. EGR cooler
2. EGR valve connector
3. EGR valve assembly
4. Intake throttle housing assembly (ITV)
5. EGR valve elbow housing

The EGR system includes the following:

- Exhaust tube assembly
- EGR cooler
- EGR valve assembly
- EGR valve control
- EGR valve elbow housing
- ITV assembly

The EGR system reduces Nitrogen Oxide (NO_X) emissions. The EGR system is also used to adjust the fuel to air ratio for regeneration.

NO_X gas forms during a reaction between nitrogen and oxygen at the high temperatures of combustion. By mixing exhaust gasses with the inlet air peak combustion temperature is reduced thus reducing the formation of NO_X emissions.

EGR Flow

Some exhaust from the exhaust tube assembly flows through a Diesel Oxidation Catalyst (DOC) into the EGR cooler. Exhaust from the EGR cooler flows into the EGR valve elbow housing, through the EGR valve, and into the intake manifold.

When EGR is required, the EGR valve opens, allowing cooled exhaust gases to enter the intake manifold to be mixed with filtered intake air. The exhaust gases are then recycled through the combustion process.

EGR Valve

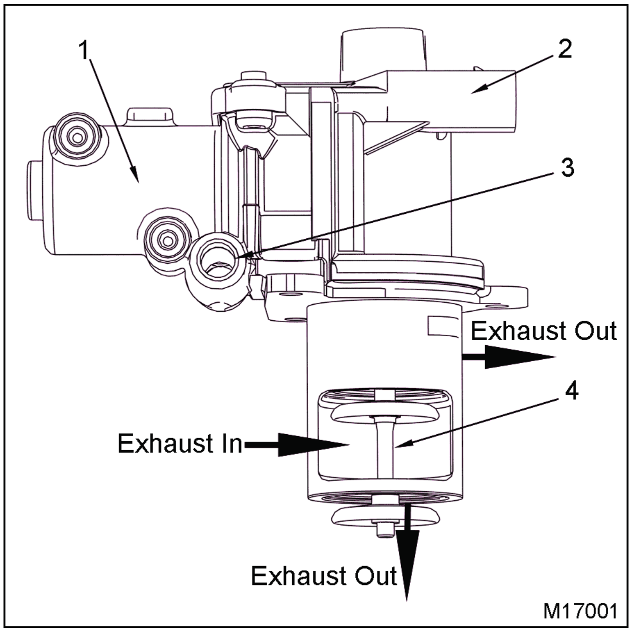

Figure 13 EGR valve

1. DC motor
2. Connector
3. Coolant return
4. Poppet valve assembly

The EGR valve uses a DC motor to control the position of the valve assembly. The motor drives the poppet valve assembly at the same time it drives the position sensor. The poppet valve assembly has two valve heads (poppets) on a common shaft.

Exhaust flow enters the EGR valve elbow housing and enters the EGR valve. Exhaust flows through the two valve poppets into the intake mixer where it mixes with incoming air from the air inlet throttle valve. The mixed air goes into the intake manifold and cylinders.

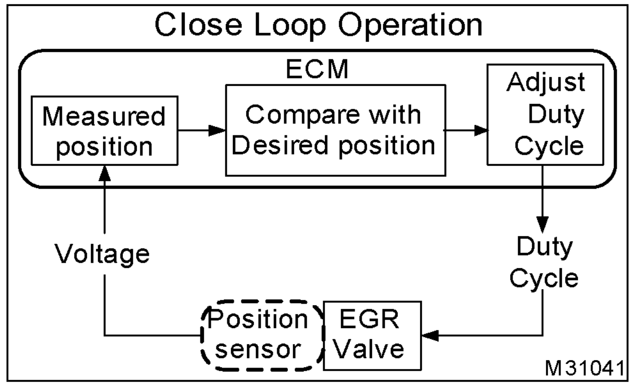

Figure 14 EGR closed loop operation

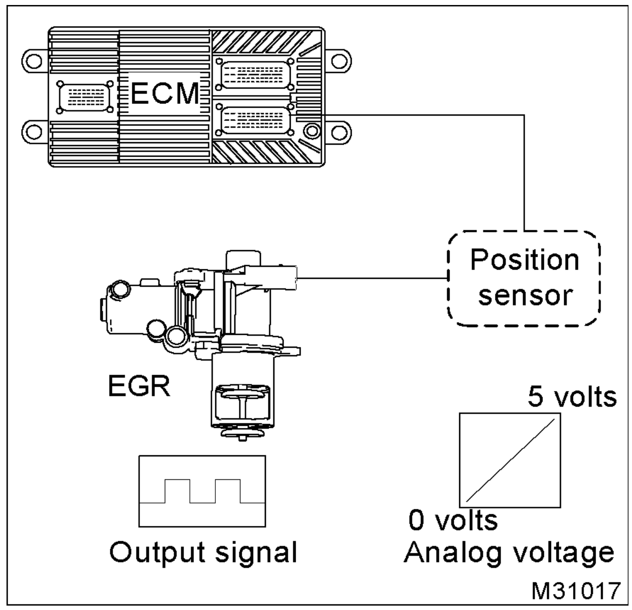

Figure 15 EGR control

The EGR valve consists of two major components; a valve body and an actuator motor. The valve has a Hall effect position sensor to monitor valve movement. The EGR valve is located at the front of the engine in the EGR valve elbow housing.

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

Intake Throttle Valve (ITV)

The ECM monitors the aftertreatment system. The ECM controls the intake throttle valve during aftertreatment regeneration and purge.

The ITV is controlled to restricts intake air flow. Restricted air flow will increase exhaust temperature.

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 and 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 a representative electronic signal based on temperature and pressure. It is used by the control system to regulate the after treatment function.

The sensors measure 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 System

Fuel System Components

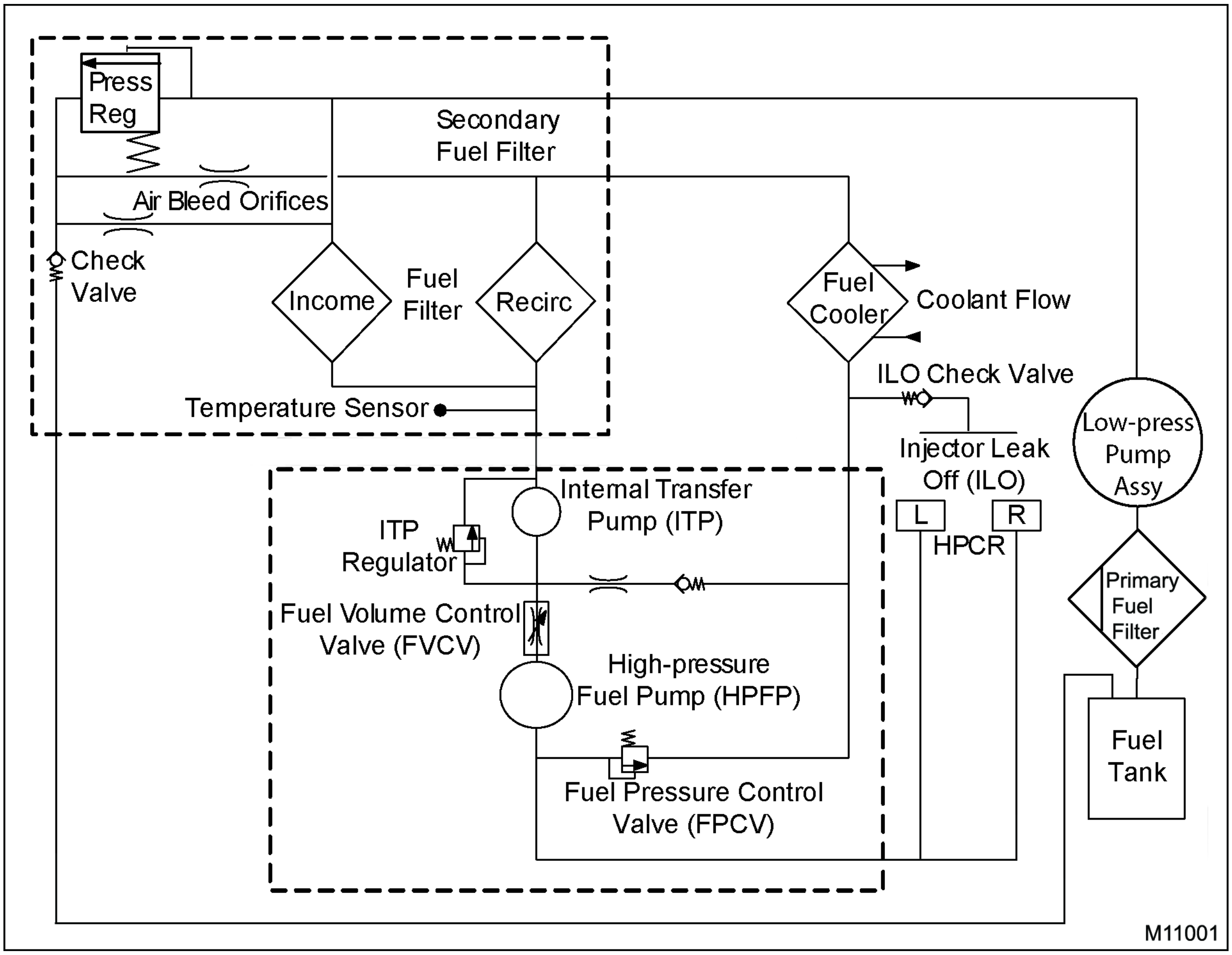

Figure 16 Fuel system schematic

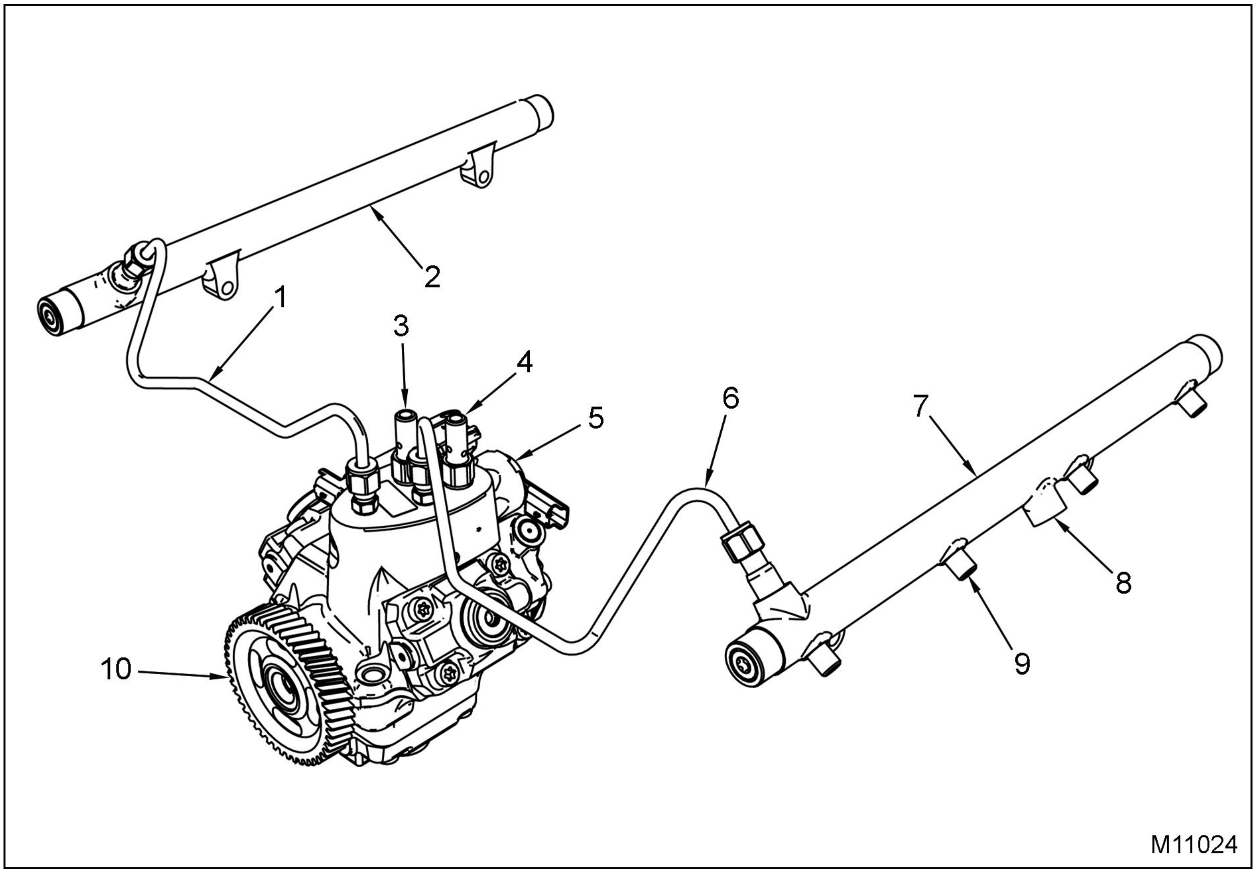

Figure 17 High-pressure fuel system

1. Pump left tube assembly (pump-to-rail)
2. Left rail assembly
3. Pump return tube connection (pump-to-cooler)
4. Filter to pump tube connection (pump-to-secondary fuel filter)
5. High-pressure Fuel Pump (HPFP) assembly
6. Pump right tube assembly (pump-to-rail)
7. Right rail assembly
8. Fuel Rail Pressure (FRP) sensor port
9. Fuel rail to injector fuel tube ports (4 for each rail)
10. HPFP gear

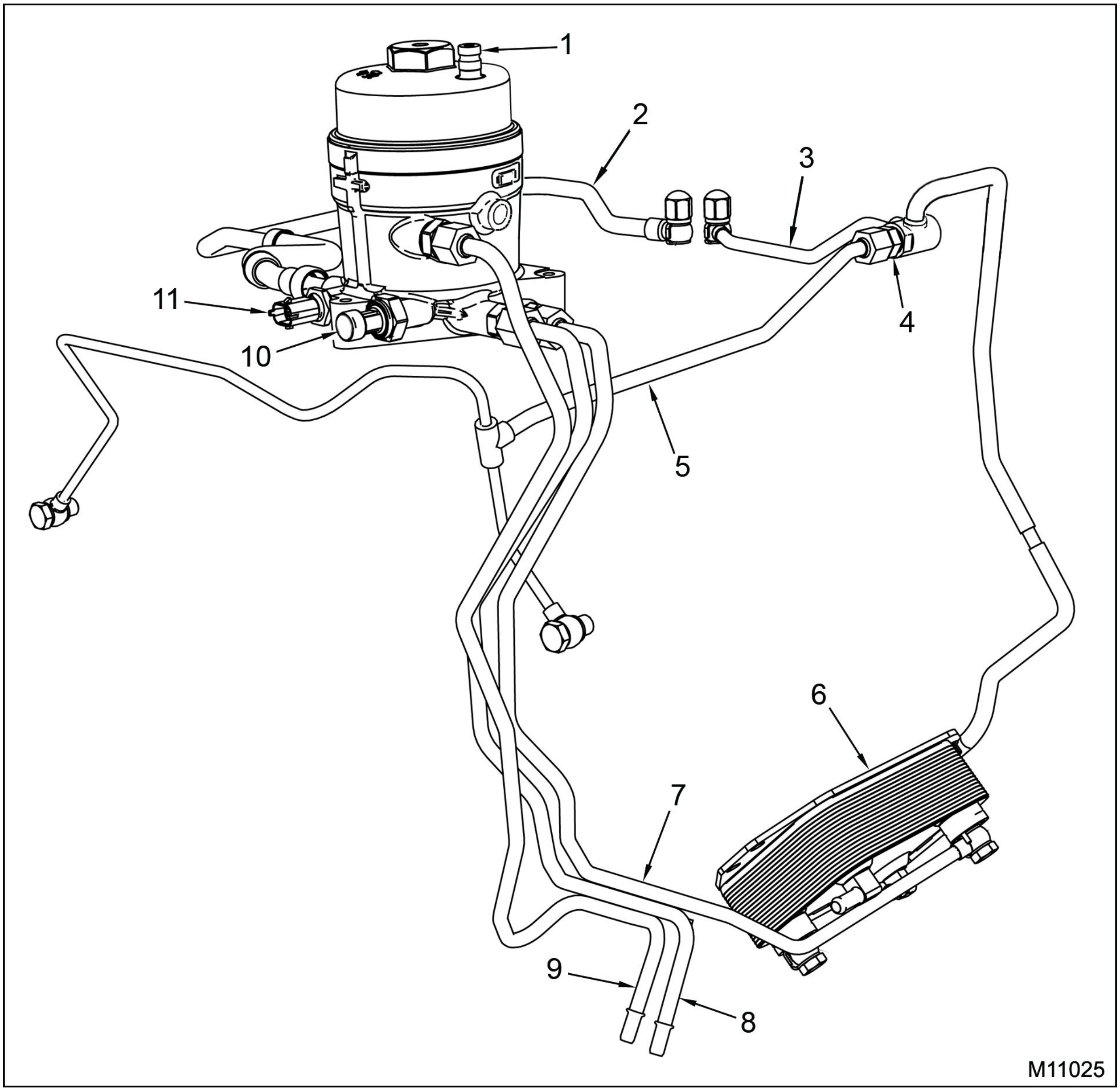

Figure 18 Low-pressure fuel system

1. Diagnostic coupling assembly
2. Filter to pump tube assembly (high-pressure pump-to-secondary fuel filter)
3. High-pressure pump to cooler tube assembly
4. Injector leak off check valve
5. Injector return tube assembly
6. Fuel cooler assembly
7. Fuel cooler to filter tube assembly (cooler-to-secondary fuel filter)
8. Fuel return to tank tube assembly (secondary fuel filter-to-fuel tank)
9. Fuel supply to filter tube (low-pressure fuel pump-to-secondary fuel filter)
10. Engine Fuel Pressure (EFP) sensor (optional)
11. Engine Fuel Temperature (EFT) sensor

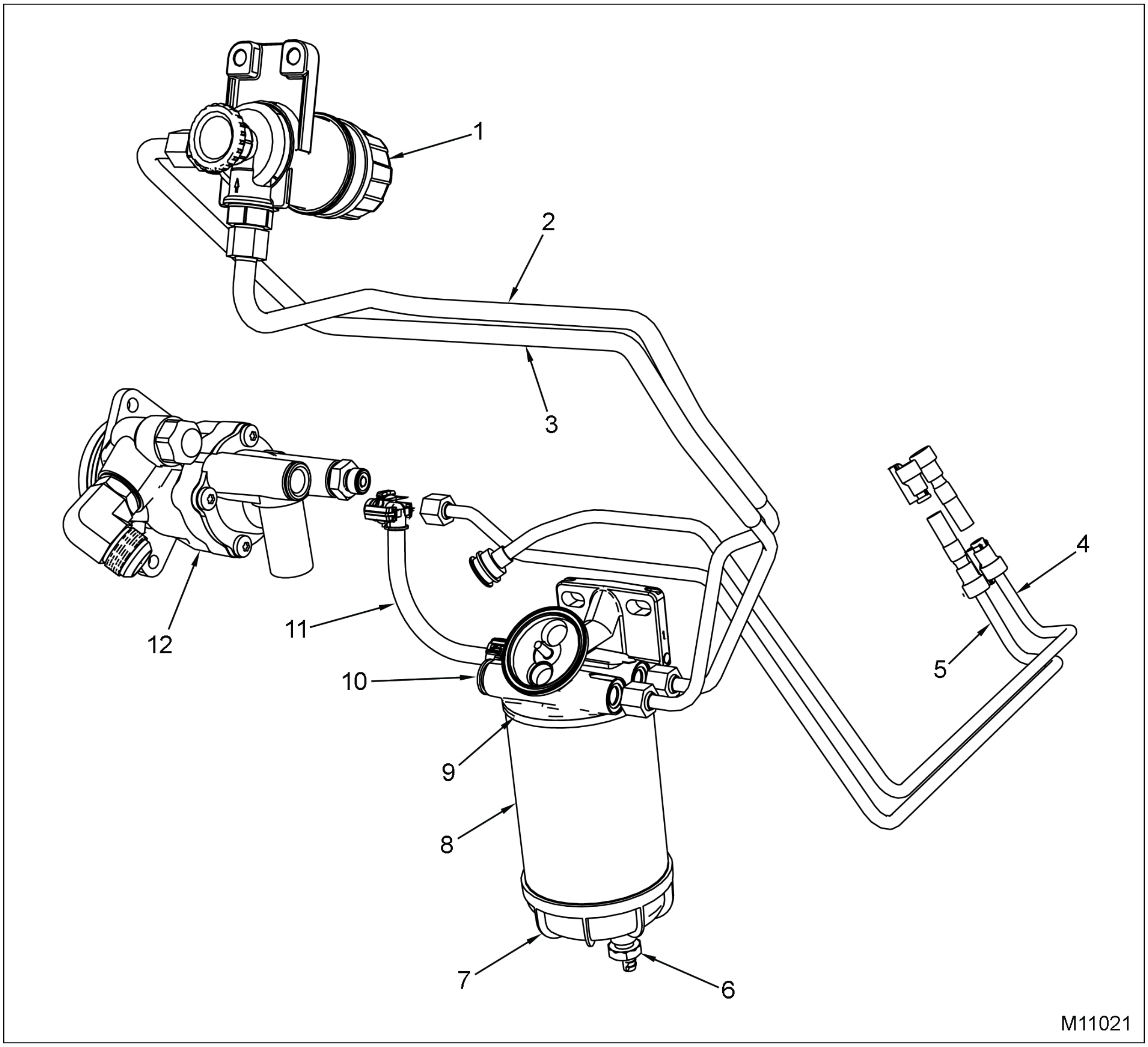

Figure 19 Low-pressure fuel supply system

1. Fuel primer pump assembly
2. Fuel supply tube assembly
3. Fuel return from primer tube assembly
4. Fuel return tube assembly (secondary fuel filter-to-fuel tank)
5. Fuel supply tube assembly (low-pressure fuel pump-to-secondary fuel filter)
6. Fuel drain valve (water and sediment drain for fuel filter)
7. Bowl assembly with fuel heater/probe (optional)
8. Primary filter element assembly
9. Fuel filter primary header
10. Fuel from tank
11. Primary filter to pump tube assembly
12. Gear driven fuel pump assembly (low-pressure fuel pump)

The fuel system includes the following:

- Low-pressure fuel system
    - Low-pressure fuel pump assembly
    - Primary fuel filter assembly
    - Secondary fuel filter assembly
    - Fuel cooler assembly
    - Fuel primer pump assembly
- High-pressure fuel system
    - High-pressure Fuel Pump (HPFP) assembly
    - High-pressure fuel rails assemblies (left and right)
    - Fuel injector assemblies (8)

Low-pressure Fuel System

Low-pressure fuel pump

The low-pressure fuel pump draws fuel from the fuel tank(s) through the primary fuel filter and supplies fuel to the secondary fuel filter. It is mounted on the right side of the flywheel housing and driven through idler gears by the crankshaft.

Primary fuel filter assembly

The primary filter removes water and filters fuel from the fuel tank(s). It is mounted in front of the low-pressure fuel pump.

Fuel primer pump

The manual priming pump draws fuel from the fuel tank(s) through the primary filter after filter replacement or when the fuel system has run out of fuel. This primes the fuel system to minimize the amount of air injected into the system on initial startup.

Secondary fuel filter assembly

The secondary fuel filter assembly is a two stage filter with an internal pressure regulator mounted adjacent to the oil filter.

An internal pressure relief valve maintains a constant pressure throughout the low-pressure system.

A five micron first stage filter filters fuel from the low-pressure fuel pump. The first stage filter has an internal drilled air bleed orifice to automatically remove air from the fuel. The filtered fuel is mixed with the cooled fuel from the fuel cooler and is directed to a four micron secondary filter. Pressure is maintained by an internal pressure regulator.

Fuel is additionally filtered in the second stage filter and is directed to the high-pressure fuel pump. This second stage filter also has an internal drilled air bleed orifice to automatically remove air from the fuel.

Fuel from the pressure regulator and both air bleed orifices return to the fuel tank(s) through a check valve that maintains constant back pressure in the bleed header.

The secondary fuel filter assembly has a temperature sensor mounted in the supply line to the HPFP.

Fuel cooler

The fuel from the fuel injectors and the HPFP flows through the fuel cooler where it is cooled by the secondary radiator. Cooled fuel is then directed to the secondary fuel filter assembly.

High-pressure Fuel System

High-pressure Fuel Pump (HPFP) assembly

The HPFP is a three piston volumetric pump that supplies fuel at high pressure to both the fuel rails. The HPFP is mounted in the rear valley on top of the engine and driven by the camshaft.

Internal Transfer Pump (ITP)

The ITP is part of the HPFP assembly and driven off the same shaft as the HPFP assembly. The ITP supplies fuel at a slightly higher pressure and flow to the Fuel Volume Control Valve (FVCV). Cooling flow for the ITP is provided by routing fuel back to the suction side of the transfer pump. The discharge of the ITP has an orifice and check valve that also provides additional cooling for the ITP by routing flow to the fuel cooler.

Fuel Volume Control Valve (FVCV)

The FVCV regulates the volume of flow sent to the HPFP. The FVCV is located in the HPFP assembly and controlled by the FRP via the ECM. The FVCV puts the necessary quantity of fuel under pressure to the HPFP.

FVCV control depends on engine speed, injector quantity, fuel temperature, and the number of injections per cycle.

Fuel Pressure Control Valve (FPCV)

The FPCV controls the fuel pressure to the fuel rails. The FPCV is located in the HPFP assembly and is controlled by the FRP via the ECM. FPCV control depends on fuel pressure and fuel temperature.

Fuel Rail Pressure (FRP) sensor

The FRP monitors the fuel pressure in the fuel rails and sends a signal to the ECM. It is located in the right fuel rail. The FRP sensor harness is routed through the right Under Valve Cover (UVC) harness along with the fuel injector connections.

High-pressure Piezo Common Rail (HPCR) System

The HPFP pumps fuel through separate tubes to each fuel rail. Each fuel rail has four fuel tubes, one for each injector, that maintain constant pressure from the high-pressure pump to each injector.

The injectors operate in five cycles; two pre-injection cycles, a main-injection cycle, a post-injection cycle, and a late post-injection cycle. The pre-injection cycles and post-injection cycle reduce combustion noise, mechanical load, and exhaust emissions. The main-injection cycle injects and atomizes fuel in the combustion chambers for combustion. The late post-injection cycle adds fuel to the exhaust to regenerate the aftertreatment system.

Each injector has an actuator that opens or closes the injector nozzle. Charging the actuator opens the nozzle. The nozzle is closed by discharging the actuator. The ECM charges and discharges each actuator by energizing the appropriate high side or low side output. The low side output supplies a return circuit for each actuator.

Fault Detection/Management

The ECM can detect if the output is shorted to ground/battery detection, the output is open, or if the injector is shorted.

Return Fuel System

The return fuel system moves unused fuel from the fuel injectors to the fuel cooler. Excess fuel out of the FVCV and the FPCV mix with fuel from the fuel injectors on the way to the fuel cooler.

Engine Lubrication System

Lubrication System Components and Oil Flow

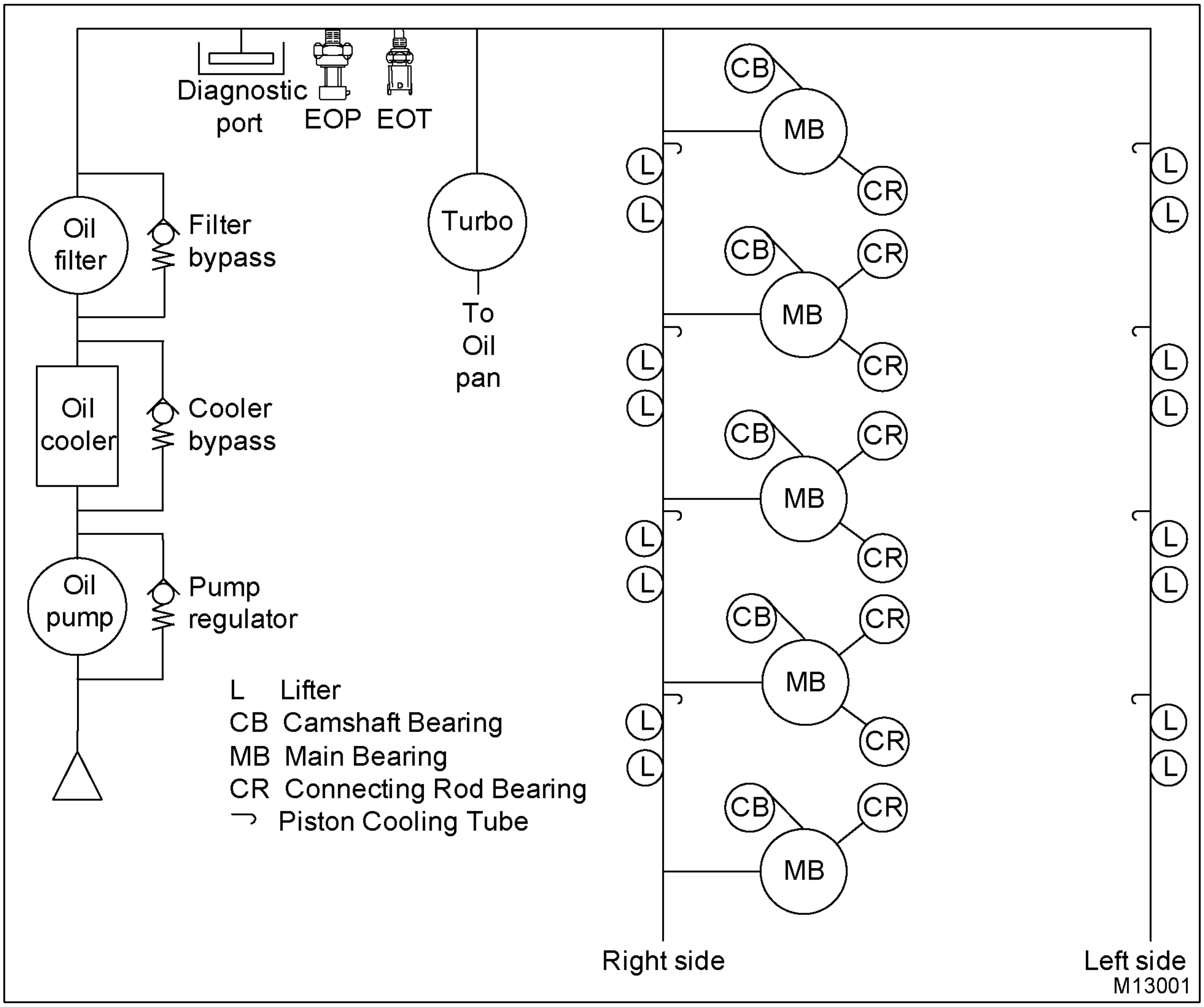

Figure 20 Lubricating system schematic

Oil Flow

The lubrication system includes:

- Oil pan assemblies
- Gerotor oil pump
- Front crankcase cover
- Oil pressure regulator valve
- Crankcase assembly
- Oil cooler cover assembly
- Oil filter base assembly
- Engine Oil Pressure (EOP) sensor
- Engine Oil Temperature (EOT) sensor
- Piston cooling tube
- Lifters
- Push rods

The lubrication system is pressure regulated, full flow cooled, and full flow filtered.

A gerotor oil pump draws oil from the oil pan through an oil pickup tube. Oil then flows through passages in the lower crankcase, front cover, and in the oil pump housing to the gerotor oil pump.

The gerotor oil pump includes the oil pump housing and cover, gerotor assembly (inner and outer gears), and the pressure regulating valve assembly. The crankshaft drives the inner rotor gear of the gerotor pump.

Oil pressure is maintained by the pressure regulating valve assembly. The pressure regulating valve in the discharge oil flow relieves excess oil pressure back to the suction side of the gerotor oil pump.

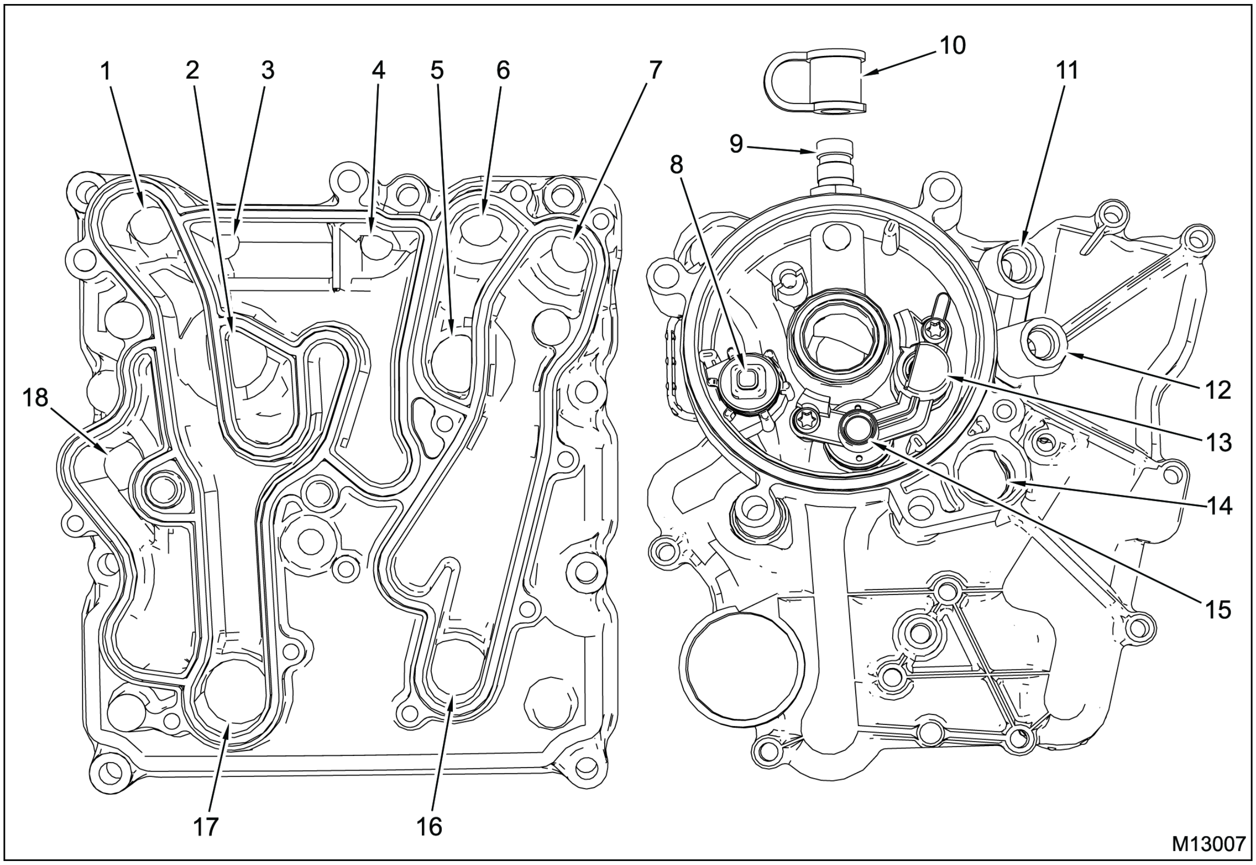

Figure 21 Oil cooler cover and oil filter base location details

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

Pressurized oil from the pump flows through passages in the oil pump housing and upper crankcase to the oil cooler cover. Oil flows through plates in the cooler, is cooled, and then flows back to the oil cooler cover.

If the oil cooler is restricted, a bypass valve in the oil filter base opens, oil bypasses the oil cooler, and flows to the oil filter base.

Oil flows through the oil filter base to the oil filter element. If the oil filter element is restricted, a bypass valve in the oil filter return line opens. Oil bypasses the oil filter element and flows to the oil filter base. Both bypass valves ensure full flow of oil to the engine if the filter or cooler is restricted. The oil filter base directs filtered oil to the oil supply tube to lubricate the turbocharger, EOP sensor, EOT sensor, diagnostic port, and oil cooler cover. Lubricating oil from the turbocharger drains back to the oil pan. When the oil filter is removed, oil flows through a drain valve in the oil filter base back to the oil pan.

Cooling System

Cooling System Components and Flow

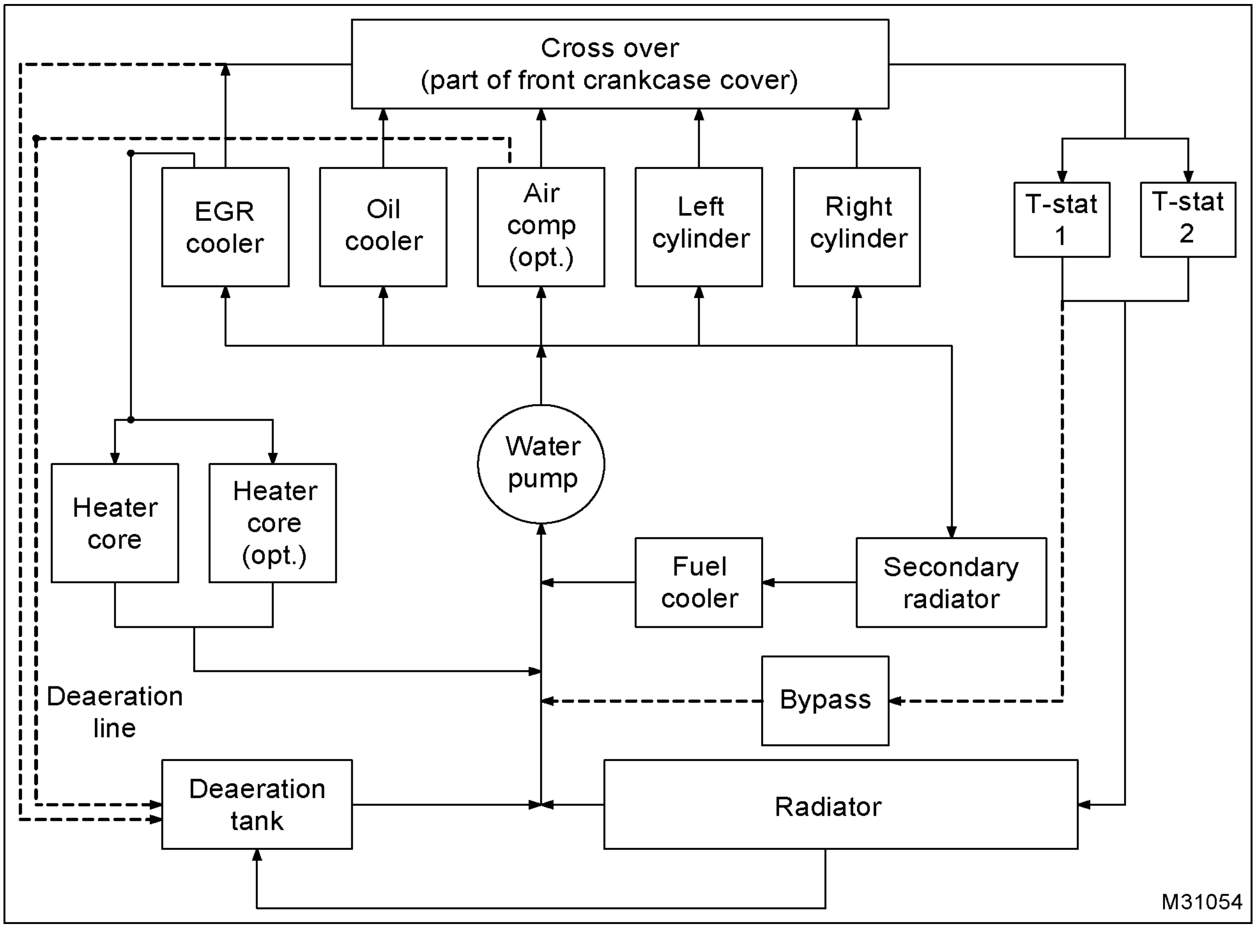

Figure 22 Cooling system schematic

The cooling system keeps the engine within a designated temperature range.

Water Pump

The centrifugal water pump is mounted in the front crankcase cover. The water pump has a built in reservoir to catch small amounts of coolant that may seep past the seal. Water pump rotation is counter-clockwise when viewed from the front of the engine.

If the dual thermostats are shut, coolant is circulated through an internal bypass in one of the thermostats.

The surge tank keeps the system full with a line to the suction of the water pump.

Front Crankcase Cover Flow

Pressurized coolant from the water pump flows through the coolant supply housing in the front cover. Flow is directed through passages in the crankcase and ports in the front cover to support cooling system requirements.

- Two passages (left and right) direct coolant through the crankcase (front to rear) to cool the cylinder walls (combustion chamber) and then directed at the rear of the crankcase up to the cylinder heads.
- A passage directs coolant from the front cover and through the crankcase to the oil cooler to cool lubricating oil.

- A port in the front cover directs coolant through tubing to the EGR cooler to cool the exhaust gasses.
- A port in the front cover directs coolant through tubing to the brake air compressor.
- A port in the front cover directs coolant through a secondary radiator to the fuel cooler, to cool unused fuel from the injectors.

Hot coolant return flow is directed through passages in the crankcase and ports in the front cover to the coolant return cross over housing.

- Two passages (left and right) through the crankcase return coolant from the cylinder heads.
- A passage through the crankcase returns coolant from the oil cooler.
- A port in the coolant return cross over housing returns coolant through tubing from the brake air compressor.
- A port in the coolant return cross over housing returns coolant through tubing from the EGR cooler.
- A port in the coolant return cross over housing returns coolant through tubing from the fuel cooler.

The coolant return housing has one temperature sensor point.

The EGR cooler supplies coolant to the heater core for cab heating.

The coolant return cross over housing directs coolant to the dual thermostat housing.

Thermostats

Two thermostats are located in the thermostat housing. If the coolant temperature is above the thermostat opening temperature, coolant flows to the radiator to be cooled. If the coolant temperature is below the opening temperature for both thermostats, both thermostats are closed. Coolant returns back to the water pump through a bypass on one of the thermostats. As the coolant temperature increases, the first thermostat starts to open and flow starts through the radiator. As coolant temperature continues to increase, the first thermostat will fully open. The second thermostat will then start to open, increasing flow to the radiator until both thermostats are fully open.

Deaeration Tank

The radiator and the coolant system are kept full and pressurized by the deaeration tank. As coolant in the radiator heats up and expands, the level in the deaeration tank goes up and pressure increases. The deaeration tank also removes air from the cooling system.

Radiator Shutters

Closing the radiator shutters will keep the engine warm during cold weather operation. This provides faster warm up of the passenger cab and faster windshield defrosting.

Fuel Coolant Valve (FCV)

The FCV is used to redirect coolant through the fuel cooler. The ECM uses the Engine Fuel Temperature (EFT) sensor to monitor fuel temperature and controls the FCV to maintain the desired fuel temperature. The valve opens automatically allowing coolant to pass through the cooler. The ECM controls this valve in cold weather to warm the fuel and also prevents the temperature from getting too hot.

Electronic Control System

Electronic Control System Components

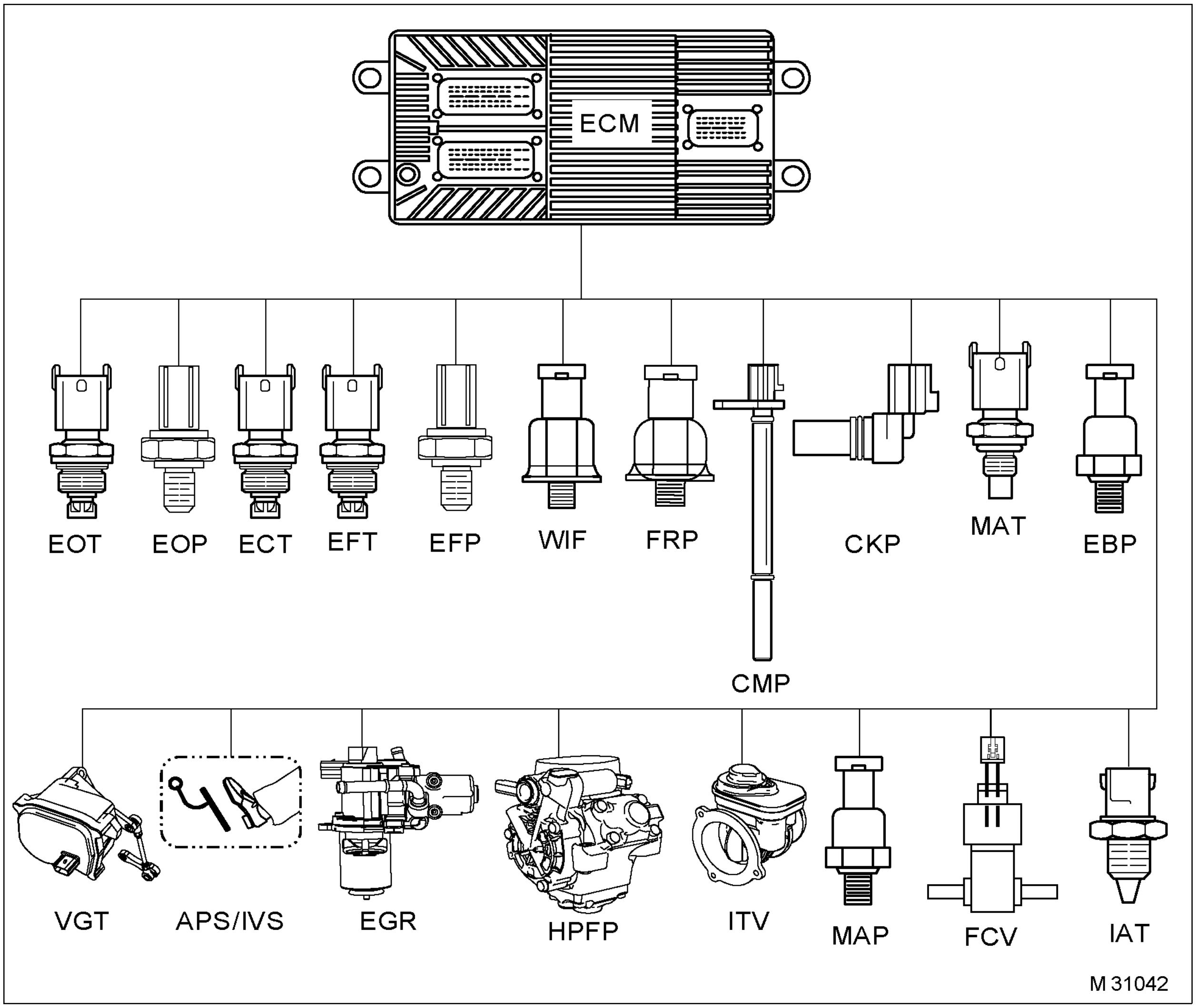

Figure 23 Electronic Control System

Operation and Function

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

- Provides Reference Voltage (VREF)
- Conditions input signals
- Processes and stores control strategies
- Controls 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 operating 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 Flash Memory and Random Access Memory (RAM).

Flash Memory

Flash memory is a non-volatile form of memory that is electrically erasable and re-programmable. ROM (Read only memory) was used when the program (control strategy and calibration) was built into the physical silicon or was burnt in with a one time programming. In ROM, the program is fixed and to change it you physically have to change the hardware. With Flash memory, you can keep reprogramming it. Flash memory is used to update vehicles in the field (over public CAN) with new calibrations, software bug fixes, or new features.

Flash memory 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 three ways, determined by the kind of actuator.

- A duty cycle (percent time on/off)
- A controlled pulse width
- Switched on or off

Actuators

The ECM controls engine operation with the following:

- EGR valve and control
- VGT control
- Intake throttle control and throttle position
- Glow plug relay

H-bridge Circuit

The EGR valve and ITV actuator motors are operated by an H-bridge (by-polar) circuit in each valve assembly.

An H-bridge circuit operates like putting a power source on one side of a motor and hooking the other side of the motor to a ground. This turns the motor. By shifting the leads on the motor it will turn in the opposite direction.

To control the motor in both forward and reverse with a processor, you will need an H-Bridge. Relays configured in this fashion make an H-Bridge. The "high side drivers" are the relays that control the positive voltage to the motor. This is called sourcing current. The "low side drivers" are the relays that control the negative voltage to sink current to the motor. "Sinking current" is the term for connecting the circuit to the negative side of the power supply, which is usually ground.

Exhaust Gas Recirculation (EGR) Valve and Control

The EGR valve controls the flow of exhaust gases to the intake manifold. The EGR valve is integrated with an EGRP sensor.

The ECM controls the EGR valve with a Pulse Width Modulation (PWM) signal through H-bridge circuitry.

The ECM controls motor speed using PWM. The EGR is closed by driving the Exhaust Gas Recirculating High (EGRH) circuit high. When driving the EGRH high, this causes Exhaust Gas Recirculating Low (EGRL) circuit to go low.

Variable voltage is needed to move the valve and minimal voltage is needed to maintain its position.

Intake Throttle Valve (ITV) Actuator and Position Sensor

The ITV is used to control air/fuel mixture during a regeneration process of the aftertreatment system. The ITV is also used to insure a smooth engine shut down by restricting air flow to the engine at shut down.

The ECM controls the ITV with a Pulse Width Modulation (PWM) signal through H-bridge circuitry.

The ECM controls motor speed using PWM. The ITV is close by driving the Intake Throttle Valve High (ITVH) circuit high. When driving the ITVH high, this causes Intake Throttle Valve Low (ITVL) circuit to go low.

Variable voltage is needed to move the valve and minimal voltage is needed to maintain its position.

Glow Plug Relay

The ECM activates the glow plug relay. The relay delivers VBAT to the glow plugs for up to 120 seconds, depending on engine coolant temperature and altitude. The ground circuit is supplied directly from the battery ground at all times. Relay is controlled by switching on a voltage source from the ECM.

Engine and Vehicle Sensors

Thermistor Sensors

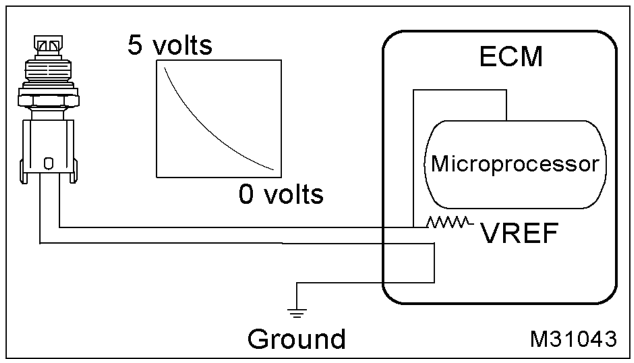

Figure 24 Thermistor sensors

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

The top half of the voltage divider limits current 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 Sensors

- Engine Coolant Temperature (ECT) Sensor
- Engine Oil Temperature (EOT) Sensor
- Engine Fuel Temperature (EFT) Sensor

- Manifold Air Temperature (MAT) Sensor
- Intake Air Temperature (IAT) Sensor

NOTE: For specific information and location see applicable sensor in the “Electronic Control Systems Diagnostics” section of EGES-350-1 MaxxForce® 7 *Engine Diagnostics Manual*.

Variable Capacitance Sensors

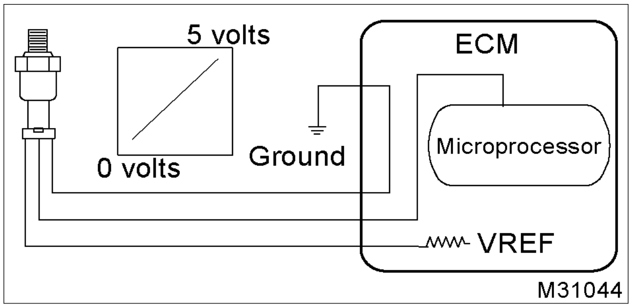

Figure 25 Variable capacitance sensors

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 three wires:

- VREF
- Signal
- Signal return (ground) (SIG GND)

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

- Exhaust Back Pressure (EBP) Sensor
- Manifold Absolute Pressure (MAP) Sensor
- Engine Oil Pressure (EOP) Sensor
- Engine Fuel Pressure (EFP) Sensor

NOTE: For specific information and location see applicable sensor in the “Electronic Control Systems Diagnostics” section of EGES-350-1 MaxxForce® 7 *Engine Diagnostics Manual*.

Micro Strain Gauge (MSG) Sensor

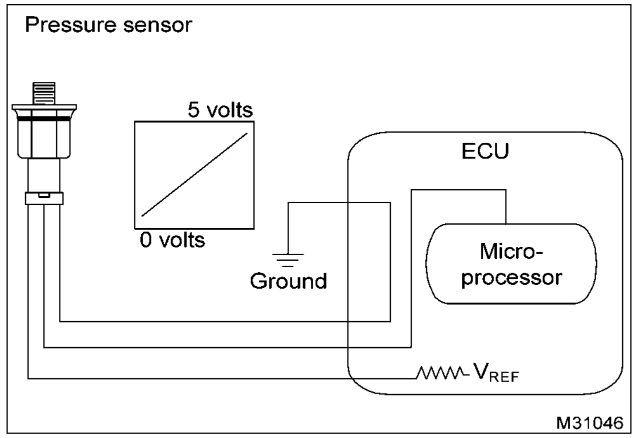

Figure 26 MSG sensor

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 three wires:

- VREF
- Signal
- Signal return (ground) (SIG GND)

The sensor is powered by VREF received from the ECM and is grounded through the ECM to a common sensor ground.

MSG Sensors

- Fuel Rail Pressure (FRP) sensor

NOTE: For specific information and location see applicable sensor in the “Electronic Control Systems Diagnostics” section of EGES-350-1 MaxxForce® 7*Engine Diagnostics Manual*.

Magnetic Pickup Sensors

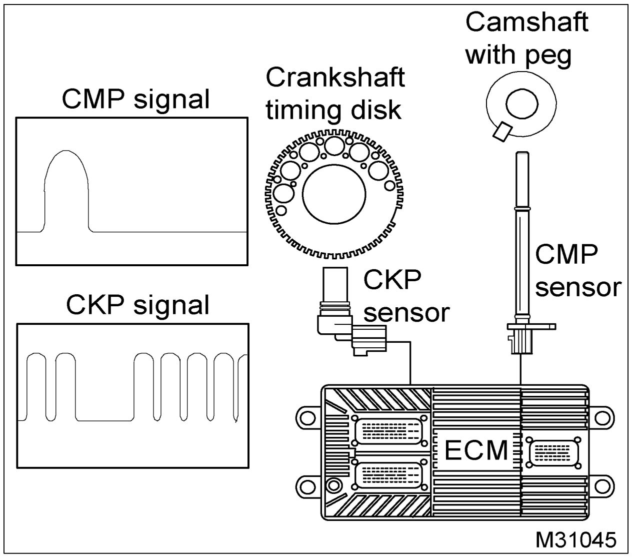

Figure 27 Magnetic pickup sensors

A magnetic pickup sensor generates an alternating frequency that indicates speed. Magnetic pickups have a two wire connection for signal and ground. This sensor has a permanent magnetic core surrounded by a wire coil. The signal frequency is generated by the rotation of gear teeth that disturb the magnetic field.

Magnetic Pickup Sensors

- Crankshaft Position (CKP) Sensor
- Camshaft Position (CMP) Sensor

NOTE: For specific information and location see applicable sensor in the “Electronic Control Systems Diagnostics” section of EGES-350-1 MaxxForce® 7 *Engine Diagnostics Manual*.

Potentiometer

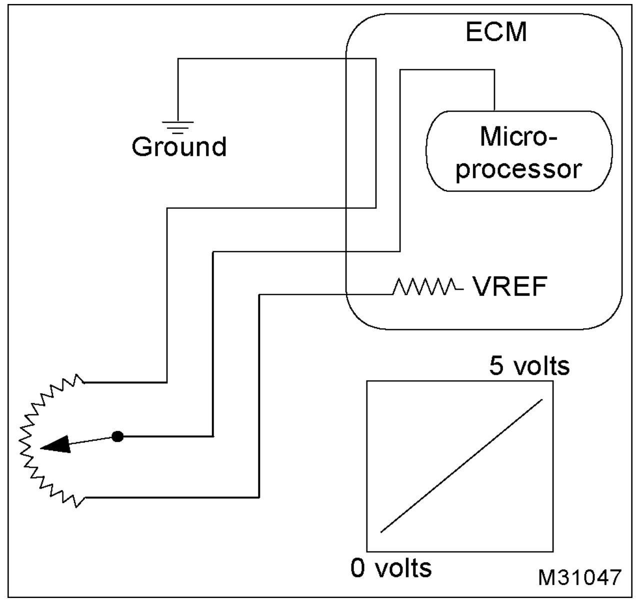

Figure 28 Potentiometer

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. Voltage is proportional to the amount of mechanical movement.

Potentiometer

- Accelerator Position Sensor (APS)

NOTE: For specific information and location see applicable sensor in the “Electronic Control Systems Diagnostics” section of EGES-350-1 MaxxForce® 7 *Engine Diagnostics Manual*.

Switches

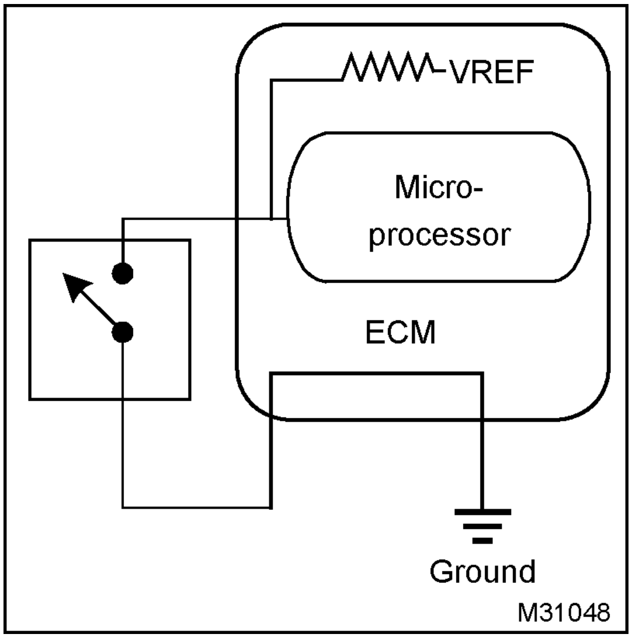

Figure 29 Switch

Switches indicate position or condition. They operate open or closed, regulating the flow of current. A switch 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

- Engine Coolant Level (ECL) Switch

NOTE: For specific information and location see applicable sensor in the "Electronic Control Systems Diagnostics" section of EGES-350-1 MaxxForce® 7 *Engine Diagnostics Manual*.

Glow Plug Control System

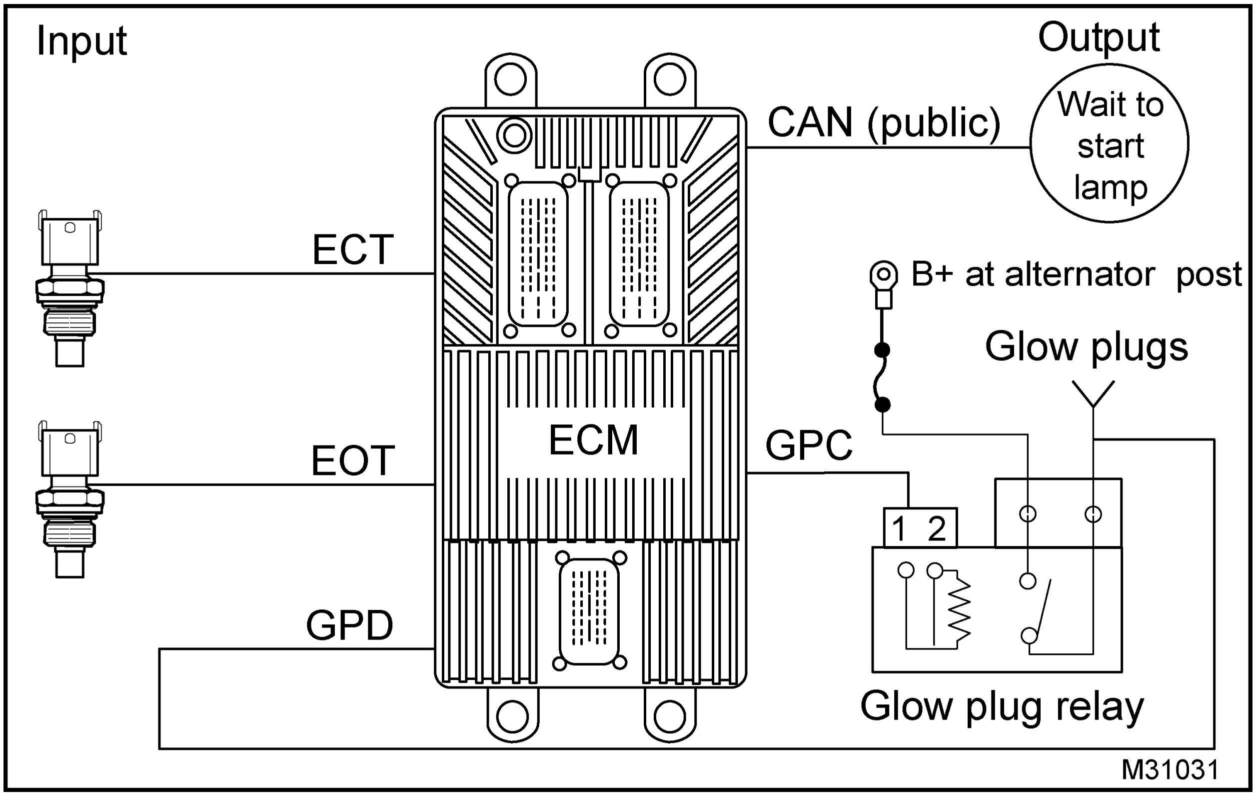

Figure 30 Glow plug control system

The glow plug control system warms the engine cylinders to aid cold engine starting and reduce exhaust emissions during warm-up.

The ECM energizes the glow plug relay while monitoring programmed conditions for engine coolant temperature and atmospheric pressure.

The ECM controls the wait to start lamp and glow plugs based on ECT and EOT. The wait to start lamp (0 to 10 seconds) ON-time is independent from the glow plugs (0 to 120 seconds) ON-time.

The ECM controls the wait to start lamp through public CAN communication to the electronic gauge cluster.

The power is supplied to the switch side of the relay from the starter motor through a fusible link. When the relay is energized, power is supplied to the glow plugs, which are grounded through the cylinder heads.

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Mounting Engine

GOVERNMENT REGULATION: Engine fluids (oil, fuel, and coolant) may be a hazard to human health and the environment. Handle all fluids and other contaminated materials (e.g. filters, rags) in accordance with applicable regulations. Recycle or dispose of engine fluids, filters, and other contaminated materials according to applicable regulations.

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, 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, remove ground cable from negative terminal of main battery before disconnecting or connecting electrical components. Always connect ground cable last.

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

NOTE: Before mounting engine on engine stand, complete steps 1 through 6.

1. Remove primary fuel filter assembly (page 139).

Figure 31 Left side coolant drain plug

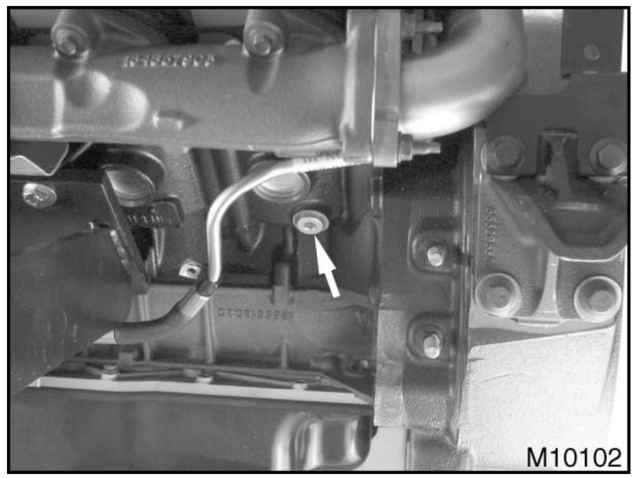

Figure 32 Right side coolant drain plug

2. Remove two coolant drain plugs and drain coolant from crankcase into a suitable container. Coolant drain plugs are in rear of crankcase, below exhaust manifolds.

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

3. Remove oil pan drain plug and drain oil into a suitable container.

NOTE: Lubricate oil pan drain plug O-ring with clean engine oil.

4. After fluids are drained from engine, reinstall plugs.

5. Tighten oil pan drain plug to special torque (page 45).

WARNING: To prevent personal injury or death, make sure the engine is supported before removing mounting hardware.

WARNING: To prevent personal injury or death, use a chain hoist rated for the weight of the engine, follow manufacturer's installation and safety instructions, and attach safety latch lifting hooks to lifting eyes on the engine.

6. Attach hoist hook lifting bracket to engine lifting eyes. Use safety catches on hoist hooks when lifting engine.

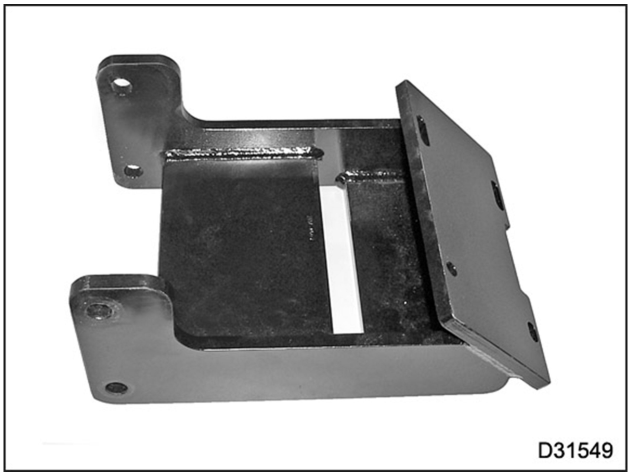

Figure 33 Engine Stand Mounting Bracket

WARNING: To prevent personal injury or death, use only grade 8 or class 10.9 bolts to secure Engine Stand Mounting Bracket to engine and engine lift stand.

NOTE: See manufacturer's safety instructions (included with engine lift stand and Engine Stand Mounting Bracket).

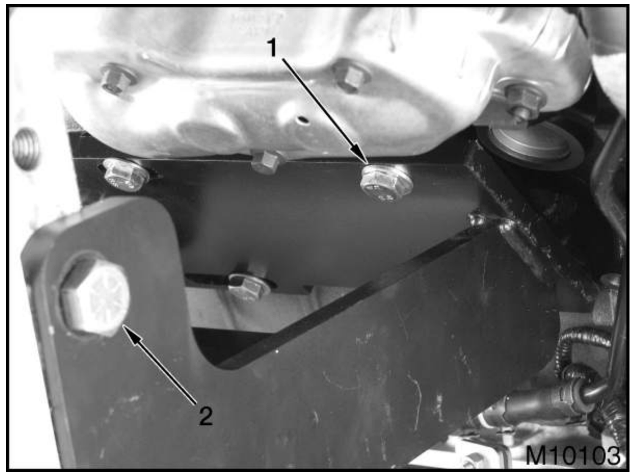

Figure 34 Mounting bolts for Engine Stand Mounting Bracket

1. M10 x 30 class 10.9 mounting bolts (4) to engine block
2. Grade 8 or class 10.9 mounting bolts (4) to engine lift stand

7. Position Engine Stand Mounting Bracket (page 45) on right side of engine. Secure bracket plate with four M10 x 30 class 10.9 mounting bolts and washers. Tighten bolts to standard torque (page 383).
8. Mount engine on engine lift stand using four grade 8 or class 10.9 mounting bolts.

Special Torque

Table 2 Mounting Engine on Stand

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

Special Service Tools

Table 3 Mounting Engine on Stand

Description	Tool Number
Engine Stand Mounting Bracket	ZTSE4507

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Engine Electronic Components

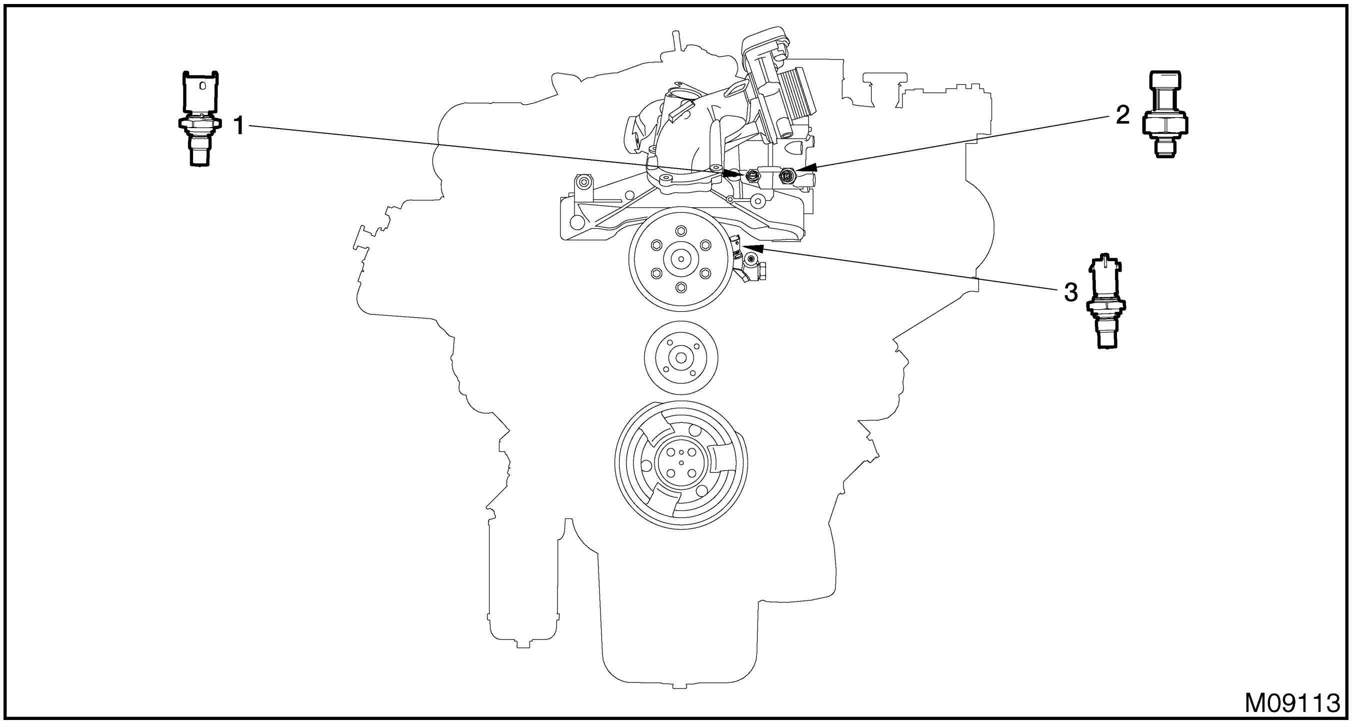

Figure 35 Electronic components – Front

1. Engine Fuel Temperature (EFT) sensor
2. Engine Fuel Pressure (EFP) sensor
3. Engine Coolant Temperature (ECT) sensor

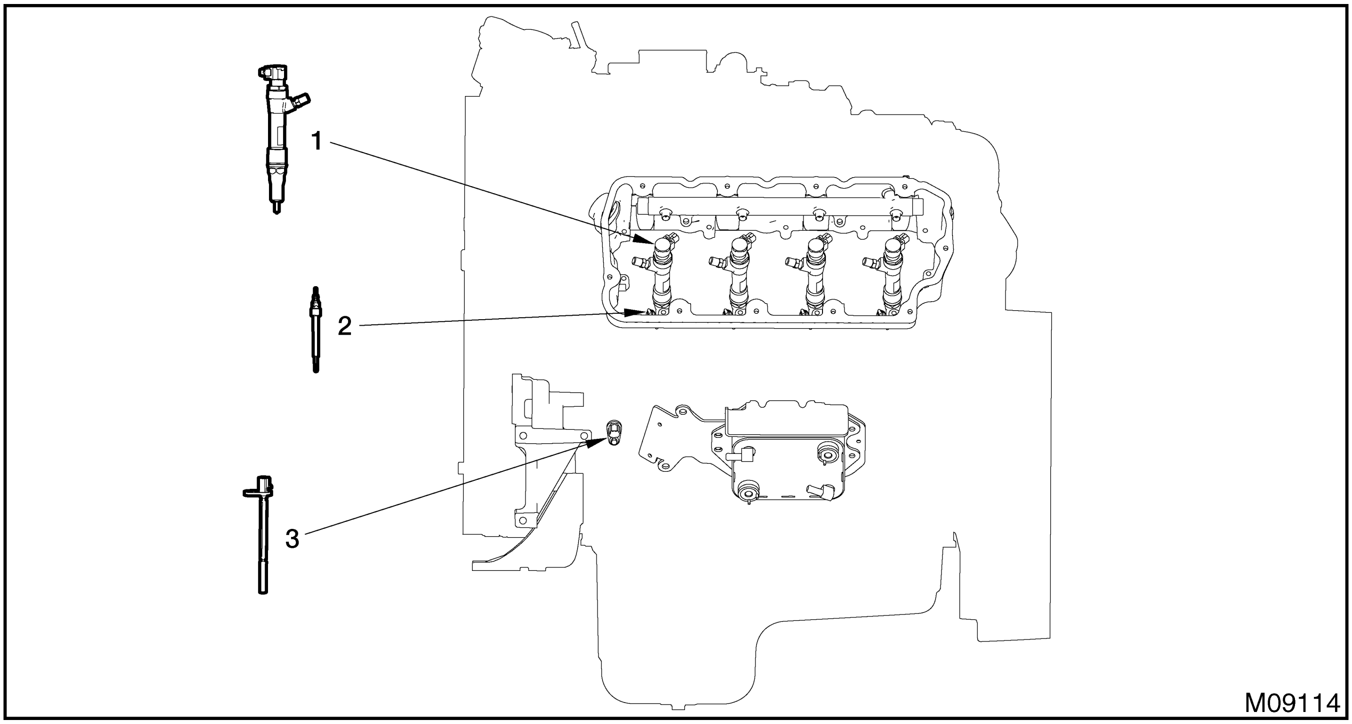

Figure 36 Electronic components – Left

1. Fuel injector assembly
2. Glow plug
3. Camshaft Position (CMP) sensor

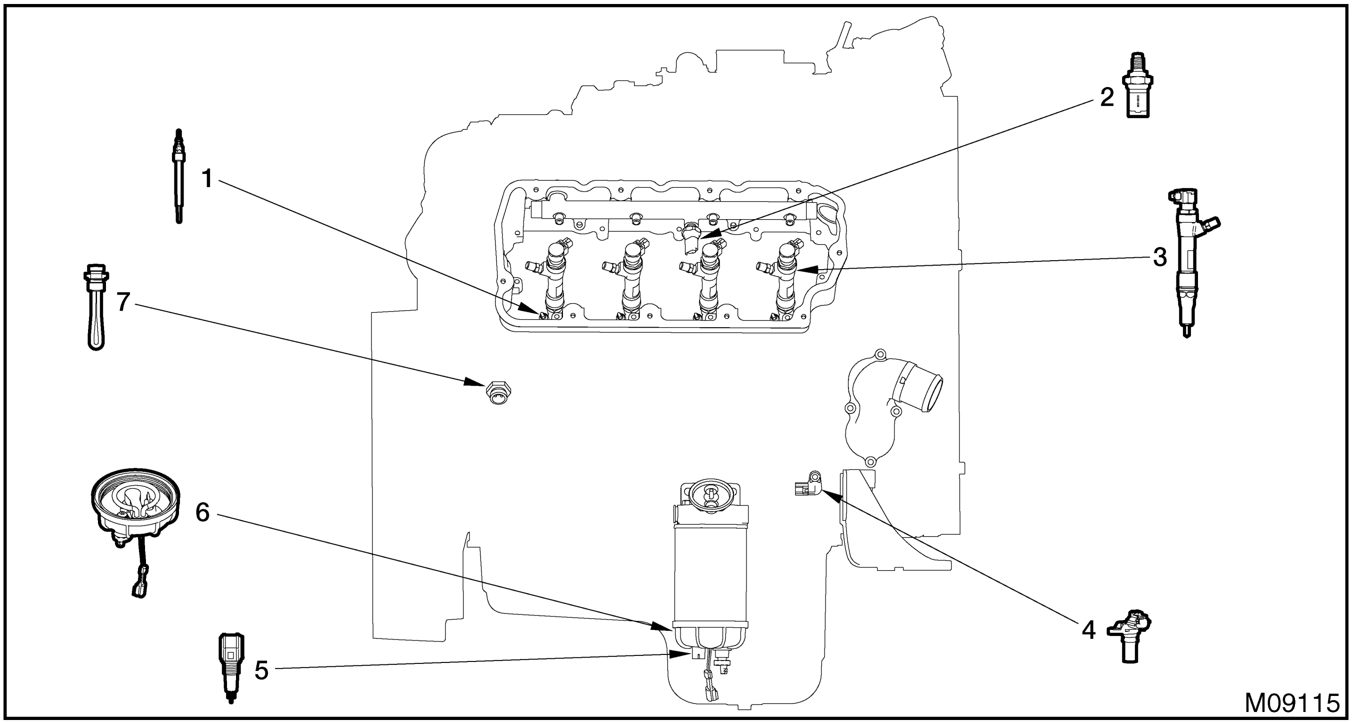

Figure 37 Electronic components – Right

1. Glow plug
2. Fuel Rail Pressure (FRP) sensor
3. Fuel injector assembly
4. Crankshaft Position (CKP) sensor
5. Water In Fuel (WIF) sensor
6. Bowl assembly with fuel heater/probe
7. Coolant heater

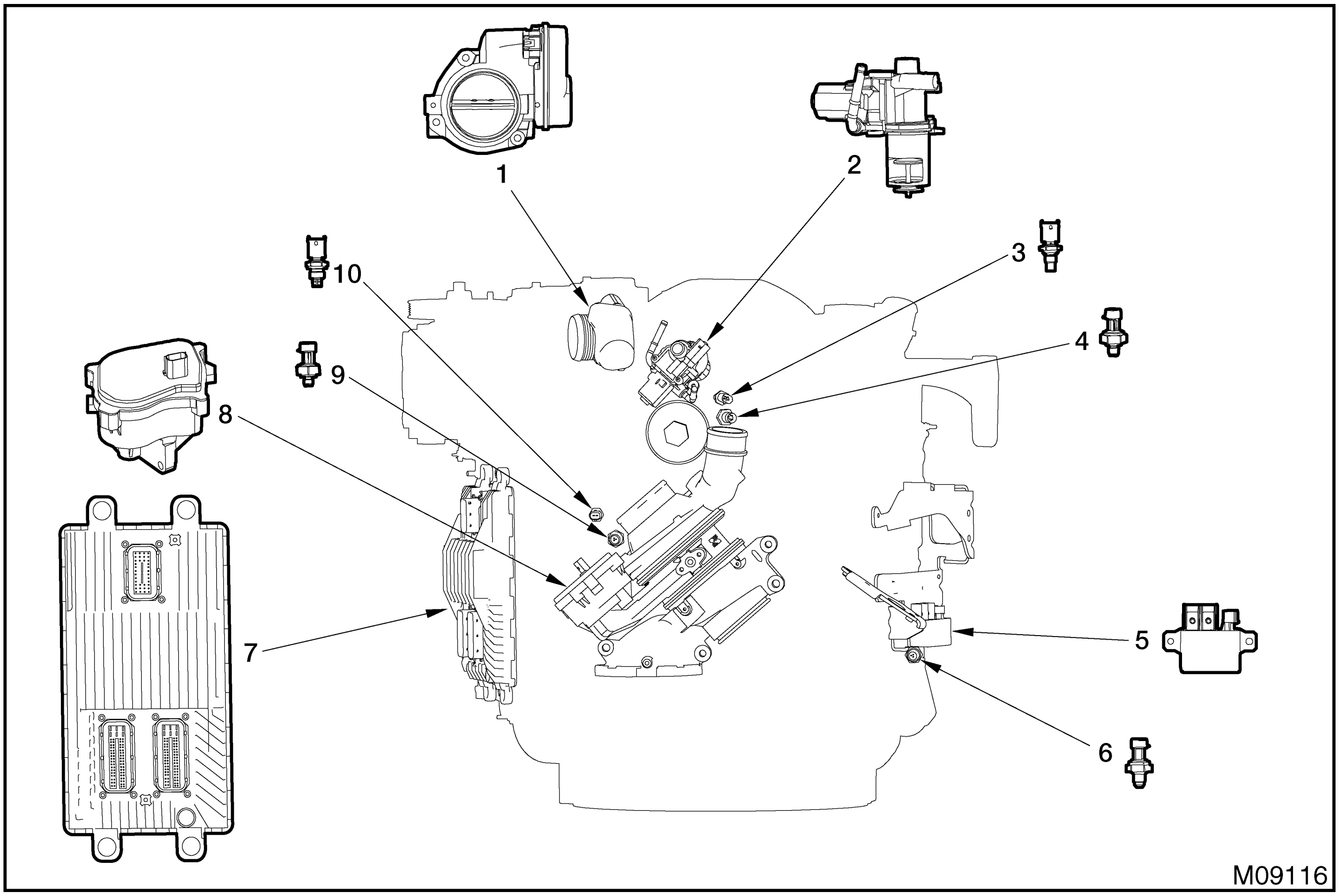

Figure 38 Electronic components – Top

1. Intake throttle housing assembly
2. Exhaust Gas Recirculating (EGR) valve
3. Engine Oil Temperature (EOT) sensor
4. Engine Oil Pressure (EOP) sensor
5. Glow plug relay
6. Exhaust Back Pressure (EBP) sensor
7. Electronic Control Module (ECM)
8. Variable Geometry Turbocharger (VGT) actuator
9. Manifold Absolute Pressure (MAP) sensor
10. Manifold Air Temperature (MAT) sensor

Description of Engine Sensors, Valves, and Actuators

NOTE: See the following publications for information on diagnostics and troubleshooting:

- EGES-350-1 MaxxForce® 7 *Engine Diagnostic Manual*
- EGED-355-1 MaxxForce® 7 Hard Start/No Start and Performance Diagnostic Form
- EGED-365 MaxxForce® 7 Electronic Control System Diagnostic Form

Crankshaft Position (CKP) Sensor

Figure 39 CKP sensor

The CKP sensor is a magnetic pickup sensor that provides the Electronic Control Module (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 Camshaft Position (CMP) signal, the ECM calculates engine rpm and timing requirements. The CKP sensor is installed in the front right side of the lower crankcase.

NOTE: When ordering this sensor, make sure the sensor is the same one pictured. This sensor is used in different Navistar applications to sense camshaft position.

Camshaft Position (CMP) Sensor

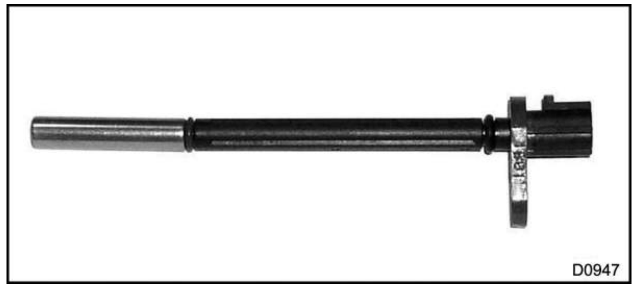

Figure 40 CMP sensor

The CMP sensor is a magnetic pickup sensor that 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 left side of the lower crankcase.

NOTE: When ordering this sensor, make sure the sensor is the same one pictured. This sensor is used in different Navistar applications to sense crankshaft position.

Exhaust Back Pressure (EBP) Sensor

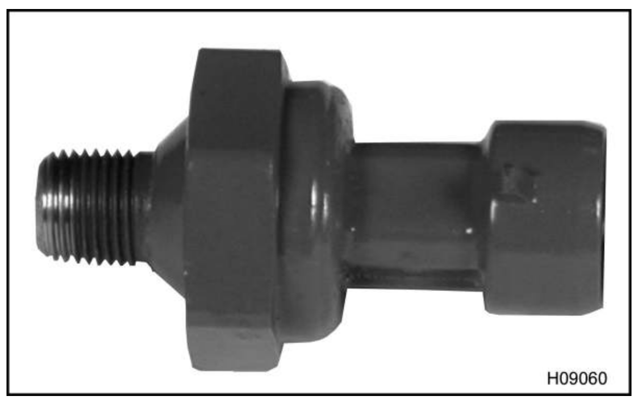

Figure 41 EBP sensor

The EBP sensor is a variable capacitance sensor. The ECM monitors exhaust pressure so that the ECM can control the Variable Geometry Turbocharger (VGT) actuator, and Exhaust Gas Recirculation (EGR) systems. The sensor provides feedback to the ECM for closed loop control of the VGT. The EBP sensor is installed in the EBP tube assembly, supplied by the right exhaust tube.

Engine Coolant Temperature (ECT) Sensor

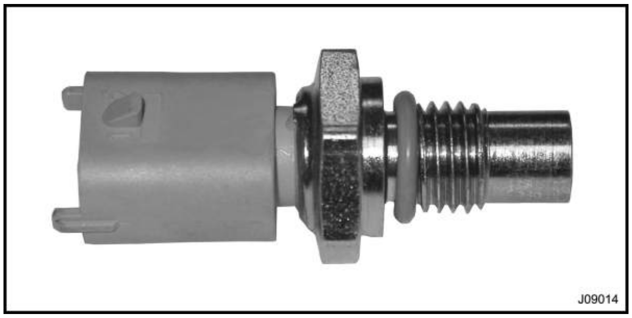

Figure 42 ECT sensor

The ECT sensor is a thermistor 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 glow plug operation. The ECT sensor is installed in the left side of the front cover assembly.

Engine Oil Temperature (EOT) Sensor

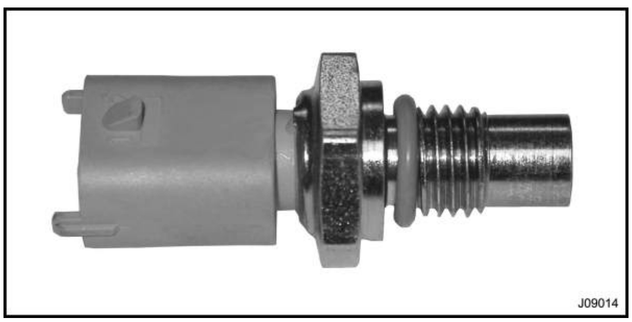

Figure 43 EOT sensor

The EOT sensor is a thermistor sensor. The ECM monitors the EOT signal and uses this information for the instrument panel oil temperature gauge. The EOT sensor is installed in the oil filter base assembly located on top of the engine.

Engine Oil Pressure (EOP) Sensor

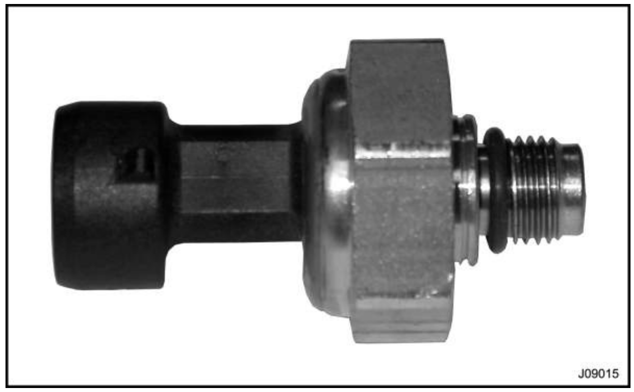

Figure 44 EOP sensor

The EOP sensor is a variable capacitance sensor. The ECM monitors the EOP signal for reference only. The ECM uses the EOP signal to control the instrument panel oil pressure gauge. For Engine Warning Protection System (EWPS) warning, the EOP sensor lights the Warn Engine Lamp (WEL) for low oil pressure. The EOP sensor closes a circuit to ground after engine oil pressure reaches 34 to 48 kPa (5 to 7 psi). When the pressure is above 48 kPa (7 psi) the gauge reads normal. If the oil pressure drops below 41 kPa (6 psi) the gauge reads 0 kPa (0 psi). The EOP sensor is in the oil filter base assembly located on top of the engine.

Engine Fuel Pressure (EFP) Sensor (optional)

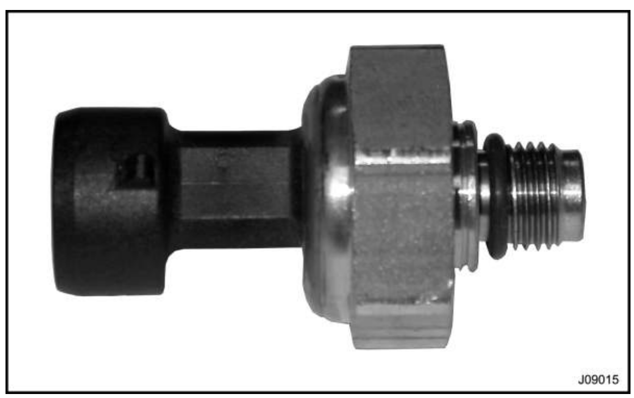

Figure 45 EFP sensor

The EFP sensor is a variable capacitance sensor that 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 base of the secondary fuel filter on the top of the engine.

Engine Fuel Temperature (EFT) Sensor

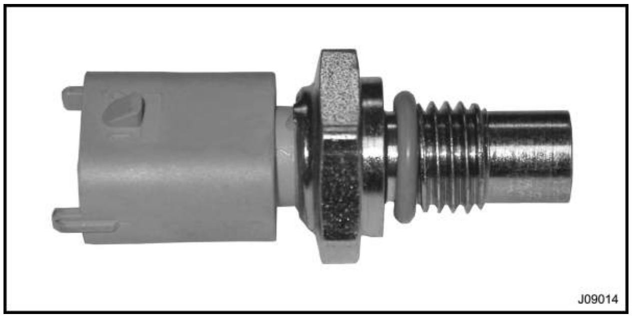

Figure 46 EFT sensor

The EFT sensor is a thermistor sensor. The ECM monitors the EFT sensor signal for the high-pressure fuel pump Fuel Volume Control Valve (FVCV) control, Fuel Pressure Control Valve (FPCV) control and injector timing and control. The EFT sensor is installed in the outlet of the secondary fuel filter on the top of the engine.

Water in Fuel (WIF) Sensor

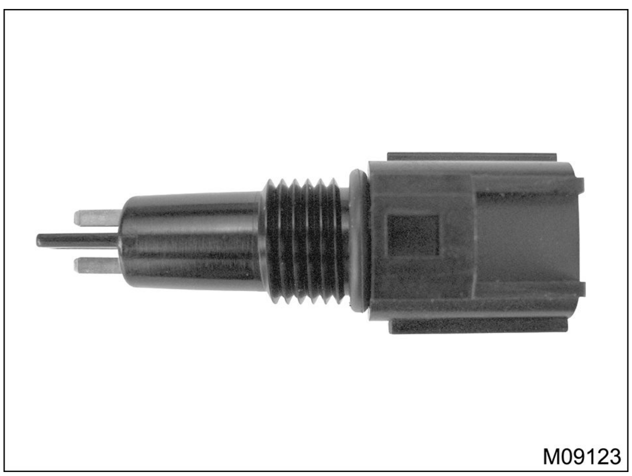

Figure 47 WIF sensor

The WIF sensor is a switch sensor that the ECM uses to detect water in the primary fuel filter. 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 bowl assembly on the lower right side of the engine.

Fuel Heater

Figure 48 Bowl assembly with fuel heater/probe

The fuel heater heats incoming fuel to prevent fuel waxing during cold operating temperatures. The fuel heater is thermostatically controlled and turns on and off at a predetermined temperature. The fuel heater is part of the bowl assembly on the lower right side of the engine, and must be replaced as an assembly.

Manifold Air Temperature (MAT) Sensor

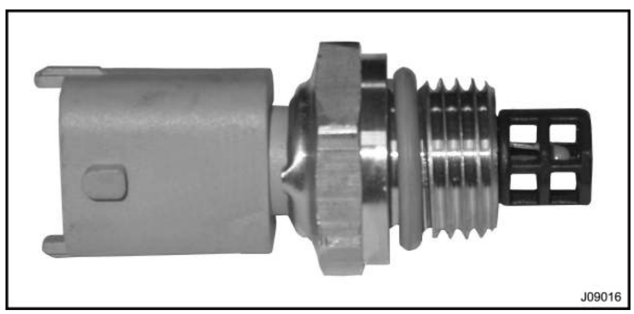

Figure 49 MAT sensor

The MAT sensor is a thermistor sensor. The ECM monitors the MAT signal to control injector timing and fuel rate during cold starts. The ECM also uses the MAT signal to control Exhaust Gas Recirculation (EGR) valve position and intake throttle control. The

MAT sensor is mounted in the top left side of the intake manifold.

Manifold Absolute Pressure (MAP) Sensor

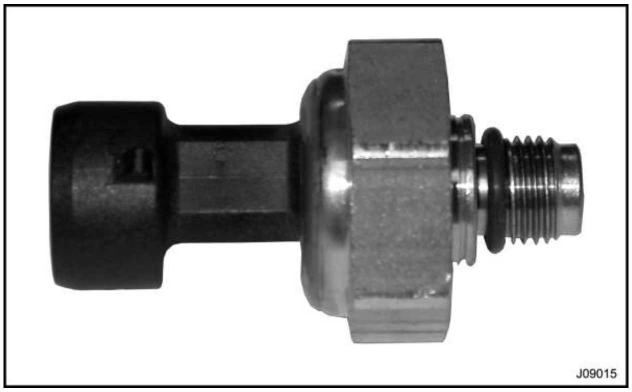

Figure 50 MAP sensor

The MAP sensor is a variable capacitance sensor. The ECM monitors the MAP signal to determine intake manifold pressure (boost). This information is used to control the Exhaust Gas Recirculation (EGR) valve and determine fueling calculations. The MAP sensor is installed in the top left side of the intake manifold.

Intake Throttle Valve (ITV)

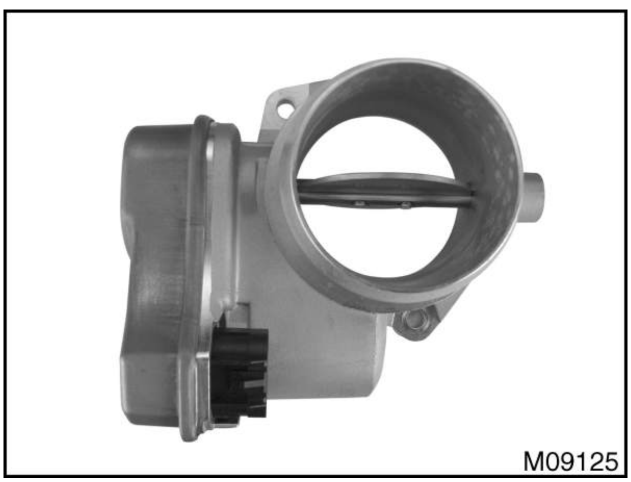

Figure 51 Intake throttle housing assembly

The ITV, a variable position actuator, restricts intake air flow to help heat the exhaust after treatment during regeneration. The ITV changes valve position in response to ECM signals. The ITV contains an internal position sensor that monitors valve position and transmits a position signal to the ECM. The ITV is mounted on the Exhaust Gas Recirculation (EGR) valve elbow housing on the top front of the engine.

Fuel Rail Pressure (FRP) Sensor

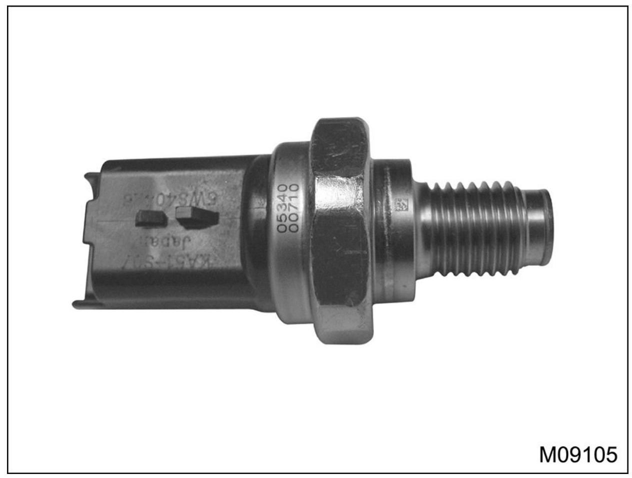

Figure 52 FRP Sensor

The FRP sensor is a variable capacitance sensor. The ECM monitors the FRP signal to determine the Fuel Volume Control Valve (FVCV) and Fuel Pressure Control Valve (FPCV) operation. The ECM monitors the FRP signal to determine the fuel injection pressure for engine operation. The FRP sensor provides feedback to the ECM for closed loop FRP control. The FRP sensor is installed in the fuel rail under the right valve cover.

Exhaust Gas Recirculation (EGR) Valve

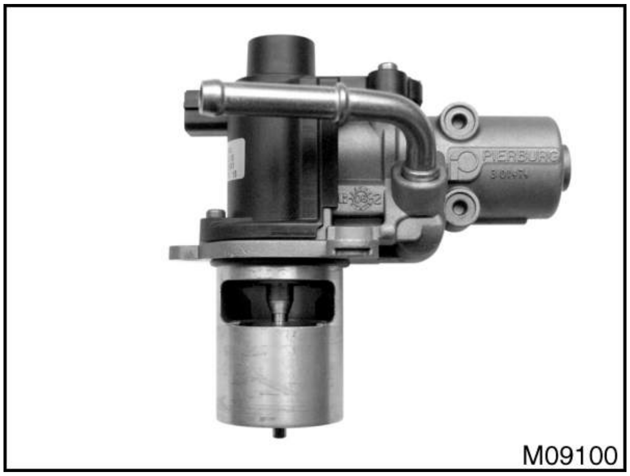

Figure 53 EGR Valve

The EGR valve consists of a valve and an actuator motor. The actuator motor has a Hall effect position sensor to monitor valve movement.

The EGR valve receives the desired EGR position from the Electronic Control Module (ECM) to activate the valve for exhaust gas recirculation. The EGR valve provides feedback to the ECM on the valve position. The ECM interprets the feedback signal and sends the command using a pulse width modulated signal to the actuator motor.

The closed loop control system uses the EGR position signal. The EGR valve is located at the front of engine in the EGR valve elbow housing.

Variable Geometry Turbocharger (VGT) Actuator

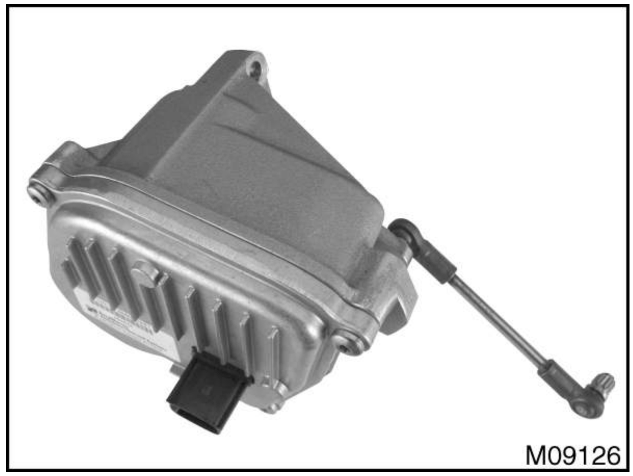

Figure 54 VGT actuator

The VGT actuator is a variable position actuator that controls turbocharger vane position.

The VGT actuator is controlled by 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 an adjusting ring in the turbine housing. Turbine exhaust gas flow and VGT boost are modified by vane position. The VGT actuator is part of the turbocharger assembly, located on the top of the engine.

Removal

GOVERNMENT REGULATION: Engine fluids (oil, fuel, and coolant) may be a hazard to human health and the environment. Handle all fluids and other contaminated materials (e.g. filters, rags) in accordance with applicable regulations. Recycle or dispose of engine fluids, filters, and other contaminated materials according to applicable regulations.

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, remove ground cable from negative terminal of main battery before disconnecting or connecting electrical components. Always connect ground cable last.

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

Crankshaft Position (CKP) Sensor

Figure 55 CKP sensor

1. Disconnect electrical connector from CKP sensor installed in front right side of lower crankcase.
2. Remove M6 x 14 bolt from CKP sensor.
3. Remove CKP sensor and discard O-ring.

Camshaft Position (CMP) Sensor

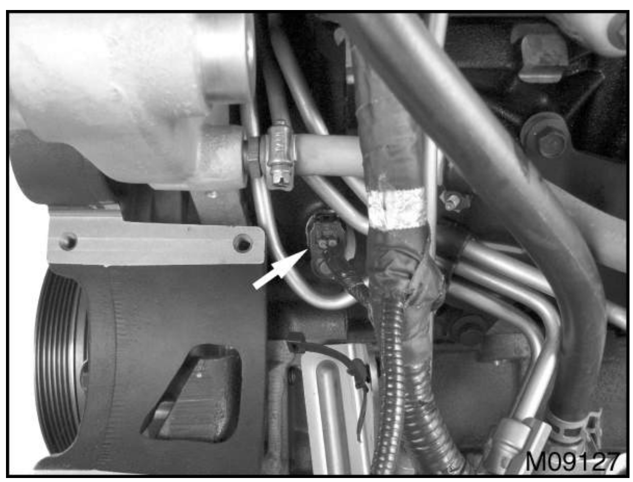

Figure 56 CMP sensor

1. Disconnect engine harness connector from CMP sensor installed in front left side of crankcase.
2. Remove M6 x 14 bolt from CMP sensor.
3. Remove CMP sensor and discard both O-rings.

Exhaust Back Pressure (EBP) Sensor

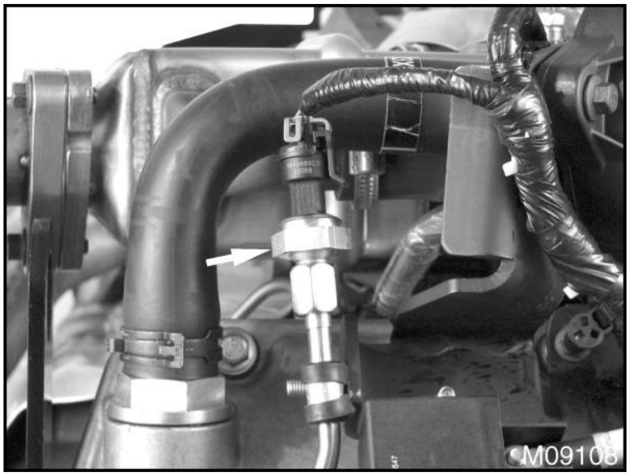

Figure 57 EBP sensor

1. Disconnect electrical connector from EBP sensor mounted in EBP tube assembly near breather support on right valve cover.
2. Remove EBP sensor.

Engine Coolant Temperature (ECT) Sensor

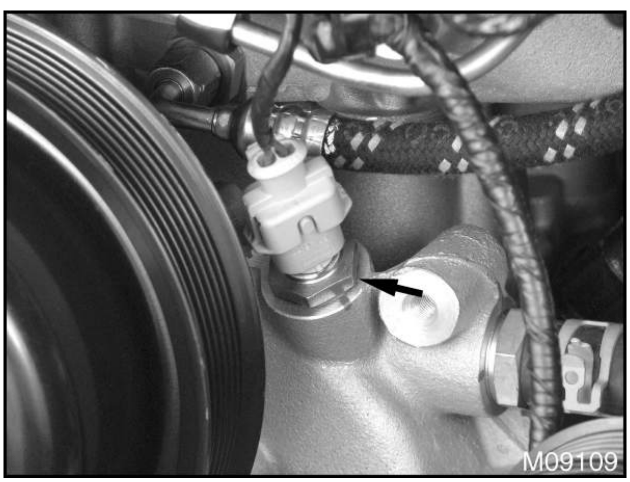

Figure 58 ECT sensor

1. Disconnect electrical connector from ECT sensor installed in left side of front cover.
2. Remove ECT sensor and discard O-ring.

Engine Oil Temperature (EOT) Sensor and Engine Oil Pressure (EOP) Sensor

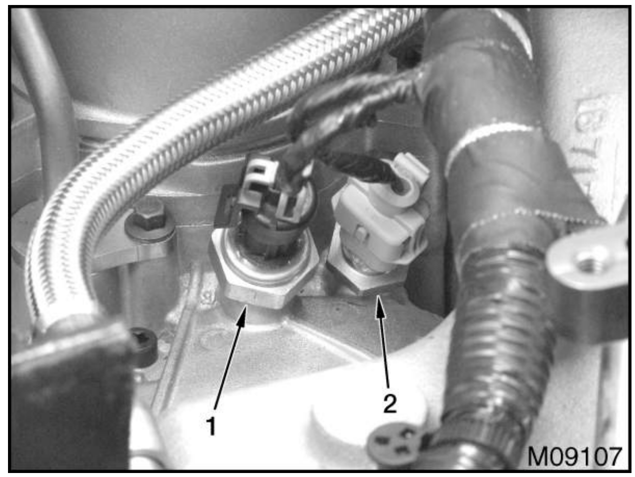

Figure 59 EOT sensor and EOP sensor

1. EOP sensor
2. EOT sensor

1. Disconnect electrical connectors from EOT sensor and EOP sensor installed in oil filter base assembly.
2. Remove EOT sensor and EOP sensor and discard O-rings.

Engine Fuel Temperature (EFT) Sensor and Engine Fuel Pressure (EFP) Sensor

Figure 60 EFT sensor and EFP sensor

1. EFT sensor
2. EFP sensor

1. Disconnect electrical connectors from EFT sensor and EFP sensor installed in secondary fuel filter base.
2. Remove EFT sensor and EFP sensor and discard O-rings.

Water In Fuel (WIF) Sensor

Figure 61 WIF sensor

WARNING: To prevent personal injury or death, store diesel fuel properly in an approved container designed for and clearly marked DIESEL FUEL.

1. Drain primary fuel filter into a suitable container.
2. Disconnect electrical connector from WIF sensor.
3. Remove WIF sensor and discard O-ring.

Fuel Heater

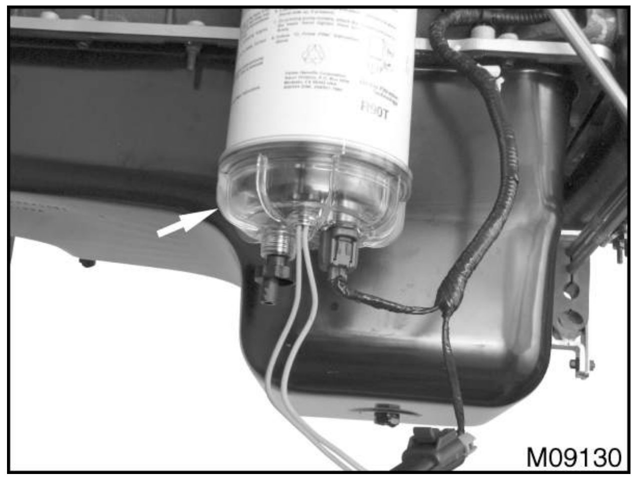

Figure 62 Bowl assembly with fuel heater/probe

WARNING: To prevent personal injury or death, store diesel fuel properly in an approved container designed for and clearly marked DIESEL FUEL.

NOTE: Fuel heater and bowl assembly must be replaced as an assembly.

1. Drain primary fuel filter into a suitable container.
2. Disconnect electrical connector from Water In Fuel (WIF) sensor.
3. Remove WIF sensor and discard O-ring.
4. Disconnect electrical connector from bowl assembly.
5. Rotate bowl assembly clockwise and remove from filter element. Use an oil filter wrench if necessary.
6. Remove and discard bowl primary filter seal.

Manifold Air Temperature (MAT) Sensor and Manifold Absolute Pressure (MAP) Sensor

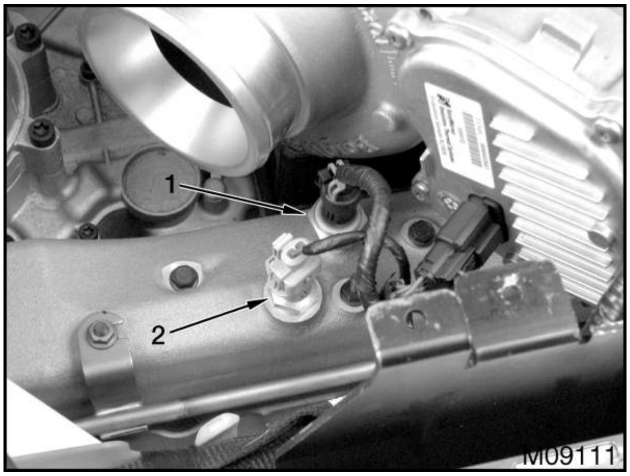

Figure 63 MAT and MAP sensors

1. MAP sensor
2. MAT sensor

1. Disconnect electrical connectors from MAT and MAP sensors.
2. Remove MAT and MAP sensors and discard O-rings.

Intake Throttle Valve (ITV)

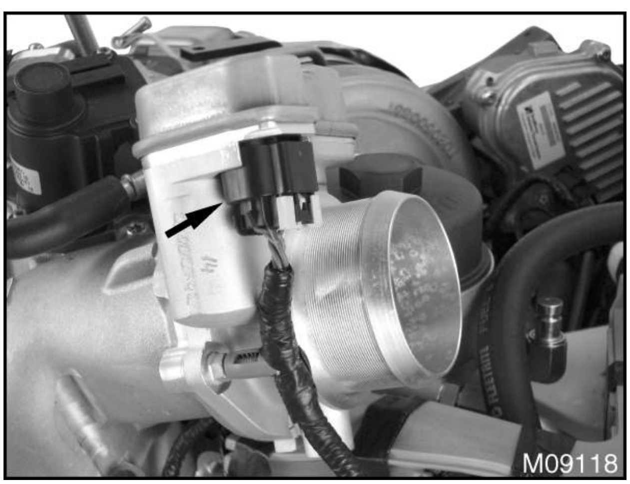

Figure 64 Intake throttle housing assembly connector

1. Disconnect electrical connector from ITV, located on top front of engine.
2. See Intake Throttle Valve (ITV) and Exhaust Gas Recirculation (EGR) Valve Elbow Housing (page 87) for removal of ITV.

Exhaust Gas Recirculation (EGR) Valve Connector

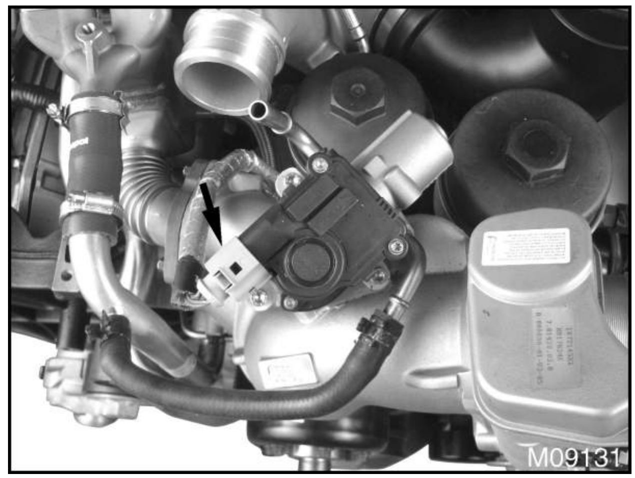

Figure 65 EGR valve connector

1. Disconnect electrical connector from EGR valve.
2. See Exhaust Gas Recirculation (EGR) Valve Assembly (page 83) for removal of EGR valve.

Variable Geometry Turbocharger (VGT) Actuator

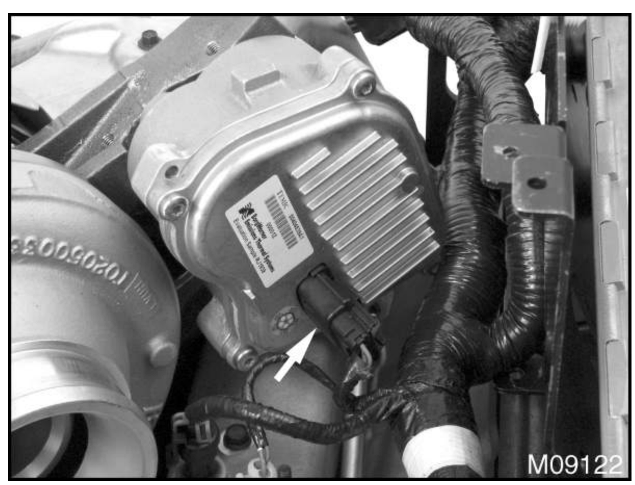

Figure 66 VGT actuator connector

1. Disconnect electrical connector from VGT actuator.

Glow Plug Harness Assemblies

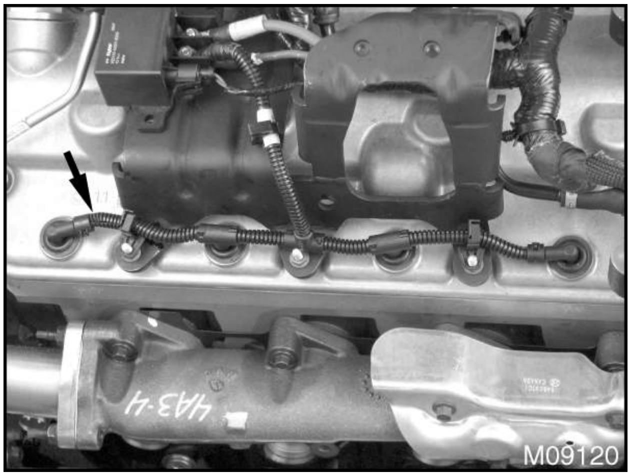

Figure 67 Glow plug harness assembly (right)

WARNING: To prevent personal injury or death, remove ground cable from negative terminal of main battery before disconnecting or connecting electrical components. Always connect ground cable last.

1. Disconnect ground (-) cable from battery.
2. Disconnect glow plug electrical connectors by releasing connector grommet from valve cover, then gently pulling connector straight out.
3. Disconnect left glow plug harness assembly from main harness and remove from engine.
4. Disconnect right glow plug harness assembly from glow plug relay and remove from engine.

Glow Plug Relay

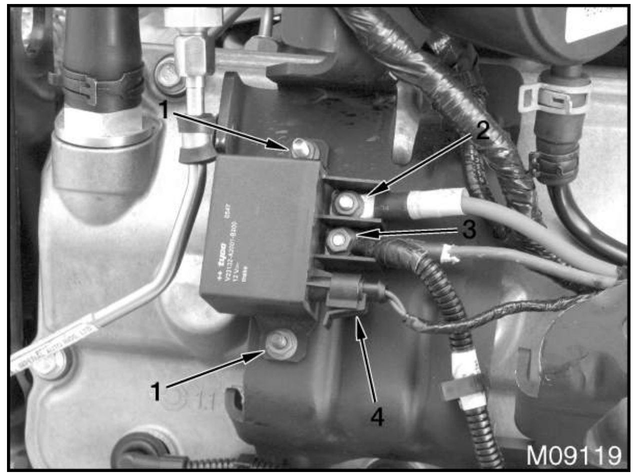

Figure 68 Glow plug relay

1. Glow plug relay nuts
2. Battery (+) cable nut
3. Glow plug harness nut
4. Glow plug relay control connector

WARNING: To prevent personal injury or death, remove ground cable from negative terminal of main battery before disconnecting or connecting electrical components. Always connect ground cable last.

1. Disconnect ground (-) cable from battery.
2. Remove nut and disconnect battery (+) cable.
3. Remove nut and disconnect glow plug harness.
4. Disconnect glow plug relay control electrical connector.
5. Remove glow plug relay nuts and relay.

Electronic Control Module (ECM) and Support

1. Disconnect ground (-) cable from battery.

NOTE: The ECM can be removed without removing support.

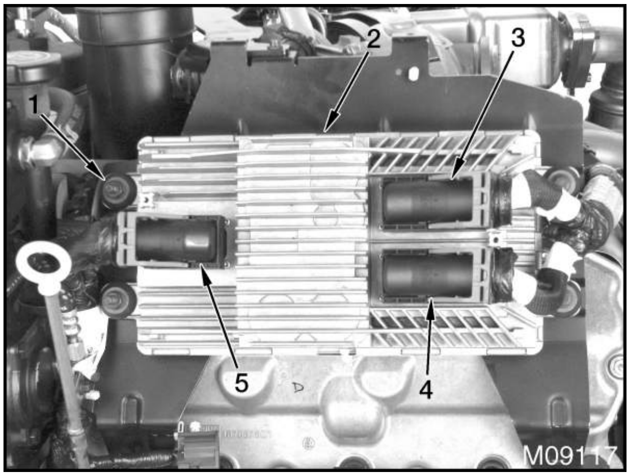

Figure 69 ECM

1. M8 x 45 bolts (4)
2. ECM
3. ECM engine connector
4. ECM chassis connector
5. ECM injector connector

2. Disconnect ECM electrical connectors.
3. Remove four M8 x 45 ECM bolts.
4. Remove ECM from support.

NOTE: Do not remove ECM support if other engine repairs are not necessary.

5. Remove M6 x 16 bolt, M6 nut, and oil level gauge tube assembly.
6. Unclip main harness retainers from ECM support.

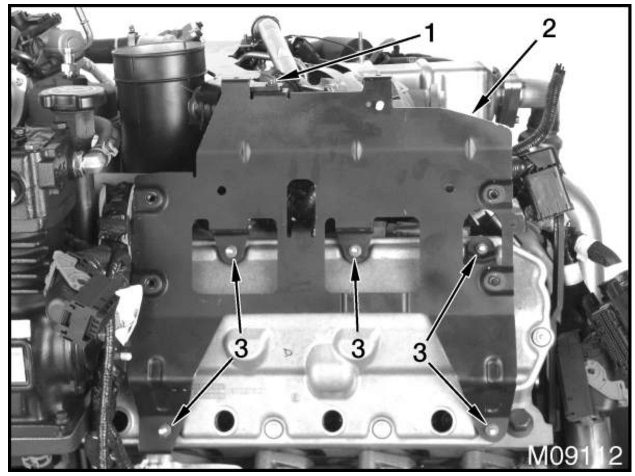

Figure 70 ECM support

1. Charging bridge bolt
2. ECM support
3. M6 nuts (5)

7. Remove charging bridge bolt.
8. Remove five M6 nuts and ECM support.

Under Valve Cover (UVC) Harnesses

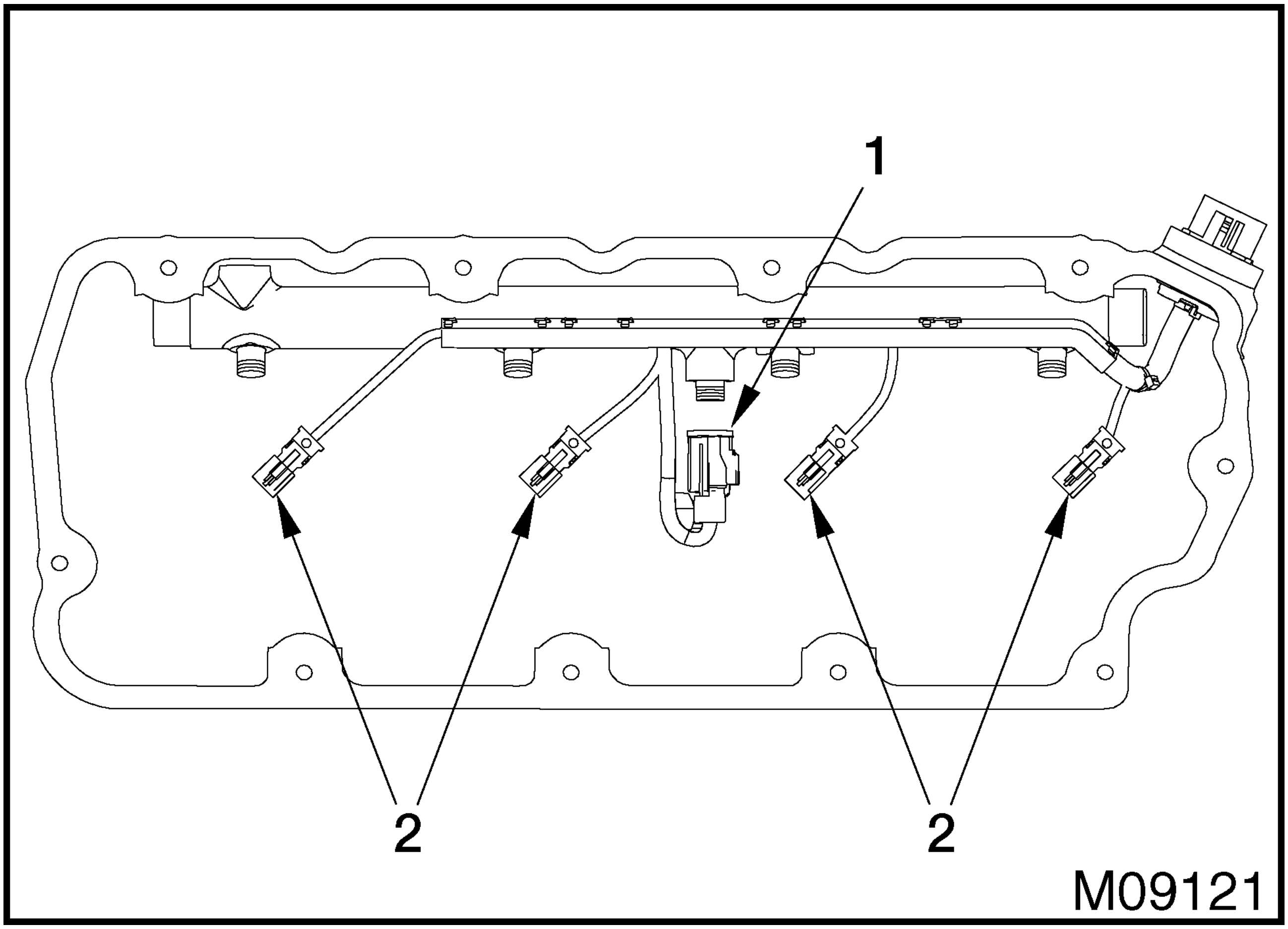

Figure 71 UVC harnesses

1. Fuel Rail Pressure (FRP) sensor connector (right UVC harness only)
2. Fuel injector assembly connectors (4)

WARNING: To prevent personal injury or death, remove ground cable from negative terminal of main battery before disconnecting or connecting electrical components. Always connect ground cable last.

1. Disconnect ground (-) cable from battery.
2. Remove valve covers (page 221).
3. Disconnect four electrical connectors from fuel injector assemblies using Fuel Injector Electrical Connector Release Tool (page 75) and FRP sensor.
4. Disconnect main harness from UVC harness connectors.
5. Disengage UVC harnesses from fuel rails, unclip UVC connectors from cylinder heads, and remove from engine.

Fuel Rail Pressure (FRP) Sensor

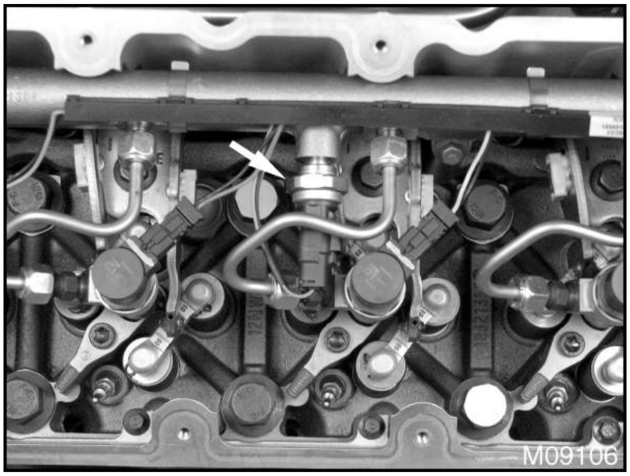

Figure 72 FRP sensor

1. If Under Valve Cover (UVC) harness was not previously removed, disconnect FRP sensor connector.
2. Remove FRP sensor.

Main Engine Wiring Harness

WARNING: To prevent personal injury or death, remove ground cable from negative terminal of main battery before disconnecting or connecting electrical components. Always connect ground cable last.

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

NOTE: The electrical harness assembly does not need to be disconnected from glow plug relay, unless harness or relay is being replaced. Instead, relay bolts may be removed from valve cover.

1. Disconnect ground (-) cable from battery.
2. If not removed, remove Electronic Control Module (ECM) and support (page 62).
3. Disconnect main harness from sensors.

NOTE: Note routing and attachment points of main harness for reinstallation.

4. Remove wiring harness clamps that secure wiring harness to cylinder heads and front cover.
5. Carefully lift main harness assembly from engine.

Cleaning and Inspection

Main Engine Wiring Harness

1. Carefully inspect wiring harness for worn conduit, frayed insulation or heat damage to wires. Repair or replace if necessary.
2. Inspect sensor and valve connectors for cracked connector bodies, bent or loose pins, chafing, and damaged or missing O-rings. Replace connectors if necessary.
3. Inspect each connector for the following conditions and replace, if necessary:
    - Corroded connectors and green, gray, or white deposits on metal terminals.
    - Terminals incorrectly latched in connector body or pushed back relative to other terminals in same connector.
    - Make sure that each connector has its seals in place. During disassembly, a seal may pull off of its connector and remain in mating socket of a sensor or actuator. A connector assembled without the correct seals can be contaminated with moisture and have corroded terminals, causing a poor electrical connection.
4. Check engine wiring harness connectors, connector covers, seals, and cover shields for cracks, cuts or worn areas. Replace if necessary.

Sensors and Valves

1. Check all connector pins on sensors or valves. If bent or corroded, replace damaged sensor.
2. Remove scale or carbon build up.
3. Check for body cracks and leakage
4. If orifices or valves are plugged, replace sensors or valves.

Glow Plug Relay

NOTE: The glow plug relay is not serviceable beyond cleaning and tightening electrical connections.

Inspect base and relay housing for damage, loose terminals, stripped threads, and cracks.

Glow Plug Harness

1. Inspect harness assemblies for right and left glow plugs for defective or twisted seals and pin receptors that are spread open.
2. Clean glow plug harness assemblies with a shop towel. Do not use solvents. Inspect glow plug harness for missing or damaged seals. Replace if necessary.

ECM

1. Inspect rubber seal on harness connector and in ECM pin recesses.
2. Check for bent pins in ECM connections.

Installation

Main Engine Wiring Harness

1. Position main harness assembly on engine.

NOTE: Be sure to route and secure main harness assembly in its correct configuration.

2. Install wiring harness clamps that secure wiring harness to cylinder heads and front cover.
3. Connect main harness to sensors.
4. If removed, install ECM and support (page 69).
5. Connect ground (-) cable to battery.

Fuel Rail Pressure (FRP) Sensor

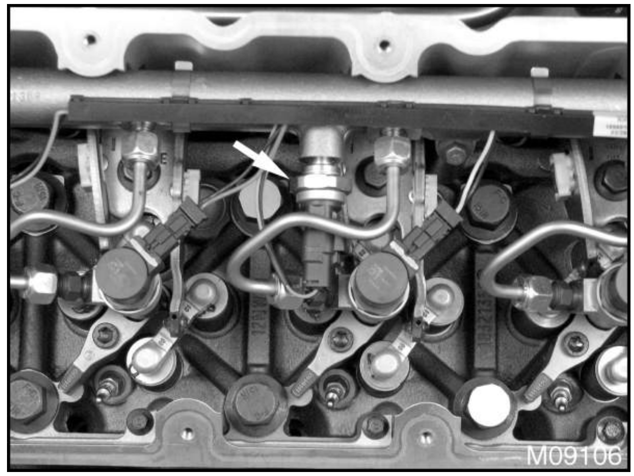

Figure 73 FRP sensor

1. Install FRP sensor. Tighten sensor to special torque (page 75).
2. If Under Valve Cover (UVC) harness not previously removed, connect electrical connector to FRP sensor.

Under Valve Cover (UVC) Harnesses

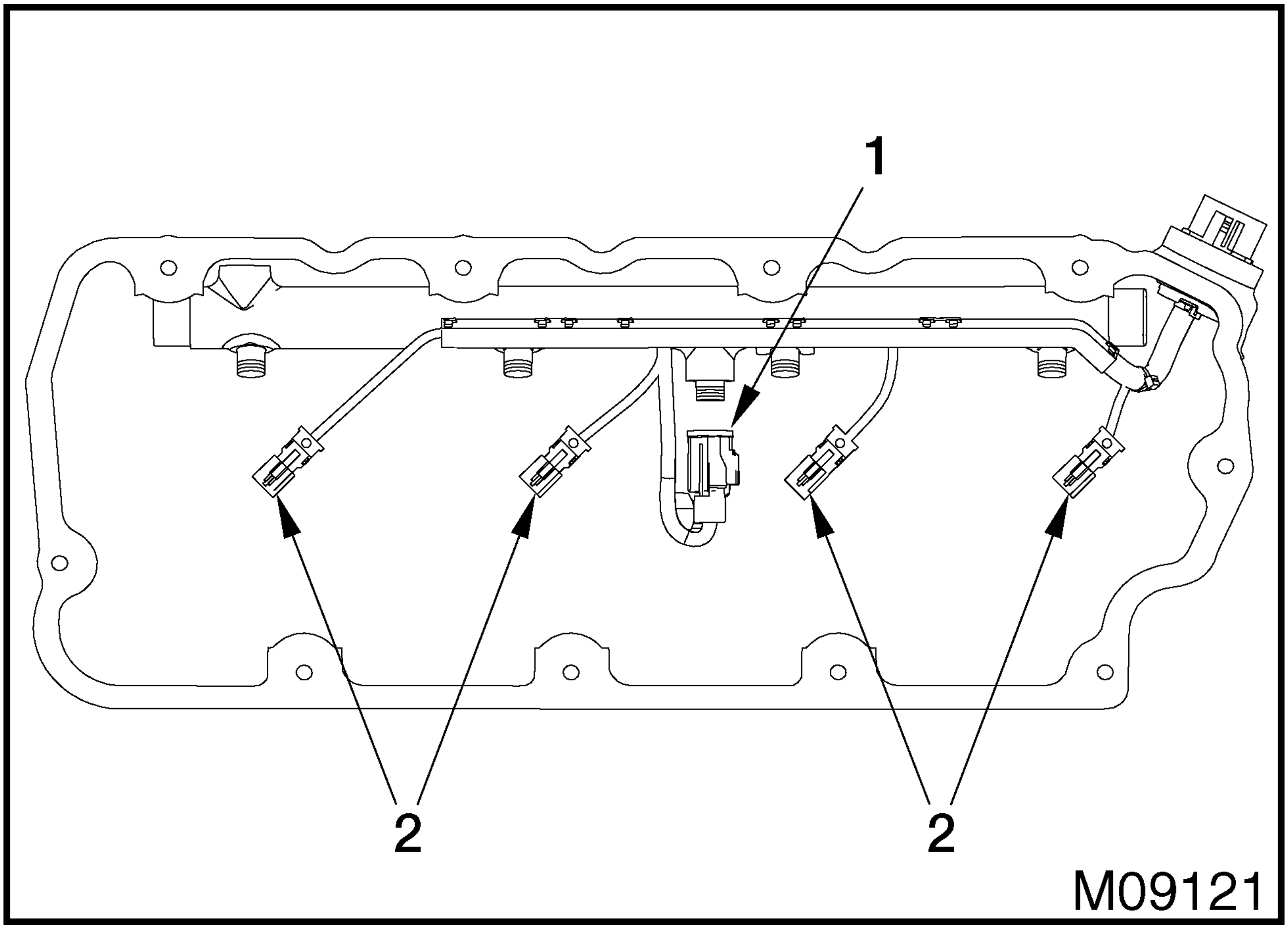

Figure 74 UVC harnesses

1. Fuel Rail Pressure (FRP) sensor connector (right UVC harness only)
2. Fuel injector assembly connectors (4)

1. Position UVC harnesses to engine, clip UVC connectors to cylinder heads, and clip UVC harnesses to fuel rails.
2. Connect main harness to UVC connectors.
3. Connect electrical connectors to four fuel injector assemblies and FRP sensor.
4. Install valve covers (page 256).
5. Connect ground (-) cable to battery.

Electronic Control Module (ECM) and Support

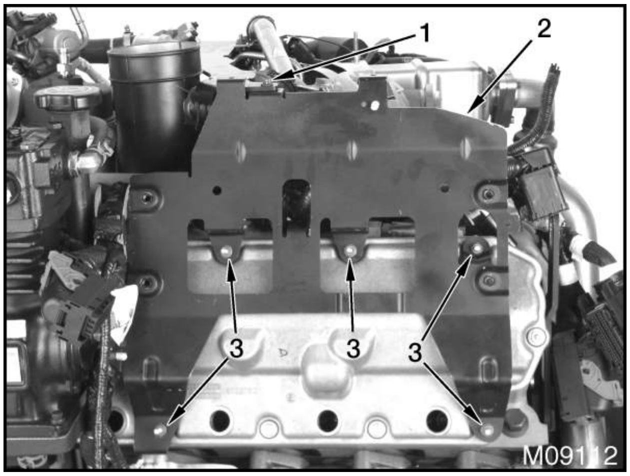

Figure 75 ECM support

1. Charging bridge bolt
2. ECM support
3. M6 nuts (5)

1. Install ECM support and five M6 nuts. Tighten nuts to special torque (page 75).
2. Install charging bridge bolt. Tighten to standard torque (page 383).
3. Clip main harness retainers to ECM support.
4. Install oil level gauge tube assembly, M6 nut, and M6 x 16 bolt. Tighten to standard torque (page 383).
5. Install ECM to support.

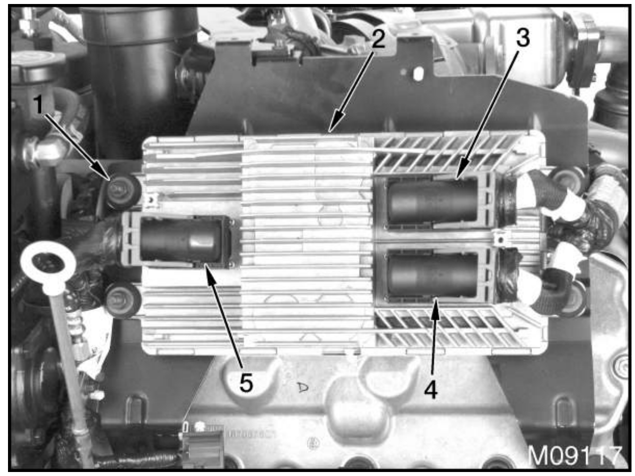

Figure 76 ECM

1. M8 x 45 bolts (4)
2. ECM
3. ECM engine connector
4. ECM chassis connector
5. ECM injector connector

6. Install four M8 x 45 ECM bolts. Tighten bolts to special torque (page 75).
7. Connect ECM electrical connectors.
8. Connect ground (-) cable to battery.

Glow Plug Relay

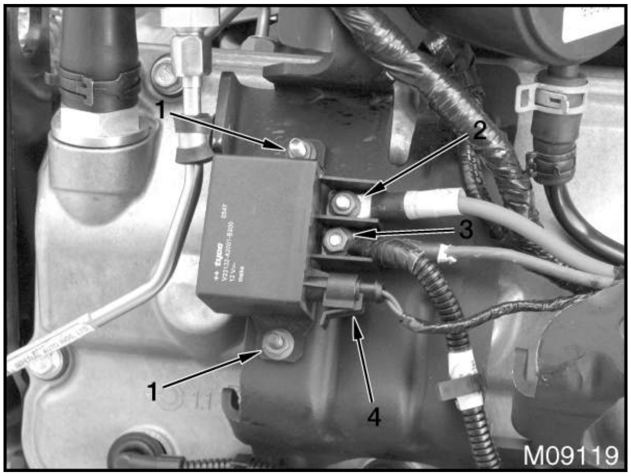

Figure 77 Glow plug relay

1. Glow plug relay nuts
2. Battery (+) cable nut
3. Glow plug harness nut
4. Glow plug relay control connector

1. Install glow plug relay and nuts. Tighten nuts to standard torque (page 383).
2. Connect electrical connections to glow plug relay. Install and tighten nuts to standard torque (page 383).
3. Connect ground (-) cable to battery.

Glow Plug Harness Assemblies

Figure 78 Glow plug harness assembly (right)

1. Install each glow plug harness assembly to engine and connect to main harness.
2. Connect glow plug electrical connectors by gently pushing connector straight in, then seating valve cover grommet.
3. Connect ground (-) cable to battery.

Variable Geometry Turbocharger (VGT) Actuator

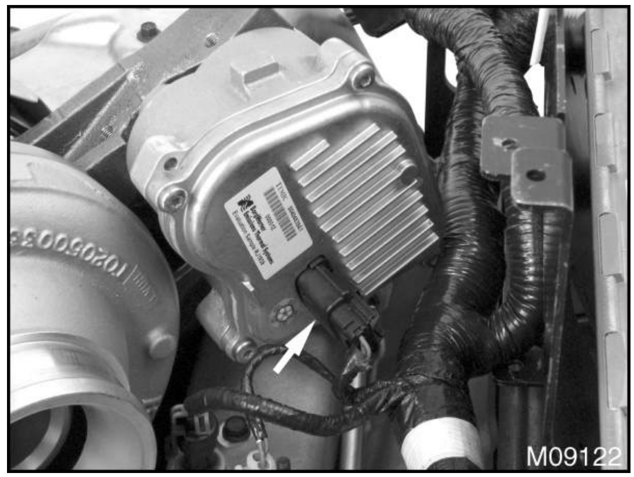

Figure 79 VGT actuator

1. Connect electrical connector to VGT actuator.

Exhaust Gas Recirculating (EGR) Valve Connector

Figure 80 EGR valve

1. If removed, see Exhaust Gas Recirculation (EGR) Valve Assembly (page 92) for installation of EGR valve.
2. Connect electrical connector to EGR valve.

Intake Throttle Valve (ITV) Connector

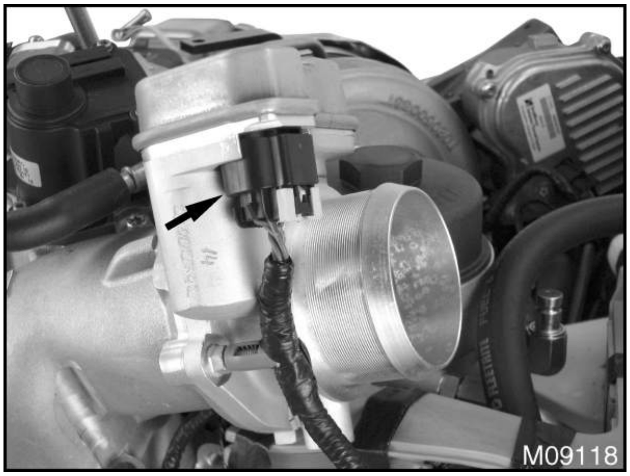

Figure 81 Intake throttle housing assembly connector

1. If removed, see Intake Throttle Valve (ITV) and Exhaust Gas Recirculation (EGR) Valve Elbow Housing (page 89) for installation of ITV.
2. Connect electrical connector to ITV, located on top front of engine.

Manifold Air Temperature (MAT) Sensor and Manifold Absolute Pressure (MAP) Sensor

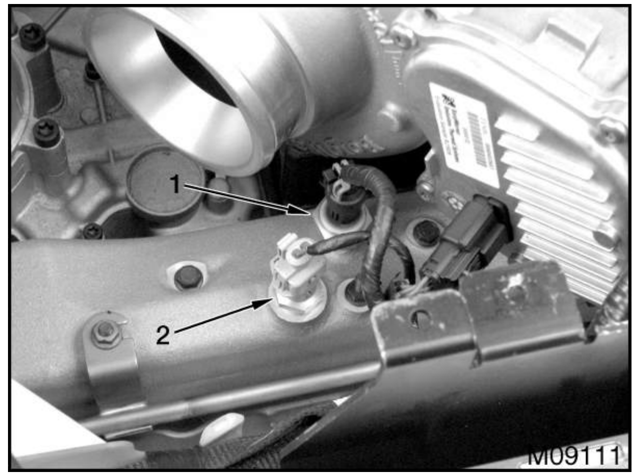

Figure 82 MAT and MAP sensors

1. MAP sensor
2. MAT sensor

1. Install new O-rings on MAT and MAP sensors and lubricate with clean engine oil.
2. Install MAT and MAP sensors. Tighten sensors to special torque (page 75).
3. Connect electrical connectors to MAT and MAP sensors.

Fuel Heater

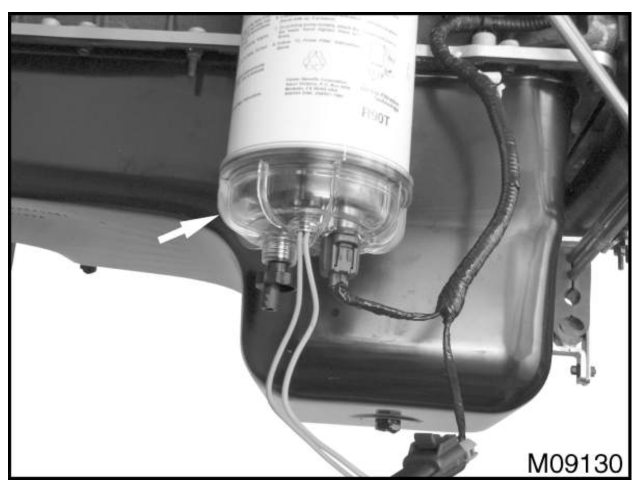

Figure 83 Bowl assembly with fuel heater/probe

NOTE: Fuel heater and bowl assembly must be replaced as an assembly.

1. Install a new bowl primary filter seal onto bowl assembly.
2. Install bowl assembly and hand tighten firmly.
3. Connect electrical connector to bowl assembly.
4. Install new O-ring on WIF sensor and lubricate with clean engine oil.
5. Install WIF sensor.
6. Connect electrical connector to WIF sensor.

Water In Fuel (WIF) Sensor

Figure 84 WIF sensor

1. Install new O-ring on WIF sensor and lubricate with clean engine oil.
2. Install WIF sensor.
3. Connect electrical connector to WIF sensor.

Engine Fuel Temperature (EFT) Sensor and Engine Fuel Pressure (EFP) Sensor

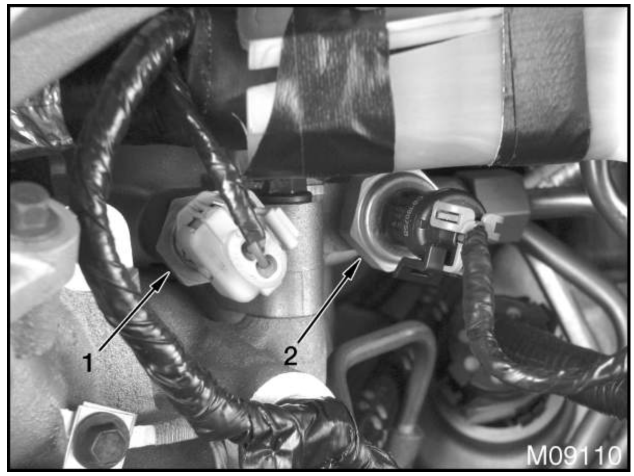

Figure 85 EFT sensor and EFP sensor

1. EFT sensor
2. EFP sensor

1. Install new O-rings on EFT sensor and EFP sensor and lubricate with clean engine oil.
2. Install EFT sensor and EFP sensor. Tighten sensors to special torque (page 75).
3. Connect electrical connectors to EFT sensor and EFP sensor installed in secondary fuel filter base.

Engine Oil Temperature (EOT) Sensor and Engine Oil Pressure (EOP) Sensor

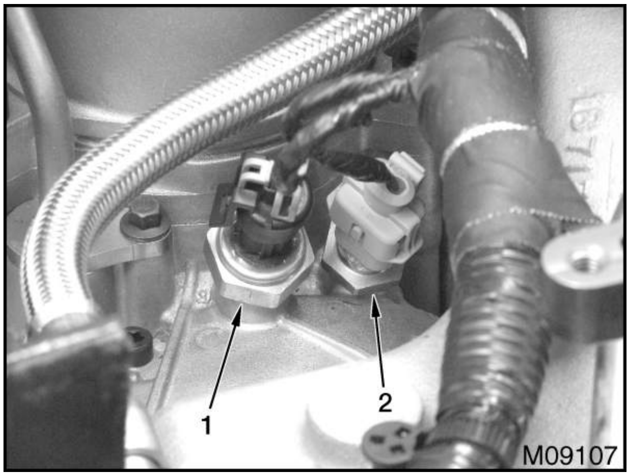

Figure 86 EOT sensor and EOP sensor

1. EOP sensor
2. EOT sensor

1. Install new O-rings on EOT sensor and EOP sensor and lubricate with clean engine oil.
2. Install EOT sensor and EOP sensor. Tighten sensors to special torque (page 75).
3. Connect electrical connectors to EOT sensor and EOP sensor installed in oil filter base assembly.

Engine Coolant Temperature (ECT) Sensor

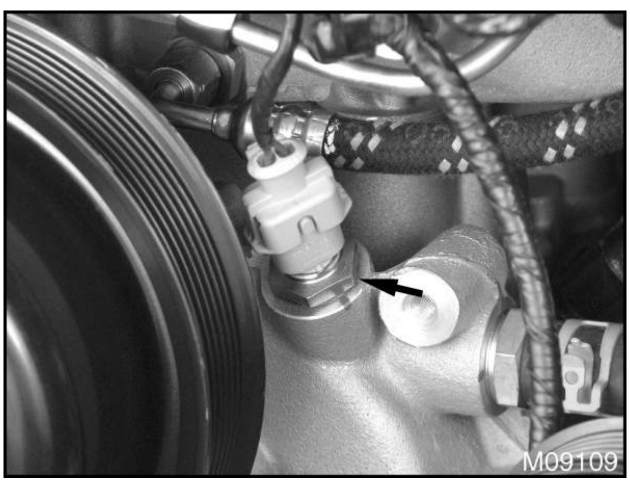

Figure 87 ECT sensor

1. Install a new O-ring on ECT sensor and lubricate with clean engine oil.
2. Install ECT sensor. Tighten sensor to special torque (page 75).
3. Connect electrical connector to ECT sensor installed in left side of front cover.

Exhaust Back Pressure (EBP) Sensor

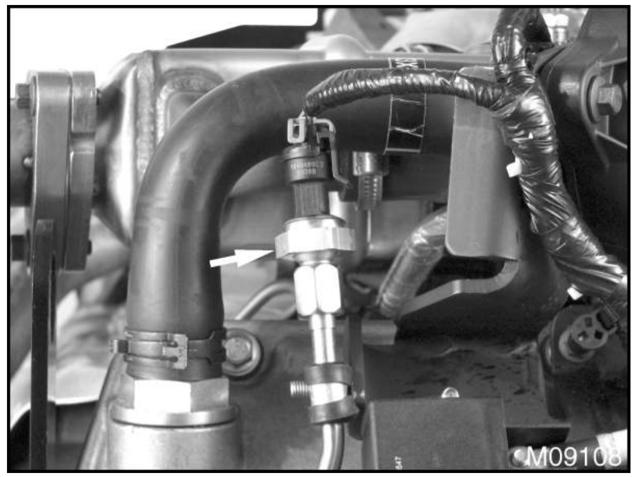

Figure 88 EBP sensor

1. Install EBP sensor. Tighten sensor to special torque (page 75).
2. Connect electrical connector to EBP sensor mounted in EBP tube assembly near breather support on right valve cover.

Camshaft Position (CMP) Sensor

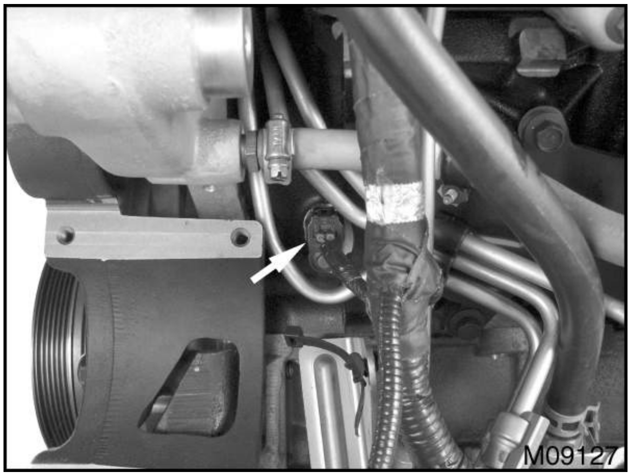

Figure 89 CMP sensor

1. Install two new O-rings on CMP sensor and lubricate with clean engine oil.
2. Install CMP sensor.
3. Install M6 x 14 bolt to CMP sensor. Tighten bolt to special torque (page 75).
4. Connect engine harness connector to CMP sensor installed in front left side of crankcase.

Crankshaft Position (CKP) Sensor

Figure 90 CKP sensor

1. Install a new O-ring on CKP sensor and lubricate with clean engine oil.
2. Install CKP sensor.
3. Install M6 x 14 bolt to CKP sensor. Tighten bolt to special torque (page 75).
4. Connect electrical connector to CKP sensor installed in front right side of lower crankcase.

Special Torque

Table 4 Engine Electrical

Crankshaft Position (CKP) sensor bolt	10 N·m (89 lbf·in)
Camshaft Position (CMP) sensor bolt	10 N·m (89 lbf·in)
Engine Coolant Temperature (ECT) sensor	18 N·m (159 lbf·in)
Engine Fuel Temperature (EFT) sensor	18 N·m (159 lbf·in)
Engine Oil Pressure (EOP) sensor	12 N·m (106 lbf·in)
Engine Oil Temperature (EOT) sensor	18 N·m (159 lbf·in)
Engine Fuel Pressure (EFP) Sensor	12 N·m (106 lbf·in)
Fuel Rail Pressure (FRP) sensor	2 N·m (18 lbf·in), then turn one hex flat (60 degrees)
Manifold Air Temperature (MAT) sensor	18 N·m (159 lbf·in)
Manifold Absolute Pressure (MAP) sensor	12 N·m (106 lbf·in)
Exhaust Back Pressure (EBP) sensor	20 N·m (177 lbf·ft)
Electronic Control Module (ECM) bolts	13 N·m (115 lbf·in)
ECM support nuts	13 N·m (115 lbf·in)

Special Service Tools

Table 5 Engine Electrical

Description	Tool Number
Fuel Injector Electrical Connector Release Tool	ZTSE4820

Table of Contents

Exploded Views

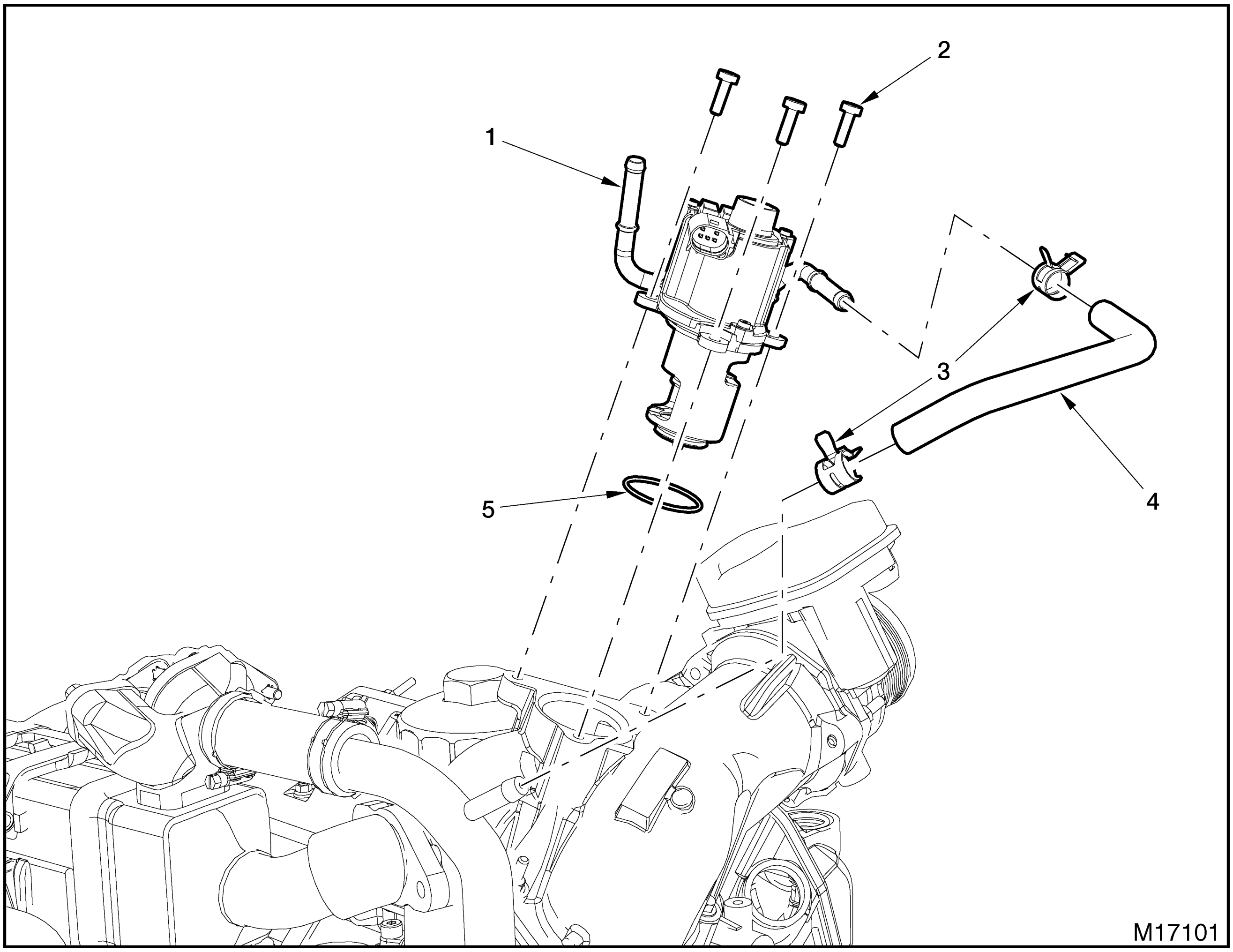

Figure 91 EGR valve

1. EGR valve assembly
2. M6 x 20 bolt (3)
3. Hose clamp (2)
4. EGR valve coolant supply hose
5. EGR valve housing gasket

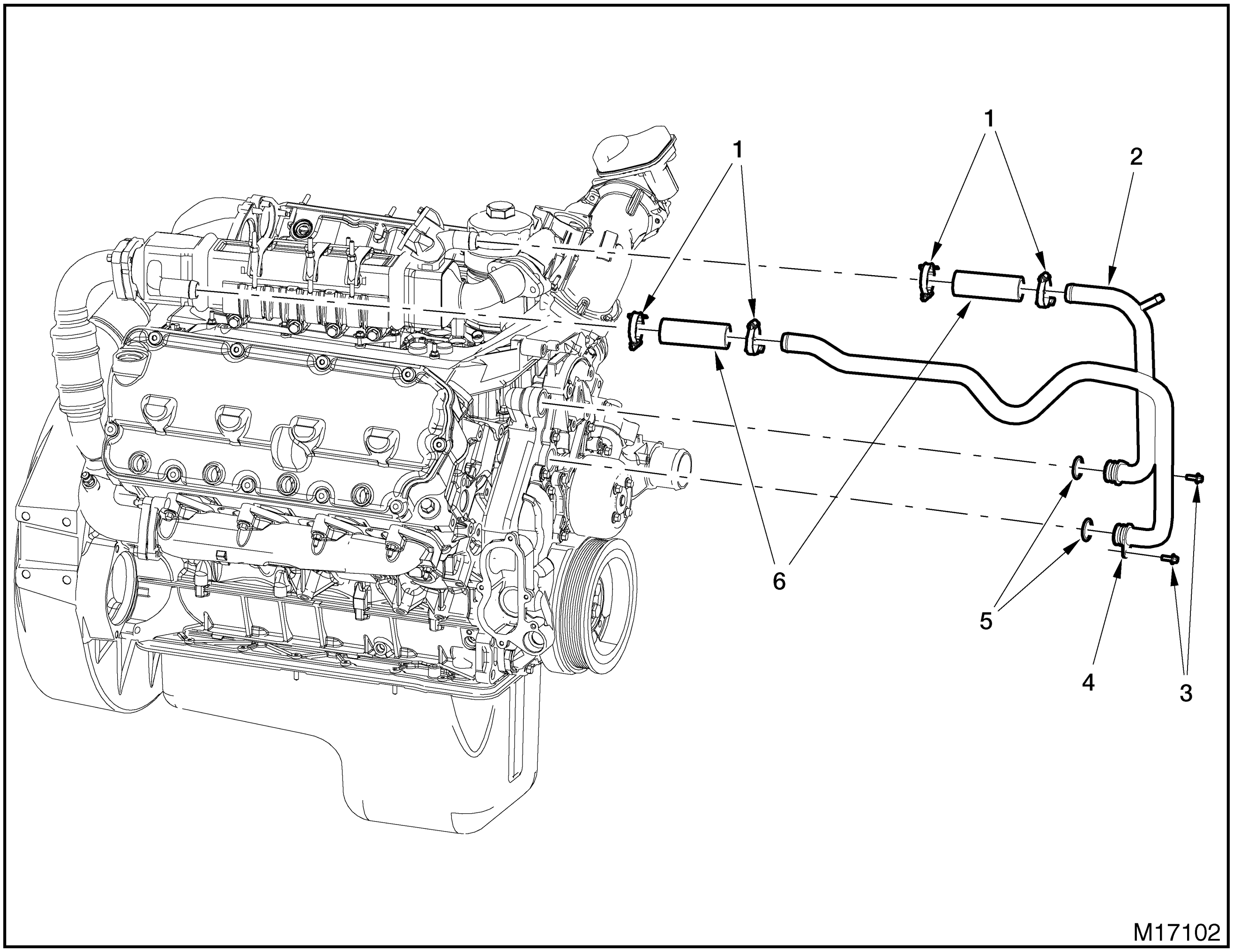

Figure 92 EGR coolant tubes

1. Coolant hose clamp(s) (4)
2. EGR coolant return tube
3. M6 x 16 bolt (2)
4. EGR coolant supply tube
5. Seal (O-ring) (2)
6. Coolant tube hose (2)

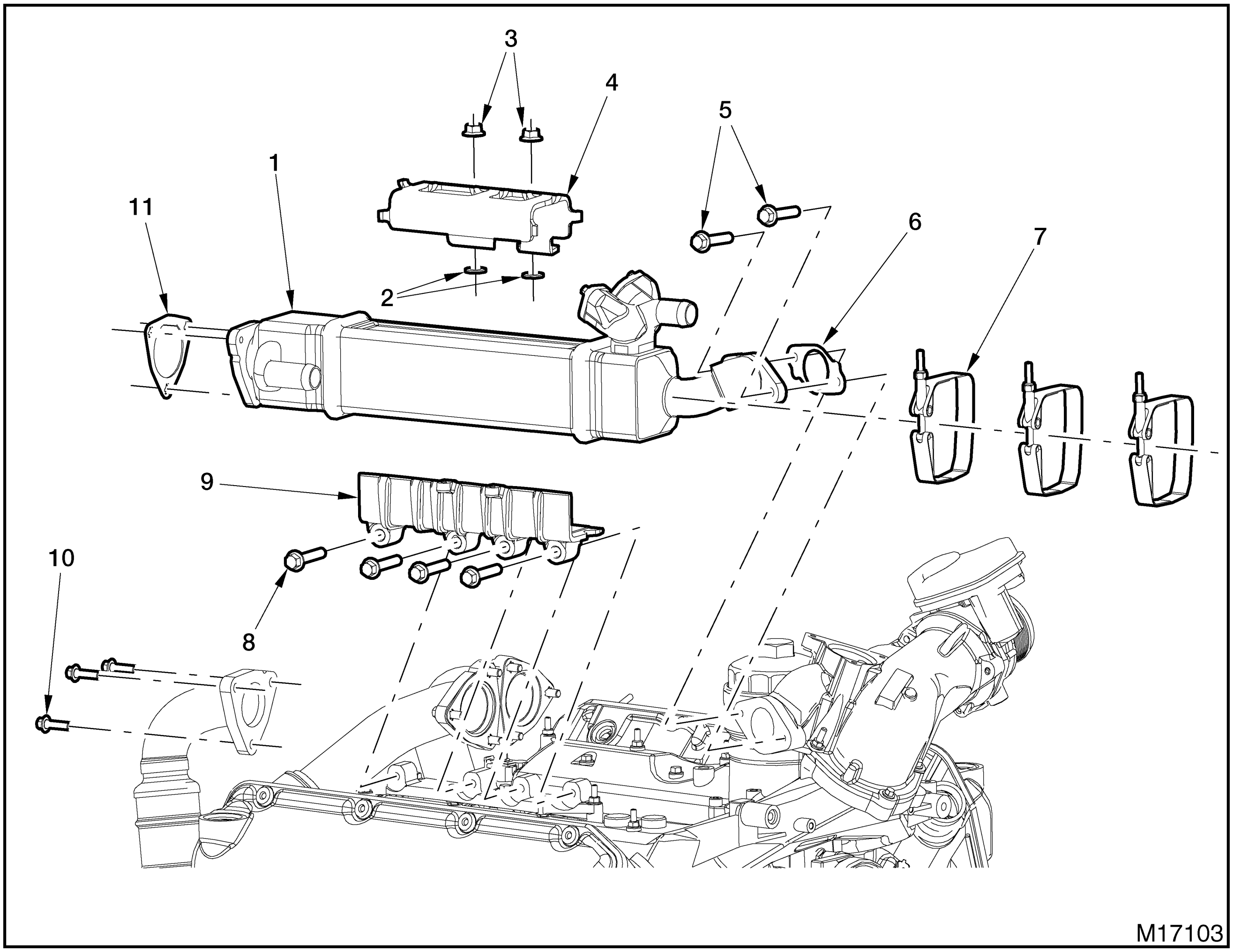

Figure 93 EGR cooler assembly

1. EGR cooler
2. #10 washer (2)
3. M10 x 1.5 nut (2)
4. EGR top bracket
5. M8 x 20 bolt (2)
6. EGR cooler 1 to 2 gasket
7. EGR cooler clamp (3)
8. M10 x 50 bolt (4)
9. EGR cooler bracket
10. M8 x 27 bolt (3)
11. Exhaust tube gasket

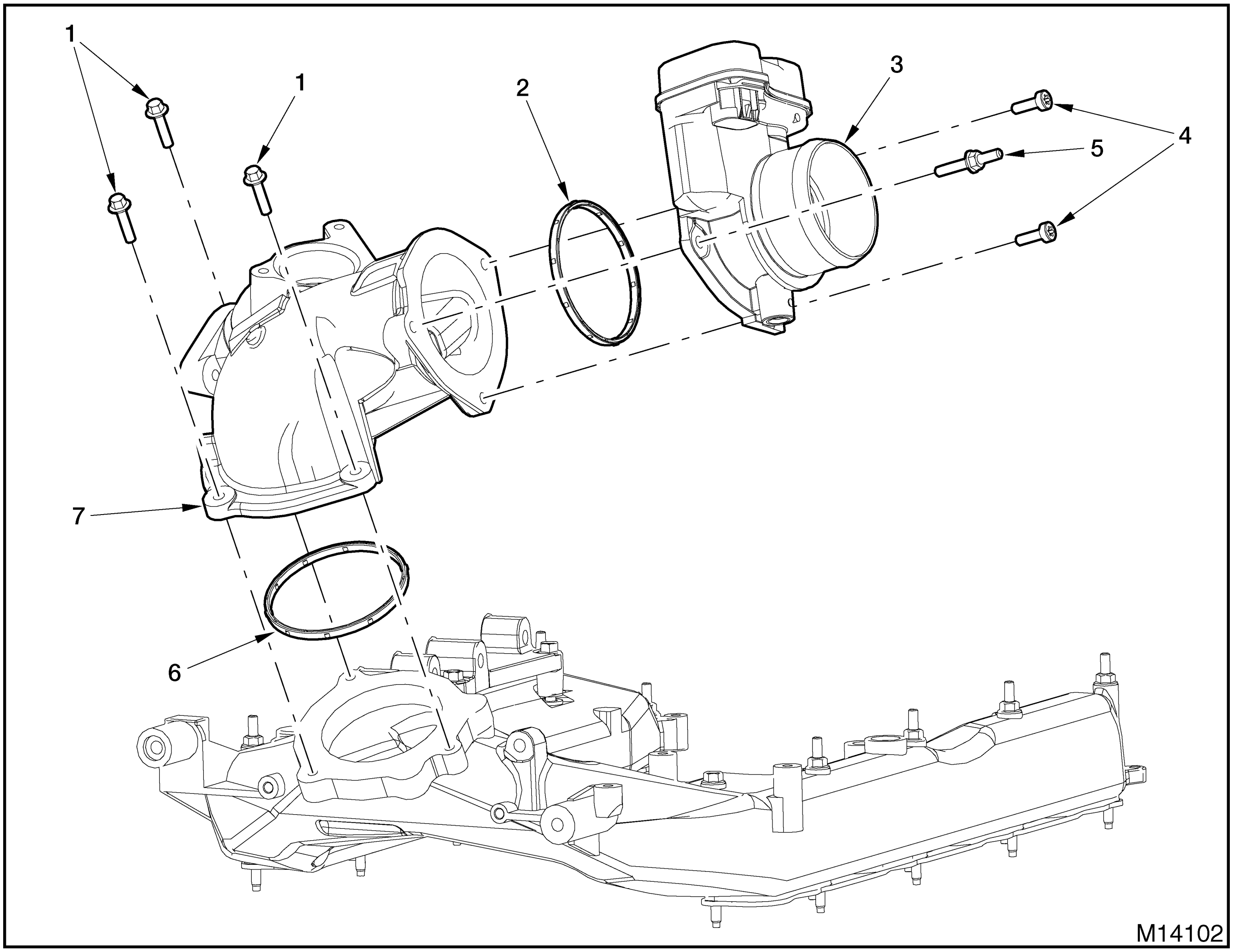

Figure 94 Intake Throttle Valve (ITV) and EGR valve elbow housing

1. M6 x 25 bolt (3)
2. Intake throttle gasket
3. ITV
4. M6 x 20 bolt (2)
5. M6 x 25 stud bolt
6. Intake throttle gasket
7. EGR valve elbow housing

Removal

GOVERNMENT REGULATION: Engine fluids (oil, fuel, and coolant) may be a hazard to human health and the environment. Handle all fluids and other contaminated materials (e.g. filters, rags) in accordance with applicable regulations. Recycle or dispose of engine fluids, filters, and other contaminated materials according to applicable regulations.

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 that the engine has cooled 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.

NOTE: See Electrical section for information on removal of components prior to this section.

Exhaust Gas Recirculation (EGR) Valve Assembly

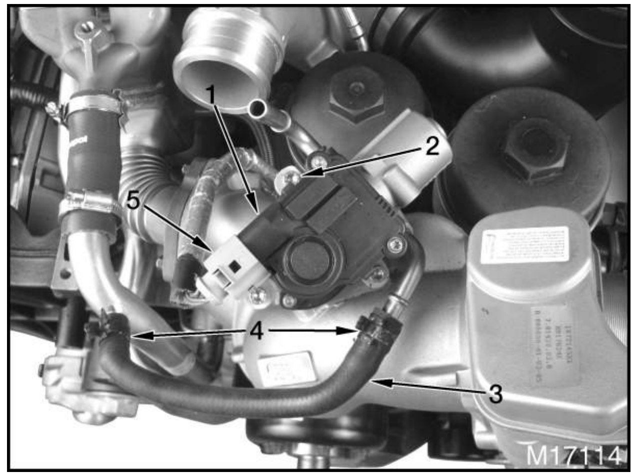

Figure 95 EGR valve assembly

1. EGR valve assembly
2. M6 x 20 bolt (3)
3. EGR valve coolant supply hose
4. Hose clamp (2)
5. EGR valve assembly electrical connector

1. Disconnect electrical connector from EGR valve assembly.
2. Loosen two hose clamps and disconnect EGR valve coolant supply hose.
3. Loosen two hose clamps and disconnect EGR valve coolant return hose (not shown in Figure 95).
4. Remove three M6 x 20 EGR valve assembly bolts.

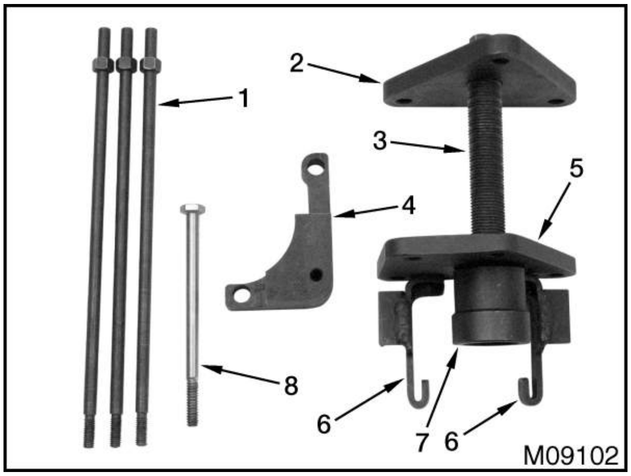

Figure 96 EGR valve puller

1. Puller studs
2. Upper plate
3. Threaded shaft
4. Collar
5. Lower plate
6. J-hook (2)
7. Puller cup
8. Collar bolt

5. Install EGR Valve Puller (page 93) onto EGR valve assembly.

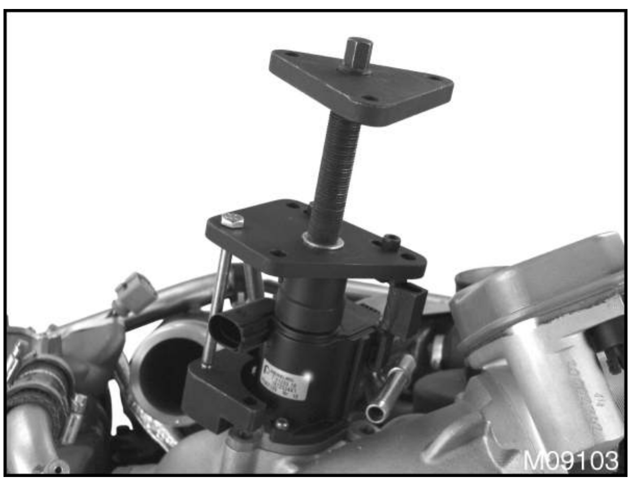

Figure 97 EGR valve puller installation

CAUTION: To prevent EGR valve assembly damage, be careful when installing puller cup, or damage to EGR valve assembly may result.

6. Install puller cup onto EGR valve assembly.
7. Align puller J-hooks into slots directly behind EGR valve assembly upper cover screws.
8. Install puller collar around base of EGR valve assembly and install collar bolt.

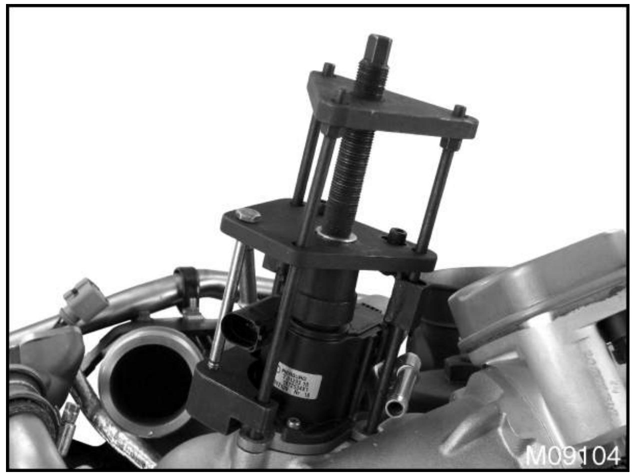

Figure 98 EGR valve puller installed

NOTE: Make sure puller studs are completely seated.

9. Thread three puller studs through puller lower plate, J-hooks and collar, EGR valve assembly, and into EGR elbow housing.
10. Rotate upper puller plate to align with puller studs, and turn threaded shaft clockwise to seat upper plate onto puller stud hex heads.
11. Turn threaded shaft clockwise to remove EGR valve assembly. Discard EGR valve housing gasket.

Exhaust Gas Recirculation (EGR) Cooler

1. Remove two coolant drain plugs and drain coolant from crankcase into a suitable container. The coolant drain plugs (page 43) are in rear of crankcase, below exhaust manifolds.

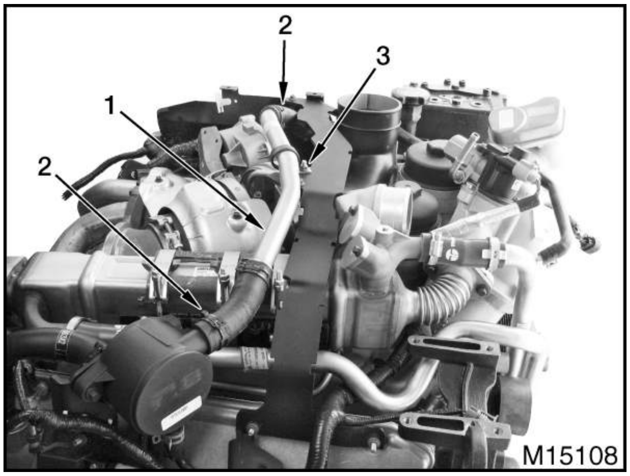

Figure 99 Breather tube

1. Breather tube
2. Breather hose clamps (2)
3. M6 nut

2. Remove M6 nut and disconnect breather tube clamp from charging circuit bridge.
3. Loosen hose clamp and disconnect breather tube hose from breather.
4. Loosen hose clamp and disconnect breather tube from turbo air inlet duct.
5. Remove breather tube.

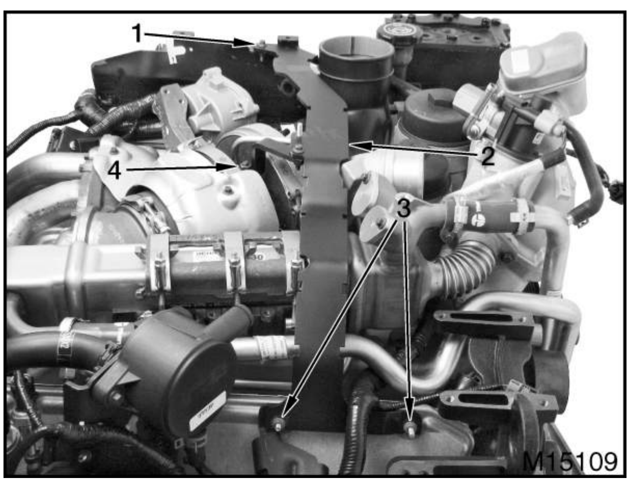

Figure 100 Charging circuit bridge

1. M6 x 16 bolt and nut
2. Charging circuit bridge
3. M6 nut (2)
4. M8 nut

6. Remove two M6 nuts from charging circuit bridge at right valve cover.
7. Remove M8 nut from charging circuit bridge bracket at turbocharger oil inlet flange.
8. Remove M6 x 16 bolt and nut from charging circuit bridge at Engine Control Module (ECM) support.
9. Remove charging circuit bridge.

Figure 101 Coolant hose clamps

10. Loosen four coolant hose clamps retaining EGR coolant supply and coolant return hoses.

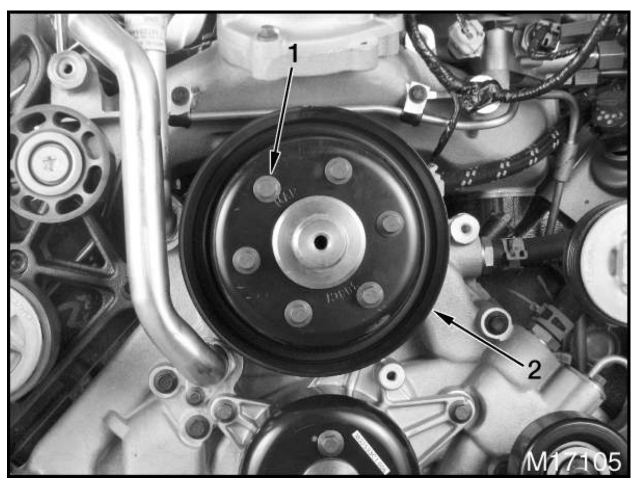

Figure 102 Fan drive pulley

1. M8 x 20 bolt (6)
2. Fan drive pulley

NOTE: If not using an impact wrench, use a holding device to lock fan drive pulley when removing bolts.

11. Remove six M8 x 20 bolts and fan drive pulley.

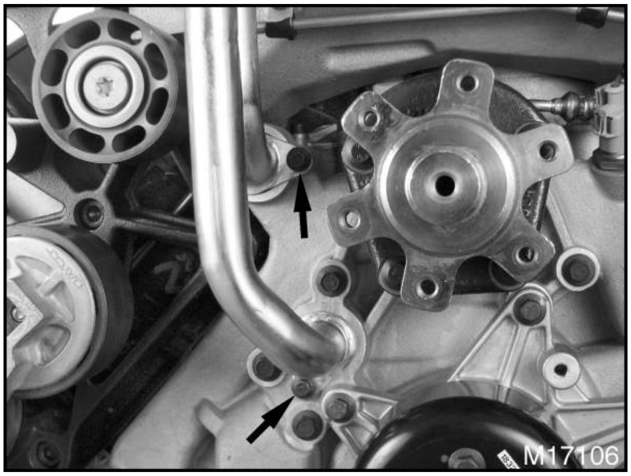

Figure 103 EGR coolant supply and coolant return tube bolts

12. Remove two M6 x 16 EGR coolant supply tube and EGR coolant return tube bolts.
13. Disconnect EGR coolant supply and EGR coolant return tubes from EGR cooler and front crankcase cover, and discard seals (O-ring).
14. Remove EGR coolant supply and EGR coolant return tubes from engine.

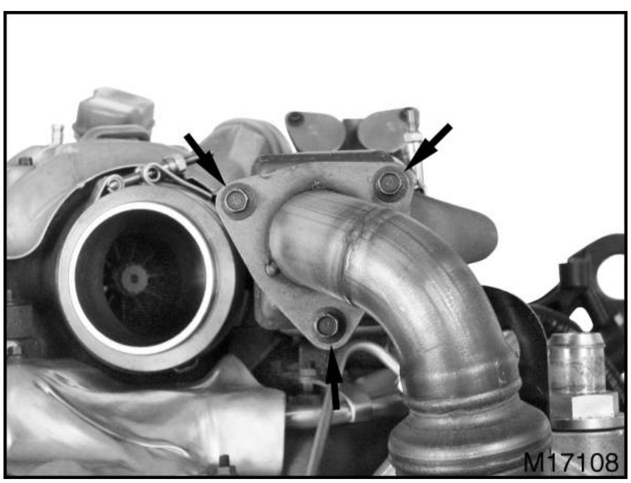

Figure 104 EGR cooler inlet bolts

15. Remove and discard three M8 x 27 EGR cooler inlet bolts.

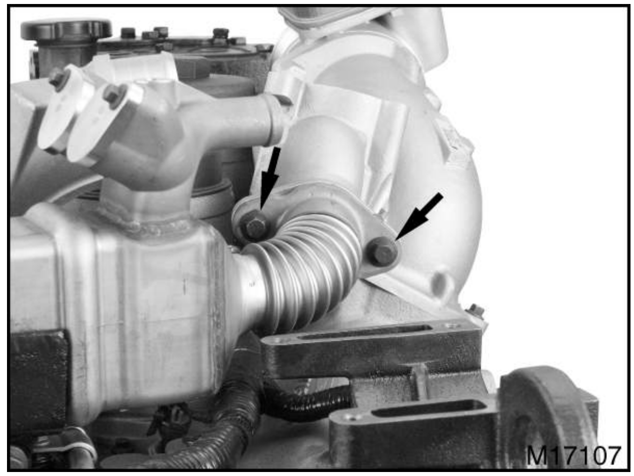

Figure 105 EGR cooler outlet bolts

16. Remove two M8 x 20 EGR cooler outlet bolts.

Figure 106 EGR top bracket nuts

NOTE: To aid in removal of two EGR top bracket nuts, loosen nuts between ⅛ and ¼ of a turn, then tap each nut using a socket or flat punch and hammer. This knocks the peaks of the stud bolt threads off the ramps of the special Spiralock® nuts, allowing the nuts to unthread easily.

17. Remove and discard two M10 x 1.5 EGR top bracket nuts.

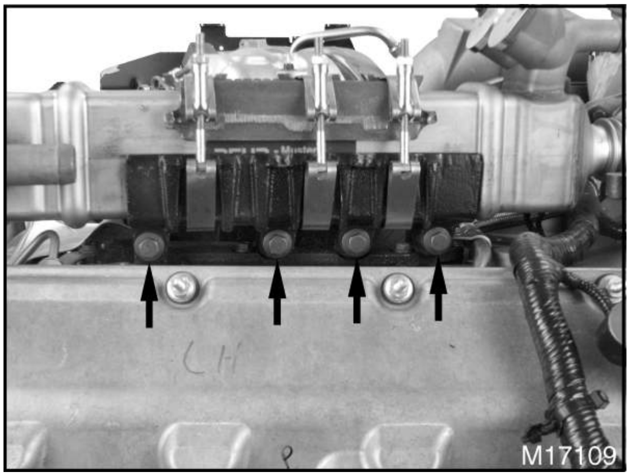

Figure 107 EGR cooler bracket bolts

18. Remove four M10 x 50 EGR cooler bracket bolts.
19. Remove EGR cooler assembly from engine and discard gaskets.

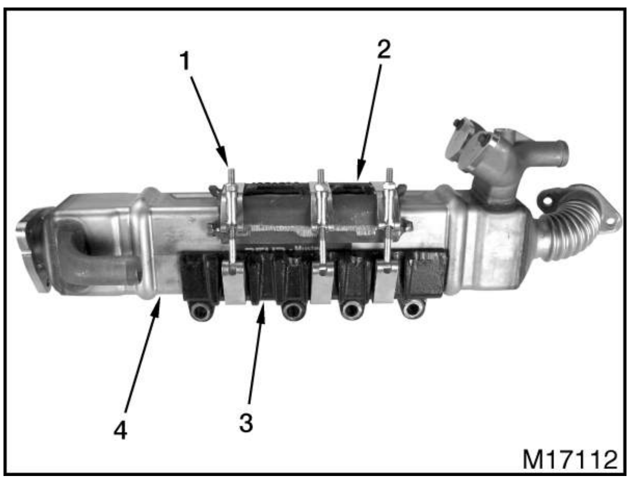

Figure 108 EGR cooler assembly

1. EGR cooler clamp (3)
2. EGR top bracket
3. EGR cooler bracket
4. EGR cooler

20. Remove and discard three EGR cooler clamps.
21. Remove EGR top bracket.

NOTE: The lower EGR cooler bracket is mounted to intake manifold with the manifold bolts. For removal of lower EGR cooler bracket, see Intake Manifold (page 177).

22. Remove EGR cooler from EGR cooler bracket.

Intake Throttle Valve (ITV) and Exhaust Gas Recirculation (EGR) Valve Elbow Housing

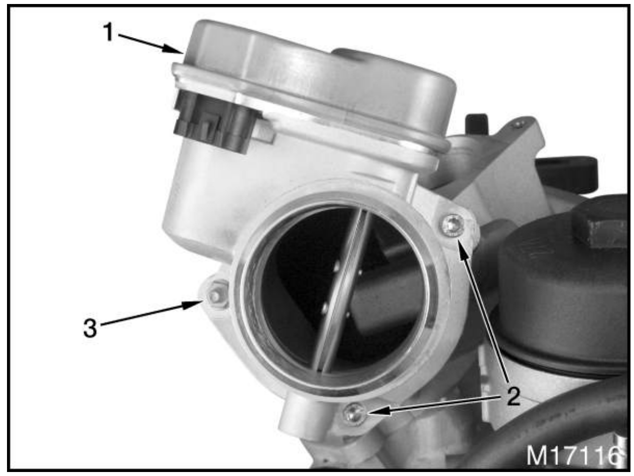

Figure 109 ITV bolts

1. ITV
2. M6 x 20 bolt (2)
3. M6 x 25 stud bolt

1. Remove M6 x 25 stud bolt and two M6 x 20 bolts retaining ITV to EGR valve elbow housing.
2. Remove ITV from EGR valve elbow housing and discard gasket.

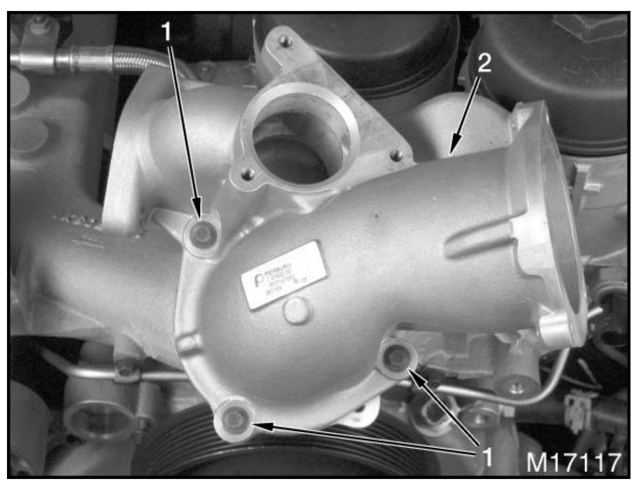

Figure 110 EGR valve elbow housing bolts

1. M6 x 25 bolt (3)
2. EGR valve elbow housing

3. Remove three M6 x 25 bolts retaining EGR valve elbow housing to intake manifold.
4. Remove EGR valve elbow housing and discard gasket.

Cleaning, Inspection, and Testing

Clean and Inspect Exhaust Gas Recirculation (EGR) System Components

1. Clean all gasket material and carbon deposits off of EGR cooler and exhaust manifold mating surfaces.
2. Clean gasket mating surfaces of EGR cooler and EGR valve elbow housing.
3. Clean gasket mating surfaces of EGR valve assembly and remove all carbon deposits, using EGR Valve Bore Cleaning Brush (page 93).
4. Clean all corrosion from ends of all EGR valve assembly coolant pipes and tubes.
5. Clean EGR coolant supply and EGR coolant return ports in front of front crankcase cover assembly.
6. Inspect all EGR system components for cracks and damage. Replace worn or damaged parts.

Exhaust Gas Recirculation (EGR) Valve Assembly

Check pintle shaft and frame for misalignment. Remove EGR valve elbow housing gasket (if not removed) and discard. For electrical inspections, see EGES-350-1 *Engine Diagnostic Manual*.

Exhaust Gas Recirculation (EGR) Cooler

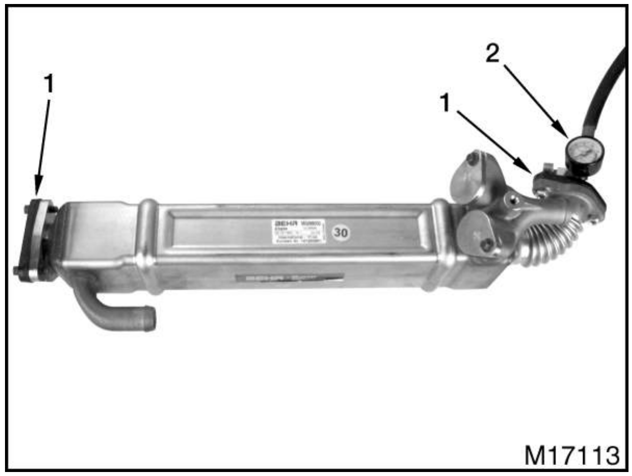

Figure 111 EGR cooler with pressure test plates installed

1. EGR cooler test plates
2. Air pressure regulator assembly

1. Install EGR Cooler Test Plates (page 93) to each end of EGR cooler assembly.

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

2. Attach an air pressure regulator to EGR cooler. Connect to shop air supply and adjust air pressure to approximately 172 to 207 kPa (25 to 30 psi).
3. Completely submerge EGR cooler in a sink or large container of water. Inspect for air bubbles coming from coolant passages.
4. If leaks are not detected, reinstall EGR cooler. If leaks are detected, install a new EGR cooler.

Exhaust Gas Recirculation (EGR) Valve Elbow Housing

The EGR valve elbow housing is a one piece casting and may be cleaned with steam or suitable non-caustic solvents.

Clean contact areas of EGR O-ring in EGR valve elbow housing. Make sure carbon above and below contact areas can be vacuumed from EGR valve elbow housing. Vacuum loose carbon debris.

Installation

Intake Throttle Valve (ITV) and Exhaust Gas Recirculation (EGR) Valve Elbow Housing

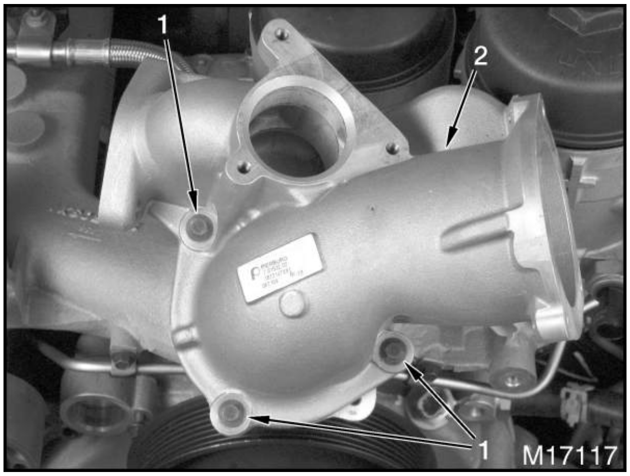

Figure 112 EGR valve elbow housing bolts

1. M6 x 25 bolt (3)
2. EGR valve elbow housing

1. Position a new gasket on intake manifold and install EGR valve elbow housing.
2. Install three M6 x 25 bolts retaining EGR valve elbow housing to intake manifold. Tighten bolts to standard torque (page 383).

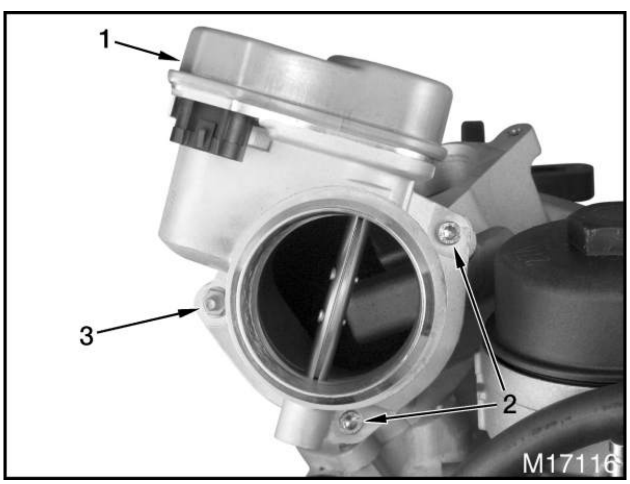

Figure 113 ITV bolts

1. ITV
2. M6 x 20 bolt (2)
3. M6 x 25 stud bolt

3. Position a new gasket and install ITV to EGR valve elbow housing.
4. Install M6 x 25 stud bolt and two M6 x 20 bolts retaining ITV to EGR valve elbow housing. Tighten bolts to special torque (page 93).

Exhaust Gas Recirculation (EGR) Cooler

CAUTION: To prevent engine damage, hand torque all nuts and bolts of EGR system. EGR hardware has a special high-temperature coating which will be damaged by air tools.

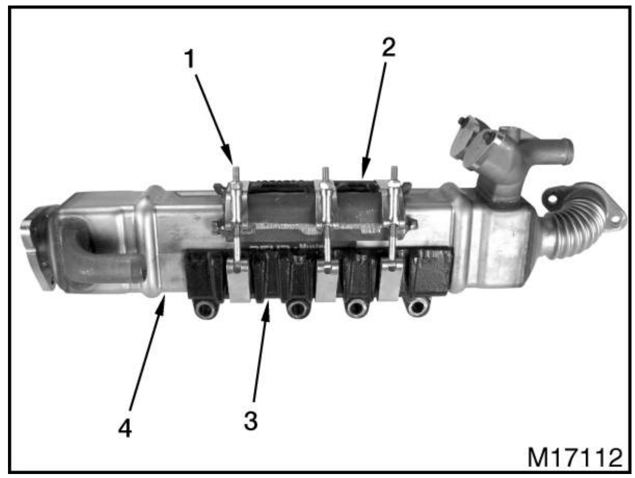

Figure 114 EGR cooler assembly

1. EGR cooler clamp (3)
2. EGR top bracket
3. EGR cooler bracket
4. EGR cooler

1. Place EGR cooler in EGR cooler bracket.
2. Install EGR top bracket on EGR cooler.

NOTE: Do not tighten EGR cooler clamps at this time.

3. Loosely install three new EGR cooler clamps.

NOTE: Make sure two #10 washers are present on turbocharger stud bolts.

4. Position new gaskets and install EGR cooler to engine.

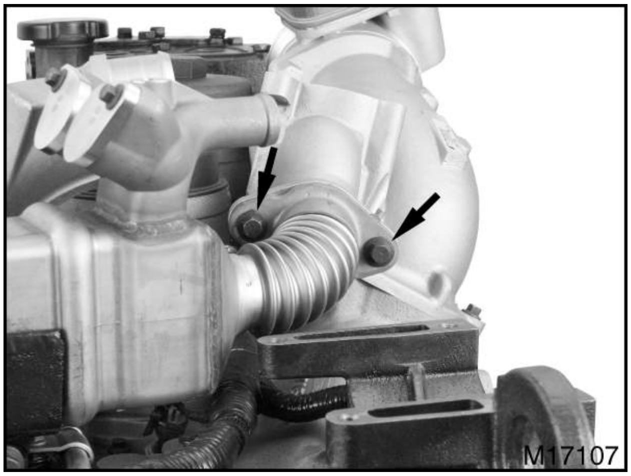

Figure 115 EGR cooler outlet bolts

5. Install two M8 x 20 EGR cooler outlet bolts. Tighten bolts to special torque (page 93).

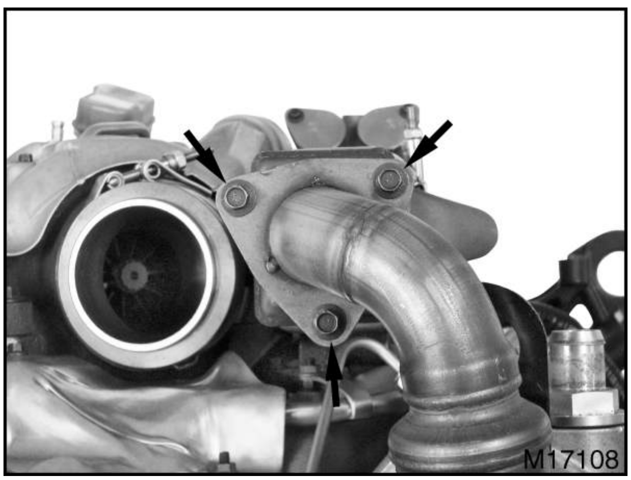

Figure 116 EGR cooler inlet bolts

6. Install three new M8 x 27 EGR cooler inlet bolts. Tighten bolts to standard torque (page 383).

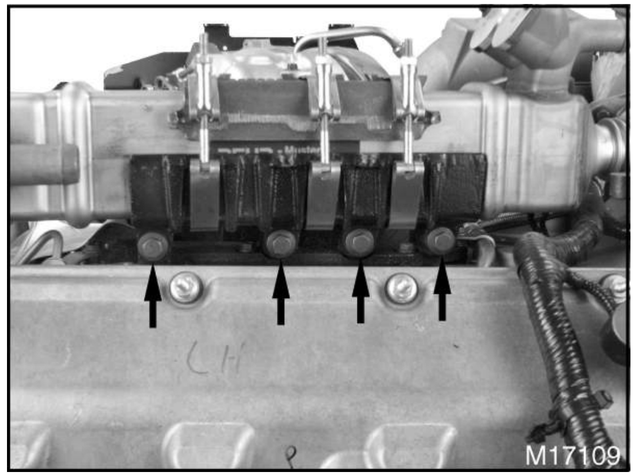

Figure 117 EGR cooler bracket bolts

7. Loosely install four M10 x 50 EGR cooler bracket bolts.
8. Tighten three EGR cooler clamps as follows:
   A. Tighten clamps to 10 N·m (89 lbf·in).
   B. Back out clamps two full turns.
   C. Re-tighten clamps to 8 N·m (71 lbf·in).
9. Tighten four M10 x 50 EGR cooler bracket bolts to standard torque (page 383).

Figure 118 EGR top bracket nuts

10. Install two M10 x 1.5 EGR top bracket nuts. Tighten nuts to special torque (page 93).
11. Install new seals on EGR coolant supply and EGR coolant return tubes.

12. Connect EGR coolant supply and EGR coolant return tubes to EGR cooler and front crankcase cover.

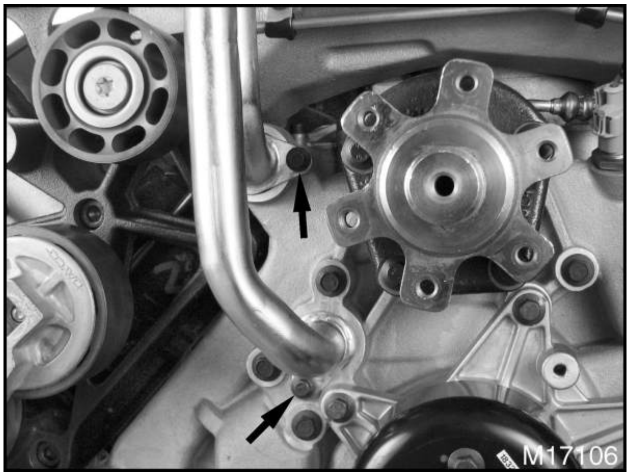

Figure 119 EGR coolant supply and EGR coolant return tube bolts

13. Install EGR coolant supply and EGR coolant return tube bolts. Tighten bolts to standard torque (page 383).

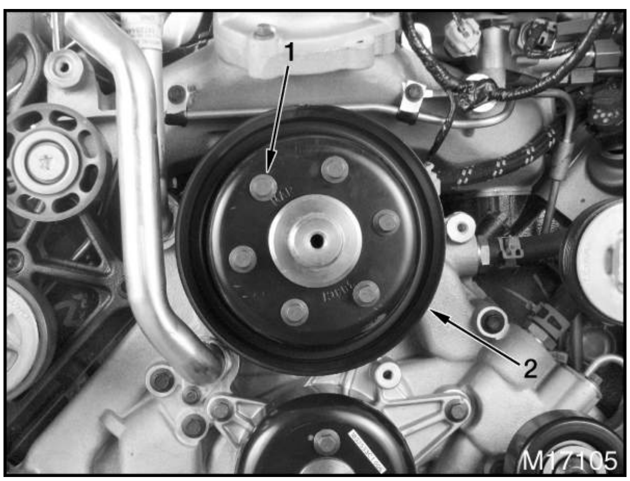

Figure 120 Fan drive pulley

1. M8 x 20 bolts (6)
2. Fan drive pulley

NOTE: Use a holding device to lock fan drive pulley when installing bolts.

14. Install fan drive pulley and six M8 x 20 bolts. Tighten bolts to standard torque (page 383).

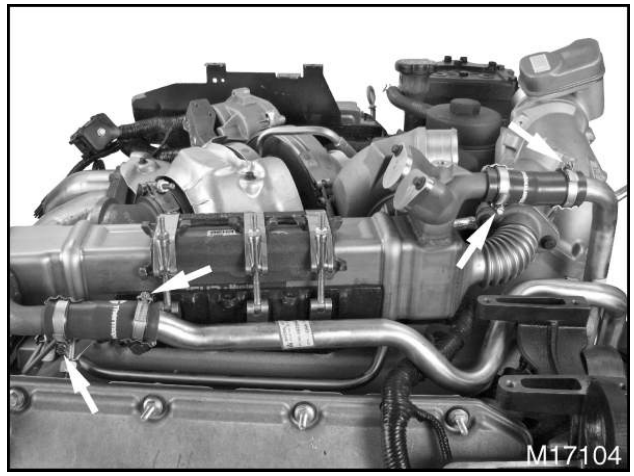

Figure 121 Coolant hose clamps

15. Tighten four coolant hose clamps to special torque (page 93).

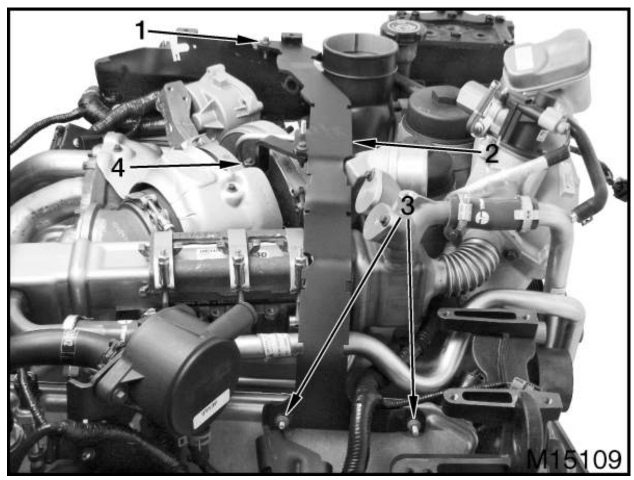

Figure 122 Charging circuit bridge

1. M6 x 16 bolt and nut (1)
2. Charging circuit bridge
3. M6 nut (2)
4. M8 nut (1)

16. Slide charging circuit bridge under wiring harness and onto two right valve cover stud bolts. Install two M6 nuts and tighten to standard torque (page 383).
17. Position charging circuit bridge bracket onto turbo oil inlet flange stud bolt. Install M8 nut and tighten to standard torque (page 383).

18. Secure charging circuit bridge to Engine Control Module (ECM) support with M6 x 16 bolt and nut. Tighten to standard torque (page 383).

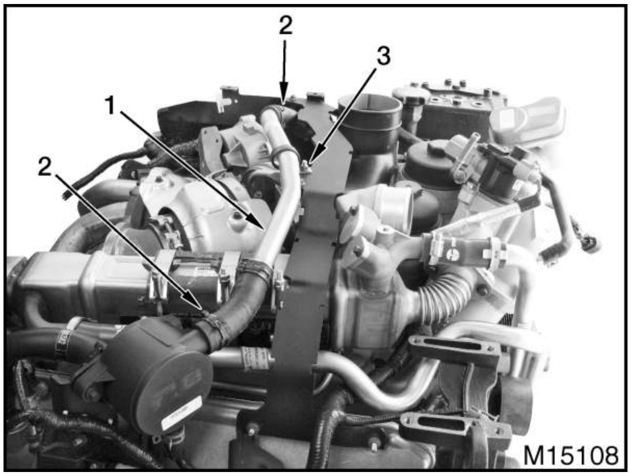

Figure 123 Breather tube

1. Breather tube
2. Breather hose clamps (2)
3. M6 nut

19. Connect breather tube hose to breather and tighten hose clamp.
20. Connect breather tube to turbo air inlet duct and tighten hose clamp.
21. Connect breather tube clamp to charging circuit bridge and secure with M6 nut. Tighten nut to standard torque (page 383).

Exhaust Gas Recirculation (EGR) Valve Assembly

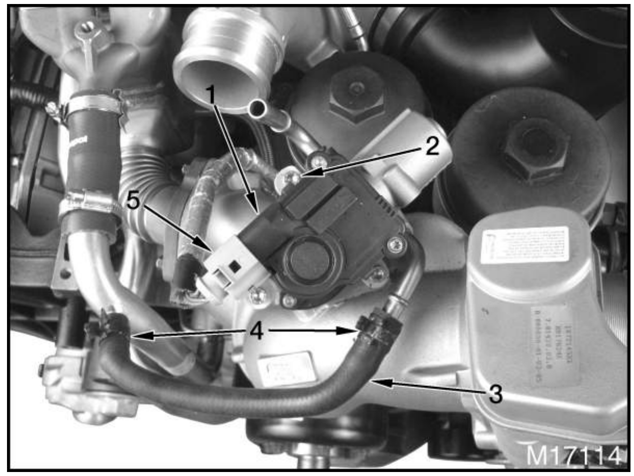

Figure 124 EGR valve assembly

1. EGR valve assembly
2. M6 x 20 bolt (3)
3. EGR valve coolant supply hose
4. Hose clamp (2)
5. EGR valve assembly electrical connector

1. Install a new EGR valve housing gasket on EGR valve assembly.
2. Install EGR valve assembly.

   NOTE: Make sure EGR valve assembly is fully seated.
3. Install three M6 x 20 EGR valve assembly bolts. Tighten bolts to special torque (page 93).
4. Connect EGR valve coolant return hose and position two hose clamps (not shown in Figure 34).
5. Connect EGR valve coolant supply hose and position two hose clamps.
6. Connect EGR valve assembly electrical connector.

Special Torque

Table 6 Exhaust Gas Recirculation (EGR) System

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

Special Service Tools

Table 7 Exhaust Gas Recirculation (EGR) System

Description	Tool Number
EGR Valve Bore Cleaning Brush	ZTSE4753
EGR Valve Puller	ZTSE4743
EGR Cooler Test Plates	ZTSE4707

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Description

Exploded View

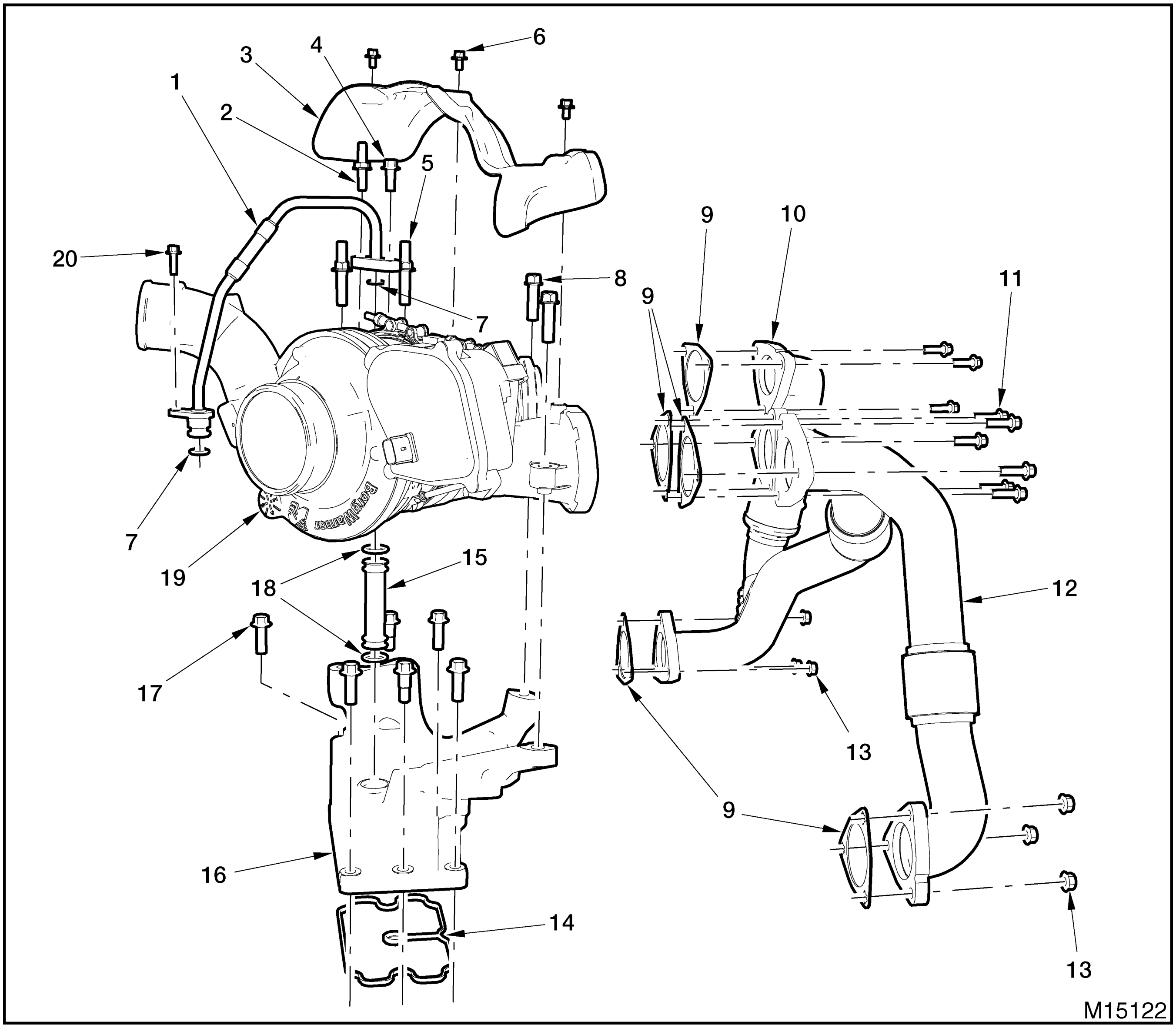

Figure 125 Variable Geometry Turbocharger (VGT) components

1. Turbo oil supply tube assembly
2. M8 stud bolt
3. Turbo heat shield
4. M8 x 20 bolt
5. M10 stud bolt (2)
6. M6 x 10 bolt (3)
7. O-ring (2)
8. M10 x 35 bolt (2)
9. Exhaust tube gasket (5)
10. Right exhaust tube
11. M8 x 27 bolt (9)
12. Left exhaust tube
13. M8 nut (6)
14. Turbo bracket gasket
15. Turbo oil drain tube
16. Turbo support
17. M10 x 30 bolt (6)
18. Turbo oil drain tube O-ring (2)
19. Turbocharger assembly
20. M6 x 20 bolt

Operation

The VGT is a closed loop system that uses the Exhaust Back Pressure (EBP) sensor to provide feedback to the Electronic Control Module (ECM). The ECM uses the EBP sensor to continuously monitor the EBP and adjust the duty cycle to the VGT to match engine requirements.

The VGT increases power output by supplying compressed air to the engine. The internal components are oil and air cooled. Engine oil is circulated through the housing, which acts as a heat barrier between the hot turbine and the cold compressor. Sleeve bearings are lubricated by engine oil. Oil is pumped directly from the oil filter base, circulates to the VGT housing, and returns to the sump through an oil drain in the VGT center housing.

Expanding exhaust gases drive the turbine shaft assembly to speeds over 100,000 rpm. Filtered air entering the compressor side of the VGT is compressed and delivered through a charge air cooler (CAC). Hot compressed air is cooled, filling the intake manifold at a pressure higher than atmospheric pressure. Because considerably more air is forced into the intake manifold, the results are increased power, fuel efficiency and the ability to maintain power at higher altitudes.

The VGT actuator, a variable position actuator, controls turbocharger turbine vane position. The VGT actuator is part of the turbocharger assembly, and is controlled by the controlled area network signals from the ECM in response to engine speed, required fuel quantity, boost, exhaust back pressure, and altitude. The VGT actuator controls the movement of the vanes linked by an adjusting ring in the turbine housing. Turbine exhaust gas flow and resulting VGT boost are modified by vane position.

The key feature of the VGT is actuated vanes in the turbine housing. The vanes modify the flow characteristics of the exhaust gases through the turbine housing. This controls boost pressure needed for various engine speeds and load conditions. An additional benefit is lower exhaust emissions.

Actuated vanes are mounted around the inside circumference of the turbine housing. An adjusting ring links all the vanes. When the adjusting ring moves, all vanes move to the same position. Adjusting ring movement occurs when the VGT actuator receives a controlled area network signal for a required position.

Exhaust gas flow can be regulated depending on the required exhaust back pressure for engine speed and load. As power demands increase, exhaust gas velocity increases in direct relation, as does intake manifold boost pressure. Conversely, as the flow of exhaust gas diminishes, intake manifold boost pressure is also reduced at the same rate.

Removal

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

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

WARNING: To prevent personal injury or death, make sure the engine and turbocharger have cooled before removing the turbocharger.

WARNING: To prevent personal injury or death, remove the ground cable from the negative terminal of the main battery before disconnecting or connecting electrical components. Always connect the ground cable last.

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

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

NOTE: See the following service sections for information on removal of components prior to this section.

- Engine Electrical
- Exhaust Gas Recirculation (EGR) System

Left Exhaust Tube

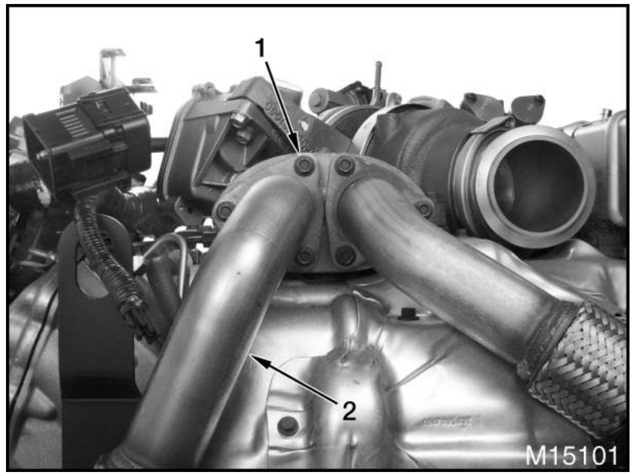

Figure 126 Left exhaust tube to turbocharger assembly connection

1. M8 x 27 bolt (3)
2. Left exhaust tube

1. Remove and discard three M8 x 27 bolts.
2. Remove and discard left exhaust tube gasket.

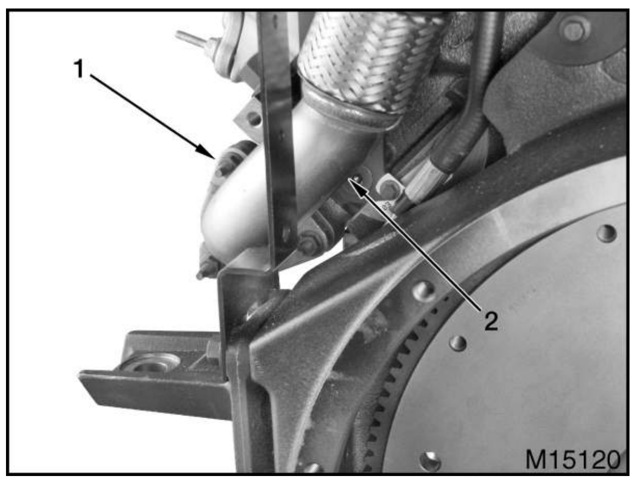

Figure 127 Left exhaust tube to exhaust manifold connection

1. M8 nut (3)
2. Left exhaust tube

3. Remove and discard three M8 nuts from left exhaust manifold studs.
4. Disconnect and remove left exhaust tube.

5. Remove and discard left exhaust tube to manifold gasket.

Right Exhaust Tube

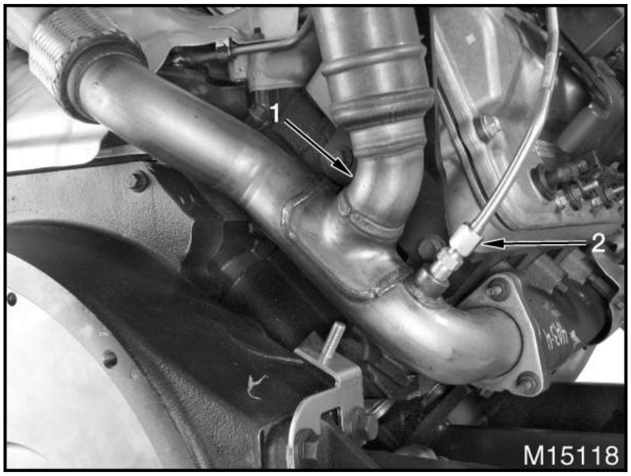

Figure 128 Exhaust Back Pressure (EBP) sensor tube connection

1. Right exhaust tube
2. EBP sensor tube fitting nut

1. Loosen EBP sensor tube fitting nut.
2. Disconnect EBP sensor tube and position aside.

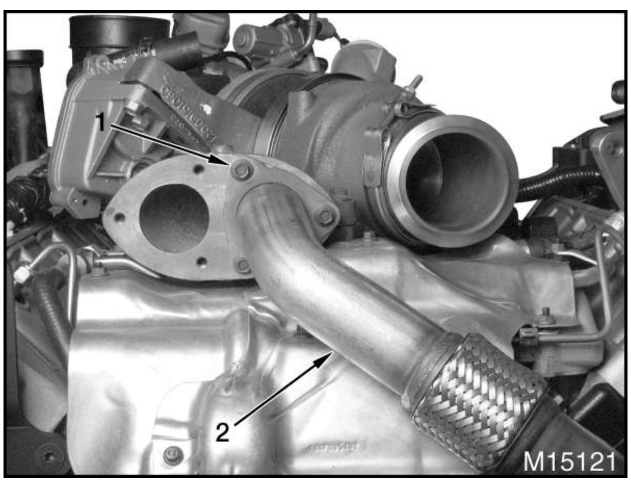

Figure 129 Right exhaust tube to turbocharger assembly connection

1. M8 x 27 bolt (3)
2. Right exhaust tube

3. Remove and discard three M8 x 27 bolts.
4. Remove and discard right exhaust tube gasket.

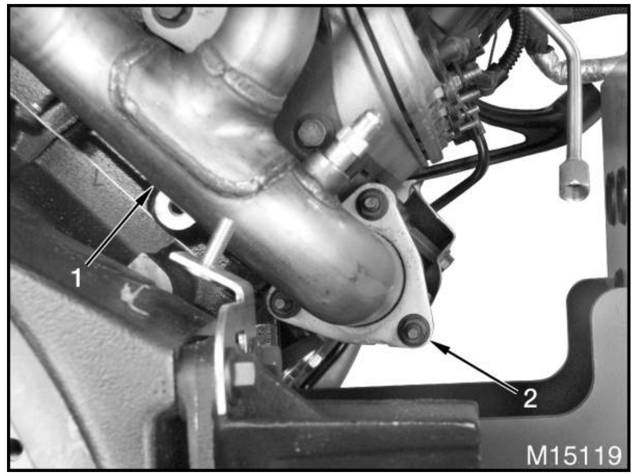

Figure 130 Right exhaust tube to exhaust manifold connection

1. Right exhaust tube
2. M8 nut (3)

5. Remove and discard three M8 nuts from right exhaust manifold studs.
6. Disconnect and remove right exhaust tube.
7. Remove and discard right exhaust tube to manifold gasket.
8. Remove EBP sensor tube fitting from right exhaust tube.

Variable Geometry Turbocharger (VGT) Assembly and Components

1. Remove Exhaust Gas Recirculation (EGR) cooler (page 84).

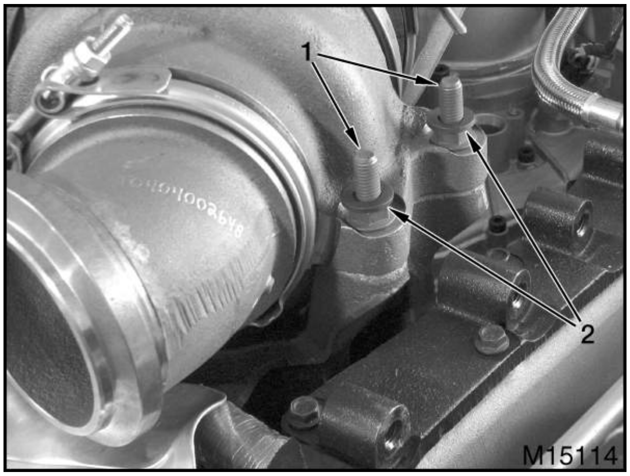

Figure 131 EGR top bracket washers

1. Stud bolt (2)
2. #10 washer (2)

2. Remove two #10 washers from turbocharger stud bolts.

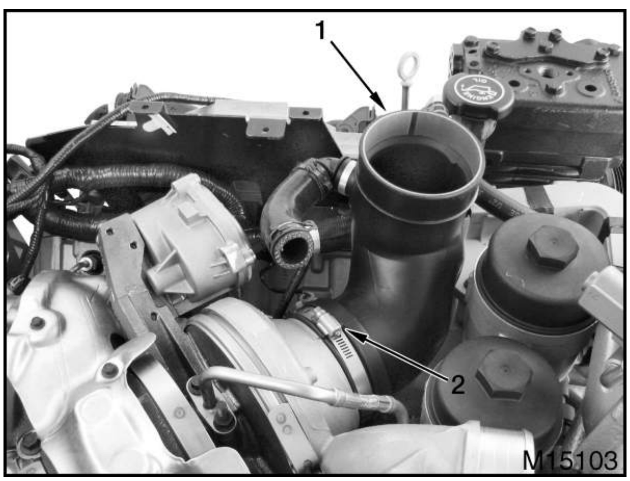

Figure 132 Turbo air inlet duct

1. Turbo air inlet duct
2. Turbo air inlet duct clamp

NOTE: Mark the orientation of the turbo air inlet duct so that it can be installed in its original position.

3. Loosen turbo air inlet duct clamp.
4. Remove turbo air inlet duct.
5. Cover opening of turbocharger assembly air inlet with Cap Kit (page 113).

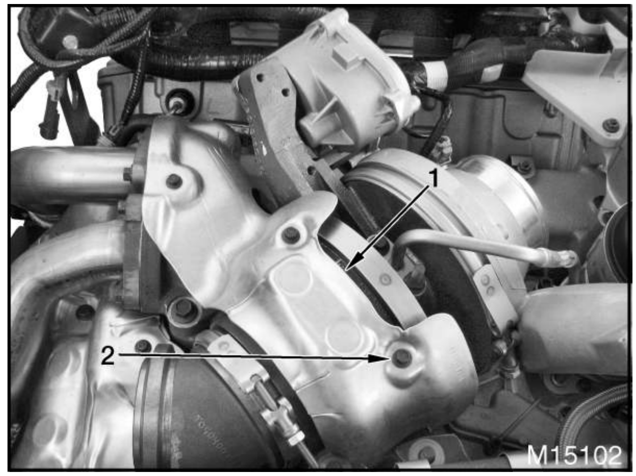

Figure 133 Turbo heat shield

1. Turbo heat shield
2. M6 x 10 bolt (3)

6. Remove three M6 x 10 bolts.
7. Remove turbo heat shield.

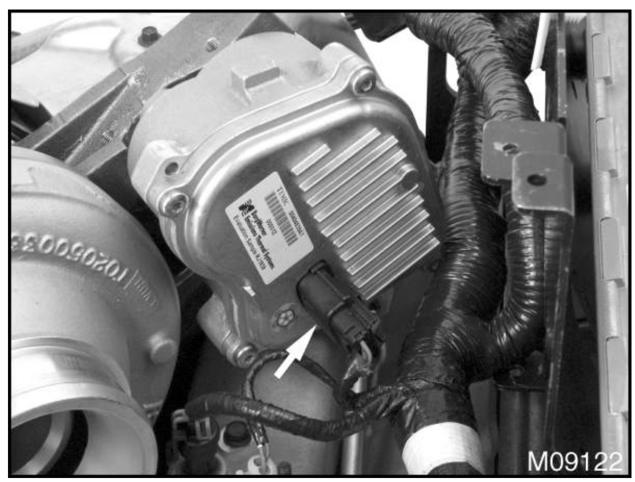

Figure 134 VGT actuator electrical connector

8. Disconnect electrical connector from VGT actuator.

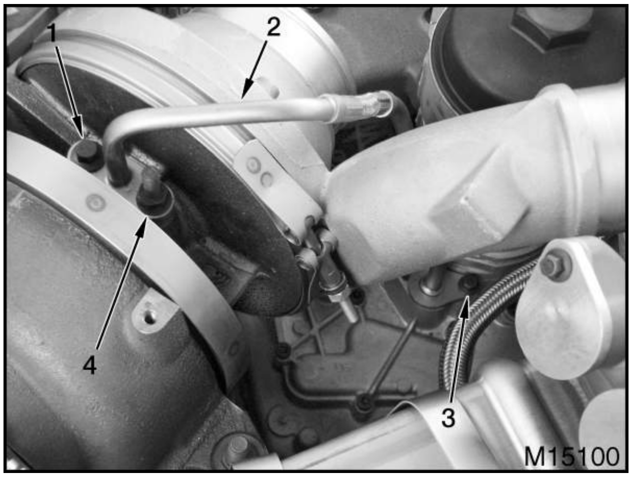

Figure 135 Turbo oil supply tube assembly

1. M8 x 20 bolt
2. Turbo oil supply tube assembly
3. M6 x 20 bolt
4. M8 stud bolt

9. Remove M6 x 20 bolt from turbo oil supply tube assembly at oil filter base assembly.
10. Remove M8 x 20 bolt from turbo oil supply tube assembly at turbocharger assembly.
11. Remove M8 stud bolt from turbo oil supply tube assembly at turbocharger assembly.
12. Remove turbo oil supply tube assembly.
13. Remove and discard O-rings.
14. Cover turbo oil supply tube port assembly port in the oil filter base assembly with Turbo Oil Supply Block Off Plug Kit (page 113).

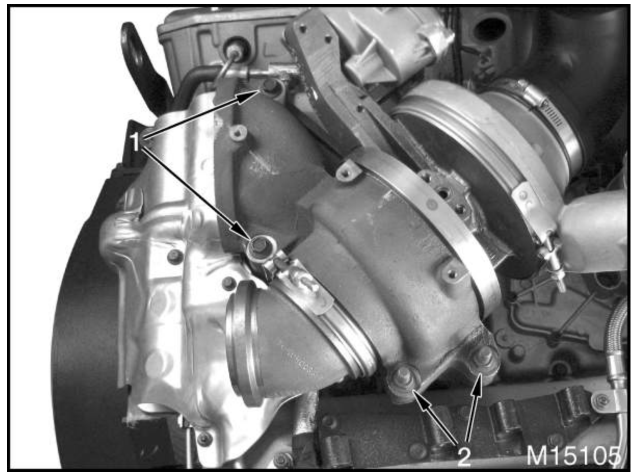

Figure 136 Turbocharger assembly mounting

1. M10 x 35 bolt (2)
2. M10 stud bolt (2)

15. Remove two turbocharger assembly M10 x 35 bolts.
16. Remove two turbocharger assembly M10 stud bolts.
17. Lift turbocharger assembly up and off engine.

NOTE: Use Cap Kit (page 113) to cover turbocharger assembly openings. If plastic caps are not available, cover openings with tape.

Figure 137 Turbo oil drain tube

18. Remove turbo oil drain tube.

NOTE: If removing turbocharger assembly only, plug drain hole in turbo support with Turbo Oil Supply Block Off Plug Kit (page 113) to keep out foreign material.

19. Remove and discard two turbo oil drain tube O-rings.

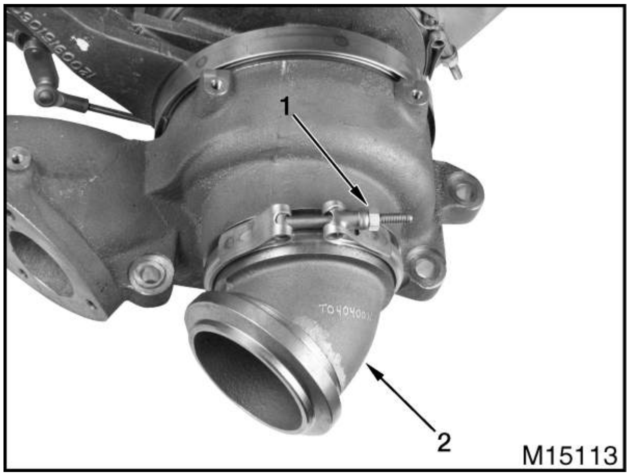

Figure 138 Turbocharger assembly exhaust outlet

1. Exhaust outlet V-clamp
2. Exhaust outlet

20. Loosen exhaust outlet V-clamp nut and remove V-clamp.

CAUTION: To prevent engine damage, do not twist the exhaust outlet or wedge a pry tool between the exhaust outlet and turbocharger; damage to the locating pin may occur, resulting in improper alignment of the exhaust outlet.

21. Remove exhaust outlet.

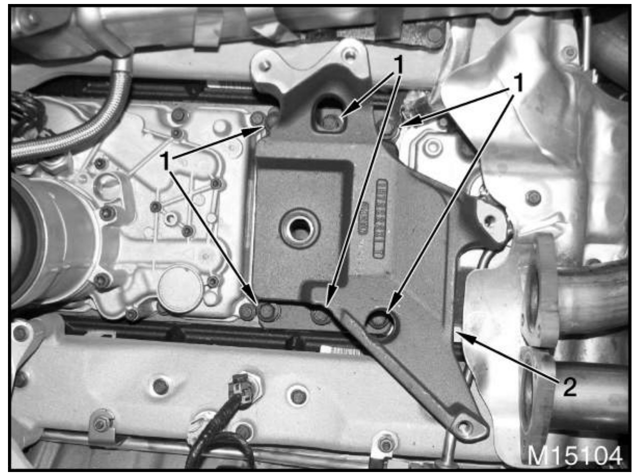

Figure 139 Turbo support

1. M10 x 30 bolt (6)
2. Turbo support

22. Remove six M10 x 30 turbo support bolts.
23. Remove turbo support.
24. Remove and discard turbo bracket gasket.

Turbo Actuator Assembly

Only remove the turbocharger actuator and linkage if the turbocharger actuator is defective.

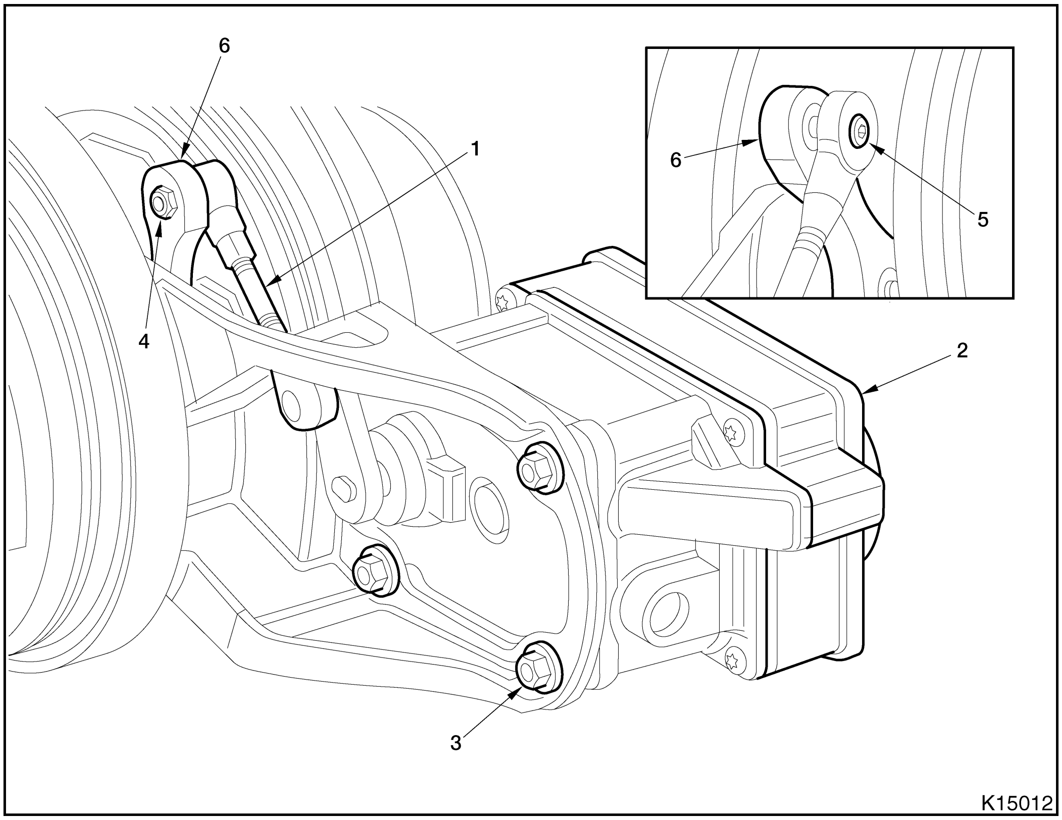

Figure 140 Turbocharger Actuator and linkage

1. Actuator linkage
2. Turbo actuator
3. Serrated lock nut (4)
4. Lock nut
5. Recessed hex area on ball stud
6. Variable Geometry Turbocharger (VGT) lever

1. To access blocked serrated lock nut, pivot actuator linkage out of the way, against spring pressure. Hold linkage in place using a tie strap against spring tension.
2. Insert a long 4 mm Allen wrench into recessed hex area on ball stud of the actuator linkage. Rotate ball stud to disengage from lock nut in recessed pocket. Remove lock nut from actuator linkage. Discard lock nut.

NOTE: Actuator shaft may require rotation or rocking motion to remove.

3. Once the actuator linkage is disconnected from the turbocharger, determine if the VGT lever is sticking or not sticking. Manually rotate the VGT lever with a slow consistent pressure.
   - If the VGT lever is not sticking, continue with step 4.
   - If the VGT lever is sticking or will not reach the endstop, stop. Clean the VGT lever; then, manually rotate the VGT lever with a slow consistent pressure. If the VGT lever does not reach the endstop, install a new turbocharger assembly.
4. Remove and discard four serrated lock nuts.
5. Lift up on actuator linkage arm and remove turbo actuator from mounting bracket.

Cleaning and Inspection

Variable Geometry Turbocharger (VGT) Assembly and Related Parts Cleaning

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

NOTE: Do not use a caustic solution on turbocharger assembly and related components.

1. Clean piping between turbocharger assembly and air cleaner assembly with soap and water. Dry all piping with filtered compressed air.
2. Clean air inlet piping and connecting hoses with filtered compressed air.
3. Clean oil inlet tube and oil drain tube with a nonchlorinated solvent and a nylon brush. Dry tubes with filtered compressed air. Replace any damaged tubes.

NOTE: Corrosion on the turbocharger or actuator shafts may inhibit the motion of the turbocharger vane mechanism.

4. Clean the area adjacent to the housing on both the turbocharger and actuator shafts and make sure both shafts turn freely. Use a suitable corrosion removal product to clean the shafts.
5. Make sure the turbocharger shaft moves freely.

Inspection

1. Inspect turbocharger assembly for cracks and leaks. Replace if necessary.
2. Inspect compressor impeller and turbine wheel for blade erosion, bending, breakage or deposits. Replace turbocharger assembly if damaged.

NOTE: Replace turbocharger assembly if blades are bent. Do not attempt to straighten bent wheel blades.

Check Free Rotation and Housing Rub

1. Place turbocharger assembly on a bench with the shaft in a horizontal position.

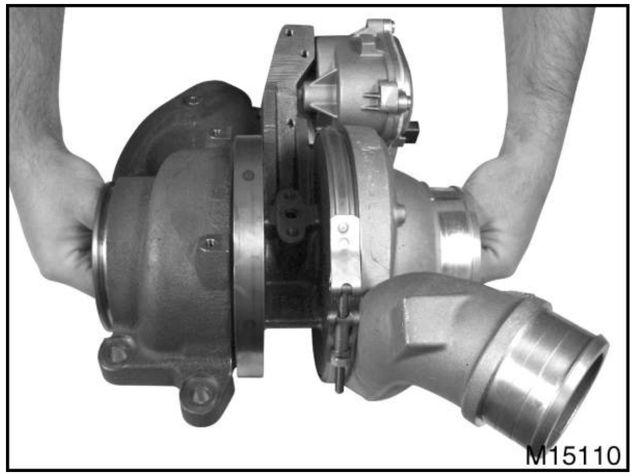

Figure 141 Free rotation of turbocharger assembly shaft

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

   The wheels must rotate freely. If there is any rubbing or interference, replace turbocharger assembly.

Check Axial End Play

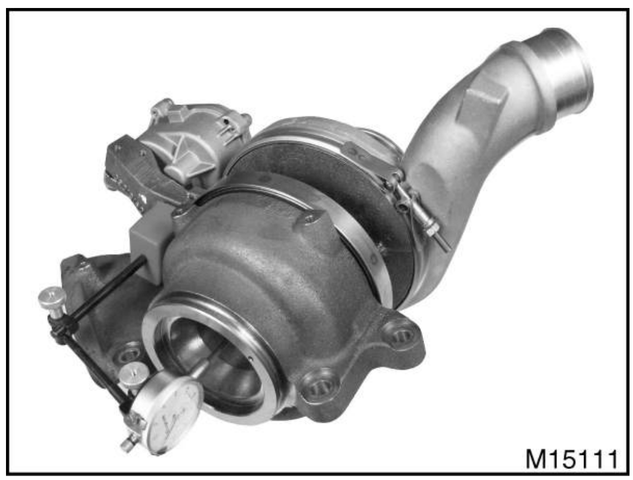

Figure 142 Axial end play

1. Install dial indicator with magnetic base (page 113) on the flat surface of turbocharger housing opposite to VGT actuator. Push turbine shaft away from dial indicator. Put tip of dial indicator on turbine shaft end and zero the indicator.

2. Manually move turbine shaft toward and then away from dial indicator. If turbine shaft axial end play exceeds specifications (page 113), replace turbocharger assembly.

Installation

Turbo Actuator Assembly

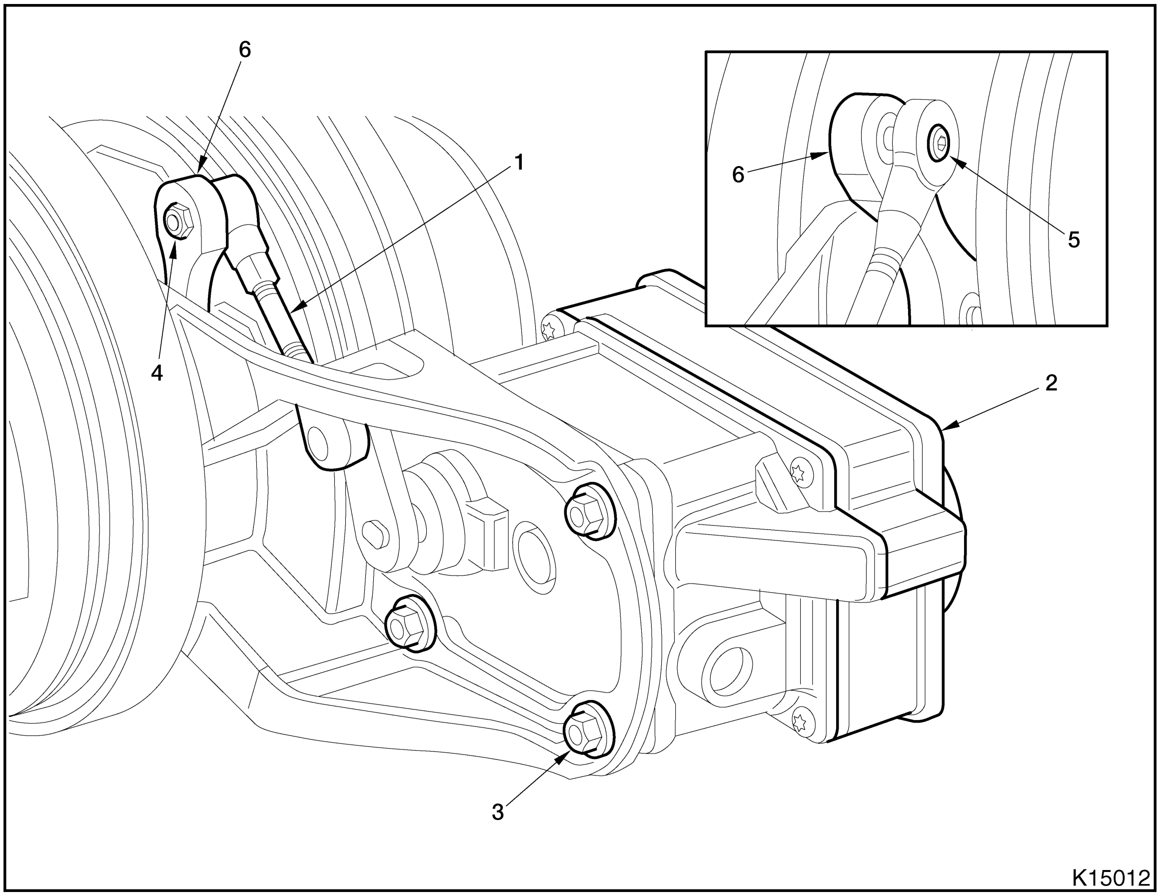

Figure 143 Turbocharger Actuator and linkage

1. Actuator linkage
2. Turbo actuator
3. Serrated lock nut (4)
4. Lock nut
5. Recessed hex area on ball stud
6. Variable Geometry Turbocharger (VGT) lever

1. Insert turbocharger linkage through mounting bracket opening.

NOTE: Rotation of shaft or linkage is required for actuator studs to be properly installed.

2. Slide actuator studs into mounting bracket holes. Install four new serrated lock nuts on studs. Torque nuts to 13.6 N·m (120 lbf·in). If used, remove tie strap holding actuator.
3. Install new lock nut into hex pocket on VGT lever with rounded side of the nut facing outward. Hold lock nut in place and insert 4 mm Allen wrench into recessed area located on the ball stud. Turn ball stud to engage the lock nut and torque ball stud to 8.5 N·m (75 lbf·in).
4. Manually rotate linkage assembly in a slow consistent manner checking to see if there is any binding due to misalignment of linkage.
   - If binding, determine source of binding or remove actuator linkage from the turbocharger and repeat steps 1 through 4.

Variable Geometry Turbocharger (VGT) Assembly and Components

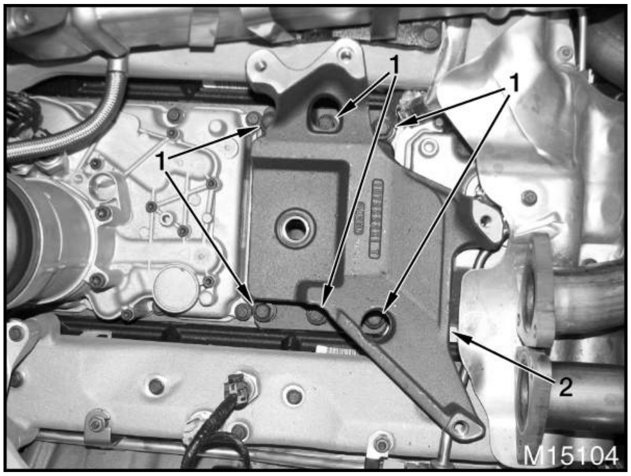

Figure 144 Turbo support

1. M10 x 30 bolt (6)
2. Turbo support

1. Place a new turbo bracket gasket in engine valley.
2. Place turbo support in engine valley.

NOTE: If not immediately installing the turbocharger assembly, cover turbo oil drain hole with Turbo Oil Supply Block Off Plug Kit (page 113).

3. Install six M10 x 30 bolts to secure turbo support to crankcase. Tighten bolts to special torque (page 113).

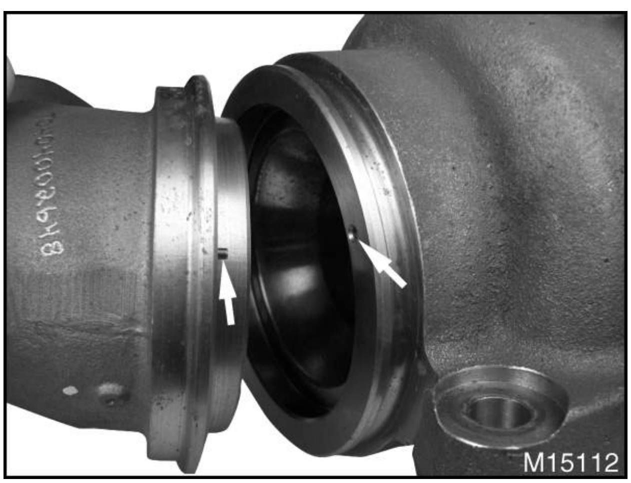

Figure 145 Align turbocharger assembly exhaust outlet

NOTE: Align pin on turbocharger assembly exhaust outlet with hole in turbocharger assembly.

4. Attach turbocharger assembly exhaust outlet to turbocharger assembly.

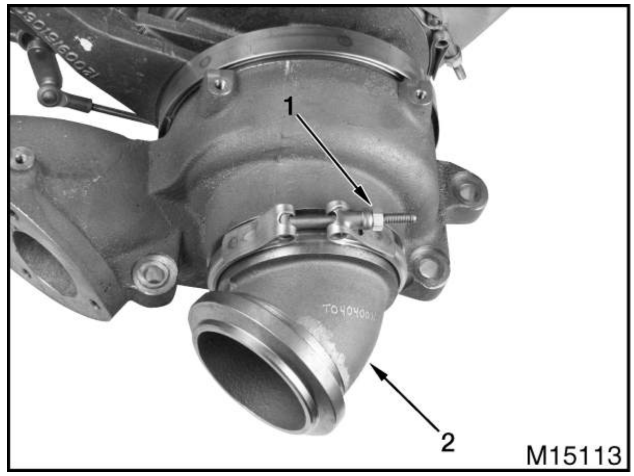

Figure 146 Turbocharger assembly exhaust outlet

1. Exhaust outlet V-clamp
2. Exhaust outlet

5. Install turbocharger assembly exhaust outlet V-clamp and tighten to special torque (page 113).
6. Remove Turbo Oil Supply Block Off Plug Kit (page 113) from turbo support.
7. Install two new turbo oil drain tube O-rings and lubricate both O-rings with clean engine oil.

Figure 147 Turbo oil drain tube

8. Install turbo drain tube into turbo support.
9. Remove turbo oil drain tube cap (if installed) and lower turbocharger assembly on turbo support and turbo oil drain tube.

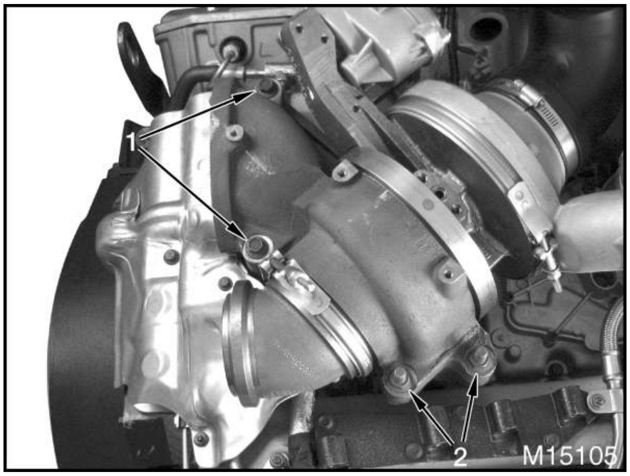

Figure 148 Turbocharger assembly mounting

1. M10 x 35 bolt (2)
2. M10 stud bolt (2)

10. Coat threads of two M10 x 35 flange head bolts and two M10 stud bolts with anti-seize compound and secure turbocharger assembly to turbo support.
11. Tighten turbocharger assembly bolts and stud bolts to special torque (page 113).
12. Remove Turbo Oil Supply Block Off Plug (page 113) from oil filter base assembly.

CAUTION: To prevent engine damage, lubricate turbocharger assembly bearings before installing the turbocharger assembly.

13. Lubricate oil inlet hole of turbocharger assembly with clean engine oil and spin compressor wheel several times to coat bearings with oil. Refill oil inlet hole up to oil supply tube assembly mounting surface.
14. Install and lubricate a new O-ring on turbo oil supply tube assembly.
15. Install a new O-ring on turbocharger assembly oil supply port.

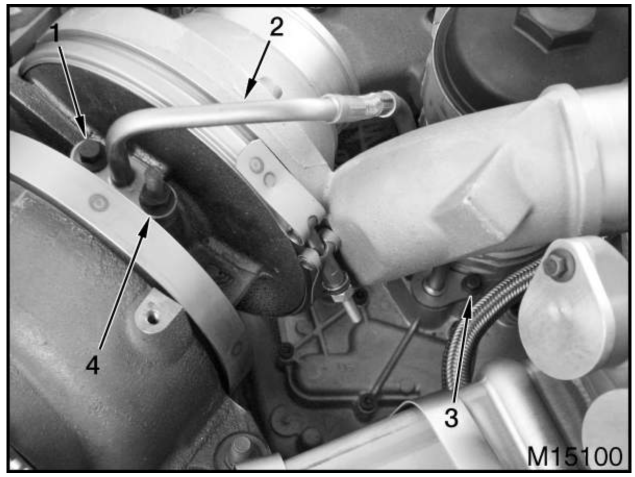

Figure 149 Turbo oil supply tube assembly

1. M8 x 20 bolt
2. Turbo oil supply tube assembly
3. M6 x 20 bolt
4. M8 stud bolt

16. Install turbo oil supply tube assembly in oil supply line port in oil filter base assembly.
17. Install M6 x 20 turbo oil supply tube assembly to oil filter base assembly bolt. Tighten bolt to special torque (page 113).
18. Position oil supply tube flange over turbocharger assembly oil supply port and secure with M8 x 20 bolt and M8 stud bolt.

NOTE: Alternate tightening between bolt and stud bolt until correct torque is reached.

19. Tighten turbo oil supply tube assembly to turbocharger bolt and stud bolt to special torque (page 113).

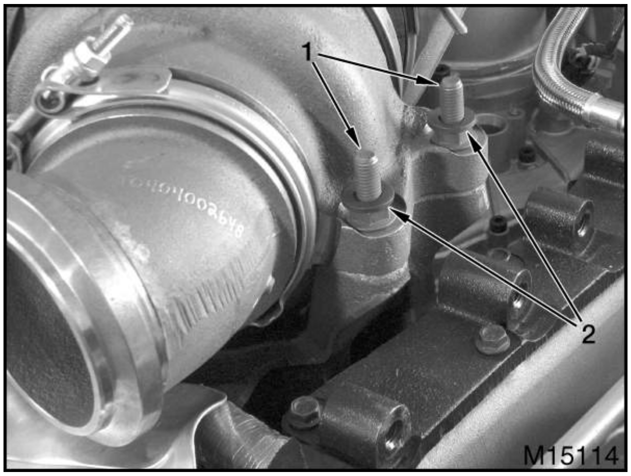

Figure 150 EGR top bracket washers

1. Stud bolt (2)
2. #10 washer (2)

20. Place two #10 washers on turbocharger stud bolts.

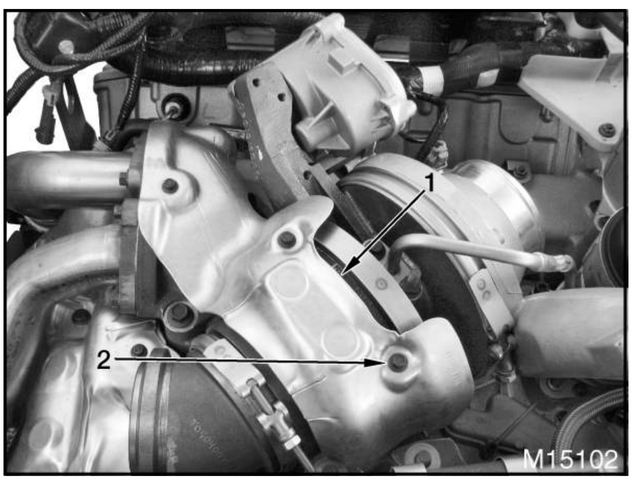

Figure 151 Turbo heat shield

1. Turbo heat shield
2. M6 x 10 bolt (3)

21. Install turbo heat shield on VGT.
22. Install three M6 x 10 bolts and tighten to special torque (page 113).

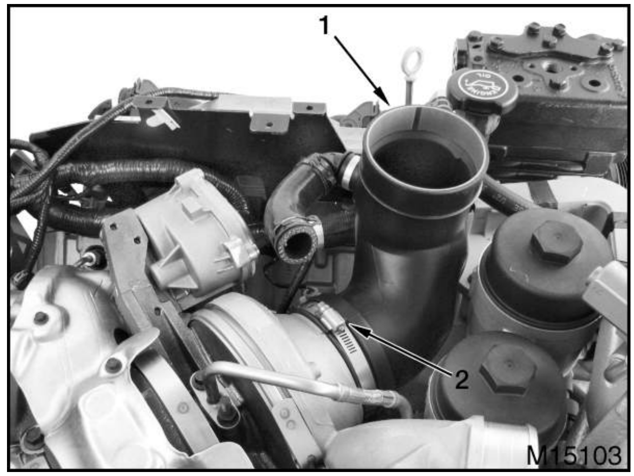

Figure 152 Turbo air inlet duct

1. Turbo air inlet duct
2. Turbo air inlet duct clamp

23. Install turbo air inlet duct on turbocharger assembly.

NOTE: Before tightening clamp, position the turbo air inlet duct according to the alignment marks made during removal.

24. Secure turbo air inlet duct to turbocharger assembly by tightening clamp to special torque (page 113).

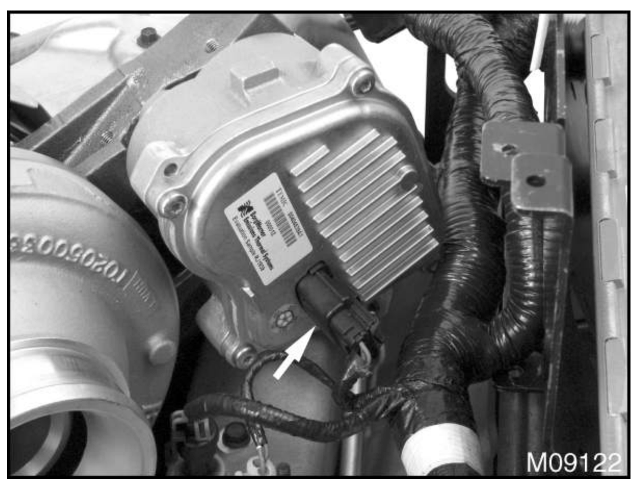

Figure 153 VGT actuator electrical connector

25. Connect electrical connector to VGT actuator.
26. Install Exhaust Gas Recirculation (EGR) cooler (page 89).

Right Exhaust Tube

1. Install a new gasket on right exhaust manifold studs.

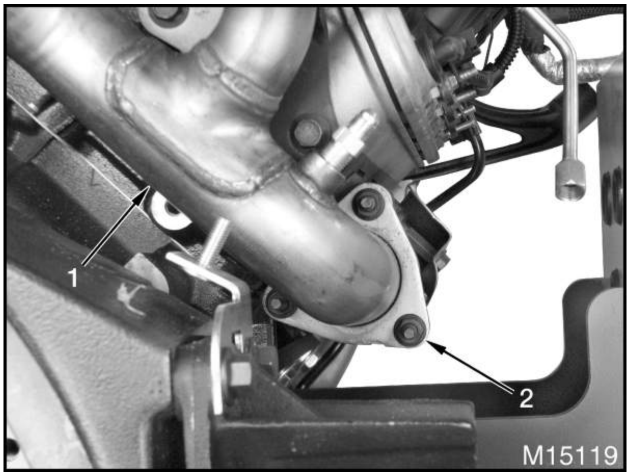

Figure 154 Right exhaust tube to exhaust manifold connection

1. Right exhaust tube
2. M8 nut (3)

2. Install right exhaust tube to manifold with three new M8 nuts. Do not tighten nuts at this time.

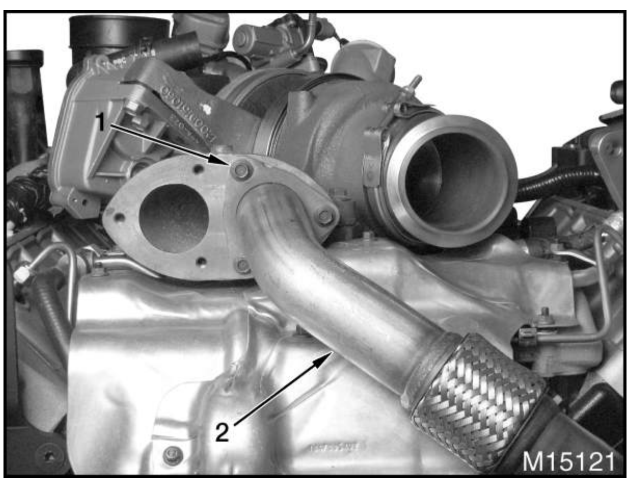

Figure 155 Right exhaust tube to turbocharger assembly connection

1. M8 x 27 bolt (3)
2. Right exhaust tube

3. Install a new gasket on right exhaust tube to turbocharger assembly and secure with three new M8 x 27 bolts.
4. Tighten three right exhaust tube to exhaust manifold M8 nuts to special torque (page 113).
5. Tighten three right exhaust tube to turbocharger assembly M8 x 27 bolts to special torque (page 113).
6. Install Exhaust Back Pressure (EBP) sensor tube fitting on right exhaust manifold. Tighten fitting to special torque (page 113).

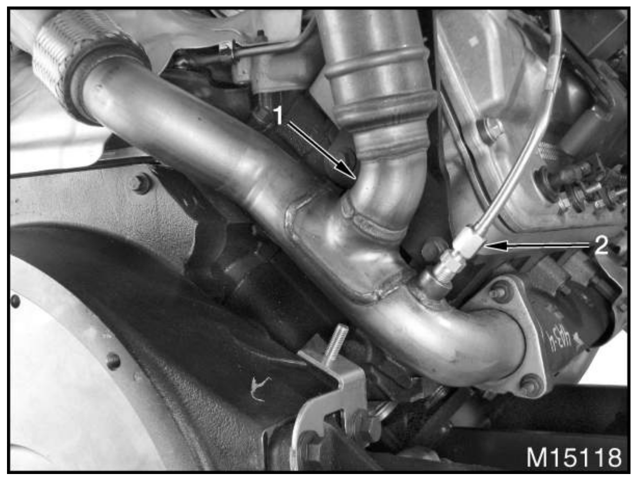

Figure 156 EBP sensor tube connection

1. Right exhaust tube
2. EBP sensor tube fitting nut

7. Connect EBP sensor tube.

NOTE: When using a crowfoot extension make sure to adjust the torque settings as necessary to compensate for any length added to the torque wrench. See Appendix B - Torques (page 384).

8. Tighten fitting nut to special torque (page 113).

Left Exhaust Tube

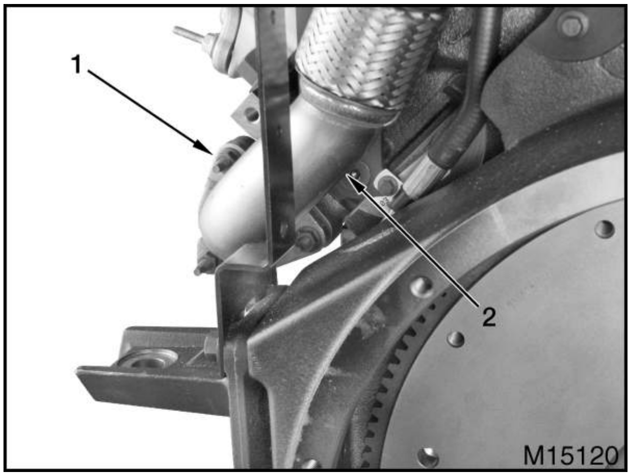

Figure 157 Left exhaust tube to exhaust manifold connection

1. M8 nut (3)
2. Left exhaust tube

1. Install a new gasket on left exhaust manifold studs.
2. Install left exhaust tube to exhaust manifold with three new M8 nuts. Do not tighten nuts at this time.

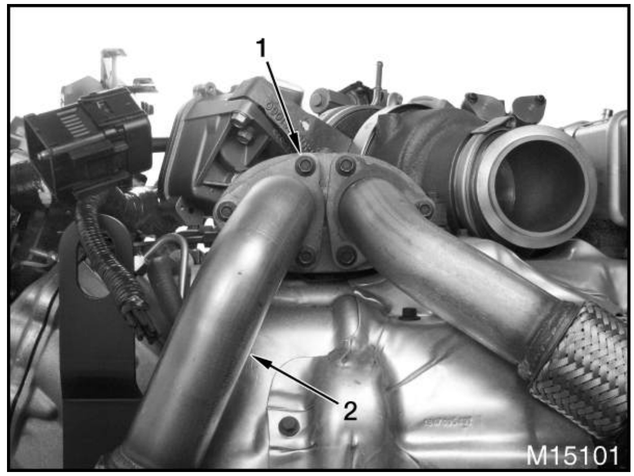

Figure 158 Left exhaust tube to turbocharger assembly connection

1. M8 x 27 bolt (3)
2. Left exhaust tube

3. Install a new gasket on left exhaust tube to turbocharger assembly and secure flange with three new M8 x 27 bolts.
4. Tighten three left exhaust tube to manifold M8 nuts to special torque (page 113).
5. Tighten three left exhaust tube to turbocharger assembly M8 x 27 bolts to special torque (page 113).

Specifications

Table 8 Variable Geometry Turbocharger (VGT) Shaft

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

Special Torque

Table 9 Turbocharger Assembly Bolts and Clamps

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

Special Service Tools

Table 10 Turbocharger

Description	Tool Number
Cap Kit (All)	Obtain locally
Dial indicator with magnetic base	Obtain locally
Turbo Oil Supply Block Off Plug Kit	ZTSE4785

Table of Contents

Exploded Views

Air Compressor

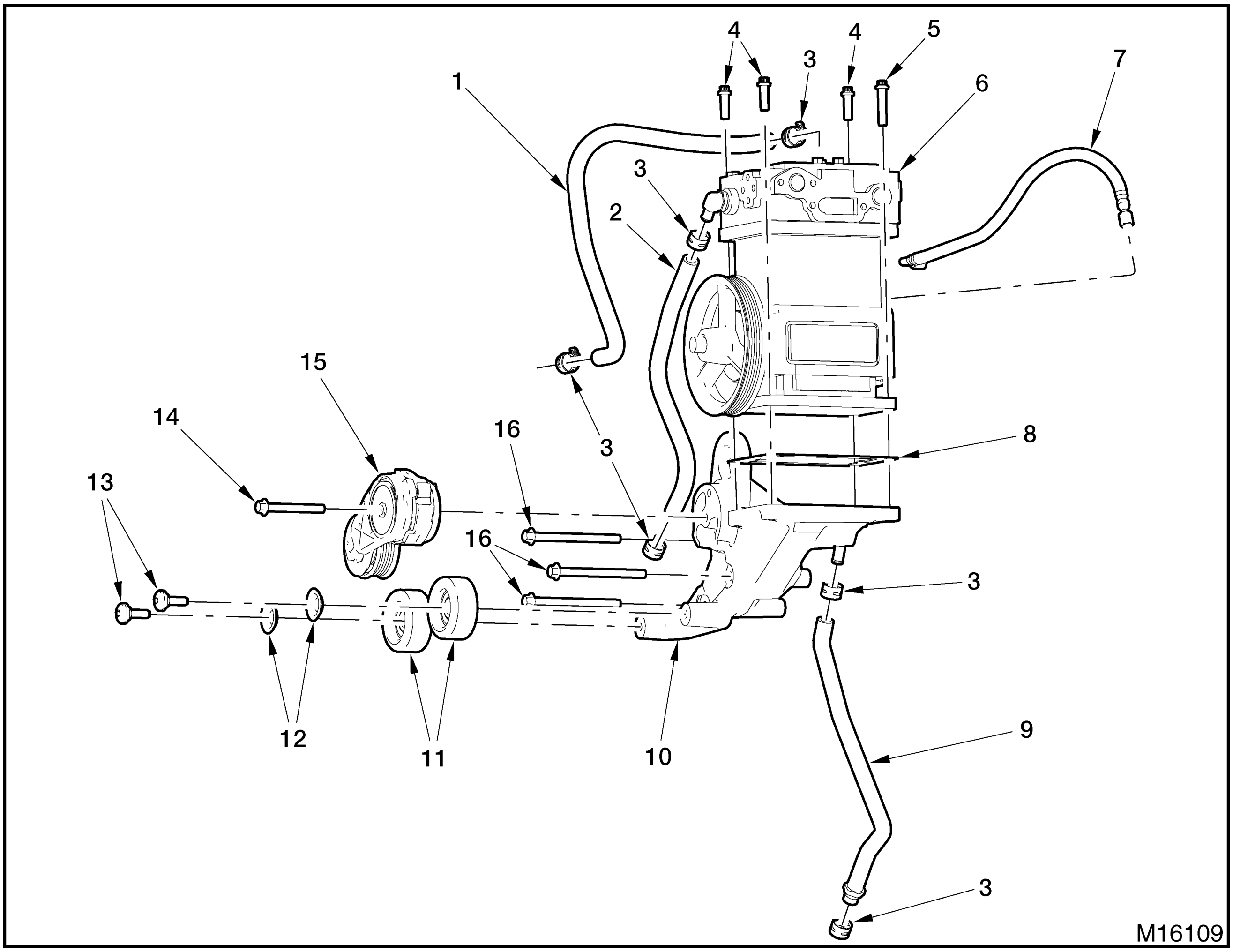

Figure 159 Air compressor

1. Coolant return hose
2. Coolant supply hose
3. Hose clamp (6)
4. M10 X 30 bolt (3)
5. M10 X 45 bolt
6. Air compressor
7. Oil supply hose
8. Air compressor gasket
9. Oil return hose
10. Air compressor bracket
11. Belt idler (2)
12. Idler dust cover (2)
13. M10 X 30 bolt (2)
14. M10 X 80 bolt
15. Belt tensioner
16. M10 X 120 bolt (3)

Power Steering/Fuel Pump and Related Components

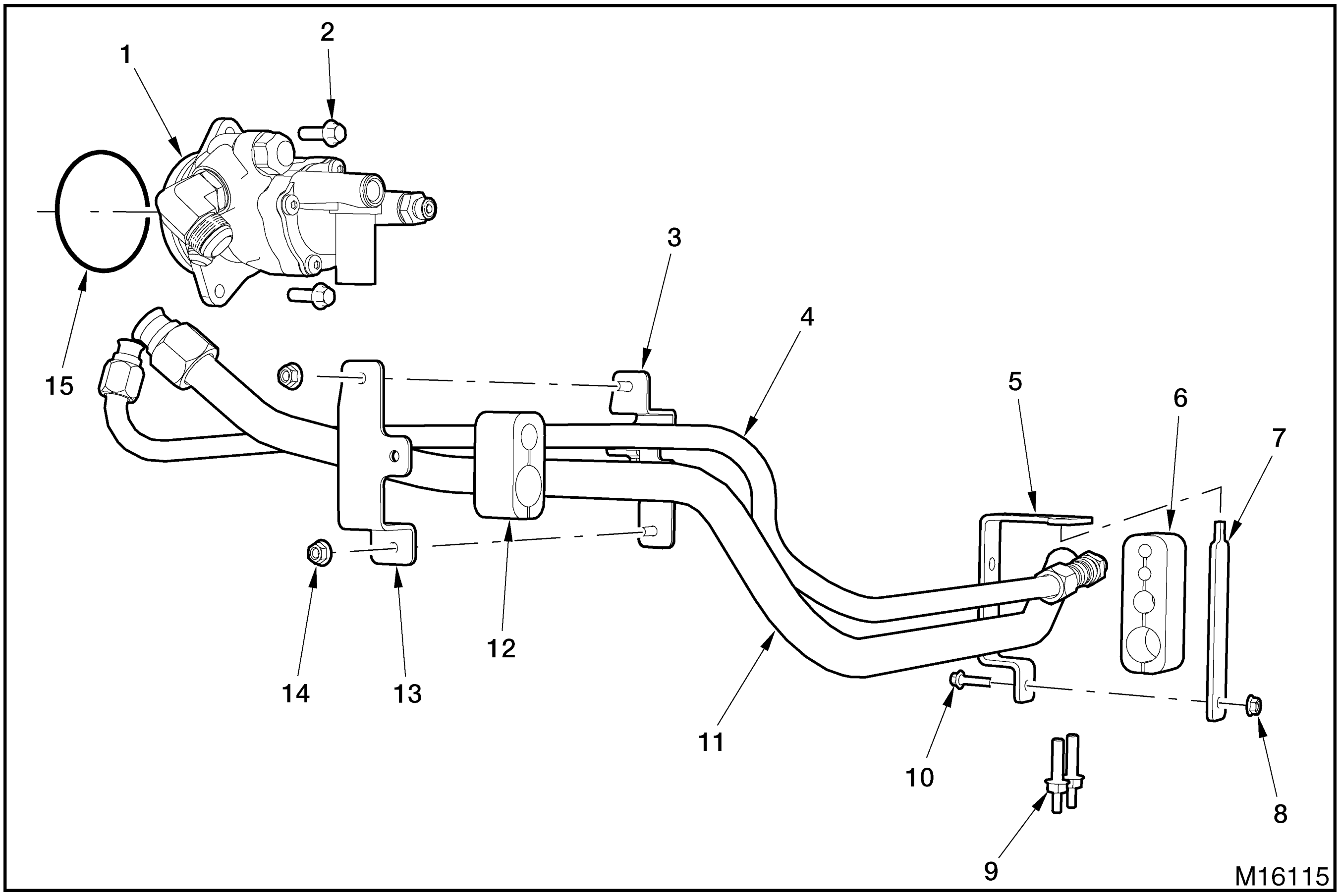

Figure 160 Power steering/fuel pump and related components

1. Gear driven fuel pump assembly
2. M10 x 30 bolt (2)
3. Tube clamp plate (side)
4. Pressure power steering tube
5. Tube clamp saddle (front)
6. Tube clamp pad (front)
7. Tube clamp plate (front)
8. M6 nut
9. M8 x 30 stud bolt (2)
10. M6 x 25 bolt
11. Suction power steering tube assembly
12. Tube clamp pad (side)
13. Tube clamp saddle (side)
14. M6 nut (2)
15. O-ring

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, make sure the engine has cooled before removing components.

WARNING: To prevent personal injury or death, remove ground cable from negative terminal of main battery before disconnecting or connecting electrical components. Always connect ground cable last.

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

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

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

NOTE: See the Engine Electrical sections for information on removal of components prior to this section.

Air Compressor

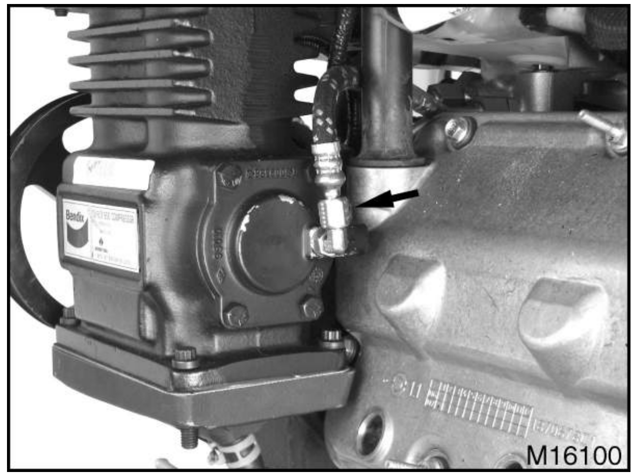

Figure 161 Oil supply hose fitting nut

1. Loosen oil supply hose fitting nut and disconnect hose from air compressor.

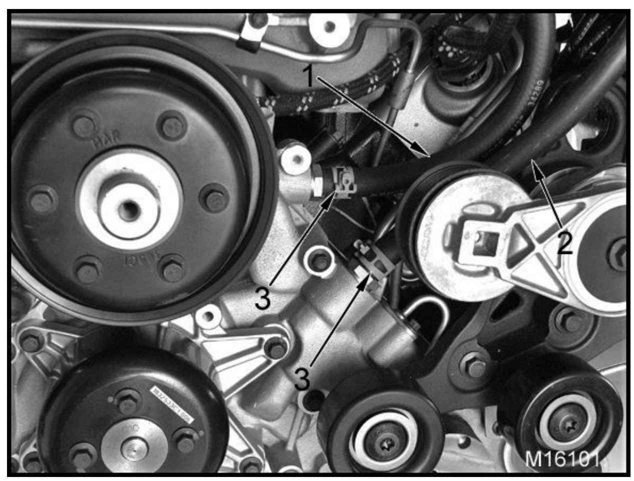

Figure 162 Air compressor coolant hoses

1. Coolant return hose
2. Coolant supply hose
3. Hose clamp (2)

2. Remove two hose clamps and disconnect air compressor coolant hoses.

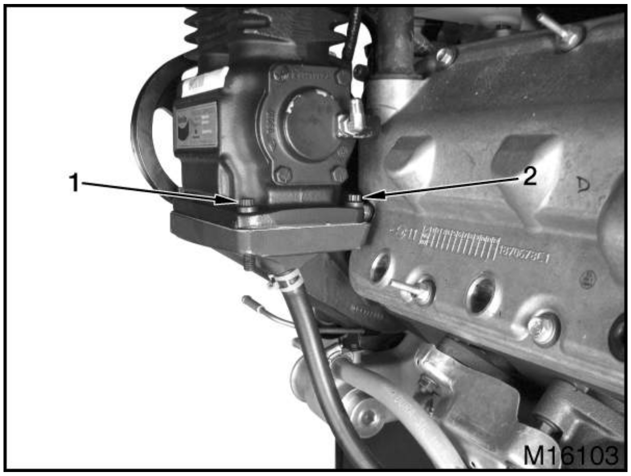

Figure 163 Air compressor to bracket rear bolts

1. M10 x 45 bolt
2. M10 x 30 bolt

3. Remove M10 x 45 and M10 x 30 air compressor to bracket rear bolts.

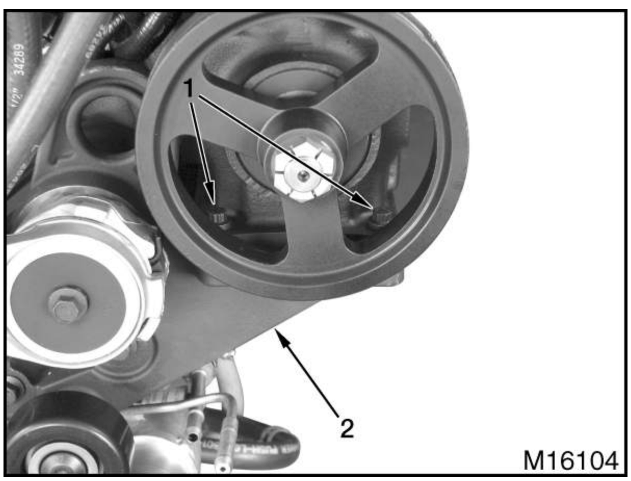

Figure 164 Air compressor to bracket front bolts

1. M10 x 30 bolt (2)
2. Air compressor bracket

4. Remove two M10 x 30 air compressor to bracket front bolts.

WARNING: To prevent personal injury or death, get help when removing or installing the air compressor.

5. Remove air compressor.
6. Remove and discard air compressor gasket.

Air Compressor Bracket and Components

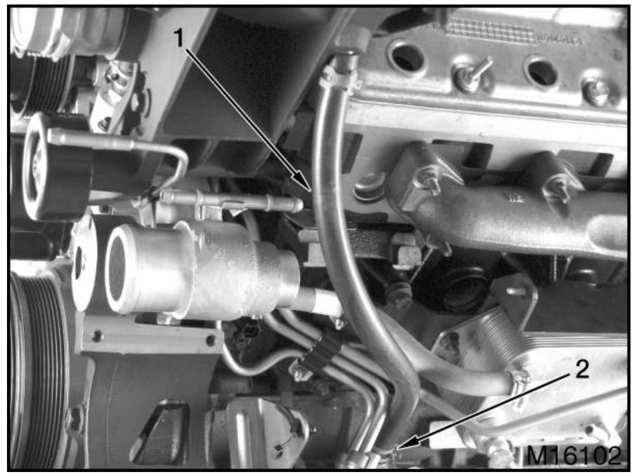

Figure 165 Air compressor oil return hose

1. Oil return hose
2. Hose clamp

1. Remove hose clamp and disconnect air compressor oil return hose.

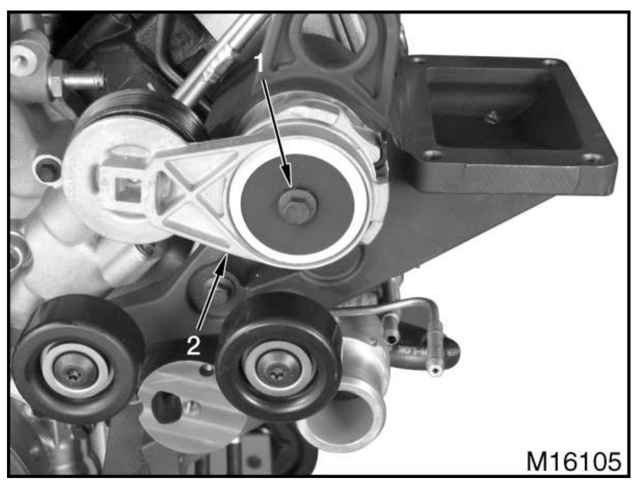

Figure 166 Air compressor belt tensioner

1. M10 x 80 bolt
2. Belt tensioner

CAUTION: To prevent engine damage, do not twist the belt tensioner; damage to the locating pin may occur, resulting in improper alignment of the belt tensioner.

2. Remove M10 x 80 bolt and air compressor belt tensioner.

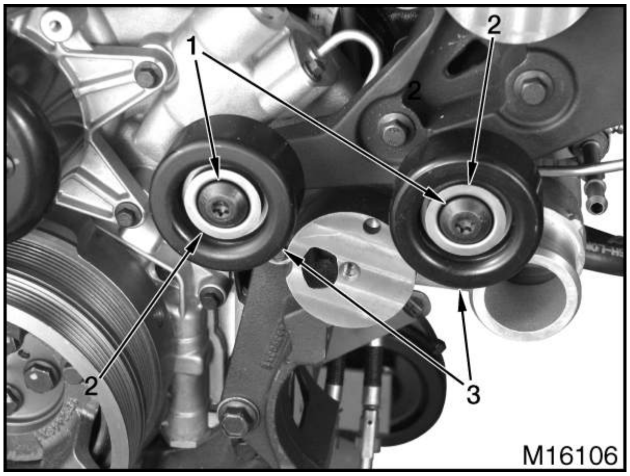

Figure 167 Air compressor belt idlers

1. M10 x 30 bolt (2)
2. Idler dust cover (2)
3. Belt idler (2)

3. Remove two M10 x 30 bolts.
4. Remove two idler dust covers and two belt idlers.

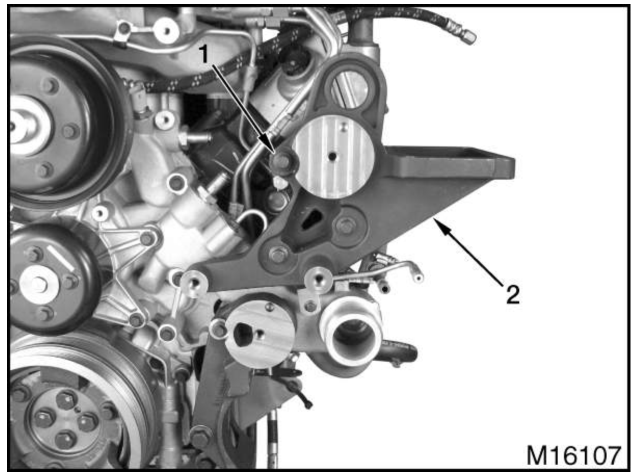

Figure 168 Air compressor bracket to cylinder head bolts

1. M10 x 120 bolt (3)
2. Air compressor bracket

5. Remove three M10 x 120 bolts and air compressor bracket.

Power Steering Lines

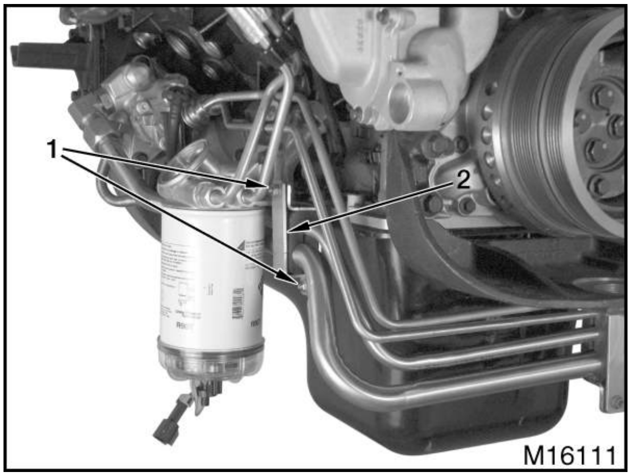

Figure 169 Tube clamp saddle (side)

1. M6 nut (2)
2. Tube clamp saddle (side)

1. Remove two M6 nuts.
2. Remove side tube clamp saddle.

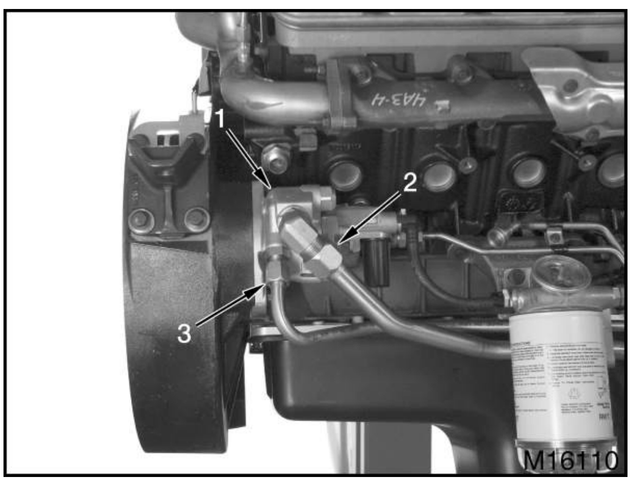

Figure 170 Power steering tubes to pump connections

1. Gear driven fuel pump assembly
2. Suction power steering tube flared tube nut
3. Pressure power steering tube flared tube nut

3. Loosen suction power steering tube flared tube nut.
4. Loosen pressure power steering tube flared tube nut.
5. Disconnect power steering tubes from power steering/fuel pump, and position power steering tubes aside.
6. Cover power steering/fuel pump ports and ends of power steering tubes with Cap Kit (page 129), to keep out foreign material. If plastic caps are not available, cover openings with tape.

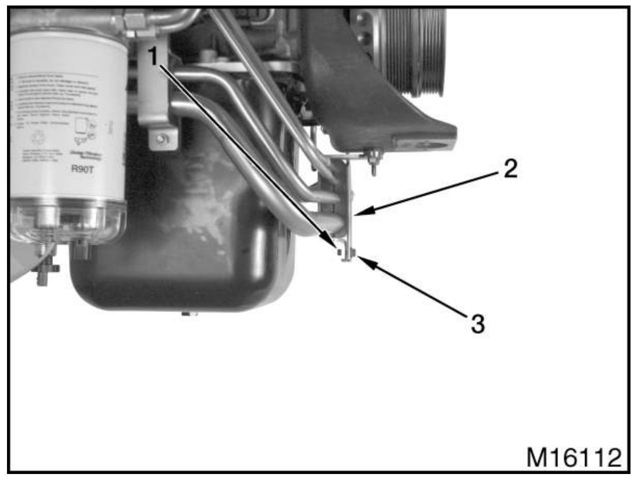

Figure 171 Tube clamp plate (front)

1. M6 x 25 bolt
2. Tube clamp plate (front)
3. M6 nut

NOTE: Support power steering tubes before removing front tube clamp plate bolt and nut.

7. Remove M6 nut.
8. Remove M6 x 25 bolt.
9. Remove front tube clamp plate.
10. Release power steering tubes from tube clamp pads and remove from engine.

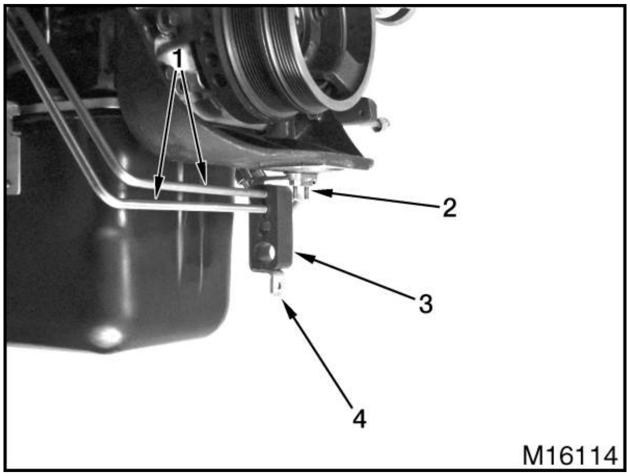

Figure 172 Tube clamp saddle (front)

1. Fuel lines
2. M8 x 30 stud bolt (2)
3. Tube clamp pad (front)
4. Tube clamp saddle (front)

11. Slide tube clamp pad out of the front tube clamp saddle and remove from fuel lines.
12. Remove two M8 x 30 stud bolts and front tube clamp saddle.

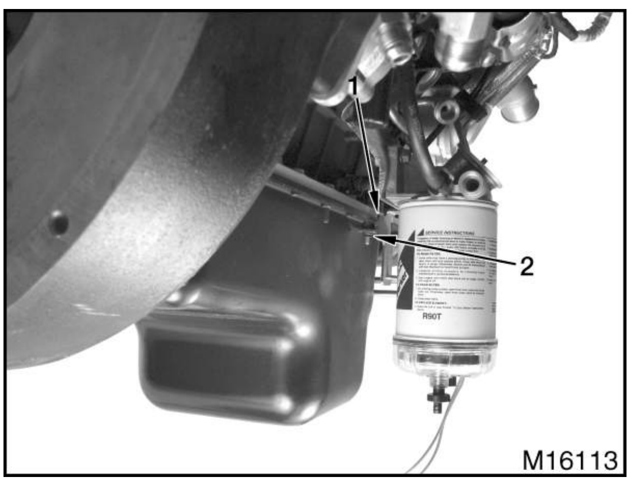

Figure 173 Tube clamp plate (side)

1. Tube clamp plate (side)
2. M6 nut

13. Remove M6 side tube clamp plate nut.
14. Remove side tube clamp plate.

Power Steering/Fuel Pump

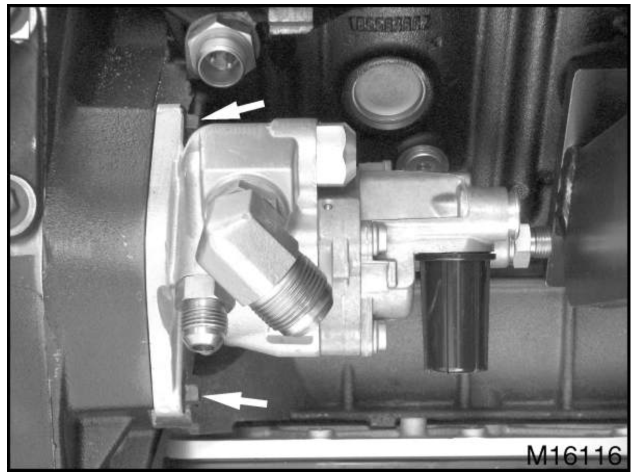

Figure 174 Mounting bolts for gear driven fuel pump assembly

NOTE: The power steering/fuel pump is serviced as a single unit.

1. Remove two M10 x 30 bolts and power steering/fuel pump.

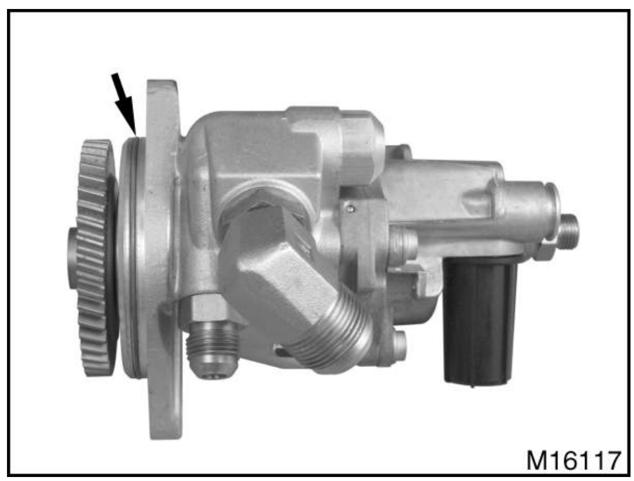

Figure 175 Gear driven fuel pump assembly O-ring

2. Remove and discard O-ring.

Cleaning

All Components

1. Clean foreign material from gasket surfaces of air compressor and air compressor bracket. Use a scraper to remove gasket from gasket surfaces.

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

2. Wash air compressor bracket. Dry with filtered compressed air.
3. Wash power steering/fuel pump gear with a stiff brush and a nonchlorinated solvent. Dry with filtered compressed air.

Installation

Power Steering/Fuel Pump

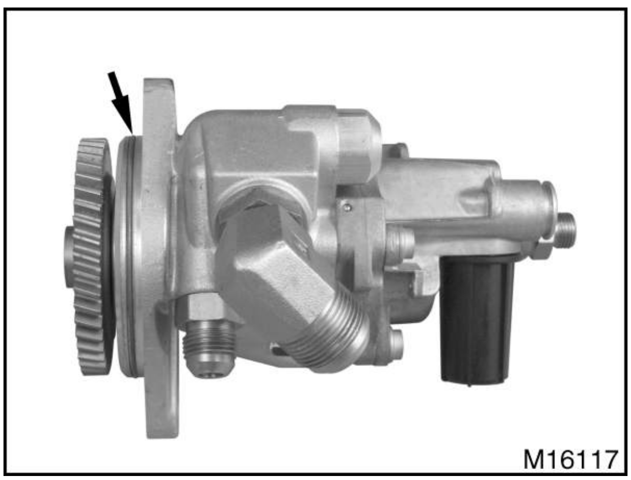

Figure 176 Gear driven fuel pump assembly O-ring

1. Install a new power steering/fuel pump O-ring.

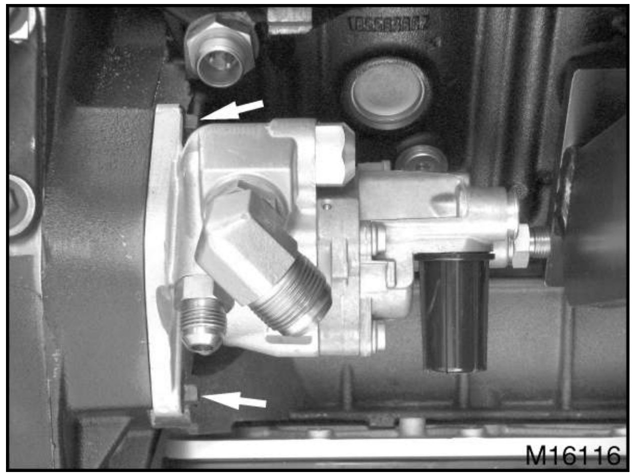

Figure 177 Mounting bolts for gear driven fuel pump assembly

2. Install power steering/fuel pump on the rear cover and secure with two M10 x 30 bolts.
3. Tighten bolts to standard torque (page 383).

Power Steering Lines

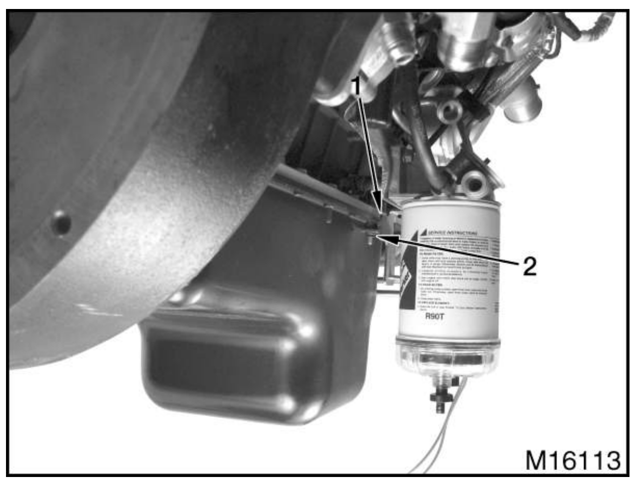

Figure 178 Tube clamp plate (side)

1. Tube clamp plate (side)
2. M6 nut

1. Install side tube clamp plate and secure with M6 nut.
2. Tighten tube clamp plate nut to standard torque (page 383).

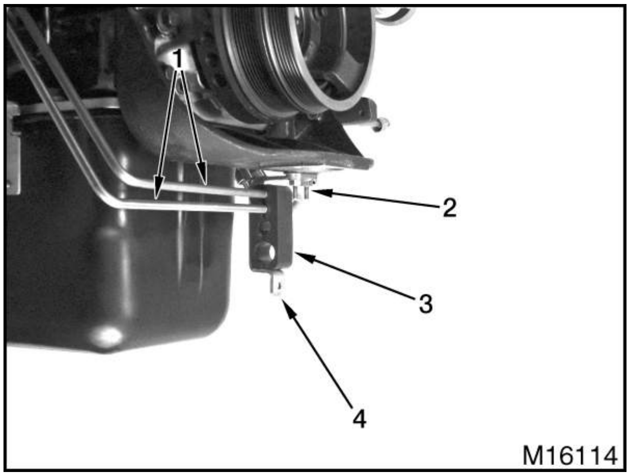

Figure 179 Tube clamp saddle (front)

1. Fuel lines
2. M8 x 30 stud bolt (2)
3. Tube clamp pad (front)
4. Tube clamp saddle (front)

3. Install front tube clamp saddle and secure with two M8 x 30 stud bolts.
4. Tighten stud bolts to special torque (page 129).
5. Install side tube clamp pad on power steering tubes.
6. Install front tube clamp pad on fuel lines and slide tube clamp pad inside the front tube clamp saddle.
7. Install power steering tubes in front tube clamp pad, and position power steering tubes and side tube clamp pad inside the side tube clamp plate.

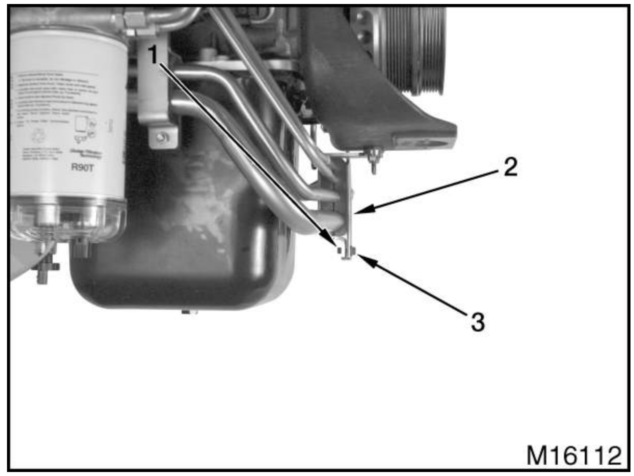

Figure 180 Tube clamp plate (front)

1. M6 x 25 bolt
2. Tube clamp plate (front)
3. M6 nut

8. Install front tube clamp plate and secure with M6 x 25 bolt and M6 nut. Do not tighten at this time.

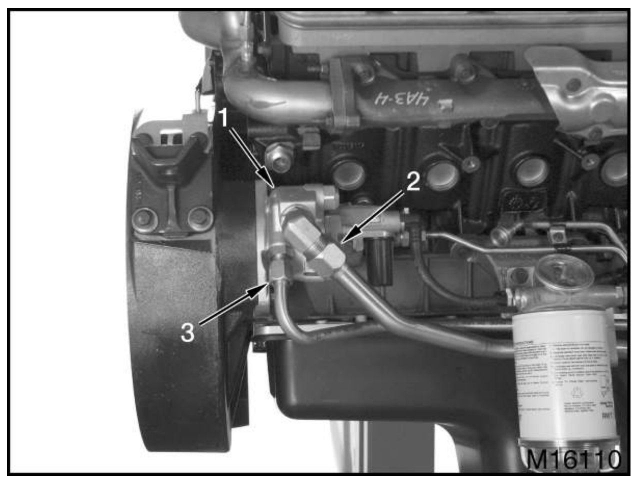

Figure 181 Power steering tubes to pump connections

1. Gear driven fuel pump assembly
2. Suction power steering tube flared tube nut
3. Pressure power steering tube flared tube nut

9. Remove all the plastic caps or tape from power steering/fuel pump and power steering tubes.

10. Connect power steering tubes to power steering/fuel pump, and secure with flared tube nuts.
11. Tighten suction power steering tube flared tube nut to special torque (page 129).
12. Tighten pressure power steering tube flared tube nut to special torque (page 129).

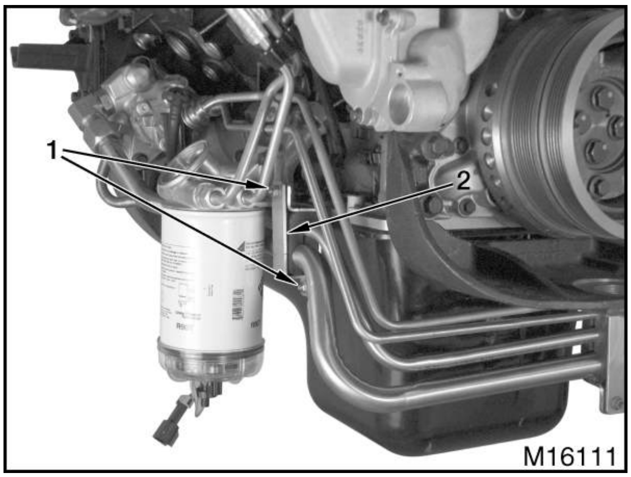

Figure 182 Tube clamp saddle (side)

1. M6 nut (2)
2. Tube clamp saddle (side)

13. Install side tube clamp saddle.
14. Install two M6 nuts and tighten to standard torque (page 383).
15. Tighten front tube clamp saddle M6 x 25 bolt and M6 nut to standard torque (page 383).

Air Compressor Bracket and Components

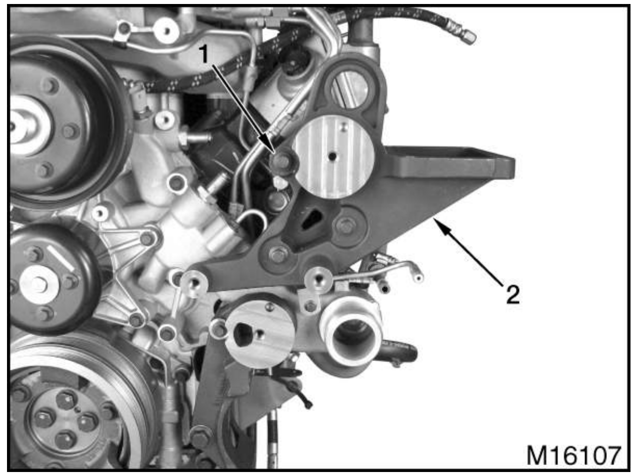

Figure 183 Air compressor bracket to cylinder head bolts

1. M10 x 120 bolt (3)
2. Air compressor bracket

1. Install and secure air compressor bracket with three M10 x 120 bolts.
2. Tighten bolts to special torque (page 129).

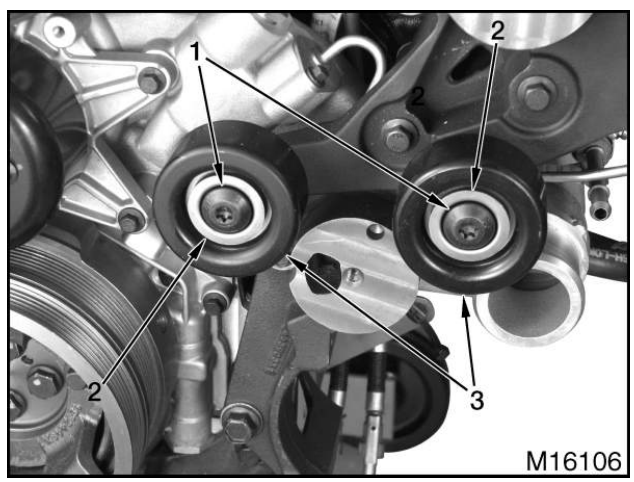

Figure 184 Air compressor belt idlers

1. M10 x 30 bolt (2)
2. Idler dust cover (2)
3. Belt idler (2)

3. Install belt idlers and idler dust covers, and secure with two M10 x 30 bolts.

4. Tighten bolts to special torque (page 129).

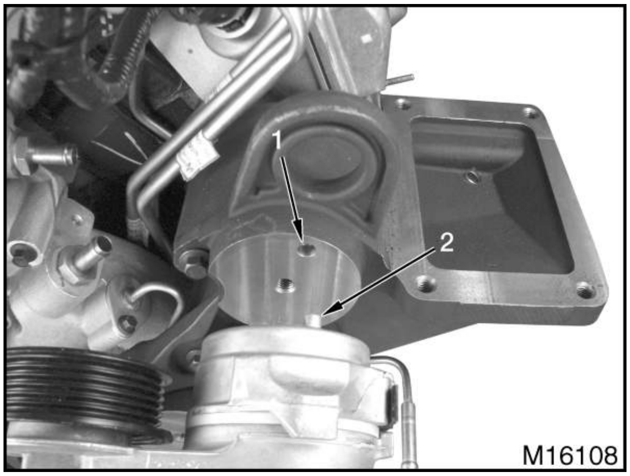

Figure 185 Air compressor belt tensioner alignment

1. Alignment hole
2. Belt tensioner dowel

5. Align belt tensioner dowel with alignment hole in air compressor bracket, and install belt tensioner.

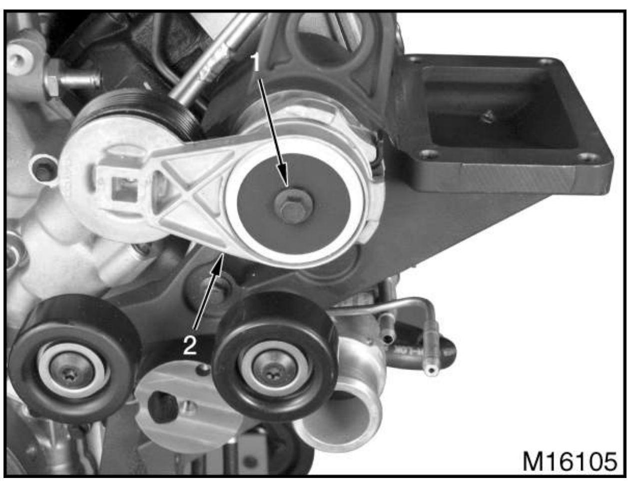

Figure 186 Air compressor belt tensioner

1. M10 x 80 bolt
2. Belt tensioner

6. Install M10 x 80 bolt and tighten to special torque (page 129).

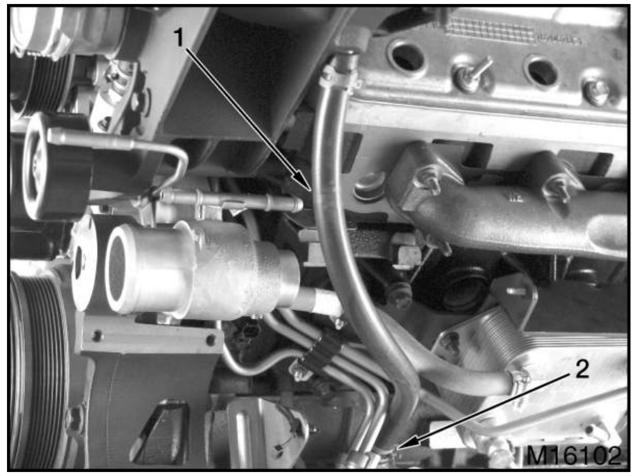

Figure 187 Air compressor oil return hose

1. Oil return hose
2. Hose clamp

7. Connect air compressor oil return hose and secure with hose clamp.

Air Compressor

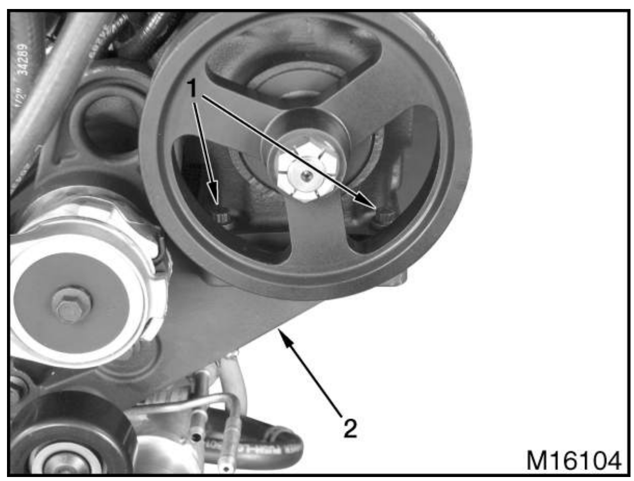

Figure 188 Air compressor to bracket front bolts

1. M10 x 30 bolts (2)
2. Air compressor bracket

WARNING: To prevent personal injury or death, get help when removing or installing the air compressor.

1. Place a new air compressor gasket and air compressor on the air compressor bracket.
2. Secure air compressor to bracket with two front M10 x 30 bolts. Do not tighten bolts at this time.

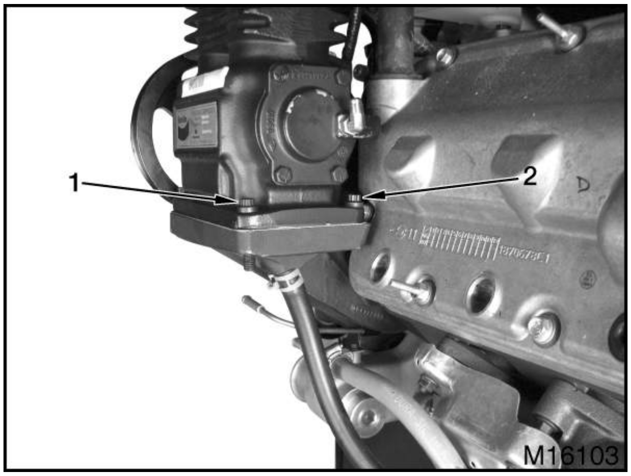

Figure 189 Air compressor to bracket rear bolts

1. M10 x 45 bolt
2. M10 x 30 bolt

3. Install M10 x 45 and M10 x 30 air compressor to bracket rear bolts.
4. Tighten all four air compressor to bracket bolts to special torque (page 129).

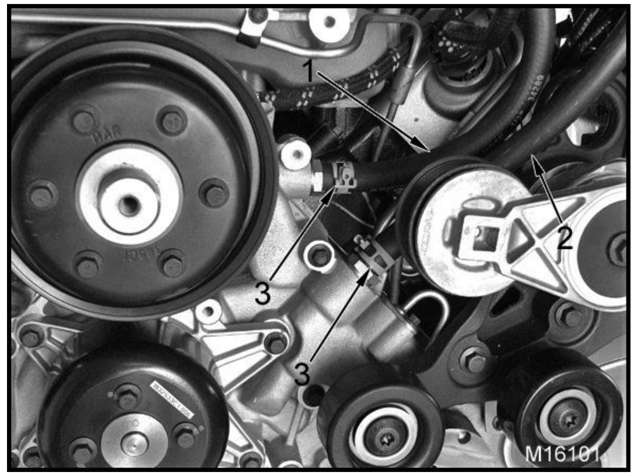

Figure 190 Air compressor coolant hoses

1. Coolant return hose
2. Coolant supply hose
3. Hose clamp (2)

5. Connect air compressor coolant hoses and secure with hose clamps.

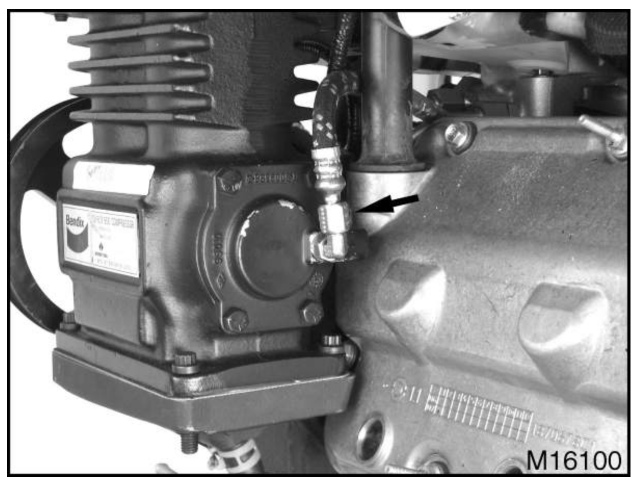

Figure 191 Oil supply hose fitting nut

6. Connect oil supply hose to air compressor.
7. Tighten oil supply hose fitting nut to special torque (page 129).

Special Torque

Table 11 Air Compressor and Power Steering/Fuel Pump

Air compressor to bracket bolts	72 N·m (53 lbf·ft)
Air compressor bracket to cylinder head bolts	61 N·m (45 lbf·ft)
Air compressor belt tensioner bolt	61 N·m (45 lbf·ft)
Air compressor idler bolts	61 N·m (45 lbf·ft)
Air compressor oil supply hose fitting nut	20 N·m (177 lbf·in)
Suction power steering tube flared tube nut	166 N·m (122 lbf·ft)
Pressure power steering tube flared tube nut	87 N·m (64 lbf·ft)
Tube clamp saddle stud bolts (front)	31 N·m (23 lbf·ft)
Air compressor pulley nut	120 N·m (88 lbf·ft)

Special Service Tools

Table 12 Power Steering/Fuel Pump

Description	Tool Number
Cap Kit (All)	ZTSE4610

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Exploded Views

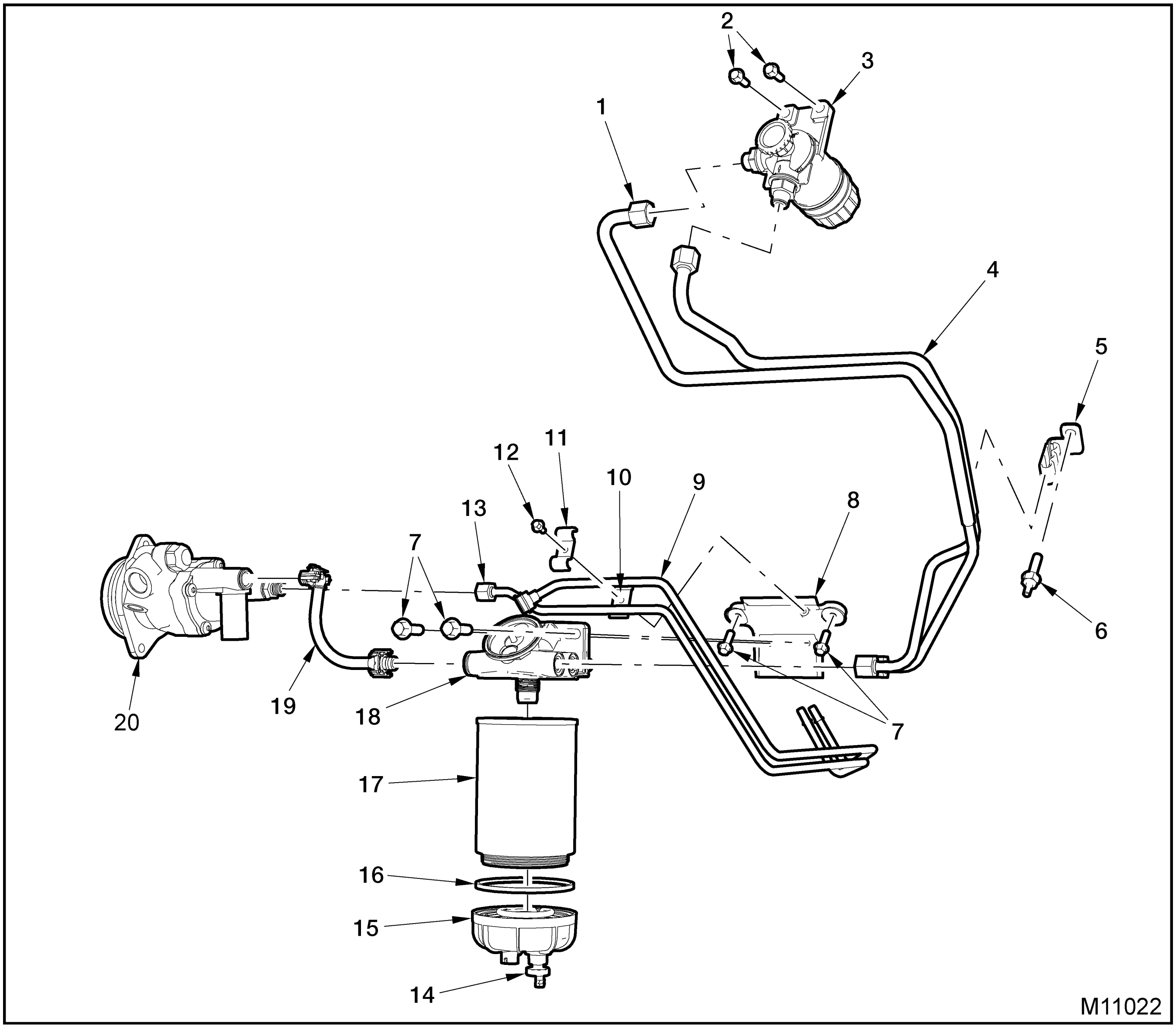

Figure 192 Primary fuel filter assembly and tubing

1. Fuel return from primer pump tube assembly
2. M8 x 30 bolt (2)
3. Fuel primer pump assembly
4. Fuel supply to primer pump tube assembly
5. Triple tube clamp
6. M8 x 30 stud bolt
7. M10 x 30 bolt (4)
8. Primary filter bracket support
9. Fuel return to tank tube assembly
10. Flat clamp
11. Saddle clamp
12. M6 x 12 bolt
13. Fuel supply tube assembly
14. Fuel drain valve
15. Bowl assembly with fuel heater/probe
16. Element and bowl primary filter seal
17. Primary filter element assembly
18. Fuel filter primary header
19. Primary fuel filter to pump tube assembly
20. Gear driven fuel pump assembly

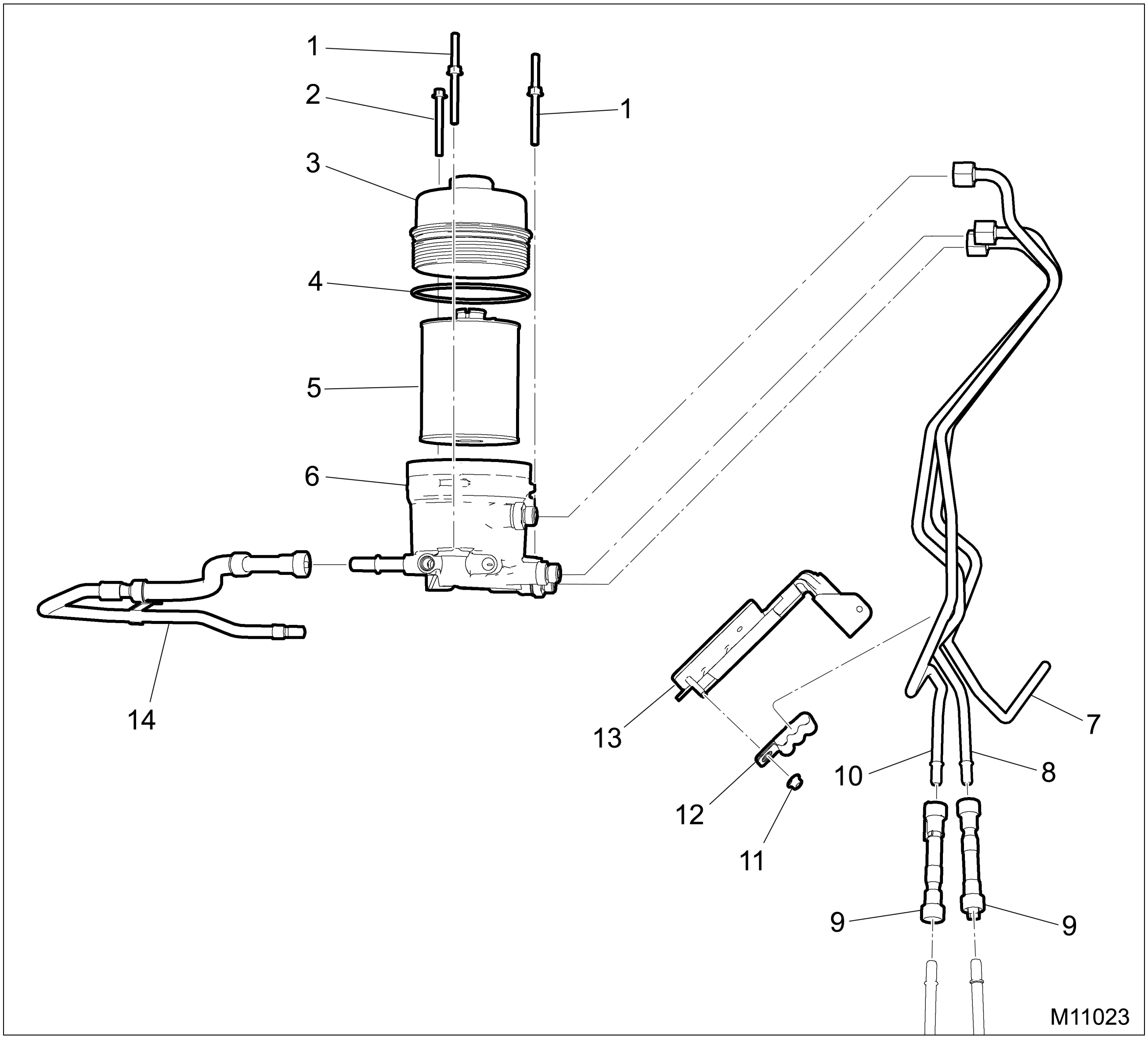

Figure 193 Secondary fuel filter and tubing

1. M6 x 45 stud bolt (2)
2. M6 x 45 bolt
3. Fuel filter cap
4. O-ring
5. Fuel filter element
6. Fuel filter housing
7. Fuel cooler to filter tube assembly
8. Fuel return to tank tube assembly
9. 3/8” hose assembly (2)
10. Fuel supply to filter tube assembly
11. M6 nut
12. Triple tube clamp
13. Cooler support bracket assembly
14. Filter to pump tube assembly

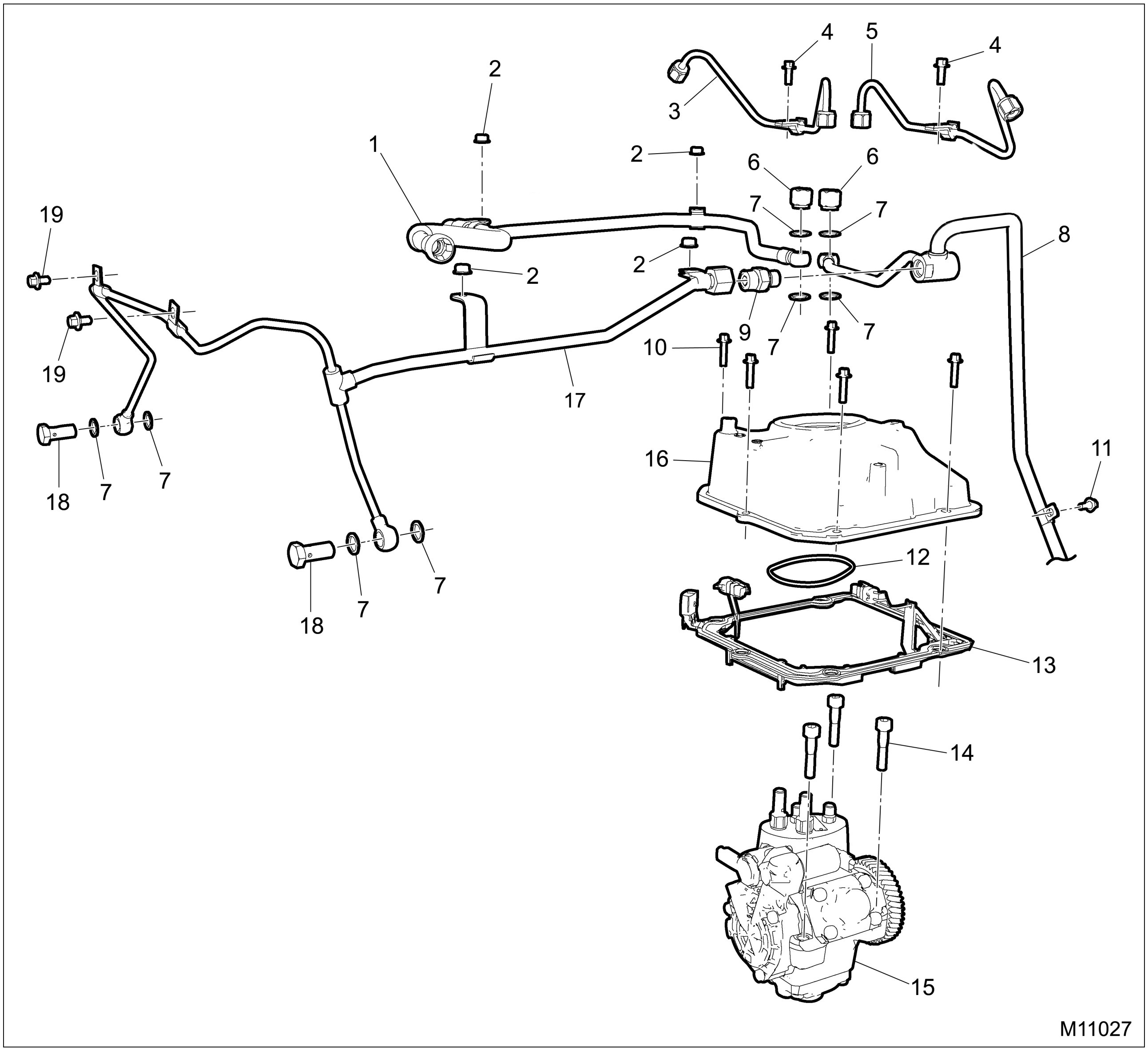

Figure 194 High-pressure Fuel Pump (HPFP) assembly and tubing

1. Filter to pump tube assembly
2. M6 nut (4)
3. Pump right tube assembly
4. M6 x 16 bolt (2)
5. Pump left tube assembly
6. M12 cap nut (2)
7. M12 Bonded seal washer (8)
8. High-pressure pump to cooler tube assembly
9. Injector leak off check valve
10. M6 x 25 bolt (5)
11. M6 x 12 bolt
12. Pump cover gasket
13. Pump cover gasket with connectors
14. M10 x 55 bolt (3)
15. HPFP assembly
16. Fuel pump cover
17. Injector return tube assembly
18. M12 banjo bolt (2)
19. M6 x 10 bolt (2)

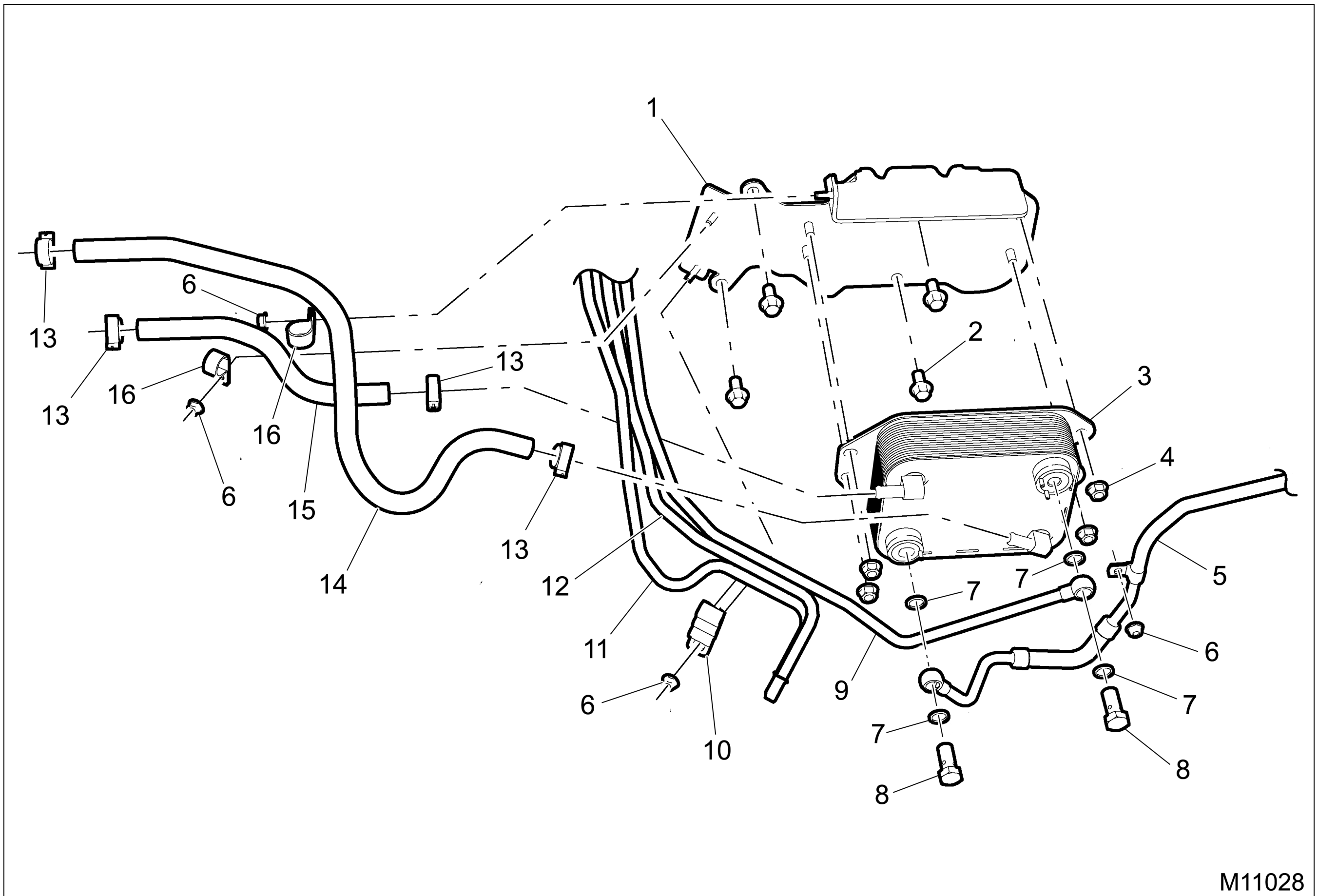

Figure 195 Fuel cooler assembly (typical)

1. Cooler support bracket assembly
2. M10 x 20 bolt (4)
3. Fuel cooler assembly
4. M8 nut (4)
5. High-pressure pump to cooler tube assembly
6. M6 nut (4)
7. M12 bonded seal washer (4)
8. M12 banjo bolt (2)
9. Fuel cooler to filter tube assembly
10. Triple tube clamp
11. Fuel supply to filter tube assembly
12. Fuel return to tank tube assembly
13. Hose clamp (4)
14. Coolant-in hose
15. Coolant-out from fuel cooler hose
16. Clamp (2)

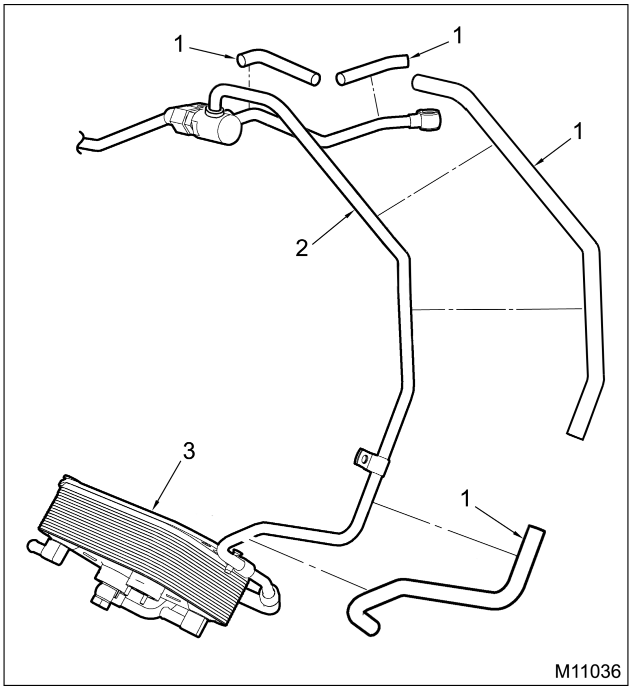

Figure 196 Fuel line sleeve — High-pressure pump to cooler tube assembly

1. Fuel line sleeve (4)
2. Fuel cooler assembly
3. High-pressure pump to cooler tube assembly

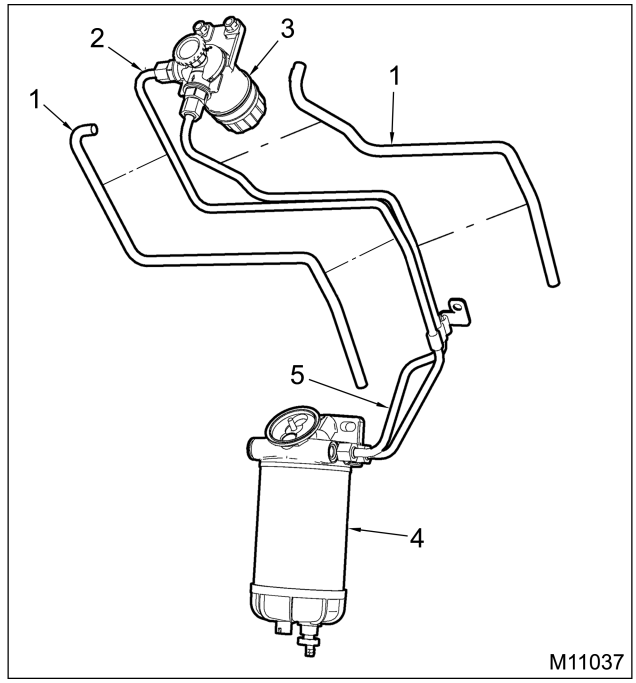

Figure 197 Fuel line sleeve (primer pump tubes)

1. Fuel line sleeve (2)
2. Fuel return from primer pump tube assembly
3. Fuel primer pump assembly
4. Primary fuel filter assembly
5. Fuel supply to primer pump tube assembly

Removal

GOVERNMENT REGULATION: Engine fluids (oil, fuel, and coolant) may be a hazard to human health and the environment. Handle all fluids and other contaminated materials (e.g. filters, rags) in accordance with applicable regulations. Recycle or dispose of engine fluids, filters, and other contaminated materials according to applicable regulations.

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.

NOTE: See the following service sections for information on removal of components prior to this section.

- Engine Electrical
- Exhaust Gas Recirculation (EGR) System
- Variable Geometry Turbocharger (VGT)
- Air Compressor and Power Steering/Fuel Pump

Primary Fuel Filter Element

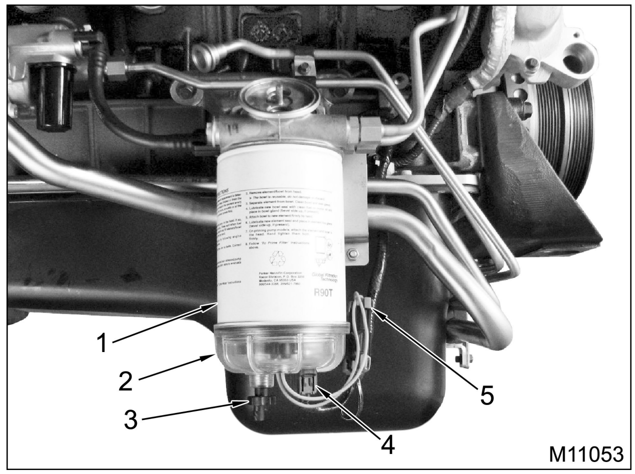

Figure 198 Primary filter element assembly

1. Primary filter element assembly
2. Bowl assembly with fuel heater/probe
3. Fuel drain valve
4. Water in Fuel (WIF) sensor electrical connector
5. Fuel heater electrical connector

1. Disconnect fuel heater electrical connector.
2. Disconnect WIF sensor electrical connector.

WARNING: To prevent personal injury or death, dispose of fuel in a container marked DIESEL FUEL, according to applicable regulations.

3. Place a suitable container under bowl assembly to catch draining fuel.
4. Turn fuel drain valve counterclockwise to drain fuel.
5. Rotate bowl assembly clockwise and remove from filter element. Use an oil filter wrench if necessary.

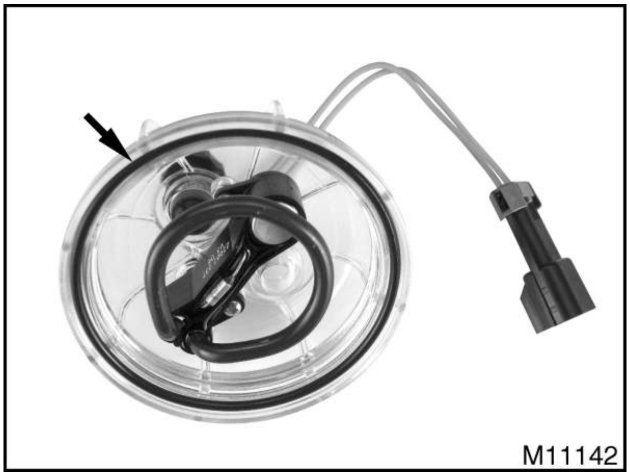

Figure 199 Element and bowl primary filter seal

6. Remove and discard bowl primary filter seal.
7. Remove primary filter element assembly. Use an oil filter wrench if necessary.

Secondary Fuel Filter Element

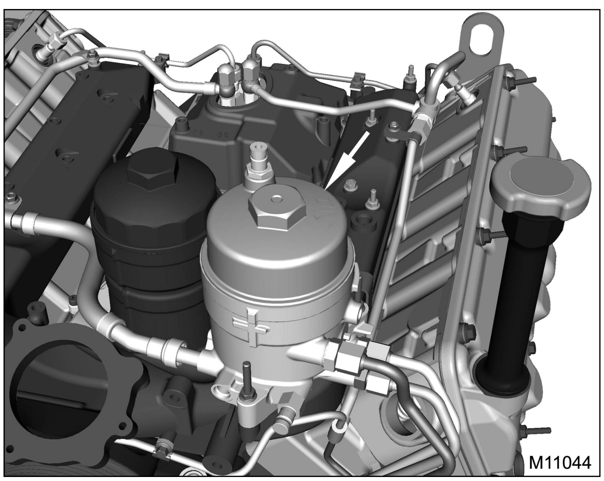

Figure 200 Fuel filter cap

1. Remove fuel filter cap by turning it counterclockwise.
2. Remove and discard fuel filter cap O-ring.
3. Lift fuel filter element from fuel filter housing.

Primary Fuel Filter Assembly and Tubing

WARNING: To prevent personal injury or death, dispose of fuel in a container marked DIESEL FUEL, according to applicable regulations.

1. Place a suitable container under bowl assembly to catch draining fuel.

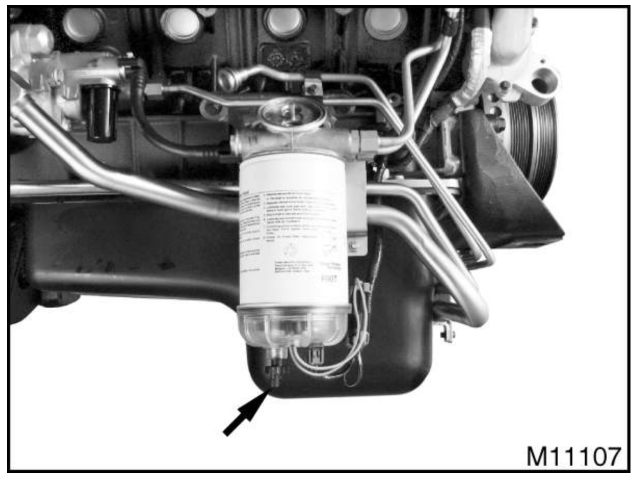

Figure 201 Fuel drain valve

2. Turn fuel drain valve counterclockwise to drain fuel.

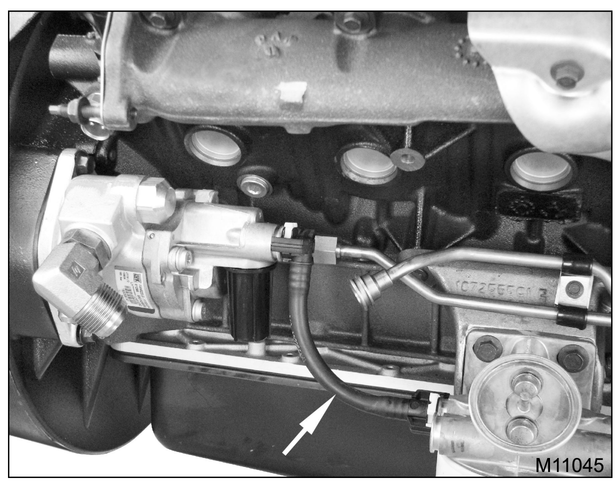

Figure 202 Primary fuel filter to pump tube assembly

3. Push tab to release fitting, and disconnect primary fuel filter to pump tube assembly.

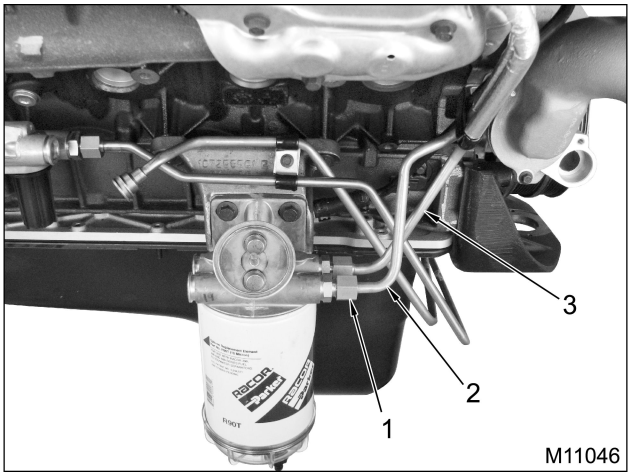

Figure 203 Primer pump tubes connection

1. 3/8” O-ring face seal nut (2)
2. Fuel return from primer pump tube assembly
3. Fuel supply to primer pump tube assembly

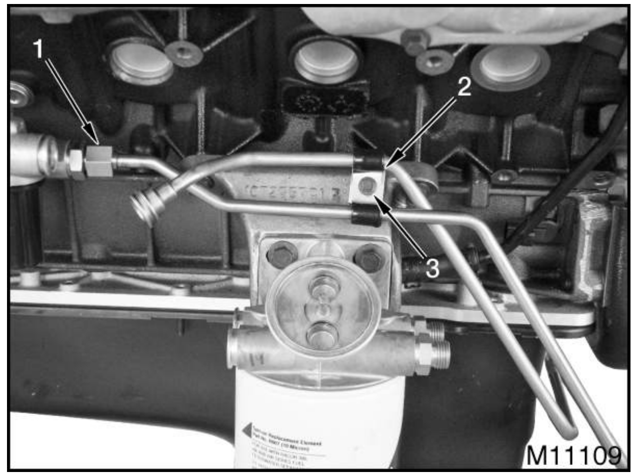

Figure 204 Primary filter bracket support clamp

1. 3/8” O-ring face seal nut
2. Saddle clamp
3. M6 x 12 bolt

4. Loosen 3/8” O-ring face seal nut on fuel return from primer pump tube assembly.
5. Loosen 3/8” O-ring face seal nut on fuel supply to primer pump tube assembly.
6. Disconnect fuel supply to primer pump tube assembly and fuel return from primer pump tube assembly.
7. Cover ports and ends of tubes with Fuel System Caps (page 169). If plastic caps are not available, cover openings with tape.
8. Remove M6 x 12 bolt.
9. Remove saddle clamp and flat clamp.
10. Loosen 3/8” O-ring face seal nut and disconnect fuel supply tube assembly.

Figure 205 Fuel filter primary header to primary filter bracket support bolts

1. Fuel filter primary header
2. M10 x 30 bolt (2)

11. Remove two M10 x 30 bolts and fuel filter primary header.

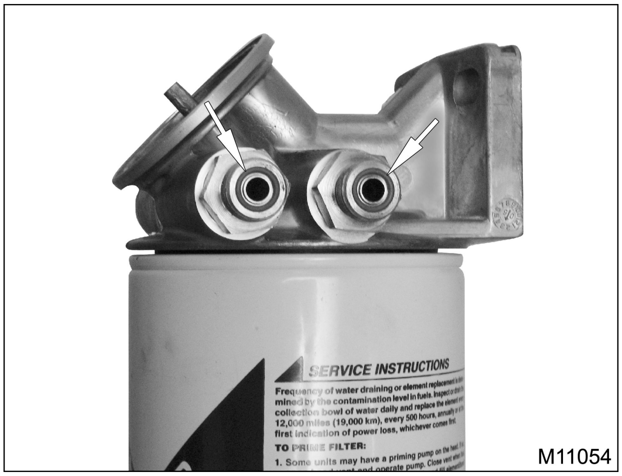

Figure 206 Fuel filter primary header O-rings

12. Remove and discard two O-rings.

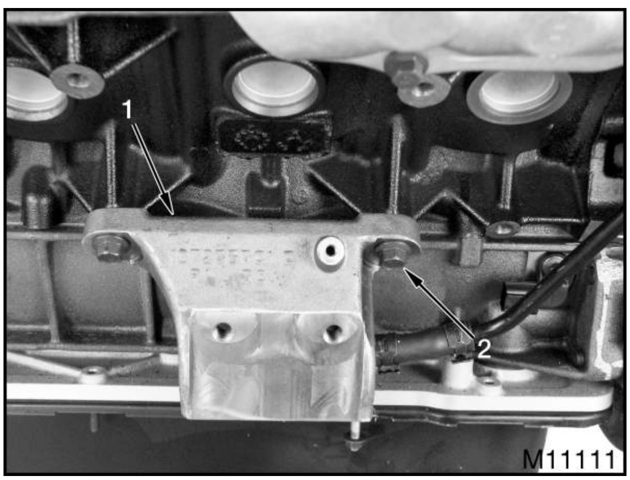

Figure 207 Primary filter bracket support bolts

1. Primary filter bracket support
2. M10 x 30 bolt (2)

13. Remove two M10 x 30 bolts and primary filter bracket support.

Fuel Primer Pump Assembly and Tubing

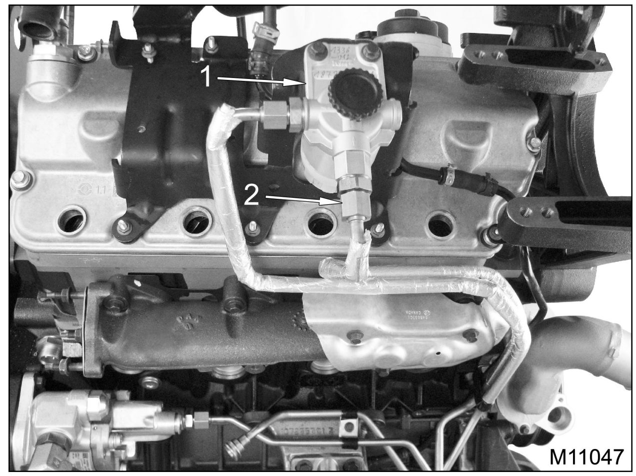

Figure 208 Fuel primer pump assembly tube connections

1. Fuel primer pump assembly
2. 3/8” O-ring face seal nut (2)

1. Loosen two 3/8” O-ring face seal nuts.
2. Disconnect fuel supply to primer pump tube assembly and fuel return from primer pump tube assembly.
3. Cover ports and ends of tubes with Fuel System Caps (page 169). If plastic caps are not available, cover openings with tape.

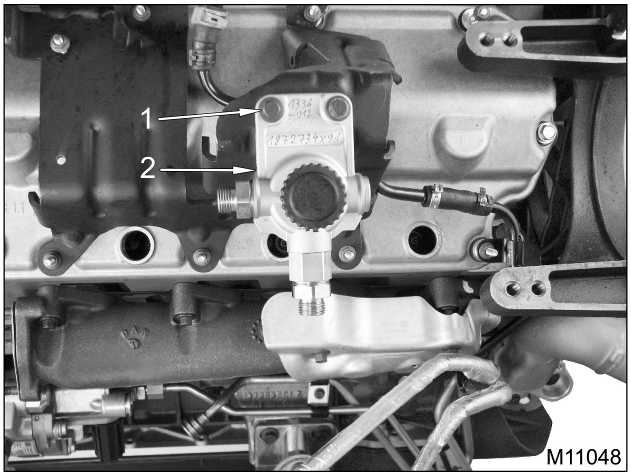

Figure 209 Fuel primer pump assembly bolts

1. M8 x 30 bolt (2)
2. Fuel primer pump assembly

4. Remove two M8 x 30 bolts and fuel primer pump assembly.

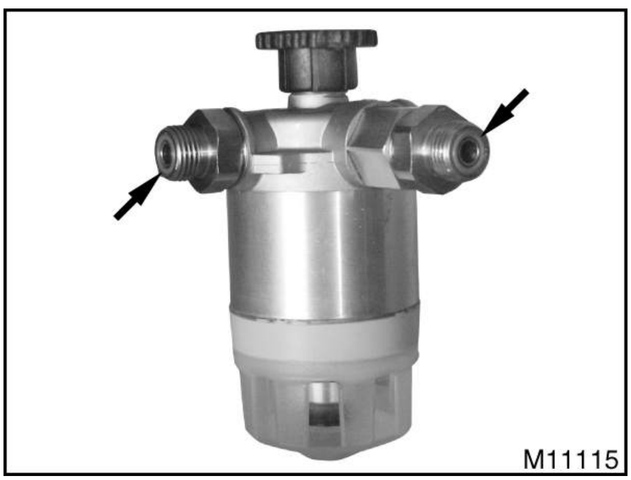

Figure 210 Fuel primer pump assembly O-rings

5. Remove and discard two O-rings.

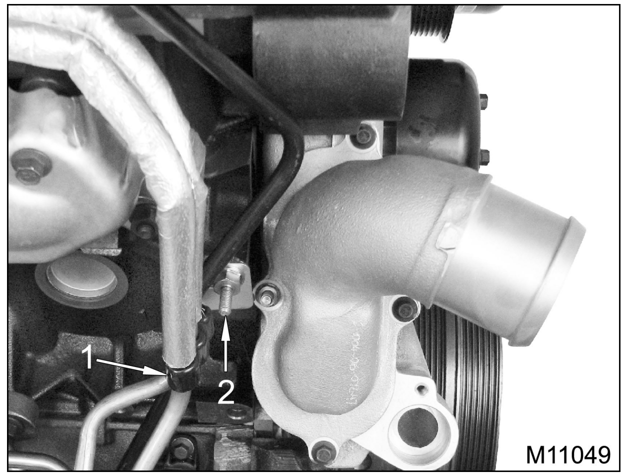

Figure 211 Triple tube clamp

1. Triple tube clamp
2. M8 x 30 stud bolt

6. Remove M8 x 30 stud bolt.
7. Remove triple tube clamp.
8. Remove fuel return from primer pump tube assembly.
9. Remove fuel supply to primer pump tube assembly.

Secondary Fuel Filter and Tubing

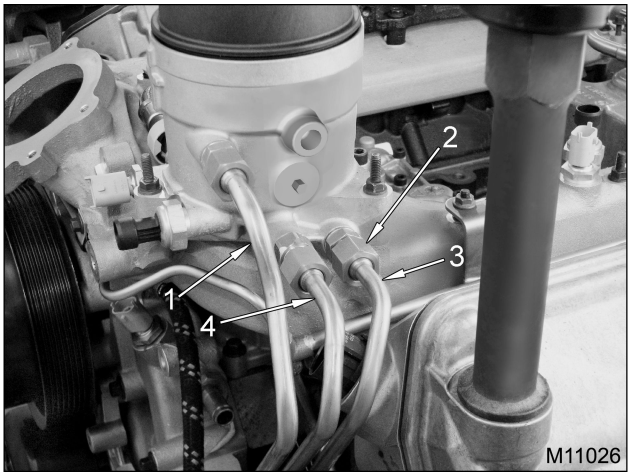

Figure 212 Fuel supply and return tubing

1. Fuel supply to filter tube assembly
2. 3/8” O-ring face seal nut (3)
3. Fuel cooler to filter tube assembly
4. Fuel return to tank tube assembly

WARNING: To prevent personal injury or death, dispose of fuel in a container marked DIESEL FUEL, according to applicable regulations.

1. Place a suitable container under tube connections to catch draining fuel.
2. Loosen three 3/8” O-ring face seal nuts.
3. Disconnect fuel supply to filter tube assembly.
4. Disconnect fuel cooler to filter tube assembly.
5. Disconnect fuel return to tank tube assembly.
6. Cover ports and ends of tubes with Fuel System Caps (page 169). If plastic caps are not available, cover openings with tape.

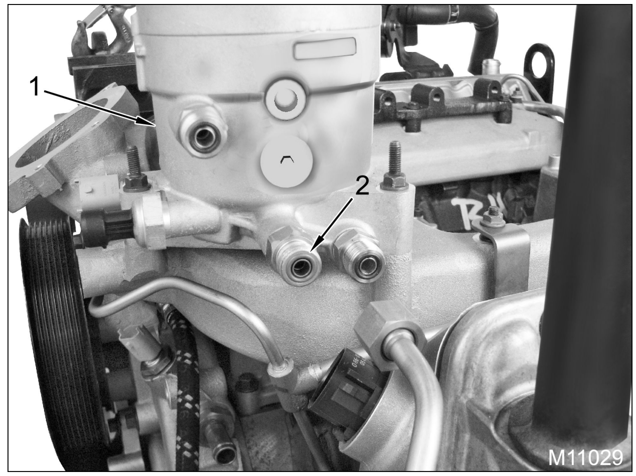

Figure 213 Fuel filter housing O-rings

1. Fuel filter housing
2. O-ring (3)

7. Remove and discard three O-rings.

Figure 214 Filter to pump tube assembly connection

1. Filter to pump tube assembly
2. Fitting release ring

8. Pull fitting release ring toward tube to release fitting lock, and disconnect filter to pump tube assembly from fuel filter housing.

9. Cover port on fuel filter housing and end of filter to pump tube assembly with Fuel System Caps (page 169). If plastic caps are not available, cover openings with tape.

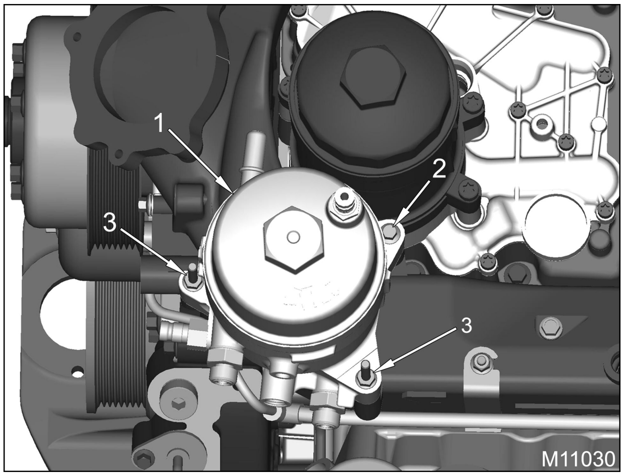

Figure 215 Secondary fuel filter assembly bolts

1. Secondary fuel filter assembly
2. M6 x 45 bolt
3. M6 x 45 stud bolt (2)

10. Remove two M6 x 45 stud bolts and M6 x 45 bolt.
11. Remove secondary fuel filter assembly.

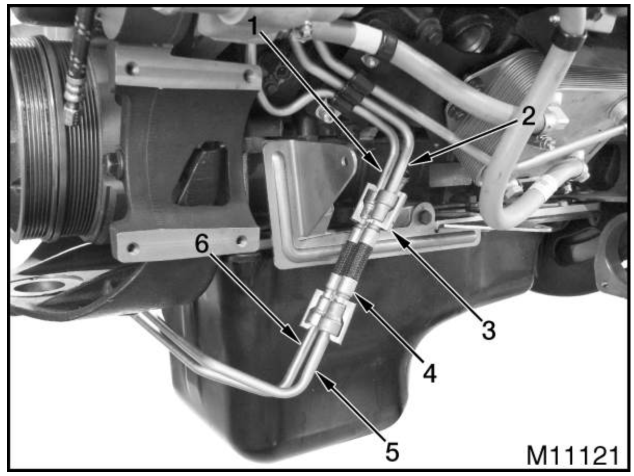

Figure 216 Fuel supply and return tube connections

1. Fuel supply to filter tube
2. Fuel return to tank tube assembly
3. 3/8” redundant clip (4)
4. 3/8” hose assembly (2)
5. Fuel return tube assembly
6. Fuel supply tube assembly

12. Remove four 3/8” redundant clips.
13. Use a Spring Lock Coupling Disconnect Tool (page 169) to disconnect and remove fuel return tube assembly and fuel supply tube assembly from 3/8” hose assemblies.
14. Use a Spring Lock Coupling Disconnect Tool (page 169) to disconnect and remove 3/8” hose assemblies from fuel return to tank tube assembly and fuel supply to filter tube.

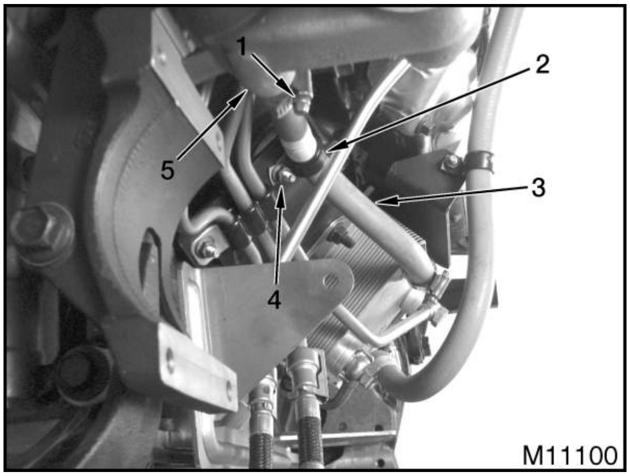

Figure 217 Coolant out from fuel cooler hose

1. Hose clamp
2. Clamp
3. Coolant out from fuel cooler hose
4. M6 nut
5. Front crankcase cover

15. Remove M6 nut and release clamp.

WARNING: To prevent personal injury or death, make sure the engine has cooled before draining coolant.

16. Place a suitable container under coolant out hose to catch draining coolant.
17. Loosen hose clamp and disconnect coolant out hose from front crankcase cover fitting.

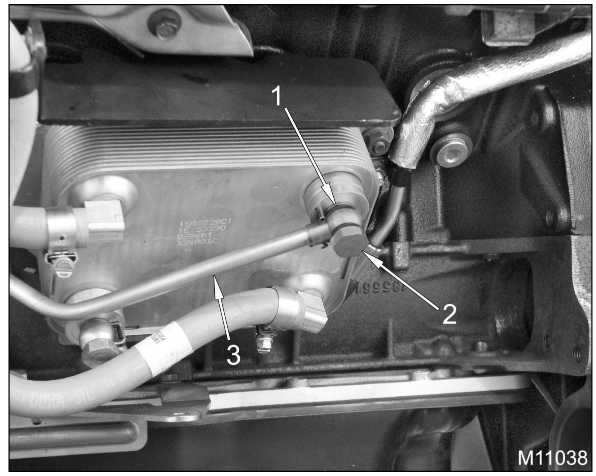

Figure 218 Fuel cooler to filter tube assembly connection

1. M12 banjo bolt
2. M12 bonded seal washer (2)
3. Fuel cooler to filter tube assembly

18. Remove M12 banjo bolt and disconnect fuel cooler to filter tube assembly.
19. Remove and discard two M12 bonded seal washers.
20. Cover fuel cooler port and end of fuel cooler to filter tube with Fuel System Caps (page 169). If plastic caps are not available, cover openings with tape.

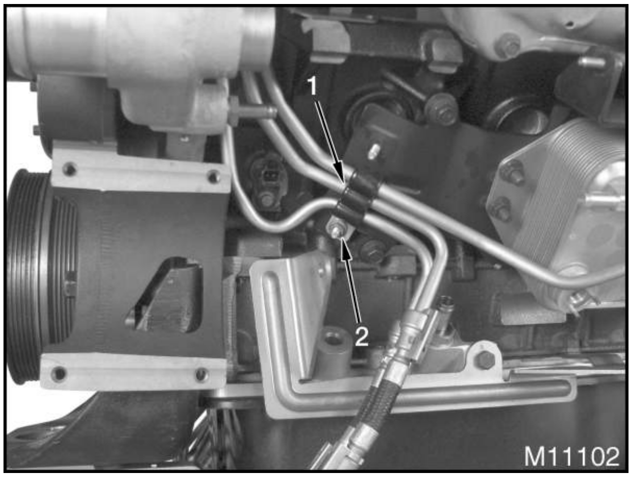

Figure 219 Triple tube clamp

1. Triple tube clamp
2. M6 nut

21. Remove M6 nut.
22. Remove triple tube clamp.
23. Remove fuel cooler to filter tube assembly.
24. Remove fuel return to tank tube assembly.
25. Remove fuel supply to filter tube assembly.

Tubing to High-pressure Fuel Pump (HPFP) Assembly

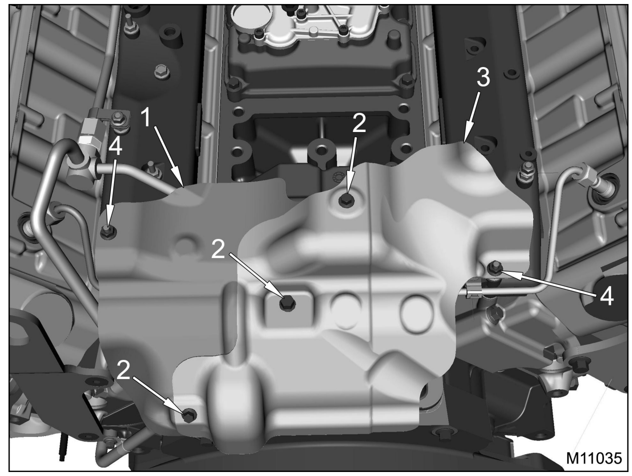

Figure 220 Heat shields

1. Left heat shield
2. M6 x 12 bolt (3)
3. Right heat shield
4. M6 nut (2)

1. Remove three M6 x 12 heat shield bolts.
2. Remove two M6 heat shield nuts.
3. Remove right and left heat shields.

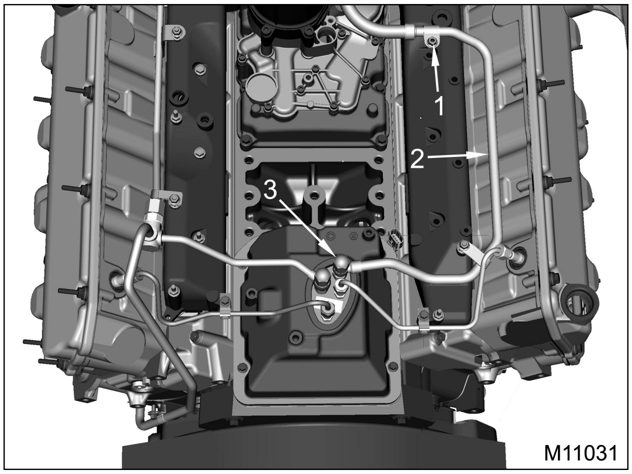

Figure 221 Filter to pump tube assembly

1. M6 nut (2)
2. Filter to pump tube assembly
3. M12 cap nut

4. Remove two M6 nuts.

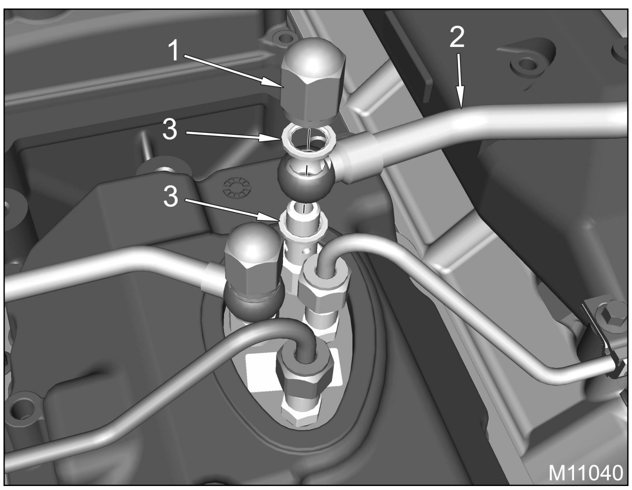

Figure 222 Filter to pump tube assembly, M12 cap nut, and M12 bonded seal washers

1. M12 cap nut
2. Filter to pump tube assembly
3. M12 bonded seal washer (2)

5. Remove M12 cap nut.
6. Remove filter to pump tube assembly.
7. Remove and discard two M12 bonded seal washers from filter to pump tube assembly.
8. Cover fuel pump port and end of filter to pump tube with Fuel System Caps (page 169). If plastic caps are not available, cover openings with tape.

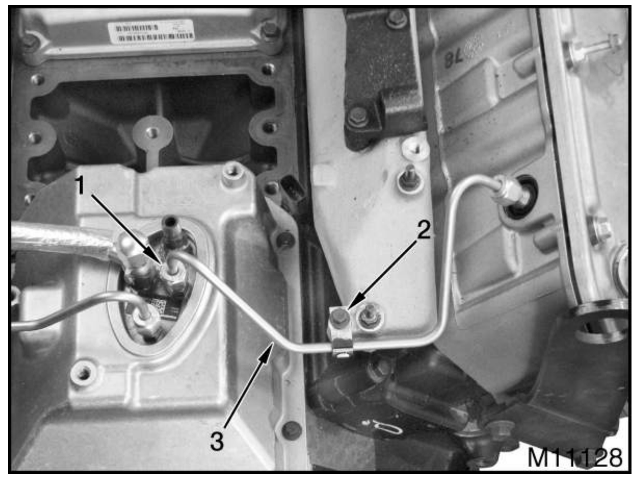

Figure 223 Pump right tube assembly

1. Tube nut (2)
2. M6 x 16 bolt
3. Pump right tube assembly

9. Loosen two tube nuts.
10. Remove M6 x 16 bolt.

WARNING: To prevent personal injury or death, whenever any fuel line (tubing) in the high-pressure fuel system is removed, it must be replaced with new.

11. Remove and discard pump right tube assembly.
12. Cover fuel pump and fuel rail ports with Fuel System Caps (page 169). If plastic caps are not available, cover openings with tape.

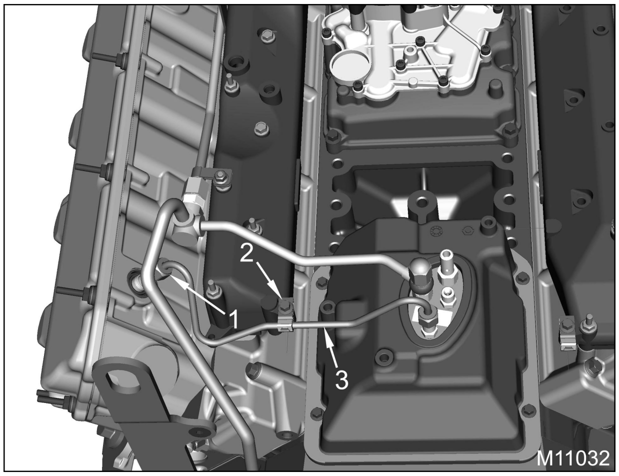

Figure 224 Pump left tube assembly

1. Tube nut (2)
2. M6 x 16 bolt
3. Pump left tube assembly

13. Loosen two tube nuts.
14. Remove M6 x 16 bolt.

WARNING: To prevent personal injury or death, whenever any fuel line (tubing) in the high-pressure fuel system is removed, it must be replaced with new.

15. Remove and discard pump left tube assembly.
16. Cover fuel pump and fuel rail ports with Fuel System Caps (page 169). If plastic caps are not available, cover openings with tape.

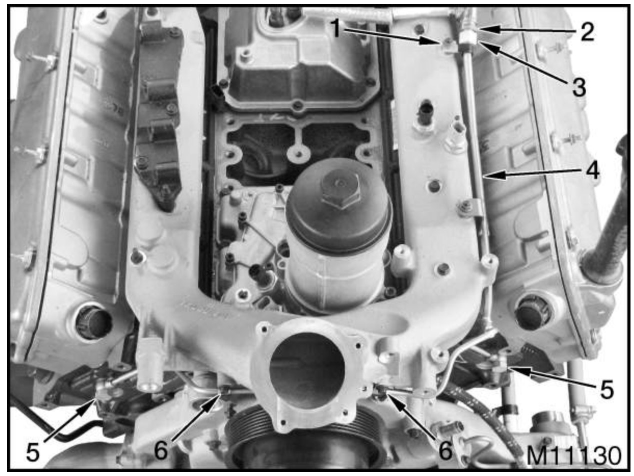

Figure 225 Injector return tube assembly

1. M6 nut (2)
2. Injector leak off check valve
3. 3/8” O-ring face seal nut
4. Injector return tube assembly
5. M12 banjo bolt (2)
6. M6 x 10 bolt (2)

17. Use a wrench to hold injector leak off check valve in place, and loosen 3/8” O-ring face seal nut.

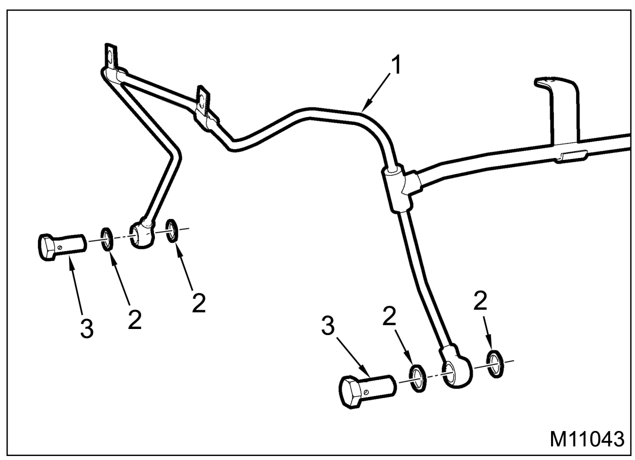

Figure 226 Injector return tube assembly, bonded seal washers, and banjo bolts

1. Injector return tube assembly
2. M12 bonded seal washer (4)
3. M12 banjo bolt (2)

18. Remove two M12 banjo bolts.

19. Remove and discard four M12 bonded seal washers.
20. Remove two M6 x 10 bolts.
21. Remove two M6 nuts.
22. Remove injector return tube assembly.
23. Cover ports and ends of tube with Fuel System Caps (page 169). If plastic caps are not available, cover openings with tape.

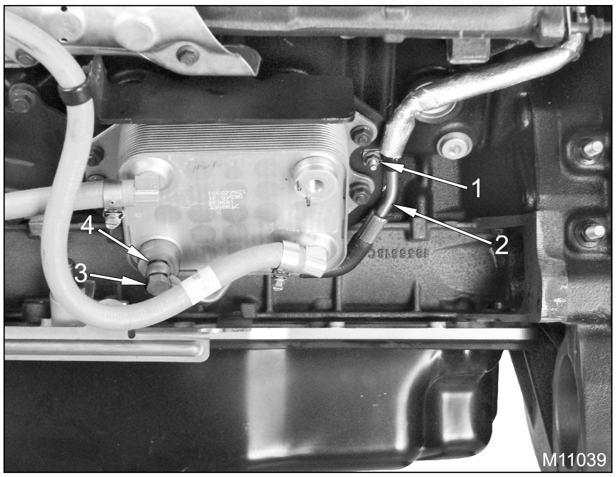

Figure 227 High-pressure pump to cooler tube assembly (lower connection)

1. M6 nut (2)
2. High-pressure pump to cooler tube assembly
3. M12 banjo bolt
4. M12 bonded seal washer (2)

24. Remove M12 banjo bolt.
25. Remove and discard two M12 bonded seal washers from high-pressure pump to cooler tube assembly.
26. Cover fuel cooler port and end of tube with Fuel System Caps (page 169). If plastic caps are not available, cover openings with tape.
27. Remove M6 high-pressure pump to cooler tube assembly clamp nut.

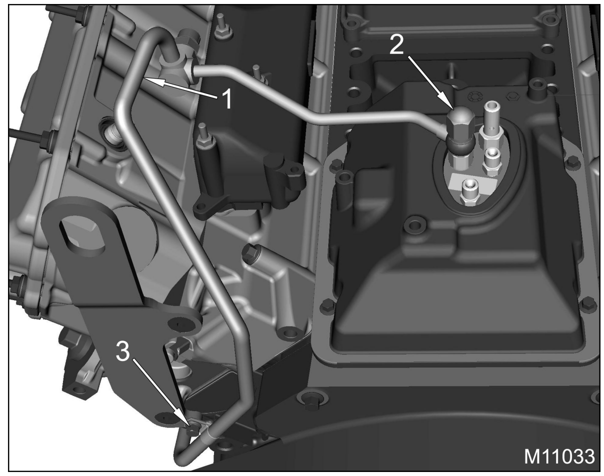

Figure 228 High-pressure pump to cooler tube assembly (upper connection)

1. High-pressure pump to cooler tube assembly
2. M12 cap nut
3. M6 x 12 bolt

28. Remove M12 cap nut.

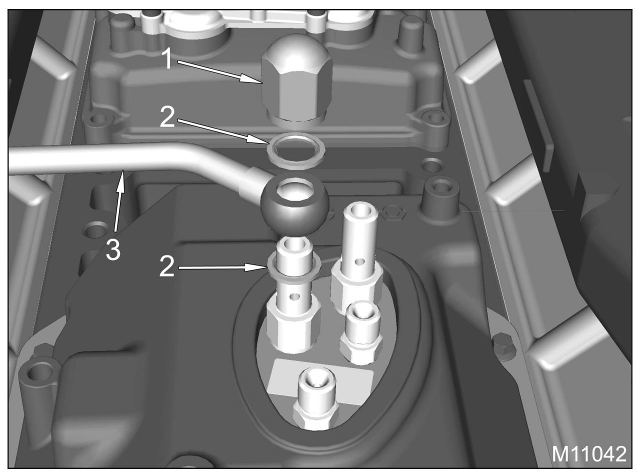

Figure 229 High-pressure pump to cooler tube assembly, M12 cap nut, and M12 bonded seal washers

1. M12 cap nut
2. M12 bonded seal washer (2)
3. High-pressure pump to cooler tube assembly

29. Remove M6 x 12 high-pressure pump to cooler tube assembly clamp bolt.
30. Remove high-pressure pump to cooler tube assembly.

31. Remove and discard two M12 bonded seal washers from high-pressure pump to cooler tube assembly.
32. Cover fuel pump port and ends of tube with Fuel System Caps (page 169). If plastic caps are not available, cover openings with tape.

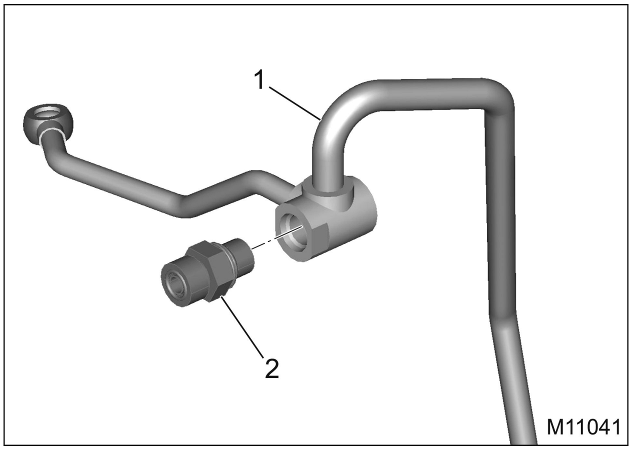

Figure 230 Injector leak off check valve

1. High-pressure pump to cooler tube assembly
2. Injector leak off check valve

33. Only if required for replacement, use a wrench to hold high-pressure pump to cooler tube assembly, and remove injector leak off check valve.

High-pressure Fuel Pump Assembly

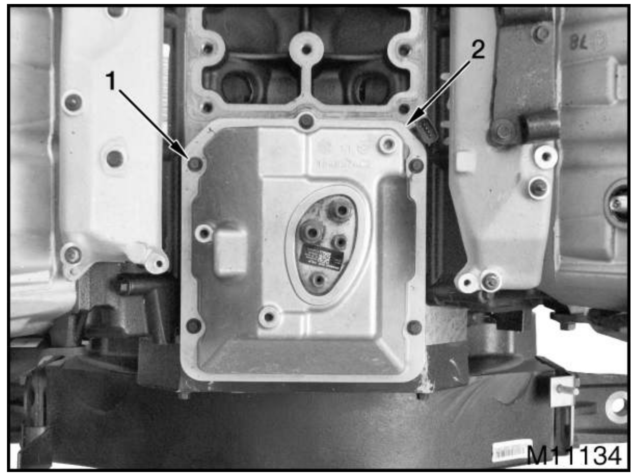

Figure 231 Fuel pump cover bolts

1. M6 x 25 bolt (5)
2. Fuel pump cover

1. Remove five M6 x 25 bolts and fuel pump cover.

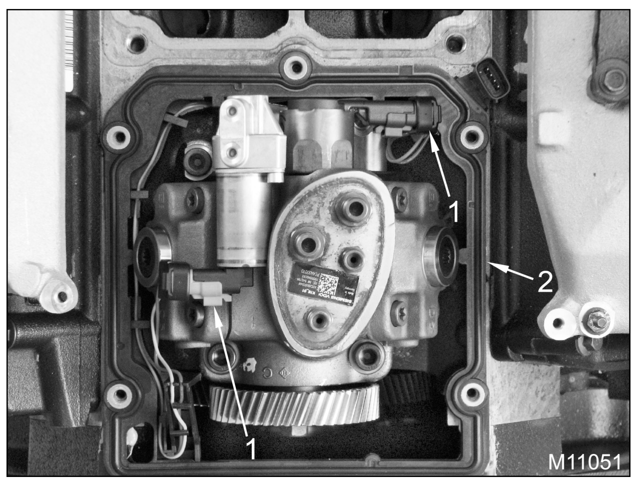

Figure 232 Pump cover gasket with connectors

1. Electrical connector (2)
2. Pump cover gasket with connectors

2. Disconnect two electrical connectors.
3. Remove and discard pump cover gasket with connectors.

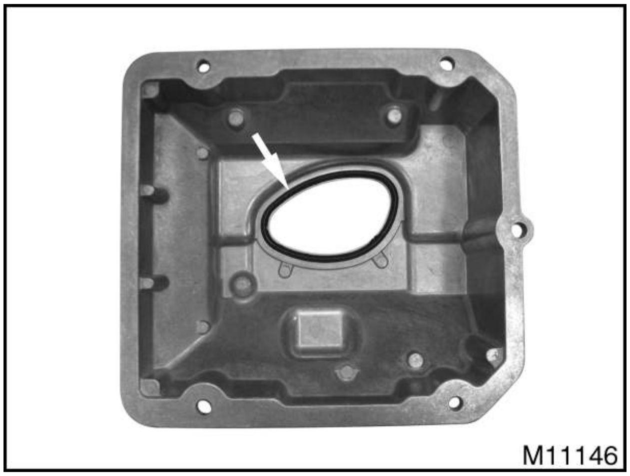

Figure 233 Pump cover gasket

4. Remove and discard pump cover gasket.

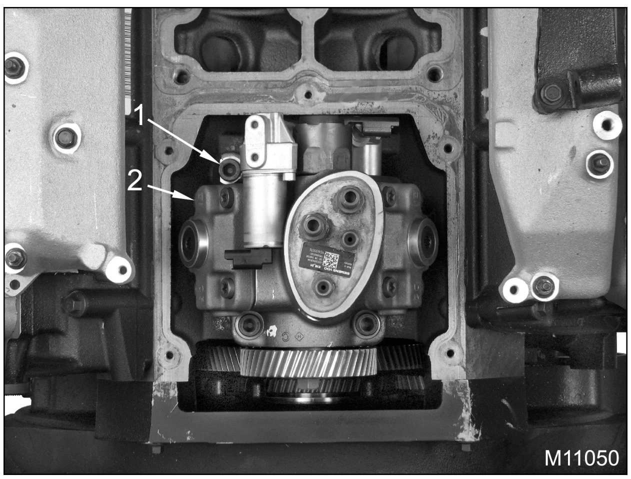

Figure 234 HPFP assembly

1. M10 x 55 bolt (3)
2. HPFP assembly

NOTE: Care must be taken to not drop the bolts into the crankcase.

5. Remove three M10 x 55 bolts and HPFP assembly.

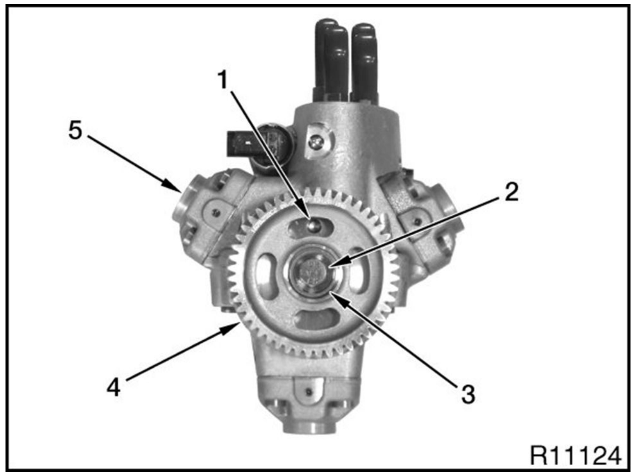

Figure 235 High-pressure fuel pump gear

1. Index hole
2. Fuel pump gear bolt
3. Fuel pump gear washer
4. Fuel pump gear
5. High-pressure fuel pump assembly with dowels

NOTE: Do steps 6–8 only, if replacing the high-pressure pump gear.

6. Insert a 1/4 inch steel punch into the index hole on the high-pressure fuel pump assembly to prevent the fuel pump gear from turning.

NOTE: The fuel pump gear bolt has left-hand threads.

7. Remove fuel pump gear bolt and washer.
8. Remove fuel pump gear.

Fuel Cooler Assembly

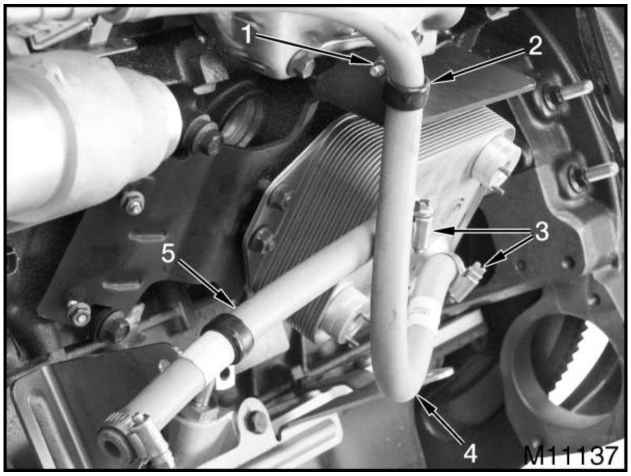

Figure 236 Fuel cooler assembly coolant hoses

1. M6 nut
2. Clamp
3. Hose clamp (2)
4. Coolant-in hose
5. Coolant-out from fuel cooler hose

1. Remove M6 nut and clamp.
2. Loosen two hose clamps.
3. Disconnect coolant-in hose and coolant-out hose from fuel cooler assembly.

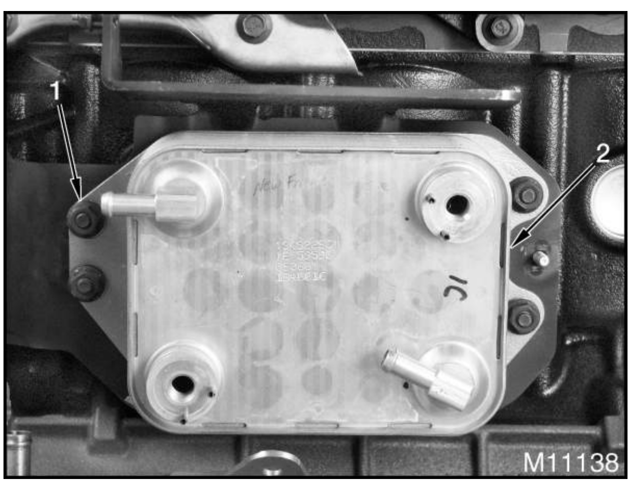

Figure 237 Fuel cooler assembly nuts

1. M8 nut (4)
2. Fuel cooler assembly

4. Remove four M8 nuts.
5. Remove fuel cooler assembly.

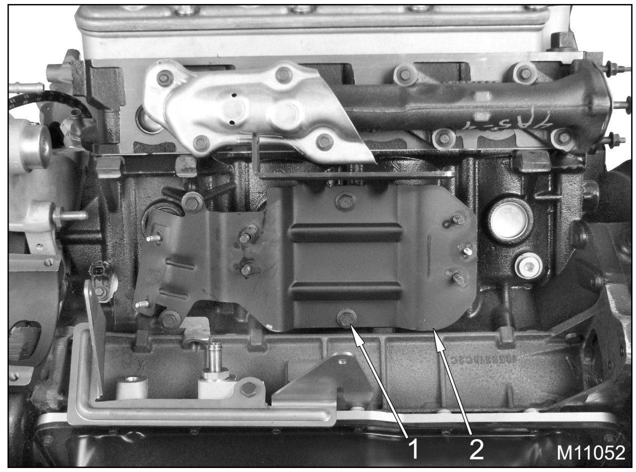

Figure 238 Cooler support bracket assembly

1. M10 x 20 bolt (4)
2. Cooler support bracket assembly

6. Remove four M10 x 20 bolts and cooler support bracket assembly.

Fuel Injectors and Fuel Rail to Injectors Tube Assemblies

NOTE: See Fuel Injector and Rail Assemblies (page 225) for removal procedures.

Inspection

1. Inspect fuel tubes for damage. Replace if necessary.
2. Inspect fuel line sleeves for damage. Replace if necessary.

Installation

Fuel Injectors and Fuel Rail to Injectors Tube Assemblies

NOTE: See Fuel Injector and Rail Assemblies (page 253) for installation procedures.

Fuel Cooler Assembly

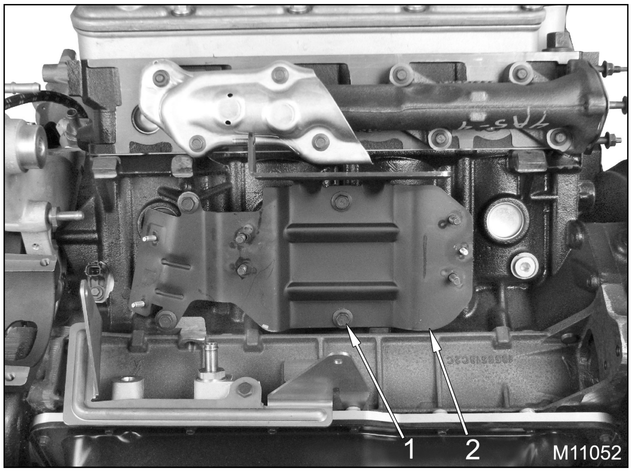

Figure 239 Cooler support bracket assembly

1. M10 x 20 bolt (4)
2. Cooler support bracket assembly

1. Install cooler support bracket assembly and four M10 x 20 bolts.
2. Tighten bolts to standard torque (page 383).

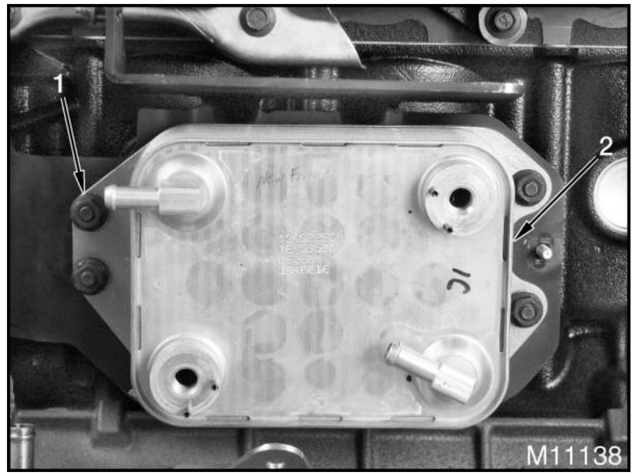

Figure 240 Fuel cooler assembly nuts

1. M8 nut (4)
2. Fuel cooler assembly

3. Install fuel cooler assembly and four M8 nuts.
4. Tighten nuts to standard torque (page 383).

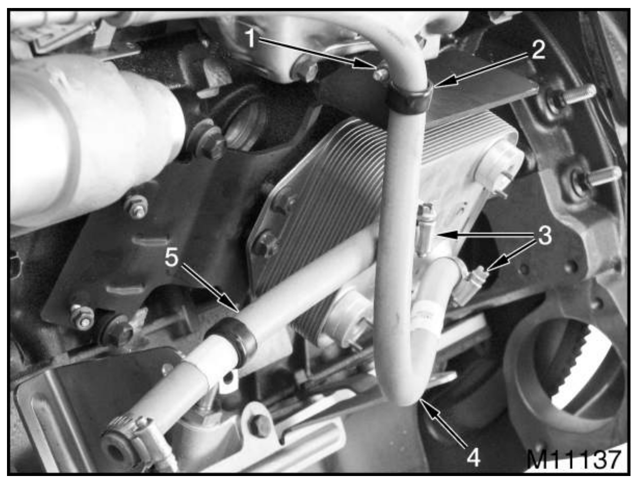

Figure 241 Fuel cooler assembly coolant hoses

1. M6 nut
2. Clamp
3. Hose clamp (2)
4. Coolant-in hose
5. Coolant-out from fuel cooler hose

5. Connect coolant-in hose and coolant-out hose to fuel cooler assembly. Do not tighten hose clamps at this time.

6. Install clamp and M6 nut. Do not tighten at this time.
7. Position coolant-in hose to maintain approximately 25.4 mm (1.0 in) clearance to exhaust manifold heat shield.
8. Tighten M6 clamp nut to standard torque (page 383).
9. Tighten two hose clamps to special torque (page 169).

High-pressure Fuel Pump Assembly

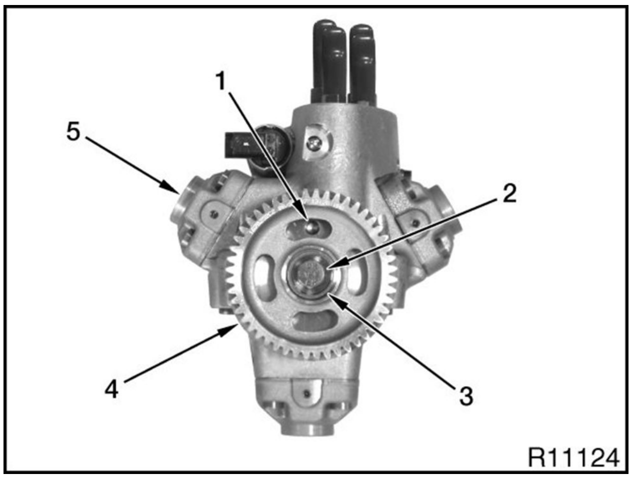

Figure 242 High-pressure fuel pump gear

1. Index hole
2. Fuel pump gear bolt
3. Fuel pump gear washer
4. Fuel pump gear
5. High-pressure fuel pump assembly with dowels

NOTE: The fuel pump gear bolt has left-hand threads.

1. Install fuel pump gear.
2. Install fuel pump gear bolt and washer.
3. Insert a 1/4 inch steel punch into the index hole on the high-pressure fuel pump assembly to prevent the fuel pump gear from turning.
4. Tighten gear bolt (counterclockwise) to special torque (page 169).

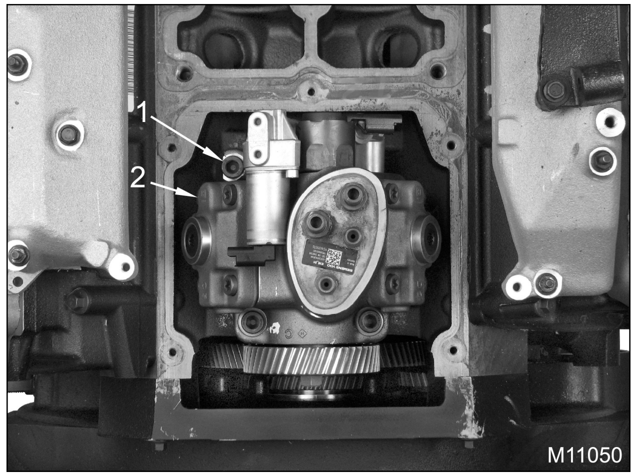

Figure 243 HPFP assembly

1. M10 x 55 bolt (3)
2. HPFP assembly

NOTE: Care must be taken to not drop the bolts into the crankcase.

5. Lower HPFP assembly into crankcase and secure with three M10 x 55 bolts. Tighten bolts to special torque (page 169).

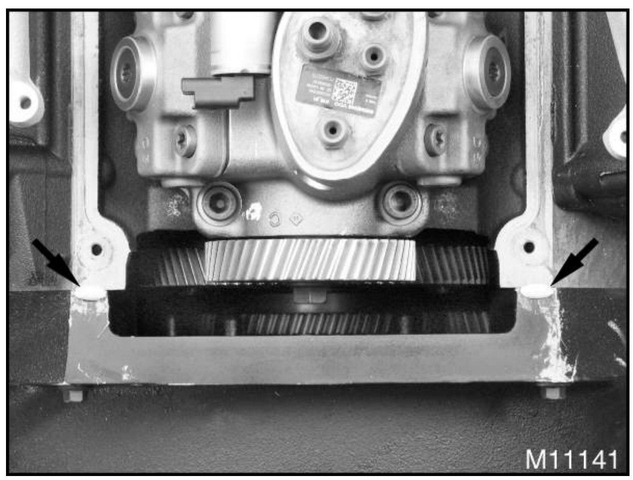

Figure 244 Liquid Gasket (RTV) application

6. Apply Liquid Gasket (RTV) (page 169) to joining surfaces of crankcase and crankcase rear cover assembly.

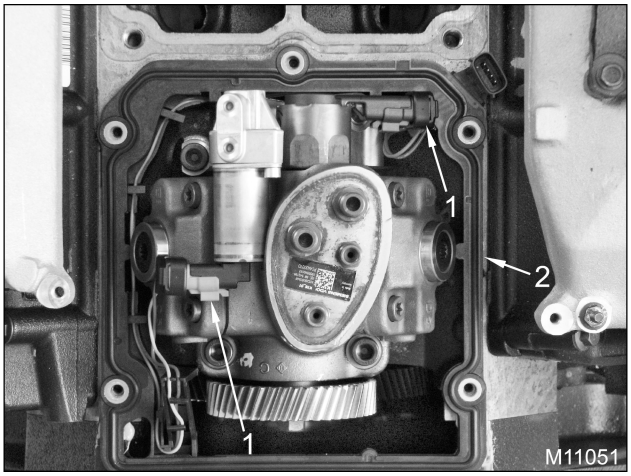

Figure 245 Pump cover gasket with connectors

1. Electrical connector (2)
2. Pump cover gasket with connectors

7. Install a new pump cover gasket with connectors and connect the two electrical connectors.

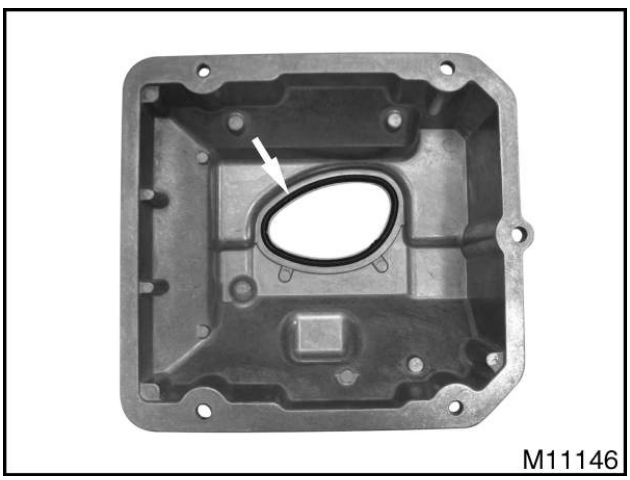

Figure 246 Pump cover gasket

8. Install a new pump cover gasket.

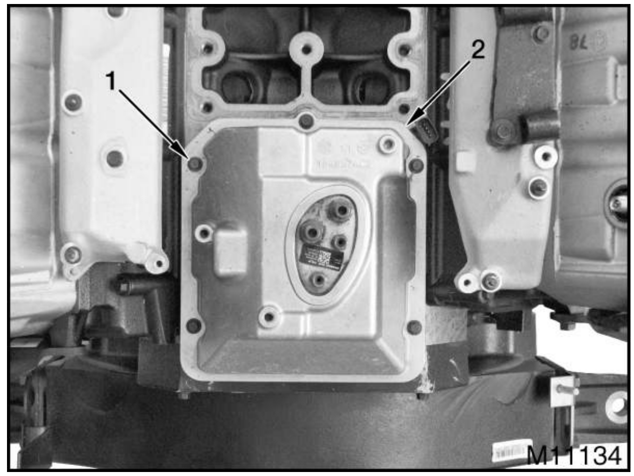

Figure 247 Fuel pump cover bolts

1. M6 x 25 bolt (5)
2. Fuel pump cover

9. Install fuel pump cover and five M6 x 25 bolts. Tighten bolts to special torque (page 169).

Tubing to High-pressure Fuel Pump (HPFP) Assembly

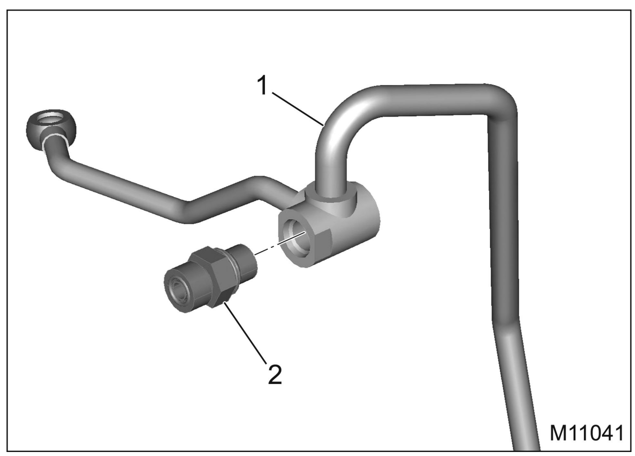

Figure 248 Injector leak off check valve

1. High-pressure pump to cooler tube assembly
2. Injector leak off check valve

1. If previously removed, install injector leak off check valve onto high-pressure pump to cooler tube assembly.

2. Use a wrench to hold high-pressure pump to cooler tube assembly, and tighten injector leak off check valve to special torque (page 169).

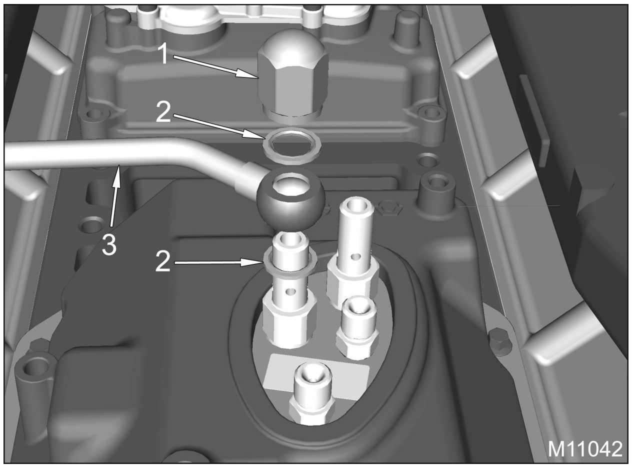

Figure 249 High-pressure pump to cooler tube assembly, M12 cap nut, and M12 bonded seal washer

1. M12 cap nut
2. M12 bonded seal washer (2)
3. High-pressure pump to cooler tube assembly

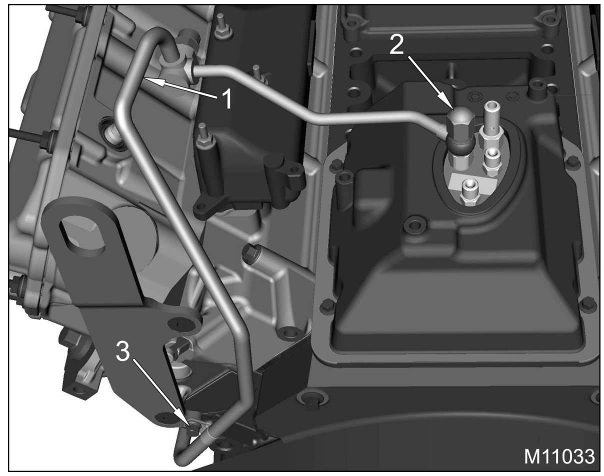

Figure 250 High-pressure pump to cooler tube assembly (upper connection)

1. High-pressure pump to cooler tube assembly
2. M12 cap nut
3. M6 x 12 bolt

3. Install a two new M12 bonded seal washers on high-pressure pump to cooler tube assembly fitting connecting to HPFP assembly.
4. Install high-pressure pump to cooler tube assembly.

5. Install M6 x 12 high-pressure pump to cooler tube assembly clamp bolt. Tighten bolt to standard torque (page 383).
6. Install M12 cap nut. Tighten cap nut to special torque (page 169).

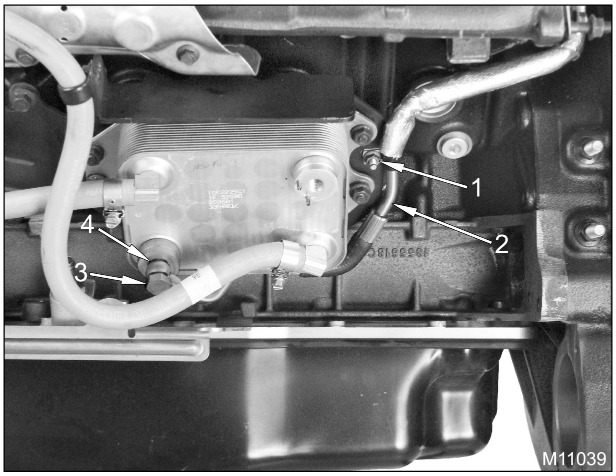

Figure 251 High-pressure pump to cooler tube assembly (lower connection)

1. M6 nut (2)
2. High-pressure pump to cooler tube assembly
3. M12 banjo bolt
4. M12 bonded seal washer (2)

7. Install M6 clamp nut. Tighten nut to standard torque (page 383).
8. Install two new M12 bonded seal washers (one each side of banjo fitting) on high-pressure pump to cooler tube assembly.
9. Install M12 banjo bolt. Tighten banjo bolt to special torque (page 169).

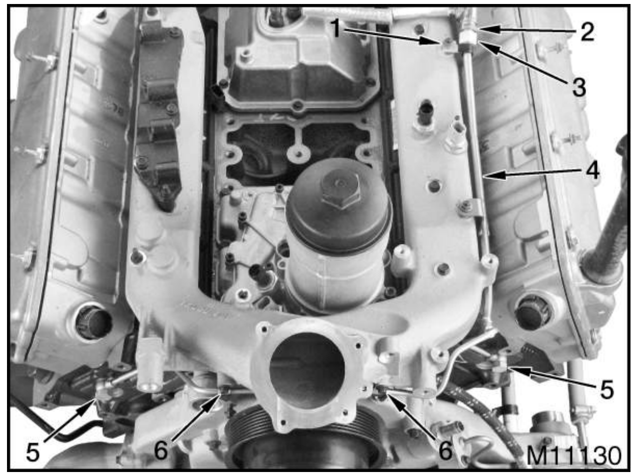

Figure 252 Injector return tube assembly

1. M6 nut (2)
2. Injector leak off check valve
3. 3/8” O-ring face seal nut
4. Injector return tube assembly
5. M12 banjo bolt (2)
6. M6 x 10 bolt (2)

10. Install injector return tube assembly.
11. Loosely install two M6 nuts and two M6 x 10 bolts. Do not tighten at this time.
12. Hand start and seat 3/8” O-ring face seal nut onto injector leak off check valve.

NOTE: When using a crowfoot extension make sure to adjust the torque settings as necessary to compensate for any length added to the torque wrench. See Appendix B - Torques (page 384).

13. Use a wrench to hold injector leak off check valve and, with a crowfoot torque wrench, tighten 3/8” O-ring face seal nut to special torque (page 169).

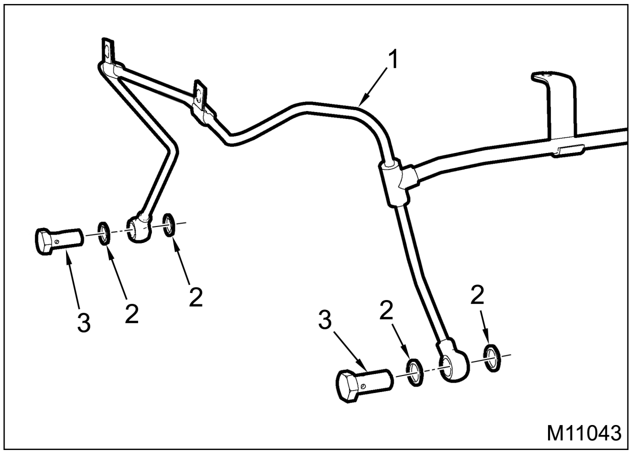

Figure 253 Injector return tube assembly, bonded seal washers, and banjo bolts

1. Injector return tube assembly
2. M12 bonded seal washer (4)
3. M12 banjo bolt (2)

14. Install four M12 bonded seal washers on injector return tube assembly.
15. Install two M12 banjo bolts. Tighten banjo bolts to special torque (page 169).
16. Tighten two M6 x 10 bolts to standard torque (page 383).
17. Tighten two M6 nuts to standard torque (page 383).

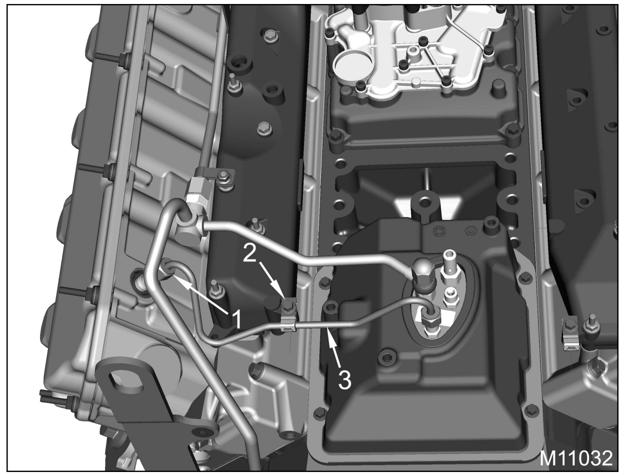

Figure 254 Pump left tube assembly

1. Tube nut (2)
2. M6 x 16 bolt
3. Pump left tube assembly

WARNING: To prevent personal injury or death, whenever any fuel line (tubing) in the high-pressure fuel system is removed, it must be replaced with new.

18. Position new pump left tube assembly between HPFP assembly and left fuel rail.

NOTE: Support pump left tube assembly while hand tightening nuts to assure proper assembly of joints.

NOTE: When using a crowfoot extension make sure to adjust the torque settings as necessary to compensate for any length added to the torque wrench. See Appendix B - Torques (page 384).

19. Hand start and seat tube assembly nuts onto mating connections, then tighten with a crowfoot torque wrench as follows:
    a. Torque to 2 N·m (18 lbf·in).
    b. Torque to 16 N·m (142 lbf·in).
    c. Tighten nuts an additional 60°.
20. Install M6 x 16 bolt. Tighten bolt to standard torque (page 383).

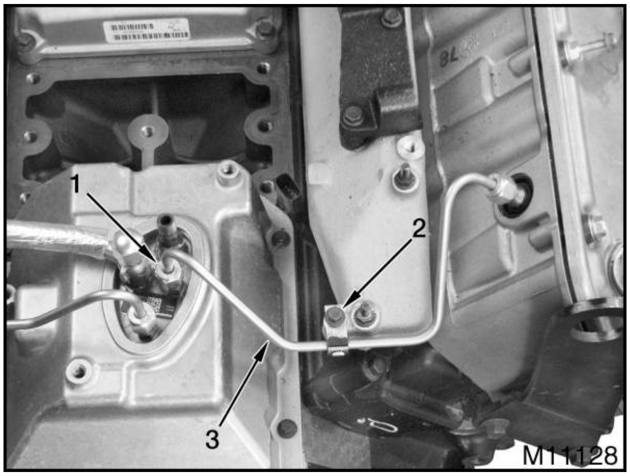

Figure 255 Pump right tube assembly

1. Tube nut (2)
2. M6 x 16 bolt
3. Pump right tube assembly

WARNING: To prevent personal injury or death, whenever any fuel line (tubing) in the high-pressure fuel system is removed, it must be replaced with new.

21. Position new pump right tube assembly between HPFP assembly and right fuel rail.

NOTE: Support pump right tube assembly while hand tightening nuts to assure proper assembly of joints.

NOTE: When using a crowfoot extension make sure to adjust the torque settings as necessary to compensate for any length added to the torque wrench. See Appendix B - Torques (page 384).

22. Hand start and seat tube assembly nuts onto mating connections, then tighten with a crowfoot torque wrench as follows:
    a. Torque to 2 N·m (18 lbf·in).
    b. Torque to 16 N·m (142 lbf·in).
    c. Tighten nuts an additional 60°.
23. Install M6 x 16 bolt. Tighten bolt to standard torque (page 383).

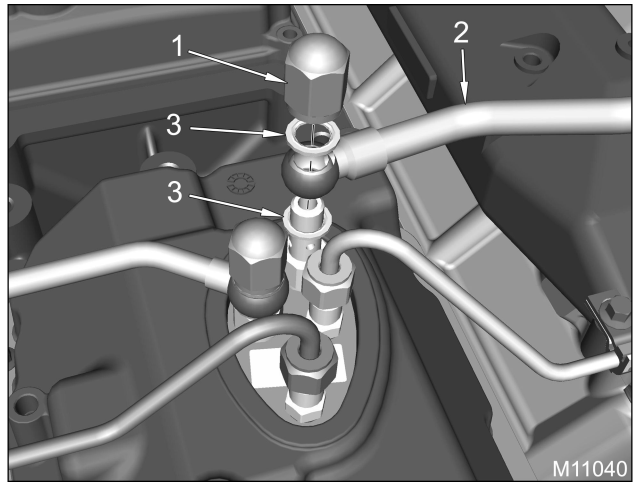

Figure 256 Injector return tube assembly, bonded seal washers, and banjo bolts

1. M12 cap nut
2. Filter to pump tube assembly
3. M12 bonded seal washer

24. Install two new M12 bonded seal washers on filter to pump tube assembly.
25. Position filter to pump tube assembly..
26. Install M12 cap nut.

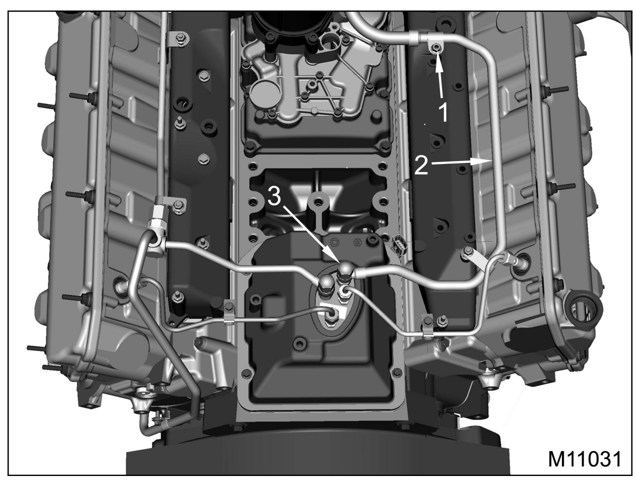

Figure 257 Filter to pump tube assembly

1. M6 nut (2)
2. Filter to pump tube assembly
3. M12 cap nut

27. Install two M6 nuts. Tighten nuts to standard torque (page 383).

28. Tighten cap nut to special torque (page 169).

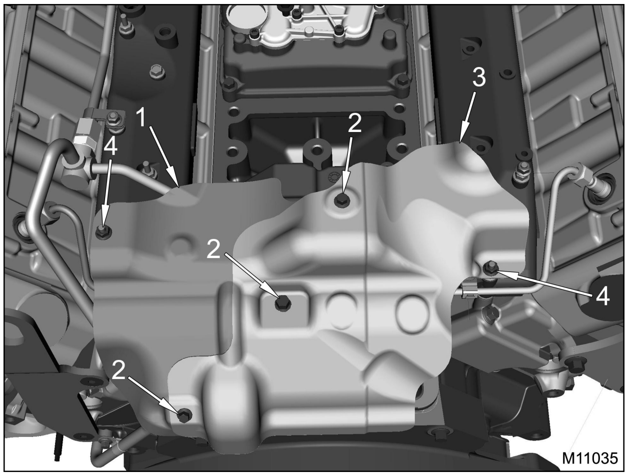

Figure 258 Heat shields

1. Left heat shield
2. M6 x 12 bolt (3)
3. Right heat shield
4. M6 nut (2)

29. Install left heat shield.
30. Install right heat shield.
31. Install three M6 x 12 heat shield bolts. Tighten bolts to standard torque (page 383).
32. Install two M6 heat shield nuts. Tighten nuts to standard torque (page 383).

Secondary Fuel Filter and Tubing

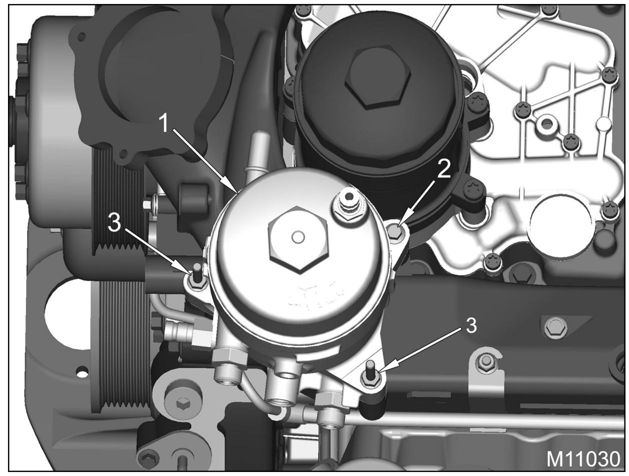

Figure 259 Secondary fuel filter assembly bolts

1. Secondary fuel filter assembly
2. M6 x 45 bolt
3. M6 x 45 stud bolt (2)

1. Install secondary fuel filter assembly.
2. Install two M6 x 45 stud bolts. Tighten stud bolts to standard torque (page 383).
3. Install M6 x 45 bolt. Tighten bolt to standard torque (page 383).

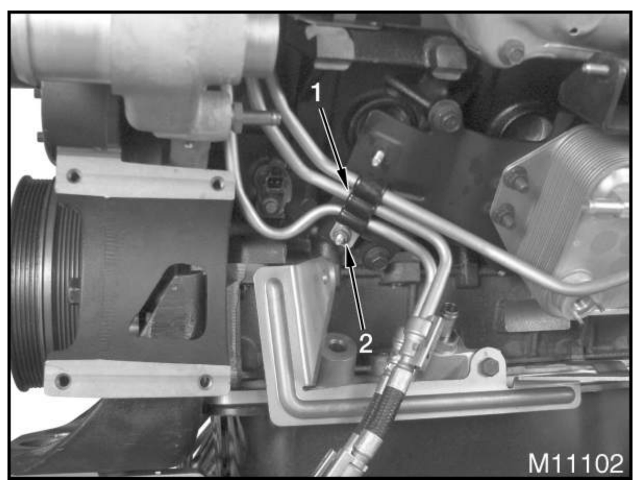

Figure 260 Triple tube clamp

1. Triple tube clamp
2. M6 nut

4. Install fuel supply to filter tube assembly, fuel cooler to filter tube assembly, and fuel return to tank tube assembly. Secure tubes with triple tube clamp.
5. Loosely install M6 nut. Do not tighten at this time.

Figure 261 Filter to pump tube assembly connection

1. Filter to pump tube assembly
2. Fitting release ring

6. Connect filter to pump tube assembly, and push tube toward fuel filter housing to lock fitting.

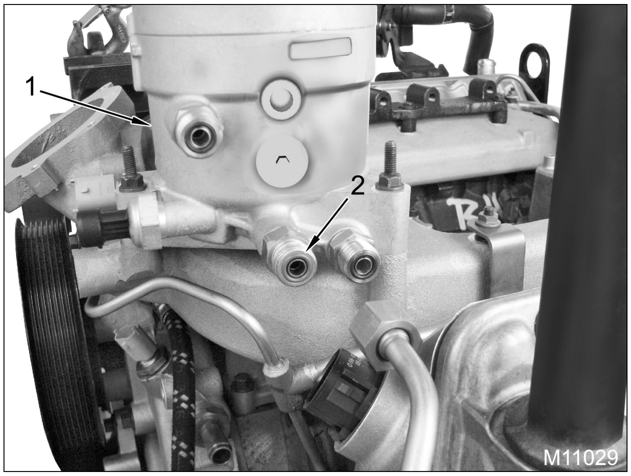

Figure 262 Fuel filter housing O-rings

1. Fuel filter housing
2. O-ring (3)

7. Install three new O-rings on fuel filter housing fittings.

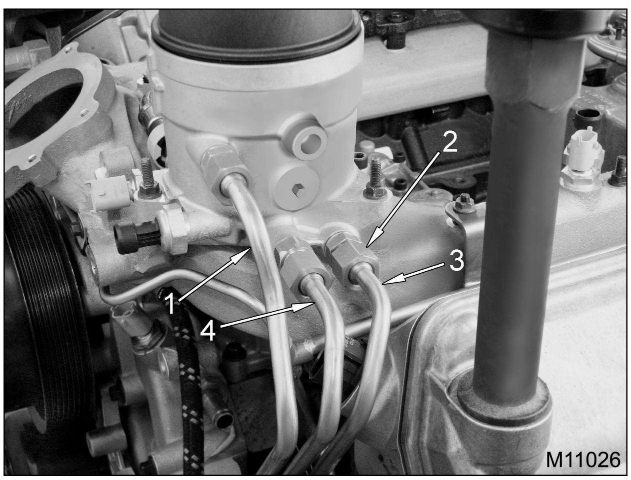

Figure 263 Fuel supply and return tubing

1. Fuel supply to filter tube assembly
2. 3/8” O-ring face seal nuts
3. Fuel cooler to filter tube assembly
4. Fuel return to tank tube assembly

NOTE: When using a crowfoot extension make sure to adjust the torque settings as necessary to compensate for any length added to the torque wrench. See Appendix B - Torques (page 384).

8. Connect fuel cooler to filter tube assembly, fuel supply to filter tube assembly, and fuel return to tank tube assembly to fuel filter housing fittings. Secure tubes with 3/8” O-ring face seal nuts. Tighten nuts to special torque (page 169).
9. Tighten M6 triple tube clamp nut to standard torque (page 383).

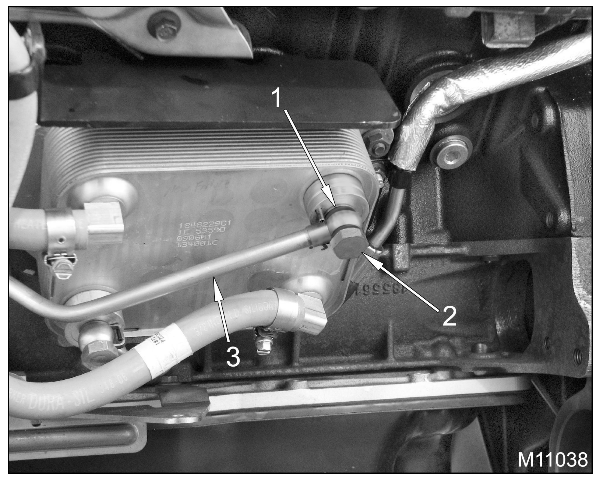

Figure 264 Fuel cooler to filter tube assembly connection

1. Dual M12 banjo washer
2. M12 banjo bolt
3. Fuel cooler to filter tube assembly

10. Install a new dual M12 banjo washer on fuel cooler to filter tube assembly.
11. Secure fuel cooler to filter tube assembly with M12 banjo bolt. Tighten banjo bolt to special torque (page 169).

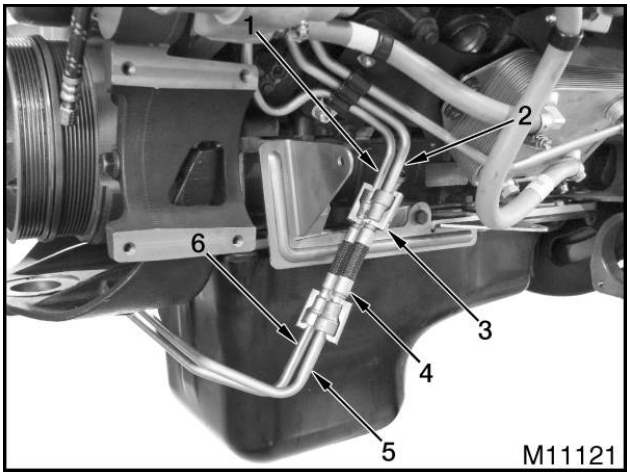

Figure 265 Fuel supply and return tube connections

1. Fuel supply to filter tube
2. Fuel return to tank tube assembly
3. 3/8” redundant clip (4)
4. 3/8” hose assembly (2)
5. Fuel return tube assembly
6. Fuel supply tube assembly

12. Connect 3/8” hose assemblies to fuel return to tank tube assembly and fuel supply to filter tube assembly and push together until audible click is heard.
13. Connect fuel return tube assembly and fuel supply tube assembly to 3/8” hose assemblies, and push together until audible click is heard.
14. Install four 3/8” redundant clips.

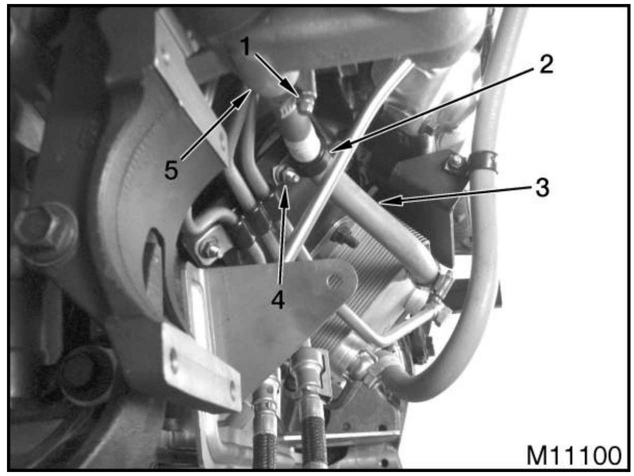

Figure 266 Coolant out from fuel cooler hose

1. Hose clamp
2. Clamp
3. Coolant out from fuel cooler hose
4. M6 nut
5. Front crankcase cover

15. Connect coolant out hose to front crankcase cover fitting and secure with hose clamp. Tighten hose clamp to special torque (page 169).
16. Install clamp and M6 nut. Tighten nut to standard torque (page 383).

Fuel Primer Pump Assembly and Tubing

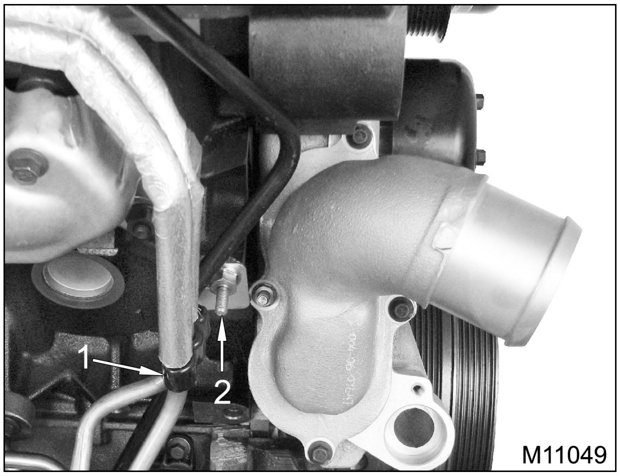

Figure 267 Triple tube clamp

1. Triple tube clamp
2. M8 x 30 stud bolt

1. Install fuel return from primer tube assembly and fuel supply to primer tube assembly in triple tube clamp.
2. Install fuel primer tubes and triple tube clamp on breather drain steel tube.
3. Secure triple tube clamp with M8 x 30 stud bolt. Do not tighten stud bolt at this time.

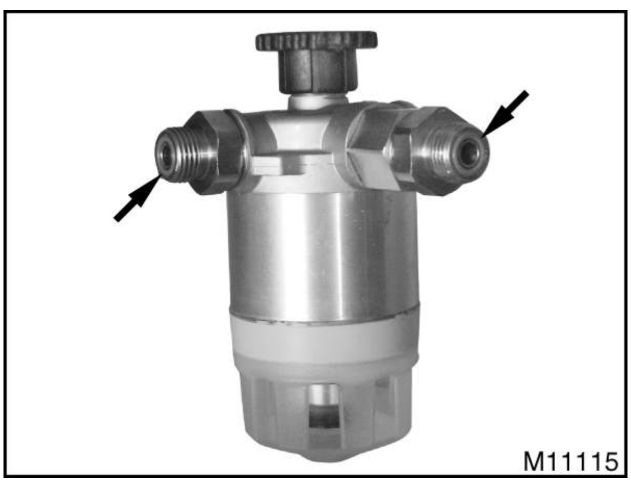

Figure 268 Fuel primer pump assembly O-rings

4. Install two new O-rings onto fuel primer pump assembly.

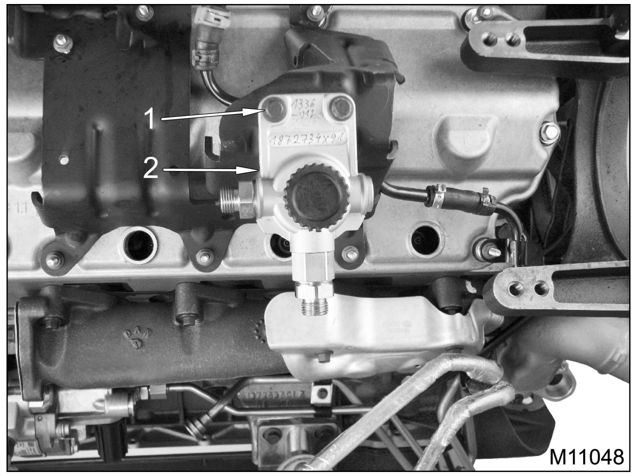

Figure 269 Fuel primer pump assembly bolts

1. M8 x 30 bolt (2)
2. Fuel primer pump assembly

5. Install fuel primer pump assembly and two M8 x 30 bolts. Tighten bolts to standard torque (page 383).

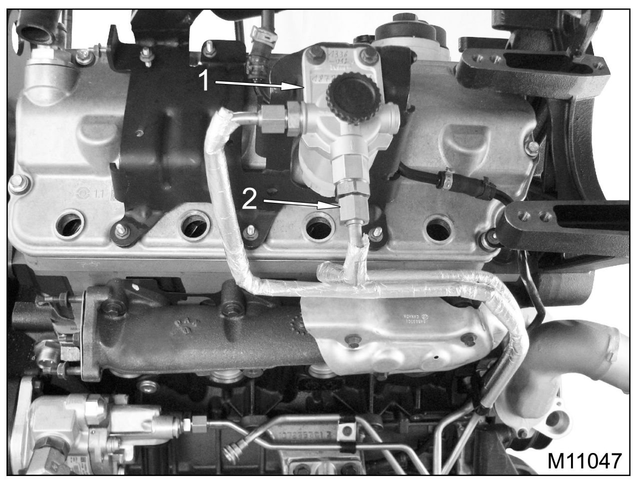

Figure 270 Fuel primer pump assembly tube connections

1. Fuel primer pump assembly
2. 3/8” O-ring face seal nut (2)

NOTE: When using a crowfoot extension make sure to adjust the torque settings as necessary to compensate for any length added to the torque wrench. See Appendix B - Torques (page 384).

6. Connect fuel supply to primer pump tube assembly and fuel return from primer pump tube assembly, and secure with two 3/8” O-ring face seal nuts. Tighten nuts to special torque (page 169).
7. Tighten M8 x 30 triple tube clamp stud bolt to standard torque (page 383).

Primary Fuel Filter Assembly and Tubing

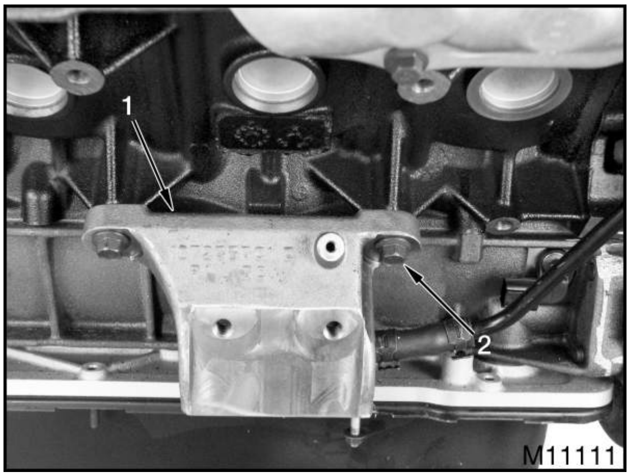

Figure 271 Primary filter bracket support bolts

1. Primary filter bracket support
2. M10 x 30 bolt (2)

1. Install primary filter bracket support and two M10 x 30 bolts. Tighten bolts to standard torque (page 383).

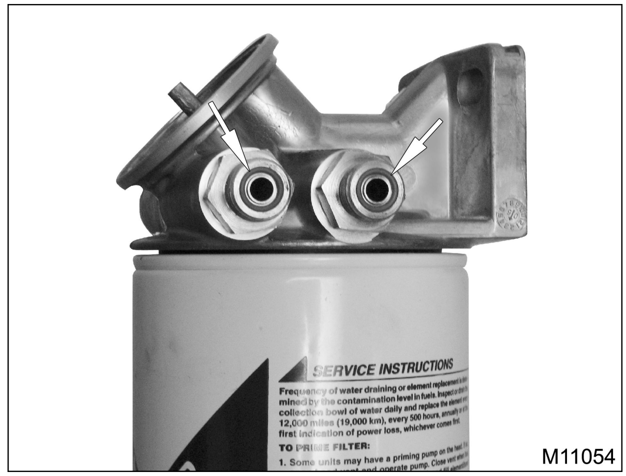

Figure 272 Fuel filter primary header O-rings

2. Install two new O-rings onto fuel filter primary header.

Figure 273 Fuel filter primary header to filter bracket support bolts

1. Fuel filter primary header
2. M10 x 30 bolt (2)

3. Install fuel filter primary header and two M10 x 30 bolts. Tighten bolts to standard torque (page 383).

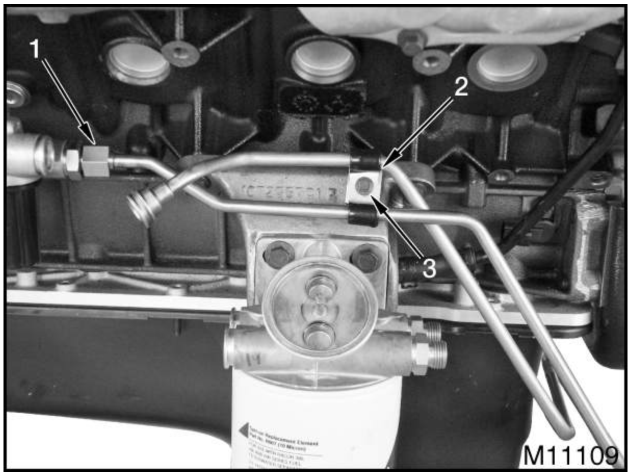

Figure 274 Primary filter bracket support clamp

1. 3/8” O-ring face seal nut
2. Saddle clamp
3. M6 x 12 bolt

NOTE: When using a crowfoot extension make sure to adjust the torque settings as necessary to compensate for any length added to the torque wrench. See Appendix B - Torques (page 384).

4. Connect fuel supply tube assembly to power steering/fuel pump and secure with 3/8” O-ring face seal nut. Tighten nut to special torque (page 169).

NOTE: Position and hold the fuel return tube assembly into flat clamp while tightening the bolt.

5. Install flat clamp and saddle clamp, and secure with M6 x 12 bolt. Tighten bolt to standard torque (page 383).

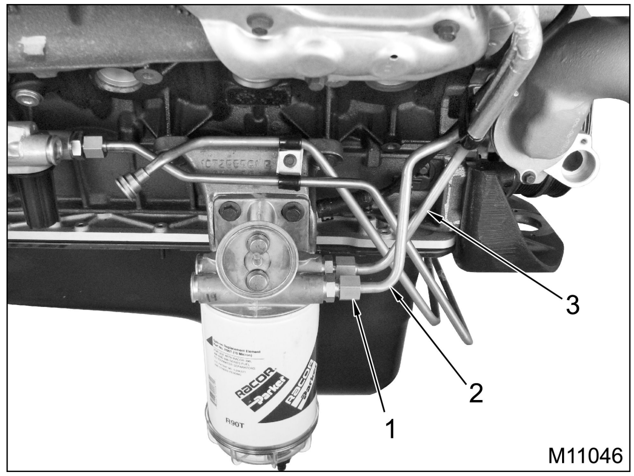

Figure 275 Primer pump tubes connection

1. 3/8” O-ring face seal nut (2)
2. Fuel return from primer pump tube assembly
3. Fuel supply to primer pump tube assembly

NOTE: When using a crowfoot extension make sure to adjust the torque settings as necessary to compensate for any length added to the torque wrench. See Appendix B - Torques (page 384).

6. Connect fuel return from primer pump tube assembly and fuel supply to primer pump tube assembly, and secure with two 3/8” O-ring face seal nuts. Tighten nuts to special torque (page 169).

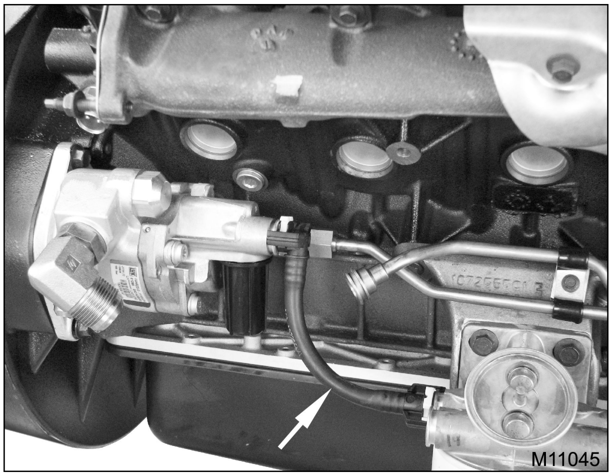

Figure 276 Primary filter to pump tube assembly

7. Push primary filter to pump tube assembly fitting into primary fuel filter. Make sure quick connector is locked in place.

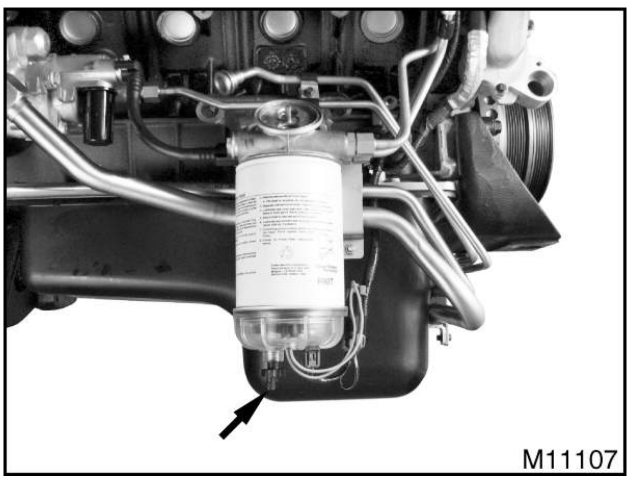

Figure 277 Fuel drain valve

8. Close fuel drain valve by turning it clockwise.

Secondary Fuel Filter Element

1. Install a new fuel filter element in fuel filter housing.

CAUTION: To prevent engine damage, do not add fuel to the fuel filter housing; this can add contaminants to the fuel.

2. Install a new O-ring on fuel filter cap.

CAUTION: To prevent engine damage, the fuel filter element must be installed in the fuel filter housing.

NOTE: The engine will not run if the filter element is not installed. The installed filter element opens a check valve in the center of the stand pipe, allowing fuel to flow.

3. Install fuel filter cap and tighten to special torque (page 169).

Primary Fuel Filter Element

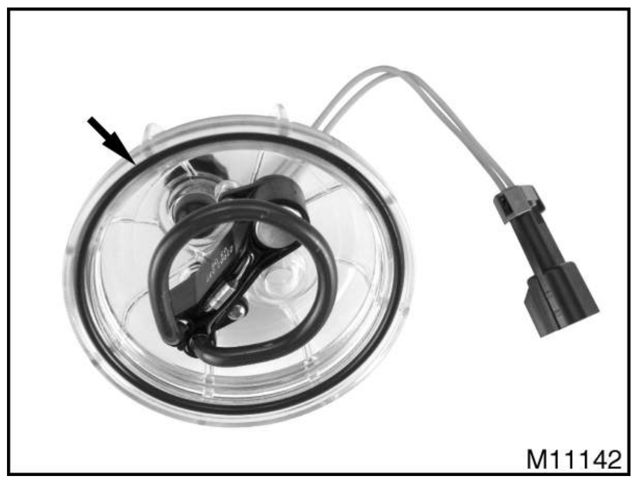

Figure 278 Element and bowl primary filter seal

1. Install a new bowl primary filter seal onto bowl assembly.

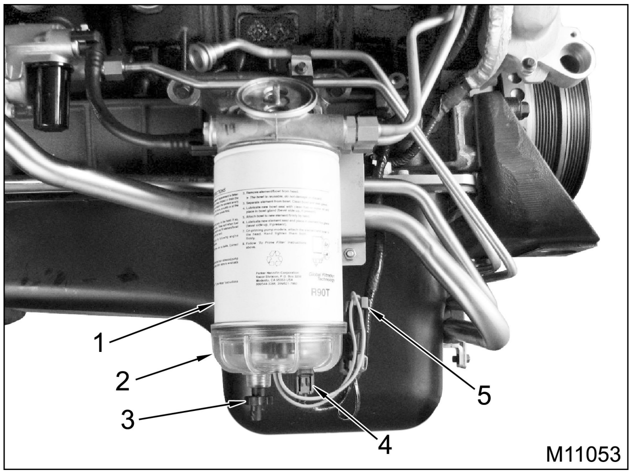

Figure 279 Primary filter element assembly

1. Primary filter element assembly
2. Bowl assembly with fuel heater/probe
3. Fuel drain valve
4. Water in Fuel (WIF) sensor electrical connector
5. Fuel heater electrical connector

2. Install a new primary filter element assembly and hand tighten firmly.
3. Install bowl assembly and hand tighten firmly.
4. Close fuel drain valve by turning it clockwise.
5. Connect fuel heater electrical connector.
6. Connect WIF sensor electrical connector.

Specifications

Table 13 Fuel Filter

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

Special Torque

Table 14 Fuel System Components

High-pressure Fuel Pump (HPFP) assembly bolts	61 N·m (45 lbf·ft)
HPFP pump gear nut	78 N·m (57 lbf·ft)
Pump right tube assembly nuts	See tightening step in procedure.
Pump left tube assembly nuts	See tightening step in procedure.
Fuel pump cover bolts	13 N·m (116 lbf·in)
Injector leak off check valve	45 N·m (33 lbf·ft)
High-pressure pump to cooler tube assembly cap nut	38 N·m (28 lbf·ft)
Banjo bolts	38 N·m (28 lbf·ft)
Filter to pump tube assembly cap nut	38 N·m (28 lbf·ft)
Hose clamps	3 N·m (26 lbf·in)
3/8” O-ring face seal nuts	41 N·m (30 lbf·ft)
Fuel filter cap (secondary)	27 N·m (20 lbf·ft)

Special Service Tools

Table 15 Fuel System

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

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Exploded Views

Exhaust Manifolds

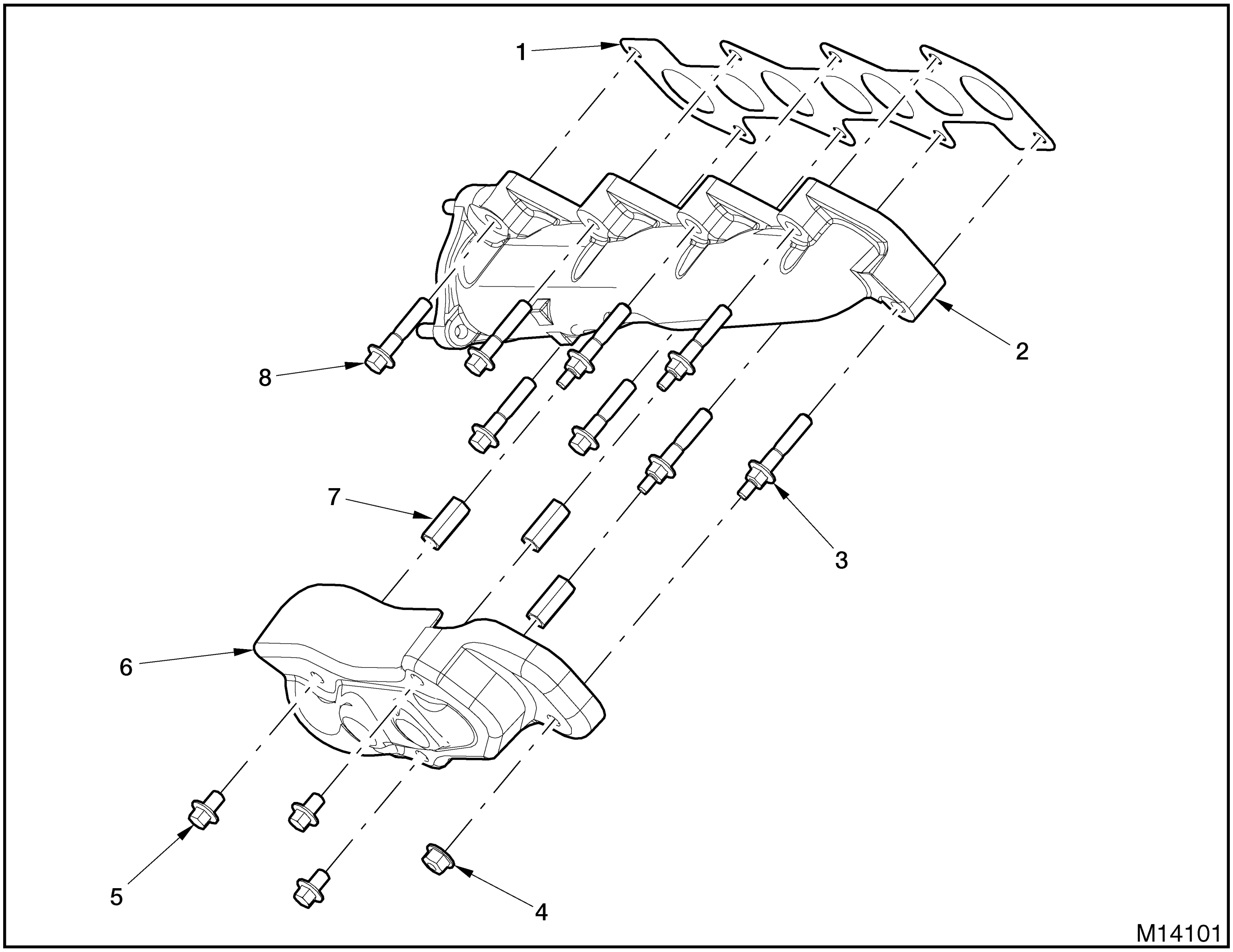

Figure 280 Left exhaust manifold (right side similar)

1. Exhaust manifold gasket
2. Left exhaust manifold
3. M8 x 40 stud bolt (4)
4. M8 nut
5. M8 x 12 bolt (3)
6. Heat shield
7. Heat shield threaded spacer (3)
8. M8 x 40 bolt (4)

Intake Manifold

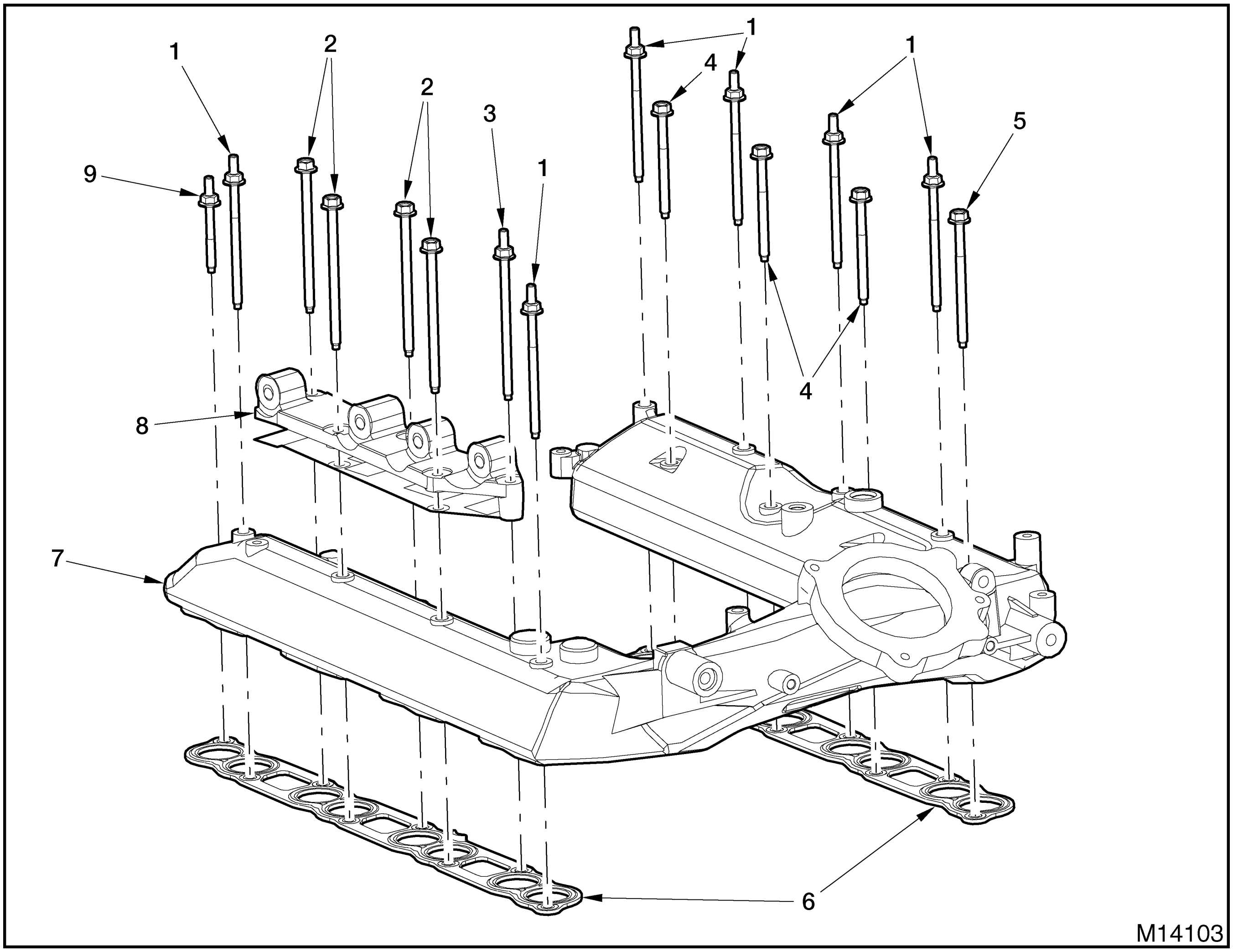

Figure 281 Intake manifold

1. M6 x 87 stud bolt (6)
2. M6 x 95 bolt (4)
3. M6 x 95 stud bolt
4. M6 x 70 bolt (3)
5. M6 x 87 bolt
6. Intake manifold gasket (2)
7. Intake manifold
8. Exhaust Gas Recirculation (EGR) cooler lower bracket
9. M6 x 47 stud bolt

Removal

GOVERNMENT REGULATION: Engine fluids (oil, fuel, and coolant) may be a hazard to human health and the environment. Handle all fluids and other contaminated materials (e.g. filters, rags) in accordance with applicable regulations. Recycle or dispose of engine fluids, filters, and other contaminated materials according to applicable regulations.

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.

NOTE: See the following service sections for information on removal of components prior to this section.

- Engine Electrical
- Exhaust Gas Recirculation (EGR) System
- Variable Geometry Turbocharger (VGT)
- Air Compressor and Power Steering/Fuel Pump
- Fuel System

Exhaust Manifolds

CAUTION: To prevent engine damage, do not reuse exhaust manifold bolts and stud bolts.

Left Exhaust Manifold

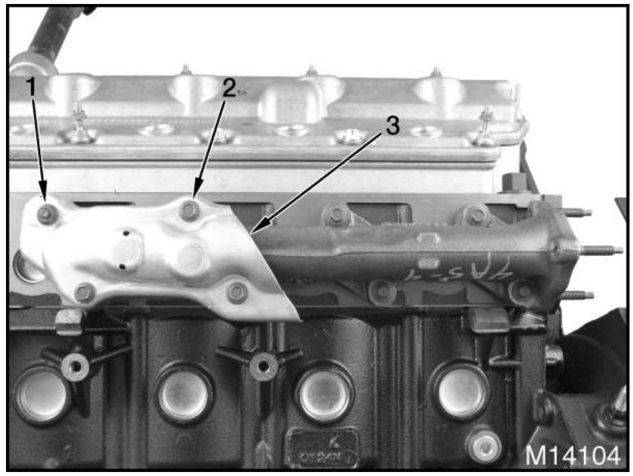

Figure 282 Left exhaust manifold heat shield

1. M8 nut
2. M8 x 12 bolt (3)
3. Heat shield

1. Remove and discard three M8 x 12 heat shield bolts and M8 heat shield nut.
2. Remove left exhaust manifold heat shield.

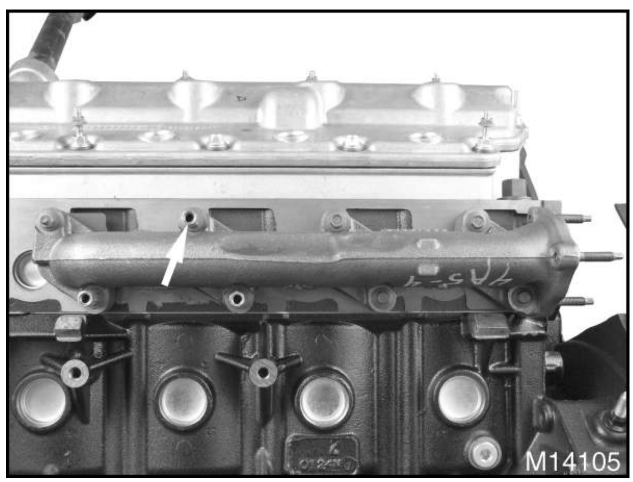

Figure 283 Left exhaust manifold heat shield spacers

3. Remove three left exhaust manifold heat shield threaded spacers.

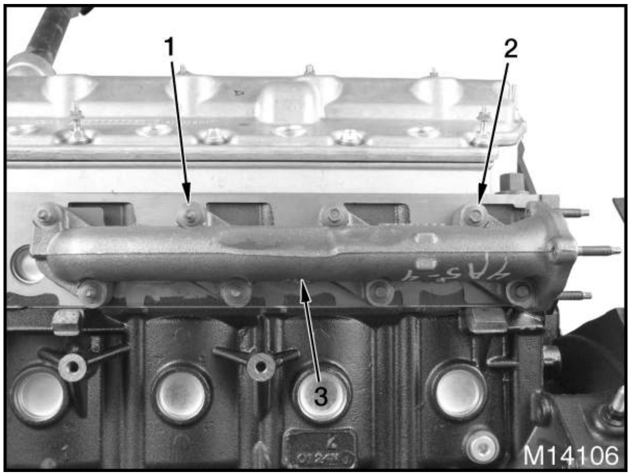

Figure 284 Left exhaust manifold

1. M8 x 40 stud bolt (4)
2. M8 x 40 bolt (4)
3. Left exhaust manifold

4. Remove and discard four M8 x 40 exhaust manifold bolts and four M8 x 40 exhaust manifold stud bolts.
5. Remove left exhaust manifold and discard gasket.

Right Exhaust Manifold

Figure 285 Right exhaust manifold heat shield

1. M8 x 12 bolt (3)
2. M8 nut
3. Heat shield

1. Remove and discard three M8 x 12 heat shield bolts and M8 heat shield nut.
2. Remove right exhaust manifold heat shield.

Figure 286 Right exhaust manifold heat shield spacers

3. Remove three right exhaust manifold heat shield threaded spacers.

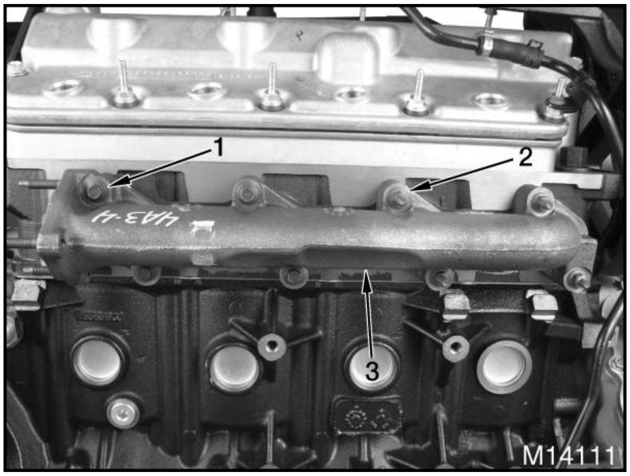

Figure 287 Right exhaust manifold

1. M8 x 40 bolt (4)
2. M8 x 40 stud bolt (4)
3. Right exhaust manifold

4. Remove and discard four M8 x 40 exhaust manifold bolts and four M8 x 40 exhaust manifold stud bolts.
5. Remove right exhaust manifold and discard gasket.

Intake Manifold

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

CAUTION: To prevent engine damage, cover the exposed portion of the engine and blow out or vacuum dirt and debris under the intake manifold. This prevents dirt and debris from entering the intake ports when the manifold is removed.

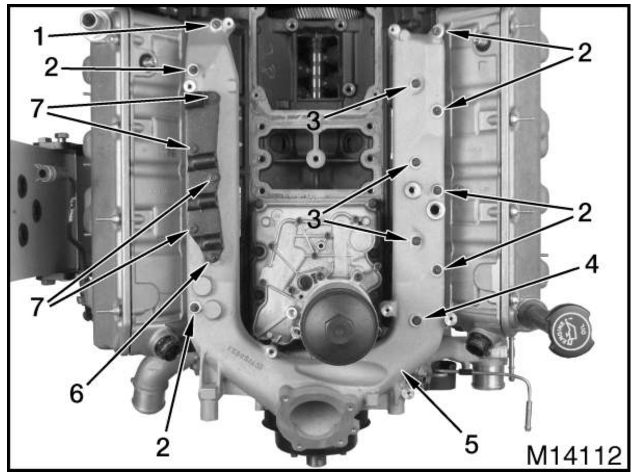

Figure 288 Intake manifold bolts

1. M6 x 47 stud bolt
2. M6 x 87 stud bolt (6)
3. M6 x 70 bolt (3)
4. M6 x 87 bolt
5. Intake manifold
6. M6 x 95 stud bolt
7. M6 x 95 bolt (4)

1. Remove eight intake manifold stud bolts and eight intake manifold bolts.
2. Remove Exhaust Gas Recirculation (EGR) cooler lower bracket.
3. Remove intake manifold by lifting straight up. Discard gaskets.
4. Place Intake Port Covers (page 184) over cylinder head intake ports.

Cleaning, Inspection, and Testing

Intake and Exhaust Manifolds

Intake and exhaust manifolds are one piece castings and may be cleaned with steam or suitable non-caustic solvents.

Manifold Warp Test for Exhaust Manifolds

1. Use a straightedge and feeler gauge to check seating surface flatness for right and left exhaust manifolds.
2. Check for flatness – across left and right and diagonally. See specifications (page 184).
3. If specifications are not met, do not resurface exhaust manifold, replace exhaust manifold.

Installation

Intake Manifold

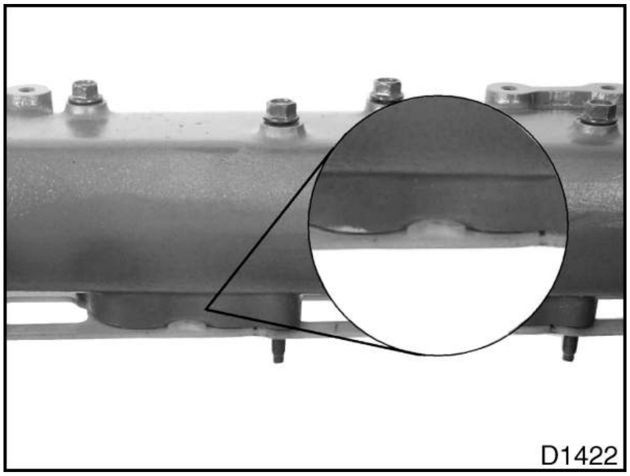

Figure 289 Intake manifold gasket with centering tab

1. Position a new intake manifold gasket on each side of intake manifold and install two bolts through each side to hold gaskets. Make sure centering tabs are facing up in the manifold, while positioned inboard toward engine valley.
2. Remove Intake Port Covers (page 184) from cylinder head intake ports.
3. Position intake manifold on cylinder heads.
4. Install Exhaust Gas Recirculation (EGR) cooler lower bracket.

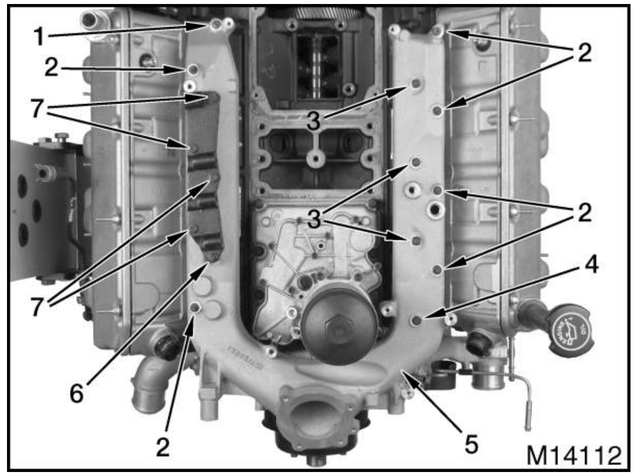

Figure 290 Intake manifold bolts

1. M6 x 47 stud bolt
2. M6 x 87 stud bolt (6)
3. M6 x 70 bolt (3)
4. M6 x 87 bolt
5. Intake manifold
6. M6 x 95 stud bolt
7. M6 x 95 bolt (4)

5. Loosely install eight intake manifold stud bolts and eight intake manifold bolts.

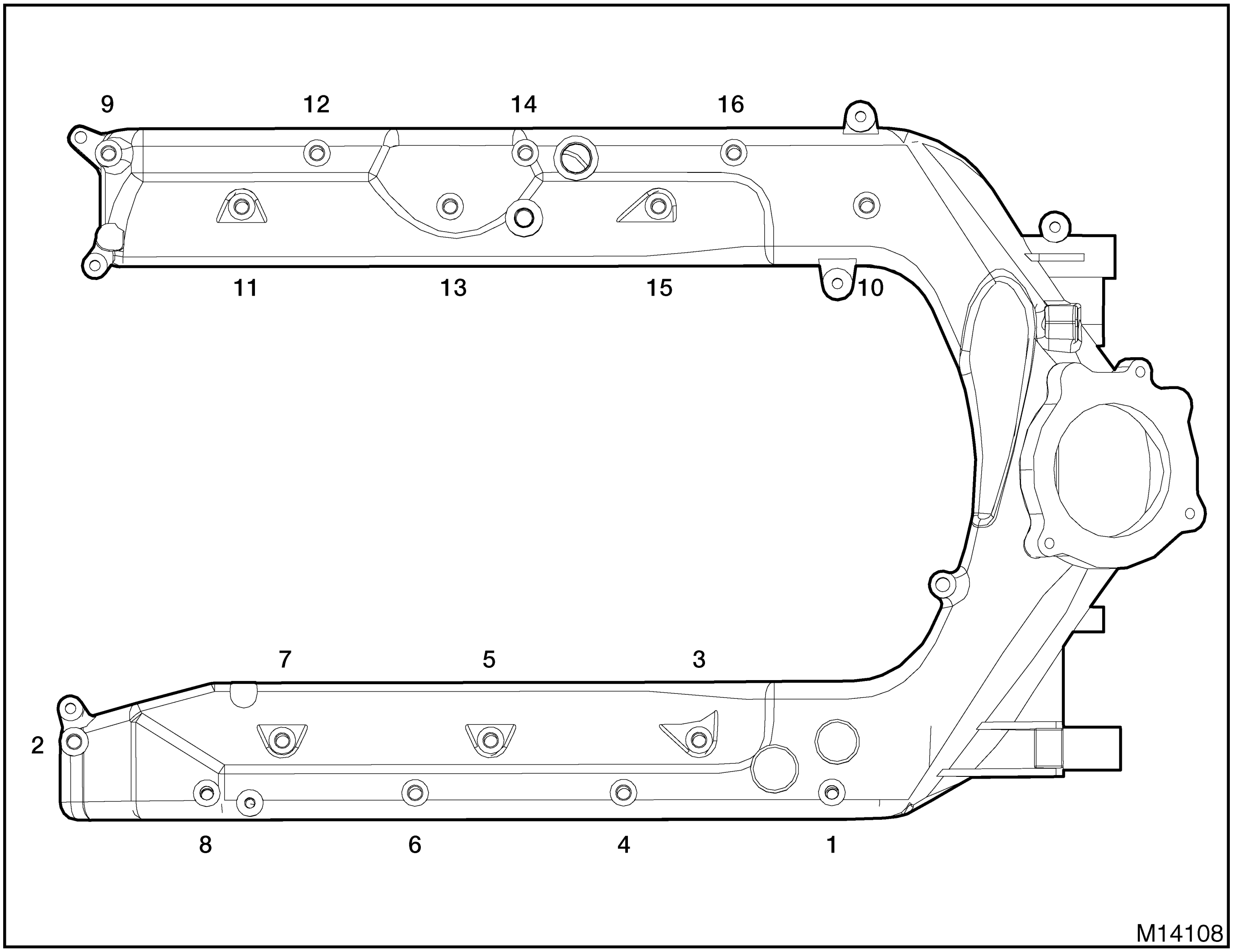

Figure 291 Torque sequence for intake manifold mounting bolts

6. Tighten intake manifold bolts and intake manifold stud bolts to special torque (page 184), following sequence (Figure 291).

Exhaust Manifolds

CAUTION: To prevent engine damage, hand torque all nuts and bolts of the exhaust manifolds. The exhaust manifold hardware has a special high-temperature coating which will be damaged by air tools.

CAUTION: To prevent engine damage, do not reuse exhaust manifold bolts or stud bolts.

NOTE: Do not apply anti-seize compound to threads.

Right Exhaust Manifold

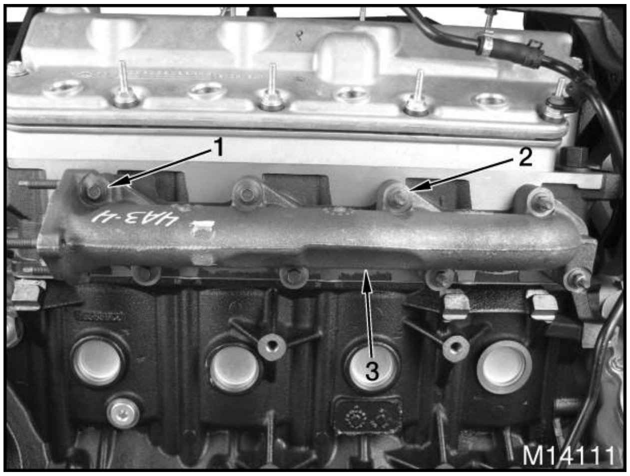

Figure 292 Right exhaust manifold

1. M8 x 40 bolt (4)
2. M8 x 40 stud bolt (4)
3. Right exhaust manifold

1. Position a new gasket and install right exhaust manifold.

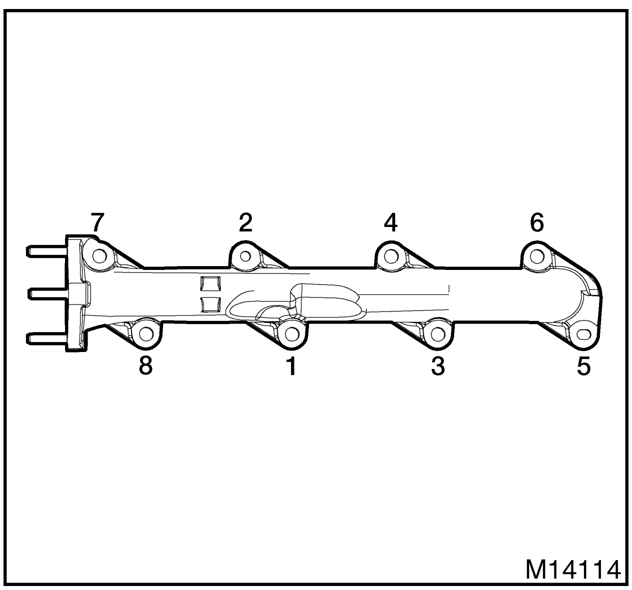

Figure 293 Torque sequence for right exhaust manifold mounting bolts

CAUTION: To prevent engine damage, align exhaust manifold gasket with exhaust manifold before tightening bolts and stud bolts to the specified torque value.

NOTE: Tighten bolts and stud bolts to special torque, then retighten using same sequence to seat manifold.

2. Install four new M8 x 40 exhaust manifold bolts and four new M8 x 40 exhaust manifold stud bolts. Tighten bolts and stud bolts to special torque (page 184) following sequence (Figure 293). Retighten bolts and stud bolts to special torque (page 184) using same sequence (Figure 293).

Figure 294 Right exhaust manifold heat shield spacers

3. Install three right exhaust manifold heat shield threaded spacers. Tighten spacers to special torque (page 184).

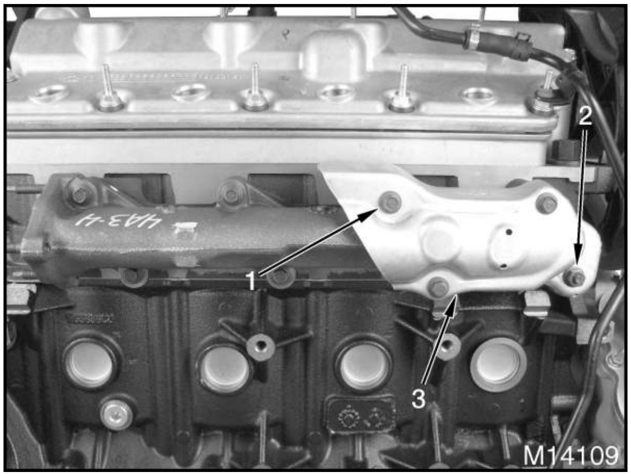

Figure 295 Right exhaust manifold heat shield

1. M8 x 12 bolt (3)
2. M8 nut
3. Heat shield

4. Install right exhaust manifold heat shield.
5. Install three new M8 x 12 heat shield bolts and a new M8 heat shield nut. Tighten bolts and nut to special torque (page 184).

Left Exhaust Manifold

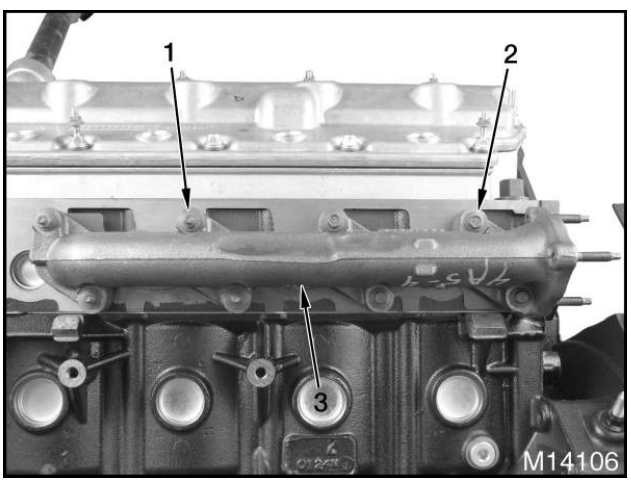

Figure 296 Left exhaust manifold

1. M8 x 40 stud bolt (4)
2. M8 x 40 bolt (4)
3. Left exhaust manifold

1. Position a new gasket and install left exhaust manifold.

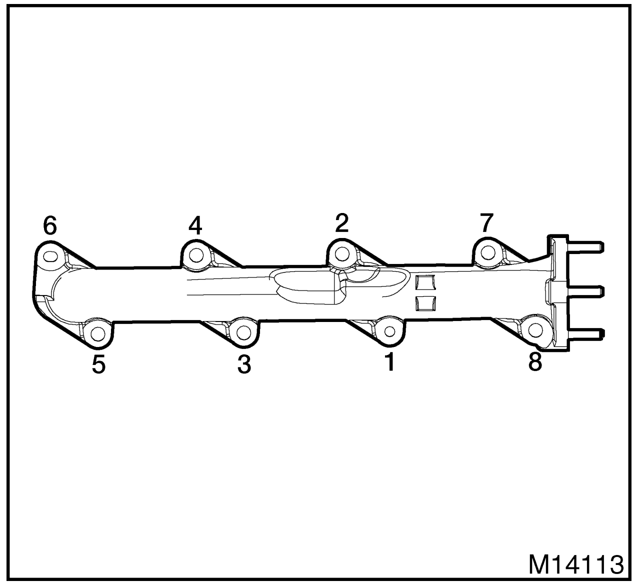

Figure 297 Torque sequence for left exhaust manifold mounting bolts

CAUTION: To prevent engine damage, align exhaust manifold gasket with exhaust manifold before tightening bolts and stud bolts to the specified torque value.

NOTE: Tighten bolts to special torque, then retighten using same sequence to seat manifold.

2. Install four new M8 x 40 exhaust manifold bolts and four new M8 x 40 exhaust manifold stud bolts. Tighten bolts and stud bolts to special torque (page 184) following sequence (Figure 297). Retighten bolts and stud bolts to special torque (page 184) using same sequence (Figure 297).

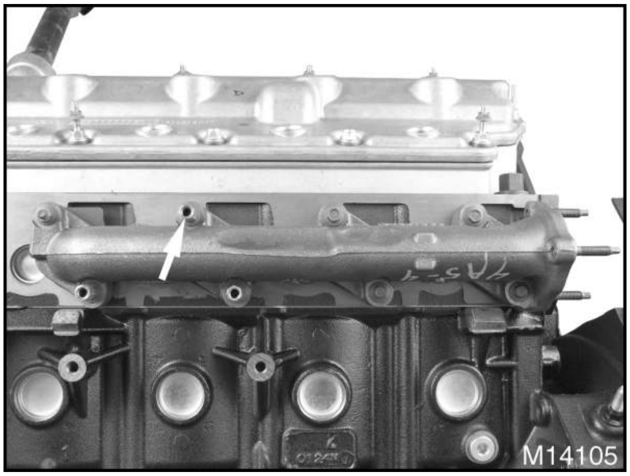

Figure 298 Left exhaust manifold heat shield spacers

3. Install three left exhaust manifold heat shield threaded spacers. Tighten spacers to special torque (page 184).

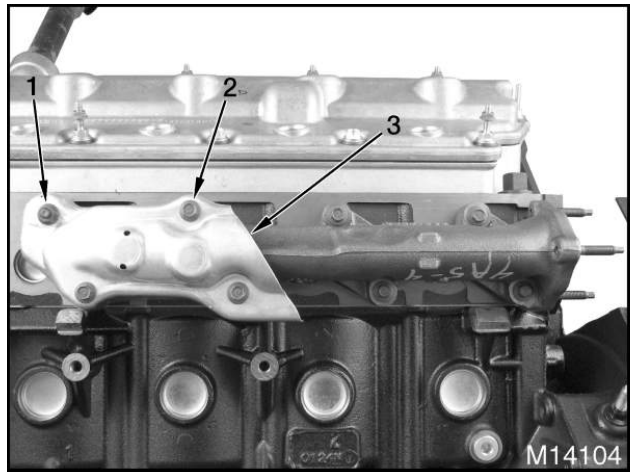

Figure 299 Left exhaust manifold heat shield

1. M8 nut
2. M8 x 12 bolt (3)
3. Heat shield

4. Install left exhaust manifold heat shield.
5. Install three new M8 x 12 heat shield bolts and a new M8 heat shield nut. Tighten bolts and nut to special torque (page 184).

Specifications

Table 16 Intake, Inlet, and Exhaust Manifolds

Exhaust Manifold	
Maximum allowable warpage	0.08 mm (0.003 in)

Special Torque

Table 17 Intake, Inlet, and Exhaust Manifolds

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

Special Service Tools

Table 18 Intake, Inlet, and Exhaust Manifolds

Description	Tool Number
Feeler Gauge	Obtain locally
Straightedge	Obtain locally
Intake Port Covers (cylinder heads)	ZTSE4559

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Exploded Views

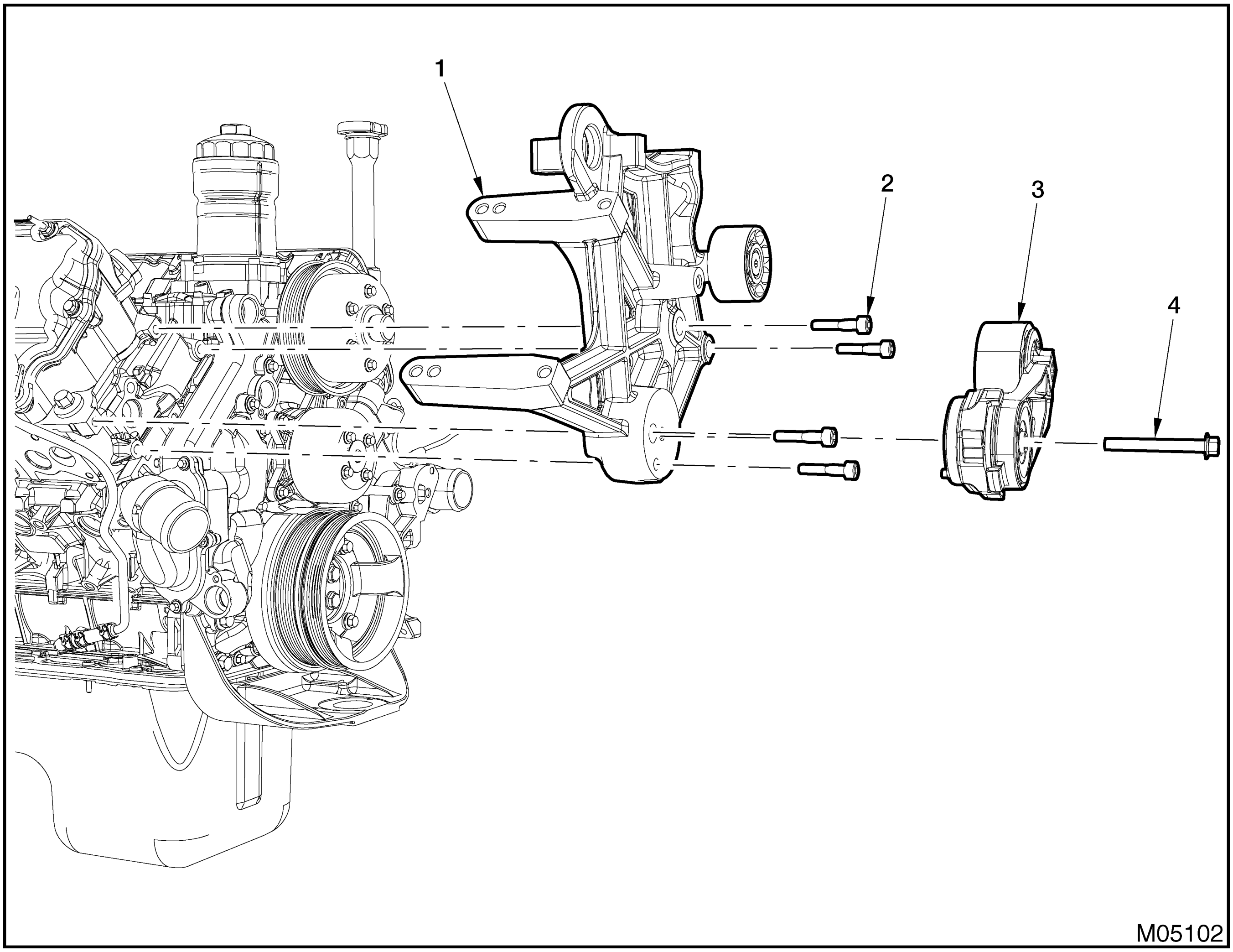

Figure 300 Alternator and Freon® mounting bracket

1. Alternator and Freon® mounting bracket
2. M10 x 45 cap screw (4)
3. Belt tensioner
4. M10 x 80 bolt

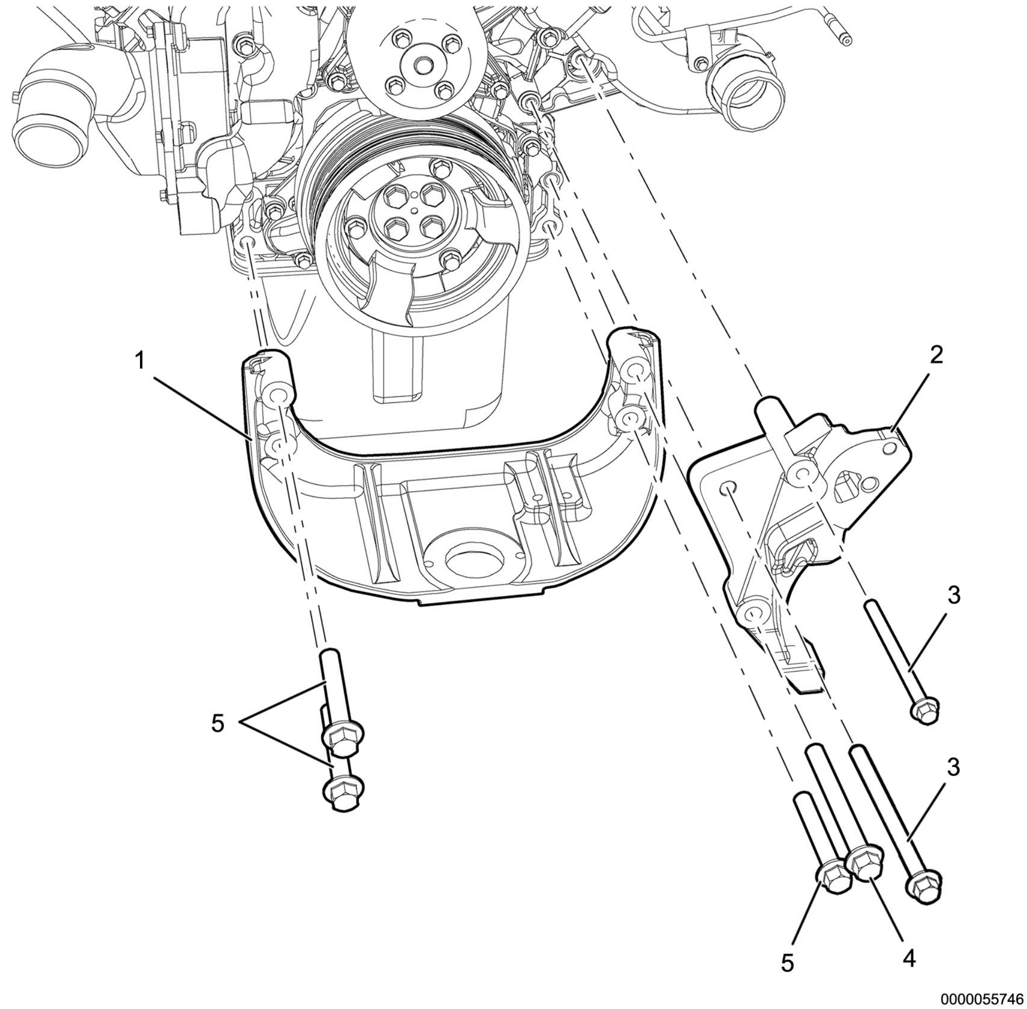

Figure 301 Front engine mount bracket

1. Front engine mount bracket
2. Auxiliary accessory mounting bracket (if equipped)
3. M8 x 90 bolt (2 if equipped)
4. M12 x 110 bolt (if equipped)
5. M12 x 70 bolt (3 if equipped with auxiliary accessory mounting bracket, 4 without)

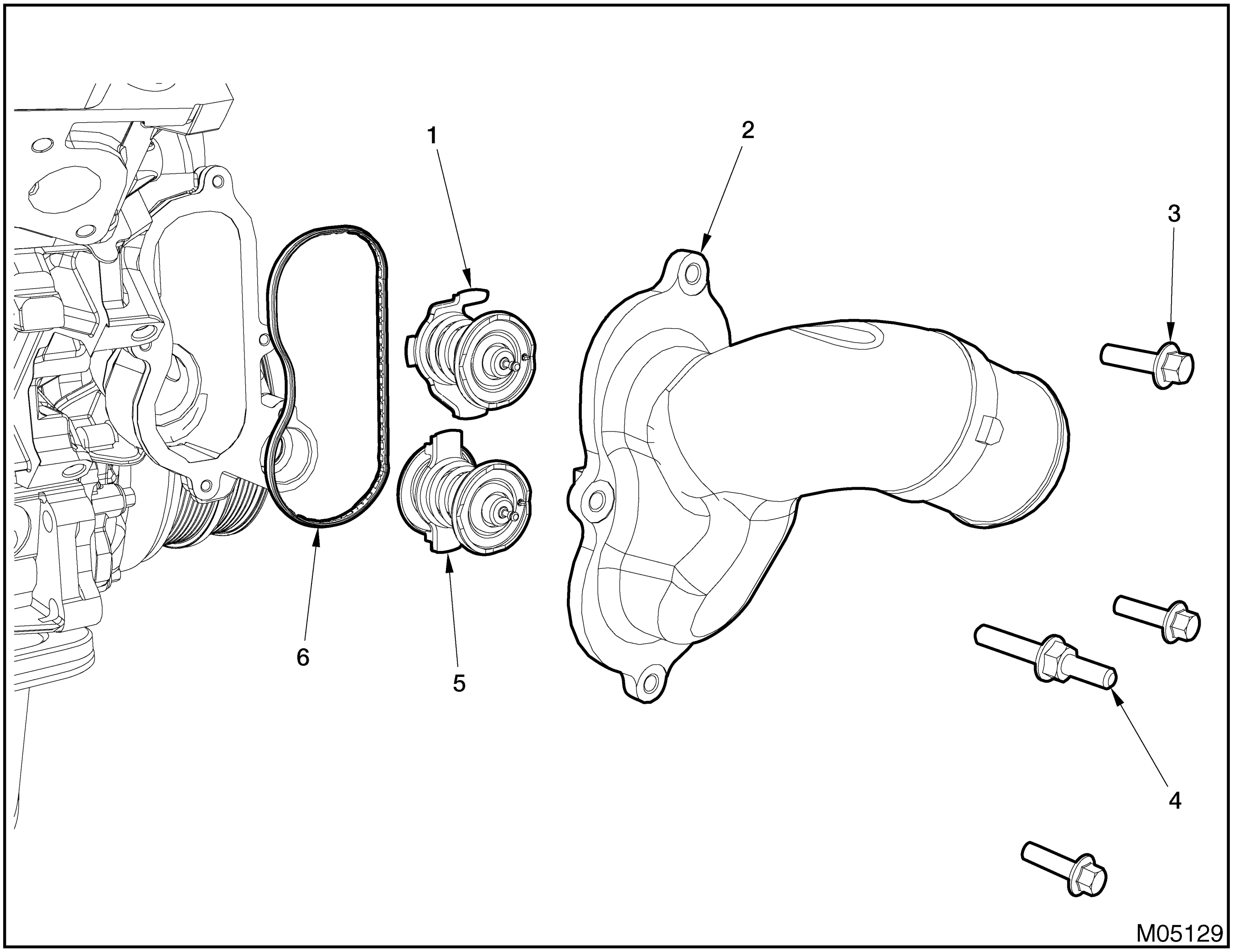

Figure 302 Thermostat assemblies and housing

1. Thermostat assembly without bypass
2. Thermostat housing
3. M6 x 20 bolt (3)
4. M6 x 25 stud bolt
5. Thermostat assembly with bypass
6. Thermostat cover gasket

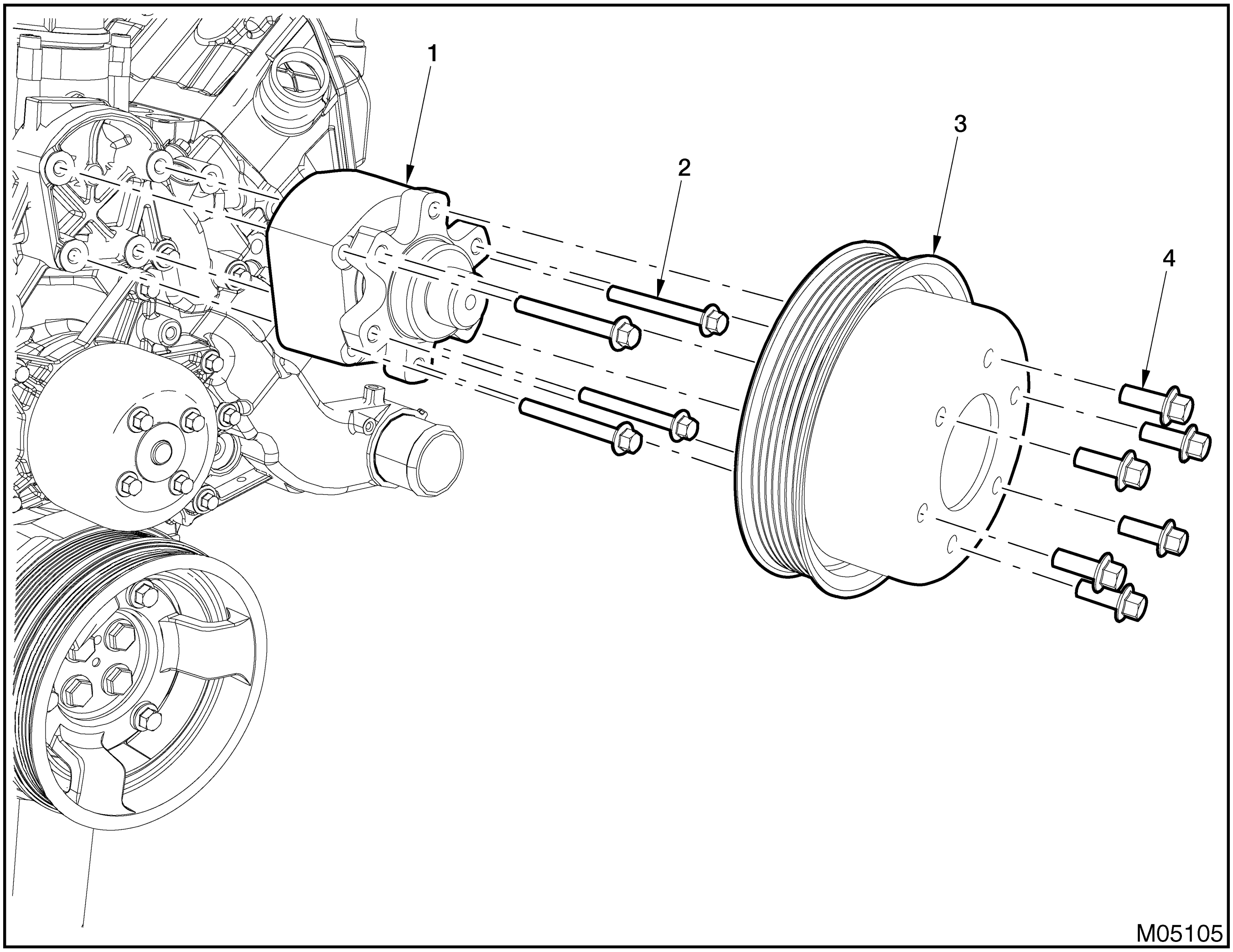

Figure 303 Fan drive

1. Fan and pulley mounting hub
2. M8 x 65 bolt (4)
3. Fan pulley
4. M8 x 20 bolt (6)

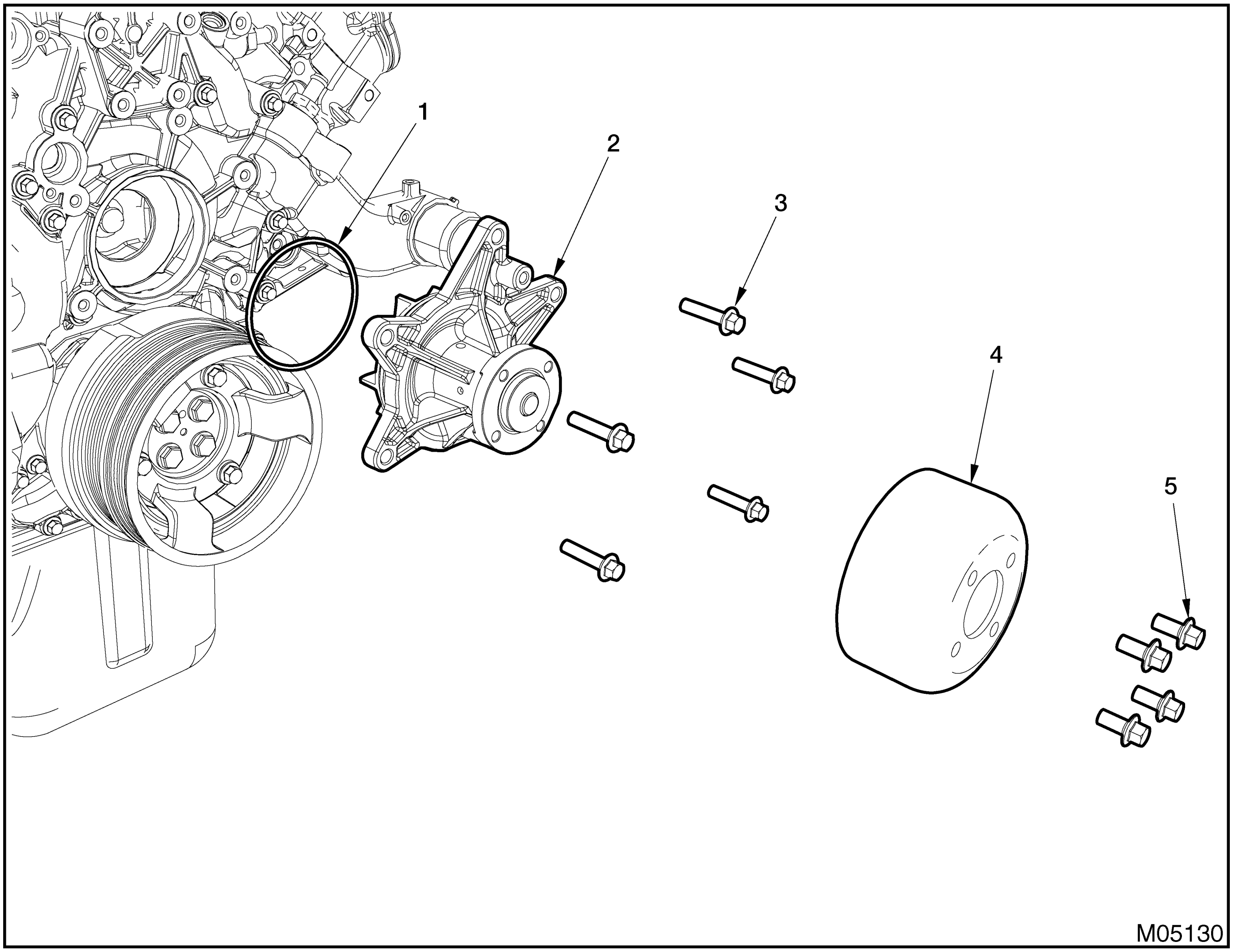

Figure 304 Water pump assembly

1. Water pump assembly gasket
2. Water pump assembly
3. M8 x 35 bolt (5)
4. Water pump pulley
5. M8 x 16 bolt (4)

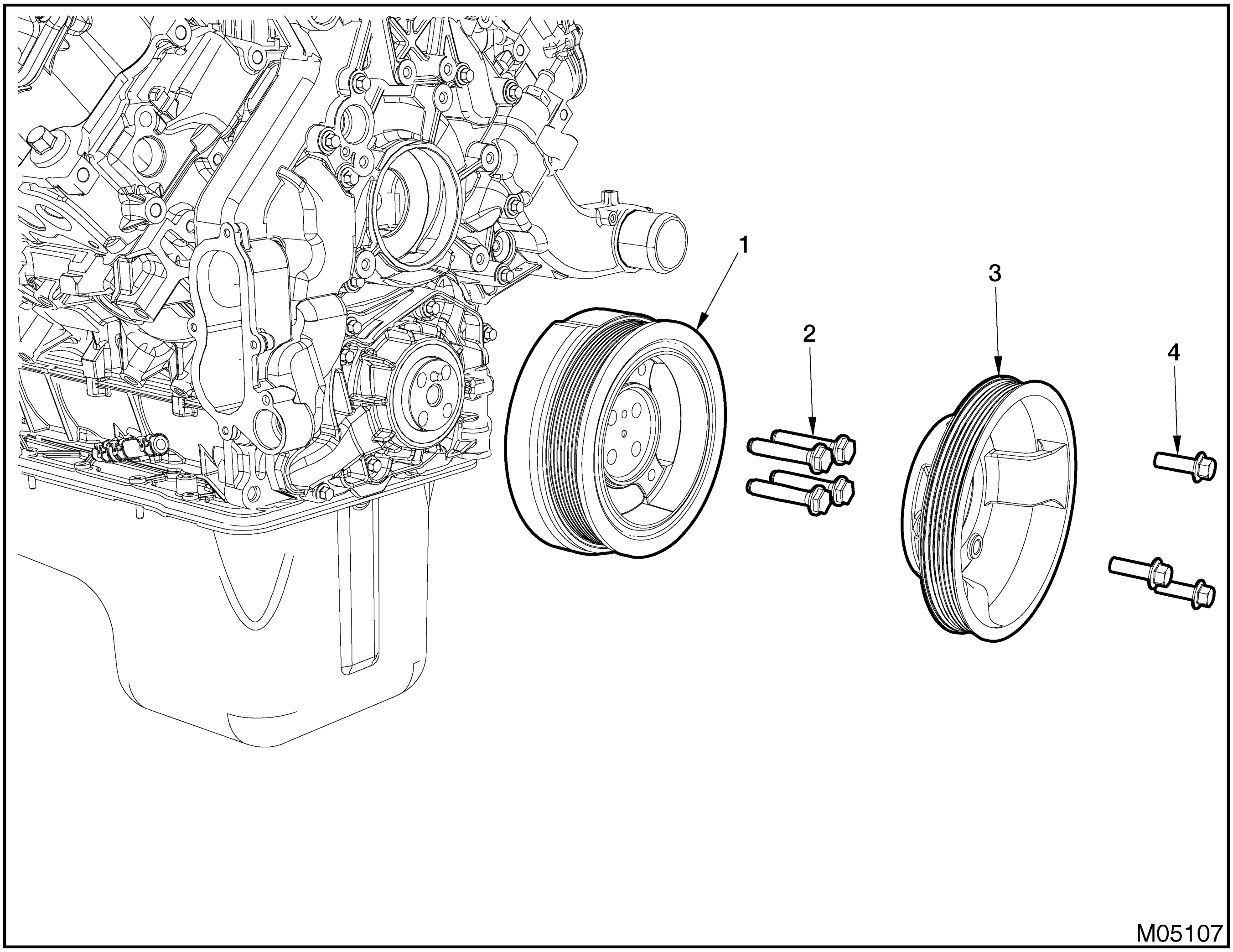

Figure 305 Vibration damper

1. Vibration damper
2. M12 x 59 bolt (4)
3. Front Power Takeoff (PTO) pulley (if equipped)
4. M10 x 30 bolt (3, if equipped with front PTO pulley)

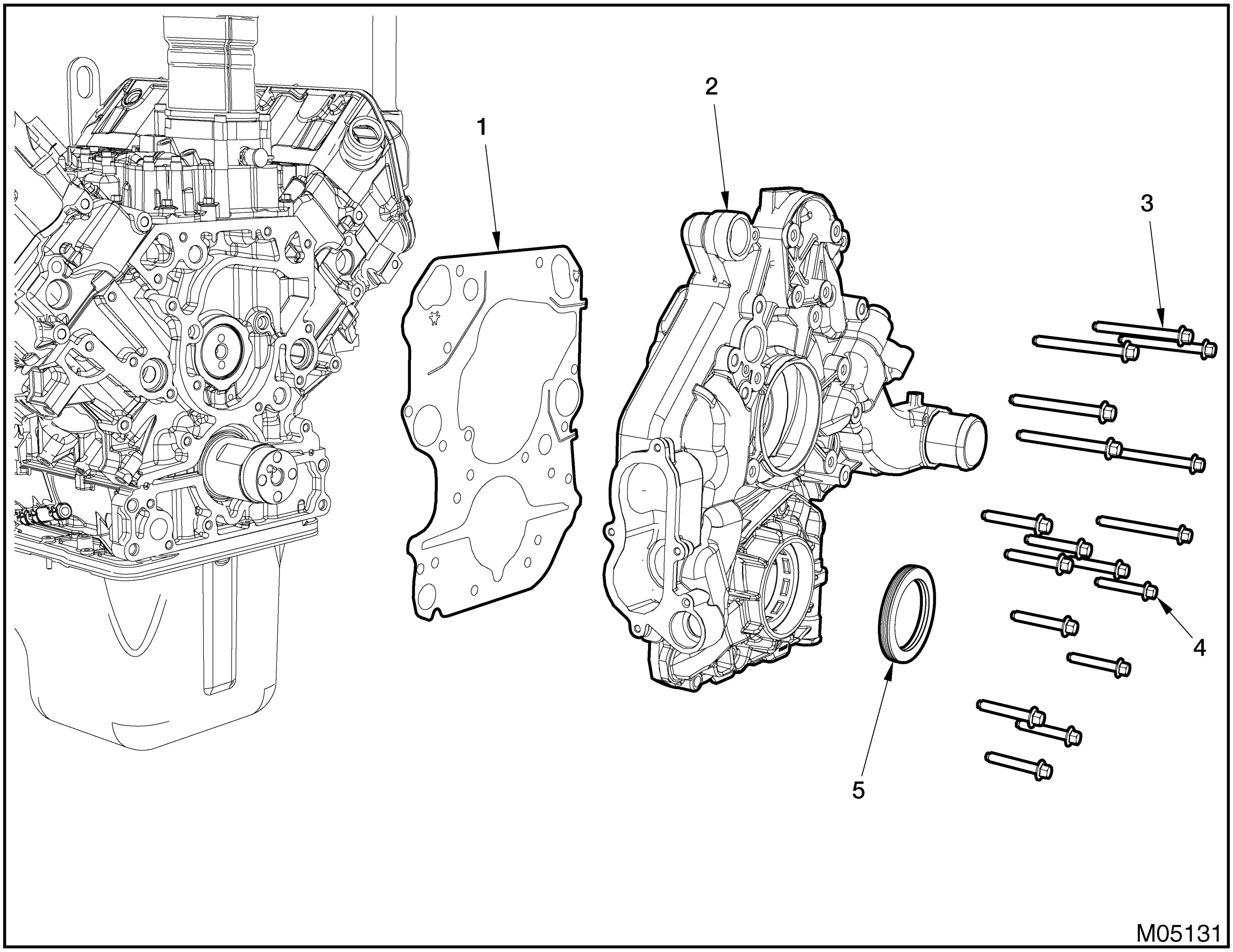

Figure 306 Front crankcase cover

1. Front cover gasket
2. Front crankcase cover
3. M8 x 75 bolt (7)
4. M8 x 45 bolt (10)
5. Front cover oil seal

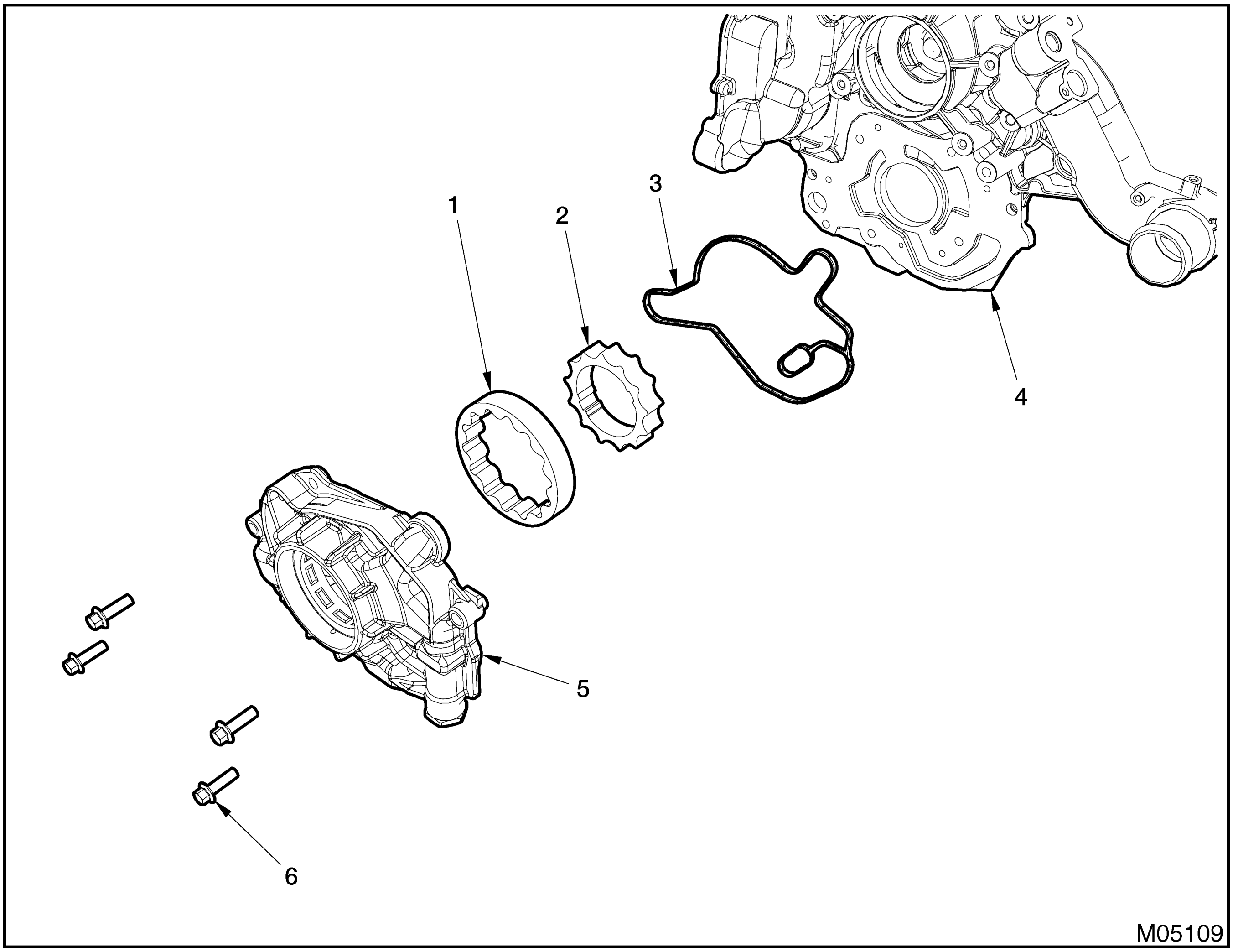

Figure 307 Oil pump assembly

1. Outer oil pump gerotor
2. Inner oil pump gerotor
3. Oil pump housing gasket
4. Front crankcase cover
5. Oil pump housing assembly
6. M8 x 25 bolt (4)

Removal

GOVERNMENT REGULATION: Engine fluids (oil, fuel, and coolant) may be a hazard to human health and the environment. Handle all fluids and other contaminated materials (e.g. filters, rags) in accordance with applicable regulations. Recycle or dispose of engine fluids, filters, and other contaminated materials according to applicable regulations.

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

NOTE: See the following service sections for information on removal of components prior to this section.

- Engine Electrical
- Exhaust Gas Recirculation (EGR) System
- Air Compressor and Power Steering/Fuel Pump
- Fuel System

Alternator and Freon® Mounting Bracket

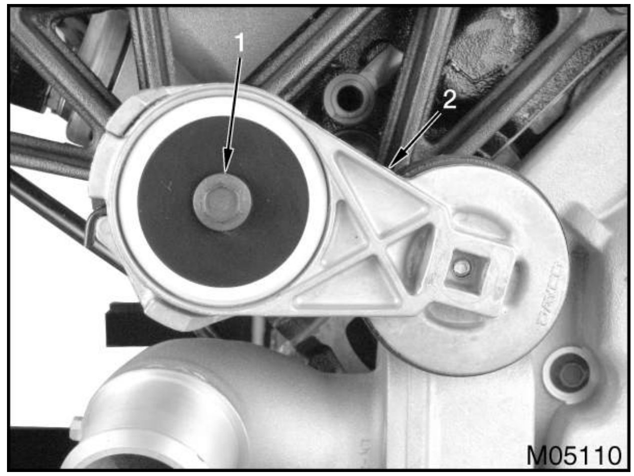

Figure 308 Belt tensioner

1. M10 x 80 bolt
2. Belt tensioner

CAUTION: To prevent engine damage, do not twist the belt tensioner; damage to the locating pin may occur, resulting in improper alignment of the belt tensioner.

1. Remove M10 x 80 bolt and belt tensioner.

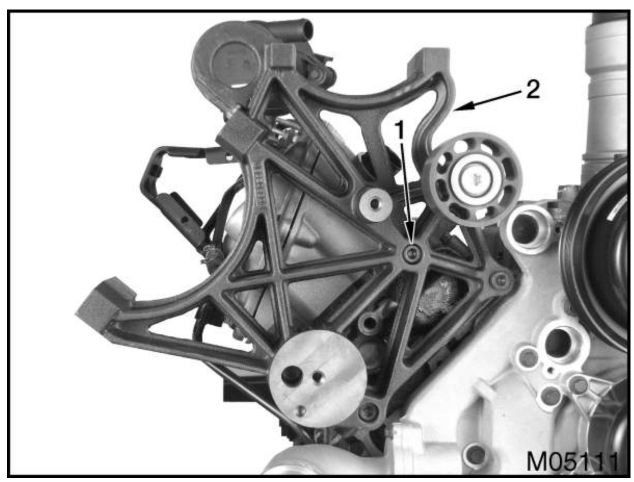

Figure 309 Alternator and Freon® mounting bracket

1. M10 x 45 cap screw (4)
2. Alternator and Freon® mounting bracket

2. Remove four M10 x 45 cap screws and alternator and Freon® mounting bracket.

Front Engine Mount Bracket

NOTE: For engines that are not equipped with auxiliary accessory mounting bracket, the front engine mount bracket is secured by four M12 x 70 bolts.

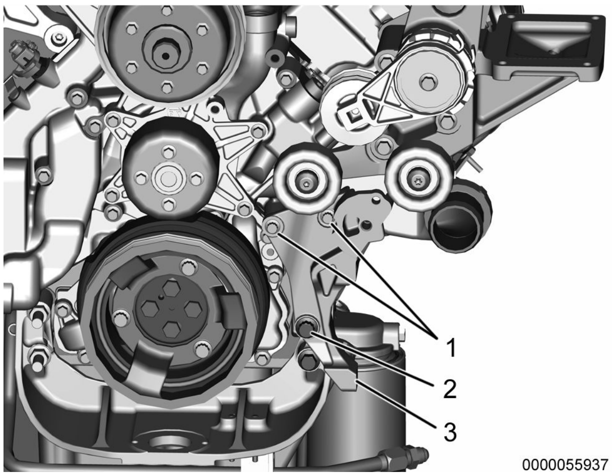

Figure 310 Auxiliary accessory mounting bracket (if equipped)

1. M8 x 90 bolt (2)
2. M12 x 110 bolt
3. Auxiliary accessory mounting bracket (if equipped)

1. Remove M8 x 90 bolts.
2. Remove M12 x 110 bolt.
3. Remove auxiliary accessory mounting bracket.

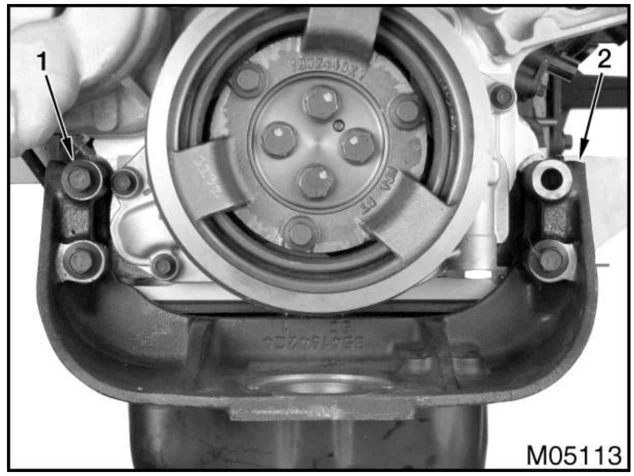

Figure 311 Front engine mount bracket

1. M12 x 70 bolt (3)
2. Front engine mount bracket

4. Remove three M12 x 70 bolts and front engine mount bracket.

Thermostat Assemblies and Housing

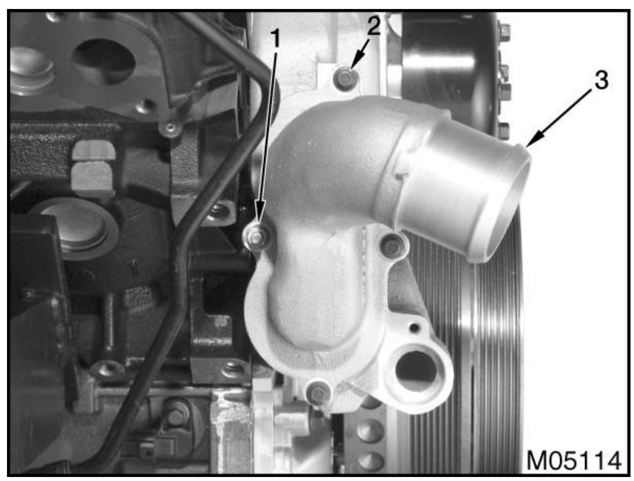

Figure 312 Thermostat housing

1. M6 x 25 stud bolt
2. M6 x 20 bolt (3)
3. Thermostat housing

1. Remove M6 x 25 stud bolt and three M6 x 20 bolts.
2. Remove thermostat housing from front crankcase cover and discard gasket.

NOTE: The thermostat assembly with bypass is the lower thermostat, and has a valve to seal against the orifice in the front crankcase cover.

3. Remove two thermostat assemblies from thermostat housing.

Fan Drive

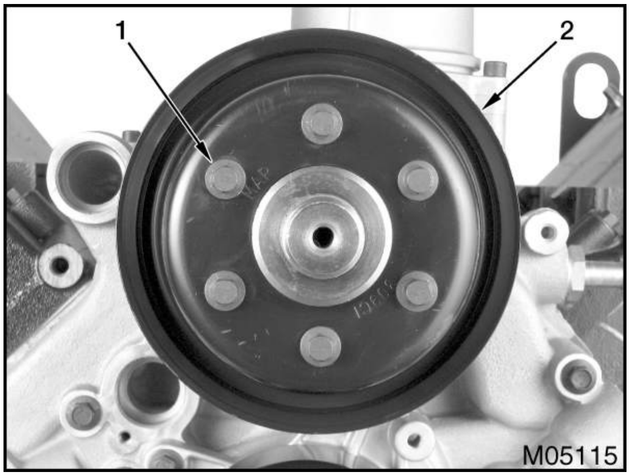

Figure 313 Fan pulley

1. M8 x 20 bolt (6)
2. Fan pulley

NOTE: If not using an impact wrench, use a holding device to lock fan pulley when removing bolts.

1. Remove six M8 x 20 bolts and fan pulley.

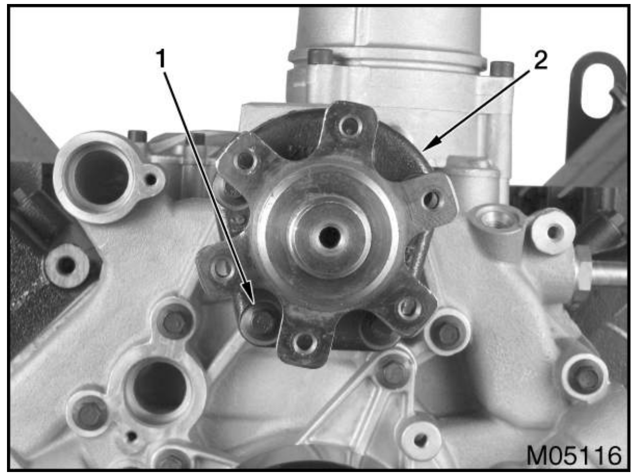

Figure 314 Fan and pulley mounting hub

1. M8 x 65 bolt (4)
2. Fan and pulley mounting hub

2. Remove four M8 x 65 bolts and fan and pulley mounting hub.

Water Pump Assembly

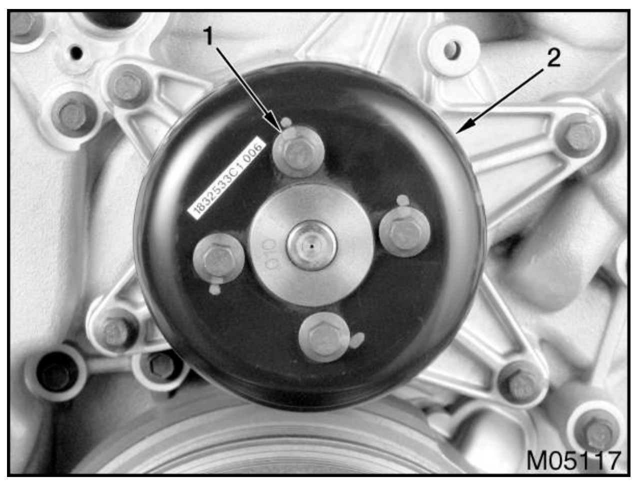

Figure 315 Water pump pulley

1. M8 x 16 bolt (4)
2. Water pump pulley

NOTE: If not using an impact wrench, use a holding device to lock water pump pulley when removing bolts.

1. Remove four M8 x 16 bolts and water pump pulley.

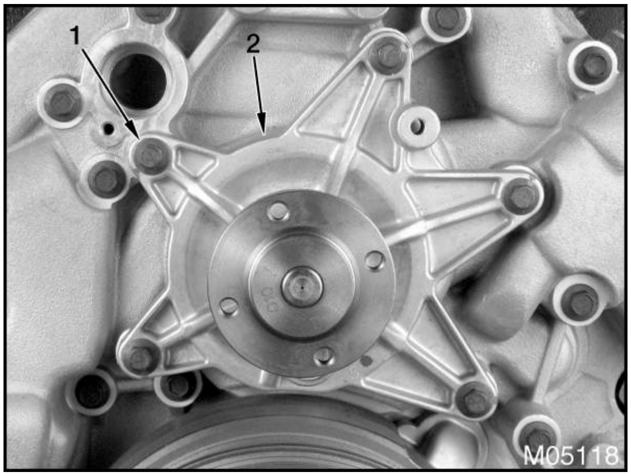

Figure 316 Water pump assembly

1. M8 x 35 bolt (5)
2. Water pump assembly

2. Remove five M8 x 35 bolts.

CAUTION: To prevent engine damage, do not drop water pump impeller or hit impeller with hard objects.

3. Remove water pump assembly and discard gasket.

Vibration Damper

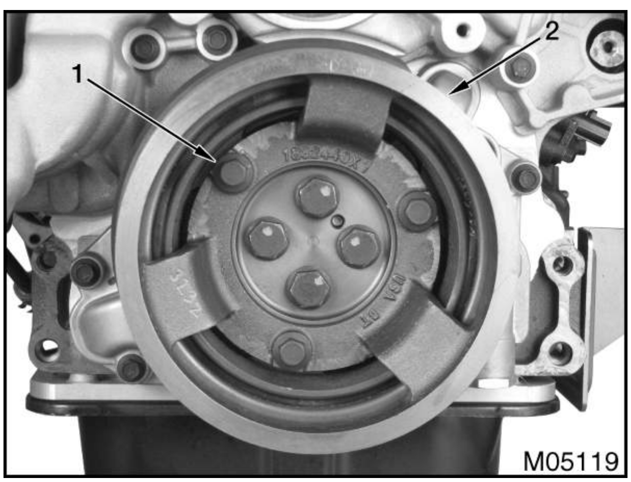

Figure 317 Front Power Takeoff (PTO) pulley (if equipped)

1. M10 x 30 bolt (3)
2. Front PTO pulley

1. Remove three M10 x 30 bolts and front PTO pulley (if equipped).

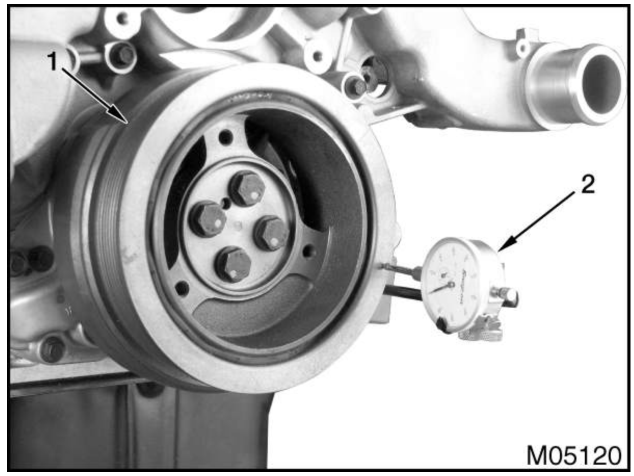

Figure 318 Vibration damper runout

1. Vibration damper
2. Dial indicator

NOTE: When prying crankshaft forward, use a block of wood between the pry bar and front crankcase cover.

2. Before removing vibration damper, inspect vibration damper for runout as follows:
   a. Attach dial indicator with magnetic base (page 213) to front of crankcase. Position indicator point on vibration damper front surface.

      NOTE: Pry only in one direction to eliminate possible error induced by crankshaft end play.

   b. Pry crankshaft forward and zero dial indicator. This becomes the baseline.
   c. Turn crankshaft 90°. Pry crankshaft forward and record reading.
   d. Repeat at each surface every 90°. If runout exceeds specification (page 212), replace vibration damper.

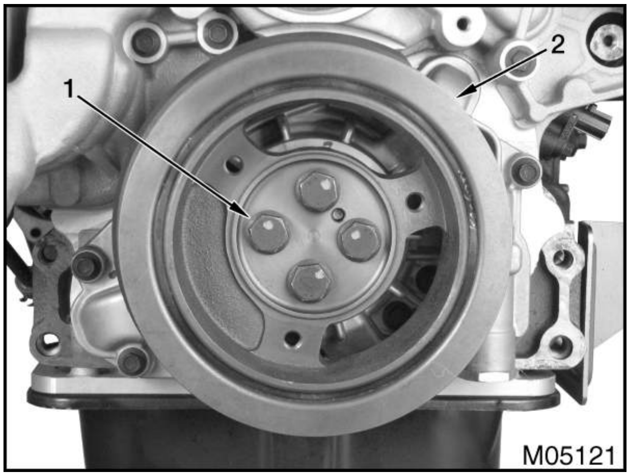

Figure 319 Vibration damper

1. M12 x 59 bolt (4)
2. Vibration damper

⚠ WARNING: To prevent personal injury or death, support the vibration damper when removing bolts. The damper can easily slide off the end of the crankshaft.

NOTE: The vibration damper retaining bolts are not reusable.

3. Remove and discard four M12 x 59 bolts.

CAUTION: To prevent engine damage, do not immerse damper in petroleum based solvents. This can damage the rubber damper element.

4. Remove vibration damper.

Front Oil Seal and Wear Sleeve

NOTE: The International® MaxxForce® 7 is not equipped with a wear sleeve during factory production. Wear sleeves are available with an oil seal service kit.

NOTE: If removing only the seal, perform steps 1 through 3. Otherwise, remove seal and wear sleeve using steps 1 through 4.

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

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

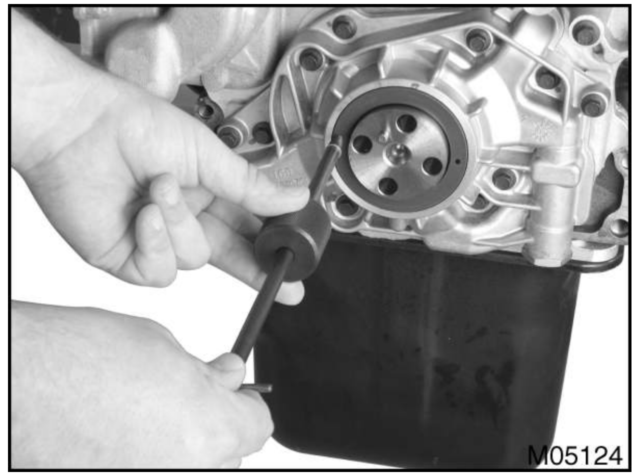

Figure 320 Front oil seal removal

2. Thread a slide hammer (page 213) with correct size screw in one of the two holes.
3. Slide hammer until one side of seal begins to pull out of oil pump housing assembly. Move slide hammer to other hole and repeat until front oil seal is removed completely.

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

4. Complete following steps to install Front Wear Sleeve Remover (page 213):

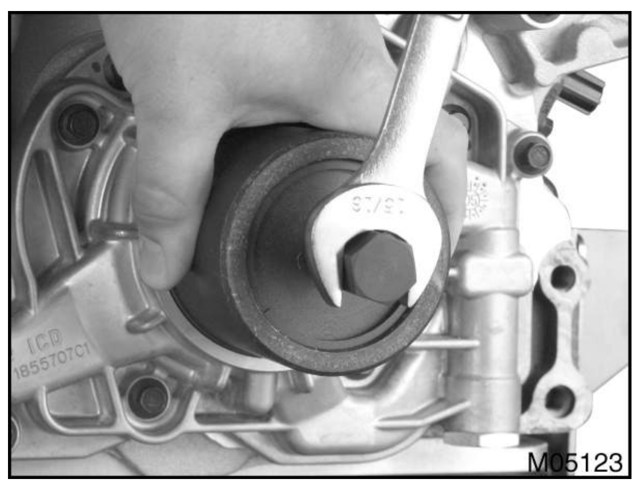

Figure 321 Removal of front wear sleeve

   a. Install two half shell ridges of tool behind front wear sleeve.

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

c. Slide outer collar of tool around two half shells.

d. Thread shaft up to crankshaft, and turn shaft to remove wear sleeve.

Front Crankcase Cover

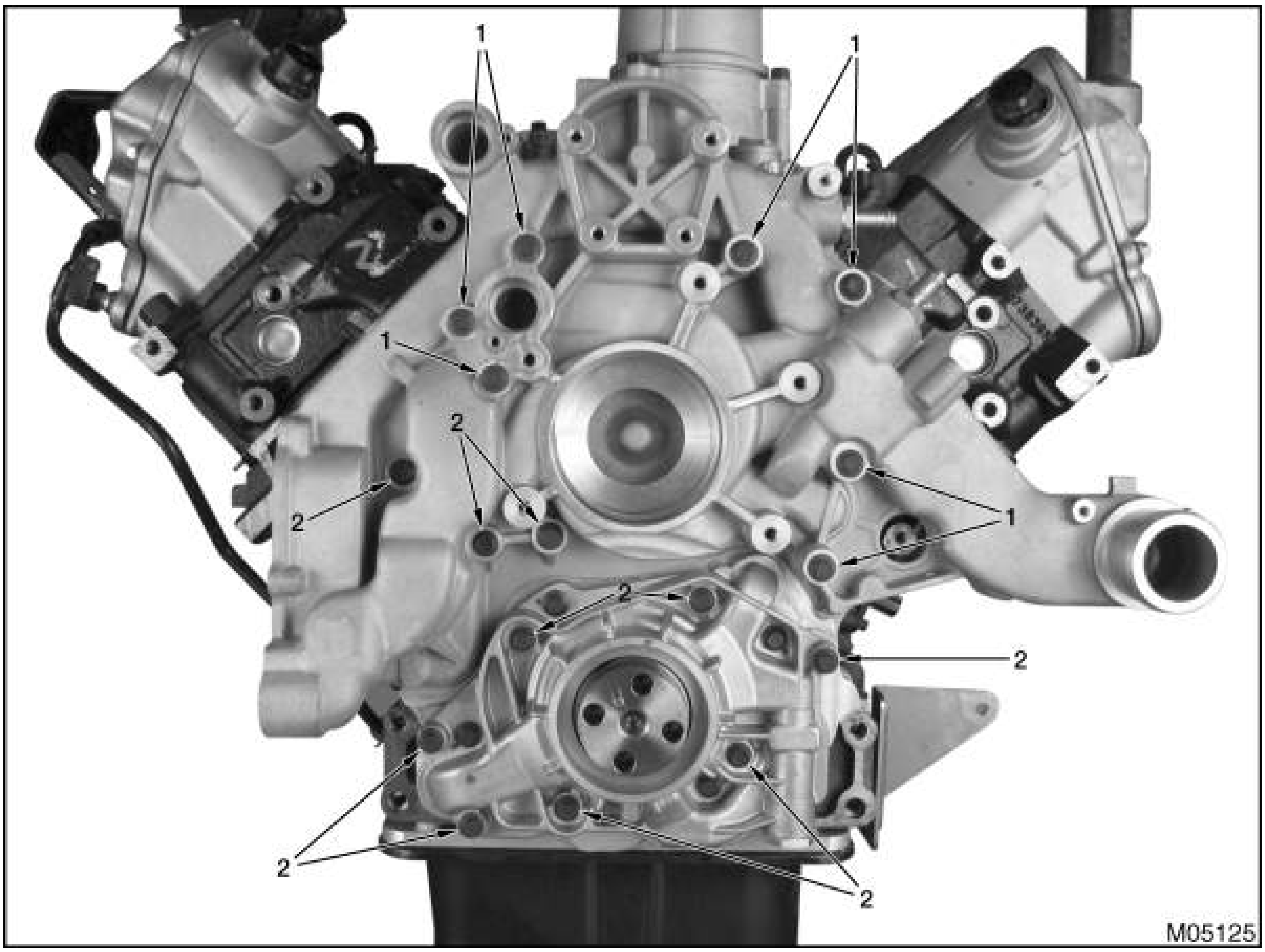

Figure 322 Front crankcase cover bolts

1. M8 x 75 bolt (7)
2. M8 x 45 bolt (10)

WARNING: To prevent personal injury or death, use a suitable lifting device and get help when removing, lowering, and installing the front cover.

CAUTION: Do not remove four M8 x 25 oil pump housing assembly bolts at this time. Damage to oil pump may result.

NOTE: Support front cover while removing bolts.

1. Remove seven M8 x 75 bolts and 10 M8 x 45 bolts.

CAUTION: To prevent engine damage, cut protruding sealant from the joint of the crankcase and lower crankcase before removing the front cover gasket. If the sealant is not cut, the seal between the crankcase and lower crankcase may fail. Complete engine removal and disassembly is required to install a new crankcase gasket.

2. Remove front crankcase cover and discard gasket.

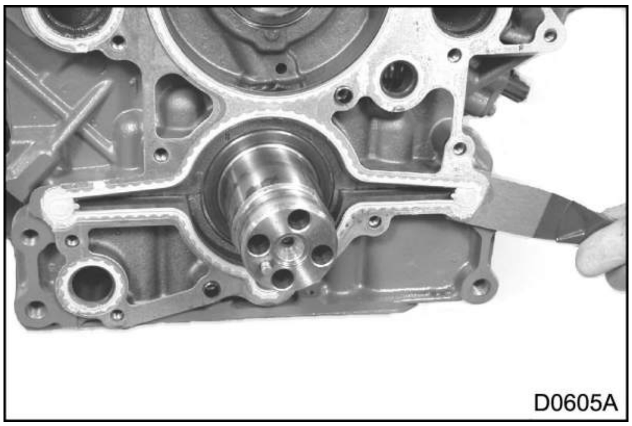

Figure 323 Sealant between crankcase and lower crankcase joint

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

Oil Pump Housing Assembly

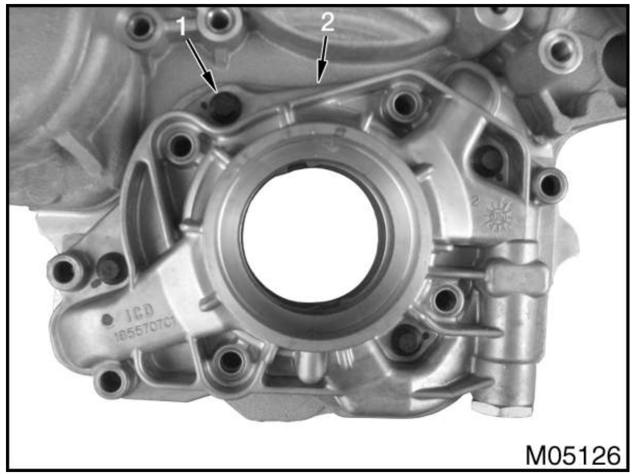

Figure 324 Oil pump housing assembly

1. M8 x 25 bolt (4)
2. Oil pump housing assembly

1. Remove four M8 x 25 bolts.

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

2. Remove oil pump housing assembly and discard gasket.
3. Use a permanent marker to mark the front of each gerotor for correct reassembly orientation.

Cleaning, Inspection, and Testing

Vibration Damper

CAUTION: To prevent engine damage, do not immerse damper in petroleum based solvents. This can damage the rubber damper element.

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

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

2. Dry damper with filtered compressed air.
3. Inspect vibration damper rubber compound for bulging (page 212). If bulging exceeds specification, replace vibration damper.
4. Inspect vibration damper rubber compound for cracks or separation. Replace vibration damper if necessary.

Oil Gerotor Pump

1. Wash all parts thoroughly in a nonchlorinated solvent.

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

2. Dry with filtered compressed air.
3. Lay oil pump housing assembly on workbench.
4. Inspect inner and outer oil pump gerotors and oil pump housing assembly for nicks, burrs or scoring.
5. Replace any damaged components.

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

   NOTE: If installing new inner and outer oil pump gerotors, correct orientation is not necessary. If installing old inner and outer oil pump gerotors, correct orientation is necessary.

6. Place inner and outer oil pump gerotors in oil pump housing assembly.

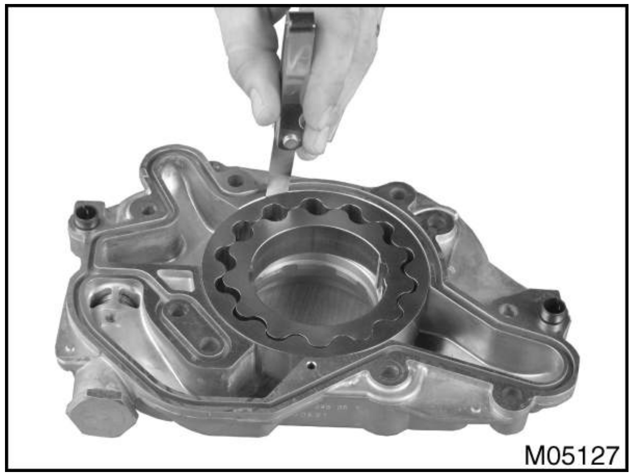

Figure 325 Outer oil pump gerotor inspection

7. Use a feeler gauge (page 213) to inspect for wear by checking radial clearance between outer oil pump gerotor and oil pump housing assembly.

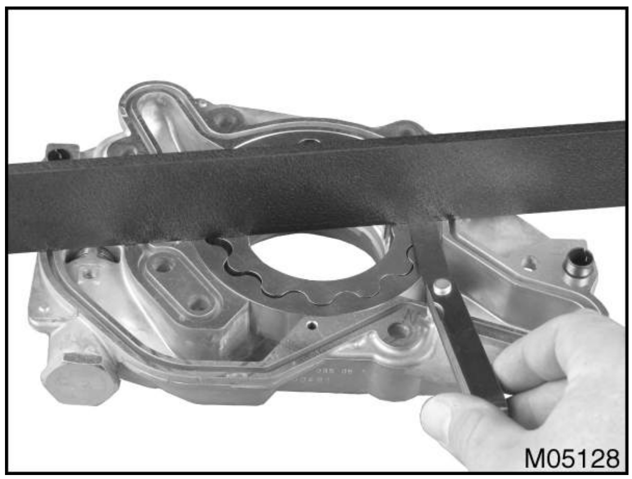

Figure 326 End clearance check for oil pump

8. Check oil pump end clearance as follows:
   a. With inner and outer oil pump gerotors in place in oil pump housing assembly, put straightedge across housing assembly.
   b. Insert feeler gauge under straightedge at inner and outer oil pump gerotors. Compare end clearance with specifications (page 212).
   c. If measurements are not within specifications, replace both inner and outer oil pump gerotors as a set.

9. Remove oil pressure regulator.

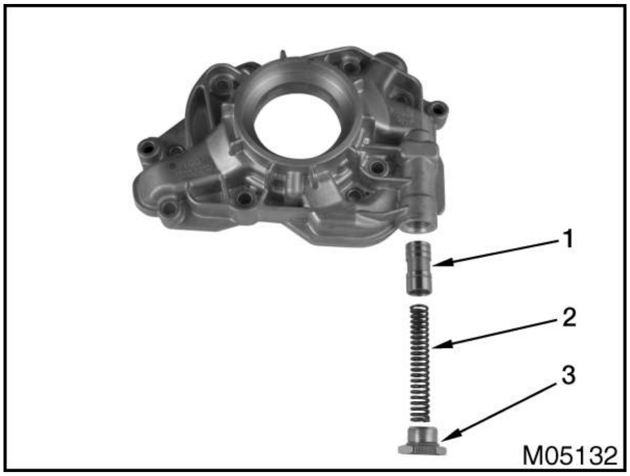

Figure 327 Oil pressure regulator components

1. Piston relief
2. Spring relief valve
3. Cap relief valve and seal relief valve retainer

10. Inspect oil pressure regulator components and bore for wear. Replace if necessary.

Front Crankcase Cover and Water Pump Assembly

1. Wash front crankcase cover and water pump assembly thoroughly in a suitable cleaning solvent.

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

2. Dry with filtered compressed air.
3. Inspect front crankcase cover for cracks. Replace if necessary.
4. Inspect water pump assembly for leaks, cracks, bearing failure, and problems with bearings or shaft seal. Replace if necessary.

Thermostat Assembly

WARNING: To prevent personal injury or death, wear heat protective gloves and appropriate eye protection when checking operation of thermostat.

CAUTION: To prevent engine damage, when testing the thermostat, make sure the thermostat assembly opens fully at the specified temperature.

Check operation of thermostat assemblies as follows:

1. Manually open thermostat enough to insert a nylon ribbon under valve seat.

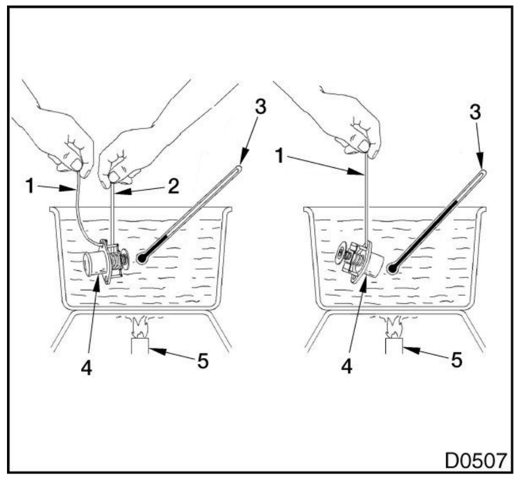

Figure 328 Thermostat operation test

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

2. Suspend thermostat assembly in a container so thermostat assembly does not touch bottom of container.
3. Heat water filled container to approximate start-to-open temperature of thermostat assembly. See Specifications for temperature (page 212).
4. Check thermometer and record temperature as soon as thermostat assembly drops from nylon ribbon. This is the start-to-open temperature.
5. Continue to heat water to full-open temperature of the thermostat assembly. See Specifications

(page 212). Check for movement of thermostat assembly valve.

6. While sleeve is off its seat, remove thermostat assembly from container and inspect seat area for pitting and foreign deposits.
7. If thermostat assembly is damaged or operates incorrectly, replace thermostat assembly.

Installation

Oil Pump Housing Assembly

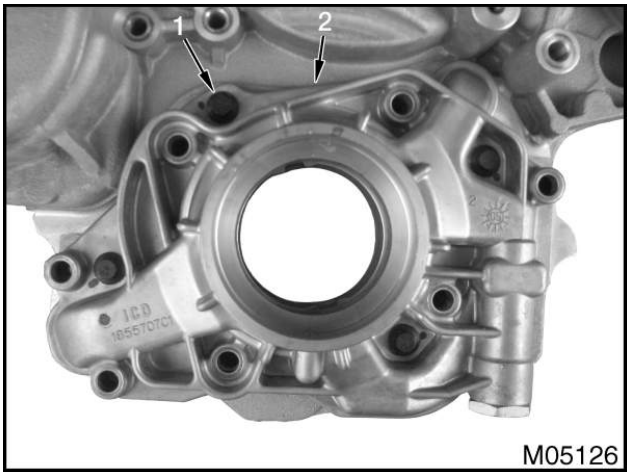

Figure 329 Oil pump housing assembly

1. M8 x 25 bolt (4)
2. Oil pump housing assembly

NOTE: If installing new inner and outer oil pump gerotors, correct orientation is not necessary. If installing old inner and outer oil pump gerotors, correct orientation is necessary.

1. Install inner and outer oil pump gerotors.
2. Position a new gasket and install oil pump housing assembly.
3. Install four M8 x 25 bolts and tighten to special torque (page 213).

Front Crankcase Cover

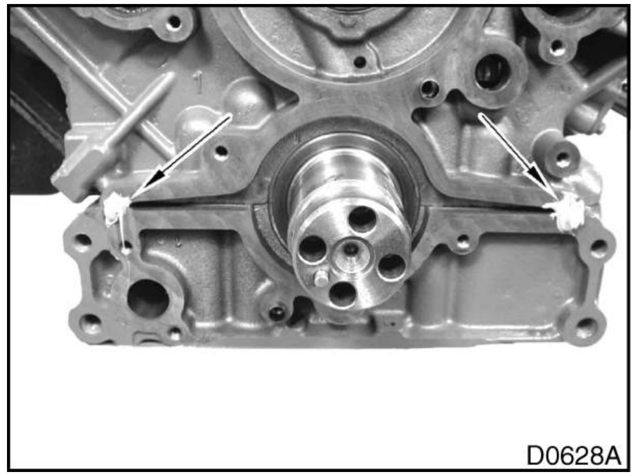

Figure 330 Liquid gasket applications

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

1. Apply Liquid Gasket (RTV) (page 213) to joining surfaces of upper crankcase and lower crankcase assemblies.
2. Position a new front cover gasket on crankcase.

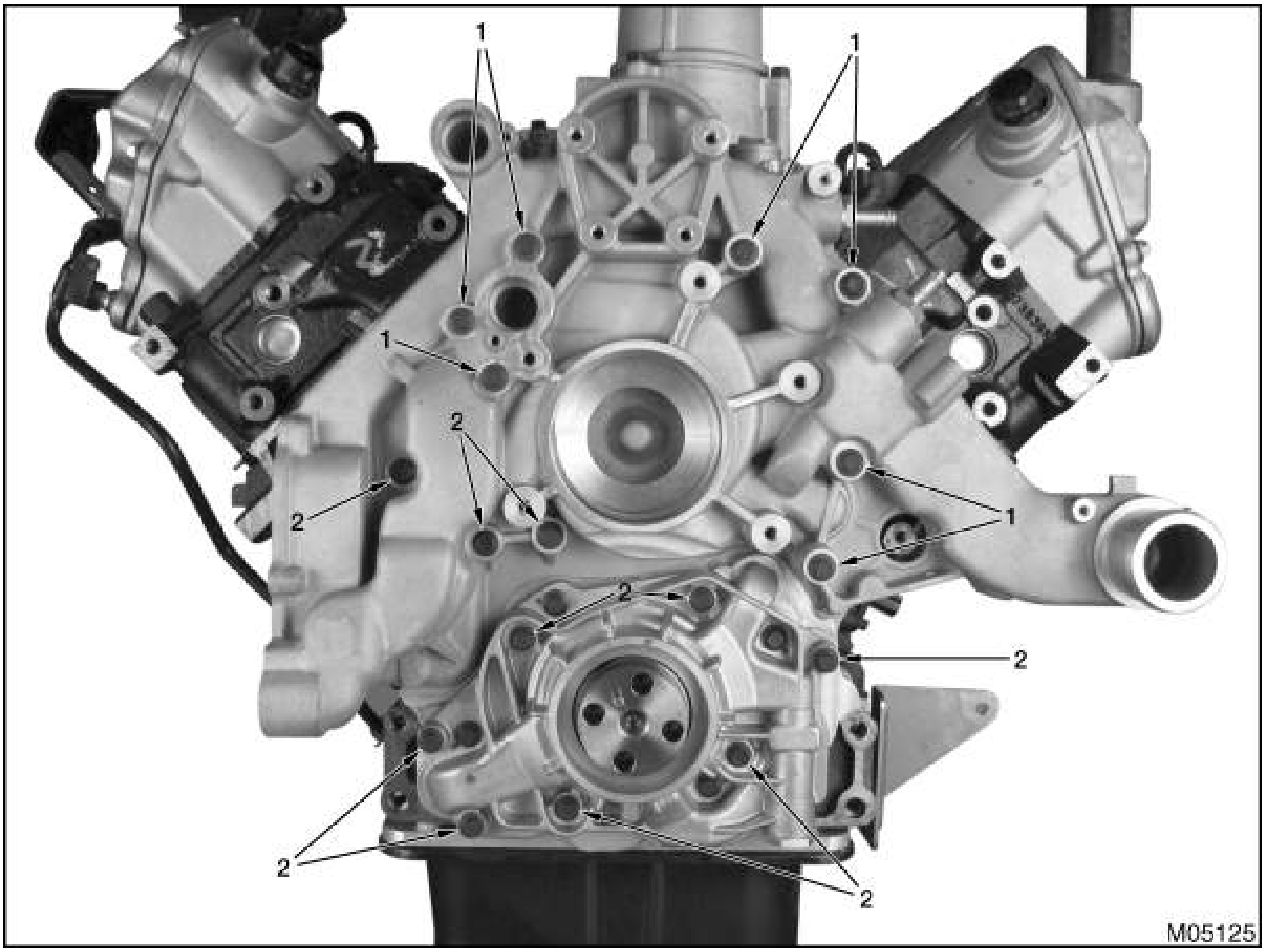

Figure 331 Front crankcase cover bolts

1. M8 x 75 bolt (7)
2. M8 x 45 bolt (10)

WARNING: To prevent personal injury or death, use a suitable lifting device and get help when removing, lowering, and installing the front cover.

NOTE: Install front crankcase cover with oil pump assembly in place for proper gerotor alignment.

NOTE: It may be necessary to manually turn oil pump gerotors, so they index onto crankshaft correctly.

NOTE: Support front crankcase cover while installing bolts.

3. Install front crankcase cover.
4. Install seven M8 x 75 bolts and 10 M8 x 45 bolts. Tighten bolts to special torque (page 213).

Front Oil Seal and Wear Sleeve

NOTE: The International® MaxxForce® 7 is not equipped with a wear sleeve during factory production. Wear sleeves are available with an oil seal service kit.

1. Put a 360° bead of hydraulic sealant such as Loctite® 569 (page 213) or equivalent on leading edge of crankshaft before wear sleeve installation.

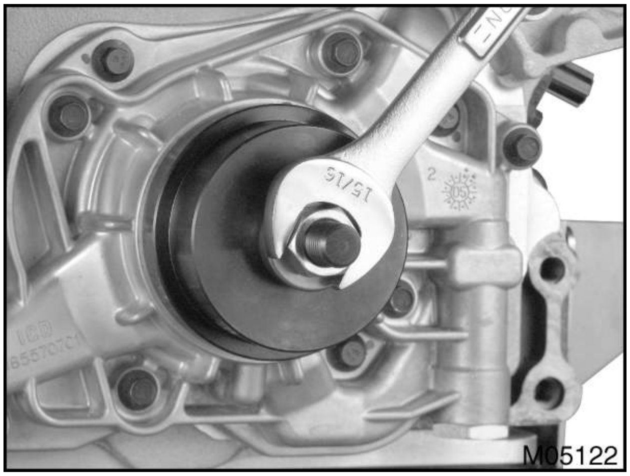

Figure 332 Front oil seal and wear sleeve

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

2. Use Front Seal (wear sleeve) Installer (page 213), to drive oil seal and wear sleeve assembly into oil pump housing assembly.

Vibration Damper

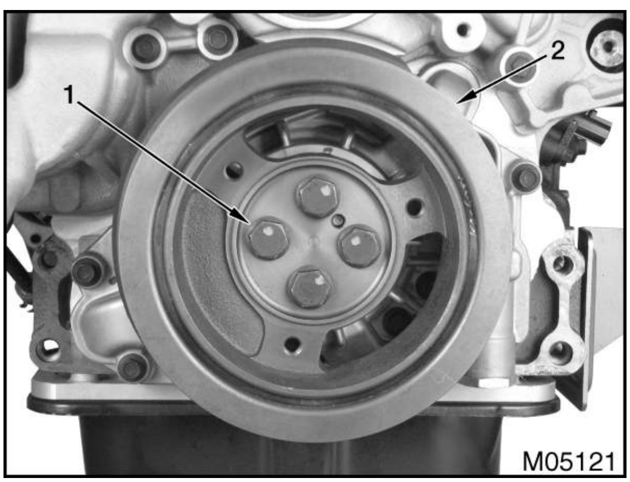

Figure 333 Vibration damper

1. M12 x 59 bolt (4)
2. Vibration damper

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

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

NOTE: Do not use anti-seize compounds, grease or lubricants. Each has an adverse effect on torque results.

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

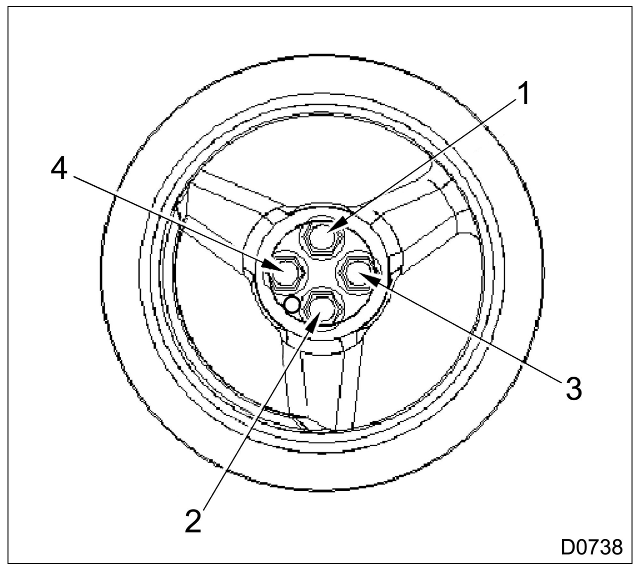

Figure 334 Torque sequence for vibration damper bolts

3. Vibration damper bolt torque sequence:
   a. Tighten each bolt to special torque (page 213) using above sequence.
   b. Rotate each bolt an additional 90° using above sequence.

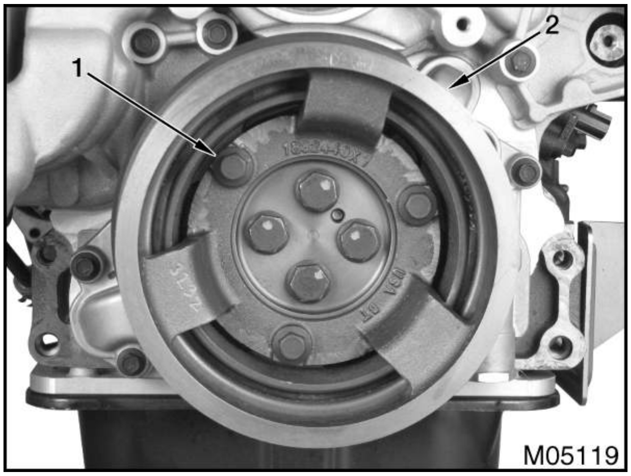

Figure 335 Front Power Takeoff (PTO) pulley (if equipped)

1. M10 x 30 bolt (3)
2. Front PTO pulley

4. Install front PTO pulley (if equipped).
5. Install three M10 x 30 bolts and tighten to special torque (page 213).

Water Pump Assembly

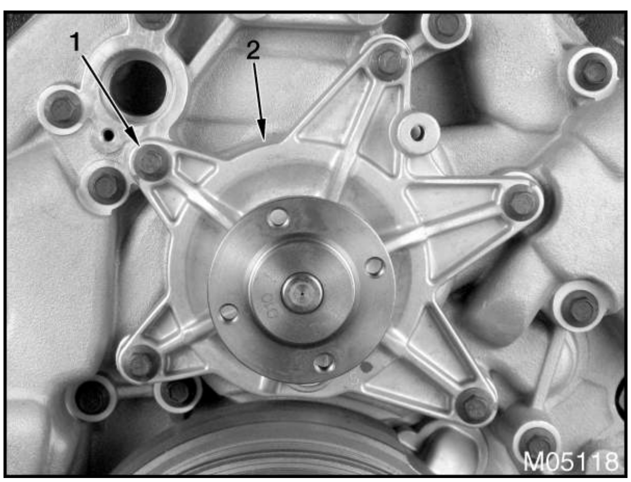

Figure 336 Water pump assembly

1. M8 x 35 bolt (5)
2. Water pump assembly

CAUTION: To prevent engine damage, do not drop water pump impeller or hit impeller with hard objects.

1. Position a new gasket and install water pump assembly.
2. Install five M8 x 35 bolts and tighten to special torque (page 213).

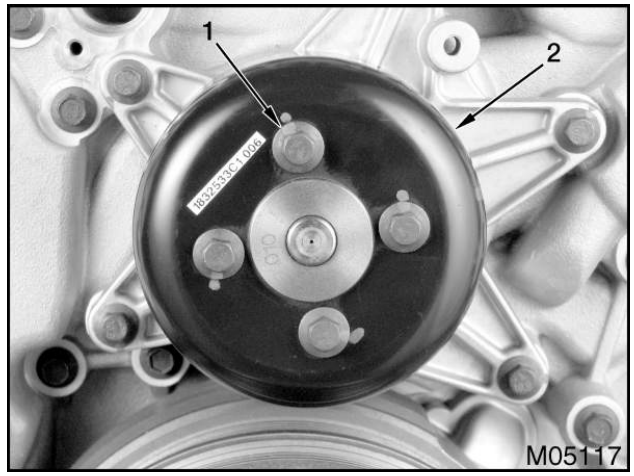

Figure 337 Water pump pulley

1. M8 x 16 bolt (4)
2. Water pump pulley

3. Install water pump pulley.

NOTE: Use a holding device to lock water pump pulley when installing bolts.

4. Install four M8 x 16 bolts and tighten to standard torque (page 383).

Fan Drive

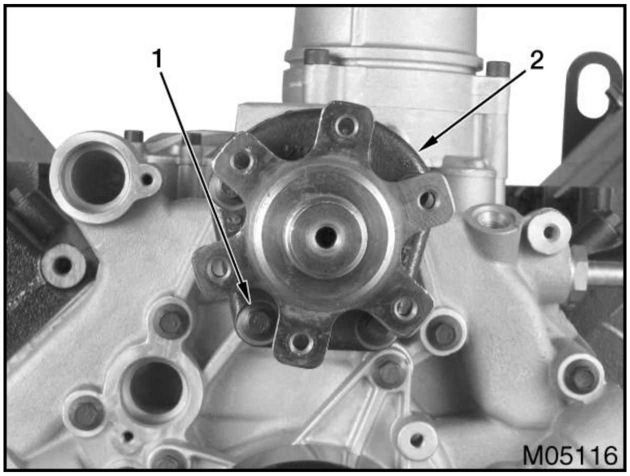

Figure 338 Fan and pulley mounting hub

1. M8 x 65 bolt (4)
2. Fan and pulley mounting hub

1. Install fan and pulley mounting hub.
2. Install four M8 x 65 bolts and tighten to special torque (page 213).

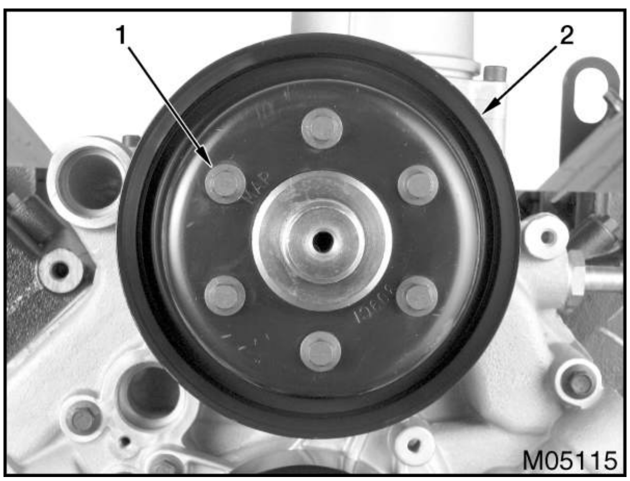

Figure 339 Fan pulley

1. M8 x 20 bolt (6)
2. Fan pulley

3. Install fan pulley.

NOTE: Use a holding device to lock fan pulley when installing bolts.

4. Install six M8 x 20 bolts and tighten to special torque (page 213).

Thermostat Assemblies and Housing

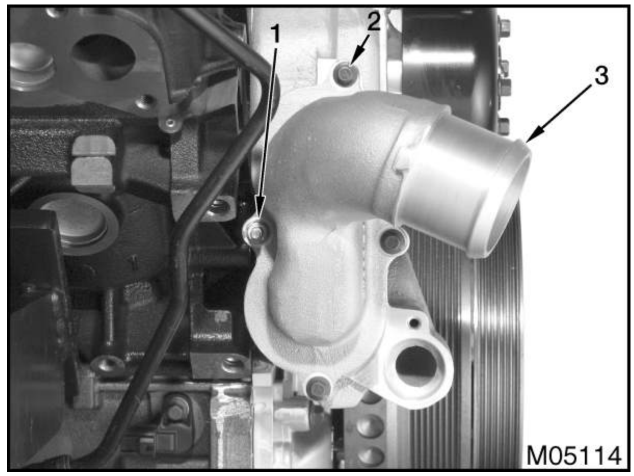

Figure 340 Thermostat housing

1. M6 x 25 stud bolt
2. M6 x 20 bolt (3)
3. Thermostat housing

NOTE: The thermostat assembly with bypass is the lower thermostat, and has a valve to seal against the orifice in the front crankcase cover.

1. Install two thermostat assemblies to thermostat housing. Verify correct position.
2. Position a new gasket and install thermostat housing.
3. Install M6 x 25 stud bolt and three M6 x 20 bolts. Tighten to special torque (page 213).

Front Engine Mount Bracket

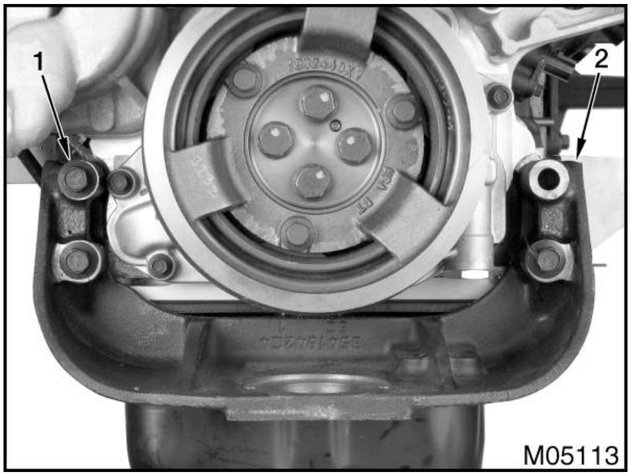

Figure 341 Front engine mount bracket

1. M12 x 70 bolt (3)
2. Front engine mount bracket

1. Install front engine mount bracket.

NOTE: For engines that are not equipped with auxiliary accessory mounting bracket, the front engine mount bracket is secured by four M12 x 70 bolts.

2. Install three M12 x 70 bolts and tighten to special torque (page 213).

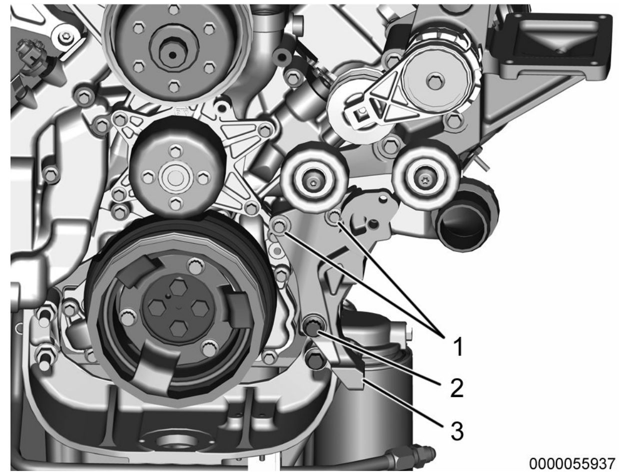

Figure 342 Auxiliary accessory mounting bracket (if equipped)

1. M8 x 90 bolt (2)
2. M12 x 110 bolt
3. Auxiliary accessory mounting bracket

3. Install auxiliary accessory mounting bracket.
4. Install M8 x 90 bolts and tighten to standard torque (page 383).
5. Install M12 x 110 bolt (front engine mount bracket) and tighten to special torque (page 213).

Alternator and Freon® Mounting Bracket

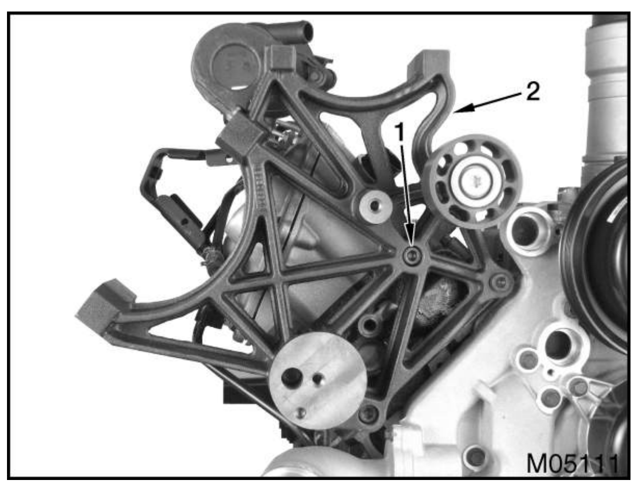

Figure 343 Alternator and Freon® mounting bracket

1. M10 x 45 cap screw (4)
2. Alternator and Freon® mounting bracket

1. Install alternator and Freon® mounting bracket.
2. Install four M10 x 45 cap screws and tighten to special torque (page 213).

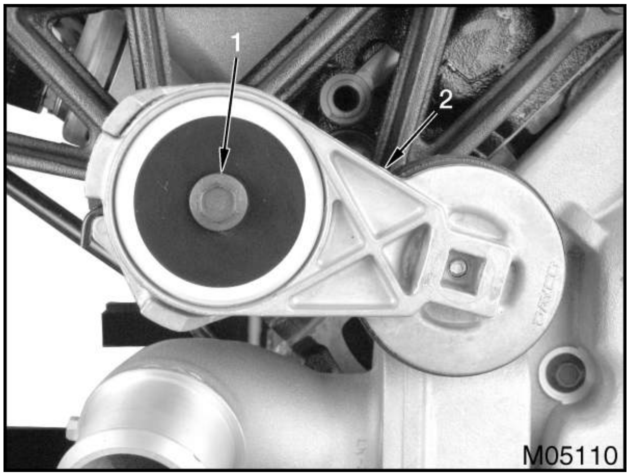

Figure 344 Belt tensioner

1. M10 x 80 bolt
2. Belt tensioner

3. Install belt tensioner.
4. Install M10 x 80 bolt and tighten to special torque (page 213).

Specifications

Table 19 Front Cover, Cooling System, and Related Components

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

Special Torque

Table 20 Front Cover, Cooling System, and Related Components

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

Special Service Tools

Table 21 Front Cover, Cooling System, and Related Components

Description	Tool Number
Dial indicator with magnetic base	Obtain locally
Feeler gauge	Obtain locally
Front Seal (wear sleeve) Installer	ZTSE4691
Front Wear Sleeve Remover	ZTSE4705
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Loctite® 569 hydraulic sealant or equivalent	Obtain locally
Slide hammer	Obtain locally
Straightedge	Obtain locally

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Exploded Views

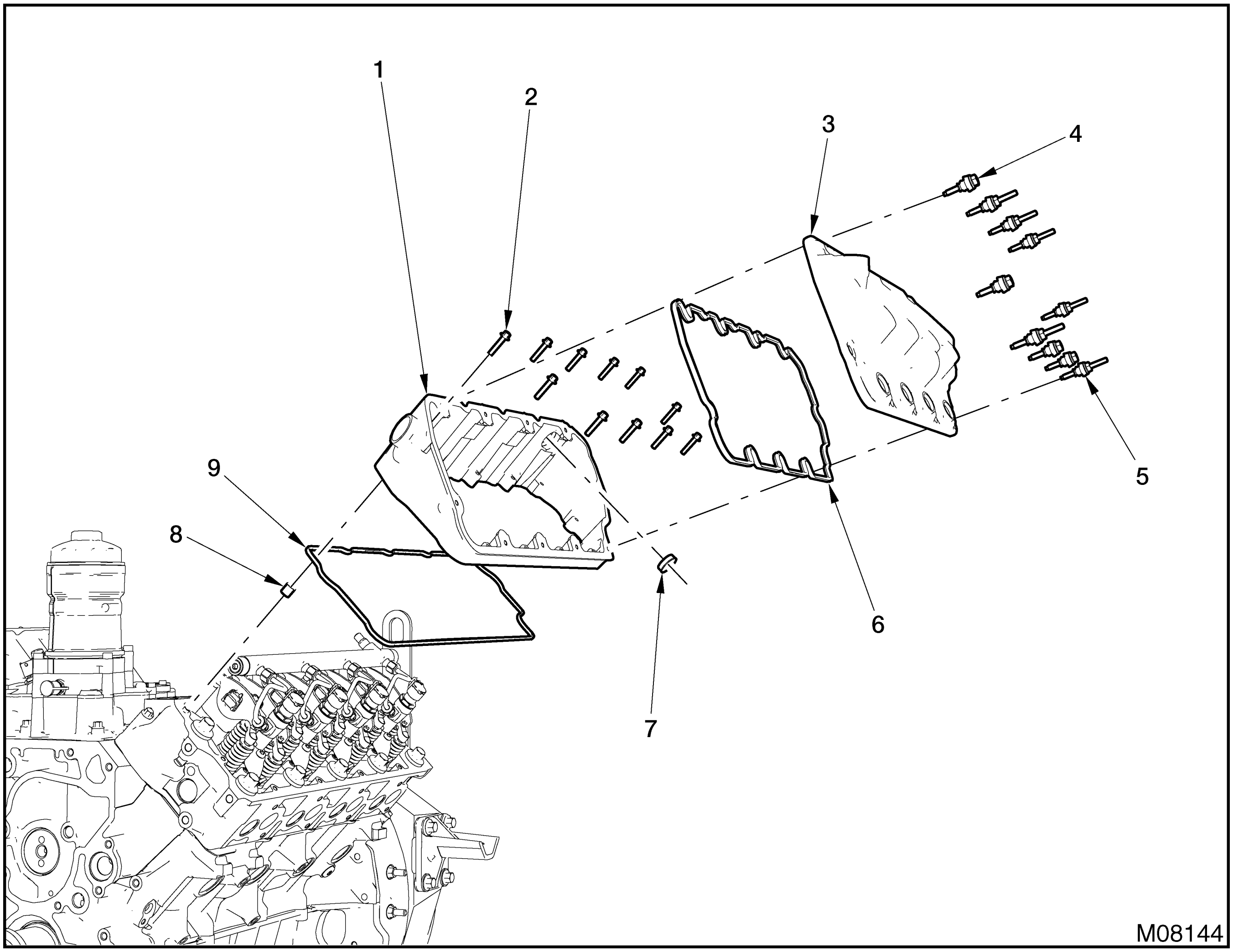

Figure 345 Valve cover and valve cover base assemblies (typical)

1. Valve cover base
2. M6 x 30 bolt (11)
3. Valve cover
4. Valve cover bolt assembly (left valve cover 4) (right valve cover 3)
5. Valve cover stud bolt assembly (left valve cover 6) (right valve cover 7)
6. Valve cover gasket
7. Fuel supply line seal
8. Slotted spring dowel pin
9. Valve cover base gasket

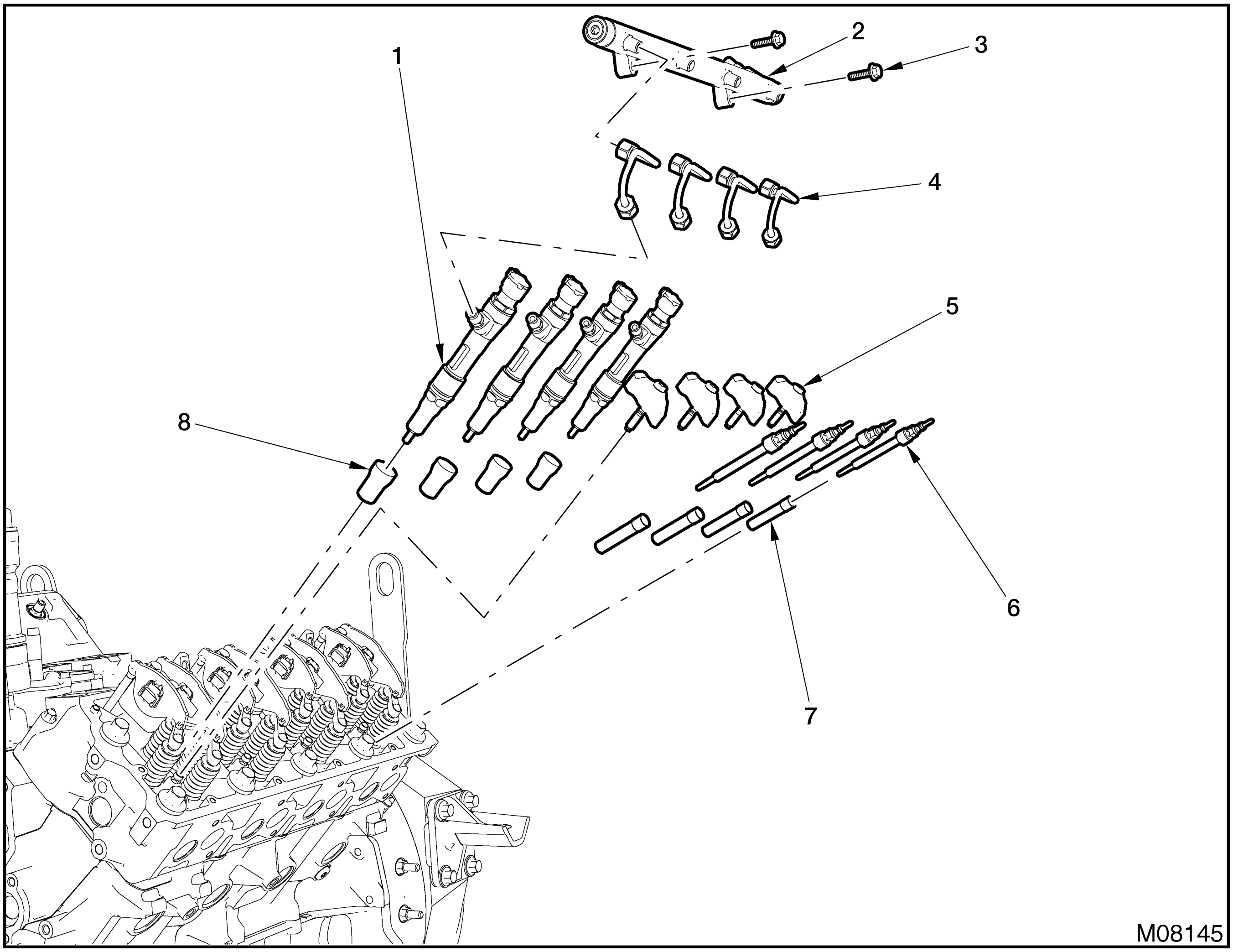

Figure 346 Fuel injectors and glow plugs (typical)

1. Fuel injector assembly (4)
2. Rail assembly
3. M8 x 30 bolt (2)
4. Fuel rail to injector tube assembly (4)
5. Injector hold down clamp assembly (4)
6. Glow plug (4)
7. Glow plug sleeve (4)
8. Injector sleeve (4)

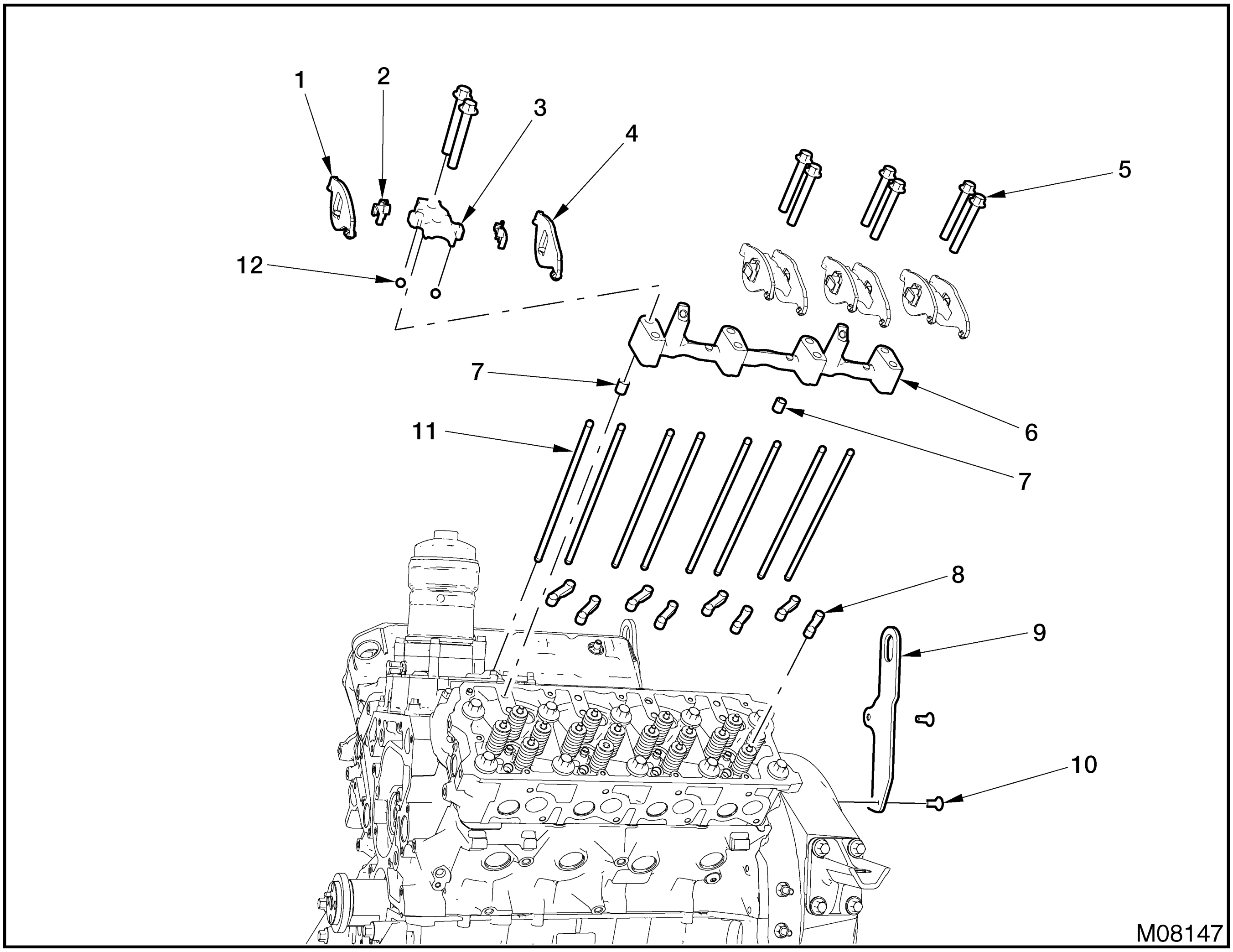

Figure 347 Rocker arm support components (typical)

1. Intake rocker arm assembly (4)
2. Rocker arm clip (8)
3. Dual rocker fulcrum plate (4)
4. Exhaust rocker arm assembly (4)
5. M10 x 70 bolt (8)
6. Rocker arm support
7. Dowel sleeve bushing (2)
8. Valve bridge (8)
9. Lifting eye
10. Flat countersunk screw (2) (left cylinder head)/ M10 x 25 bolt (2) (right cylinder head)
11. Push rod assembly (8)
12. 3/8” pivot ball (8)

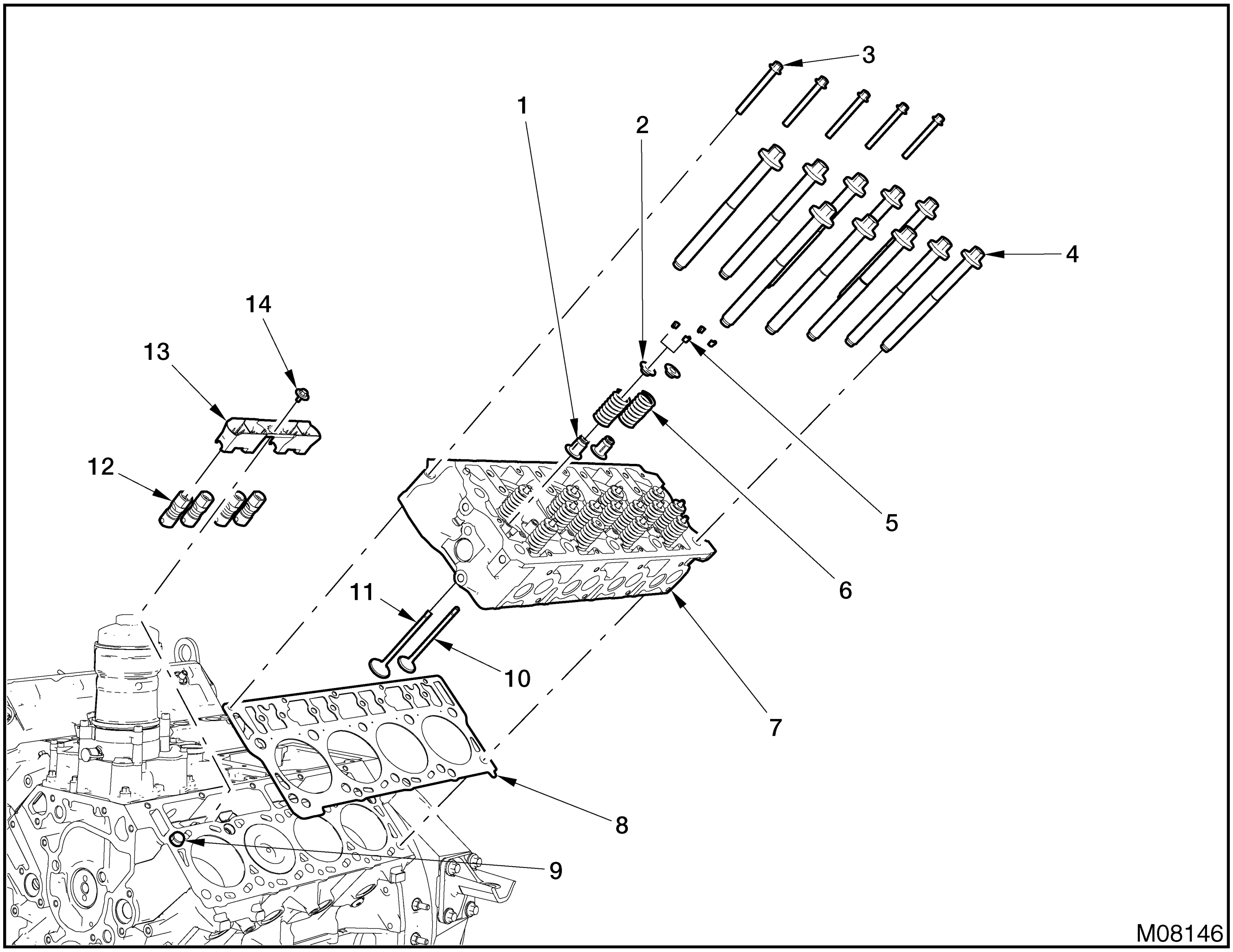

Figure 348 Cylinder head components (typical)

1. Valve seal assembly (16)
2. Valve spring retainer (16)
3. M8 x 70 bolt (5)
4. Cylinder head bolt (10)
5. Valve stem key (32)
6. Valve spring (16)
7. Cylinder head assembly
8. Cylinder head gasket
9. Spring dowel pin (2)
10. Exhaust valve (8)
11. Intake valve (8)
12. Roller hydraulic cam follower (8)
13. Roller follower guide (2)
14. Lifter guide bolt with washer assembly (2)

Removal

GOVERNMENT REGULATION: Engine fluids (oil, fuel, and coolant) may be a hazard to human health and the environment. Handle all fluids and other contaminated materials (e.g. filters, rags) in accordance with applicable regulations. Recycle or dispose of engine fluids, filters, and other contaminated materials according to applicable regulations.

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.

NOTE: See the following service sections for information on removal of components prior to this section.

- Engine Electrical
- Exhaust Gas Recirculation (EGR) System
- Variable Geometry Turbocharger (VGT)
- Air Compressor and Power Steering/Fuel Pump
- Fuel System
- Intake and Exhaust Manifolds

Valve Covers and Related Components

Breather Assembly and Components

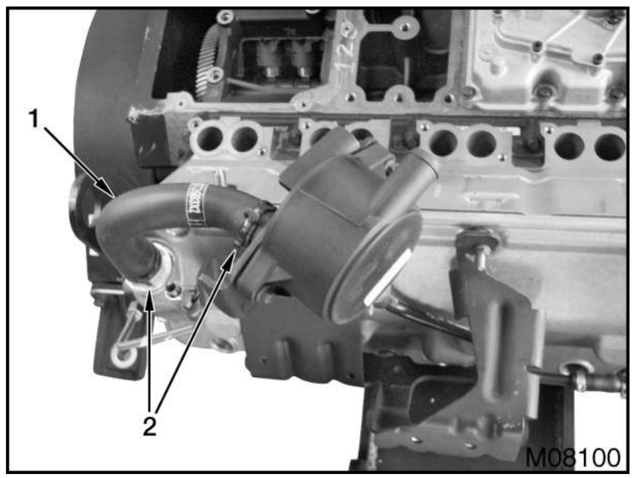

Figure 349 Breather inlet hose

1. Breather inlet hose
2. Clamp (2)

1. Release two clamps and remove breather inlet hose.

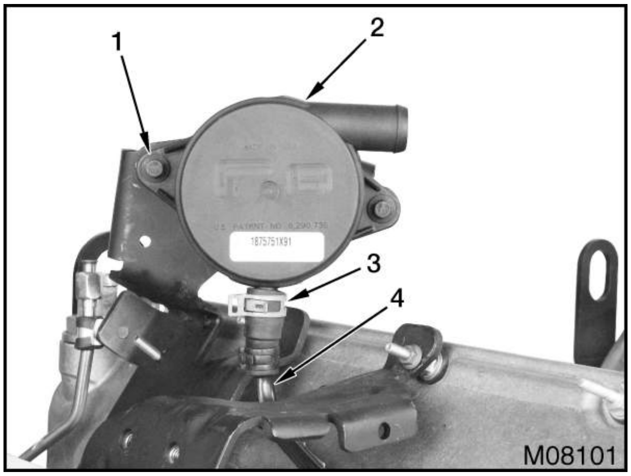

Figure 350 Breather assembly

1. M8 x 35 bolt (2)
2. Breather assembly
3. 1/2” preload clamp
4. Breather oil drain assembly

2. Remove two M8 x 35 bolts.
3. Release clamp and remove breather assembly.

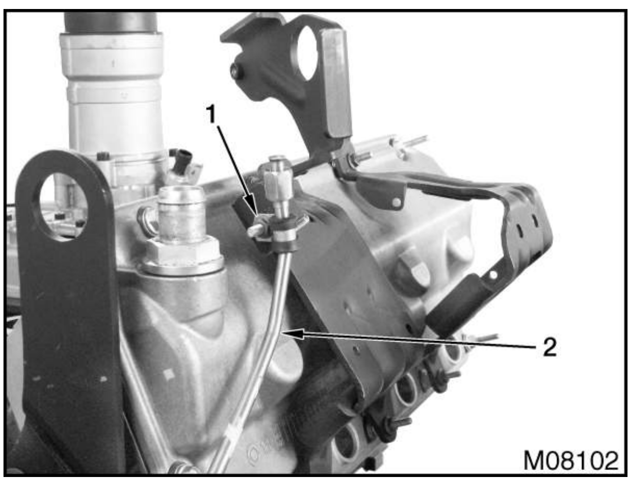

Figure 351 Exhaust Back Pressure (EBP) tube assembly

1. M6 nut
2. EBP tube assembly

4. Remove M6 nut.
5. Remove EBP tube assembly.

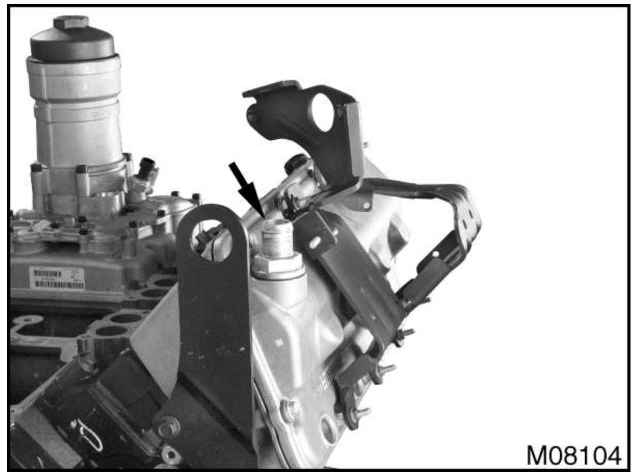

Figure 352 Breather inlet adapter

6. Remove breather inlet adapter.

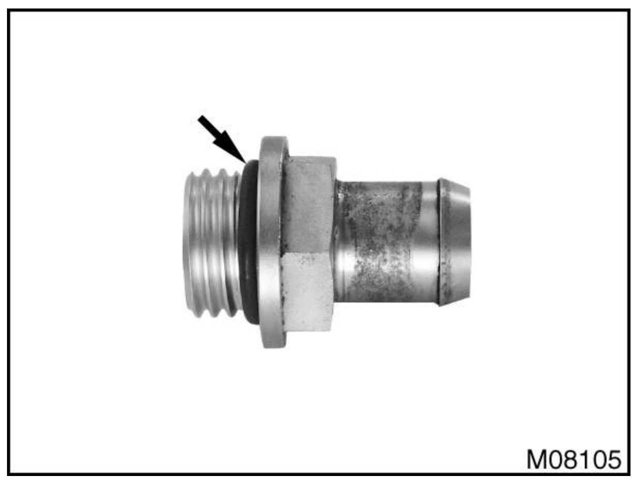

Figure 353 Breather inlet adapter O-ring seal

7. Remove and discard O-ring seal.

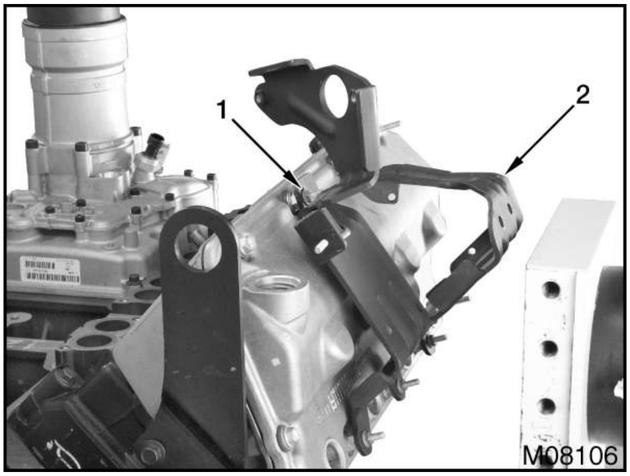

Figure 354 Breather support

1. M6 nut (4)
2. Breather support

8. Remove four M6 breather support nuts.
9. Remove breather support.

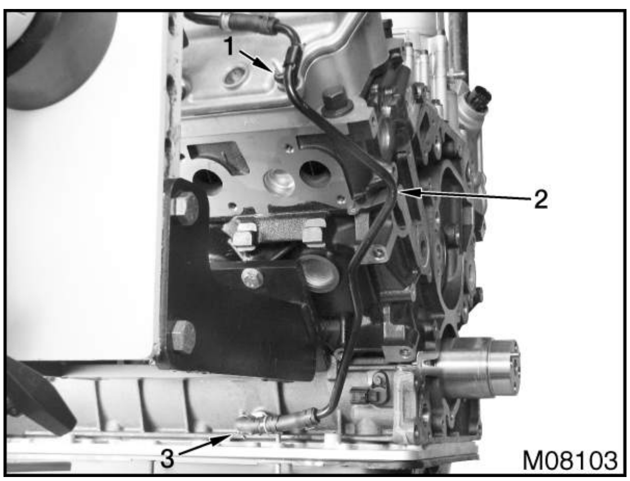

Figure 355 Breather oil drain assembly

1. M6 nut
2. Breather oil drain assembly
3. 3/8” preload clamp

10. Remove M6 breather oil drain assembly nut.
11. Release clamp and remove breather oil drain assembly.

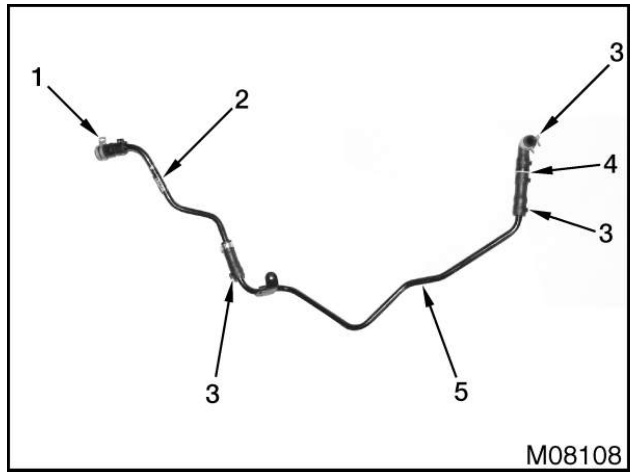

Figure 356 Breather oil drain assembly components

1. 1/2” preload clamp
2. Nylon tube assembly
3. 3/8” preload clamp (3)
4. Check valve assembly
5. Steel tube

12. Release and position aside three 3/8” preload clamps.
13. Disconnect and remove nylon tube, steel tube, and check valve.

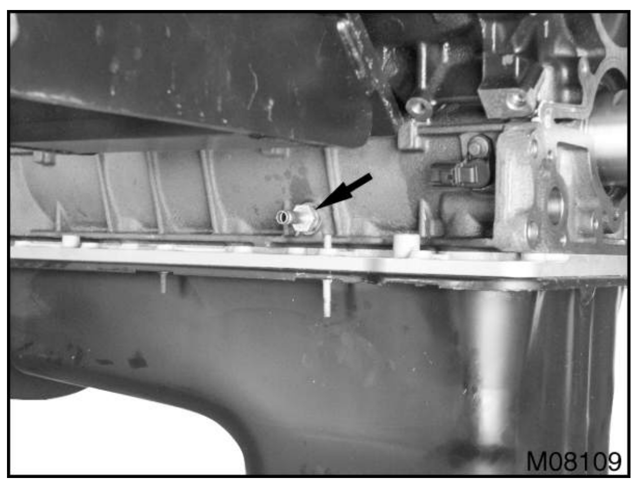

Figure 357 Breather oil drain assembly to crankcase M12 fitting

14. Remove M12 fitting.

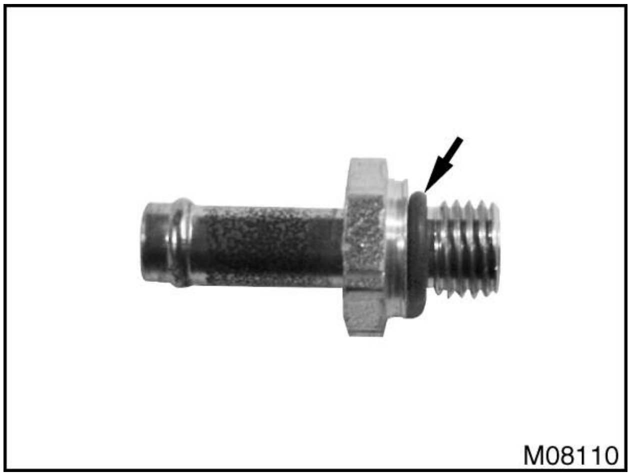

Figure 358 M12 fitting O-ring seal

15. Remove and discard O-ring seal.

Left Valve Cover

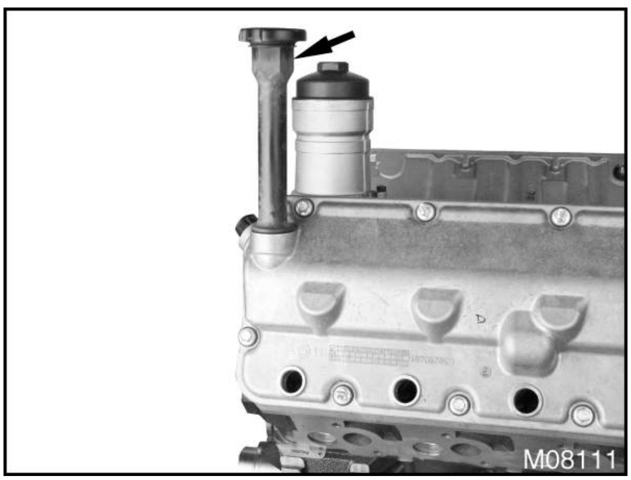

Figure 359 Oil fill extension

1. Remove oil fill extension.

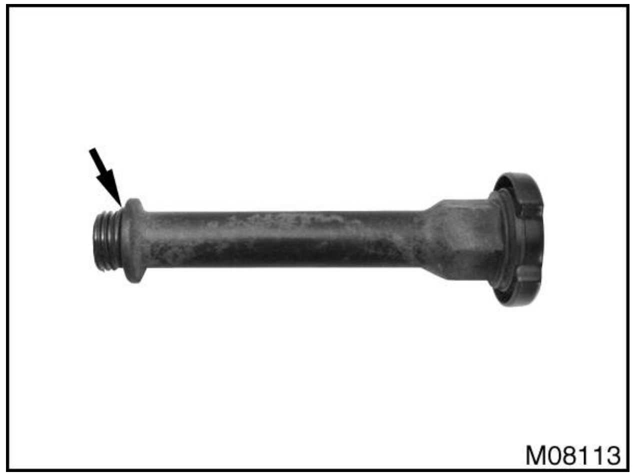

Figure 360 Oil fill extension O-ring seal

2. Remove and discard oil fill extension O-ring seal.

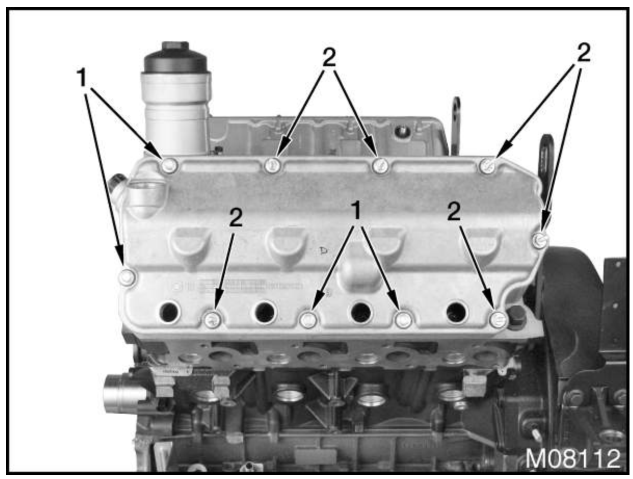

Figure 361 Left valve cover bolt and stud bolt assemblies

1. Valve cover bolt assembly (4)
2. Valve cover stud bolt assembly (6)

CAUTION: To prevent engine damage, do not use air tools to remove or install valve covers.

3. Remove four valve cover bolt assemblies and six valve cover stud bolt assemblies.
4. Remove left valve cover.
5. Remove and discard left valve cover gasket.

Right Valve Cover

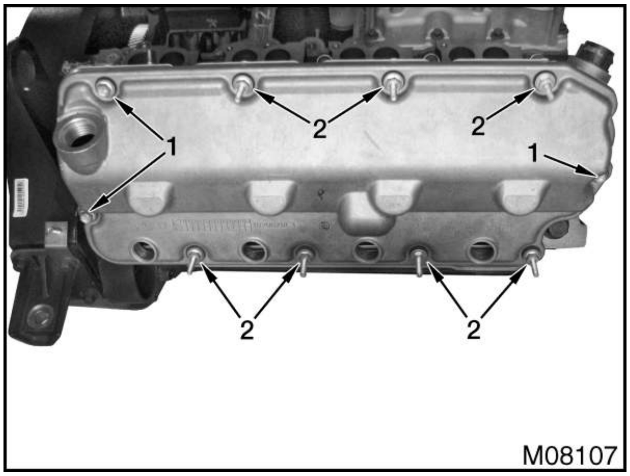

Figure 362 Right valve cover bolt and stud bolt assemblies

1. Valve cover bolt assembly (3)
2. Valve cover stud bolt assembly (7)

CAUTION: To prevent engine damage, do not use air tools to remove or install valve covers.

1. Remove three valve cover bolt assemblies and seven valve cover stud bolt assemblies.
2. Remove right valve cover.
3. Remove and discard right valve cover gasket.

Fuel Injector and Rail Assemblies

1. Remove Under Valve Cover (UVC) harness (page 64).

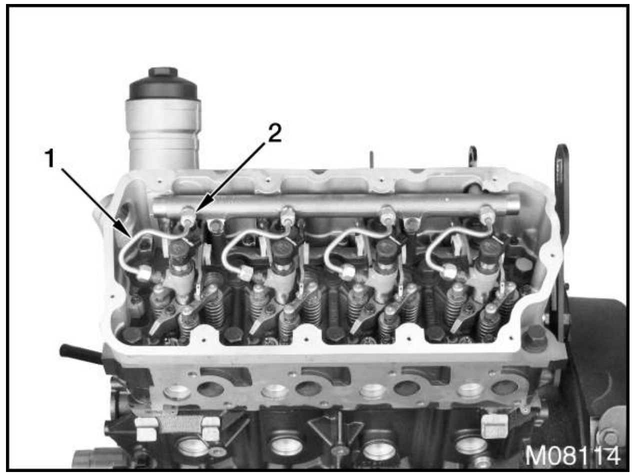

Figure 363 Fuel rail to injector tube assemblies (typical)

1. Fuel rail to injector tube assembly (4)
2. Tube nut (8)

WARNING: To prevent personal injury or death, whenever any fuel line (tubing) in the high-pressure fuel system is removed, it must be replaced with new.

2. Use a wrench to hold fuel injector fittings and loosen four tube nuts from fuel injectors.
3. Loosen four tube nuts on fuel rail. Remove and discard four fuel rail to injector tube assemblies.
4. Cover fuel rail inlet and outlet ports with Fuel System Caps (page 262).
5. Cover fuel injector ports with Fuel System Caps (page 262).

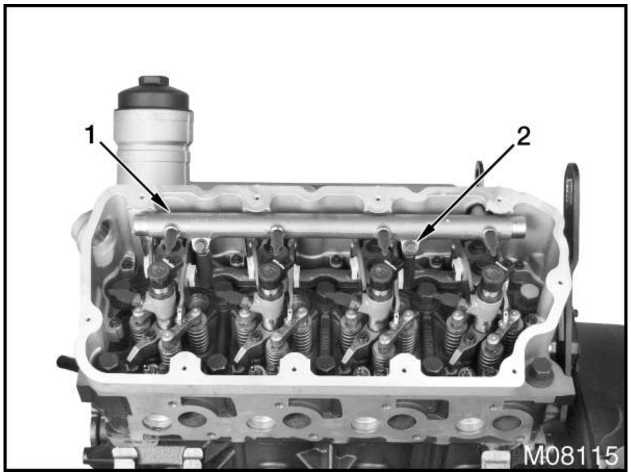

Figure 364 Rail assembly (typical)

1. Rail assembly
2. M8 x 30 bolt (2)

6. Remove two M8 x 30 bolts.
7. Remove rail assembly.

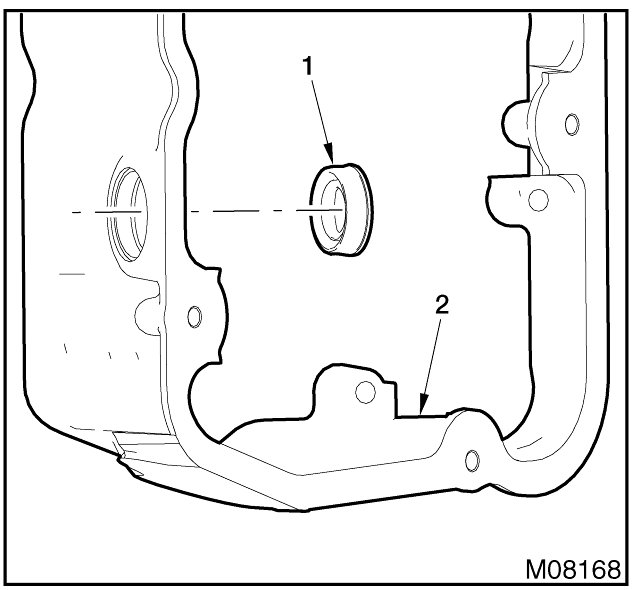

Figure 365 Fuel supply line seal removal (typical)

1. Fuel supply line seal
2. Valve cover base

8. Remove fuel supply line seal by pressing it with a proper size socket toward the inside of the valve cover base. Discard fuel supply line seal.

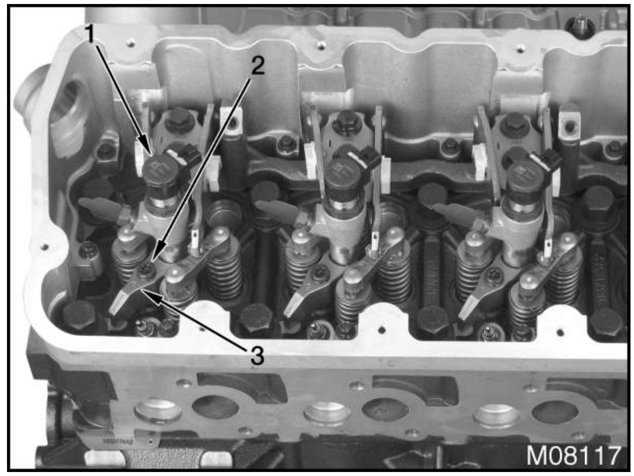

Figure 366 Fuel injector assembly (typical)

1. Fuel injector assembly (4)
2. Injector clamp bolt (4)
3. Injector hold down clamp (4)

CAUTION: To prevent engine damage, remove injectors before removing cylinder head.

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

9. Loosen injector clamp bolt to extract fuel injector assembly from cylinder head.
10. Remove fuel injector assembly from cylinder head by lifting fuel injector assembly and injector hold down clamp assembly straight up and out.

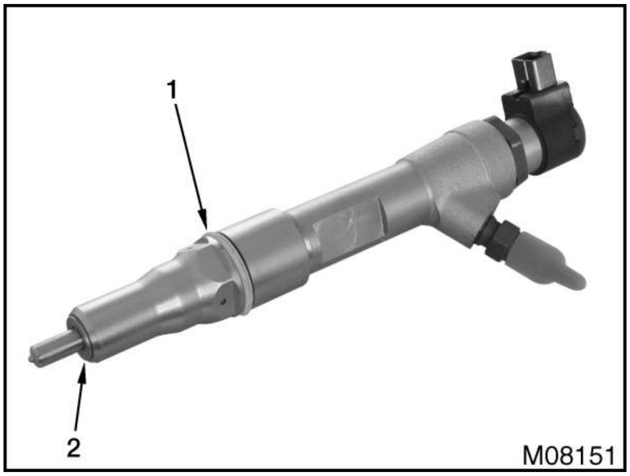

Figure 367 Fuel injector seal and combustion gasket (typical)

1. Fuel injector seal
2. Combustion gasket

CAUTION: To prevent engine damage, install new fuel injector seal and combustion gasket if a fuel injector is removed.

NOTE: Observe combustion gasket orientation at removal and be sure to install the new combustion gasket with the same orientation. If the combustion gasket remains stuck inside the fuel injector sleeve, remove it carefully so the original orientation can be noted. As a reference in establishing its orientation, the combustion gasket has a groove on one side and a rolled edge on the opposite side.

11. Using a small hand tool, remove and discard combustion gasket. Wipe injector nozzle with a lint free cloth.

CAUTION: To prevent engine damage, do not clean fuel injectors with solvents or brake cleaner.

12. Clean injector tip with Fuel Injector Tip Cleaning Brush (page 262).
13. Remove and discard old fuel injector seal.
14. Insert fuel injector assembly in Injector Cup (page 262), and place in Fuel Injector Rack Holder (page 262).

Glow Plugs

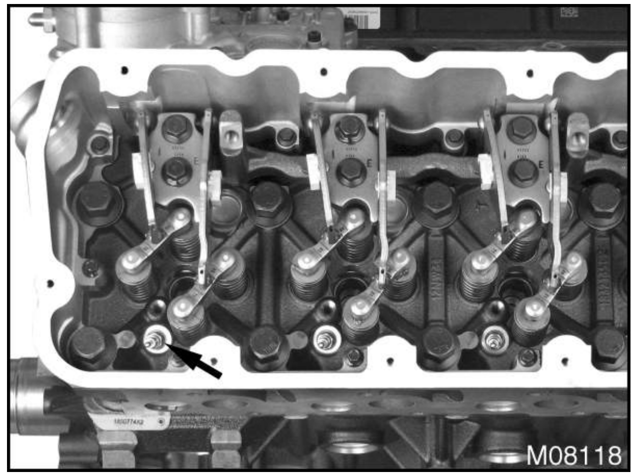

Figure 368 Glow plugs (typical)

Remove four glow plugs.

Valve Cover Base

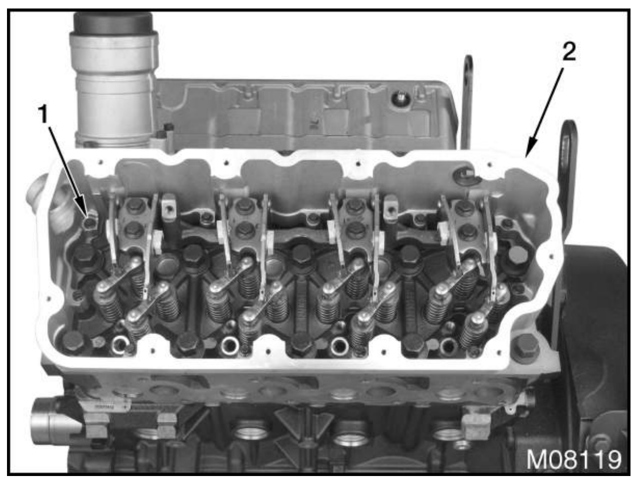

Figure 369 Valve cover base assembly (typical)

1. M6 x 30 bolt (11)
2. Valve cover base assembly

1. Remove 11 M6 x 30 bolts.
2. Remove valve cover base assembly.

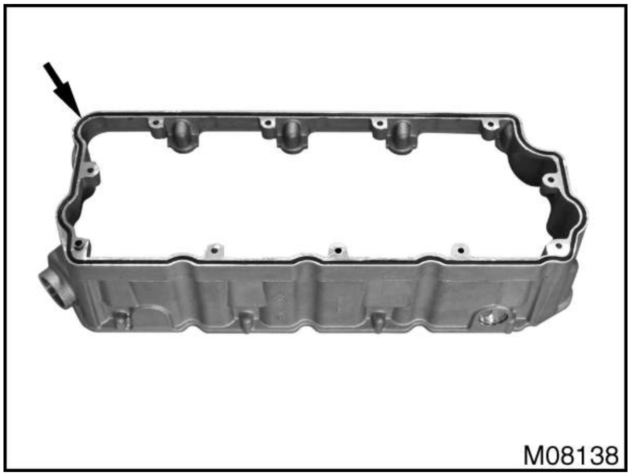

Figure 370 Valve cover base gasket (typical)

3. Remove and discard valve cover base gasket.

Rocker Arm Support, Push Rods, and Valve Bridges

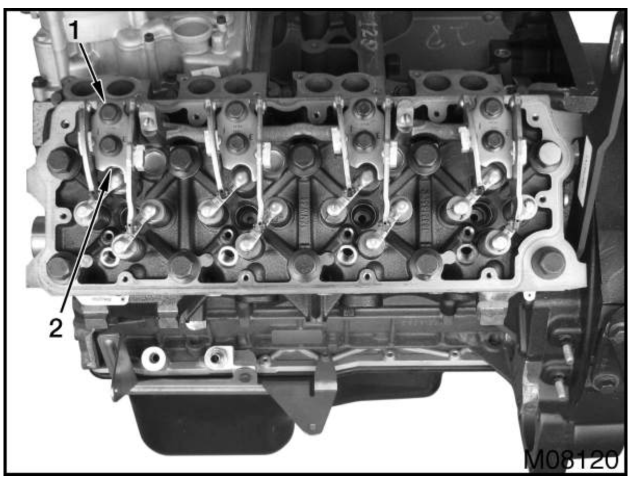

Figure 371 Dual rocker fulcrum plates (typical)

1. M10 x 70 bolt (8)
2. Dual fulcrum plate assembly (4)

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

1. Mark dual rocker fulcrum plates so they can be installed in their original location.
2. Remove eight M10 x 70 bolts and four dual fulcrum plate assemblies.

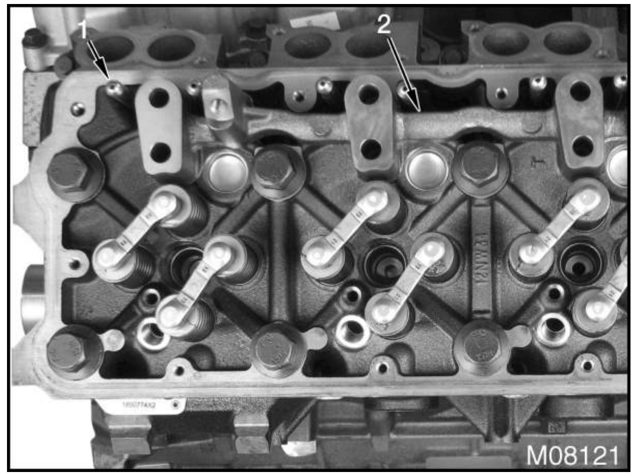

Figure 372 Push rod assemblies and rocker arm support (typical)

1. Push rod assembly (8)
2. Rocker arm support

3. Remove rocker arm support.

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

CAUTION: To prevent engine damage, keep cam followers and push rods in the order removed and install in original order.

4. Remove and identify each push rod so they can be installed in their original locations.

   Example: 2 - I

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

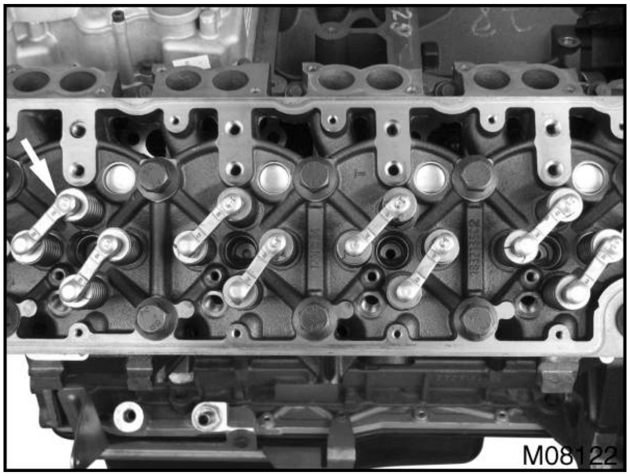

Figure 373 Valve bridge (typical)

NOTE: Identify each valve bridge and corresponding valve set so they can be installed in their original locations.

5. Remove eight valve bridges.

Cylinder Heads

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

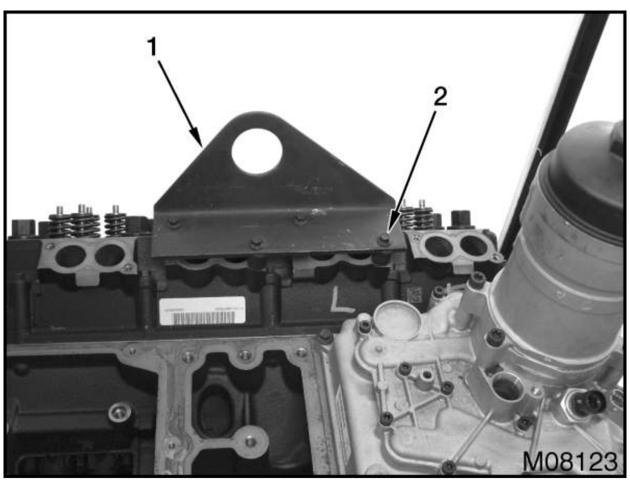

Figure 374 Cylinder Head Lifting Bracket

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

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

1. Position Cylinder Head Lifting Bracket (page 262) on cylinder head over the center two cylinders, install and tighten four lifting bracket mounting bolts.
2. Attach a lifting hoist hook or suitable lifting sling to lifting bracket.

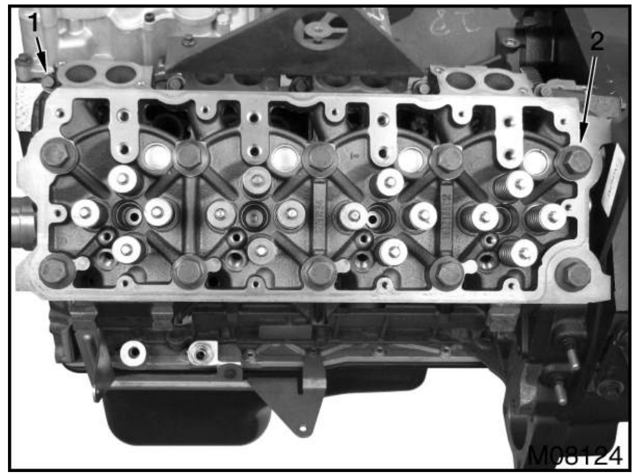

Figure 375 Cylinder head bolts (typical)

1. M8 x 70 bolt (5)
2. Cylinder head bolt (10)

3. Using a circular pattern loosen, remove, and discard ten cylinder head bolts. Begin with the outer bolts and move inward.
4. Remove five M8 x 70 bolts.
5. Lift cylinder head from crankcase.

CAUTION: To prevent engine damage, do not scratch gasket surface of cylinder head.

6. Place cylinder head on a protected surface.
7. Remove and discard cylinder head gasket.

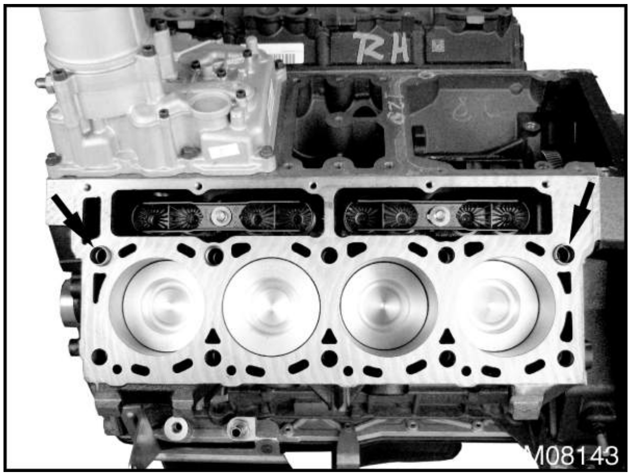

Figure 376 Cylinder head spring dowel pins in crankcase (typical)

8. Remove two spring dowel pins.
9. For left cylinder head, remove two flat countersunk screws and lifting eye.
10. For right cylinder head, remove two M10 x 25 bolts and lifting eye.

Roller Hydraulic Cam Followers

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

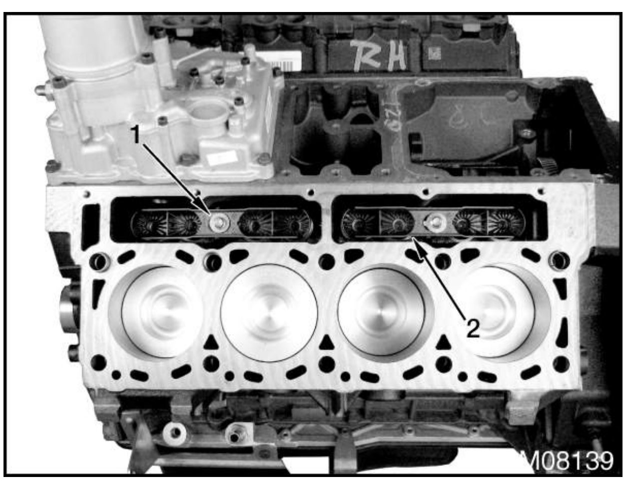

Figure 377 Cam follower and guide assemblies (typical)

1. Lifter guide bolt with washer assembly (2)
2. Cam follower and guide assembly (2)

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

CAUTION: To prevent engine damage, keep cam followers and push rods in the order removed and install in original order.

NOTE: To remove the cam followers lift the guide straight up. A hand tool may be required.

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

1. Remove two lifter guide bolt with washer assemblies and two cam follower and guide assemblies.

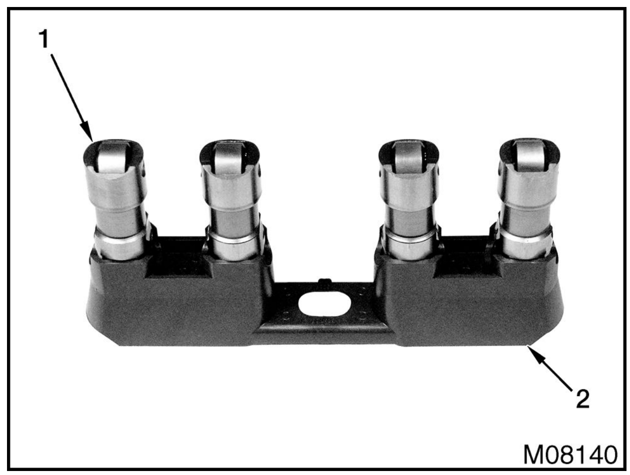

Figure 378 Roller hydraulic cam followers (typical)

1. Roller hydraulic cam follower (4)
2. Roller follower guide

NOTE: Identify and note the position of each roller hydraulic cam follower based on the orientation of its lubrication hole. The roller hydraulic cam followers must be installed in their original position.

2. Remove four roller hydraulic cam followers from roller follower guide.

Valves

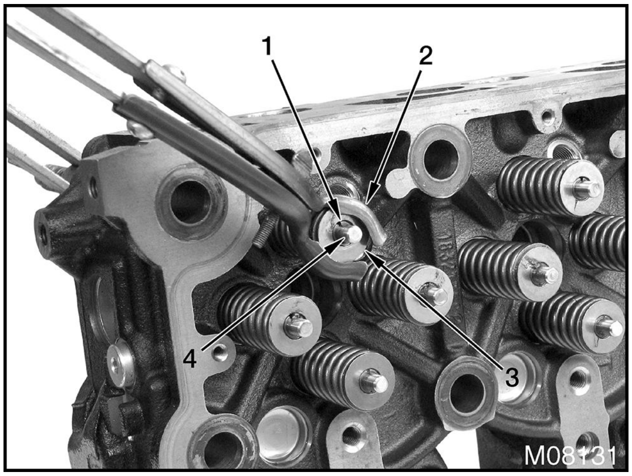

Figure 379 Valve spring compression (typical)

1. Valve stem key (2)
2. C Type Valve Spring Compressor
3. Valve spring retainer
4. Valve

NOTE: A small magnet is useful to remove the valve stem keys.

1. Compress valve springs with C Type Valve Spring Compressor (page 262), and remove two valve stem keys.
2. Release valve spring compressor and remove valve spring retainer and valve spring.
3. Remove valve from cylinder head.

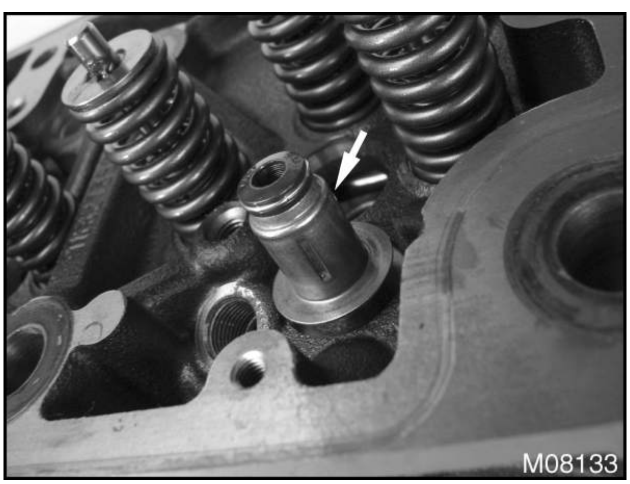

Figure 380 Valve seal assembly (typical)

NOTE: Valve seal assemblies are not reusable. Use pliers to remove valve seal assembly from end of valve stem guide.

4. Remove and discard valve seal assembly.

Fuel Injector Sleeves

CAUTION: To prevent engine damage, if replacing fuel injector sleeves in chassis, install a small plug in the bottom of the injector sleeve before cutting threads. This will keep small metal chips out of the combustion chamber.

NOTE: Fuel injector sleeve removal is not required unless sleeve is damaged.

NOTE: Use Injector Sleeve Remover (page 262) to remove injector sleeves.

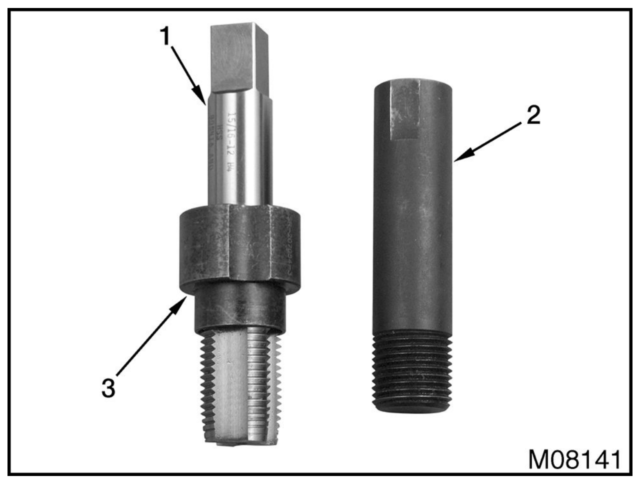

Figure 381 Injector Sleeve Remover

1. Thread tap
2. Injector sleeve remover
3. Thread tap guide collar

NOTE: The fuel injector sleeve is made of stainless steel. Lubrication of the thread tap is required.

1. Lubricate thread tap.

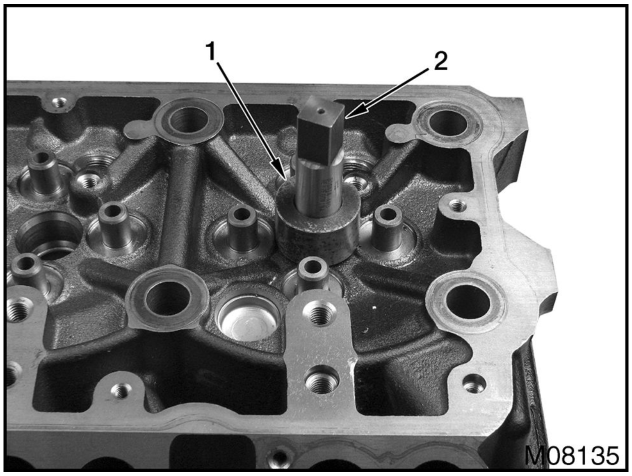

Figure 382 Thread tap guide collar installed (typical)

1. Thread tap guide collar
2. Thread tap

2. Insert thread tap into fuel injector sleeve and install thread tap guide collar on thread tap.
3. Cut at least 19 mm (0.75 in) deep threads to accommodate injector sleeve remover.

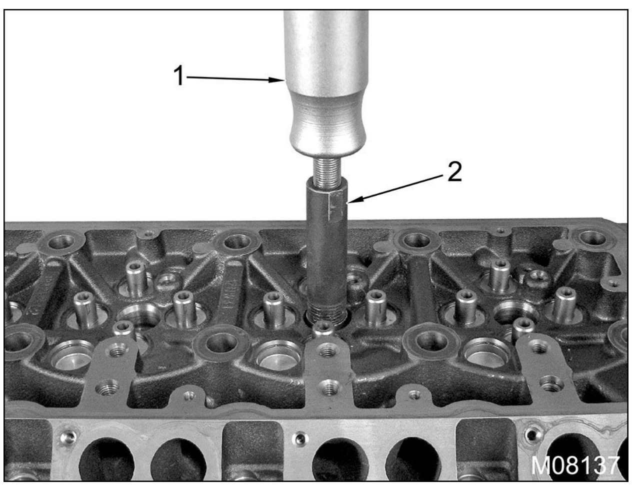

Figure 383 Injector sleeve remover installed (typical)

1. Slide hammer
2. Injector sleeve remover

4. Install and tighten injector sleeve remover in fuel injector sleeve.
5. Thread Slide Hammer (page 262) in injector sleeve remover.
6. Remove and discard fuel injector sleeve.

Glow Plug Sleeves

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

NOTE: Glow plug sleeve removal is not required unless sleeves are damaged.

NOTE: Use Glow Plug Sleeve Remover (page 262) to remove glow plug sleeves.

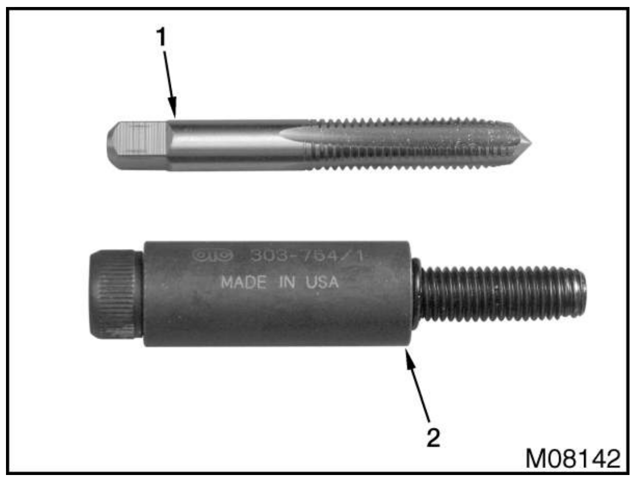

Figure 384 Glow Plug Sleeve Remover

1. Thread tap
2. Glow plug sleeve remover

NOTE: The glow plug sleeve is made of stainless steel. Lubrication of the thread tap is required.

1. Lubricate thread tap.

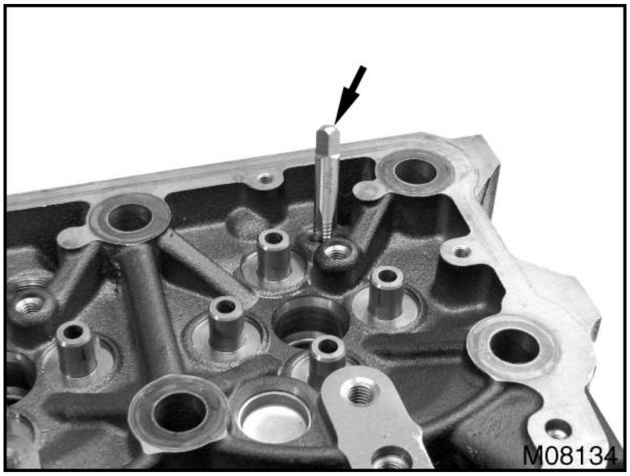

Figure 385 Glow plug sleeve tap (typical)

2. Insert thread tap into glow plug sleeve.
3. Cut at least 19 mm (0.75 in) deep threads to accommodate glow plug sleeve remover.

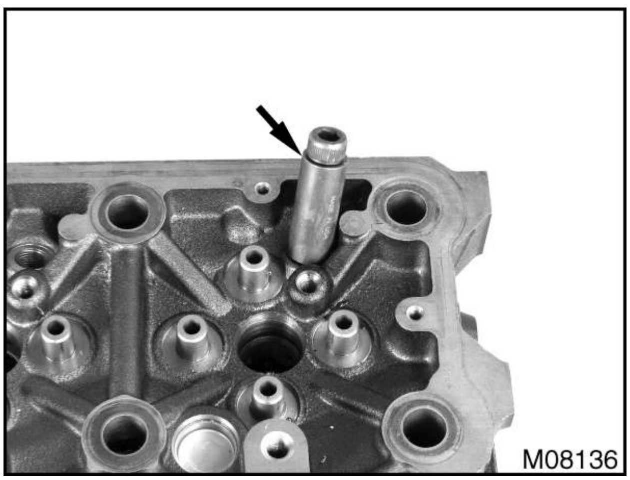

Figure 386 Glow Plug Sleeve Remover installed

4. Thread Glow Plug Sleeve Remover into glow plug sleeve and tighten bolt until sleeve is extracted.
5. Remove and discard glow plug sleeve.

Dual Fulcrum Plate Assemblies

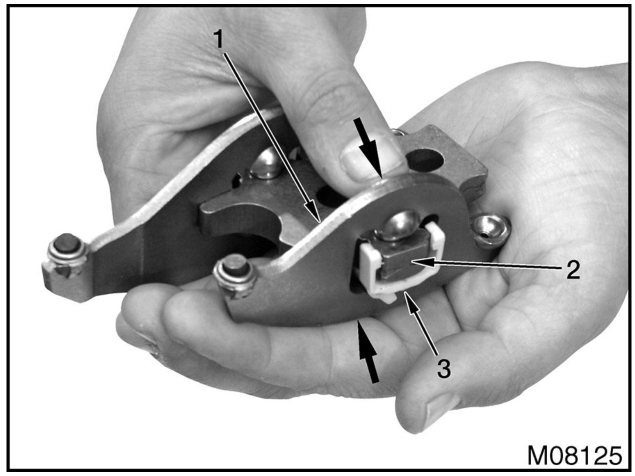

Figure 387 Separation of rocker arm assembly from dual rocker fulcrum plate (typical)

1. Rocker arm assembly
2. Dual rocker fulcrum plate
3. Rocker arm clip

1. Place dual fulcrum plate assembly upside down in your palm.
2. Push up on rocker arm assembly with palm and forward on dual rocker fulcrum plate with thumb of opposite hand.

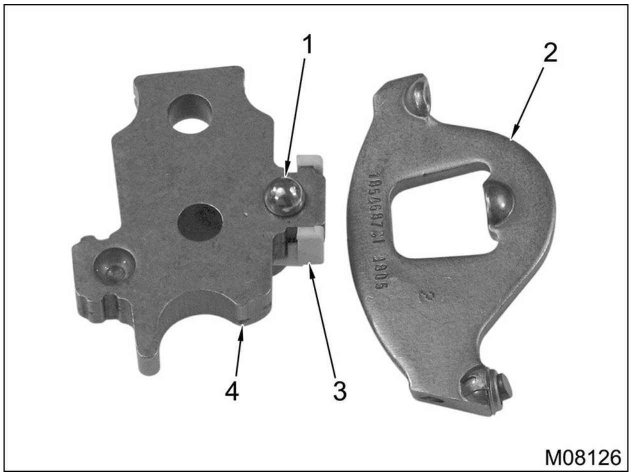

Figure 388 Rocker arm assembly separated (typical)

1. 3/8” pivot ball
2. Rocker arm assembly
3. Rocker arm clip
4. Dual rocker fulcrum plate

3. Remove rocker arm assembly and 3/8” pivot ball.

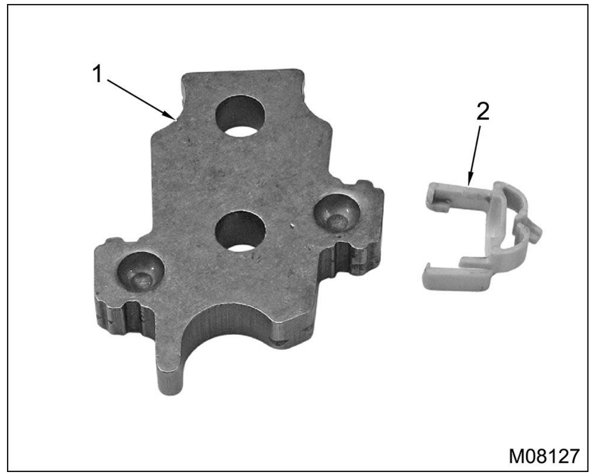

Figure 389 Rocker arm clip removed (typical)

1. Dual rocker fulcrum plate
2. Rocker arm clip

4. Remove and discard rocker arm clip.

Cleaning, Inspection, and Testing

Cylinder Head and Crankcase Components

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

CAUTION: To prevent engine damage, do not scratch gasket surface of cylinder head.

1. With valves installed to protect seats, use a scraper and wire brush to remove deposits and gasket material from valve heads and gasket surface.
2. Use a suitable solvent to remove dirt, grease, and deposits from removed parts.
3. Clean all bolt holes. Make sure gasket surfaces, oil return, and coolant passages are clean. After rinsing thoroughly with hot water, dry with filtered compressed air.
4. Clean all bolts (except head bolts) with a nonchlorinated solvent and dry thoroughly. New head bolts must be installed.

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

5. Clean crankcase threads with compressed air.

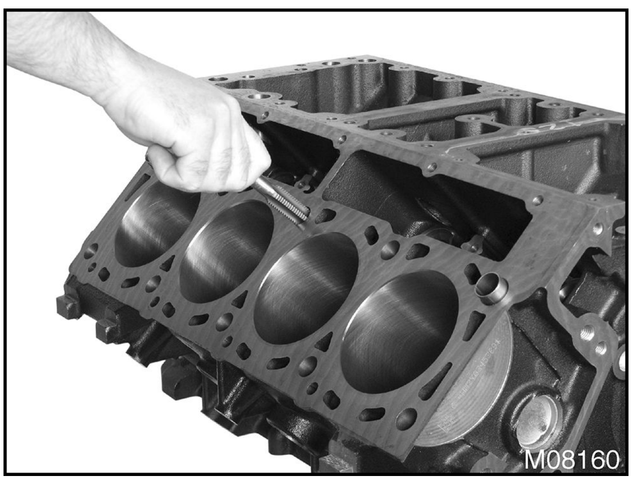

Figure 390 Cylinder Head Bolt Tap

6. Use Cylinder Head Bolt Tap (page 262) to clean each tapped hole in crankcase top deck. Remove debris with filtered compressed air.
7. Thoroughly clean push rods with a suitable solvent. Dry with filtered compressed air.

Cylinder Head Inspection – Valves Installed

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

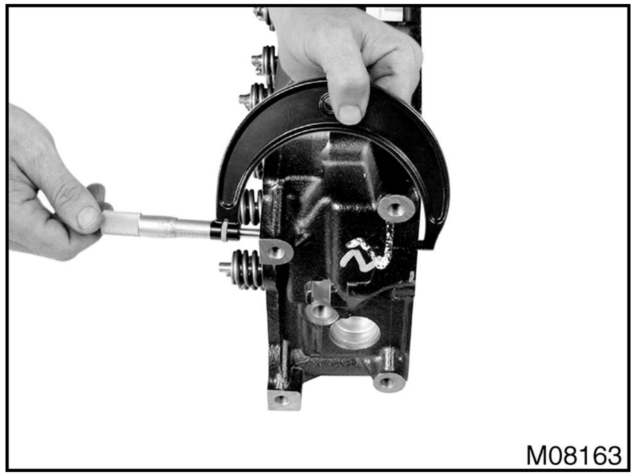

Figure 391 Measurement of cylinder head thickness

1. To determine if cylinder head has been resurfaced previously, use a 3-4 inch micrometer to measure deck thickness of cylinder head at four corner locations. If overall cylinder head thickness (deck-to-deck) specification (page 260) is not met, install new cylinder head.

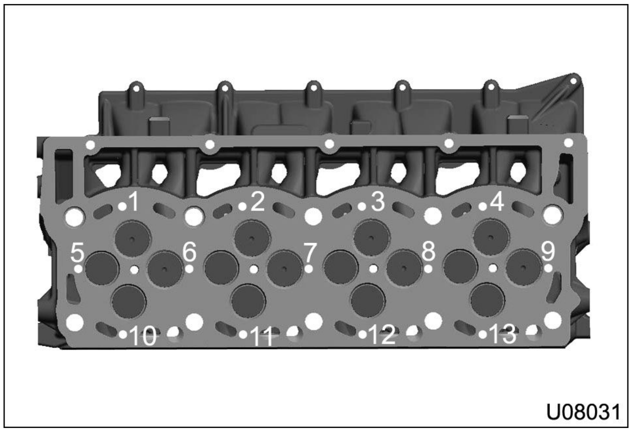

Figure 392 Points to check for cylinder head flatness

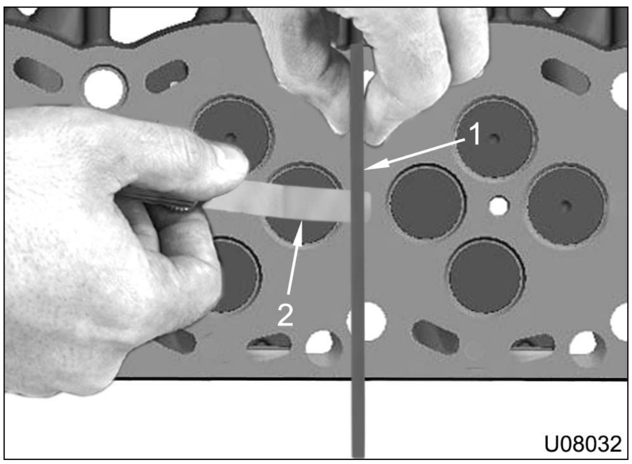

Figure 393 Check point inspection

1. Straightedge
2. Feeler gauge

CAUTION: To prevent engine damage, do not machine the cylinder head if it is out of flatness.

NOTE: Use a straight edge that is calibrated by the manufacturer to be flat within 0.0002 inches (0.005 mm) per running foot length. Do not place straightedge over and past the lifter opening area of the cylinder head, when inspecting check points for cylinder head flatness.

2. Put the 0.051 mm (0.002 inch) blade of the feeler gauge (page 262) on the check point, and place the straight edge (page 262) on top of the feeler gauge at 90° across the width of the cylinder head.
   - If the feeler gauge blade can not be pulled out from under the straight edge, that check point passes the flatness check. Continue inspection of remaining check points. If all check points pass, continue with step 3.
   - If the feeler gauge blade pulls out easily or is loose, the cylinder head is out of flat. Install a new cylinder head.

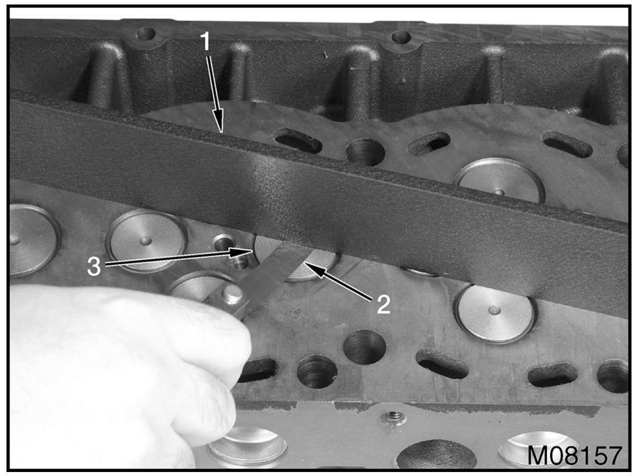

Figure 394 Checking valve head recession

1. Straightedge
2. Feeler gauge
3. Valve head

3. Before removing valves, check valve head recession (relative to deck) as follows:
   a. Place a straightedge across each valve.
   b. Place a feeler gauge between straightedge and valve head.
   c. If out of specification (page 260), replace valve. Repeat step 2 with new valve, and if specifications are still not met, replace cylinder head.
4. Use the Dye Penetrant Kit PT-7191 (page 262), to inspect for cracks in cylinder head

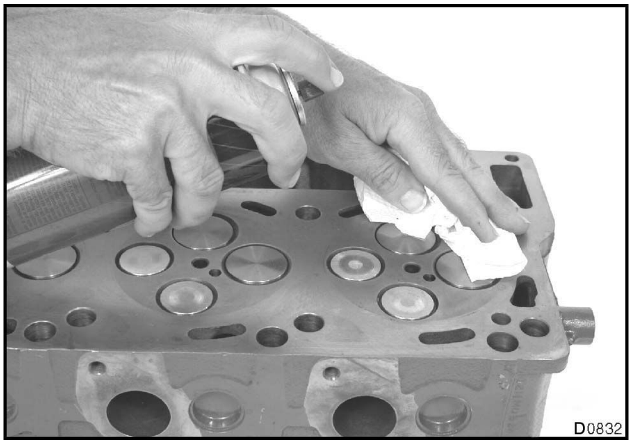

Figure 395 Cleaner sprayed on cylinder head (typical)

5. Spray cleaner on lower deck (gasket surface) of cylinder head and wipe dry.

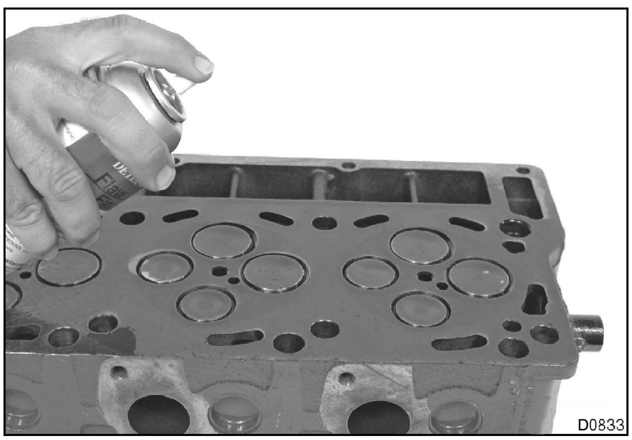

Figure 396 Dye penetrant sprayed on cylinder head (typical)

6. Spray dye penetrant on lower deck (gasket surface) of cylinder head and let dry for 5 to 15 minutes.
7. Wipe dye off cylinder head surface.

   NOTE: Dye will remain in cracks.

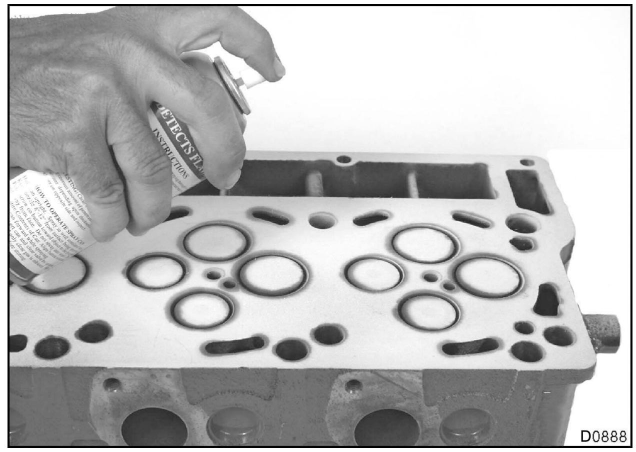

Figure 397 Spraying developer onto cylinder head (typical)

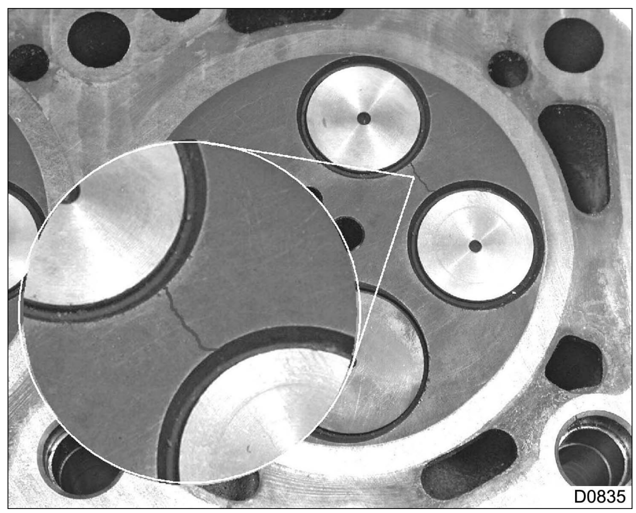

Figure 398 Cylinder head crack between intake and exhaust valves (typical)

8. Spray developer on lower deck (gasket surface) of cylinder head and let dry for 5 to 15 minutes. Cracks show up as purple lines against white developer.

CAUTION: To prevent engine damage, install a new cylinder head if cylinder head is cracked.

9. Position cylinder head on wooden blocks with gasket surface facing down and spray mineral spirits into intake and exhaust ports.

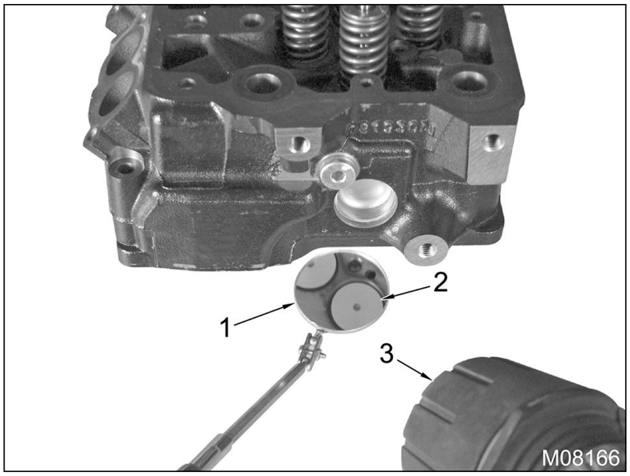

Figure 399 Leak inspection

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

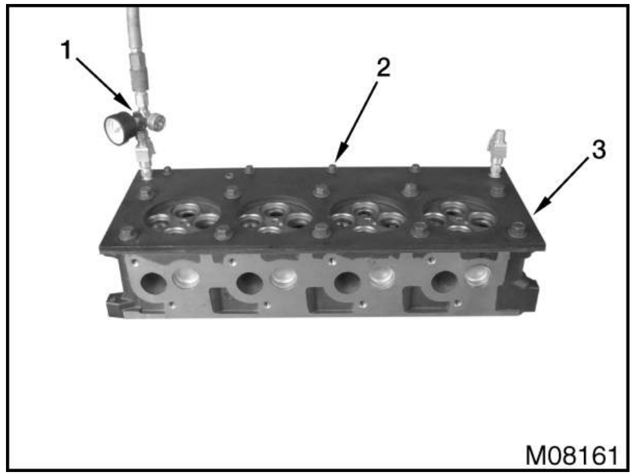

Figure 400 Cylinder Head Pressure Test Plate

1. Pressure test regulator and gauge assembly
2. Mounting bolts (15)
3. Cylinder Head Pressure Test Plate

10. Wait five minutes. Use an inspection mirror to inspect valve seat area for leakage of mineral spirits.

NOTE: Valve seats must not leak. Valve replacement is not required if the cylinder head passes the mineral spirits test. If valve seats leak, install new valves. See Valves (page 231).

Cylinder Head Inspection – Valves Removed

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

1. Pressure testing the cylinder head reveals cracks in ports or sleeve leakage which cannot be seen using dye penetrant. Pressure test the cylinder head as follows:
2. Fasten Cylinder Head Pressure Test Plate (page 262) with rubber gasket attached to gasket side of cylinder head. Secure plate with ten M14 and five M8 mounting bolts.
3. Install pressure test regulator and gauge assembly to Cylinder Head Pressure Test Plate (page 262).
4. Immerse cylinder head in water. Apply air pressure and adjust to 124 to 138 kPa (18 to 20 psi) and inspect for leaks in the following places.
   - Ports
   - Upper cylinder head deck
   - Lower cylinder head deck
   - Nozzle sleeve area
   - Glow plug sleeve area
5. If leaks are observed, install a new cylinder head.
6. Clean all valve guides using a nylon brush, soap and water. Blow out any residue with filtered compressed air.
7. Position an inspection light at the bottom of the valve guide bores and examine the walls for burning or cracking. Replace cylinder head, if necessary.

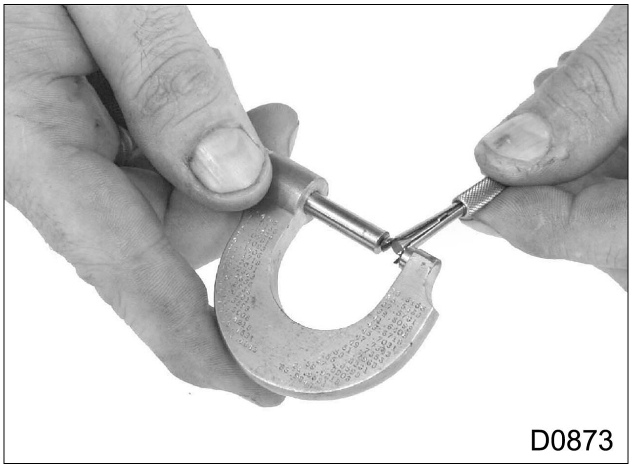

Figure 401 Measurement of Small Hole Gauge (valve guide ID)

8. Measure each valve guide using a Valve Guide Gauge Tool (page 262) and a 0-1 inch micrometer.

NOTE: If valve guide inside diameter exceeds specifications (page 260), install a new cylinder head.

9. Measure the valve guides within 0.64 mm (0.025 in) of each end and 90° from the crankshaft center line. Record the readings in order to determine the valve-to-guide running clearance.
10. Using valve guide inside diameter and valve stem diameter measurements, determine valve stem-to-guide running clearance. See Specifications (page 260). Replace valve if necessary.
11. Clean valve seat area using suitable solvent, before inspection.
12. Inspect exhaust valve seats for burned or cracked conditions. If any of these conditions exist, replace cylinder head.
13. Using a dial caliper, measure valve seat width. See Specifications (page 260). Replace cylinder head if necessary.

Push Rods

1. Inspect push rods for wear and deposits that may restrict oil flow into rocker arm assemblies. Replace push rod if necessary.

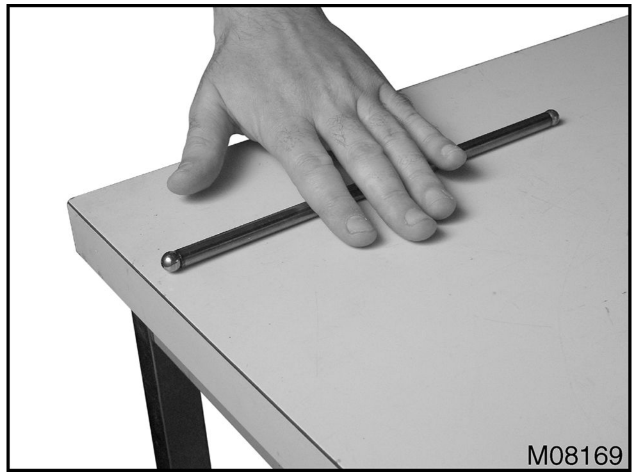

Figure 402 Push rod runout

2. Roll push rod on a flat surface to check runout. If a push rod is not straight, see Specifications (page 260) for runout. If specifications are exceeded, replace push rod.

Valves

1. Use a wire brush to remove all carbon from valve stems and heads.
2. Inspect each valve. Replace valves having burn marks, warping, scuffing, bending or valve tip spalling.
3. Measure each valve stem diameter for wear using a 0-1 inch micrometer. Measure valves at three locations 90° apart. Replace valves with stem diameter less than minimum valve stem diameter specification. See Specifications (page 260).

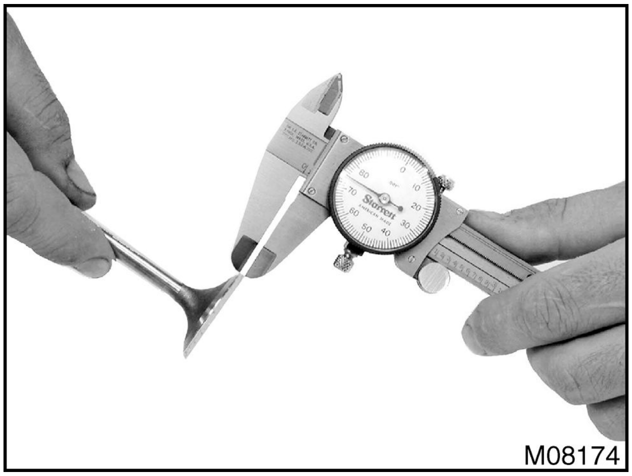

Figure 403 Measurement of valve face margin

CAUTION: To prevent engine damage, maintain a minimum valve face margin across the entire valve face. An insufficient margin will not provide correct heat dissipation, leading to valve warping or breakage. Replace valve if margin is less than specification. See Specifications (page 260).

4. Use a dial caliper to measure valve face margin at four locations (90° apart).

Valve Springs

CAUTION: To prevent engine damage, do not wire brush or grind valve springs. This can cause fatigue cracks and spring failure.

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

Figure 404 Flatness check of valve spring

3. Inspect to verify valve spring ends are flat and square to prevent lateral loads on valve stem. Replace valve springs if necessary.
4. Measure valve spring tension using a Valve Spring Tester (page 262).

Figure 405 Measurement of valve spring free length under load

5. Apply correct test loads to each spring and determine whether specified heights are achieved. See Specifications (page 260). Replace valve springs if necessary.

Valve Stem Keys

1. Clean all valve stem keys with a suitable cleaning solvent.
2. Inspect inside and outside of valve stem keys for wear. Replace worn valve stem keys, if necessary.

Fuel Injector Sleeve Bore and Gallery

1. Use Injector Sleeve Brushes (page 262) in fuel injector bore to remove deposits and hardened sealant.
2. Remove fuel rail plug assembly.

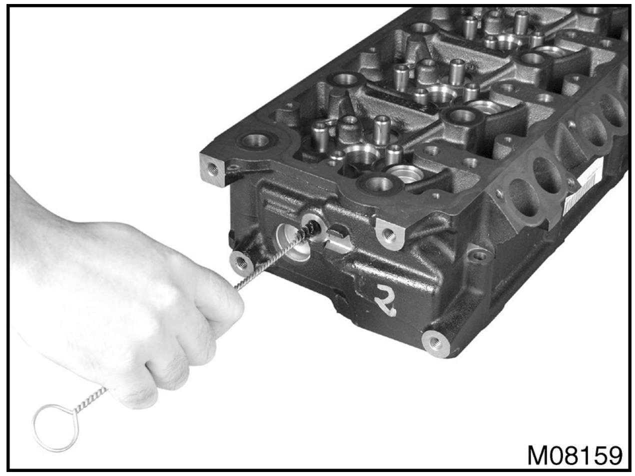

Figure 406 Fuel gallery

3. Clean fuel gallery with Fuel Gallery Cleaning Brush (page 262).

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

4. Use filtered compressed air to clean out debris from fuel gallery port.
5. Install a new seal on fuel rail plug.
6. Install fuel rail plug assembly and tighten to special torque (page 261).

Glow Plug Sleeve Bore

Clean glow plug bore with Glow Plug Sleeve Seat Wire Brush (page 262).

Dual Rocker Fulcrums

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

1. Clean parts with a suitable solvent. Use filtered compressed air to dry parts.
2. Inspect each rocker arm pivot foot for excessive wear, and corresponding valve bridge for pitting or scuffing. Replace rocker arm assemblies and valve bridges, if necessary.

3. Inspect each 3/8” pivot ball and rocker arm socket for scuffing. Replace 3/8” pivot ball and rocker arm, if necessary.

4. Inspect fulcrum plate ball socket for excessive wear. Inspect bolts for thread damage. Replace worn components, if necessary.

Installation

Dual Fulcrum Plate Assemblies

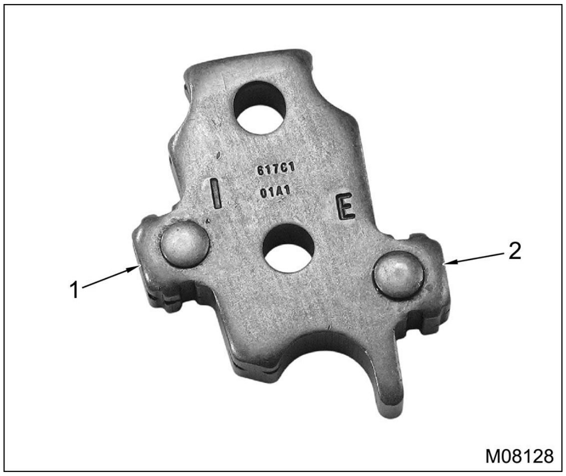

Figure 407 Dual rocker fulcrum plate (typical)

1. Intake end
2. Exhaust end

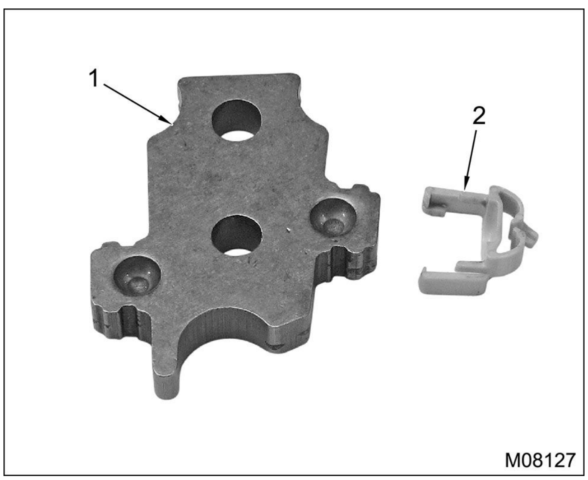

Figure 408 Rocker arm clip (typical)

1. Dual rocker fulcrum plate
2. Rocker arm clip

1. Install a new rocker arm clip on both sides of dual rocker fulcrum plate.

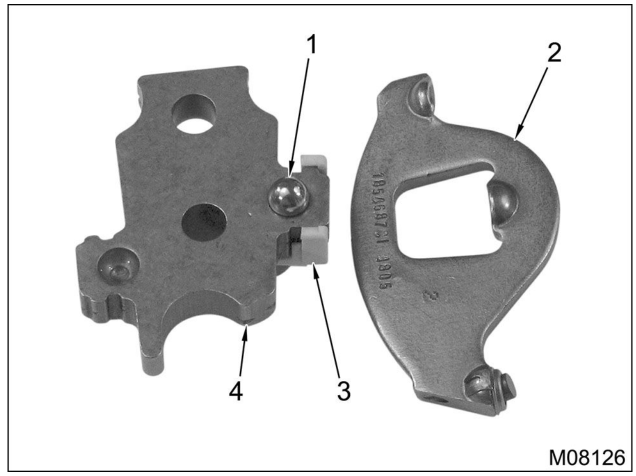

Figure 409 Rocker arm assembly installation (typical)

1. 3/8” pivot ball
2. Rocker arm assembly
3. Rocker arm clip
4. Dual rocker fulcrum plate

2. Apply a small amount of lithium grease (page 262) to dual rocker fulcrum plate pockets.
3. Insert 3/8” pivot ball in dual rocker fulcrum plate pockets.

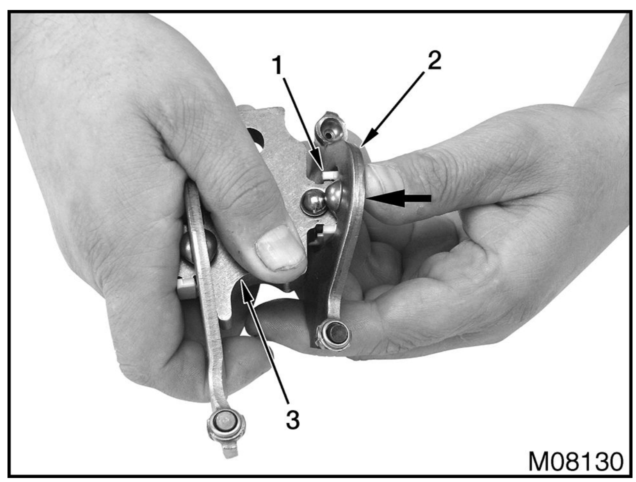

Figure 410 Installation of rocker arm (typical)

1. Rocker arm clip
2. Rocker arm assembly
3. Dual rocker fulcrum plate

4. Position lower part of rocker arm assembly under rocker arm clip and push it upward. Use thumb to push upper part of rocker arm assembly over 3/8” pivot ball.
5. Check for freedom of movement of rocker arm on dual rocker fulcrum plate.
6. Repeat steps 1–4 for the other rocker arm on the dual rocker fulcrum plate.

Glow Plug Sleeves

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

NOTE: Make sure the glow plug recess was cleaned out with the Glow Plug Sleeve Seat Wire Brush (page 262), rinsed with a suitable cleaning solution, and dried with compressed air.

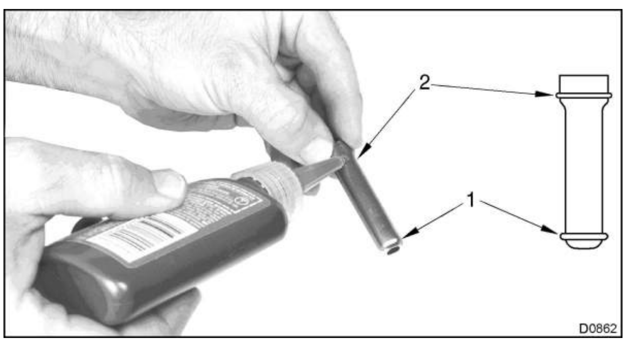

Figure 411 Application of Loctite® 620 Retaining Compound to glow plug sleeve

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

1. Apply Loctite® 620 Retaining Compound (page 262) to the wall and upper wall on glow plug sleeve.

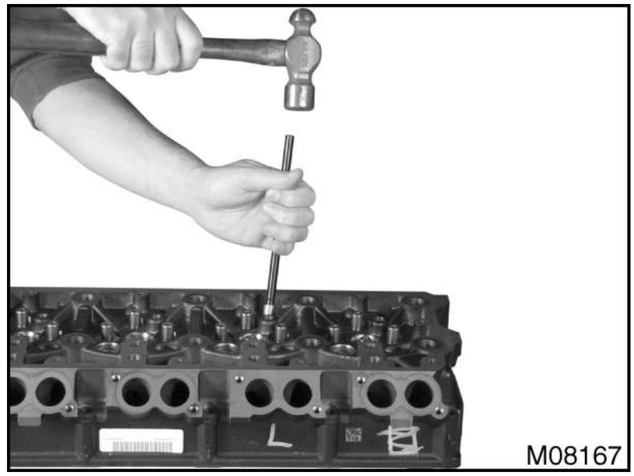

Figure 412 Glow Plug Sleeve Installer

2. Install glow plug sleeve in cylinder head with Glow Plug Sleeve Installer (page 262). Continue to tap the Glow Plug Sleeve Installer until the glow plug sleeve bottoms out in the recess.
3. Clean glow plug sleeve with Glow Plug Sleeve Brush (nylon) (page 262) and solvent. Make sure liquid gasket is cleaned out before it hardens.
4. Inspect the inside surface of the installed glow plug sleeve. If nicks and scratches are evident, replace the glow plug sleeve again. Make sure that the installation tool is not causing such damage. Use a different installation tool if necessary.

Fuel Injector Sleeves

NOTE: Verify injector bore is completely clean and dry.

1. Place new fuel injector sleeve on Injector Sleeve Installer (page 262).

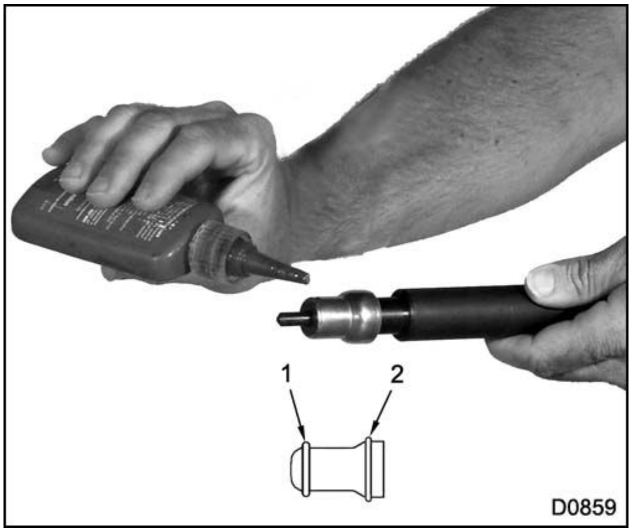

Figure 413 Application of Loctite® 620 Retaining Compound to fuel injector sleeve

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

2. Apply Loctite® 620 Retaining Compound (page 262) to fuel injector sleeve.
3. Center fuel injector sleeve into injector bore.

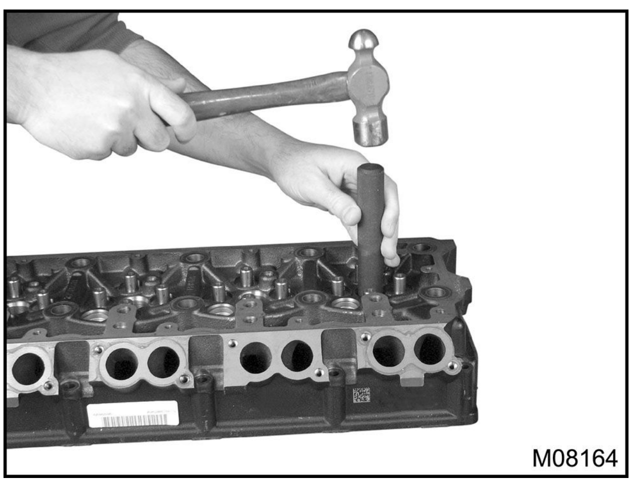

Figure 414 Installation of fuel injector sleeve into injector bore

4. Use a hammer to drive Injector Sleeve Installer (page 262) with fuel injector sleeve in fuel injector bore until the sleeve bottoms. If any liquid gasket gets inside injector sleeve, it must be cleaned out before it hardens.
5. Inspect the inside surface of the installed fuel injector sleeve. If nicks and scratches are evident, replace the fuel injector sleeve again. Make sure that the installation tool is not causing such damage. Use a different installation tool if necessary.

CAUTION: To prevent engine damage, insert a clean paper towel inside injector sleeve to keep foreign material out.

6. Cover injector sleeve.

Valves

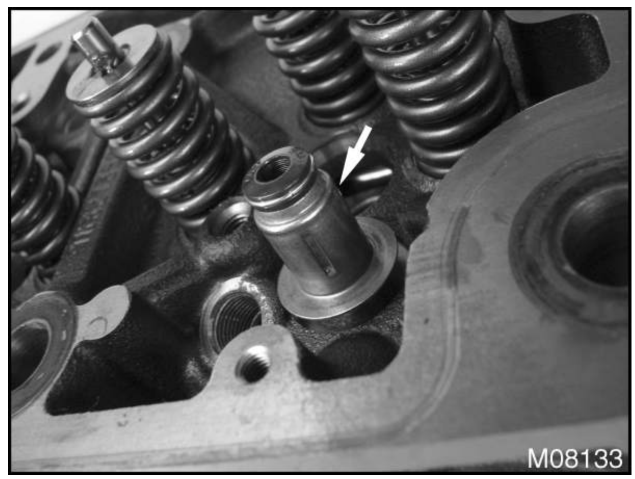

Figure 415 Valve seal assembly (typical)

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

1. Lubricate inside of new valve seal assembly with clean engine oil and install on valve guide.
2. Lubricate valve stem with clean engine oil and insert valve in cylinder head.
3. Install valve spring over valve seal.
4. Install valve spring retainer on top of valve spring.

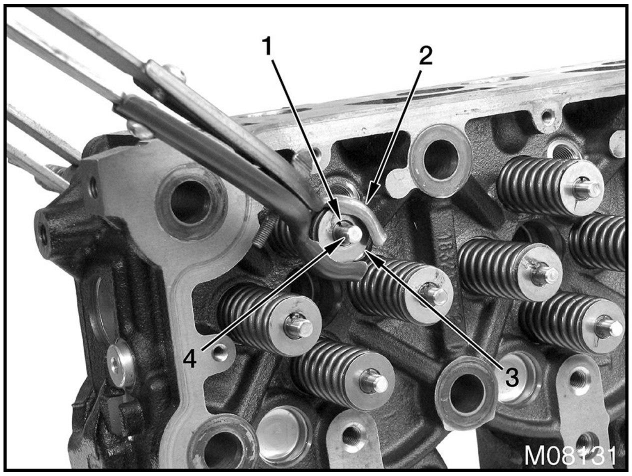

Figure 416 Valve spring compression (typical)

1. Valve stem key (2)
2. C Type Valve Spring Compressor
3. Valve spring retainer
4. Valve

CAUTION: To prevent engine damage, make sure when the valve spring compressor is released the inside bead of each key locks into the key groove of the valve stem.

5. Compress valve spring with C Type Valve Spring Compressor (page 262), install two valve stem keys, and release spring compressor.
6. After valve replacement, measure valve head recession relative to deck to confirm reconditioning. See Specifications (page 260).

Roller Hydraulic Cam Followers

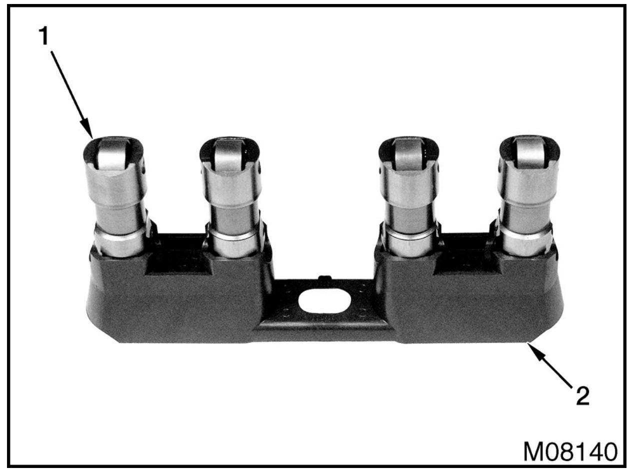

Figure 417 Roller hydraulic cam followers (typical)

1. Roller hydraulic cam follower (4)
2. Roller follower guide

CAUTION: To prevent engine damage, keep cam followers and push rods in the order removed and install in original order.

NOTE: Place rollers hydraulic cam followers in roller follower guides with the lubrication holes oriented as noted during removal.

1. Lubricate and place each roller hydraulic cam follower in its respective roller follower guide.

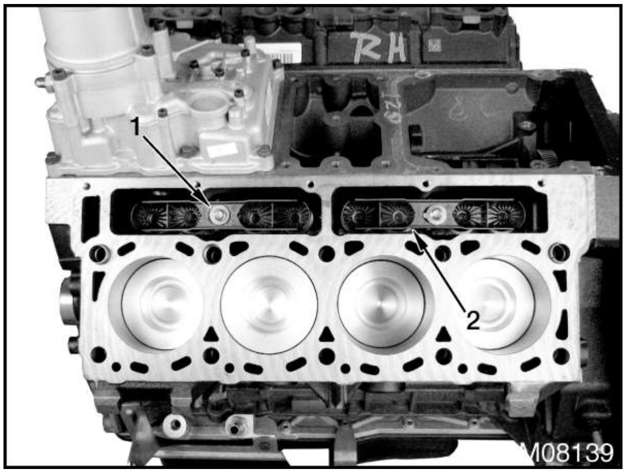

Figure 418 Cam follower and guide assemblies (typical)

1. Lifter guide bolt with washer assembly (2)
2. Cam follower and guide assembly (2)

2. Lubricate roller hydraulic cam followers with clean engine oil and install cam followers and guide assemblies in correct location.
3. Install two lifter guide bolt with washer assemblies. Tighten bolts to special torque (page 261).

Cylinder Heads

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

1. For left cylinder head, install lifting eye and two flat countersunk screws. Tighten screws to special torque (page 261).
2. For right cylinder head, install lifting eye and two M10 x 25 bolts. Tighten bolts to special torque (page 261).

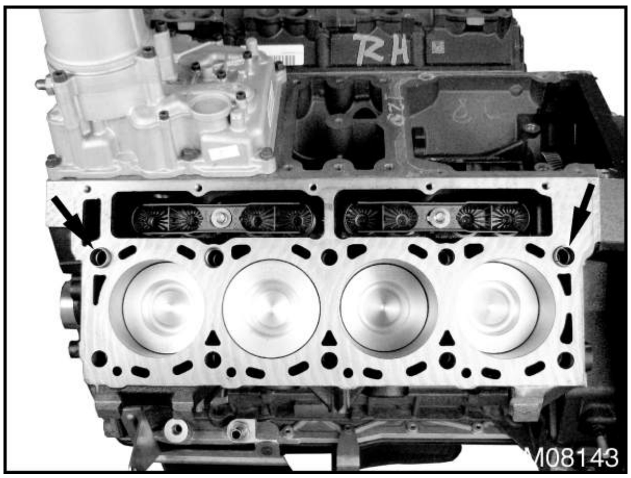

Figure 419 Cylinder head spring dowel pins in crankcase (typical)

3. Install two spring dowel pins in upper crankcase assembly.

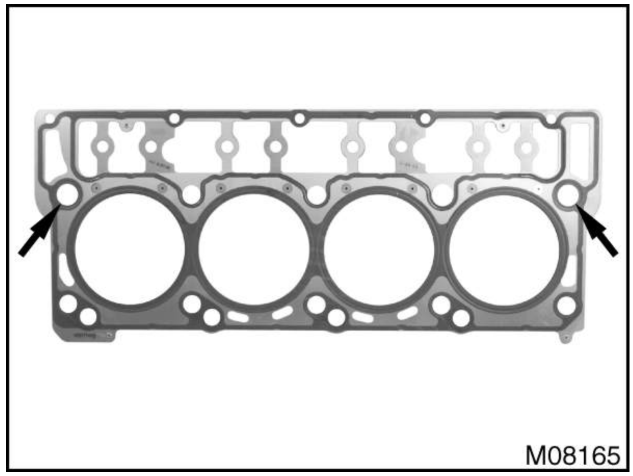

Figure 420 Clearance holes for spring dowel pins (typical)

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

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

CAUTION: To prevent engine damage, remove debris from cylinder head. If debris is not removed, a faulty seal between the cylinder head and gasket will cause oil, coolant, and compression leaks. Do not apply sealant to head gasket surfaces.

CAUTION: To prevent engine damage, install a new cylinder head gasket with part number facing up.

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

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

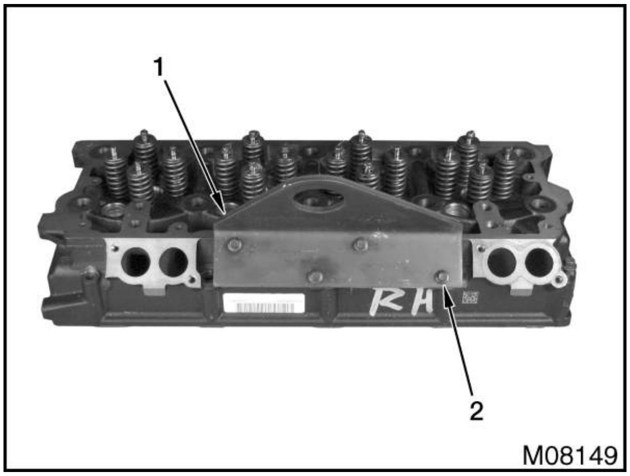

Figure 421 Installation of cylinder head lifting bracket (typical)

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

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

5. Install Cylinder Head Lifting Bracket (page 262) and four bolts on center of cylinder head (if removed). Tighten lifting bracket mounting bolts.

CAUTION: To prevent engine damage, do not drop or slide cylinder head on head gasket. This will damage the head gasket and spring dowel pins, resulting in leakage.

6. Attach lifting hoist hook or lifting sling to lifting bracket. Raise cylinder head and align with dowel sleeves previously installed in crankcase.
7. Lower cylinder head on crankcase.

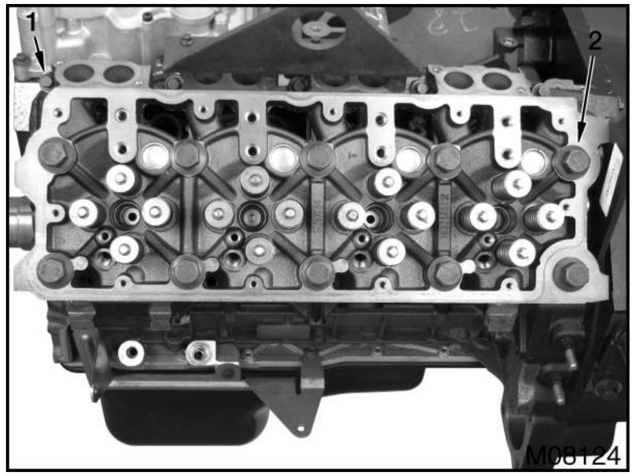

Figure 422 Cylinder head bolts (typical)

1. M8 x 70 bolt (5)
2. Cylinder head bolt (10)

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

CAUTION: To prevent engine damage, lubricate threads of new cylinder head bolts with clean engine oil. Do not use anti-seize compounds, grease or other lubricants. This will cause an incorrect torque reading.

8. Install and finger tighten 10 cylinder head bolts and five M8 x 70 bolts.
9. Remove four lifting bracket bolts and cylinder head lifting bracket.

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

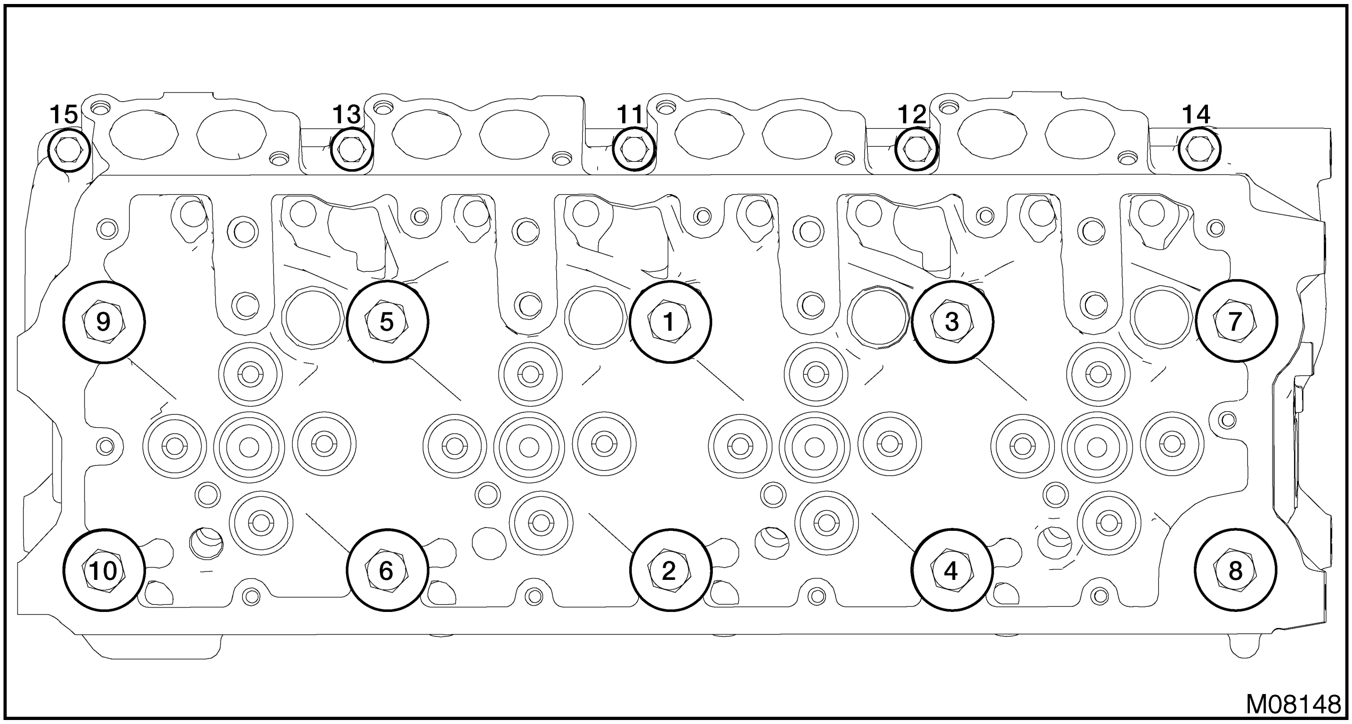

Figure 423 Cylinder head bolts tightening sequence

NOTE: For proper cylinder head surface seating and sealing, follow the correct tightening sequence.

10. Tighten the cylinder head bolts according to the following steps:
    1. Tighten cylinder head bolts numbered 1 through 10 to 95 N·m (70 lbf·ft) in numerical sequence.
    2. Loosen cylinder head bolts numbered 1 through 10 in numerical sequence.
    3. Tighten cylinder head bolts numbered 1 through 10 to 156 N·m (115 lbf·ft) in numerical sequence.
    4. Rotate cylinder head bolts numbered 1 through 10 an additional 90° (1/4 turn) clockwise in numerical sequence.
    5. Rotate cylinder head bolts numbered 1 through 10 another 90° (1/4 turn) clockwise in numerical sequence.
    6. Tighten M8 x 70 cylinder head bolts numbered 11 through 15 to 24 N·m (18 lbf·ft).
    7. Tighten M8 x 70 cylinder head bolts numbered 11 through 15 to 31 N·m (23 lbf·ft).

Rocker Arm Supports, Push Rods, and Valve Bridges

1. Apply lithium grease (page 262) to valve stem tips and to valve bridge pockets.

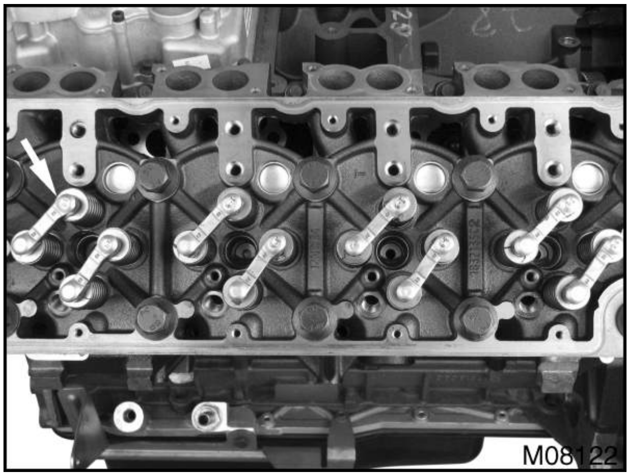

Figure 424 Valve bridge (typical)

2. Place each of the previously marked valve bridges on their respective valve stems.

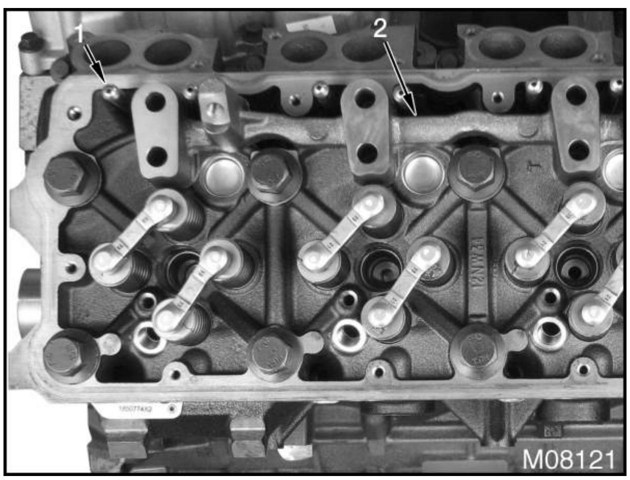

Figure 425 Push rod assemblies and rocker arm support (typical)

1. Push rod assembly (8)
2. Rocker arm support

3. Install rocker arm support.

CAUTION: To prevent engine damage, keep cam followers and push rods in the order removed and install in original order.

CAUTION: To prevent engine damage, seat push rods in the hydraulic roller follower sockets.

4. Apply clean engine oil to end of each push rod and install to original locations with the copper finish end on top.

NOTE: Rotate crankshaft and observe the intake push rod at number 3 cylinder. Cylinder number 1 is in firing position when intake push rod at cylinder number 3 indicates cam lift, and the crankshaft damper dowel pin is at the 10:30 position.

5. Position crankshaft so that cylinder number 1 is at Top Dead Center (TDC) and in firing position.

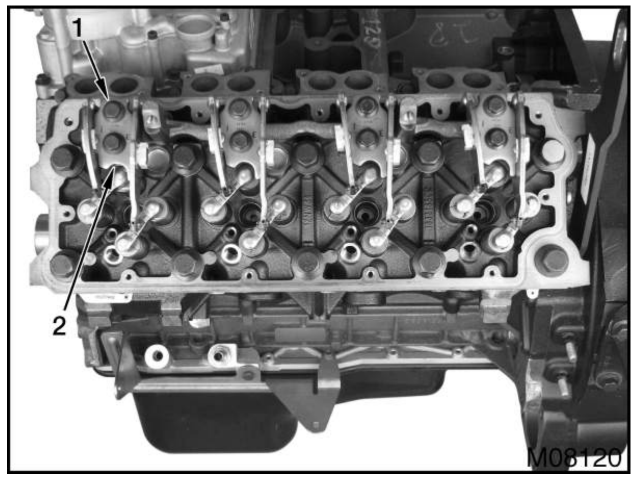

Figure 426 Dual rocker fulcrum plates (typical)

1. M10 x 70 bolt (8)
2. Dual fulcrum plate assembly (4)

CAUTION: To prevent engine damage, make sure push rods have seated in the rocker arm pocket.

6. Install dual fulcrum plate assemblies for cylinder numbers 1, 2, 7, and 8.
7. Install and tighten M10 x 70 bolts for cylinder numbers 1, 2, 7, and 8 as follows:
   1. Hand tighten all bolts.
   2. Make sure that pivot foot is centered on valve bridge.
   3. Tighten inboard (upper) bolts to 61 N·m (45 lbf·ft).
   4. Tighten outboard (lower) bolts to 61 N·m (45 lbf·ft).

5. Make sure that pivot foot is centered on valve bridge. If pivot foot is not centered on valve bridge, remove and reinstall dual fulcrum plate assembly in question.

NOTE: Rotate crankshaft and observe the intake push rod at number 8 cylinder. Cylinder number 4 is in firing position when intake push rod at cylinder number 8 indicates cam lift, and the crankshaft damper dowel pin is at the 10:30 position.

8. Rotate crankshaft 360° (full turn) so that cylinder number 4 is in firing position.

CAUTION: To prevent engine damage, make sure push rods have seated in the rocker arm pocket.

9. Install dual fulcrum plate assemblies for cylinder numbers 3, 4, 5, and 6.
10. Install and tighten M10 x 70 bolts for cylinder numbers 3, 4, 5, and 6 as follows:
    1. Hand tighten all bolts.
    2. Make sure that pivot foot is centered on valve bridge.
    3. Tighten inboard (upper) bolts to 61 N·m (45 lbf·ft).
    4. Tighten outboard (lower) bolts to 61 N·m (45 lbf·ft).
    5. Make sure that pivot foot is centered on valve bridge. If pivot foot is not centered on valve bridge, remove and reinstall dual fulcrum plate assembly in question.

Valve Cover Base

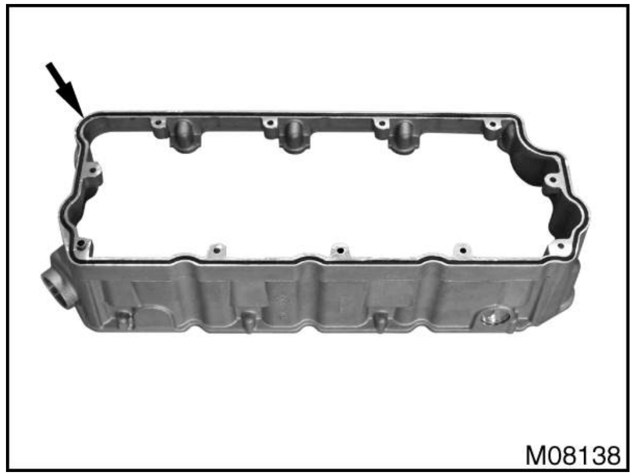

Figure 427 Valve cover base gasket (typical)

1. Install a new valve cover base gasket.

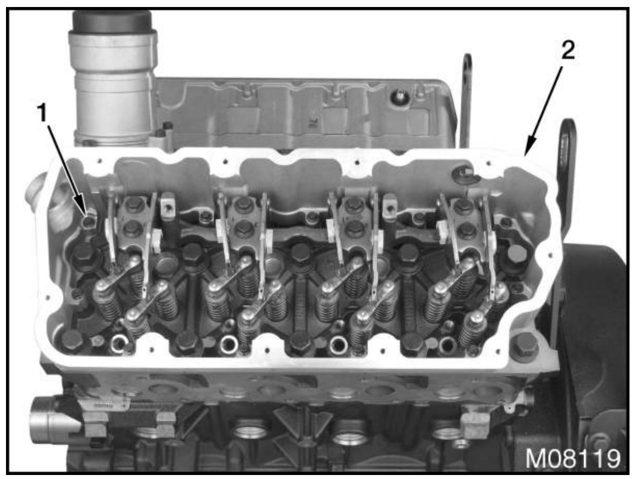

Figure 428 Valve cover base assembly (typical)

1. M6 x 30 bolt (11)
2. Valve cover base assembly

2. Install valve cover base assembly and 11 M6 x 30 bolts. Tighten bolts to special torque (page 261).

Glow Plugs

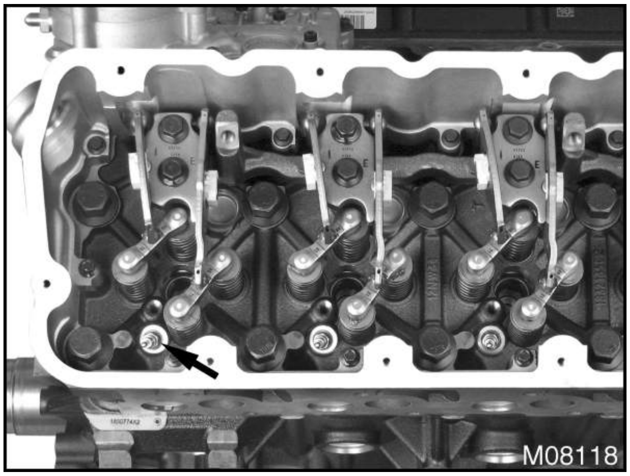

Figure 429 Glow plugs (typical)

Install four glow plugs. Tighten glow plugs to special torque (page 261).

Fuel Injector and Rail Assemblies

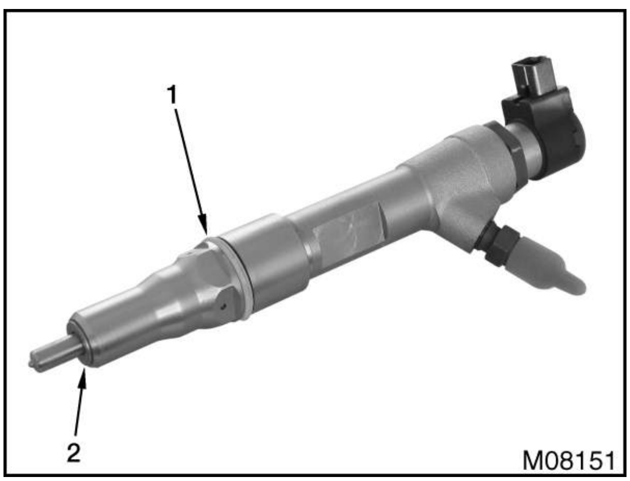

Figure 430 Fuel injector seal and combustion gasket (typical)

1. Fuel injector seal
2. Combustion gasket

CAUTION: To prevent engine damage, install new fuel injector seal and combustion gasket if a fuel injector is removed.

NOTE: Make sure to install new combustion gasket oriented as noted during removal.

1. Install a new combustion gasket onto injector tip.
2. To seat gasket, push on gasket with a deep socket.
3. Remove and discard old fuel injector seal.
4. Install a new fuel injector seal. Lubricate fuel injector seal with clean engine oil.

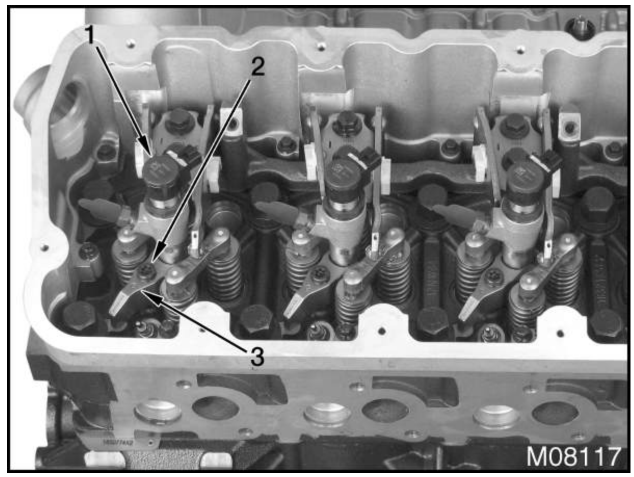

Figure 431 Fuel injector assembly (typical)

1. Fuel injector assembly (4)
2. Injector clamp bolt (4)
3. Injector hold down clamp (4)

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

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

NOTE: Injectors must be fully seated, but moveable, for installation of fuel rail to injector tube assemblies.

6. Hand start clamp bolts. Pre-tighten injector clamp bolts to 2 N·m (18 lbf·in).
7. Apply a water based rubber lubricant, such as P-80® Rubber Lubricant or equivalent (page 262), to outer and inner diameters of fuel supply line seal.

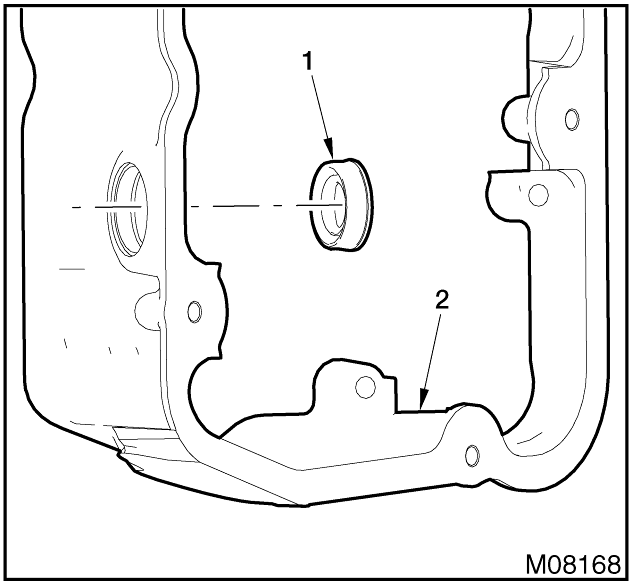

Figure 432 Fuel supply line seal installation (typical)

1. Fuel supply line seal
2. Valve cover base

8. Install a new fuel supply line seal by pressing it with a proper size socket toward the outside of the valve cover base.

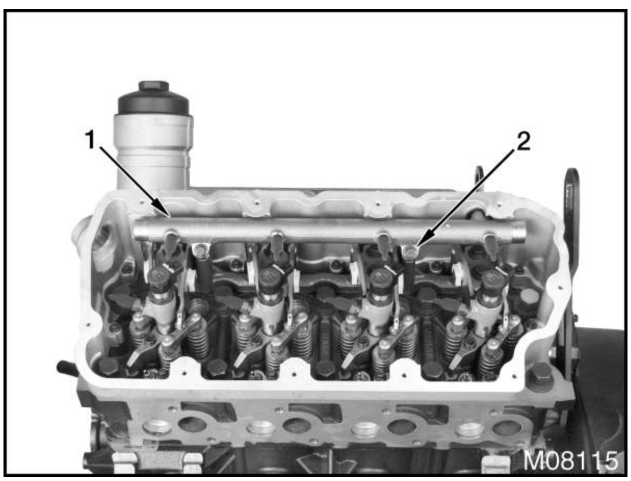

Figure 433 Rail assembly (typical)

1. Rail assembly
2. M8 x 30 bolt (2)

NOTE: Rail assembly must be fully seated but moveable for installation of fuel rail to injector tube assemblies.

9. Install rail assembly and two M8 x 30 bolts. Hand tighten bolts.
10. Remove all Fuel System Caps (page 262) from fuel rail and fuel injector assemblies.

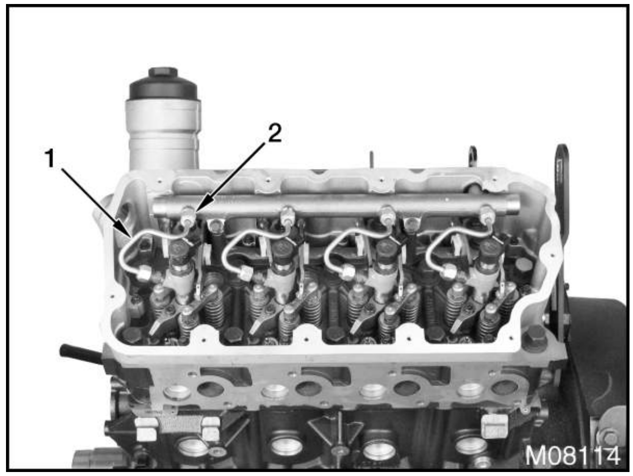

Figure 434 Fuel rail to injector tube assemblies (typical)

1. Fuel rail to injector tube assembly (4)
2. Tube nut (8)

WARNING: To prevent personal injury or death, whenever any fuel line (tubing) in the high-pressure fuel system is removed, it must be replaced with new.

11. Position four new fuel rail to injector tube assemblies between fuel injector assemblies and rail assembly.

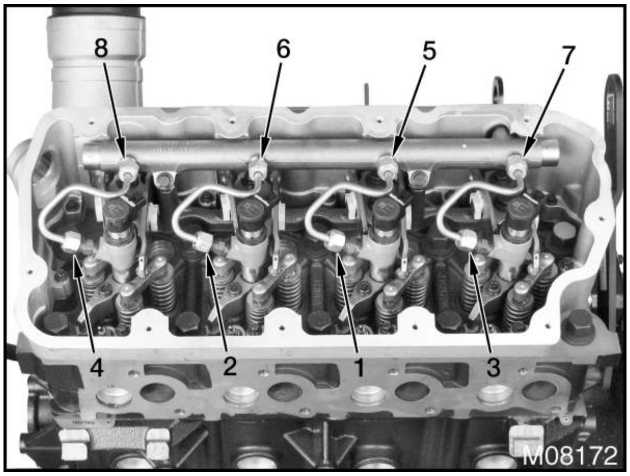

Figure 435 Fuel rail to injector tube assemblies tightening sequence (typical)

NOTE: Hold fuel rail to injector tube assemblies while hand tightening nuts to assure proper assembly of joints.

NOTE: When using a crowfoot extension make sure to adjust the torque settings as necessary to compensate for any length added to the torque wrench. See Appendix B - Torques (page 384).

12. Fully hand start and seat nuts onto mating connections of all fuel tubes, then pre-tighten with a crowfoot torque wrench following sequence shown in (Figure 435) to 2 N·m (18 lbf·in).
13. Tighten injector clamp bolts to 38 N·m (28 lbf·ft).
14. Tighten two M8 x 30 rail assembly bolts to 31 N·m (23 lbf·ft).
15. Using a crowfoot torque wrench and a second wrench to hold the fuel injector fittings, continue to tighten fuel rail to injector tube assembly nuts following sequence shown in (Figure 435). Tighten four nuts on the fuel injector assemblies first, then four nuts on the rail assembly as follows:
    a. Tighten nuts to 12 N·m (106 lbf·in).
    b. Tighten nuts an additional 60°.
16. Install Under Valve Cover (UVC) harness (page 68).

Valve Covers and Related Components

Right Valve Cover

1. Install a new valve cover gasket.

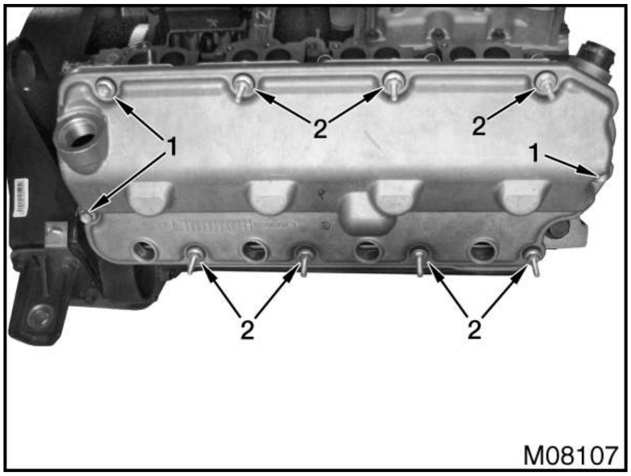

Figure 436 Right valve cover bolt and stud bolt assemblies

1. Valve cover bolt assembly (3)
2. Valve cover stud bolt assembly (7)

2. Position right valve cover on valve cover base assembly.

CAUTION: To prevent engine damage, do not use air tools to remove or install valve covers.

3. Install three valve cover bolt assemblies and seven valve cover stud bolt assemblies. Tighten bolts and stud bolts to special torque (page 261).

Left Valve Cover

1. Install a new valve cover gasket.

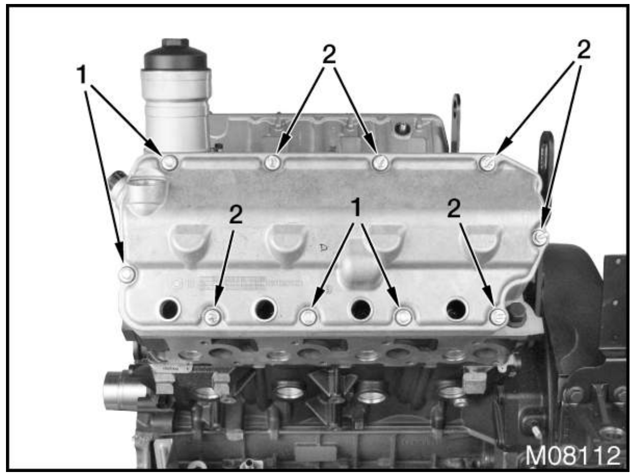

Figure 437 Left valve cover bolt and stud bolt assemblies

1. Valve cover bolt assembly (4)
2. Valve cover stud bolt assembly (6)

2. Position left valve cover on valve cover base.

CAUTION: To prevent engine damage, do not use air tools to remove or install valve covers.

3. Install four valve cover bolt assemblies and six valve cover stud bolt assemblies. Tighten bolts and stud bolts to special torque (page 261).

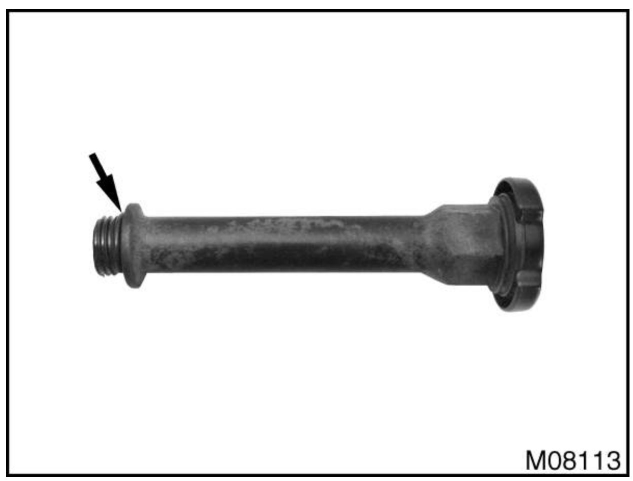

Figure 438 Oil fill extension O-ring seal

4. Install a new oil fill extension O-ring seal. Lubricate O-ring seal with clean engine oil.

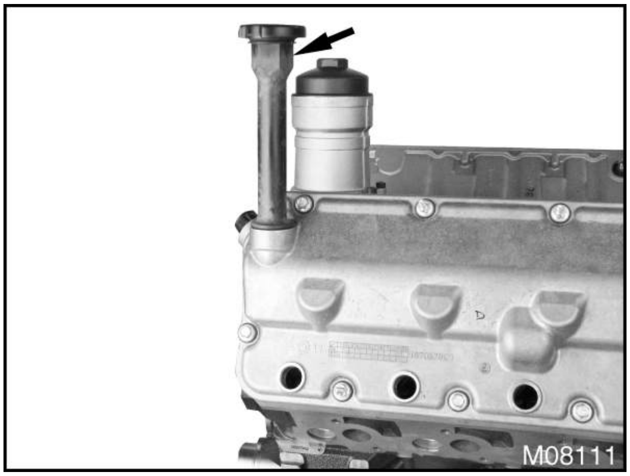

Figure 439 Oil fill extension

5. Install oil fill extension. Tighten to special torque (page 261).

Breather Assembly and Components

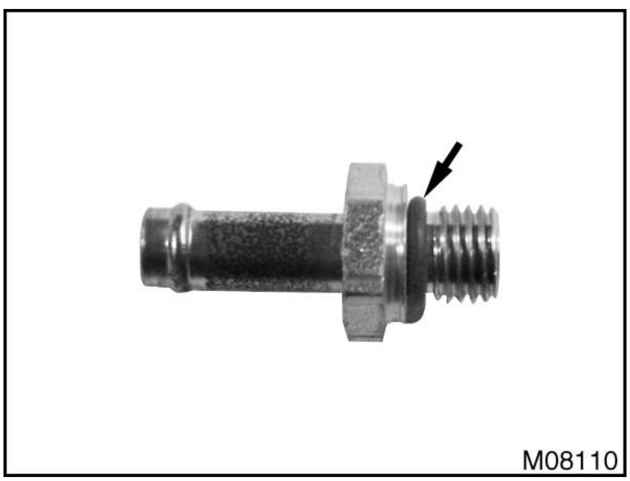

Figure 440 M12 fitting O-ring seal

1. Install a new breather oil drain assembly to crankcase M12 fitting O-ring seal.

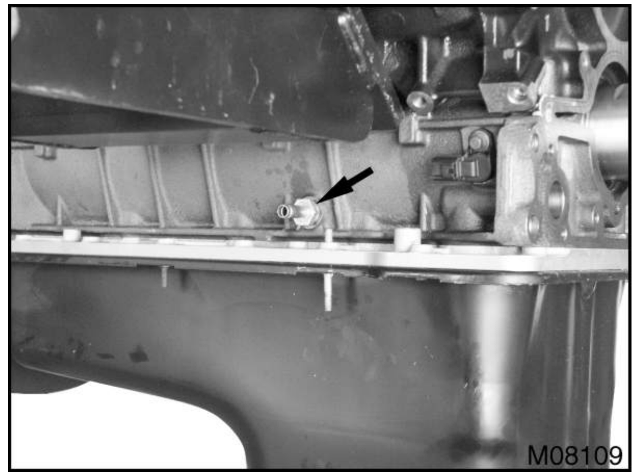

Figure 441 Breather oil drain assembly to crankcase M12 fitting

2. Install M12 fitting. Tighten fitting to special torque (page 261).

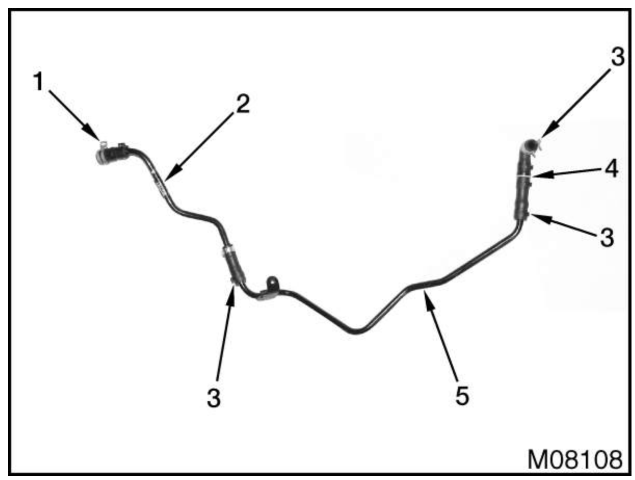

Figure 442 Breather oil drain assembly components

1. 1/2” preload clamp
2. Nylon tube assembly
3. 3/8” preload clamp (3)
4. Check valve assembly
5. Steel tube

3. Connect steel tube to 3/8” hose on nylon tube assembly and secure with a 3/8” preload clamp.
4. Connect steel tube to check valve assembly and secure with a 3/8” preload clamp.

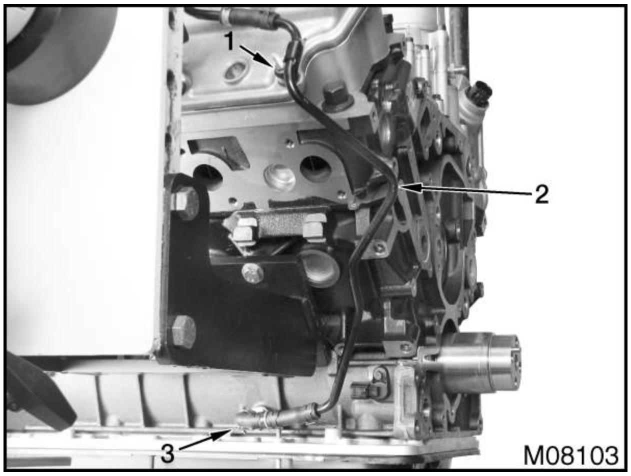

Figure 443 Breather oil drain assembly

1. M6 nut
2. Breather oil drain assembly
3. 3/8” preload clamp

5. Connect breather oil drain assembly to M12 fitting and secure with clamp.
6. Install M6 nut at breather oil drain assembly clamp, and tighten to standard torque (page 383).

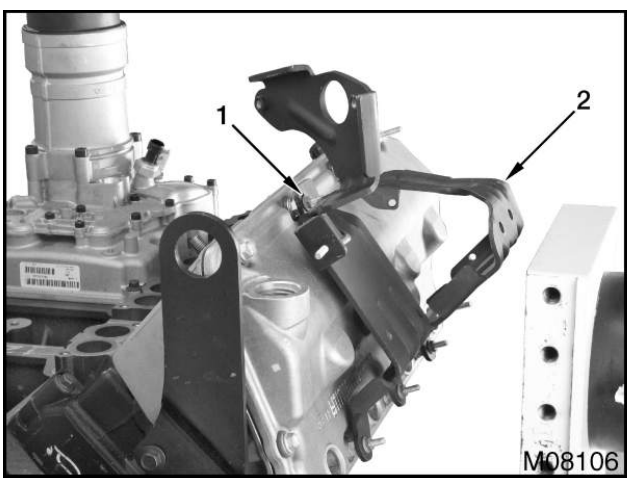

Figure 444 Breather support

1. M6 nut (4)
2. Breather support

7. Install breather support and four M6 nuts. Tighten nuts to special torque (page 261).

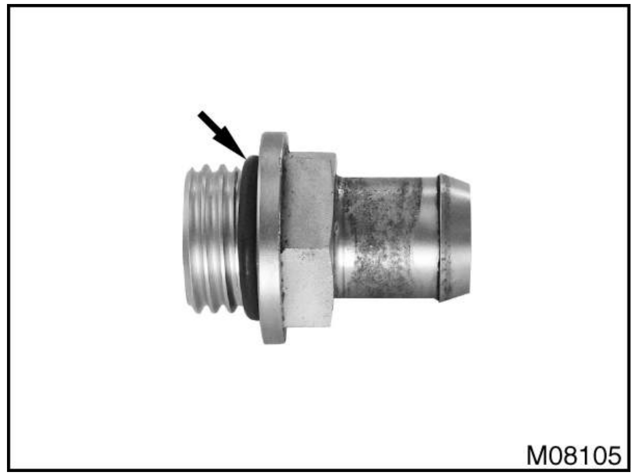

Figure 445 Breather inlet adapter O-ring seal

8. Install a new O-ring seal on breather inlet adapter. Lubricate O-ring seal with clean engine oil.

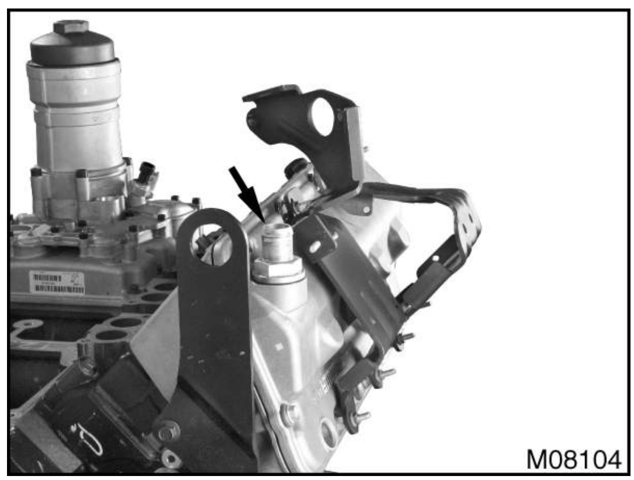

Figure 446 Breather inlet adapter

9. Install breather inlet adapter. Tighten to special torque (page 261).

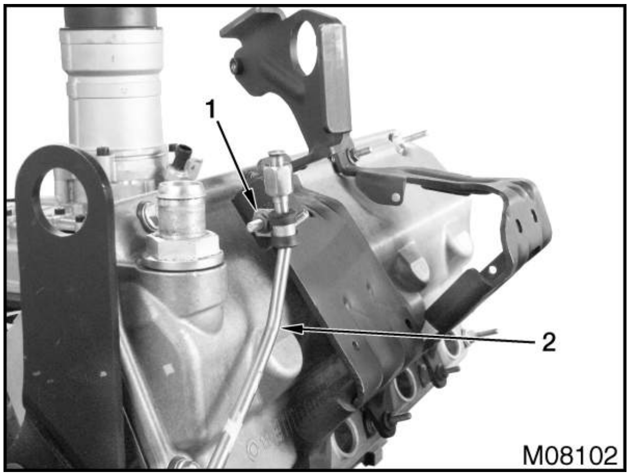

Figure 447 Exhaust Back Pressure (EBP) tube assembly

1. M6 nut
2. EBP tube assembly

10. Install EBP tube assembly and M6 nut. Tighten nut to special torque (page 261).

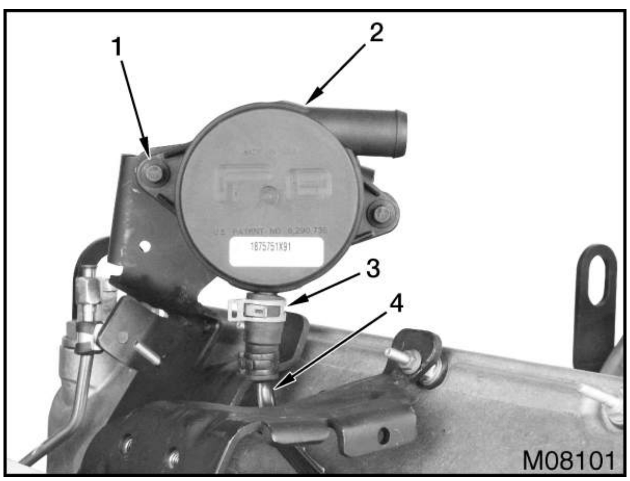

Figure 448 Breather assembly bolts

1. M8 x 35 bolt (2)
2. Breather assembly
3. 1/2” preload clamp
4. Breather oil drain assembly

11. Connect breather assembly to breather oil drain assembly and secure with clamp.
12. Install two M8 x 35 bolts and tighten to standard torque (page 383).

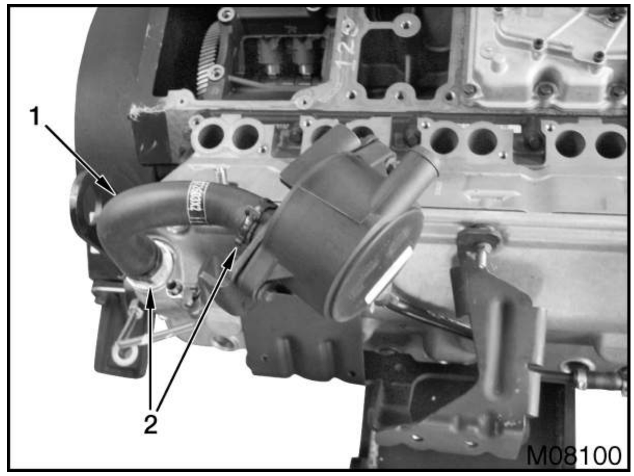

Figure 449 Breather inlet hose

1. Breather inlet hose
2. Clamp (2)

13. Install breather inlet hose and two clamps.

Specifications

Table 22 Cylinder Head and Valve Train

Exhaust Valves	
Stem diameter	6.946 to 6.964 mm (0.2735 to 0.2742 in)
Stem to guide running clearance (max. allowable before replacement) diametrically	0.1846 mm (0.00727 in)
Valve face angle from center line	50.5 – 50.75°
Valve margin (minimum)	1.53 mm (0.060 in)
Valve recession in head	0.37 – 0.73 mm (0.0146 – 0.0287 in)
Intake Valves	
Stem diameter	6.946 to 6.964 mm (0.2735 to 0.2742 in)
Stem to guide running clearance (max. allowable before replacement)	0.1846 mm (0.00727 in)
Valve face angle from center line	53.0 – 53.25°
Valve margin (minimum)	1.40 mm (0.055 in)
Valve recession in head	0.37 – 0.73 mm (0.0146 – 0.0287 in)
Cylinder Heads	
Valve guide inside diameter	7.003 to 7.029 mm (0.276 to 0.277 in)
Valve guide bore runout	0.06 mm (0.00236 in)
Valve guide taper (maximum)	0.10 mm (0.004 in)
Valve seat width (intake)	1.80 to 2.56 mm (0.071 to 0.101 in)
Valve seat width (exhaust)	1.48 to 2.24 mm (0.058 to 0.088 in)
Valve seat angle (intake) from center line of valve guide	52.5 – 52.75°
Valve seat angle (exhaust) from center line of valve guide	50.0 – 50.25°
Gasket surface flatness	0.025 mm per 25 x 25 mm Maximum 0.051 mm (0.002 in) per check point
Overall thickness of cylinder head (deck-to-deck)	95 ± 0.48 mm (3.74 ± 0.018 in)
Valve Spring:	
Solid height	36.1 mm (1.42 in)
Compressed*	46.50 mm @ 340 ± 17 N (1.83 in @ 76.5 ± 3.8 lbf)
Compressed*	38.30 mm @ 850 ± 43 N (1.51 in @ 191.1 ± 9.7 lbf)

* Spring must be compressed to a solid height before checking test loads.

Table 22 Cylinder Head and Valve Train (cont.)

Push Rods	
Runout (maximum)	0.5 mm (0.02 in)

Special Torque

Table 23 Cylinder Head and Valve Train

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

Special Service Tools

Table 24 Cylinder Head and Valve Train

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

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Exploded Views

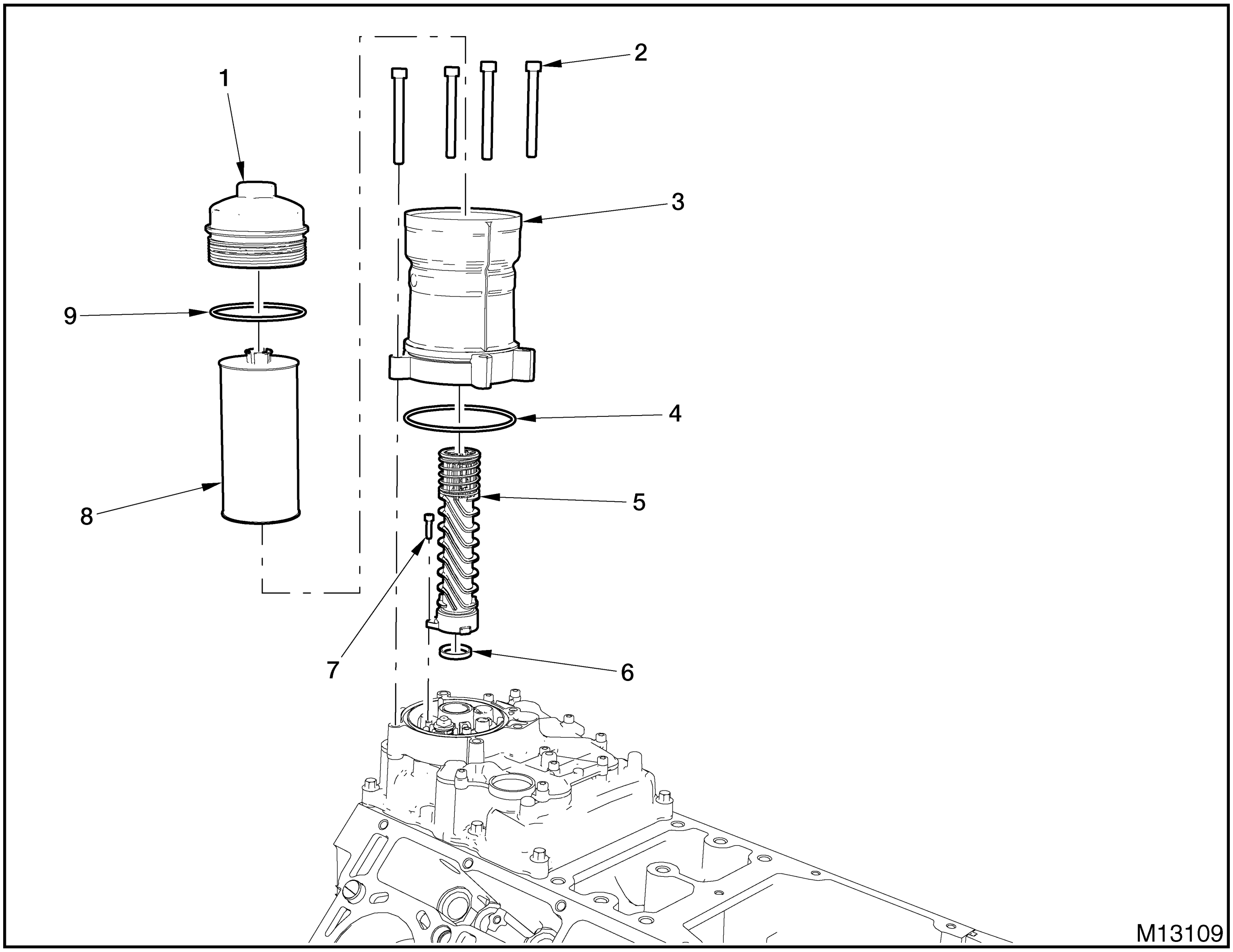

Figure 450 Oil filter housing assembly

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

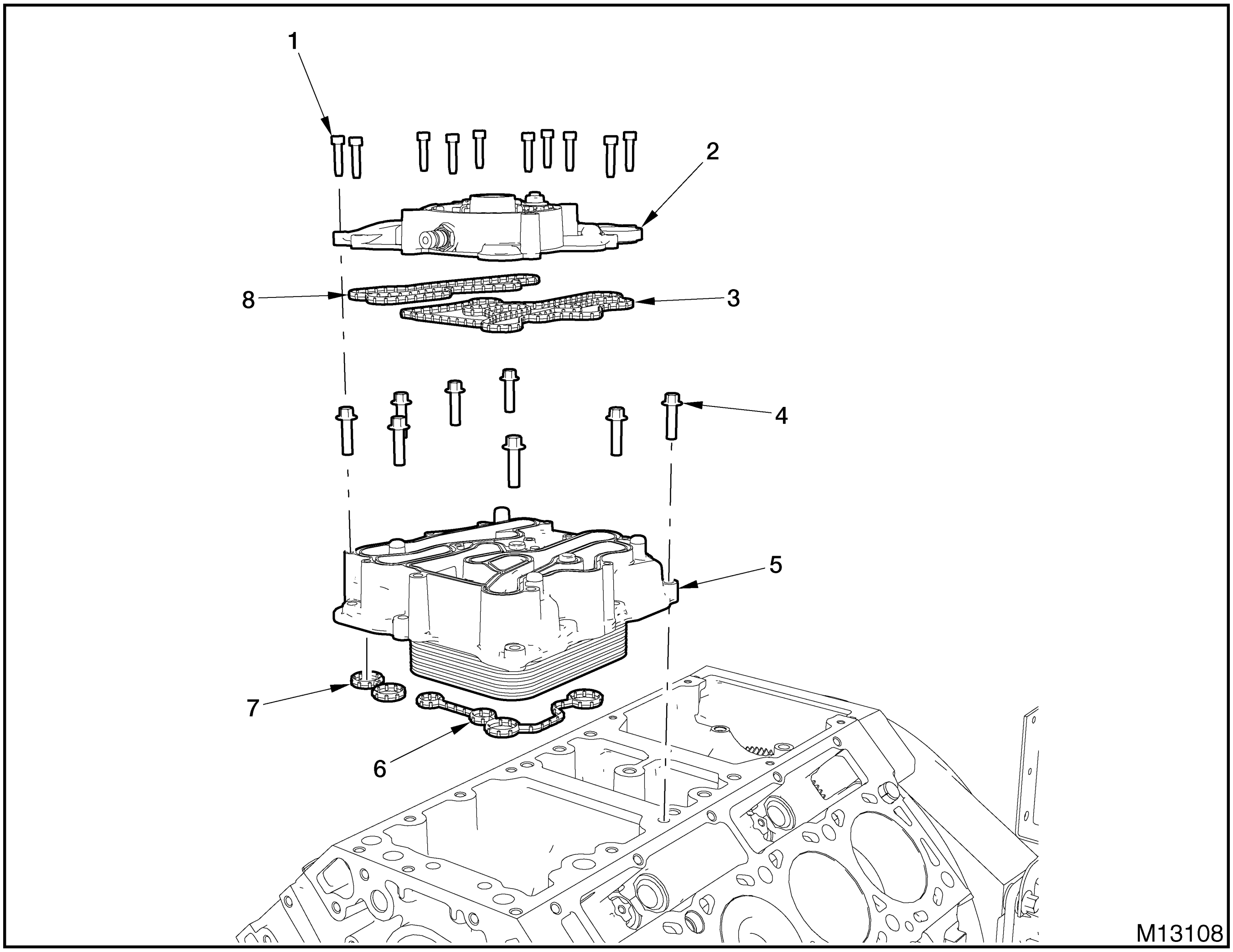

Figure 451 Oil filter base and oil cooler cover assemblies

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

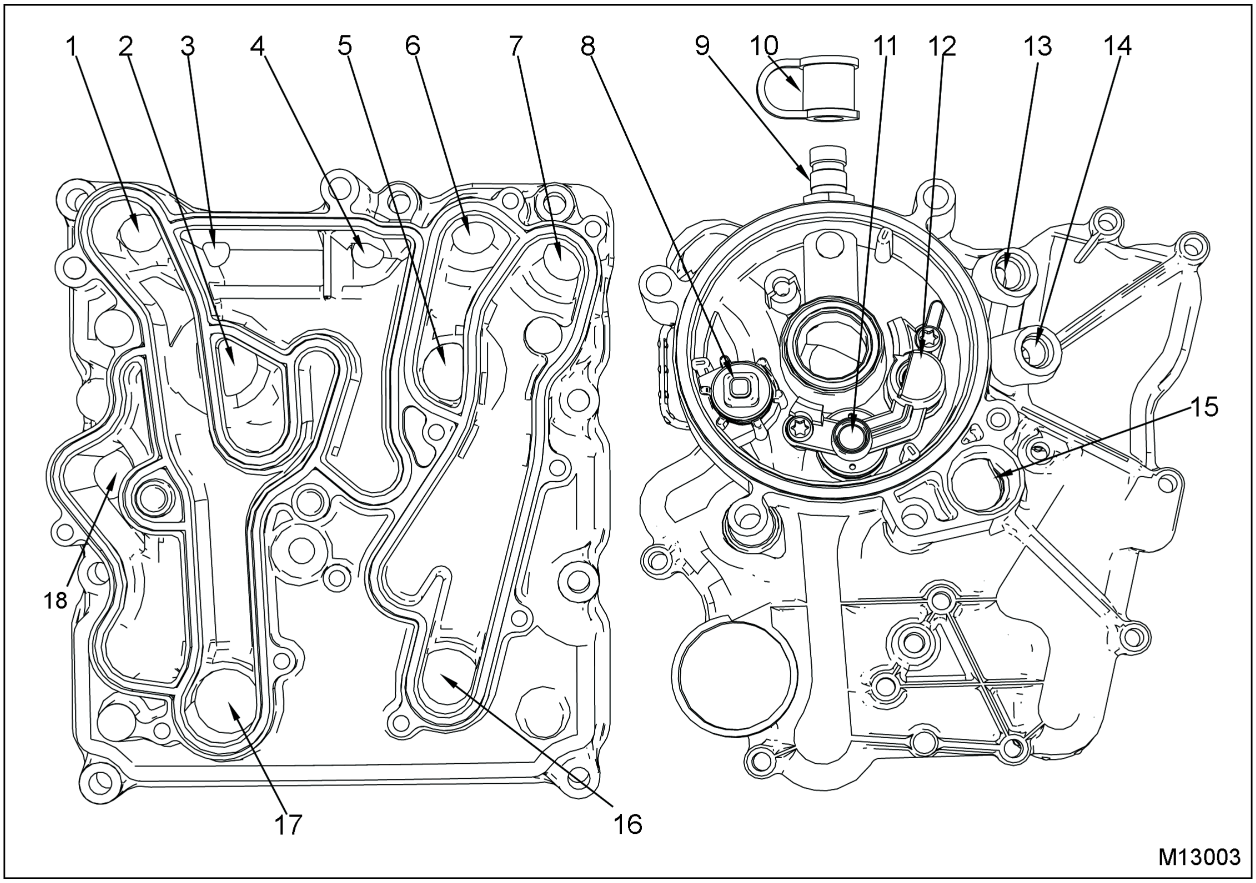

Figure 452 Oil cooler cover assembly and oil filter base assembly location details

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

Removal

GOVERNMENT REGULATION: Engine fluids (oil, fuel, and coolant) may be a hazard to human health and the environment. Handle all fluids and other contaminated materials (e.g. filters, rags) in accordance with applicable regulations. Recycle or dispose of engine fluids, filters, and other contaminated materials according to applicable regulations.

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.

NOTE: See the following service sections for information on removal of components prior to this section.

- Engine Electrical
- Exhaust Gas Recirculation (EGR) System
- Variable Geometry Turbocharger (VGT)
- Fuel System

Oil Filter Housing and Oil Filter Base Assemblies

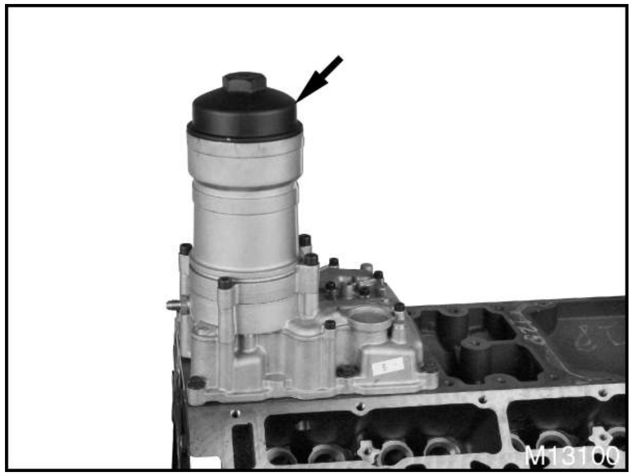

Figure 453 Oil filter cap

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

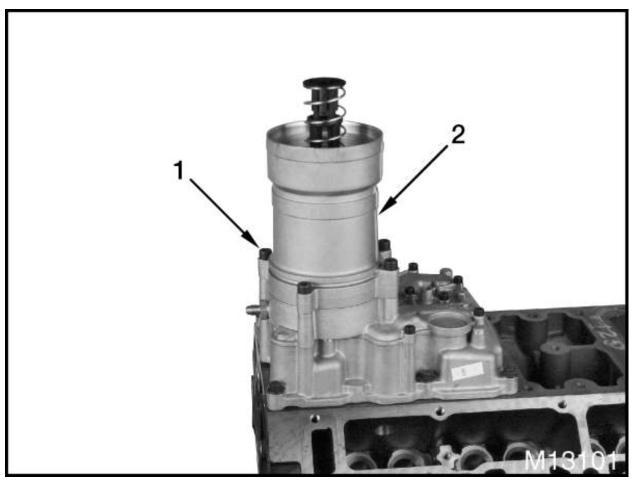

Figure 454 Oil filter housing

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

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

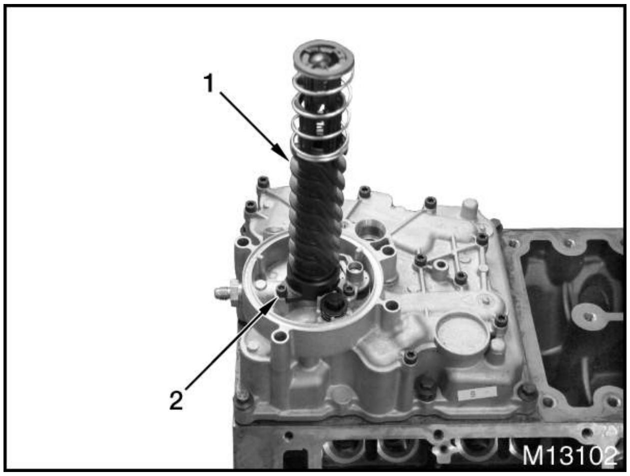

Figure 455 Oil filter return tube assembly

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

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

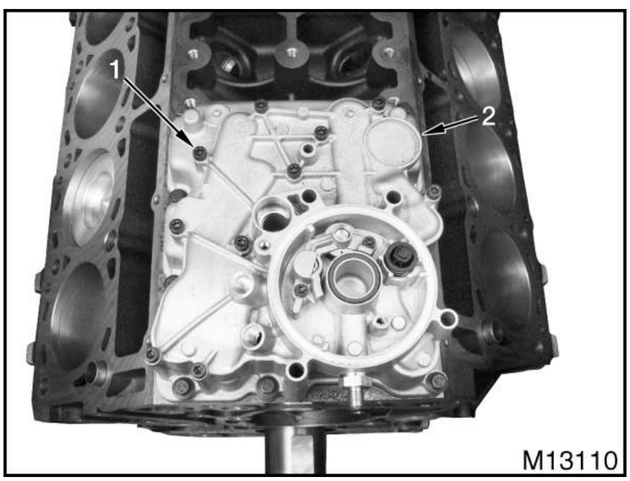

Figure 456 Oil filter base assembly

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

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

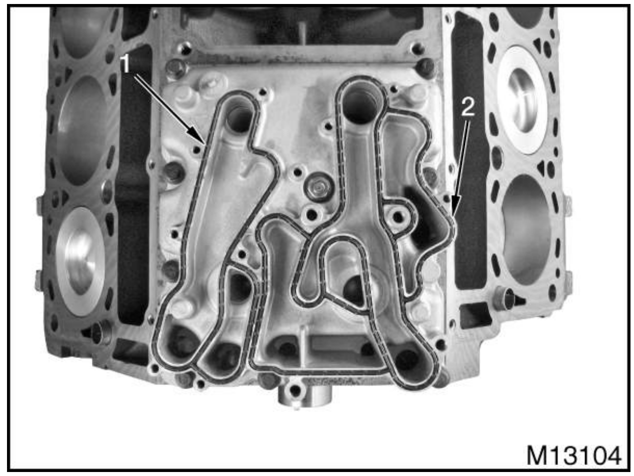

Figure 457 Oil filter base assembly gaskets

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

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

Oil Cooler Cover Assembly

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

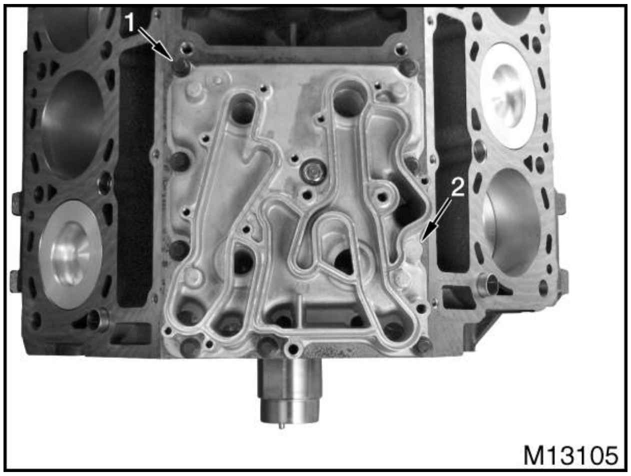

Figure 458 Oil cooler cover assembly

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

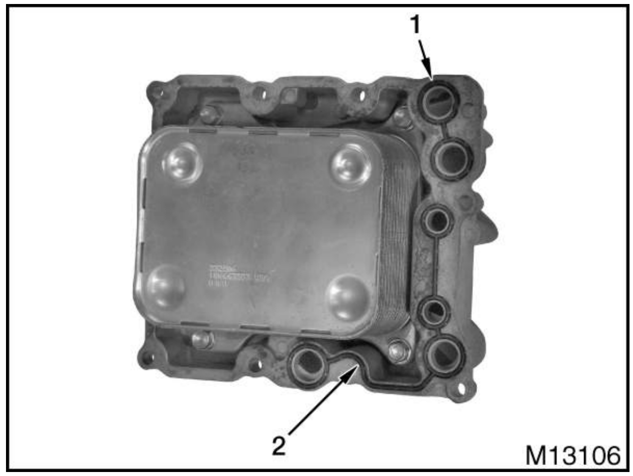

Figure 459 Oil cooler cover assembly gaskets

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

1. Remove eight M8 x 30 bolts and oil cooler cover assembly.
2. Remove and discard oil cooler cover gasket (coolant side).
3. Perform air pressure leakage test for oil cooler cover assembly leaks (coolant side) (page 271).
4. Remove and discard oil cooler cover gasket (oil side).

Cleaning, Inspection, and Testing

Oil Cooler Cover and Oil Filter Base Assemblies

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

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

2. Dry all components thoroughly with compressed air.

Oil Cooler Cover Assembly Leaks (Coolant Side)

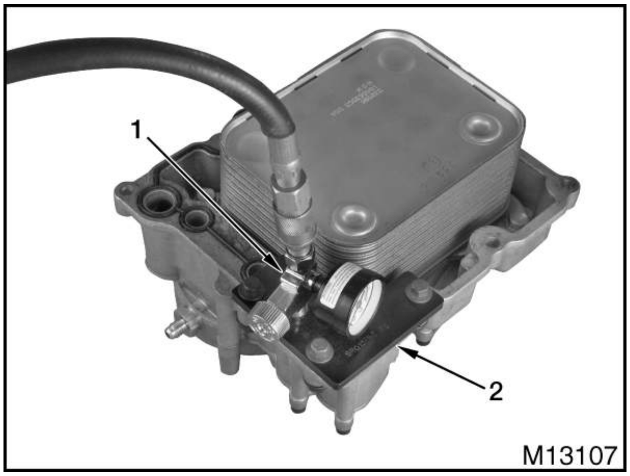

Figure 460 Oil cooler cover assembly pressure test

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

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

1. Install Oil Cooler Pressure Test Plate (page 275) on oil cooler cover assembly.

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

2. Attach an air pressure regulator (page 275) to oil cooler pressure test plate. Connect to compressed air supply and adjust air pressure to approximately 172 to 207 kPa (25 to 30 psi).

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

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

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

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

Installation

Oil Cooler Cover Assembly

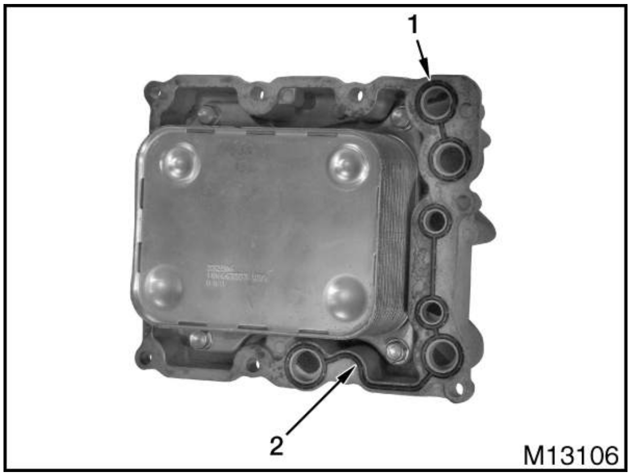

Figure 461 Oil cooler cover gaskets

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

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

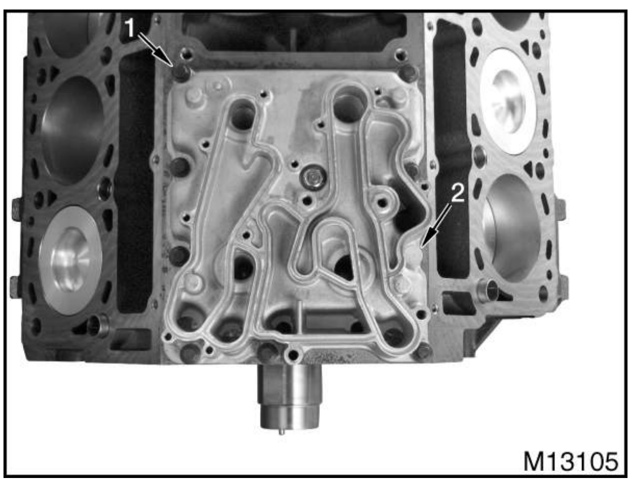

Figure 462 Oil cooler cover assembly

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

3. Install oil cooler cover assembly and eight M8 x 30 bolts. Tighten bolts to special torque (page 275).

Oil Filter Housing and Oil Filter Base Assemblies

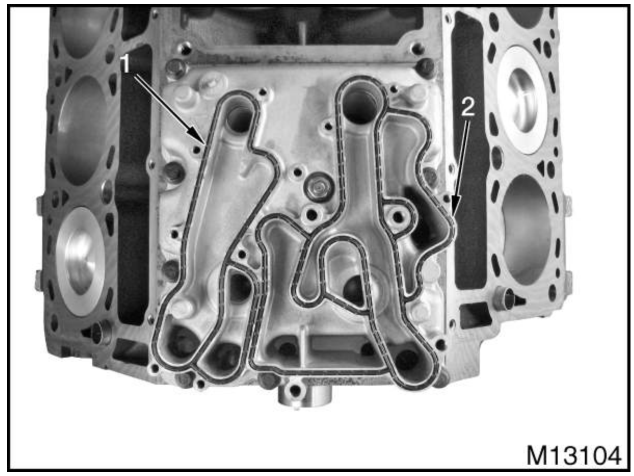

Figure 463 Oil filter base assembly gaskets

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

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

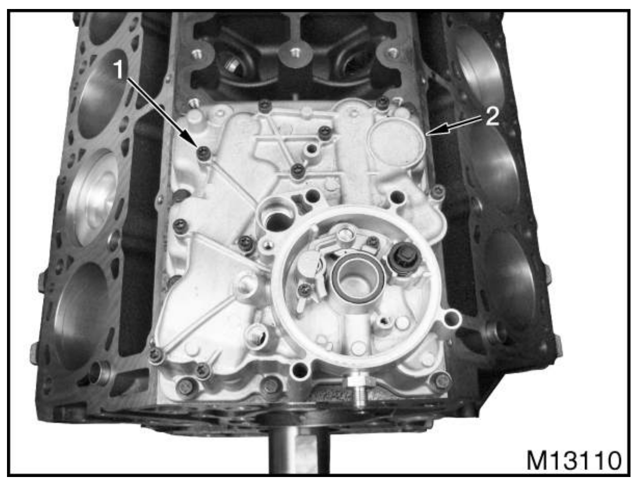

Figure 464 Oil filter base assembly

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

3. Install oil filter base assembly and ten M6 x 25 screws. Tighten screws to special torque (page 275).

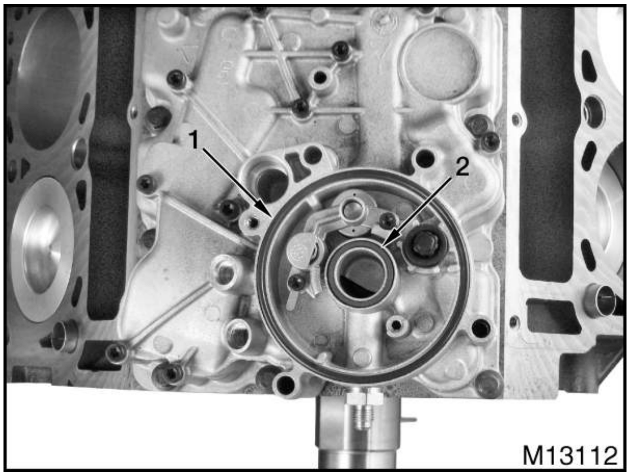

Figure 465 Return tube gasket and O-ring seal

1. O-ring seal
2. Return tube gasket

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

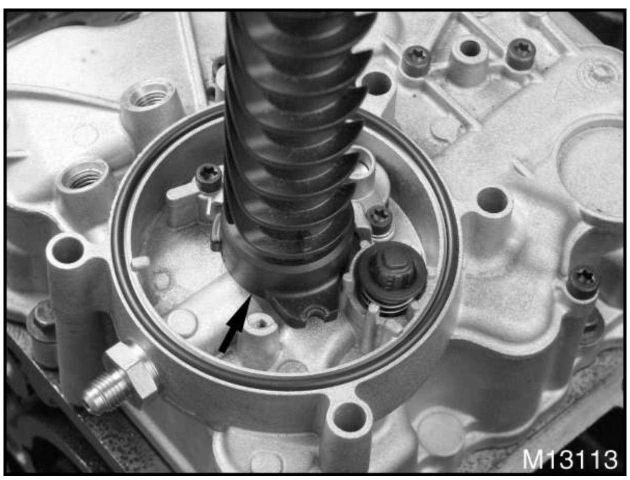

Figure 466 Oil Filter return tube assembly position

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

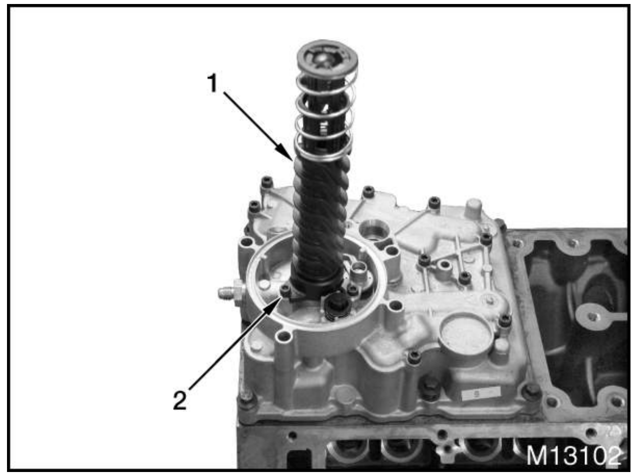

Figure 467 Oil filter return tube assembly

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

6. Install and tighten M5 x 18 oil filter return tube assembly screw to special torque (page 275).

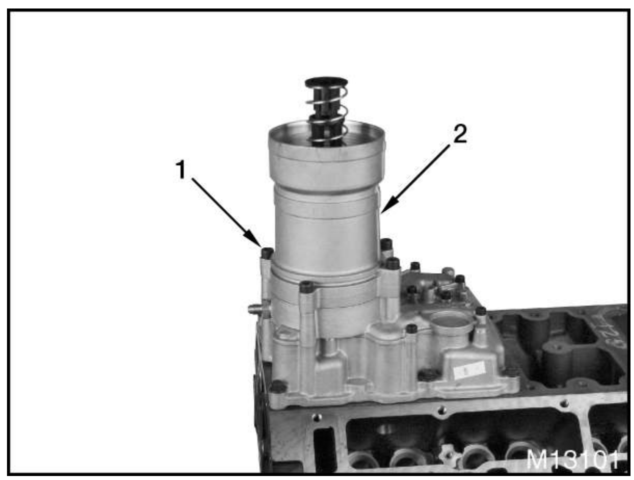

Figure 468 Oil filter housing

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

7. Install oil filter housing and four M8 x 75 bolts. Tighten bolts to special torque (page 275).

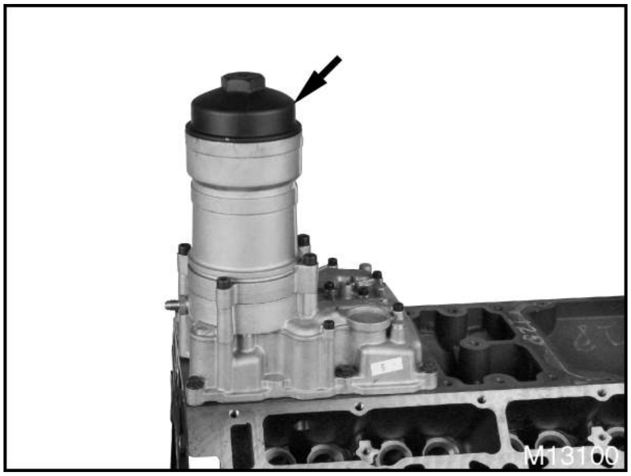

Figure 469 Oil filter cap

8. Install a new oil filter element.
9. Install oil filter cap seal. Lubricate seal with clean engine oil.
10. Install oil filter cap and tighten to special torque (page 275).

Specifications

Table 25 Oil Cooler and Oil Filter

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

Special Torque

Table 26 Oil Cooler Cover and Oil Filter Housing

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

Special Service Tools

Table 27 Oil Cooler

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

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Exploded Views

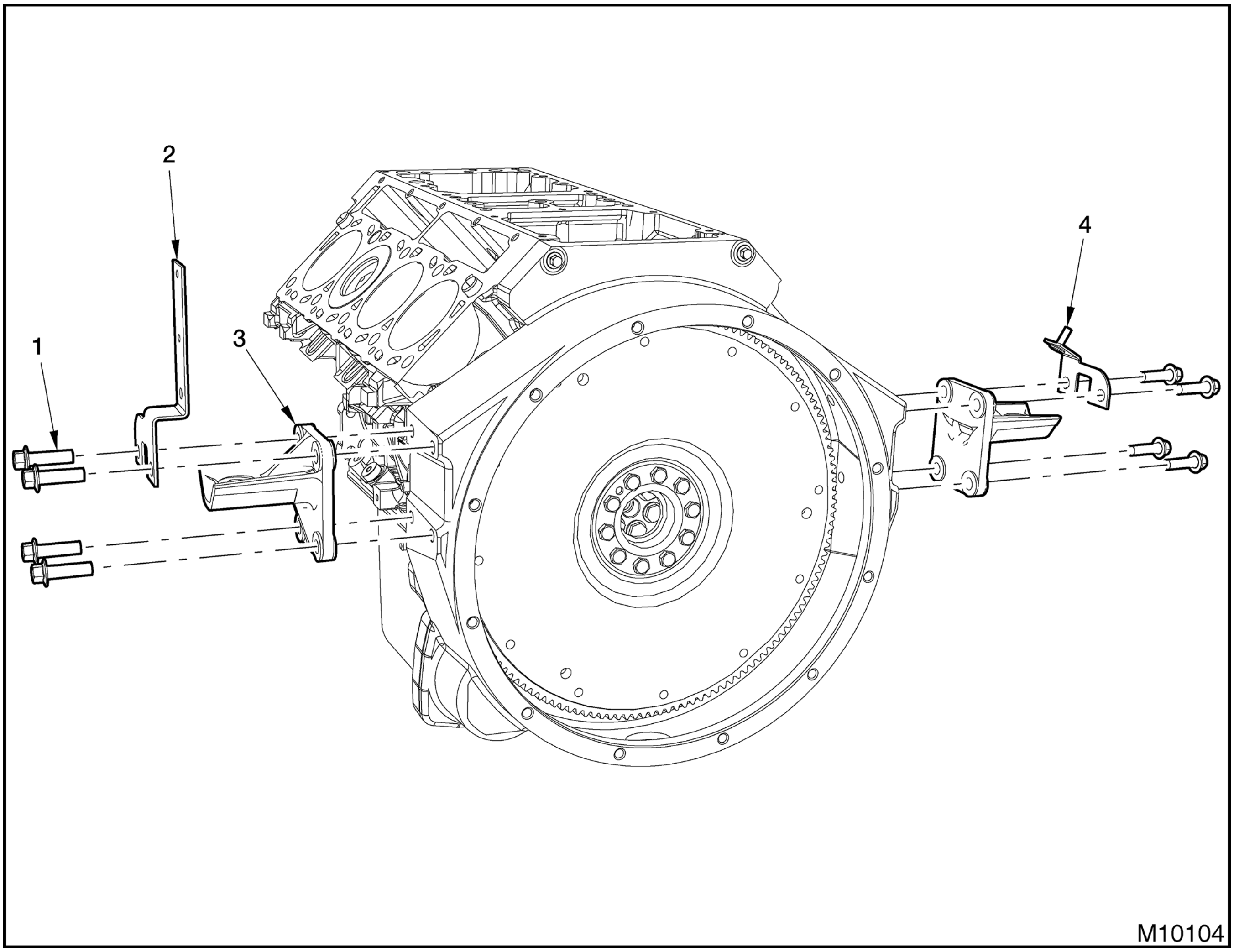

Figure 470 Engine mount rear brackets

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

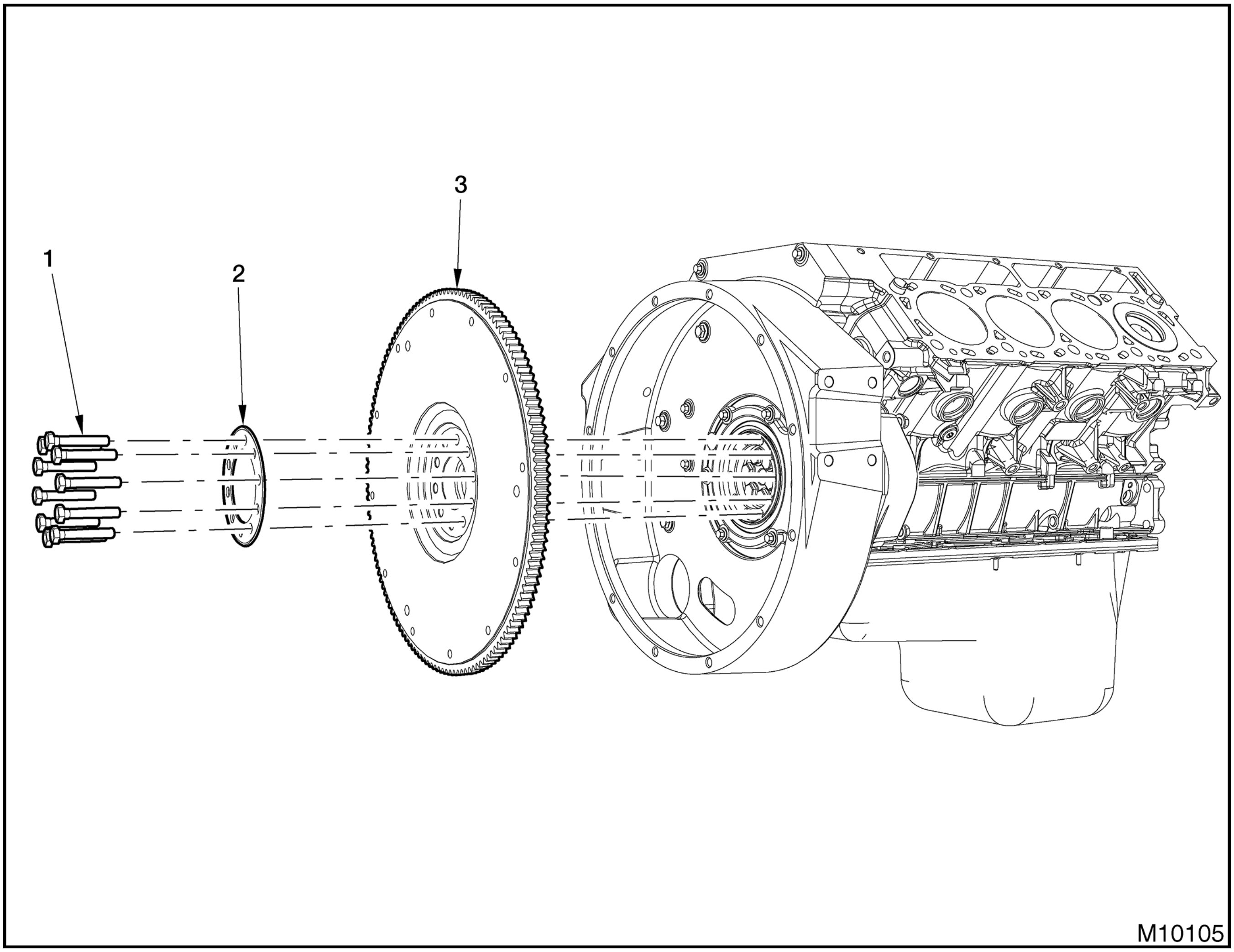

Figure 471 Flywheel assembly (manual transmission)

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

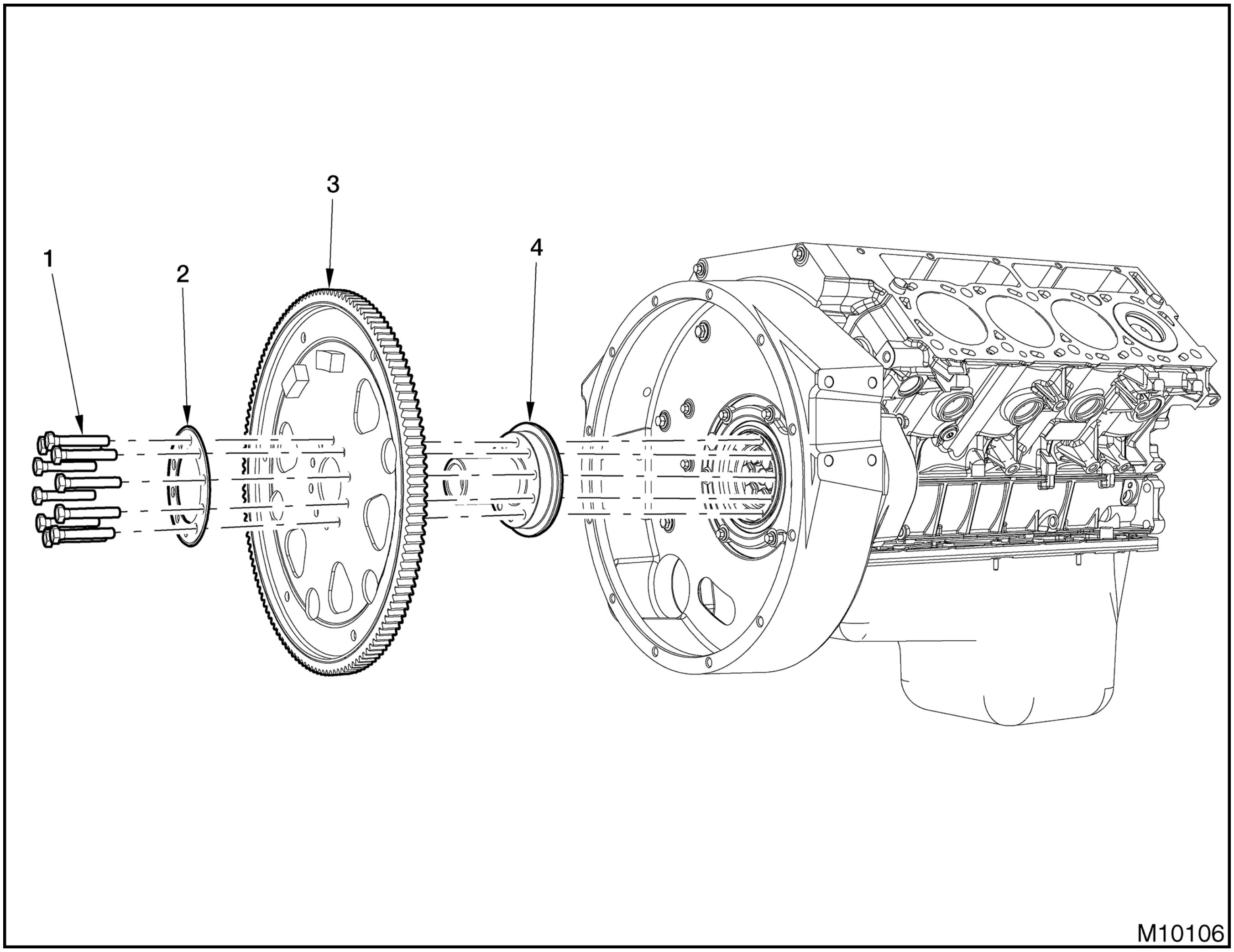

Figure 472 Flex plate flywheel assembly (automatic transmission)

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

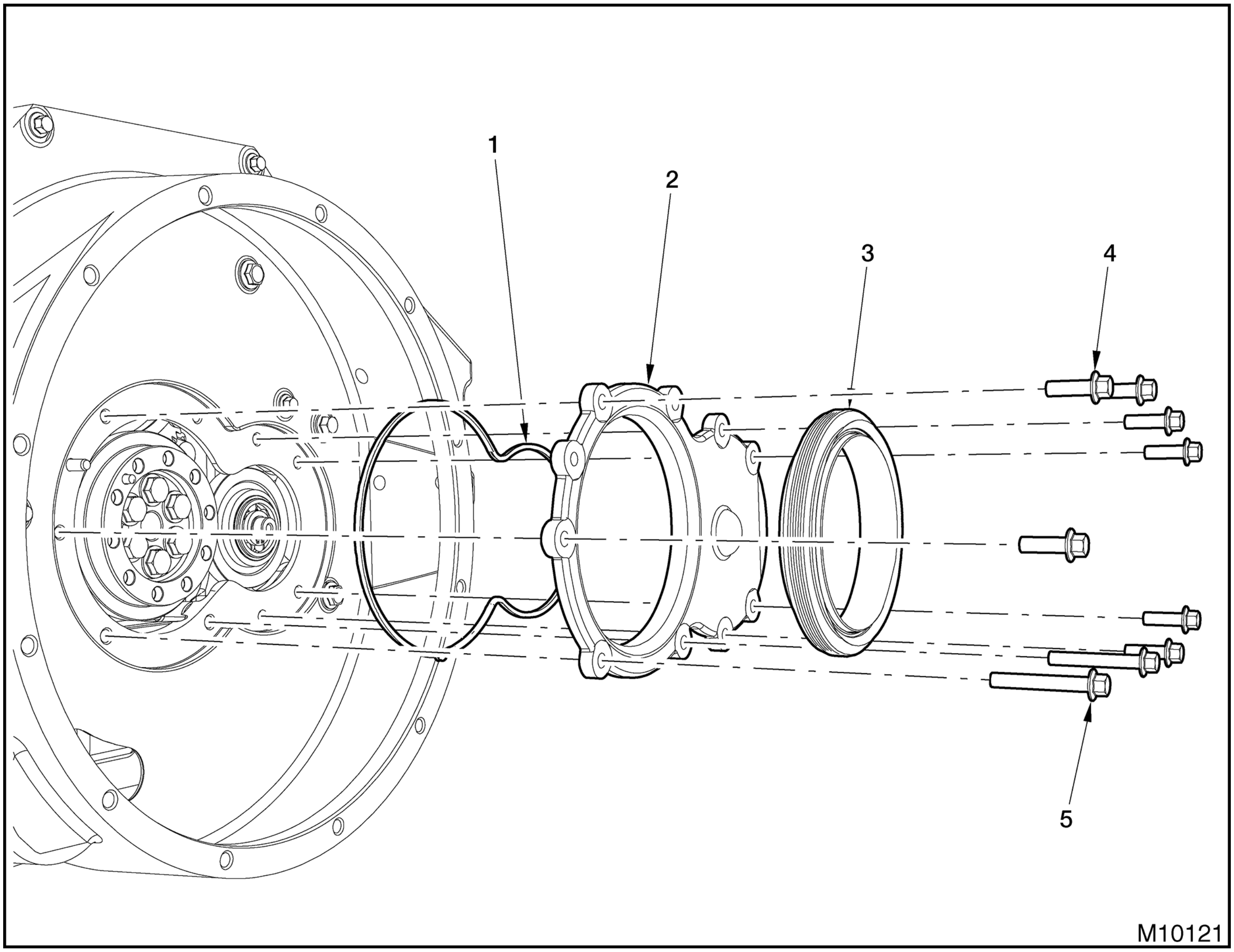

Figure 473 Crankshaft rear oil seal and crankshaft rear oil seal carrier

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

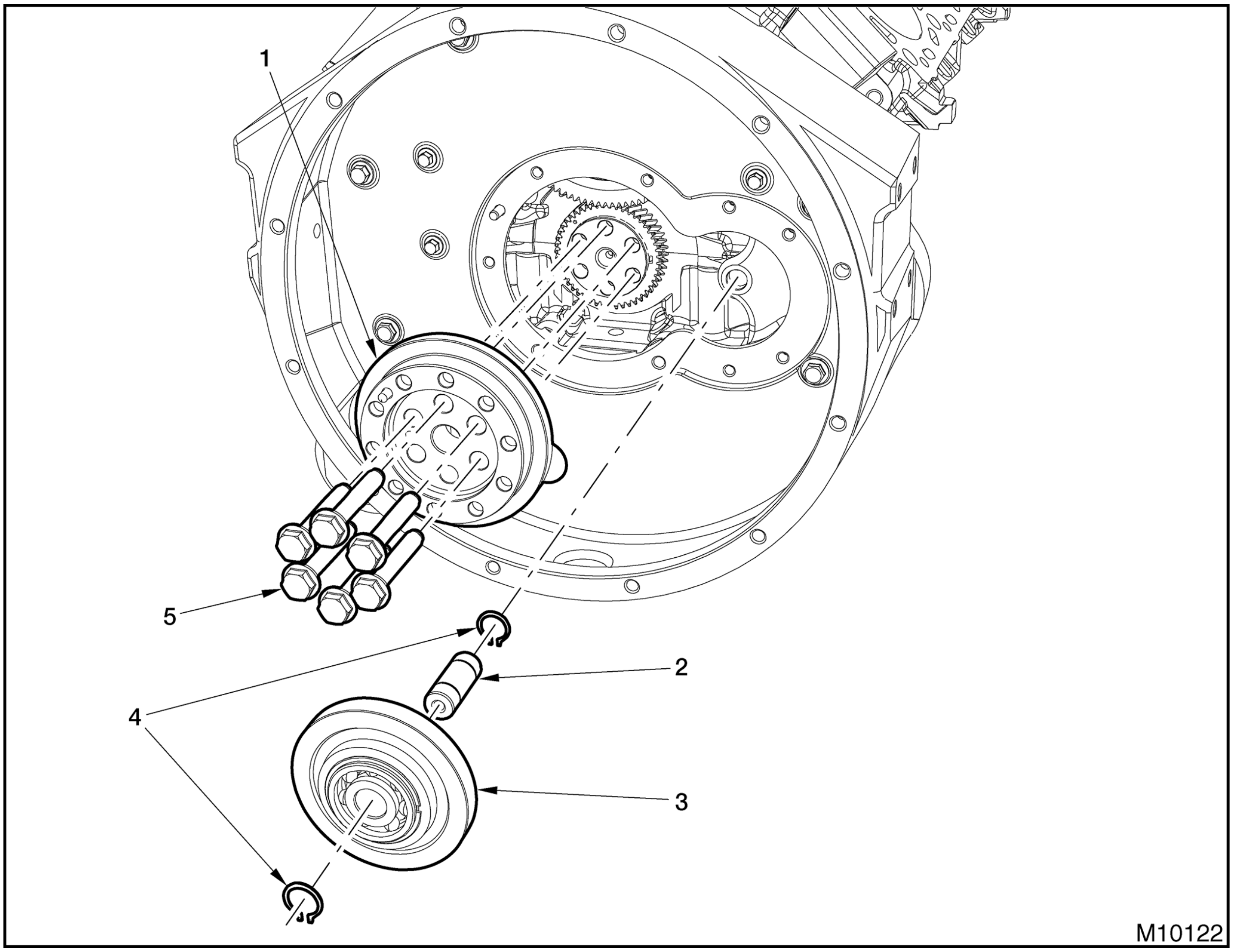

Figure 474 Crankshaft flange and power steering idler gear assembly

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

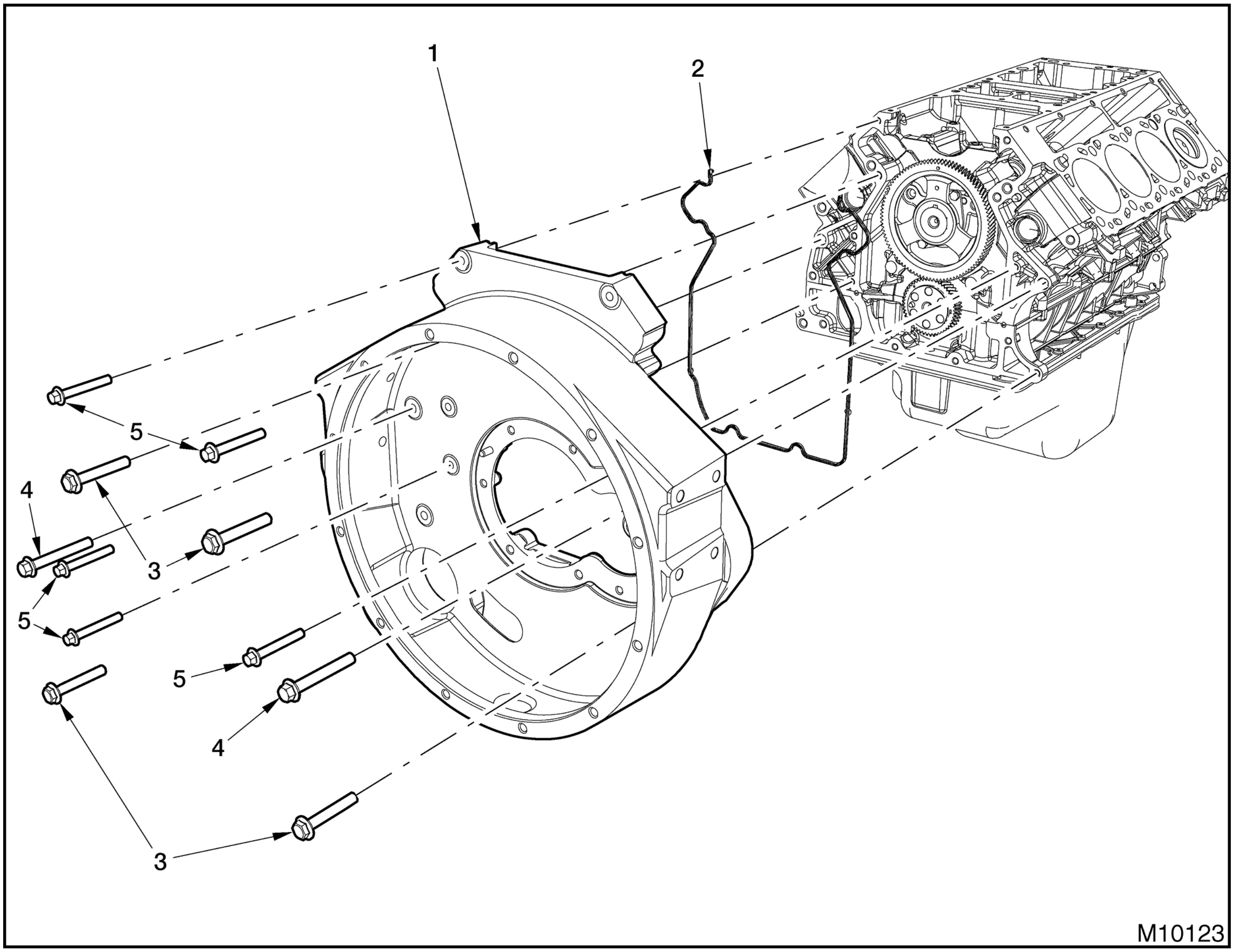

Figure 475 Flywheel housing

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

Removal

GOVERNMENT REGULATION: Engine fluids (oil, fuel, and coolant) may be a hazard to human health and the environment. Handle all fluids and other contaminated materials (e.g. filters, rags) in accordance with applicable regulations. Recycle or dispose of engine fluids, filters, and other contaminated materials according to applicable regulations.

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

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

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

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

NOTE: If a new (flywheel, flywheel housing or power steering idler gear) will not be installed, the following measurements are required before disassembly:

- Flywheel surface runout (page 292)
- Flywheel housing runout (page 293)
- Power steering idler gear backlash (page 293)

NOTE: See the following service sections for information on removal of components prior to this section.

- Engine Electrical
- Exhaust Gas Recirculation (EGR) System
- Variable Geometry Turbocharger (VGT)
- Air Compressor and Power Steering Pump
- Fuel System
- Front Cover, Cooling System, and Related components
- Cylinder Heads and Valve Train
- Oil Cooler and Filter Housing

Engine Mount Rear Brackets

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

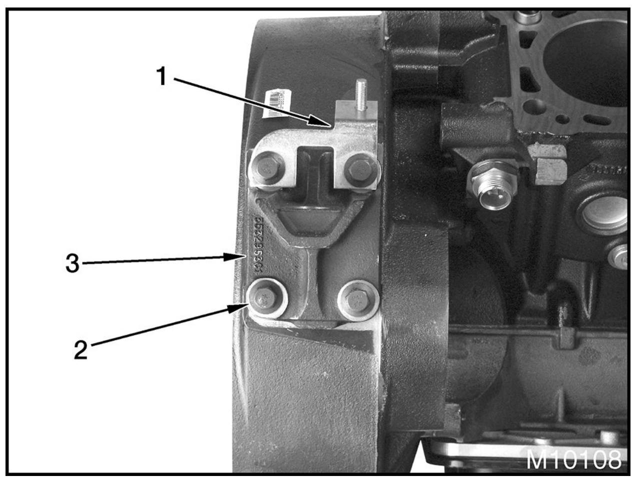

Figure 476 Engine mount rear bracket (right)

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

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

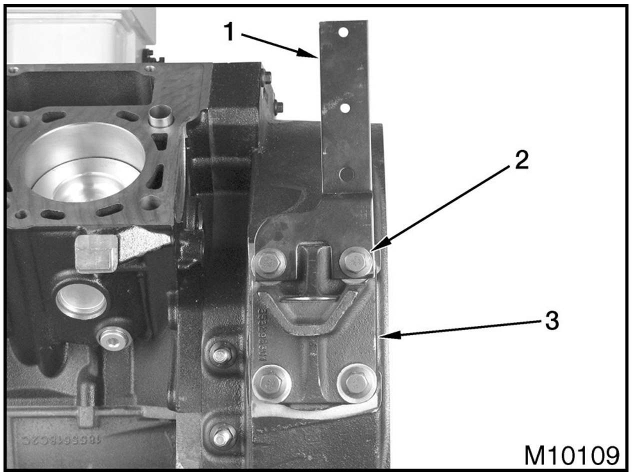

Figure 477 Engine mount rear bracket (left)

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

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

Flywheel Assembly (Manual Transmission)

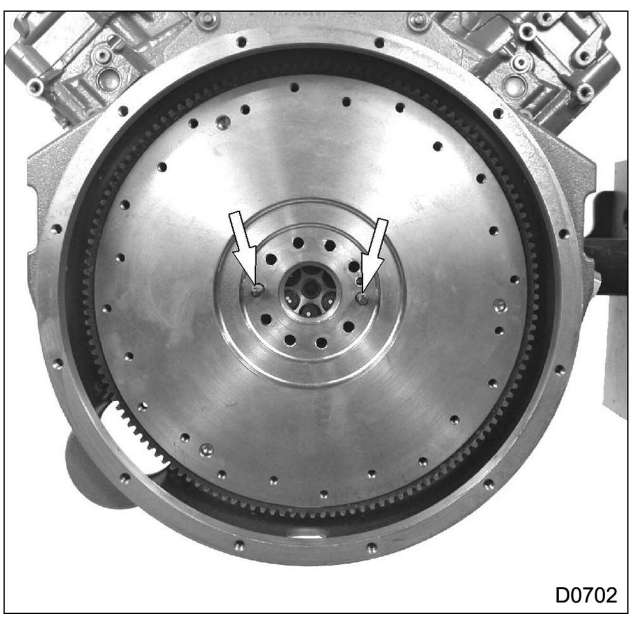

Figure 478 Flywheel assembly guide pins

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

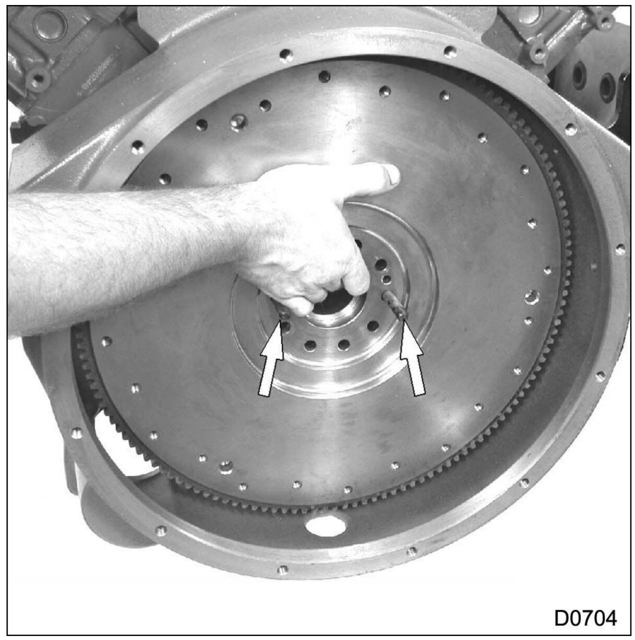

Figure 479 Flywheel assembly removal

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

Flex Plate flywheel Assembly (Automatic Transmission)

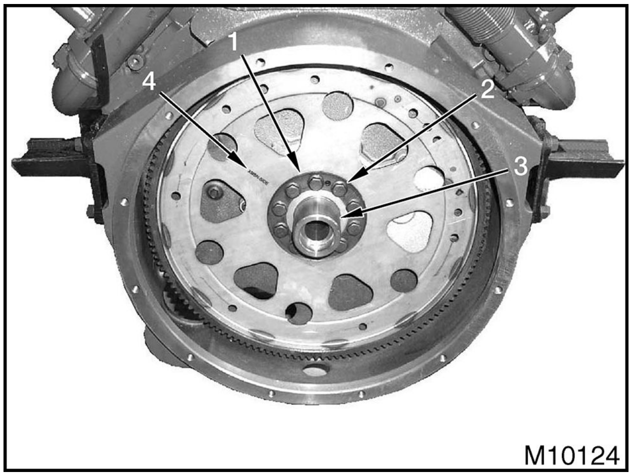

Figure 480 Flex plate flywheel assembly (typical)

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

1. Remove and discard 10 M10 x 55 bolts.

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

2. Remove reinforcement ring, flex plate flywheel assembly, and adapter hub.

Crankshaft Rear Oil Seal and Wear Sleeve

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

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

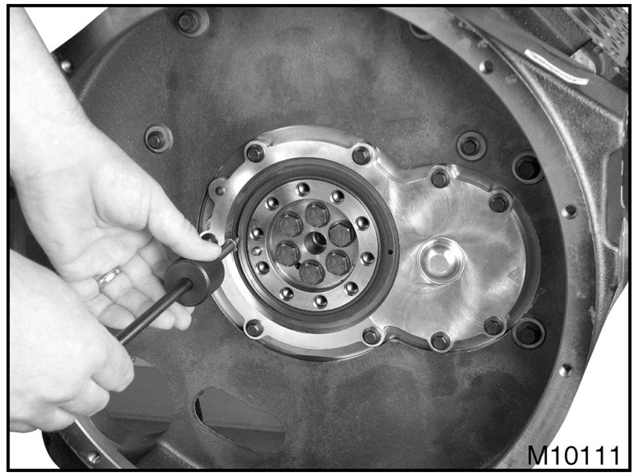

Figure 481 Crankshaft rear oil seal removal

2. Thread slide hammer (page 303) screw into one of the starter holes.
3. Remove seal evenly, by using a slide hammer on one side, and then alternate to other side.
4. Remove and discard crankshaft rear oil seal from crankshaft rear oil seal carrier.

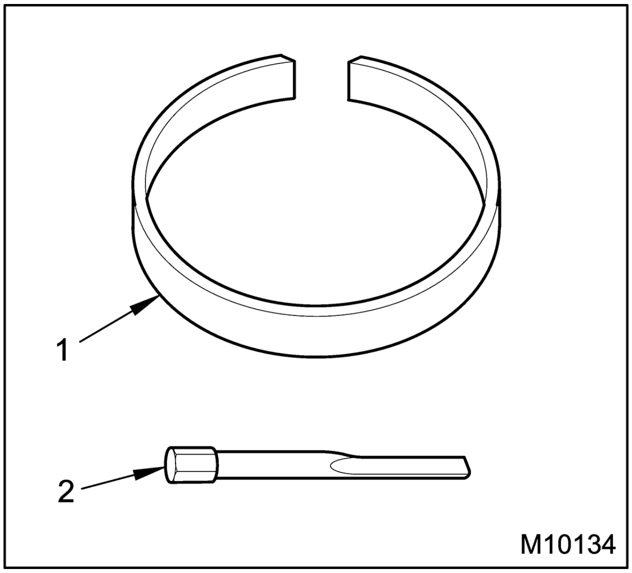

Figure 482 Rear Wear Sleeve Remover

1. Distorter Ring
2. Distorter Shaft

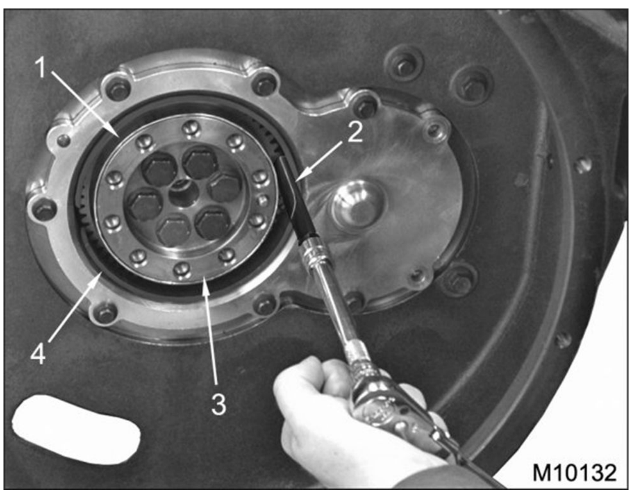

Figure 483 Rear wear sleeve removal

1. Wear sleeve
2. Distorter Shaft
3. Crankshaft flange
4. Distorter Ring

NOTE: Production engines did not include a wear sleeve with the crankshaft rear oil seal. A wear sleeve is part of the crankshaft rear oil seal used for service. If engine being serviced does not have a wear sleeve, skip steps 5-10.

5. Install Distorter Ring of Rear Wear Sleeve Remover (page 303).

NOTE: A socket wrench with an extension should be used with the Distorter Shaft.

6. Position Distorter Shaft (pointed edge facing wear sleeve) and insert between wear sleeve and Distorter Ring until it bottoms out against gear.
7. Slowly turn Distorter Shaft clockwise to apply force against the wear sleeve.

   NOTE: The Distorter Shaft will dent and expand the wear sleeve at the contact point, without cutting through the wear sleeve.

8. Repeat steps 6 and 7 three times 120° apart.
9. Remove wear sleeve.
10. Remove Distorter Ring.

Crankshaft Rear Oil Seal Carrier and Power Steering Idler Gear Assembly

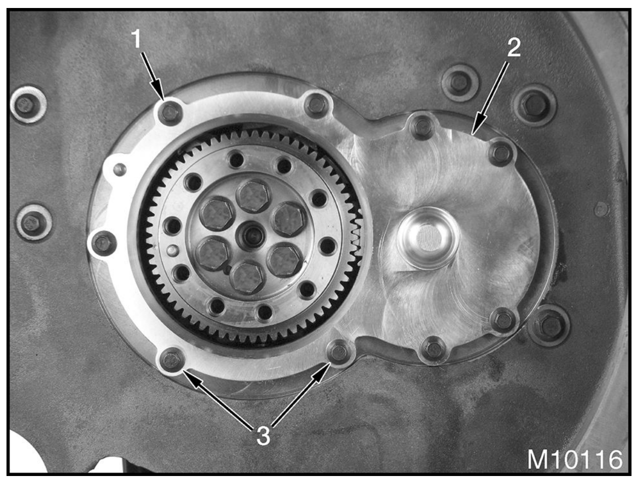

Figure 484 Crankshaft rear oil seal carrier

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

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

NOTE: Check power steering idler gear backlash (page 293).

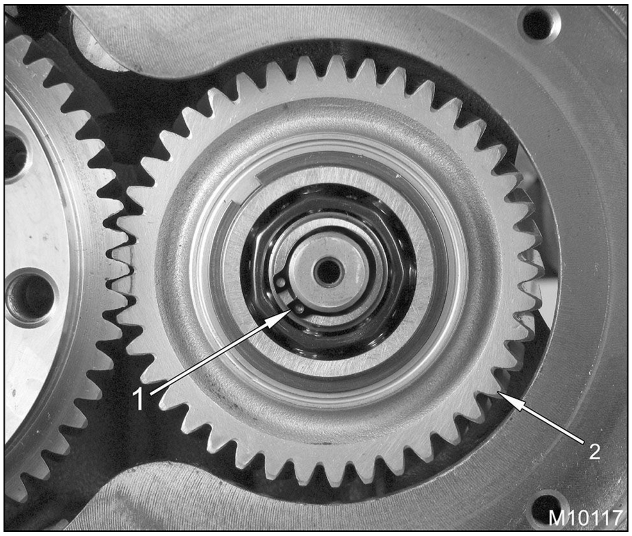

Figure 485 Power steering idler gear assembly

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

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

3. Remove external retaining ring from power steering idler gear assembly with external snap ring pliers (page 303).
4. Remove power steering idler gear assembly.

Crankshaft Flange

1. Rotate crankshaft until cylinder 1 is at Top Dead Center (TDC).

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

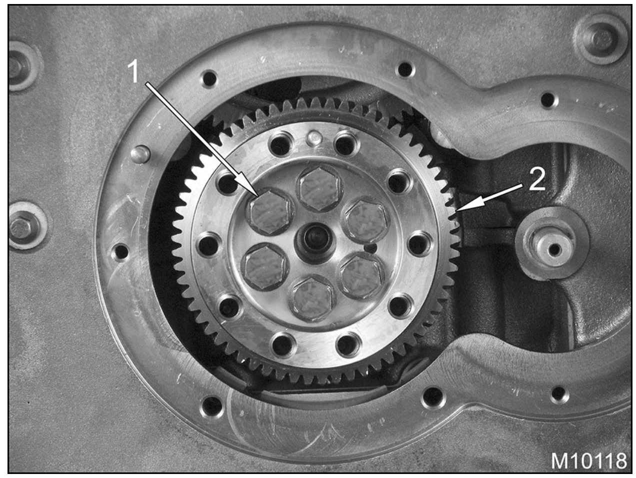

Figure 486 Crankshaft flange

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

NOTE: Save crankshaft flange bolts to check flange face runout.

2. Remove six M12 x 68 bolts from crankshaft flange. Note position of flange before removing. Flange must be installed in the same location as removed.

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

3. Use a bar type gear puller (page 303) and remove crankshaft flange from crankshaft.

Flywheel Housing and Power Steering Idler Shaft

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

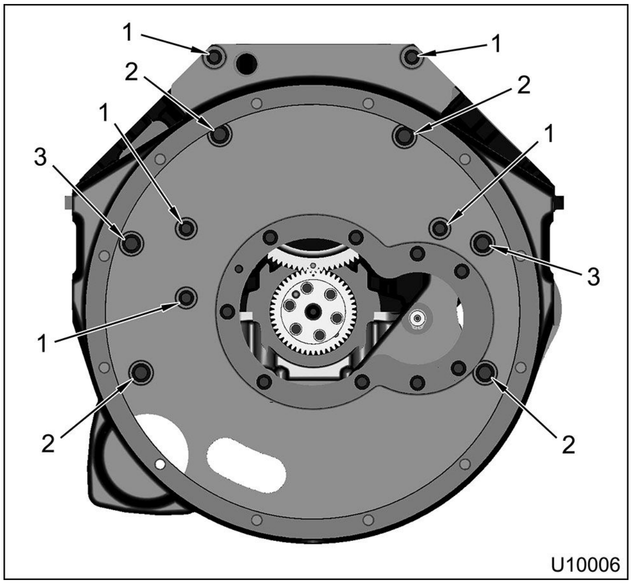

Figure 487 Flywheel housing mounting bolts

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

1. Loosen two M8 x 55 bolts installed in top of flywheel housing, but do not completely unthread.
2. Remove the remaining nine bolts: three M8 x 55 bolts, four M10 x 60 bolts, and two M10 x 70 bolts.

CAUTION: To prevent engine damage, when removing flywheel housing, do not pull out crankcase lower seals between upper and lower crankcase.

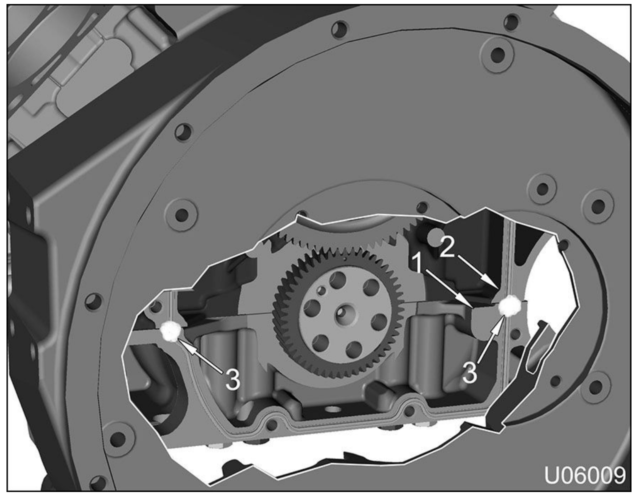

Figure 488 Liquid Gasket (RTV) sealant (reference)

1. Lower crankcase
2. Upper crankcase
3. RTV sealant (two locations)

NOTE: Steps 3 and 4 are required to prevent pulling out the crankcase lower seals, when removing the flywheel housing.

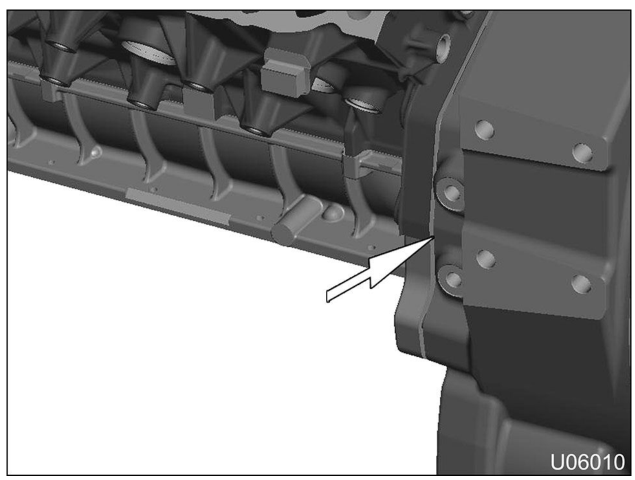

Figure 489 Left side of flywheel housing

3. Insert a thin gasket scraper into left side of engine between flywheel housing and upper and lower crankcase and push scraper in to cut through RTV sealant at the joint of the upper and lower crankcase.

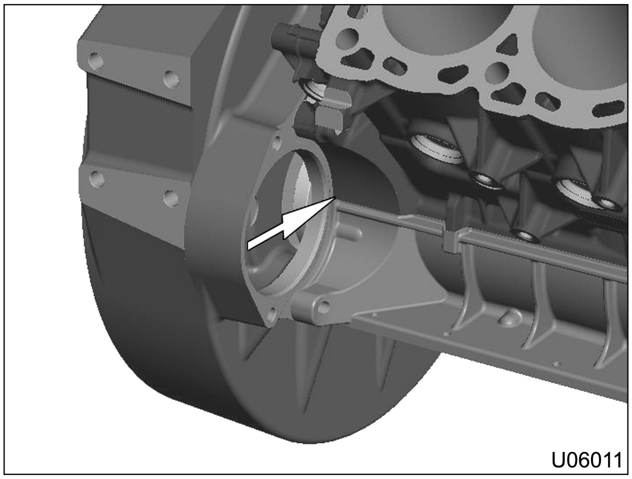

Figure 490 Right side of flywheel housing

4. Insert a thin gasket scraper into right side of engine between flywheel housing and upper and lower crankcase and push scraper in to cut through RTV sealant at the joint of the upper and lower crankcase.

WARNING: To prevent personal injury or death, get assistance when removing or installing the flywheel housing.

5. Support the flywheel housing and remove two loosened M8 x 55 bolts.
6. With aid of an assistant, slide flywheel housing off dowel pins and remove housing.
7. Remove RTV and clean areas of the flywheel housing.

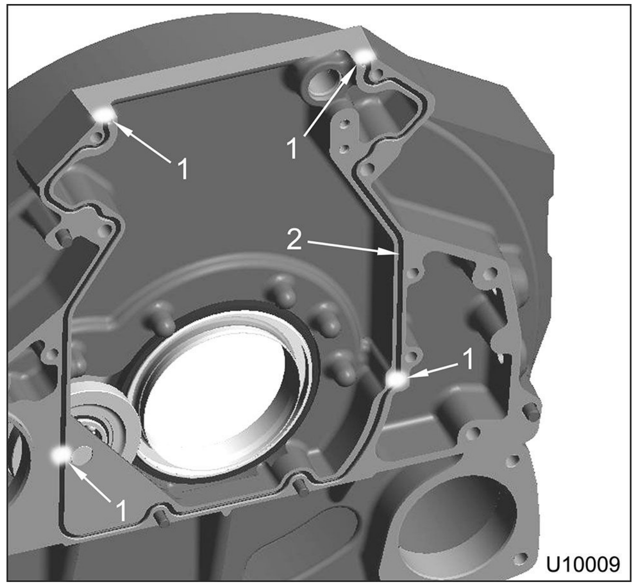

Figure 491 Removal of rear cover gasket and Liquid Gasket (RTV)

1. Liquid Gasket (RTV)
2. Rear cover gasket

8. Remove and discard crankcase rear cover gasket.
9. Remove RTV and clean areas of the flywheel housing.
10. If necessary, use a slide hammer (page 303) to remove power steering idler shaft.

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).

1. Clean foreign material from gasket surfaces of upper and lower crankcase assemblies and flywheel housing. Use a scraper or wire brush to remove sealant from gasket surfaces.
2. Gasket surfaces must be oil-free for good adhesion of liquid gasket during assembly. Use a commercially available, non-caustic brake cleaner to clean gasket surfaces of upper and lower crankcase assemblies and flywheel housing.
3. Wash crankshaft rear oil seal carrier, flywheel assembly or flex plate flywheel assembly, and flywheel housing. Dry all with filtered compressed air.
4. Wash crankcase flange, power steering idler gear assembly, and power steering idler shaft with a stiff brush and a nonchlorinated solvent. Dry all with filtered compressed air.

Flex Plate Flywheel Assembly (Automatic Transmission)

CAUTION: To prevent engine damage, install a new flex plate flywheel assembly if damaged. Flex plates for automatic transmissions cannot be resurfaced.

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

Flywheel Assembly (Manual Transmission)

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

Flywheel Surface Runout

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

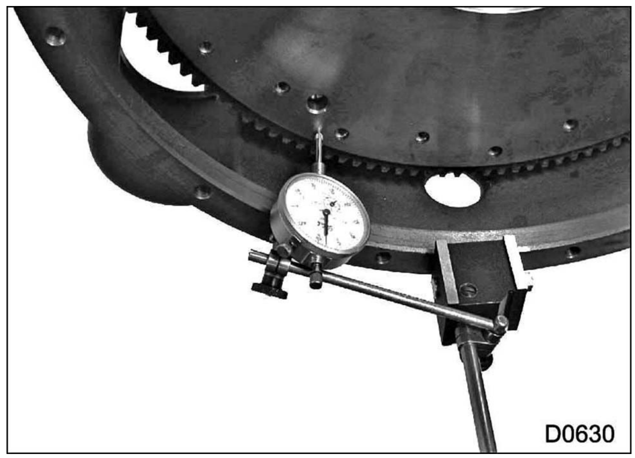

Figure 492 Flywheel surface runout

1. Attach dial indicator with magnetic base (page 303) to the flywheel housing. Place indicator tip against the flywheel surface between the ring gear and outer bolt circle.
2. Zero the dial indicator.

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

3. Slowly rotate the crankshaft 360 degrees and observe dial indicator measurements.
4. Compare the total dial indicator variation (highest – lowest reading) to flywheel surface maximum runout specification (page 303).

Flywheel Housing Runout

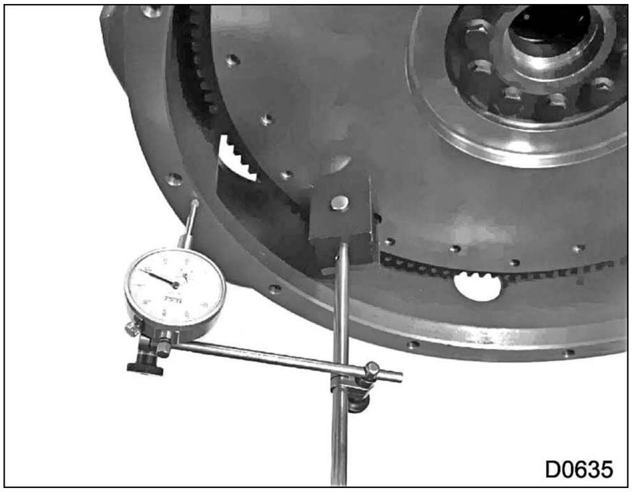

Figure 493 Flywheel housing runout

1. Attach dial indicator with magnetic base (page 303) onto the surface of the flywheel. Place indicator tip against flywheel housing.
2. Zero the dial indicator.

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

3. Measure at four points 90° apart for total variation. Verify readings are within flywheel housing maximum runout specification (page 303).

Backlash Measurement for Power Steering Idler Gear Assembly

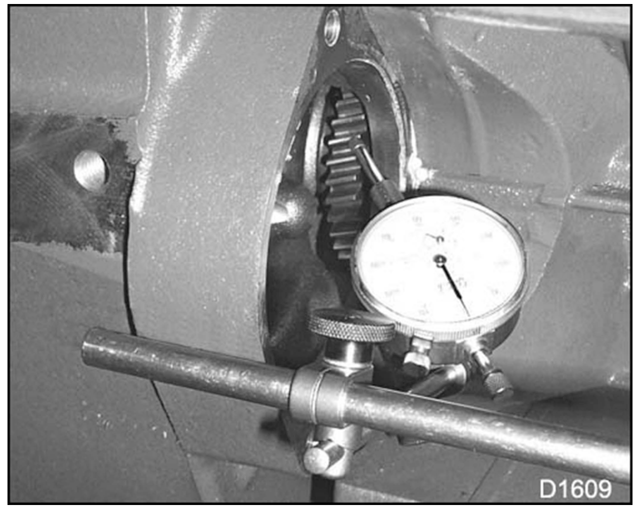

Figure 494 Power steering idler gear assembly backlash (typical)

1. Attach dial indicator with magnetic base (page 303) to flywheel housing.
2. Place indicator tip against power steering idler gear assembly.
3. Zero the dial indicator.
4. Move power steering idler gear assembly and record dial indicator reading. Verify reading is within specification (page 303). If out of specification, install a new gear.

Installation

Flywheel Housing

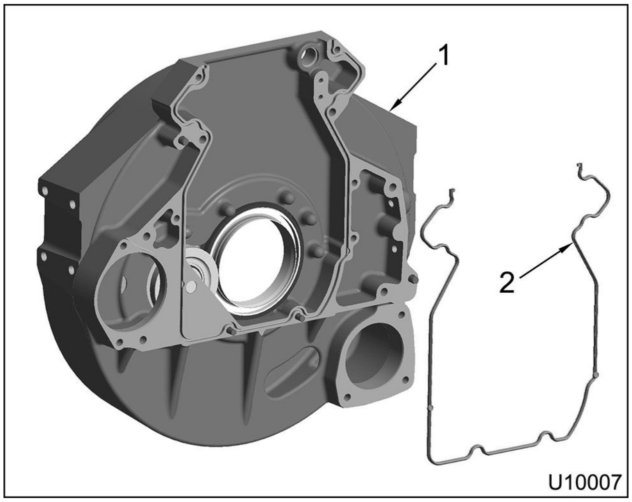

Figure 495 Rear cover gasket

1. Rear cover (flywheel housing)
2. Rear cover gasket

1. Install new crankcase rear cover gasket.

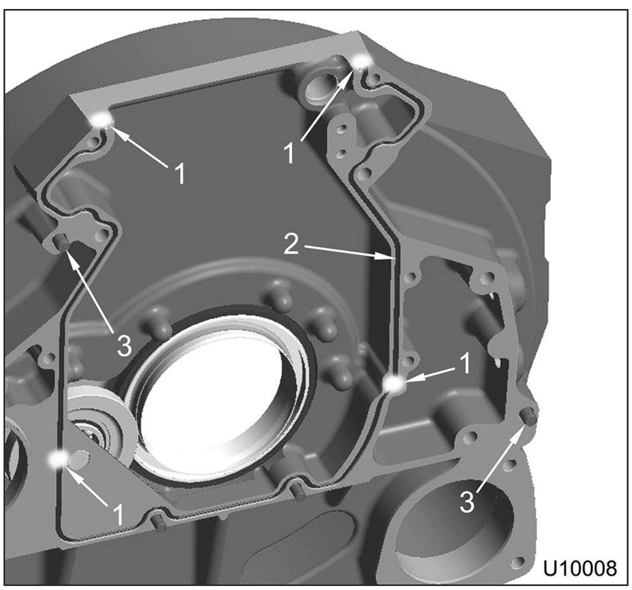

Figure 496 Liquid Gasket (RTV) and assembly pins

1. Liquid Gasket (RTV)
2. Rear cover gasket
3. Assembly pin (2)

2. Apply clean engine oil to assembly pins.

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

3. Apply Liquid Gasket (RTV) (page 303) on gasket area at points where crankcase and lower crankcase meet and on top of gasket ends.

WARNING: To prevent personal injury or death, get help when removing or installing the flywheel housing.

4. With aid of an assistant, slide flywheel housing over dowel pins to install housing.

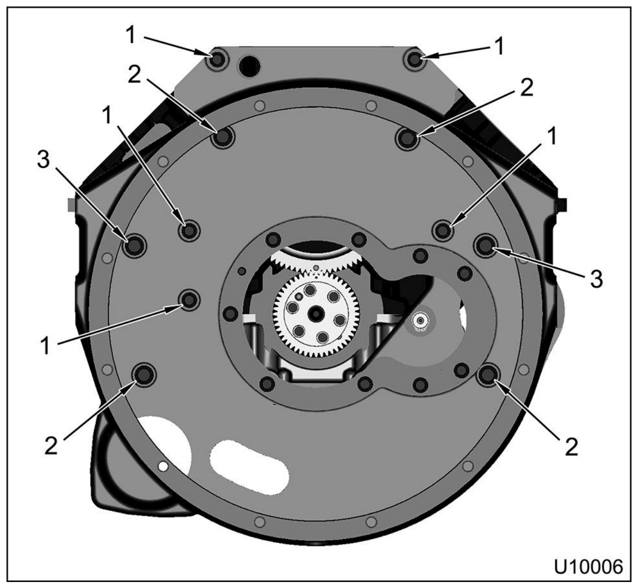

Figure 497 Flywheel housing mounting bolts

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

5. Install 11 flywheel housing bolts in the correct location, as shown. Tighten bolts to standard torque (page 383) for specific bolt size.

Power Steering Idler Shaft

NOTE: Skip this subsection, if the power steering idler shaft was not removed.

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

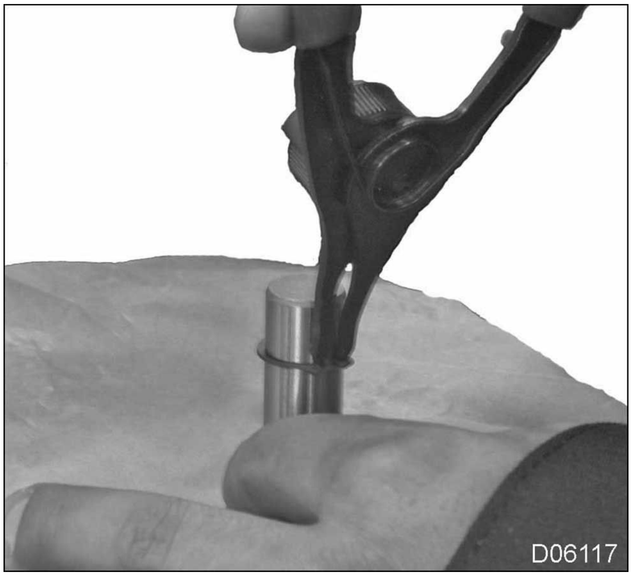

Figure 498 External retaining ring on power steering idler shaft

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

Figure 499 Power steering idler shaft and external retaining ring in Power Steering Idler Shaft Installation Tool

2. Put threaded hole end of power steering idler shaft into Power Steering Idler Shaft Installation Tool (page 303) to set correct shaft height (page 303).

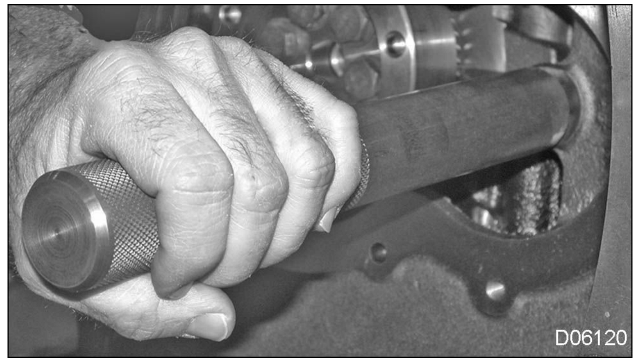

Figure 500 Power steering idler shaft installation

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

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

3. Align power steering idler shaft in flywheel housing at correct location. Using Power Steering Idler Shaft Installation Tool , drive power steering idler shaft into bore in transmission side of flywheel housing, until power steering idler shaft installation tool bottoms out.

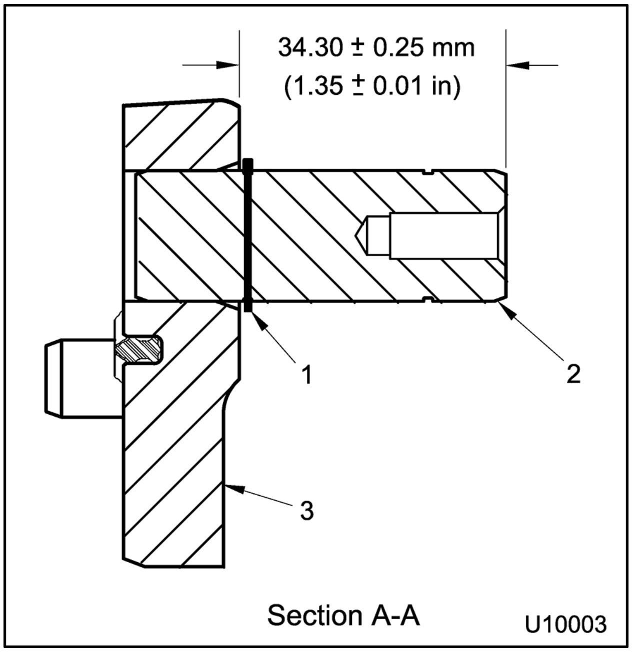

Figure 501 Power steering idler shaft installation height

1. Retaining external ring
2. Power steering idler shaft
3. Flywheel housing

4. If installation tool is not available, use a brass drift to install power steering idler shaft into the flywheel housing, to correct height.

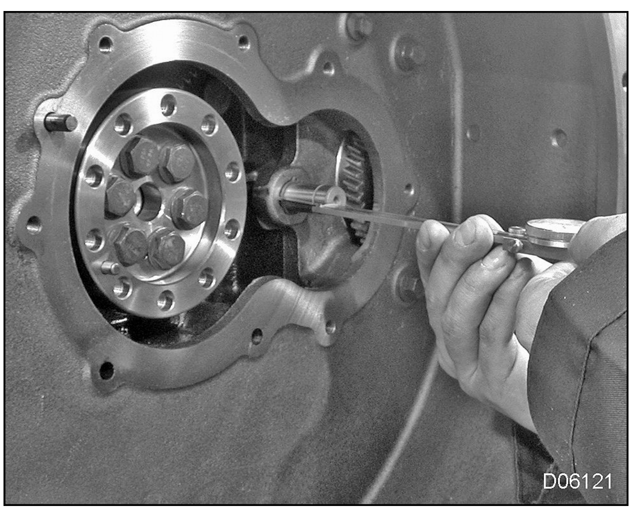

Figure 502 Power steering idler shaft height measurement

5. Measure power steering idler shaft height, using a dial caliper (page 303). Power steering idler shaft height should match specification (page 303).

Crankshaft Flange

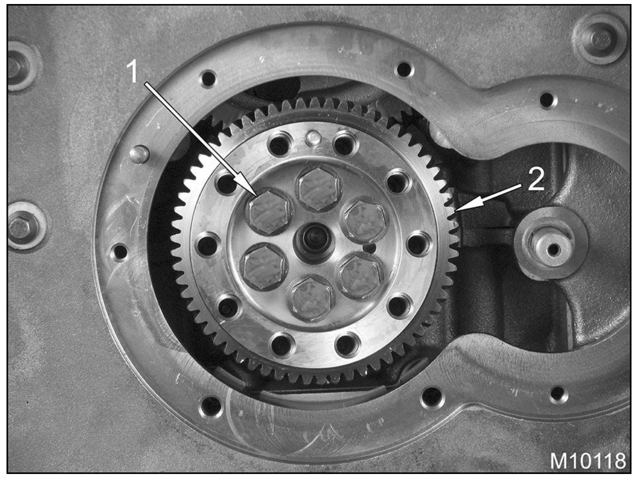

Figure 503 Crankshaft flange

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

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

1. Rotate crankshaft until cylinder number 1 is at Top Dead Center (TDC).
2. Inspect the crankshaft gear and crankshaft flange mating surfaces. Make sure they are free of debris, nicks, and dirt.
3. Install two guide pins (made locally) into crankshaft gear bolt holes, 180° from each other.

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

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

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

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

5. Using a heat insulated glove, install crankshaft flange over guide pins and onto crankshaft, with dowel pin pointing at 12 o'clock position.
6. Remove guide pins and install six old M12 x 68 bolts. Tighten bolts alternately to seat crankshaft flange.
7. Check face runout of crankshaft flange, using dial indicator with magnetic base (page 303). If face runout exceeds specification (page 303), remove and reinstall crankshaft flange to ensure there is no trapped debris and crankshaft flange is seated against gear. If after reinstallation of crankshaft flange the face runout still exceeds specification, install new crankshaft flange.

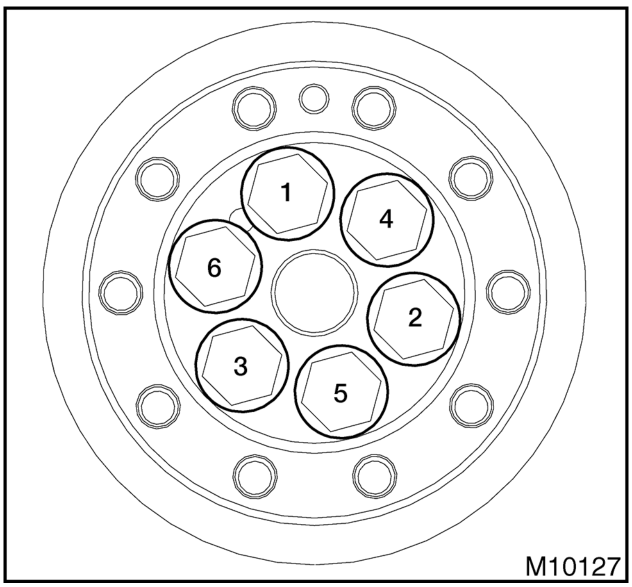

Figure 504 Crankshaft flange torque sequence

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

8. Remove and discard six old bolts. Lubricate underside of bolt heads on six new M12 x 68 bolts with clean engine oil and install bolts loosely. Tighten bolts as follows using above sequence:
   a. Tighten bolts to 41 N·m (30 lbf·ft) using above sequence.
   b. Rotate bolts 90 degrees using above sequence.
   c. Rotate bolts an additional 90 degrees using above sequence.

Power Steering Idler Gear Assembly and Crankshaft Rear Oil Seal Carrier

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

1. With circular witness grove facing out, install power steering idler gear assembly on power steering idler shaft.
2. Verify correct gear orientation and gear tooth engagement.

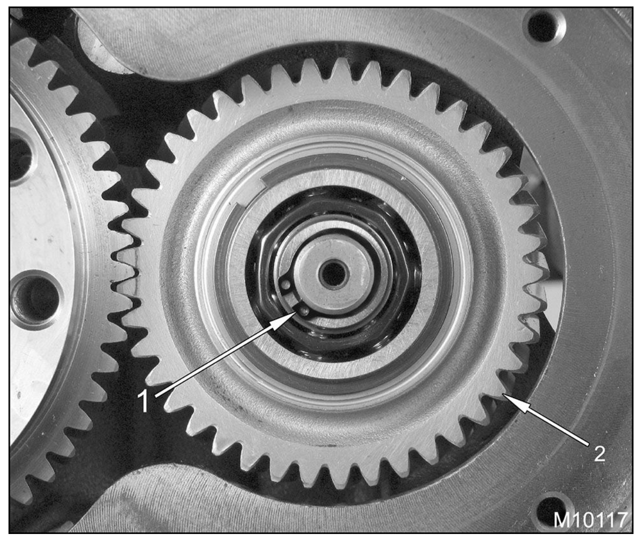

Figure 505 Power steering idler gear assembly

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

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

3. Install external retaining ring onto power steering idler shaft for power steering idler gear assembly.
4. Do Backlash Test for Power Steering Idler Gear Assembly (page 293).
5. Install new rear seal carrier gasket on crankshaft rear oil seal carrier.

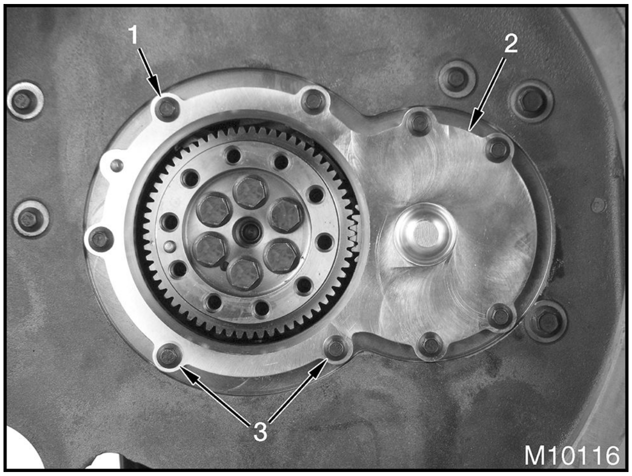

Figure 506 Crankshaft rear oil seal carrier

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

6. Install crankshaft rear oil seal carrier on flywheel housing.
7. Install two M8 x 55 bolts in lower holes of crankshaft rear oil seal carrier finger tight.
8. Install seven M8 x 25 bolts in crankshaft rear oil seal carrier finger tight.
9. Tighten two M8 x 55 and seven M8 x 25 bolts to standard torque (page 383).

Crankshaft Rear Oil Seal and Wear Sleeve

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

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

1. Clean crankshaft flange with a suitable solvent and dry flange with filtered compressed air.

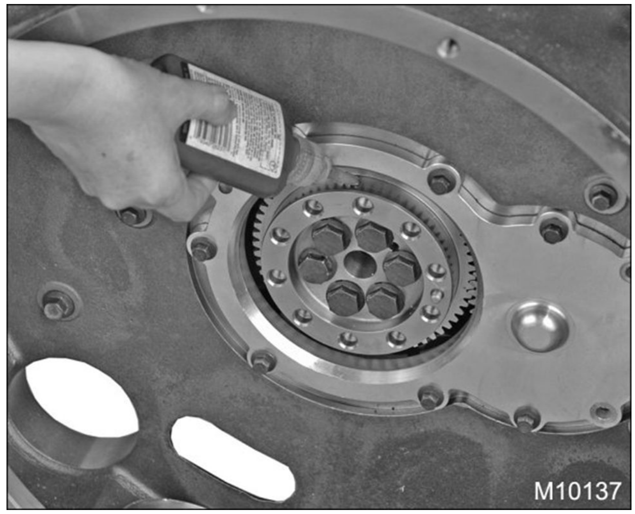

Figure 507 Application of hydraulic sealant

2. Apply a 360° bead of Loctite® 569 Hydraulic Sealant (page 303) on rear edge of crankshaft flange.

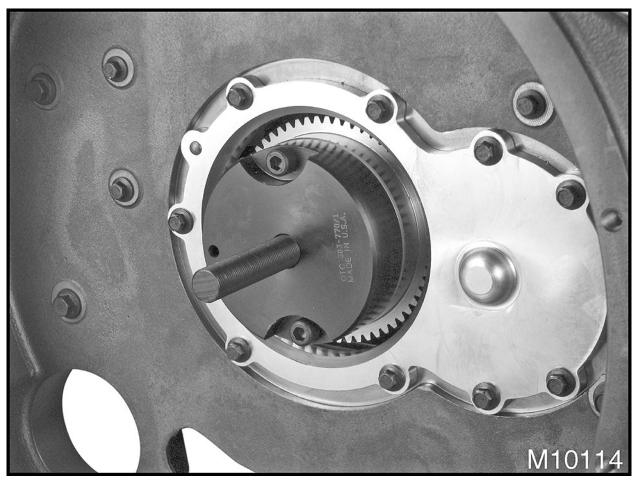

Figure 508 Crankshaft Rear Seal / Wear Sleeve Installer (base)

3. Align base of Crankshaft Rear Seal / Wear Sleeve Installer (page 303) with alignment dowel on crankshaft flange and install base.

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

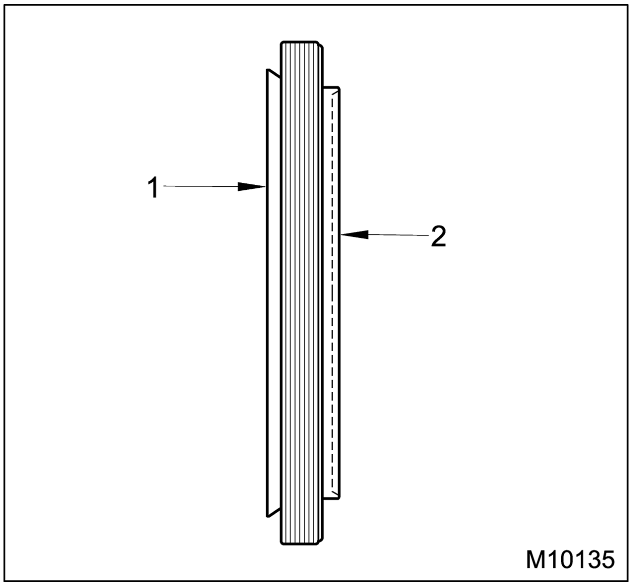

Figure 509 Crankshaft rear oil seal and wear sleeve assembly

1. Dust seal lip
2. Wear sleeve

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

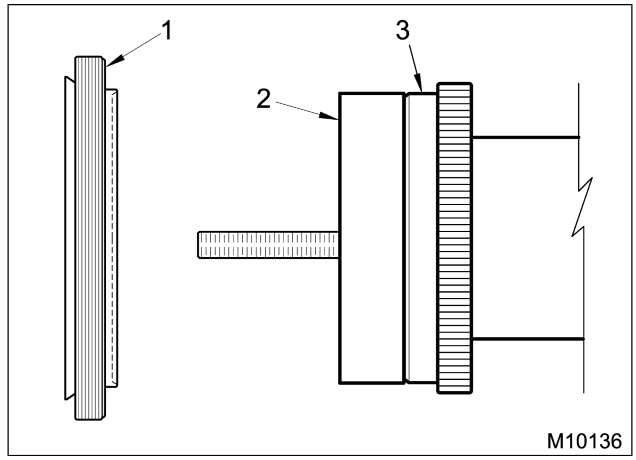

Figure 510 Installation of Crankshaft rear oil seal and wear sleeve assembly

1. Crankshaft rear oil seal and wear sleeve assembly
2. Rear Oil Seal Installer (base)
3. Crankshaft flange

4. Position new (soap and water lubricated) crankshaft rear oil seal and wear sleeve assembly onto hub of Crankshaft Rear Seal / Wear Sleeve Installer (page 303).

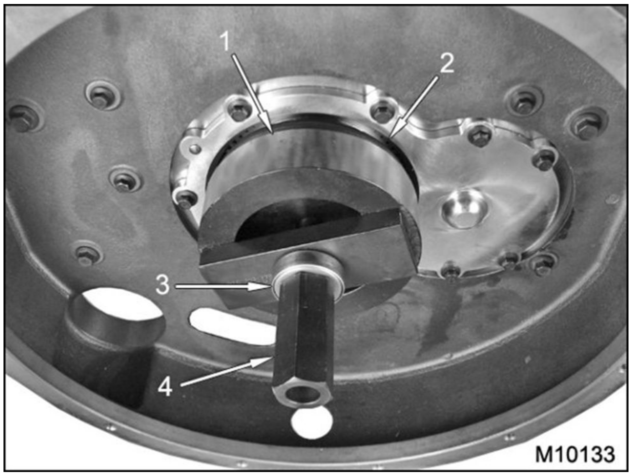

Figure 511 Installation of Crankshaft rear oil seal and wear sleeve assembly

1. Rear Seal Installer w/ 40 mm Cap Screws (forcing collar)
2. Crankshaft Rear Seal / Wear sleeve Installer
3. Thrust bearing
4. Drive nut

5. Put forcing collar (page 303), thrust bearing, and drive nut on threaded shaft.

   CAUTION: To prevent engine damage, do not use an impact wrench to tighten drive nut.

6. Tighten drive nut until the forcing collar bottoms out on Crankshaft Rear Seal / Wear Sleeve Installer (base). Rear oil sleeve and wear sleeve assembly will be placed at correct depth.

Flex Plate Flywheel Assembly (Automatic Transmission)

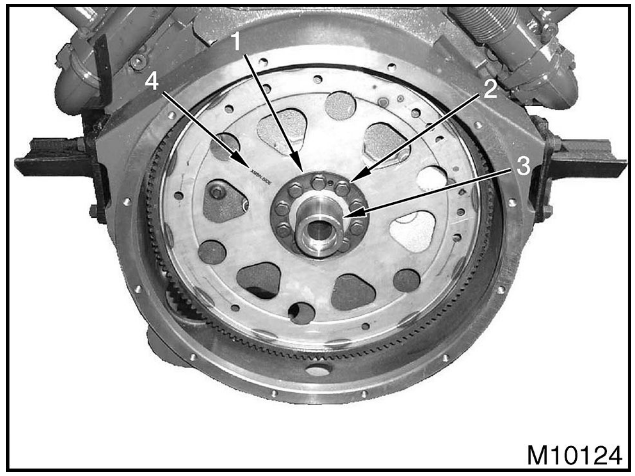

Figure 512 Flex plate flywheel assembly

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

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

CAUTION: To prevent engine damage, always install new flywheel assembly or flex plate flywheel assembly mounting bolts.

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

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

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

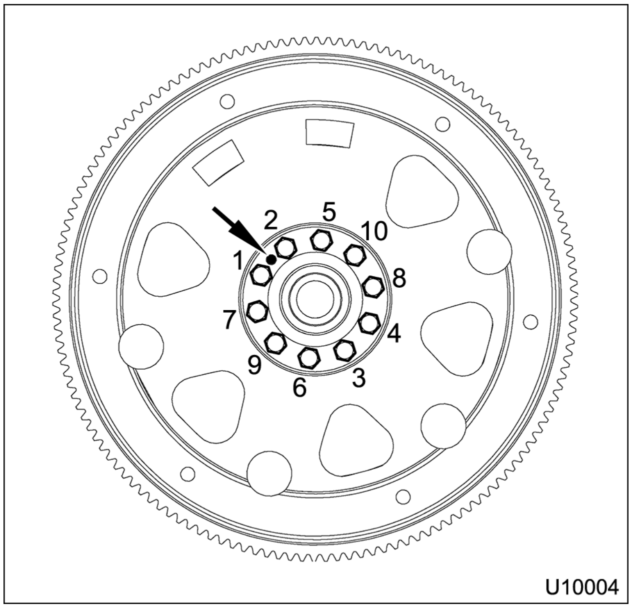

Figure 513 Torque sequence for flex plate flywheel assembly bolts and dowel location

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

4. Snug all bolts in sequence shown (Figure 513) to initial torque of 4 N·m (35 lbf·in).
5. Tighten all bolts in sequence shown (Figure 513) to final torque of 94 N·m (69 lbf·ft).

Flywheel Assembly (Manual Transmission)

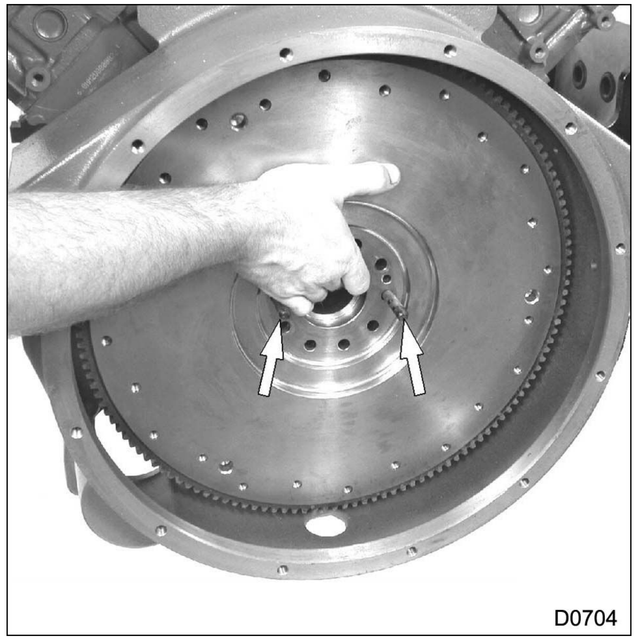

Figure 514 Flywheel assembly installation (typical)

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

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

CAUTION: To prevent engine damage, always install new flywheel assembly or flex plate flywheel assembly mounting bolts.

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

4. Install two new M10 x 55 bolts 180° from each other to secure flywheel assembly to the crankshaft flange. Remove both guide pins.
5. Install eight remaining new M10 x 55 bolts.

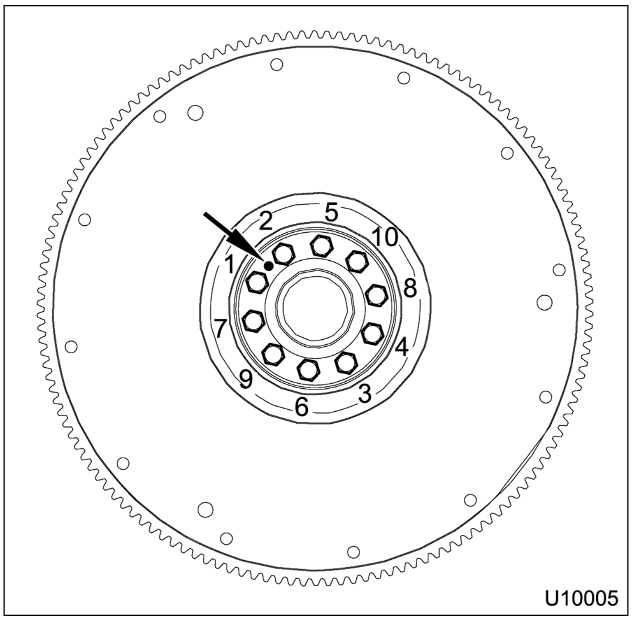

Figure 515 Torque sequence for flywheel assembly bolts and dowel location

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

6. Snug all bolts in sequence shown (Figure 515) to initial torque of 4 N·m (35 lbf·in).
7. Tighten all bolts in sequence shown (Figure 515) to final torque of 94 N·m (69 lbf·ft).
8. Measure Flywheel Surface Runout. (page 292).
9. Measure Flywheel housing runout (page 293)

Engine Mount Rear Brackets

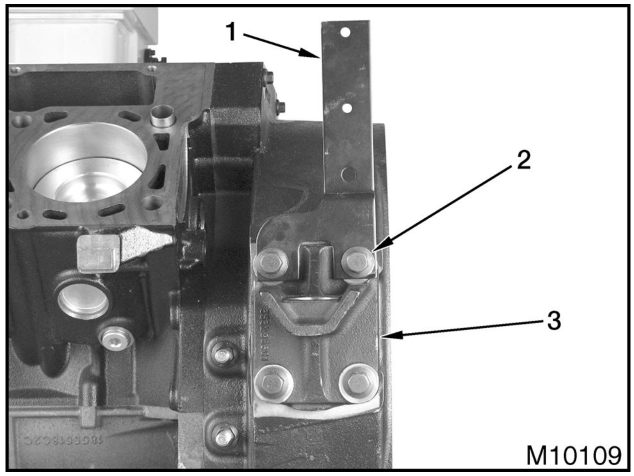

Figure 516 Engine mount rear bracket (left)

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

1. Install left engine mount rear bracket, pipe clip bracket, and four M12 x 40 bolts. Tighten bolts to standard torque (page 383).

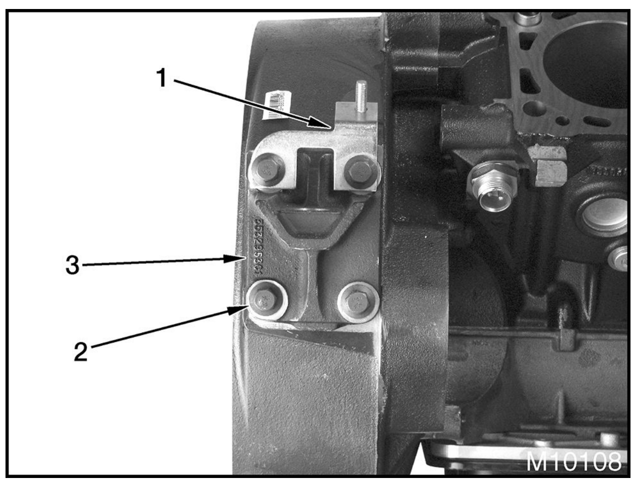

Figure 517 Engine mount rear bracket (right)

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

2. Install right engine mount rear bracket, extension clip, and four M12 x 40 bolts. Tighten bolts to standard torque (page 383).

Specifications

Flywheel Assembly and Flywheel Housing

Flywheel Assembly	
Flywheel surface maximum runout (manual)	0.25 mm (0.010 in)
Power Steering Idler Shaft	
Power steering idler shaft installation height	34.30 ± 0.25 mm (1.35 ± 0.01 in)
Flywheel Housing	
Flywheel housing maximum runout	0.51 mm (0.020 in)
Crankshaft Flange and Power Steering Idler Gear Assembly	
Face runout:	
Crankshaft flange	0.050 mm (0.002 in) maximum
Backlash:	
Power steering idler gear assembly	0.066 to 0.290 mm (0.0026 to 0.0114 in)

Special Torque

Crankshaft flange bolts, M12 x 68	See tightening steps in procedure.
Flex plate flywheel assembly bolts, M10 x 55	See tightening steps in procedure.
Flywheel assembly bolts, M10 x 55	See tightening steps in procedure.

Special Service Tools

Description	Tool Number
Dial caliper	Obtain locally
Dial indicator with magnetic base	Obtain locally
External snap ring pliers	Obtain locally
Gear puller (bar type)	Obtain locally
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Loctite® 569 hydraulic sealant or equivalent	Obtain locally
Power Steering Idler Shaft Installation Tool	ZTSE4719
Crankshaft Rear Seal / Wear Sleeve installer (base)	ZTSE4515-B
Rear Seal Installer w/ 40 mm Cap Screws (forcing collar)	ZTSE4515-2C
Rear Wear Sleeve Remover (Distorter Ring and Distorter Shaft)	ZTSE4889
Slide hammer	Obtain locally
Heat insulated glove	Obtain locally

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Exploded Views

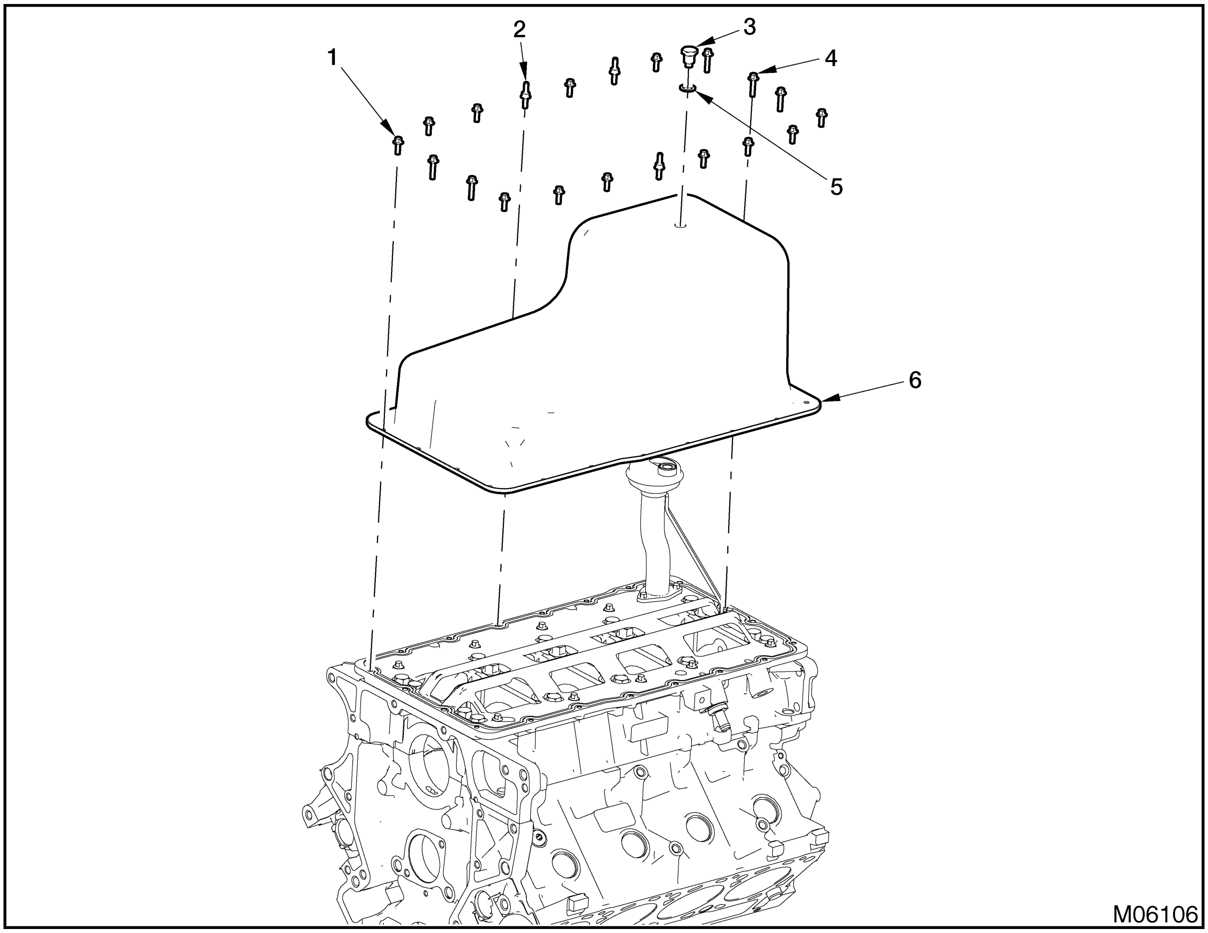

Figure 518 Lower oil pan

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

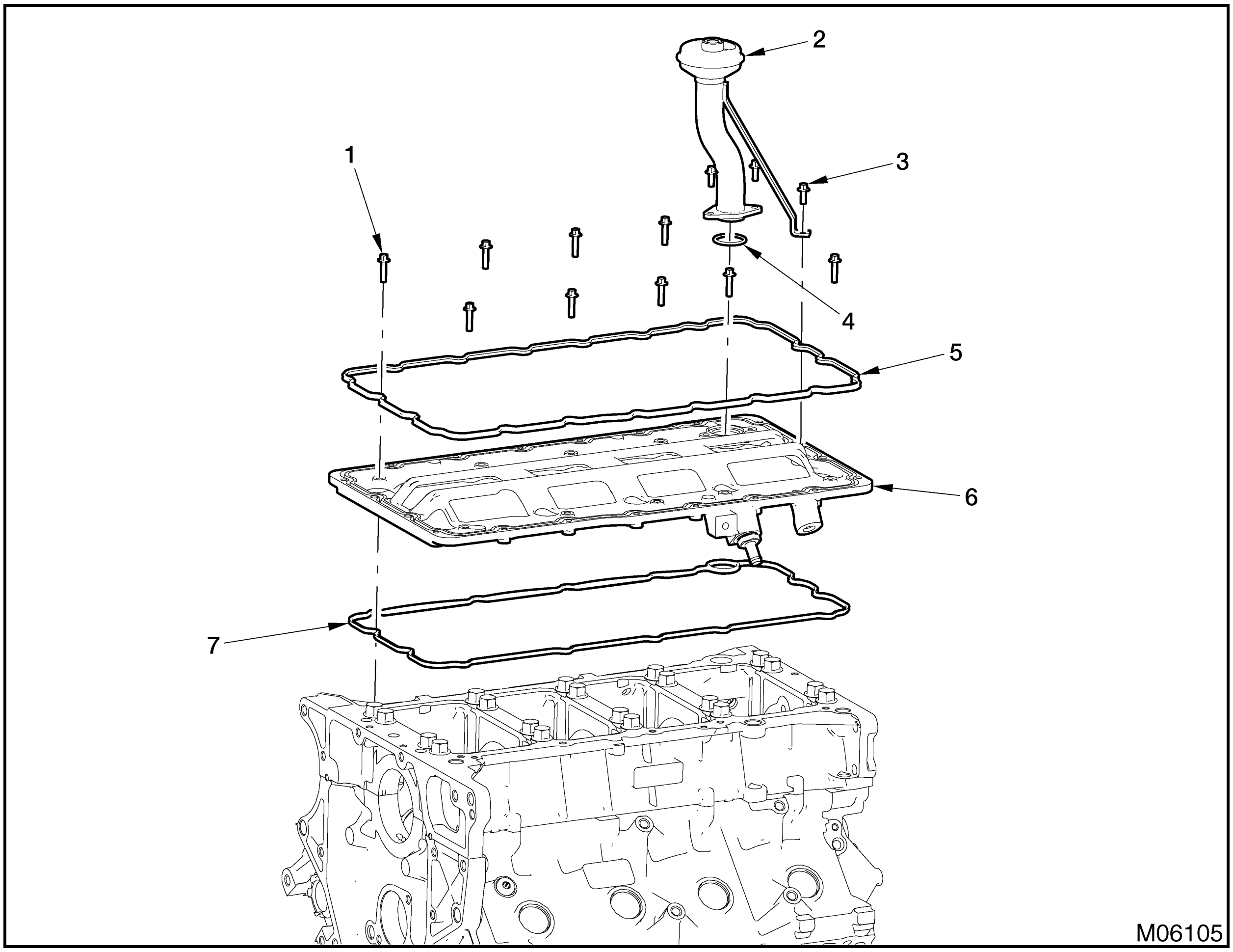

Figure 519 Oil pickup tube and upper oil pan

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

Removal

GOVERNMENT REGULATION: Engine fluids (oil, fuel, and coolant) may be a hazard to human health and the environment. Handle all fluids and other contaminated materials (e.g. filters, rags) in accordance with applicable regulations. Recycle or dispose of engine fluids, filters, and other contaminated materials according to applicable regulations.

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

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

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

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

NOTE: See the following service sections for information on removal of components prior to this section.

- Engine Electrical
- Air Compressor and Power Steering/Fuel Pump

Lower Oil Pan

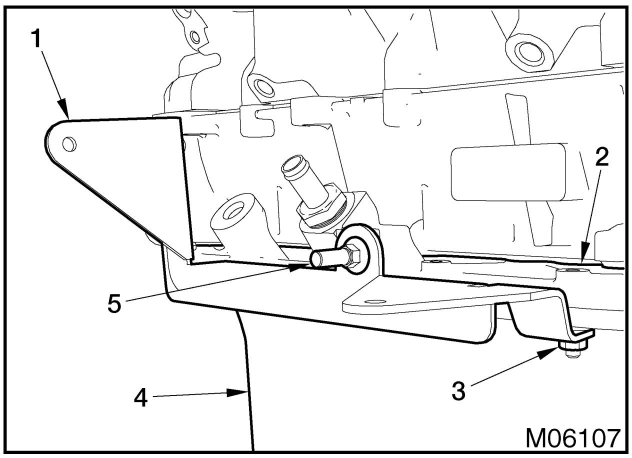

Figure 520 Harness bracket mounting

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

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

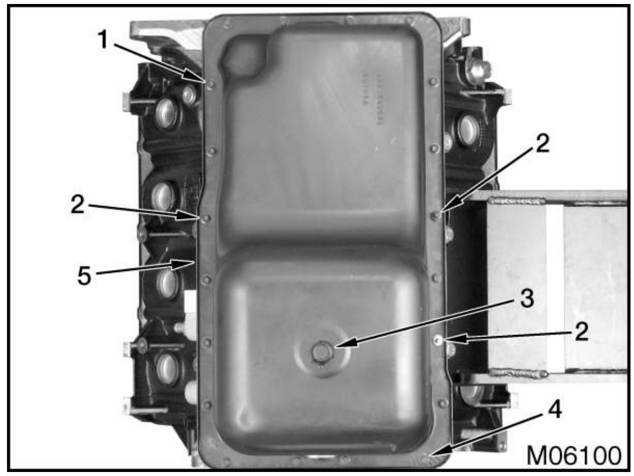

Figure 521 Lower oil pan and oil pan drain plug

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

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

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

Oil Pickup Tube

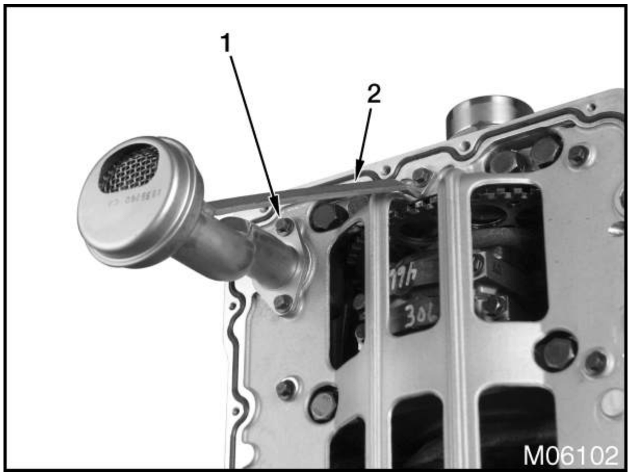

Figure 522 Oil pickup tube

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

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

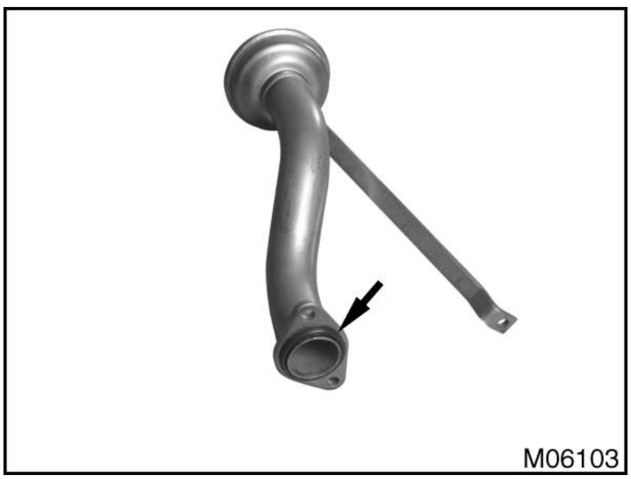

Figure 523 Oil pickup tube O-ring

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

Upper Oil Pan

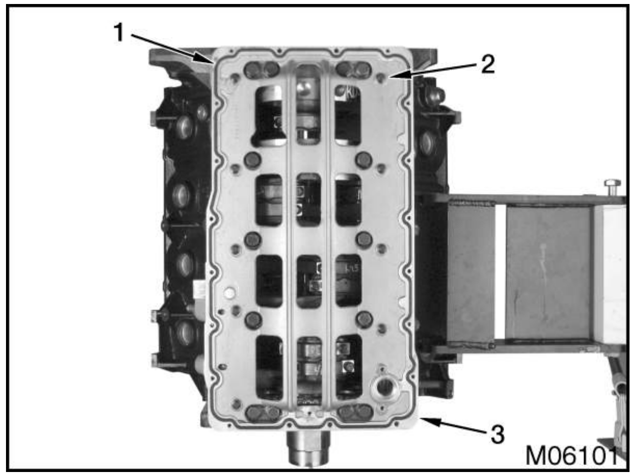

Figure 524 Upper oil pan

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

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

Cleaning and Inspection

Lower Oil Pan

1. Inspect bottom of lower oil pan for metallic debris or other evidence of engine damage. Investigate any abnormalities as required.
2. Clean lower oil pan with a nonchlorinated solvent.

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

3. Dry with filtered compressed air.
4. Look for warping, dents, and cracking. Replace the lower oil pan if necessary.

Oil Pickup Tube

1. Clean oil pickup tube in a nonchlorinated solvent.

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

2. Dry with filtered compressed air.
3. Inspect oil pickup tube and bracket for cracking. Replace if necessary.

Upper Oil Pan

1. Clean upper oil pan in a nonchlorinated solvent.

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

2. Dry with filtered compressed air.
3. Inspect for warping or cracking. Replace upper oil pan if necessary.

Installation

Upper Oil Pan

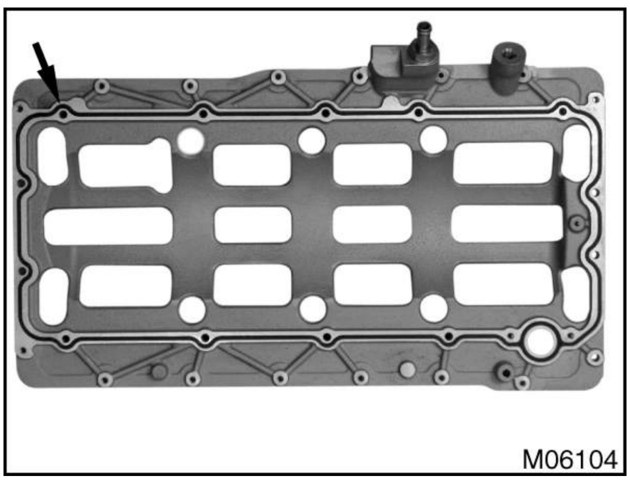

Figure 525 Upper oil pan gasket

1. Install a new upper oil pan gasket.

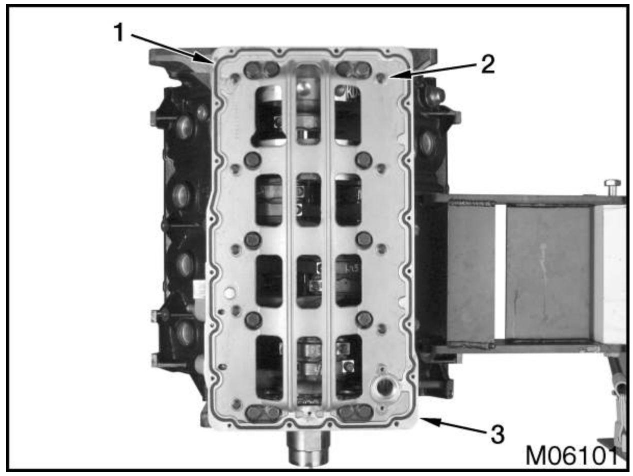

Figure 526 Upper oil pan

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

2. Install upper oil pan and nine M6 x 25 bolts. Tighten bolts to standard torque (page 383).
3. Install a new lower oil pan gasket.

Oil Pickup Tube

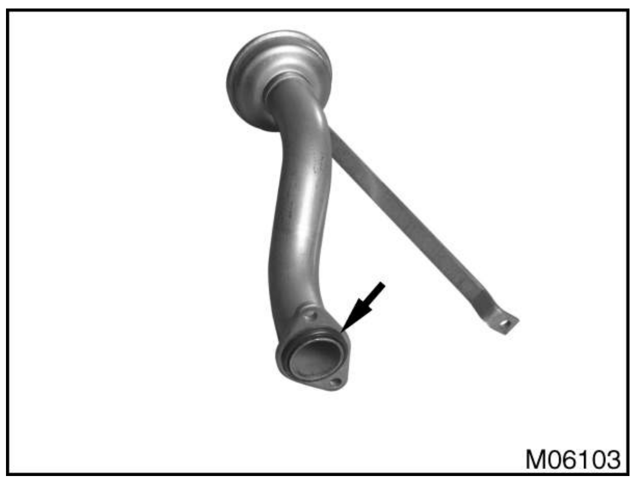

Figure 527 Oil pickup tube O-ring

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

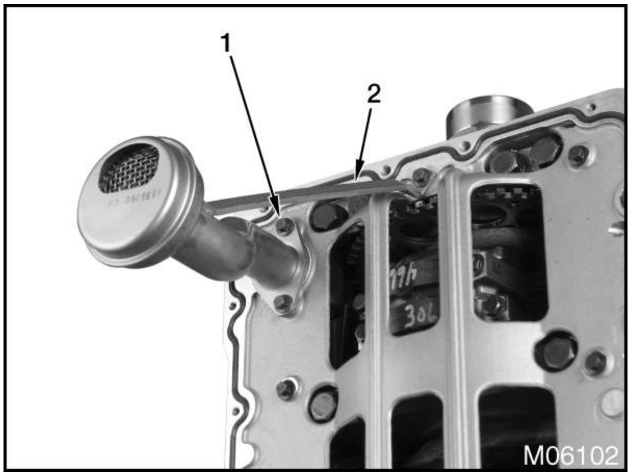

Figure 528 Oil pickup tube

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

2. Install oil pickup tube and three M6 x 16 bolts. Do not tighten at this time.
3. Tighten two M6 x 16 bolts on oil pickup tube flange to standard torque (page 383).
4. Tighten M6 x 16 bolt on oil pickup tube bracket to standard torque (page 383).

Lower Oil Pan

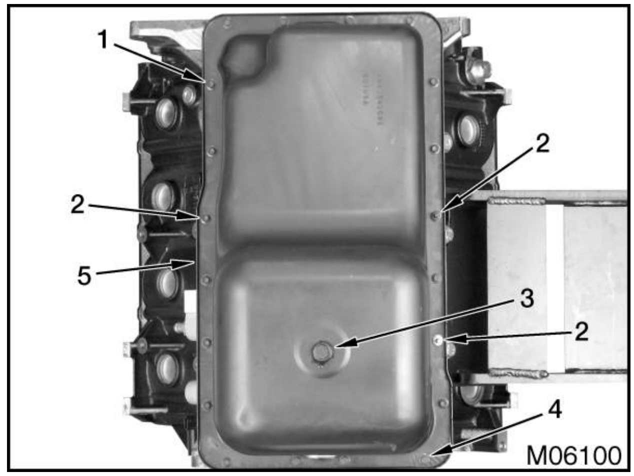

Figure 529 Lower oil pan and oil pan drain plug

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

1. Position lower oil pan on upper oil pan mating surface.
2. Install 12 M6 x 16 bolts.
3. Install five M6 x 25 bolts.
4. Install three M6 x 16 stud bolts.
5. Tighten lower oil pan bolts and stud bolts to special torque (page 313).
6. Install oil pan drain plug with new O-ring, and tighten to special torque (page 313).

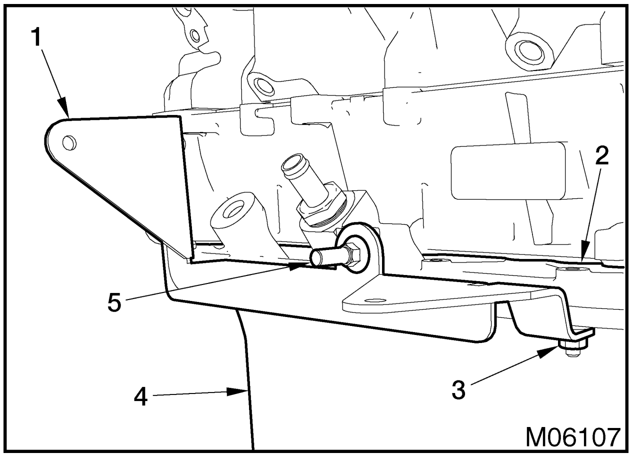

Figure 530 Harness bracket mounting

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

7. Position harness bracket and install M8 stud bolt. Tighten stud bolt to standard torque (page 383).
8. Install M6 harness bracket nut. Tighten nut to standard torque (page 383).

Special Torque

Table 28 Lower Oil Pan

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

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Exploded View

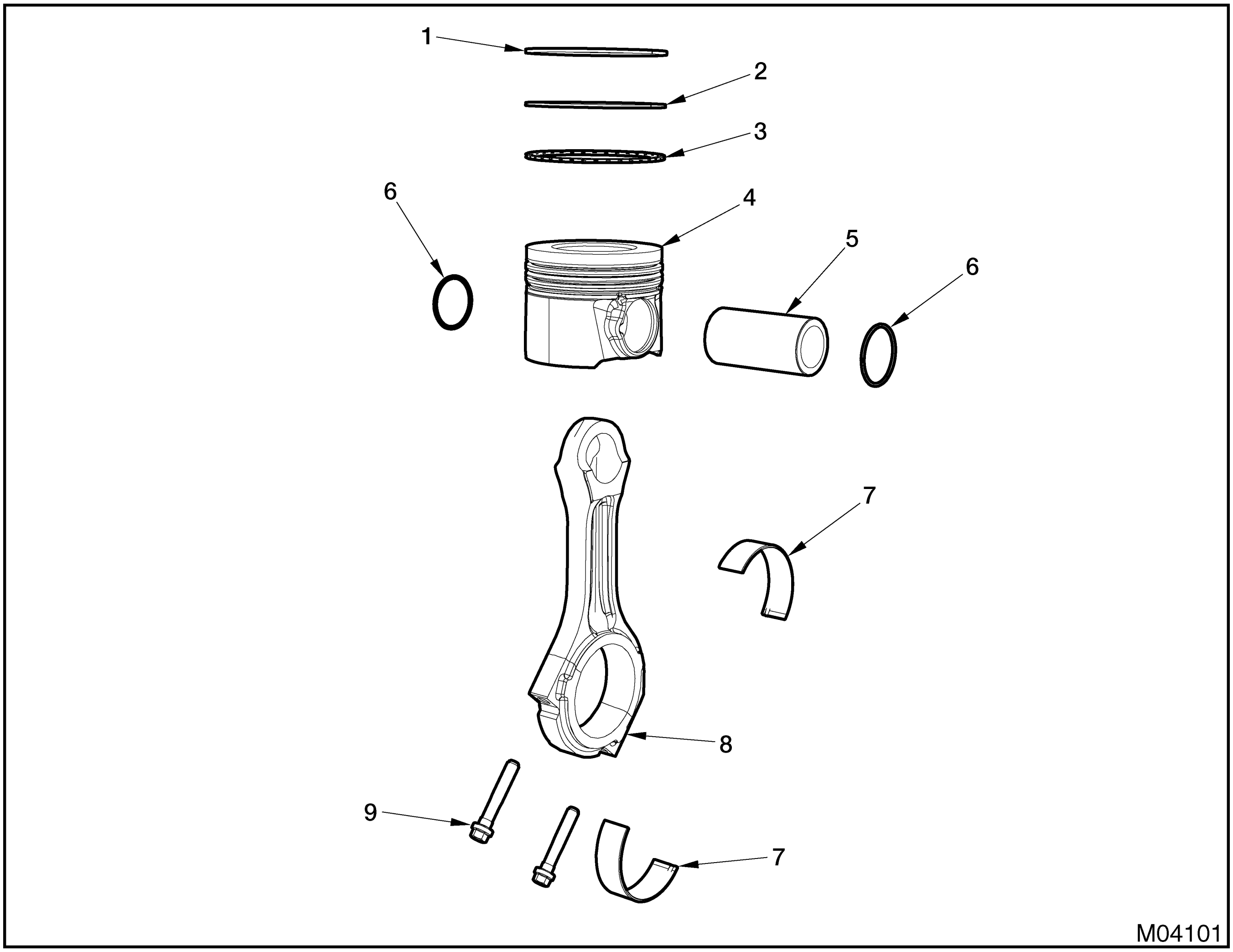

Figure 531 Power cylinder and components

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

Removal

GOVERNMENT REGULATION: Engine fluids (oil, fuel, and coolant) may be a hazard to human health and the environment. Handle all fluids and other contaminated materials (e.g. filters, rags) in accordance with applicable regulations. Recycle or dispose of engine fluids, filters, and other contaminated materials according to applicable regulations.

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 let engine fluids stay on your skin. Clean skin and nails using hand cleaner and wash with soap and water. Wash or discard clothing and rags contaminated with engine fluids.

NOTE: See the following service sections for information on removal of components prior to this section.

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

Preliminary Checks

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

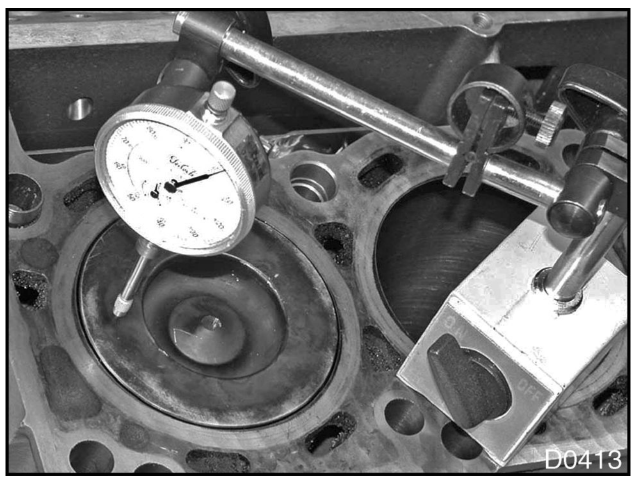

Figure 532 Checking piston protrusion

NOTE: Before checking piston protrusion, make sure upper crankcase assembly deck surface is flat and level. See Crankcase Inspection (page 342).

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

1. Check piston protrusion above upper crankcase assembly as follows:
   a. Zero dial indicator with magnetic base (page 332) on upper crankcase assembly deck surface.
   b. Position dial indicator tip over piston head at 3 o'clock position.
   c. Rotate crankshaft in direction of normal rotation to raise piston to its maximum outward protrusion at cylinder Top Dead Center (TDC). Read this maximum protrusion on dial indicator.
   d. Reposition dial indicator tip on piston head at 9 o'clock position.
   e. Rotate crankshaft to raise the piston to its maximum protrusion. Read maximum protrusion on dial indicator.
   f. Average the two readings. Replace piston and connecting rod if protrusion is outside specifications .

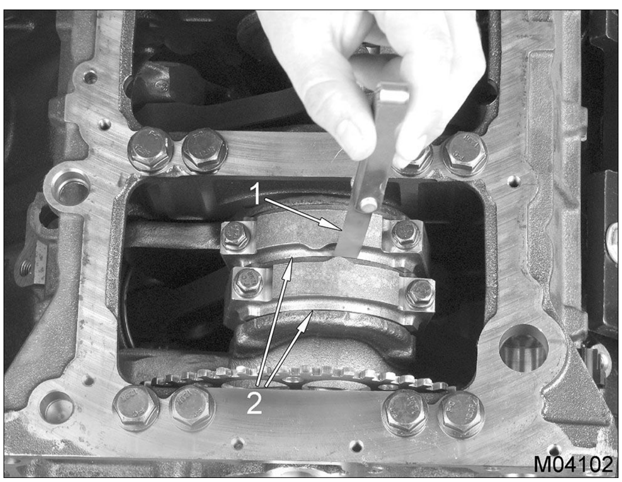

Figure 533 Side clearance check for connecting rod and cap

1. Feeler gauge
2. Connecting rod and cap

2. Use a feeler gauge (page 332) to check connecting rod side clearance as follows:
   a. Pry apart a pair of connecting rods on a crankshaft rod journal. Insert largest possible feeler gauge between connecting rods to check side clearance.
   b. Repeat for each pair of connecting rods on each crankshaft rod journal and compare with specification .

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

Connecting Rod and Piston Assembly

CAUTION: To prevent engine damage, check for a carbon ridge on top of cylinder bores. If found, remove carbon ridge with a razor knife, before removing rod and piston assemblies.

1. Scrape carbon ridge from top of cylinder bore, if necessary. Use care not to damage cylinder bore surface.

CAUTION: To prevent engine damage, stamp, mark, or tag each connecting rod and cap with the correct cylinder number.

This engine has fractured connecting rods. Do not alter or damage fractured mating surfaces of the rod and cap. A cap from one connecting rod is not interchangeable with another connecting rod. The matching connecting rod and cap numbers or symbols indicate a matched set.

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

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

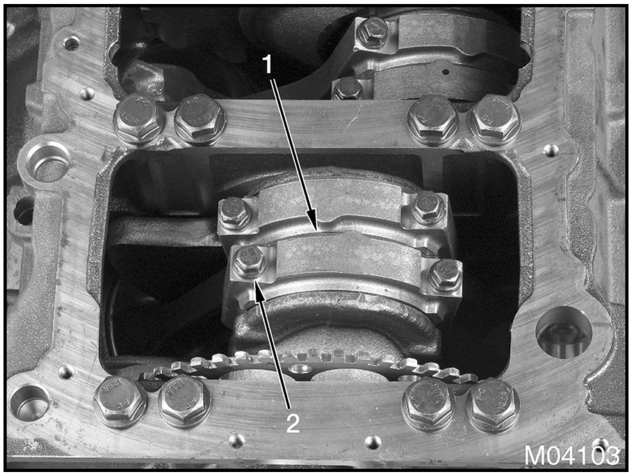

Figure 534 Connecting rod cap bolts

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

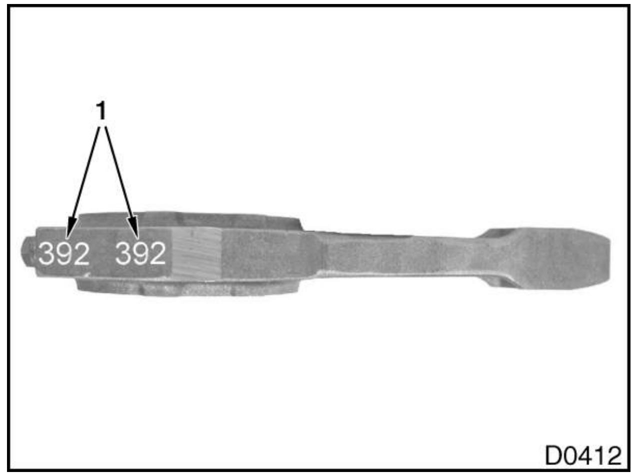

Figure 535 Cap and rod numbers

1. Matching numbers or symbols

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

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

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

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

CAUTION: To prevent engine damage, keep the fractured mating surfaces of the connecting rod and cap clean and free of lint and debris. Do not allow the mating surfaces to rest on other surfaces. Do not bump the mating surfaces or drop the connecting rod or cap. This could chip or mar the mating surfaces, causing incorrect mating of rod and cap.

CAUTION: To prevent engine damage, assemble connecting rod cap and connecting rod with their fractured mating surfaces in the original orientation. Matching numbers must be next to each other.

5. When removed, make sure matching connecting rod and connecting rod cap numbers stay together as a set. A cap from one connecting rod is not interchangeable with any other connecting rod.
6. Check the crankpin fillets for damage. If crankpin fillets are damaged, replace crankshaft assembly. See Crankshaft Assembly (page 338).

Piston Disassembly

WARNING: To prevent personal injury or death, wear safety glasses with side shields when removing piston pin retaining rings.

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

CAUTION: To prevent engine damage, do not stamp marks on any machined surface of piston. If piston must be marked with a stamp, place mark on a non-machined as-cast surface only.

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

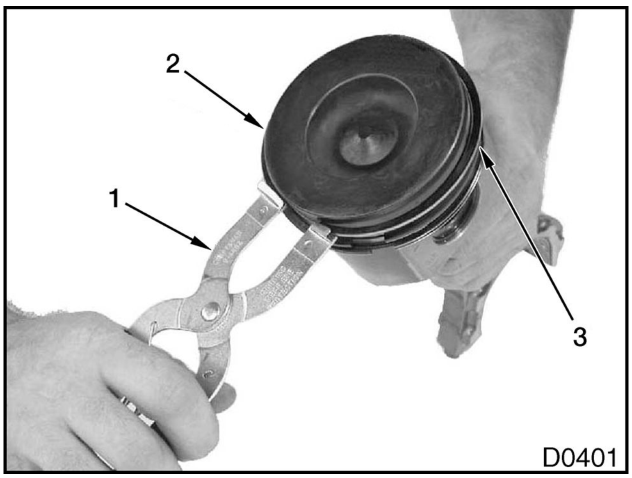

Figure 536 Piston ring removal

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

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

NOTE: Keep piston rings organized for each cylinder.

1. Use piston ring expansion pliers (page 332) to remove top compression ring, intermediate ring, and oil control ring.

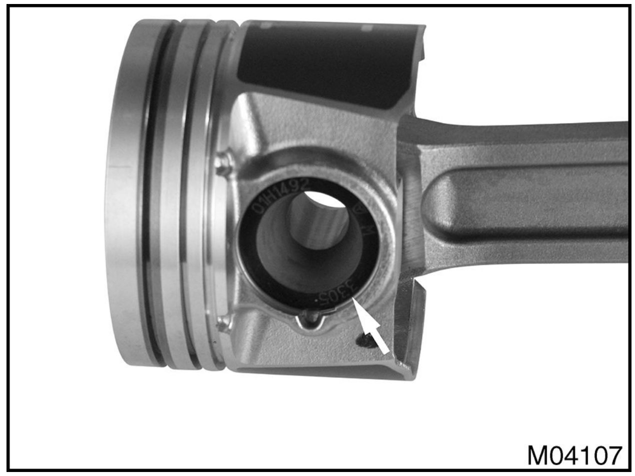

Figure 537 Piston pin retainer ring

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

CAUTION: To prevent engine damage, do not mark piston pin for cylinder and location on outer diameter; place mark only on flat end or tapered inside surface.

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

Cleaning and Inspection

CAUTION: To prevent engine damage, do not use caustic solvents, wire brushes or bead blasting media to clean aluminum pistons.

CAUTION: To prevent engine damage, do not use solvents or a wire brush to clean the fractured mating surface of connecting rods.

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

Pistons

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

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

2. Check top compression ring groove for wear.

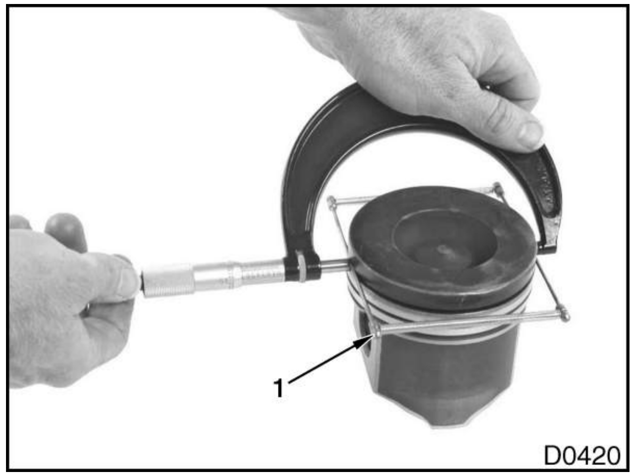

Figure 538 Top compression ring groove

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

3. Install Piston Gauge Pins (2.0828 mm [0.082 in]) (page 332) in top compression ring groove. Piston Gauge Pins must be parallel.
4. Use a 3 - 4 inch micrometer (page 332) to measure diameter over piston gauge pins.
5. If measurement over gauge pin is not within specifications , excessive piston groove wear exists. Replace piston.

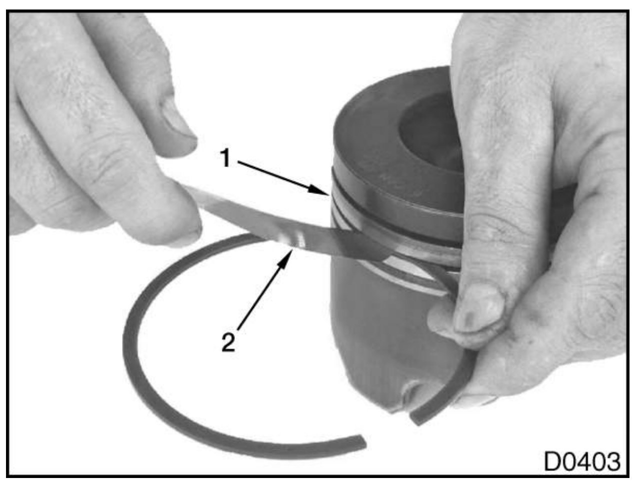

Figure 539 Second and third ring groove clearance check (intermediate ring shown)

1. Intermediate ring groove
2. Feeler gauge

6. Check side clearance of intermediate ring groove as follows:
    a. Place outer edge of new ring in its respective ring groove.
    b. Roll ring entirely around piston in its respective groove. Make sure ring is able to move freely in its groove.
    c. Use a feeler gauge (page 332) to check side clearance of each ring in its respective groove . Excessive side clearance indicates ring groove wear and requires piston replacement.
7. Check side clearance of oil control ring groove as follows:
    a. Place outer edge of new ring in oil control ring groove.
    b. Roll ring entirely around piston in its respective groove. Make sure ring moves freely in groove.
    c. Use a feeler gauge (page 332) to check side clearance of oil control ring in its respective groove . Excessive side clearance indicates ring groove wear and requires piston replacement.

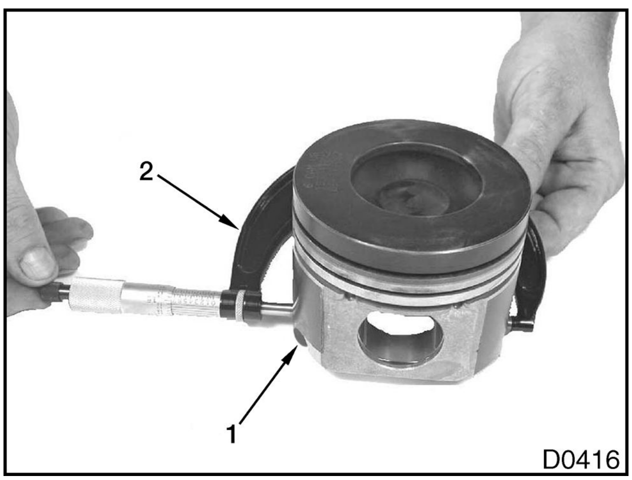

Figure 540 Piston skirt diameter

1. Piston skirt
2. 3 - 4 inch micrometer

8. When considering piston replacement, check cylinder bore out-of-round specifications. See Crankcase Inspection (page 342).
9. If not within specification , cylinder boring may be required. Bore reconditioning requires oversize service pistons. Verify piston size by measuring skirt diameter under conditions indicated in specifications .

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

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

10. If cylinder walls have minor surface damage, but are otherwise within specification (out-of-round), it may be possible to remove such damage by honing. If cylinder bore is suitable for use without reconditioning, deglaze bore using a glaze breaker brush (page 332), then reassemble.

NOTE: See Cylinder Deglazing (page 343) for correct procedure.

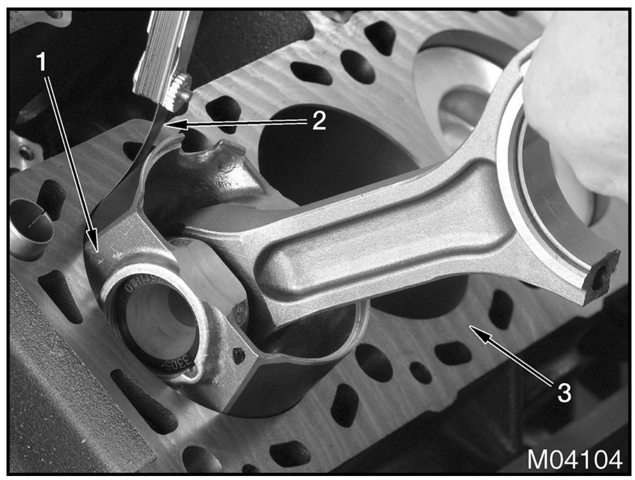

Figure 541 Piston skirt clearance check in cylinder bore

1. Piston
2. Feeler gauge
3. Crankcase

11. Check piston skirt clearance in cylinder bore . Correct as required.

Piston Rings

CAUTION: To prevent engine damage, install new piston rings if a piston is removed. Faulty piston rings cannot always be detected visually.

1. Inspect new piston rings for cleanliness.
2. Before installing new piston rings, check gap for each ring as follows:
   a. Push piston ring down into cylinder bore. Make sure the piston ring is square with cylinder wall. An inverted piston head can be used to push piston ring to desired location of measurement (usually at top of piston stroke).
   b. Use a feeler gauge (page 332) to measure gap between ends of each piston ring.

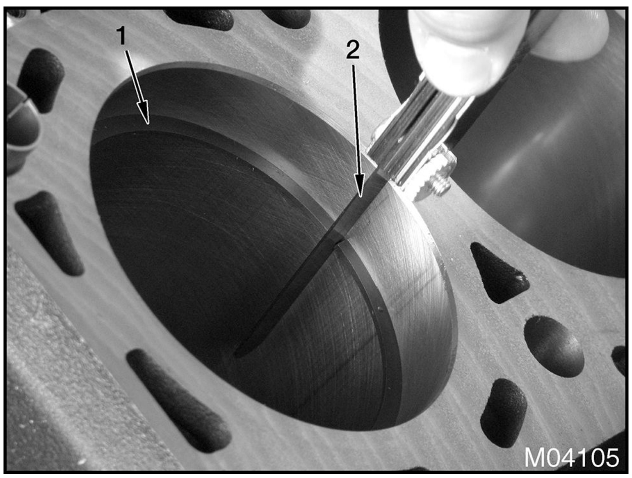

Figure 542 Piston ring end gap clearance in cylinder bore

1. Piston ring
2. Feeler gauge

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

Connecting Rods

CAUTION: To prevent engine damage, keep the fractured mating surfaces of the connecting rod and cap clean and free of lint and debris. Do not allow the mating surfaces to rest on other surfaces. Do not bump the mating surfaces or drop the connecting rod or cap. This could chip or mar the mating surfaces, causing incorrect mating of rod and cap.

CAUTION: To prevent engine damage, do not use solvents or a wire brush to clean the fractured mating surface of connecting rods.

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

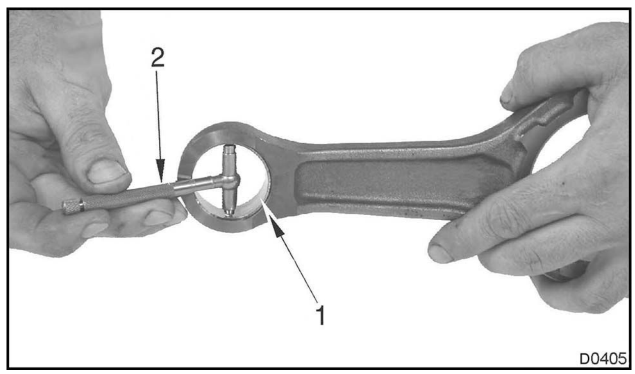

Figure 543 Inside diameter of piston pin bore

1. Piston pin bore
2. Telescoping gauge

3. Inspect connecting rod piston pin bore for wear as follows:
   a. Use a telescoping gauge (page 332) and a 1-2 inch micrometer (page 332) to measure piston pin bore at two locations 90° apart.
   b. If inside diameter of piston pin bore exceeds specification , replace connecting rod.

Connecting Rod Bore Out-of-round Check

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

1. Lubricate connecting rod bolts with clean engine oil. Assemble cap to rod without bearing insert. Tighten bolts to initial and final torque values (page 332).

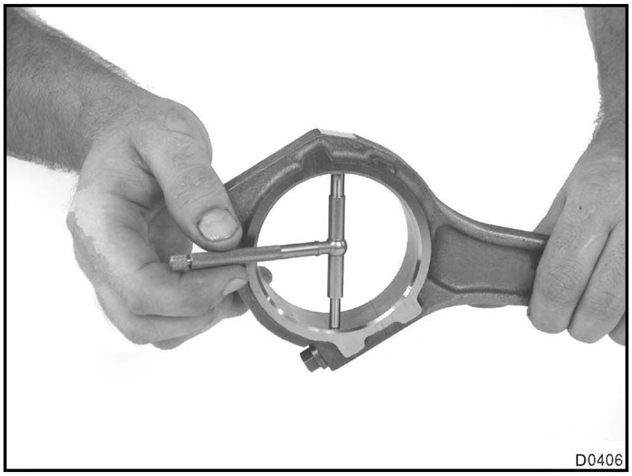

Figure 544 Measurement for out-of-round of connecting rod

2. Using a telescoping gauge (page 332), measure connecting rod bearing bore at two locations, 90° apart.
3. If the difference between dimension A and B exceeds out-of-round specifications , replace connecting rod.
4. With connecting rod cap removed, inspect surface finish of connecting rod bearing bore. Bore must be smooth and free of scoring, nicks or burrs. Replace as required.

Connecting Rod Bearing Fit Check

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

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

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

1. Lubricate connecting rod bolts with clean engine oil. Assemble cap to connecting rod with new bearing shells installed. Tighten bolts to initial and final torque values (page 332).
2. Using a telescoping gauge (page 332), measure inside diameter of connecting rod bearing at two locations 90° apart. Average the two inside diameters.
3. Use a 2–3 inch micrometer (page 332) to measure each crankshaft rod journal diameter.
4. Subtract crankshaft rod journal diameter from respective connecting rod bearing inside diameter to obtain connecting rod bearing running clearance. Repeat for each crankshaft rod journal.

CAUTION: To prevent engine damage, do not rework bearings or bearing caps to reduce journal-to-bearing running clearances. Grind or install new crankshaft.

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

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

Piston Pin Inspection

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

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

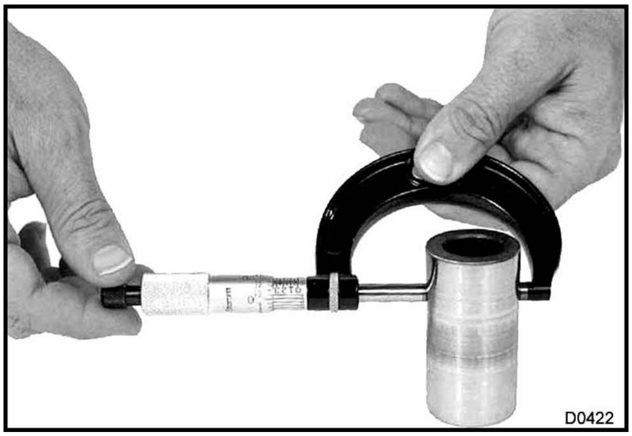

Figure 545 Piston pin wear

2. Use a 1-2 inch micrometer (page 332), measure piston pin outside diameter at two locations 90° apart.
3. Measure each end of the pin. If piston pin wear exceeds specifications , replace piston pin.

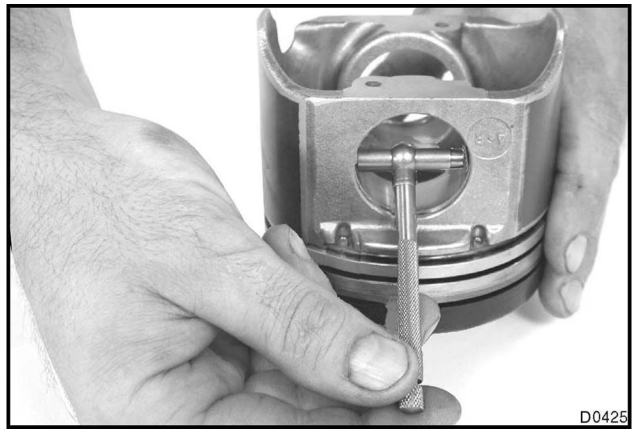

Figure 546 Inside diameter measurement of piston pin bore

4. Using a telescoping gauge (page 332) and 1–2 inch micrometer (page 332), measure each piston pin bore inside diameter, at two locations 90° apart.
5. To check piston pin clearance, subtract outside diameter of piston pin from inside diameter of piston pin bore. If clearance exceeds specifications , replace piston pin and check piston pin clearance using new piston pin.

Installation

Piston Assembly

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

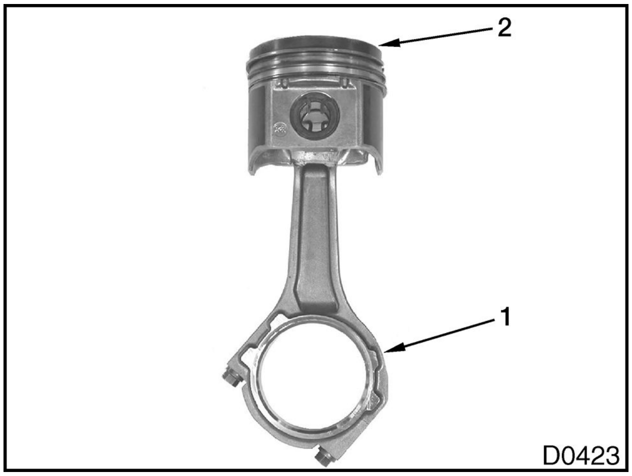

Figure 547 Correct position of installed connecting rod

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

1. Connect piston to connecting rod as follows:
   a. Lubricate connecting rod piston pin bore, piston pin bore, and piston pin with clean engine oil.
   b. Position the longer leg of the connecting rod with the side of the piston showing the CAM SIDE stamped in its crown.
   c. Place connecting rod into piston.

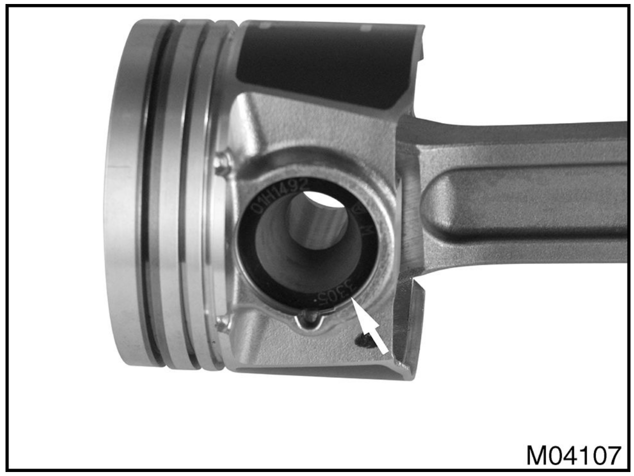

Figure 548 Piston pin retainer ring

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

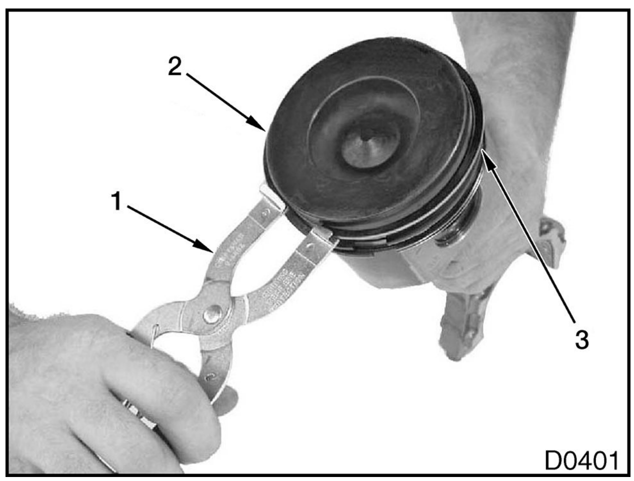

Figure 549 Piston rings installed

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

CAUTION: To prevent engine damage, install piston rings correctly. Both intermediate and compression rings have the same identification markings. The marking must face up for the ring to be installed correctly. The intermediate ring has a rectangular cross section and goes in the middle groove. The top compression ring has a keystone cross section and goes in the top groove.

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

2. Use piston ring expansion pliers (page 332) to install piston rings.
   a. Install expansion spring component of two piece oil control ring into bottom piston groove.
   b. Install oil scraper component of two piece oil control ring over expansion spring with the gap 180° from the spring wire latch.

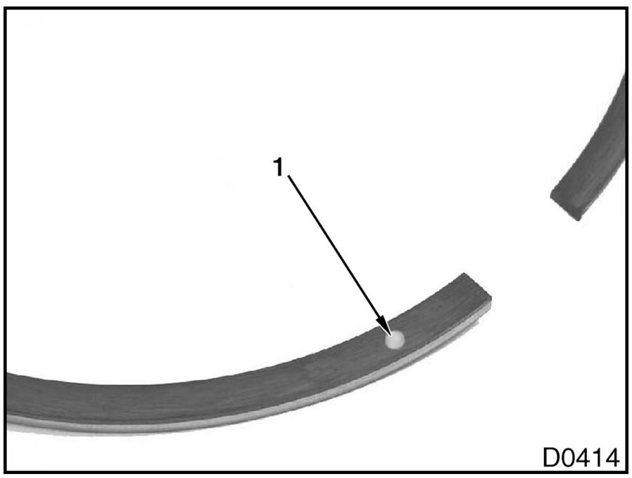

Figure 550 Piston ring identification mark (top compression ring)

1. Identification mark

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

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

Connecting Rod and Piston Assembly

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

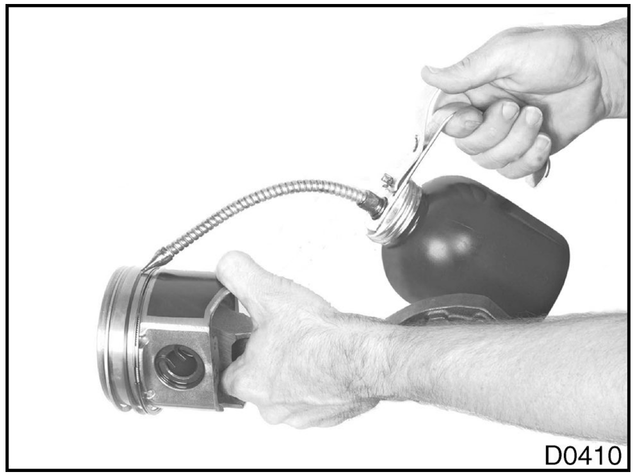

Figure 551 Piston and piston ring lubrication

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

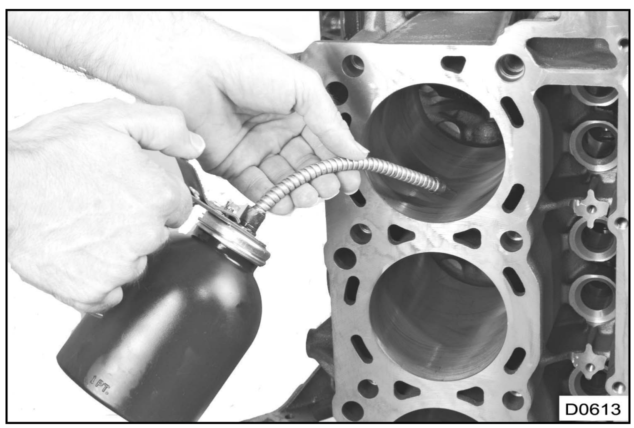

Figure 552 Cylinder wall lubrication

3. Coat cylinder walls, crankshaft journals, and Piston Ring Compressor (page 332) with clean engine oil.

Figure 553 Piston installed in piston ring compressor

4. Place piston in Piston Ring Compressor (page 332).
5. Install bearing shells in connecting rod and cap. Coat bearing shell in connecting rod with clean engine oil.

Figure 554 CAM SIDE stamp on piston

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

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

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

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

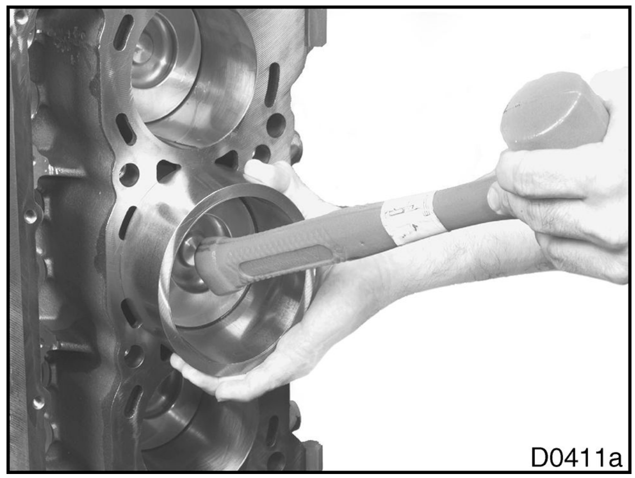

Figure 555 Installation of piston in cylinder bore

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

CAUTION: To prevent engine damage, lightly lubricate bolt threads and mating surfaces of bolt flanges with clean engine oil. Too much oil will cause hydrostatic lock and give incorrect torque reading.

8. Apply clean engine oil to bolt hole threads for connecting rod and bearing shell in cap before installing bolts.

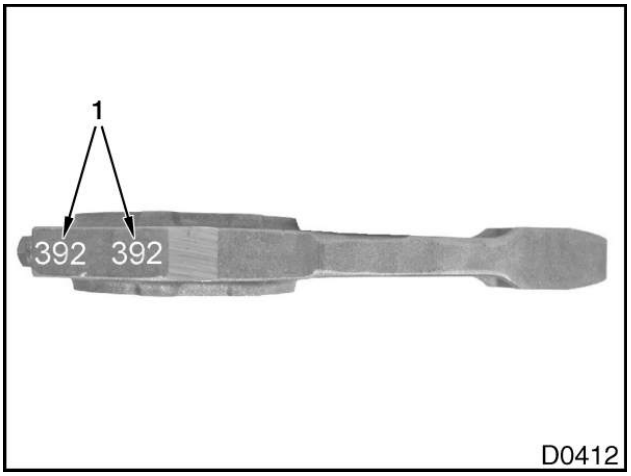

Figure 556 Connecting rod and cap

1. Matching numbers or symbols

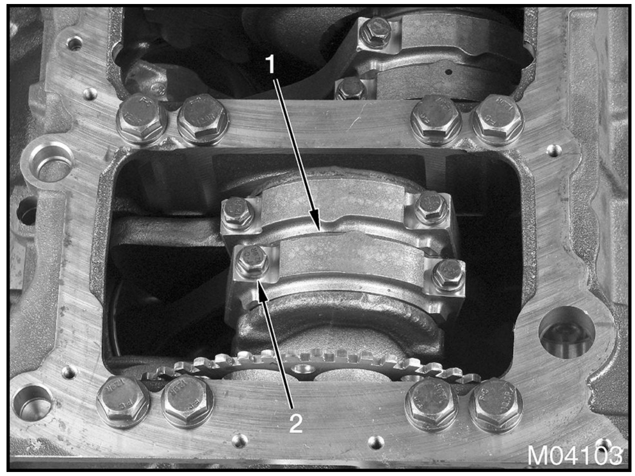

Figure 557 Connecting rod cap

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

CAUTION: To prevent engine damage, install connecting rods with correct caps in the correct direction. If a rod cap is reversed, an offset will be seen at the mating surfaces. If a reverse assembly is installed on the crankshaft, the connecting rod must be replaced. Also, check crank pin fillets for damage that would require replacement of the crankshaft.

9. Assemble cap to connecting rod with matching identification code on same crankshaft journal from which it was removed. Be certain that longer leg of connecting rod and CAM SIDE stamp on piston crown are positioned towards camshaft.

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

CAUTION: To prevent engine damage, do not rotate crankshaft until connecting rod is fully tightened, as this may cause bearing shells to rotate in place.

10. Install and tighten connecting rod bolts evenly to initial and final torque values (page 332).
11. Repeat installation procedure for remaining connecting rod and piston assemblies.
12. Check connecting rod side clearance with feeler gauge. See procedure in removal section (page 319).

Specifications

Table 29 Power Cylinders

Connecting Rods	
Connecting rod length (center to center)	176 mm (6.929 in)
Piston pin bore inside diameter	38.542 to 38.849 mm (1.5174 to 1.5295 in)
Material	I-Beam section - powdered metal
Bearing bore diameter (crankshaft end)	75.987 to 76.013 mm (2.9916 to 2.9926 in)
Bearing bore maximum out-of-round	0.013 mm (0.0005 in)
Connecting rod bearing inside diameter	72.031 to 72.073 mm (2.8359 to 2.8375 in)
Connecting rod bearing running clearance (diameter)	0.015 to 0.089 mm (0.0006 to 0.0035 in)
Connecting rod side clearance	0.230 to 0.730 mm (0.0091 to 0.0287 in)
Weight (complete rod without bearing)	1274.89 to 1295.89 g (2.811 to 2.857 lb)
Pistons	
Material	Aluminum Alloy
Skirt diameter [1]	98.114 to 98.146 mm (3.863 to 3.864 in)
[1] Measure 15.5 mm (0.610 in) from bottom, at 90° to the piston pin. Measure only at room temperature of 19 to 21 °C (66 to 70 °F).	
Service Piston:	
Standard size	98.114 to 98.146 mm (3.863 to 3.864 in)
0.254 mm (0.010 in) oversize	98.368 to 98.400 mm (3.873 to 3.874 in)
0.508 mm (0.020 in) oversize	98.622 to 98.654 mm (3.883 to 3.884 in)
0.762 mm (0.030 in) oversize	98.876 to 98.908 mm (3.893 to 3.894 in)
Top compression ring groove width (measured over 2.10 mm (0.082 in) gauge pins):	
Upper limit	96.606 mm (3.8033 in)
Replacement limit	96.406 mm (3.7955 in)
Ring groove (side clearance):	
Intermediate compression	0.050 to 0.096 mm (0.0020 to 0.0038 in)
Oil control	0.040 to 0.095 mm (0.00157 to 0.00374 in)
Piston height above crankcase deck (protrusion)	0.609 to 0.863 mm (0.0240 to 0.0340 in)
Piston skirt clearance	0.045 to 0.095 mm (0.0018 to 0.0037 in)
Piston Pins	
Length	74.6 to 75.0 mm (2.9371 to 2.9528 in)
Diameter	38.491 to 38.501 mm (1.5154 to 1.5158 in)
Pin fit at room temperature of 19 to 21 °C (66 to 70 °F):	

Table 29 Power Cylinders (cont.)

Clearance in connecting rod (piston pin bore)	0.041 to 0.058 mm (0.0016 to 0.0022 in)
Clearance in piston (piston pin bore)	0.011 to 0.027 mm (0.0004 to 0.0011 in)
End clearance	0.84 mm (0.0331 in)
Piston Rings	
Ring diameter (standard):	98.2 mm (3.866 in)
Ring gap in bore:	
Top compression	0.29 to 0.55 mm (0.011 to 0.021 in)
Intermediate compression	1.42 to 1.68 mm (0.0559 to 0.0661 in)
Oil control	0.24 to 0.50 mm (0.009 to 0.019 in)

Special Torque

Table 30 Power Cylinders

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

Special Service Tools

Table 31 Power Cylinders

Description	Tool Number
1–2 inch micrometer	Obtain locally
2–3 inch micrometer	Obtain locally
3–4 inch micrometer	Obtain locally
Dial indicator with magnetic base	Obtain locally
Feeler gauge	Obtain locally
Glaze breaker brush	Obtain locally
Piston Gauge Pins (2.0828 mm [0.082 in])	ZTSE4513
Piston Ring Compressor	ZTSE4714
Piston ring expansion pliers	Obtain locally
Telescoping gauge set	Obtain locally

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Exploded View

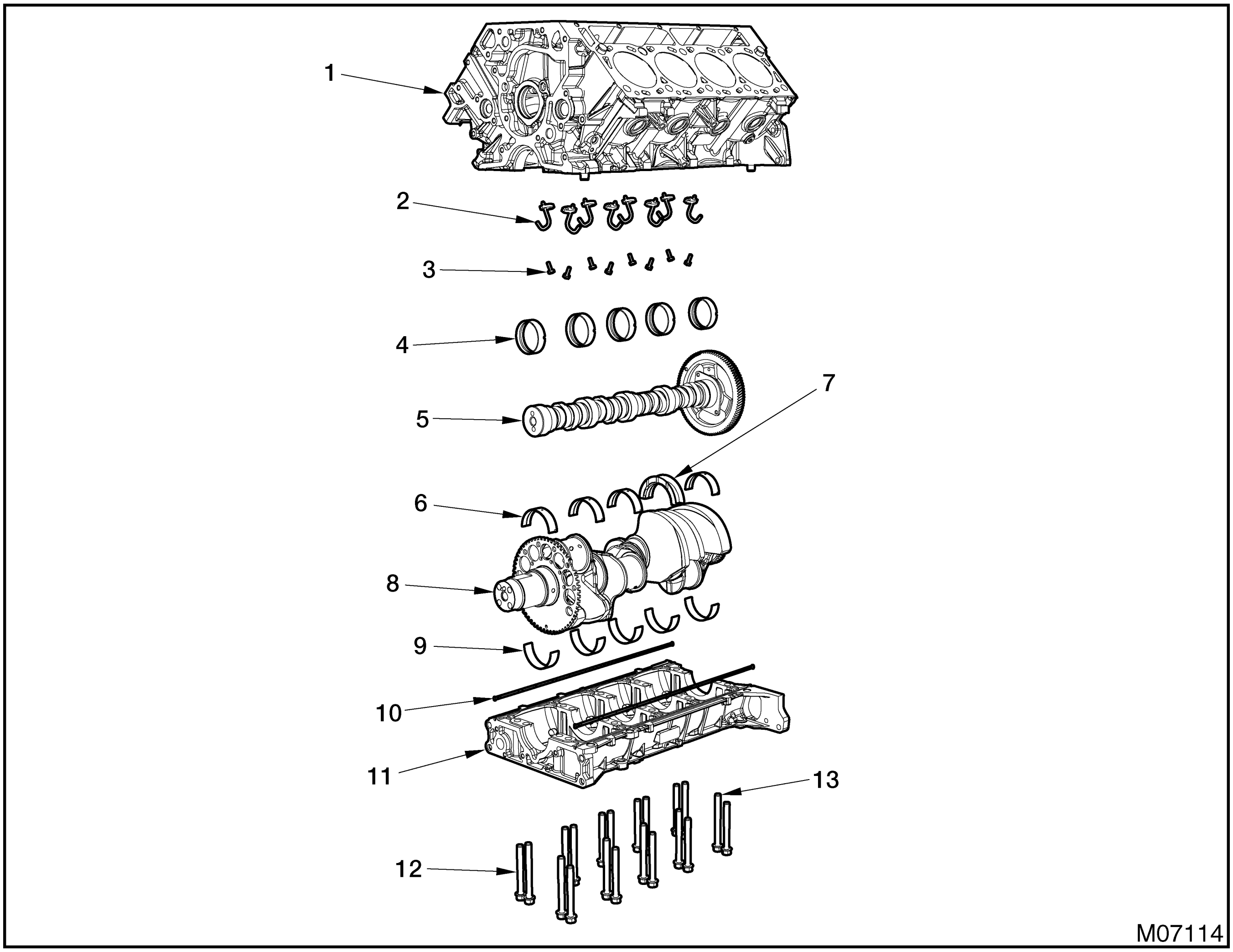

Figure 558 Crankcase, Crankshaft, and Camshaft

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

Removal

GOVERNMENT REGULATION: Engine fluids (oil, fuel, and coolant) may be a hazard to human health and the environment. Handle all fluids and other contaminated materials (e.g. filters, rags) in accordance with applicable regulations. Recycle or dispose of engine fluids, filters, and other contaminated materials according to applicable regulations.

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 let engine fluids stay on your skin. Clean skin and nails using hand cleaner and wash with soap and water. Wash or discard clothing and rags contaminated with engine fluids.

NOTE: See the following service sections for information on removal of components prior to this section.

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

Preliminary Checks

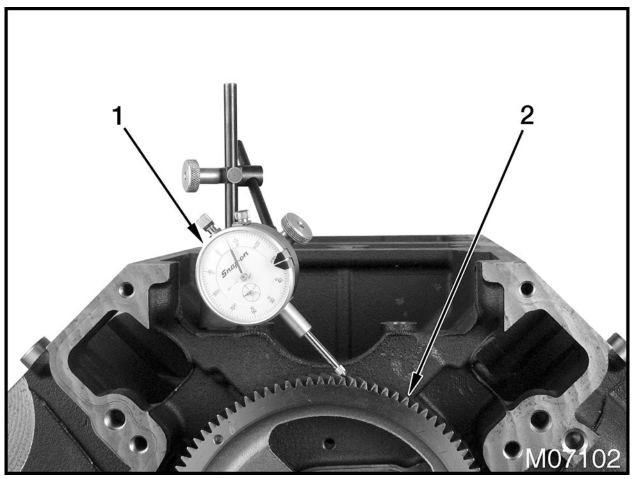

Figure 559 Camshaft assembly gear backlash check (camshaft gear to crankshaft gear)

1. Dial indicator with magnetic base
2. Camshaft gear

1. Check and record camshaft gear backlash as follows:
   a. Mount dial indicator with magnetic base (page 353) on rear of engine.

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

c. Zero the dial indicator.

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

e. If camshaft gear backlash exceeds specified limits (page 352), replace camshaft assembly.

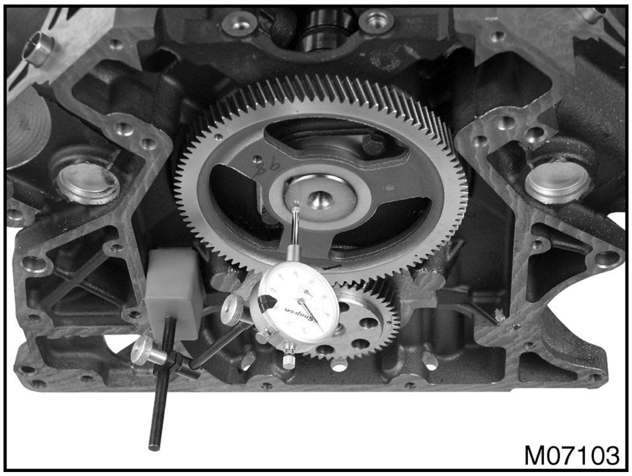

Figure 560 Camshaft end play

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

a. Push camshaft to front of engine.

b. Zero the dial indicator.

c. Place a small pry bar between camshaft gear and crankcase and gently pry camshaft forward. Compare dial indicator reading with specifications (page 352).

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

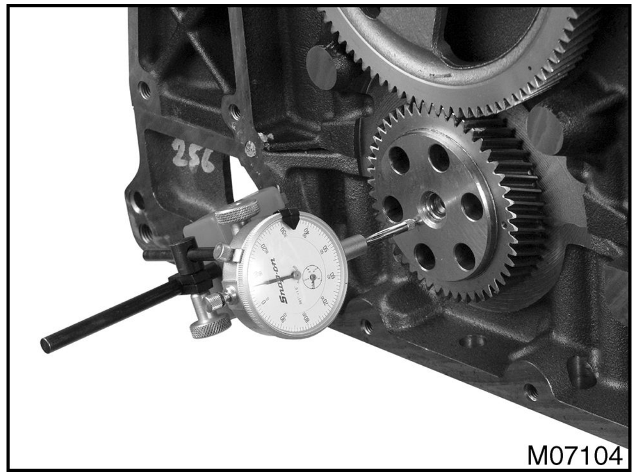

Figure 561 Crankshaft end play

3. Check crankshaft end play as follows:

a. Mount dial indicator on lower crankcase assembly with indicator tip on end of crankshaft gear as shown.

b. Move crankshaft forward with pry bar and zero the dial indicator.

c. Move crankshaft back and forth while reading dial indicator. Compare dial indicator reading with specifications (page 352).

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

Lower Crankcase Assembly

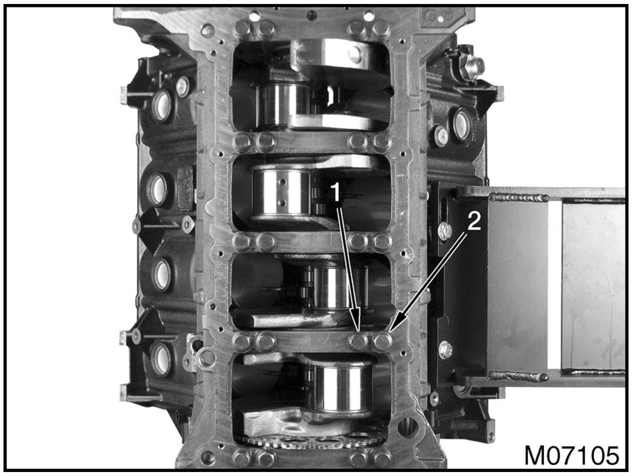

Figure 562 Main bearing bolts

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

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

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

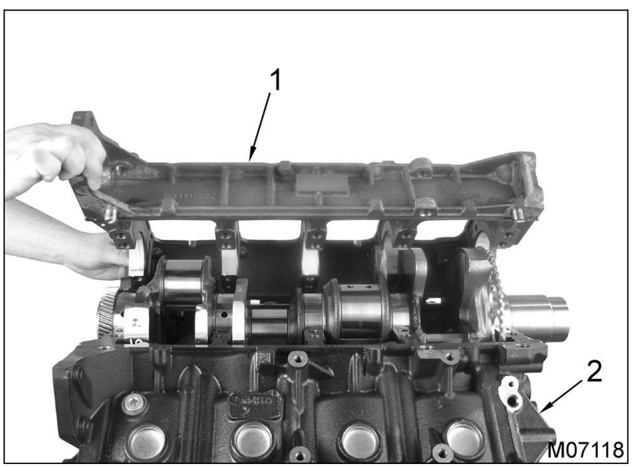

Figure 563 Lower crankcase assembly

1. Lower crankcase assembly
2. Upper crankcase assembly

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

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

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

Crankshaft Assembly

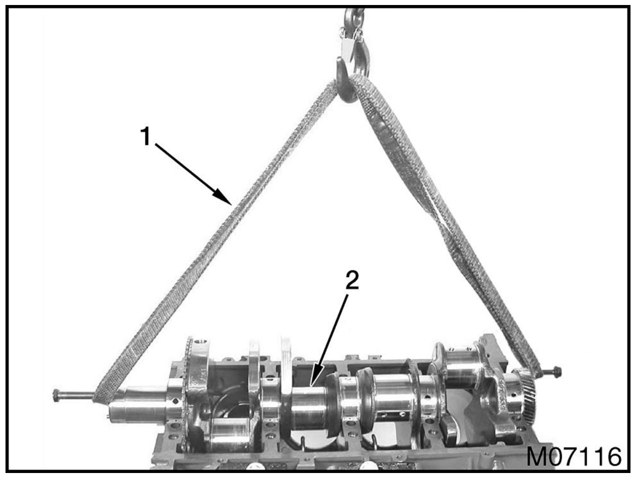

Figure 564 Lifting sling

1. Lifting sling
2. Crankshaft assembly

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

1. Install a bolt in each end of crankshaft.

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

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

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

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

Piston Cooling Tubes

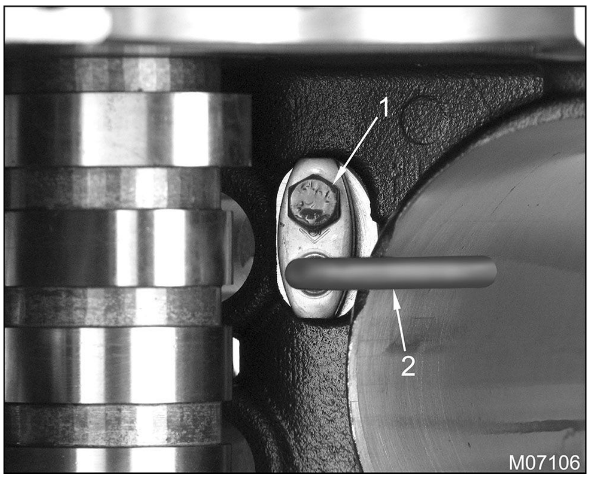

Figure 565 Piston cooling tube

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

Remove each piston cooling tube by removing its special patch type mounting bolt (M6 x 18). The bolts are reusable, providing bolt is cleaned and inspected, and Liquid Gasket (RTV) (page 353) is added to bolt threads before installation.

Camshaft Assembly

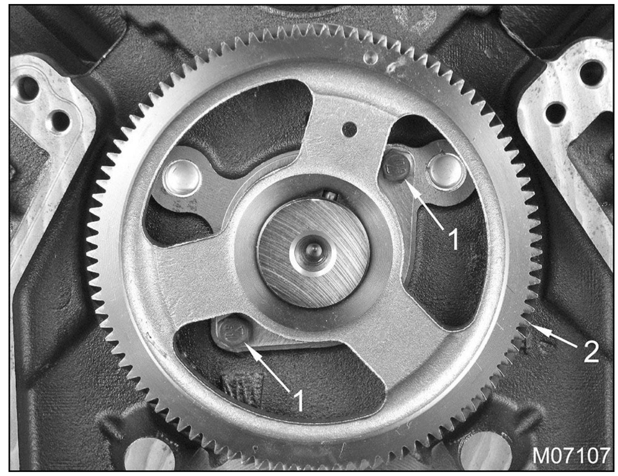

Figure 566 Camshaft thrust plate bolts

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

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

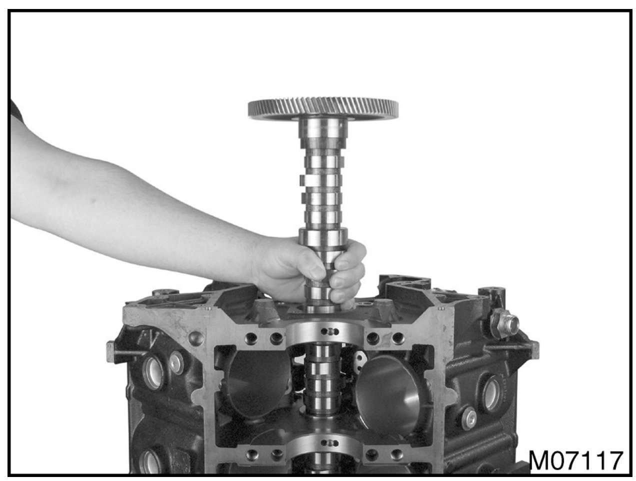

Figure 567 Camshaft assembly

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

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

Camshaft Bushings

1. Determine necessity of replacing bushings based on running clearance (page 345).

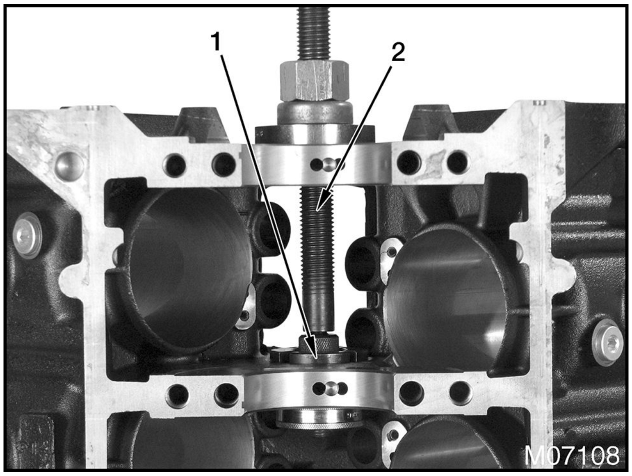

Figure 568 Camshaft bushing

1. Camshaft bushing remover/installer (expanding collet)
2. Pulling screw (from Camshaft Bushing Service Set)

2. Use Camshaft Bushing Service Set (page 353) with Camshaft Bushing Remover/Installer (expanding collet) (page 353) to remove all camshaft bushings. Install Camshaft Bushing Remover/Installer (expanding collet in collapsed state) in camshaft bushing.

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

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

Coolant Heater

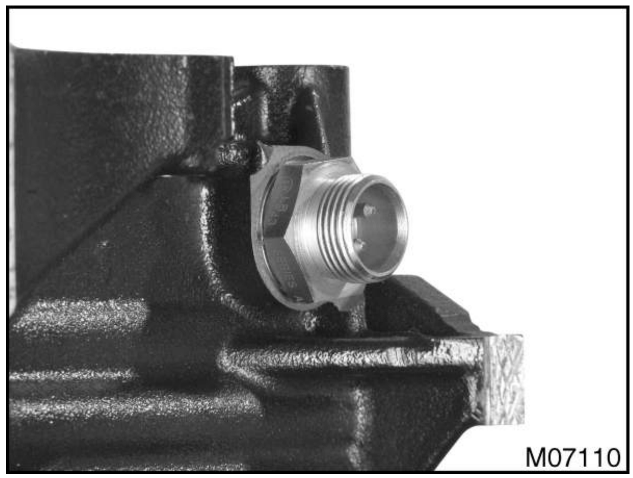

Figure 569 Coolant heater

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

Cleaning, Inspection, and Testing

Crankcase Assembly

Crankcase Cleaning

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

1. Clean upper and lower crankcase assemblies in a chemical bath or hot tank. This removes all carbonized material and mineral deposits in coolant passages.

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

2. If a hot tank is not available, do the following steps:
   a. Use non-metallic stiff bristle brushes and scrapers to clean gasket material from machined surfaces of upper crankcase assembly.
   b. Clean cylinder bore with soap, water, and a stiff nylon brush.
   c. Clean upper and lower crankcase assemblies in a nonchlorinated solvent.
   d. Dry with filtered compressed air.
3. Remove main oil gallery cup plugs (in rear of upper crankcase assembly) using a punch and hammer near edge of plug and striking with hammer.
4. Remove plugs from upper crankcase assembly and discard.

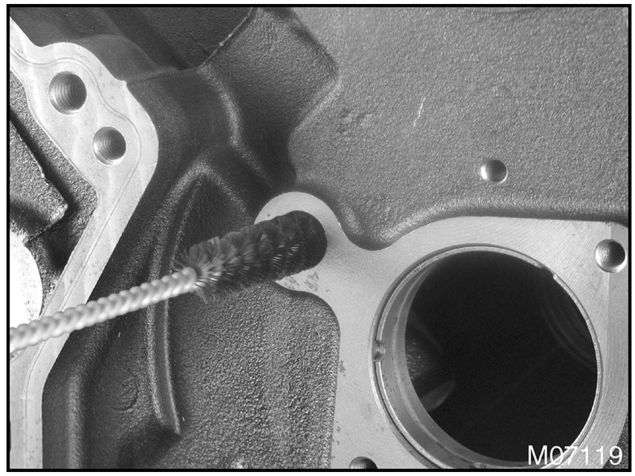

Figure 570 Main oil gallery cleaning

5. Clean main oil galleries with Oil Gallery Cleaning Brush (page 353).

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

NOTE: Use Liquid Gasket (RTV) (page 353) before installing main oil gallery cup plugs.

6. Coat edges of new oil gallery cup plugs with Liquid Gasket (RTV) (page 353). Use Oil Gallery Plug Driver (page 353) and install new oil gallery cup plugs. The Oil Gallery Plug Driver installs oil gallery cup plugs to correct depth. They should be flush with upper crankcase assembly surface to approximately 1.50 mm (0.060 in) below surface.

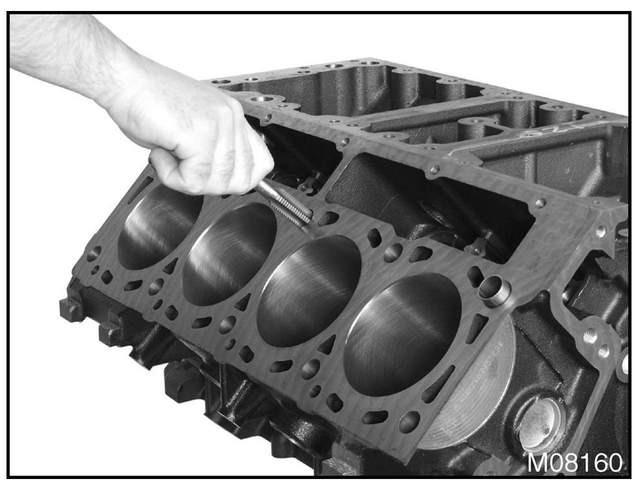

Figure 571 Cylinder head bolt holes

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

7. Clean cylinder head bolt holes with Cylinder Head Bolt Tap (page 353).

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

8. Blow out chips with filtered compressed air.

Crankcase Inspection

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

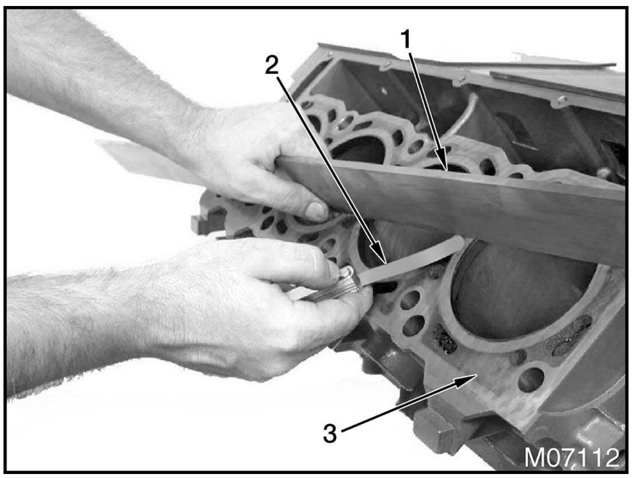

Figure 572 Flatness check for top surface of upper crankcase assembly

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

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

2. Use a straightedge (page 353) to check top surface of upper crankcase assembly (firing deck) for flatness. Insert a feeler gauge (page 353) between straightedge and upper crankcase assembly head surface.
   a. Measure entire deck surface. If gap exceeds specifications (page 352), replace upper crankcase assembly.

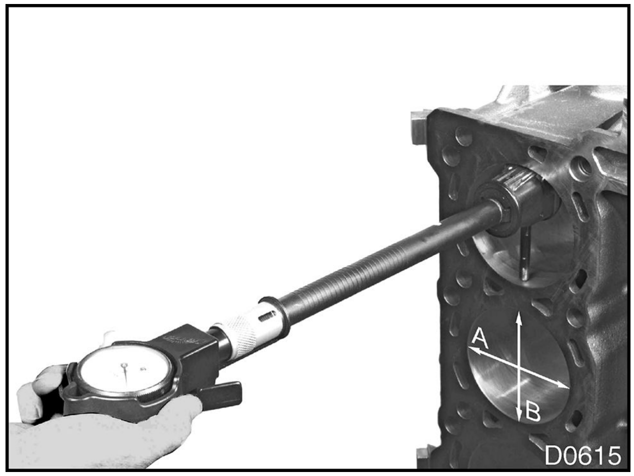

Figure 573 Out-of-round cylinder bore check

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

NOTE: If cylinder walls have minor surface damage, but are otherwise within out-of-round specifications, it may be possible to remove damage by deglazing (page 343) .

3. Use a cylinder bore gauge (page 353) to check cylinder bore out-of-round conditions.
   a. Measure diameter of each cylinder bore at top of piston ring travel. Be sure to measure at a right angle to center line of crankshaft assembly (dimension A).
   b. Measure each bore so gauge reading coincides with center line of crankshaft assembly (dimension B).
   c. The difference between dimension A and dimension B is out-of-round condition at top of cylinder bore.
4. Repeat procedure at bottom of ring travel to check for out-of-round condition.

NOTE: If cylinder bore is suitable for use without reconditioning, deglaze cylinder bore before assembling. See Cylinder Deglazing (page 343) for further details.

5. If cylinder bore is within specifications (page 352), standard size pistons and rings may be used.

Cylinder Deglazing

NOTE: Remove piston cooling tubes before deglazing cylinder bores.

1. Use deglazing hone (four inch) (page 353) to deglaze cylinder bore. This brush quickly deglazes cylinder walls and produces a crosshatch pattern on cylinder wall surface in a single operation. The brush contours itself to cylinder wall and conditions wall surface without altering cylinder bore.

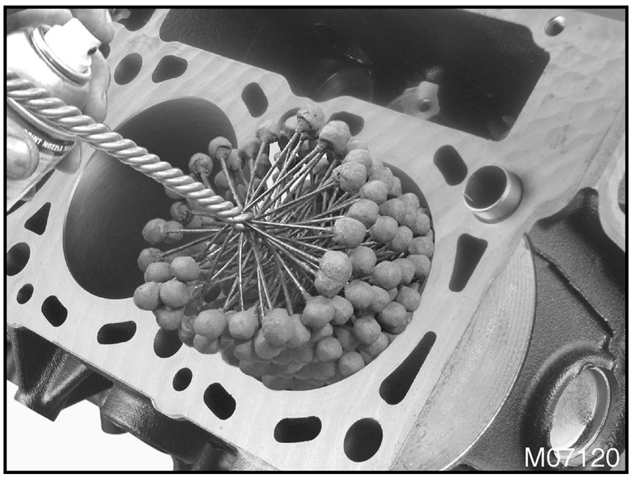

Figure 574 Deglazing hone (four-inch)

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

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

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

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

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

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

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

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

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

Crankshaft Assembly

1. Clean and inspect crankshaft and main bearings.
2. Clean crankshaft with a suitable solvent.

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

3. Dry with filtered compressed air.
4. Use a stiff nylon brush to clean oil passages in crankshaft. Loosen accumulated dirt, sludge, and deposits.
5. Flush oil passages with a suitable solvent.
6. Inspect crankshaft journals (main and connecting rod) for scratches, grooves, and scoring.
7. Inspect main bearings for scratches, grooves, scoring, pitting, and inconsistent coloring.

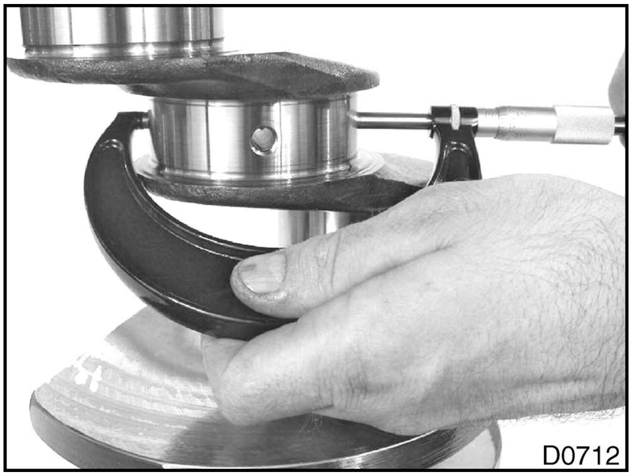

Figure 575 Measurement of crankshaft main journal

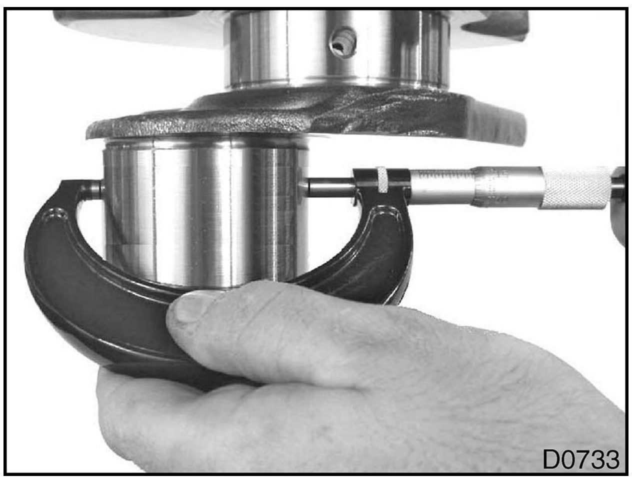

Figure 576 Measurement of crankshaft connecting rod journal

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

CAUTION: To prevent engine damage, do not rework bearings or bearing caps to reduce journal-to-bearing running clearances. Grind or install new crankshaft.

8. Use a 3–4 inch micrometer (page 353) to measure diameter of each journal (main and connecting rod). Measure each journal at two points 90° apart. Move micrometer over entire width of journal. If journal wear exceeds specifications (page 352), grind or replace crankshaft.

Main Bearing Fit Check

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

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

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

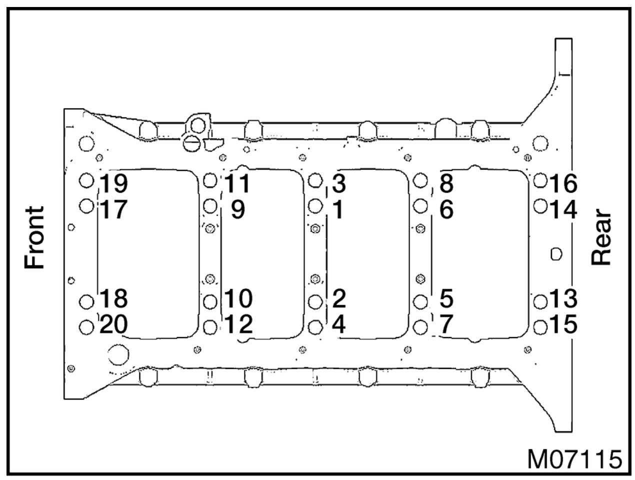

Figure 577 Torque sequence for main bearing bolts

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

1. Lubricate old main bearing bolts with clean engine oil. Assemble lower crankcase assembly to upper crankcase assembly with new bearing shells installed.
2. Tighten bolts using above sequence as follows:
   - Tighten bolts to 149 N·m (110 lbf·ft).
   - Tighten bolts to 176 N·m (130 lbf·ft).

- Tighten bolts to 231 N·m (170 lbf·ft).

3. Using a telescoping gauge (page 353), measure inside diameter of main bearing at two locations 90° apart. Average the two inside diameters.
4. Use a 3–4 inch micrometer (page 353) to measure each crankshaft main journal diameter.
5. Subtract crankshaft main journal diameter from respective main bearing inside diameter to obtain bearing-to-crankshaft running clearance. Repeat for each crankshaft main journal.

CAUTION: To prevent engine damage, do not rework bearings or bearing caps to reduce journal-to-bearing running clearances. Grind or install new crankshaft.

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

6. If bearing-to-crankshaft running clearances exceed specifications (page 352) because of wear on crankshaft, replace or grind crankshaft and install under-size precision type bearing shells.

Piston Cooling Tubes

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

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

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

Camshaft Assembly

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

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

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

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

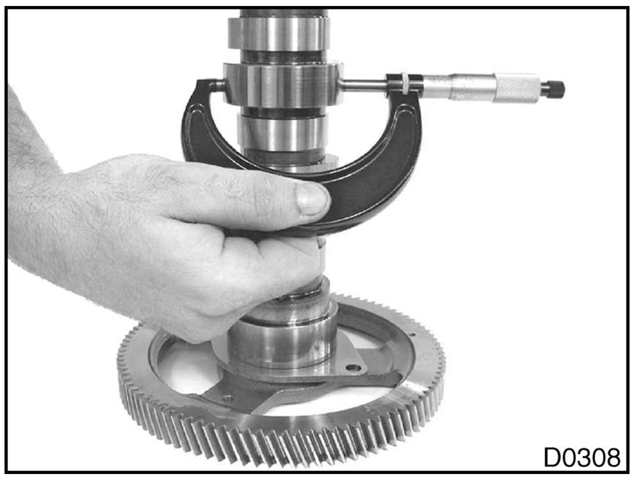

Figure 578 Measurement of camshaft bearing journal

   a. Use a 2-3 inch micrometer (page 353) to measure journal diameter of camshaft bearing. If bearing journals are worn beyond specification (page 352), install a new camshaft assembly.

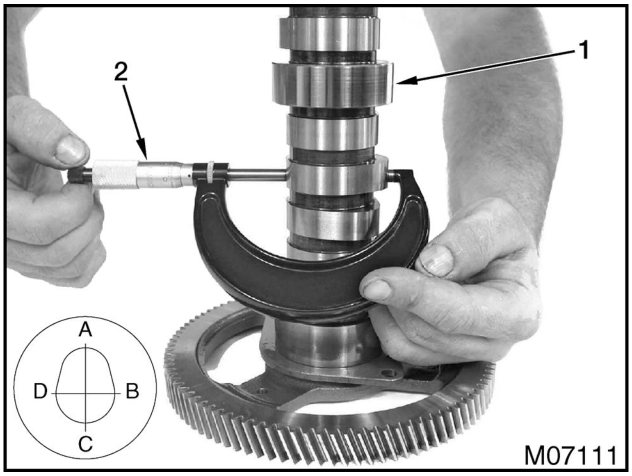

Figure 579 Measurement of camshaft intake and exhaust lobes

1. Camshaft assembly
2. Micrometer

b. To check camshaft intake and exhaust lobes, measure across (A to C) and across (B to D). Subtract (B to D) from (A to C). This will give cam lobe lift. Subtract this amount from maximum lobe lift in specifications (page 352) to obtain cam lobe wear measurement. Replace camshaft assembly if cam lobe wear exceeds specifications (page 352).

3. Inspect thrust plate for wear, cracks or distortion. Use a 0–1 inch micrometer (page 353) to measure thrust plate thickness. If thickness does not meet specification (page 352), replace camshaft assembly.
4. Inspect camshaft gear for worn or damaged teeth.
5. Wash camshaft in cleaning solvent with a soft brush.

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

6. Dry with filtered compressed air.

Measuring Camshaft Bushings

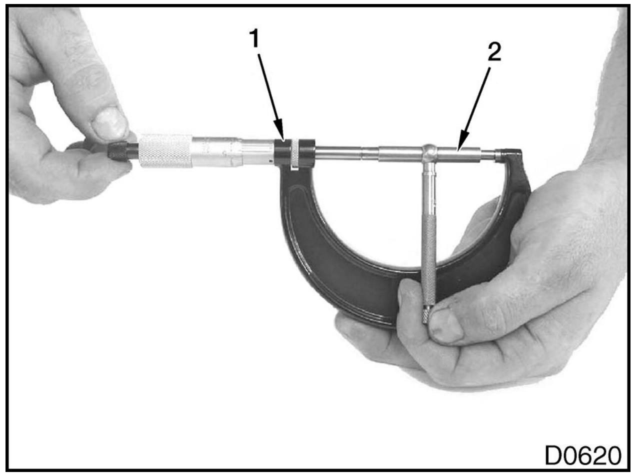

Figure 580 Measurement of camshaft bushing inside diameter

1. Outside micrometer
2. Telescoping gauge

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

1. Use a telescoping gauge set (page 353) and 2-3 inch micrometer to measure camshaft bushing inside diameters with bushings installed in crankcase.
2. To determine running clearance, subtract previous camshaft journal diameter readings from camshaft bushing inside diameter readings.
3. If maximum allowable running clearance is exceeded (page 352), replace camshaft bushings. See camshaft bushing removal (page 340) in this section.
4. Inspect each bushing bore in upper crankcase assembly for burrs or debris that could damage new bushings.
5. Remove burrs and clean bores thoroughly before installing new camshaft bushings.

Coolant Heater

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

Installation

Camshaft Bushings

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

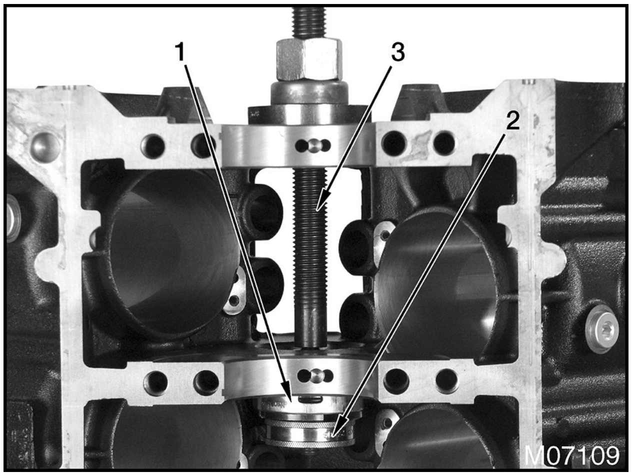

Figure 581 Installation of cam bushing

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

2. Slide a new bushing onto Camshaft Bushing Remover/Installer (expanding collet) ZTSE4489 (page 353).
3. Thread pulling screw (from Camshaft Bushing Service Set), backup nut, and Camshaft Bushing Remover/Installer (expanding collet) (page 353) together.
4. Tighten expanding collet by turning backup nut until bushing is securely held on Camshaft Bushing Remover/Installer (expanding collet) (page 353).

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

5. To aid in alignment of bushing and upper crankcase assembly oil holes, use a marker to indicate oil hole location on backup nut of installation tool. Repeat this step for each camshaft bushing.
6. Install all camshaft bushings through rear of upper crankcase assembly. Pull bushings in place at rear of upper crankcase assembly by turning pulling nut on pulling screw until bushing is flush on both sides with upper crankcase assembly. Remove Camshaft Bushing Remover/Installer (expanding collet) (page 353) and inspect oil hole alignment.

Camshaft Assembly

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

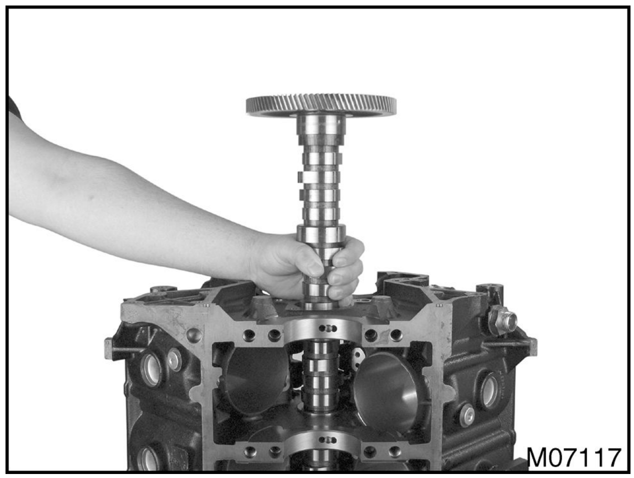

Figure 582 Camshaft assembly

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

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

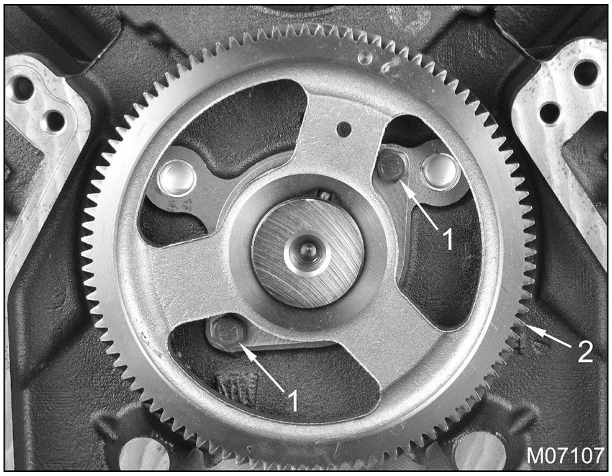

Figure 583 Camshaft thrust plate bolts

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

3. Install two M8 x 16 camshaft thrust plate bolts. Tighten bolts to standard torque (page 383).
4. Verify that camshaft end play is within specifications (page 352).

Piston Cooling Tubes

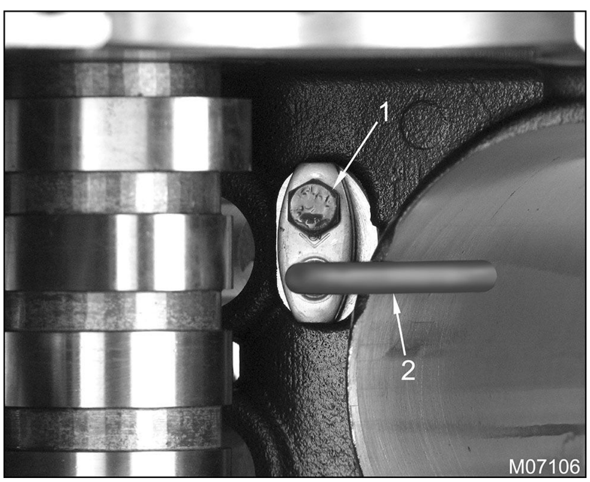

Figure 584 Piston cooling tube

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

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

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

1. Place piston cooling tubes on upper crankcase assembly mounting pad.
2. When installing piston cooling tube bolts, do one of the following:
   a. Install new special patch type mounting bolts (M6 x 18).
   b. Remove oil residue and apply Liquid Gasket (RTV) (page 353) to threads of existing special patch type mounting bolts (M6 x 18).
3. Install and tighten bolts to standard torque (page 383).

Crankshaft Assembly

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

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

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

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

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

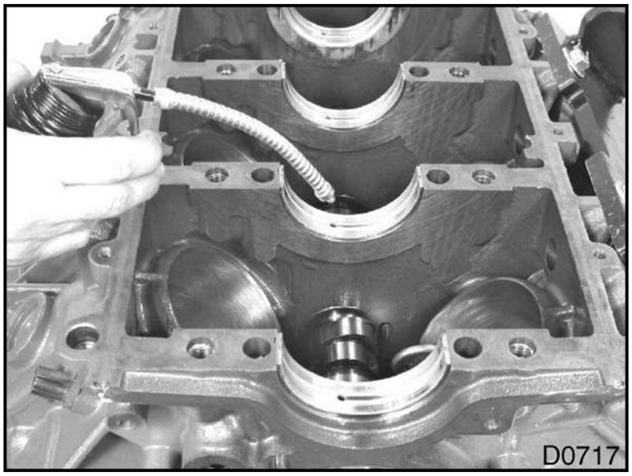

Figure 585 Upper main bearings lubrication

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

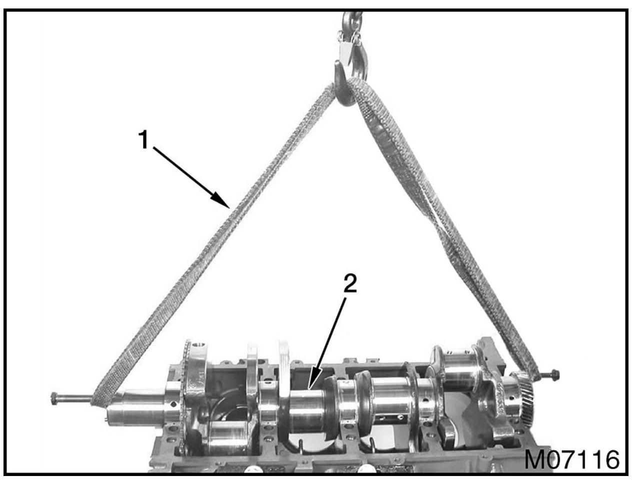

Figure 586 Lifting sling

1. Lifting sling
2. Crankshaft assembly

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

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

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

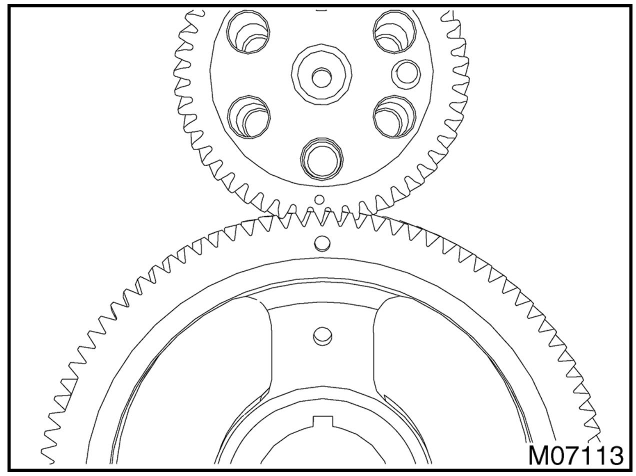

Figure 587 Crankshaft and camshaft timing marks

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

Lower Crankcase Assembly

With acceptable bearing clearance as determined in Main Bearing Fit Check (page 344), install lower crankcase assembly as follows:

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

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

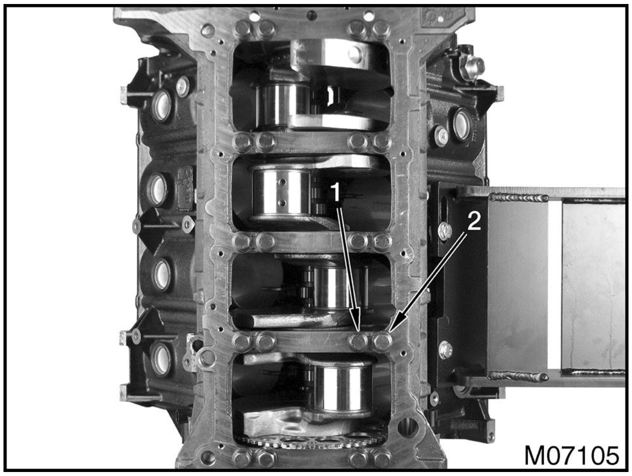

Figure 588 Main bearing bolts

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

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

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

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

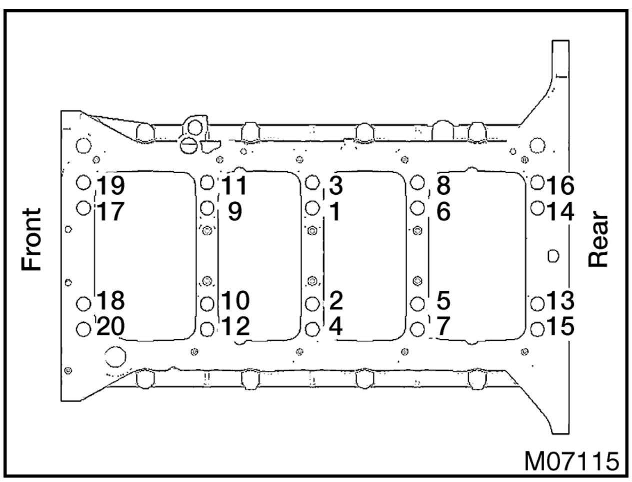

Figure 589 Torque sequence for main bearing bolts

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

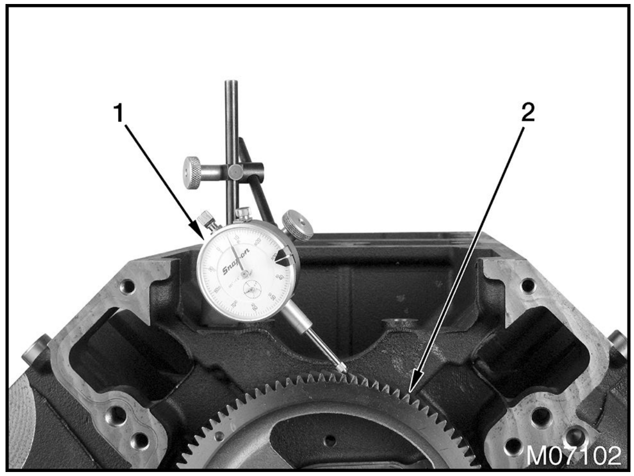

Figure 590 Camshaft assembly gear backlash check (camshaft gear to crankshaft gear)

1. Dial indicator with magnetic base
2. Camshaft gear

NOTE: Confirm that camshaft gear backlash is within specifications.

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

7. Check and record backlash for camshaft gear-to-crankshaft gear as follows:
   a. Mount dial indicator with magnetic base (page 353) on rear of engine.
   b. Position dial indicator tip on a gear tooth and remove lash.
   c. Zero the dial indicator.
   d. Rotate gear by hand and read indicator.
   e. If backlash exceeds specified limits (page 352), replace camshaft assembly.

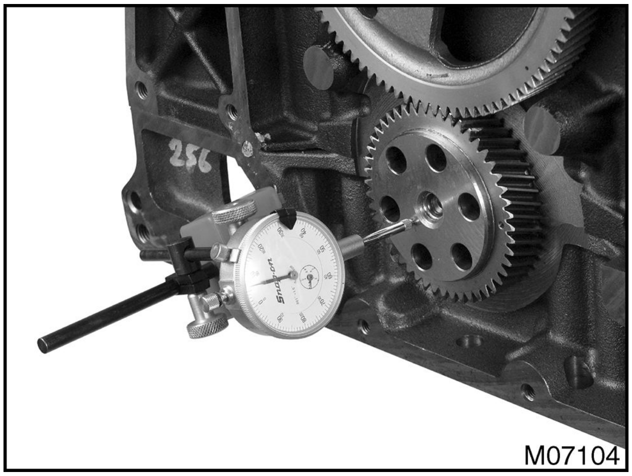

Figure 591 Crankshaft end play

8. Check crankshaft end play as follows:
   a. Mount dial indicator on lower crankcase assembly with indicator tip on end of crankshaft gear as shown.
   b. Move crankshaft forward with pry bar and zero the dial indicator.
   c. Move crankshaft back and forth while reading dial indicator. Compare dial indicator reading with specifications (page 352).
   d. If end play exceeds specified limits, replace upper thrust bearing.

Coolant Heater

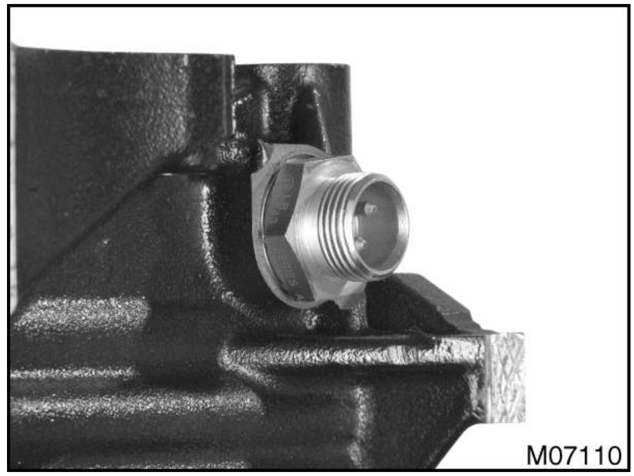

Figure 592 Coolant heater

1. Lubricate a new O-ring and install on coolant heater.
2. Install coolant heater in upper crankcase assembly and tighten to special torque (page 353).

Specifications

Table 32 Crankcase, Crankshaft, and Camshaft

Upper Crankcase Assembly	
Maximum firing deck gap	0.130 mm (0.005 in)
Maximum cylinder bore out-of round allowance	0.0125 mm (0.005 in)
Cylinder bore diameter:	
Standard size	98.200 mm (3.8661 in)
0.254 mm (0.010 in) over size	98.454 mm (3.8761 in)
0.508 mm (0.020 in) over size	98.708 mm (3.8861 in)
0.762 mm (0.030 in) over size	98.962 mm (3.8961 in)
Crankshaft Assembly	
Main Bearing Journal Diameter:	
Standard size	80.9873 to 81.0127 mm (3.1885 to 3.1895 in)
0.254 mm (0.010 in) under size	80.7333 to 80.7587 mm (3.1785 to 3.1795 in)
0.508 mm (0.020 in) under size	80.4793 to 80.5047 mm (3.1685 to 3.1695 in)
0.762 mm (0.030 in) under size	80.2253 to 80.2507 mm (3.1585 to 3.1595 in)
Main bearing thrust face maximum runout	0.050 mm (0.002 in)
Main bearing to crankshaft running clearance	0.020 to 0.086 mm (0.0008 to 0.0034 in)
Connecting Rod Journal Diameter:	
Standard size	71.987 to 72.013 mm (2.834 to 2.835 in)
0.254 mm (0.010 in) under size	71.733 to 71.759 mm (2.824 to 2.825 in)
0.508 mm (0.020 in) under size	71.479 to 71.505 mm (2.814 to 2.815 in)
0.762 mm (0.030 in) under size	71.225 to 71.251 mm (2.804 to 2.805 in)
Crankshaft end play:	
Nominal new	0.203 mm (0.008 in)
Maximum service	0.508 mm (0.020 in)
Camshaft Assembly	
Bearing journal diameter (all journals)	61.987 to 62.013 mm (2.440 to 2.441 in)
Bearing inside diameter (installed)	62.05 to 62.14 mm (2.443 to 2.446 in)
Camshaft journal and bushing running clearance	0.037 to 0.153 mm (0.0015 to 0.0060 in)
Camshaft end play	0.051 to 0.211 mm (0.002 to 0.008 in)
Camshaft gear backlash	0.179 to 0.315 mm (0.007 to 0.012 in)
Maximum permissible cam lobe wear	0.51 mm (0.02 in)
Camshaft thrust plate thickness	3.589 to 3.649 mm (0.1413 to 0.1436 in)

Table 32 Crankcase, Crankshaft, and Camshaft (cont.)

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

Special Torque

Table 33 Crankcase, Crankshaft, and Camshaft

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

Special Service Tools

Table 34 Crankcase, Crankshaft, and Camshaft

Description	Tool Number
0–1 inch micrometer	Obtain locally
2–3 inch micrometer	Obtain locally
3–4 inch micrometer	Obtain locally
Camshaft Bushing Service Set	ZTSE2893B
Camshaft Bushing Remover/Installer (expanding collet)	ZTSE4489
Cylinder bore gauge	Obtain locally
Deglazing hone (four inch)	Obtain locally
Dial indicator with magnetic base	Obtain locally
Feeler gauge	Obtain locally
Cylinder Head Bolt Tap	ZTSE4744
Lifting sling	Obtain locally
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Oil Gallery Cleaning Brush	ZTSE4511
Oil Gallery Plug Driver	ZTSE4512
Straightedge	Obtain locally
Telescoping gauge set	Obtain locally

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Abbreviations and Acronyms

Abbreviations and Acronyms

A or amp – Ampere
ABDC – After Bottom Dead Center
ABS – Antilock Brake System
AC – Alternating Current
A/C – Air Conditioner
ACC – Air Conditioner Control
ACCEL – Accelerate
ACD – Air Conditioner Demand
ACT PWR GND – Actuator Power Ground
AF – Air to Fuel ratio
AFT – Aftertreatment
AIT – Air Intake Temperature
Amb – Ambient
amp or A – Ampere
AMS – Air Management System
API – American Petroleum Institute
APS – Accelerator Position Sensor
APS/IVS – Accelerator Position Sensor / Idle Validation Switch
ASTM – American Society for Testing and Materials
ATA – American Trucking Association
ATDC – After Top Dead Center
AWG – American Wire Gauge

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

C – Celsius
CAC – Charge Air Cooler
CAN – Controller Area Network
CAP – Cold Ambient Protection
CARB – California Air Resources Board
cc – Cubic centimeter
CCA – Cold Cranking Ampere
CID – Cubic Inch Displacement
cfm – Cubic feet per minute
cfs – Cubic feet per second
CKP – Crankshaft Position
CKPO – Crankshaft Position Out
cm – Centimeter
CMP – Camshaft Position
CMPO – Camshaft Position Out
CO – Carbon Monoxide
COO – Cruise On / Off switch
CPU – Central Processing Unit
CTC – Coolant Temperature Compensation
Cyl – Cylinder

DB – Decibel
DCA – Diesel Coolant Additive
DDI – Digital Direct Fuel Injection
DDS – Driveline Disengagement Switch
DLC – Data Link Connector
DME – Dimethyl Ether
DMM – Digital Multimeter
DOC – Diesel Oxidation Catalyst
DPF – Diesel Particulate Filter
DT – Diesel Turbocharged
DTC – Diagnostic Trouble Code
DTRM – Diesel Thermo Recirculation Module

EBP – Exhaust Back Pressure
EBPD – Exhaust Back Pressure Desired
ECI – Engine Crank inhibit
ECL – Engine Coolant Level
ECM – Electronic Control Module
ECM PWR – Electronic Control Module Power
ECT – Engine Coolant Temperature
EFP – Engine Fuel Pressure
EFRC – Engine Family Rating Code
EFT – Engine Fuel Temperature
EG – Ethylene Glycol
EGC – Electronic Gauge Cluster
EGDP – Exhaust Gas Differential Pressure
EGR – Exhaust Gas Recirculation
EGRH – Exhaust Gas Recirculation High control
EGRL – Exhaust Gas Recirculation Low control
EGRP – Exhaust Gas Recirculation Position
EGT1 – Exhaust Gas Temperature 1
EGT2 – Exhaust Gas Temperature 2
EGT3 – Exhaust Gas Temperature 3
EMI – Electromagnetic Interference
EOP – Engine Oil Pressure
EOT – Engine Oil Temperature
EPA – Environmental Protection Agency
EPR – Engine Pressure Regulator
ESC – Electronic System Controller
ESN – Engine Serial Number
EST – Electronic Service Tool
EWPS – Engine Warning Protection System

F – Fahrenheit
FCV – Fuel Coolant Valve
FEL – Family Emissions Limit
fhp – Friction horsepower
FMI – Failure Mode Indicator
FPC – Fuel Pump Control
FPCV – Fuel Pressure Control Valve
fpm – Feet per minute
fps – Feet per second
FRP – Fuel Rail Pressure
ft – Feet
FVCV – Fuel Volume Control Valve

GND – Ground (electrical)
gal – Gallon
gal/h – U.S. Gallons per hour
gal/min – U. S. Gallons per minute
GCW – Gross Combined Weight
GCWR – Gross Combined Weight Rating
GPC – Glow Plug Control
GPD – Glow Plug Diagnostic
GPR – Glow Plug Relay
GVW – Gross Vehicle Weight

H_2O – Water
HC – Hydrocarbons
HFCM – Horizontal Fuel Conditioning Module
Hg – Mercury
hp – Horsepower
HPFP – High-Pressure Fuel Pump
hr – Hour
Hyd – Hydraulic

IAT – Intake Air Temperature
IAHC – Inlet Air Heater Control
IAHD – Inlet Air Heater Diagnostic
IAHR – Inlet Air heater Relay
IC – Integrated Circuit
ICP – Injector Control Pressure
ID – Inside Diameter
IDM – Injector Drive Module
IGN – Ignition
ILO – Injector Leak Off
in – Inch
inHg – Inch of mercury
inH_2O – Inch of water
INJ – Injector
IPR – Injection Pressure Regulator
ISIS – International® Service Information System
IST – Idle Shutdown Timer
ITP – Internal Transfer Pump
ITV – Intake Throttle Valve
ITVH – Intake Throttle Valve High control
ITVL – Intake Throttle Valve Low control
ITVP – Intake Throttle Valve Position
IVS – Idle Validation Switch

JCT – Junction (electrical)

kg – Kilogram
km – Kilometer
km/h – Kilometers per hour
km/l – Kilometers per liter
KOEO – Key-On Engine-Off
KOER – Key-On Engine-Running
kPa – Kilopascal

L – Liter
L/h – Liters per hour
L/m – Liters per minute
L/s – Liters per second
lb – Pound
lbf – 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

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Terminology

Terms

Accessory work – The work per cycle required to drive engine accessories (normally, only those essential to engine operation).

Actuator – A device that performs work in response to an input signal.

Aeration – The entrainment of air or combustion gas in coolant, lubricant, or fuel.

Aftercooler (Charge Air Cooler) – A heat exchanger mounted in the charge air path between the turbocharger and engine intake manifold. The aftercooler reduces the charge air temperature by transferring heat from the charge air to a cooling medium (usually air).

Ambient temperature – The environmental air temperature in which a unit is operating. In general, the temperature is measured in the shade (no solar radiation) and represents the air temperature for other engine cooling performance measurement purposes. Air entering the radiator may or may not be the same ambient due to possible heating from other sources or recirculation. (SAE J1004 SEP81)

Ampere (amp) – The standard unit for measuring the strength of an electrical current. The flow rate of a charge in a conductor or conducting medium of one coulomb per second. (SAE J1213 NOV82)

Analog – A continuously variable voltage.

Analog to digital converter (A/D) – A circuit in the ECM processing section that converts an analog signal (DC or AC) to a usable digital signal for the microprocessor.

American Trucking Association (ATA) Datalink – A serial datalink specified by the American Trucking Association and the SAE.

Boost pressure – 1. The pressure of the charge air leaving the turbocharger.

2. Inlet manifold pressure that is greater than atmospheric pressure. Obtained by turbocharging.

Bottom Dead Center (BDC) – The lowest position of the piston during the stroke.

Brake Horsepower (bhp) – The power output from an engine, not the indicated horsepower. The power output of an engine, sometimes-called flywheel horsepower is less than the indicated horsepower by the amount of friction horsepower consumed in the engine.

Brake Horsepower (bhp) net – Net brake horsepower is measured with all engine components. The power of an engine when configured as a fully equipped engine. (SAE J1349 JUN90)

Calibration – The data values used by the strategy to solve equations and make decisions. Calibration values are stored in ROM and put into the processor during programming to allow the engine to operate within certain parameters.

Catalyst – A substance that produces a chemical reaction without undergoing a chemical change itself.

Catalytic converter – An antipollution device in the exhaust system that contains a catalyst for chemically converting some pollutants in the exhaust gases (carbon monoxide, unburned hydrocarbons, and oxides of nitrogen) into harmless compounds.

Cavitation – A dynamic condition in a fluid system that forms gas-filled bubbles (cavities) in the fluid.

Cetane number – 1. The auto-ignition quality of diesel fuel.

2. A rating applied to diesel fuel similar to octane rating for gasoline.

3. A measure of how readily diesel fuel starts to burn (self-ignites) at high compression temperature.

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

Charge air – Dense, pressurized, heated air discharged from the turbocharger.

Charge Air Cooler (CAC) – See **Aftercooler**.

Closed crankcase – A crankcase ventilation that recycles crankcase gases through a breather, then back to the clean air intake.

Closed loop operation – A system that uses a sensor to provide feedback to the ECM. The ECM uses the sensor to continuously monitor variables and adjust to match engine requirements.

Cloud point – The point when wax crystals occur in fuel, making fuel cloudy or hazy. Usually below -12 °C (10 °F).

Cold cranking ampere rating (battery rating) – The sustained constant current (in amperes) needed to produce a minimum terminal voltage under a load of 7.2 volts per battery after 30 seconds.

Continuous Monitor Test – An ECM function that continuously monitors the inputs and outputs to ensure that readings are within set limits.

Coolant – A fluid used to transport heat from one point to another.

Coolant level switch – A switch sensor used to indicate low coolant level.

Crankcase – The housing that encloses the crankshaft, connecting rods, and allied parts.

Crankcase breather – A vent for the crankcase to release excess interior air pressure.

Crankcase pressure – The force of air inside the crankcase against the crankcase housing.

Current – The flow of electrons passing through a conductor. Measured in amperes.

Damper – A device that reduces the amplitude of torsional vibration. (SAE J1479 JAN85)

Deaeration – The removal or purging of gases (air or combustion gas) entrained in coolant or lubricating oil.

Deaeration tank – A separate tank in the cooling system used for one or more of the following functions:

- Deaeration
- Coolant reservoir (fluid expansion and afterboil)
- Coolant retention
- Filling
- Fluid level indication (visible)

Diagnostic Trouble Code (DTC) – Formerly called a Fault Code or Flash Code. A DTC is a three digit numeric code used for troubleshooting.

Digital Multimeter (DMM) – An electronic meter that uses a digital display to indicate a measured value. Preferred for use on microprocessor systems because it has a very high internal impedance and will not load down the circuit being measured.

Disable – A computer decision that deactivates a system and prevents operation of the system.

Displacement – The stroke of the piston multiplied by the area of the cylinder bore multiplied by the number of cylinders in the engine.

Driver (high side) – A transistor within an electronic module that controls the power to an actuator circuit.

Driver (low side) – A transistor within an electronic module that controls the ground to an actuator circuit.

Duty cycle – A control signal that has a controlled on/off time measurement from 0 to 100%. Normally used to control solenoids.

Engine lamp – An instrument panel lamp that comes on when DTCs are set. DTCs can be read as flash codes (red and amber instrument panel lamps).

Engine OFF tests – Tests that are done with the ignition switch ON and the engine OFF.

Engine rating – Engine rating includes **Rated hp** and **Rated rpm**.

Engine RUNNING tests – Tests done with the engine running.

Exhaust brake – A brake device using engine exhaust back pressure as a retarding medium.

Exhaust manifold – Exhaust gases flow through the exhaust manifold to the turbocharger exhaust inlet and are directed to the EGR cooler.

Fault detection/management – An alternate control strategy that reduces adverse effects that can be caused by a system failure. If a sensor fails, the ECM substitutes a good sensor signal or assumed sensor value in its place. A lit amber instrument panel lamp signals that the vehicle needs service.

Filter restriction – A blockage, usually from contaminants, that prevents the flow of fluid through a filter.

Flash code – See **Diagnostic Trouble Code (DTC)**.

Fuel inlet restriction – A blockage, usually from contaminants, that prevents the flow of fluid through the fuel inlet line.

Fuel pressure – The force that the fuel exerts on the fuel system as it is pumped through the fuel system.

Fuel strainer – A pre-filter in the fuel system that keeps larger contaminants from entering the fuel system.

Fully equipped engine – A fully equipped engine is an engine equipped with only those accessories necessary to perform its intended service. A fully equipped engine does not include components that are used to power auxiliary systems. If these components are integral with the engine or for any reason are included on the test engine, the power absorbed may be determined and added to the net brake power. (SAE J1995 JUN90)

Fusible link (fuse link) – A fusible link is a special section of low tension cable designed to open the circuit when subjected to an extreme current overload. (SAE J1156 APR86)

Gradeability – The maximum percent grade which the vehicle can transverse for a specified time at a specified speed. The gradeability limit is the grade upon which the vehicle can just move forward. (SAE J227a)

Gross Combined Weight Rating (GCWR) – Maximum combined weight of towing vehicle (including passengers and cargo) and the trailer. The GCWR indicates the maximum loaded weight that the vehicle is allowed to tow.

Gross brake horsepower – The power of a complete basic engine, with air cleaner, without fan, and alternator and air compressor not charging.

Hall effect – The development of a transverse electric potential gradient in a current-carrying conductor or semiconductor when a magnetic field is applied.

Hall effect sensor – Generates a digital on/off signal that indicates speed and timing.

High speed digital inputs – Inputs to the ECM from a sensor that generates varying frequencies (engine speed and vehicle speed sensors).

Horsepower (hp) – Horsepower is the unit of work done in a given period of time, equal to 33,000 pounds multiplied by one foot per minute. **1hp = 33,000 lb x 1 ft /1 min**.

Hydrocarbons – Unburned or partially burned fuel molecules.

Idle speed –

- Low idle is minimum rpm at no load.
- High idle is maximum rpm at no load.

Intake manifold – A collection of tubes through which the fuel-air mixture flows from the fuel injector to the intake valves of the cylinders.

International NGV Tool Utilized for Next Generation Electronics (INTUNE) – The diagnostics software for chassis related components and systems.

Low speed digital inputs – Switched sensor inputs that generate an on/off (high/low) signal to the ECM. The input to the ECM from the sensor could be from a high input source switch (usually 5 or 12 volts) or from a grounding switch that grounds the signal from a current limiting resistor in the ECM that creates a low signal (0 volts).

Lubricity – Lubricity is the ability of a substance to reduce friction between solid surfaces in relative motion under loaded conditions.

Lug (engine) – A condition when the engine is operating at or below maximum torque speed.

Manometer – A double-leg liquid-column gauge, or a single inclined gauge, used to measure the difference between two fluid pressures. Typically, a manometer records in inches of water.

MasterDiagnostics® (MD) – The diagnostics software for engine related components and systems.

Microprocessor – An integrated circuit in a microcomputer that controls information flow.

Nitrogen Oxides (NO_x) – Nitrogen oxides form by a reaction between nitrogen and oxygen at high temperatures and pressures in the combustion chamber.

Normally closed – Refers to a switch that remains closed when no control force is acting on it.

Normally open – Refers to a switch that remains open when no control force is acting on it.

Ohm (Ω) – The unit of resistance. One ohm is the value of resistance through which a potential of one volt will maintain a current of one ampere. (SAE J1213 NOV82)

On demand test – A self test that the technician initiates using the EST and is run from a program in the processor.

Output Circuit Check (OCC) – An On demand test done during an Engine OFF self test to check the continuity of selected actuators.

pH – A measure of the acidity or alkalinity of a solution.

Particulate matter – Particulate matter includes mostly burned particles of fuel and engine oil.

Piezometer – An instrument for measuring fluid pressure.

Power – Power is a measure of the rate at which work is done. Compare with **Torque**.

Power TakeOff (PTO) – Accessory output, usually from the transmission, used to power a hydraulic pump for a special auxiliary feature (garbage packing, lift equipment, etc).

Pulse Width Modulate (PWM) – The time that an actuator, such as an injector, remains energized.

Random Access Memory (RAM) – Computer memory that stores information. Information can be written to and read from RAM. Input information (current engine speed or temperature) can be stored in RAM to be compared to values stored in Read Only Memory (ROM). All memory in RAM is lost when the ignition switch is turned off.

Rated gross horsepower – Engine gross horsepower at rated speed as declared by the manufacturer. (SAE J1995 JUN90)

Rated horsepower – Maximum brake horsepower output of an engine as certified by the engine manufacturer. The power of an engine when configured as a basic engine. (SAE J1995 JUN90)

Rated net horsepower – Engine net horsepower at rated speed as declared by the manufacturer. (SAE J1349 JUN90)

Rated speed – The speed, as determined by the manufacturer, at which the engine is rated. (SAE J1995 JUN90)

Rated torque – Maximum torque produced by an engine as certified by the manufacturer.

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

Reference voltage (V_{REF}) – A 5 volt reference supplied by the ECM to operate the engine sensors.

Reserve capacity – Time in minutes that a fully charged battery can be discharged to 10.5 volts at 25 amperes.

Signal ground – The common ground wire to the ECM for the sensors.

Speed Control Command Switches (SCCS) – A set of switches used for cruise control, Power TakeOff (PTO), and remote hand throttle system.

Steady state condition – An engine operating at a constant speed and load and at stabilized temperatures and pressures. (SAE J215 JAN80)

Strategy – A plan or set of operating instructions that the microprocessor follows for a desired goal. Strategy is the computer program itself, including all equations and decision making logic. Strategy is always stored in ROM and cannot be changed during calibration.

Stroke – Stroke is the movement of the piston from Top Dead Center (TDC) to Bottom Dead Center (BDC).

Substrate – Material that supports the washcoating or catalytic materials.

System restriction (air) – The static pressure differential that occurs at a given air flow from air entrance through air exit in a system. Usually measured in inches (millimeters) of water. (SAE J1004 SEP81)

Tachometer output signal – Engine speed signal for remote tachometers.

Thermistor – A semiconductor device. A sensing element that changes resistance as the temperature changes.

Thrust load – A thrust load pushes or reacts through a bearing in a direction parallel to the shaft.

Top Dead Center (TDC) – The uppermost position of the piston during the stroke.

Torque – A force having a twisting or turning effect. For a single force, the cross product of a vector from some reference point to the point of application of the force within the force itself. Also known as moment of force or rotation moment. Torque is a measure of the ability of an engine to do work.

Truck Computer Analysis of Performance and Economy (TCAPE) – Truck Computer Analysis of Performance and Economy is a computer program that simulates the performance and fuel economy of trucks.

Turbocharger – A turbine driven compressor mounted to the exhaust manifold. The turbocharger increases the pressure, temperature and density of intake air to charge air.

Variable capacitance sensor – A variable capacitance sensor is measures pressure. The pressure forces a ceramic material closer to a thin metal disc in the sensor, changing the capacitance of the sensor.

Vehicle Electronic System Programming System – The computer system used to program electronically controlled vehicles.

Vehicle Retarder Enable/Engage – Output from the ECM to a vehicle retarder.

Vehicle Speed Sensor (VSS) – Normally a magnetic pickup sensor mounted in the tailshaft housing of the transmission, used to indicate ground speed.

Viscosity – The internal resistance to the flow of any fluid.

Viscous fan – A fan drive that is activated when a thermostat, sensing high air temperature, forces fluid through a special coupling. The fluid activates the fan.

Volt (v) – A unit of electromotive force that will move a current of one ampere through a resistance of one Ohm.

Voltage – Electrical potential expressed in volts.

Voltage drop – Reduction in applied voltage from the current flowing through a circuit or portion of the circuit current multiplied by resistance.

Voltage ignition – Voltage supplied by the ignition switch when the key is ON.

Washcoat – A layer of alumina applied to the substrate in a monolith-type converter.

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Variable Geometry Turbocharger (VGT)

Table 35 Variable Geometry Turbocharger (VGT) Shaft

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

Fuel System

Table 36 Fuel Filter

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

Intake and Exhaust Manifolds

Table 37 Intake, Inlet, and Exhaust Manifolds

Exhaust Manifold	
Maximum allowable warpage	0.08 mm (0.003 in)

Front Cover, Cooling System, and Related Components

Table 38 Front Cover, Cooling System, and Related Components

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

Cylinder Head and Valve Train

Table 39 Cylinder Head and Valve Train

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

Table 39 Cylinder Head and Valve Train (cont.)

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

Oil Cooler and Filter Housing

Table 40 Oil Cooler and Oil Filter

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

Flywheel and Flywheel Housing

Table 41 Flywheel and Flywheel Housing

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

Table 42 Power Cylinders

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

Table 42 Power Cylinders (cont.)

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

Crankcase, Crankshaft, and Camshaft

Table 43 Crankcase, Crankshaft, and Camshaft

Upper Crankcase Assembly	
Maximum firing deck gap	0.130 mm (0.005 in)
Maximum cylinder bore out-of round allowance	0.0125 mm (0.005 in)
Cylinder bore diameter:	
Standard size	98.200 mm (3.8661 in)
0.254 mm (0.010 in) over size	98.454 mm (3.8761 in)
0.508 mm (0.020 in) over size	98.708 mm (3.8861 in)
0.762 mm (0.030 in) over size	98.962 mm (3.8961 in)
Crankshaft Assembly	
Main Bearing Journal Diameter:	
Standard size	80.9873 to 81.0127 mm (3.188 to 3.1895 in)
0.254 mm (0.010 in) under size	80.7333 to 80.7587 mm (3.178 to 3.1795 in)
0.508 mm (0.020 in) under size	80.4793 to 80.5047 mm (3.168 to 3.1695 in)
0.762 mm (0.030 in) under size	80.2253 to 80.2507 mm (3.158 to 3.1595 in)
Main bearing thrust face maximum runout	0.050 mm (0.002 in)
Main bearing to crankshaft running clearance	0.020 to 0.086 mm (0.0008 to 0.0034 in)
Connecting Rod Journal Diameter:	
Standard size	71.987 to 72.013 mm (2.834 to 2.835 in)
0.254 mm (0.010 in) under size	71.733 to 71.759 mm (2.824 to 2.825 in)
0.508 mm (0.020 in) under size	71.479 to 71.505 mm (2.814 to 2.815 in)
0.762 mm (0.030 in) under size	71.225 to 71.251 mm (2.804 to 2.805 in)
Crankshaft end play:	
Nominal new	0.203 mm (0.008 in)
Maximum service	0.508 mm (0.020 in)
Camshaft Assembly	
Bearing journal diameter (all journals)	61.987 to 62.013 mm (2.440 to 2.441 in)
Bearing inside diameter (installed)	62.05 to 62.14 mm (2.443 to 2.446 in)
Camshaft journal and bushing running clearance	0.037 to 0.153 mm (0.0015 to 0.0060 in)
Camshaft end play	0.051 to 0.211 mm (0.002 to 0.008 in)
Camshaft gear backlash	0.179 to 0.315 mm (0.007 to 0.012 in)
Maximum permissible cam lobe wear	0.51 mm (0.02 in)
Camshaft thrust plate thickness	3.589 to 3.649 mm (0.1413 to 0.1436 in)

Table 43 Crankcase, Crankshaft, and Camshaft (cont.)

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

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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 593 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 594 Special fasteners – Classification and identification

General Torque Guidelines

CAUTION: To prevent engine damage, do not substitute fasteners. All original equipment fasteners are hardened and phosphate coated.

NOTE: Inspect parts for cleanliness and defects before assembly.

Many conditions affect torque and the results of torque applications. The major purpose in tightening a fastener to a specified torque is to obtain a clamping load which exceeds any possible loading imposed on parts.

New phosphate coated fasteners do not require oil lubrication during assembly and torque application. Reused fasteners (even if originally phosphate coated) do require oil lubrication to threads and under head area for correct torque application.

Threads that are dry, excessively rough, battered, or filled with dirt require considerable effort just to rotate. Then when the clamping load is developed or the bolt tension is applied, the torque reading mounts rapidly (due to thread friction) to the specified torque value. However, the desired bolt tension and correct clamping load is not achieved. This condition can lead to failure of the fastener to maintain component integrity. The correct bolt tension and clamping effect can never be attained if the fastener is dry. Fastener threads must be new condition phosphate coated or have a film of clean lubricant (engine oil) to be considered lubricated.

Standard Torque Charts

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.

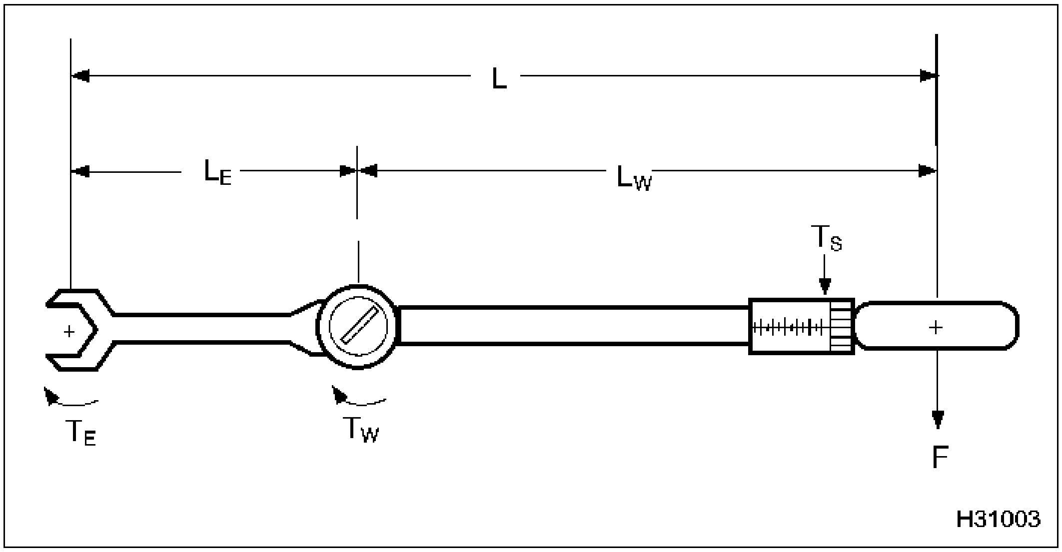

Figure 595 Torque wrench and extension

- F - Force applied by technician
- L - Total length through which force is applied to fastener
- T_W - Torque applied at end of torque wrench

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

- T_S - Torque wrench setting
- T_E - Torque specified at fastener
- L_W - Length of torque wrench
- L_E - Length of extension

Example: A component requires a specified torque value of 65 lbf·ft and a 6 inch extension is required to reach it. What should the torque wrench setting (T_S) be to compensate for the extension?

- Torque specified at fastener (T_E) = 65 lbf·ft
- Length of torque wrench (L_W) = 12 inches
- Length of extension (L_E) = 6 inches

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

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

T_S = 65 lbf·ft (12 inches / (18 inches)

T_S = 65 lbf·ft (0.666)

T_S = 43.33 lbf·ft

Special Torques

Mounting Engine on Stand

Table 44 Mounting Engine on Stand

Oil pan drain plug	25 N·m (18 lbf·ft)

Engine Electrical

Table 45 Engine Electrical

Crankshaft Position sensor (CKP) bolt	10 N·m (89 lbf·in)
Camshaft Position sensor (CMP) bolt	10 N·m (89 lbf·in)
Engine Coolant Temperature (ECT) sensor	18 N·m (159 lbf·in)
Fuel Temperature Sensor (FTS)	18 N·m (159 lbf·in)
Engine Oil Pressure (EOP) sensor	12 N·m (106 lbf·in)
Engine Oil Temperature (EOT) sensor	18 N·m (159 lbf·in)
Fuel Pressure Sensor (FPS)	12 N·m (106 lbf·in)
Rail Fuel Pressure (RFP) sensor	2 N·m (18 lbf·in), then turn one hex flat (60 degrees)
Manifold Air Temperature (MAT) sensor	18 N·m (159 lbf·in)
Manifold Absolute Pressure (MAP) sensor	12 N·m (106 lbf·in)
Exhaust Back Pressure (EBP) sensor	20 N·m (177 lbf·ft)
Electronic Control Module (ECM) bolts	13 N·m (115 lbf·in)
ECM support nuts	13 N·m (115 lbf·in)

Exhaust Gas Recirculation (EGR) System

Table 46 Exhaust Gas Recirculation (EGR) System

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

Variable Geometry Turbocharger (VGT)

Table 47 Turbocharger Assembly Bolts and Clamps

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

Air Compressor and Power Steering/Fuel Pump

Table 48 Air Compressor and Power Steering/Fuel Pump

Air compressor to bracket bolts	72 N·m (53 lbf·ft)
Air compressor bracket to cylinder head bolts	61 N·m (45 lbf·ft)
Air compressor belt tensioner bolt	61 N·m (45 lbf·ft)
Air compressor idler bolts	61 N·m (45 lbf·ft)
Air compressor oil supply hose fitting nut	20 N·m (177 lbf·in)
Suction power steering tube flared tube nut	166 N·m (122 lbf·ft)
Pressure power steering tube flared tube nut	87 N·m (64 lbf·ft)
Tube clamp saddle stud bolts (front)	31 N·m (23 lbf·ft)
Air compressor pulley nut	120 N·m (88 lbf·ft)

Fuel System

Table 49 Fuel System Components

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

Intake and Exhaust Manifolds

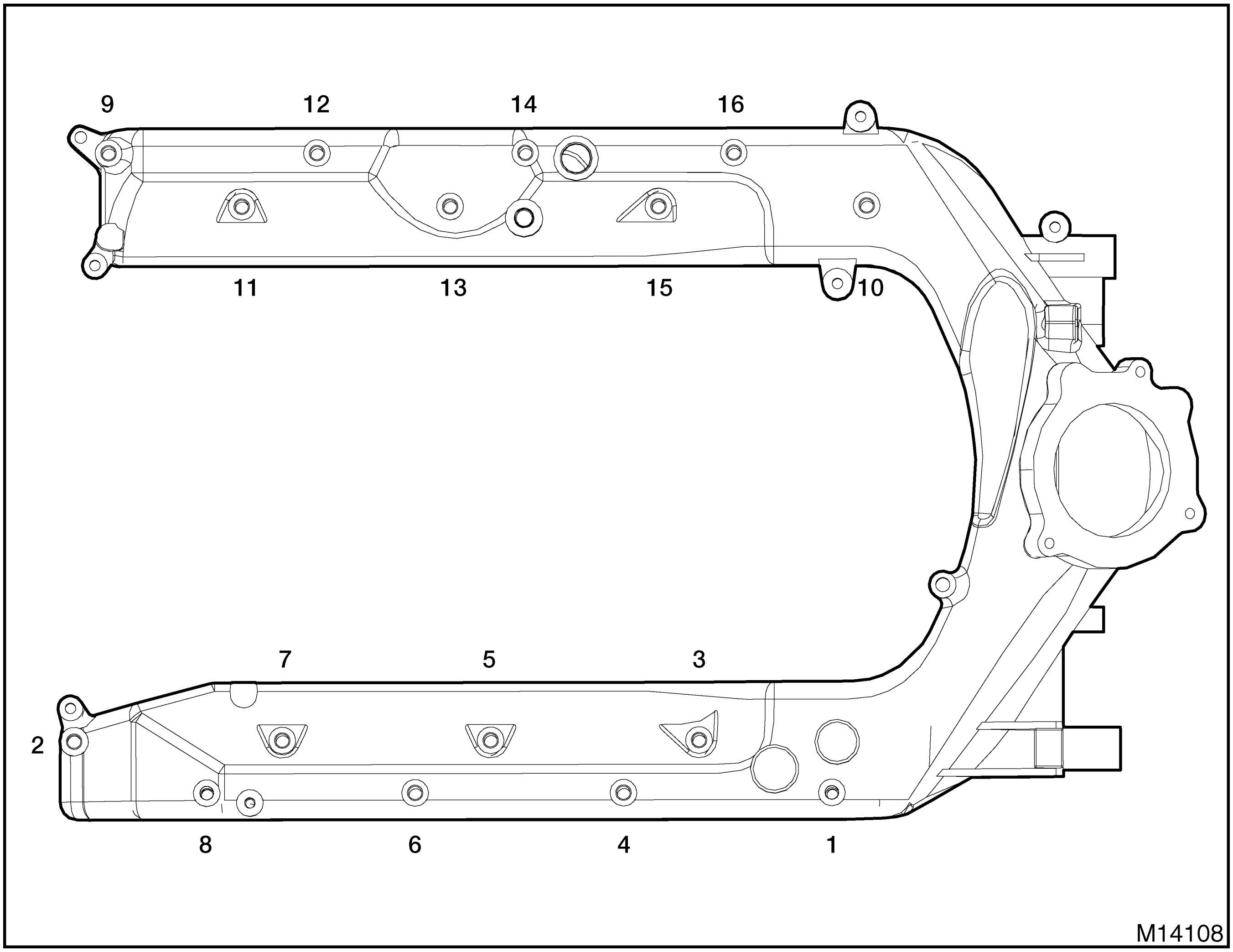

Figure 596 Torque sequence for intake manifold mounting bolts

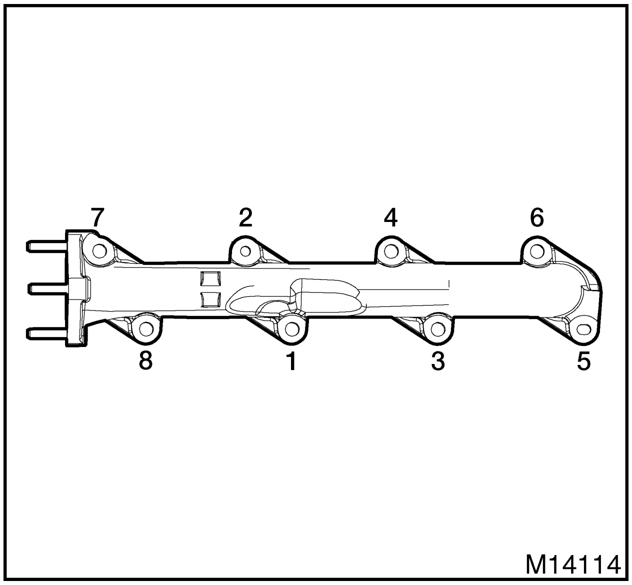

Figure 597 Torque sequence for right exhaust manifold mounting bolts

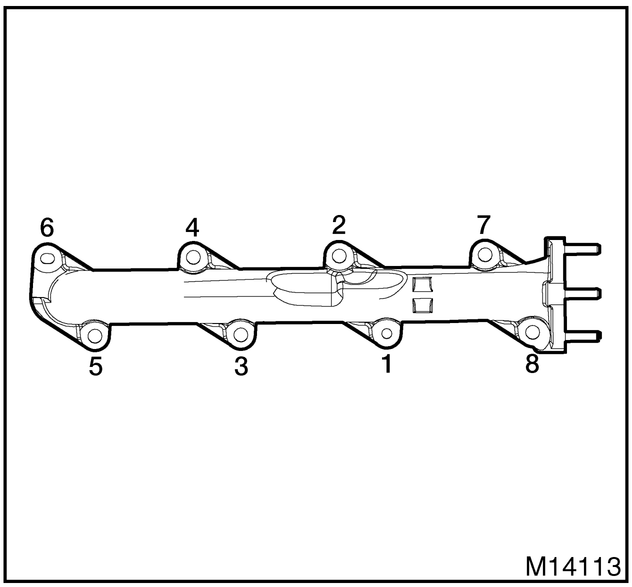

Figure 598 Torque sequence for left exhaust manifold mounting bolts

Table 50 Intake, Inlet, and Exhaust Manifolds

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

Front Cover, Cooling System, and Related Components

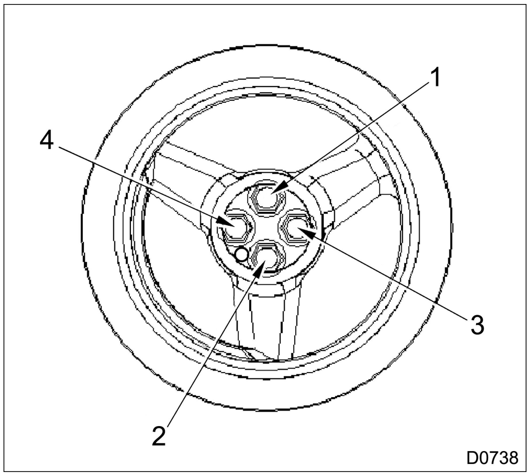

Figure 599 Torque sequence for vibration damper bolts

Table 51 Front Cover, Cooling System, and Related Components

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

Cylinder Head and Valve Train

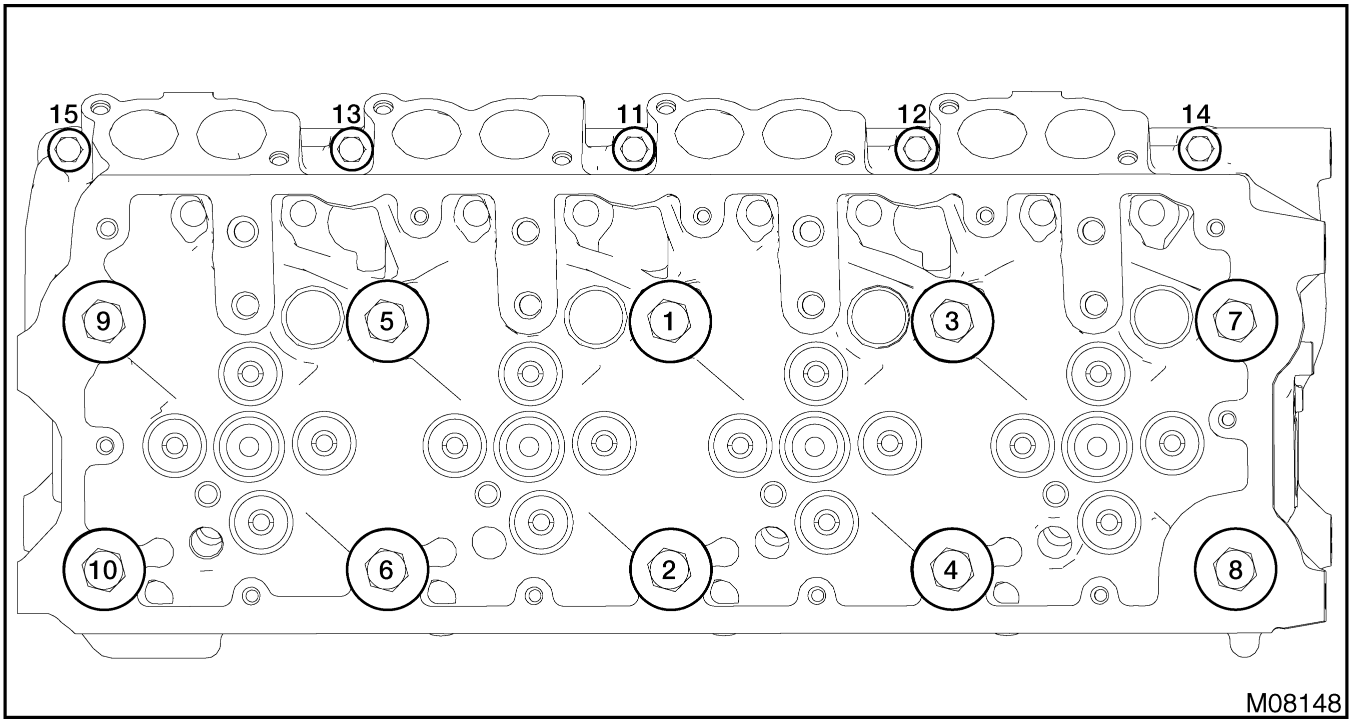

Figure 600 Cylinder head bolts tightening sequence

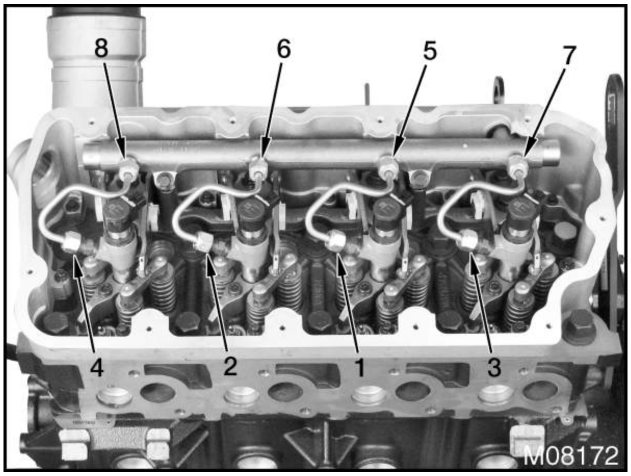

Figure 601 Fuel rail to injector tube assemblies tightening sequence (typical)

Table 52 Cylinder Head and Valve Train

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

Oil Cooler and Filter Housing

Table 53 Oil Cooler Cover and Oil Filter Housing

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

Flywheel and Flywheel Housing

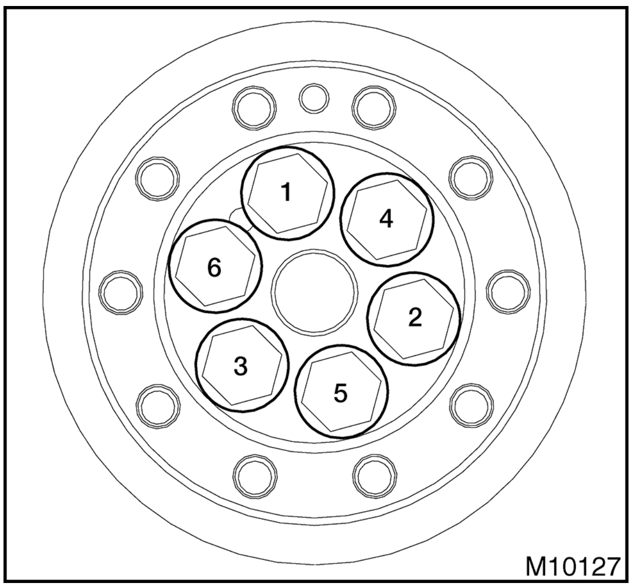

Figure 602 Crankshaft flange torque sequence

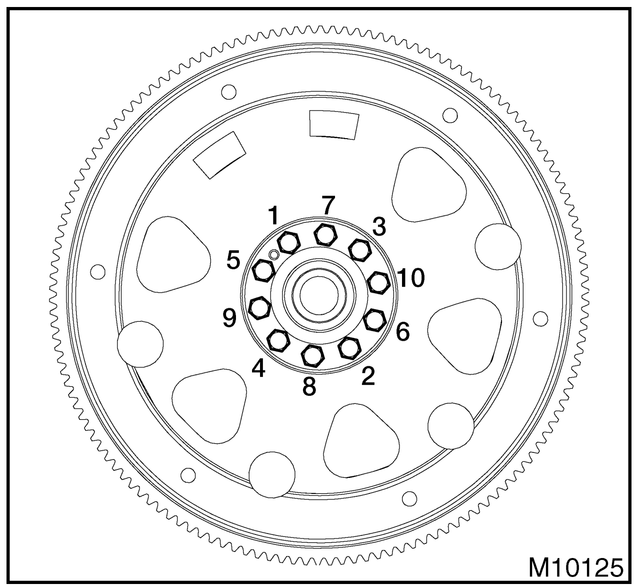

Figure 603 Torque sequence for flexplate assembly

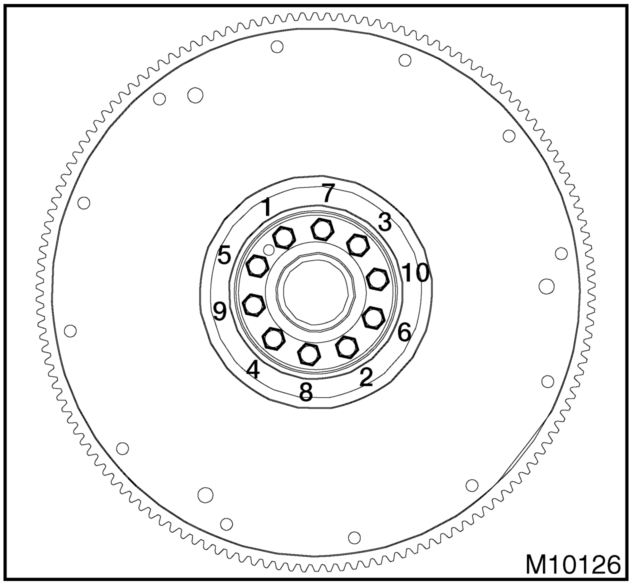

Figure 604 Torque sequence for flywheel assembly

Table 54 Flywheel and Flywheel Housing

Crankshaft flange bolts	See tightening steps in procedure.
Flexplate assembly bolts	See tightening steps in procedure.
Flywheel assembly bolts	See tightening steps in procedure.

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

Table 55 Lower Oil Pan

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

Power Cylinders

Table 56 Power Cylinders

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

Crankcase, Crankshaft, and Camshaft

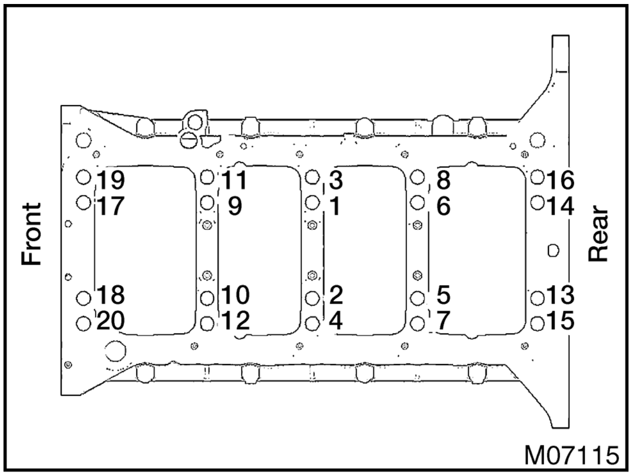

Figure 605 Torque sequence for main bearing bolts

Table 57 Crankcase, Crankshaft, and Camshaft

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

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Special Tools

Special tools for the MaxxForce® 7 engine can be ordered from the SPX Corporation, 1-800-520-2584.

Mounting Engine on Stand

Table 58 Mounting Engine on Stand

Description	Tool Number
Engine Stand Mounting Bracket	ZTSE4507

Engine Electrical

Table 59 Engine Electrical

Description	Tool Number
Fuel Injector Electrical Connector Release Tool	ZTSE4820

Exhaust Gas Recirculation (EGR) System

Table 60 Exhaust Gas Recirculation (EGR) System

Description	Tool Number
EGR Valve Bore Cleaning Brush	ZTSE4753
EGR Valve Puller	ZTSE4743
EGR Cooler Test Plates	ZTSE4707

Variable Geometry Turbocharger (VGT)

Table 61 Turbocharger

Description	Tool Number
Cap Kit (All)	Obtain locally
Dial indicator with magnetic base	Obtain locally
Turbo Oil Supply Block Off Plug Kit	ZTSE4785

Air Compressor and Power Steering/Fuel Pump

Table 62 Power Steering/Fuel Pump

Description	Tool Number
Cap Kit (All)	Obtain locally

Fuel System

Table 63 Fuel System

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

Intake and Exhaust Manifolds

Table 64 Intake, Inlet, and Exhaust Manifolds

Description	Tool Number
Feeler Gauge	Obtain locally
Straightedge	Obtain locally
Intake Port Covers (cylinder heads)	ZTSE4559

Front Cover, Cooling System, and Related Components

Table 65 Front Cover, Cooling System, and Related Components

Description	Tool Number
Dial indicator with magnetic base	Obtain locally
Feeler gauge	Obtain locally
Front Seal (wear sleeve) Installer	ZTSE4691
Front Wear Sleeve Remover	ZTSE4705
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Loctite® 569 hydraulic sealant or equivalent	Obtain locally
Slide hammer	Obtain locally
Straightedge	Obtain locally

Cylinder Head and Valve Train

Table 66 Cylinder Head and Valve Train

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

Oil Cooler and Filter Housing

Table 67 Oil Cooler

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

Flywheel and Flywheel Housing

Table 68 Flywheel and Flywheel Housing

Description	Tool Number
Dial caliper	Obtain locally
Dial indicator with magnetic base	Obtain locally
Gear puller (bar type)	Obtain locally
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Loctite® 569 hydraulic sealant or equivalent	Obtain locally
Power Steering Idler Shaft Installation Tool	ZTSE4719
Rear Wear Sleeve Installer	ZTSE4515-2C
Rear Wear Sleeve Remover	ZTSE4889
Slide hammer	Obtain locally

Power Cylinders

Table 69 Power Cylinders

Description	Tool Number
1–2 inch micrometer	Obtain locally
2–3 inch micrometer	Obtain locally
3–4 inch micrometer	Obtain locally
Dial indicator with magnetic base	Obtain locally
Feeler gauge	Obtain locally
Glaze breaker brush	Obtain locally
Piston Gauge Pins (2.0828 mm [0.082 in])	ZTSE4513
Piston Ring Compressor	ZTSE4714
Piston ring expansion pliers	Obtain locally
Telescoping gauge set	Obtain locally

Crankcase, Crankshaft, and Camshaft

Table 70 Crankcase, Crankshaft, and Camshaft

Description	Tool Number
0–1 inch micrometer	Obtain locally
2–3 inch micrometer	Obtain locally
3–4 inch micrometer	Obtain locally
Camshaft Bushing Service Set	ZTSE2893B
Camshaft Bushing Remover/Installer (expanding collet)	ZTSE4489
Cylinder bore gauge	Obtain locally
Deglazing hone (four inch)	Obtain locally
Dial indicator with magnetic base	Obtain locally
Feeler gauge	Obtain locally
Cylinder Head Bolt Tap	ZTSE4744
Lifting sling	Obtain locally
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Oil Gallery Cleaning Brush	ZTSE4511
Oil Gallery Plug Driver	ZTSE4512
Straightedge	Obtain locally
Telescoping gauge set	Obtain locally

Special Tools

Essential Tools

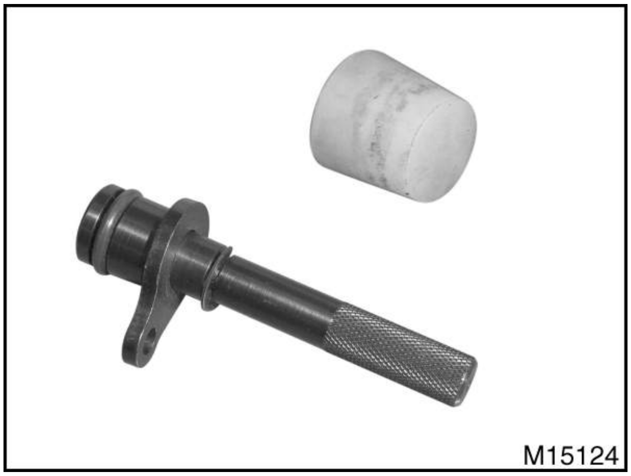

Figure 606 ZTSE4785 Turbo Oil Supply Block Off Plug Kit

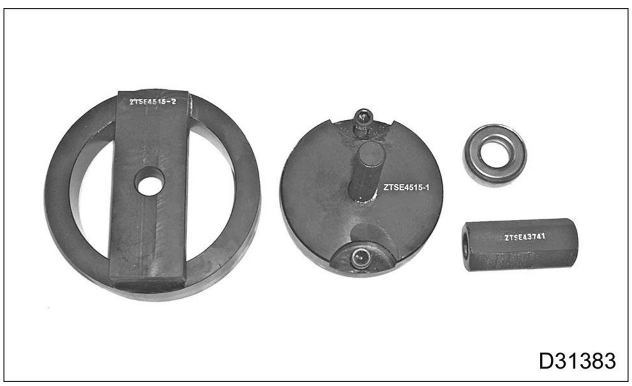

Figure 607 ZTSE4515–2C Rear Seal Installer w/ 40 mm Cap Screws

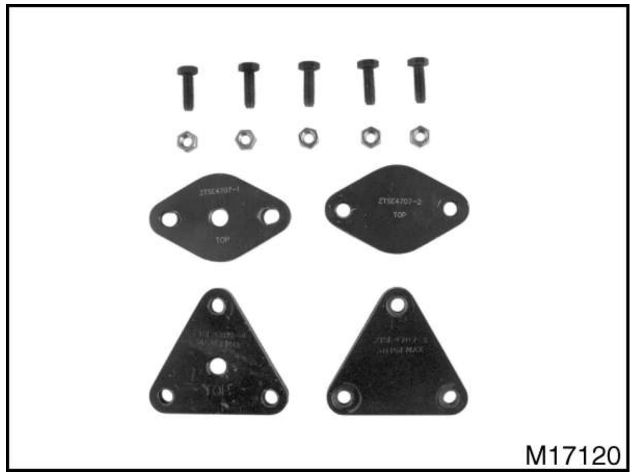

Figure 608 ZTSE4707 EGR Cooler Test Plates

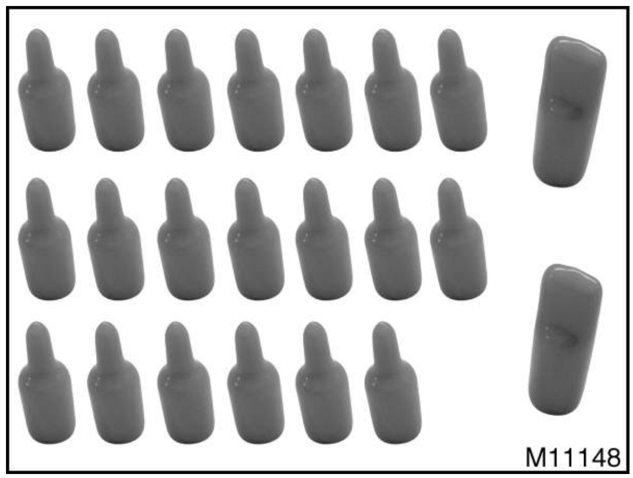

Figure 609 ZTSE4710 Fuel System Caps

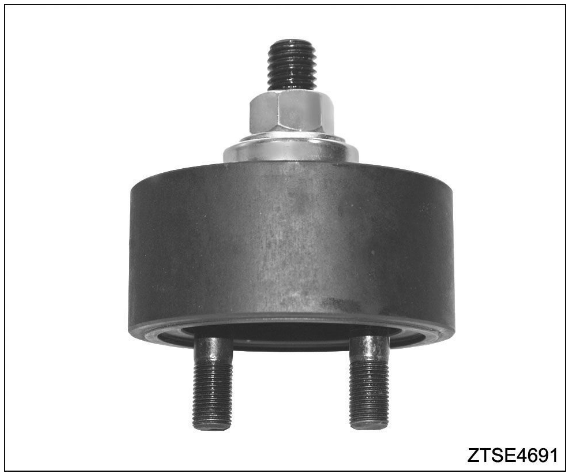

Figure 610 ZTSE4691 Front Seal Installer

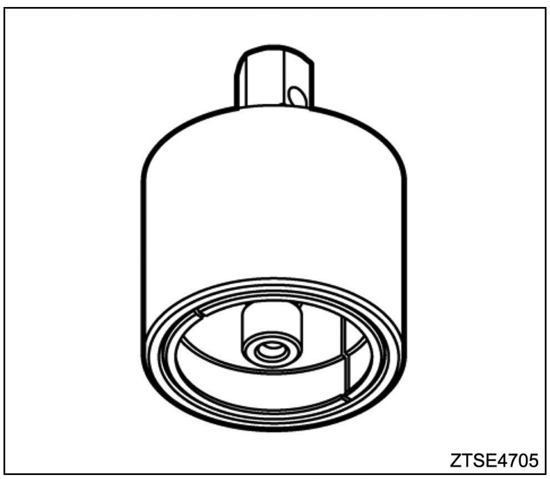

Figure 611 ZTSE4705 Front Wear Sleeve Remover

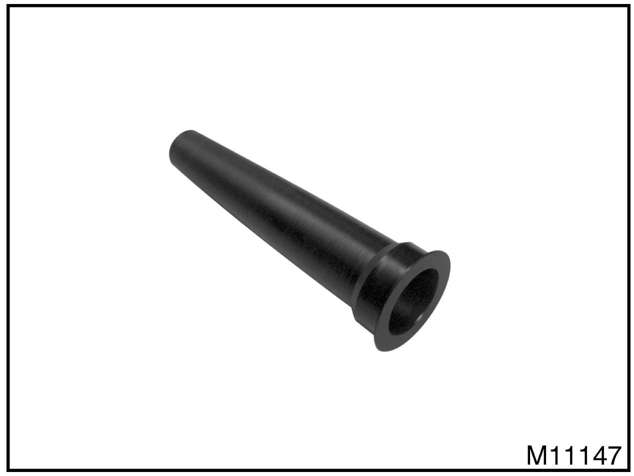

Figure 612 ZTSE4709 Injector Cups for ZTSE4299 (8)

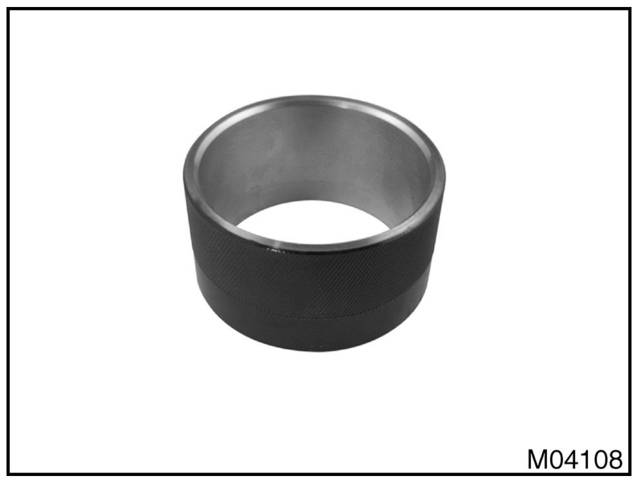

Figure 613 ZTSE4714 Piston Ring Compressor

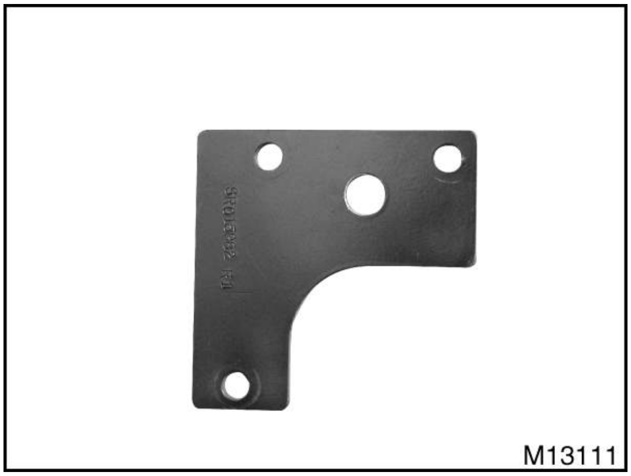

Figure 614 ZTSE4730 Oil Cooler pressure Test Plate

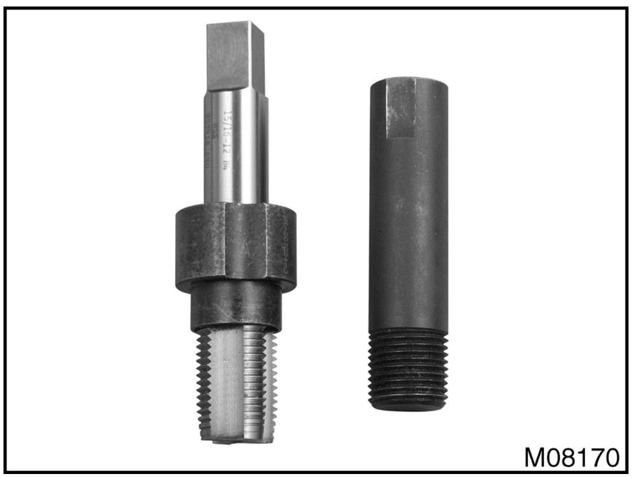

Figure 615 ZTSE4732 Injector Sleeve Remover

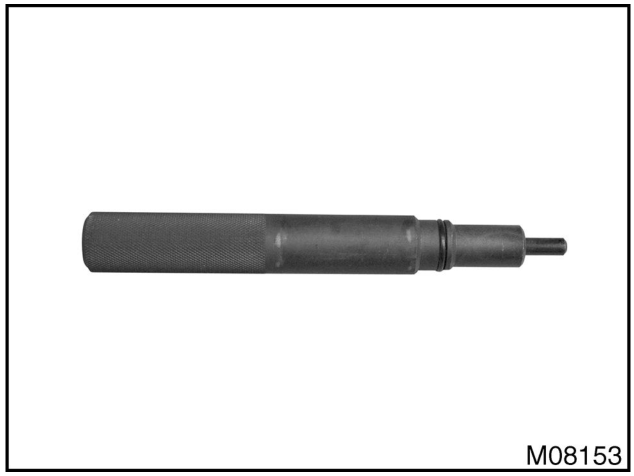

Figure 616 ZTSE473 Injector Sleeve Installer

Figure 617 ZTSE4743 EGR Valve Puller

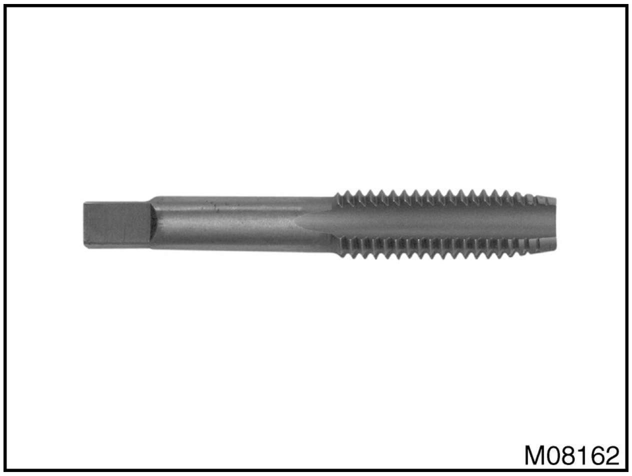

Figure 618 ZTSE4744 Cylinder Head Bolt Tap

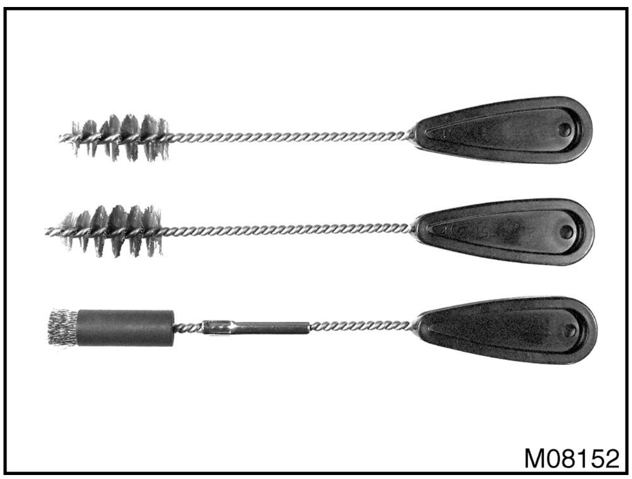

Figure 619 ZTSE4751 Injector Sleeve Brushes

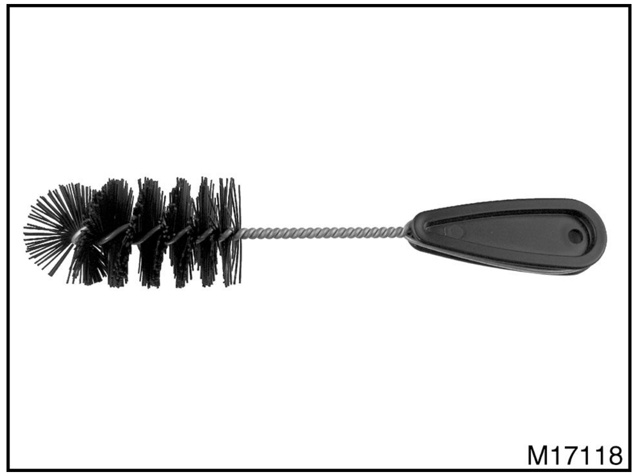

Figure 620 ZTSE4753 EGR Valve Bore Cleaning Brush

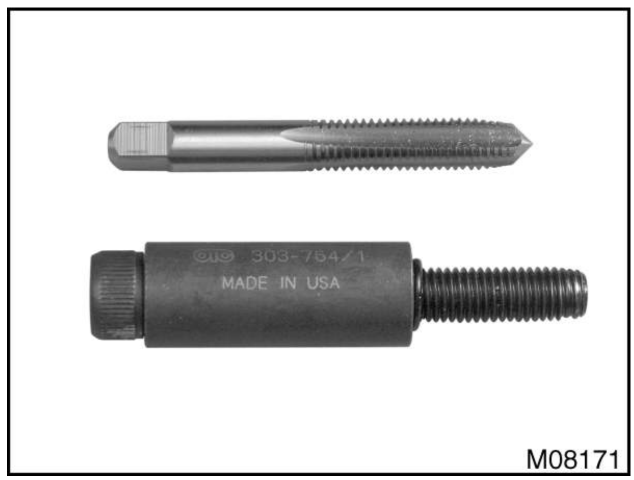

Figure 621 ZTSE4783 Glow Plug Installer Sleeve

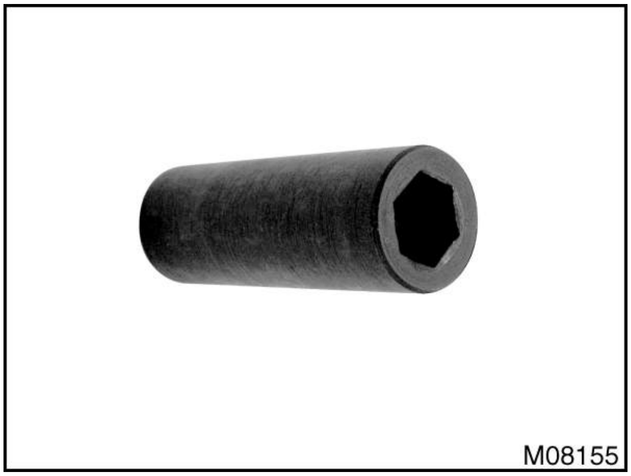

Figure 622 ZTSE4723 Glow Plug Socket

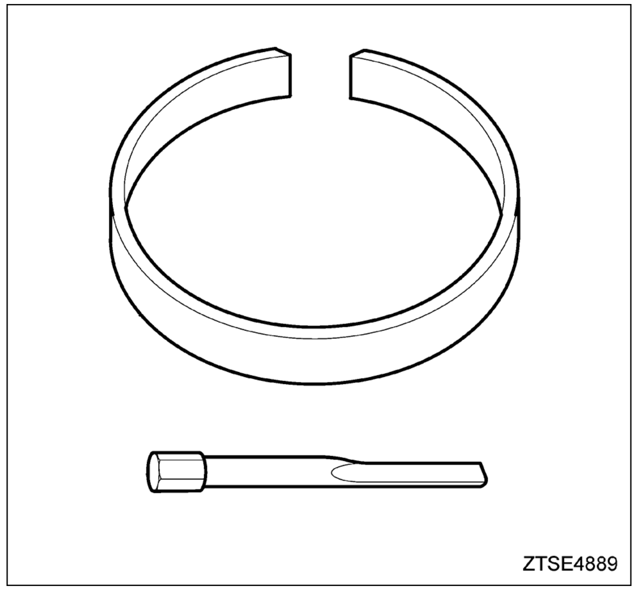

Figure 623 ZTSE4889 Rear Wear Sleeve Remover