ENGINE SERVICE MANUAL

2010 MaxxForce® 7

Navistar, Inc.

2701 Navistar Drive, Lisle, IL 60532 USA

©2014 Navistar, Inc. All rights reserved. All marks are trademarks of their respective owners.

0000002383
Revision 2
February 2014

TABLE OF CONTENTS

Foreword....1

Service Diagnosis....2

Safety Information....3

Engine Systems....5

Mounting Engine on Engine Stand....45

Engine Electrical....53

Exhaust Gas Recirculation (EGR) System....113

Dual Turbocharger, Exhaust Manifolds, and Piping....141

Air Compressor and Power Steering Pump....185

Fuel System....207

Front Cover, Cooling System, and Related Components....263

Oil Cooler, Oil Pump, Oil Filter, and Oil Pan....285

Cylinder Heads, Valve Covers, and Valve Train....309

Flywheel Assembly and Flywheel Housing....367

Power Cylinders....395

Crankcase, Crankshaft, and Camshaft....417

Abbreviations and Acronyms....443

Terminology....449

Appendix A – Specifications....461

Appendix B – Torques....469

Appendix C – Special Service Tools....479

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

1171971R1	*MaxxForce® 7 Engine Operation and Maintenance Manual*
0000002383	*MaxxForce® 7 (EPA 10) with HD-OBD Engine Service Manual*
0000001681	*MaxxForce® 7 (EPA 10) with HD-OBD Engine Diagnostic Manual*
0000003382	*MaxxForce® 7 (EPA 10) with HD-OBD Hard Start and No Start Diagnostic Form*
0000003381	*MaxxForce® 7 (EPA 10) with HD-OBD Performance Diagnostic Form*
0000003201	*MaxxForce® 7 (EPA 10) with HD-OBD Engine Wiring Schematic Form*

Technical Service Literature is revised periodically. If a technical publication is ordered, the latest revision will be supplied.

To order technical service literature, contact your International® dealer.

All marks are trademarks of their respective owners.

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, diagnostic test equipment, and diagnostic software.
- 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.

Table of Contents

Engine Identification....7
Engine Serial Number....7
Emission Label....7
Engine Accessories....7
Engine Description....8
Standard Features....9
Optional Features....10
Thermal Management Valve (TMV)....10
Chassis-mounted Features....10
Engine Components....11

Air Management System....16
Air Management Components and Air Flow....16
Air Flow....17
Charge Air Cooler (CAC)....17
Charge Air Cooler Outlet Temperature (CACOT) Sensor....17
Dual Turbocharger Assembly....19
High-pressure Turbocharger....20
Turbocharger 1 Compressor Outlet Temperature (TC1COT) Sensor....20
Thermal Management Valve (TMV) (optional)....20
Low-pressure Turbocharger....20
Turbocharger 1 Wastegate Control (TC1WC) Solenoid....20
Exhaust Gas Recirculation (EGR) System....21
EGR Flow....21
EGR Control Valve and Position Sensor....22
Engine Throttle Valve (ETV) and Position Sensor....23
Aftertreatment (AFT) System....24
AFT Control System....24
Sensors....24
Diesel Oxidation Catalyst (DOC)....24
Diesel Particulate Filter (DPF)....24
AFT Conditions and Responses....24

Fuel System....25
Fuel System Components....25
High-pressure Fuel System....26
High-pressure Fuel Pump (HPFP) Assembly....26
Internal Transfer Pump (ITP)....26
Fuel Pressure Control Valve (FPCV)....26
Fuel Volume Control Valve (FVCV)....27
Fuel Rail Pressure (FRP) Sensor....27
High-pressure Piezo Common Rail (HPCR) System....27
Return Fuel System....27
Low-pressure Fuel System....29
Fuel Pump....29
Primary Fuel Filter....29

Secondary Fuel Filter....29
Fuel Cooler....29
Fault Detection/Management....29

Engine Lubrication System....30
Lubrication System Components and Oil Flow....30

Cooling System....32
Cooling System Components and Flow....32
Water Pump....32
Front Crankcase Cover Flow....33
Thermostats....33
Deaeration Tank....33
Radiator Shutters (220 Horsepower only)....33
Fuel Coolant Valve (FCV)....33

Engine Speed Position System....34

Electronic Control System....35
Electronic Control System Components....35
Operation and Function....37
Reference Voltage (VREF)....37
Signal Conditioner....37
Microprocessor....37
Microprocessor Memory....37
Flash Memory....37
RAM....37
Engine Fan Control (EFC)....38
Inlet Air Heater (IAH)....38
Actuator Control....38
Actuators....38
H-Bridge Circuit....38
Exhaust Gas Recirculation (EGR) Valve and Control....38
ETV and Engine Throttle Position Sensor....39
Engine and Vehicle Sensors....39
Thermistor Sensors....39
Variable Capacitance Sensors....40
Micro Strain Gauge (MSG) Sensor....40
Magnetic Pickup Sensors....41
Potentiometer....41
Switches....42
Inlet Air Heater (IAH) System....43

Engine Identification

Engine Serial Number

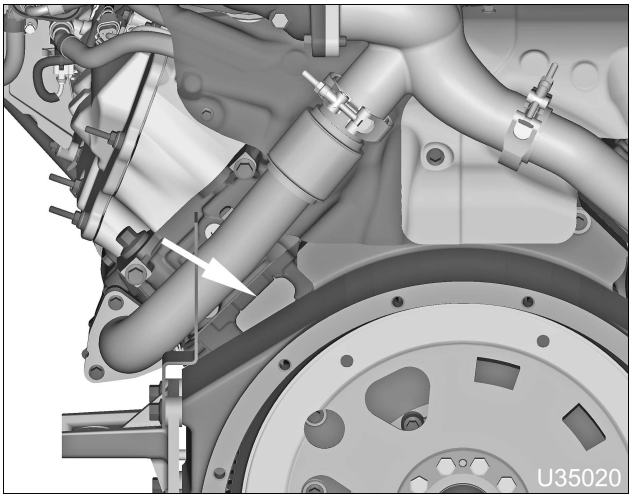


Figure 1 Engine Serial Number

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

Engine Serial Number Example

6.5HM2YXXXXXXX

6.5 – Engine family code
H – Diesel, turbocharged, air-intercooled and electronically controlled
M2 – Motor truck
Y – United States, Huntsville
7 digit suffix – Sequence number

Emission Label

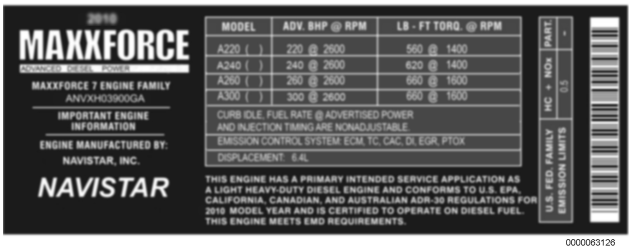


Figure 2 U.S. Environmental Protection Agency (EPA) Exhaust Emission Label (example)

The U.S. Environmental Protection Agency (EPA) exhaust emission label is on top of the EGR manifold mixer on the front of the engine. 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

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	16.5:1
Aspiration	Dual Turbocharger and Charge Air Cooled (CAC)
Rated power @ rpm	See EPA exhaust emission label
Peak torque @ rpm	See EPA exhaust emission label
Engine rotation (facing flywheel)	Counterclockwise
Combustion system	Direct injection, turbocharged advanced EGR
Fuel system	Direct injection, common rail
Cooling system capacity (engine only)	10.23 liters (10.8 quarts US)
Lube system capacity (including filter)	18.9 liters (20 quarts US)
Lube system capacity (overhaul only, with filter)	19.9 liters (21 quarts US)
Firing order	1-2-7-3-4-5-6-8

Standard Features

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

The electronic governor controls the engine rpm within a safe and stable operating range for ideal performance. A low-idle governor prevents the engine rpm from dropping below a stable speed to prevent stalling when various loads are demanded on the engine. A 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 five bushings pressed into the crankcase. The camshaft is crankshaft-driven and thrust is controlled by a plate mounted behind the rear bulkhead.

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 composed of two major matching components. The upper crankcase houses the cylinders, main bearing saddles, and oil and coolant passages. 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 fourth 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 Engine 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, Intake Air Heater (IAH), and Engine Throttle Valve (ETV). The EGR valve assembly is mounted on the manifold mixer on the front top of the engine. The ETV is installed on the Intake Air Heater (IAH) mounted on the manifold mixer.

A gerotor lube oil pump, mounted on the front crankcase bulkhead, is driven by the crankshaft to supply pressurized oil to engine components. All MaxxForce® 7 engines use an engine oil cooler and spin-on oil filter. The oil filter is located at the lower driver-side corner of the engine where there is an integrated filter header to the cast-aluminum oil pan.

An open crankcase breather system draws crankcase vapors through a breather element. The breather element coalesces (separates) and oil migrates towards the low point in the housing which then gets returned back to crankcase. Clean blow-by gas (vapors) exit the breather cover and vents out to atmosphere.

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, which allows multiple injections and more precise fuel delivery to improve combustion, emissions, and cold-start performance.

The low-pressure fuel system uses an electric fuel lift pump to draw fuel from the fuel tank(s) to the engine. This eliminates the need for a hand primer. The pump is located in the primary and secondary fuel module mounted over the left valve cover. 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 illuminates and 'Water in Fuel' message is displayed when water needs to be drained. A manual drain valve is provided in the water separator bowl to drain water out. Fuel is discharged to the secondary fuel filter. The secondary fuel filter assembly is pressure-regulated and incorporates an air bleed orifice to automatically purge air introduced into the system.

A two-stage turbocharger provides boost air pressure to the engine for various speed and load conditions. An electronically controlled solenoid modulates boost air to a wastegate actuator.

The 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.

A relay-controlled grid heater is used to aid cold, ambient starting.

A coolant heater raises the temperature of the coolant surrounding the cylinders for improved performance during cold weather startups.

Optional Features

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

An optional fuel heater is available and installed in the primary fuel filter assembly. It warms the supply fuel to prevent waxing during cold conditions where the fuel filter module's internal fuel passages between the primary and secondary filter do not provide sufficient warming.

Thermal Management Valve (TMV)

A TMV is available to enable engine braking and to reduce the amount of time needed to bring the engine to operating temperature.

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 emission requirements at the tailpipe.

- The oxidation catalyst removes oxygen and hydrocarbons in the exhaust stream.
- The Diesel Particulate Filter (DPF) captures and removes particulates in the exhaust stream.

Engine Components

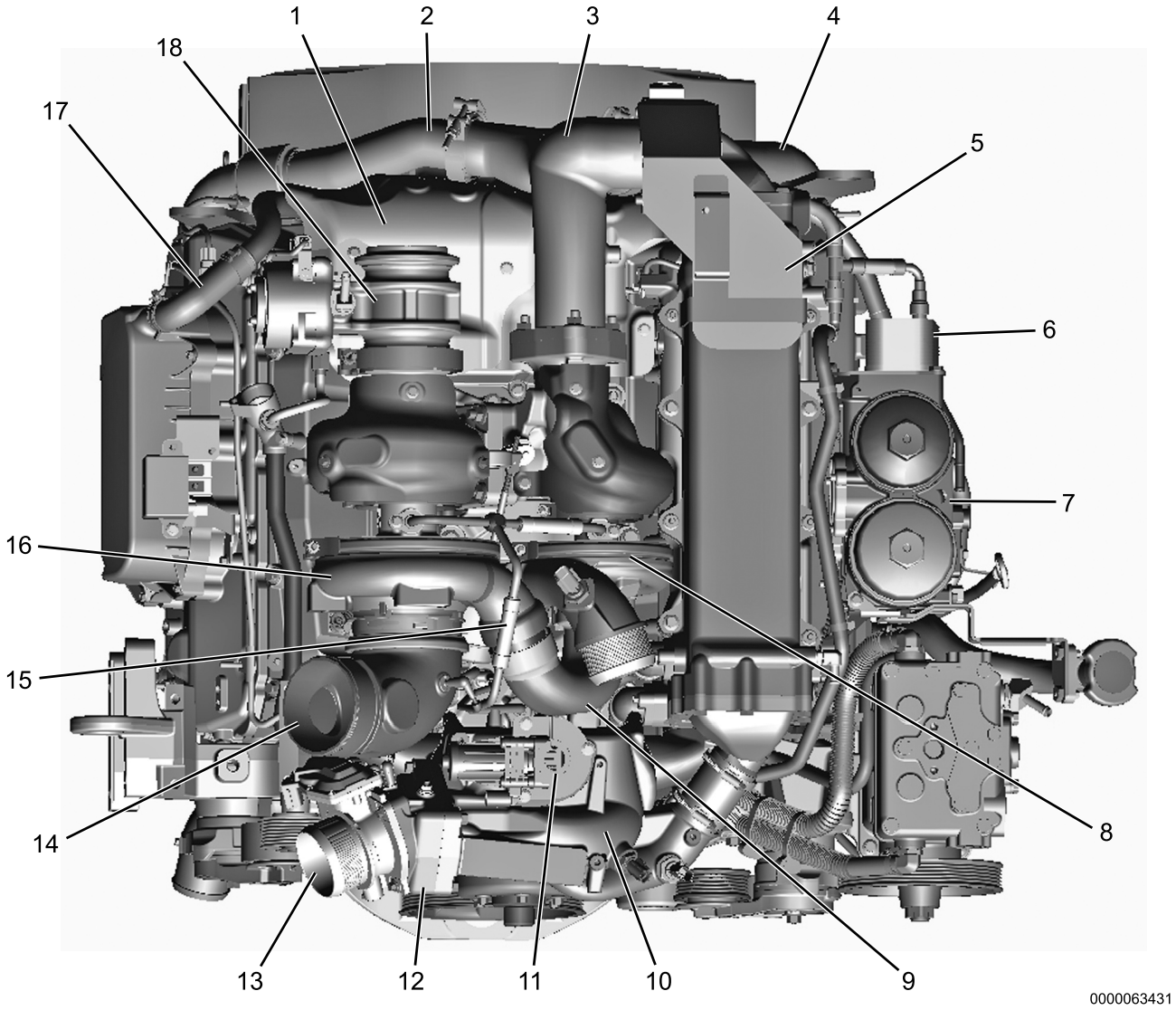


Figure 3 Top

1. Pump cover heat shield (right)
2. Right exhaust tube assembly
3. Exhaust turbocharger inlet manifold
4. Left exhaust tube assembly
5. EGR cooler
6. Fuel cooler
7. Fuel filter module housing
8. High-pressure turbocharger assembly
9. Crossover tube
10. Manifold mixer
11. EGR valve
12. Inlet Air Heater (IAH)
13. Engine Throttle Valve (ETV)
14. Turbocharger inlet duct assembly
15. Turbocharger oil supply tube
16. Low-pressure turbocharger assembly
17. Draft tube
18. Thermal Management Valve (TMV) (optional)

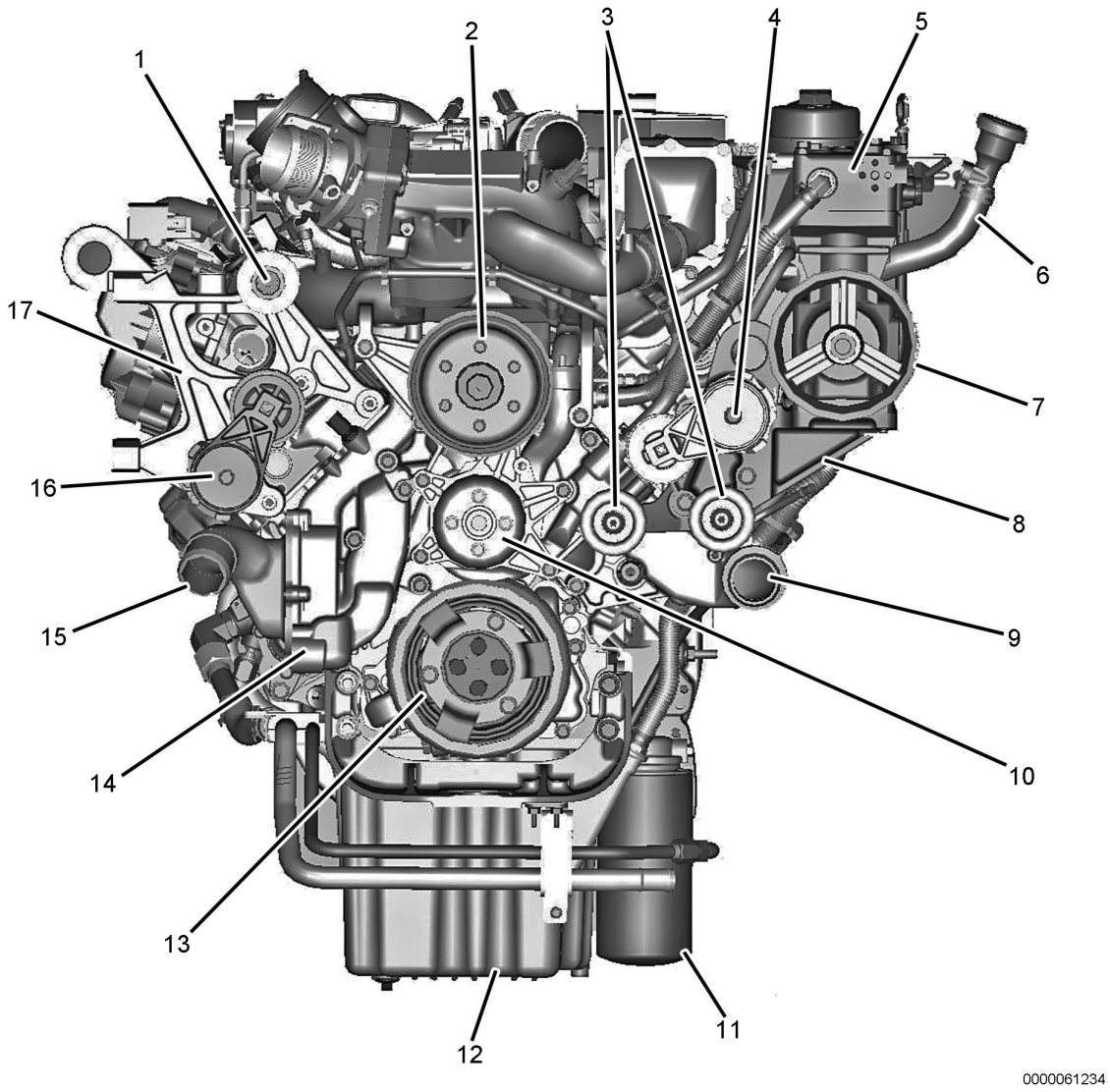


Figure 4 Front

1. Grooved idler pulley
2. Fan pulley
3. Flat idler pulley (2)
4. Belt tensioner (if equipped with air compressor)
5. Air compressor
6. Oil fill tube assembly
7. Air compressor pulley
8. Air compressor bracket
9. Coolant inlet
10. Water pump pulley
11. Oil filter assembly
12. Oil pan
13. PTO air compressor front pulley
14. Front crankcase cover (heater return)
15. Thermostat housing (coolant outlet)
16. Belt tensioner
17. Alternator bracket

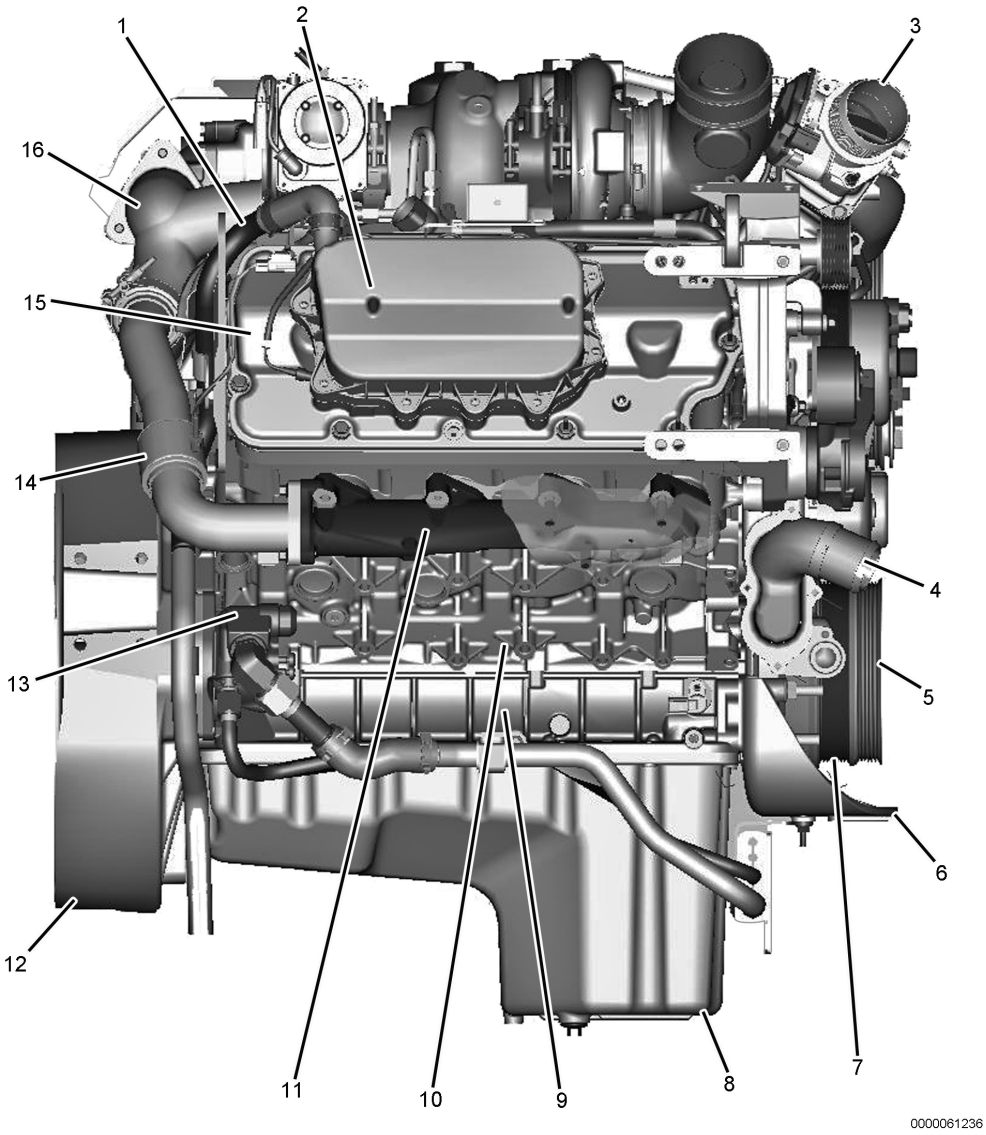


Figure 5 Right

1. Draft tube
2. Breather cover
3. ETV
4. Thermostat housing (coolant return)
5. PTO air compressor front pulley
6. Front engine mounting support
7. Vibration damper
8. Oil pan
9. Lower crankcase
10. Upper crankcase
11. Right exhaust manifold
12. Rear crankcase cover assembly (flywheel housing)
13. Power steering pump
14. Right exhaust tube assembly
15. Right valve cover
16. Exhaust turbocharger inlet manifold

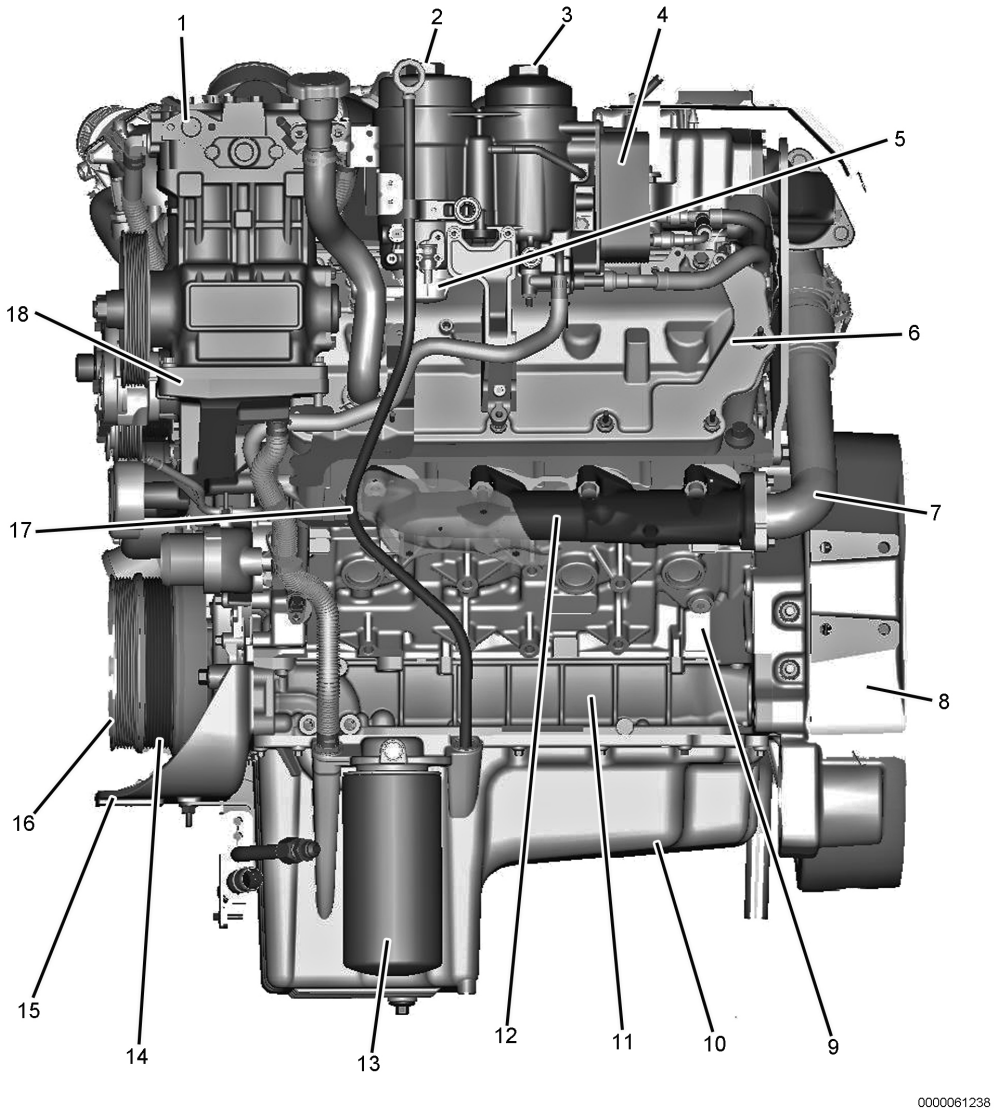


Figure 6 Left

1. Air compressor assembly
2. Filter cap (primary)
3. Filter cap (secondary)
4. Fuel cooler
5. Fuel pump
6. Left valve cover
7. Left exhaust tube assembly
8. Crankcase rear cover (flywheel housing)
9. Upper crankcase
10. Oil pan
11. Lower crankcase
12. Left exhaust manifold
13. Oil filter
14. Vibration damper
15. Front engine mounting support
16. PTO air compressor front pulley
17. Oil level gauge tube
18. Air compressor bracket

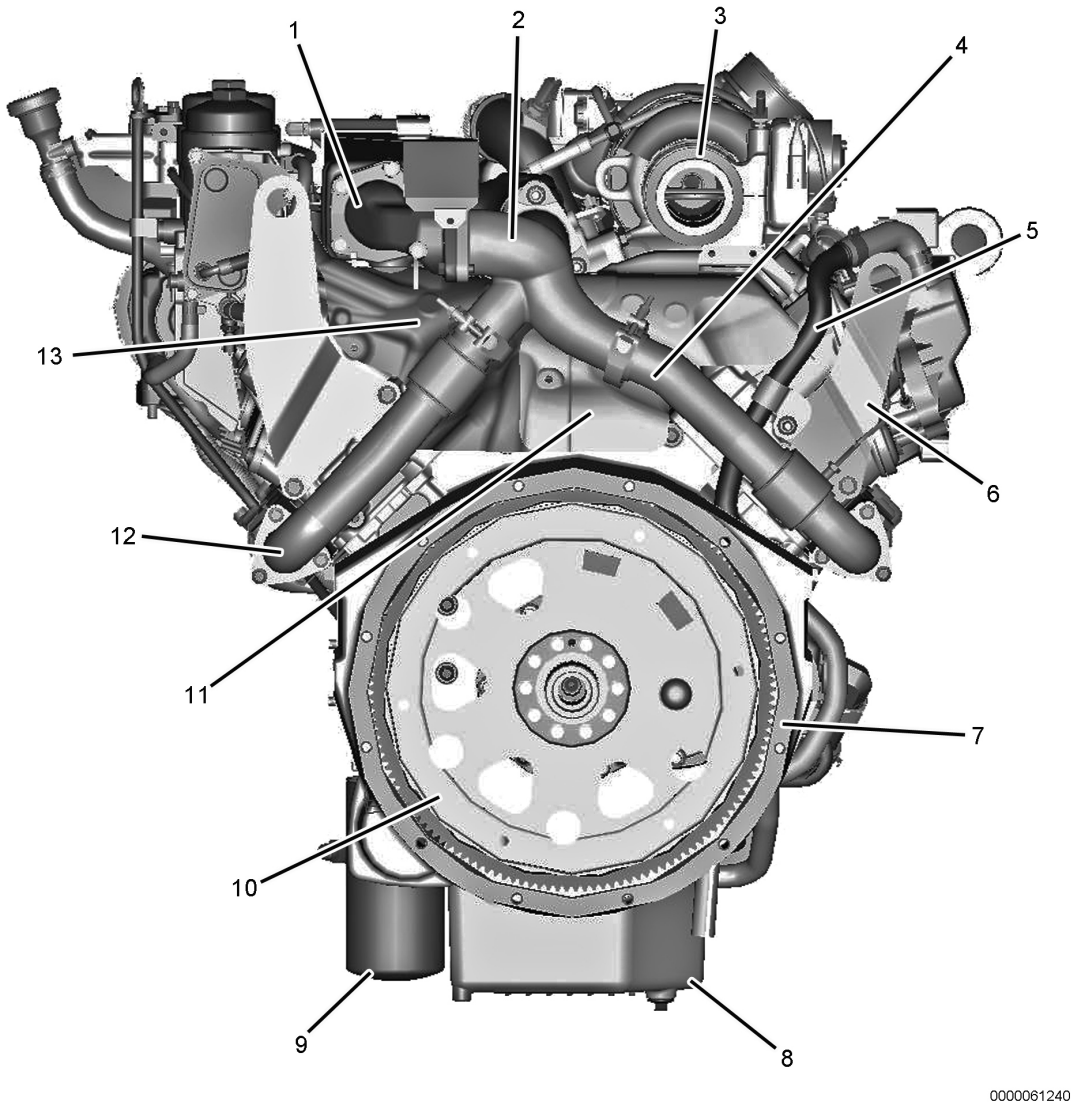


Figure 7 Rear

1. EGR cooler
2. Exhaust turbocharger inlet manifold
3. Low-pressure turbocharger assembly
4. Right exhaust tube assembly
5. Draft tube
6. Lifting eye
7. Crankcase rear cover (flywheel housing)
8. Oil pan
9. Oil filter
10. Flexplate
11. Pump cover heat shield (right)
12. Left exhaust tube assembly
13. Pump cover heat shield (left)

Air Management System

Air Management Components and Air Flow

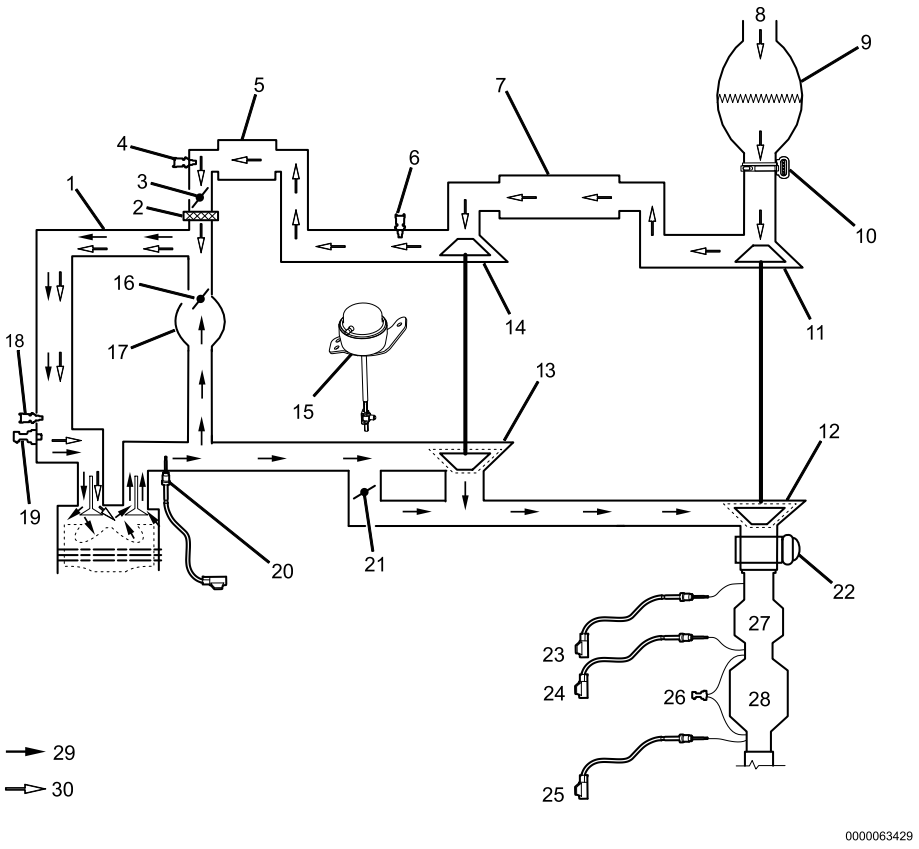


Figure 8 Air Management System (AMS)

1. Air intake manifold
2. Inlet Air Heater (IAH)
3. ETV and Engine Throttle Position (ETP) sensor
4. Charge Air Cooler Outlet Temperature (CACOT) sensor
5. Charge Air Cooler (CAC)
6. Turbocharger 1 Compressor Outlet Temperature (TC1COT) sensor
7. Air crossover tube assembly
8. Air inlet
9. Air filter
10. Mass Air Flow/Air Inlet Temperature (MAF/AIT) sensor
11. Low-pressure turbocharger compressor
12. Low-pressure turbocharger turbine
13. High-pressure turbocharger turbine
14. High-pressure turbocharger compressor
15. Turbocharger 1 Wastegate Control (TC1WC) actuator
16. EGR Control Valve and EGR Position sensor
17. EGR cooler
18. Intake Manifold Temperature (IMT) sensor
19. Intake Manifold Pressure (IMP) sensor
20. Exhaust Gas Temperature (EGT) sensor
21. Turbocharger wastegate valve
22. Thermal Management Valve (TMV) (optional)
23. DOC Inlet Temperature (DOCIT) sensor
24. DPF Inlet Temperature (DPFIT) sensor
25. DPF Outlet Temperature (DPFOT) sensor
26. DPF Differential Pressure (DPFDP) sensor
27. Diesel Oxidation Catalyst (DOC)
28. Diesel Particulate Filter (DPF)
29. Exhaust gas
30. Intake air

Air Flow

Air flows through the air filter assembly and enters the low-pressure turbocharger. Some vehicles are fitted with an optional Thermal Management Valve (TMV) between the air filter and the low-pressure turbocharger. The purpose of this valve is to enable engine braking and allow faster engine warm-ups. The compressor in the low-pressure turbocharger increases pressure, temperature, and density of the intake air before it enters the air crossover tube. From the air crossover tube assembly, air enters the high-pressure turbocharger. The high-pressure turbocharger compressor further increases the pressure, temperature, and density of the intake air. The high-pressure Turbocharger 1 Wastegate Control (TC1WC) solenoid and the TC1WC actuator control the output of the high-pressure turbocharger by adjusting the wastegate valve inside the turbocharger. From the high-pressure turbocharger, air enters the Charge Air Cooler (CAC). Cooled compressed air flows from the CAC through the ETV and Exhaust Gas Recirculation (EGR) mixer into the intake manifold.

If the EGR valve is open, some exhaust gas mixes with compressed intake air inside the EGR mixer and flows into the cylinders. If the EGR valve is closed, only compressed intake air flows into the cylinders.

After combustion, exhaust gas is forced through the exhaust manifolds to the EGR cooler and turbochargers. Some exhaust gas is cooled in the EGR cooler and flows through the EGR valve to the intake air stream. When exhaust gas mixes with air and fuel, it reduces the formation of Nitrogen Oxides (NO_X) engine emissions. The rest of the exhaust gas flows through the high-pressure turbocharger turbine and then through the low-pressure turbocharger turbine. The high-pressure turbine is on the same shaft as the high-pressure turbocharger compressor and compresses the mixture of filtered air. The low-pressure turbocharger turbine is on the same shaft as the low-pressure compressor. Some vehicles are fitted with an optional Thermal Management Valve (TMV) in the exhaust system between the low-pressure turbocharger and the DOC. The purpose of this valve is to enable engine braking and allow faster engine warm-ups.

The high-pressure TC1WC actuator is controlled by the Engine Control Module (ECM) and responds to engine loads. During heavy loads, increased exhaust flow turns the turbine wheel faster. This increased speed turns the compressor impeller faster and supplies greater boost pressure to the intake manifold. To prevent too much boost from building, the wastegate valve diverts exhaust away from the turbine wheel. Conversely, when engine load is light, the flow of exhaust decreases and less air is forced into the intake manifold. Therefore, the wastegate valve forces more exhaust towards the turbine wheel to compensate.

Charge Air Cooler (CAC)

Air from the dual stage turbocharger assembly passes through a network of heat exchanger tubes inside the CAC before entering the ETV. Outside air flows through the CAC and cools the charged air. Cooled intake air improves the fuel-to-air ratio during combustion. This results in improved emission control and power output.

Charge Air Cooler Outlet Temperature (CACOT) Sensor

The CACOT is a thermistor-style sensor that measures charged-air temperature entering the Engine Throttle Valve (ETV). As temperature increases, resistance drops, causing the voltage signal interpreted by the Engine Control Module (ECM) to vary. The ECM monitors this signal for Exhaust Gas Recirculation (EGR) system control and Charge Air Cooler (CAC) performance.

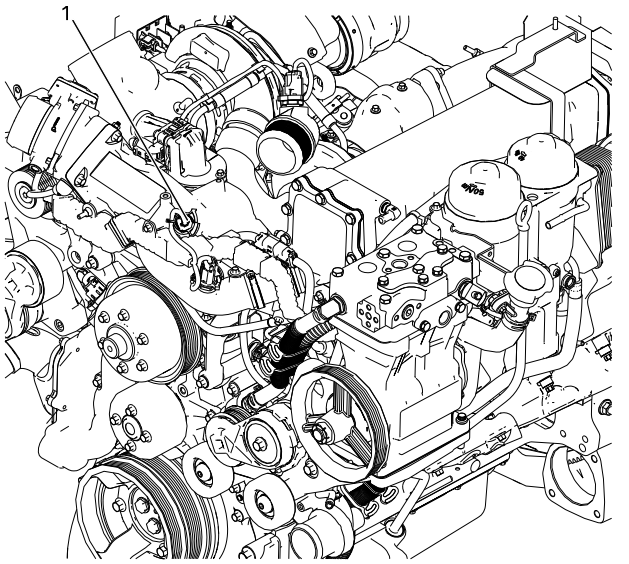


Figure 9 Charge Air Cooler Outlet Temperature (CACOT) Sensor

1. CACOT Sensor

Dual Turbocharger Assembly

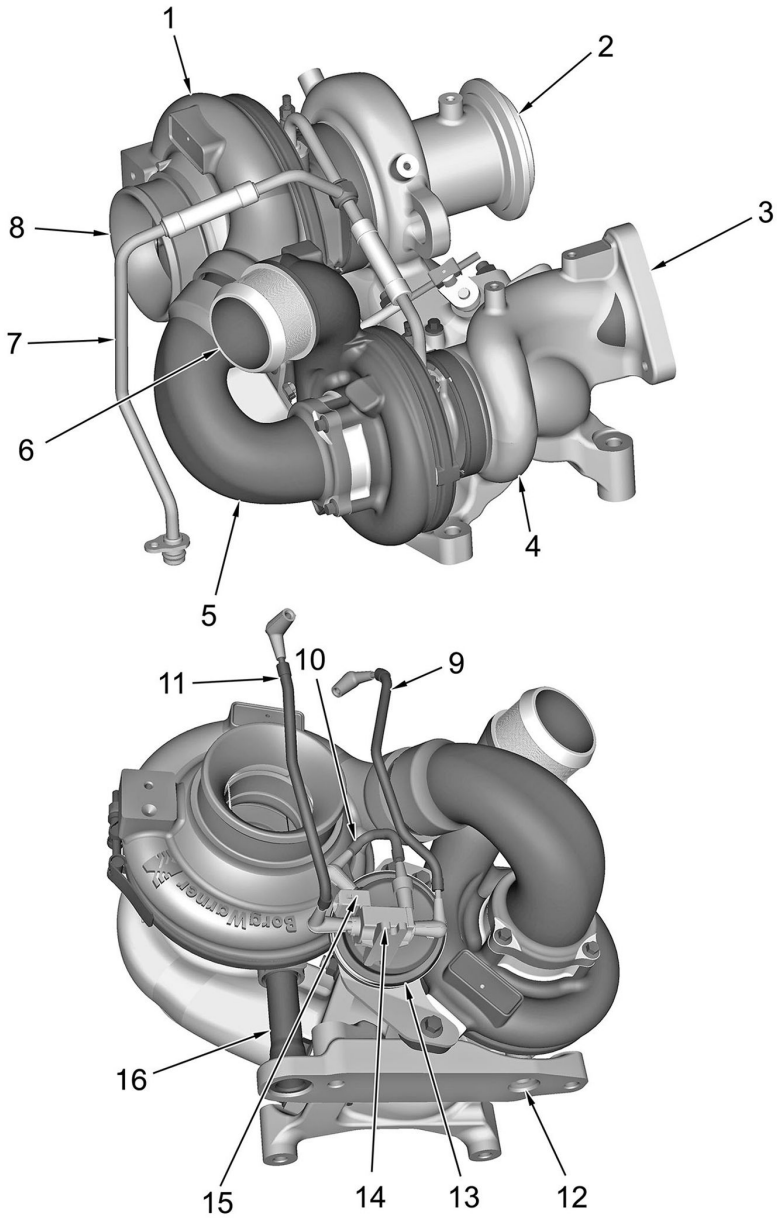


Figure 10 Dual Turbocharger Assembly

1. Low-pressure turbocharger
2. Low-pressure turbocharger turbine outlet
3. Exhaust inlet
4. High-pressure turbocharger
5. Crossover tube
6. High-pressure turbocharger compressor outlet
7. Turbocharger oil supply tube
8. Air inlet
9. Relief-to-duct tube assembly
10. Wastegate tube assembly
11. Boost solenoid tube assembly
12. High-pressure turbocharger drain port
13. TC1WC actuator
14. TC1WC solenoid
15. TC1WC solenoid electrical connector
16. Low-pressure turbocharger drain tube

MaxxForce® 7 engines are equipped with an electronically controlled dual turbocharging system. This system provides high levels of charge air pressure to improve engine performance and reduce emissions. The dual turbocharger assembly is connected to the turbocharger exhaust inlet manifold. Because of its ability to generate very high charge air pressure levels and to prevent Charge Air Cooler (CAC) overloading conditions, the system is fitted with a spring-loaded turbocharger wastegate valve.

The turbocharger wastegate valve is actuated by boost air pressure. Boost air pressure to the TC1WC actuator is controlled by an electronically controlled TC1WC solenoid, based on a Pulse Width Modulation (PWM) signal supplied by the Engine Control Module (ECM).

High-pressure Turbocharger

The high-pressure turbocharger assembly is equipped with a wastegate valve that regulates turbocharger boost by controlling the amount of exhaust gases that pass through the high-pressure turbine. When the boost demand is high, or when the boost demand reaches a predetermined value, the TC1WC actuator opens the wastegate valve. This allows part of the exhaust gas flow to bypass the high-pressure turbine. Compressed air from the low-pressure compressor housing enters the high-pressure turbine compressor through the air crossover tube. Where it is further compressed and sent to the charge air cooler.

Turbocharger 1 Compressor Outlet Temperature (TC1COT) Sensor

The TC1COT is a thermistor-style sensor that measures charged-air temperature leaving the turbocharger compressor before the Charge Air Cooler (CAC). As temperature increases, resistance drops, causing the voltages interpreted by the Engine Control Module (ECM) to vary. The ECM monitors this signal for engine protection.

Thermal Management Valve (TMV) (optional)

The TMV is a “smart” valve in the exhaust and is used as an engine retarder / brake and to reduce the amount of time needed to bring the engine to operating temperature. The TMV detects faults internally and reports them to the ECM via the Control Area Network (CAN) bus. To prevent the valve from overheating, it is cooled by engine coolant.

Low-pressure Turbocharger

The low-pressure turbine is attached directly to the output of the high-pressure turbine. The exhaust gases enter the low-pressure turbine housing and exit through the low-pressure turbine outlet. Fresh air from the air filter enters the low-pressure compressor where it is compressed and air from the low-pressure compressor is piped directly to the high-pressure compressor inlet.

Turbocharger 1 Wastegate Control (TC1WC) Solenoid

The TC1WC solenoid controls the TC1WC actuator by regulating the boost control air supply based on a Pulse Width Modulation (PWM) signal received from the ECM.

With no PWM signal, the TC1WC solenoid is open and control air is supplied to the TC1WC actuator maintaining it in the open position. When an increase in the charge air pressure is required, the ECM supplies PWM voltage to close the TC1WC solenoid. When the TC1WC solenoid closes, it interrupts the control air supply to the TC1WC actuator and at the same time relieves the air pressure from the TC1WC actuator by allowing it to vent to the turbocharger inlet duct. The TC1WC actuator then closes, resulting in increased charge air pressure.

Exhaust Gas Recirculation (EGR) System

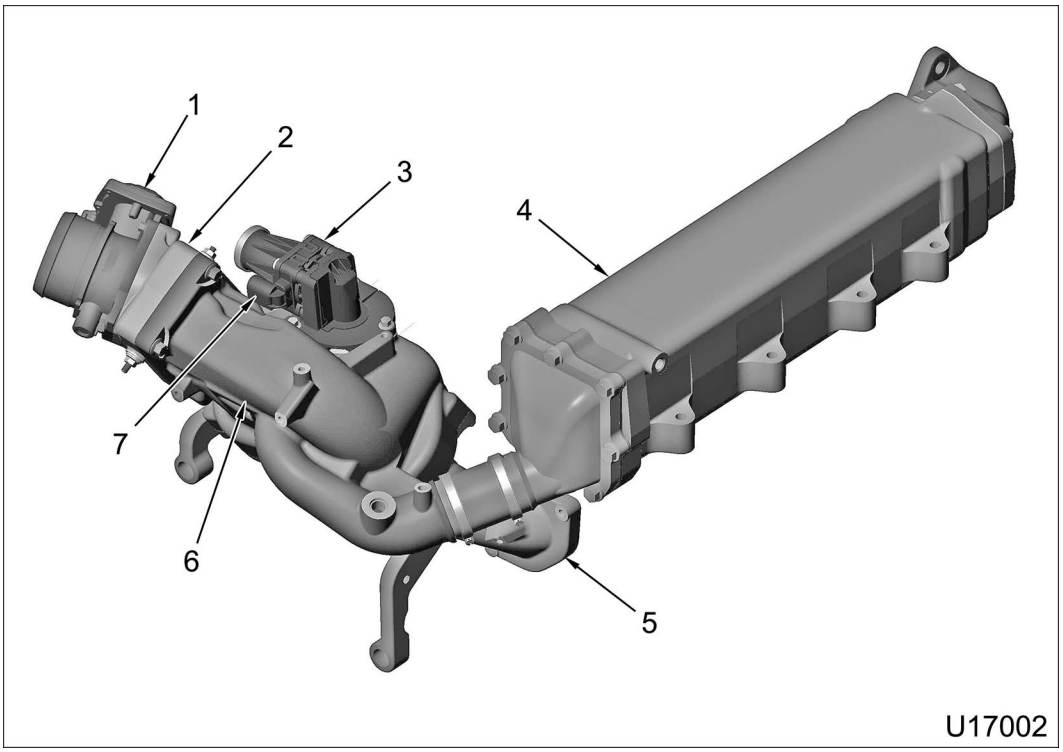


Figure 11 EGR System

1. Engine Throttle Valve (ETV)
2. Inlet Air Heater (IAH)
3. EGR valve
4. EGR cooler
5. Distribution duct
6. Manifold mixer
7. EGR valve connector

Exhaust Gas Recirculation (EGR) is an emission-control technology, which significantly reduces Nitrogen Oxide (NO_X) emissions. The EGR system is also used to adjust the fuel-to-air ratio for Diesel Particulate Filter (DPF) regeneration.

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

EGR Flow

Some exhaust from the turbocharger inlet manifold flows into the EGR cooler. Exhaust from the EGR cooler flows into a manifold mixer, through the EGR valve, and then 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 Control Valve and Position Sensor

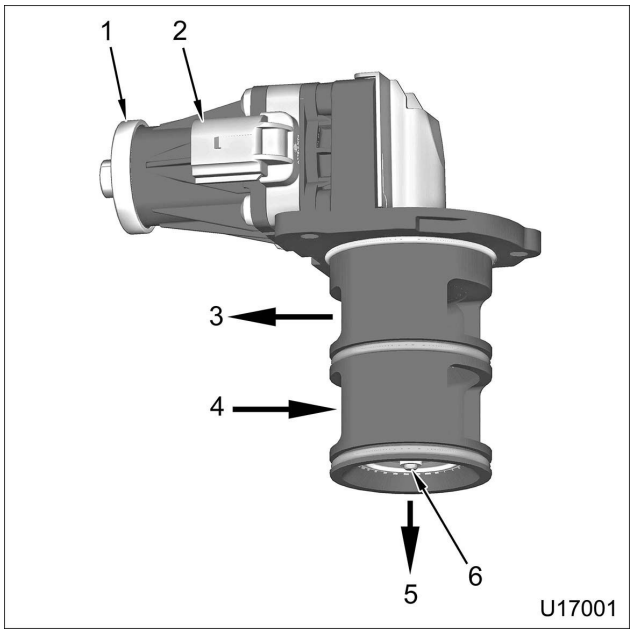


Figure 12 EGR Valve

1. Direct Current (DC) motor
2. Electrical connector
3. Exhaust outlet
4. Exhaust inlet
5. Exhaust outlet
6. Poppet valve assembly

The EGR valve uses a DC motor to control the position of the poppet valve assembly. The motor drives the poppet valve assembly, while driving 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 manifold mixer, where it mixes with incoming air from the air inlet throttle valve. The mixed air goes into the intake manifold and cylinders.

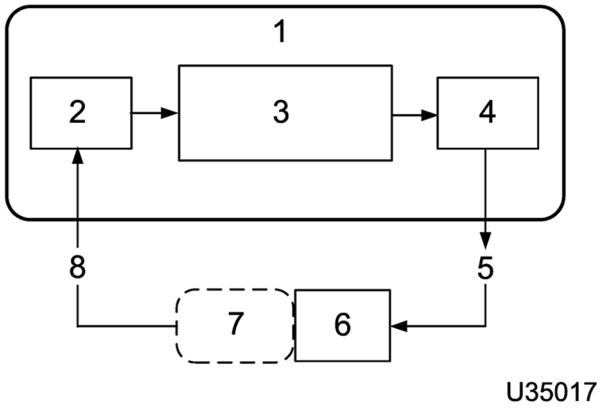


Figure 13 EGR Closed Loop Operation

1. ECM
2. Measured position
3. Compare with desired position
4. Adjust duty cycle
5. Duty cycle
6. EGR valve
7. Position sensor
8. Voltage

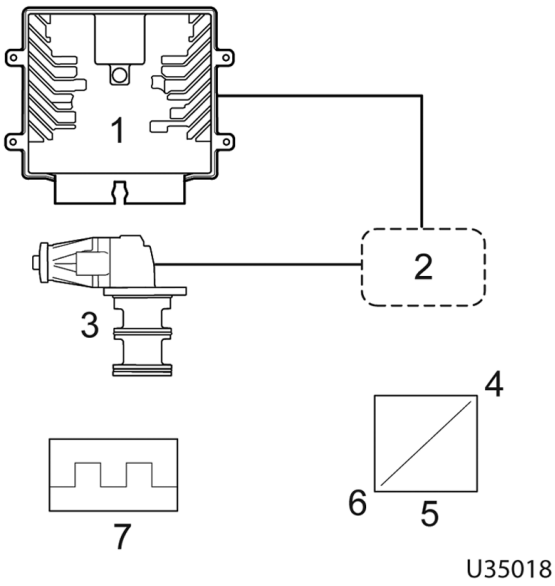


Figure 14 EGR Control

1. ECM
2. Position sensor
3. EGR valve
4. 5 volts
5. Analog voltage
6. 0 volts
7. Output signal

The EGR valve consists of two major components: a valve body and an actuator motor. A Hall-effect position sensor monitors valve movement. The EGR valve assembly is mounted on the manifold mixer on the front top of the engine.

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.

Engine Throttle Valve (ETV) and Position Sensor

ETV regulates the amount of fresh air flow coming into the system. When the engine needs fresh air, the default state of the ETV is opened. When air flow needs to be restricted, the ETV is commanded to close by the ECM.

The ECM monitors the Aftertreatment System. The ECM controls the ETV during AFT regeneration and purge. The ETV is controlled to restrict intake air, which increases the exhaust temperature to clean the Diesel Particulate Filter (DPF). The ETV is also used to help drive more EGR during normal operation.

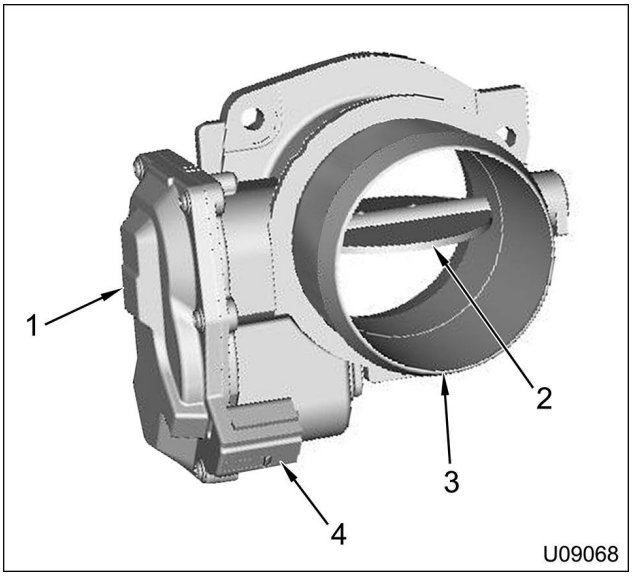


Figure 15 ETV

1. DC motor
2. Throttle blade
3. Inlet air intake
4. Electrical connector

The ETV uses a DC motor to control the position of the throttle blade. The motor drives the throttle blade, while at the same time the position sensor is being read. The ETV consists of two major components, the valve body and actuator motor. A Hall-effect position sensor monitors valve movement.

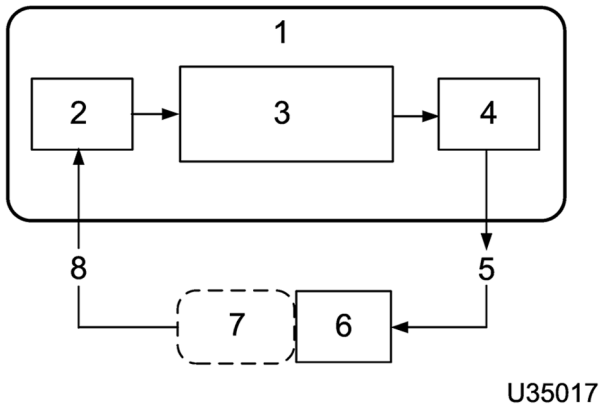


Figure 16 ETV Closed Loop Operation

1. ECM
2. Measured position
3. Compare with desired position
4. Adjust duty cycle
5. Duty cycle
6. ETV
7. Position sensor
8. Voltage

The ETV motor receives the desired valve position from the ECM to position the valve for fresh air flow. The position sensor provides feedback to the ECM on valve position.

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 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 aftertreatment function.

The sensors measure temperature and pressure in 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)
- Reduces exhaust back pressure for optimized engine performance by reducing the soot load through regeneration into ash
- 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

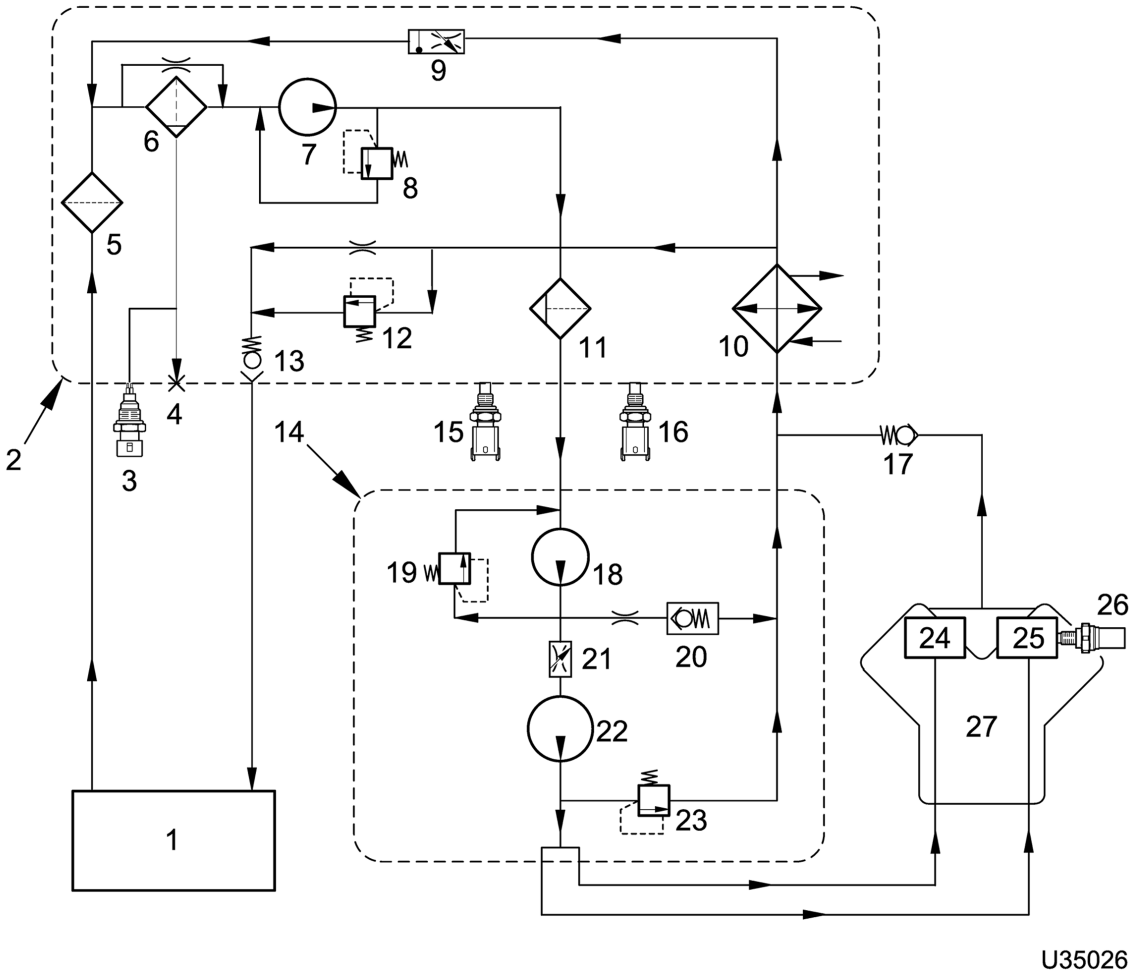


Figure 17 Fuel System Schematic

1. Fuel tank
2. Fuel filter module housing
3. Water In Fuel (WIF) sensor
4. Manual water drain
5. Fuel heater (Optional)
6. Primary fuel filter
7. Fuel Pump
8. Pressure relief valve
9. Thermal recirculation valve
10. Liquid fuel cooler
11. Secondary fuel filter
12. Pressure regulator
13. Shutoff valve
14. Engine High Pressure Fuel Pump (HPFP)
15. Fuel Delivery Pressure (FDP) sensor (optional)
16. Engine Fuel Temperature (EFT) sensor
17. Injector Leak Off (ILO) check valve
18. Internal Transfer Pump (ITP)
19. ITP regulator
20. HPFP cooling and lubrication flow valve
21. Fuel Volume Control Valve (FVCV)
22. HPFP
23. Fuel Pressure Control Valve (FPCV)
24. High-pressure Common Rail (HPCR) (Left)
25. High-pressure Common Rail (HPCR) (Right)
26. Fuel Rail Pressure (FRP) sensor
27. Engine

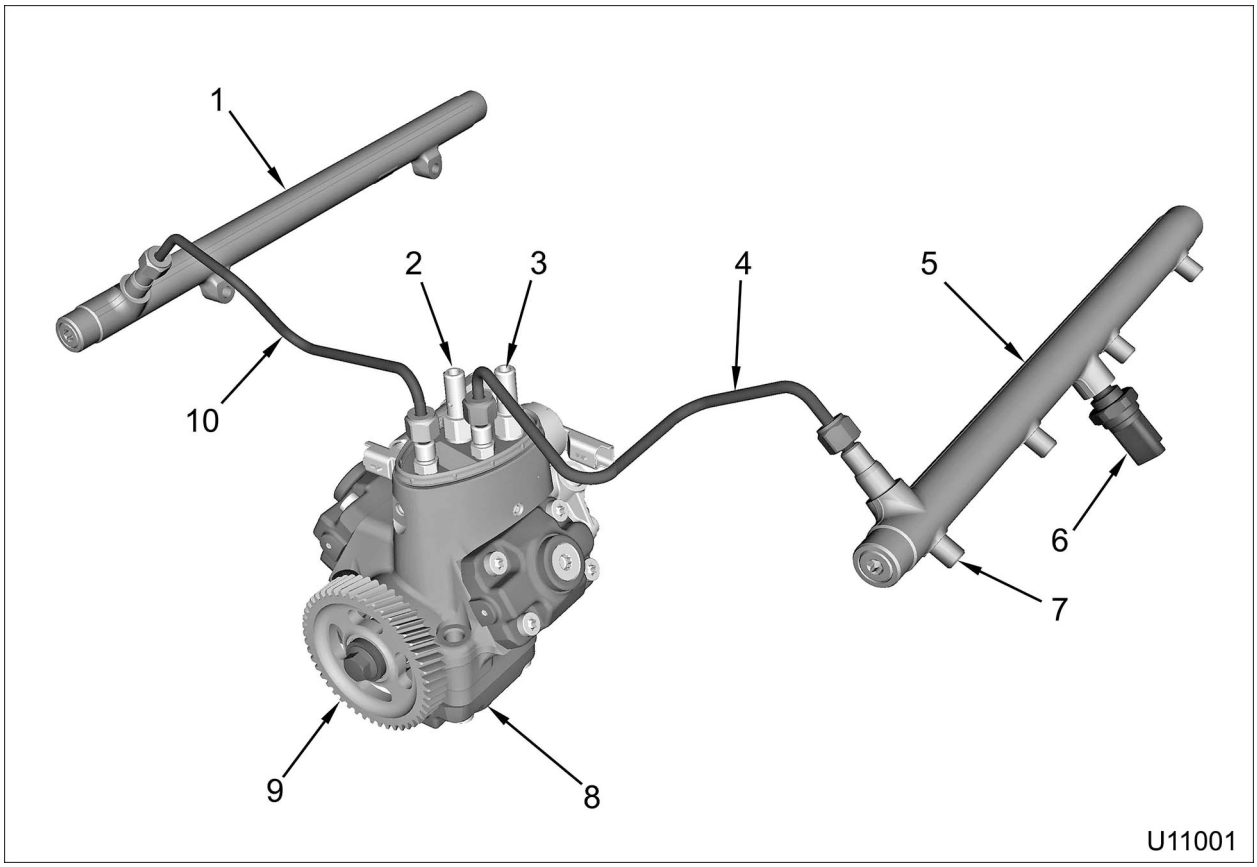


Figure 18 High-pressure Fuel System

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

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 fuel rails. The HPFP is mounted in the rear valley on top of the engine and is 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 HPFP through the Fuel Volume Control Valve (FVCV). The ITP also provides fuel for cooling and lubrication of the HPFP. Fuel is rerouted as pump return flow through the HPFP cooling and lubrication valve. Pressure is maintained at the inlet of the HPFP piston pump by an ITP regulator.

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 ECM. FPCV control depends on fuel pressure and fuel temperature.

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 is controlled by fuel rail pressure, via the ECM. The FVCV allows just sufficient quantity of fuel to be delivered to the HPFP depending on engine load, speed, injector quantity, fuel temperature, and number of injections per cycle.

Fuel Rail Pressure (FRP) Sensor

The FRP sensor monitors fuel pressure in the fuel rails and sends a signal to the ECM. The FRP sensor is installed 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 are capable of five injections; two pre-injection, a main-injection, a post-injection, and a late post-injection. Pre-injection and post-injection 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 holes. Charging the actuator opens the nozzle holes; discharging the actuator closes the nozzle holes. 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.

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.

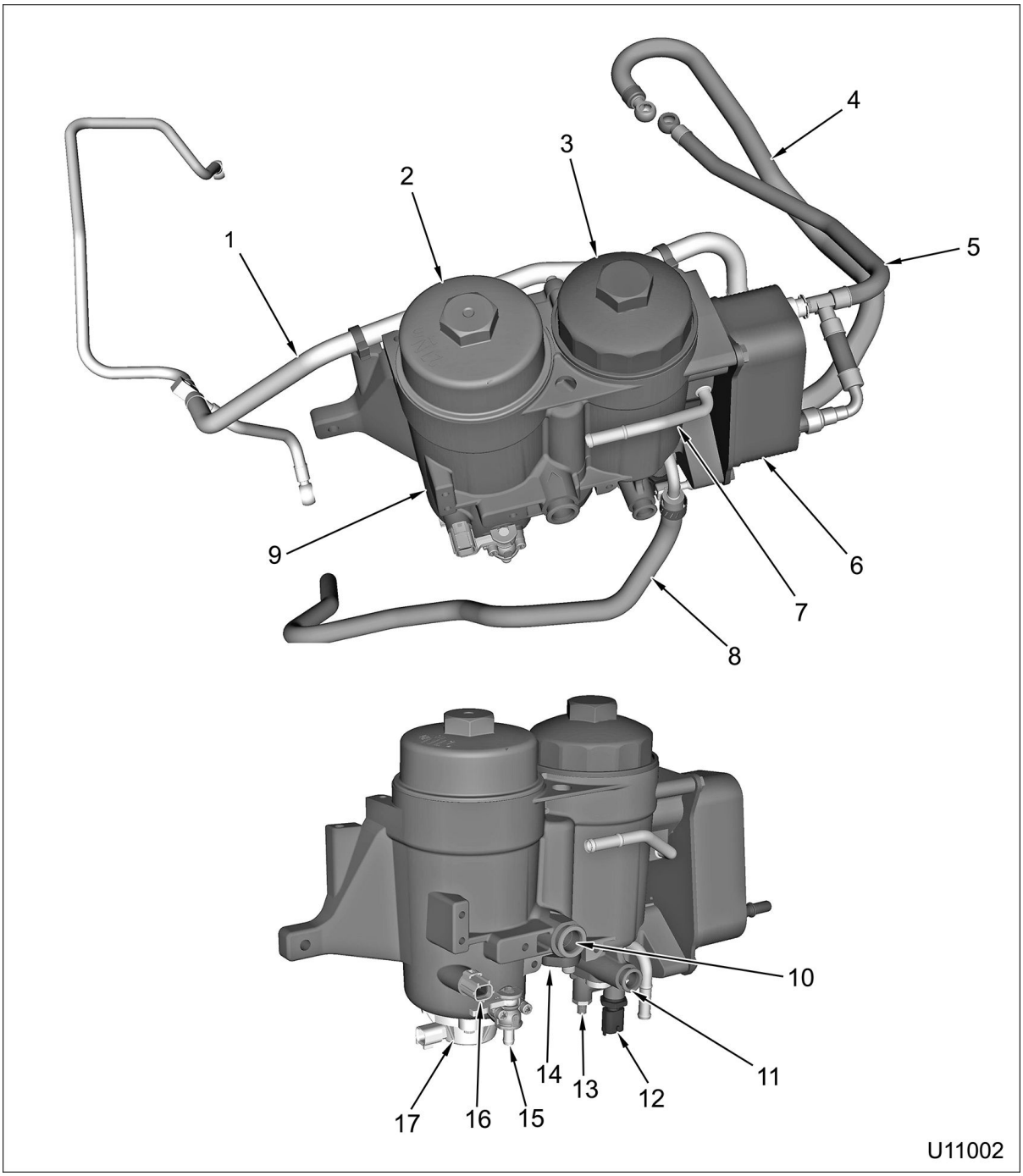


Figure 19 Low-pressure Fuel System

1. Injector return hose assembly
2. Filter cap (primary)
3. Filter cap (secondary)
4. Filter-to-pump hose assembly
5. Pump-to-cooler hose assembly
6. Fuel cooler
7. Coolant supply hose
8. Coolant return hose
9. Fuel filter module housing
10. Fuel inlet from tank
11. Fuel return to tank
12. Engine Fuel Temperature (EFT) sensor
13. Diagnostic valve (standard) or Fuel Delivery Pressure (FDP) sensor (optional)
14. Fuel heater block-off plate or fuel heater (optional)
15. Water drain valve
16. Water In Fuel (WIF) sensor
17. Fuel Pump

Low-pressure Fuel System

Fuel Pump

A constant-flow electric pump draws fuel from the fuel tank(s) through the primary fuel filter and supplies fuel to the secondary fuel filter. The fuel pump is mounted at the bottom center of the primary fuel filter.

Primary Fuel Filter

A 10–micron primary filter removes water and filters fuel from the fuel tank(s). The primary filter is above the low-pressure fuel pump.

Secondary Fuel Filter

A 3–5 micron secondary fuel filter assembly also removes water and filters fuel from the low-pressure fuel pump. The filter has an internal drilled air bleed orifice to automatically remove air from the fuel. The filtered fuel from the primary fuel filter is mixed with the cooled fuel from the fuel cooler and is directed to a secondary fuel filter. System pressure is maintained by an internal pressure regulator.

Fuel from the pressure regulator and air bleed orifice returns to the fuel tank(s).

The fuel module has a temperature sensor mounted in the supply line to the HPFP. A fuel temperature sensitive recirculation fuel valve allows some warmer recirculated fuel from the fuel cooler to flow to the primary filter when tank fuel is colder. This helps prevent filter waxing. When fuel temperatures are warm to hot, the valve closes and all recirculated fuel goes into the secondary housing where it mixes with fuel from the primary filter, electric pump, and tank.

Fuel Cooler

The combined fuel from the fuel injectors and the HPFP is cooled by the fuel cooler using engine coolant. Cooled fuel is then directed to the inlet of the secondary fuel filter.

Fault Detection/Management

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

Engine Lubrication System

Lubrication System Components and Oil Flow

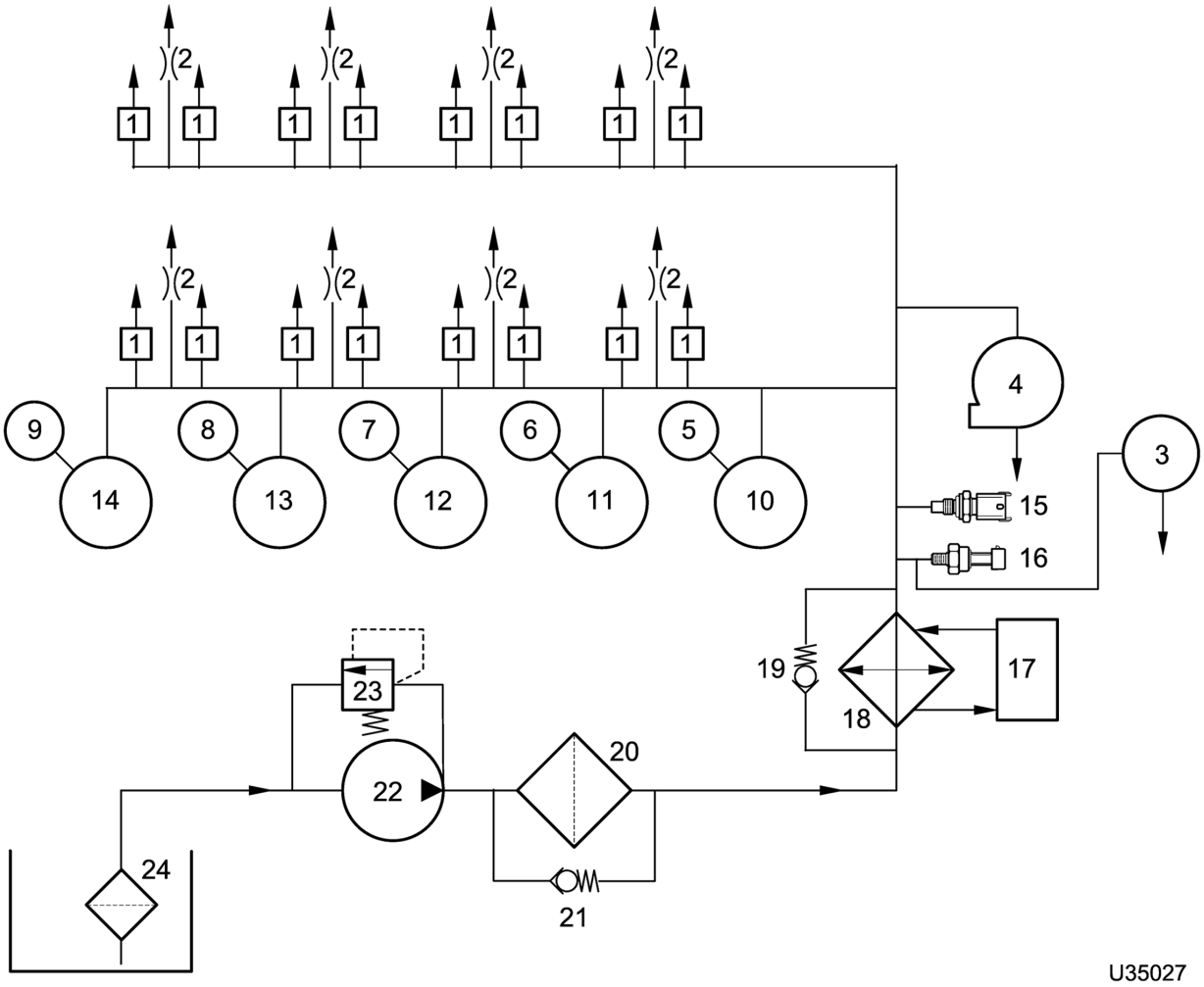


Figure 20 Lubrication System

1. Camshaft follower
2. Piston cooling tube
3. Air compressor (optional)
4. Dual turbocharger assembly
5. Cam bearing 1
6. Cam bearing 2
7. Cam bearing 3
8. Cam bearing 4
9. Cam bearing 5
10. Main bearing 1 and crank pins
11. Main bearing 2 and crank pins
12. Main bearing 3 and crank pins
13. Main bearing 4 and crank pins
14. Main bearing 5 and crank pins
15. Engine Oil Temperature (EOT) sensor
16. Engine Oil Pressure (EOP) sensor
17. Engine coolant
18. Oil cooler
19. Bypass valve
20. Oil filter
21. Bypass valve
22. Oil Pump
23. Pressure regulator
24. Oil pickup and screen

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

A gerotor oil pump includes an oil pump housing, cover plate, gerotor assembly (inner and outer gears), and pressure-regulating valve assembly. The inner rotor gear of the gerotor pump is driven by the crankshaft.

The gerotor oil pump draws and pressurizes oil from the oil pan through an oil pickup tube and screen. Pressurized oil in the pump flows through passages in the oil pump housing, enters a passage in the lower crankcase dirty side, flows through a passage in the oil pan dirty side to the dirty side of the oil filter. Oil is filtered in the oil filter (outside to inside) and flows from the center of the oil filter into a passage in the clean side of the oil pan and lower crankcase before returning to the passage in the clean side of the oil pump.

If the oil cooler is restricted, a bypass valve in the oil cooler cover opens; oil bypasses the oil cooler and flows directly to the various systems in the engine. If the oil filter element is restricted, a bypass valve in the oil filter housing opens; oil bypasses the filter element and flows through passages in the (clean side) of the oil pan-lower crankcase-upper crankcase, before going to the oil cooler.

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

Oil flows from the oil pump into the upper crankcase, to a passage in the oil cooler cover, and through the oil cooler plates; cooled oil flows back to the cooler cover and is distributed to various systems in the engine.

Each bypass valve ensures full flow of oil to the engine, if the filter or cooler is restricted, including high oil viscosity cold start conditions.

The oil cooler passage directs cooled, filtered oil to the optional air compressor, oil supply tube to lubricate the turbocharger bearings, and oil to the main oil galleries. Lubrication oil from the turbocharger drains back to the oil pan through slotted passages in the cooler cover plate and upper crankcase. The cooler cover has ports for EOP and EOT sensors.

Cooling System

Cooling System Components and Flow

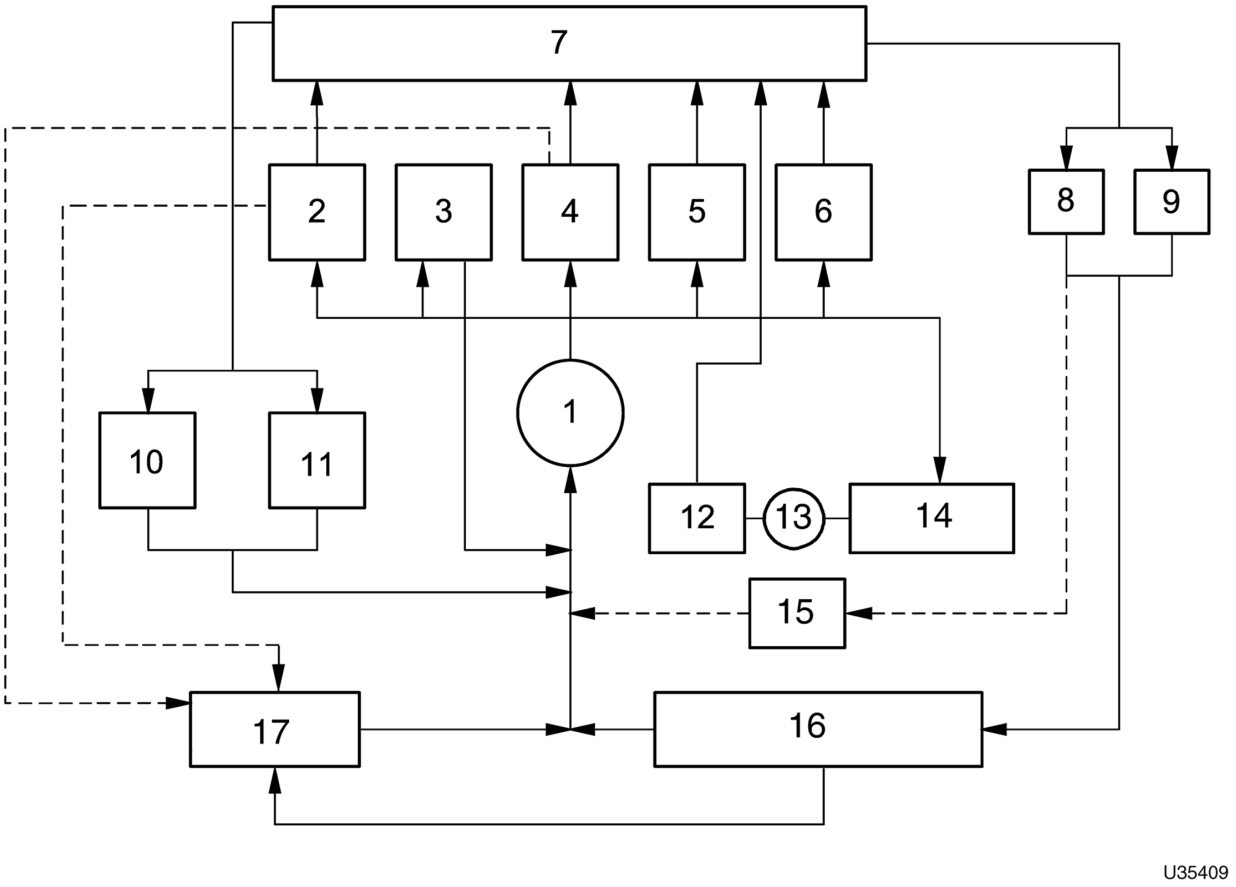


Figure 21 Cooling System Schematic

1. Water pump
2. EGR cooler
3. Oil cooler
4. Air compressor (optional)
5. Left cylinder head/crankcase
6. Right cylinder head/crankcase
7. Cross-over
8. Thermostat 1
9. Thermostat 2
10. Heater core
11. Heater core (optional)
12. Fuel cooler
13. Fuel Coolant Valve (FCV)
14. Secondary radiator
15. Bypass
16. Radiator
17. Deaeration tank

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 counterclockwise 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 vehicle mounted deaeration 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 and then directed up to the cylinder head through ports in the top deck.
- A passage directs coolant from the front cover and through the crankcase to the oil cooler to cool the lubricating oil.
- A port in the front cover directs coolant through tubing to the EGR cooler to cool the exhaust gases.
- A port in the front cover directs coolant through tubing to the air compressor.
- A port in the front cover directs coolant through a secondary radiator to the fuel cooler, to cool unused fuel.

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 port in the coolant return cross-over housing returns coolant through tubing from the 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 coolant return cross-over supplies coolant to the vehicle heater core for cab heating.

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

A passage through the crankcase returns coolant from the oil cooler directly to the water pump eye.

Thermostats

Two thermostats are located in the thermostat housing. If the coolant temperature is above the thermostat opening temperature, coolant flows to the vehicle mounted 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 allows flow 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 (220 Horsepower only)

Closing the radiator shutters keeps 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.

Engine Speed Position System

The Engine Speed Position System provides a summary of camshaft and crankshaft synchronization status information to the system. It sets the operating modes of camshaft and crankshaft acquisition depending on synchronization status, availability, and detected failures. The signal source for engine position is selected on the activated operating mode.

Camshaft and crankshaft signal acquisition is set passive for a calibrated delay after key-off has been detected at low engine speed and for another calibrated delay after a loss of synchronization at low engine speed. This avoids wrong injection, ignition and diagnosis with backward rotation after rapid key-off/on or stalling.

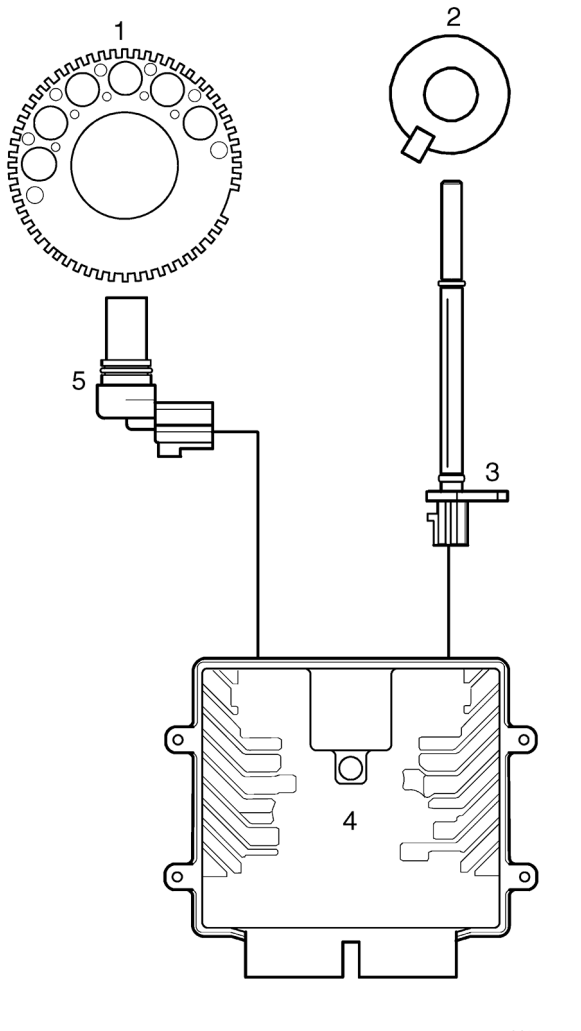


Figure 22 Engine Speed Position System

1. Crankshaft target wheel
2. Camshaft target wheel
3. Camshaft Position (CMP) sensor
4. ECM
5. Crankshaft Position (CKP) sensor

Electronic Control System

Electronic Control System Components

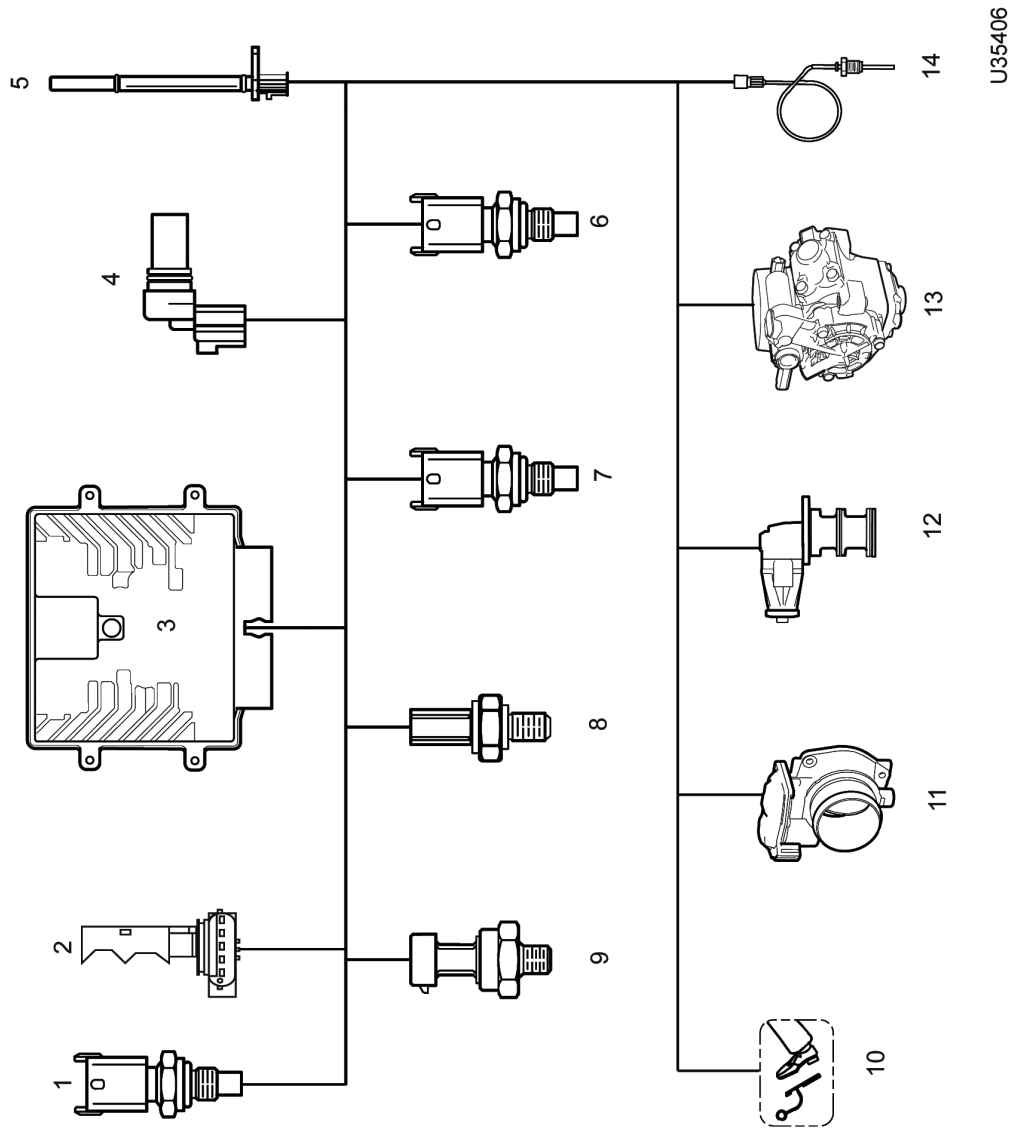


Figure 23 Electronic Control System

1. Engine Coolant Temperature (ECT) sensor
2. Mass Air Flow/Air Inlet Temperature (MAF/AIT) sensor
3. Engine Control Module (ECM)
4. Crankshaft position (CKP) sensor
5. Camshaft position (CMP) sensor
6. Engine Fuel Temperature sensor
7. Engine Oil Temperature 1 (EOT) sensor
8. Engine Oil Pressure (EOP) sensor
9. Intake Manifold Pressure (IMP) sensor
10. Accelerator Pedal Position (APP) sensor
11. Engine Throttle Valve (ETV) and position sensor
12. EGR Control Valve and position sensor
13. High Pressure Fuel Pump (HPFP)
14. Exhaust Gas Temperature (EGT) sensor

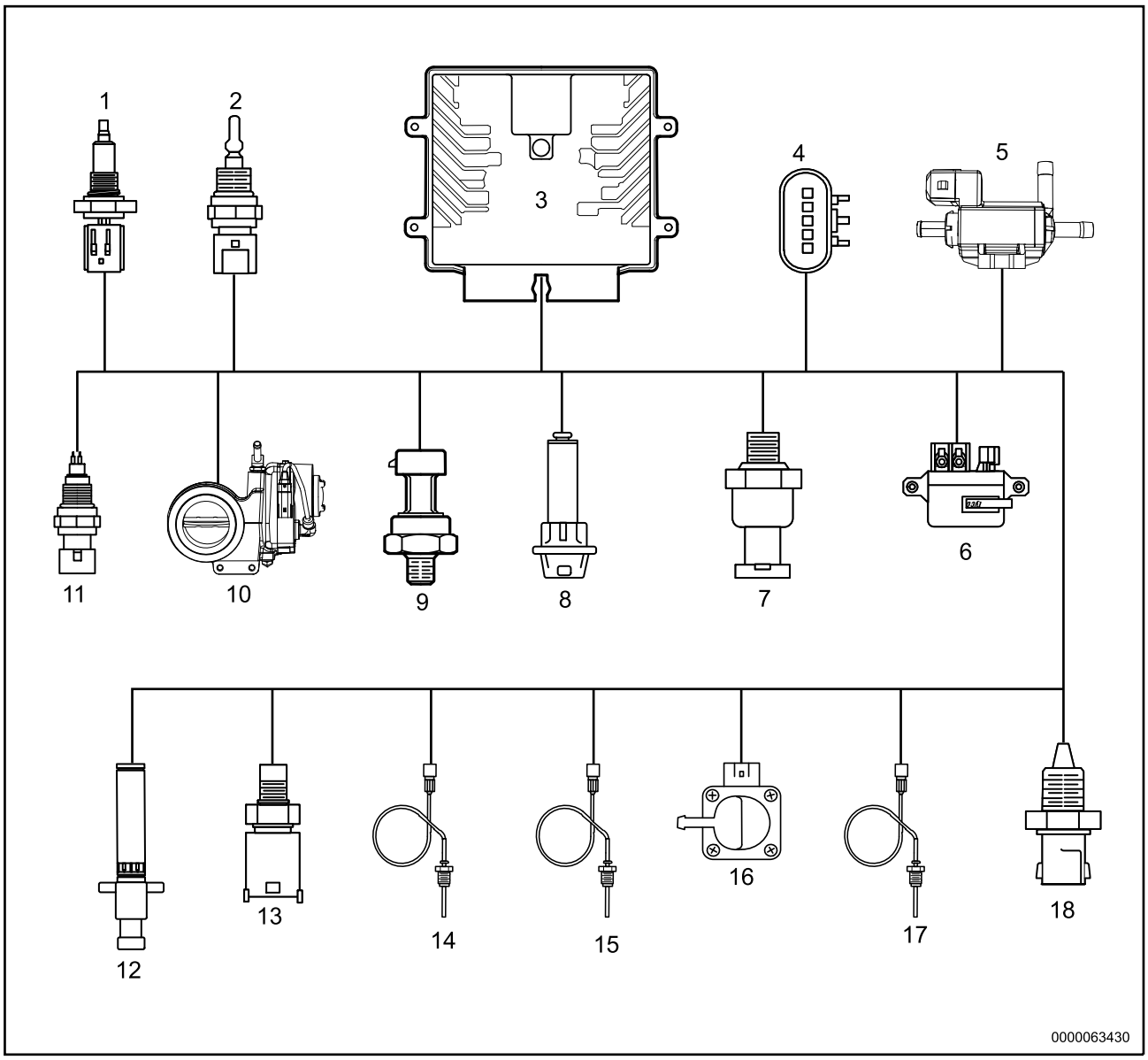


Figure 24 Electronic Control System

1. Exhaust Gas Recirculation Temperature (EGRT) sensor
2. Intake Manifold Temperature (IMT) sensor
3. Engine Control Module (ECM)
4. Engine Fan Control (EFC) (optional)
5. Turbocharger 1 Wastegate Control (TC1WC) solenoid
6. Inlet Air Heater (IAH) relay
7. Fuel Rail Pressure (FRP) sensor
8. Fuel Pump
9. Fuel Delivery Pressure (FDP) sensor (optional)
10. Thermal Management Valve (TMV) (optional)
11. Water In Fuel (WIF) sensor
12. Fuel Heater (optional)
13. Transmission Outlet Temperature (manual)
14. DOC Inlet Temperature (DOCIT) sensor
15. DPF Inlet Temperature (DPFIT) sensor
16. DPF Differential Pressure (DPFDP) sensor
17. DPF Outlet Temperature (DPFOT) sensor
18. Engine Coolant Level (ECL) sensor

Operation and Function

The Engine 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 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.

Suspect Parameter Numbers (SPN) and Fault Mode Indicators (FMI) 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 nonvolatile 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

Engine Fan Control (EFC)

The purpose of the engine fan is to prevent engines in trucks with smaller cooling systems from overheating and to act as a vehicle retarding device.

The electrically controlled viscous fan drive consists of a fluid port that controls the amount of fluid flow which in turn leads to rotation of the fan. The opening and closing of the valve is activated with a pulse-width modulated output (PWM) from the ECM.

The valve is wired to Vehicle Power (VPWR) on one side and is connected to a switching low side driver in the ECM.

Inlet Air Heater (IAH)

The IAH is primarily used to assist the engine in starting under cold weather conditions. In addition, it helps to reduce white smoke emissions by heating the incoming air.

The ECM controls a relay through a 12V digital high side driver. When the relay coil is charged with 12 volts, the high current contacts inside are drawn together. This completes an electric circuit between the IAH and the vehicle's battery.

The ECM disables the relay by outputting zero volts. With no voltage across the relay coil, the contacts separate and the connection to the battery is broken, shutting down the IAH.

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 Position Sensor
- ETV and Position Sensor
- TC1WC Actuator
- Engine Fan Control (EFC)
- Exhaust Throttle
- Inlet Air Heater (IAH)
- Exhaust Back Pressure Valve (EBPV)

H-Bridge Circuit

The EGR valve and ETV actuator motors are operated by an H-Bridge (bipolar) circuit in each valve assembly.

An H-Bridge circuit operates like putting a power source on one side of a motor and connecting 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 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 EGR Position (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 EGR High (EGRH) circuit high. When driving the EGRH high, this causes EGR Low (EGRL) circuit to go low.

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

ETV and Engine Throttle Position Sensor

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

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

The ECM controls motor speed using PWM. The Engine Throttle Valve is close by driving the ETV circuit high. When driving the ETV high, this causes ETV circuit to go low.

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

Engine and Vehicle Sensors

Thermistor Sensors

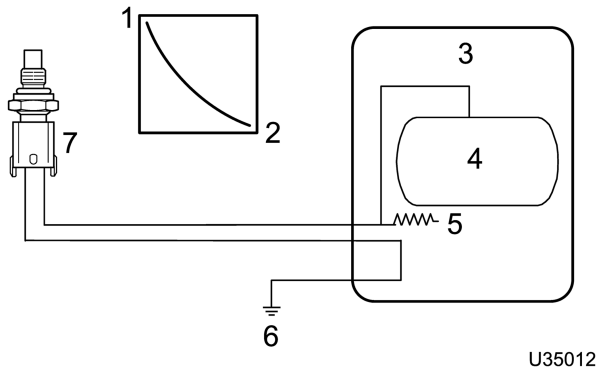


Figure 25 Thermistor Sensors

1. 5 Volts
2. 0 Volts
3. ECM
4. Microprocessor
5. VREF
6. Ground
7. Temperature sensor

A thermistor sensor changes 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 type sensors include the following:

- Engine Coolant Temperature 1 (ECT) sensor
- Engine Oil Temperature (EOT) sensor
- Engine Fuel Temperature (EFT) sensor
- EGT sensor
- EGRT sensor
- DOC Inlet Temperature (DOCIT) sensor
- DPF Inlet Temperature (DPFIT) sensor
- DPF Outlet Temperature (DPFOT) sensor
- Transmission Outlet Temperature (manual) sensor
- Mass Air Flow/Air Inlet Temperature (MAF/AIT) sensor
- Intake Manifold Temperature (IMT) sensor

Variable Capacitance Sensors

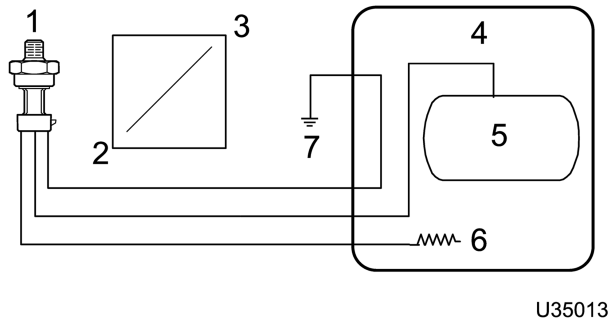


Figure 26 Variable Capacitance Sensors

1. Sensor
2. 0 Volts
3. 5 Volts
4. ECM
5. Microprocessor
6. VREF
7. Ground

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 type sensors include the following:

- Intake Manifold Pressure (IMP) sensor
- Engine Oil Pressure (EOP) sensor
- Fuel Delivery Pressure (FDP) sensor
- Fuel Rail Pressure (FRP) sensor

Micro Strain Gauge (MSG) Sensor

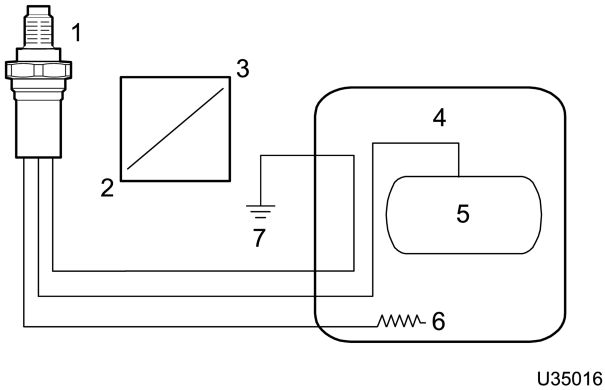


Figure 27 MSG Sensor

1. Pressure Sensor
2. 0 Volts
3. 5 Volts
4. ECM
5. Microprocessor
6. VREF
7. Ground

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

Magnetic Pickup Sensors

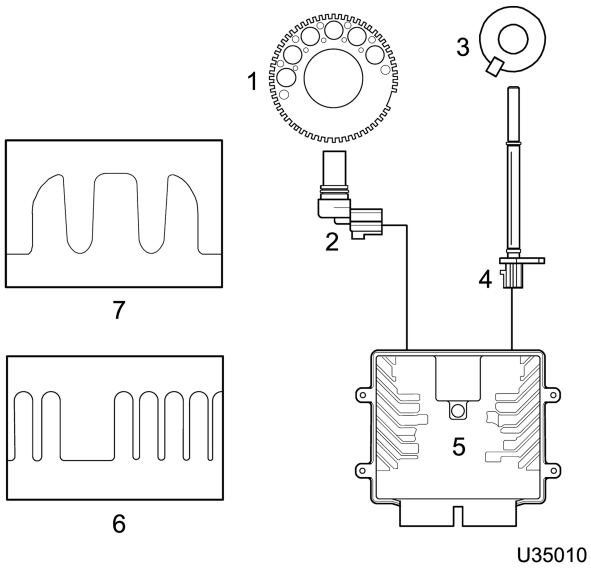


Figure 28 Magnetic Pickup Sensors (typical)

1. Crankshaft Timing Disk
2. CKP Sensor
3. Camshaft with Peg
4. CMP Sensor
5. ECM
6. CKP signal
7. CMP signal

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

Potentiometer

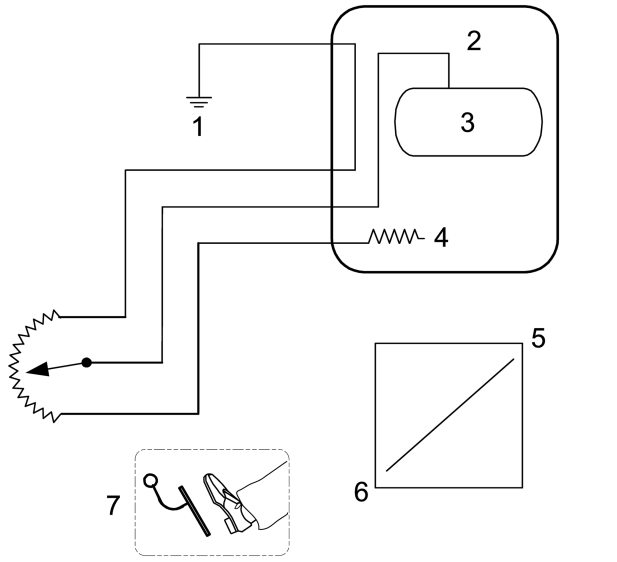


Figure 29 Potentiometer

1. Ground
2. ECM
3. Microprocessor
4. VREF
5. 5 Volts
6. 0 Volts
7. Accelerator pedal

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 Pedal Position (APP) sensor

Switches

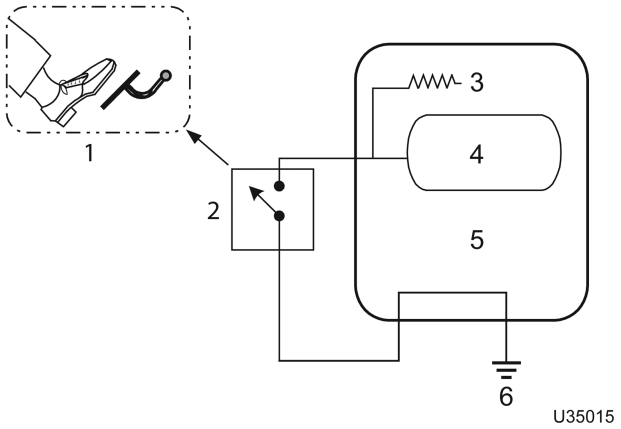


Figure 30 Switch

1. Accelerator pedal
2. Accelerator Pedal Position (APP)
3. VREF
4. Microprocessor
5. ECM
6. Ground

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
- Water In Fuel (WIF) sensor

Inlet Air Heater (IAH) System

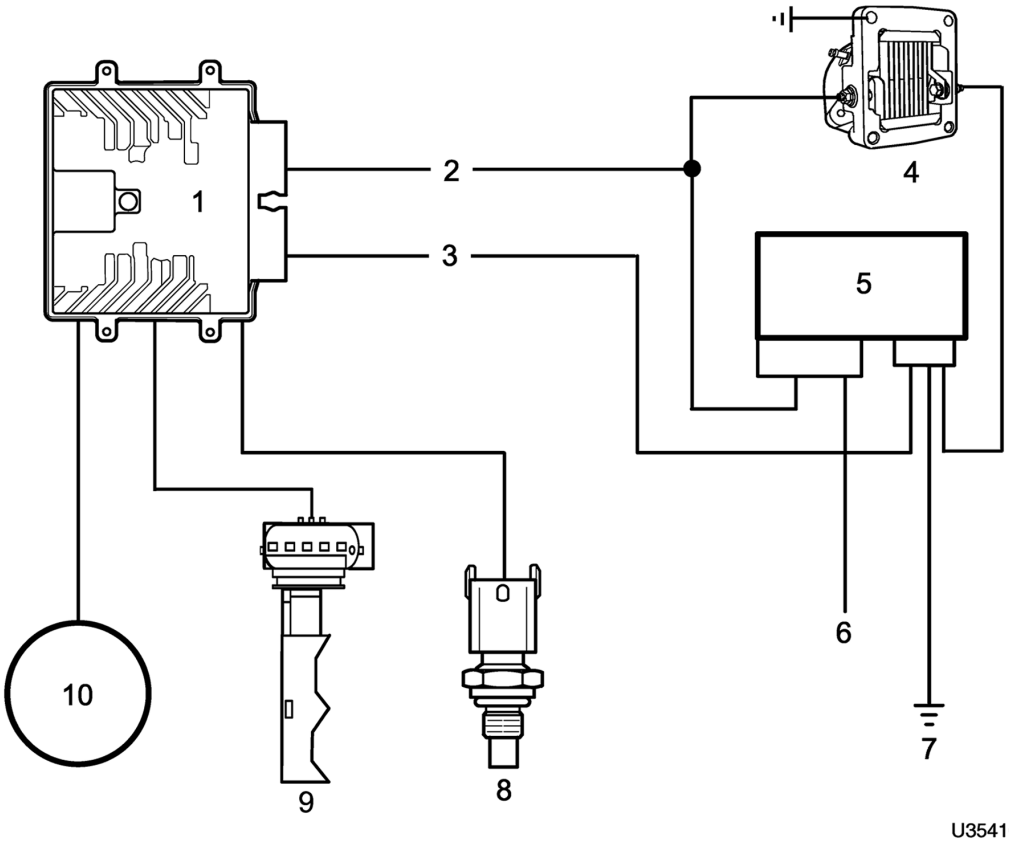


Figure 31 IAH System

1. ECM
2. IAHD - Inlet Air Heater Diagnostics
3. IAHC - Inlet Air Heater Control
4. Inlet Air Heater (IAH)
5. IAH relay
6. B+ at alternator motor post
7. Ground
8. ECT sensor
9. Mass Air Flow / Air Inlet Temperature (MAF / AIT) sensor
10. WAIT TO START lamp

The IAH system warms the incoming air to aid cold engine starting and reduce exhaust emissions during warm-up.

The ECM activates the IAH by energizing the IAH relay while monitoring programmed conditions for engine coolant temperature, air inlet temperature, and atmospheric pressure.

The ECM controls the WAIT TO START lamp and IAH relay separately.

The engine is ready to start when the WAIT TO START lamp is turned off by the ECM. The ECM turns the IAH on for a predetermined amount of time, based on ECT, AIT, and BAP. The IAH can remain on while the engine is running to reduce exhaust emissions and white smoke during engine warm-up.

If the ECT is above 50 °C (122 °F), the IAH will not reactivate when restarting the engine unless the AIT is 10 °C (50 °F) or colder.

Table of Contents

Engine Preparation.....47
Cleaning the Engine.....47
Draining Coolant and Engine Oil.....47

Mounting Engine 49

Special Torque.....51

Special Service Tools.....51

Engine Preparation

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

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.

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

NOTE: See manufacturer's instructions for specific directions on safe use of Engine Stand and Engine Stand Mounting Bracket.

Cleaning the Engine

1. Cap all engine openings to prevent water and degreasing agents from entering engine.
2. Cover exposed electrical connections and Engine Control Module (ECM), using plastic and duct tape.
3. Clean engine using an appropriate detergent mixed in the correct ratio and a hot pressure washer or similar cleaning equipment.

Draining Coolant and Engine Oil

NOTE: Before mounting engine on Engine Stand, do steps 1 through 11.

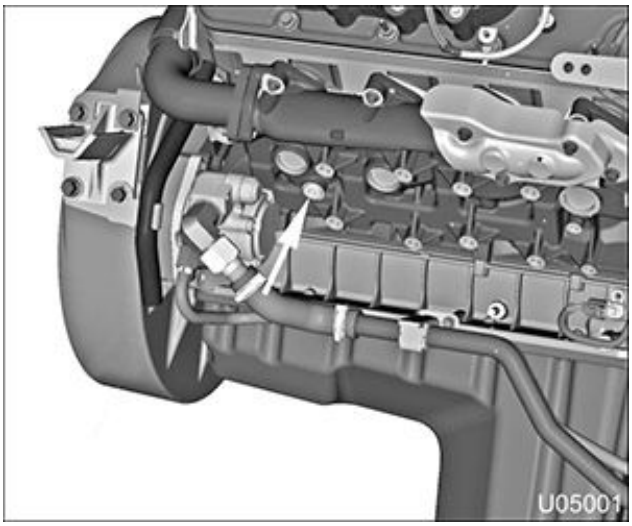


Figure 32 Coolant Drain Plug (Right side)

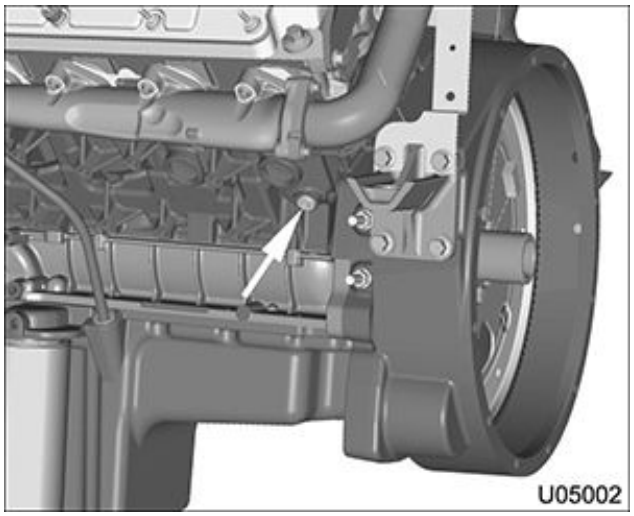


Figure 33 Coolant Drain Plug (Left side)

1. Put coolant drain pan under the left and right drain plugs.
2. Remove coolant drain plugs, discard O-rings, and drain coolant.
3. After coolant has drained, put new O-ring on each drain plug and install plugs. Tighten plugs to special torque (page 51).
4. Recycle or dispose of coolant, according to applicable regulations.
5. Put oil drain pan beneath oil drain plug.

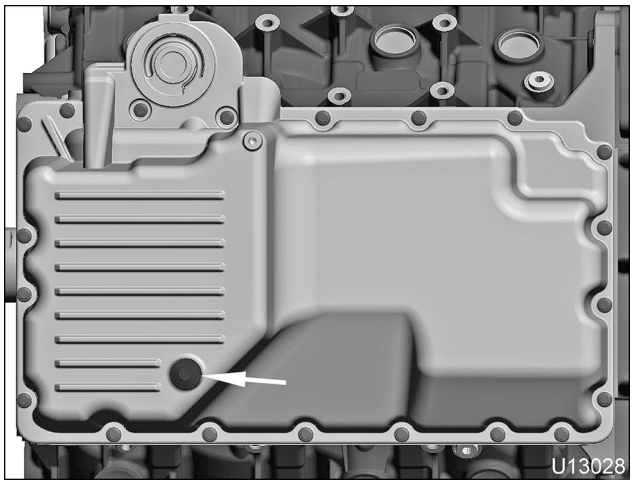


Figure 34 Oil Pan Drain Plug

6. Remove oil pan drain plug and drain oil.
7. Inspect oil drain plug and seal. Replace if necessary.
8. Lubricate drain plug seal with clean engine oil.
9. After oil has drained, install oil drain plug.
10. Tighten oil pan drain plug to special torque (page 51).
11. Recycle or dispose of oil, according to applicable regulations.

Mounting Engine

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.

1. Attach hoist hook lifting bracket to engine lifting eyes. Secure safety catches on hoist hooks before lifting engine.

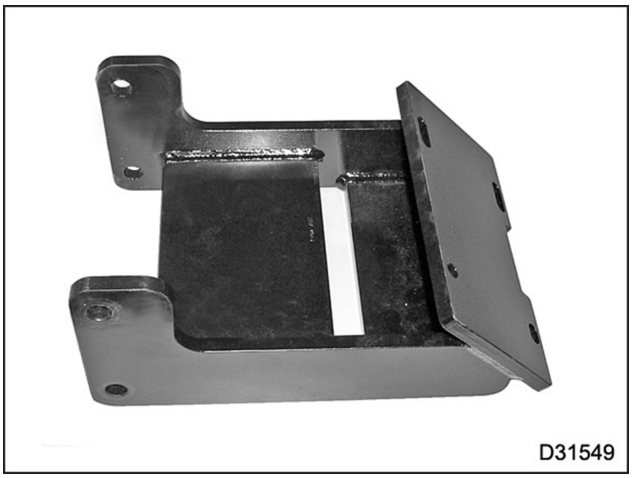


Figure 35 Engine Stand Mounting Bracket

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

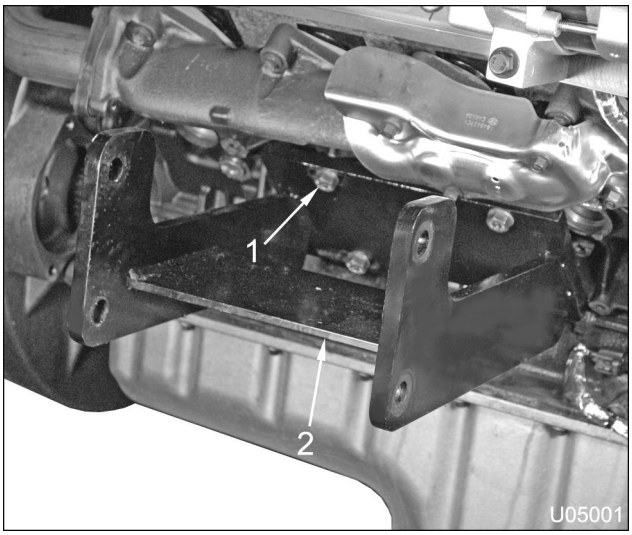


Figure 36 Mounting Bolts for Engine Stand Mounting Bracket

1. M10 x 30 class 10.9 mounting bolts (4)
2. Engine Stand Mounting Bracket

2. Position Engine Stand Mounting Bracket (page 51) 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 473).

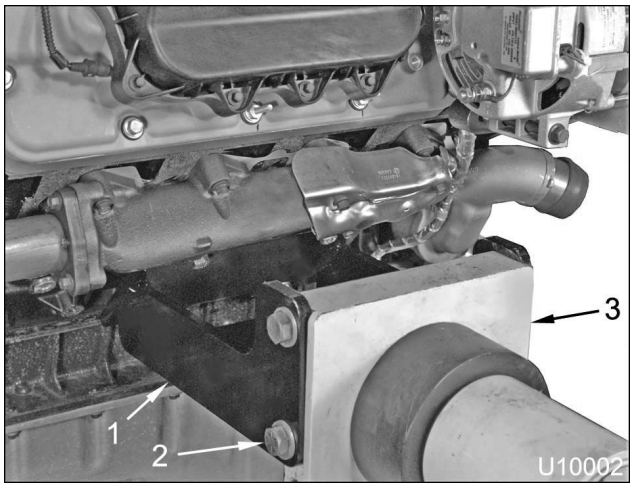


Figure 37 Mounting Engine to Engine Stand

1. Engine Stand Mounting Bracket
2. M10 x 30 class 10.9 mounting bolts (4)
3. Engine Stand

3. Mount engine on Engine Stand (page 51) using four class 10.9 mounting bolts.
4. Slowly release tension from engine hoist.
5. Remove hoist safety chain hooks from engine lifting eyes.

Special Torque

Crankcase coolant drain plug (M16)	20 N·m (15 lb·ft)
Oil pan drain plug (M14)	44 N·m (32 lb·ft)

Special Service Tools

Description	Tool Number
Engine Stand	OTC1750A
Engine Stand Mounting Bracket	ZTSE4507

Table of Contents

Diagnostics and Troubleshooting Publications.....55

Location of Engine Electronic Components.....56

Description of Engine Electronic Components.....60
- **Charge Air Cooler Outlet Temperature (CACOT) Sensor.....60**
- **Camshaft Position (CMP) Sensor.....60**
- **Crankshaft Position (CKP) Sensor.....60**
- **Engine Control Module (ECM).....61**
- **Engine Coolant Temperature (ECT1) Sensor.....61**
- **Engine Oil Pressure (EOP) Sensor.....62**
- **Engine Oil Temperature (EOT) Sensor.....62**
- **Engine Fuel Temperature (EFT) Sensor.....62**
- **Exhaust Gas Recirculation (EGR) Valve 63**
- **Exhaust Gas Temperature (EGT) Sensor.....63**
- **Exhaust Gas Recirculation Temperature (EGRT) Sensor.....63**
- **Engine Throttle Valve (ETV) 64**
- **Fuel Heater (optional).....65**
- **Fuel Pump.....65**
- **Fuel Rail Pressure (FRP) Sensor.....66**
- **Intake Air Heater (IAH) 66**
- **Intake Air Heater (IAH) Relay.....67**
- **Intake Manifold Pressure (IMP) Sensor.....67**
- **Intake Manifold Temperature (IMT) Sensor.....67**
- **Mass Air Flow / Air Inlet Temperature (MAF / AIT) Sensor.....68**
- **Thermal Management Valve (TMV) (optional).....68**
- **Turbocharger 1 Compressor Outlet Temperature (TC1COT) Sensor.....68**
- **Turbocharger 1 Wastegate Control (TC1WC) Solenoid.....69**
- **Water In Fuel (WIF) Sensor.....69**

Removal.....70
- **Mass Air Flow / Air Inlet Temperature (MAF / AIT) Sensor.....70**
- **Charge Air Cooler Outlet Temperature (CACOT) Sensor.....71**
- **Crankshaft Position (CKP) Sensor.....71**
- **Camshaft Position (CMP) Sensor.....72**
- **Engine Coolant Temperature (ECT1) Sensor.....72**
- **Engine Throttle Valve (ETV).....73**
- **Intake Air Heater (IAH).....74**
- **Exhaust Gas Recirculation (EGR) Valve Assembly 74**
- **Exhaust Gas Recirculation Temperature (EGRT) Sensor.....75**
- **Intake Manifold Temperature (IMT) Sensor and Intake Manifold Pressure (IMP) Sensor.....75**
- **Thermal Management Valve (TMV).....76**
- **Turbocharger 1 Compressor Outlet Temperature (TC1COT) Sensor.....77**
- **Turbocharger 1 Wastegate Control (TC1WC) Solenoid.....77**
- **Engine Oil Temperature (EOT) Sensor and Engine Oil Pressure (EOP) Sensor.....78**
- **Water In Fuel (WIF) Sensor.....78**

Fuel Pump....79
Fuel Heater (optional) and Fuel Delivery Pressure (FDP) Sensor (optional)....79
Engine Fuel Temperature (EFT) Sensor....80
Exhaust Gas Temperature (EGT) Sensor....80
Engine Harness....81
Harness Channel Shield Assemblies....85
Intake Air Heater (IAH) Relay and Relay Support....86
Fuel Rail Pressure (FRP) Sensor....87
Under Valve Cover (UVC) Harnesses....87

Cleaning and Inspection....90
Main Engine Wiring Harness....90
Harness Retainers and Stud Clips....90
Sensors and Valves....90
Engine Control Module....90

Installation....91
Under Valve Cover (UVC) Harnesses....91
Fuel Rail Pressure (FRP) Sensor....93
Intake Air Heater (IAH) Relay and Relay Support....93
Harness Channel Shield Assemblies....94
Engine Harness....96
Exhaust Gas Temperature (EGT) Sensor....100
Fuel Heater (optional) and Fuel Delivery Pressure (FDP) Sensor (optional)....101
Fuel Pump....101
Water In Fuel (WIF) Sensor....102
Engine Fuel Temperature (EFT) Sensor....102
Engine Oil Temperature (EOT) Sensor and Engine Oil Pressure (EOP) Sensor....103
Turbocharger 1 Wastegate Control (TC1WC) Solenoid....103
Turbocharger 1 Compressor Outlet Temperature (TC1COT) Sensor....104
Thermal Management Valve (TMV)....104
Intake Manifold Temperature (IMT) Sensor and Intake Manifold Pressure (IMP) Sensor....105
Exhaust Gas Recirculation Temperature (EGRT) Sensor....106
Exhaust Gas Recirculation (EGR) Valve Assembly....106
Intake Air heater (IAH)....106
Engine Throttle Valve (ETV)....107
Engine Coolant Temperature (ECT1) Sensor....108
Camshaft Position (CMP) Sensor....108
Crankshaft Position (CKP) Sensor....109
Charge Air Cooler Outlet Temperature (CACOT) sensor....109
Mass Air Flow / Air Inlet Temperature (MAF / AIT) Sensor....110

Special Torque....111

Special Service Tools....111

Diagnostics and Troubleshooting Publications

- 0000001681 2010 MaxxForce® 7 Engine Diagnostic Manual (EPA 10) 2013 HD-OBD
- 0000003382 MaxxForce® 7 (EPA 10) with HD-OBD Hard Start and No Start Diagnostic Form
- 0000003381 MaxxForce® 7 (EPA 10) with HD-OBD Performance Diagnostic Form
- 0000003201 MaxxForce® 7 (EPA 10) with HD-OBD Engine Wiring Schematic Form

Location of Engine Electronic Components

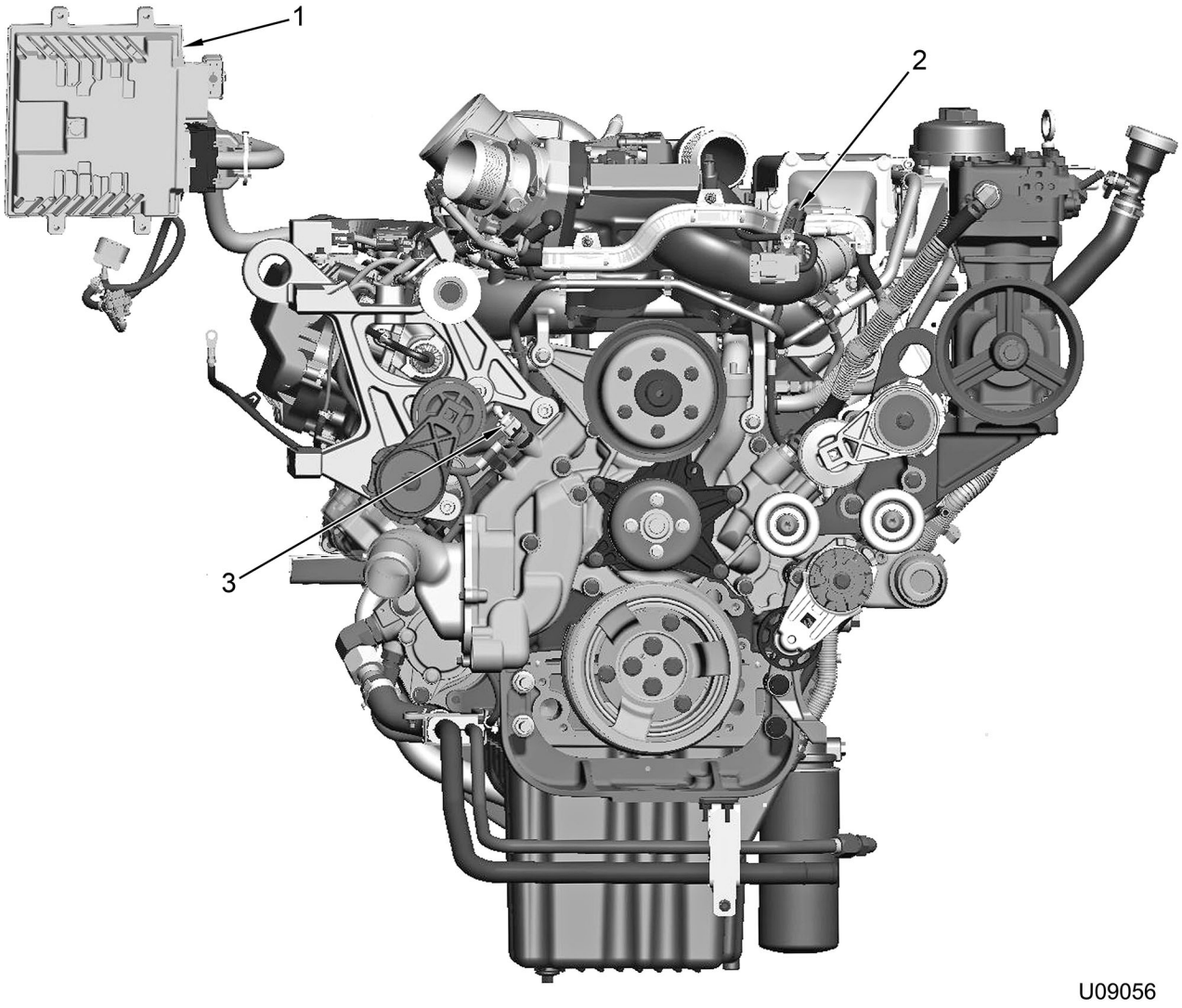


Figure 38 Electronic Components – Front

1. Engine Control Module (ECM)
2. Exhaust Gas Recirculation Temperature (EGRT) sensor
3. Engine Coolant Temperature (ECT1) sensor

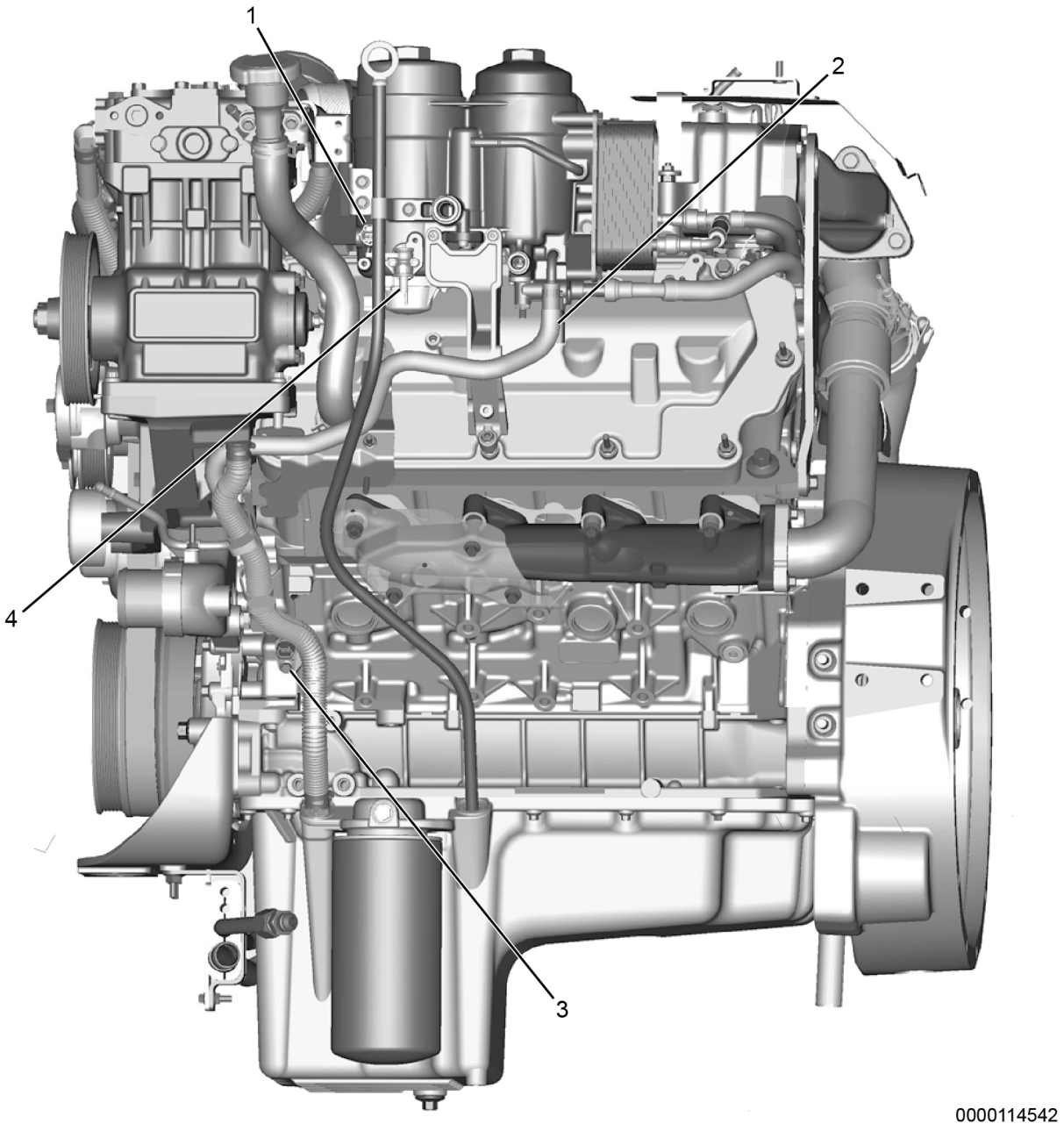


Figure 39 Electronic Components – Left

1. Water In Fuel (WIF) sensor
2. Engine Fuel Temperature (EFT) sensor
3. Camshaft Position (CMP) sensor
4. Fuel Pump

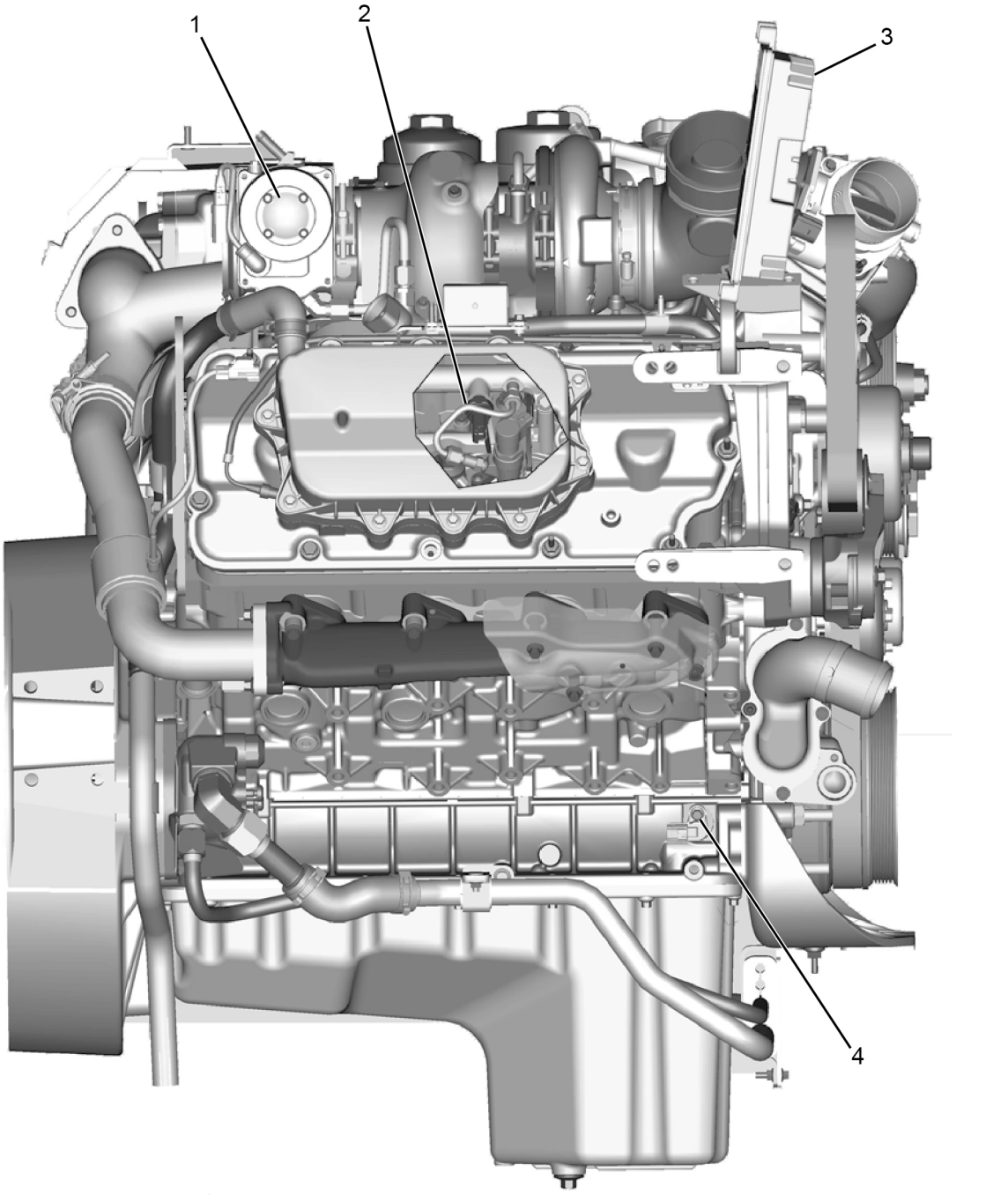


Figure 40 Electronic Components – Right

1. Thermal Management Valve (TMV)
2. Fuel Rail Pressure (FRP) sensor (under valve cover)
3. Engine Control Module (ECM)
4. Crankshaft Position (CKP) sensor

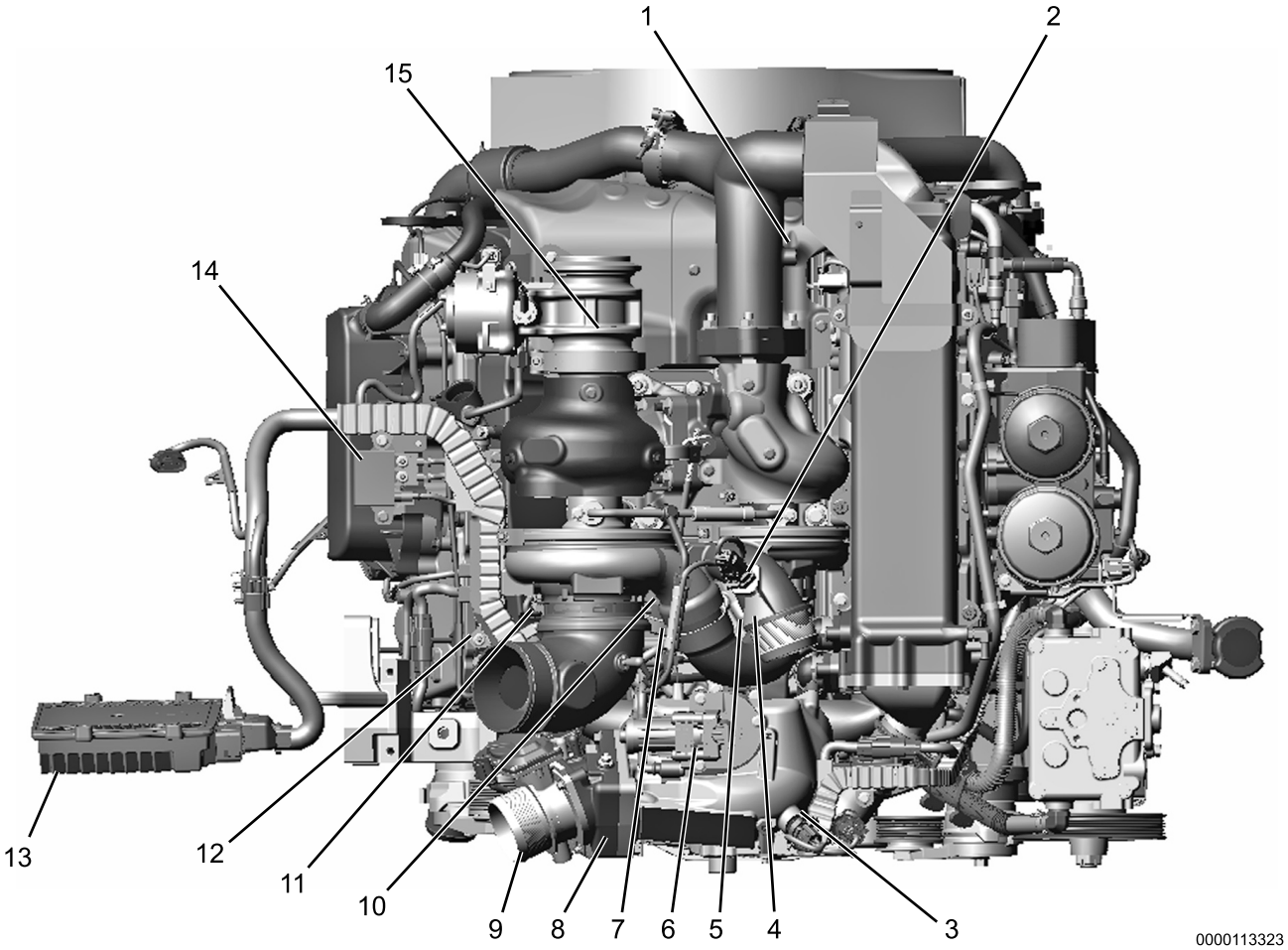


Figure 41 Electronic Components – Top

1. Exhaust Gas Temperature (EGT) sensor
2. Turbocharger 1 Compressor Outlet Temperature (TC1COT) sensor
3. Charge Air Cooler Outlet Temperature (CACOT) sensor
4. Engine Oil Pressure (EOP) sensor
5. Engine Oil Temperature (EOT) sensor
6. Exhaust Gas Recirculation (EGR) valve
7. Turbocharger 1 Wastegate Control (TC1WC) solenoid
8. Intake Air Heater (IAH)
9. Engine Throttle Valve (ETV)
10. TC1WC actuator
11. Intake Manifold Pressure (IMP) sensor
12. Engine Control Module (ECM)
13. Intake Manifold Temperature (IMT) sensor
14. IAH relay
15. Thermal Management Valve (TMV) (optional)

Description of Engine Electronic Components

Charge Air Cooler Outlet Temperature (CACOT) Sensor

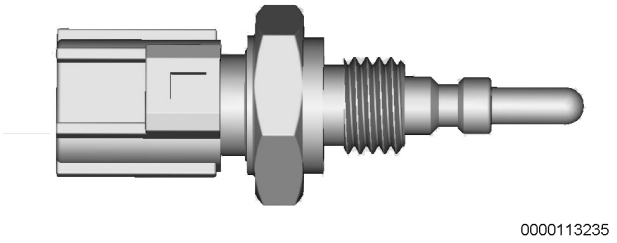


Figure 42 CACOT Sensor

The CACOT is a thermistor sensor. The CACOT sensor provides a feedback signal to the ECM indicating CACOT in the intake air mixer.

The CACOT sensor is installed in the intake air mixer, located on the front of the engine.

Camshaft Position (CMP) Sensor

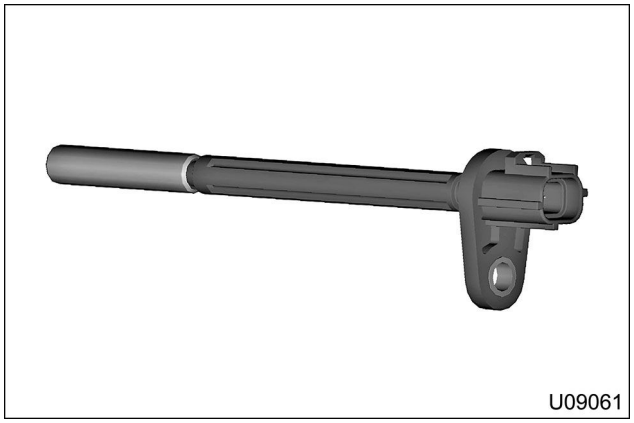


Figure 43 CMP Sensor

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 long CMP sensor, make sure it is the one pictured. This sensor is used in other Navistar, Inc. engines to sense crankshaft position.

Crankshaft Position (CKP) Sensor

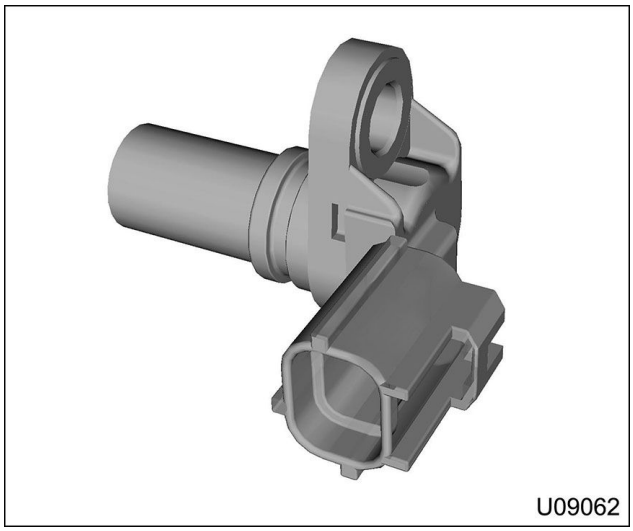


Figure 44 CKP Sensor

The CKP sensor is a magnetic pickup sensor that provides the Engine 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 short CKP sensor, make sure it is the one pictured. This sensor is used in other Navistar, Inc. engines to sense camshaft position.

Engine Control Module (ECM)

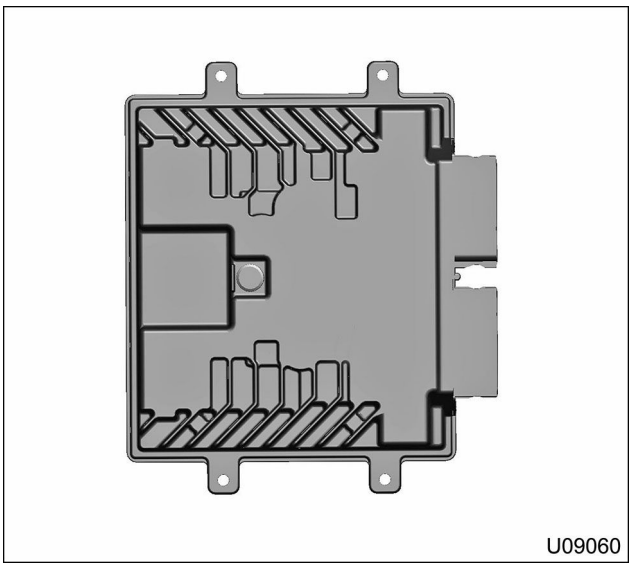


Figure 45 Engine Control Module (ECM)

The Engine 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

The ECM is installed on the right side of engine compartment on the air cleaner bracket.

Engine Coolant Temperature (ECT1) Sensor

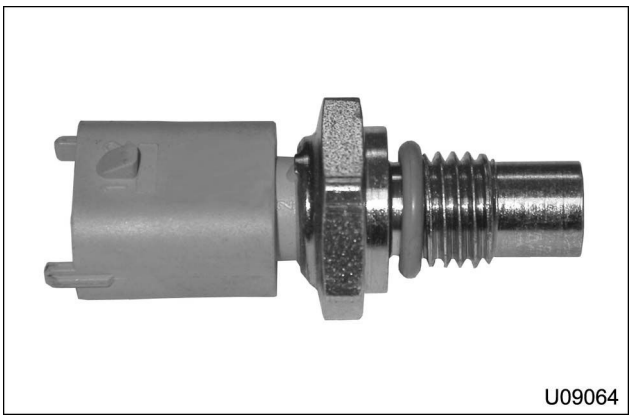


Figure 46 ECT1 Sensor

The ECT1 sensor is a thermistor sensor. The ECM monitors the ECT1 signal and uses this information for the instrument panel temperature gauge, coolant compensation, and the Engine Warning Protection System (EWPS).

The ECT1 sensor is installed in the front crankcase cover, near the alternator bracket.

Engine Oil Pressure (EOP) Sensor

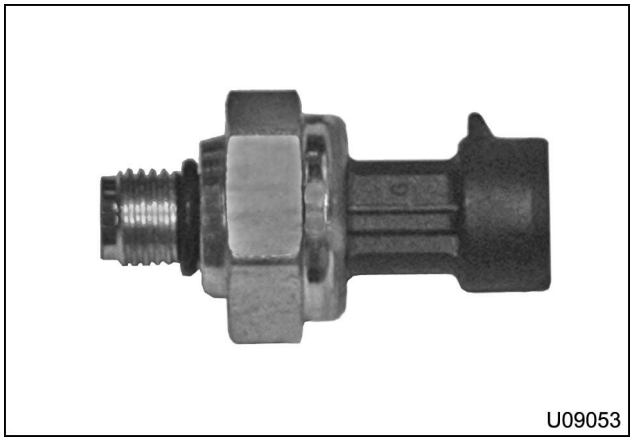


Figure 47 EOP Sensor

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 red ENGINE warning lamp 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 installed on the oil cooler cover on top of the engine.

Engine Oil Temperature (EOT) Sensor

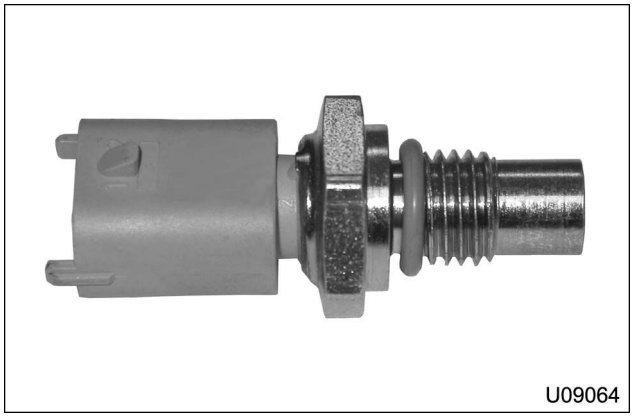


Figure 48 EOT Sensor

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 on the oil cooler cover on top of the engine.

Engine Fuel Temperature (EFT) Sensor

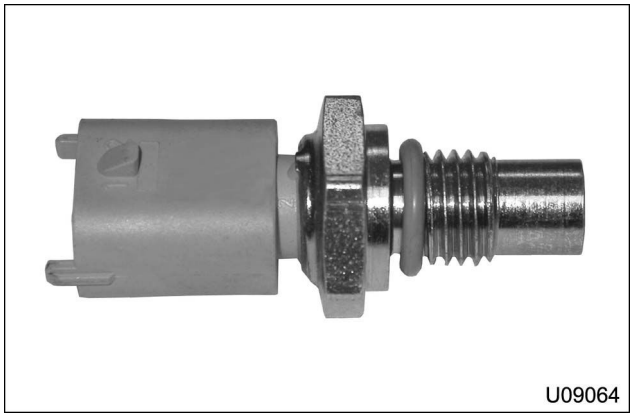


Figure 49 EFT Sensor

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 base of the fuel filter module housing on upper left side of engine.

Exhaust Gas Recirculation (EGR) Valve

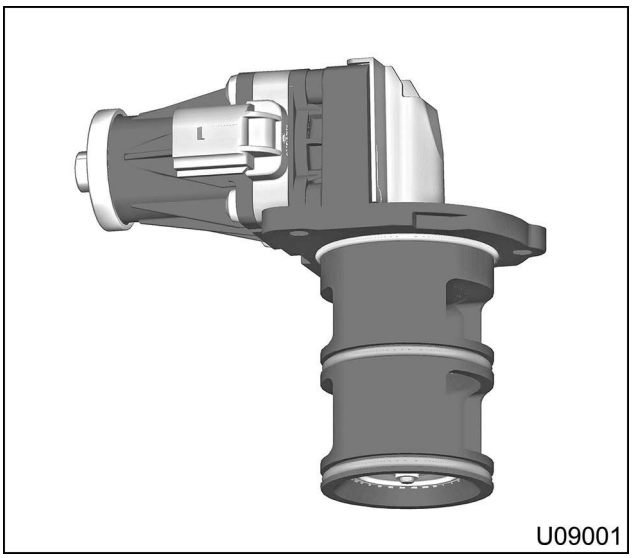


Figure 50 EGR Valve

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

The EGR valve assembly receives the desired EGR position from the Engine Control Module (ECM) to activate the valve for exhaust gas recirculating. 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 assembly is mounted on the manifold mixer on the front top of the engine.

Exhaust Gas Temperature (EGT) Sensor

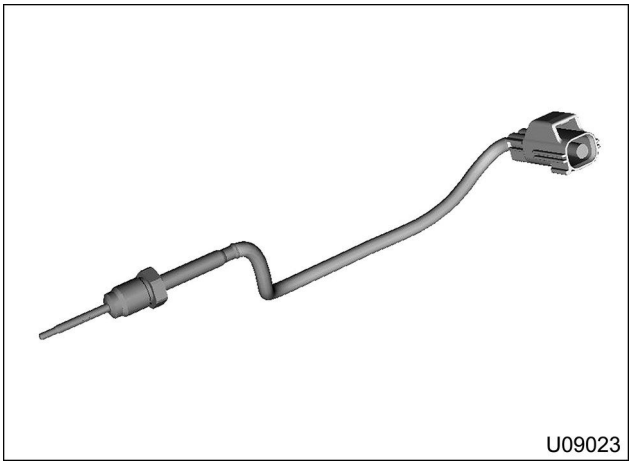


Figure 51 EGT Sensor

The EGT is a thermistor sensor. The EGT sensor provides a feedback signal to the ECM indicating exhaust gas temperature.

The EGT sensor is installed on the turbo exhaust inlet manifold rear top of the engine.

Exhaust Gas Recirculation Temperature (EGRT) Sensor

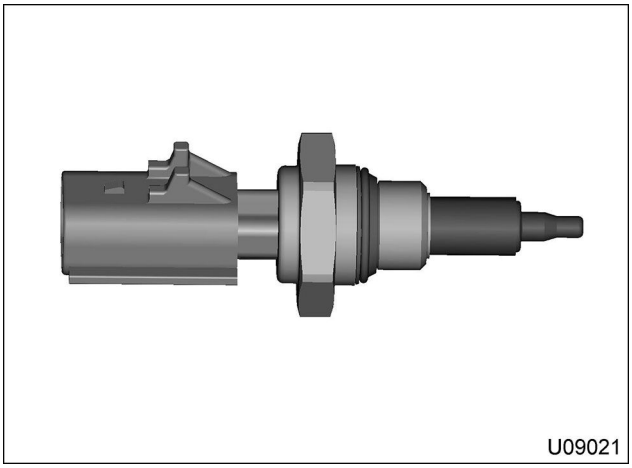


Figure 52 EGRT Sensor

The EGRT is a thermistor sensor. The EGRT sensor provides a feedback signal to the ECM indicating exhaust gas temperature in the manifold mixer.

The EGRT sensor is installed on the manifold mixer on the front top of the engine.

Engine Throttle Valve (ETV)

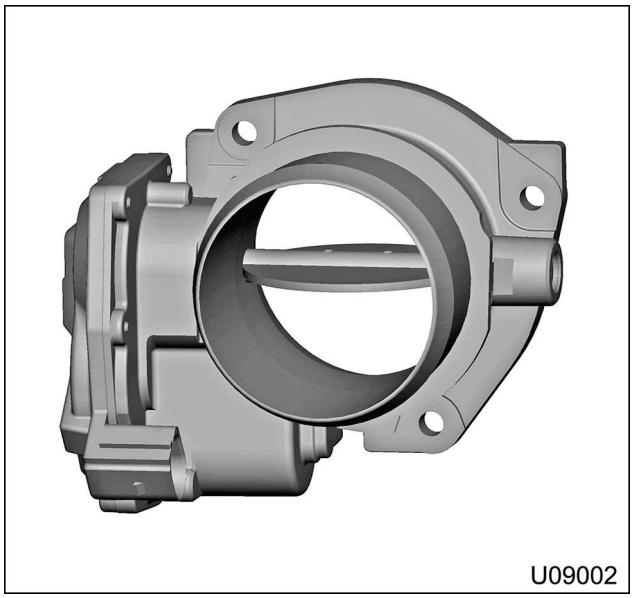


Figure 53 Engine Throttle Valve (ETV)

The ETV, a variable position actuator, restricts intake air flow to help heat the exhaust aftertreatment during regeneration. The ETV changes valve position in response to ECM signals. The ETV contains an internal position sensor that monitors valve position and transmits a position signal to the ECM.

The ETV is mounted to the Intake Air Heater (IAH) on the manifold mixer on the front top of the engine.

Fuel Heater (optional)

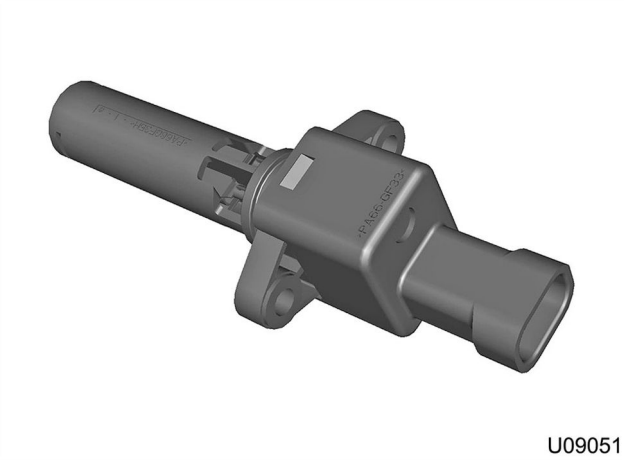


Figure 54 Fuel Heater

The fuel heater warms incoming fuel to prevent fuel waxing, and improves performance and fuel economy during cold weather start-up.

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

The fuel heater is installed in the fuel filter module on the upper left side of engine.

Fuel Pump

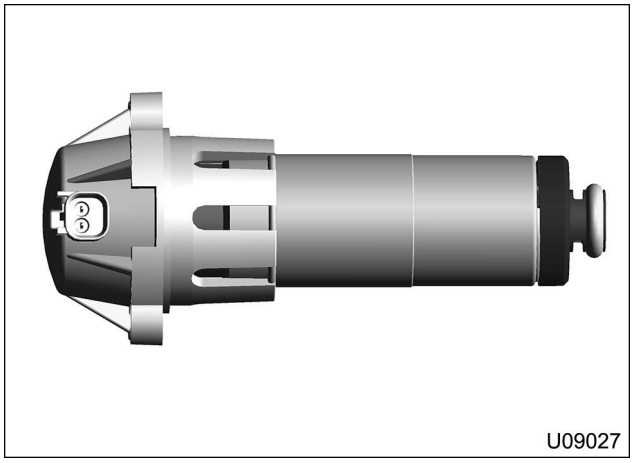
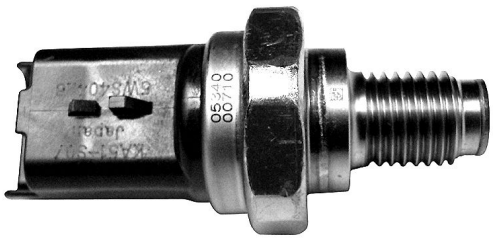


Figure 55 Fuel Pump

The low-pressure fuel pump is a constant-flow electric pump that draws fuel from the fuel tank(s) through the primary fuel filter and supplies fuel to the secondary fuel filter.

The low-pressure fuel pump is installed in the fuel filter module on the upper left side of engine.

Fuel Rail Pressure (FRP) Sensor



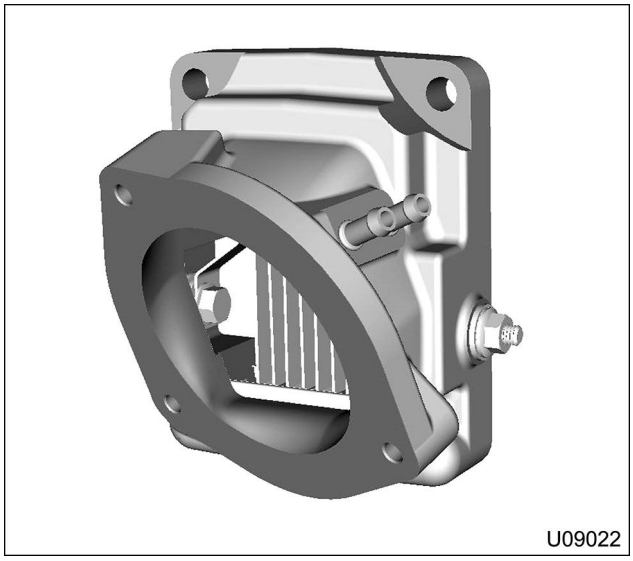
M09105

Figure 56 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.

Intake Air Heater (IAH)



U09022

Figure 57 Intake Air Heater (IAH)

The IAH is an electric grid heater. The IAH system warms the incoming air to aid cold engine starting and reduce exhaust emissions during warm-up.

The IAH is installed on the manifold mixer on the front top of the engine.

Intake Air Heater (IAH) Relay

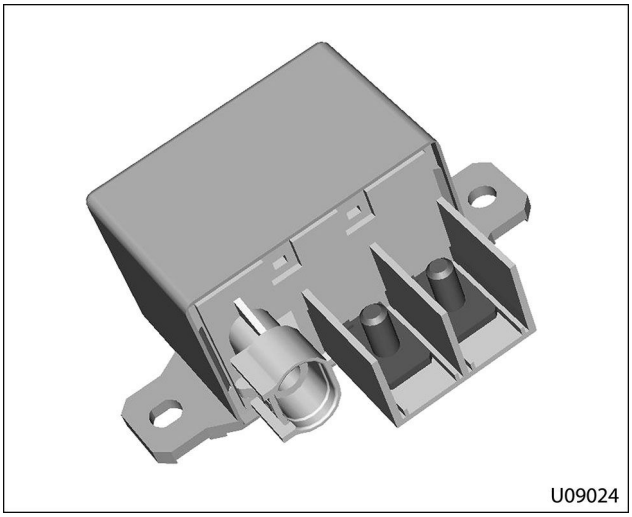


Figure 58 Intake Air Heater (IAH) Relay

The IAH relay delivers VBAT to the Intake Air Heater. The ECM activates the IAH by energizing the IAH relay while monitoring programmed conditions for engine coolant temperature, air inlet temperature, and atmospheric pressure. The ECM controls the WAIT TO START lamp and IAH relay separately.

The IAH relay is mounted to the relay support installed on top of the right valve cover.

Intake Manifold Pressure (IMP) Sensor

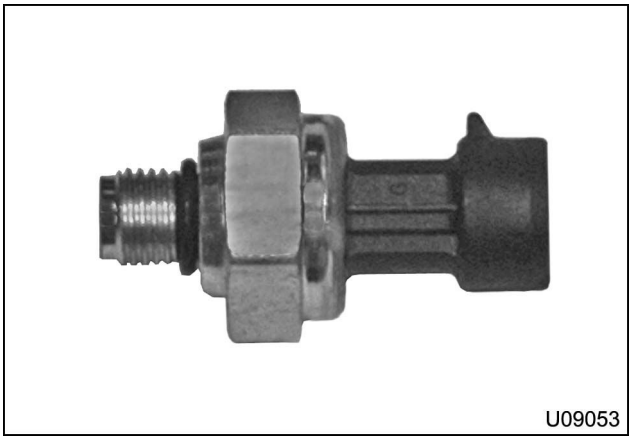


Figure 59 IMP Sensor

The IMP sensor is a variable capacitance sensor. The ECM monitors the IMP signal to determine intake manifold pressure (boost). This information is used to control the Exhaust Gas Recirculation (EGR) valve and determine fueling calculations.

The IMP sensor is installed (above the IMT sensor) in the top of the right valve cover and intake manifold base assembly, under the low-pressure turbocharger assembly.

Intake Manifold Temperature (IMT) Sensor

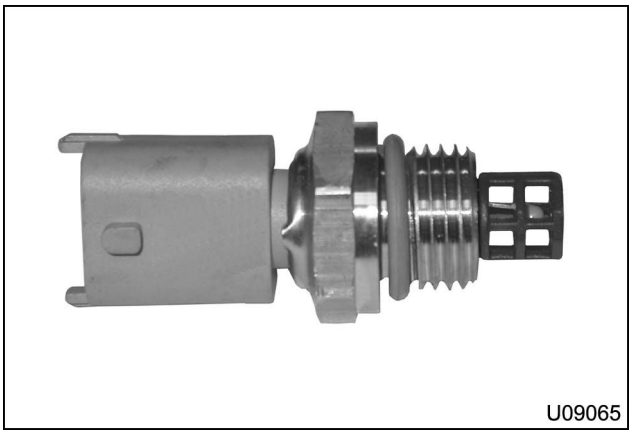


Figure 60 IMT Sensor

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

The IMT sensor is installed (below the IMP sensor) in the top of the right valve cover and intake manifold base assembly, under the low-pressure turbocharger assembly.

Mass Air Flow / Air Inlet Temperature (MAF / AIT) Sensor

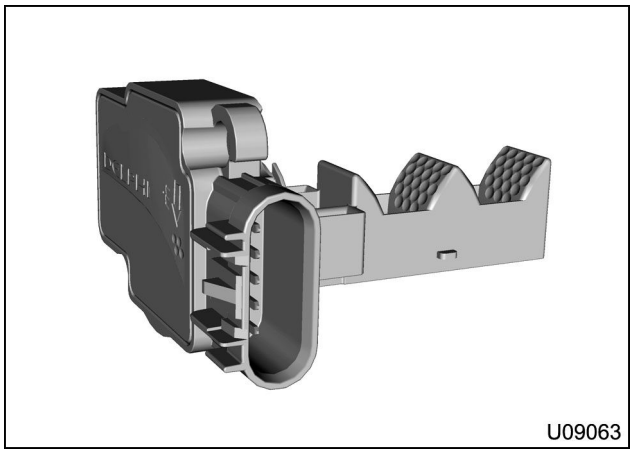


Figure 61 MAF / AIT Sensor

The MAF / AIT sensor measures the volume, density, and temperature of air entering the engine at any given time.

The ECM uses this information to calculate the correct amount of EGR during engine operation. The MAF sensor assembly also contains the AIT sensor. The AIT monitors the temperature of the air entering the intake system. The MAF and AIT sensors are integrated into this single component. The ECM determines the volume, density, and temperature of the incoming air by processing input signals from the MAF and AIT sensors.

The MAF / AIT sensor is installed in the vehicle air cleaner assembly.

Thermal Management Valve (TMV) (optional)

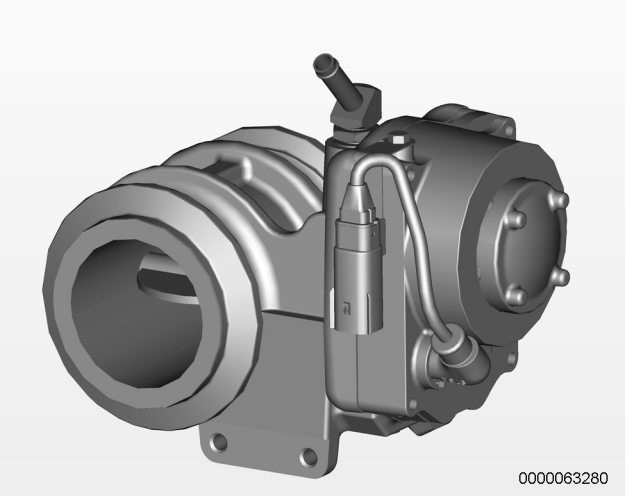


Figure 62 TMV

Some vehicles are fitted with an optional Thermal Management Valve (TMV) in the exhaust system between the low-pressure turbocharger and the DOC. The TMV is an actuator used to increase exhaust back-pressure to enable engine braking and allow faster engine warm-ups.

Turbocharger 1 Compressor Outlet Temperature (TC1COT) Sensor

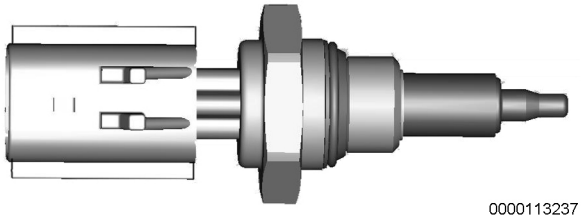


Figure 63 TC1COT sensor

The TC1COT is a thermistor sensor. The TC1COT sensor provides a feedback signal to the ECM indicating TC1COT in the turbocharger 1 outlet pipe.

The TC1COT sensor is installed in the turbocharger 1 outlet pipe, located on top of the engine.

Turbocharger 1 Wastegate Control (TC1WC) Solenoid

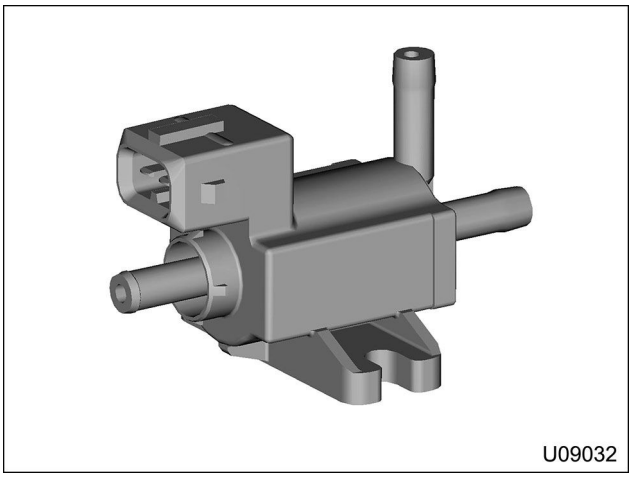


Figure 64 TC1WC Solenoid

The TC1WC solenoid controls the TC1WC actuator by regulating the boost control air supply based on a Pulse Width Modulation (PWM) signal received from the ECM. Signals from the ECM are in response to engine speed, required fuel quantity, boost, exhaust back pressure, and altitude.

The TC1WC solenoid is mounted on top of the engine on the oil cooler cover, near the TC1WC actuator.

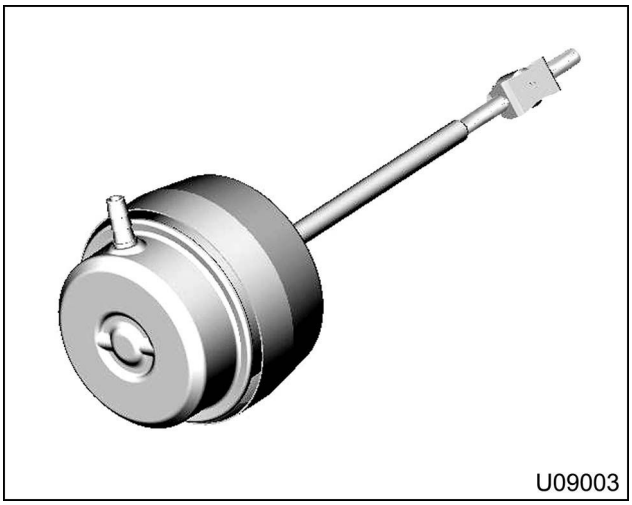


Figure 65 TC1WC Actuator

The TC1WC actuator is part of the turbocharger assembly on top of the engine.

Water In Fuel (WIF) Sensor

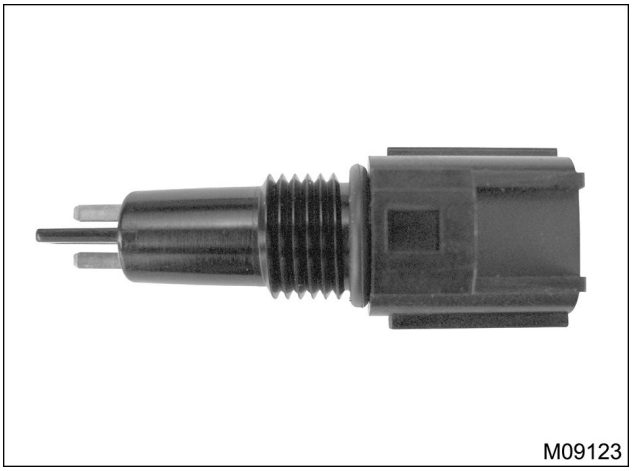


Figure 66 WIF Sensor

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; when water is in the fuel, the message ‘Water in Fuel’ is displayed on the instrument panel.

The WIF sensor is installed in the fuel filter module housing on upper left side of 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.

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

Mass Air Flow / Air Inlet Temperature (MAF / AIT) Sensor

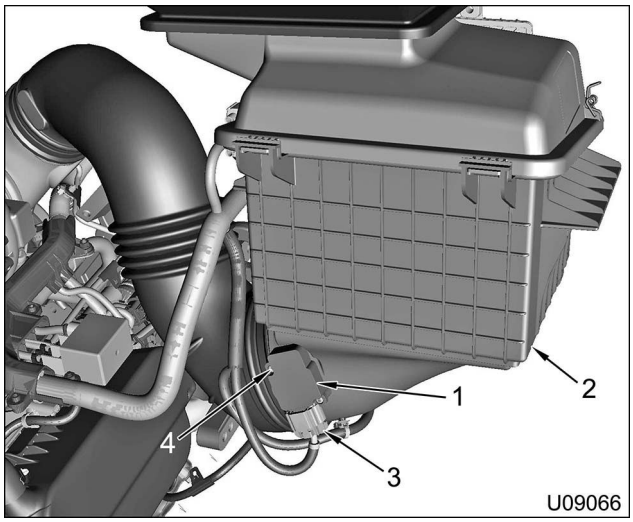


Figure 67 MAF / AIT Sensor

1. MAF / AIT sensor
2. Vehicle air cleaner assembly
3. 5-pin engine harness connector
4. Torx screw (2)

1. Push release tab down on the 5-pin engine harness connector and pull connector from the MAF / AIT sensor.
2. Remove two Torx screws that mount the MAF / AIT sensor.
3. Remove the MAF / AIT sensor.
4. Remove and discard O-ring.

NOTE: Anytime the MAF / AIT sensor is disconnected, the MAF Sensor Test must be run to auto-calibrate the MAF / AIT sensor.

The MAF Sensor Test is in the "Performance Diagnostics" section of the 0000001681 MaxxForce® 7 *Engine Diagnostic Manual*.

Charge Air Cooler Outlet Temperature (CACOT) Sensor

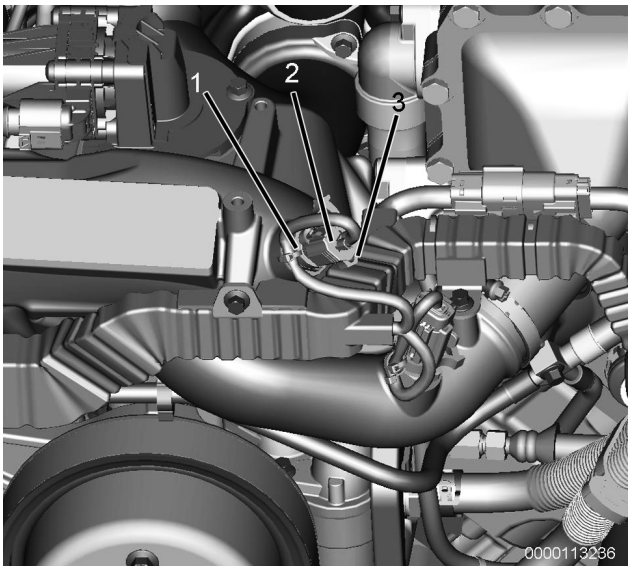


Figure 68 CACOT Sensor

1. CACOT sensor
2. 2-pin engine harness connector
3. Clamp

1. Open clamp on engine harness.
2. Pull out red CPA lock, press release tab on 2-pin engine harness connector, and pull connector from CACOT sensor.
3. Remove CACOT sensor from intake mixer housing.

Crankshaft Position (CKP) Sensor

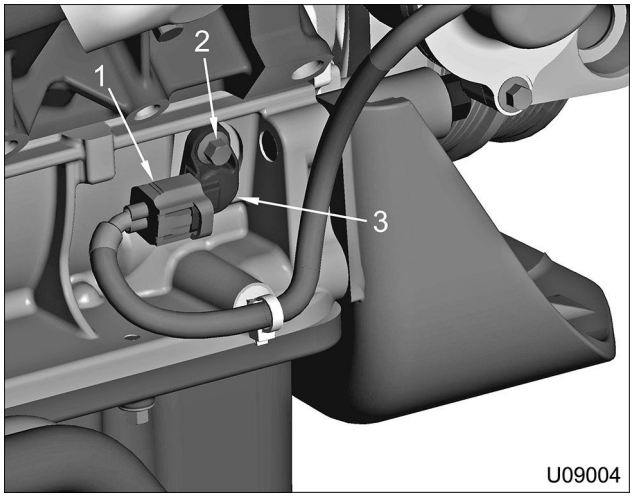


Figure 69 CKP Sensor

1. 2-pin engine harness connector
2. M6 x 14 bolt
3. CKP sensor

1. Push release tab down on the 2-pin engine harness connector and pull connector from the CKP sensor.
2. Remove M6 x 14 bolt from CKP sensor.
3. Remove CKP sensor and discard sensor O-ring.

Camshaft Position (CMP) Sensor

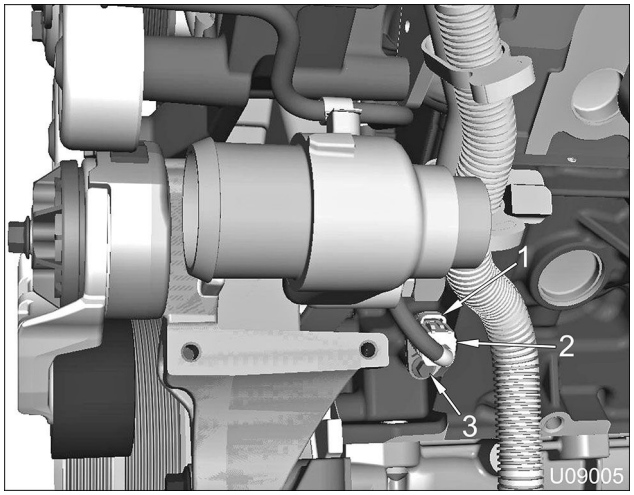


Figure 70 CMP Sensor

1. CMP sensor
2. 2-pin engine harness connector
3. M6 x 14 bolt

1. Push release tab down on the 2-pin engine harness connector and pull connector from the CKP sensor.
2. Disconnect engine harness connector from CMP sensor.
3. Remove M6 x 14 bolt from CMP sensor.
4. Remove CMP sensor and discard both sensor O-rings.

Engine Coolant Temperature (ECT1) Sensor

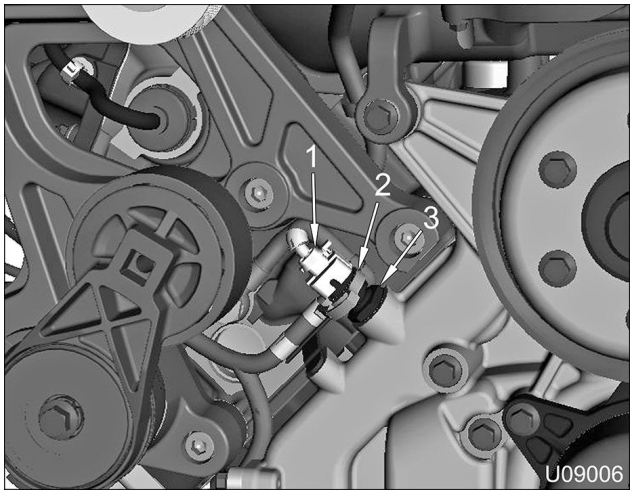


Figure 71 ECT1 Sensor

1. 2-pin engine harness connector
2. Clamp
3. ECT1 sensor

NOTE: Remove alternator bracket. See Alternator and Refrigerant Compressor Mounting Bracket (page 268)

1. Open clamp on engine harness.
2. Pull out yellow CPA lock and press release tab on 2-pin engine harness connector, and pull connector from ECT1 sensor.
3. Remove ECT1 sensor and discard sensor O-ring.

Engine Throttle Valve (ETV)

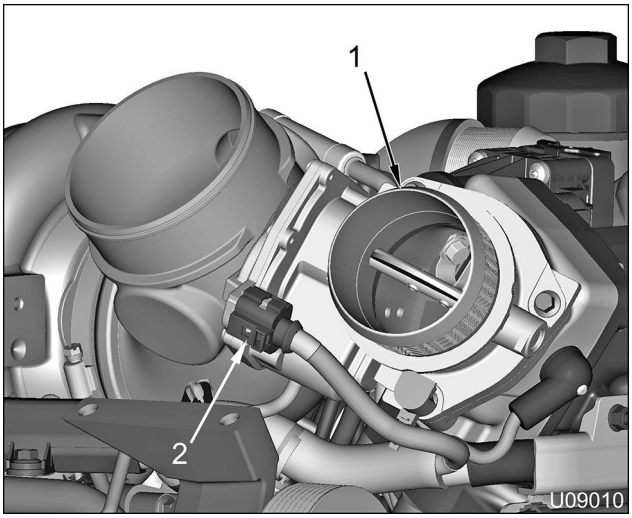


Figure 72 Engine Throttle Valve (ETV)

1. ETV
2. 6-pin engine harness connector

1. Push back release tab on 6-pin engine harness connector and pull connector from the ETV.
2. Disconnect engine harness connector from ETV.
3. See Engine Throttle Valve (ETV) (page 122) for removal.

Intake Air Heater (IAH)

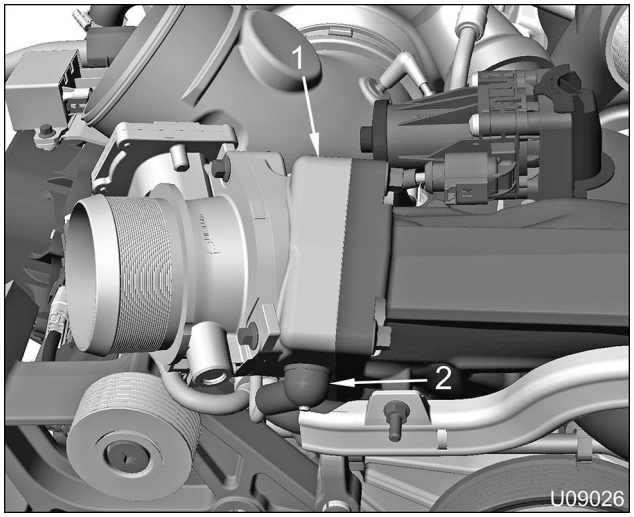


Figure 73 Intake Air Heater (IAH)

1. IAH
2. Boot

1. Pull back boot on engine harness connection to the IAH.
2. Remove nut and ring terminal connection from stud bolt.
3. See Intake Air Heater (page 122) for removal.

Exhaust Gas Recirculation (EGR) Valve Assembly

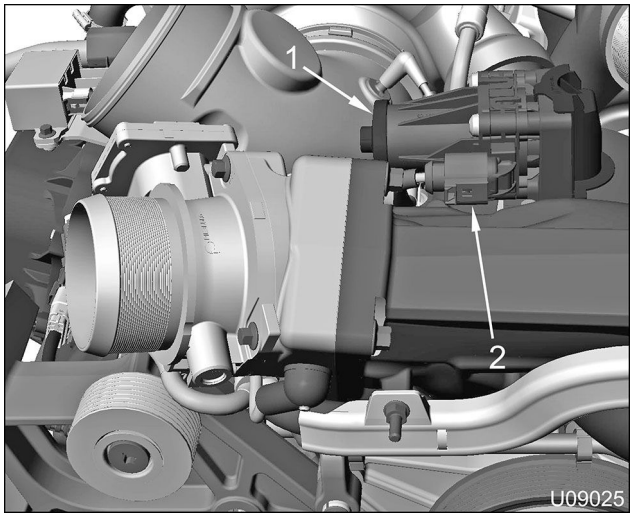


Figure 74 EGR Valve Assembly

1. EGR valve assembly
2. 6-pin engine harness connector

1. Push back release tab on 6-pin engine harness connector and pull connector from the EGR valve assembly.
2. See EGR Valve Assembly (page 117) for removal of EGR valve assembly.

Exhaust Gas Recirculation Temperature (EGRT) Sensor

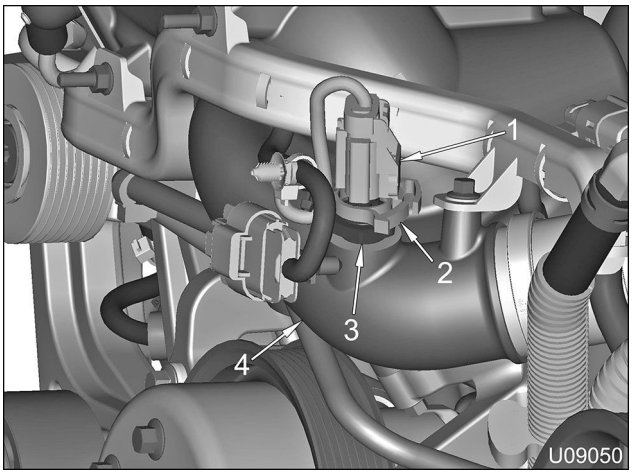


Figure 75 EGRT Sensor

1. 2-pin engine harness connector
2. Clamp
3. EGRT sensor
4. Manifold mixer

1. Open clamp on engine harness.
2. Pull out red CPA lock and press release tab on 2-pin engine harness connector, and pull connector from EGRT sensor.
3. Remove EGRT sensor and discard O-ring.

Intake Manifold Temperature (IMT) Sensor and Intake Manifold Pressure (IMP) Sensor

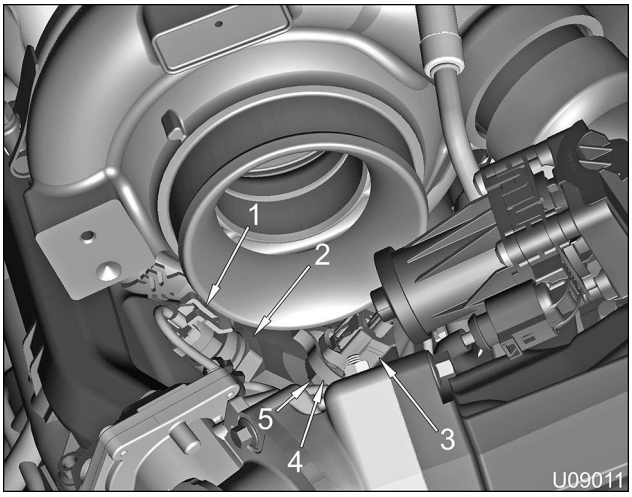


Figure 76 IMT and IMP Sensors

1. 2-pin engine harness connector
2. IMP sensor
3. 3-pin engine harness connector
4. Clamp
5. IMT sensor

NOTE: See Air Duct Assembly, Relief Tube Assembly, Wastegate Tube Assembly, and TC1WC solenoid (page 156) for removal of air duct assembly.

1. Remove air duct assembly.
2. Open clamp on engine harness.
3. Push release tab down on 2-pin engine harness connector and pull connector from IMT sensor.
4. Pull out release tab on the 3-pin engine harness connector, and pull connector from the IMP sensor.
5. Remove IMT and IMP sensors and discard O-rings.

Thermal Management Valve (TMV)

NOTE: Drain cooling system prior to removing TMV.

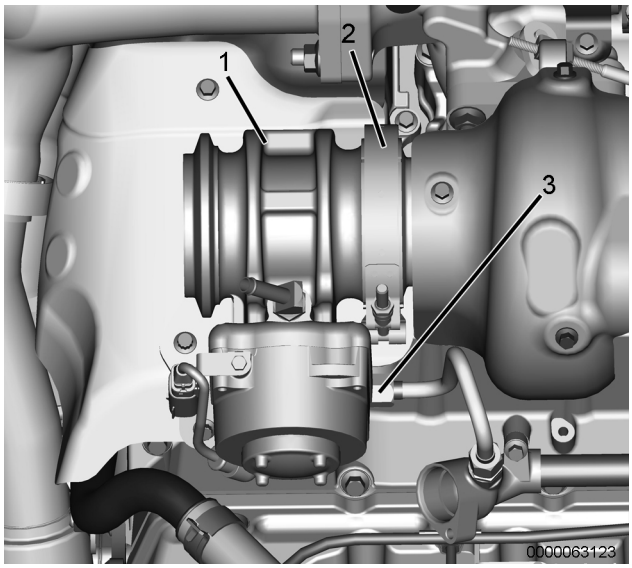
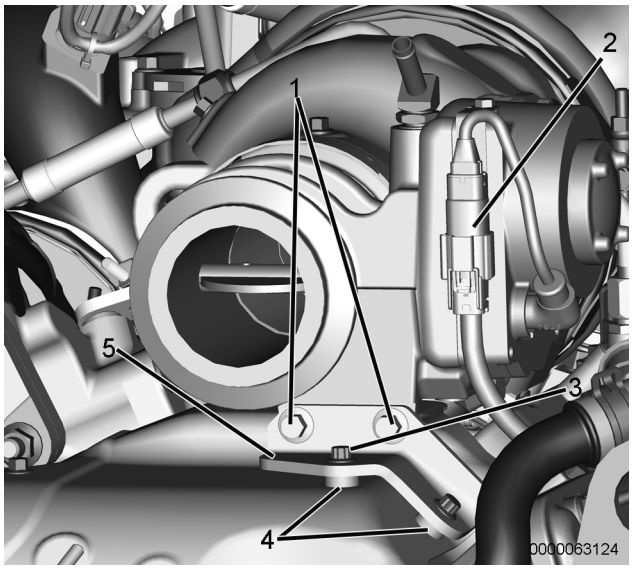


Figure 77 V-band Clamp and Coolant Line

1. TMV
2. V-band clamp
3. Coolant tube

1. Remove coolant tube from TMV.
2. Loosen T-bolt on V-band clamp and remove V-band clamp from TMV.



GRAPHIC-12361-4ADAE2D0

Figure 78 TMV

1. M8 x 16 bolt (2)
2. TMV engine harness connector
3. M6 x 25 bolt (2)
4. TMV support spacer
5. TMV support

3. Disconnect TMV engine harness connector from TMV.
4. Remove two M8 x 16 bolts from TMV and support.
5. Remove two M6 x 25 bolts and TMV support spacers from TMV support. Remove support from engine.
6. Remove TMV from engine.

Turbocharger 1 Compressor Outlet Temperature (TC1COT) Sensor

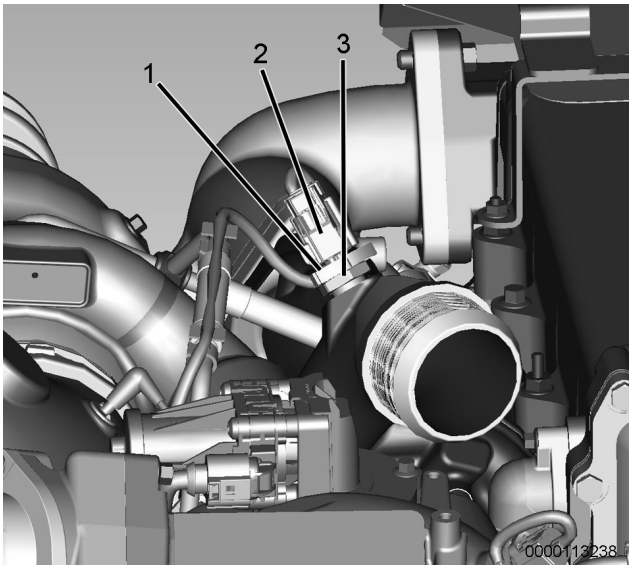


Figure 79 TC1COT Sensor

1. Clamp
2. 2-pin engine harness connector
3. TC1COT sensor

1. Open clamp on engine harness.
2. Pull out red CPA lock, press release tab on 2-pin engine harness connector, and pull connector from TC1COT sensor.
3. Remove TC1COT sensor from turbocharger 1 outlet.

Turbocharger 1 Wastegate Control (TC1WC) Solenoid

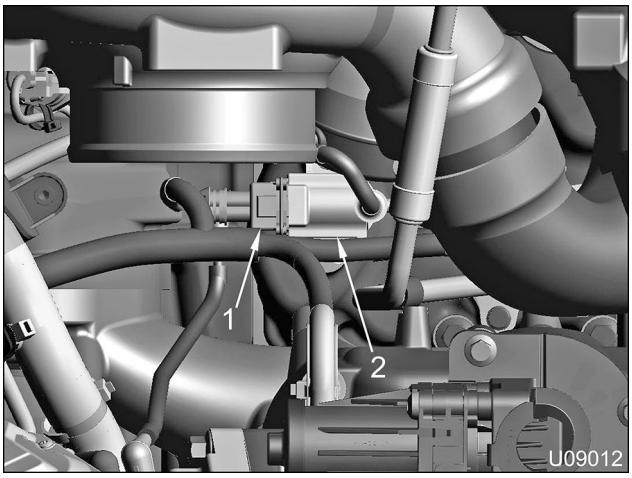


Figure 80 TC1WC Solenoid

1. 2-pin engine harness connector
2. TC1WC solenoid

NOTE: See Air Duct Assembly, Relief Tube Assembly, Wastegate Tube Assembly, and TC1WC Solenoid (page 156) for removal of TC1WC solenoid.

1. Remove air duct assembly.
2. Push down the metal clip on the 2-pin engine harness connector and disconnect connector from TC1WC solenoid.
3. Remove TC1WC solenoid.

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

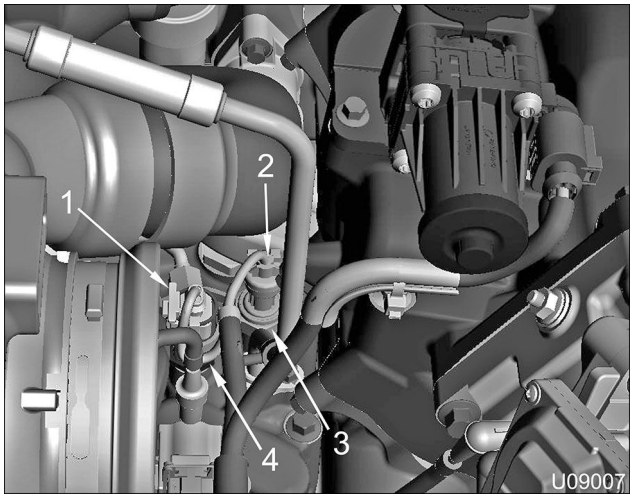


Figure 81 EOT Sensor and EOP Sensor

1. 2-pin engine harness connector
2. 3-pin engine harness connector
3. EOP sensor
4. EOT sensor

1. See Distribution Duct and Manifold Mixer (page 122) for removal of manifold mixer.
2. Pull out yellow CPA lock and press release tab on 2-pin engine harness connector, and pull connector from EOT sensor.
3. Remove EOT sensor and discard sensor O-ring.
4. Pull out release tab on the 3-pin engine harness connector, and pull connector from the EOP sensor.
5. Remove EOP sensor and discard sensor O-ring.

Water In Fuel (WIF) Sensor

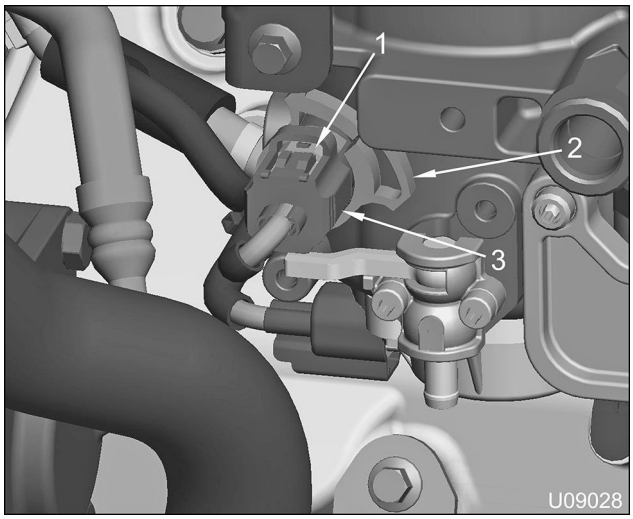


Figure 82 Water In Fuel (WIF) Sensor

1. WIF sensor
2. Clamp
3. 2-pin engine harness connector

1. Open clamp on engine harness.
2. Push release tab down on the 2-pin engine harness connector and pull connector from the WIF sensor.
3. Remove WIF sensor and discard O-ring seal.

Fuel Pump

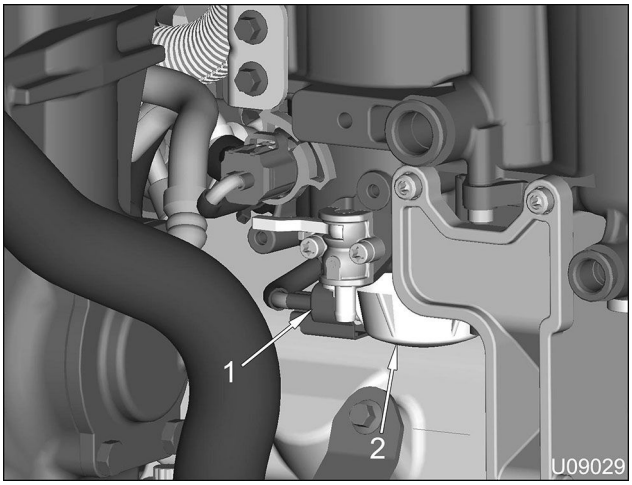


Figure 83 Fuel Pump

1. 2-pin engine harness connector
2. Fuel pump

1. Push release tab down on the 2-pin engine harness connector and pull connector from the fuel pump.
2. See Fuel Pump (page 230) for removal.

Fuel Heater (optional) and Fuel Delivery Pressure (FDP) Sensor (optional)

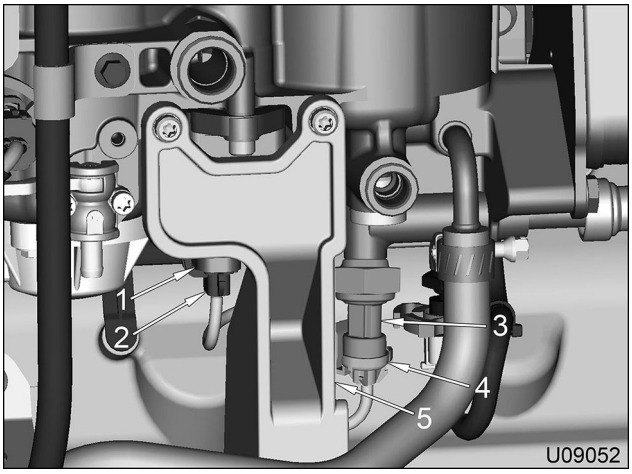


Figure 84 Fuel Heater (optional) and Fuel Delivery Pressure (FDP) Sensor (optional)

1. Fuel heater
2. 2-pin engine harness connector
3. FDP sensor
4. 2-pin engine harness connector
5. Filter cooler pump module support

1. Pull up latch on 2-pin engine harness connector and pull connector from the fuel heater.
2. See Fuel Heater (optional) and Fuel Delivery Pressure (FDP) Sensor (optional) (page 232) for removal.
3. Pull out release tab on the 3-pin engine harness connector, and pull connector from the FDP sensor.
4. Remove FDP sensor and discard O-ring.

Engine Fuel Temperature (EFT) Sensor

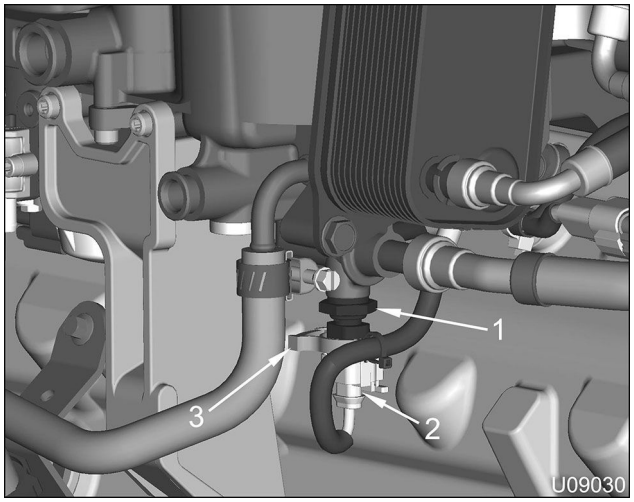


Figure 85 EFT Sensor

1. EFT sensor
2. 2-pin engine harness connector
3. Clamp

1. Open clamp on engine harness.
2. Pull out yellow CPA lock, press release tab on 2-pin engine harness connector, and pull connector from EFT sensor.
3. Remove EFT sensor and discard O-ring.

Exhaust Gas Temperature (EGT) Sensor

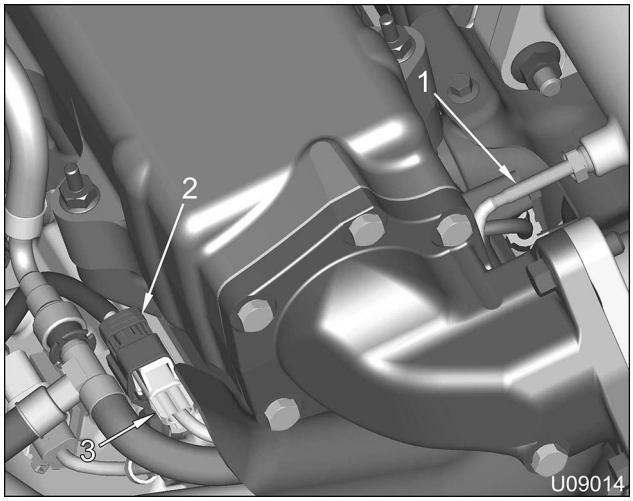


Figure 86 Exhaust Gas Temperature (EGT) Sensor

1. EGT sensor
2. 2-pin engine harness connector
3. Connector on EGT sensor

1. Pull out red CPA lock, press release tab on 2-pin engine harness connector, and pull connector from EGT sensor.
2. Remove EGT sensor from turbo exhaust inlet manifold.

Engine 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.

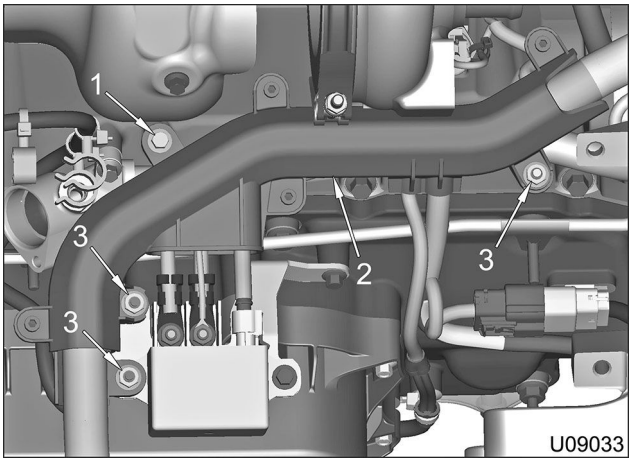


Figure 87 Harness Channel Shield Assembly (upper and lower)

1. M6 x 14 bolt
2. Harness channel shield assembly (upper and lower)
3. M6 nut (3)

1. Remove M6 x 14 bolt.
2. Remove three M6 nuts.

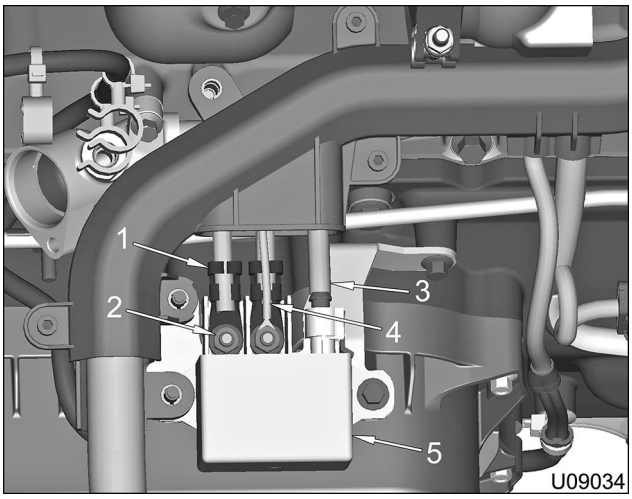


Figure 88 Engine Harness to IAH Relay

1. Ring terminal (power)
2. M6 nut (2)
3. Plug connector
4. Ring terminal (IAH) (2)
5. IAH relay

3. Remove two M6 nuts that secure ring terminals to IAH relay.
4. Remove ring terminals and plug connector from IAH relay.

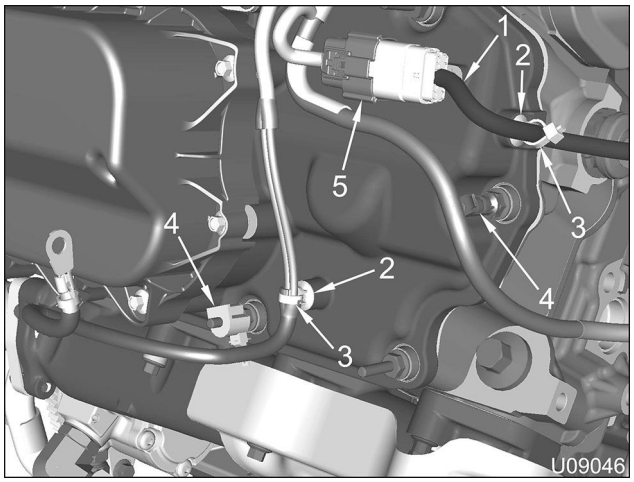


Figure 89 Harness Connection to Right Valve Cover

1. Right Under Valve Cover (UVC) harness
2. Harness fir zip retainer (2)
3. Tie strap (2)
4. Stud clip (2)
5. 12-way engine harness injector connector

5. Pull out red CPA lock, push down on latch on 12-way engine harness injector connector, and pull connector from right Under Valve Cover (UVC) harness.
6. Cut and remove tie straps, without cutting fir zip retainers.
7. Disengage plastic stud clips.

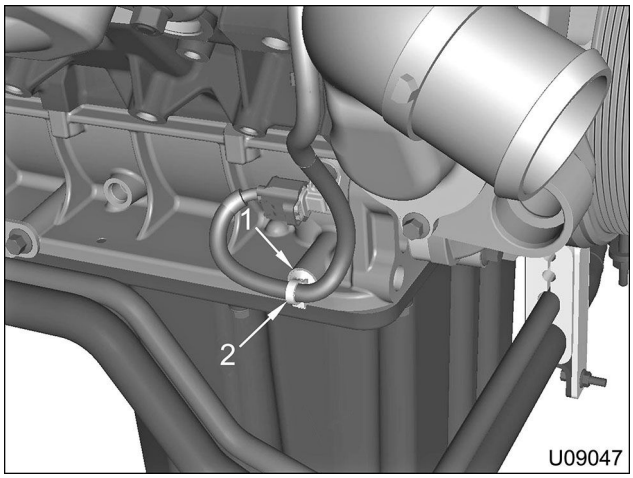


Figure 90 Harness Connection to Lower Crankcase

1. Harness fir zip retainer
2. Tie strap

8. Cut and remove tie strap, without cutting fir zip retainer.

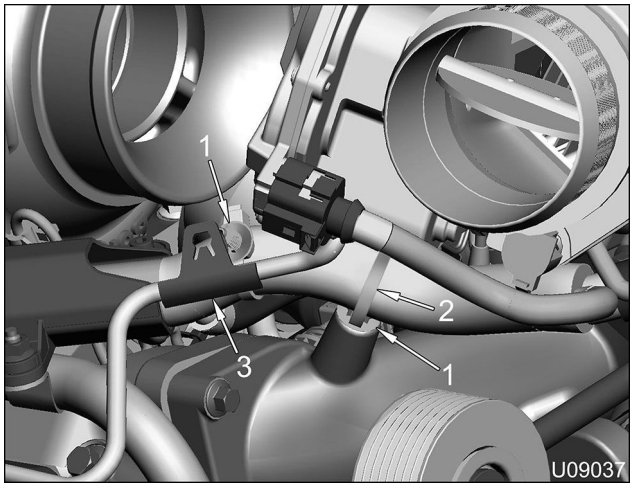


Figure 91 Jet Pump Tube Assembly and Tie Strap to Distribution Duct

1. Fir zip retainer (2)
2. Tie strap
3. Jet pump tube assembly

9. Separate jet pump tube assembly from fir zip retainer secured to engine harness.

10. Without cutting fir zip retainer, cut and remove tie strap that secures engine harness to the distribution duct.

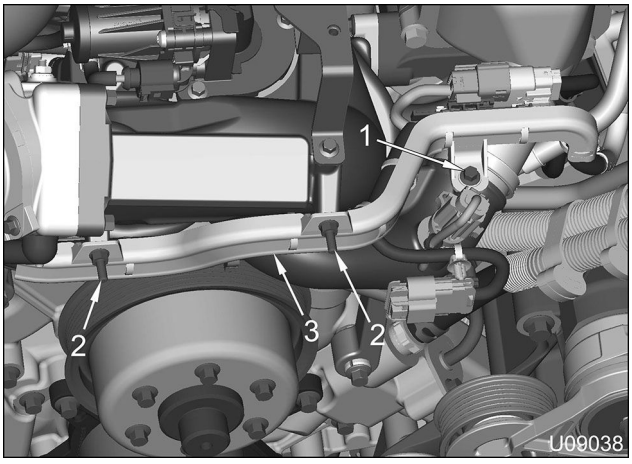


Figure 92 Harness Channel Shield Assembly (front)

1. M6 x 16 bolt
2. M6 x 16 stud bolt (2)
3. Harness channel shield

11. Remove M6 x 16 bolt and two M6 x 16 stud bolts that secure the harness channel shield to the manifold mixer.

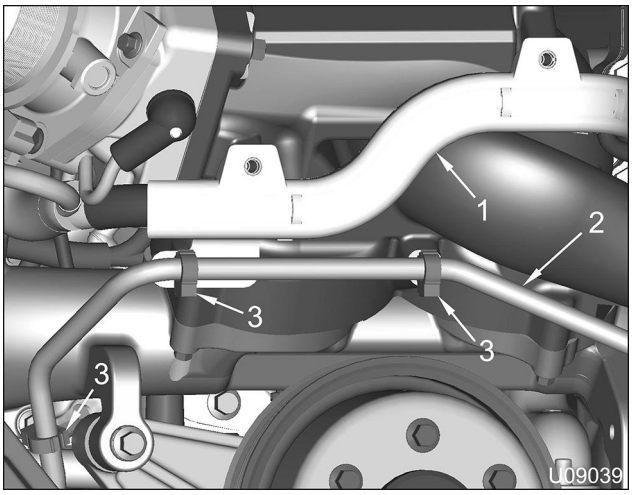


Figure 93 Harness Channel Shield

1. Harness channel shield
2. Injector hose assembly
3. .25 hose clip (3)

12. Separate hose clip from harness channel shield, manifold mixer, and bracket on heater supply tube.

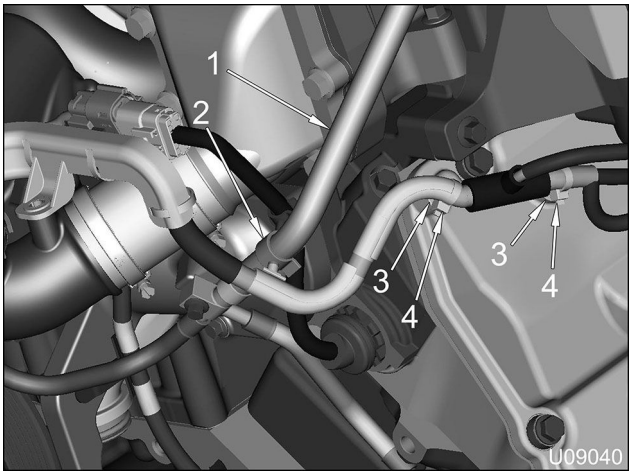


Figure 94 Engine Harness to Injector Hose Assembly and Tie Straps to Left Valve Cover

1. Injector hose assembly
2. Engine harness clip
3. Harness fir zip retainer (2)
4. Tie strap (2)

13. Without cutting fir zip retainer, cut and remove two tie straps that secure engine harness to left valve cover.
14. Separate engine harness clip from injector hose assembly.

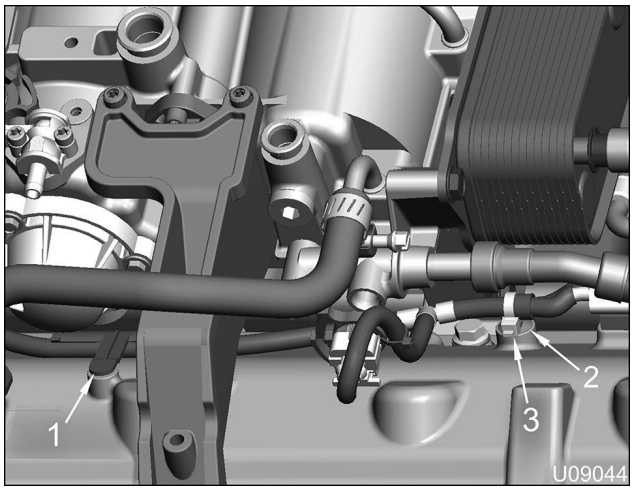


Figure 95 Engine Harness and Tie Strap to Left Valve Cover

1. Engine harness
2. Harness fir zip retainer
3. Tie strap

15. Without cutting fir zip retainer, cut and remove tie strap that secure engine harness to left valve cover.
16. Separate engine harness from left valve cover.

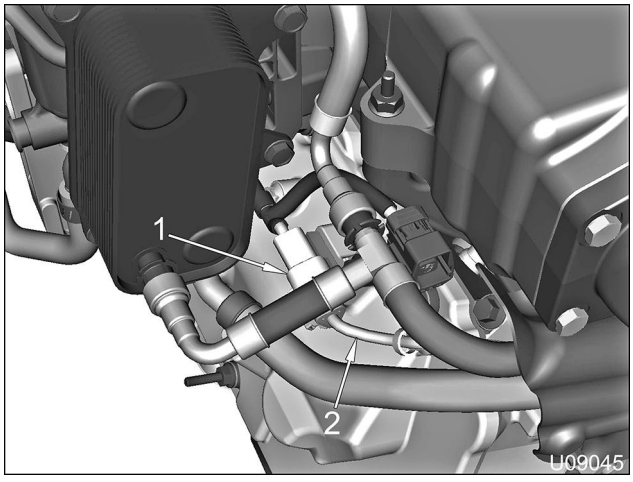


Figure 96 Engine Harness to High-Pressure Pump Harness

1. 3-pin engine harness connector
2. High-pressure pump harness

17. Push down release tab on 3-pin engine harness connector and pull connector from the high-pressure pump harness connector.
18. Pull back cam lever lock on 98-way engine harness connector and pull connector from the ECM.
19. Remove engine harness from engine and vehicle.

Harness Channel Shield Assemblies

NOTE: Only remove harness channel shields from engine harness, if required for harness repair.

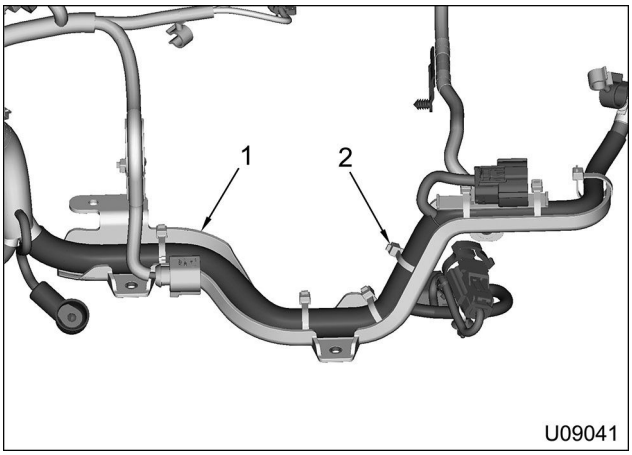


Figure 97 Removal of Harness Channel Shield

1. Harness channel shield
2. Tie strap (5)

1. Cut and remove five tie straps and separate harness channel shield from engine harness.

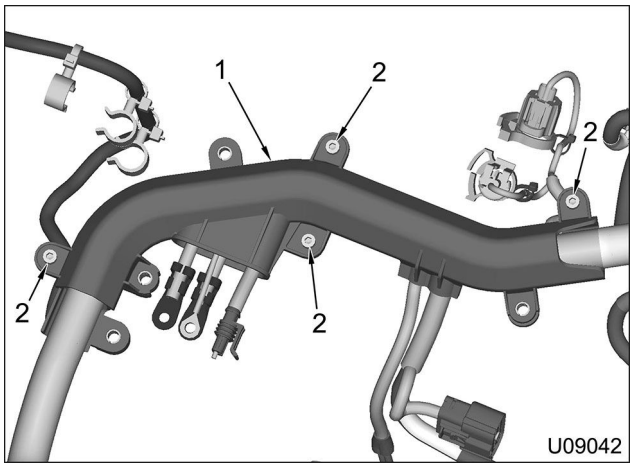


Figure 98 Removal of Upper Harness Channel Shield

1. Upper harness channel shield
2. M5 x 10 socket head bolt (4)

2. Remove four M5 x 10 socket head bolts.
3. Remove upper harness channel shield.

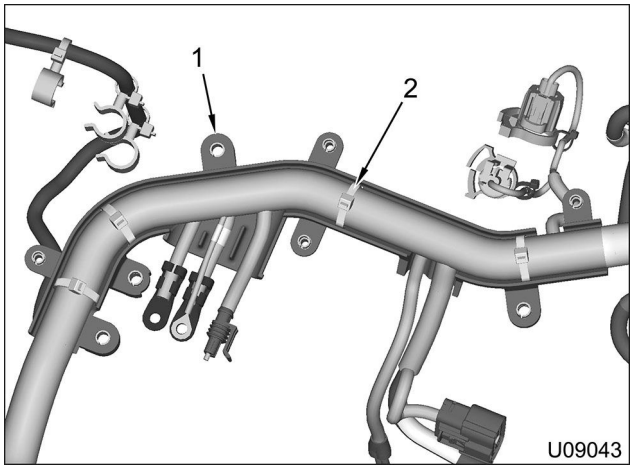


Figure 99 Removal of Lower Harness Channel Shield

1. Lower harness channel shield
2. Tie strap (4)

4. Cut and remove four tie straps and separate lower harness channel shield from engine harness.

Intake Air Heater (IAH) Relay and Relay Support

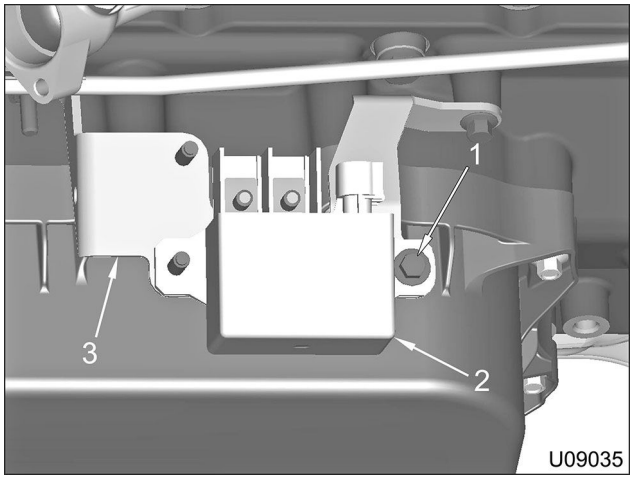


Figure 100 IAH Relay

1. M6 x 14 bolt
2. IAH relay
3. Relay support

1. Remove M6 x 14 bolt that secures IAH relay to the relay support and remove relay.

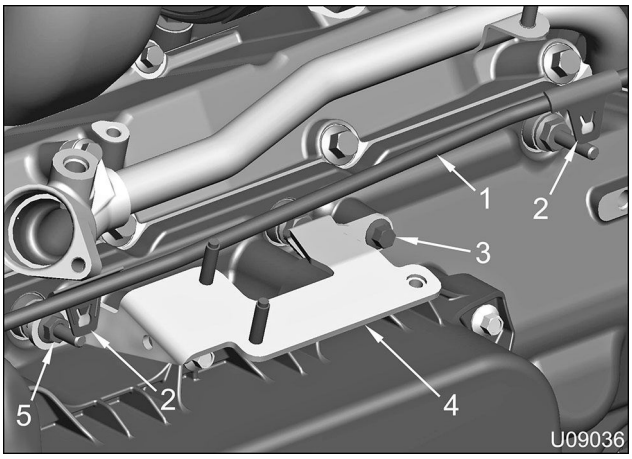


Figure 101 Relay Support

1. Jet pump tube assembly
2. Clip (2)
3. M6 x 14 bolt
4. Relay support
5. M6 nut

2. Pull out two clips on jet pump tube assembly and move up and away from stud bolts in valve cover.
3. Remove M6 x 14 bolt and M6 nut.
4. Remove relay support.

Fuel Rail Pressure (FRP) Sensor

NOTE: The FRP sensor is installed in the right fuel rail.

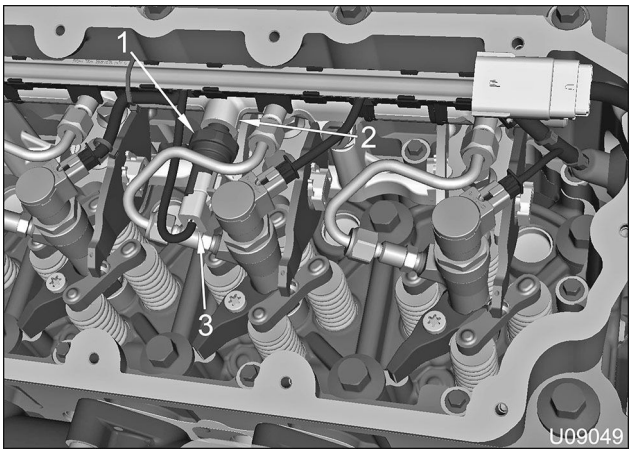


Figure 102 Fuel Rail Pressure (FRP) Sensor

1. Fuel Rail Pressure (FRP) sensor
2. Fuel rail
3. UVC Connector to FRP sensor (right harness only)

NOTE: See procedures in the "Cylinder Heads, Valve Covers, and Valve Train" section to remove the right valve cover (page 315).

1. Disconnect UVC Connector from FRP sensor, using Injector Connector Release Tool (page 111).
2. Remove FRP sensor from right fuel rail.
3. Remove and discard FRP sensor gasket from FRP sensor.

Under Valve Cover (UVC) Harnesses

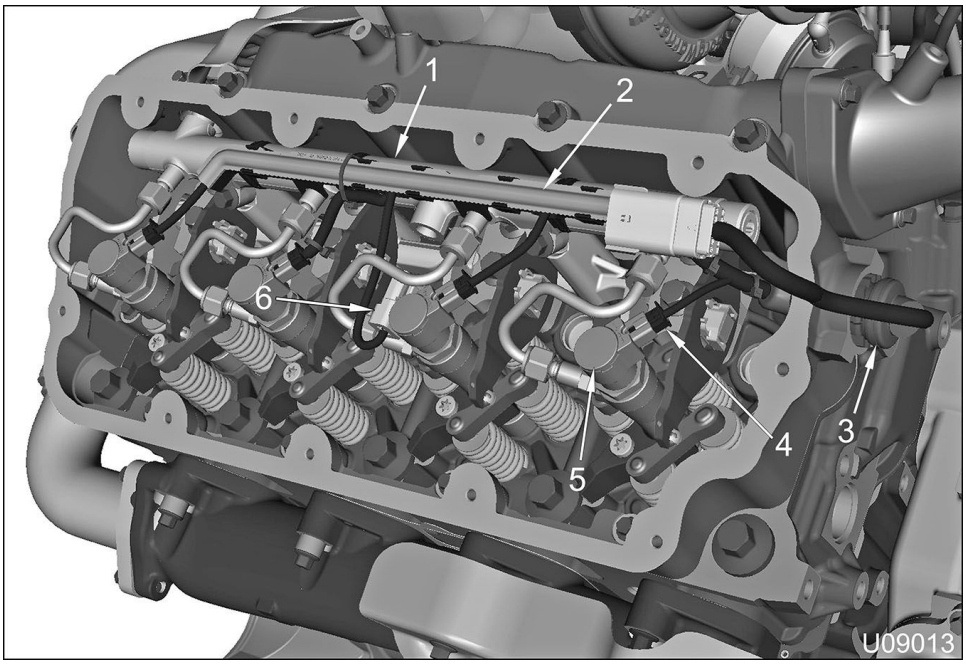


Figure 103 UVC Harness (typical)

1. Fuel rail
2. Right UVC harness
3. Pass-through overmold plug
4. Fuel injector assembly connectors (4)
5. Fuel injector (4)
6. UVC connector to FRP sensor (right harness only)

NOTE: See procedures in the "Cylinder Heads, Valve Covers, and Valve Train" section to remove valve covers (page 315).

1. If not previously disconnected, disconnect UVC Connector from FRP sensor (right harness only), using Injector Connector Release Tool (page 111).
2. Disconnect electrical connectors from fuel injector assemblies using Injector Connector Release Tool (page 111).

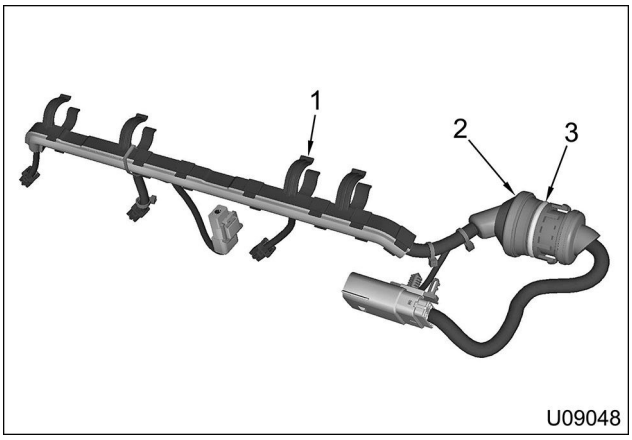


Figure 104 Right Under Valve Cover (UVC) Harness

1. Semi-circular clip (4)
2. Pass-through overmold plug
3. O-ring seal

3. Disengage the UVC harness, secured by four semi-circular clips, from fuel rail.
4. Depress two latches in the pass-through overmold plug, and pull the UVC harness to the inside of valve cover and intake manifold base to release and remove the UVC harness.
5. Remove and discard O-ring seal from pass-through overmold plug.

Cleaning and Inspection

Main Engine Wiring Harness

1. Carefully inspect wiring harness for worn conduit, frayed insulation or heat damage to wires. Repair or install new engine harness, if necessary.
2. Check engine wiring harness connectors, connector covers, seals, and cover shields for cracks, cuts or worn areas. Install new connectors, connector covers, seals, and cover shields, if necessary.
3. Inspect sensor and valve connectors for cracked connector bodies, bent or loose pins, chafing, and damaged or missing O-rings. Install new connectors, if necessary.
4. 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.

Harness Retainers and Stud Clips

If harness fir zip retainers or stud clips were damaged or missing during removal of the engine harness, install new fir zip retainers or stud clips.

Sensors and Valves

1. Check all connector pins on sensors or valves. If connector pins are bent or corroded, install a new sensor or valve.
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.

Engine Control Module

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

Installation

Under Valve Cover (UVC) Harnesses

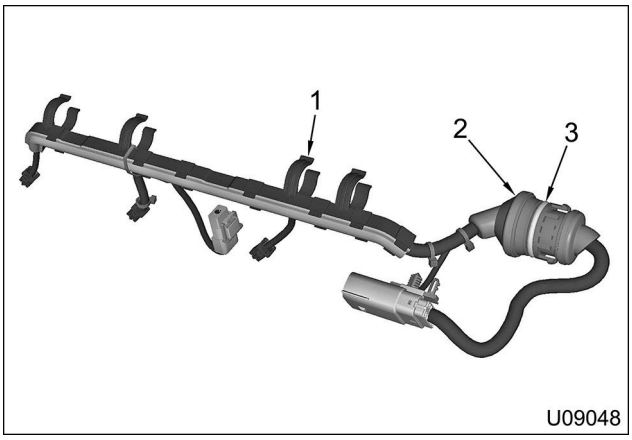


Figure 105 Right Under Valve Cover (UVC) Harness

1. Semi-circular clip (4)
2. Pass-through overmold plug
3. O-ring seal

1. Coat a new O-ring seal with P-80® Rubber Lubricant or equivalent (page 111), and install O-ring onto pass-through overmold plug.

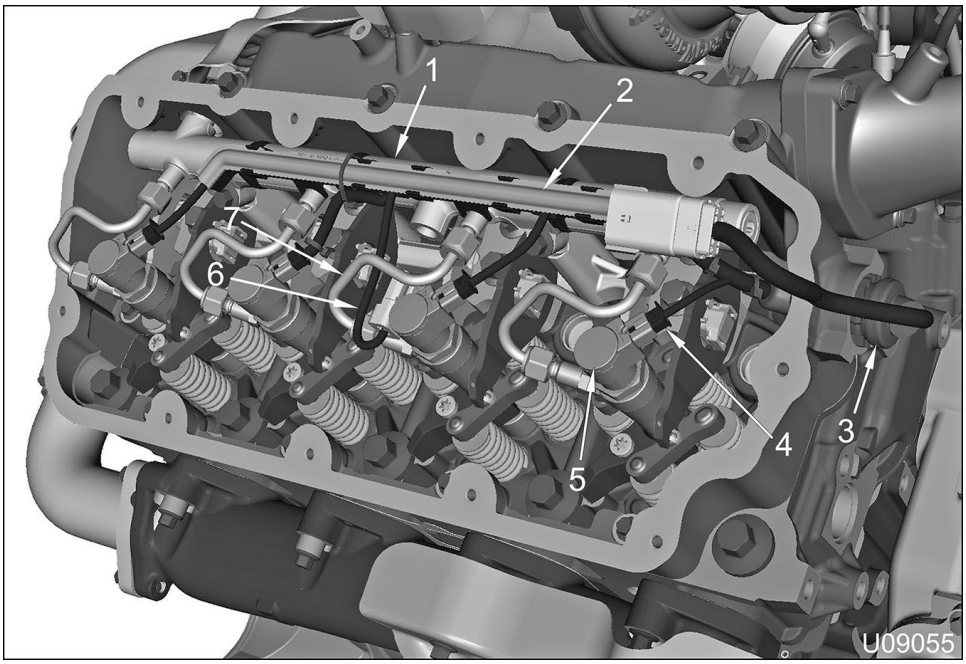


Figure 106 UVC Harness (typical)

1. Fuel rail
2. Right UVC harness
3. Pass-through overmold plug
4. Fuel injector assembly connectors (4)
5. Fuel injector (4)
6. UVC breakout from UVC harness (right harness only)
7. No. 3 injector tube assembly

Lubricate the opening in valve cover and intake manifold base, for the Pass-through overmold plug, with P-80® Rubber Lubricant or equivalent (page 111).

2. Install the UVC harness assembly (inside to out) through the opening valve cover and intake manifold base and push the pass-through overmold plug into the opening.
3. Engage four semi-circular clips and clip the UVC harness to the fuel rail.
4. Connect electrical connectors to fuel injector assemblies.
5. For right side only, connect UVC breakout to FRP sensor.

NOTE: See procedures in the "Cylinder Heads, Valve Covers, and Valve Train" section to install right valve cover (page 357).

Fuel Rail Pressure (FRP) Sensor

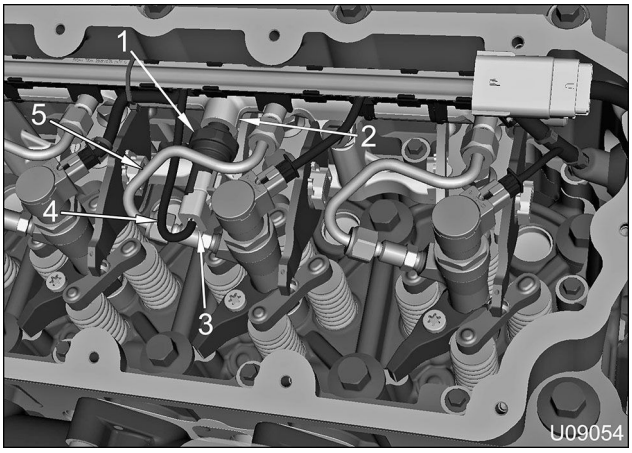


Figure 107 Fuel Rail Pressure (FRP) Sensor

1. Fuel Rail Pressure (FRP) sensor
2. Fuel rail
3. UVC Connector to FRP sensor (right harness only)
4. UVC breakout from UVC harness
5. No. 3 injector tube assembly

1. Lubricate a new FRP sensor gasket with clean diesel fuel and install gasket onto FRP sensor.
2. Install FRP sensor into right fuel rail and tighten to special torque (page 111).
3. Connect UVC connector to FRP sensor.

NOTE: See procedures in the "Cylinder Heads, Valve Covers, and Valve Train" section to install valve covers (page 357).

Intake Air Heater (IAH) Relay and Relay Support

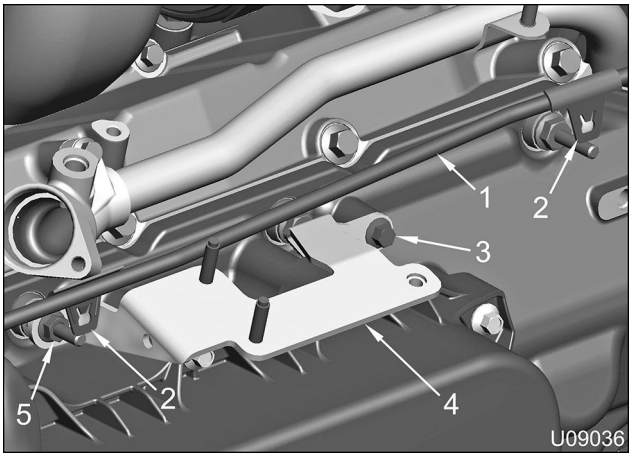


Figure 108 Relay Support

1. Jet pump tube assembly
2. Clips (2)
3. M6 x 14 bolt
4. Relay support
5. M6 nut

1. Position relay support onto right valve cover.
2. Install M6 x 14 bolt and M6 nut.
3. Tighten M6 x 14 bolt and M6 nut to standard torque (page 473).
4. Position jet pump tube assembly and push two clips onto stud bolts.

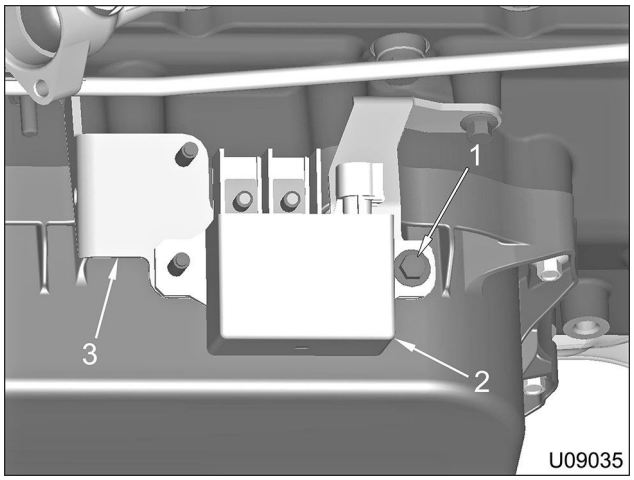


Figure 109 IAH Relay

1. M6 x 14 bolt
2. IAH relay
3. Relay support

5. Position IAH relay onto relay support.
6. Install M6 x 14 bolt to secure IAH relay to relay support.
7. Tighten M6 x 14 bolt to standard torque (page 473).

Harness Channel Shield Assemblies

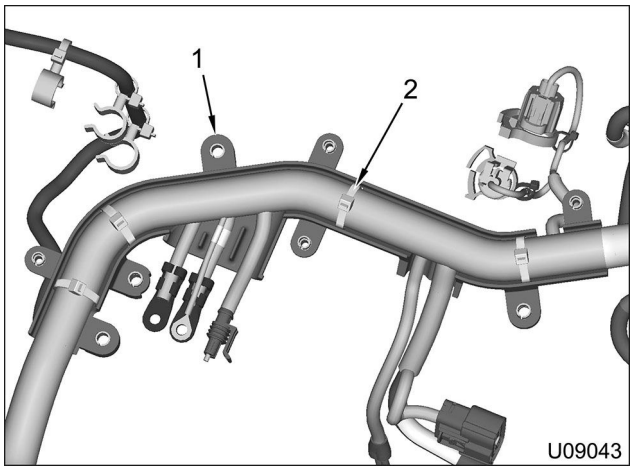


Figure 110 Installation of Lower Harness Channel Shield

1. Lower harness channel shield
2. Tie strap (4)

1. Install four new tie straps to secure engine harness to lower harness channel shield.

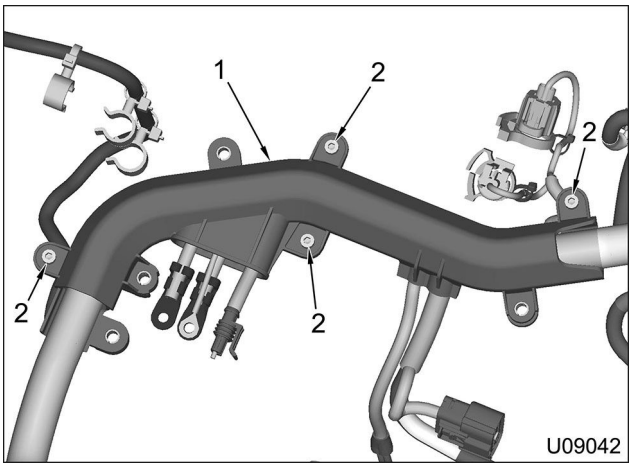


Figure 111 Installation of Upper Harness Channel Shield

1. Upper harness channel shield
2. M5 x 10 socket head bolt (4)

2. Position upper harness channel shield onto lower harness channel shield.
3. Install four M5 x 10 socket head bolts to secure upper harness channel shield to lower harness channel shield.
4. Tighten M5 x 10 socket head bolts to special torque (page 111).

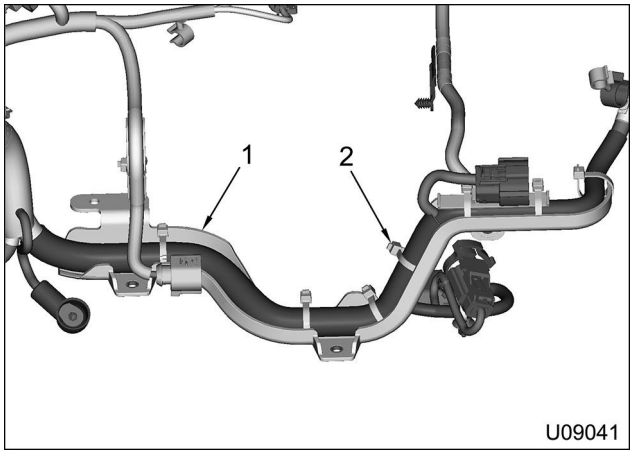


Figure 112 Installation of Harness Channel Shield

1. Harness channel shield
2. Tie strap (5)

5. Install five new tie straps to secure engine harness to harness channel shield.

Engine 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.

1. Position engine harness on engine.

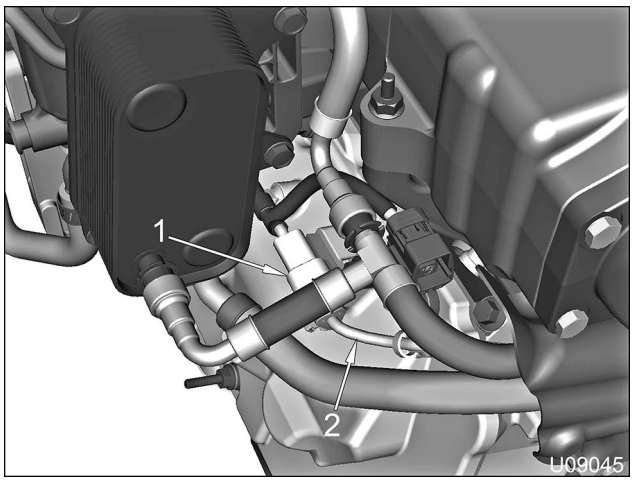


Figure 113 Connection of Engine Harness to High-Pressure Pump Harness

1. 3-pin engine harness connector
2. High-pressure pump harness

2. Connect 3-pin engine harness connector to high-pressure pump harness.

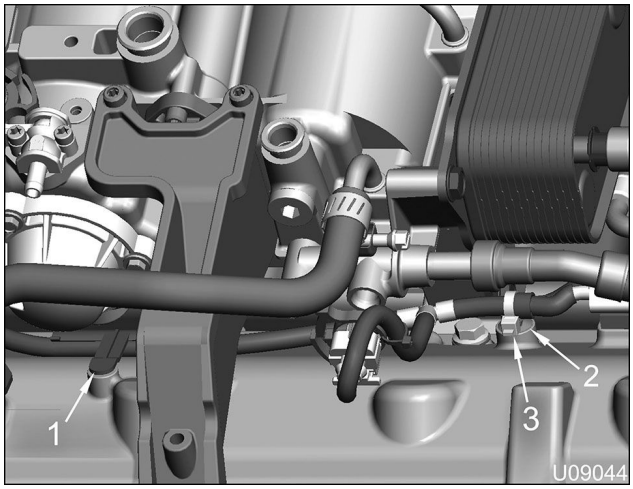


Figure 114 Engine Harness and Tie Strap to Left Valve Cover

1. Engine harness
2. Harness fir zip retainer
3. Tie strap

3. Engage engine harness to left valve cover.
4. Install a new tie strap to secure engine harness to fir zip retainer in left valve cover.

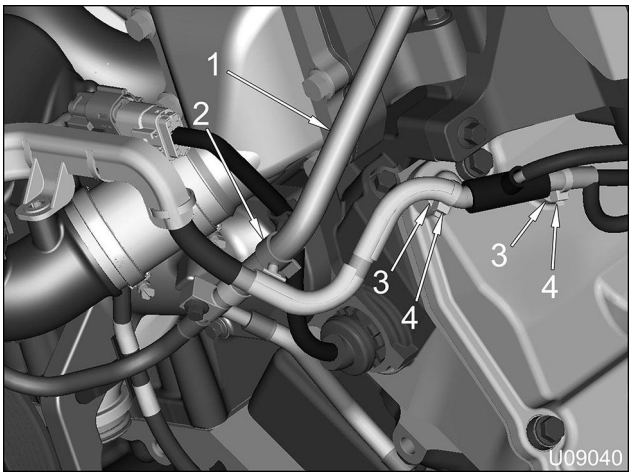


Figure 115 Engine Harness to Injector Hose Assembly and Tie Straps to Left Valve Cover

1. Injector hose assembly
2. Engine harness clip
3. Harness fir zip retainer (2)
4. Tie strap (2)

5. Connect engine harness clip to injector hose assembly.
6. Install two tie straps to secure engine harness to fir zip retainer in left valve cover.

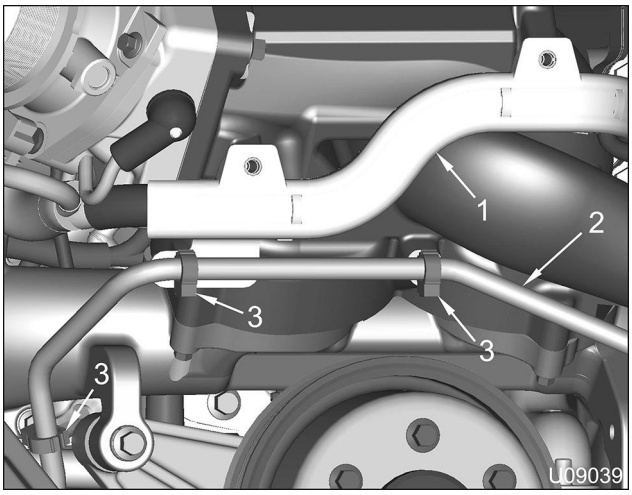


Figure 116 Harness Channel Shield

1. Harness channel shield
2. Injector hose assembly
3. .25 hose clip (3)

7. Engage hose clip to harness channel shield, manifold mixer, and bracket on heater supply tube.

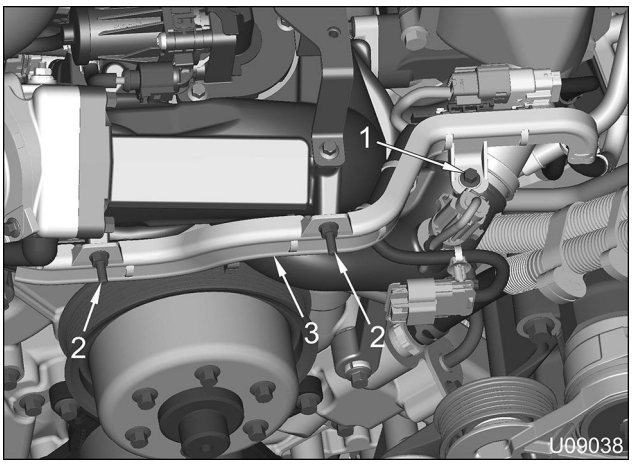


Figure 117 Harness Channel Shield Assembly (front)

1. M6 x 16 bolt
2. M6 x 16 stud bolt (2)
3. Harness channel shield

8. Install one M6 x 16 bolt and two M6 x 16 stud bolts to secure the harness channel shield to the manifold mixer.

9. Tighten M6 x 16 bolt and two M6 x 16 stud bolts to standard torque (page 473).

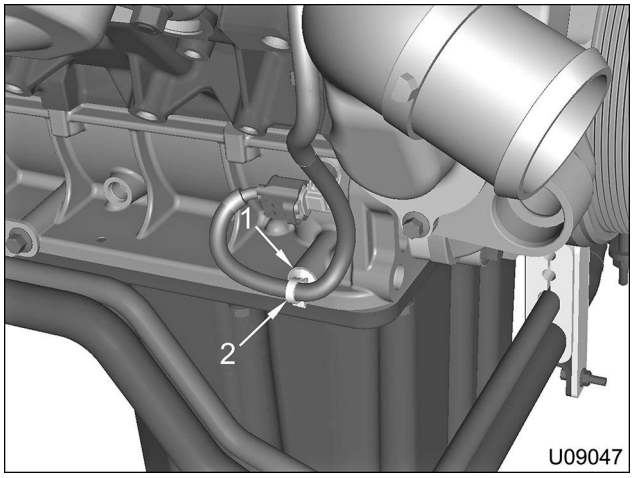


Figure 118 Engine Harness Connection to Lower Crankcase

1. Harness fir zip retainer
2. Tie strap

10. Install new tie strap to secure engine harness to fir zip retainer in lower crankcase.

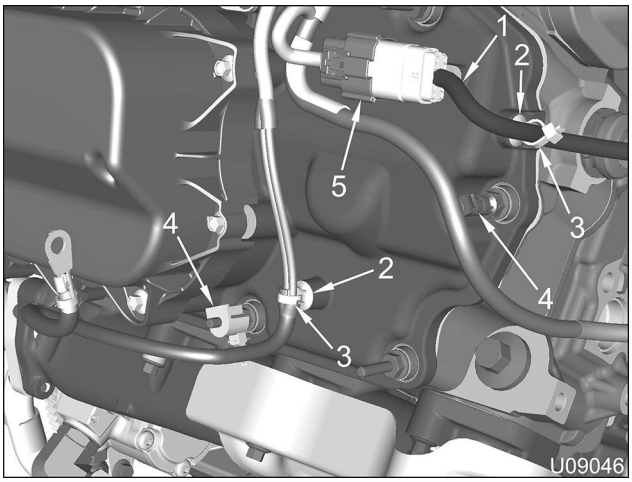


Figure 119 Harness Connection to Right Valve Cover

1. Right Under Valve Cover (UVC) harness
2. Harness fir zip retainer (2)
3. Tie strap (2)
4. Stud clip (2)
5. 12-way engine harness injector connector

11. Engage plastic stud clips.
12. Install new tie straps to secure engine harness to fir zip retainers in right valve cover.
13. Connect 12-way engine harness injector connector to right Under Valve Cover (UVC) harness and push in red CPA lock.

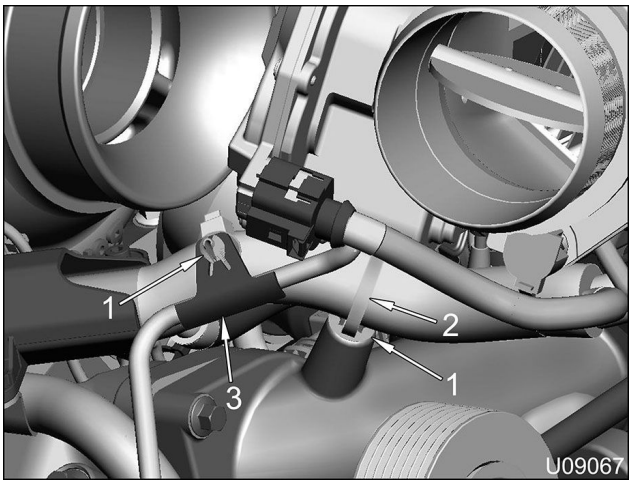


Figure 120 Jet Pump Tube Assembly and Tie Strap to Distribution Duct

1. Fir zip retainer (2)
2. Tie strap
3. Jet pump tube assembly

14. Install a new tie strap to secure engine harness to fir zip retainer in distribution duct.
15. Push jet pump tube assembly onto fir zip retainer secured to engine harness.

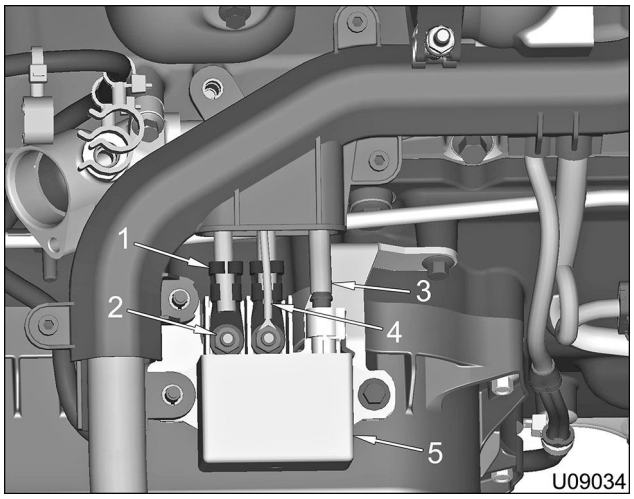


Figure 121 Engine Harness to IAH Relay

1. Ring terminal (power)
2. M6 nut (2)
3. Plug connector
4. Ring terminal (IAH) (2)
5. IAH relay

16. Install ring terminals and plug connector to IAH relay.
17. Install two M6 nuts and tighten to standard torque (page 473).

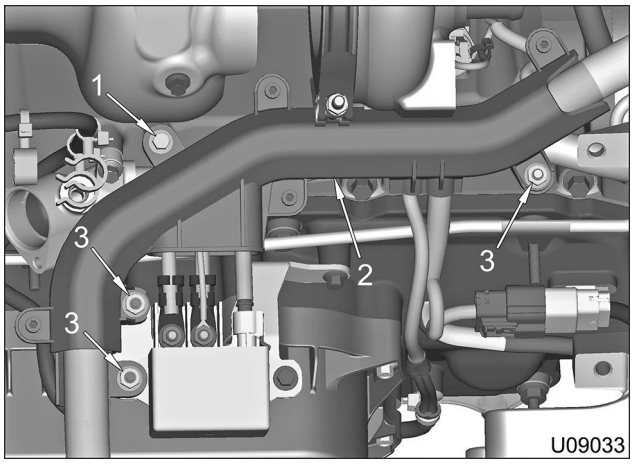


Figure 122 Install Harness Channel Shield Assembly (upper and lower)

1. M6 x 14 bolt
2. Harness channel shield assembly (upper and lower)
3. M6 nut (3)

18. Install three M6 nuts.
19. Install M6 x 14 bolt.
20. Tighten three M6 nuts and M6 x 14 bolt to standard torque (page 473).

Exhaust Gas Temperature (EGT) Sensor

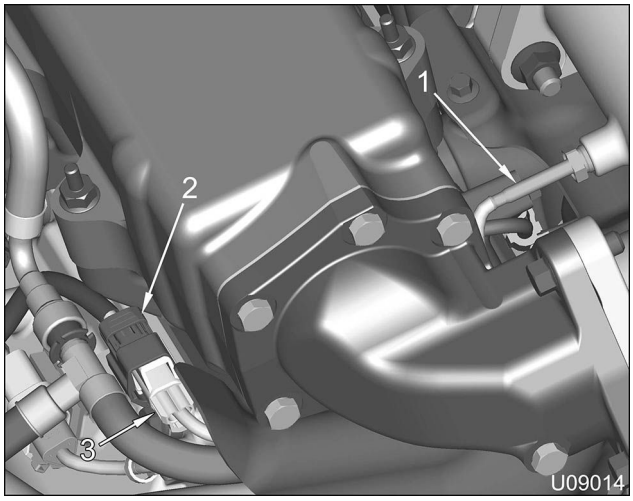


Figure 123 Exhaust Gas Temperature (EGT) Sensor

1. EGT sensor
2. 2-pin engine harness connector
3. Connector on EGT sensor

1. Install EGT sensor into turbo exhaust inlet manifold and tighten to special torque (page 111).
2. Connect 2-pin engine harness connector to EGT sensor and push in red CPA lock.

Fuel Heater (optional) and Fuel Delivery Pressure (FDP) Sensor (optional)

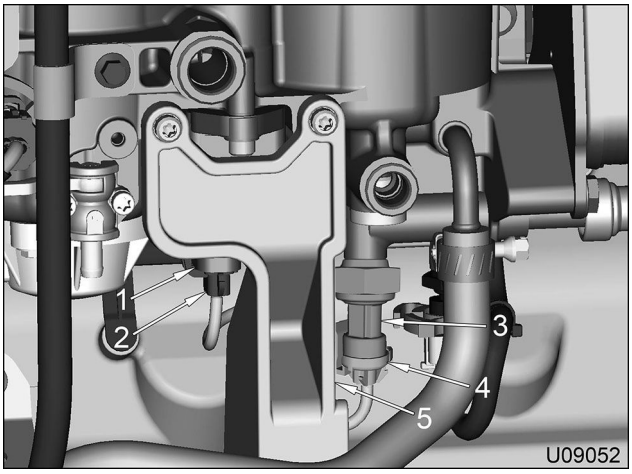


Figure 124 Fuel heater (optional) and Fuel Delivery Pressure (FDP) Sensor (optional)

1. Fuel heater
2. 2-pin engine harness connector
3. FDP sensor
4. 2-pin engine harness connector
5. Filter cooler pump module support

1. Lubricate a new O-ring with clean diesel fuel and install O-ring onto FDP sensor.
2. Install FDP sensor and tighten to special torque (page 111).
3. Connect 2-pin engine harness connector to FDP sensor.
4. See Fuel Heater (page 241) for installation.
5. Connect 2-pin engine harness connector to fuel heater.

Fuel Pump

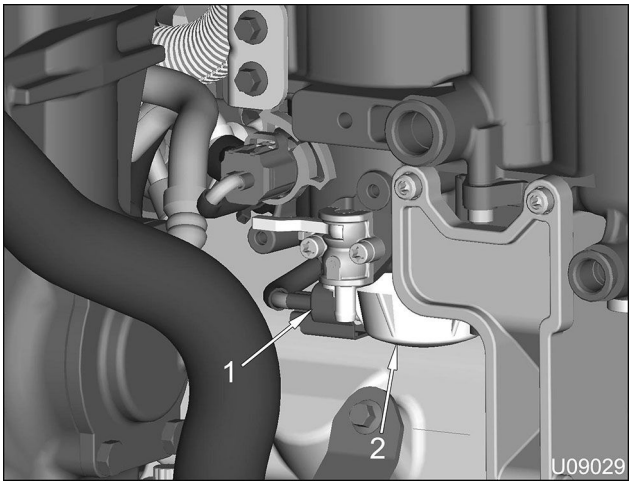


Figure 125 Fuel Pump

1. 2-pin engine harness connector
2. Fuel pump

1. See Fuel Pump (page 242) for installation.
2. Connect 2-pin engine harness connector to fuel pump.

Water In Fuel (WIF) Sensor

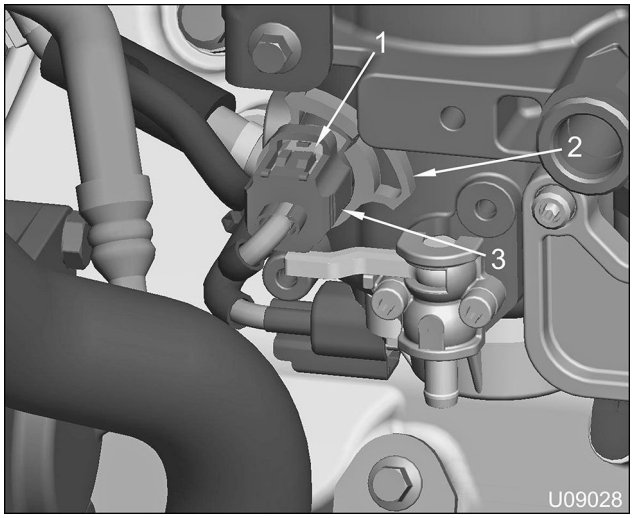


Figure 126 Water In Fuel (WIF) Sensor

1. WIF sensor
2. Clamp
3. 2-pin engine harness connector

1. Lubricate a new O-ring seal with clean diesel fuel and install O-ring onto WIF sensor.
2. Install WIF sensor and tighten to special torque (page 111).
3. Connect 2-pin engine harness connector to WIF sensor.
4. Close clamp on engine harness.

Engine Fuel Temperature (EFT) Sensor

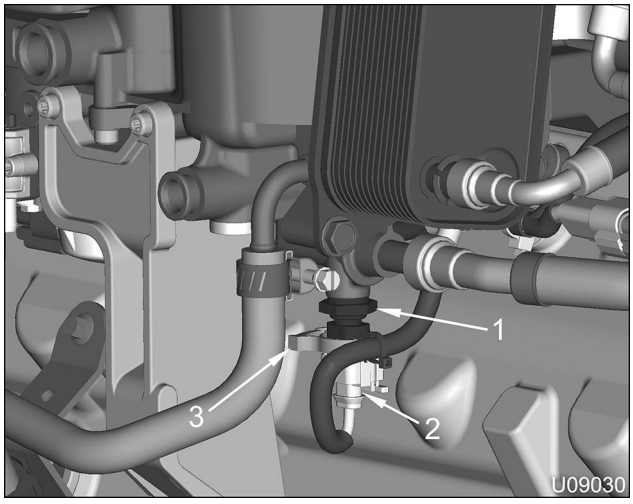


Figure 127 EFT Sensor

1. EFT sensor
2. 2-pin engine harness connector
3. Clamp

1. Lubricate a new O-ring with clean diesel fuel and install O-ring onto EFT sensor.
2. Install EFT sensor and tighten to special torque (page 111).
3. Connect 2-pin engine harness connector to EFT sensor and push in yellow CPA lock.
4. Close clamp on engine harness.

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

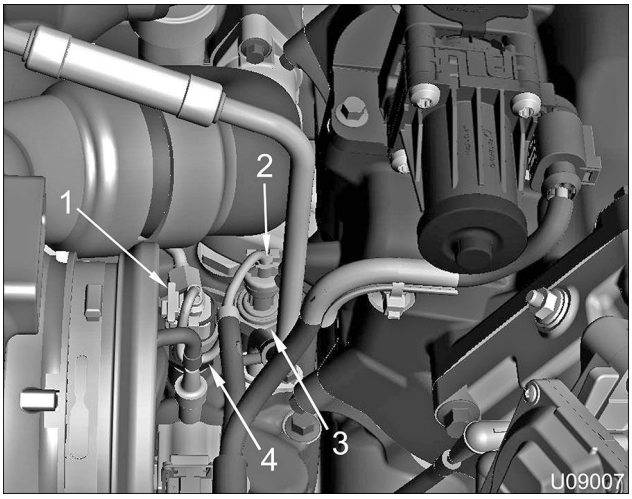


Figure 128 EOT Sensor and EOP Sensor

1. 2-pin engine harness connector
2. 3-pin engine harness connector
3. EOP sensor
4. EOT sensor

1. Lubricate a new sensor O-ring with clean engine oil and install O-ring onto EOP sensor.
2. Lubricate a new sensor O-ring with clean engine oil and install O-ring onto EOT sensor.
3. Install EOT sensor and EOP sensor on oil cooler assembly. Tighten sensors to special torque (page 111).
4. Connect 3-pin engine harness connector to EOP sensor.
5. Connect 2-pin engine harness connector to EOT sensor and push in yellow CPA lock.
6. See EGR Manifold Mixer (page 131) for installation of manifold mixer.

Turbocharger 1 Wastegate Control (TC1WC) Solenoid

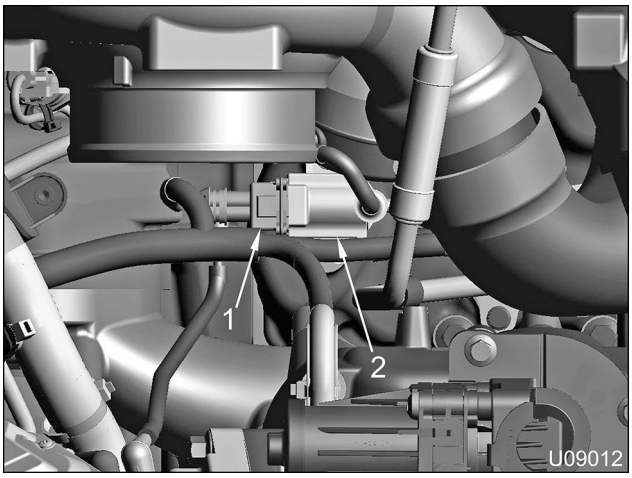


Figure 129 TC1WC Solenoid

1. 2-pin engine harness connector
2. TC1WC solenoid

NOTE: See TC1WC solenoid, Wastegate Tube Assembly, Relief Tube Assembly, and Air Duct Assembly (page 174) for installation of TC1WC solenoid.

1. Install TC1WC solenoid.
2. Connect 2-pin engine harness connector to TC1WC solenoid.
3. Install air duct assembly.

Turbocharger 1 Compressor Outlet Temperature (TC1COT) Sensor

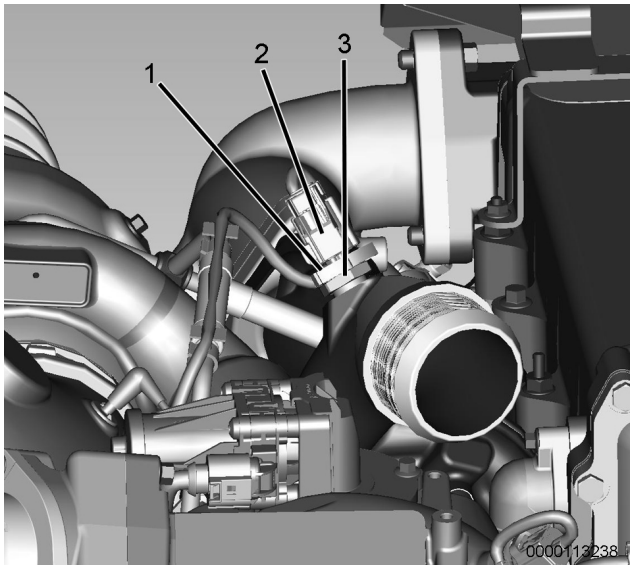
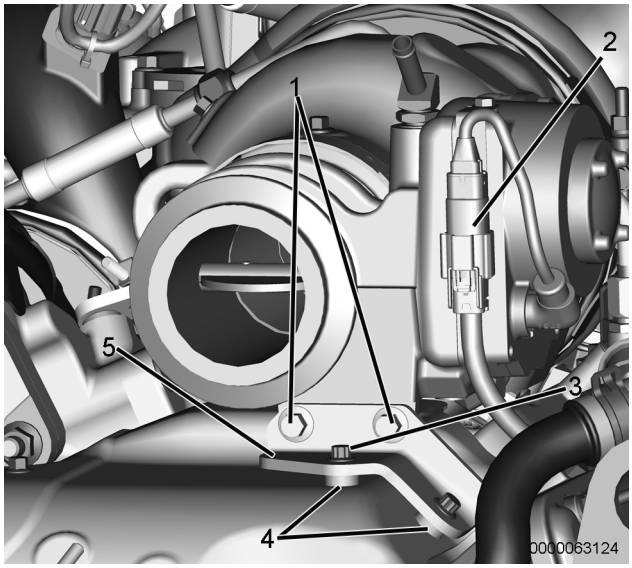


Figure 130 TC1COT Sensor

1. Clamp
2. 2-pin engine harness connector
3. TC1COT sensor

1. Install TC1COT sensor into turbocharger 1 outlet pipe, located on top of the engine.
2. Push 2-pin engine harness connector onto TC1COT sensor until you hear a click, then push in red CPA lock tab.
3. Re-install clamp onto engine harness.

Thermal Management Valve (TMV)



GRAPHIC-12361-4ADAE2D0

Figure 131 TMV

1. M8 x 16 bolt (2)
2. TMV engine harness connector
3. M6 x 25 bolt (2)
4. TMV support spacer
5. TMV support

1. Move TMV into place for installation.
2. Using two M6 x 25 bolts and TMV support spacers, install TMV support. Tighten bolts to special torque.
3. Install two M8 x 16 bolts into TMV. Tighten bolts to special torque.
4. Connect TMV engine harness connector to TMV.

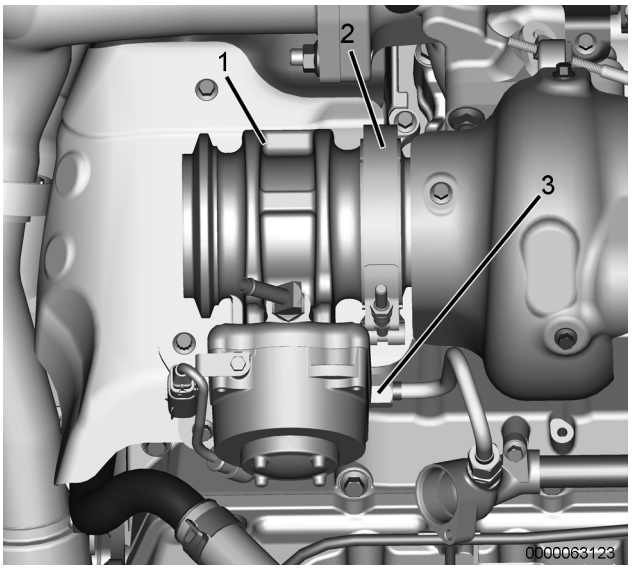


Figure 132 V-band Clamp and Coolant Line

1. TMV
2. V-band clamp
3. Coolant tube

5. Install coolant tube onto TMV. Tighten tube to special torque.
6. Install V-band clamp between TMV and turbocharger assembly. Tighten t-bolt on V-band clamp to special torque.

Intake Manifold Temperature (IMT) Sensor and Intake Manifold Pressure (IMP) Sensor

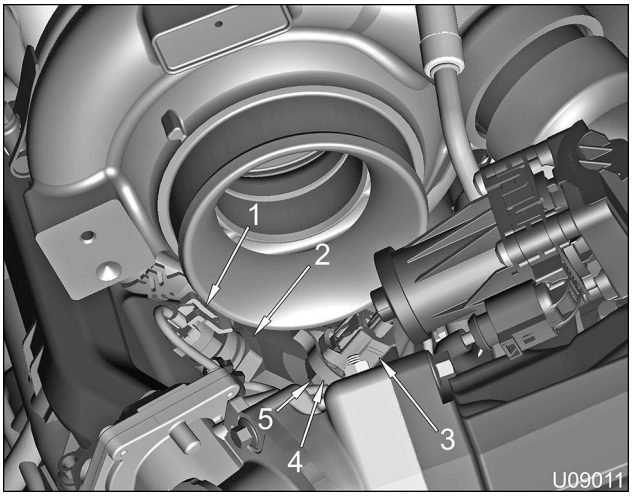


Figure 133 IMT and IMP Sensors

1. 2-pin engine harness connector
2. IMP sensor
3. 3-pin engine harness connector
4. Clamp
5. IMT sensor

1. Lubricate a new sensor O-ring with P-80® Rubber Lubricant or equivalent (page 111) and install O-ring onto IMT sensor.
2. Lubricate a new O-ring with P-80® Rubber Lubricant or equivalent (page 111) and install O-ring onto IMP sensor.
3. Install IMT and IMP sensors. Tighten sensors to special torque (page 111).
4. Connect 2-pin engine harness connector to IMT sensor.
5. Connect 3-pin engine harness connector to IMP sensor.
6. Close clamp on engine harness.

NOTE: See Air Duct Assembly, Relief Tube Assembly, Wastegate Tube Assembly, and TC1WC solenoid (page 174) for installation of air duct assembly.

7. Install air duct assembly.

Exhaust Gas Recirculation Temperature (EGRT) Sensor

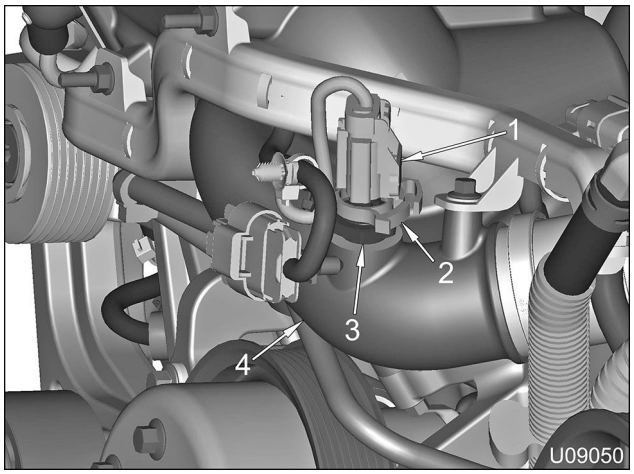


Figure 134 EGRT Sensor

1. 2-pin engine harness connector
2. Clamp
3. EGRT sensor
4. Manifold mixer

1. Lubricate a new O-ring with P-80® Rubber Lubricant or equivalent (page 111) and install O-ring onto EGRT sensor.
2. Install EGRT sensor into manifold mixer and tighten to special torque (page 111).
3. Connect 2-pin engine harness connector to EGRT sensor and push in red CPA lock.
4. Close clamp on engine harness.

Exhaust Gas Recirculation (EGR) Valve Assembly

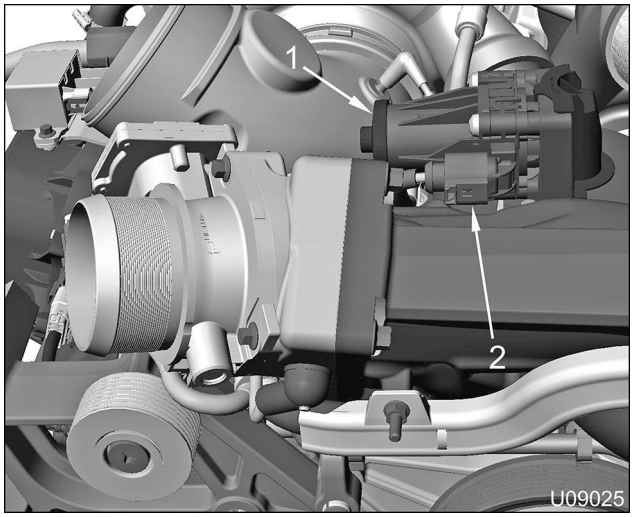


Figure 135 EGR Valve Assembly

1. EGR valve assembly
2. 6-pin engine harness connector

1. See EGR Valve Assembly (page 139) for installation.
2. Connect 6-pin engine harness connector to EGR valve assembly.

Intake Air heater (IAH)

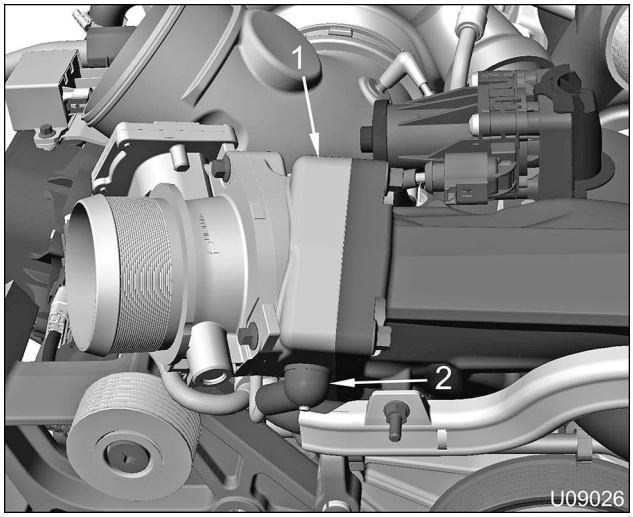


Figure 136 Intake Air Heater (IAH)

1. IAH
2. Boot

1. See Intake Air Heater (page 134) for installation.
2. Install ring terminal of engine harness and nut onto stud bolt in the IAH. Tighten nut to standard torque (page 473).
3. Push boot onto engine harness connection.

Engine Throttle Valve (ETV)

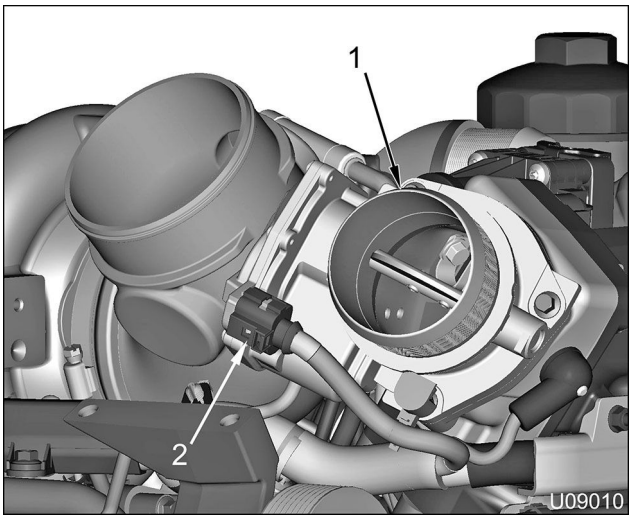


Figure 137 Engine Throttle Valve (ETV)

1. ETV
2. 6-pin engine harness connector

1. See Engine Throttle Valve (ETV) (page 135) for installation.
2. Connect 6-pin engine harness connector harness to ETV.

Engine Coolant Temperature (ECT1) Sensor

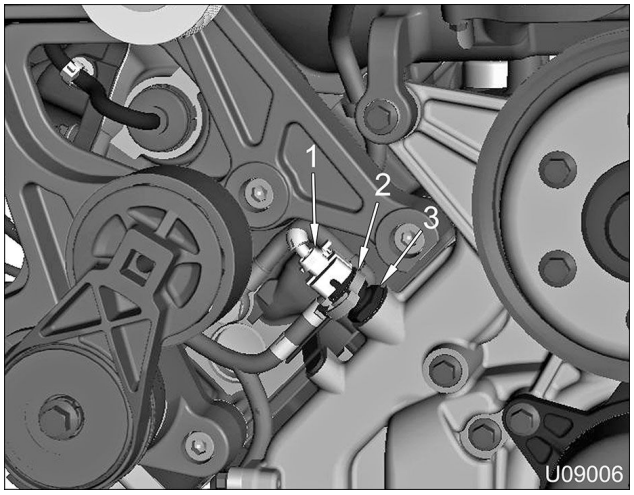


Figure 138 ECT1 Sensor

1. 2-pin engine harness connector
2. Clamp
3. ECT1 sensor

1. Lubricate a new sensor O-ring with P-80® Rubber Lubricant or equivalent (page 111) and install O-ring onto ECT1 sensor.
2. Install ECT1 sensor into left side of front cover. Tighten sensor to special torque (page 111).
3. Connect 2-pin engine harness connector to ECT1 sensor and push in yellow CPA lock.
4. Close clamp on engine harness.

NOTE: If alternator bracket was removed, install alternator bracket. See Alternator and Refrigerant Compressor Mounting Bracket (page 282).

Camshaft Position (CMP) Sensor

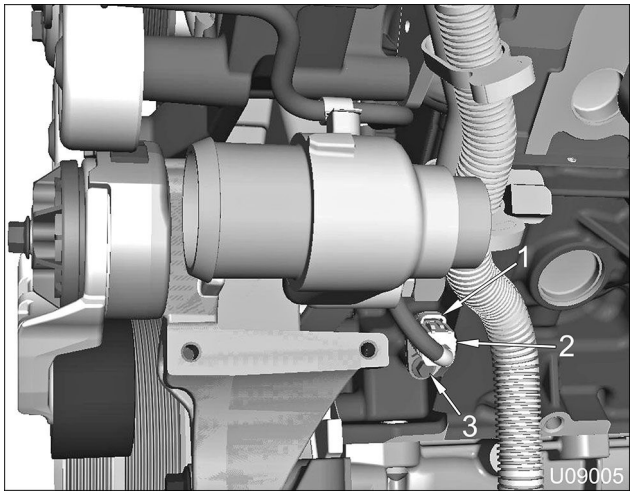


Figure 139 CMP Sensor

1. CMP sensor
2. 2-pin engine harness connector
3. M6 x 14 bolt

1. Lubricate two new sensor O-rings with clean engine oil and install O-rings onto CMP sensor.
2. Install CMP sensor into front left side of crankcase.
3. Install M6 x 14 bolt to CMP sensor. Tighten bolt to special torque (page 111).
4. Connect 2-pin engine harness connector to CMP.

Crankshaft Position (CKP) Sensor

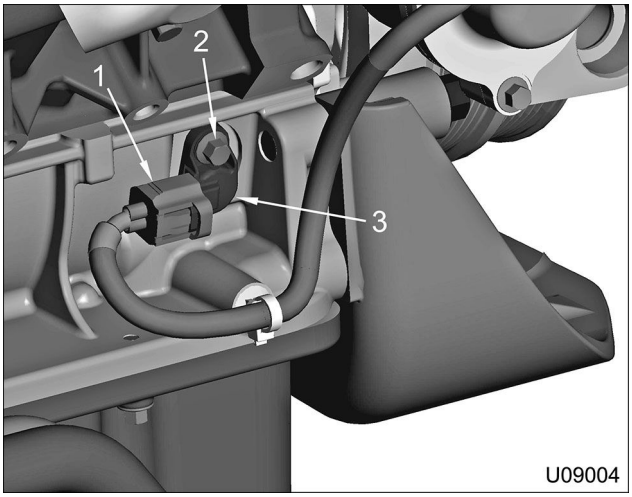


Figure 140 CKP Sensor

1. 2-pin engine harness connector
2. M6 x 14 bolt
3. CKP sensor

1. Lubricate a new sensor O-ring with clean engine oil and install O-ring onto CKP sensor.
2. Install CKP sensor into front right side of lower crankcase.
3. Install M6 x 14 bolt to secure CKP sensor. Tighten bolt to special torque (page 111).
4. Connect 2-pin engine harness connector to CKP.

Charge Air Cooler Outlet Temperature (CACOT) sensor

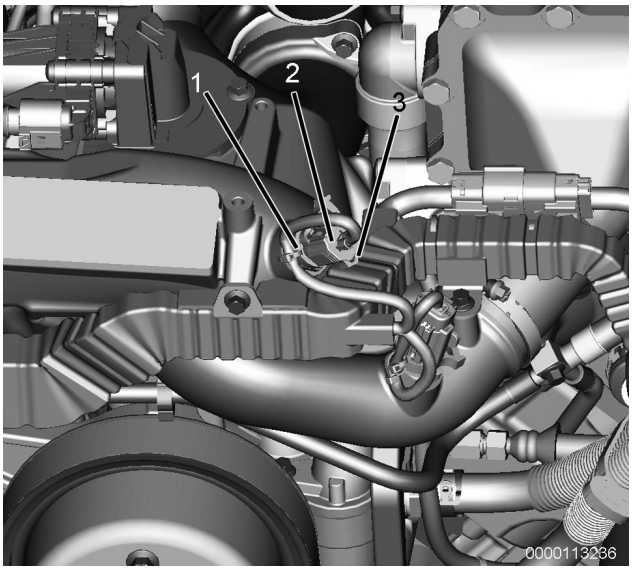


Figure 141 CACOT Sensor

1. CACOT sensor
2. 2-pin engine harness connector
3. Clamp

1. Install CACOT sensor into intake mixer housing, located on front of the engine.
2. Push 2-pin engine harness connector onto CACOT sensor until you hear a click, then push in red CPA lock tab.
3. Re-install clamp onto engine harness.

Mass Air Flow / Air Inlet Temperature (MAF / AIT) Sensor

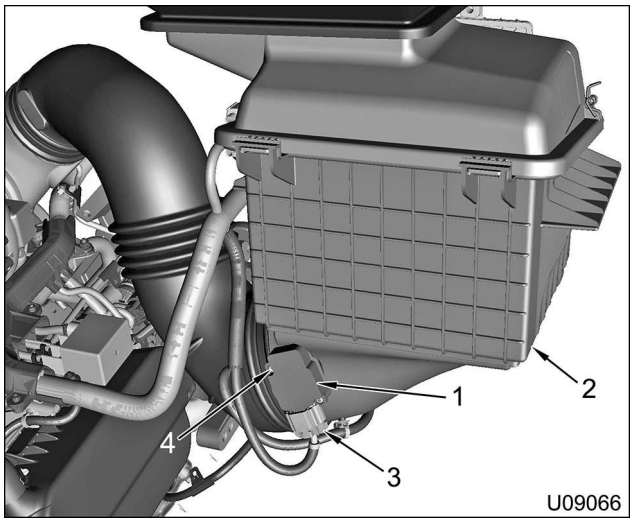


Figure 142 MAF / AIT Sensor

1. MAF / AIT sensor
2. Vehicle air cleaner assembly
3. 5-pin engine harness connector
4. Torx screw (2)

1. Lubricate a new O-ring with P-80® Rubber Lubricant or equivalent (page 111) and install O-ring onto MAF / AIT sensor.
2. Install the MAF/AIT sensor to the vehicle air cleaner assembly.
3. Install two Torx screws to secure the MAF / AIT sensor and tighten Torx screws to special torque (page 111).
4. Connect 5-pin engine harness connector to the MAF / AIT sensor.

NOTE: Anytime the MAF / AIT sensor is disconnected, the MAF Sensor Test must be run to auto-calibrate the sensor. See "Performance Diagnostics" section in the 0000001681 MaxxForce® 7 *Engine Diagnostic Manual*.

Special Torque

Crankshaft Position (CKP) sensor bolt	10 N·m (89 lb·in)
Camshaft Position (CMP) sensor bolt	10 N·m (89 lb·in)
Engine Coolant Temperature (ECT1) sensor	18 N·m (159 lb·in)
Engine Fuel Temperature (EFT) sensor	18 N·m (159 lb·in)
Exhaust Gas Recirculation Temperature (EGRT) Sensor	38 N·m (30 lb·ft)
Exhaust Gas Temperature (EGT) Sensor	44 N·m (32 lb·ft)
Engine Oil Pressure (EOP) sensor	12 N·m (106 lb·in)
Engine Oil Temperature (EOT) sensor	18 N·m (159 lb·in)
Fuel Delivery Pressure (FDP) Sensor	12 N·m (106 lb·in)
Fuel Rail Pressure (FRP) sensor	7 N·m (62 lb·in), then turn one hex flat
Intake Manifold Temperature (IMT) sensor	18 N·m (159 lb·in)
Intake Manifold Pressure (IMP) sensor	12 N·m (106 lb·in)
MAF / AIT Torx screw	1 N·m (10 lb·in)
Upper harness channel shield bolt, M5 x 10	4 N·m (35 lb·in)
Water In Fuel (WIF) sensor	20 N·m (15 lb·ft)

Special Service Tools

Description	Tool Number
Injector Connector Release Tool	ZTSE6074
P-80® Rubber Lubricant or equivalent	Obtain locally

Table of Contents

Exploded Views.....115

Removal.....117
- **EGR Valve Assembly**.....117
- **EGR Cooler**.....120
- **EGR Mixer Assembly**.....121
- **Distribution Duct and Manifold Mixer**.....122
- **EGR Coolant Supply and Return Tubes**.....125

Cleaning, Inspection, and Testing.....127
- **EGR System Components**.....127
- **Manifold Mixer**.....127
- **Exhaust Gas Recirculation (EGR) Cooler Pressure Test**.....128
  - **EGR Leak Detection Kit**.....128
  - **Installation and Testing of EGR Cooler**.....128

Installation.....130
- **EGR Coolant Supply and Return Tubes**.....130
- **EGR Manifold Mixer**.....131
- **EGR Cooler**.....137
- **EGR Valve Assembly**.....139

Special Torque.....140

Special Service Tools.....140

Exploded Views

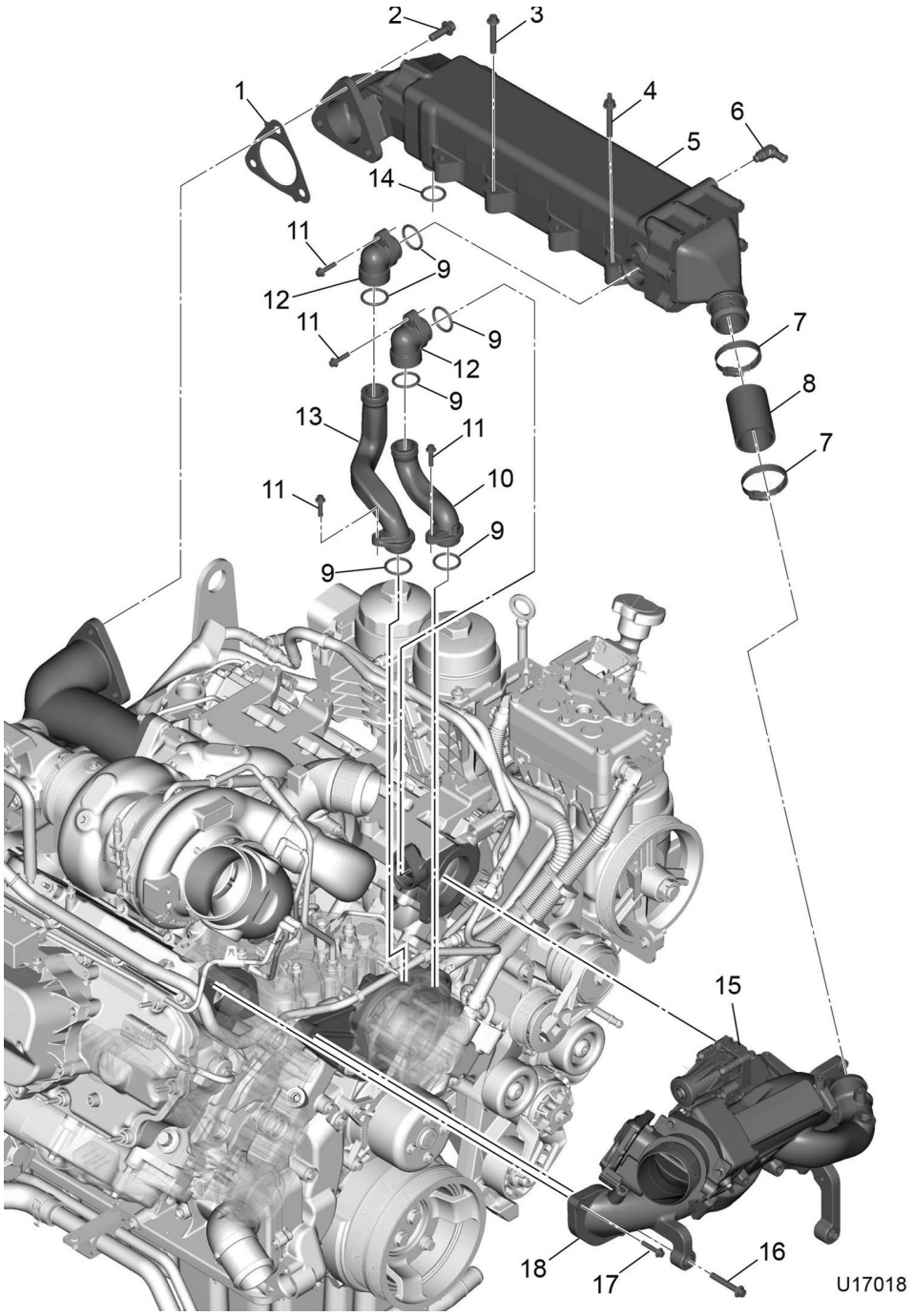


Figure 143 EGR Cooler

1. Turbo inlet gasket
2. M10 x 30 bolt (3)
3. M8 x 50 bolt (4)
4. M8 x 50 stud bolt (4)
5. EGR cooler assembly
6. EGR vent elbow
7. Worm drive clamp (2)
8. Air cooler hose
9. O-ring (6)
10. EGR coolant supply pipe
11. M6 x 25 bolt (4)
12. Elbow connector (2)
13. EGR coolant return tube
14. O-ring seal
15. Manifold mixer assembly
16. M8 x 50 bolt (2)
17. M6 x 30 bolt (4)
18. Distribution duct

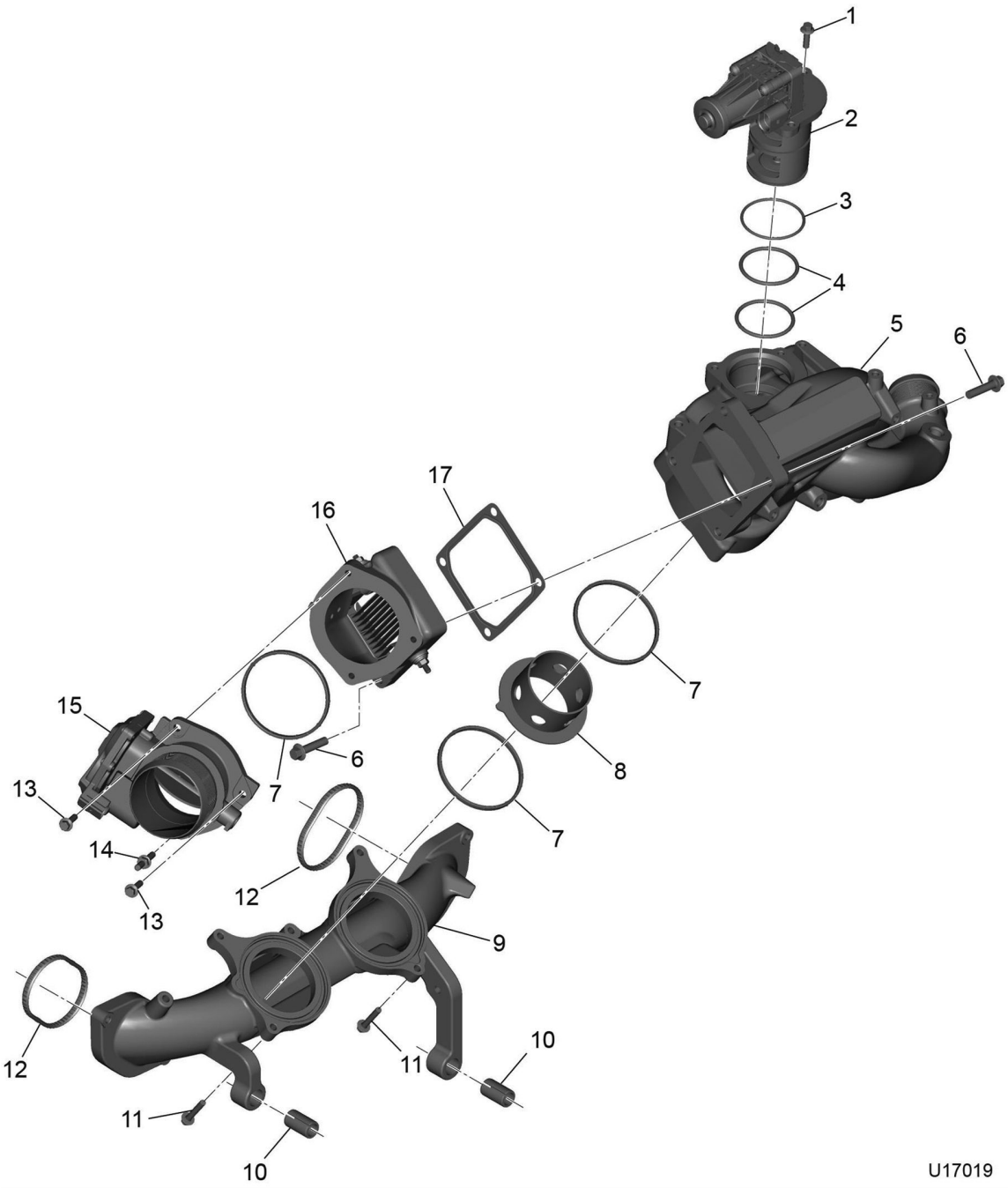


Figure 144 Manifold Mixer and Distribution Duct

1. M6 X 20 bolt (3)
2. EGR valve assembly
3. O-ring, No. 2-140
4. O-ring, No. 2-226 (2)
5. Manifold mixer
6. M8 x 35 bolt (4)
7. Intake throttle gasket (5)
8. EGR mixer bushing (2)
9. Distribution duct
10. Split seam bushing (2)
11. M6 x 35 bolt (5)
12. Distribution duct gasket (2)
13. M6 x 25 bolt (2)
14. M6 x 25 stud bolt
15. Intake throttle valve
16. Intake air heater
17. Inlet duct to intake manifold 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 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 the following sections for removal of components.

- Engine Electrical
- Dual Turbocharger
- Air Compressor and Power Steering Pump
- Fuel System

EGR Valve Assembly

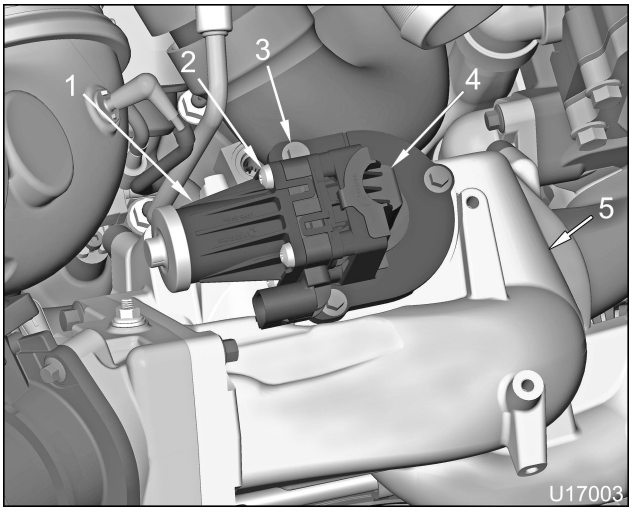


Figure 145 EGR Valve Assembly

1. DC motor
2. T-30 Torx screw (4)
3. M6 x 20 bolt (3)
4. Inspection cover
5. Manifold mixer

1. Remove inspection cover from EGR valve.
2. Remove four T-30 Torx screws from DC motor and remove DC motor from EGR valve.
3. Remove three M6 x 20 bolts that secure EGR valve assembly to manifold mixer.

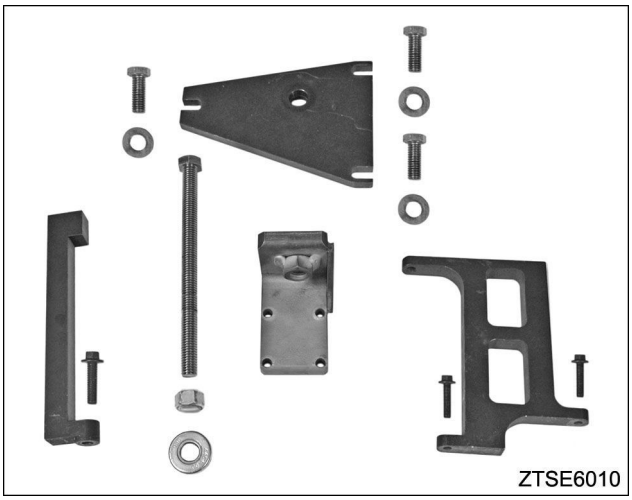


Figure 146 EGR Valve Puller

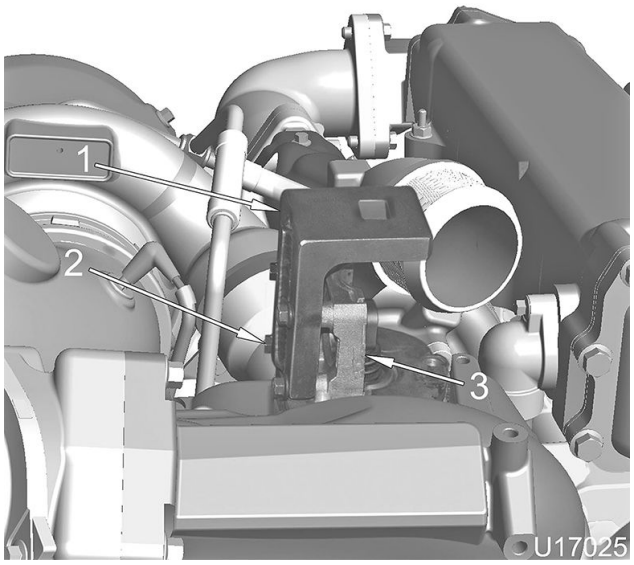


Figure 147 Installation of Lower Section of EGR Valve Puller

1. EGR Valve Puller
2. M6 x 25 bolt (4)
3. EGR valve

4. Position lower section of EGR Valve Puller (page 140) onto EGR valve and install four M6 x 35 bolts. Tighten bolts to standard torque (page 473).
5. Turn lower section of EGR Valve Puller to break seal on EGR valve.

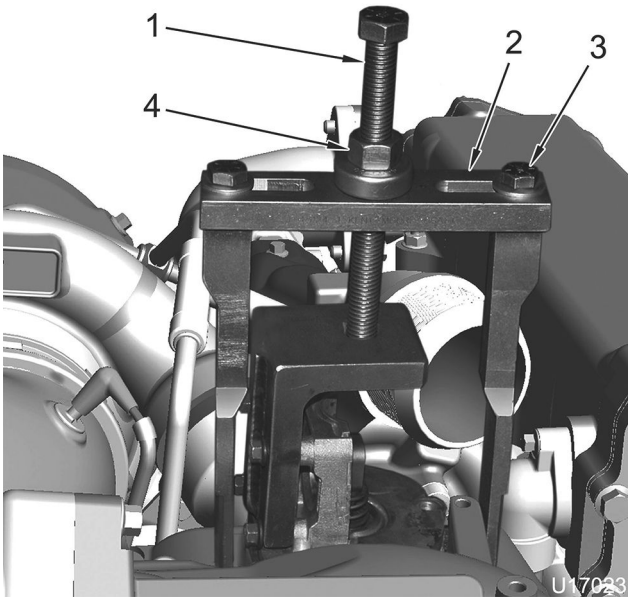


Figure 148 Installation EGR Valve Puller

1. Puller screw
2. Upper section of EGR valve puller
3. Bolt
4. Nut

6. Position upper section of EGR Valve Puller and install puller screw into lower section of EGR Valve Puller.
7. Hold puller screw and turn nut clockwise to remove EGR valve from manifold mixer.
8. Remove EGR Valve Puller.

CAUTION: To prevent damage to the EGR valve, do not over tighten T-30 Torx bolts.

9. Position DC motor onto EGR valve; install and hand tighten four T-30 Torx screws.
10. Install inspection cover onto EGR valve.

EGR Cooler

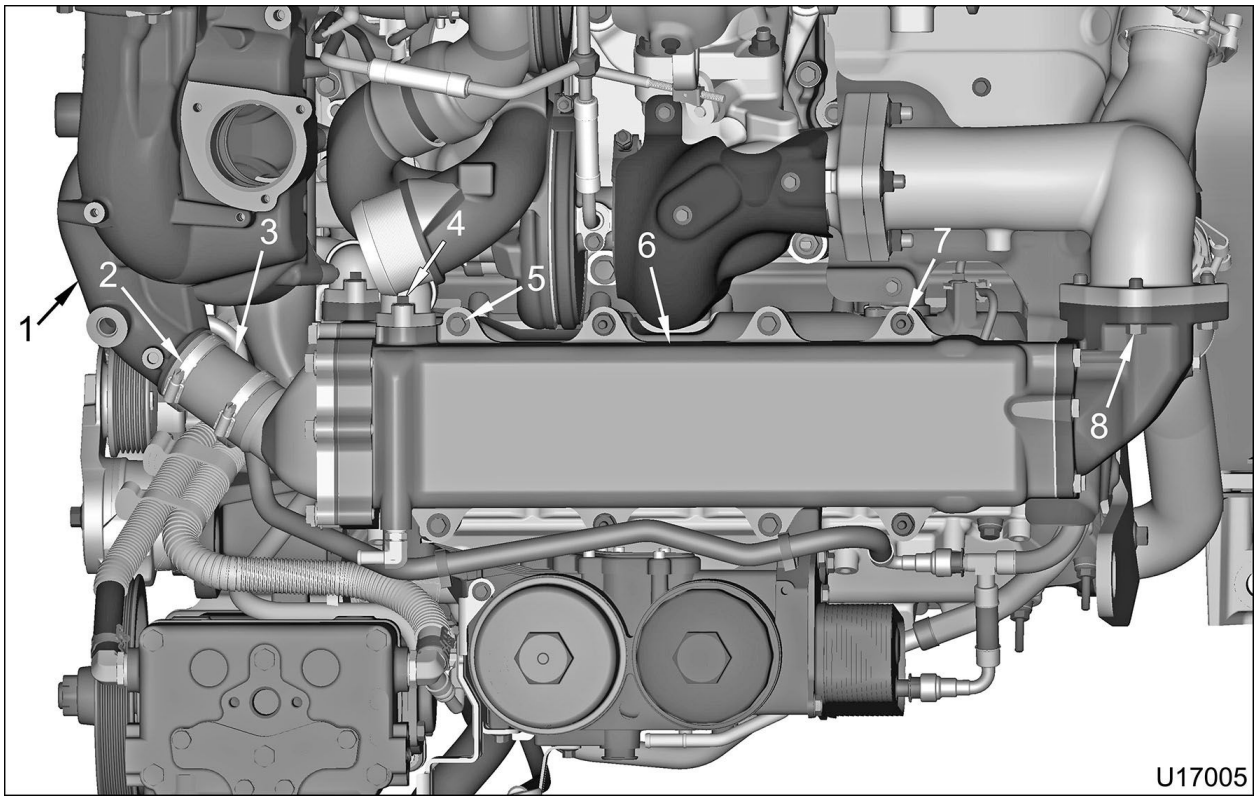


Figure 149 EGR Cooler

1. Manifold mixer
2. No. 56 worm drive clamp (2)
3. Air cooler hose
4. M6 x 25 bolt
5. M8 x 50 bolt (4)
6. EGR cooler assembly
7. M8 x 50 stud bolt (4)
8. M10 x 30 bolt, high temperature (3)

NOTE: Do not remove EGR cooler end caps prior to inspection. Removing end caps will result in rejection of warranty claim.

1. Loosen worm drive clamp on air cooler hose (manifold mixer end).
2. Remove M6 x 25 bolt from connector elbow on EGR coolant return tube.
3. Remove four M8 x 50 bolts and four M8 x 50 stud bolts securing EGR cooler.
4. Remove three M10 x 30 bolts from EGR cooler flange.
5. Lift up on turbocharger connection end of EGR cooler assembly to disengage the O-ring seal nipple, before pulling outward to disengage the air cooler hose and EGR tubes.

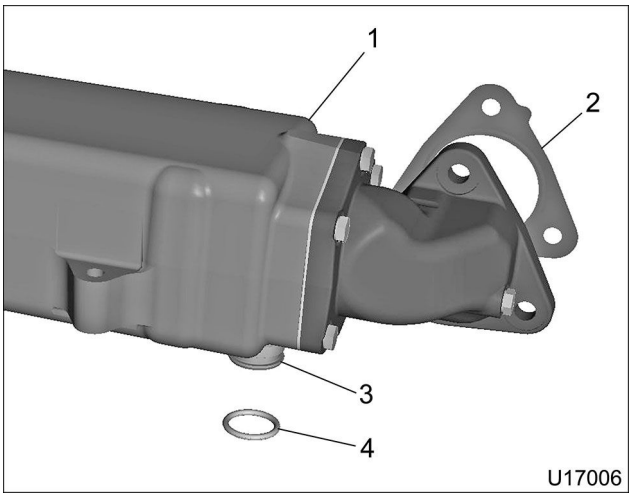


Figure 150 Coolant Gasket and O-ring Seal

1. EGR cooler
2. Turbocharger inlet gasket
3. O-ring seal nipple
4. O-ring seal

6. Remove and discard turbocharger inlet gasket.

7. Remove and discard O-ring seal from EGR cooler.

CAUTION: To prevent engine damage, do not remove end caps from EGR cooler assembly.

EGR Mixer Assembly

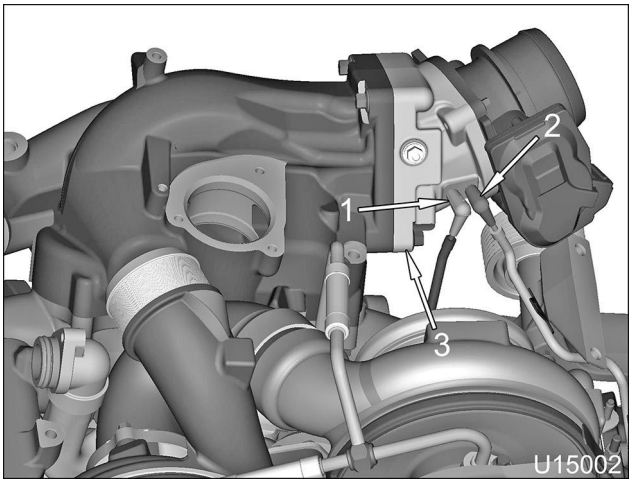


Figure 151 Boost Tube Connections

1. Boost to solenoid tube assembly
2. Jet pump boost tube assembly
3. Intake Air Heater (IAH)

CAUTION: To prevent damage to TC1WC solenoid, do not disconnect the end of the boost to solenoid tube assembly from the TC1WC solenoid. Disconnect only the end of the boost to solenoid tube assembly from the Intake Air Heater (IAH).

1. Disconnect boost to solenoid tube assembly from the IAH; leave other end connected to TC1WC solenoid.
2. Disconnect jet pump boost tube assembly from IAH.

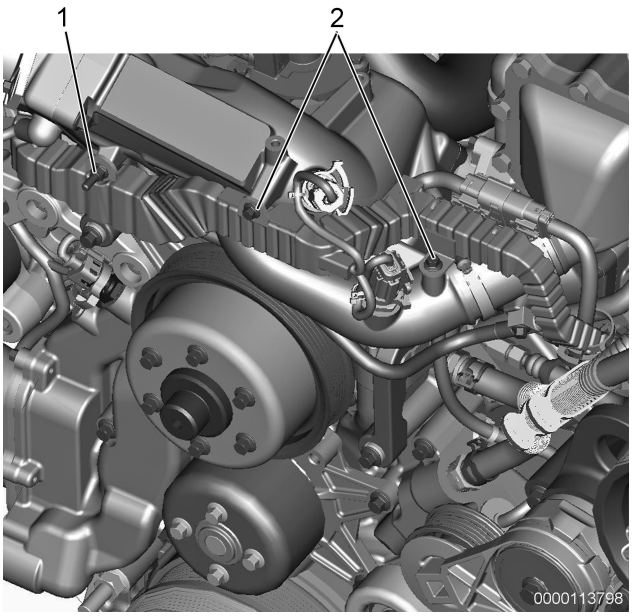


Figure 152 Wiring Harness Bolts

1. Wiring harness stud-bolt
2. M6 x 14 wiring harness bolts (2)

NOTE: Some engines are equipped with an M6 stud-bolt securing harness conduit to engine. Clearance between stud-bolt and cooling fan is very small (approximately 4mm) and contact with fan can occur. If wiring harness is secured with stud-bolt, replace stud-bolt with M6 x 16 bolt.

NOTE: Some engines were built with M6 x 16 harness retaining bolts that are too long and can bottom out when tightened. If bolts securing wiring harness measure M6 x 16, replace with M6 x 14 bolts.

3. Remove two wiring harness bolts.

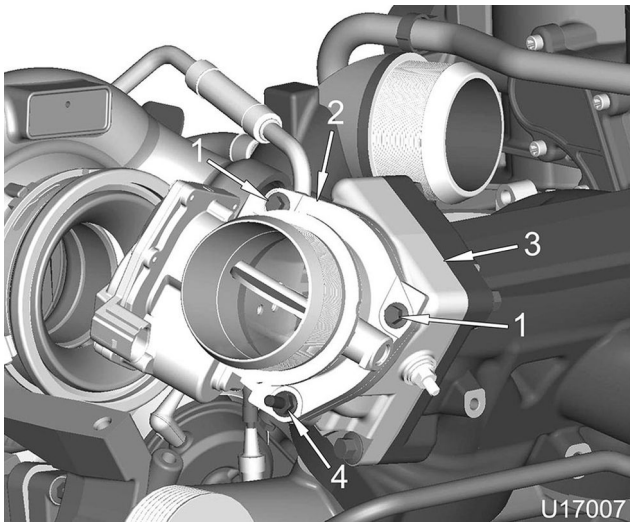


Figure 153 Engine Throttle Valve (ETV)

1. M6 x 25 bolt (2)
2. Engine Throttle Valve (ETV)
3. Intake Air Heater (IAH)
4. M6 x 25 stud bolt

4. Remove two M6 x 25 bolts and one M6 x 25 stud bolt retaining the ETV to the IAH.
5. Remove ETV and discard intake throttle gasket.

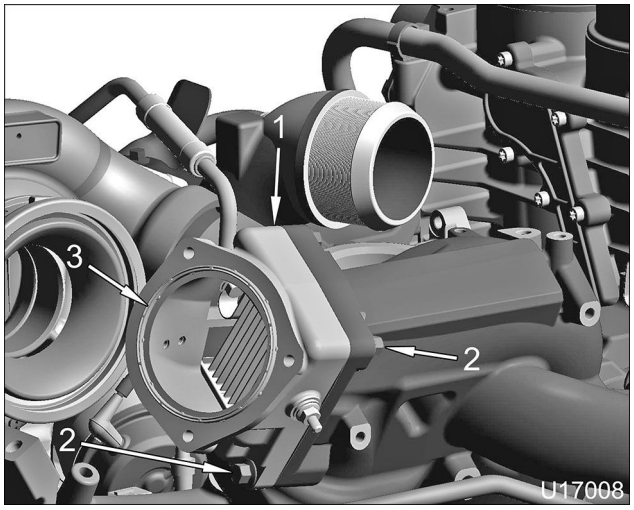


Figure 154 Intake Air Heater (IAH)

1. Intake Air Heater (IAH)
2. M8 x 35 bolt (4)
3. Intake throttle gasket

6. Remove four M8 x 35 bolts.
7. Remove the IAH.

Distribution Duct and Manifold Mixer

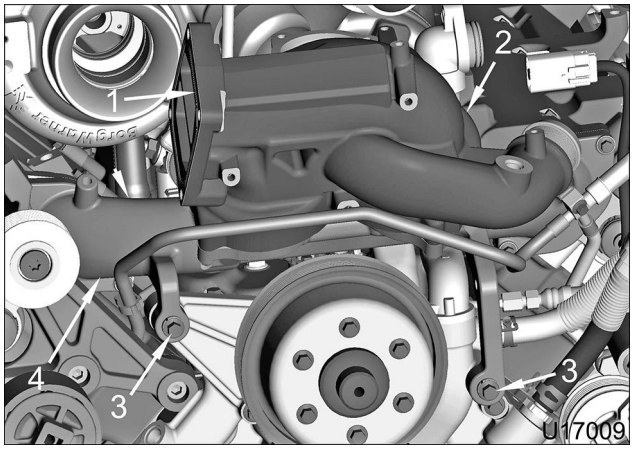


Figure 155 Distribution Duct and Manifold Mixer

1. Inlet duct gasket
2. Manifold mixer
3. M8 x 50 bolt (2)
4. Distribution duct

1. Remove and discard inlet duct gasket.
2. Remove two M8 x 50 bolts from distribution duct.

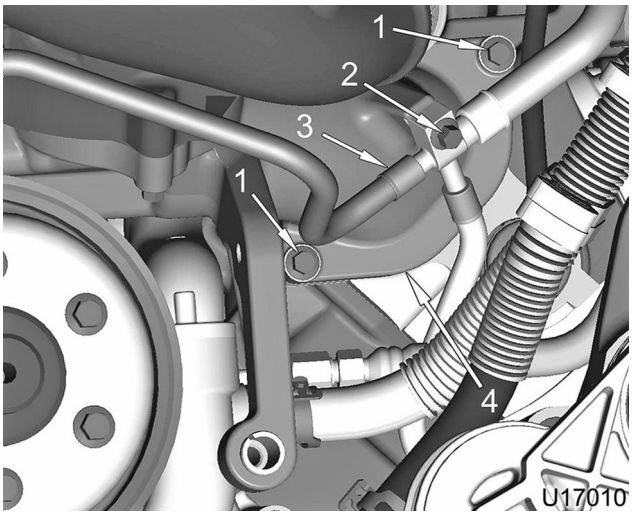


Figure 156 Distribution Duct Flange to Left Valve Cover and Intake Manifold Base Assembly

1. M6 x 30 bolt (2)
2. M6 x 25 bolt
3. Injector hose assembly
4. Distribution duct

3. Remove M6 x 25 bolt from injector hose assembly.
4. Remove two M6 x 30 bolts from distribution duct flange to left valve cover and intake manifold base assembly.

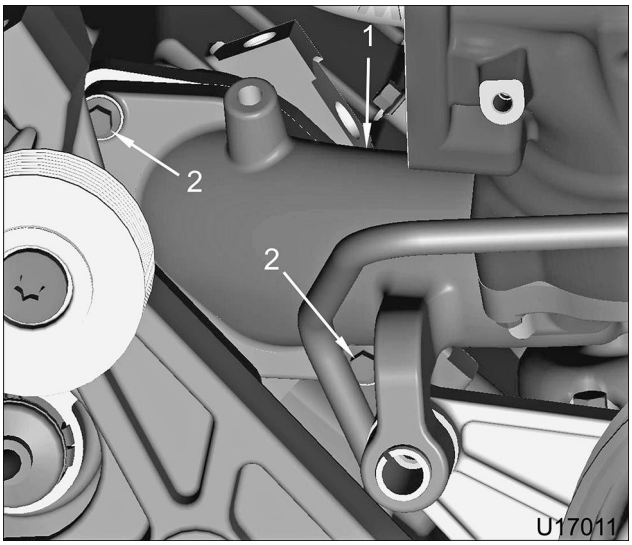


Figure 157 Distribution Duct Flange to Right Valve Cover and Intake Manifold Base Assembly.

1. Distribution duct
2. M6 x 30 bolt (2)

5. Remove two M6 x 30 bolts from distribution duct flange to right valve cover and intake manifold base assembly.
6. Remove distribution duct and manifold mixer assembly.
7. Install Intake Manifold Mixing Bowl Covers (page 140) onto left and right intake manifold base assembly.

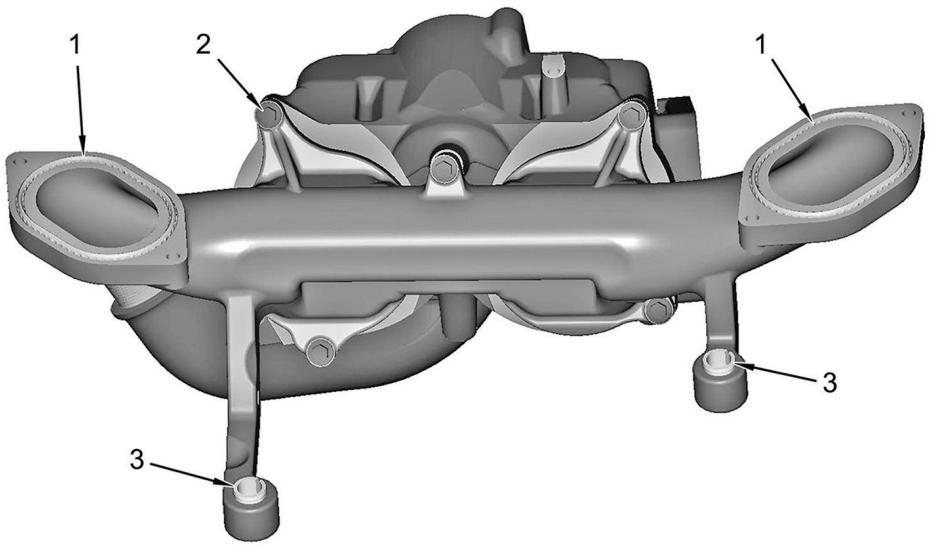


Figure 158 Distribution Duct and Manifold Mixer Assembly

1. Distribution duct gasket (2)
2. M6 x 35 bolt (5)
3. Split seam bushing (2)

8. Remove and discard two distribution duct gaskets from distribution duct.
9. Remove and discard two split seam bushings.
10. Remove five M6 x 35 bolts that secure the distribution duct to the manifold mixer assembly.

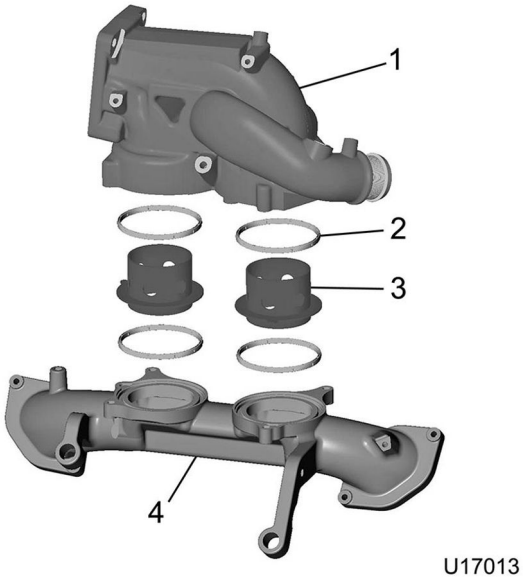


Figure 159 EGR Manifold Mixer Bushings

1. Manifold mixer
2. Intake throttle gasket (4)
3. EGR mixer bushing (2)
4. Distribution duct

11. Separate manifold mixer and two EGR mixer bushings from distribution duct.
12. Remove and discard four intake throttle gaskets.

EGR Coolant Supply and Return Tubes

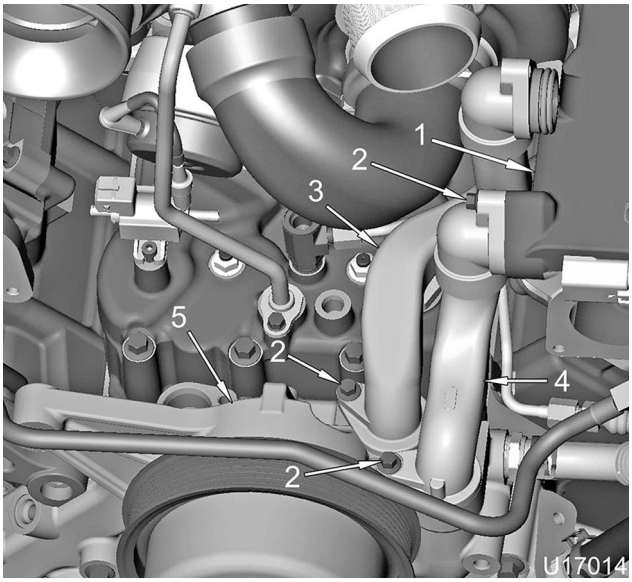


Figure 160 EGR Coolant Supply and Return Tubes

1. Valve cover intake manifold base
2. M6 x 25 bolt (3)
3. EGR coolant return tube
4. EGR coolant supply tube
5. Front cover

1. Remove M6 x 25 bolt from EGR coolant return tube to front cover.
2. Remove EGR coolant return tube.
3. Remove M6 x 25 bolt from EGR coolant supply tube to valve cover intake manifold base.
4. Remove M6 x 25 bolt from EGR coolant supply tube to front cover.
5. Remove EGR coolant supply tube.

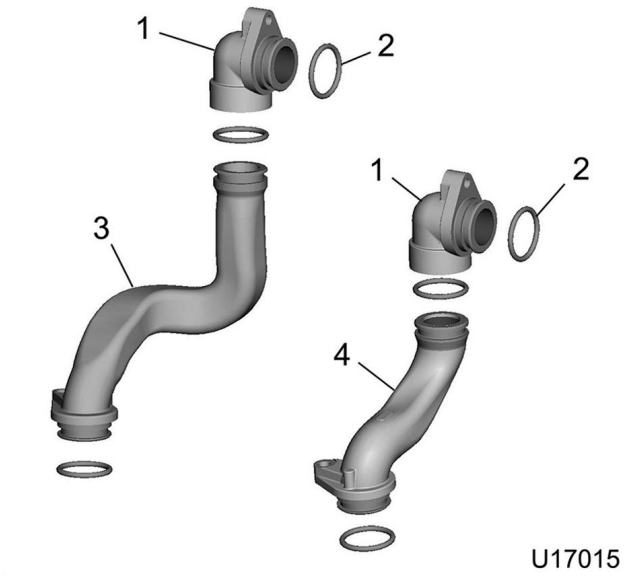


Figure 161 EGR Coolant Supply and Return Tubes

1. Connector elbow (2)
2. O-ring (6)
3. EGR coolant return tube
4. EGR coolant supply tube

6. Separate EGR coolant supply tube and coolant return tube from connector elbow.
7. Remove and discard six O-rings.

Cleaning, Inspection, and Testing

EGR System Components

NOTE: Do not remove EGR cooler end caps prior to inspection. Removing end caps will result in rejection of warranty claim.

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 Brush (page 140).
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. Install new components if necessary.

Manifold Mixer

Clean manifold mixer with steam or suitable non-caustic solvents.

Clean contact areas of EGR O-ring in manifold mixer housing. Make sure carbon debris is removed above and below contact areas of manifold mixer.

Exhaust Gas Recirculation (EGR) Cooler Pressure Test

The following procedure is used in order to diagnose a leaking EGR cooler. The procedure uses air pressure while the operator looks for leaks in the form of bubbles in water while using the EGR leak detection kit.

EGR Leak Detection Kit

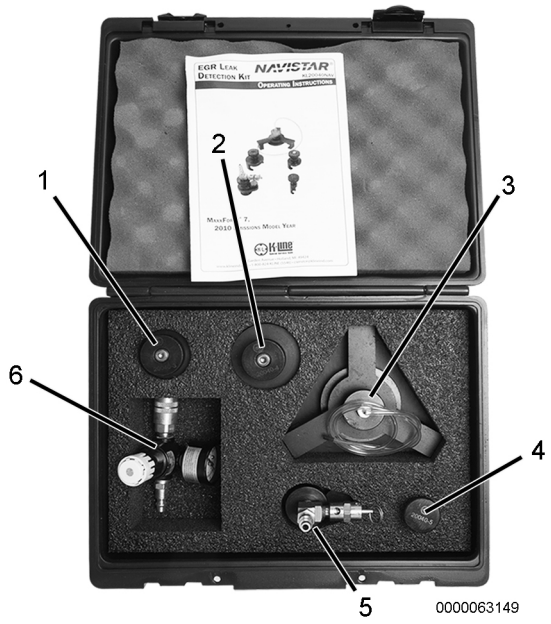


Figure 162 EGR Leak Detection Kit

1. KL20040-3 EGR Cooler Inlet Tool (End Seal [small diameter])
2. KL20040-4 EGR Gas Outlet Tool (End Seal [large diameter])
3. KL20040-2 EGR Turbocharger Inlet Flange Tool (Flange End Seal Leak Detection)
4. KL20040-5 EGR Cooler Vent Tool (small port plug)
5. KL20040-1 EGR Coolant Return Tool (Single Hole Seal Air Inlet)
6. KL20020-13 air regulator

Installation and Testing of EGR Cooler

CAUTION: This tool kit uses compressed air at high pressures. Use extreme caution during testing. For safety, ensure all fittings are tight. Do not stand in front of fittings while under pressure.

NOTE: Clean all sealing surfaces on the EGR cooler. This will ensure proper sealing of all tools, and will eliminate any error in procedure.

NOTE: To reduce the chance of damage to EGR cooler, set pressure regulator (KL20020-13) to 45 psi before connecting it to system and beginning test.

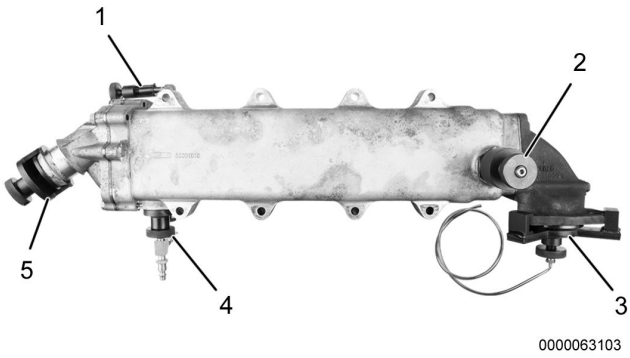


Figure 163 EGR Leak Detection Kit Components (Installed)

1. KL20040-5
2. KL20040-3
3. KL20040-2
4. KL20040-1
5. KL20040-4

KL20040-1 Installation

1. Before installing component, back knurled knob out several turns to ensure there is enough clearance for proper tool installation.
2. Line up tool with hole, and tighten knurled knob down into threaded hole.

NOTE: To prevent damage to O-ring, tighten knurled knob to hand-tight.

3. Tighten knurled knob in order to compress O-ring seal against inside of pipe.

KL20040-3, KL20040-4, and KL20040-5 Installation

4. Before installing component, back knurled knob out several turns to ensure there is enough clearance for proper tool installation.
5. Slide tool onto pipe and hook lower part of tool onto outside of pipe.
6. Turn knurled knob slowly, ensuring that center of tool aligns with center of pipe.

NOTE: To prevent damage to O-ring, tighten knurled knob to hand-tight.

7. Tighten knurled knob in order to compress O-ring seal against inside of pipe.

KL20040-2 Installation

8. Before installing component, back knurled knob out several turns to ensure there is enough clearance for proper tool installation.
9. Set tool over flange, allowing flange into tool opening.
10. Turn tool clockwise until flange contacts stops inside tool.

NOTE: To prevent damage to O-ring, tighten knurled knob to hand-tight.

11. Tighten knurled knob in order to compress O-ring seal against inside of pipe.

KL20020-13 Installation

12. Connect pressurized air line to regulator assembly and verify air pressure is regulated to 45 psi (310 kPa). If pressure is not regulated to 45 psi (310 kPa), adjust pressure accordingly.

Pressurize the System

13. Connect KL20020-13 to KL20040-1 (installed on cooler).

NOTE: Very small leaks may take up to 5 minutes to appear. Test for sufficient amount of time before recording results.

14. Place end of hose connected to KL20040-2 into a container of water to a depth of at least 0.375 in. (marked on hose with red dye). Keep system pressurized while observing end of hose submerged inside container. Bubbles indicate a leak.

NOTE: Ensure test results are recorded.

Disassembly

15. Disconnect compressed air line from KL20040-1.
16. Remove all tools from EGR cooler. Clean EGR cooler.
17. Refer to Installation located in the Engine Service Manual for installation of EGR cooler.

Installation

EGR Coolant Supply and Return Tubes

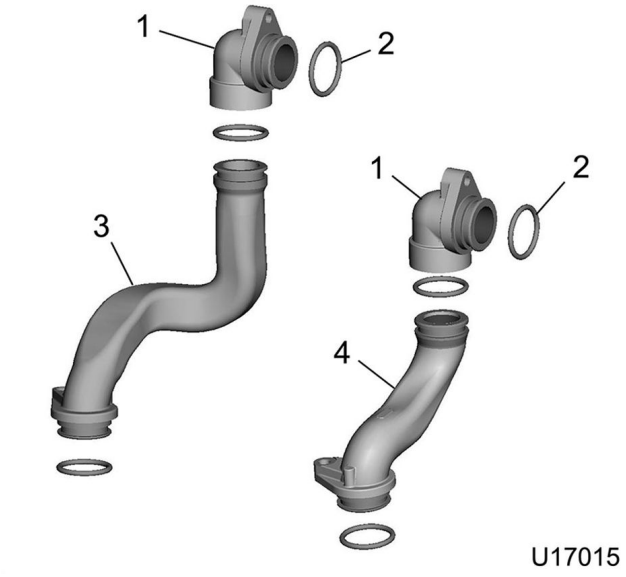


Figure 164 EGR Coolant Supply and Return Tubes

1. Connector elbow (2)
2. O-ring (6)
3. EGR coolant return tube
4. EGR coolant supply tube

1. Lubricate O-ring with P-80® Rubber Lubricant or equivalent (page 140). Assemble EGR coolant return tube, new O-ring, and connector elbow.
2. Lubricate O-ring with P-80® Rubber Lubricant or equivalent (page 140). Assemble EGR coolant supply tube, new O-ring, and connector elbow.

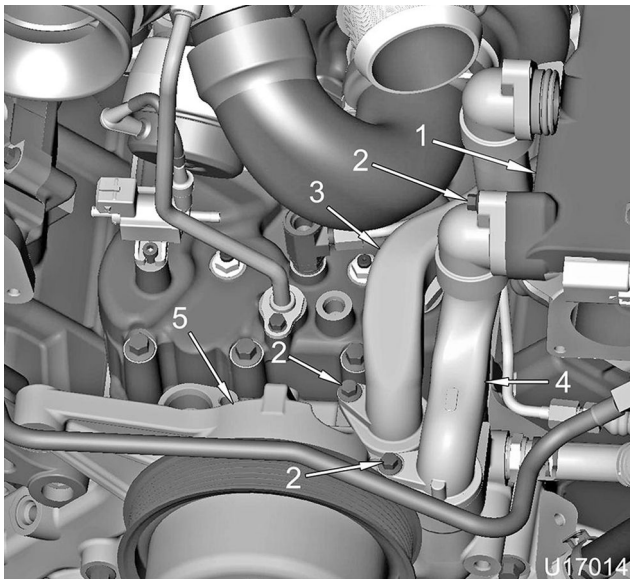


Figure 165 EGR Coolant Supply and Return Tubes

1. Valve cover intake manifold base
2. M6 x 25 bolt (3)
3. EGR coolant return tube
4. EGR coolant supply tube
5. Front cover

3. Lubricate new O-rings with P-80® Rubber Lubricant or equivalent (page 140). Install O-rings onto EGR coolant return tube and insert tube end into front cover.
4. Install M6 x 25 bolt through tube flange into front cover and tighten to standard torque (page 473).
5. Lubricate new O-rings with P-80® Rubber Lubricant or equivalent (page 140). Install O-rings onto EGR coolant supply tube and insert tube end into front cover and valve cover intake manifold base.
6. Install two M6 x 25 bolts: one into front cover and one into valve cover intake manifold base. Tighten bolts to standard torque (page 473).

EGR Manifold Mixer

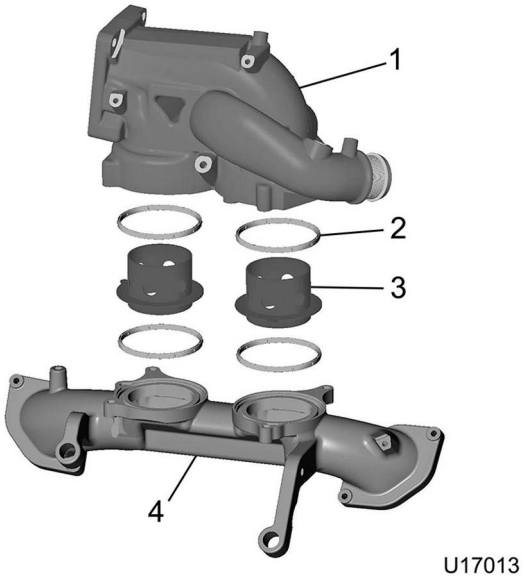


Figure 166 EGR Manifold Mixer Bushings

1. Manifold mixer
2. Intake throttle gasket (4)
3. EGR mixer bushing (2)
4. Distribution duct

1. Lubricate four new Intake throttle gaskets with P-80® Rubber Lubricant or equivalent (page 140). Install intake throttle gaskets onto each EGR mixer bushing.

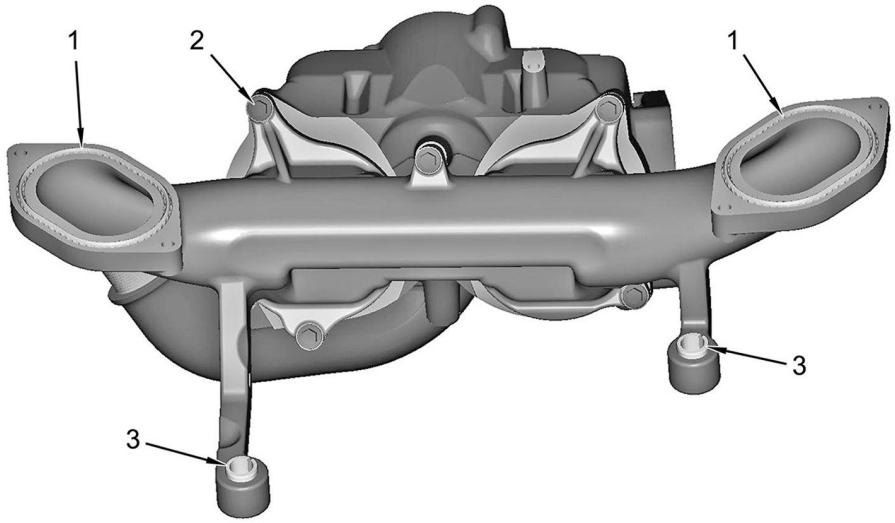


Figure 167 Distribution Duct and Manifold Mixer Assembly

1. Distribution duct gasket (2)
2. M6 x 35 bolt (5)
3. Split seam bushing (2)

2. Assemble manifold mixer, two EGR mixer bushings, distribution duct, and install five M6 x 35 bolts. Tighten bolts to standard torque (page 473).
3. Install two new distribution duct gaskets.

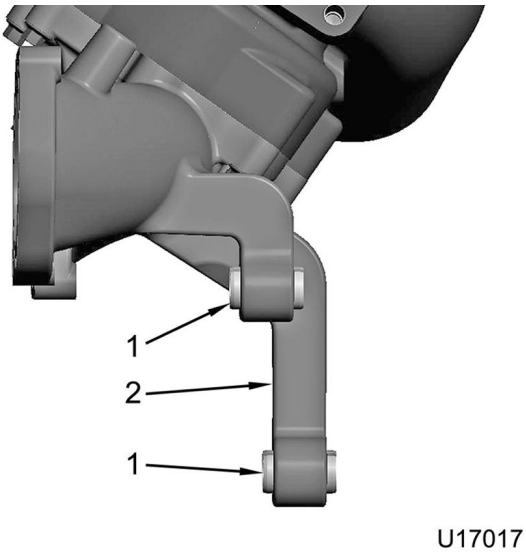


Figure 168 Installation of Split Bushings

1. Split seam bushing (2)
2. Distribution duct

4. Install two new split seam bushings to the original position (centered).

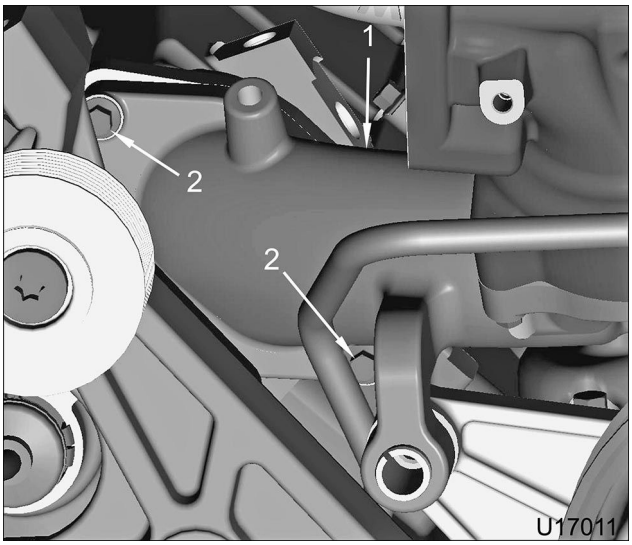


Figure 169 Distribution Duct Flange to Right Valve Cover and Intake Manifold Base Assembly

1. Distribution duct
2. M6 x 30 bolt (2)

5. Position distribution duct and manifold mixer assembly and install two M6 x 30 bolts (distribution duct flange to right valve cover and intake manifold base assembly).

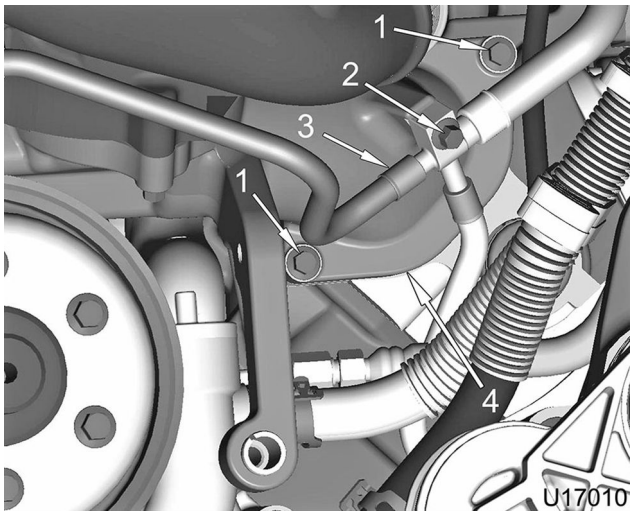


Figure 170 Distribution Duct Flange to Left Valve Cover and Intake Manifold Base Assembly

1. M6 x 30 bolt (2)
2. M6 x 25 bolt
3. Injector hose assembly
4. Distribution duct

6. Install two M6 x 30 bolts (distribution duct flange to left valve cover and intake manifold base assembly).
7. Tighten two M6 x 30 bolts to standard torque (page 473).
8. Install M6 x 25 bolt to secure injector hose assembly.
9. Tighten M6 x 25 bolt to standard torque (page 473).

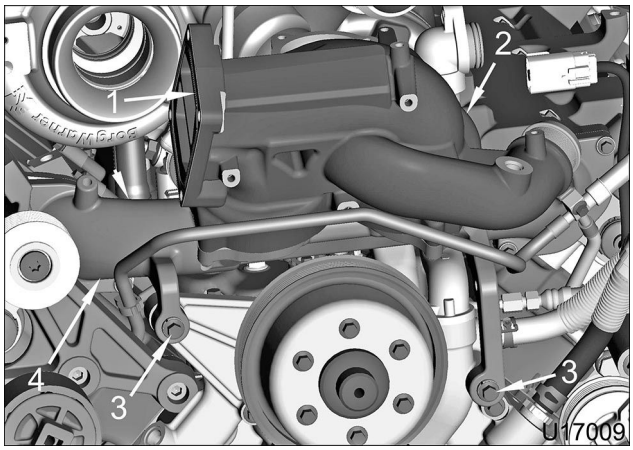


Figure 171 Distribution Duct and Manifold Mixer

1. Inlet duct gasket
2. Manifold mixer
3. M8 x 50 bolt (2)
4. Distribution duct

10. Install two M8 x 50 bolts into manifold mixer and tighten bolts to standard torque (page 473).
11. Install new inlet duct gasket.

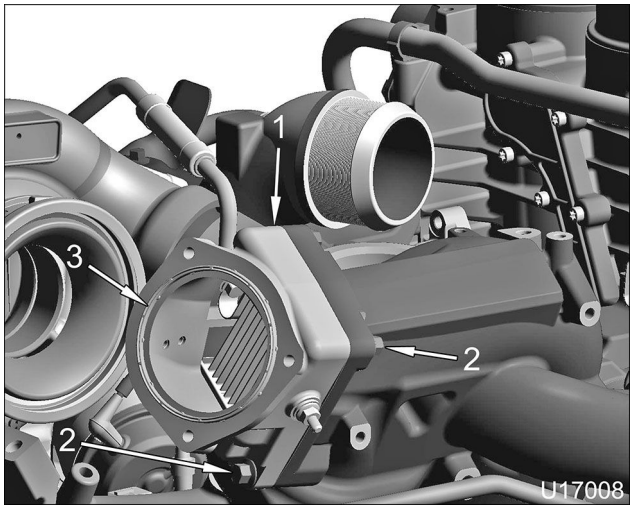


Figure 172 Intake Air Heater (IAH)

1. Intake Air Heater (IAH)
2. M8 x 35 bolt (4)
3. Intake throttle gasket

12. Install the IAH.
13. Install four M8 x 35 bolts to secure the IAH.

14. Tighten M8 x 35 bolts to standard torque (page 473).
15. Lubricate new intake throttle gasket with P-80® Rubber Lubricant or equivalent (page 140). Install intake throttle gasket.

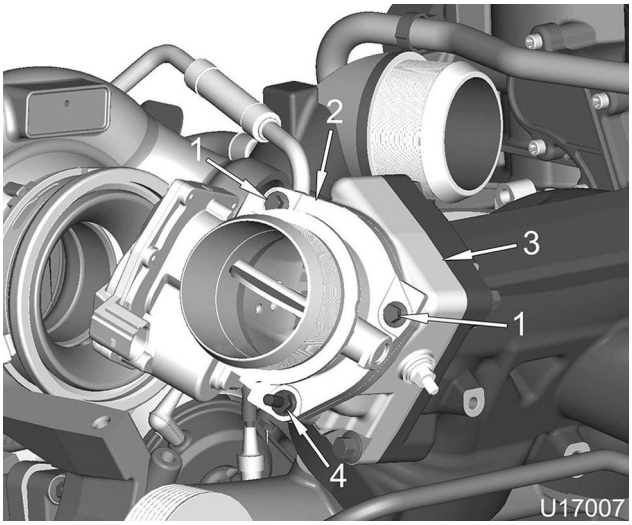


Figure 173 Engine Throttle Valve (ETV)

1. M6 x 25 bolt (2)
2. Engine Throttle Valve (ETV)
3. Intake Air Heater (IAH)
4. M6 x 25 stud bolt

16. Install two M6 x 25 bolts and one M6 x 25 stud bolt to retain the ETV.
17. Tighten M6 x 25 bolts and stud bolt to standard torque (page 473).

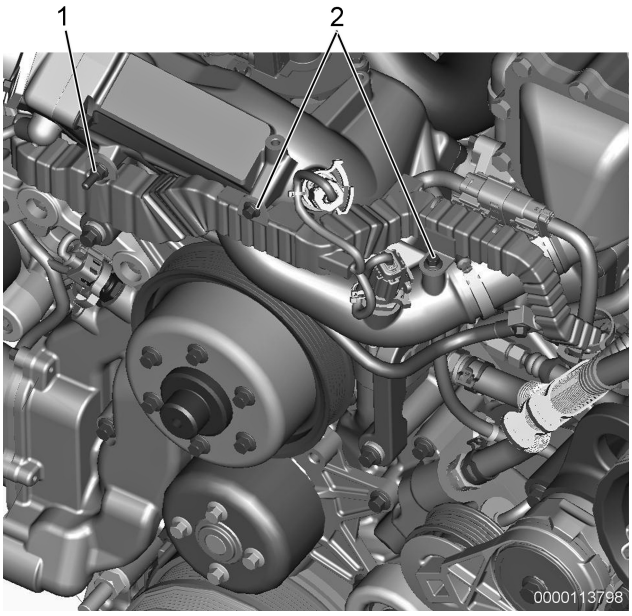


Figure 174 Wiring Harness Bolts

1. M6 x 14 bolt
2. M6 x 16 bolt

NOTE: Some engines are equipped with an M6 stud-bolt securing harness conduit to engine. Clearance between stud-bolt and cooling fan is very small (approximately 4mm) and contact with fan can occur. If wiring harness is secured with stud-bolt, replace stud-bolt with M6 x 16 bolt.

NOTE: Some engines were built with M6 x 16 harness retaining bolts that are too long and can bottom out when tightened. If bolts securing wiring harness measure M6 x 16, replace with M6 x 14 bolts.

18. Install two M6 x 14 harness retention bolts.
19. Tighten both bolts to standard torque (page 473).

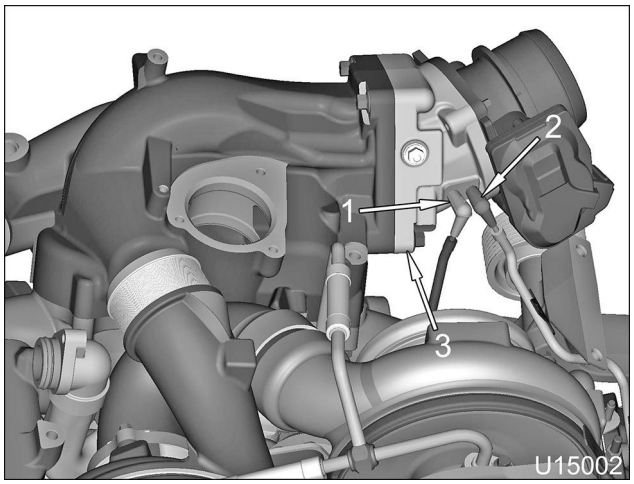


Figure 175 Boost Tube Connections

1. Boost to solenoid tube assembly
2. Jet pump boost tube assembly
3. Intake Air Heater (IAH)

20. Install jet pump boost tube assembly to the IAH.
21. Install boost to solenoid tube assembly to the IAH.

EGR Cooler

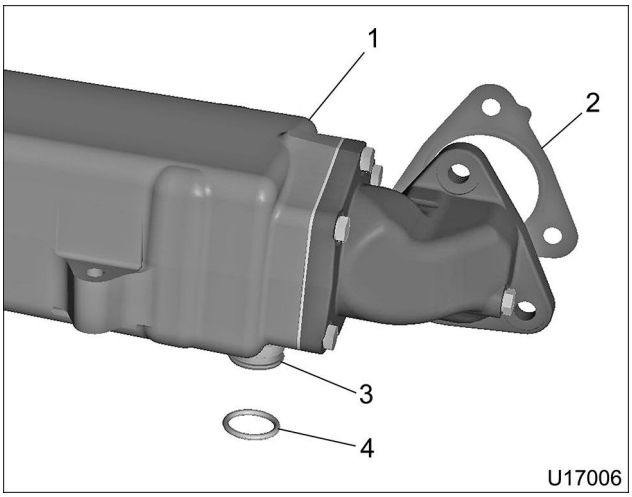


Figure 176 Coolant Gasket and O-ring Seal

1. EGR cooler
2. Turbocharger inlet gasket
3. O-ring seal nipple
4. O-ring seal

1. Lubricate new O-ring seal with P-80® Rubber Lubricant or equivalent (page 140). Install O-ring on nipple of EGR cooler.

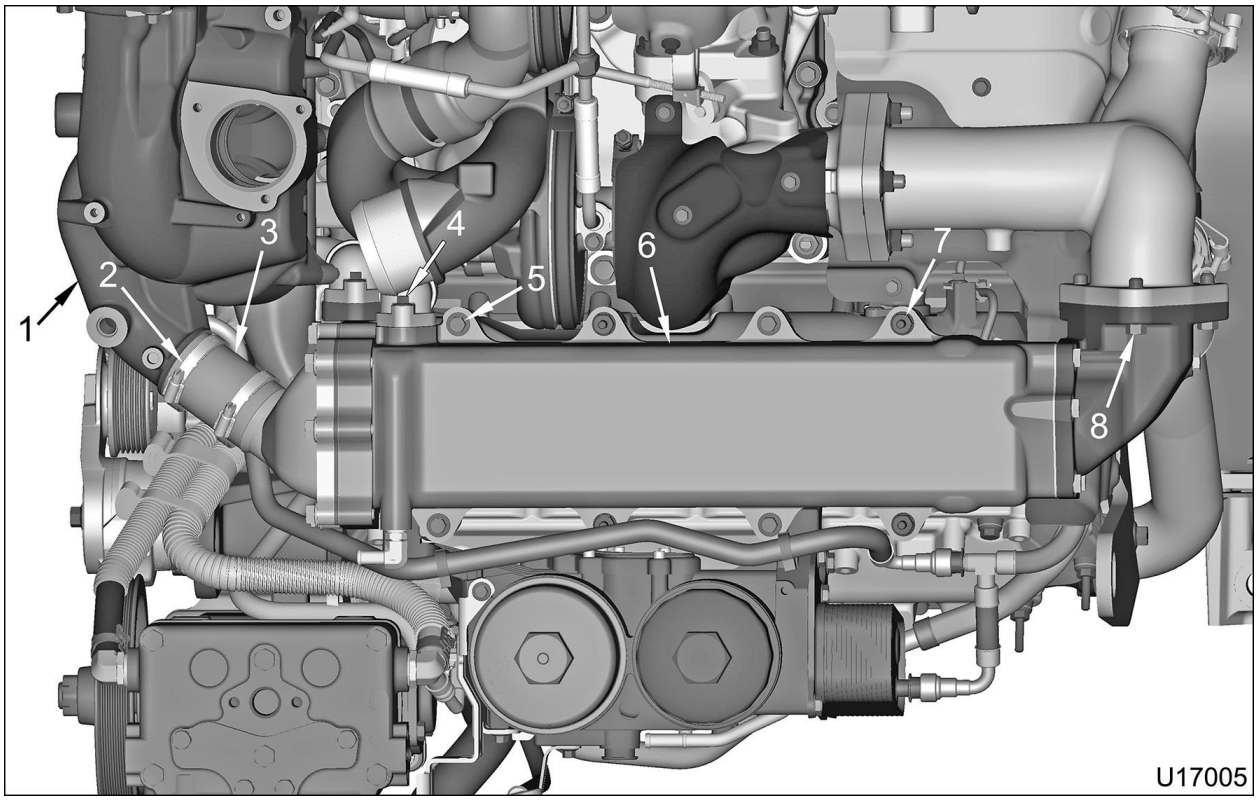


Figure 177 EGR Cooler

1. Manifold mixer assembly
2. No. 56 worm drive clamp (2)
3. Air cooler hose
4. M6 x 25 bolt
5. M8 x 50 bolt (4)
6. EGR cooler assembly
7. M8 x 50 stud bolt (4)
8. M10 x 30 bolt, high temperature (3)

2. Install two worm drive clamps on air cooler hose.
3. Slide air cooler hose onto EGR cooler assembly.
4. Slide air cooler hose onto manifold mixer inlet, while positioning turbocharger connection end of EGR cooler assembly to engage the O-ring seal nipple and align with EGR coolant return tube.
5. Install new turbocharger inlet gasket and install three M10 x 30 bolts (finger tight) to secure EGR cooler flange to flange on turbocharger exhaust inlet manifold.
6. Install four M8 x 50 bolts (finger tight) and four M8 x 50 stud bolts (finger tight) to secure EGR cooler.
7. Tighten M10 x 30 bolts to standard torque (page 473).
8. Tighten M8 x 50 bolts and M8 x 50 stud bolts to standard torque (page 473).
9. Tighten worm drive clamp to special torque (page 140).
10. Install M6 x 25 bolt to secure EGR coolant return tube to EGR cooler.
11. Tighten M8 x 35 bolt to standard torque (page 473).

EGR Valve Assembly

CAUTION: To prevent engine damage, do not use power tools to remove or install EGR system nuts and bolts. Threads will be damaged if installed or removed too quickly.

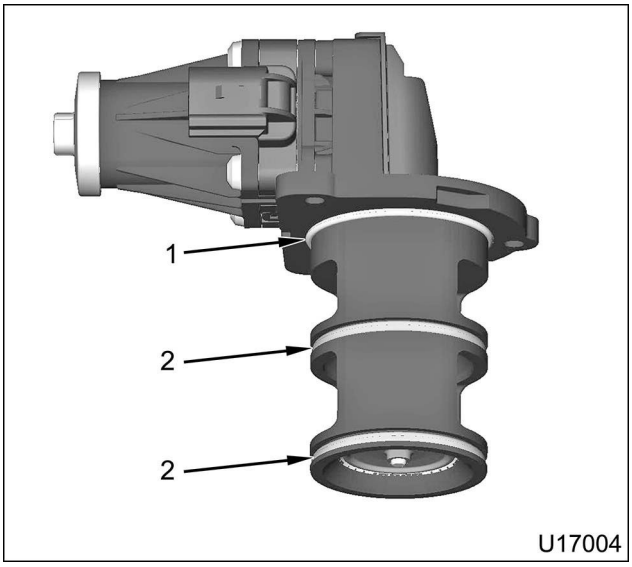


Figure 178 EGR Valve O-rings

1. O-ring, No. 2-140
2. O-ring, No. 2-226 (2)

1. Lubricate No. 2-140 O-ring and two No. 2-226 O-rings with P-80® Rubber Lubricant or equivalent (page 140).

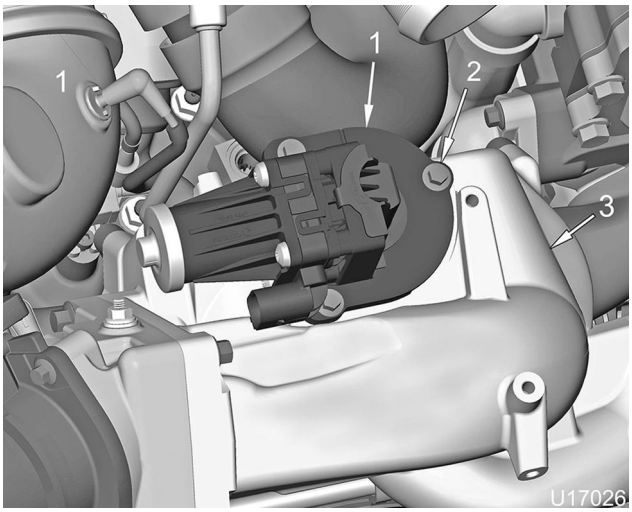


Figure 179 EGR Valve Assembly

1. EGR valve assembly
2. M6 x 20 bolt (3)
3. Manifold mixer

CAUTION: To prevent engine damage, vacuum loose ash, carbon deposits, and debris from the manifold mixer before installing the EGR valve.

2. Vacuum loose ash, carbon deposits, and debris from the manifold mixer.
3. Install EGR valve assembly.

   NOTE: Make sure EGR valve assembly is fully seated.

4. Install three M6 x 20 bolts to secure EGR valve assembly.
5. Tighten M6 x 20 bolts to standard torque (page 473).

Special Torque

Worm drive clamp	3.5 N·m (31 lb·in)

Special Service Tools

Description	Tool Number
EGR Leak Detection Kit	KL20040NAV
• EGR Coolant Return Tool (Single Hole Seal Air Inlet)	KL20040-1
• EGR Turbocharger Inlet Flange Tool (Flange End Seal Leak Detection)	KL20040-2
• EGR Cooler Inlet Tool (End Seal {small diameter})	KL20040-3
• EGR Gas Outlet Tool (End Seal {large diameter})	KL20040-4
• EGR Cooler Vent Tool (Small Port Plug)	KL20040-5
• Air Regulator	KL20020-13
EGR Valve Bore Cleaning Brush	ZTSE4753
EGR Valve Puller	ZTSE6010
Intake Manifold Mixing Bowl Covers (Intake Plate Covers)	ZTSE6034
P-80® Rubber Lubricant or equivalent	Obtain locally

Table of Contents

Description.....143
- **Exploded Views**.....143

Removal.....146
- **Exhaust Tubes**.....147
- **Exhaust Manifolds**.....149
  - **Left Exhaust Manifold**.....149
  - **Right Exhaust Manifold**.....150
- **Pump Cover Heat Shields**.....151
- **Dual Turbocharger Heat Shields**.....152
- **Turbocharger Oil Supply Tube Assembly**.....153
- **Air Duct Assembly, Relief Tube Assembly, Wastegate Tube Assembly, and TC1WC Solenoid**...155
- **Dual Turbocharger Assembly**.....156

Cleaning, Inspection, and Testing.....160
- **Dual Turbocharger Assembly and Related Parts**.....160
- **Dual Turbocharger Assembly Cleaning and Inspection**.....160
- **Check Free Rotation and Housing Rub**.....167
- **Check Axial End Play**.....168
- **TC1WC Wastegate Actuator Set Procedure**.....169
- **Exhaust Manifolds**.....170
- **Manifold Warp Test for Exhaust Manifolds**.....170

Installation.....171
- **Dual Turbochargers**.....171
- **TC1WC Solenoid, Wastegate Hose Assembly, Relief Tube Assembly, and Air Duct Assembly**.....174
- **Turbocharger Oil Supply Tube**.....175
- **Dual Turbocharger Heat Shields**.....177
- **Pump Cover Heat Shields**.....177
- **Exhaust Manifolds**.....179
  - **Right Exhaust Manifold**.....179
  - **Left Exhaust Manifold**.....180
- **Exhaust Tubes**.....182

Specifications.....184

Special Torque.....184

Special Service Tools.....184

Description

Exploded Views

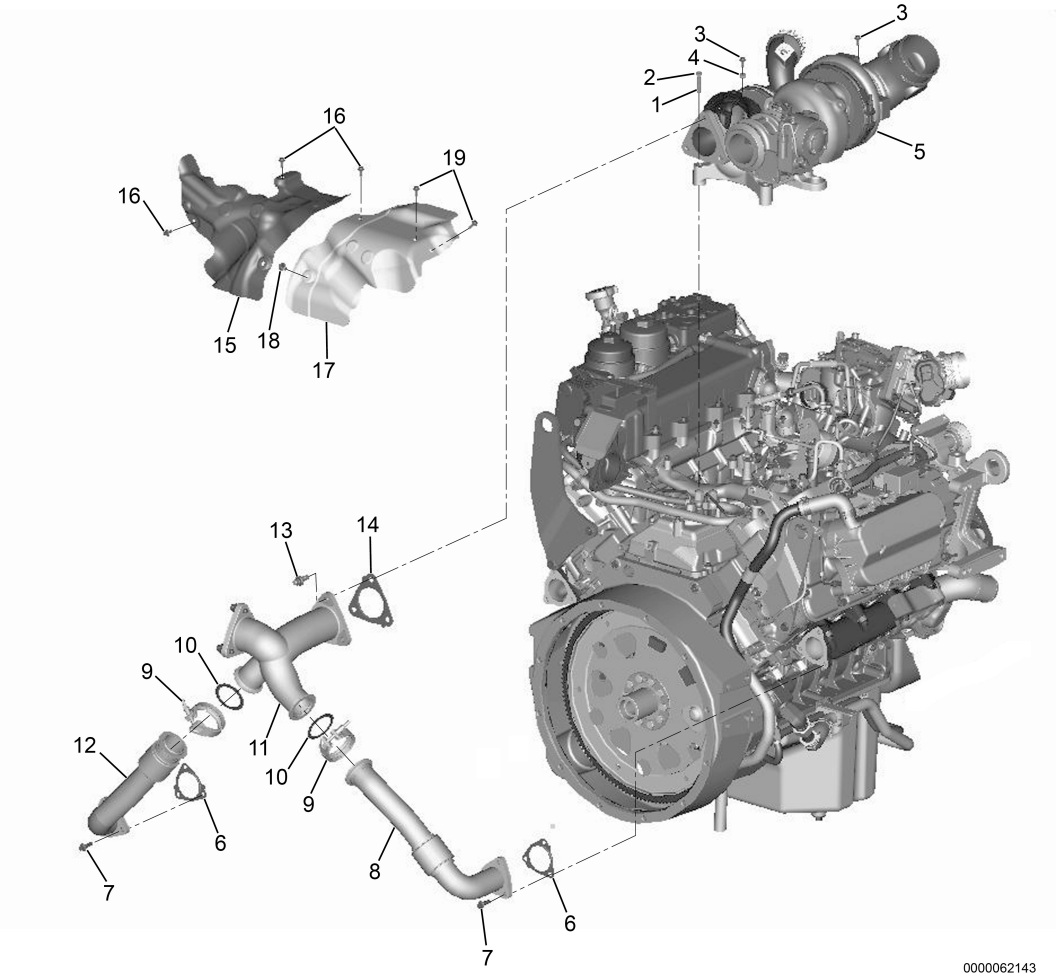


Figure 180 Dual Turbocharger

1. M10 x 142 stud (2)
2. M10 nut (2)
3. M10 x 55 bolt (2)
4. Turbo bolt spacer
5. Turbocharger assembly
6. Exhaust gasket (2)
7. M8 x 27 bolt (6)
8. Right exhaust tube assembly
9. V-band clamp (2)
10. V-band gasket (2)
11. Turbo exhaust inlet manifold
12. Left exhaust tube assembly
13. M10 nut (3)
14. Turbo inlet gasket
15. Right pump cover heat shield
16. M6 x 14 bolt (3)
17. Left pump cover heat shield
18. M8 x 12 bolt
19. M6 x 25 bolt (2)

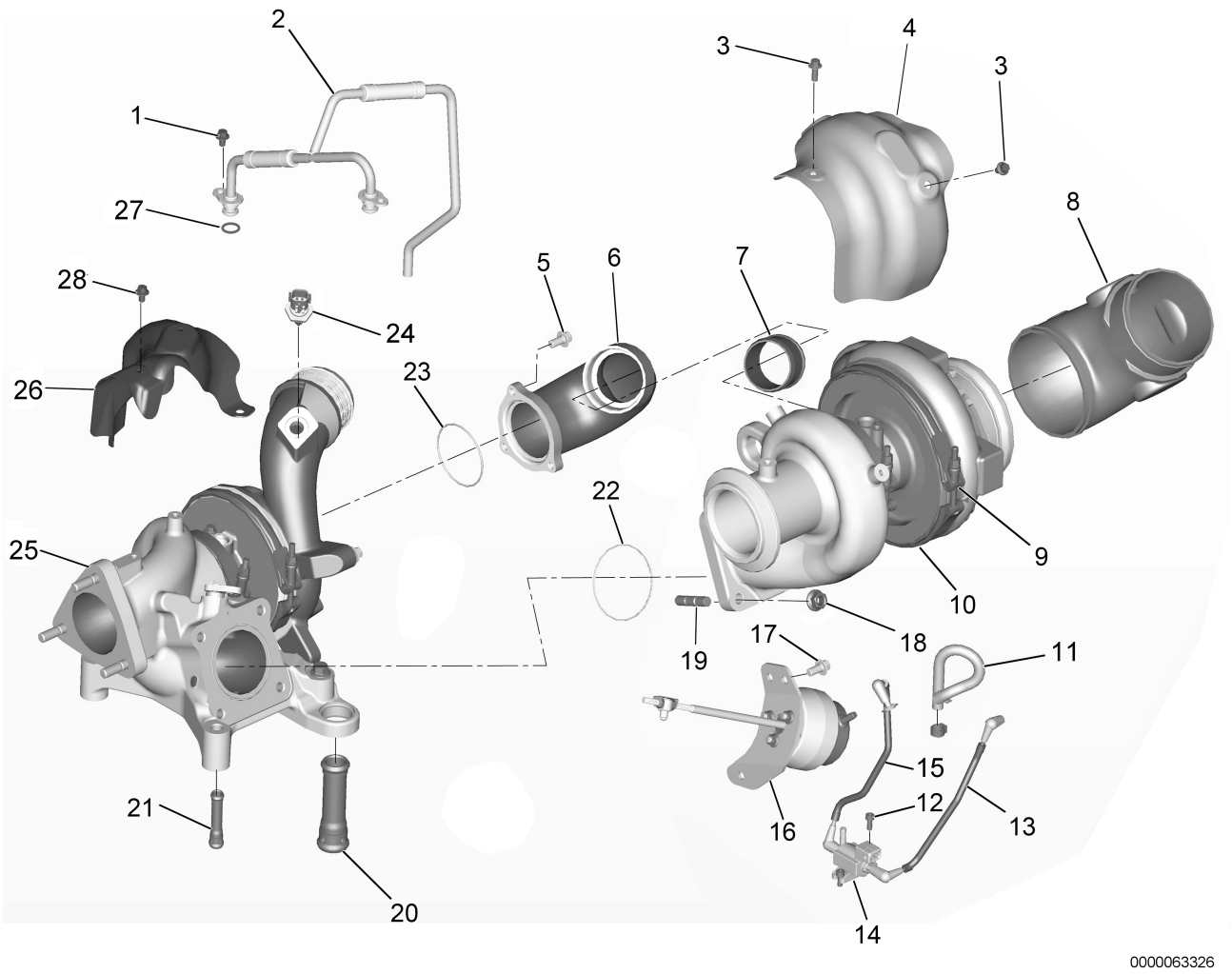


Figure 181 Dual Turbocharger

1. M6 x 14 bolt (3)
2. Turbo oil supply tube assembly
3. M6 x 10 bolt (6)
4. LP turbo heat shield
5. M6 x 20 bolt (3)
6. Crossover tube
7. LP turbo seal
8. Air duct assembly
9. Turbo inlet clamp
10. LP turbo assembly
11. Wastegate hose assembly
12. M5 x 12 socket head bolt (2)
13. Boost to solenoid tube assembly
14. Turbocharger 1 Wastegate Control (TC1WC) solenoid
15. Relief to duct tube assembly
16. Turbocharger 1 Wastegate Control (TC1WC) actuator
17. M8 x 16 bolt (3)
18. M10 nut (4)
19. Turbo stud (4)
20. LP turbo drain tube
21. HP turbo drain tube
22. Exhaust sealing ring
23. O-ring seal
24. Turbocharger 1 Compressor Outlet Temperature (TC1COT) sensor
25. HP turbo assembly
26. HP turbo heat shield
27. SPL turbo seal (3)
28. M6 x 10 bolt

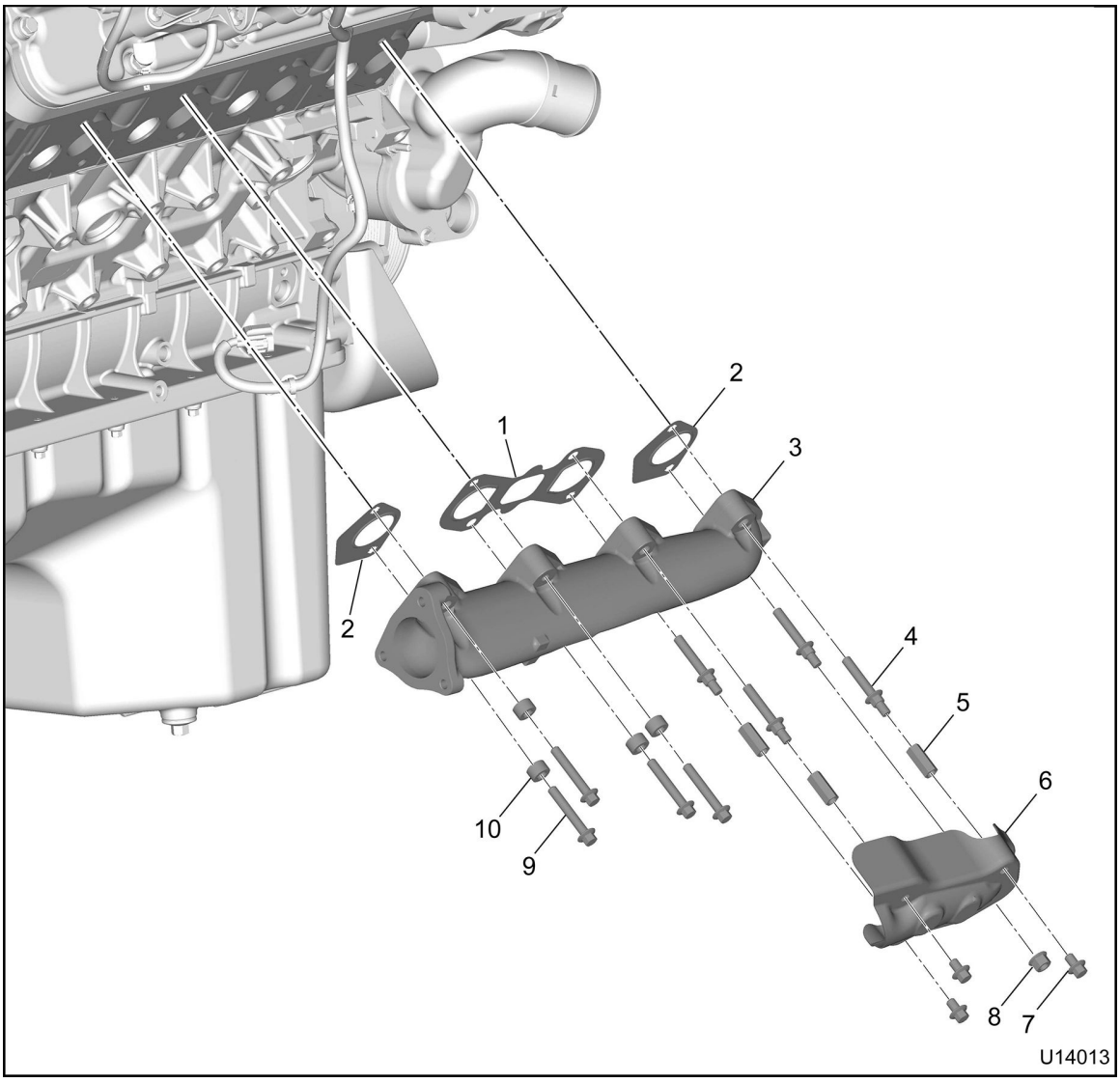


Figure 182 Right Exhaust Manifold (Left Similar)

1. Dual port gasket
2. Single port gasket (2)
3. Exhaust Manifold
4. Exhaust manifold stud bolt (4)
5. Heat shield spacer (3)
6. Heat shield
7. M8 x 12 bolt (3)
8. M8 nut
9. M8 x 50 bolt (4)
10. Exhaust manifold bolt spacer (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, 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.

NOTE: See the following sections for removal of components.

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

Exhaust Tubes

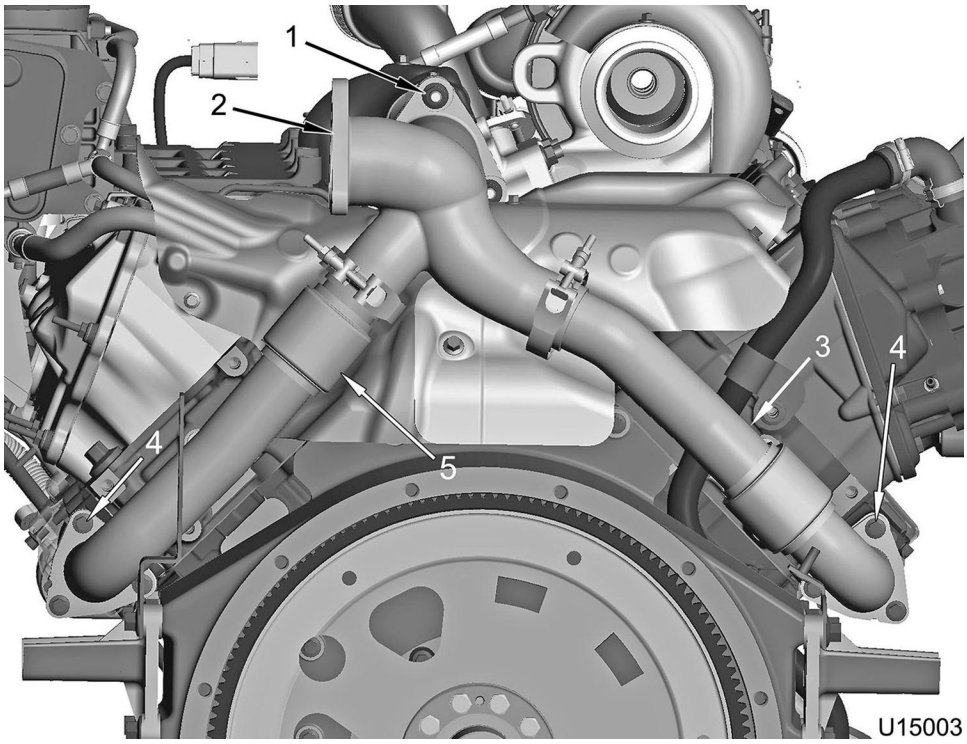


Figure 183 Exhaust Tubes

1. M10 nut (3)
2. Turbo exhaust inlet manifold
3. Right exhaust tube assembly
4. M8 x 27 bolt (6)
5. Left exhaust tube assembly

1. Remove three M10 nuts.
2. Remove three M8 x 27 bolts securing right exhaust tube assembly to right exhaust manifold.
3. Remove three M8 x 27 bolts securing left exhaust tube assembly to left exhaust manifold.
4. Remove turbocharger exhaust inlet manifold, right exhaust tube assembly, and left exhaust tube assembly – as a group.

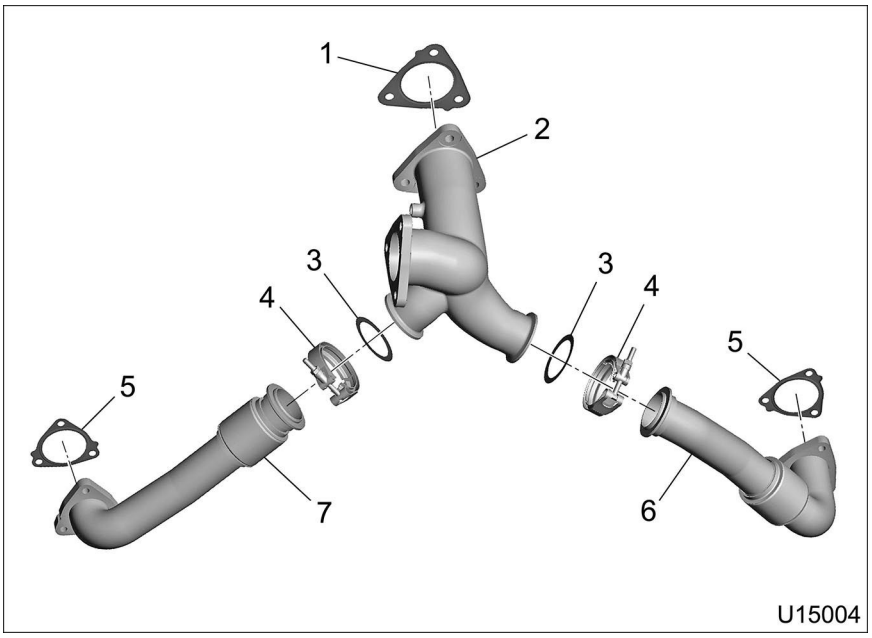


Figure 184 Turbocharger Exhaust Inlet Manifold and Right and Left Exhaust Tube Assemblies

1. Turbocharger inlet gasket
2. Turbo exhaust inlet manifold
3. V-band gasket (2)
4. V-band clamp (2)
5. Exhaust gasket (2)
6. Right exhaust tube assembly
7. Left exhaust tube assembly

5. Remove and discard turbocharger inlet gasket.
6. Remove and discard exhaust gasket from right and left exhaust tube assembly.
7. Loosen two V-band clamps and separate right and left exhaust tube assemblies from turbocharger exhaust inlet manifold.
8. Remove and discard two V-band clamps and two V-band gaskets.

Exhaust Manifolds

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

Left Exhaust Manifold

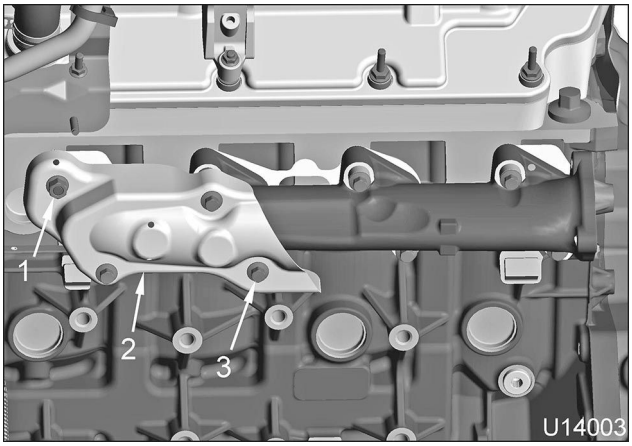


Figure 185 Left Exhaust Manifold Heat Shield

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

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

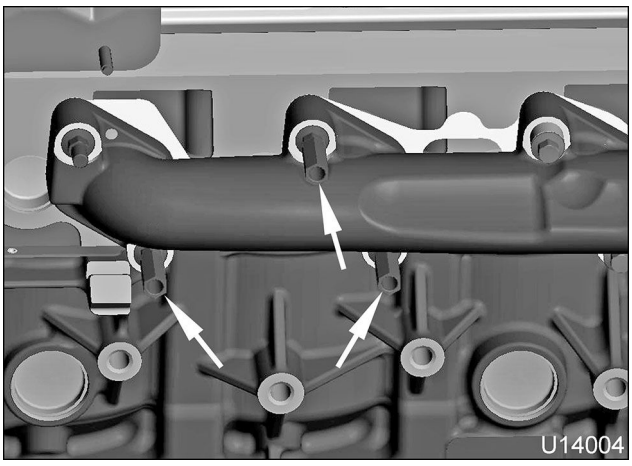


Figure 186 Left Exhaust Manifold Heat Shield Spacers

3. Remove three threaded heat shield spacers.

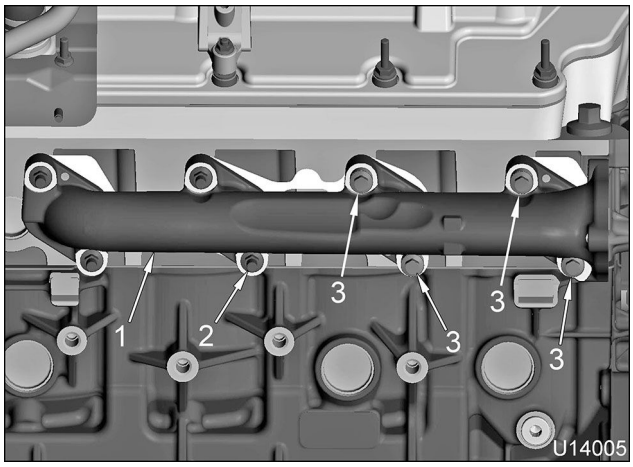


Figure 187 Left Exhaust Manifold

1. Left exhaust manifold
2. M8 x 40 stud bolt (4)
3. M8 x 50 bolt (4) and spacer (4)

4. Remove and discard four M8 x 40 exhaust manifold stud bolts and four M8 x 50 exhaust manifold bolts.
5. Remove four exhaust bolt spacers.

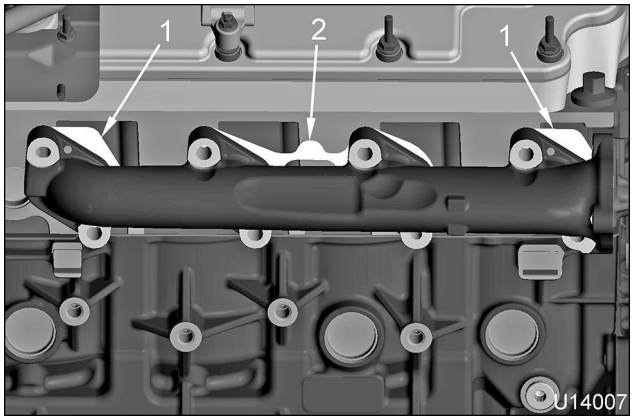


Figure 188 Exhaust Manifold Gaskets

1. Single port gasket (2)
2. Dual port gasket

6. Remove left exhaust manifold and discard two single port gaskets and one dual port gasket.

Right Exhaust Manifold

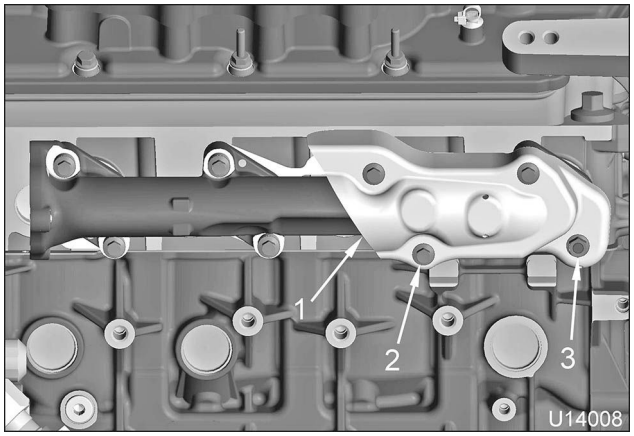


Figure 189 Right Exhaust Manifold Heat Shield

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

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

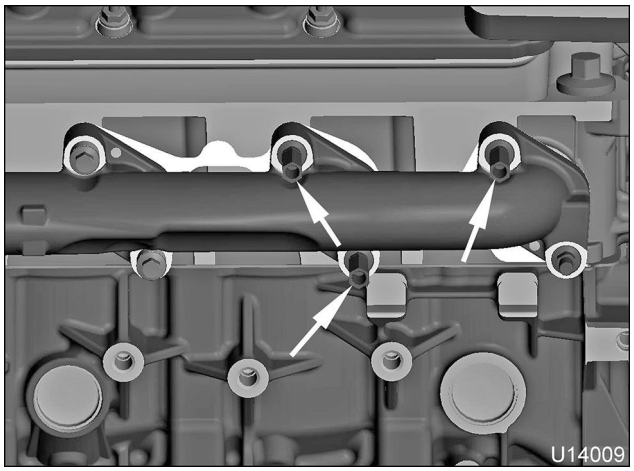


Figure 190 Right Exhaust Manifold Heat Shield Spacers

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

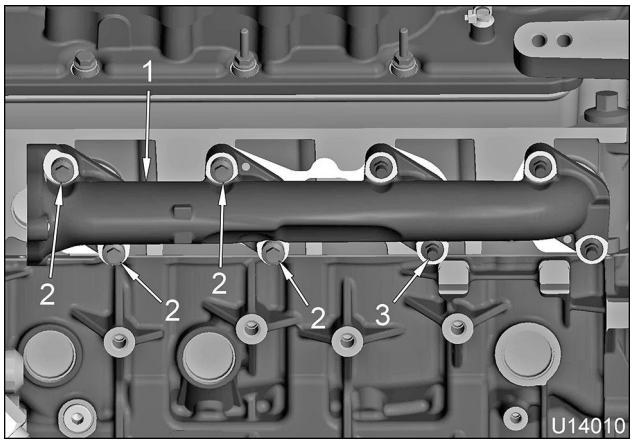


Figure 191 Right Exhaust Manifold

1. Right exhaust manifold
2. M8 x 50 bolt (4) and spacer (4)
3. M8 x 40 stud bolt (4)

4. Remove and discard four M8 x 50 exhaust manifold bolts and four M8 x 40 exhaust manifold stud bolts.
5. Remove four exhaust bolt spacers.

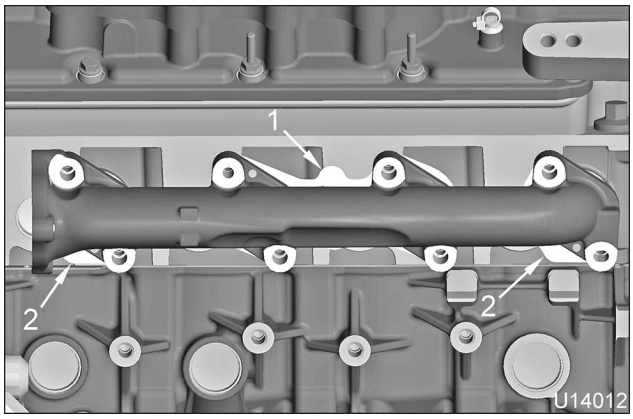


Figure 192 Exhaust Manifold Gaskets

1. Dual port gasket
2. Single port gasket (2)

6. Remove right exhaust manifold and discard two single port gaskets and one dual port gasket.

Pump Cover Heat Shields

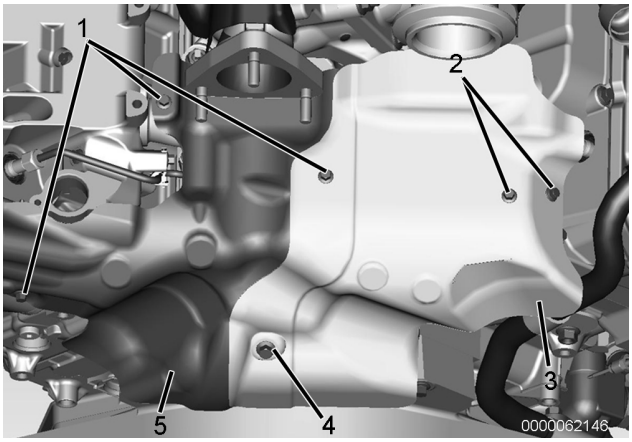


Figure 193 Pump Cover Heat Shields

1. M6 x 14 bolt (3)
2. M6 x 25 bolt (2)
3. Right pump cover heat shield
4. M8 x 12 bolt
5. Left pump cover heat shield

1. Remove M8 x 12 bolt from right pump cover heat shield that overlaps left pump cover heat shield.
2. Remove two M6 x 25 bolts and one M6 x 14 bolt from right pump cover heat shield and remove shield.
3. Remove two M6 x 14 bolts from left pump cover heat shield and remove shield.

Dual Turbocharger Heat Shields

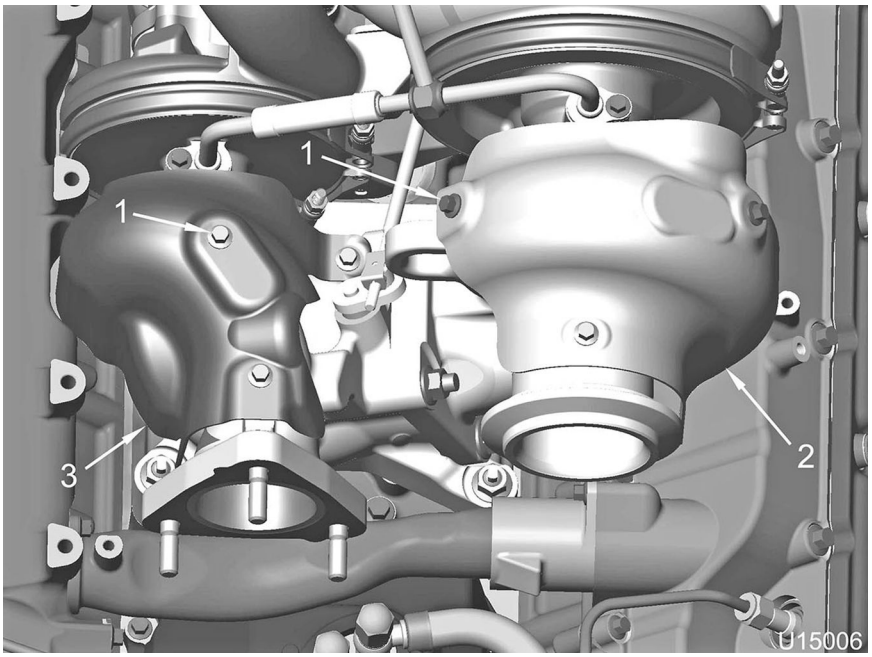
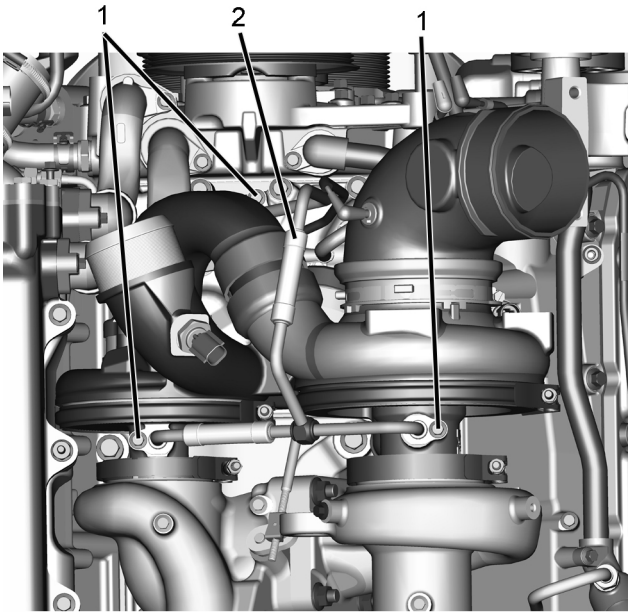


Figure 194 Turbocharger Heat Shields

1. M6 x 10 bolt (6)
2. Low-pressure turbocharger heat shield
3. High-pressure turbocharger heat shield

1. Remove three M6 x 10 bolts from high-pressure turbocharger heat shield.
2. Remove high-pressure turbocharger heat shield.
3. Remove three M6 x 10 bolts from low-pressure turbocharger heat shield.
4. Remove low-pressure turbocharger heat shield.

Turbocharger Oil Supply Tube Assembly



GRAPHIC-121-4CE70D31

Figure 195 Turbocharger Oil Supply Tube Assembly

1. M6 x 14 bolt (3)
2. Turbocharger oil supply tube assembly

1. Remove three M6 x 14 bolts securing turbocharger oil supply tube assembly.
2. Remove turbocharger oil supply tube assembly.

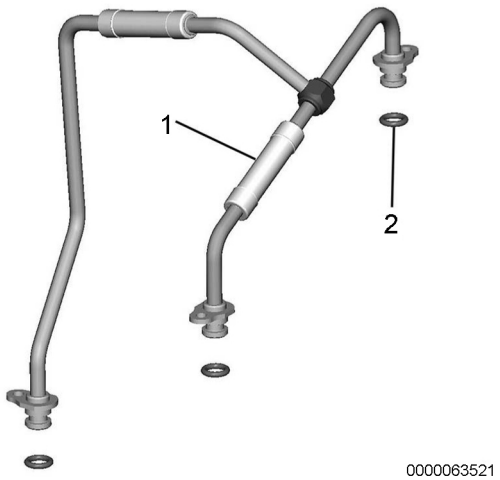


Figure 196 Turbocharger Oil Supply Tube Assembly and O-ring Seals

1. Turbocharger oil supply tube assembly
2. O-ring seal (3)

3. Remove and discard three O-ring seals.

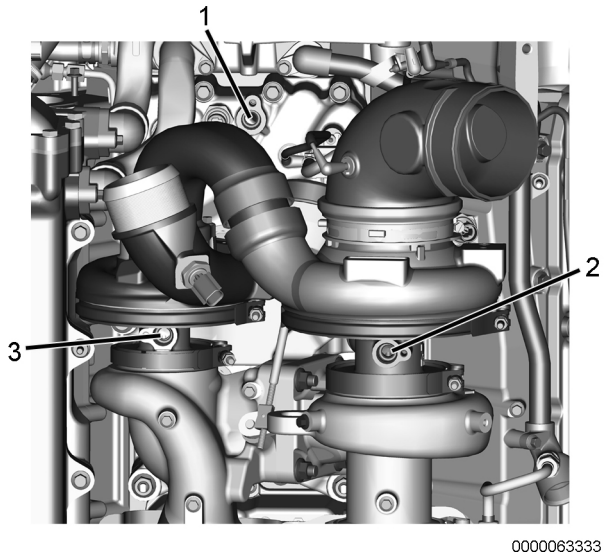


Figure 197 Turbocharger Oil Supply Tube Ports

1. Oil supply tube port in oil cooler cover
2. Oil supply tube port in low-pressure turbocharger assembly
3. Oil supply tube port in high-pressure turbocharger assembly

4. Block turbo oil supply tube port in oil cooler cover with Turbo Oil Supply Blockoff (page 184).
5. Block oil supply tube port for low-pressure turbocharger assembly and high-pressure turbocharger assembly with Turbo Oil Supply Blockoff Plugs (page 184).

Air Duct Assembly, Relief Tube Assembly, Wastegate Tube Assembly, and TC1WC Solenoid

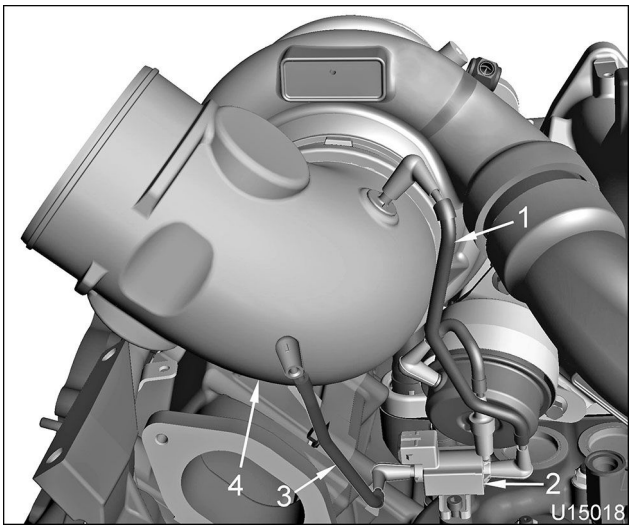


Figure 198 Relief Tube Assembly

1. Relief tube assembly
2. Turbocharger 1 Wastegate Control (TC1WC) solenoid
3. Boost tube assembly
4. Air duct assembly

1. Remove relief tube assembly from air duct assembly and TC1WC solenoid.

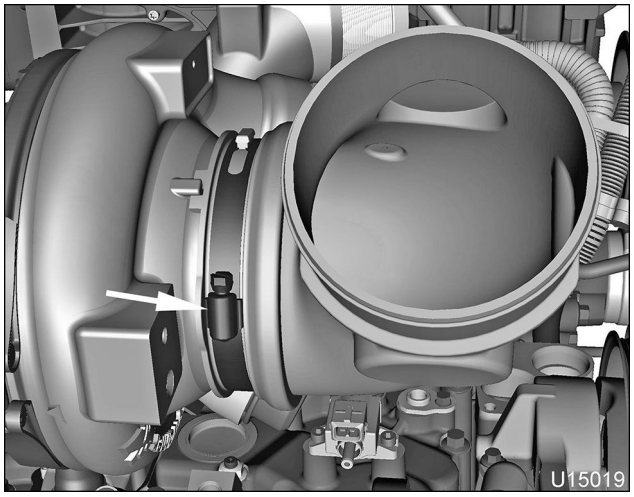


Figure 199 Turbocharger Inlet Clamp

2. Loosen turbocharger inlet clamp and remove air duct assembly.
3. Cover opening of turbocharger assembly air inlet with Cap Kit (page 184).

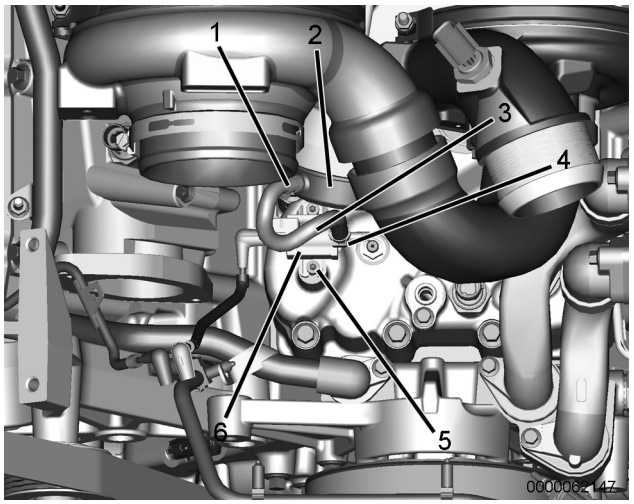


Figure 200 TC1WC Solenoid

1. Hose clamp
2. TC1WC actuator
3. Wastegate hose
4. Crimp clamp
5. M5 x 12 socket head bolt (2)
6. TC1WC solenoid

CAUTION: To prevent damage to TC1WC solenoid, do not disconnect end of wastegate hose from TC1WC solenoid. Disconnect only the end of wastegate hose from TC1WC actuator.

4. Remove two M5 x 12 socket head bolts.
5. Disengage hose clamp from wastegate hose, and remove wastegate hose from TC1WC actuator. Leave other end connected to TC1WC solenoid.
6. Remove two M5 x 12 socket head bolts.
7. Remove TC1WC solenoid.

Dual Turbocharger Assembly

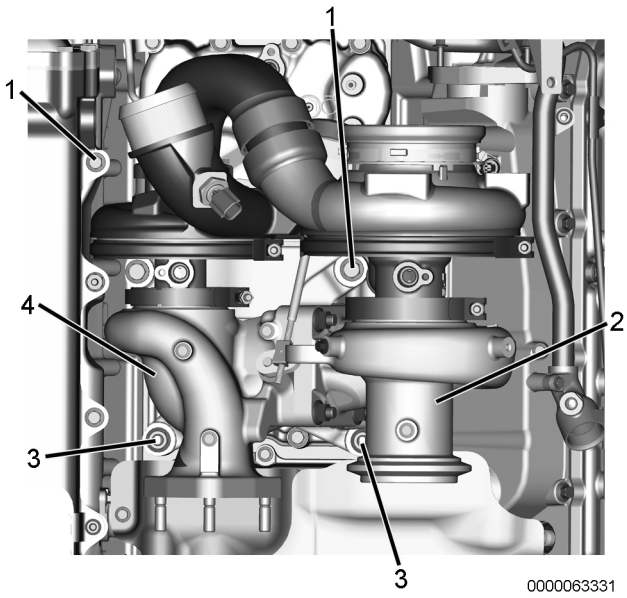


Figure 201 Turbocharger

1. M10 x 55 bolt (2)
2. Low-pressure turbocharger assembly
3. M10 nut (2)
4. High-pressure turbocharger assembly

1. Remove and discard two M10 x 55 bolts.
2. Remove two M10 nuts.

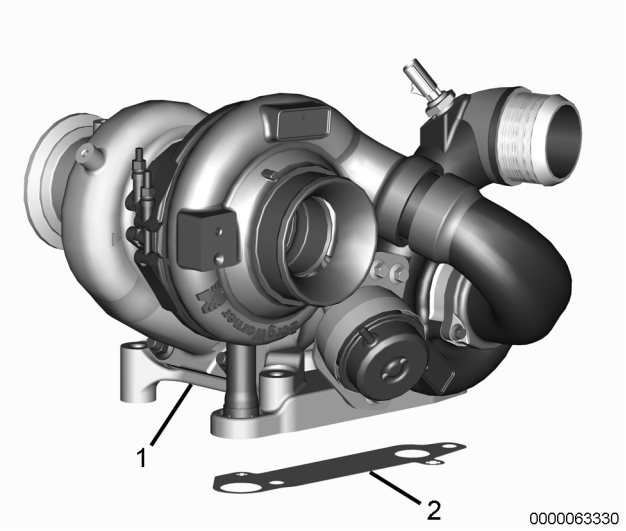


Figure 202 Dual Turbocharger and Turbocharger Oil Drain Gasket

1. Dual turbocharger
2. Turbocharger oil drain gasket

3. Remove dual turbocharger and discard turbocharger oil drain gasket.
4. Put turbocharger on a bench for additional disassembly.

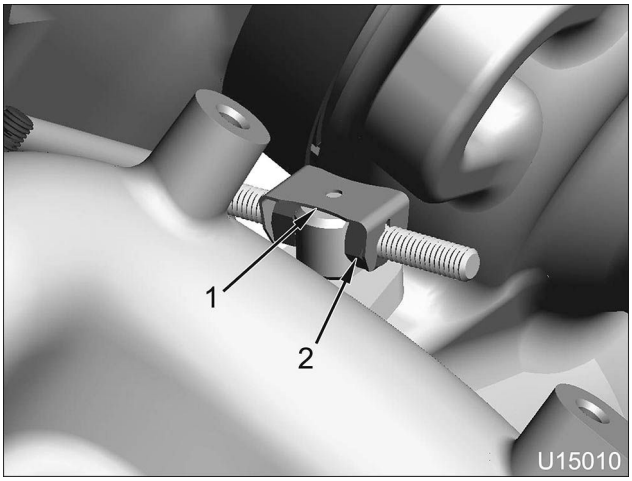


Figure 203 Wastegate Actuator Clip

1. Wastegate actuator clip
2. Nut (2)

5. Use flat head screw driver to pry off wastegate actuator clip covering actuator nuts.
6. Remove nut closest to rod end.

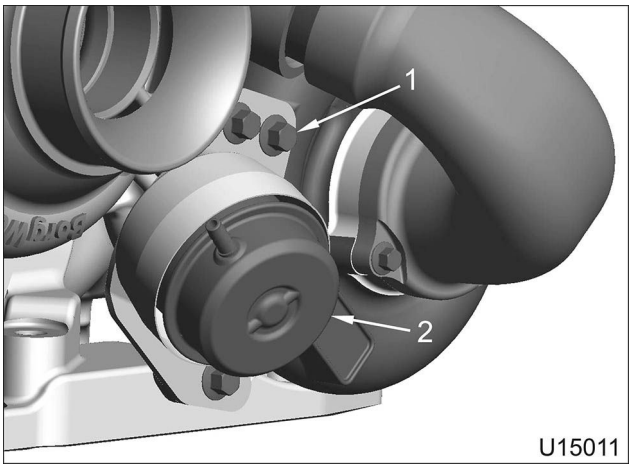


Figure 204 TC1WC Wastegate Actuator Bolts

1. M8 x 16 bolt (3)
2. TC1WC actuator

7. Remove three M8 x 16 bolts and TC1WC actuator.

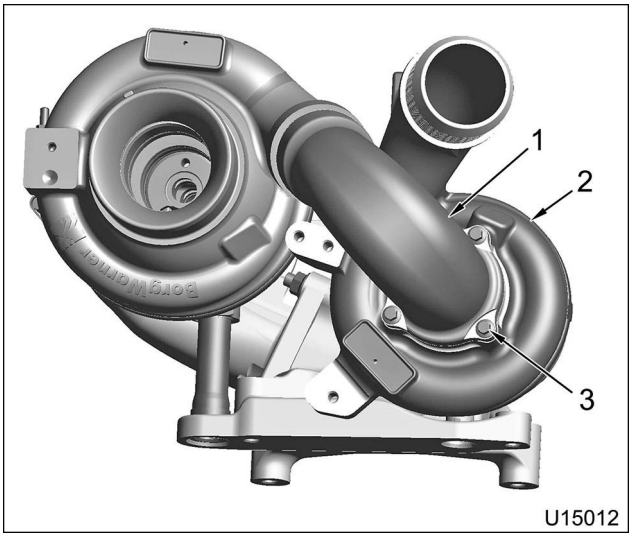


Figure 205 Crossover Tube

1. Crossover tube
2. High-pressure turbocharger assembly
3. M6 x 20 bolt (3)

8. Remove three M6 x 20 bolts from crossover tube flange.
9. Remove crossover tube.

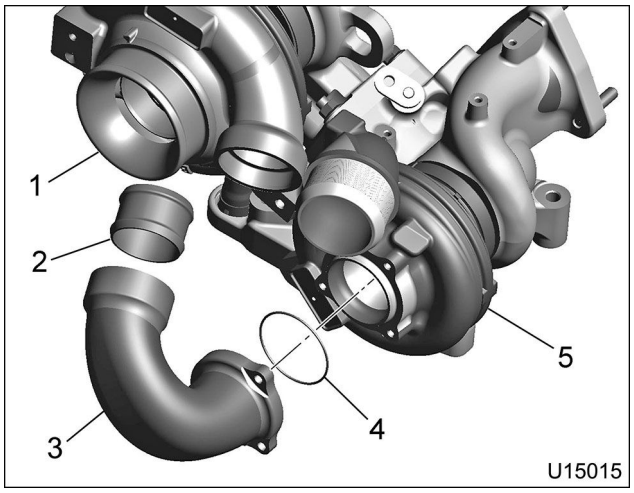


Figure 206 Low-Pressure Turbocharger Seal, Crossover Tube, and O-ring Seal

1. Low-pressure turbocharger
2. Low-pressure turbocharger seal
3. Crossover tube
4. O-ring seal
5. High-pressure turbocharger

10. Remove low-pressure turbocharger seal and discard.

11. Remove and discard O-ring seal from low-pressure turbocharger.

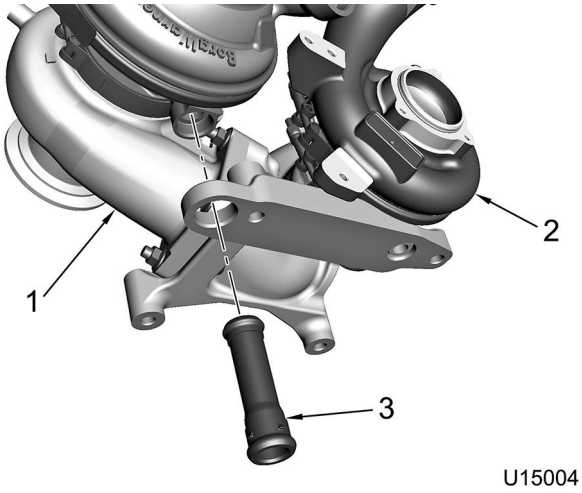


Figure 207 Turbocharger Drain Tubes

1. Low-pressure turbocharger
2. High-pressure turbocharger
3. Low-pressure turbocharger drain tube

12. Remove and discard low-pressure turbocharger drain tube.

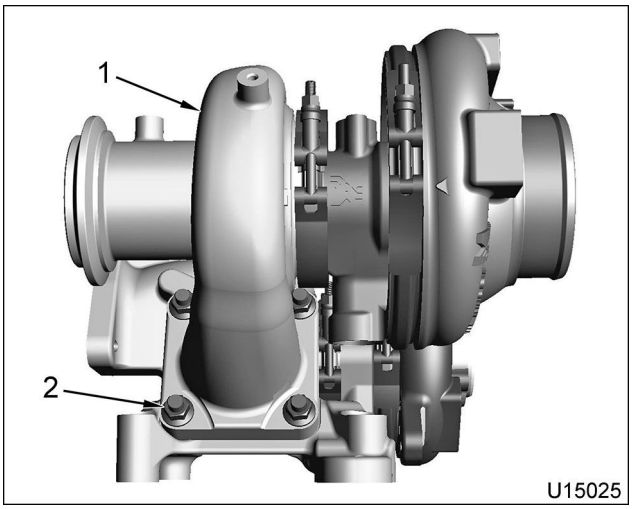


Figure 208 Low-Pressure Turbocharger Assembly

1. Low-pressure turbocharger assembly
2. M10 nut (4)

13. Remove four M10 nuts from flange of low-pressure turbocharger.

14. Separate and remove low-pressure turbocharger from high-pressure turbocharger.

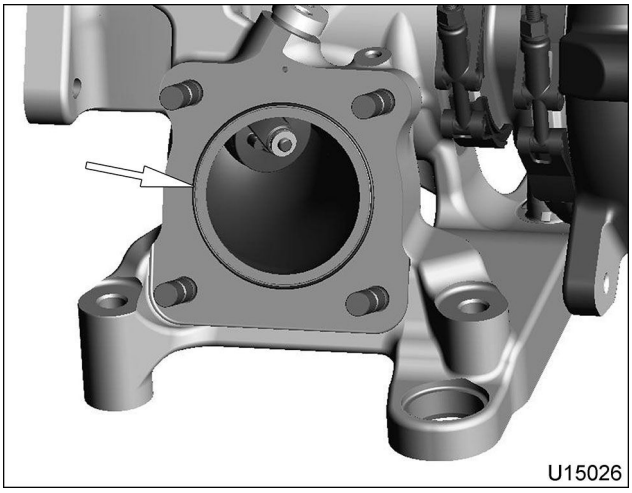


Figure 209 Exhaust Sealing Ring

15. Remove exhaust sealing ring from high-pressure turbocharger assembly.

Cleaning, Inspection, and Testing

Dual Turbocharger Assembly and Related Parts

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 assemblies and related components.

1. Clean piping between turbocharger assemblies 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 supply tube and oil drain tube with suitable solvent and a nylon brush. Dry tubes with filtered compressed air. Replace any damaged tubes.

Dual Turbocharger Assembly Cleaning and Inspection

1. Inspect turbocharger assemblies 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 straighten bent wheel blades.

3. Rotate High-Pressure (HP) and Low-Pressure (LP) turbocharger shafts by hand and check for impeller and compressor wheel contact in housings. Shaft, impeller, and compressor wheel must rotate freely.
   - if metal-to-metal contact or interference is detected, replace turbocharger assembly.
   - If metal-to-metal contact is not detected, do the following procedures.

Disassembly

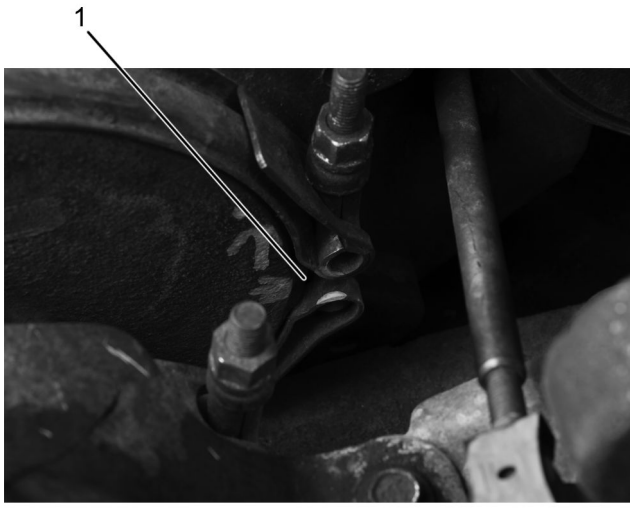


Figure 210 Turbocharger Marking

1. Paint mark

4. Paint mark HP V-band clamp to aid in installation.

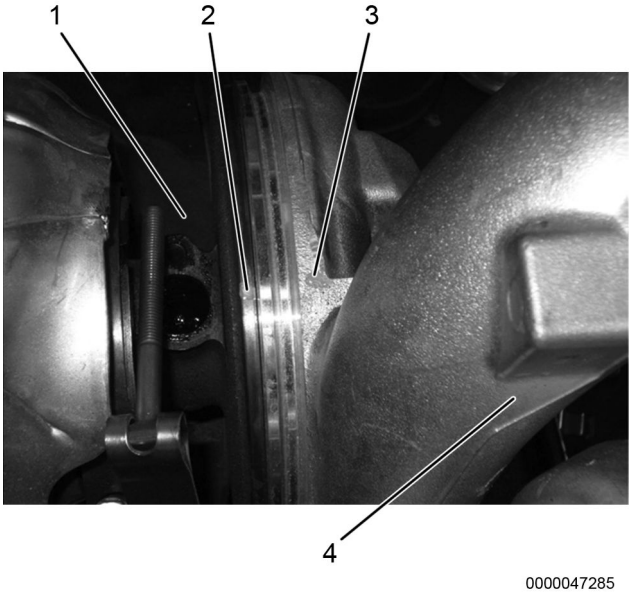


Figure 211 Turbocharger Marking

1. Bearing housing
2. Paint mark on bearing housing
3. Paint mark on compressor cover
4. Compressor cover

5. To aid in installation, mark compressor cover with paint as shown.
6. To aid in installation, mark bearing housing with paint as shown.

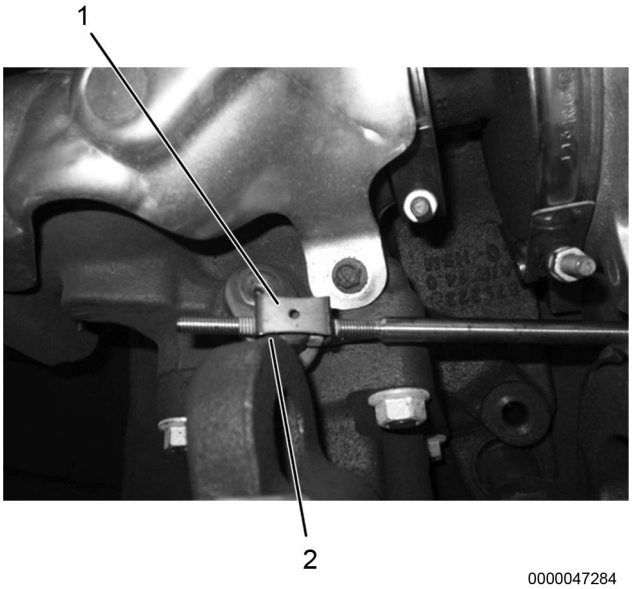


Figure 212 Wastegate Actuator Rod Marking

1. Wastegate actuator rod assembly clip
2. Wastegate actuator rod assembly nut

7. Mark wastegate actuator rod assembly clip and rod with paint.
8. Remove wastegate actuator rod assembly clip from turbocharger assembly.
9. Mark wastegate actuator rod assembly nut and rod with paint.
10. Remove wastegate actuator rod assembly nut from turbocharger assembly.

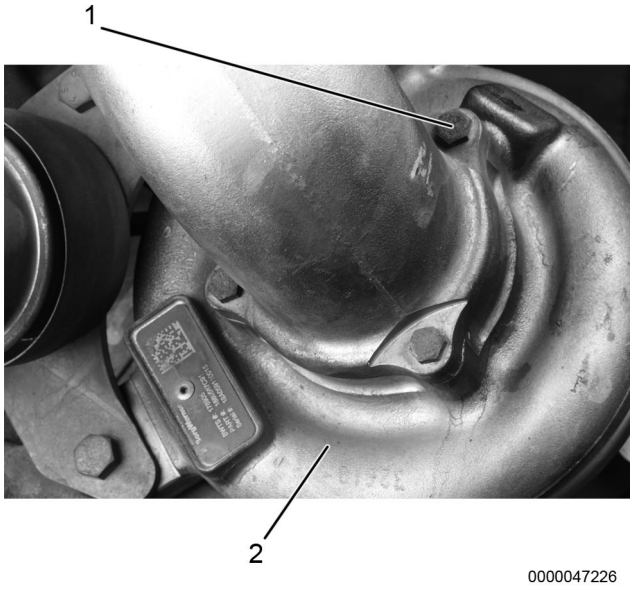


Figure 213 Crossover Tube Mounting

1. Bolt (3)
2. Turbocharger assembly

11. Remove three bolts from turbocharger assembly.

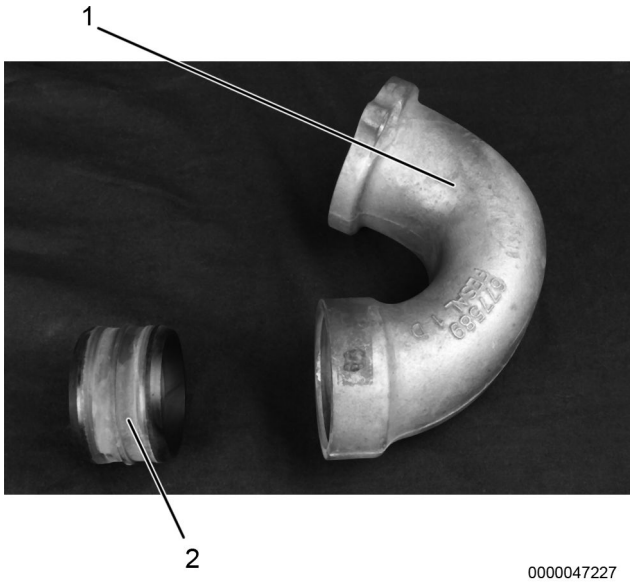


Figure 214 Crossover Tube

1. Crossover tube
2. Crossover tube seal

12. Remove turbocharger crossover tube and turbocharger crossover tube seal from turbocharger assembly. Discard turbocharger crossover tube seal.

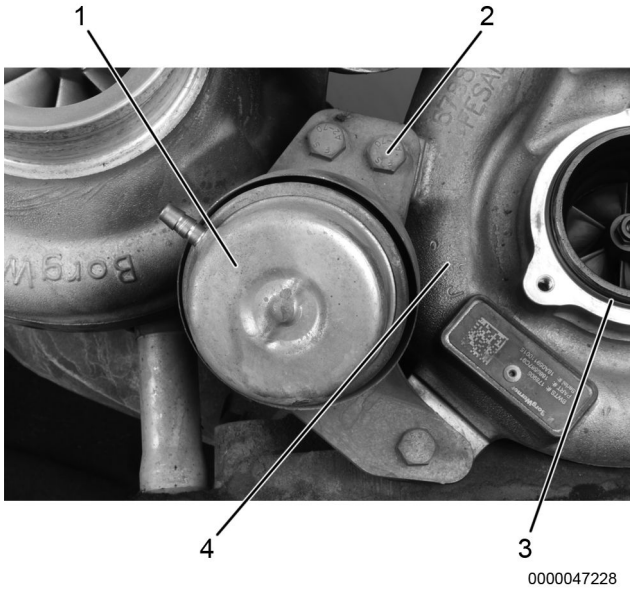


Figure 215 Wastegate Actuator

1. Wsategate actuator assembly
2. Bolt (3)
3. Crossover tube O-ring
4. HP turbocharger assembly

13. Remove and discard turbocharger crossover tube O-ring from HP turbocharger assembly.
14. Remove three bolts from wastegate actuator assembly.
15. Remove wastegate actuator assembly and wastegate actuator rod from turbocharger assembly.

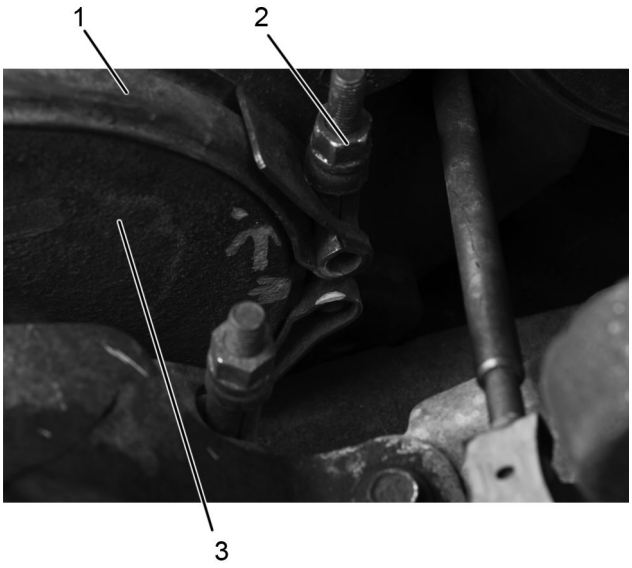


Figure 216 V-Band Clamp

1. HP compressor cover
2. V-band clamp
3. Bearing housing

NOTE: Not removing V-band clamp at this time will help prevent compressor cover hitting compressor wheel when cover is unseated.

16. Loosen V-band clamp securing HP compressor cover to bearing housing. Do not remove V-band clamp.

CAUTION: To prevent contact between compressor cover and aluminum vanes of compressor wheel, the compressor cover must be removed along the axis of the turbocharger shaft. If the vanes are damaged, a new turbocharger must be installed.

17. Tap on HP compressor cover with rubber mallet to unseat compressor cover from bearing housing. Finish loosening V-band clamp and remove compressor cover along axis of turbocharger shaft.

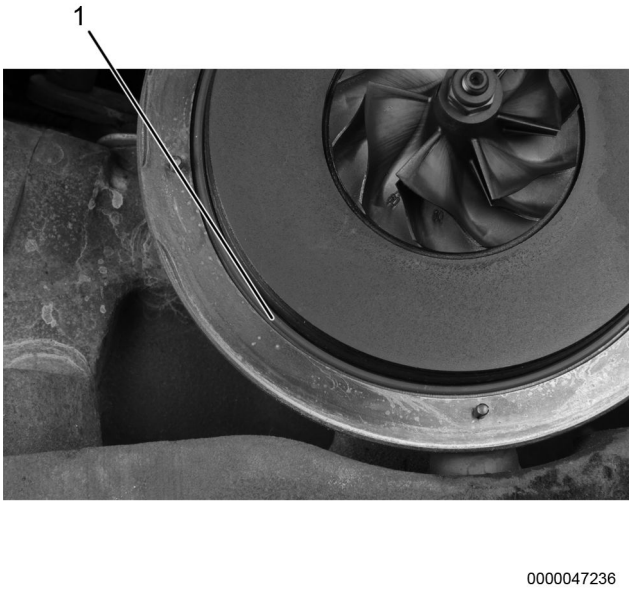
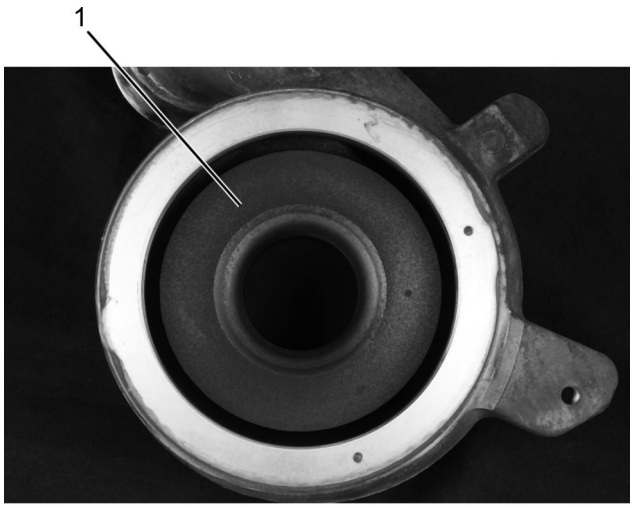


Figure 217 HP Compressor Cover O-ring

1. Compressor cover O-ring

18. Remove and discard O-ring from bearing housing.
19. Match new V-band clamp to old V-band clamp and paint a mark on new V-band clamp, opposite the mark on old V-band clamp. Discard old V-band clamp an nut.



0000047231

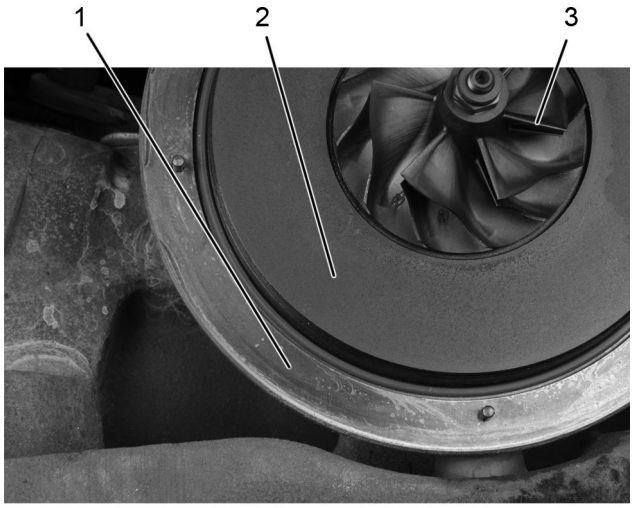
Figure 218 HP Compressor Cover

1. HP compressor cover

CAUTION: To avoid damage to compressor cover, do not use metal tools to remove coked oil deposits from cover. Use wooden or plastic tools to remove deposits.

NOTE: A parts washer should work well to clean compressor cover.

20. Clean coked oil from turbocharger compressor cover with non-metallic scraper, suitable solvent, and lint-free cloth.



0000047234

Figure 219 HP Compressor Housing

1. Bearing housing
2. Diffuser face
3. Compressor vane wheel

21. Place lint-free cloth under bearing housing to absorb solvent and catch debris from cleaning process.

CAUTION: To avoid damage to compressor housing, do not use metal tools to remove coked oil deposits from diffuser face. Use wooden or plastic tools to remove deposits.

CAUTION: To prevent engine damage, do not allow cleaning solvent to contact bearings behind compressor wheel.

NOTE: A scraper may be used to removed coked oil from diffuser face prior to cleaning with solvent.

22. Clean diffuser face and compressor vanes with non-metallic scraper, suitable solvent, and lint-free cloth.

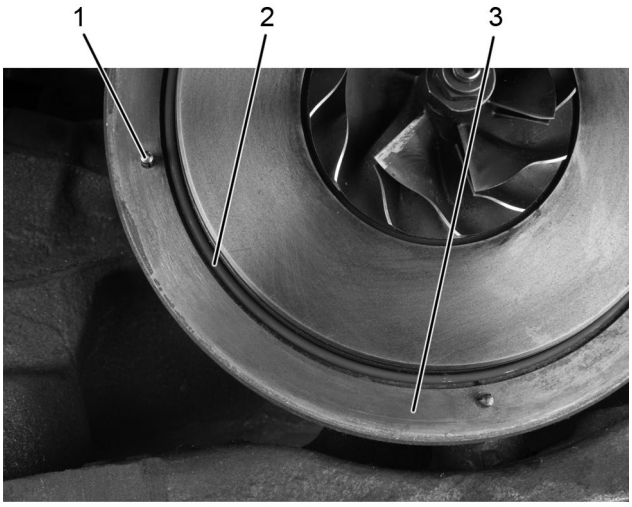
CAUTION: To avoid compressor damage, do not use compressed air to dry diffuser face.

23. After removing all coked oil deposits from HP turbocharger compressor cover and diffuser face, wipe remaining residue with damp, lint-free cloth and dry thoroughly before beginning assembly

procedure. Do no use compressed air to dry components.

24. Repeat steps 16 to 23 for LP compressor.

Assembly

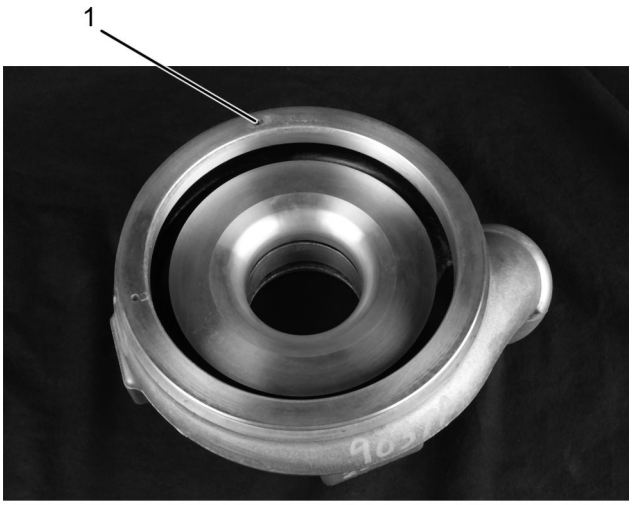


0000047233

Figure 220 LP Compressor Housing

1. Dowel pin (2)
2. Compressor cover O-ring
3. Bearing housing

25. Clean mating surface of bearing housing and dowel pins with suitable solvent and lint-free cloth.
26. Lubricate O-ring with P-80® lubricant or equivalent.
27. Install new LP compressor cover O-ring on bearing housing.
28. Place new V-band clamp loosely on bearing housing and loosely install new V-band nut on new V-band clamp.

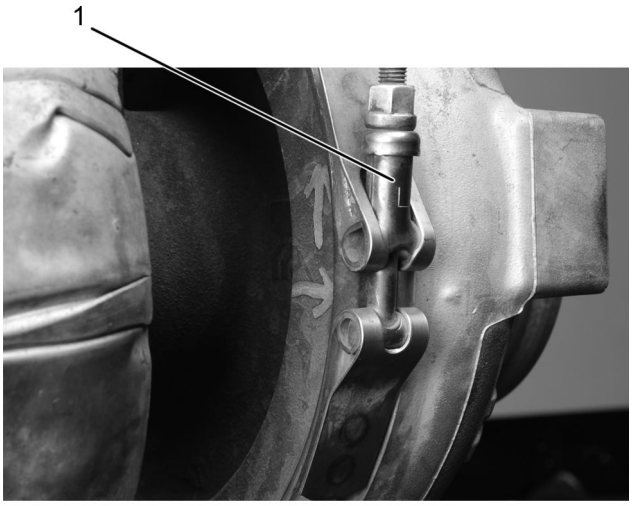


0000047224

Figure 221 LP Compressor Cover

1. LP compressor cover

29. Position LP compressor cover squarely on bearing housing. Align to dowel pin and paint mark that was made during removal.



0000047232

Figure 222 LP Compressor V-band Clamp

1. LP turbocharger V-band clamp

30. Slowly tighten V-band clamp nut to 111 lb-in (12.5 N•m) to seat V-band clamp.
31. Repeat steps 25 to 30 for HP compressor cover.

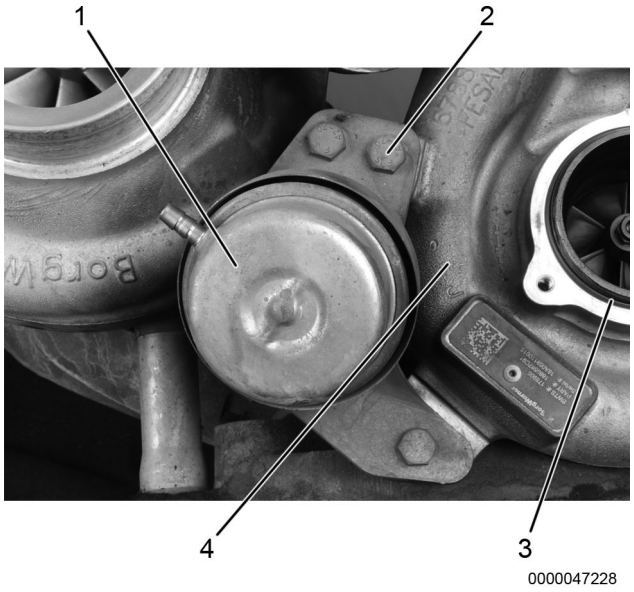


Figure 223 Wastegate Actuator

1. Wastegate actuator assembly
2. Bolt (3)
3. Crossover tube O-ring
4. HP turbocharger assembly

32. Install turbocharger wastegate actuator and rod assembly on HP turbocharger assembly with three bolts. Tighten bolts to 115 lb-in (13 N•m).
33. Lubricate O-ring with P-80® lubricant or equivalent.
34. Install new turbocharger crossover tube O-ring on HP turbocharger assembly.

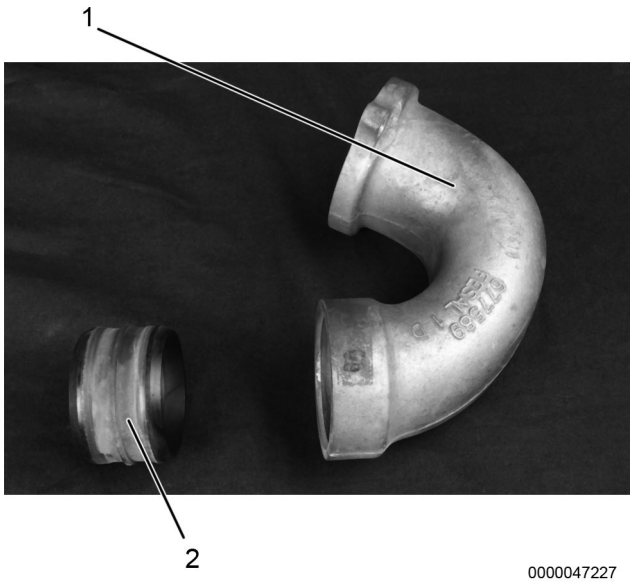


Figure 224 Crossover Tube

1. Crossover tube
2. Crossover tube seal

35. Install new turbocharger crossover tube seal to turbocharger crossover tube.

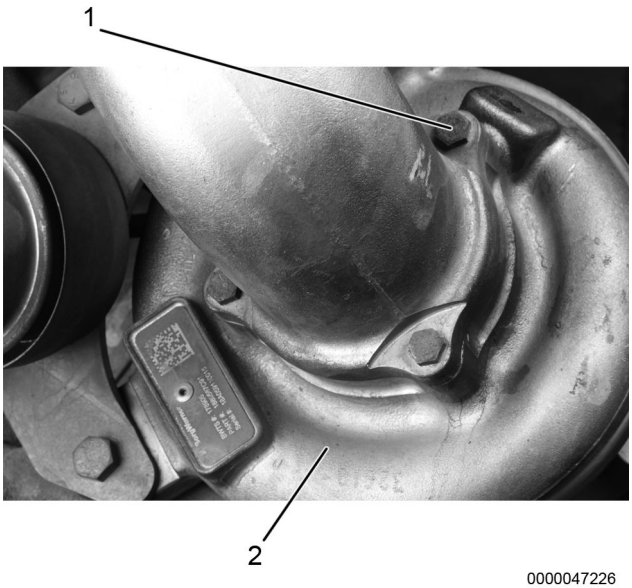


Figure 225 Crossover Tube Mounting

1. Bolt (3)
2. Turbocharger assembly

36. Install turbocharger crossover tube on turbocharger assembly with three bolts. Tighten bolts to 115 lb-in (13 N•m).

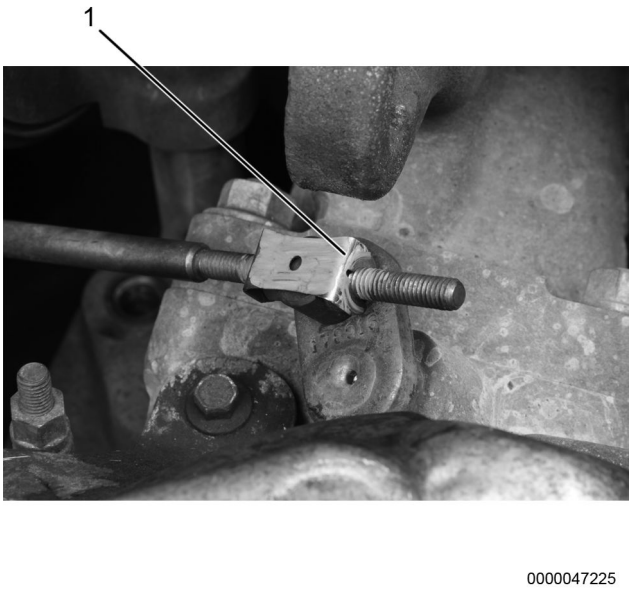


Figure 226 Wastegate Actuator Rod Assembly Clip

1. Wastegate actuator rod assembly clip

37. Adjust wastegate actuator assembly. Refer to (TC1WC Wastegate Actuator Set Procedure, page 169).
38. Install wastegate actuator rod assembly clip.

Check Free Rotation and Housing Rub

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

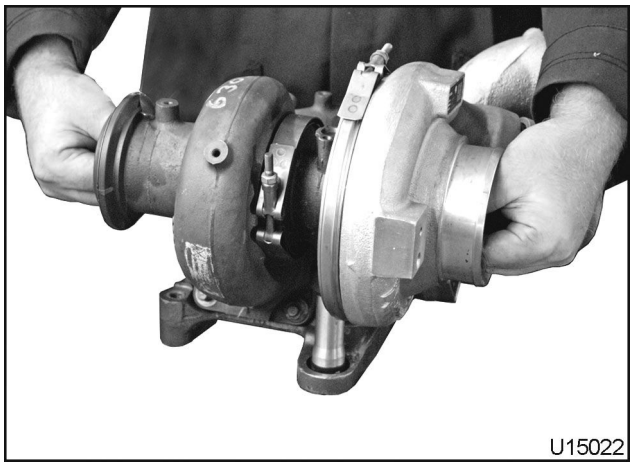


Figure 227 Free Rotation of Turbocharger Assembly Shaft

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

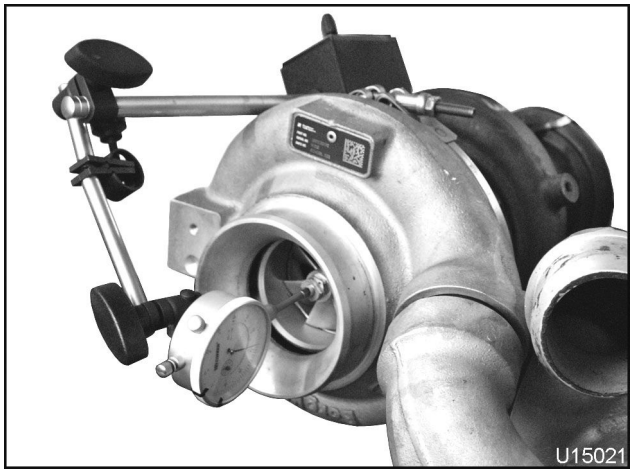


Figure 228 Axial End Play

1. Install dial indicator with magnetic base (page 184). 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 184), replace turbocharger assembly.

TC1WC Wastegate Actuator Set Procedure

NOTE: If the entire high-pressure turbocharger assembly is replaced, the TC1WC actuator does not need any adjustment, since it was set at the factory.

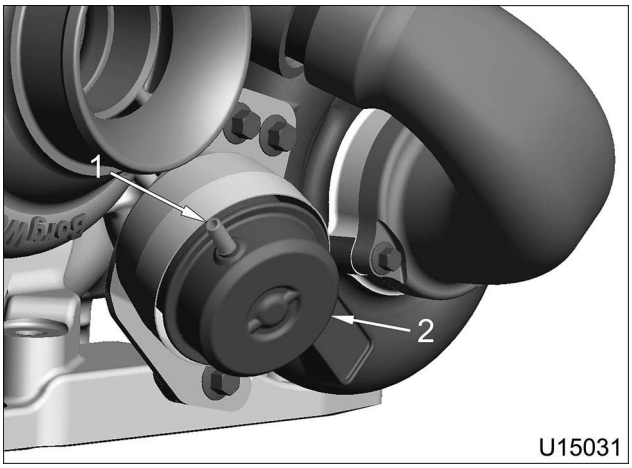


Figure 229 TC1WC Actuator

1. Wastegate actuator nipple
2. TC1WC actuator

1. Connect shop air pressure input line with air pressure regulator to the TC1WC actuator nipple.

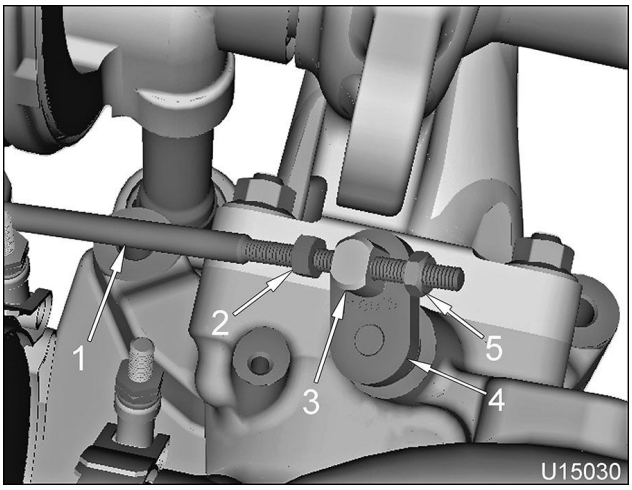


Figure 230 Wastegate Actuator Rod and Nuts

1. Wastegate actuator rod
2. Inner nut
3. Pivot block
4. Lever arm
5. Outer nut

2. Loosely install outer rod nut.
3. Fully seat TC1WC wastegate actuator on valve seat of wastegate port and hold closed.
4. Run inner nut up to linkage pivot block until it sits firmly against block, then run outer nut to other side of pivot block.

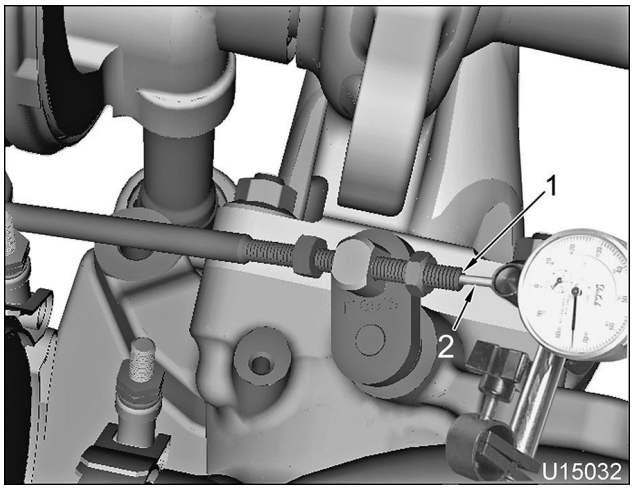


Figure 231 Magnetic Dial Indicator

1. Actuator rod end
2. Dial indicator tip

5. Use a dial indicator with magnetic base (page 184) to measure travel of actuator rod. Place indicator tip against end of actuator rod parallel to the axis of the actuator rod.

Set Point	Pressure	Extension
	kPa (psig)	mm (inches)
Set point	96.5 ± 3	0
	(14.0 ± 0.5)	(0)
A	110.3 ± 3	2.02 ± 2.01
	(16.0 ± 0.5)	(0.0795 ± .079)
B	144.8 ± 3	5.97 ± 2.59
	(21.0 ± 0.5)	(.235 ± .102)
C	193.1 ± 3	10.71 ± 1.87
	(28.0 ± 0.5)	(.4215 ± .074)

6. Check TC1WC actuator set point:
   - If set point is above limit, tighten top nut and loosen bottom nut, and recheck hysteresis.
   - Follow above steps until set point meets specification.

7. Release pressure from TC1WC actuator.

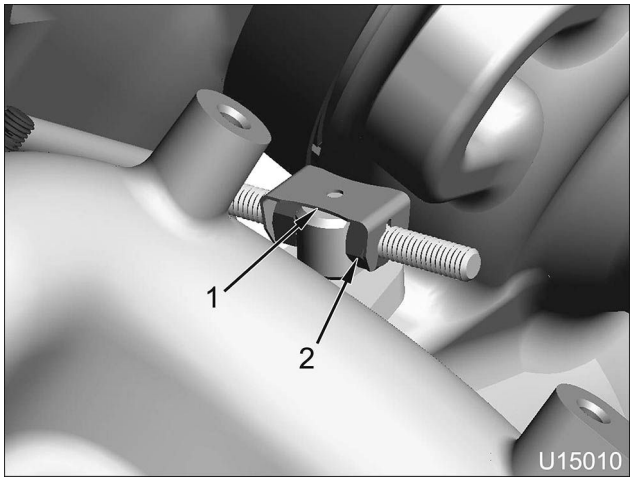


Figure 232 Wastegate Actuator Clip

1. Wastegate actuator clip
2. Nut (2)

8. Install actuator clip over lever arm assembly.
9. Disconnect pressure input line to actuator nipple.

Exhaust Manifolds

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

Dual Turbochargers

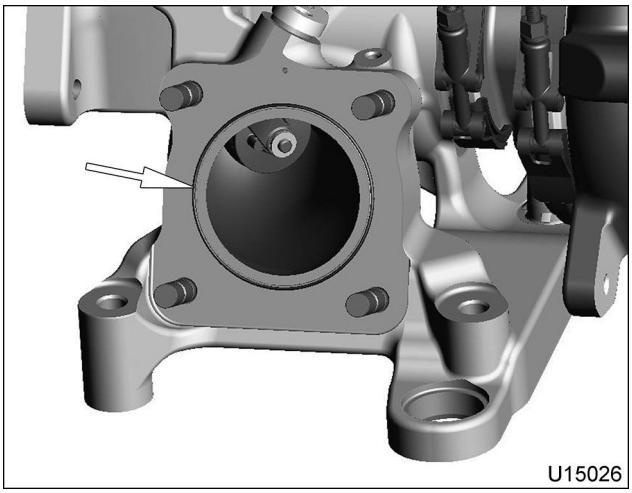


Figure 233 Exhaust Sealing Ring

1. Install new exhaust sealing ring.

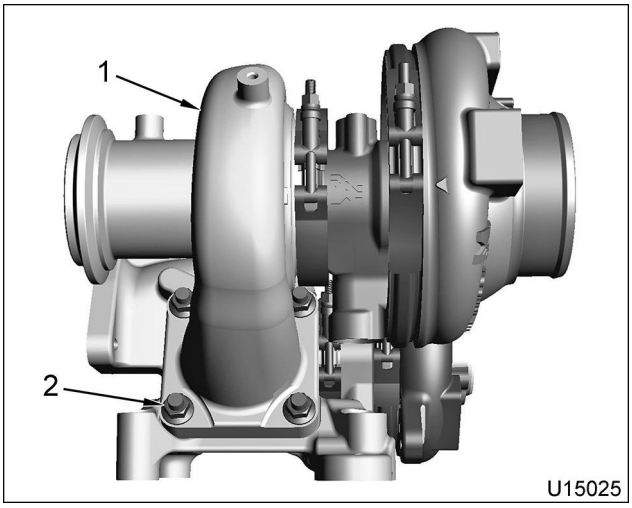


Figure 234 Low-Pressure Turbocharger Assembly

1. Low-pressure turbocharger assembly
2. M10 nut (4)

2. Join low-pressure turbocharger and high-pressure turbocharger.
3. Install four M10 nuts to secure low-pressure turbocharger to high-pressure turbocharger. Tighten M10 nuts to standard torque (page 473).

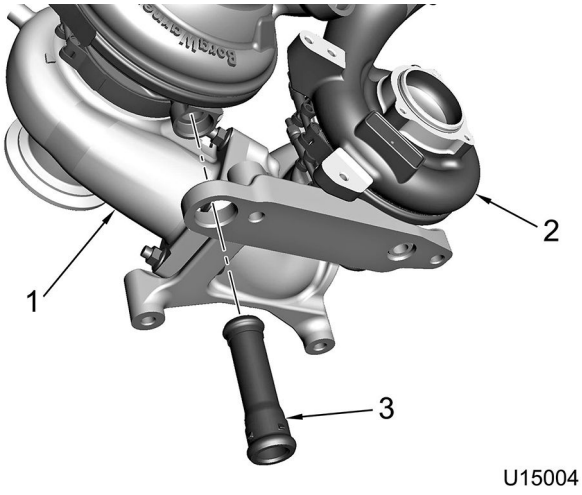


Figure 235 Turbocharger Drain Tube

1. Low-pressure turbocharger
2. High-pressure turbocharger
3. Low-pressure turbocharger drain tube

4. Lubricate new low-pressure turbocharger drain tube with P-80® Rubber Lubricant or equivalent (page 184) and install drain tube.

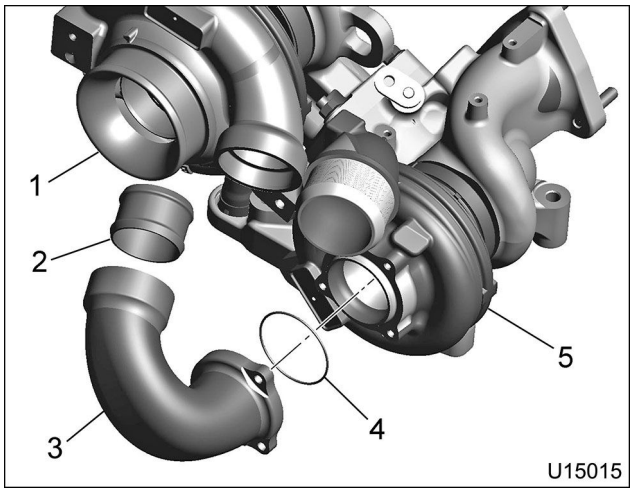


Figure 236 Low-Pressure Turbocharger Seal, Crossover Tube, and O-ring Seal

1. Low-pressure turbocharger
2. Low-pressure turbocharger seal
3. Crossover tube
4. O-ring seal
5. High-pressure turbocharger

5. Lubricate new low-pressure turbocharger seal with P-80® Rubber Lubricant or equivalent (page 184). Install low-pressure turbocharger seal into high-pressure turbocharger.
6. Lubricate new O-ring seal with P-80® Rubber Lubricant or equivalent (page 184). Install O-ring seal into low-pressure turbocharger.

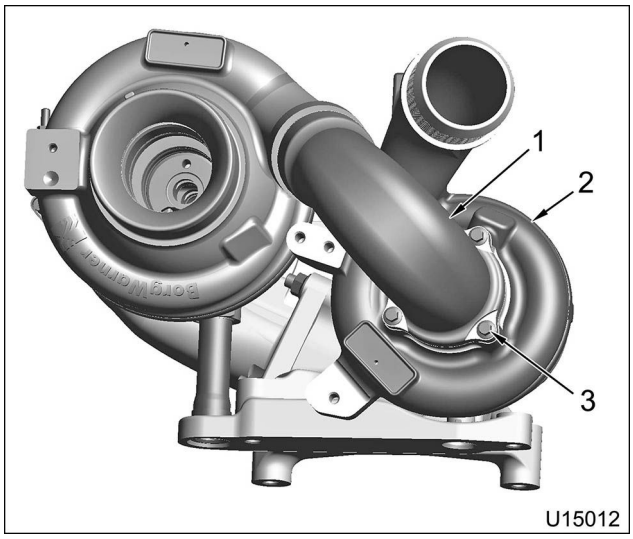


Figure 237 Crossover Tube

1. Crossover tube
2. High-pressure turbocharger assembly
3. M6 x 20 bolt (3)

7. Install crossover tube.
8. Install three M6 x 20 bolts to secure crossover tube flange to high-pressure turbocharger. Tighten bolts to standard torque (page 473).

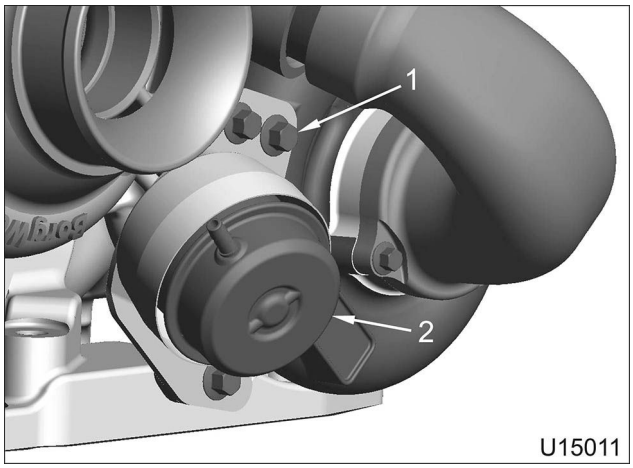


Figure 238 Wastegate Actuator Bolts

1. M8 x 16 bolt (3)
2. TC1WC actuator

9. Remove outer nut, thread down inner nut, slide actuator rod into pivot block, and position TC1WC actuator against mounting flange.

10. Install three M8 x 16 bolts to secure TC1WC actuator. Tighten bolts to standard torque (page 473).

NOTE: See TC1WC Actuator Set Procedure (page 169).

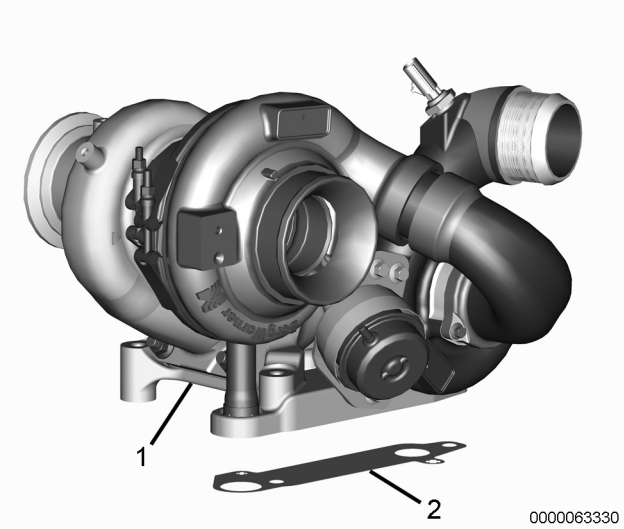


Figure 239 Dual Turbocharger and Turbocharger Oil Drain Gasket

1. Dual turbocharger
2. Turbocharger oil drain gasket

11. Install new turbocharger oil drain gasket and dual turbocharger onto engine.

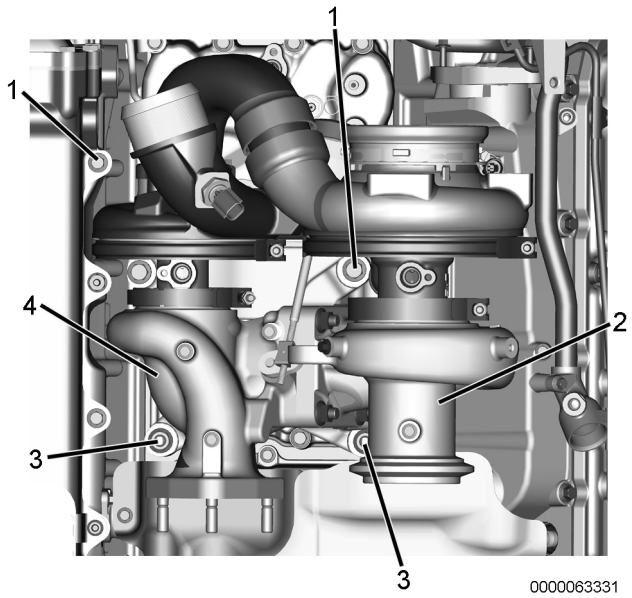


Figure 240 Turbocharger

1. M10 x 55 bolt (2)
2. Low-pressure turbocharger assembly
3. M10 nut (2)
4. High-pressure turbocharger assembly

12. Install two M10 x 55 bolts. Tighten bolts to standard torque (page 473).
13. Install two M10 nuts. Tighten nuts to standard torque (page 473).

TC1WC Solenoid, Wastegate Hose Assembly, Relief Tube Assembly, and Air Duct Assembly

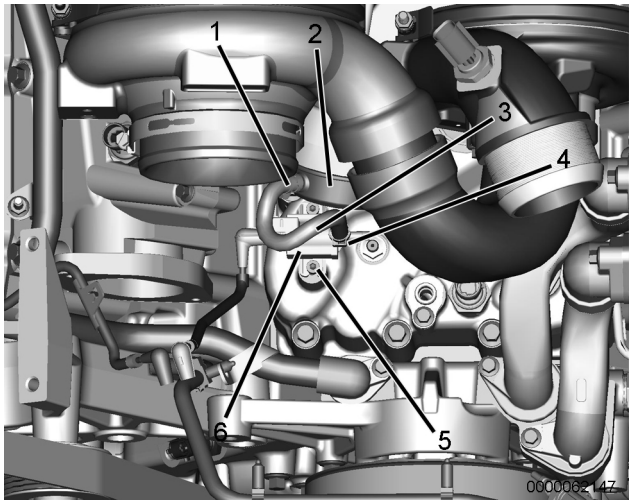


Figure 241 TC1WC solenoid

1. Hose clamp
2. TC1WC actuator
3. Wastegate hose
4. Crimp clamp
5. M5 x 12 socket head bolt (2)
6. TC1WC solenoid

1. Install TC1WC solenoid.
2. Install two M5 x 12 socket head bolts. Tighten bolts to standard torque (page 473).
3. Connect wastegate hose to TC1WC actuator with hose clamp.

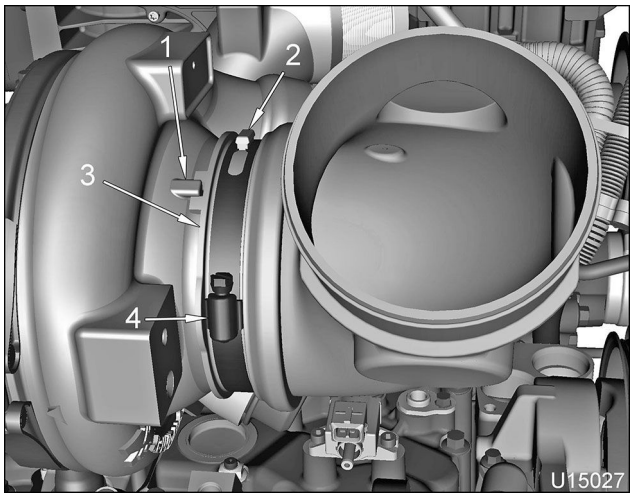


Figure 242 Turbocharger Inlet Clamp

1. Tab on inlet flange of low-pressure turbocharger
2. Tab on duct cuff
3. Duct cuff
4. Turbocharger inlet clamp

4. Align duct cuff with tab on inlet flange of low-pressure turbocharger and install air duct assembly.
5. Rotate clamp to engage narrow slot in clamp with tab on duct cuff and tighten turbocharger inlet clamp to special torque (page 184).

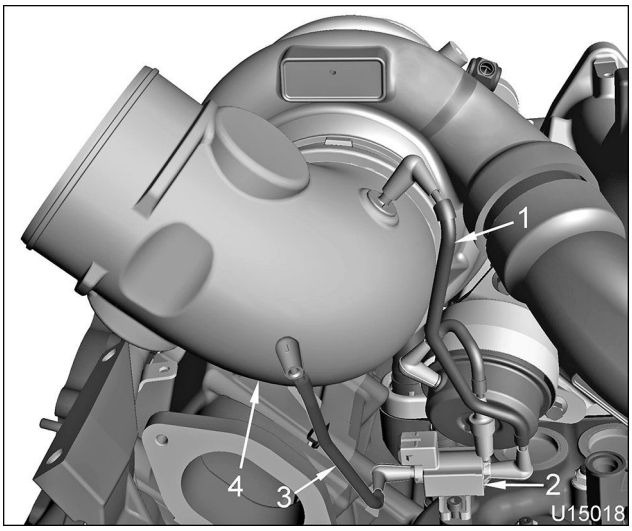


Figure 243 Relief Tube Assembly

1. Relief tube assembly
2. TC1WC solenoid
3. Boost tube assembly
4. Air duct assembly

6. Install relief tube assembly to air duct assembly and TC1WC solenoid.

Turbocharger Oil Supply Tube

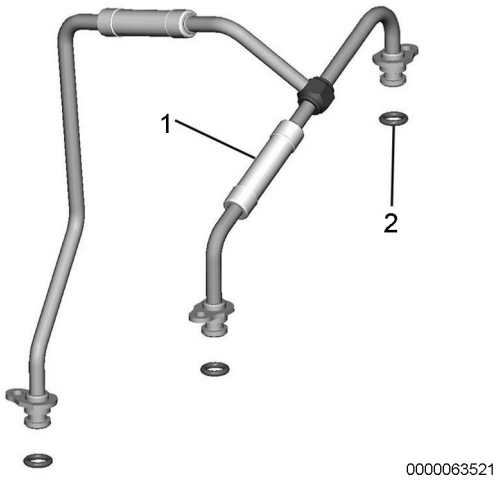
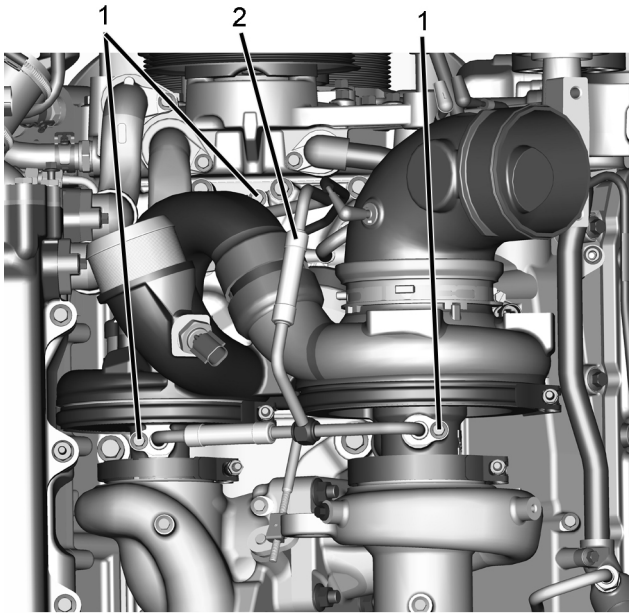


Figure 244 Turbocharger Oil Supply Tube and O-ring Seals

1. Turbocharger oil supply tube
2. O-ring seal (3)

1. Lubricate three new O-ring seals with P-80® Rubber Lubricant or equivalent (page 184) and install O-rings seals.
2. Remove plugs from three oil supply tube ports.



GRAPHIC-121-4CE70D31

Figure 245 Turbocharger Oil Supply Tube

1. M6 x 14 bolt (3)
2. Turbocharger oil supply tube assembly

3. Lubricate oil supply tube port of each turbocharger assembly with clean engine oil and spin compressor wheel several times to coat bearings with oil. Refill supply tube port of each turbocharger assembly up to oil supply tube assembly mounting surface.
4. Install turbocharger oil supply tube assembly.
5. Install three M6 x 14 bolts securing turbocharger oil supply tube. Tighten bolts to standard torque (page 473).

Dual Turbocharger Heat Shields

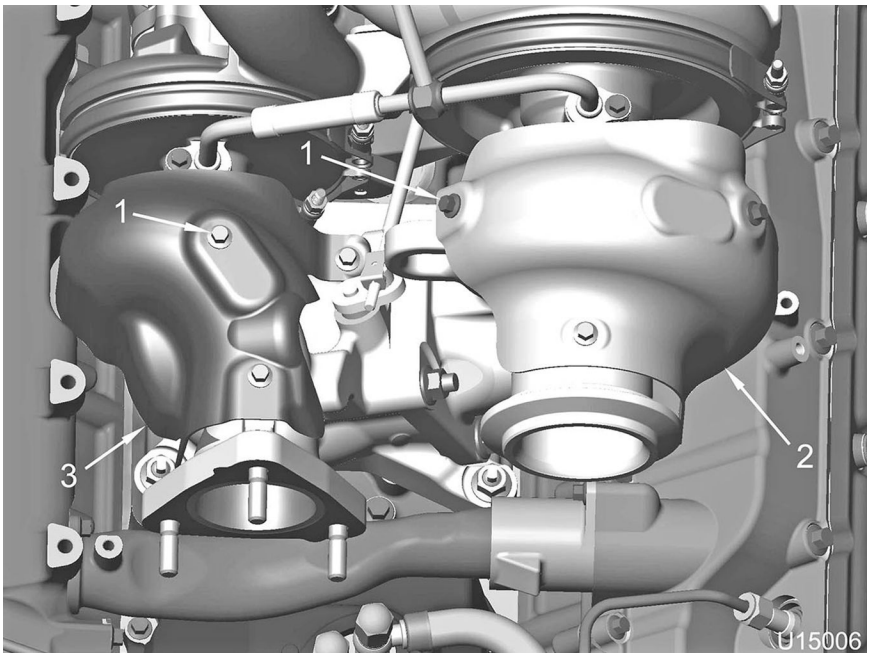


Figure 246 Dual Turbocharger Heat Shields

1. M6 x 10 bolt (6)
2. Low-pressure turbocharger heat shield
3. High-pressure turbocharger heat shield

1. Position high-pressure turbocharger heat shield.
2. Install three M6 x 10 bolts to secure high-pressure turbocharger heat shield. Tighten bolts to standard torque (page 473).
3. Position low-pressure turbocharger heat shield.
4. Install three M6 x 10 bolts to secure low-pressure turbocharger heat shield. Tighten bolts to standard torque (page 473).

Pump Cover Heat Shields

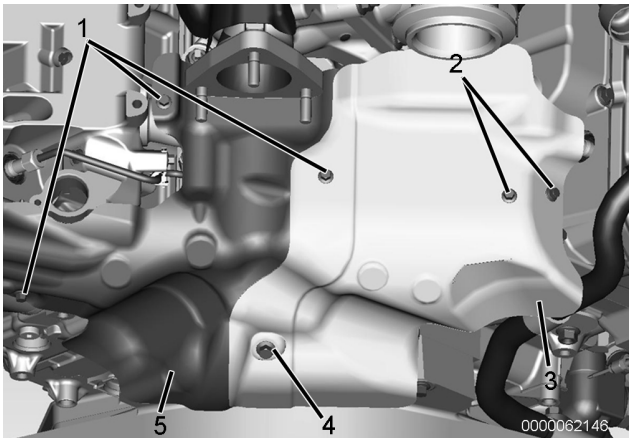


Figure 247 Pump Cover Heat Shields

1. M6 x 14 bolt (3)
2. M6 x 25 bolt (2)
3. Right pump cover heat shield
4. M8 x 12 bolt
5. Left pump cover heat shield

1. Position left pump cover heat shield over pump and install two M6 x 14 bolts. Tighten bolts to standard torque (page 473).
2. Position right pump cover heat shield over pump and install two M6 x 25 bolts and one M6 x 14 bolt. Tighten bolts to standard torque (page 473).
3. Install M8 x 12 bolt and M6 x 14 bolt to secure overlapping heat shields. Tighten bolts to standard torque (page 473).

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

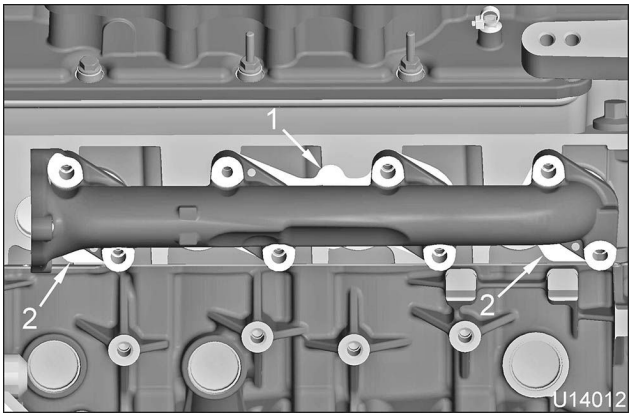


Figure 248 Exhaust Manifold Gaskets (Right Ride)

1. Dual port gasket
2. Single port gasket (2)

1. Position new single port gaskets, new dual port gasket, and right exhaust manifold on engine.

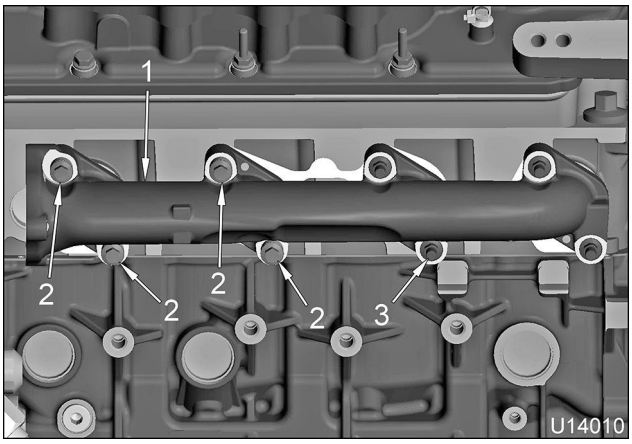


Figure 249 Right Exhaust Manifold

1. Right exhaust manifold
2. M8 x 50 bolt (4) and spacer (4)
3. M8 x 40 stud bolt (4)

2. Install four exhaust bolt spacers, four new M8 x 50 exhaust manifold bolts, and four M8 x 40 exhaust manifold stud bolts.
3. Hand tighten bolts and stud bolts.

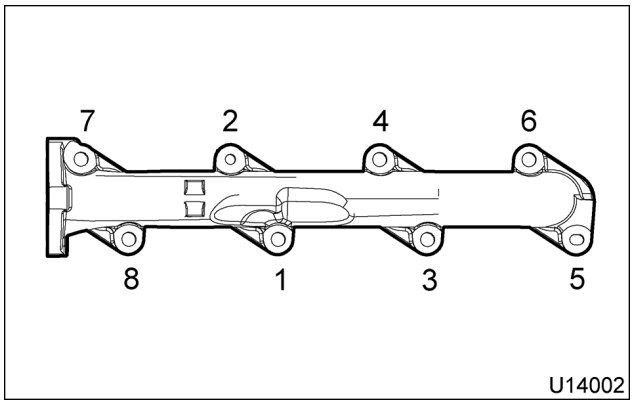


Figure 250 Torque Sequence for Right Exhaust Manifold Bolts and Stud Bolts

4. Tighten bolts and stud bolts as follows:
   - If cylinder head is new, tighten bolts and stud bolts to 30 N·m (22 lb·ft) following torque sequence. Retighten bolts and stud bolts to 30 N·m (22 lb·ft) using same sequence.
   - If cylinder head is used, tighten bolts and stud bolts to 25 N·m (18 lb·ft) following torque sequence. Retighten bolts and stud bolts to 25 N·m (18 lb·ft) using same sequence.

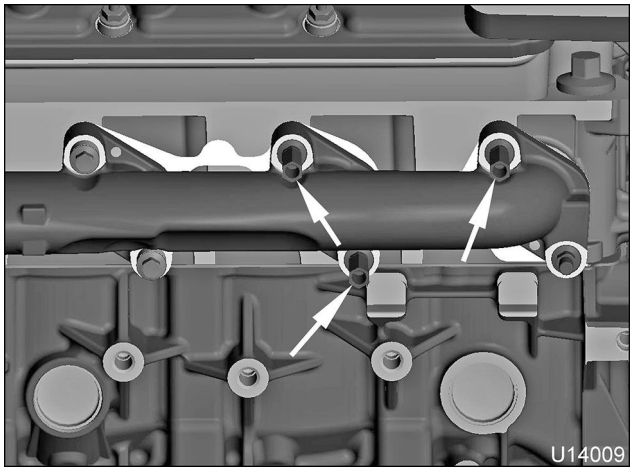


Figure 251 Right Exhaust Manifold Heat Shield Spacers

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

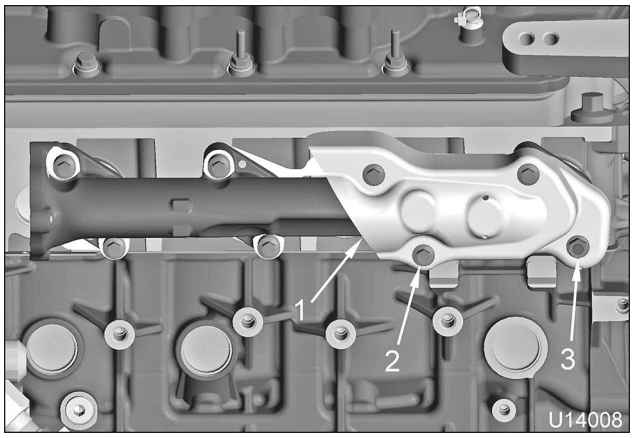


Figure 252 Right Exhaust Manifold Heat Shield

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

6. Install right exhaust manifold heat shield.
7. 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

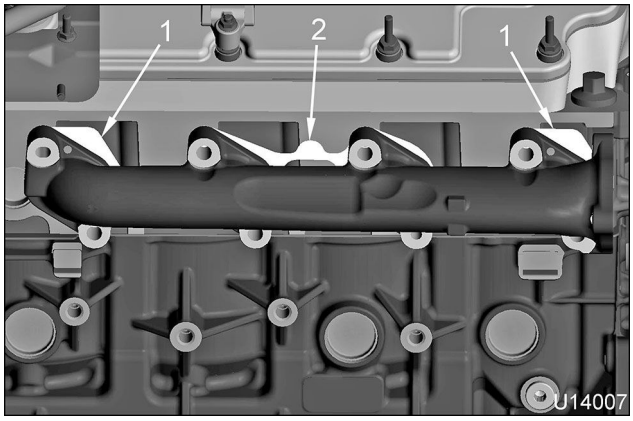


Figure 253 Exhaust Manifold Gaskets (Left Side)

1. Dual port gasket
2. Single port gasket (2)

1. Position new single port gaskets, new dual port gasket, and right exhaust manifold on engine.

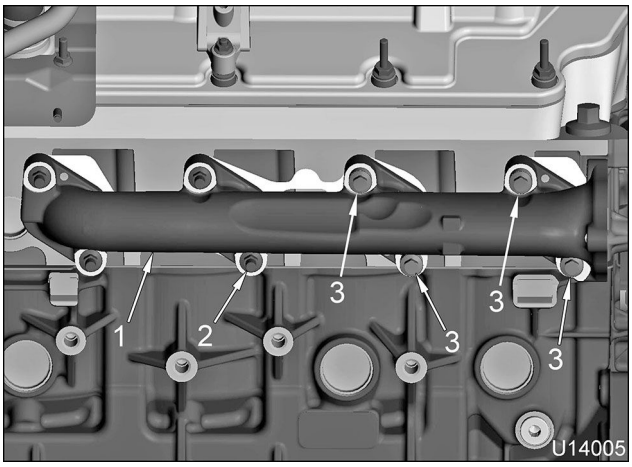


Figure 254 Left Exhaust Manifold

1. Left exhaust manifold
2. M8 x 40 stud bolt (4)
3. M8 x 50 bolt (4) and spacer (4)

2. Install four exhaust bolt spacers, four new M8 x 50 exhaust manifold bolts, and four M8 x 40 exhaust manifold stud bolts.
3. Hand tighten bolts and stud bolts.

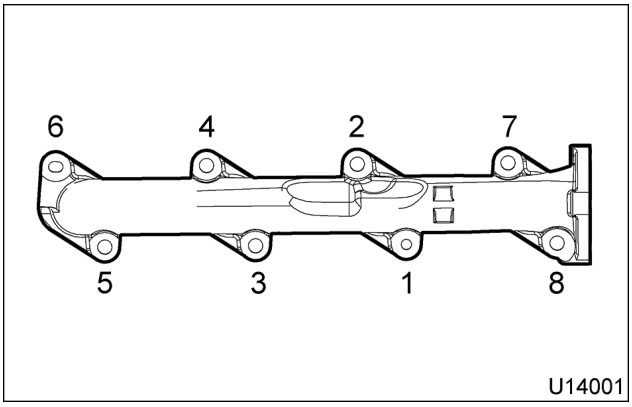


Figure 255 Torque Sequence for Left Exhaust Manifold Bolts and Stud Bolts

4. Tighten bolts and stud bolts as follows:

- If cylinder head is new, tighten bolts and stud bolts to 30 N·m (22 lb·ft) following torque sequence. Retighten bolts and stud bolts to 30 N·m (22 lb·ft) using same sequence.
- If cylinder head is used, tighten bolts and stud bolts to 25 N·m (18 lb·ft) following torque sequence. Retighten bolts and stud bolts to 25 N·m (18 lb·ft) using same sequence.

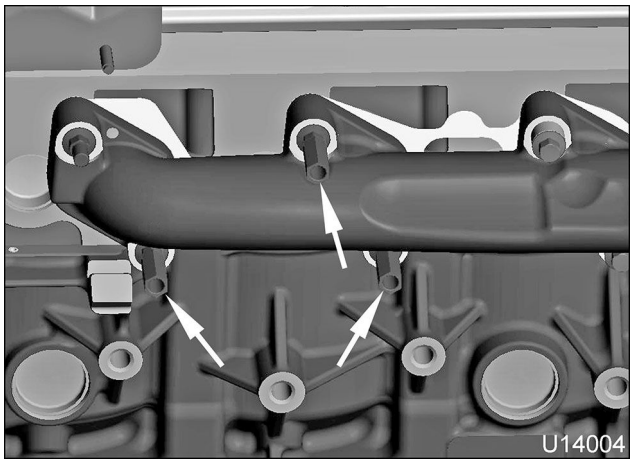


Figure 256 Left Exhaust Manifold Heat Shield Spacers

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

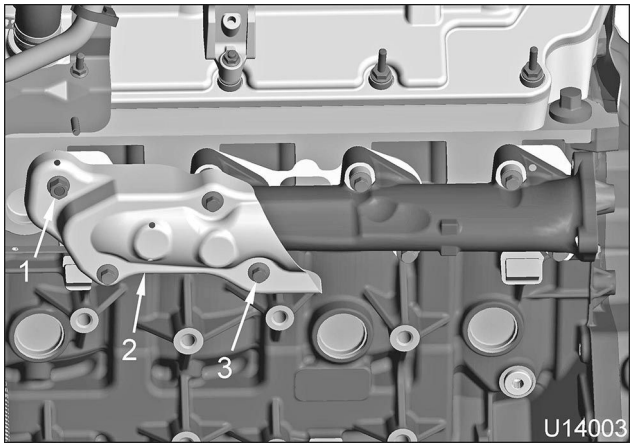


Figure 257 Left Exhaust Manifold Heat Shield

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

6. Install left exhaust manifold heat shield.

7. 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).

Exhaust Tubes

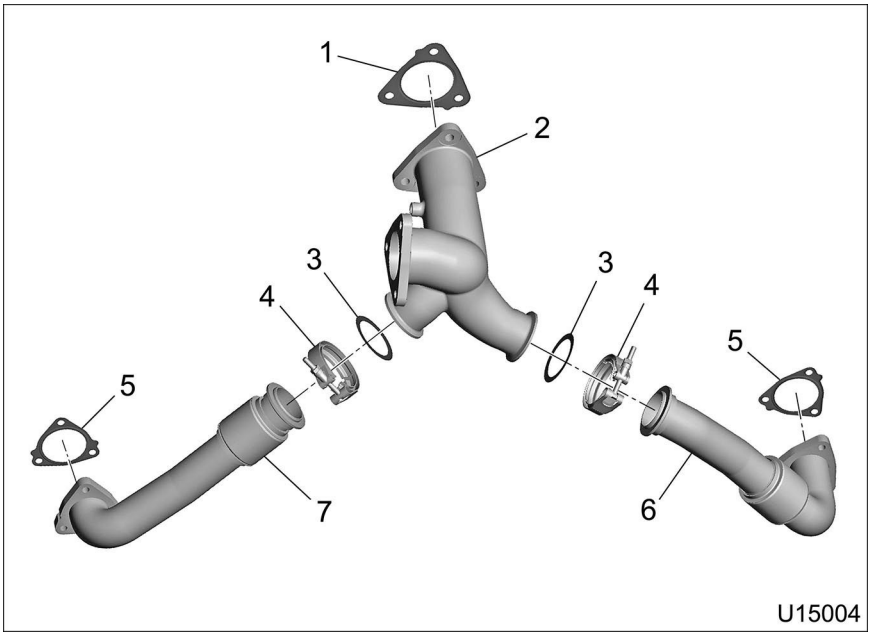


Figure 258 Turbocharger Exhaust Inlet Manifold and Right and Left Exhaust Tube Assemblies

1. Turbocharger inlet gasket
2. Turbo exhaust inlet manifold
3. V-band gasket (2)
4. V-band clamp (2)
5. Exhaust gasket (2)
6. Right exhaust tube assembly
7. Left exhaust tube assembly

1. Install two new V-band gaskets and two new V-band clamps.
2. Join right and left exhaust tubes to turbocharger exhaust inlet manifold.
3. Loosely secure V-band clamps.

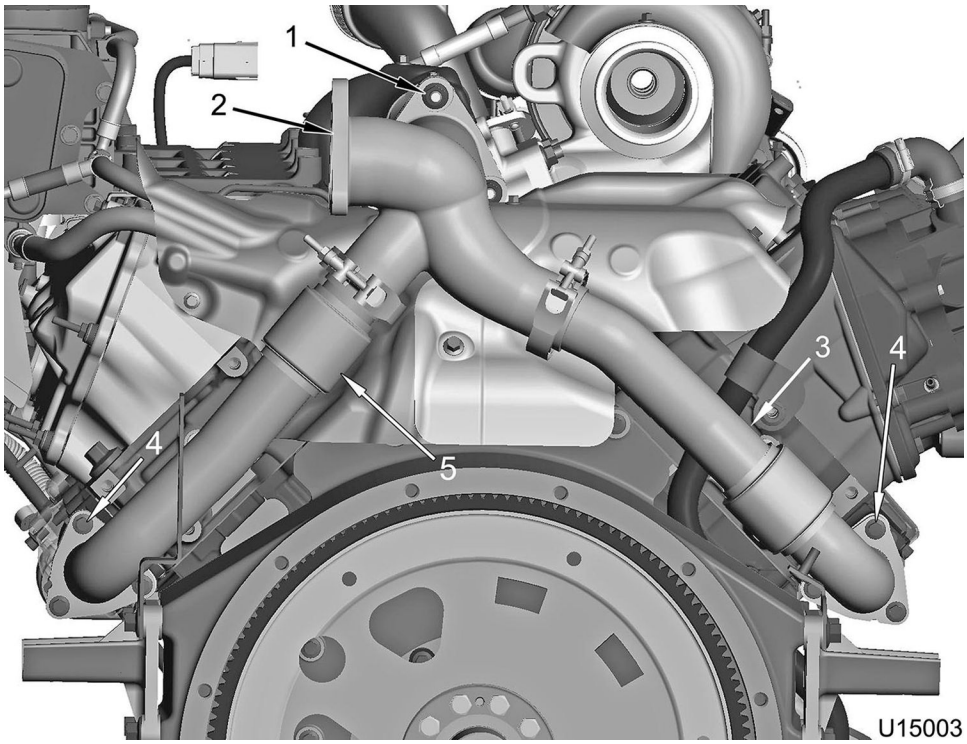


Figure 259 Exhaust Tubes

1. M10 nut (3)
2. Turbo exhaust inlet manifold
3. Right exhaust tube assembly
4. M8 x 27 bolt (6)
5. Left exhaust tube assembly

4. Position turbocharger inlet gasket between turbo exhaust inlet manifold and turbocharger and loosely install three M10 nuts on turbocharger studs.
5. Position exhaust gasket between right exhaust tube assembly and right exhaust manifold and loosely install three M8 x 27 bolts.
6. Position exhaust gasket between left exhaust tube assembly and left exhaust manifold and loosely install three M8 x 27 bolts.
7. Pretighten V-band clamps to 14 N·m (124 lb·in), loosen clamp nuts two full turns (720°), and tighten clamp nuts to 12 N·m (106 lb·in).
8. Tighten three M10 nuts (on turbocharger studs) to standard torque (page 473).
9. Tighten three M8 x 27 bolts (installed for right exhaust tube assembly) to standard torque (page 473).
10. Tighten three M8 x 27 bolts (installed for left exhaust tube assembly) to standard torque (page 473).

Specifications

Dual Turbocharger	
Turbine shaft axial end play	0.05 - 0.10 mm (0.002 - 0.004 in)
Turbocharger wastegate actuator bolts	13 N·m (115 lb-in)
Turbocharger crossover tube bolts	13 N·m (115 lb-in)

Exhaust Manifold	
Maximum allowable warpage	0.08 mm (0.003 in)

Special Torque

Turbocharger Clamps	
Turbo air inlet duct clamp	5 N·m (48 lb·in)
Turbocharger assembly exhaust outlet V-clamps	See tightening steps in procedure.
Turbocharger V-band clamps	12.5 N·m (111 lb-in)

Exhaust Manifolds	
Exhaust manifold bolts, M8 x 50	See tightening steps in procedure.
Exhaust manifold stud bolts, M8 x 40	See tightening steps in procedure.
Exhaust manifold heat shield threaded spacers	30 N·m (21 lb·ft)
Heat shield bolts, M8 x 12	30 N·m (21 lb·ft)
Heat shield nut, M8	30 N·m (21 lb·ft)

Special Service Tools

Description	Tool Number
Cap kit (All)	Obtain locally
Dial indicator with magnetic base	Obtain locally
Turbo Supply Blockoff Plugs (silicone)	ZTSE6012
Turbo Oil Supply Blockoff (Steel)	ZTSE6013
P-80® Rubber Lubricant or equivalent	Obtain locally

Table of Contents

Exploded Views.....187

Removal.....190
- **Air Compressor Coolant Supply and Return Hoses**.....190
- **Air Compressor Oil Supply Tube, Oil Supply and Return Hose**.....191
- **Air Compressor Assembly**.....192
- **Belt Tensioner, Flat Idler Pulleys, and Secondary Freon Compressor Bracket**.....193
- **Lifting Eye and Optional Belt Tensioner**.....194
- **Air Compressor Bracket**.....194
- **Power Steering Suction and Pressure Tube Assemblies**.....195
- **Power Steering Pump**.....196

Cleaning and Testing.....197
- **All Components**.....197
- **Power Steering Pump Idler Gear Backlash Measurement**.....197

Installation.....198
- **Power Steering Pump**.....198
- **Power Steering Suction and Pressure Tube Assemblies**.....198
- **Air Compressor Bracket**.....199
- **Lifting Eye and Optional Belt Tensioner**.....200
- **Belt Tensioner, Flat Idler Pulleys, and Secondary Freon Compressor Bracket**.....200
- **Air Compressor Assembly**.....201
- **Air Compressor Oil Return Hose, Oil Supply Hose, Oil Supply Tube**.....202
- **Air Compressor Coolant Supply and Return Hoses**.....203

Specifications.....205

Special Torque.....205

Special Service Tools.....205

Exploded Views

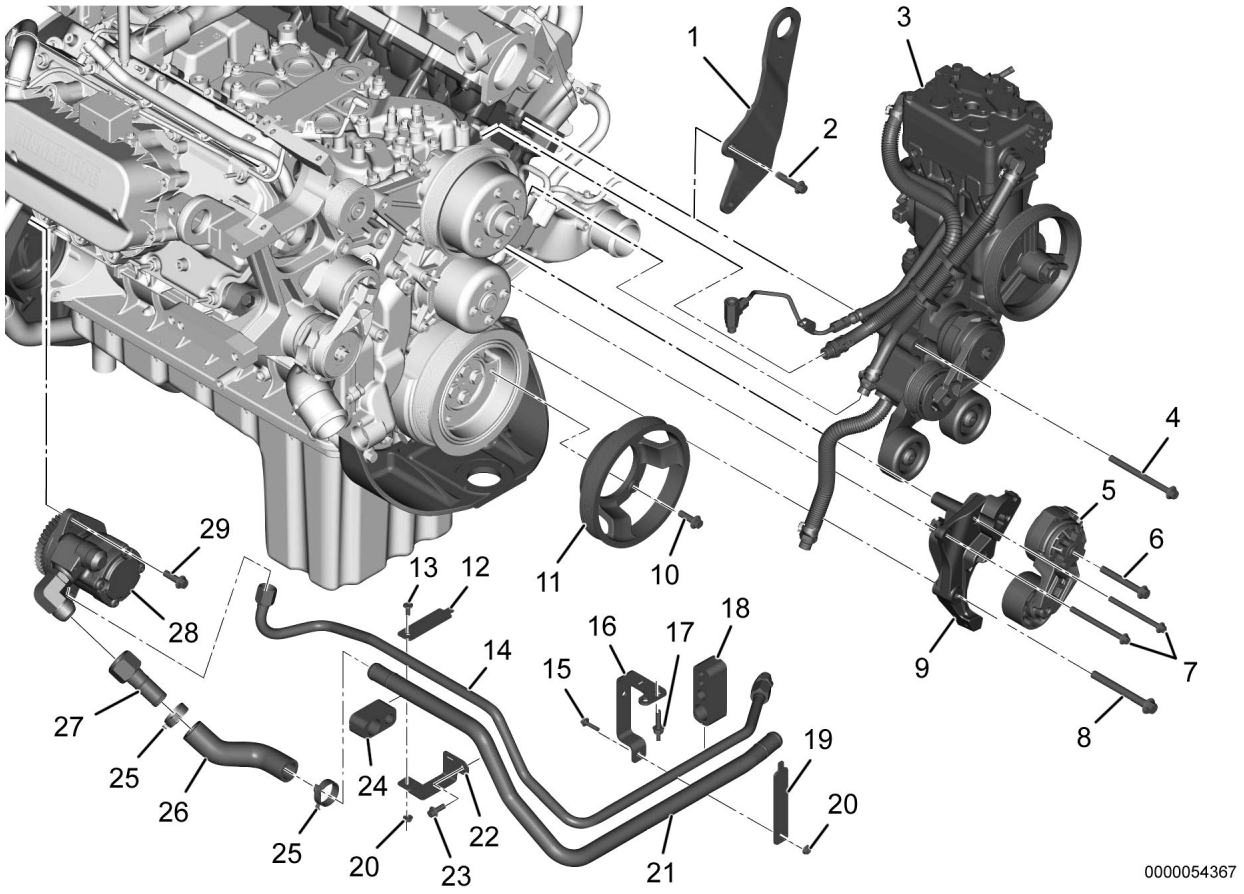


Figure 260 Air Compressor and Power Steering Pump

1. Lifting eye (for engines w/o air compressor)
2. M10 x 25 bolt (3) (for engines w/o air compressor)
3. Air compressor assembly and air compressor bracket assembly
4. M10 x 120 bolt (3)
5. Belt auto tensioner (w/o air compressor)
6. M10 x 80 bolt
7. M8 x 90 bolt (2)
8. M12 x 110 bolt
9. Secondary freon compressor bracket – see NOTE
10. M10 x 30 bolt (3)
11. Crank PTO for air compressor pulley
12. Tube support strap
13. Projection weld stud
14. Tube pressure power steering
15. M6 x 25 bolt
16. Tube clamp saddle
17. M8 x 30 stud bolt (3)
18. Tube clamp pad
19. Tube clamp plate
20. M6 nut
21. Suction power steering tube
22. Tube support
23. M8 x 20 bolt
24. Tube clamp pad
25. CTB 1 in diameter clamp (2)
26. Power steering suction hose
27. Power steering suction tube assembly
28. Power steering pump assembly
29. M10 x 30 bolt (2)

NOTE: If engine has 2-bolt bracket, upgrade to 3-bolt bracket. Refer to AFC 13915 for instructions.

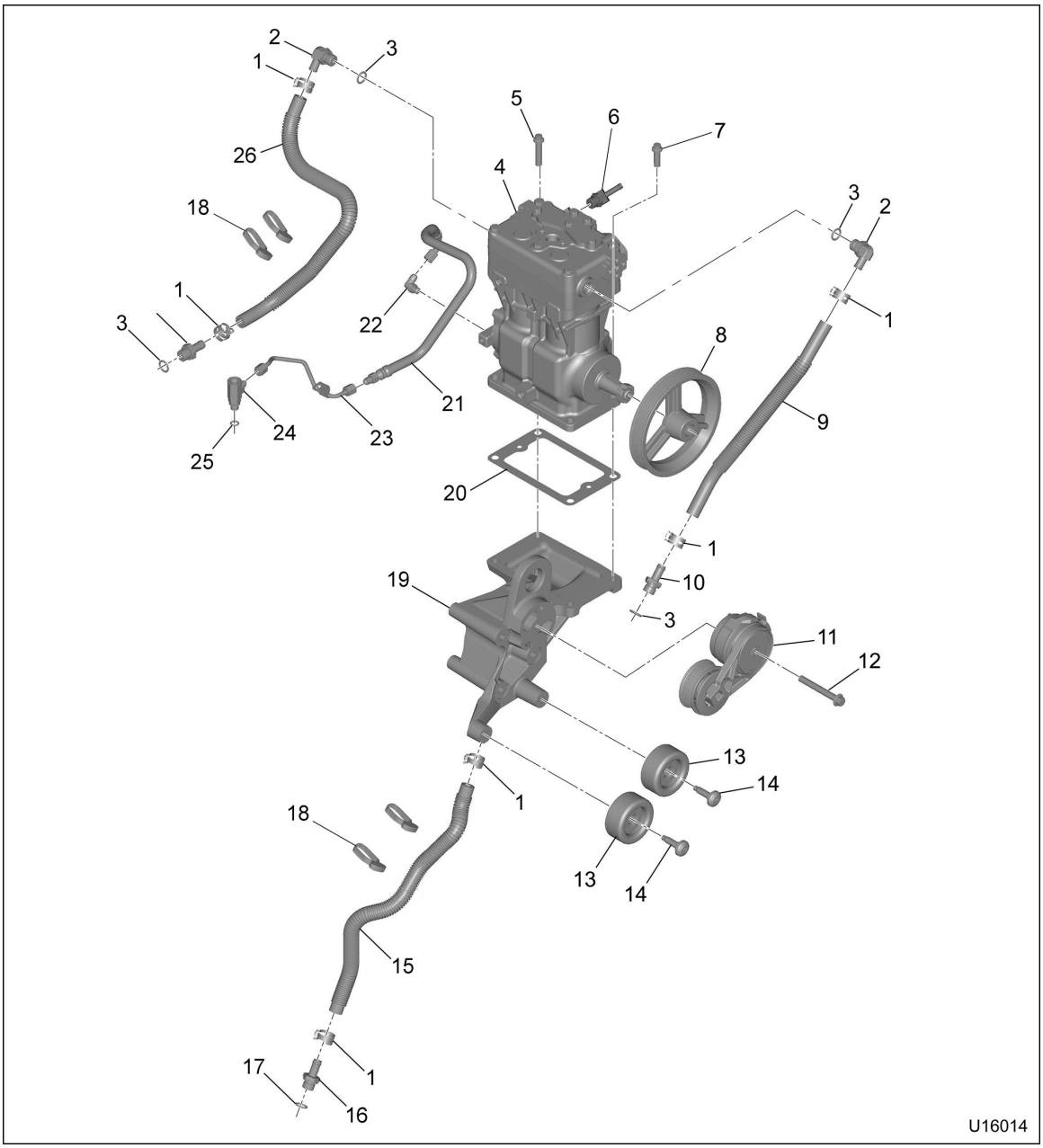


Figure 261 Air Compressor

1. Hose clamp (6)
2. 90° M18 adj str thd elbow (2)
3. (O-ring) seal (4)
4. Air compressor assembly
5. M10 x 45 12 point screw
6. Elbow
7. M10 x 30 12 point screw (3)
8. Air compressor pulley
9. Air compressor coolant supply hose
10. M18 connector assembly
11. Belt grooved 6 pk tensioner
12. M10 x 80 bolt
13. Flat idler pulley assembly (2)
14. M10 x 30 shoulder bolt (2)
15. Air compressor oil return hose
16. 1/2 in hose to M18 connector assembly
17. O-ring seal
18. Herbie™ size R clip (4)
19. Air compressor bracket
20. Air compressor gasket
21. Air compressor oil supply hose
22. Flare to M10 90 degree elbow
23. Air compressor oil supply tube assembly
24. Oil outlet fitting
25. O-ring seal
26. Air compressor coolant return hose

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, 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.

NOTE: See the following sections for removal of components prior to this section:

- Engine Electrical
- Exhaust Gas Recirculation (EGR) System
- Dual Turbocharger, Exhaust Manifolds, and Piping

NOTE: See removal of oil fill support bracket and oil fill hose assembly (page 319).

Air Compressor Coolant Supply and Return Hoses

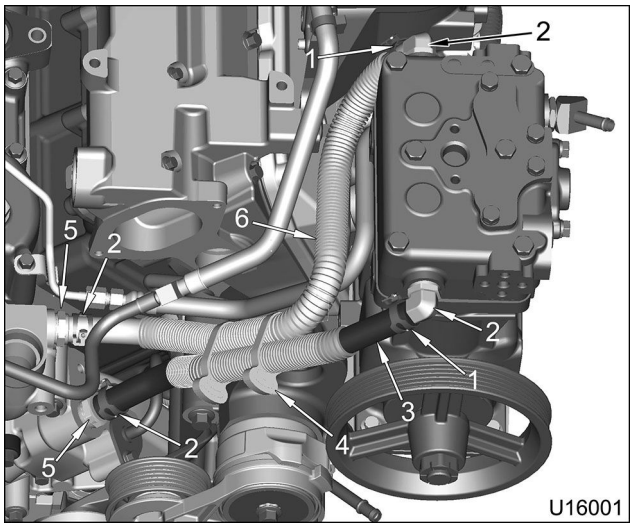


Figure 262 Air Compressor Coolant Supply and Return Hoses

1. Hose clamp (4)
2. M18 elbow assembly (2)
3. Air compressor coolant supply hose
4. Herbie™ size R clip (2)
5. M18 connector assembly (2)
6. Air compressor coolant return hose

1. Remove two Herbie™ size R clips.
2. Loosen hose clamps and remove coolant return and supply hoses from front crankcase cover and air compressor connections. If necessary, remove convoluted tube conduits.
3. If necessary, remove two M18 elbow assemblies from air compressor and discard O-rings.
4. If necessary, remove two M18 connector assemblies from front cover and discard O-rings.

Air Compressor Oil Supply Tube, Oil Supply and Return Hose

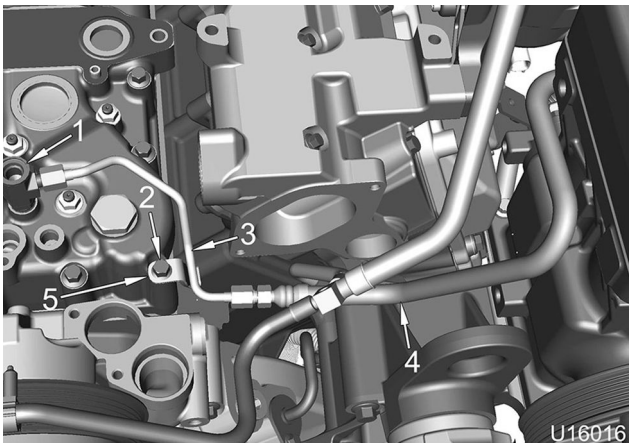


Figure 263 Air Compressor Oil Supply Tube Assembly and Oil Supply Hose

1. Oil outlet fitting assembly
2. M8 x 70 bolt
3. Air compressor oil supply tube assembly
4. Air compressor oil supply hose assembly
5. Oil supply tube support

1. Loosen air compressor oil supply hose fitting and disconnect oil supply hose from the air compressor oil supply tube assembly.
2. Remove M8 x 70 bolt that secures the oil supply tube support to the oil cooler cover.
3. Loosen air compressor oil supply hose fitting and disconnect oil supply tube assembly from oil outlet fitting assembly.
4. If necessary, remove oil outlet fitting assembly and O-ring seal. Discard O-ring seal.

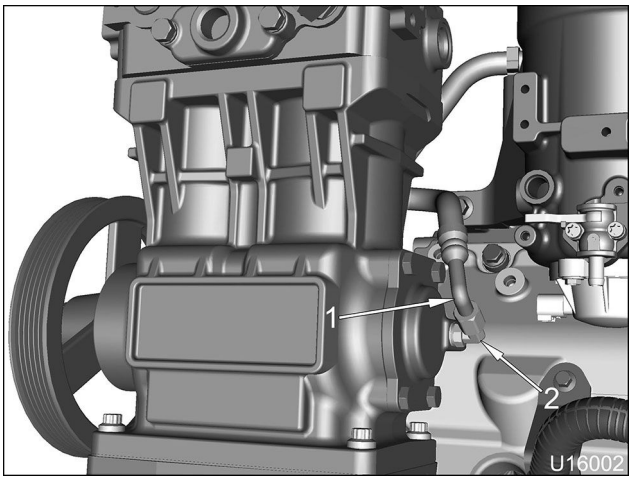


Figure 264 Air Compressor Oil Supply Hose

1. Air compressor oil supply hose
2. 45° flare to M10 90° elbow

5. Loosen oil supply hose fitting and disconnect oil supply hose from 90° elbow.
6. If necessary, remove 90° elbow.

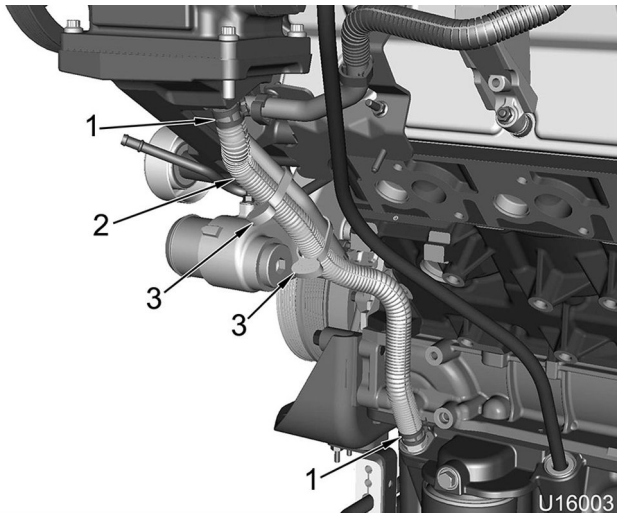


Figure 265 Air Compressor Oil Return Hose

1. Hose clamp (2)
2. Air compressor oil return hose
3. Herbie™ size R clip (2)

7. Remove two Herbie™ size R clips.
8. Loosen two hose clamps and pull the air compressor oil return hose off the press-in connector in the air compressor bracket and off the connector in the oil pan.
9. If necessary, remove convoluted tube conduit.

Air Compressor Assembly

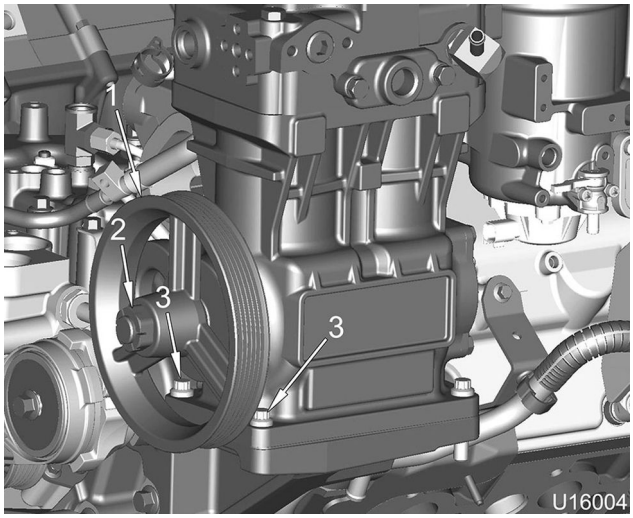


Figure 266 Air Compressor, Air Compressor Pulley, and Front Mounting Screws

1. Air compressor pulley
2. Shaft nut
3. M10 x 30 12 point screw (2)

1. Remove two M10 x 30 12 point screws.

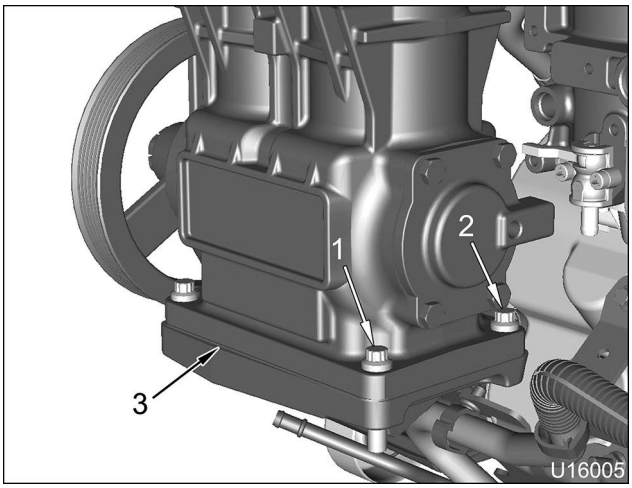


Figure 267 Air Compressor Rear Mounting Screws

1. M10 x 45 12 point screw
2. M10 x 30 12 point screw
3. Air compressor gasket

2. Remove M10 x 45 and M10 x 30 12 point screws.

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

3. Remove air compressor assembly.
4. Remove and discard air compressor gasket.

Belt Tensioner, Flat Idler Pulleys, and Secondary Freon Compressor Bracket

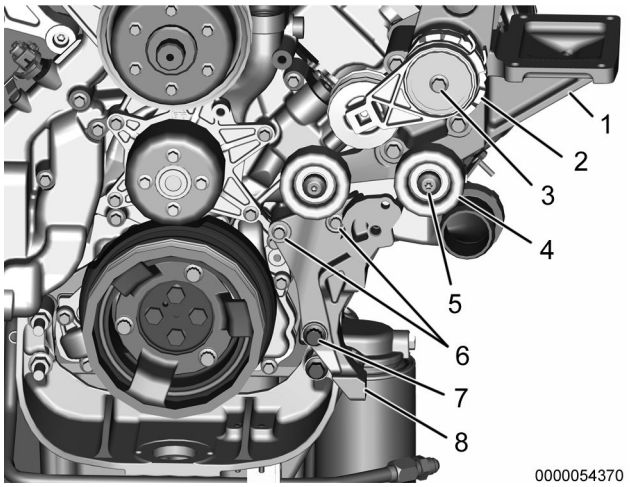


Figure 268 Belt Tensioner Assembly, Flat Idler Pulleys, and (Secondary Freon Compressor Bracket)

1. Air compressor bracket
2. 6 pk grooved belt tensioner
3. M10 x 80 bolt
4. Flat idler pulley assembly (2)
5. M10 x 30 shoulder bolt
6. M8 x 90 bolt (2)
7. M12 x 110 bolt
8. 3-bolt secondary freon compressor bracket – see NOTE

NOTE: If engine has 2-bolt bracket, upgrade to 3-bolt bracket. Refer to AFC 13915 for instructions.

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 from belt tensioner and remove belt tensioner.
2. Remove M10 x 30 shoulder bolt from each flat idler pulley assembly and remove two flat idler pulley assemblies.
3. Remove two M8 x 90 bolts and one M12 x 110 bolt securing the secondary freon compressor bracket.
4. Remove secondary freon compressor bracket.

Lifting Eye and Optional Belt Tensioner

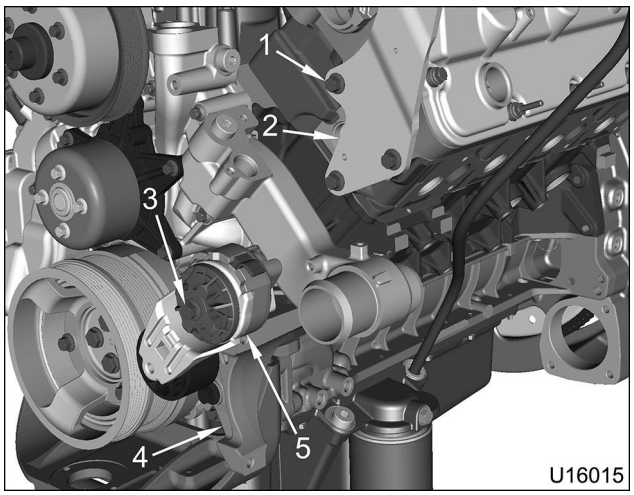


Figure 269 Lifting Eye and Optional Belt Tensioner

1. M10 x 25 bolt (3)
2. Lifting eye
3. M10 X 80 bolt
4. Secondary freon compressor bracket (optional)
5. Belt tensioner (optional)

1. Remove three M10 x 25 bolts that secure the lifting eye.
2. Remove lifting eye.

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.

3. Remove M10 x 80 bolt that secures the belt tensioner.
4. Remove belt tensioner.

Air Compressor Bracket

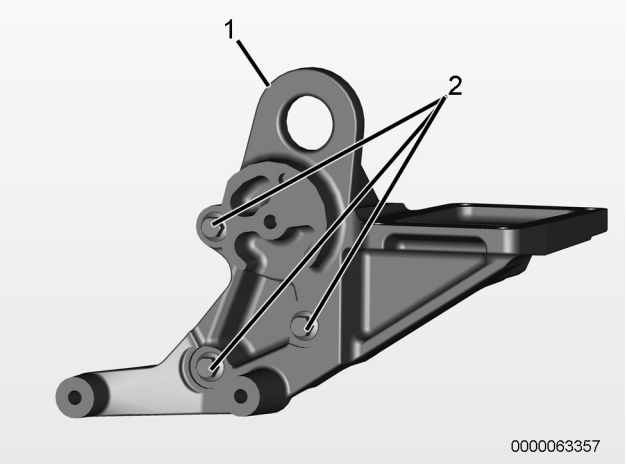


Figure 270 Air Compressor Bracket

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

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

Power Steering Suction and Pressure Tube Assemblies

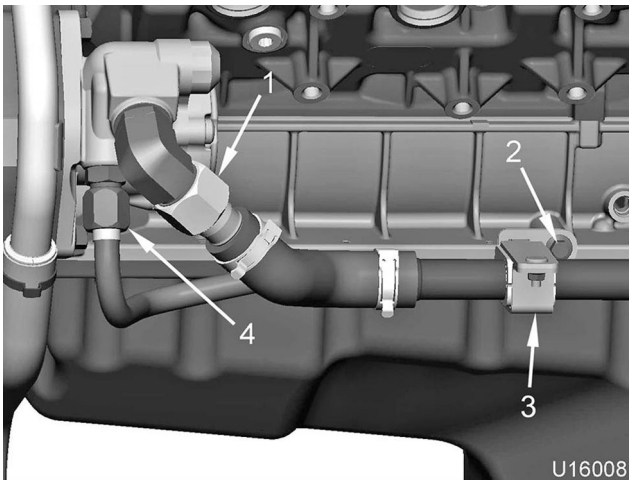


Figure 271 Power Steering Suction Tube Assembly, Power Steering Pressure Tube Assembly, and Tube Support

1. Power steering suction tube assembly
2. M8 x 20 bolt
3. Tube support
4. Power steering pressure tube assembly

1. Remove M8 x 20 bolt from tube support.
2. Loosen flared tube nut on power steering suction tube assembly.
3. Loosen flared tube nut on pressure power steering tube assembly.

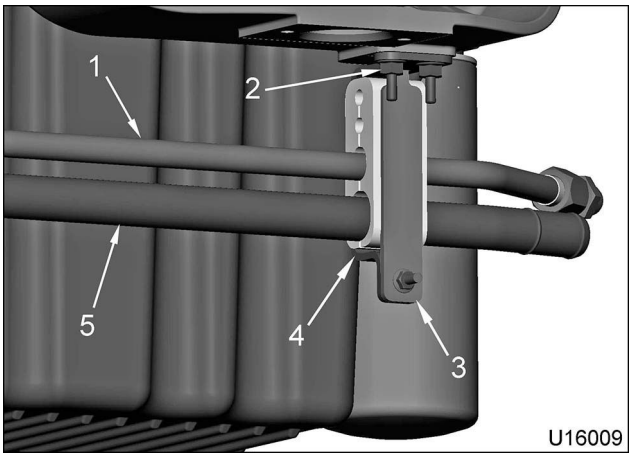


Figure 272 Power Steering Suction Tube Assembly, Power Steering Pressure Tube Assembly, and Tube Clamp Saddle

1. Power steering pressure tube assembly
2. M8 x 30 stud bolt (2)
3. Tube clamp plate
4. Tube clamp saddle
5. Power steering suction tube assembly

NOTE: Support power steering tubes before removing M8 x 30 stud bolts.

4. Remove two M8 x 30 stud bolts from tube clamp saddle.
5. Disconnect and remove steering suction tube assembly and power steering pressure tube assembly.
6. Cover power steering ports, ends of power steering suction tube assembly, and power steering pressure tube assembly with caps in Cap Protector Kit (page 205). If plastic caps are not available, cover openings with tape.

Power Steering Pump

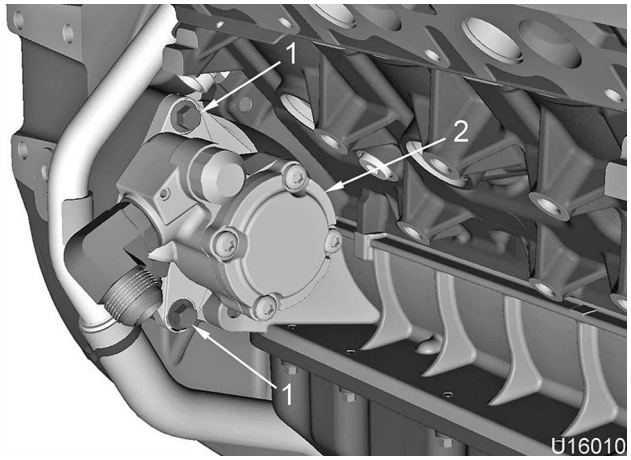


Figure 273 Power Steering Pump

1. M10 x 30 bolt (2)
2. Power steering pump assembly

1. Remove two M10 x 30 bolts from power steering pump.

2. Remove power steering pump from crankcase rear cover.

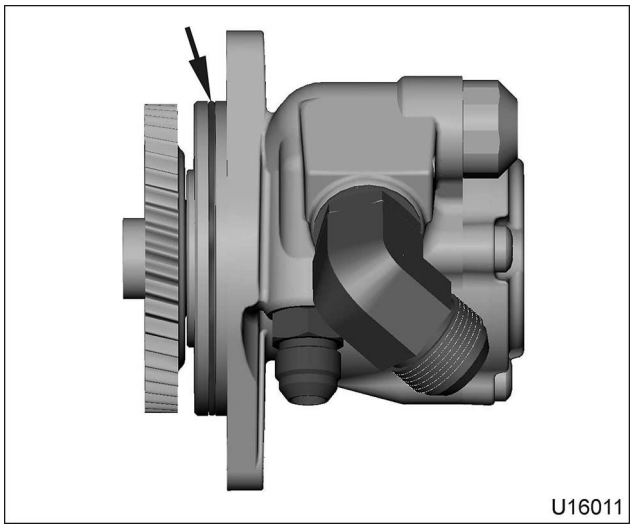


Figure 274 O-ring on Power Steering Pump

3. Remove and discard O-ring.

Cleaning and Testing

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 pump gear with a stiff brush and suitable solvent. Dry with filtered compressed air.

Power Steering Pump Idler Gear Backlash Measurement

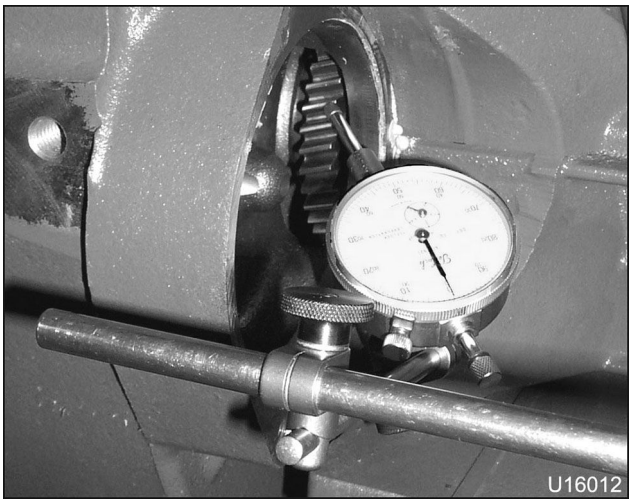


Figure 275 Power Steering Idler Gear Backlash

1. Attach dial indicator with magnetic base to crankcase rear cover.
2. Place indicator tip against power steering idler gear assembly.
3. Rotate gear by hand in one direction and zero the dial indicator.
4. Rock power steering idler gear assembly back and forth and verify that backlash reading is within specification (page 205).

Installation

Power Steering Pump

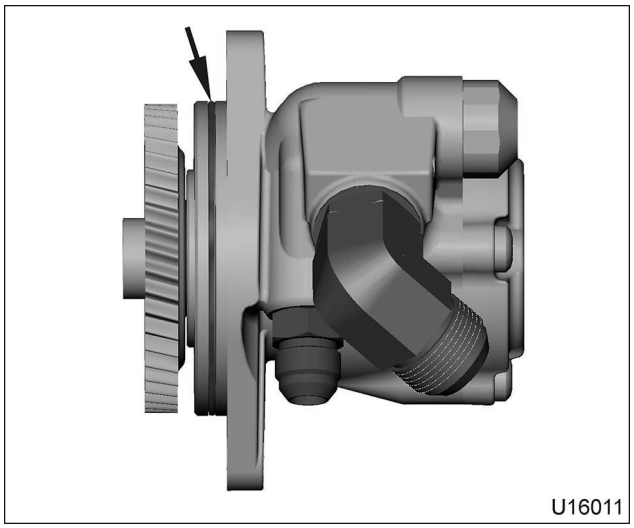


Figure 276 Power Steering Pump O-ring

1. Lubricate a new O-ring with P-80® Rubber Lubricant or equivalent (page 205) and install O-ring onto power steering pump assembly.

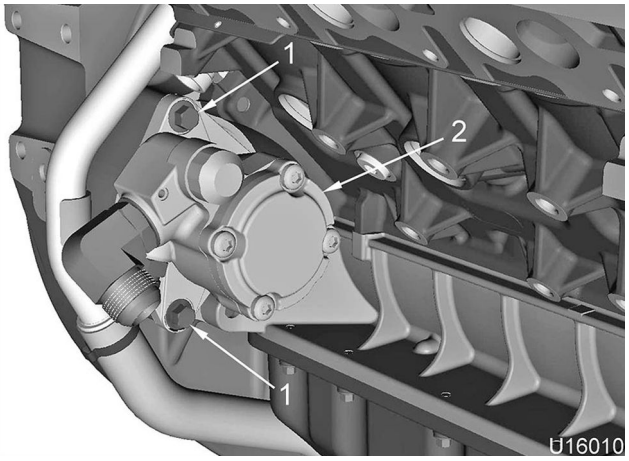


Figure 277 Power Steering Pump Assembly and Bolts

1. M10 x 30 bolt (2)
2. Power steering pump assembly

2. Install power steering pump on crankcase rear cover and secure with two M10 x 30 bolts.
3. Tighten bolts to standard torque (page 473).

Power Steering Suction and Pressure Tube Assemblies

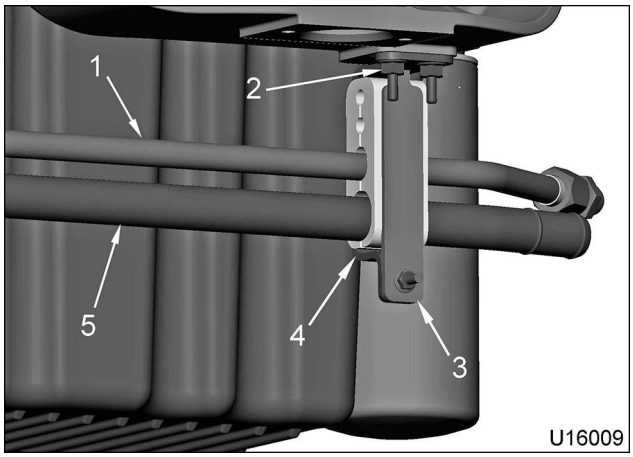


Figure 278 Power Steering Suction Tube Assembly, Power Steering Pressure Tube Assembly, and Tube Clamp Saddle

1. Pressure power steering pressure tube assembly
2. M8 x 30 stud bolt (2)
3. Tube clamp plate
4. Tube clamp saddle
5. Power steering suction tube assembly

1. Hold power steering tube assemblies in place with a clamp and install two M8 x 30 studs and tighten to standard torque (page 473).

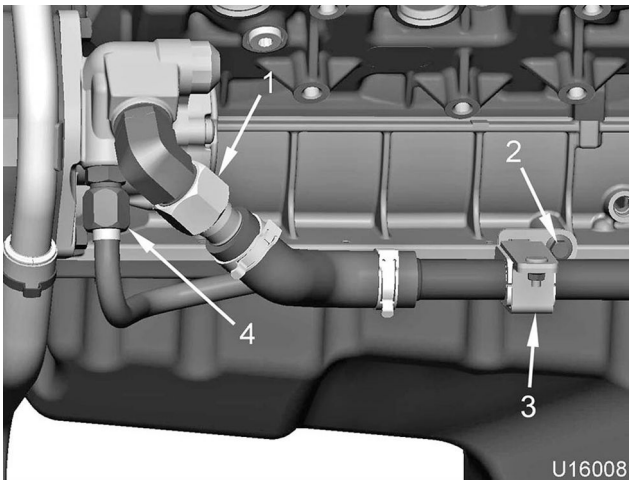


Figure 279 Power Steering Suction Tube Assembly, Power Steering Pressure Tube Assembly, and Tube Support

1. Power steering suction tube assembly
2. M8 x 20 bolt
3. Tube support
4. Pressure power steering pressure tube assembly

2. Install M8 x 20 bolt through the tube support and tighten to standard torque (page 473).
3. Connect power steering suction tube assembly to the power steering pump and tighten flared tube nut to special torque (page 205).
4. Connect power steering pressure tube to the power steering pump and tighten flared tube nut to special torque (page 205).

Air Compressor Bracket

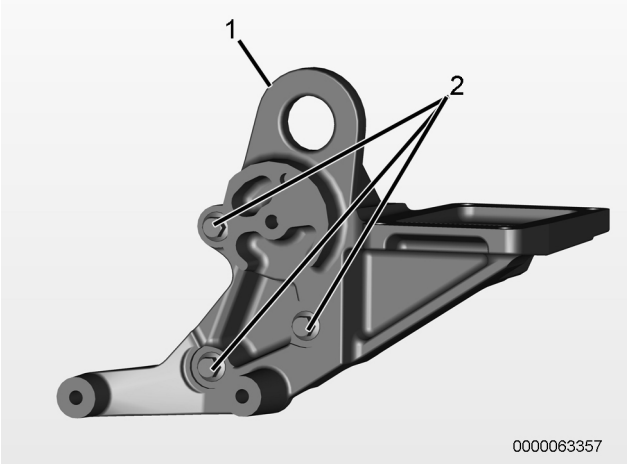


Figure 280 Air Compressor Bracket

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

1. Position air compressor bracket, install three M10 x 120 bolts, and tighten bolts to standard torque (page 473).

Lifting Eye and Optional Belt Tensioner

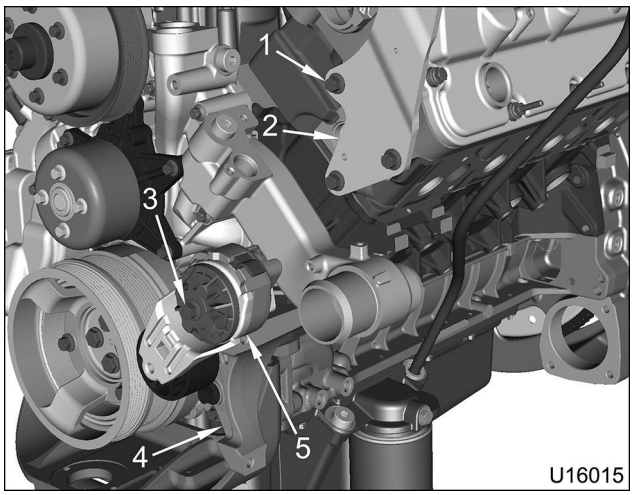


Figure 281 Lifting Eye and Optional Belt Tensioner

1. M10 x 25 bolt (3)
2. Lifting eye
3. M10 X 80 bolt
4. Secondary freon compressor bracket (optional)
5. Belt tensioner (optional)

1. Position lifting eye, install three M10 x 25 bolts, and tighten bolts to standard torque (page 473).
2. Position belt tensioner with locating dowel into bracket hole, install M10 x 80 bolt, and tighten bolt to standard torque (page 473).

Belt Tensioner, Flat Idler Pulleys, and Secondary Freon Compressor Bracket

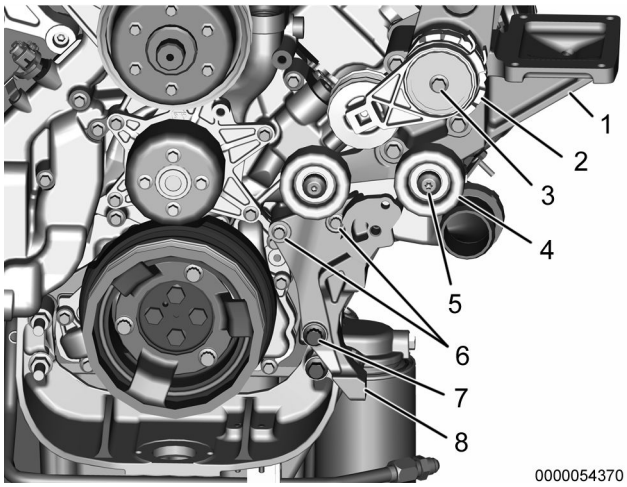


Figure 282 Belt Tensioner Assembly, Flat Idler Pulleys, and (Secondary Freon Compressor Bracket)

1. Air compressor bracket
2. 6 pk grooved belt tensioner
3. M10 x 80 bolt
4. Flat idler pulley assembly (2)
5. M10 x 30 shoulder bolt
6. M8 x 90 bolt (2)
7. M12 x 110 bolt
8. 3-bolt secondary freon compressor bracket

1. Position secondary freon compressor bracket.
2. Install two M8 x 90 bolts and one M12 x 110 bolt securing secondary freon compressor bracket. Tighten bolts to standard torque (page 473).
3. Install two flat idler pulley assemblies and two M10 x 30 shoulder bolts. Tighten bolts to standard torque (page 473).
4. Position grooved belt tensioner with locating dowel into bracket and install M10 x 80 bolt. Tighten bolt to standard torque (page 473).

Air Compressor Assembly

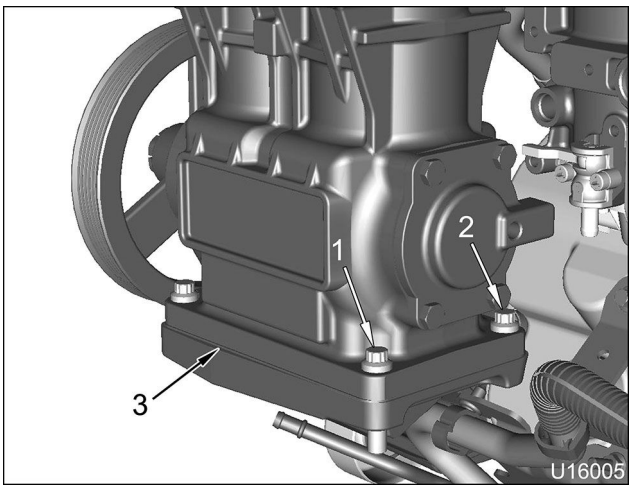


Figure 283 Air Compressor Rear Mounting Screws

1. M10 x 45 12 point screw
2. M10 x 30 12 point screw
3. Air compressor gasket

1. Install a new air compressor gasket.

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

2. Position air compressor assembly onto air compressor bracket.
3. Install M10 x 45 and M10 x 30 screws finger tight.

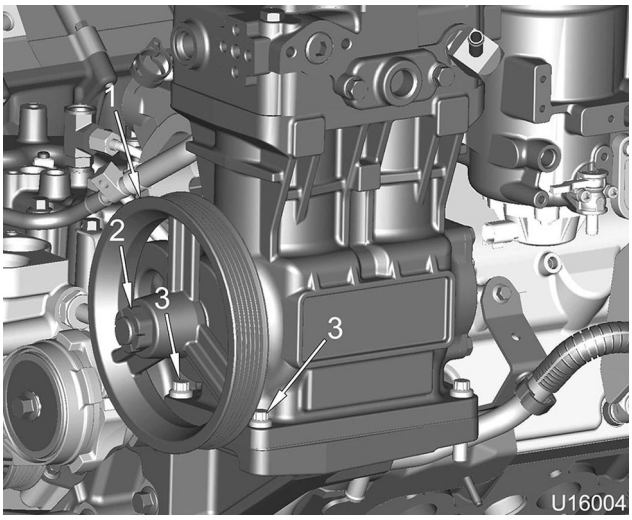


Figure 284 Air Compressor, Air Compressor Pulley, and Front Mounting Screws

1. Air compressor pulley
2. Shaft nut
3. M10 x 30 12 point screw (2)

4. Install two M10 x 30 12 point screws finger tight.
5. Tighten four 12 point screws to special torque (page 205).

Air Compressor Oil Return Hose, Oil Supply Hose, Oil Supply Tube

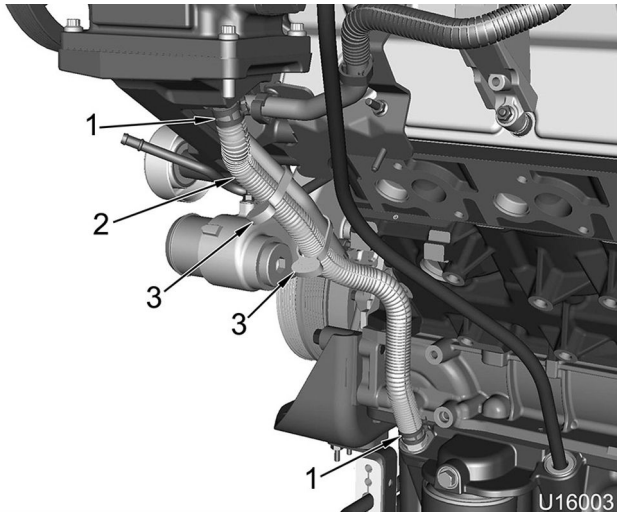


Figure 285 Air Compressor Oil Return Hose

1. Hose clamp (2)
2. Air compressor oil return hose
3. Herbie™ size R clip

1. Install hose clamps on the air compressor oil return hose.
2. Push air compressor oil return hose on the air compressor bracket fitting and on the fitting in the oil pan. Locate hose clamps to secure hose to fittings.
3. If removed, install convoluted tube conduit over air compressor oil return hose.
4. Install two Herbie™ size R clips.

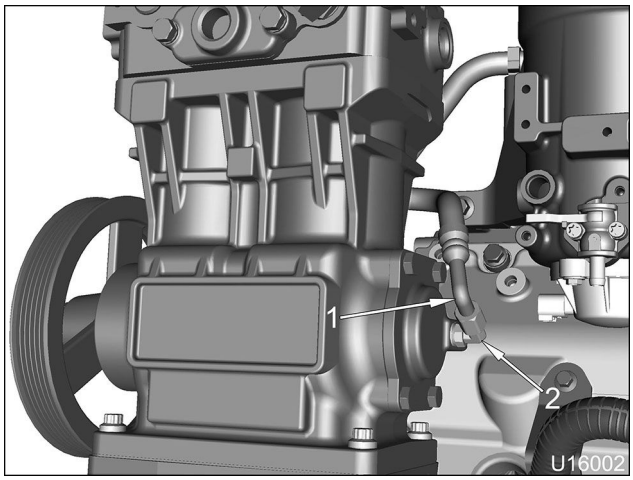


Figure 286 Air Compressor Oil Supply Hose to Air Compressor

1. Air compressor oil supply hose
2. 45° flare to M10 90° elbow

5. If removed, install 45° flare to M10 90 degree elbow and tighten to special torque (page 205).
6. Connect air compressor oil supply hose to 45° flare to M10 90 degree elbow and tighten nut to special torque (page 205).

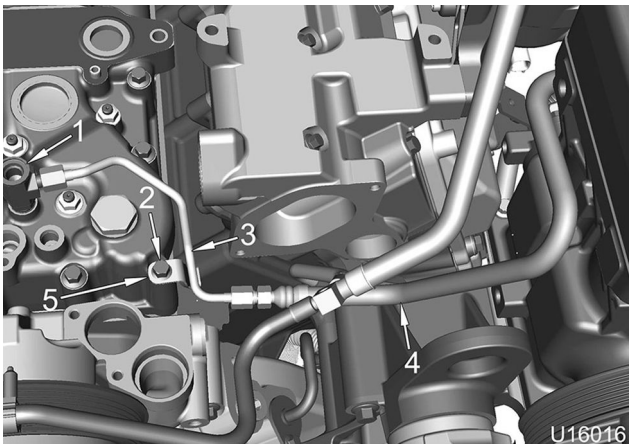


Figure 287 Air Compressor Oil Supply Tube Assembly and Oil Supply Hose

1. Oil outlet fitting assembly
2. M8 x 70 bolt
3. Air compressor oil supply tube assembly
4. Air compressor oil supply hose assembly
5. Oil supply tube support

7. If the oil outlet fitting assembly was removed, lubricate a new O-ring seal with a light coat of clean engine oil, and install O-ring seal onto oil outlet fitting.
8. Install oil outlet fitting assembly into oil cooler cover and tighten fitting to special torque (page 205).
9. Connect oil supply tube assembly to oil outlet fitting assembly. Tighten fitting to special torque (page 205).
10. Install M8 x 70 bolt to secure the oil supply tube support to oil cooler cover. Tighten bolt to standard torque (page 473).
11. Connect oil supply hose to air compressor oil supply tube assembly. Tighten fitting to special torque (page 205).

Air Compressor Coolant Supply and Return Hoses

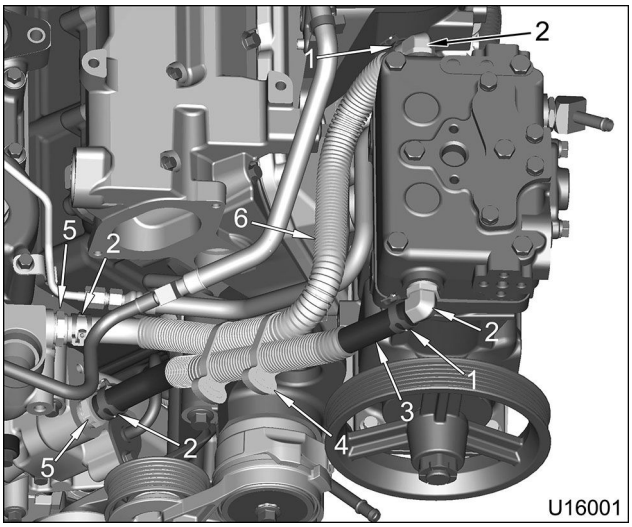


Figure 288 Air Compressor Coolant Supply and Return Hoses

1. Hose clamp (4)
2. M18 elbow assembly (2)
3. Air compressor coolant supply hose
4. ™ size R clip (2)
5. M18 connector assembly (2)
6. Air compressor coolant return hose

1. If the M18 elbow assembly was removed, lubricate a new O-ring seal with P-80® Rubber Lubricant or equivalent (page 205), and install O-ring seal onto M18 elbow.
2. Install M18 elbow assembly into air compressor and elbow to special torque (page 205).
3. If the M18 connector assembly was removed, lubricate a new O-ring seal with P-80® Rubber Lubricant or equivalent (page 205), and install O-ring seal onto M18 connector.

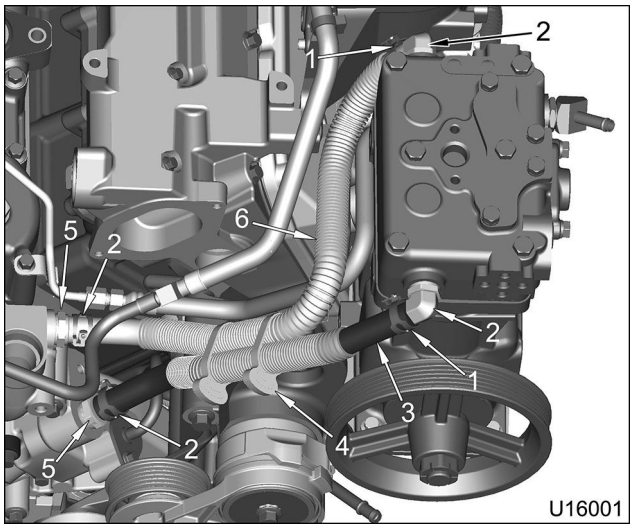


Figure 289 Air Compressor Coolant Supply and Return Hoses

1. Hose clamp (4)
2. M18 elbow assembly (2)
3. Air compressor coolant supply hose
4. Herbie™ size R clip (2)
5. M18 connector assembly (2)
6. Air compressor coolant return hose

4. Install M18 connector assembly into front cover and tighten to special torque (page 205).
5. Connect air compressor coolant return and supply hoses. If necessary, install convoluted tube conduits. Locate hose clamps to secure hose to fittings.
6. Install two Herbie™ size R clips to secure coolant return and supply hoses.

NOTE: See installation of oil fill support bracket and oil fill hose assembly (page 357).

Specifications

Power Steering Pump	
Backlash: Power steering idler gear assembly	0.066 - 0.290 mm (0.0026 - 0.0114 in)

Special Torque

Air Compressor and Power Steering Pump	
Air compressor to air compressor bracket bolts, M10 x 30 and M10 x 45	72 N·m (53 lb·ft)
Connector assembly, M18 (for air compressor coolant return and supply hoses)	25 N·m (18 lb·ft)
Elbow assembly, M18 (for air compressor coolant return and supply hoses)	25 N·m (18 lb·ft)
Air compressor oil supply hose fitting nut	20 N·m (177 lb·in)
Air compressor pulley nut	120 N·m (88 lb·ft)
Oil outlet fitting assembly	25 N·m (18 lb·ft)
Power steering suction tube assembly flared tube nut	166 N·m (122 lb·ft)
Power steering pressure tube assembly flared tube nut	87 N·m (64 lb·ft)
45° flare to M10 90° elbow	19 N·m (14 lb·ft)

Special Service Tools

Description	Tool Number
Cap Protector kit (All)	Obtain locally
Dial indicator with magnetic base	Obtain locally
P-80® Rubber Lubricant or equivalent	Obtain locally

Table of Contents

Exploded Views.....209

Removal.....214
- **High-pressure Fuel Tube Assemblies**.....214
- **Draining the Low-pressure Fuel System**.....216
- **Pump to Cooler Hose and Filter to Pump Hose Assemblies**.....217
- **Injector Return Hose Assembly**.....219
- **High-pressure Fuel Pump Assembly**.....220
- **Fuel Injectors and Fuel Rail Assemblies**.....224
- **Oil Level Tube Assembly and Coolant Return Hose**.....226
- **Fuel Coolant Supply Tube Assembly**.....227
- **Fuel Filter and Cooler Assembly**.....227
- **Fuel Filter Cooler Assembly and Filter Cooler Pump Module Support**.....228
- **Primary Fuel Filter, Secondary Fuel Filter, and Fuel Housing Cover**.....229
- **Fuel Pump**.....230
- **Fuel Heater Port Cover, Diagnostic Valve, Pressure Regulator, and Engine Fuel Temperature (EFT) Sensor**.....231
- **Fuel Heater (Optional) and Fuel Delivery Pressure (FDP) Sensor (Optional)**.....232
- **Water In Fuel (WIF) Sensor and Water Drain Valve**.....233

Inspection.....234
- **Fuel Filter and Fuel Hose Inspection**.....234
- **Fuel Filter in Low-Pressure Line at High-Pressure Pump**.....234

Flushing the Low-pressure Fuel System.....236

Installation.....239
- **Water In Fuel (WIF) Sensor and Water Drain Valve**.....239
- **Fuel Heater Port Cover, Diagnostic Valve, Pressure Regulator, and Engine Fuel Temperature (EFT) Sensor**.....240
- **Fuel Heater (Optional) and Fuel Delivery Pressure (FDP) Sensor (Optional)**.....241
- **Fuel Pump**.....242
- **Primary Fuel Filter, Secondary Fuel Filter, and Fuel Housing Cover**.....243
- **Fuel Filter Cooler Assembly and Filter Cooler Pump Module Support**.....245
- **Fuel Filter and Cooler Assembly**.....246
- **Fuel Coolant Supply Tube Assembly**.....246
- **Oil Level Tube Assembly and Coolant Return Hose**.....247
- **High-Pressure Fuel Pump Assembly**.....247
- **Fuel Injectors and Fuel Rail Assemblies**.....251
- **Injector Return Hose Assembly**.....254
- **Pump to Cooler Hose and Filter to Pump Hose Assemblies**.....255
- **Priming the High-pressure Fuel System**.....258

Specifications.....260

Special Torque.....260

Special Service Tools……261

Exploded Views

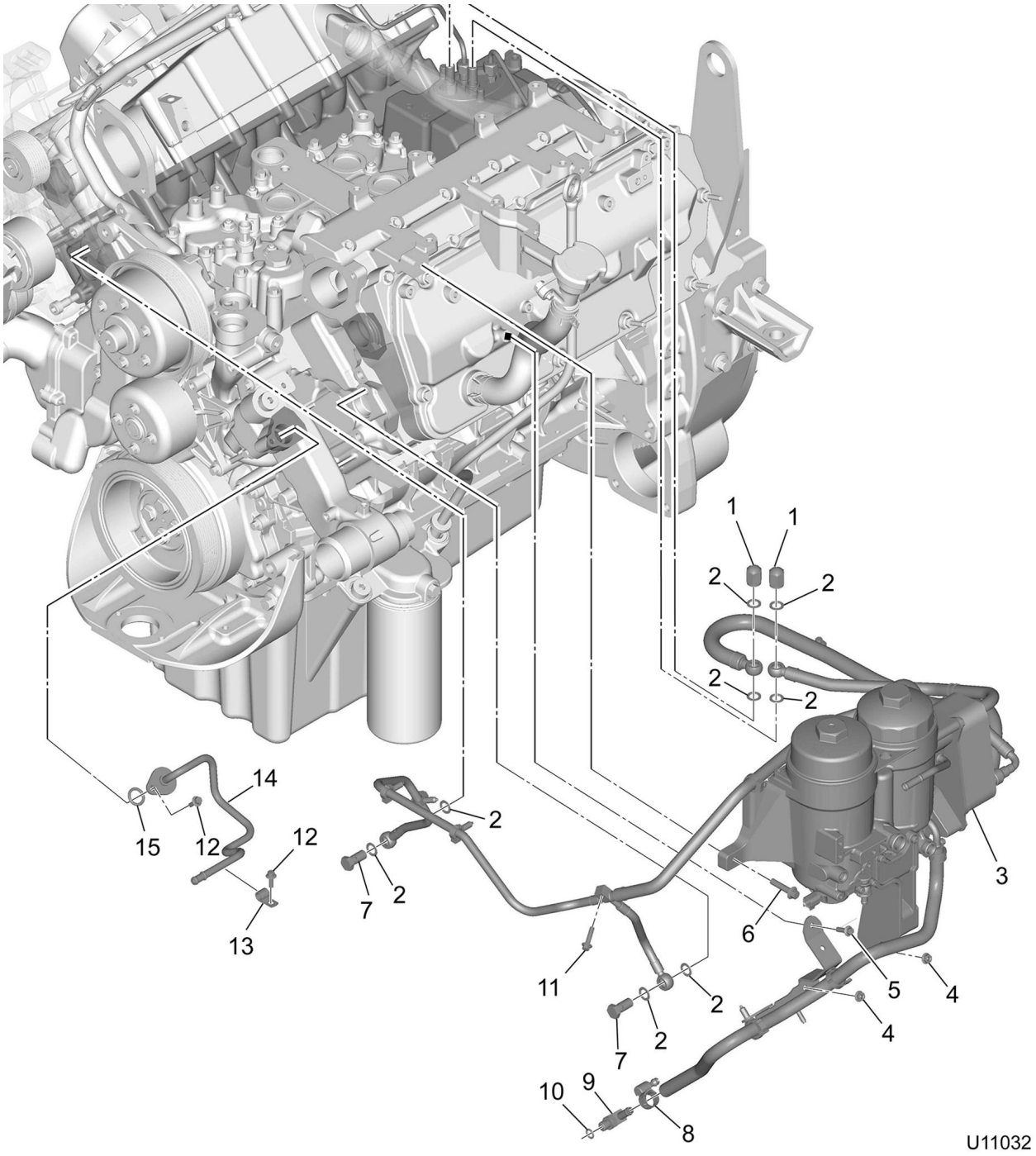


Figure 290 Fuel Filter Module Removal

1. M12 nut (2)
2. Bonded seal washer (8)
3. Fuel filter module
4. M6 nut (2)
5. M6 x 20 bolt
6. M8 x 35 bolt
7. M12 banjo bolt (2)
8. Hose Clamp
9. M12 to 3/8 hose fitting assembly
10. O-ring seal
11. M6 x 28 bolt
12. M6 x 16 bolt
13. Closed clamp
14. Fuel coolant supply tube
15. O-ring seal

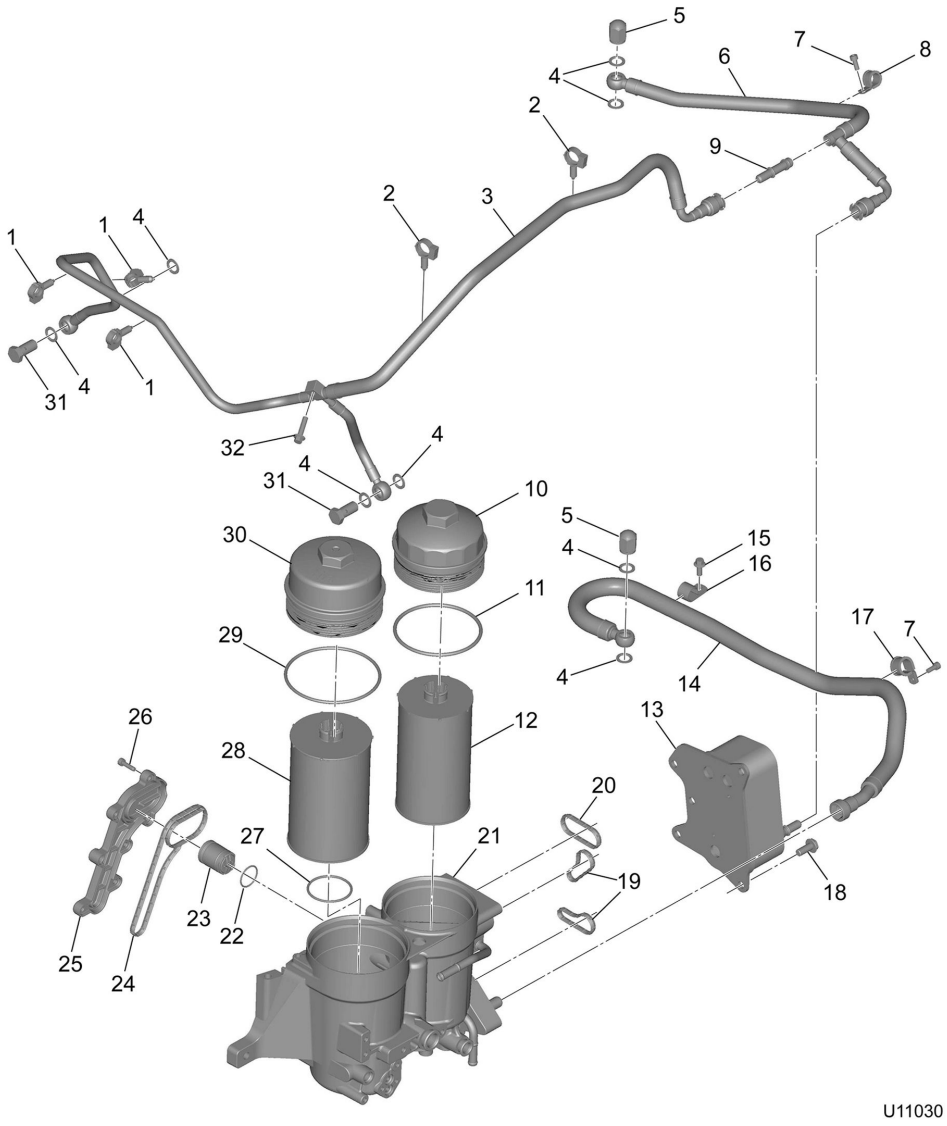


Figure 291 Fuel Filter Module

1. 0.25 inch hose clip (3)
2. 0.375 inch hose clip (2)
3. Injector return hose assembly
4. Bonded seal washer (6)
5. M12 nut (2)
6. Pump to cooler hose assembly
7. M5 x 12 socket head bolt
8. Cushion dash clamp 8
9. Fuel check valve assembly
10. Filter cap (secondary)
11. Fuel cap secondary O-ring
12. Secondary fuel element assembly
13. Fuel cooler
14. Filter to pump hose assembly
15. M6 x 14 hex flange bolt
16. Hose clamp 0.5 in
17. Cushion dash clamp 11
18. M8 x 20 thread forming screw (5)
19. Fuel cooler coolant gasket (2)
20. Fuel gasket
21. Fuel filter module housing
22. Fuel O-ring
23. Fuel thermal bypass valve assembly
24. Fuel housing cover gasket
25. Fuel housing cover
26. M5 x 18 screw (9)
27. Primary fuel element O-ring
28. Primary filter assembly
29. Primary fuel cap O-ring
30. Filter cap (primary)
31. M12 banjo bolt (2)
32. M6 x 25 bolt

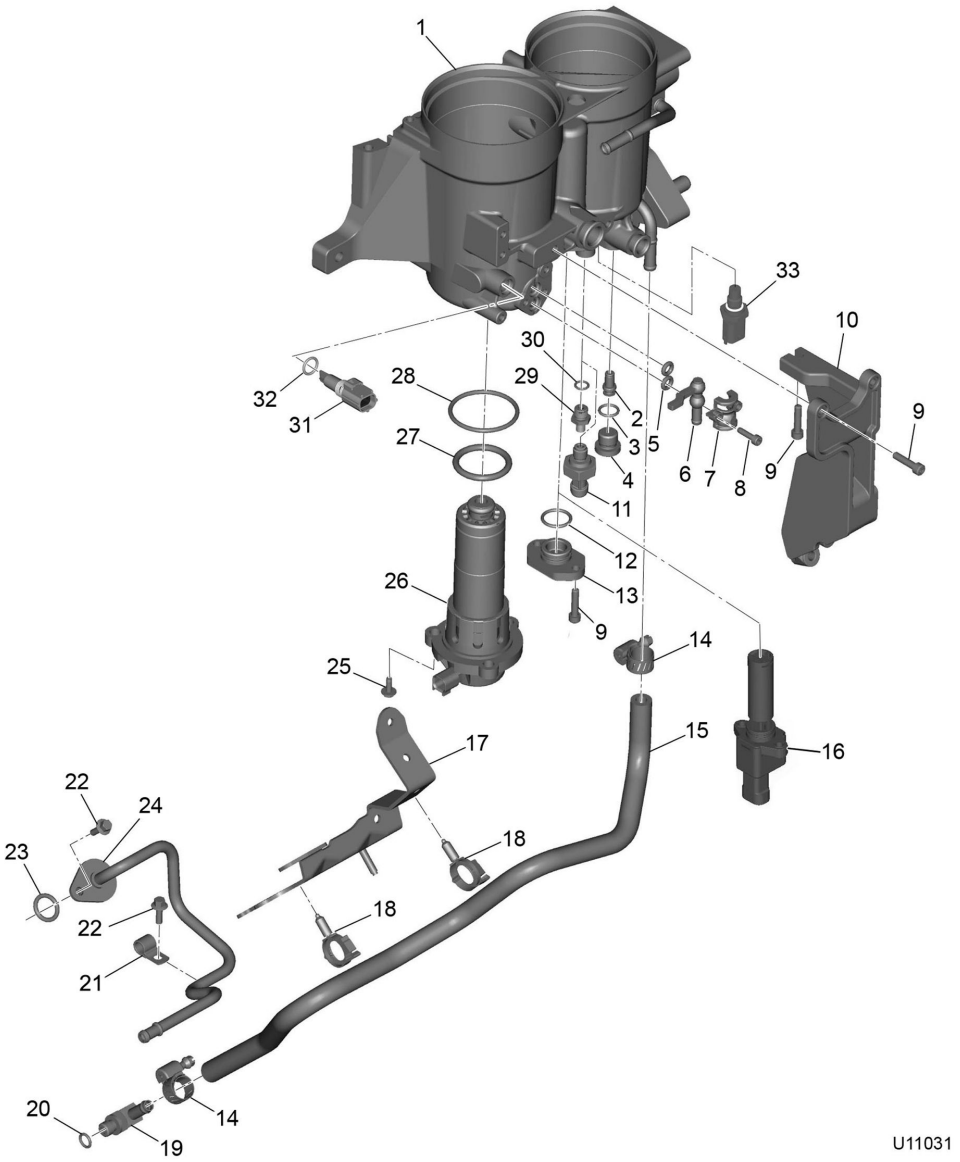


Figure 292 Fuel Filter Module

1. Fuel filter module housing
2. Pressure regulator valve assembly
3. O-ring seal
4. M16 straight thread plug
5. W/valve O-ring (2)
6. Water drain stem
7. Water drain retainer
8. M5 x 18 screw (9)
9. M6 screw (5)
10. Coolant filter support module
11. Fuel Delivery Pressure (FDP) sensor (optional)
12. Fuel O-ring
13. Fuel heater port cover
14. Hose Clamp (2)
15. Coolant return hose
16. Heater assembly (optional)
17. Hose support assembly
18. Hose clip (2)
19. M12 to 3/8 hose fitting assembly
20. O-ring seal
21. Clamp
22. M6 x 16 bolt (2)
23. O-ring seal
24. Fuel coolant supply tube
25. No. 10 rolled thread screw (3)
26. Fuel pump
27. Pump cover and housing O-ring
28. Pump body and housing O-ring
29. Diagnostic valve
30. W/probe O-ring
31. Water in Fuel (WIF) Sensor
32. O-ring seal.
33. Engine Fuel Temperature (EFT) Sensor

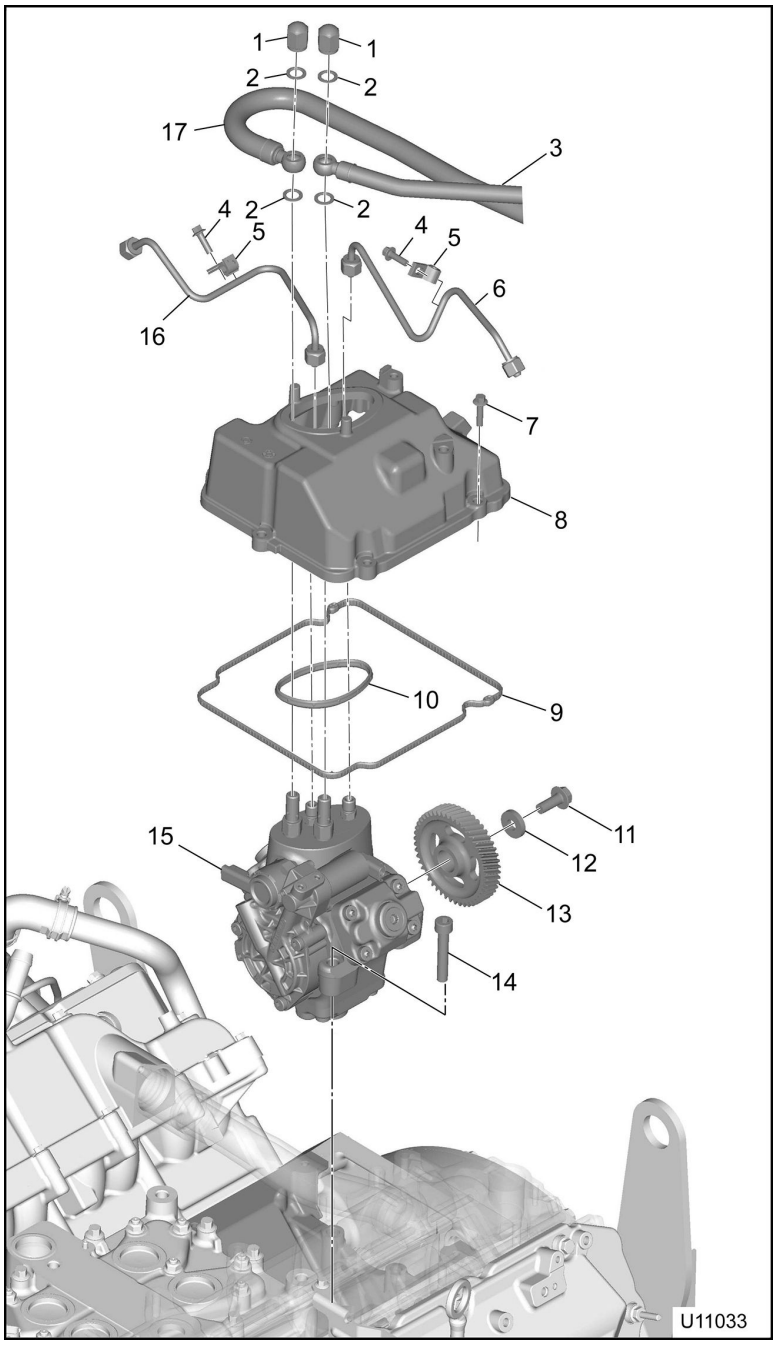


Figure 293 High-Pressure Fuel System

1. M12 nut (2)
2. Bonded seal washer (4)
3. Pump to cooler hose assembly
4. M6 x 20 bolt (2)
5. 1/4 tube clamp (2)
6. Left high-pressure fuel tube assembly
7. M6 x 25 bolt (5)
8. High-pressure fuel pump cover
9. Lower high-pressure pump cover gasket
10. Pump cover gasket
11. Fuel pump gear bolt
12. Fuel pump gear washer
13. Fuel pump gear
14. M10 x 55 bolt (3)
15. High-pressure fuel pump assembly
16. Right high-pressure fuel tube assembly
17. Filter to pump hose assembly

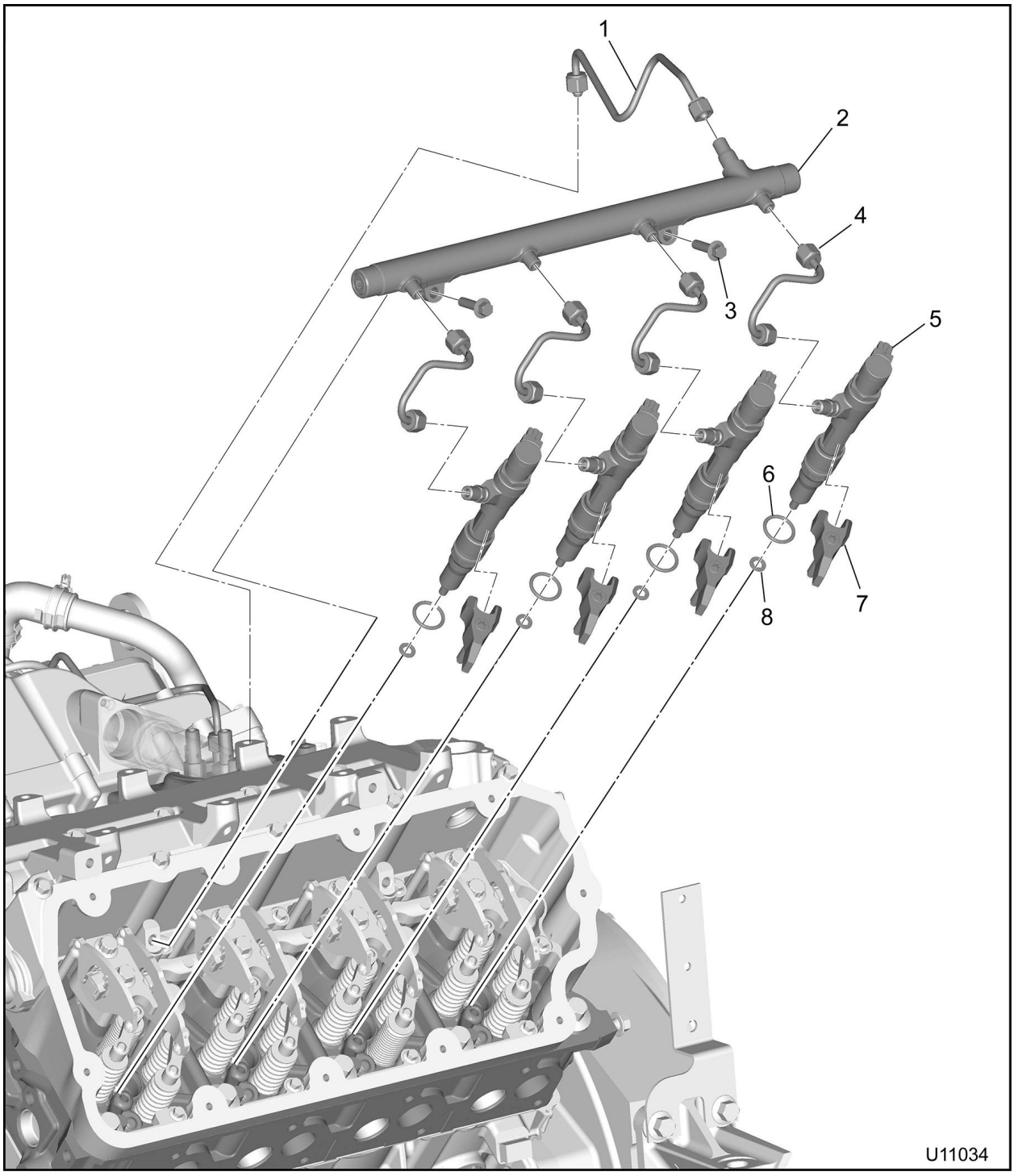


Figure 294 Fuel Injectors Per Cylinder Head (typical)

1. High-pressure fuel tube assembly
2. Fuel rail assembly
3. M8 x 30 bolt (2)
4. Fuel rail to injector tube assembly (4)
5. Fuel injector body (4)
6. Fuel injector seal (4)
7. Injector hold down clamp assembly (4)
8. Combustion gasket (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, 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 sections for removal of components prior to this section:

- Engine Electrical
- Exhaust Gas Recirculation (EGR) System
- Dual Turbocharger, Exhaust Manifolds, and Piping
- Air Compressor and Power Steering Pump
- Cylinder Heads, Valve Covers, and Valve Train

High-pressure Fuel Tube Assemblies

NOTE: See removal procedure for Balance Duct and Balance Tube Flange (page 315) before doing the following procedures.

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.

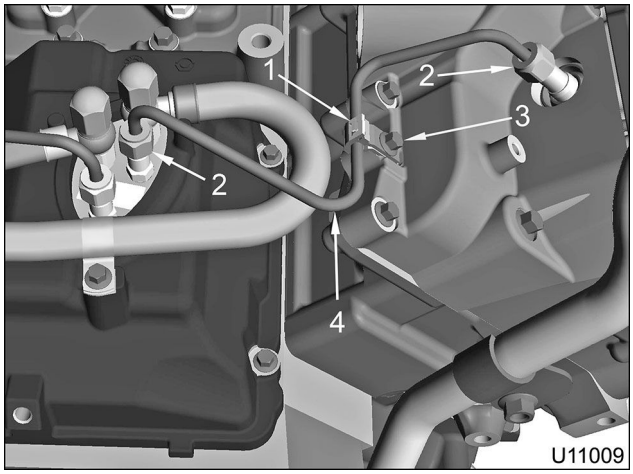


Figure 295 Right High-Pressure Fuel Tube Assembly

1. 1/4 tube clamp
2. Tube nut (2)
3. M6 x 20 bolt
4. Right high-pressure fuel tube assembly

1. Remove M6 x 20 bolt that secures clamp on right high-pressure fuel tube assembly.

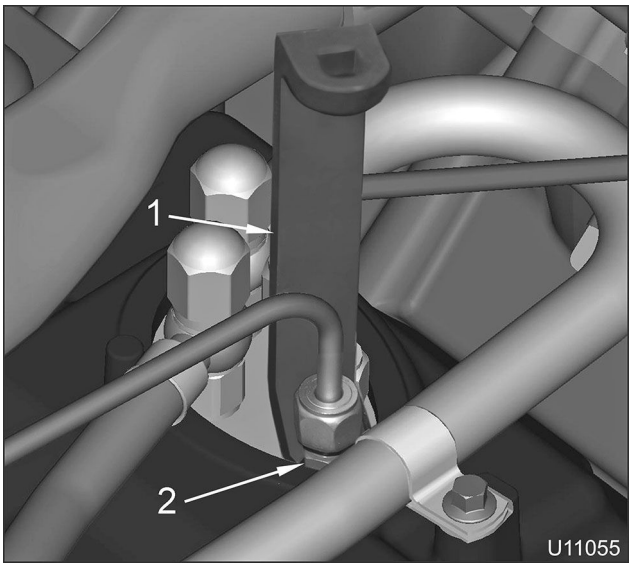


Figure 296 Fuel Fitting Wrench (typical)

1. High-pressure Fuel Pump Wrench
2. Fitting on high-pressure fuel pump

2. Completely loosen tube nuts on right high-pressure fuel tube assembly.
3. Install High-pressure Fuel Pump Wrench (page 261) onto fitting on high-pressure fuel pump.
4. Remove and discard right high-pressure fuel tube assembly.
5. Install Fuel System Caps (page 261). Cap high-pressure fuel pump port and fuel rail port.

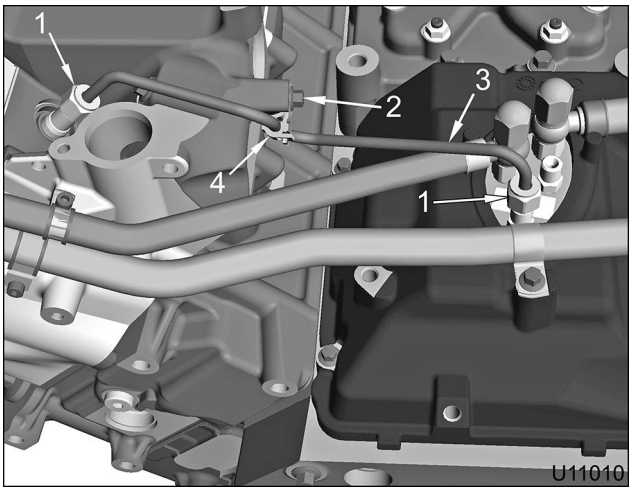


Figure 297 Left High-Pressure Fuel Tube Assembly

1. Tube nut (2)
2. M6 x 20 bolt
3. Left high-pressure fuel tube assembly
4. 1/4 closed clamp

6. Remove M6 x 20 bolt.
7. Install High-pressure Fuel Pump Wrench (page 261) onto fitting on high-pressure fuel pump.
8. Completely loosen tube nuts on left high-pressure fuel tube assembly.
9. Remove and discard left high-pressure fuel tube assembly.
10. Install Fuel System Caps (page 261). Cap high-pressure fuel pump port and fuel rail port.

Draining the Low-pressure Fuel System

1. Clean the primary fuel filter cap, secondary fuel filter cap, and fuel filter module assembly to prevent debris entering fuel system when removing caps.

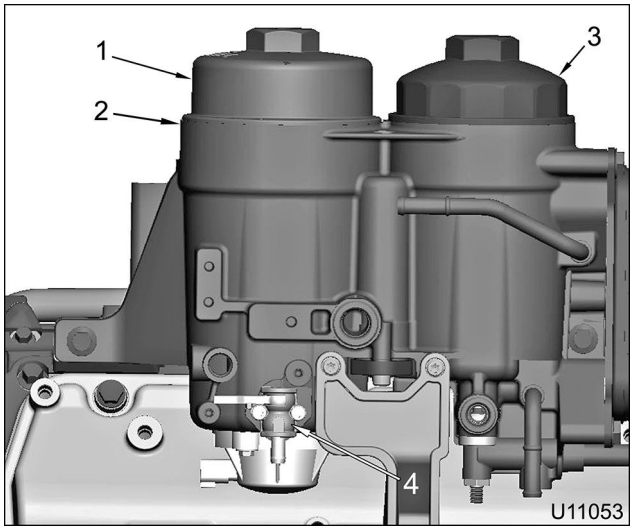


Figure 298 Water Drain Valve

1. Primary fuel filter cap
2. Fuel filter module assembly
3. Secondary fuel filter cap
4. Water drain valve

2. Loosen the primary fuel filter cap counterclockwise three and one-half turns to vent the fuel filter module assembly.
3. Attach a hose to the end of the water drain valve.
4. Position a suitable container under the water drain valve and put end of hose into container.
5. Open water drain valve and drain fuel.
6. After fuel is drained, remove container and recycle or dispose of fuel according to applicable regulations.
7. Remove hose and close water drain valve.
8. Turn the primary fuel filter cap clockwise to seat the cap to the fuel filter module assembly, but do not tighten to torque.

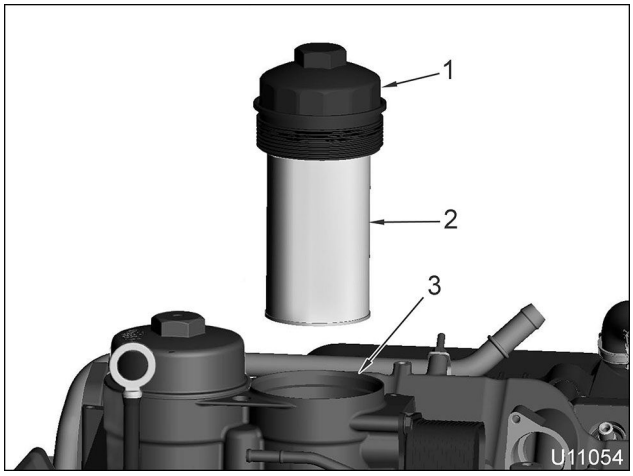


Figure 299 Removal of Secondary Fuel Filter Cap and Fuel Element Filter

1. Secondary fuel filter cap
2. Secondary fuel element filter
3. Fuel filter module assembly

9. Remove the secondary fuel filter cap and fuel element filter to allow fuel to drain to the tank.
10. Reinstall the secondary fuel filter cap and fuel element filter to seat the cap to the fuel filter module assembly, but do not tighten to torque.

Pump to Cooler Hose and Filter to Pump Hose Assemblies

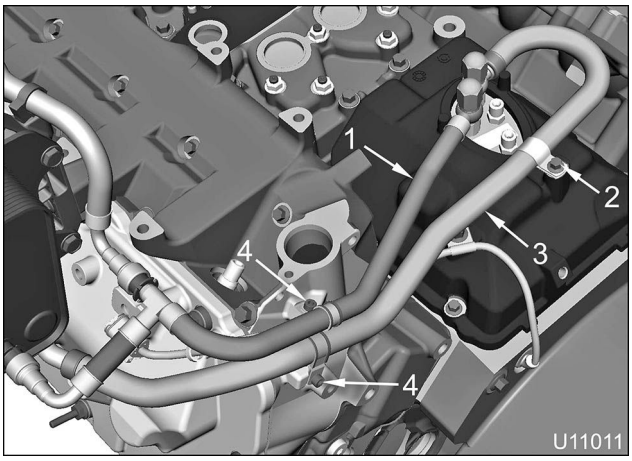


Figure 300 Pump to Cooler Hose and Filter to Pump Hose Assemblies

1. Pump to cooler hose assembly
2. M6 x 14 bolt
3. Filter to pump hose assembly
4. M5 x 12 socket head bolt (2)

1. Remove M6 x 14 bolt and M5 x 12 socket head bolt that secure filter to pump hose assembly.
2. Remove M5 x 12 socket head bolt that secures pump to cooler hose assembly.

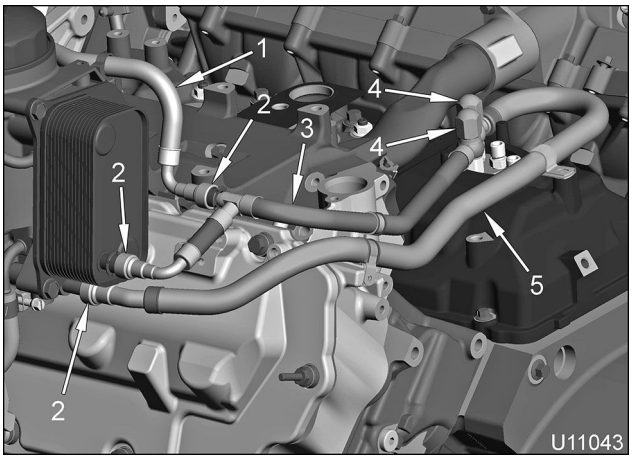


Figure 301 Quick Connectors and Cap Nuts

1. Injector return hose assembly
2. Quick connector
3. Pump to cooler hose assembly
4. M12 cap nut (2)
5. Filter to pump hose assembly

3. Loosen M12 cap nuts that secure the filter to pump hose assembly and pump to cooler hose assembly to the high-pressure fuel pump.

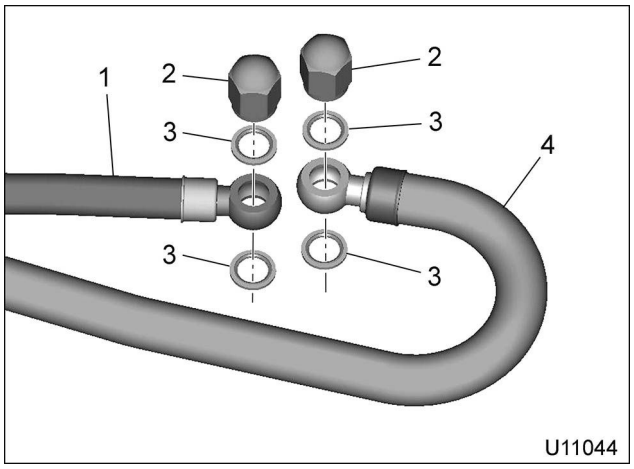


Figure 302 M12 Cap Nuts and Bonded Seal Washer

1. Pump to cooler hose assembly
2. M12 cap nut (2)
3. Bonded seal washer (4)
4. Filter to pump hose assembly

4. Remove M12 cap nut and two M12 bonded seal washers that secure pump to cooler hose assembly. Discard bonded seal washers.
5. Using a Fuel Line Disconnect Tool, disconnect quick connector between injector return hose assembly and pump to cooler hose assembly. Also using tool, disconnect quick connector between pump to cooler hose assembly and fuel cooler.
6. Remove pump to cooler hose assembly

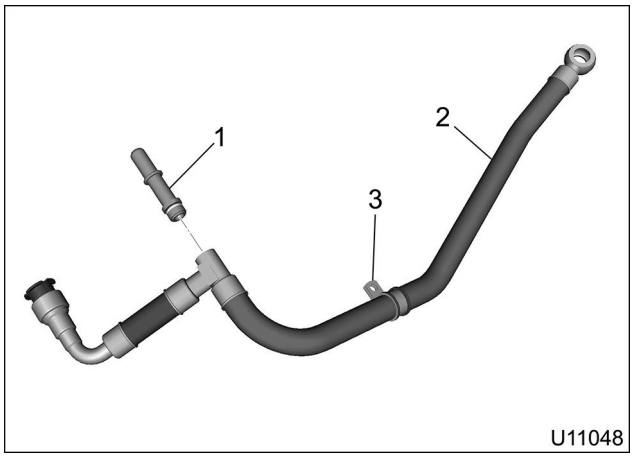


Figure 303 Pump to Cooler Hose Assembly

1. Fuel check valve
2. Pump to cooler hose assembly
3. Dash 8 Cushioned hose clamp

7. Remove fuel check valve.
8. Remove Dash 8 Cushioned hose clamp from pump to cooler hose assembly, if replacing hose.
9. Remove M12 cap nut and two M12 banjo washers that secure filter to pump hose assembly. Discard banjo washers.
10. Use a Spring Lock Coupling Disconnect Tool (page 261) to disconnect quick connector on filter to pump hose assembly to fuel filter module housing.
11. Remove filter to pump hose assembly.

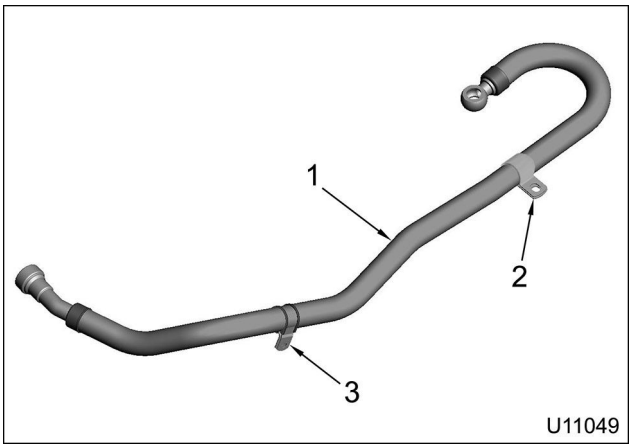


Figure 304 Filter to Pump Hose Assembly

1. Filter to pump hose assembly
2. .5 in hose clamp
3. Dash 10 cushioned hose clamp

12. If required, remove dash 11 cushioned hose clamp and .5 in hose clamp from filter to pump hose assembly, if replacing hose.
13. Install Fuel System Caps (page 261). Cap high-pressure pump ports, hose assembles, fuel filter module port, and fuel cooler port.

Injector Return Hose Assembly

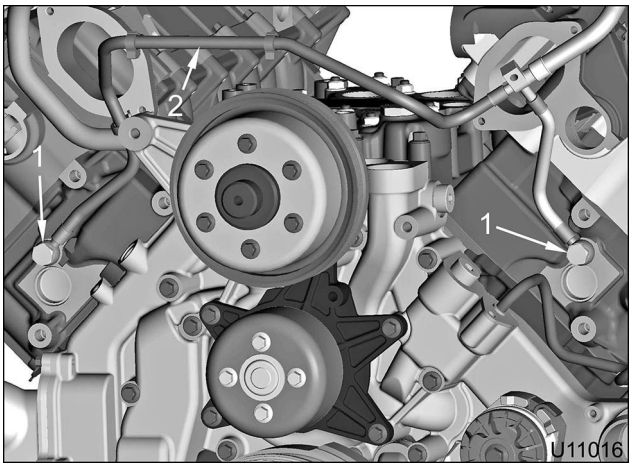


Figure 305 Injector Hose Assembly

1. M12 banjo bolt (2)
2. Injector return hose assembly

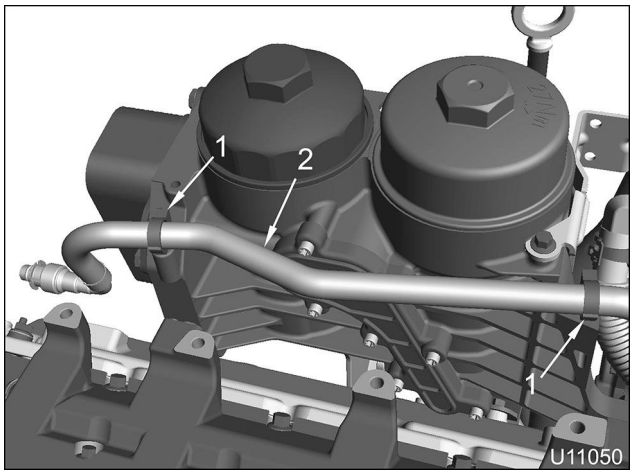


Figure 306 Hose Clips on Injector Return Hose Assembly

1. .375 in hose clip (2)
2. Injector return hose assembly

1. Disconnect .375 in hose clips that secure injector return hose assembly to fuel filter module.

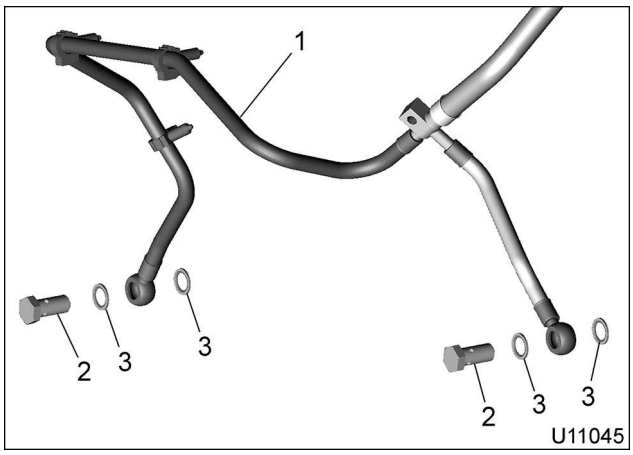


Figure 307 Injector Return Hose Assembly, Banjo Bolts, Bonded Seal Washers

1. Injector return hose assembly
2. M12 Banjo bolt (2)
3. Bonded seal washer (4)

2. Remove two M12 banjo bolts and four bonded seal washers.
3. Remove injector return hose assembly.

High-pressure Fuel Pump Assembly

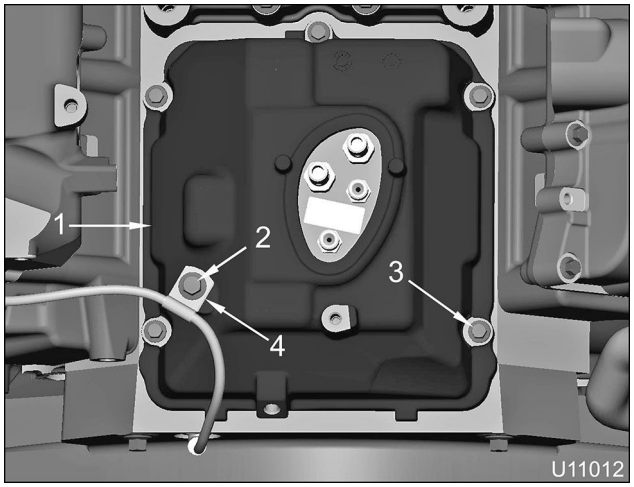


Figure 308 High-Pressure Fuel Pump Cover

1. High-pressure fuel pump cover
2. M8 x 12 bolt
3. M6 x 25 bolt (5)
4. Closed clamp

1. Remove M8 x 12 bolt and closed clamp that secure the high-pressure pump harness assembly to the high-pressure fuel pump cover.
2. Remove five M6 x 25 bolts from the high-pressure fuel pump cover.

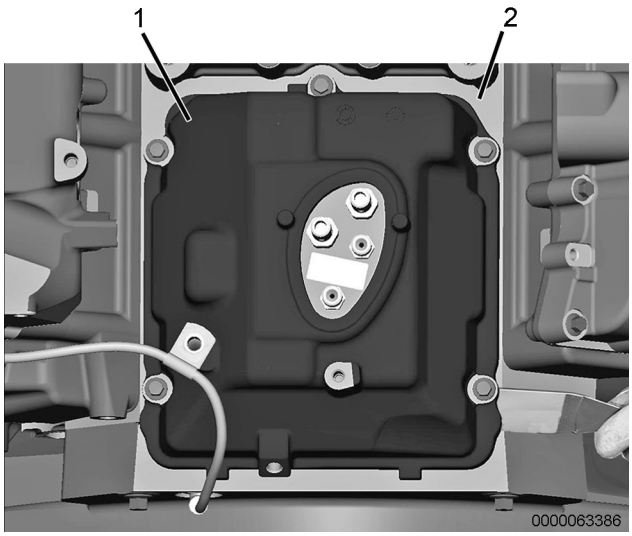


Figure 309 Location of RTV Sealant

1. Fuel pump cover
2. Crankcase mating surface

3. Using a thin, sharp blade scraper, cut RTV sealant between two joining surfaces of crankcase and fuel pump cover assembly.

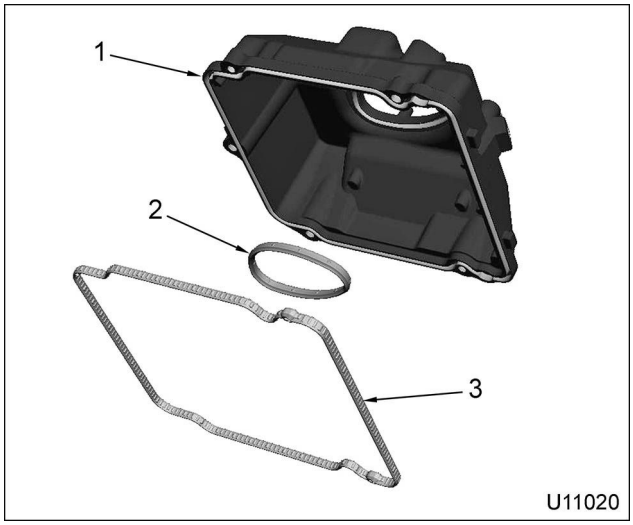


Figure 310 High-Pressure Fuel Pump Cover and Gaskets

1. High-pressure fuel pump cover
2. Pump cover gasket
3. Lower high-pressure pump gasket

4. Remove high-pressure fuel pump cover.

5. Remove and discard the pump cover gasket and lower high-pressure pump gasket.

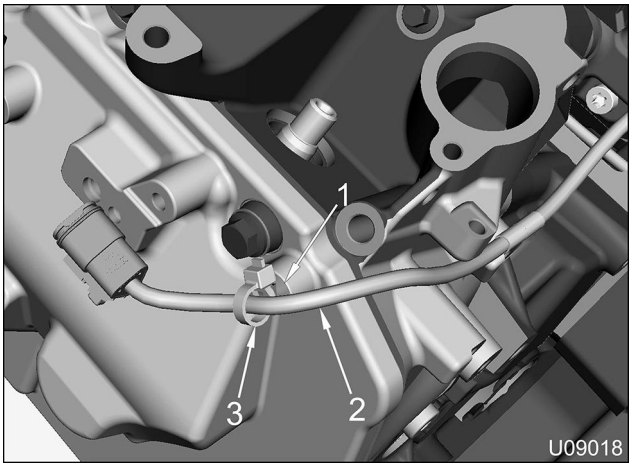


Figure 311 Harness Retainer on High-Pressure Pump Harness Assembly

1. Harness fir zip retainer
2. High-pressure pump harness assembly
3. Tie strap

6. Cut and remove tie strap from harness fir zip retainer in left valve cover.

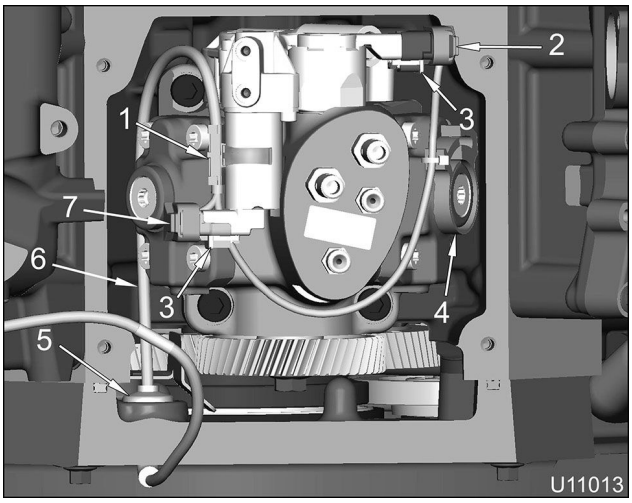


Figure 312 High-Pressure Pump Harness Assembly

1. C-clip
2. Connector (black)
3. Yellow CPA
4. Snapper clip
5. Pass-through overmold plug
6. High-pressure pump harness assembly
7. Connector (orange)

7. Unlock yellow CPA on orange connector and black connector; disconnect both connectors from high-pressure pump.
8. Disconnect C-clip and snapper clip; separate the high-pressure pump harness assembly from the high-pressure pump.
9. Push in pass-through overmold plug and harness assembly from the outside of crankcase and pull harness assembly out.

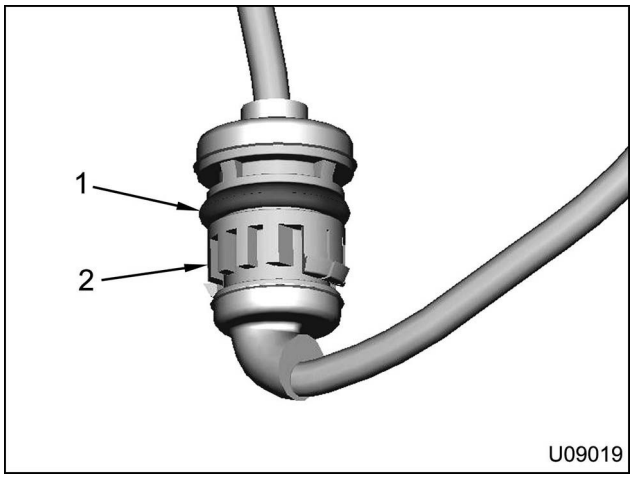


Figure 313 O-ring on Pass-Through Overmold Plug

1. O-ring
2. Pass-through overmold plug

10. Remove O-ring from pass-through overmold plug and harness assembly. Discard O-ring.

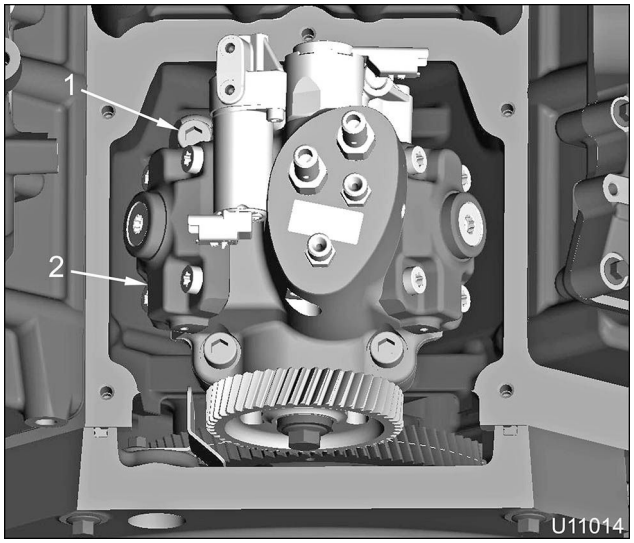


Figure 314 High-Pressure Fuel Pump Assembly

1. M10 x 55 socket head bolt (3)
2. High-pressure fuel pump assembly

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

11. Remove three M10 x 55 bolts and high-pressure fuel pump assembly.

Figure 315 Engine Wiring Harness Guide

1. M6 x 14 bolt (2)
2. Engine wiring harness guide

12. Only if required, remove two M6 x 14 bolts and engine wiring harness guide.

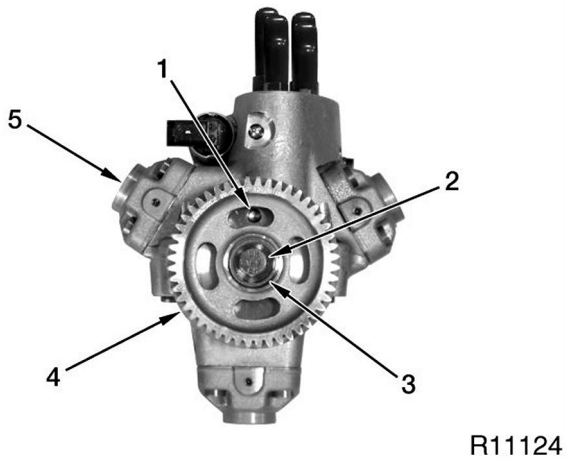


Figure 316 High-Pressure Fuel Pump Gear

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 12–15 only if replacing the high-pressure pump gear.

13. 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.

14. Remove fuel pump gear bolt and washer.
15. Remove fuel pump gear.

Fuel Injectors and Fuel Rail Assemblies

NOTE: See procedures to remove valve covers in the "Cylinder Heads, Valve Covers, and Valve Train" section (page 315) before removing fuel injector and rail assemblies.

1. Remove Fuel Rail Pressure (FRP) sensor from right fuel rail. See page (page 87).
2. Remove Under Valve Cover (UVC) harnesses (page 88).

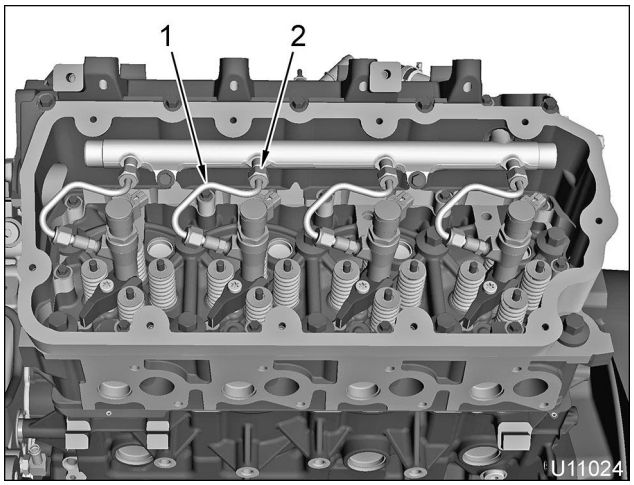


Figure 317 Fuel Rail to Injector Tube Assemblies (typical)

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.

3. Use a wrench to hold fuel injector fittings and loosen four tube nuts from fuel injectors.
4. Loosen four tube nuts on fuel rail. Remove and discard four fuel rail to injector tube assemblies.
5. Cover outlet ports of fuel rail with Fuel System Caps (page 261).
6. Cover fuel injector ports with Fuel System Caps (page 261).

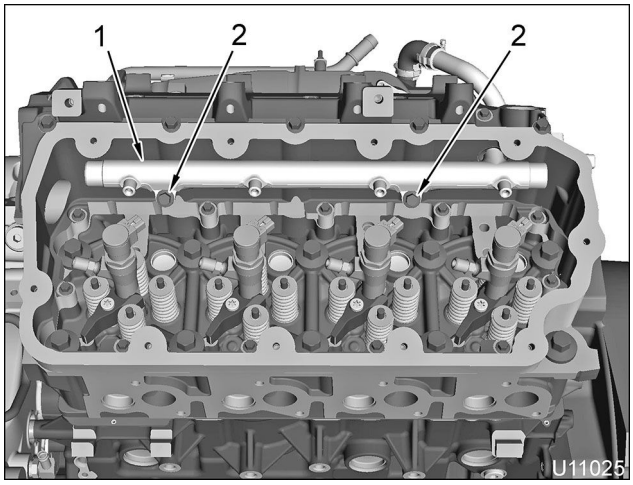


Figure 318 Fuel Rail Assembly (typical)

1. Fuel rail
2. M8 x 30 bolt (2)

7. Remove two M8 x 30 bolts.
8. Remove fuel rail assembly.

CAUTION: To prevent engine damage, remove injectors before removing cylinder head.

CAUTION: To prevent engine damage, do not use power tools to remove or install fuel injector clamp bolts. Threads will be damaged if a bolt or nut is rotated too quickly.

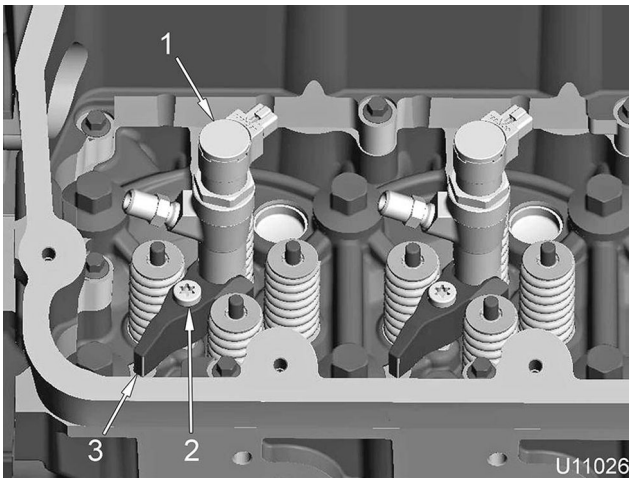


Figure 319 Fuel Injector Assembly (typical)

1. Fuel injector assembly (4)
2. Injector clamp bolt (4)
3. Injector hold down clamp (4)

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.

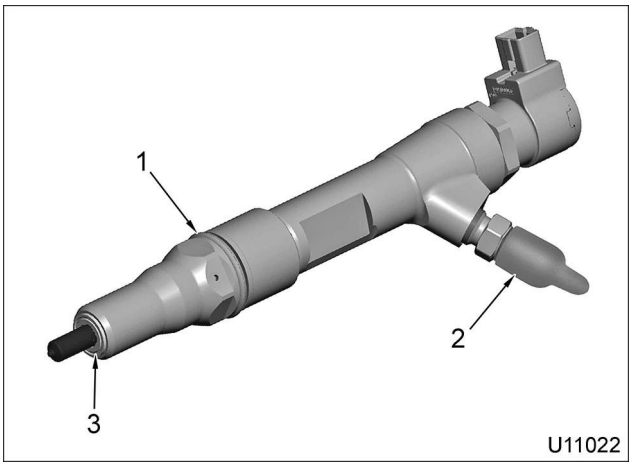


Figure 320 Fuel Injector Seal and Combustion Gasket

1. Fuel injector seal
2. Plastic protective cap
3. Combustion gasket

CAUTION: To prevent engine damage, install new fuel injector seal and combustion gasket if a fuel injector is removed.

11. Using a small hand tool, remove and discard combustion gasket. Wipe injector nozzle with a lint free cloth.

CAUTION: To prevent engine damage, make sure the combustion gasket does not remain in the injector sleeve.

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 261).
13. Remove and discard fuel injector seal.
14. Install plastic protective cap over injector tip.
15. Insert fuel injector assembly in Injector Cup (page 261), and place in Fuel Injector Rack Holder (page 261).
16. Repeat steps 9–15 for each fuel injector.

Oil Level Tube Assembly and Coolant Return Hose

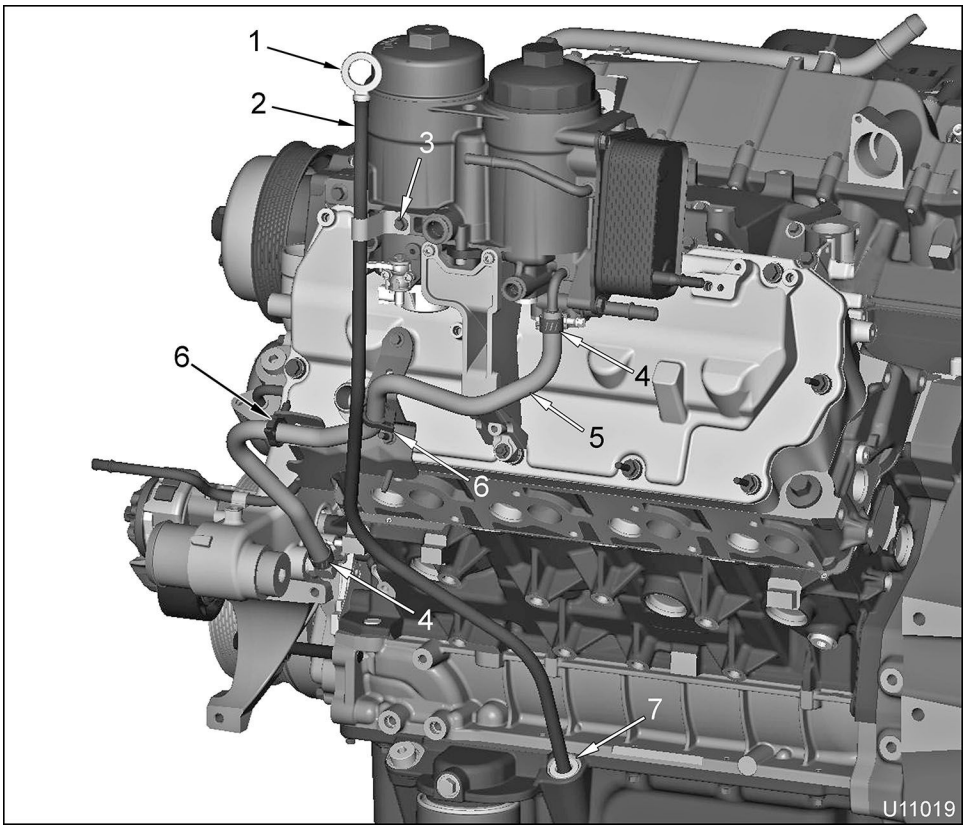


Figure 321 Oil Level Tube Assembly and Coolant Return Hose

1. Oil level gauge assembly
2. Oil level gauge tube with support
3. M6 x 16 bolt
4. Hose clamp (2)
5. Coolant return hose
6. Hose clip (2)
7. Oil level tube gauge gasket

1. Remove oil fill support bracket and oil fill hose assembly (page 319).
2. Remove oil level gauge assembly.
3. Remove M6 x 16 bolt from oil level gauge tube and remove oil level gauge tube.
4. Remove oil level tube gauge gasket.
5. Open hose clips, loosen hose clamps on coolant return hose, and remove hose.

Fuel Coolant Supply Tube Assembly

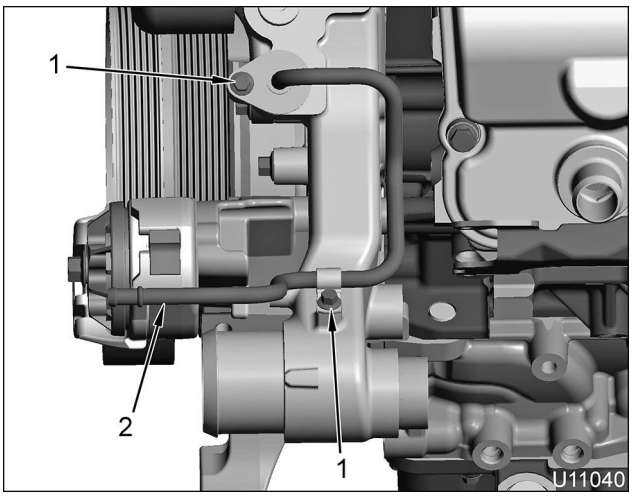


Figure 322 Fuel Coolant Supply Tube Assembly

1. M6 x 16 bolt (2)
2. Fuel coolant supply tube assembly

1. Remove two M6 x 16 bolts and fuel coolant supply tube assembly.

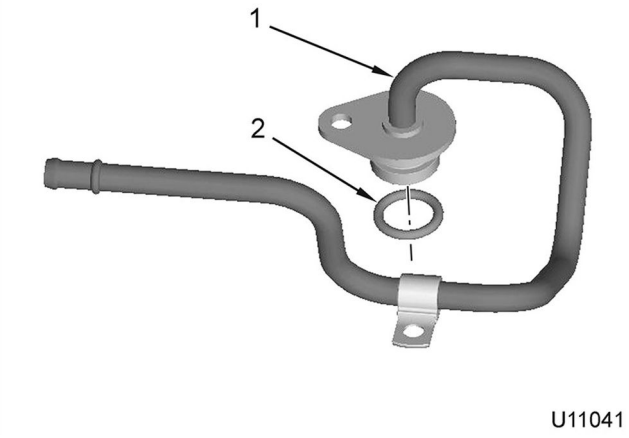


Figure 323 Fuel Coolant Supply Tube and O-ring Seal

1. Fuel coolant supply tube
2. O-ring seal

2. Remove O-ring seal from fuel coolant supply tube and discard O-ring seal.

Fuel Filter and Cooler Assembly

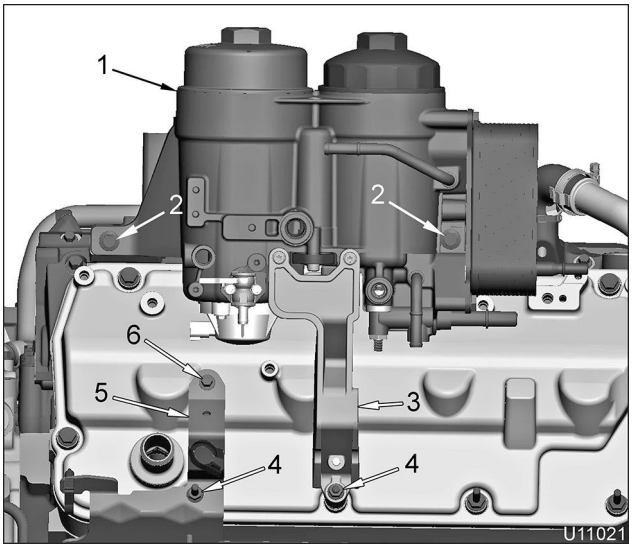


Figure 324 Fuel Filter and Cooler Assembly

1. Fuel filter cooler assembly
2. M8 x 35 bolt (2)
3. Filter cooler pump module support
4. M6 nut (2)
5. Hose bracket assembly
6. M6 x 20 bolt

1. Remove M6 nut from filter cooler pump module support.
2. Remove two M8 x 35 bolts that secure the fuel filter cooler assembly.
3. Remove fuel filter cooler assembly with filter cooler pump module support.
4. Remove M6 x 20 bolt, M6 nut, and hose bracket assembly.

Fuel Filter Cooler Assembly and Filter Cooler Pump Module Support

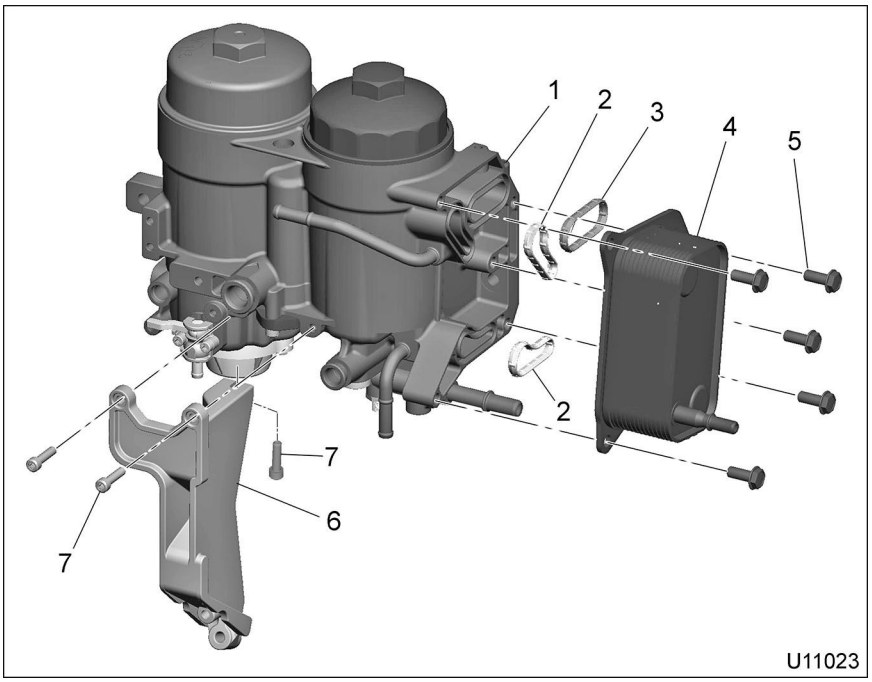


Figure 325 Fuel Filter Cooler Assembly and Filter Cooler Pump Module Support

1. Fuel filter module housing
2. Fuel cooler coolant gasket (2)
3. Fuel gasket
4. Fuel cooler
5. M8 x 20 thread forming screw (5)
6. Filter cooler pump module support
7. M6 screw (3)

1. Remove five M8 x 20 screws that secure the fuel cooler.
2. Remove and discard the fuel gasket and two fuel cooler coolant gaskets.
3. Remove three M6 screws that secure the filter cooler pump module support and remove module support.

Primary Fuel Filter, Secondary Fuel Filter, and Fuel Housing Cover

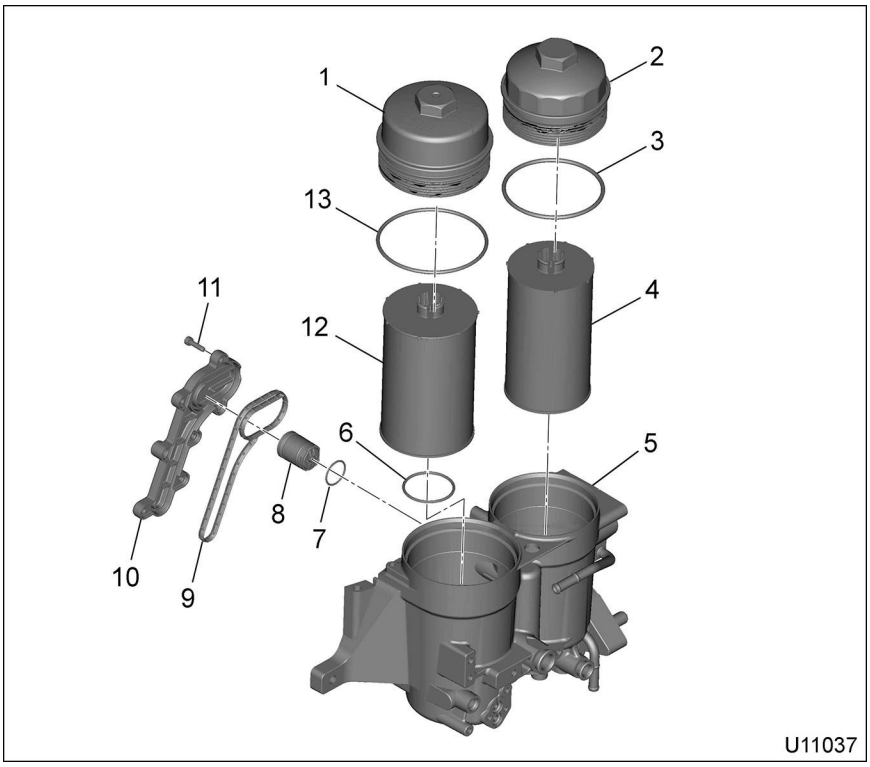


Figure 326 Primary Fuel Filter, Secondary Fuel Filter, and Fuel Housing Cover

1. Filter cap (primary)
2. Filter cap (secondary)
3. Fuel cap secondary O-ring
4. Secondary fuel element assembly
5. Fuel filter module housing
6. Primary fuel element O-ring
7. Fuel O-ring
8. Fuel thermal bypass valve assembly
9. Fuel housing cover gasket
10. Fuel housing cover
11. M5 x 18 screw (9)
12. Primary filter assembly
13. Primary fuel cap O-ring

1. Remove primary fuel filter cap.
2. Remove and discard primary fuel cap O-ring, primary filter assembly, and primary fuel element O-ring.
3. Remove secondary fuel filter cap.
4. Remove and discard fuel cap secondary O-ring and secondary fuel element assembly.
5. Remove nine M5 x 18 screws and fuel housing cover.
6. Remove and discard fuel housing cover gasket.
7. Remove fuel thermal bypass valve assembly.
8. Remove and discard fuel O-ring.

Fuel Pump

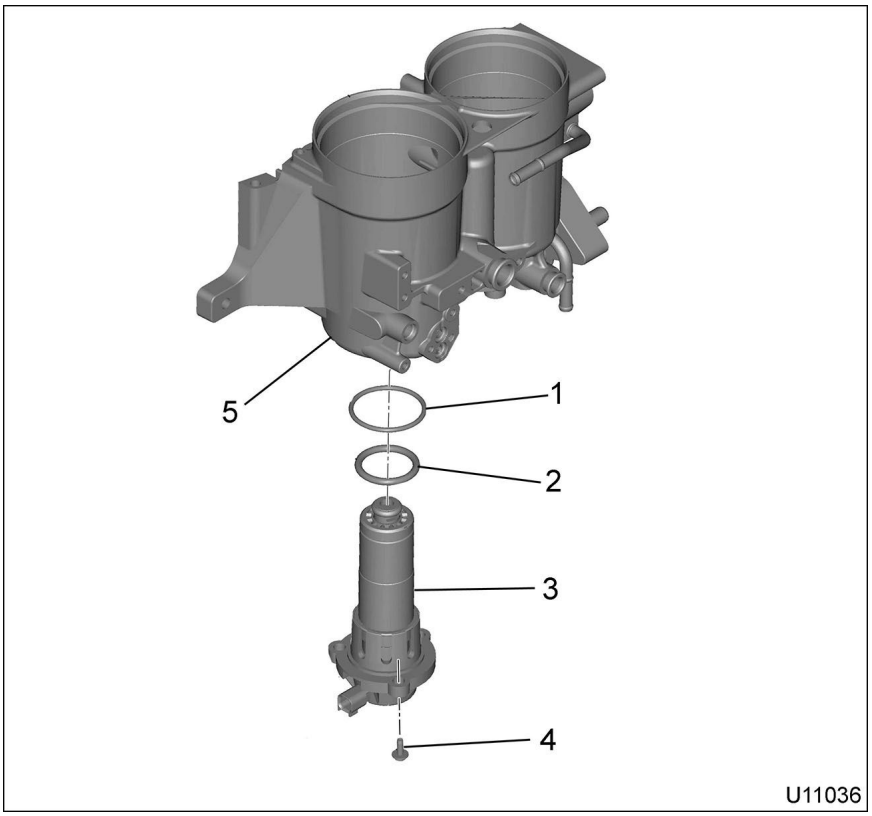


Figure 327 Fuel Pump

1. Pump cover and housing O-ring
2. Pump body and housing O-ring
3. Fuel pump
4. No. 10 rolled thread screw (3)
5. Fuel filter module housing

1. Remove three No. 10 rolled thread screws and fuel pump.
2. Remove and discard pump cover and housing O-ring.
3. Remove and discard pump body and housing O-ring.

Fuel Heater Port Cover, Diagnostic Valve, Pressure Regulator, and Engine Fuel Temperature (EFT) Sensor

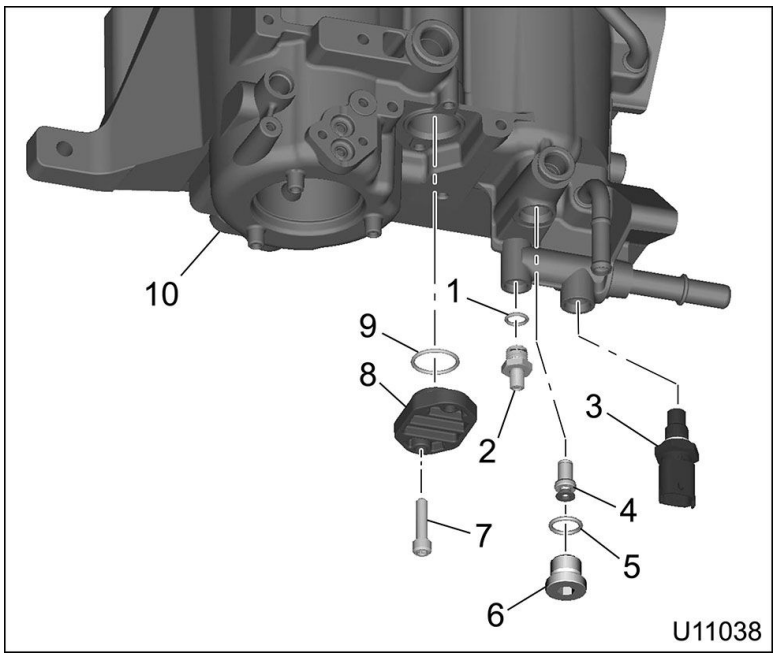


Figure 328 Fuel Heater Port Cover, Diagnostic Valve, Pressure Regulator, and Engine Fuel Temperature (EFT) Sensor

1. Probe O-ring
2. Diagnostic valve
3. Engine Fuel Temperature (EFT) sensor with O-ring
4. Pressure regulator valve assembly
5. O-ring seal
6. M16 straight thread plug
7. M6 screw (2)
8. Fuel heater port cover
9. Fuel O-ring
10. Fuel filter module housing

1. Remove two M6 screws from fuel heater port cover.
2. Remove fuel heater port cover.
3. Remove and discard fuel O-ring.
4. Remove diagnostic valve.
5. Remove and discard probe O-ring.
6. Remove M16 straight thread plug
7. Remove and discard O-ring seal.
8. Remove pressure regulator valve assembly.
9. Remove Engine Fuel Temperature (EFT) sensor and O-ring. Discard O-ring.

Fuel Heater (Optional) and Fuel Delivery Pressure (FDP) Sensor (Optional)

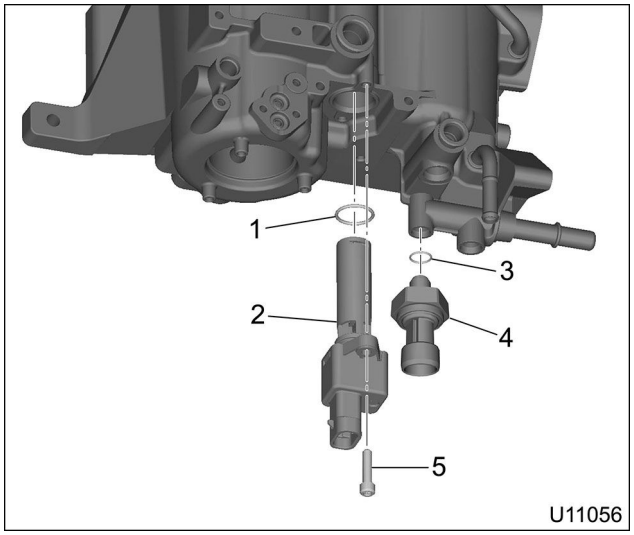


Figure 329 Fuel Heater (Optional) and Fuel Delivery Pressure (FDP) Sensor (Optional)

1. Fuel O-ring
2. Heater assembly (optional)
3. O-ring
4. FDP sensor
5. M6 screw (2)

1. Remove two M6 screws from fuel heater.
2. Remove fuel heater.
3. Remove fuel O-ring from fuel heater and discard fuel O-ring.
4. Remove FDP sensor.
5. Remove O-ring from FDP sensor and discard O-ring.

Water In Fuel (WIF) Sensor and Water Drain Valve

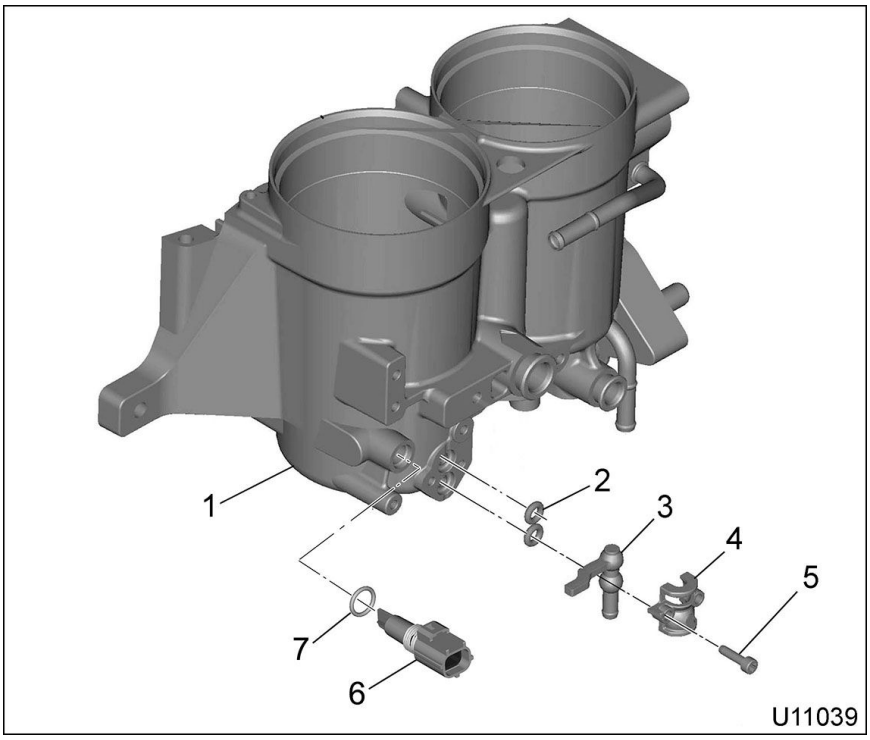


Figure 330 Water In Fuel (WIF) Sensor and Water Drain Valve

1. Fuel filter module housing
2. Valve O-ring (2)
3. Water drain stem
4. Water drain retainer
5. M5 x 18 screw (2)
6. WIF sensor
7. O-ring seal

1. Remove WIF sensor.
2. Remove O-ring seal from WIF sensor assembly. Discard O-ring seal.
3. Remove two M5 x 18 screws, water drain retainer, and water drain stem.
4. Remove and discard two valve O-rings.

Inspection

Fuel Filter and Fuel Hose Inspection

1. Inspect filter to pump hose assembly and pump to cooler hose assembly for damage. Install new pump hose assembly and pump to cooler hose assembly, if necessary.
2. Inspect fuel coolant supply tube assembly for damage. Install new fuel coolant supply tube assembly, if necessary.

Fuel Filter in Low-Pressure Line at High-Pressure Pump

The following procedure is used to determine if a fuel filter installation is necessary in the Low-Pressure (LP) fuel line at the High-Pressure Fuel Pump (HPFP).

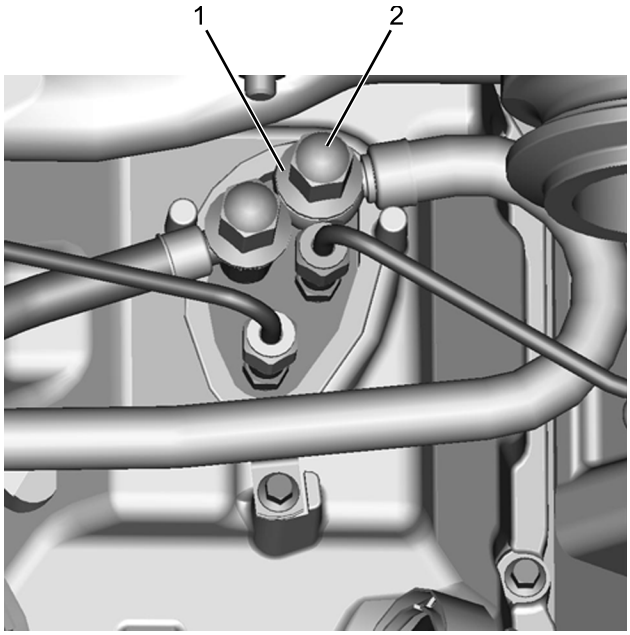


Figure 331 LP Fuel Line Removal

1. LP fuel line banjo fitting
2. M12 hex nut

1. Remove hex nut from LP fuel line banjo fitting.

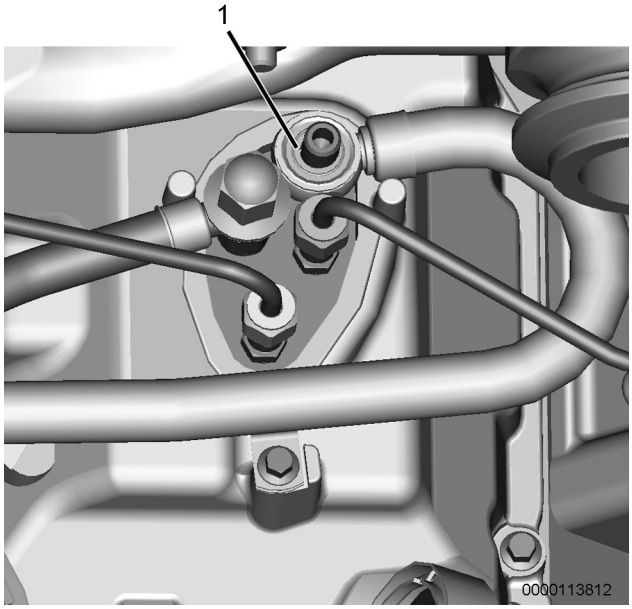


Figure 332 Bonded Washer Removal

1. M12 bonded seal washer

2. Remove bonded seal washer from LP fuel line.

Upon removal of bonded seal washer from LP fuel line, inspect for presence of fuel filter. View A (located below) shows presence of fuel filter in LP fuel line. View B (located below) shows no fuel filter in LP fuel line.

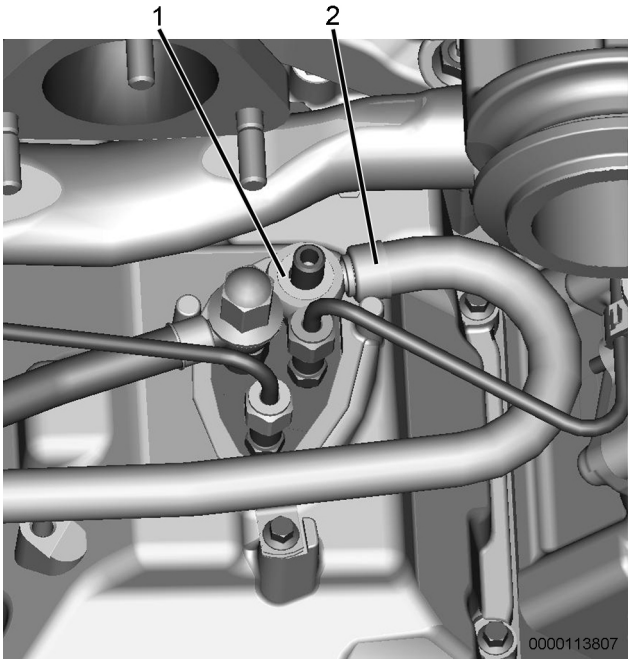


Figure 333 View A (Presence of Fuel Filter)

1. Fuel filter
2. LP fuel line

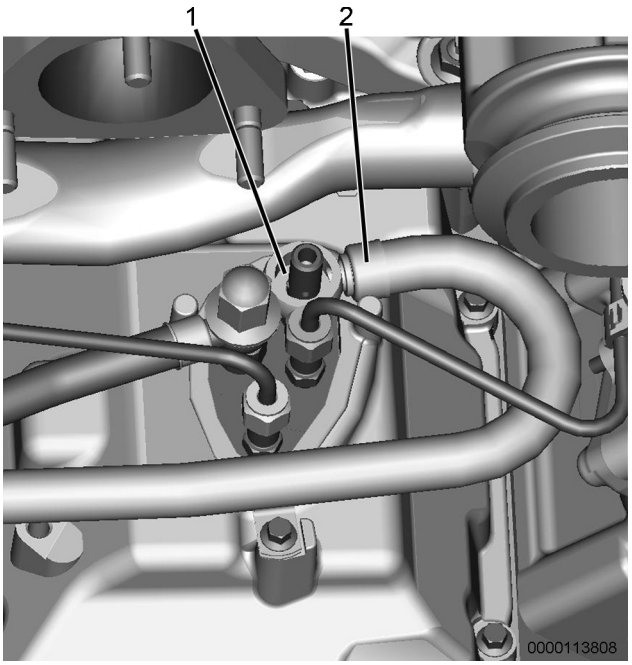


Figure 334 View B (No Fuel Filter Present)

1. No fuel filter present in banjo fitting
2. LP fuel line

NOTE: If no fuel filter is present in the LP fuel line, a new fuel filter should be installed.

CAUTION: If fuel filter is present, inspect filter condition and determine if clogged. Replace as necessary.

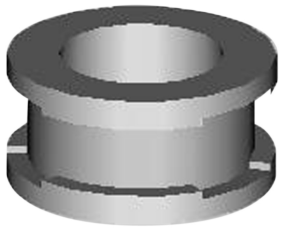


Figure 335 Fuel Filter

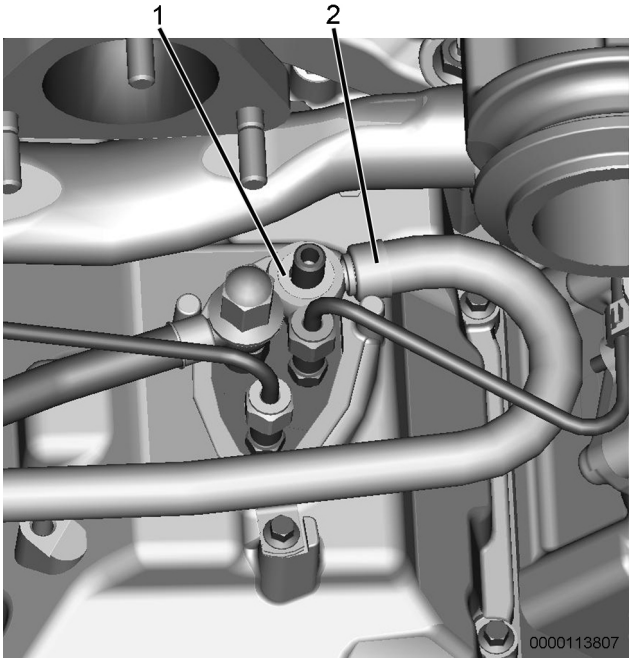


Figure 336 Fuel Filter Installation

1. Fuel filter inside banjo fitting
2. LP fuel line

3. Install fuel filter into banjo fitting end of LP fuel line.

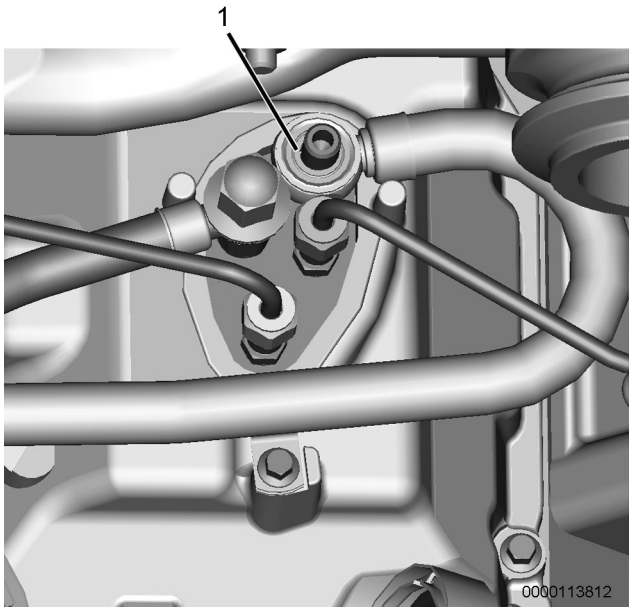


Figure 337 Bonded Washer Installation

1. M12 bonded seal washer

4. Place new M12 bonded seal washer on top of banjo.

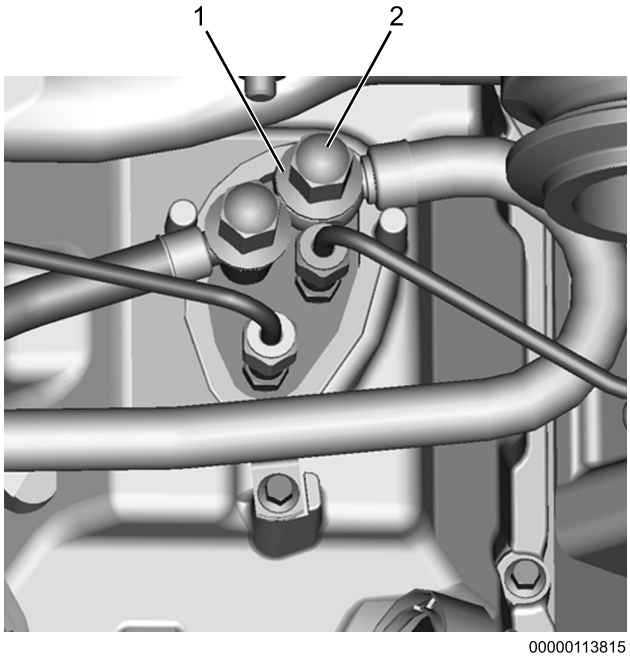


Figure 338 LP Fuel Line Installation

1. LP fuel line banjo fitting
2. M12 hex nut

5. Install M12 hex nut onto LP fuel line banjo fitting and torque to 18-20 lb ft (25-27 N•m)

Flushing the Low-pressure Fuel System

CAUTION: To prevent damage to the engine, the low pressure fuel system must be flushed before priming or starting the engine, if the diagnostic valve, Fuel Delivery Pressure (FDP) sensor or Engine Fuel Temperature (EFT) sensor were removed. Failure to correctly flush the low-pressure fuel system may damage the high-pressure fuel injection system.

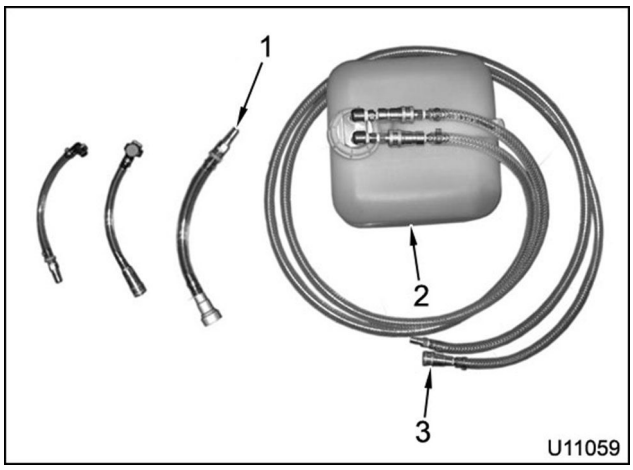


Figure 339 Clean Fuel Tank Kit

1. Fuel Filter Purge Line
2. 2.5 Gallon Clean Fuel Tank
3. Return Line

1. Use the Clean Fuel Tank Kit (page 261) for this procedure.
2. Attach Return Line to the 2.5 Gallon Clean Fuel Tank.

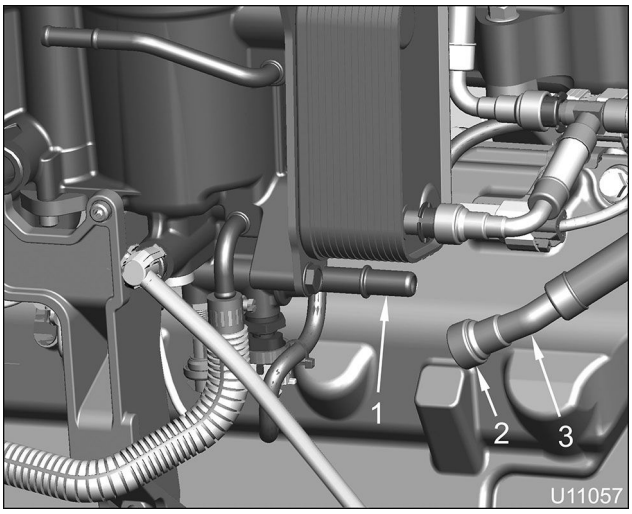


Figure 340 Quick Disconnect on Filter to Pump Hose Assembly

1. Clean outlet
2. 1/2 inch quick disconnect
3. Filter to pump hose assembly

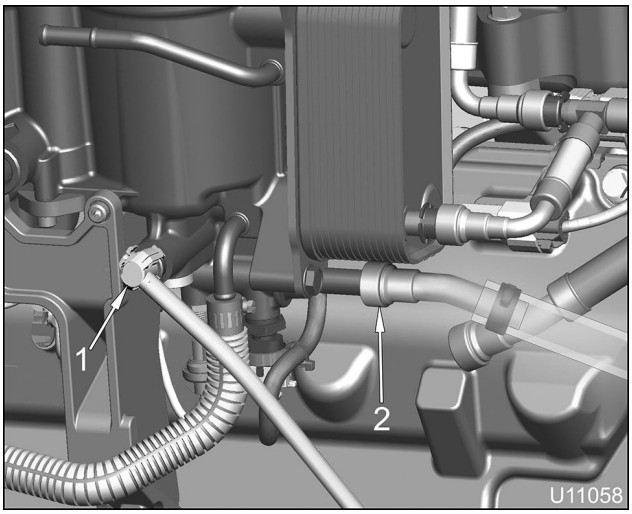


Figure 341 Fuel Filter Purge Line Connection to the Clean Outlet

1. Fuel Filter Purge Line
2. Return-to-tank hose

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

3. Position a suitable container under the clean outlet on the fuel filter module housing, disconnect the 1/2 inch quick disconnect, and remove the filter to pump hose assembly. Cap the quick disconnect on the filter to pump hose assembly.
4. Attach Fuel Filter Purge Line to the clean outlet on the fuel filter module housing.
5. Connect the other end of the Fuel Filter Purge Line the Return Line attached to the 2.5 Gallon Clean Fuel Tank.
6. Restore electrical power to the system.
7. Remove the return-to-tank hose from fuel filter module housing.
8. Turn ignition key to ON for one Key-ON / Key-OFF sequence to energize the low pressure fuel pump.
   - Key - On for 15 seconds
   - Key - Off for 20 seconds

   Ensure that fuel is flowing into the 2.5 Gallon Clean Fuel Tank and check for leaks.

9. Turn ignition key to ON to repeat seven Key-ON/Key-OFF sequences.
   - Key - On for 15 seconds
   - Key - Off for 20 seconds

   Make sure fuel continues flowing into the 2.5 Gallon Clean Fuel Tank and check for leaks.
10. Turn ignition key to OFF to stop low pressure pump.
11. Remove the Fuel Filter Purge Line from the clean outlet. Use a suitable container to catch fuel from the clean outlet.
12. Remove cap from quick disconnect on the filter to pump hose assembly and reconnect the filter to pump hose assembly to the clean outlet.
13. Reconnect the return-to-tank hose to fuel filter module housing.
14. Purge air, that may have been introduced, into the system. See Priming the Fuel System after Running Out of Fuel (Section 4 – ENGINE OPERATION) in the *Engine Operation and Maintenance Manual*.
15. Dispose of fuel, according to applicable regulations.

Installation

Water In Fuel (WIF) Sensor and Water Drain Valve

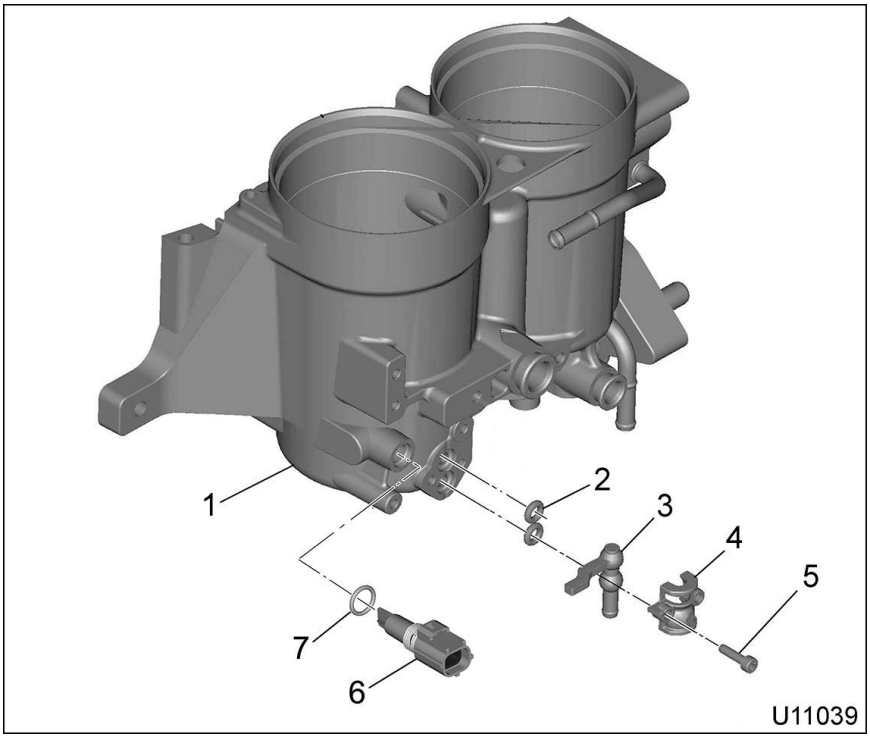


Figure 342 Water In Fuel (WIF) Sensor and Water Drain Valve

1. Fuel filter module housing
2. Valve O-ring (2)
3. Water drain stem
4. Water drain retainer
5. M5 x 18 screw (2)
6. WIF sensor
7. O-ring seal

1. Lubricate two new valve O-rings with clean diesel fuel.
2. Install lubricated O-rings, water drain retainer, water drain stem, and two M5 x 18 screws. Tighten screws to special torque (page 260).
3. Lubricate new O-ring seal with clean diesel fuel and install onto WIF sensor assembly.
4. Install WIF sensor and tighten to special torque (page 260).

Fuel Heater Port Cover, Diagnostic Valve, Pressure Regulator, and Engine Fuel Temperature (EFT) Sensor

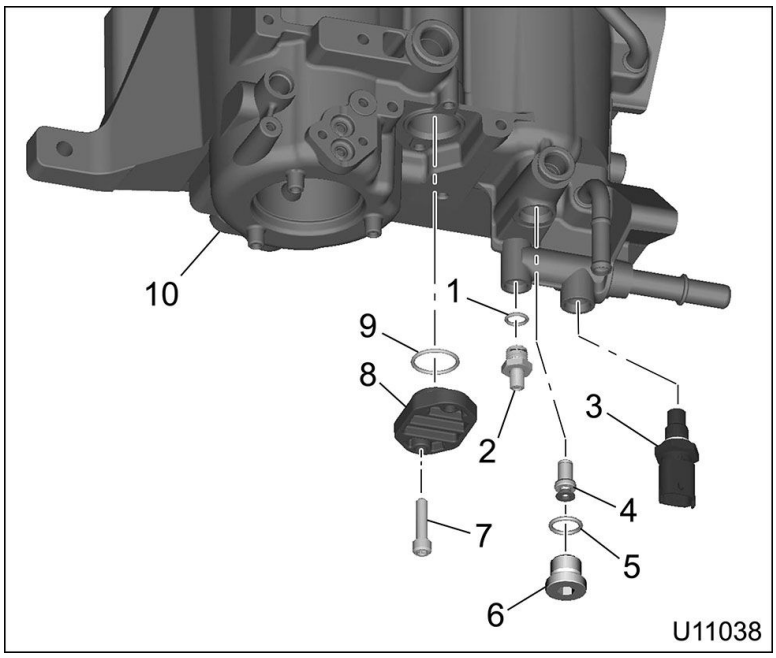


Figure 343 Fuel Heater Port Cover, Diagnostic Valve, Pressure Regulator, and Engine Fuel Temperature (EFT) Sensor

1. W/probe O-ring
2. Diagnostic valve
3. Engine Fuel Temperature (EFT) sensor with O-ring
4. Pressure regulator valve assembly
5. O-ring seal
6. M16 straight thread plug
7. M6 screw (2)
8. Fuel heater port cover
9. Fuel O-ring
10. Fuel filter module housing

1. Lubricate a new fuel O-ring with clean diesel fuel and install fuel O-ring onto fuel heater port cover.
2. Install two M6 screws to secure fuel heater port cover and tighten screws to standard torque (page 473).
3. Lubricate a new w/probe O-ring with clean diesel fuel and install O-ring onto diagnostic valve.

CAUTION: To prevent damage to the engine, the low pressure fuel system must be flushed before priming or starting the engine, after installation of the diagnostic valve.

4. Install diagnostic valve and tighten to special torque (page 260).

   NOTE: See Flushing the Low-pressure Fuel System (page 237).

5. Install pressure regulator valve assembly.
6. Lubricate a new O-ring seal with clean diesel fuel and install onto M16 straight thread plug.
7. Install M16 straight thread plug and tighten standard torque (page 473).
8. Lubricate a new O-ring seal with clean diesel fuel and install onto EFT sensor.

CAUTION: To prevent damage to the engine, the low pressure fuel system must be flushed before priming or starting the engine, after installation of the Engine Fuel Temperature (EFT) sensor.

9. Install EFT sensor and tighten to special torque (page 260).

   NOTE: See Flushing the Low-pressure Fuel System (page 237).

Fuel Heater (Optional) and Fuel Delivery Pressure (FDP) Sensor (Optional)

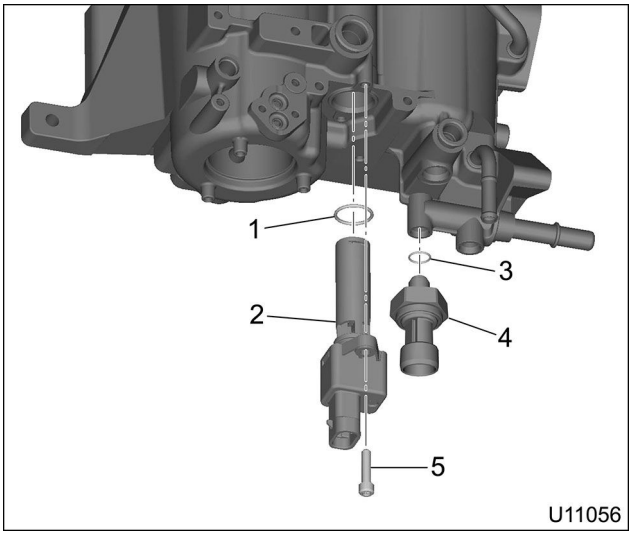


Figure 344 Fuel Heater (Optional) and Fuel Delivery Pressure (FDP) Sensor (Optional)

1. Fuel O-ring
2. Heater assembly (optional)
3. O-ring
4. FDP sensor
5. M6 screw (2)

1. Lubricate a new fuel O-ring with clean diesel fuel and install onto fuel heater.
2. Install fuel heater into fuel filter module housing.
3. Install two M6 screws and tighten screws to standard torque (page 473).
4. Lubricate a new O-ring with clean diesel fuel and install onto FDP sensor.

CAUTION: To prevent damage to the engine, the low pressure fuel system must be flushed before priming or starting the engine, after installation of the Fuel Delivery Pressure (FDP) sensor.

5. Install FDP sensor and tighten to special torque (page 260).

   NOTE: See Flushing the Low-pressure Fuel System (page 237).

Fuel Pump

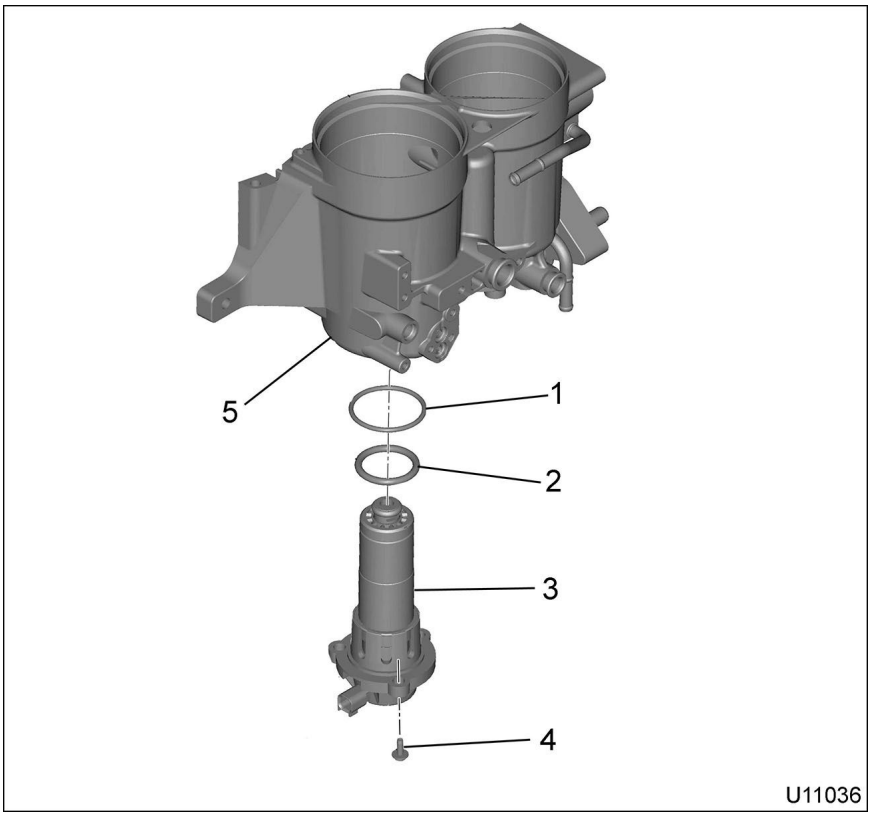


Figure 345 Fuel Pump

1. Pump cover and housing O-ring
2. Pump body and housing O-ring
3. Fuel pump
4. No. 10 rolled thread screw (3)
5. Fuel filter module housing

1. Lubricate new pump body and housing O-ring with clean diesel fuel, and install O-ring onto fuel pump.
2. Lubricate new pump cover and housing O-ring with clean diesel fuel, and install O-ring fuel pump.
3. Install fuel pump and three No. 10 rolled thread screws. Tighten screws to special torque (page 260).

Primary Fuel Filter, Secondary Fuel Filter, and Fuel Housing Cover

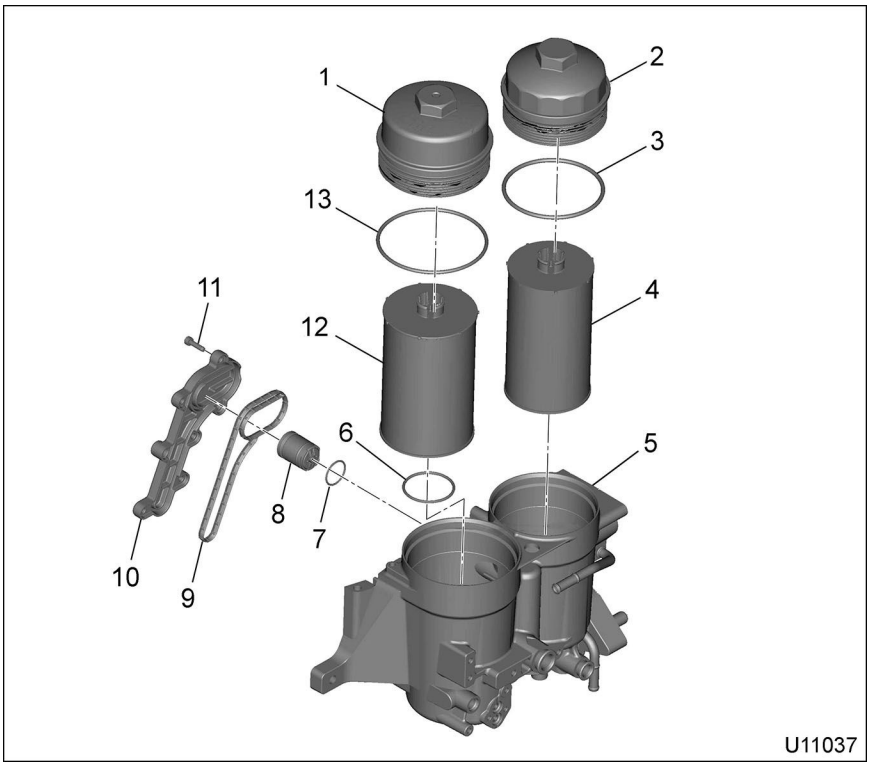


Figure 346 Primary Fuel Filter, Secondary Fuel Filter, and Fuel Housing Cover

1. Filter cap (primary)
2. Filter cap (secondary)
3. Fuel cap secondary O-ring
4. Secondary fuel element assembly
5. Fuel filter module housing
6. Primary fuel element O-ring
7. Fuel O-ring
8. Fuel thermal bypass valve assembly
9. Fuel housing cover gasket
10. Fuel housing cover
11. M5 x 18 screw (9)
12. Primary filter assembly
13. Primary fuel cap O-ring

1. Coat a new fuel O-ring with clean diesel fuel and install onto the fuel thermal bypass valve assembly.
2. Install fuel thermal bypass valve assembly into fuel housing cover.
3. Install new fuel housing cover gasket, fuel housing cover, and nine M5 x 18 screws. Tighten fuel housing cover screws to special torque (page 260).

Primary Fuel Filter Assembly

4. Coat a new O-ring for the primary fuel filter cap with clean diesel fuel and install onto the fuel filter cap.
5. Attach fuel filter cap to a new filter assembly, by pushing the cap onto the filter assembly. The cap will snap onto filter assembly.
6. Coat the threads of the fuel filter cap with clean diesel fuel.

NOTE: Verify that the primary fuel element O-ring is installed on the bottom of the primary filter assembly.

- If the O-ring is loose or not installed, coat the O-ring with clean diesel fuel and install the O-ring in the bottom groove of the primary filter assembly.
- If the O-ring is installed, coat the O-ring with clean diesel fuel.

CAUTION: To prevent engine damage, slowly install the primary fuel filter cap and filter assembly into the fuel filter module housing to prevent distortion of the O-ring.

7. Slowly install the primary fuel filter cap and filter assembly into the fuel filter module housing.
8. Secure the fuel filter cap and filter assembly into the fuel filter module housing by turning the fuel filter cap clockwise until finger-tight.
9. Tighten the primary fuel filter cap to special torque (page 260).

Secondary Fuel Filter Assembly

10. Coat a new O-ring for the secondary fuel filter cap with clean diesel fuel and install onto the primary fuel filter cap.
11. Attach secondary fuel filter cap to a new fuel element assembly, by pushing the cap onto the fuel element assembly. The cap will snap into the element assembly.
12. Coat the threads of the fuel filter cap with clean diesel fuel.
13. Secure the fuel filter cap and fuel element assembly into the fuel filter module housing by turning the secondary fuel filter cap clockwise until finger-tight.
14. Tighten the secondary fuel filter cap to special torque (page 260).

Fuel Filter Cooler Assembly and Filter Cooler Pump Module Support

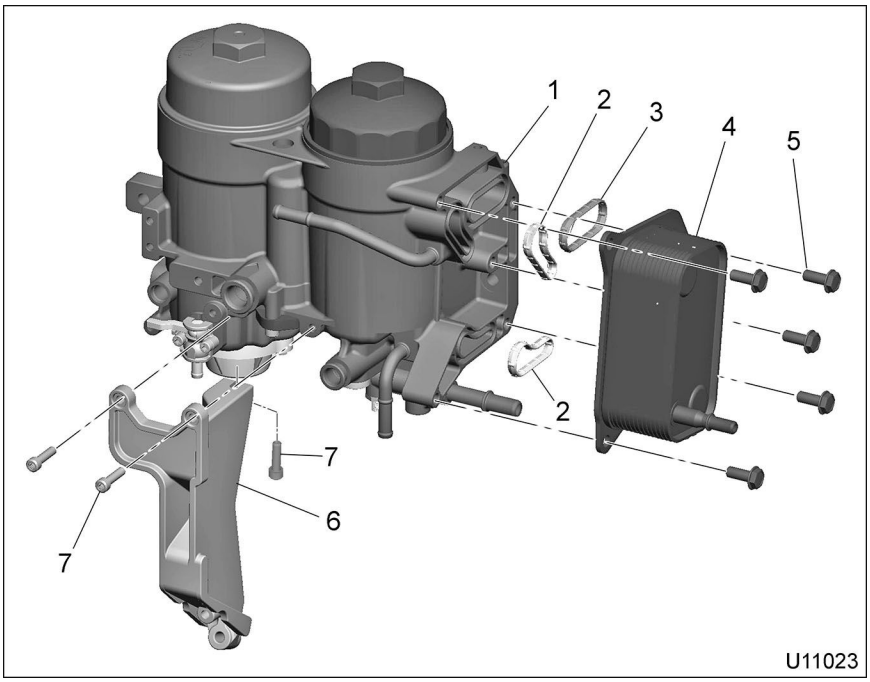


Figure 347 Fuel Filter Cooler Assembly and Filter Cooler Pump Module Support

1. Fuel filter module housing
2. Fuel cooler coolant gasket (2)
3. Fuel gasket
4. Fuel cooler
5. M8 x 20 thread forming screw (5)
6. Filter cooler pump module support
7. M6 screw (3)

1. Position filter cooler pump module support, install three M6 screws, and tighten screws to standard torque (page 473).
2. Install a new fuel gasket and two new fuel cooler coolant gaskets.
3. Position fuel cooler, install five M8 x 20 screws, and tighten screws to special torque (page 260).

Fuel Filter and Cooler Assembly

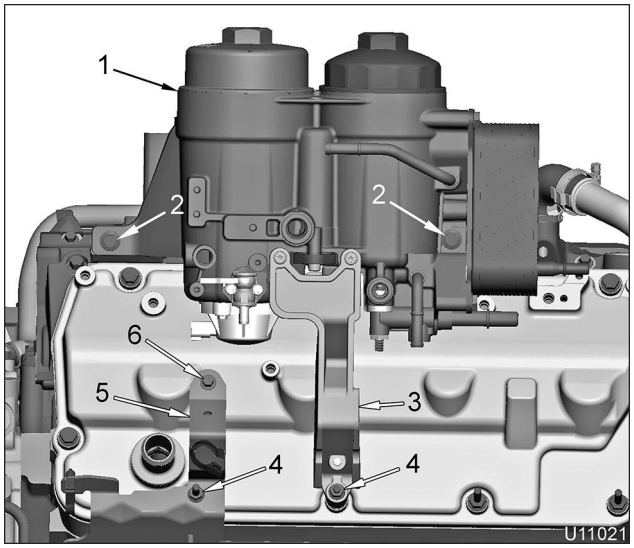


Figure 348 Fuel Filter and Cooler Assembly

1. Fuel filter module assembly
2. M8 x 35 bolt (2)
3. Filter cooler pump module support
4. M6 nut (2)
5. Hose bracket assembly
6. M6 x 20 bolt

1. Position fuel filter and cooler assembly with filter cooler pump module support onto engine.
2. Install two M8 x 35 bolts to secure the fuel filter cooler assembly and tighten bolts to standard torque (page 473).
3. Install M6 nut to secure filter cooler pump module support and tighten nut to standard torque (page 473).
4. Install hose bracket assembly, M6 x 20 bolt, and M6 nut.
5. Tighten M6 x 20 bolt and M6 nut to standard torque (page 473).

Fuel Coolant Supply Tube Assembly

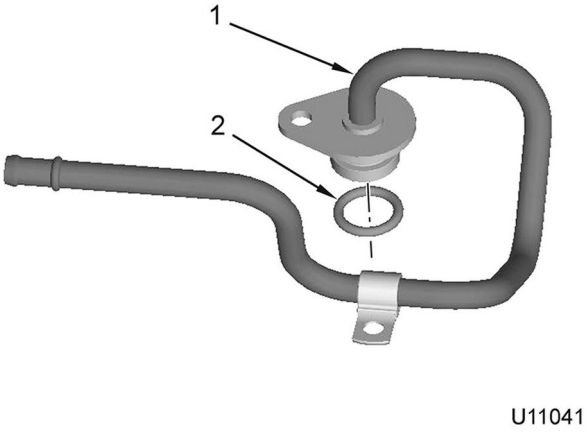


Figure 349 Fuel Coolant Supply Tube and O-ring Seal

1. Fuel coolant supply tube
2. O-ring seal

1. Lubricate new O-ring seal with P-80® Rubber Lubricant or equivalent (page 261), and install O-ring seal onto fuel coolant supply tube.

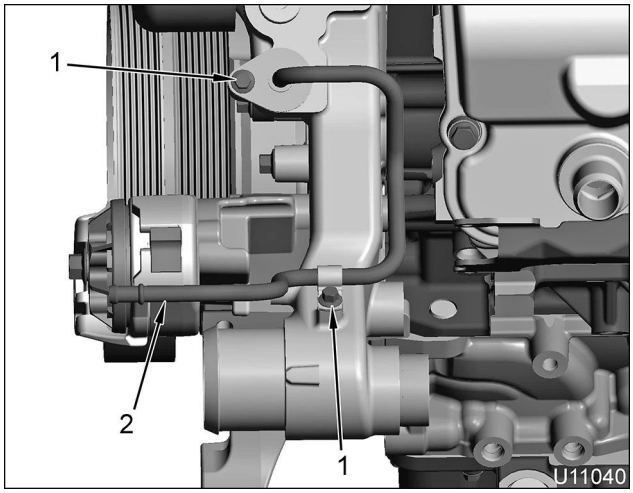


Figure 350 Fuel Coolant Supply Tube Assembly

1. M6 x 16 bolt (2)
2. Fuel coolant supply tube assembly

2. Position fuel coolant supply tube assembly, install M6 x 16 bolts, and tighten bolts to standard torque (page 473).

Oil Level Tube Assembly and Coolant Return Hose

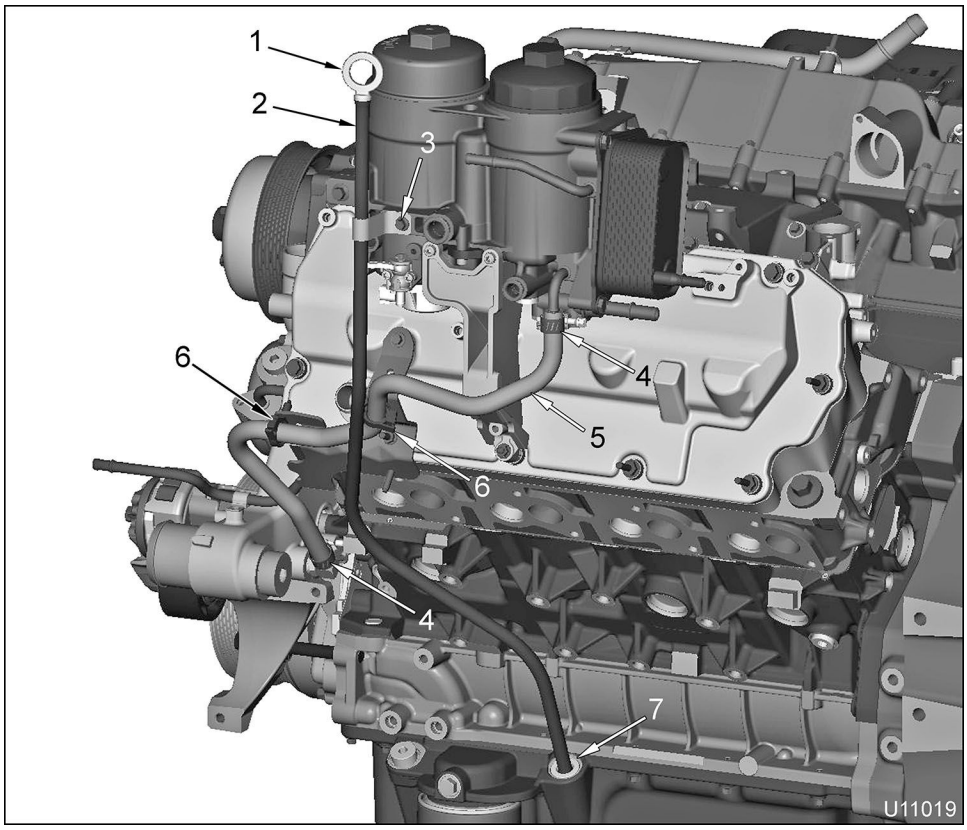


Figure 351 Oil Level Tube Assembly and Coolant Return Hose

1. Oil level gauge assembly
2. Oil level gauge tube with support
3. M6 x 16 bolt
4. Hose clamp (2)
5. Coolant return hose
6. Hose clip (2)
7. Oil level tube gauge gasket

1. Install coolant return hose, close hose clips, and tighten hose clamps to special torque (page 260).
2. Install new oil level tube gauge gasket.
3. Install M6 x 16 bolt to secure oil level gauge tube with support and tighten bolt to standard torque (page 473).
4. Install oil level gauge assembly.
5. Install oil fill support bracket and oil fill hose assembly (page 357).

High-Pressure Fuel Pump Assembly

NOTE: If the high-pressure fuel pump gear bolt was not removed, skip steps 1–4.

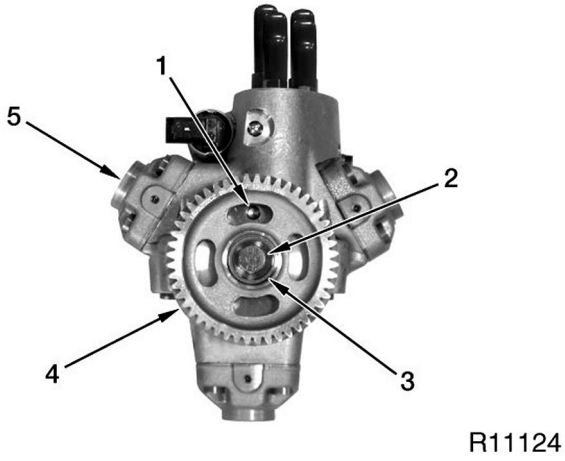


Figure 352 High-Pressure Fuel Pump Gear

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.

NOTE: After repairing a leak in high-pressure fuel system, fuel pressure adaptation values must be reset. See "Diagnostic Software Operation" section in 0000001681 MaxxForce® 7 Engine Diagnostic Manual.

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 260).

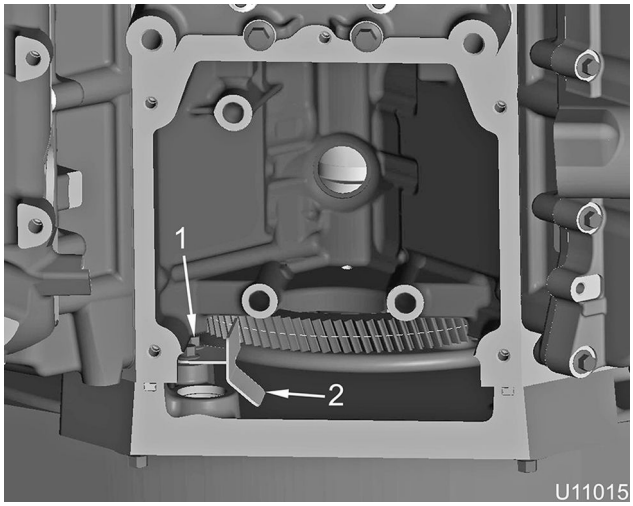


Figure 353 Engine Wiring Harness Guide

1. M6 x 14 bolt (2)
2. Engine wiring harness guide

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

5. If previously removed, position engine wiring harness guide, install two M6 x 14 bolts, and tighten bolts to standard torque (page 473).

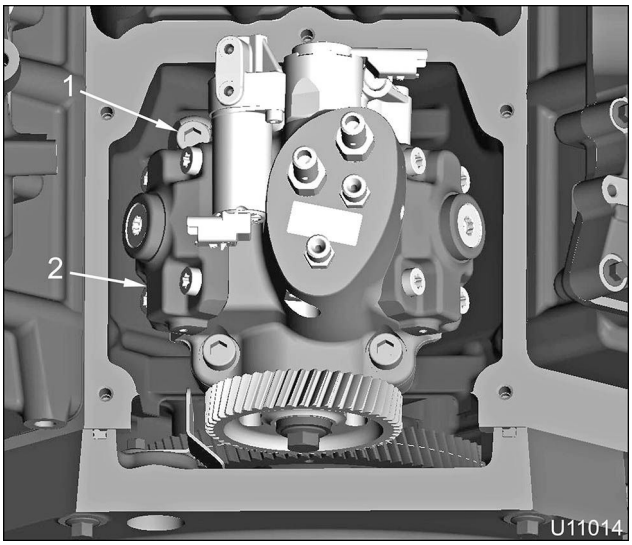


Figure 354 High-Pressure Fuel Pump Assembly

1. M10 x 55 socket head bolt (3)
2. High-pressure fuel pump assembly

6. Lower high-pressure fuel pump assembly into crankcase and secure with three M10 x 55 bolts.
7. Tighten M10 x 55 bolts to standard torque (page 473).

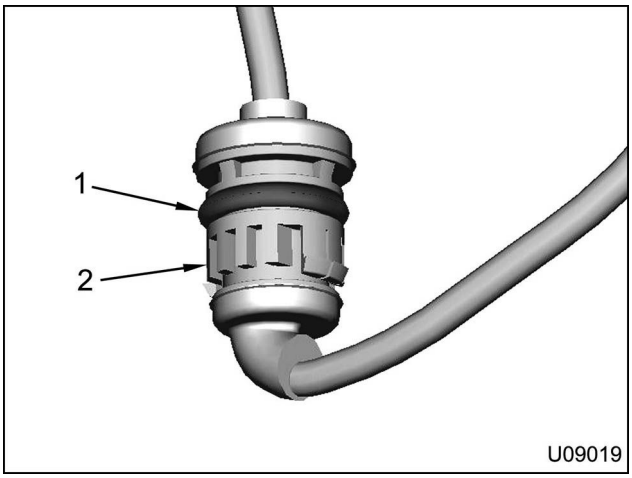


Figure 355 O-ring on Pass-Through Overmold Plug

1. O-ring
2. Pass-through overmold plug

8. Coat new O-ring with P-80® Rubber Lubricant or equivalent (page 261), and install onto pass-through overmold plug.

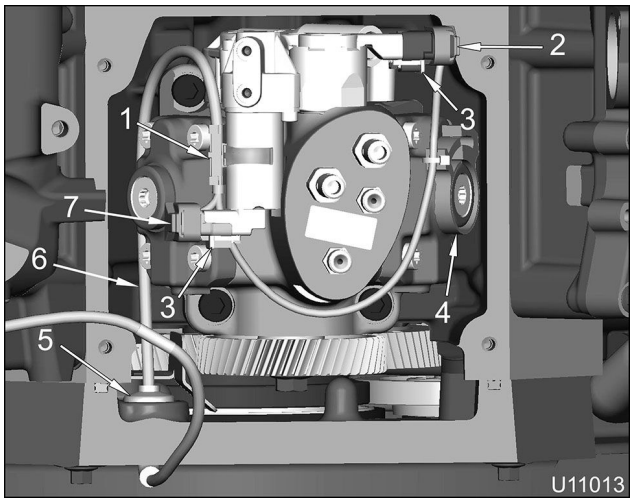


Figure 356 High-Pressure Pump Harness Assembly

1. C-clip
2. Connector (black)
3. Yellow CPA
4. Snapper clip
5. Pass-through overmold plug
6. High-pressure pump harness assembly
7. Connector (orange)

Lubricate the opening in rear crankcase cover, for the Pass-through overmold plug, with P-80® Rubber Lubricant or equivalent (page 261).

9. Install the high-pressure pump harness assembly (inside to out) through the opening in rear crankcase cover, and push the pass-through overmold plug into the opening.
10. Connect orange and black connectors. Lock yellow CPA on each connector.
11. Install C-clip and snapper clip to secure harness assembly.

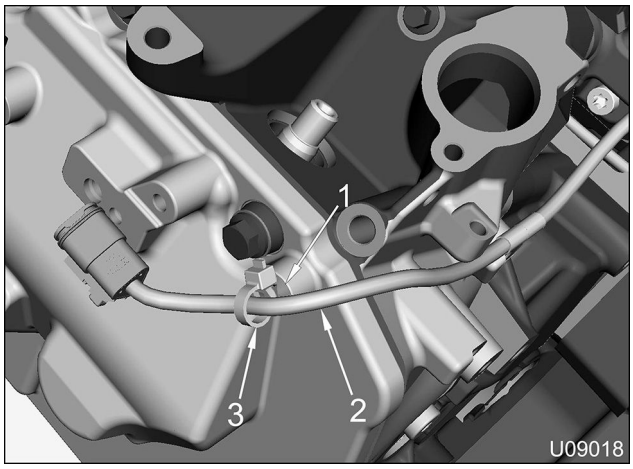


Figure 357 Harness Retainer on High-Pressure Pump Harness Assembly

1. Harness fir zip retainer
2. High-pressure pump harness assembly
3. Tie strap

12. Install new tie strap to secure high-pressure pump harness assembly to harness fir zip retainer in left valve cover.

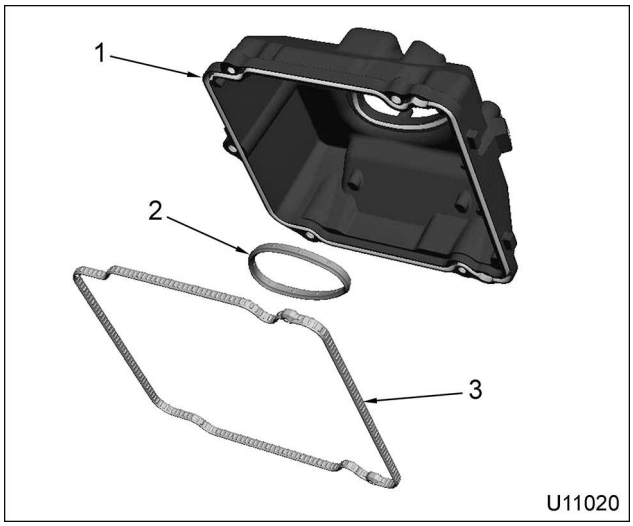


Figure 358 High-Pressure Fuel Pump Cover and Gaskets

1. High-pressure fuel pump cover
2. Pump cover gasket
3. Lower high-pressure pump cover gasket

13. Install new pump cover gasket and lower high-pressure pump cover gasket.

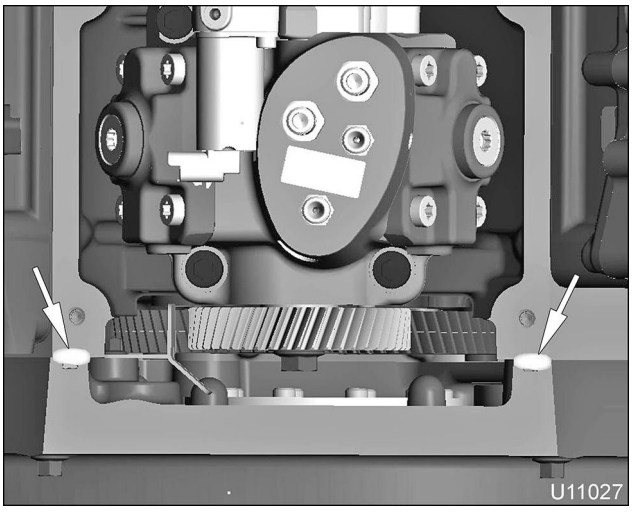


Figure 359 Liquid Gasket (RTV) Application

14. Apply Liquid Gasket (RTV) (page 261) to joining surfaces of crankcase and fuel pump cover assembly.

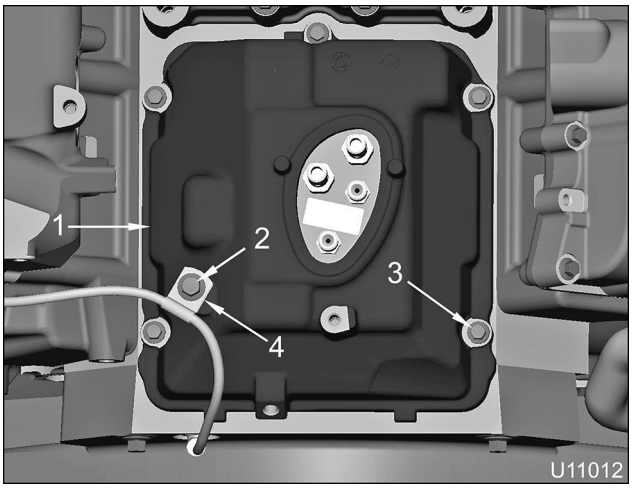


Figure 360 High-Pressure Fuel Pump Cover

1. High-pressure fuel pump cover
2. M8 x 12 bolt
3. M6 x 25 bolt (5)
4. Closed clamp

15. Install five M6 x 25 bolts to secure high-pressure fuel pump cover and tighten bolts to standard torque (page 473).

16. Install M8 x 12 bolt to secure high-pressure pump harness assembly and tighten bolt to standard torque (page 473).

Fuel Injectors and Fuel Rail Assemblies

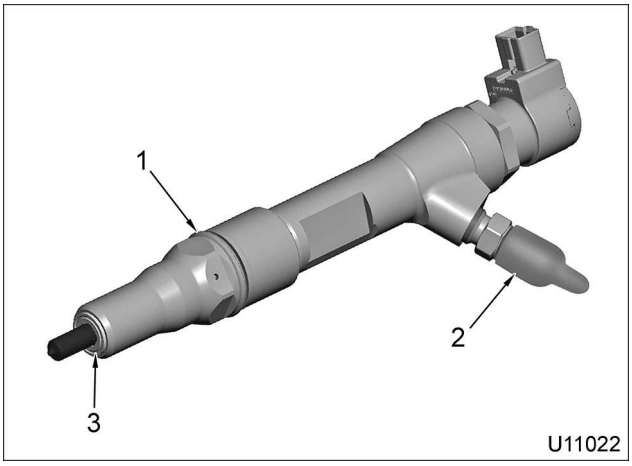


Figure 361 Fuel Injector Seal and Combustion Gasket

1. Fuel injector seal
2. Plastic protective cap
3. Combustion gasket

CAUTION: To prevent engine damage, install new fuel injector seal and combustion gasket if a fuel injector is removed.

NOTE: After repairing a leak in high-pressure fuel system, fuel pressure adaptation values must be reset. See "Diagnostic Software Operation" section in 0000001681 MaxxForce® 7 Engine Diagnostic Manual.

1. Position a new combustion gasket (with the grooved side of gasket facing away from the fuel injector tip) onto injector tip, and seat combustion gasket with a deep socket.
2. Lubricate a new fuel injector seal with clean engine oil and install seal onto fuel injector.

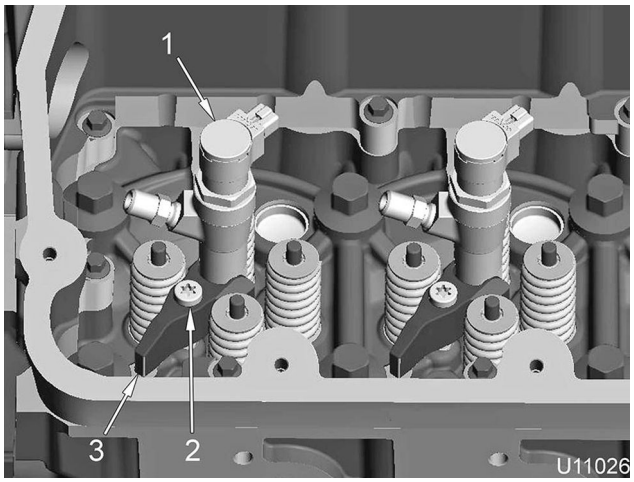


Figure 362 Fuel Injector Assembly (typical)

1. Fuel injector assembly (4)
2. Injector clamp bolt (4)
3. injector hold down clamp assembly (4)

3. Remove all Fuel System Caps (page 261) from fuel rail and fuel injectors and fuel rail.
4. 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 and moveable, for installation of fuel rail to injector tube assemblies.

5. Hand start injector hold down clamp bolts. Pretighten bolts to 2 N·m (18 lb·in).

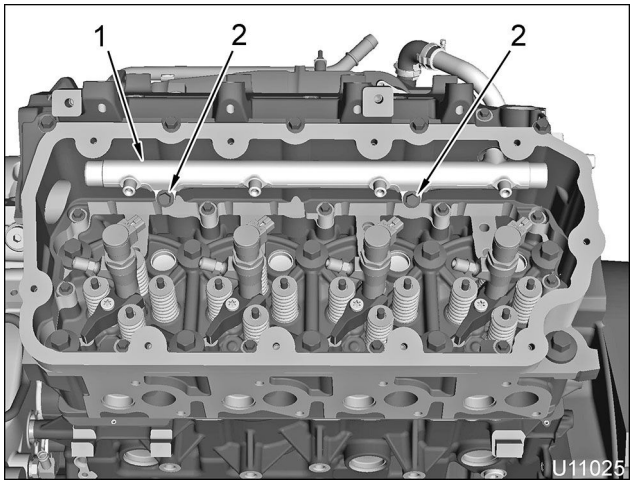


Figure 363 Fuel Rail Assembly (typical)

1. Fuel rail
2. M8 x 30 bolt (2)

6. Position fuel rail assembly, install two M8 x 30 bolts, and tighten bolts to standard torque (page 473).

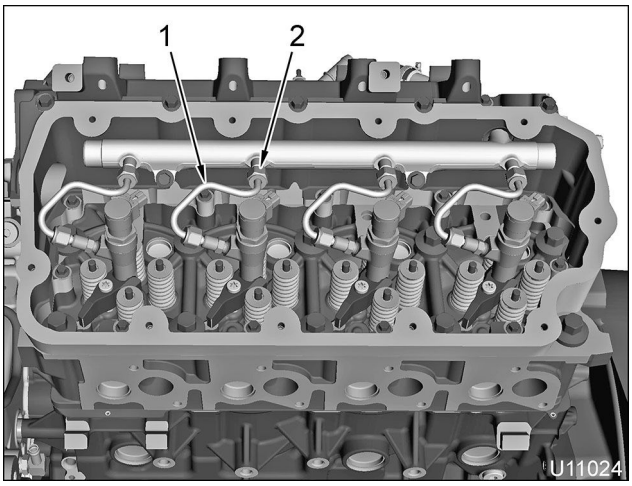


Figure 364 Fuel Rail to Injector Tube Assemblies (typical)

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.

7. Position four new fuel rail to injector tube assemblies between fuel injector assemblies and rail assembly.

   NOTE: Hold fuel rail to injector tube assemblies while hand tightening nuts to assure correct assembly of joints.

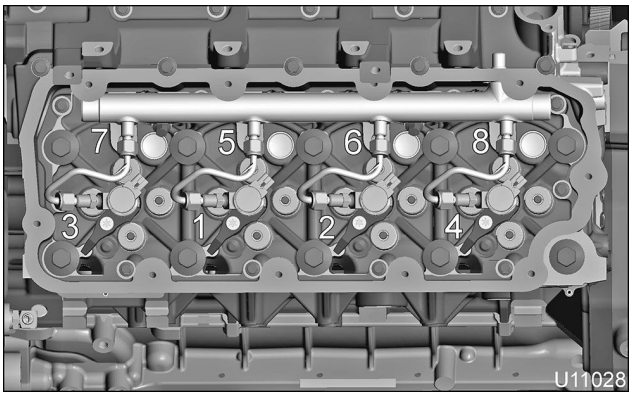


Figure 365 Torque Sequence for Fuel Rail to Injector Tube Assemblies (typical)

NOTE: When using a crowfoot extension, make sure to adjust the torque settings to compensate for any length added to the torque wrench. See Appendix B - Torques (page 474).

8. Hand start and fully seat nuts on fuel rail to injector tube assemblies to fuel injector and fuel rail connections; then, use a torque wrench with a crowfoot extension to pretighten nuts in the sequence shown above to 2 N·m (18 lb·in).

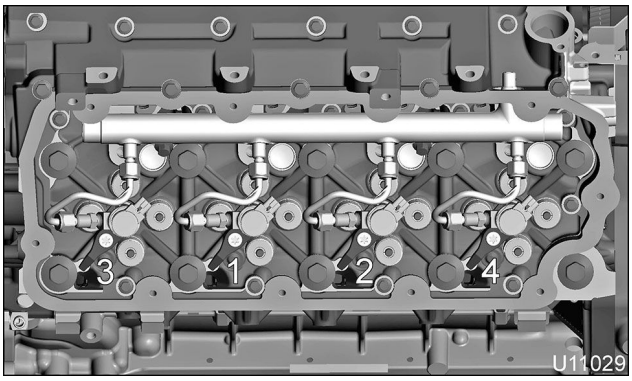


Figure 366 Torque Sequence for Injector Hold Down Clamps (typical)

9. Tighten injector hold down clamp bolts to 38 N·m (28 lb·ft).

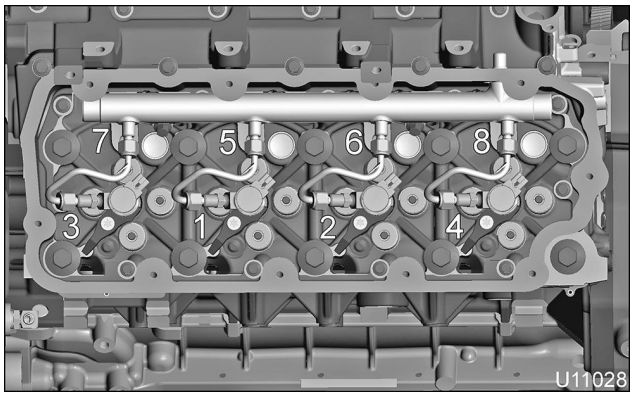


Figure 367 Torque Sequence for Fuel Rail to Injector Tube Assemblies (typical)

NOTE: When using a crowfoot extension make sure to adjust the torque settings to compensate for any length added to the torque wrench. See Appendix B - Torques (page 474).

10. Use a torque wrench with a crowfoot extension and a second wrench to hold each fuel injector fitting, and tighten each nut to the in the sequence shown above to 12 N·m (106 lb·in).
11. Use a torque wrench with a crowfoot extension to tighten each nut to the fuel rail in the sequence shown above to 12 N·m (106 lb·in).
12. Use a torque wrench with a crowfoot extension, tighten all nuts an additional 60° (one nut flat) to the sequence shown above.
13. Install Under Valve Cover (UVC) harnesses. (page 91).
14. Install Fuel Rail Pressure (FRP) sensor into right fuel rail. (page 93).

NOTE: See procedures in the "Cylinder Heads, Valve Covers, and Valve Train" section to install valve covers (page 357).

Injector Return Hose Assembly

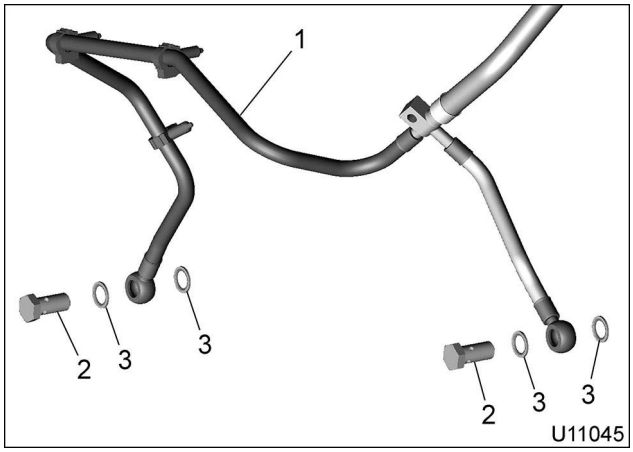


Figure 368 Injector Return Hose Assembly, Banjo Bolts, Bonded Seal Washers

1. Injector return hose assembly
2. M12 Banjo bolt (2)
3. Bonded seal washer (4)

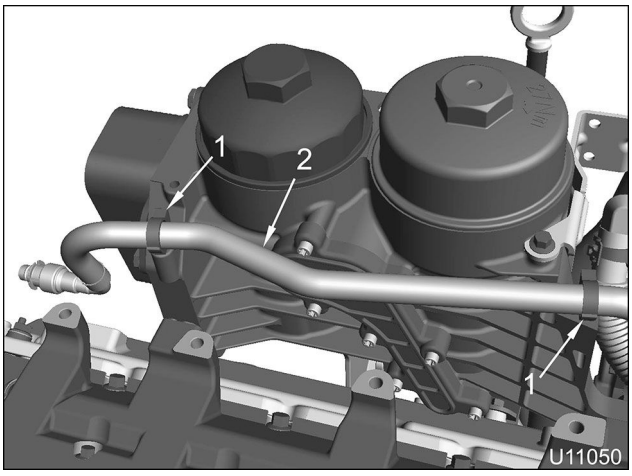


Figure 369 Hose Clips on Injector Return Hose Assembly

1. .375 in hose clip (2)
2. Injector return hose assembly

1. If necessary install new .375 in hose clips onto injector return hose assembly.
2. Position injector return hose assembly and push in .375 in hose clips to secure hose assembly to the fuel filter module.

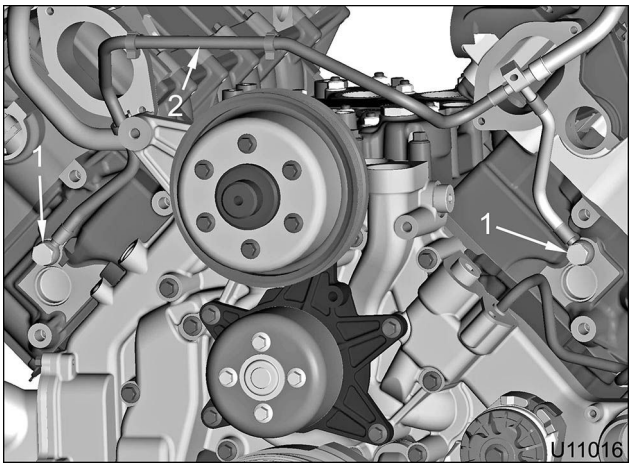


Figure 370 Injector Return Hose Assembly

1. M12 banjo bolt
2. Injector return hose assembly

3. Install one end of injector return tube assembly by sandwiching banjo end between two new bonded seal washers and loosely installing a M12 banjo bolt into the cylinder head. Repeat for other end of injector return tube assembly.
4. Tighten M12 banjo bolts to special torque (page 260).

Pump to Cooler Hose and Filter to Pump Hose Assemblies

CAUTION: To prevent engine damage, flush the filter to pump hose assembly with clean diesel fuel before installation.

NOTE: After repairing a leak in high-pressure fuel system, fuel pressure adaptation values must be reset. See "Diagnostic Software Operation" section in 0000001681 MaxxForce® 7 Engine Diagnostic Manual.

1. Flush the filter to pump hose assembly with clean diesel fuel.

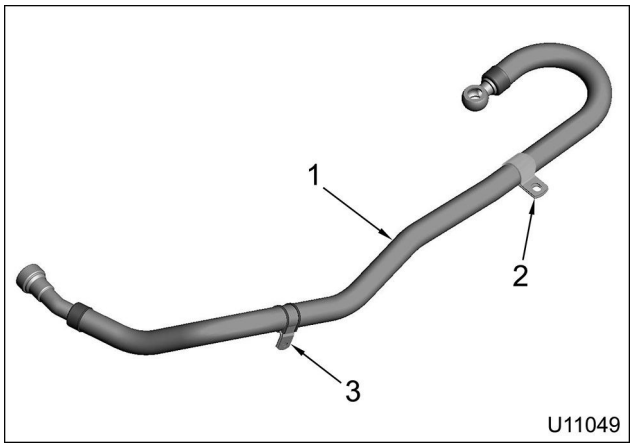


Figure 371 Cushioned Hose Clamp and Hose Clamp on Filter to Pump Hose Assembly

1. Filter to pump hose assembly
2. .5 in hose clamp
3. Dash 11 cushioned hose clamp

2. Install dash 11 cushioned hose clamp and .5 in hose clamp onto filter to pump hose assembly.

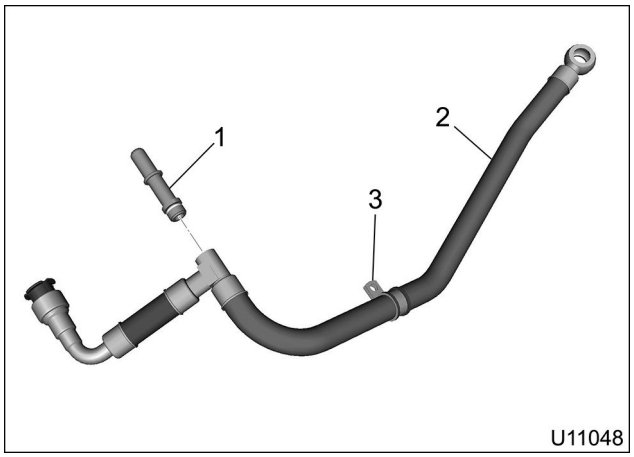


Figure 372 Pump to Cooler Hose Assembly

1. Fuel check valve
2. Pump to cooler hose assembly
3. Dash 8 Cushioned hose clamp

3. Install fuel check valve and tighten to standard torque (page 473).
4. Install Dash 8 Cushioned hose clamp on pump to cooler hose assembly.

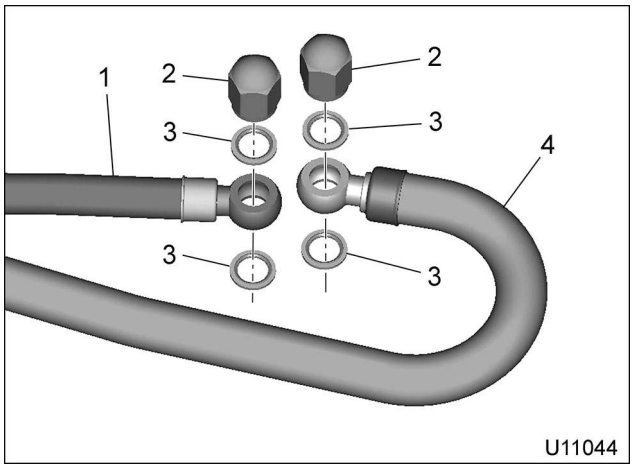


Figure 373 M12 Cap Nuts and Bonded Seal Washer

1. Pump to cooler hose assembly
2. M12 cap nut (2)
3. Bonded seal washer (4)
4. Filter to pump hose assembly

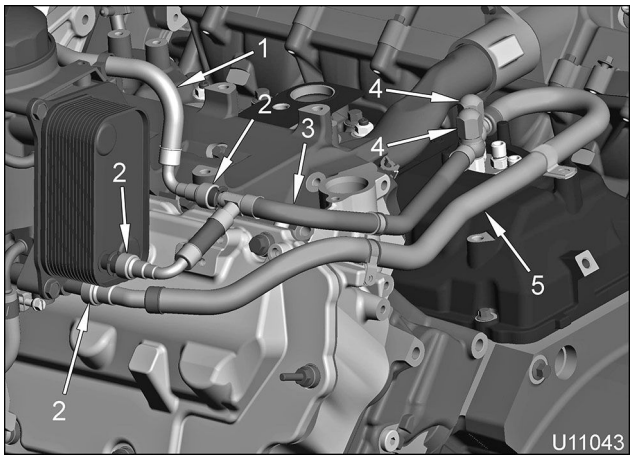


Figure 374 Quick Connectors and Cap Nuts

1. Injector return hose assembly
2. Quick connector
3. Pump to cooler hose assembly
4. M12 cap nut (2)
5. Filter to pump hose assembly

NOTE: Make sure quick connectors are fully seated when connected. Do not rely on the click noise; pull back on hose assembly to ensure a fully seated connection.

5. Connect quick connector on filter to pump hose assembly to fuel filter module housing.
6. Loosely install M12 cap nut, two new bonded seal washers, and filter to pump hose assembly onto correct high-pressure pump fitting as shown.
7. Connect quick connector on injector return hose assembly to pump to cooler hose assembly, and quick connector on pump to cooler hose assembly to fuel cooler.
8. Loosely install M12 cap nut, two new bonded seal washers, and pump to cooler hose assembly onto correct high-pressure pump fitting as shown.

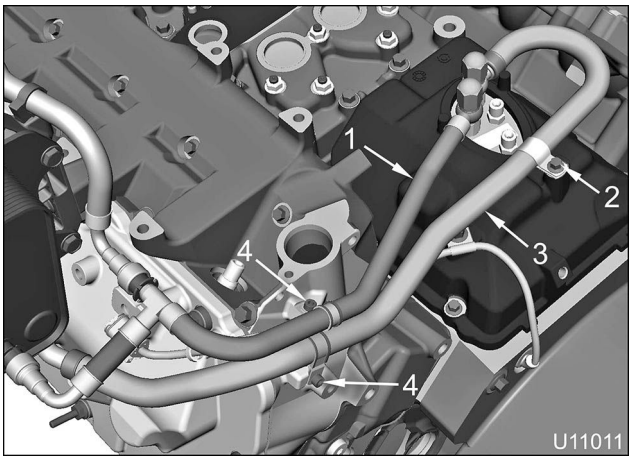


Figure 375 Pump to Cooler Hose and Filter to Pump Hose Assemblies

1. Pump to cooler hose assembly
2. M6 x 14 bolt
3. Filter to pump hose assembly
4. M5 x 12 socket head bolt (2)

9. Install M6 x 14 bolt and M5 x 12 socket head bolt to secure filter to pump hose assembly. Tighten M6 x 14 bolt and M5 x 12 socket head bolt to standard torque (page 473).
10. Install M5 x 12 socket head bolt to secures pump to cooler hose assembly. Tighten M5 x 12 socket head bolt to standard torque (page 473).
11. Tighten cap nuts, for filter to pump hose assembly and pump to cooler hose assembly, to special torque (page 260).

NOTE: See installation procedure for Balance Duct and Balance Tube Flange (page 361).

Priming the High-pressure Fuel System

NOTE: This procedure applies only when the high-pressure pump is removed or replaced, or high-pressure fuel tube assemblies from the high-pressure pump to the fuel rails are disconnected.

NOTE: It is not necessary to reprime the high-pressure fuel system after removal or replacement of injectors, fuel rail, rail to injector lines, or FRP sensor.

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

CAUTION: To prevent possible engine damage, high-pressure fuel tube assemblies from the high-pressure pump to the fuel rails must be replaced whenever they are disconnected from the rails or the high-pressure pump. High pressure high-pressure fuel tube assemblies should never be reused.

1. Loosely install new high-pressure fuel tube assemblies between the high-pressure fuel pump and the fuel rails.

NOTE: Put wire tags on the high-pressure fuel tube assemblies, stating that the tube nuts are loose and the following procedure is required before completing this test.

2. Hand tighten tube nuts to the high-pressure fuel pump.
3. Do not tighten tube nuts to the fuel rails; leave two threads loose.
4. Position a suitable container or rag under tube nuts on high-pressure fuel tube assemblies to fuel rail.
5. Ensure that the low-pressure fuel system is primed with fuel. See the low-pressure fuel system priming procedure in the *Engine Operation and Maintenance Manual.*
6. Engage starter for 20 seconds and allow starter to cool for two minutes. Continue to crank the engine in 20 second intervals until a stream of fuel (no air) flows at both connections.

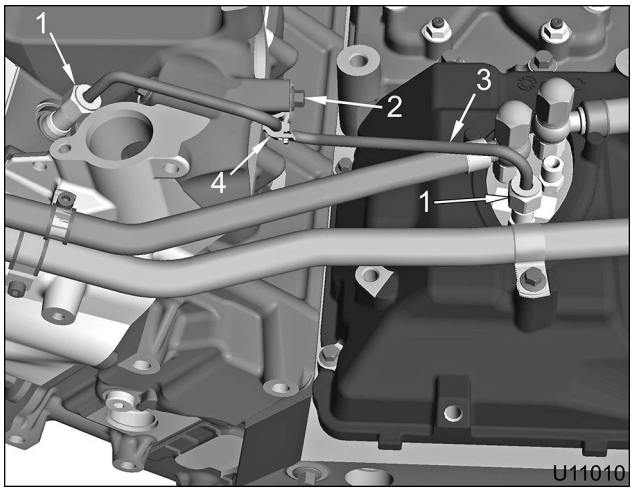


Figure 376 Left High-Pressure Fuel Tube Assembly

1. Tube nut (2)
2. M6 x 20 bolt
3. Left high-pressure fuel tube assembly
4. 1/4 closed clamp

7. Pretighten tube nuts, on left high-pressure fuel tube assembly, to 2 N·m (18 lb·in).
8. Install M6 x 20 bolt to secure fuel tube assembly and tighten bolt to standard torque (page 473).
9. Tighten tube nuts, on left high-pressure fuel tube assembly, to 12 N·m (106 lb·in).
10. Turn tube nuts an additional 60° (one nut flat).

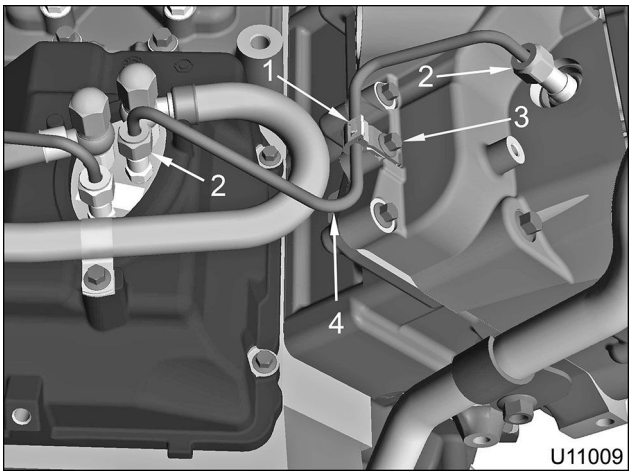


Figure 377 Right High-Pressure Fuel Tube Assembly

1. 1/4 closed clamp
2. Tube nut (2)
3. M6 x 20 bolt
4. Right high-pressure fuel tube assembly

11. Pretighten tube nuts, on right high-pressure fuel tube assembly, to 2 N·m (18 lb·in).
12. Install M6 x 20 bolt to secure fuel tube assembly and tighten bolt to standard torque (page 473).
13. Tighten tube nuts, on right high-pressure fuel tube assembly, to 12 N·m (106 lb·in).
14. Turn tube nuts an additional 60°.
15. After tightening tube nuts on both high-pressure fuel tube assemblies, remove wire tags and the engine is ready to start.

Specifications

Primary fuel filter type	10 micron with water separation
Secondary fuel filter type	4 micron with water separation

Special Torque

Banjo bolts, M12	25 N·m (18 lb·ft)
High-pressure pump cap nuts	25 N·m (18 lb·ft)
Diagnostic valve	13 N·m (115 lb·in)
Right high-pressure tube assembly nuts	See tightening steps in procedure.
Left high-pressure tube assembly nuts	See tightening steps in procedure.
Fuel cooler screws, M8 x 20	23 N·m (16 lb·ft)
Fuel housing cover screws, M5 x 18	7 N·m (62 lb·in)
High-pressure fuel pump gear bolt	78 N·m (57 lb·ft)
Fuel rail to injector tube fittings	See tightening steps in procedure
Injector clamp bolts	See tightening steps in procedure
Coolant return hose clamps	3 N·m (26 lb·in)
Primary fuel filter cap	50 N·m (37 lb·ft)
Secondary fuel filter cap	40 N·m (29 lb·ft)
Water drain retainer screws, M5 x18	7 N·m (62 lb·in)
WIF sensor	2 N·m (18 lb·in)
EFT sensor	18 N·m (159 lb·in)
FDP sensor	18 N·m (159 lb·in)

Special Service Tools

Description	Tool Number
Clean Fuel Source Kit	15-637-01
Cross-over Tube Removal Tool	ZTSE6015
Fuel System Caps	ZTSE4710
Fuel Injector Rack Holder	ZTSE4299B
Fuel Injector Tip Cleaning Brush	ZTSE4301
High-pressure Fuel Pump Wrench	ZTSE4959
Injector Cup	ZTSE4709
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
P-80® Rubber Lubricant or equivalent	Obtain locally
Spring lock coupling disconnect tool	Obtain locally

Table of Contents

Exploded Views.....265

Removal.....267
- **Alternator and Refrigerant Compressor Mounting Bracket**.....267
- **Front Engine Mounting Support**.....268
- **Thermostat Housing and Thermostats**.....269
- **Fan Drive**.....270
- **Water Pump Assembly**.....270
- **Crank Power Takeoff (PTO) for Air Compressor Pulley (if equipped)**.....272
- **Vibration Damper**.....272
- **Front Crankcase Cover Assembly**.....273

Cleaning, Inspection, and Testing.....274
- **Vibration Damper**.....274
- **Vibration Damper Runout**.....274
- **Front Crankcase Cover and Water Pump Assembly**.....274
- **Thermostat Assemblies**.....274

Installation.....276
- **Front Crankcase Cover**.....276
- **Vibration Damper**.....277
- **Crank Power Takeoff (PTO) for Air Compressor Pulley (if equipped)**.....278
- **Water Pump Assembly**.....278
- **Fan Drive**.....279
- **Thermostat Housing and Thermostats**.....280
- **Front Engine Mounting Support**.....281
- **Alternator and Refrigerant Compressor Mounting Bracket**.....282

Specifications.....284

Special Torque.....284

Special Service Tools.....284

Exploded Views

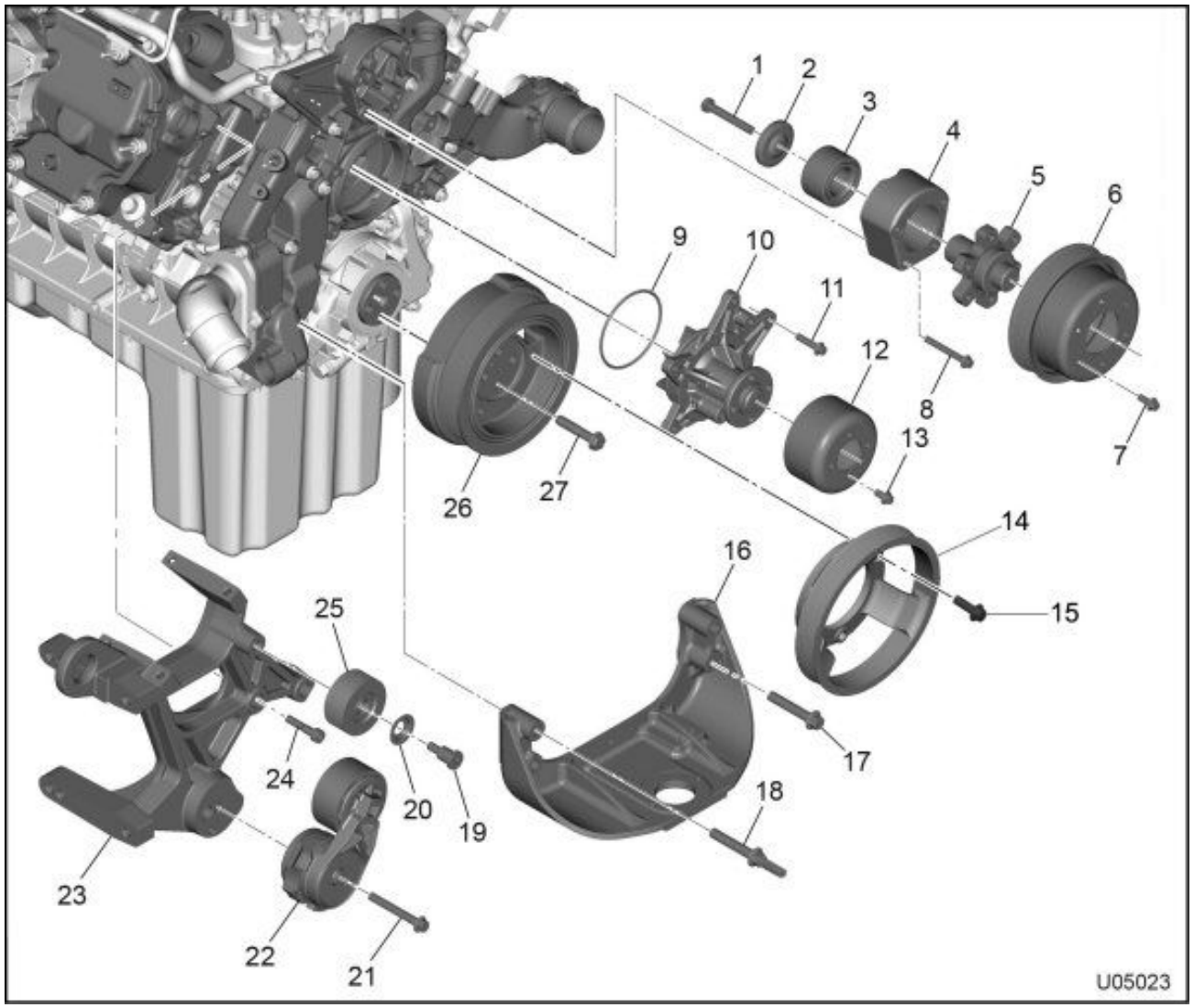


Figure 378 Alternator Bracket, Front Engine Mounting Support, Fan Drive, Water Pump, and Vibration Damper

1. M10 x 70 bolt
2. Fan bearing retainer
3. Bearing assembly
4. Fan bearing housing
5. Fan pulley mounting hub
6. Fan pulley
7. M8 x 20 bolt (6)
8. M8 x 65 bolt (4)
9. O-ring seal (size 240)
10. Water pump assembly
11. M8 x 35 bolt (5)
12. Water pump pulley
13. M8 x 16 bolt (4)
14. Crank PTO for air compressor pulley (if equipped)
15. M10 x 30 bolt (3)
16. Front engine mounting support
17. M12 x 70 bolt
18. M12 x 70 stud bolt (2)
19. Shoulder bolt
20. Dust cover Idler
21. M10 x 80 bolt
22. Belt tensioner
23. Alternator and refrigerant compressor mounting bracket
24. M10 x 45 screw (4)
25. Grooved idler pulley assembly
26. Vibration damper
27. M12 x 59 bolt (4)

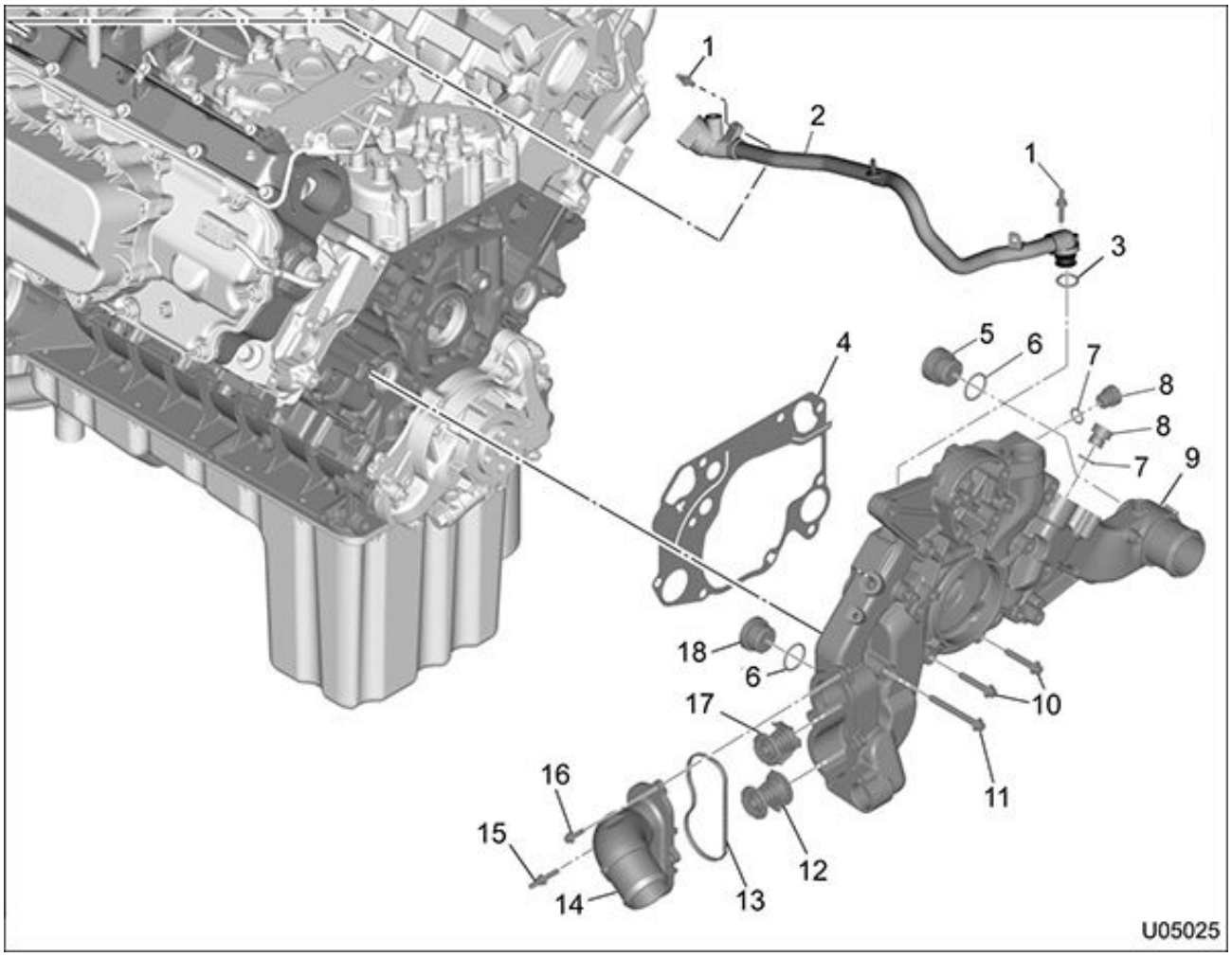


Figure 379 Front Crankcase Cover, Tubes, Hoses, and Thermostat Assemblies

1. M6 x 25 bolt (2)
2. Heater supply tube assembly
3. O-ring seal
4. Front cover gasket
5. M33 O-ring plug
6. M33 O-ring
7. Seal (2)
8. M18 O-ring boss plug (2)
9. Front crankcase cover
10. M8 x 45 dog point bolt (2)
11. M8 x 75 dog point bolt (8)
12. Thermostat assembly (with bypass)
13. Thermostat cover gasket
14. Thermostat housing
15. M6 x 25 stud bolt
16. M6 x 20 bolt (3)
17. Thermostat assembly (without bypass)
18. M33 plug

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: Failure to observe the following warning may cause property damage, personal injury, or death. To prevent personal injury or death, read all safety instructions in the "Safety Information" section of this manual.

WARNING: Failure to observe the following warning may cause property damage, personal injury, or death. 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: Failure to observe the following warning may cause property damage, personal injury, or death. To prevent personal injury or death, disconnect the main battery negative terminal before disconnecting or connecting electrical components.

WARNING: Failure to observe the following warning may cause property damage, personal injury, or death. To prevent personal injury or death, wear safety glasses with side shields. Limit compressed air pressure to 207 kPa (30 psi).

WARNING: Failure to observe the following warning may cause property damage, personal injury, or death. 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: Failure to observe the following warning may cause property damage, personal injury, or death. 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**
- **Air Compressor and Power Steering Pump**
- **Fuel System**

Alternator and Refrigerant Compressor Mounting Bracket

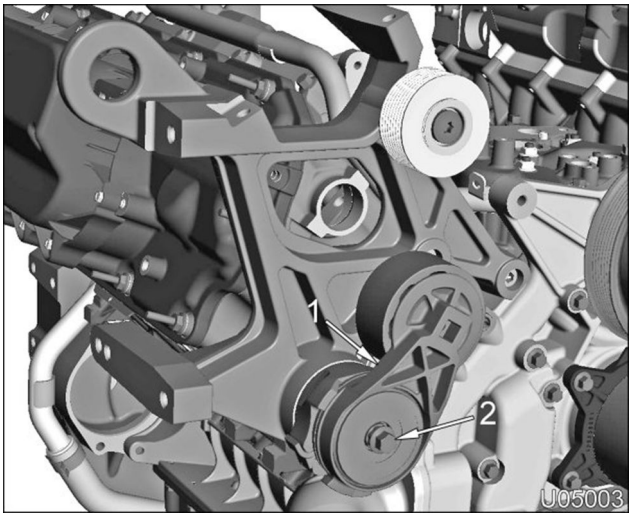


Figure 380 Belt Tensioner

1. Belt tensioner
2. M10 x 80 bolt

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.

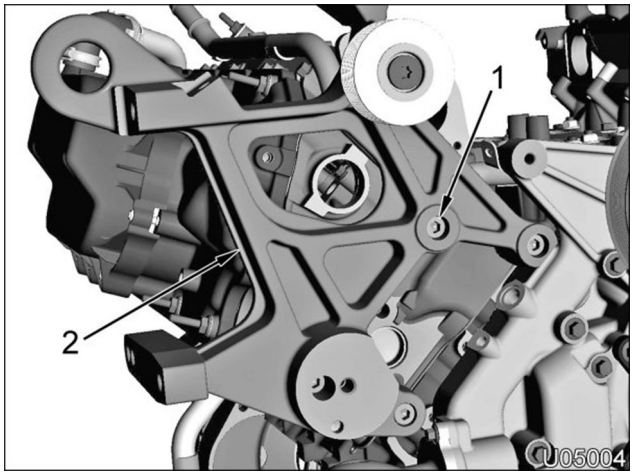


Figure 381 Alternator and Refrigerant Compressor Mounting Bracket

1. M10 x 45 screw (4)
2. Alternator and refrigerant compressor mounting bracket

2. Remove four M10 x 45 screws, and the alternator and refrigerant compressor mounting bracket.

Front Engine Mounting Support

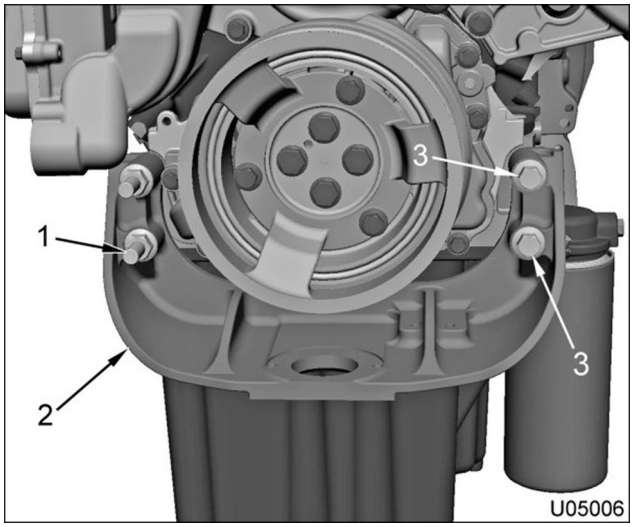


Figure 382 Front Engine Mounting Support on Engines without (optional secondary freon compressor bracket)

1. M12 x 70 stud bolt (2)
2. Front engine mounting support
3. M12 x 70 bolt (2)

1. Remove two M12 x 70 stud bolts and two M12 x 70 bolts that secure the front engine mounting support.
2. Remove front engine mounting support.

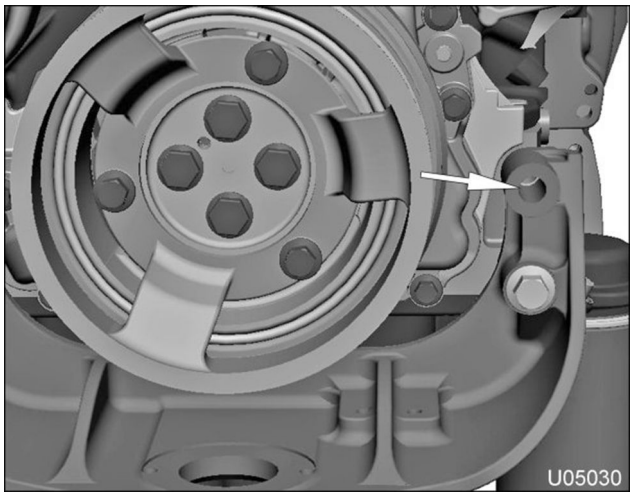


Figure 383 M12 x 110 Bolt Location for Engines with (optional secondary freon compressor bracket)

NOTE: See (page 193) for removal of M12 x 110 bolt.

3. Remove two M12 x 70 stud bolts and one M12 x 70 bolt.
4. Remove front engine mounting support.

Thermostat Housing and Thermostats

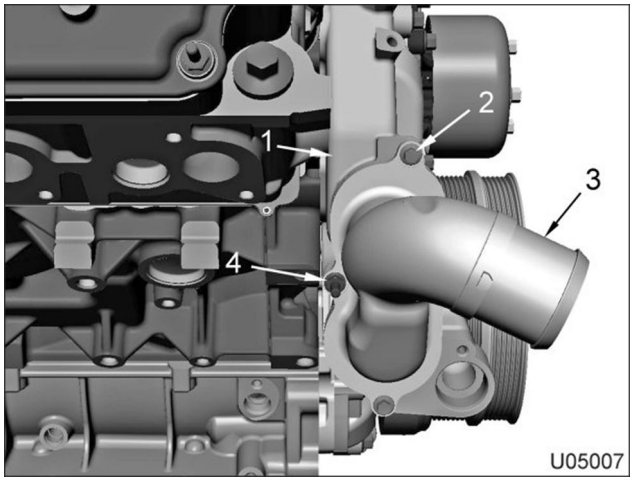


Figure 384 Thermostat Housing

1. Front crankcase cover
2. M6 x 20 bolt (3)
3. Thermostat housing
4. M6 x 25 stud bolt

1. Remove M6 x 25 stud bolt and three M6 x 20 bolts.
2. Remove thermostat housing from front crankcase cover.

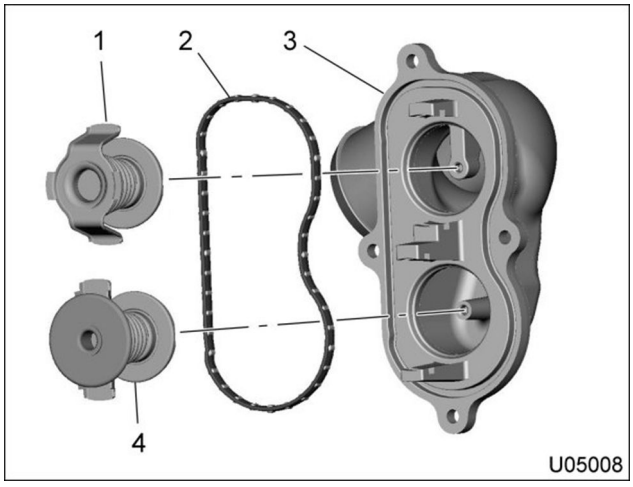


Figure 385 Thermostats, Thermostat Housing Gasket, and Thermostat Housing

1. Thermostat assembly (without bypass)
2. Thermostat housing gasket
3. Thermostat housing
4. Thermostat assembly (with bypass)

3. Remove and discard thermostat housing gasket.
4. Remove two thermostat assemblies from thermostat housing.

Fan Drive

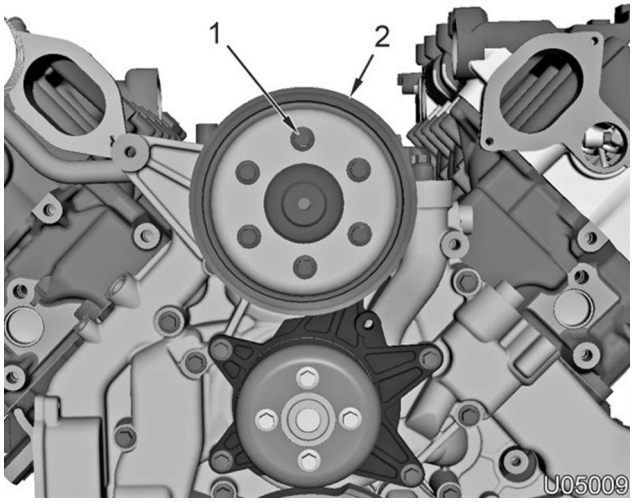


Figure 386 Fan Pulley

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.

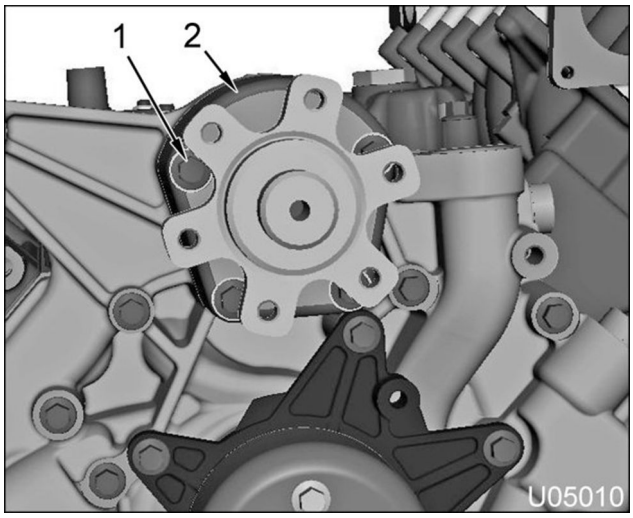


Figure 387 Fan Pulley Mounting Hub

1. M8 x 65 bolt (4)
2. Fan pulley mounting hub

2. Remove four M8 x 65 bolts and fan pulley mounting hub.

Water Pump Assembly

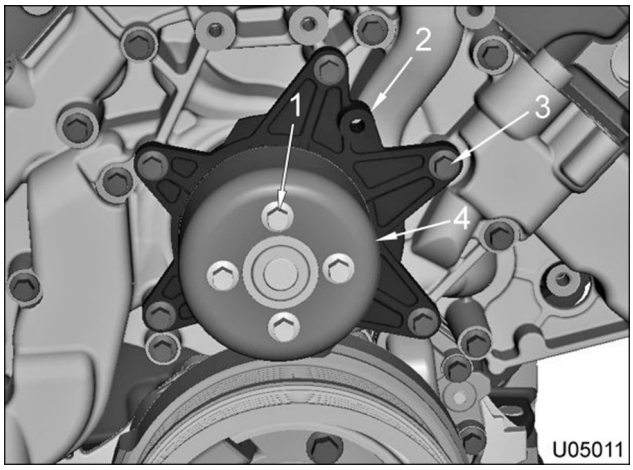


Figure 388 Water Pump Assembly and Pulley

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

CAUTION: To prevent engine damage, do not drop water pump impeller or hit impeller with hard objects.

2. Remove five M8 x 35 bolts and water pump assembly.

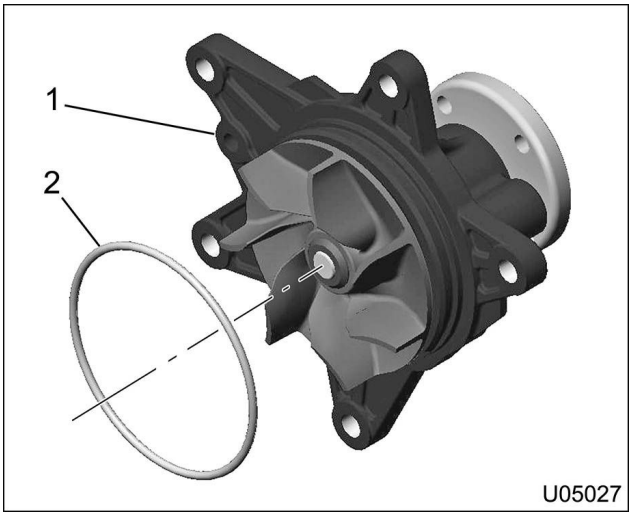


Figure 389 Water Pump Assembly and O-ring Seal

1. Water pump assembly
2. O-ring seal (size 240)

3. Remove and discard O-ring seal.

Crank Power Takeoff (PTO) for Air Compressor Pulley (if equipped)

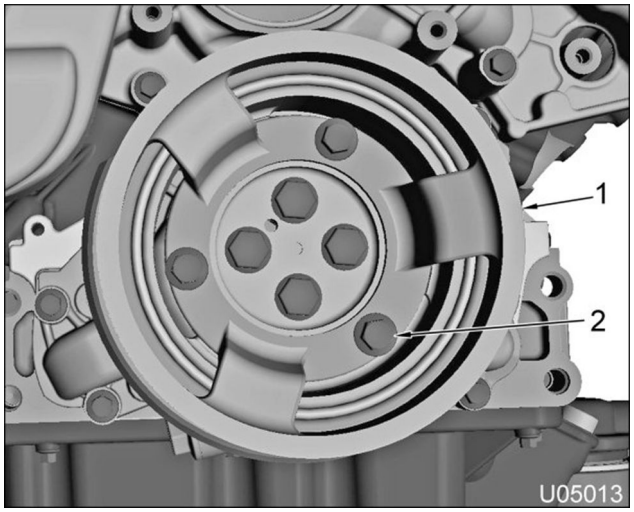


Figure 390 Crank PTO for Air Compressor Pulley (if equipped)

1. Crank PTO for air compressor pulley
2. M10 x 30 bolt (3)

1. Remove three M10 x 30 bolts and air compressor pulley.

Vibration Damper

1. See Vibration Damper Runout (page 274) for procedures.

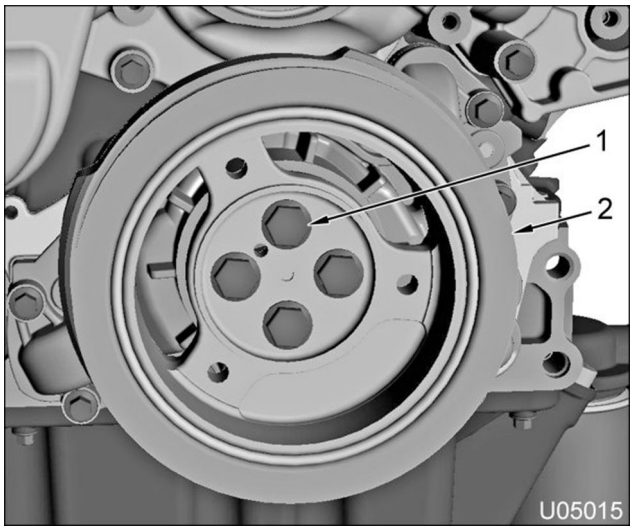


Figure 391 Vibration Damper

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.

2. Remove and discard four M12 x 59 bolts.
3. Remove vibration damper.

CAUTION: To prevent engine damage, do not immerse damper in petroleum based solvents. This can damage the rubber damper element.

Front Crankcase Cover Assembly

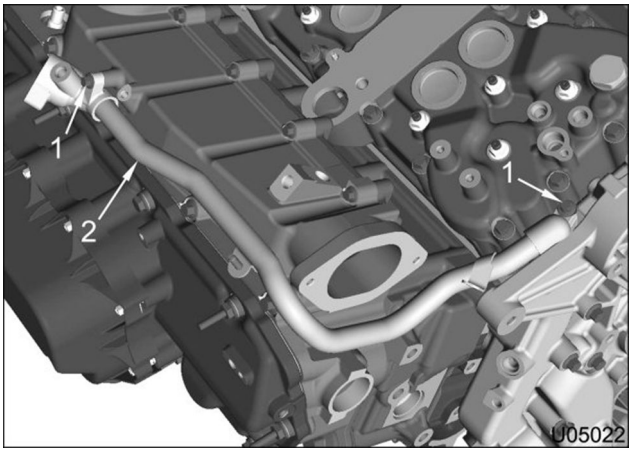


Figure 392 Heater Supply Tube Assembly

1. M6 x 25 bolt (2)
2. Heater supply tube assembly

1. Remove two M6 x 25 bolts that secure heater supply tube assembly.
2. Remove heater supply tube assembly.

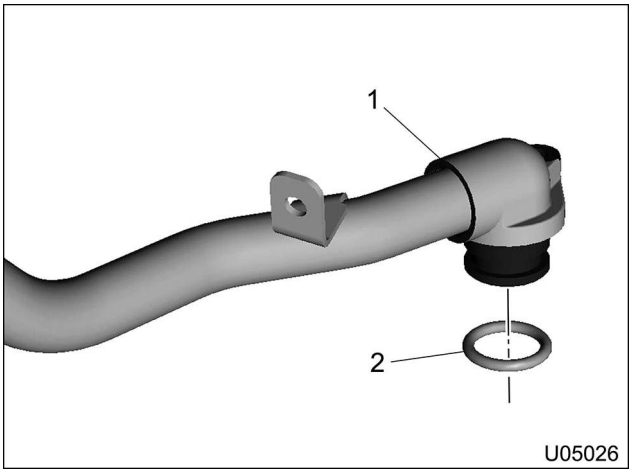


Figure 393 Heater Supply Tube Assembly O-ring

1. Heater supply tube assembly
2. O-ring seal

3. Remove O-ring seal from elbow of heater supply tube assembly. Discard O-ring seal.

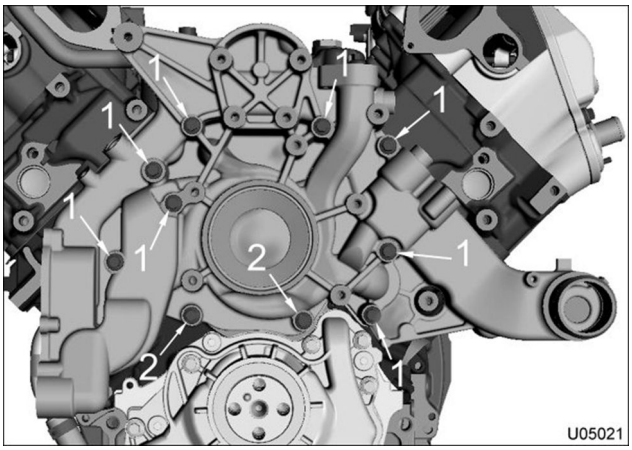


Figure 394 Front Crankcase Cover Bolts

1. M8 x 75 dog point bolt (8)
2. M8 x 45 dog point bolt (2)

NOTE: Support front cover while removing bolts.

4. Remove eight M8 x 75 bolts and two M8 x 45 bolts.

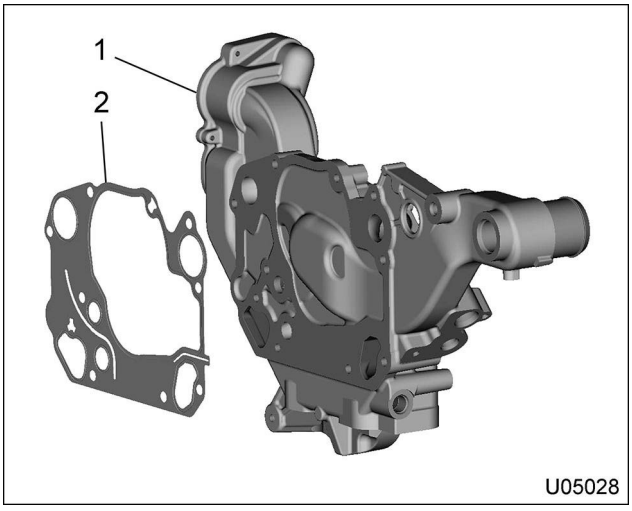


Figure 395 Front Cover Gasket

1. Front crankcase cover
2. Front cover gasket

5. Remove front crankcase cover and discard front cover gasket.

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 284). If bulging exceeds specification, replace vibration damper.
4. Inspect vibration damper rubber compound for cracks or separation. Replace vibration damper if necessary.

Vibration Damper Runout

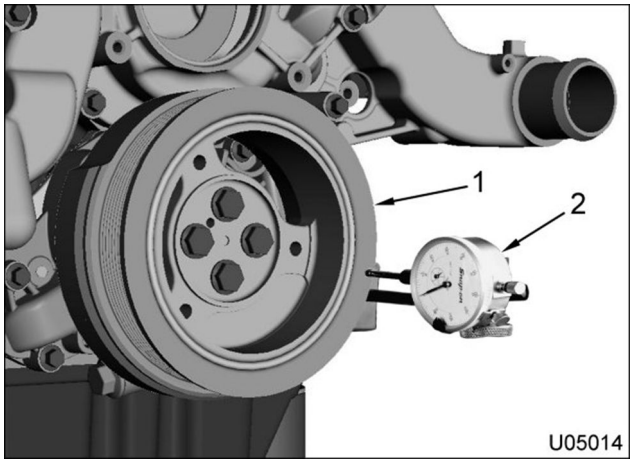


Figure 396 Vibration Damper Runout

1. Vibration damper
2. Dial indicator

NOTE: When prying crankshaft forward, use a block of wood between the prybar and front crankcase cover.

1. Before removing vibration damper, inspect vibration damper for runout as follows:
   a. Attach dial indicator with magnetic base (page 284) 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 284), replace vibration damper.

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 Assemblies

⚠ 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.

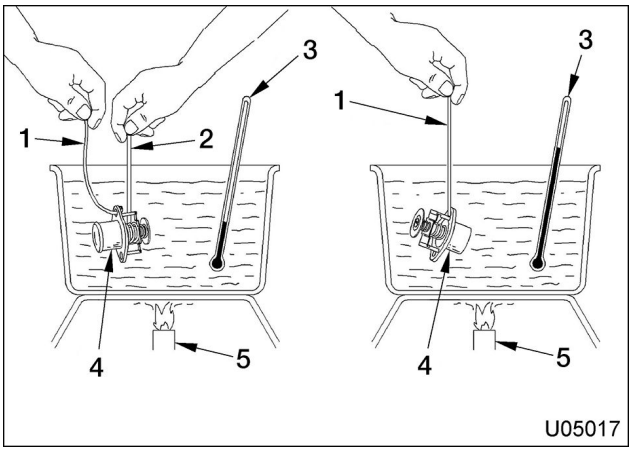


Figure 397 Thermostat Operation Test

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 284).
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 284). 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, install a new thermostat assembly.

Installation

Front Crankcase Cover

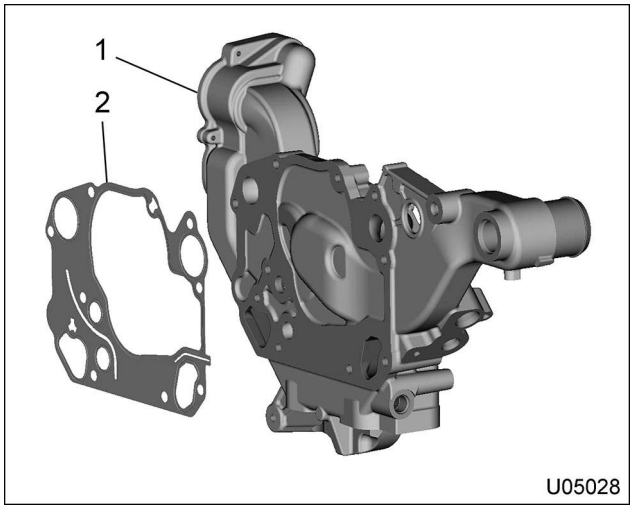


Figure 398 Front Cover Gasket

1. Front crankcase cover
2. Front cover gasket

1. Position a new front cover gasket on the crankcase.

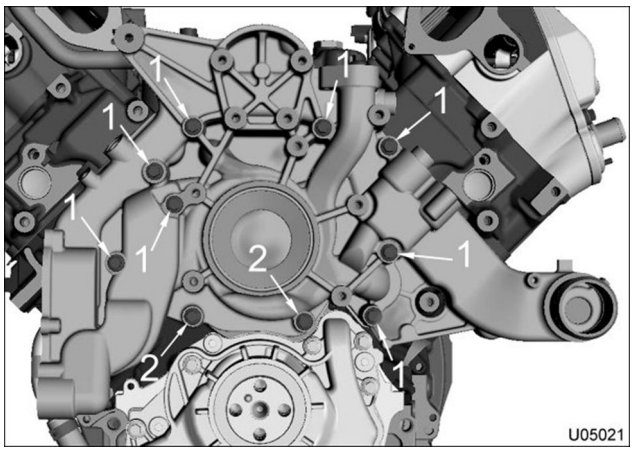


Figure 399 Front Crankcase Cover Bolts

1. M8 x 75 dog point bolt (8)
2. M8 x 45 dog point bolt (2)

2. Install front crankcase cover.

3. Install eight M8 x 75 bolts and two M8 x 45 bolts finger tight.

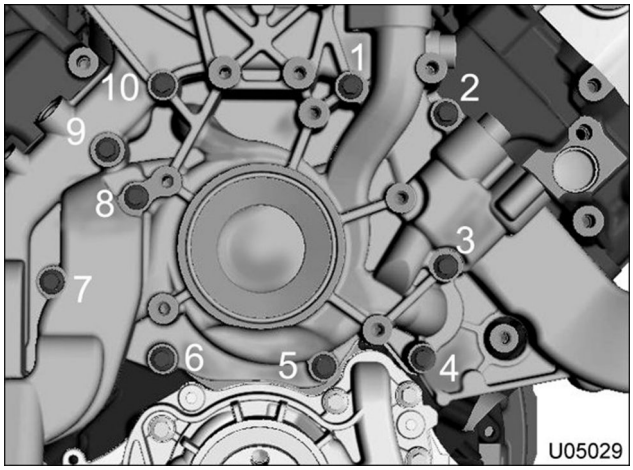


Figure 400 Torque Sequence for Front Crankcase Cover Bolts

4. Tighten bolts in the torque sequence to standard torque (page 473).

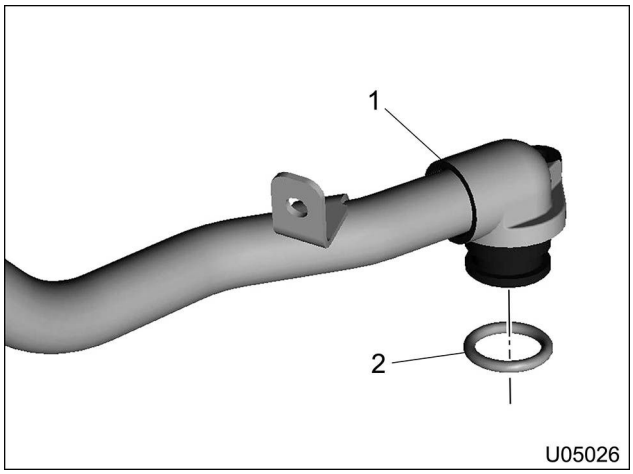


Figure 401 Heater Supply Tube Assembly O-ring

1. Heater supply tube assembly
2. O-ring seal

5. Lubricate new O-ring seal with P-80® Rubber Lubricant or equivalent (page 284), and install O-ring seal onto elbow of heater supply tube assembly.

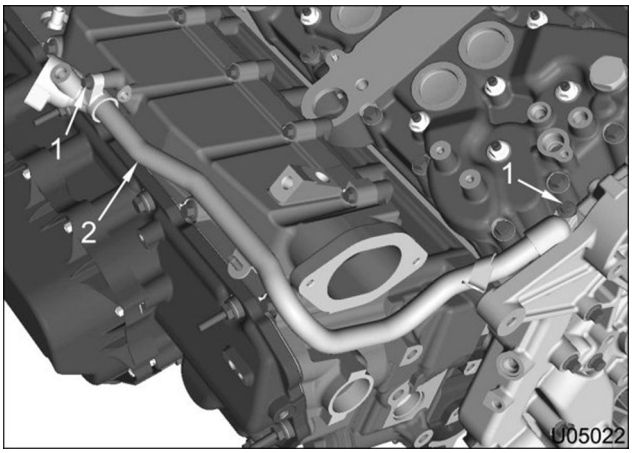


Figure 402 Heater Supply Tube Assembly

1. M6 x 25 bolt (2)
2. Heater supply tube assembly

6. Install two M6 x 25 bolts to secure heater supply tube assembly. Tighten bolts to standard torque (page 473).

Vibration Damper

1. See Vibration Damper Runout (page 274) for procedures.

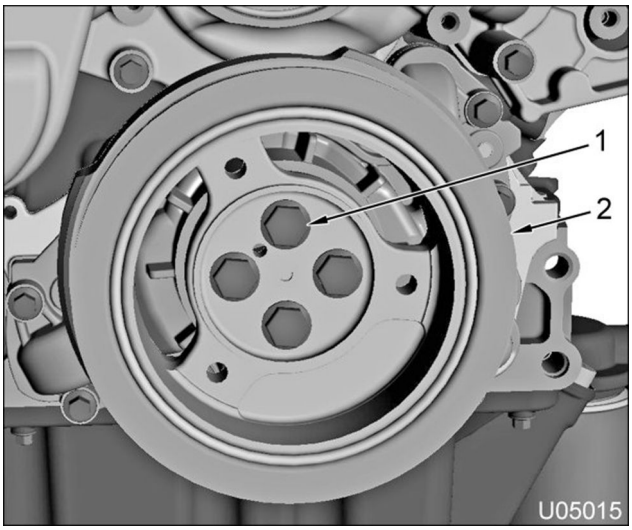


Figure 403 Vibration Damper

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.

2. Align vibration damper with dowel pin on front of crankshaft.

NOTE: Do not use anti-seize compounds, grease or lubricants on mounting bolts. Each has an adverse effect on torque results.

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

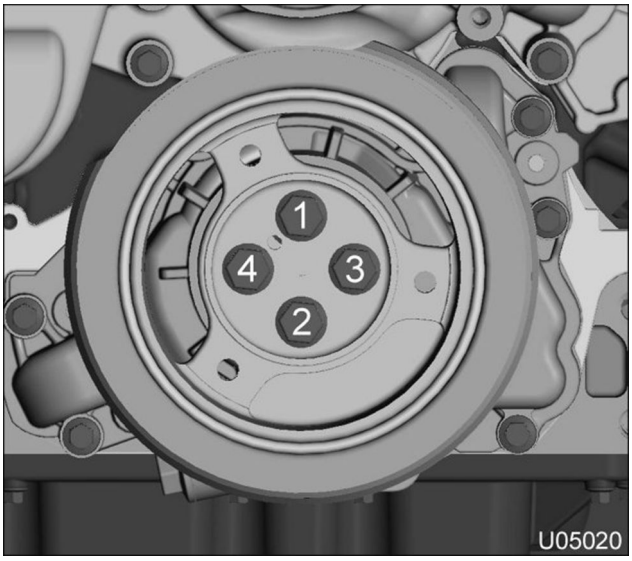


Figure 404 Torque Sequence for Vibration Damper Bolts

4. Tighten each bolt in torque sequence to special torque 68 N·m (50 lb·ft).
5. Rotate each bolt an additional 90° using torque sequence.

Crank Power Takeoff (PTO) for Air Compressor Pulley (if equipped)

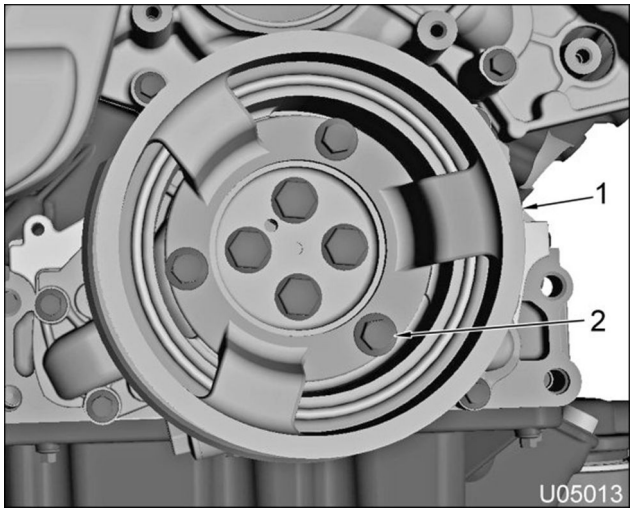


Figure 405 Crank PTO for Air Compressor Pulley (if equipped)

1. Crank PTO for air compressor pulley
2. M10 x 30 bolt (3)

1. Install air compressor pulley.
2. Install three M10 x 30 bolts and tighten to standard torque (page 473).

Water Pump Assembly

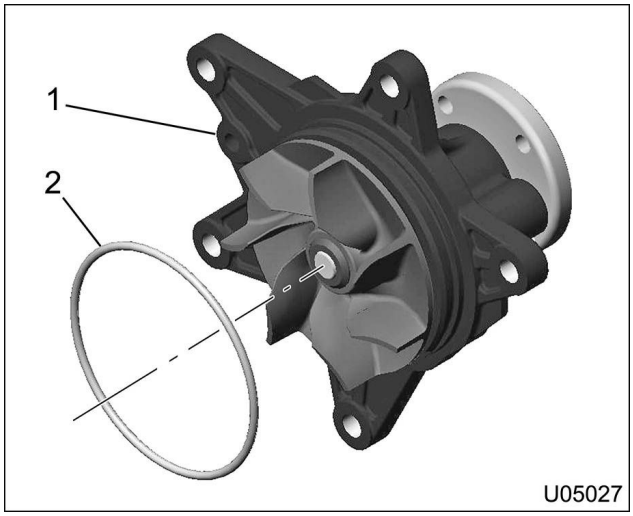


Figure 406 Water Pump Assembly and O-ring Seal

1. Water pump assembly
2. O-ring seal

1. Lubricate a new O-ring seal with P-80® Rubber Lubricant or equivalent (page 284), install O-ring onto water pump assembly.

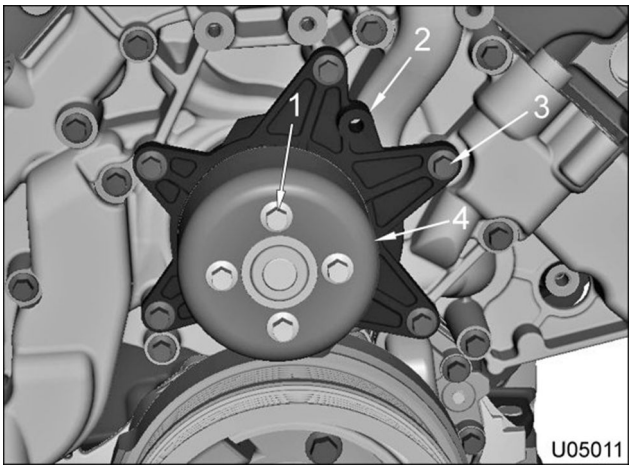


Figure 407 Water Pump Assembly and Pulley

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

CAUTION: To prevent engine damage, do not drop water pump impeller or hit impeller with hard objects.

2. Position water pump assembly onto engine, install five M8 x 35 bolts, and tighten bolts to standard torque (page 473).
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 473).

Fan Drive

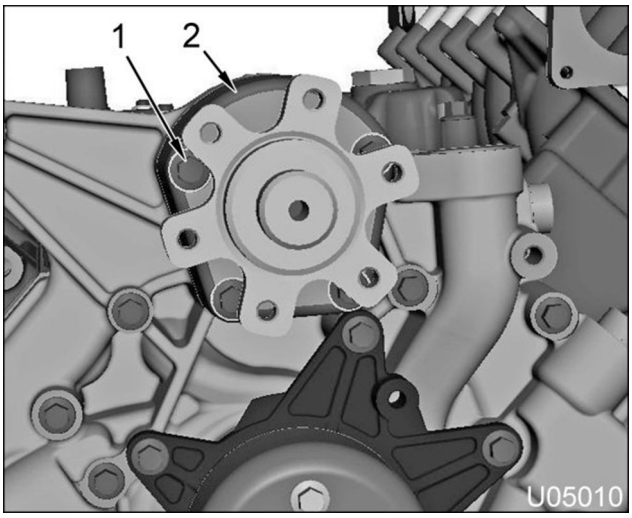


Figure 408 Fan Pulley Mounting Hub

1. M8 x 65 bolt (4)
2. Fan pulley mounting hub

1. Install fan pulley mounting hub.
2. Install four M8 x 65 bolts and tighten to standard torque (page 473).

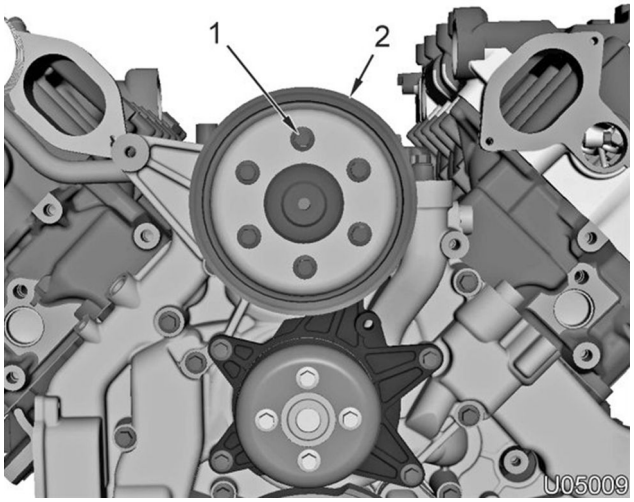


Figure 409 Fan Pulley

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 standard torque (page 473).

Thermostat Housing and Thermostats

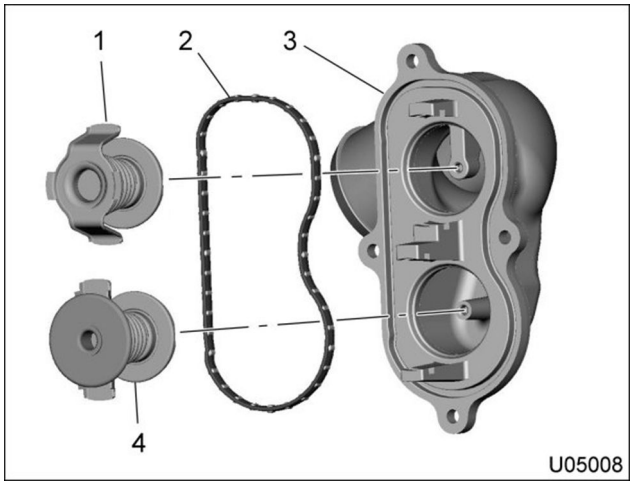


Figure 410 Thermostats, Thermostat Housing Gasket, and Thermostat Housing

1. Thermostat assembly (without bypass)
2. Thermostat housing gasket
3. Thermostat housing
4. Thermostat assembly (with bypass)

NOTE: The lower thermostat assembly (with bypass) seals against an orifice in the front crankcase cover.

1. Install thermostat assembly (with bypass) into thermostat housing.
2. Install thermostat assembly (without bypass) into thermostat housing.
3. Install a new thermostat housing gasket into the recess of the thermostat housing.

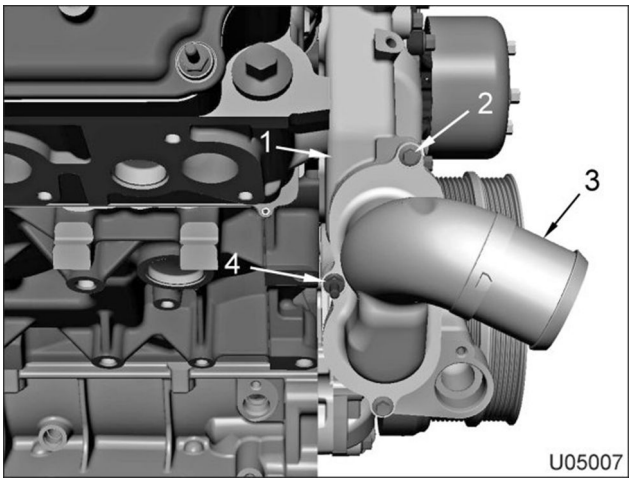


Figure 411 Thermostat Housing

1. Front crankcase cover
2. M6 x 20 bolt (3)
3. Thermostat housing
4. M6 x 25 stud bolt

4. Position thermostat housing on front crankcase cover.
5. Install one M6 x 25 stud bolt and three M6 x 20 bolts and tighten all bolts to standard torque (page 473).

Front Engine Mounting Support

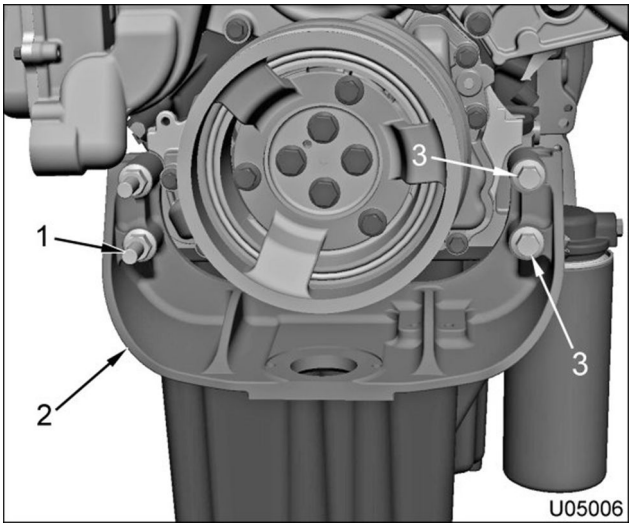


Figure 412 Front Engine Mounting Support on Engines without (optional secondary freon compressor bracket)

1. M12 x 70 stud bolt (2)
2. Front engine mounting support
3. M12 x 70 bolt

1. Position front engine mounting support. Install two M12 x 70 stud bolts and one M12 x 70 bolt.
2. Tighten bolts to standard torque (page 473).

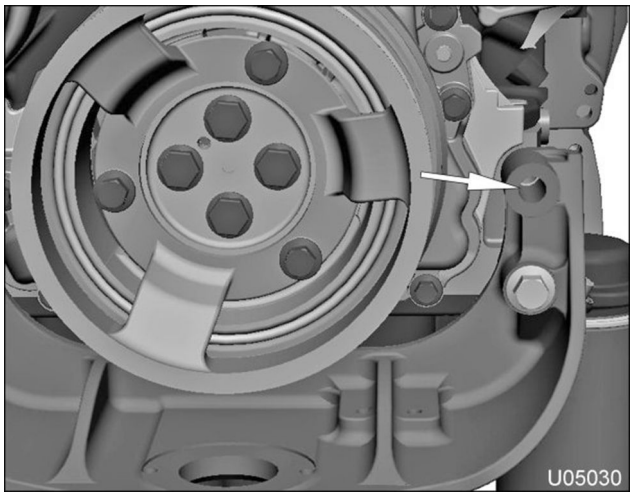


Figure 413 M12 x 110 Bolt Location for Engines with (optional secondary freon compressor bracket)

3. Position front engine mounting support.

NOTE: See (page 200) for installation of M12 x 110 bolt.

4. Install M12 x 110 bolt.
5. Install two M12 x 70 stud bolts and one M12 x 70 bolt.
6. Tighten bolts to standard torque (page 473).

Alternator and Refrigerant Compressor Mounting Bracket

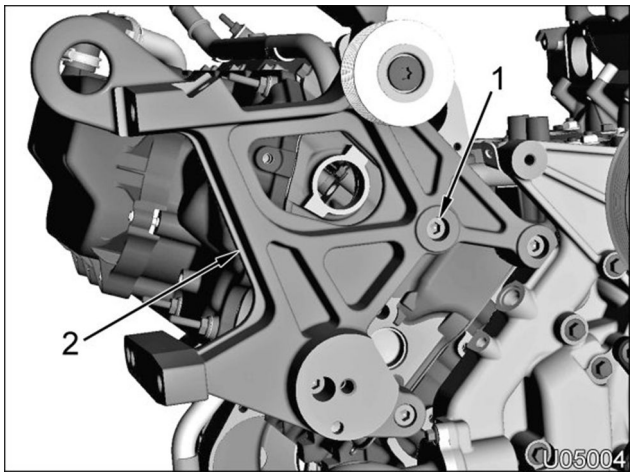


Figure 414 Alternator and Refrigerant Compressor Mounting Bracket

1. M10 x 45 screw (4)
2. Alternator and refrigerant compressor mounting bracket

1. Position alternator and refrigerant compressor mounting bracket.
2. Install four M10 x 45 screws and tighten to standard torque (page 473).

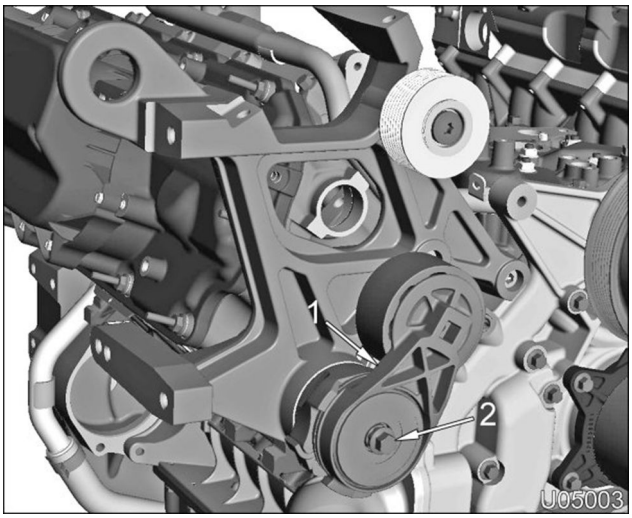


Figure 415 Belt Tensioner

1. Belt tensioner
2. M10 x 80 bolt

3. Install belt tensioner.
4. Install M10 x 80 bolt and tighten to standard torque (page 473).

Specifications

Vibration Damper	
Face runout (maximum)	0.635 mm (0.025 in)
Rubber bulging (maximum)	1.5 mm (0.060 in)
Thermostat Assembly with Bypass	
Type	Balanced pressure, wax pellet
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
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

Vibration damper bolts	See Vibration Damper Installation Procedure

Special Service Tools

Description	Tool Number
Dial indicator with magnetic base	Obtain locally
P-80® Rubber Lubricant or equivalent	Obtain locally

Table of Contents

Exploded Views.....287

Removal.....290
- **Oil Cooler Assembly**.....290
- **Oil Cooler Assembly Leak Test (Coolant Side)**.....291
  - **Oil Cooler Assembly Leak Test Procedure**.....291
  - **Disassembly**.....291
  - **Service Parts**.....291
  - **Assembly**.....292
- **Oil Cooler Cover Assembly**.....293
- **Front Crankshaft Oil Seal**.....293
- **Oil Pump Assembly**.....295
- **Oil Level Tube assembly**.....296
- **Oil Pan Plugs and Oil Level Gauge Tube Gasket**.....296
- **Oil Filter Assembly**.....297
- **Oil Pan**.....297
- **Lube Oil Suction Tube**.....297

Cleaning, Inspection, and Measurement.....299
- **Cleaning and Inspection**.....299
- **Oil Pump Rotor Assembly**.....299
- **Oil Pressure Regulator Components**.....300

Installation.....301
- **Lube Oil Suction Tube**.....301
- **Oil Pan**.....301
- **Oil Pan Plugs and Oil Level Gauge Tube Gasket**.....302
- **Oil Filter Assembly**.....302
- **Oil Level Tube Assembly**.....303
- **Oil Pump Housing Assembly**.....303
- **Front Crankshaft Oil Seal**.....305
- **Oil Cooler Assembly**.....305

Specifications.....307

Special Torque.....307

Special Service Tools.....308

Exploded Views

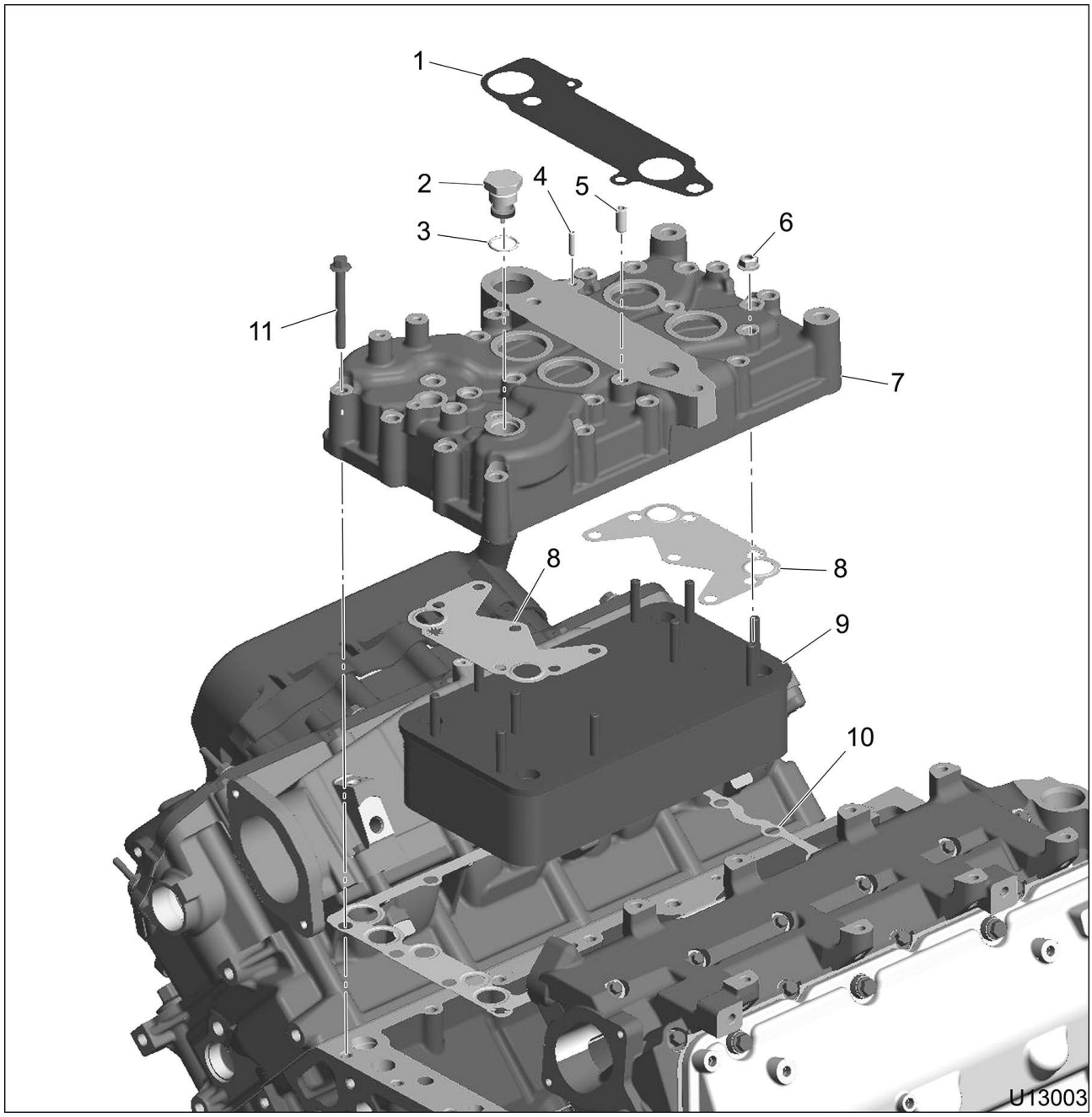


Figure 416 Oil Cooler Assembly

1. Turbo oil drain gasket
2. Oil cooler bypass valve assembly
3. Bypass valve cap seal
4. M5 x 20 slotted pin
5. M8 x 20 slotted pin
6. Serrated nut (10)
7. Oil cooler cover
8. Cooler to cover gasket (2)
9. Oil cooler
10. Cover to crankcase gasket
11. M8 x 70 bolt (12)

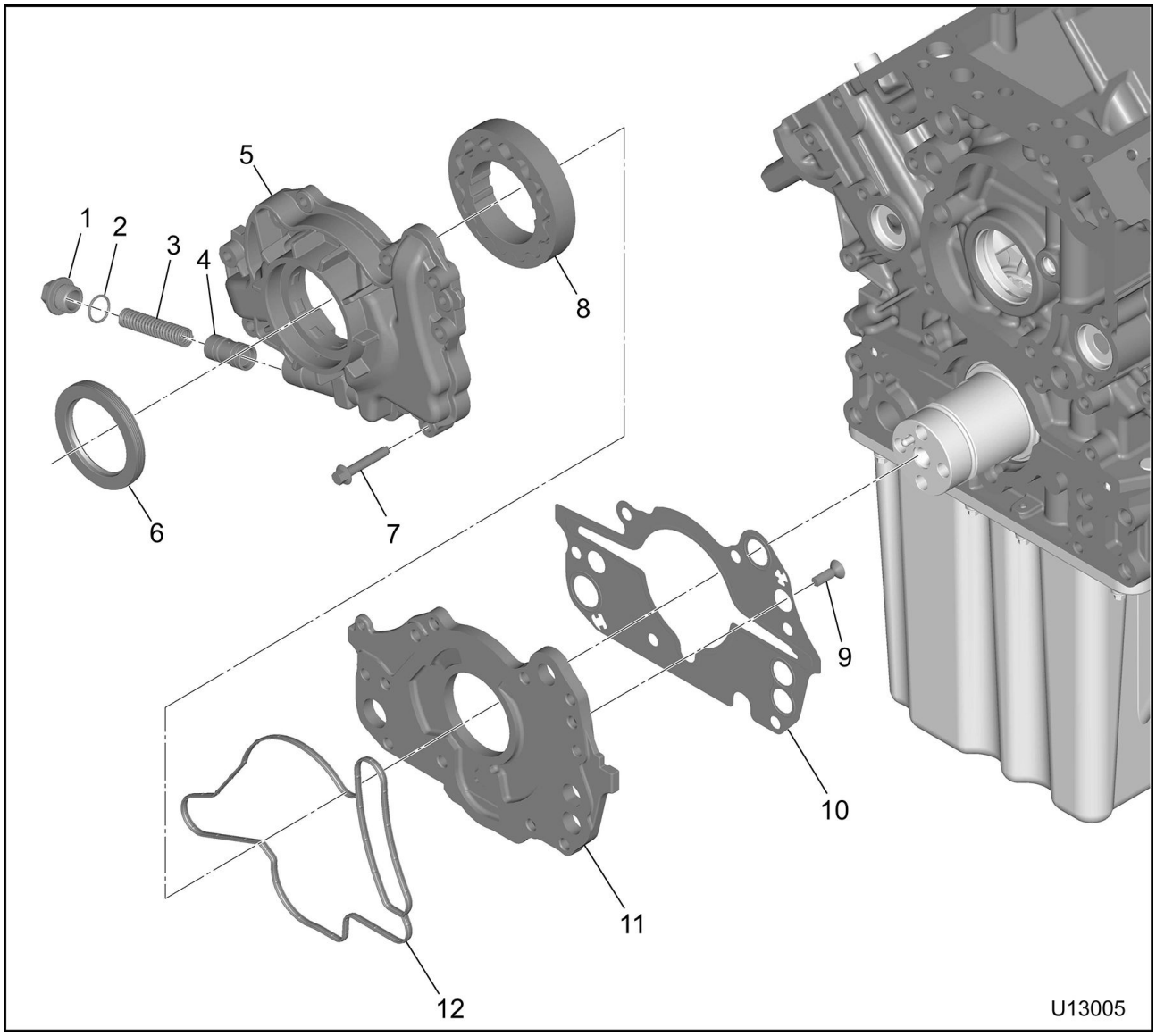


Figure 417 Oil Pump

1. Relief valve cap
2. Relief valve retainer seal
3. Relief valve spring
4. Relief valve piston
5. Oil pump housing
6. Oil crankshaft front seal
7. M8 x 45 dog point bolt (8)
8. Oil pump rotor assembly
9. M8 x 25 screw (4)
10. Oil pump to engine gasket
11. Oil pump housing plate
12. Oil pump housing gasket

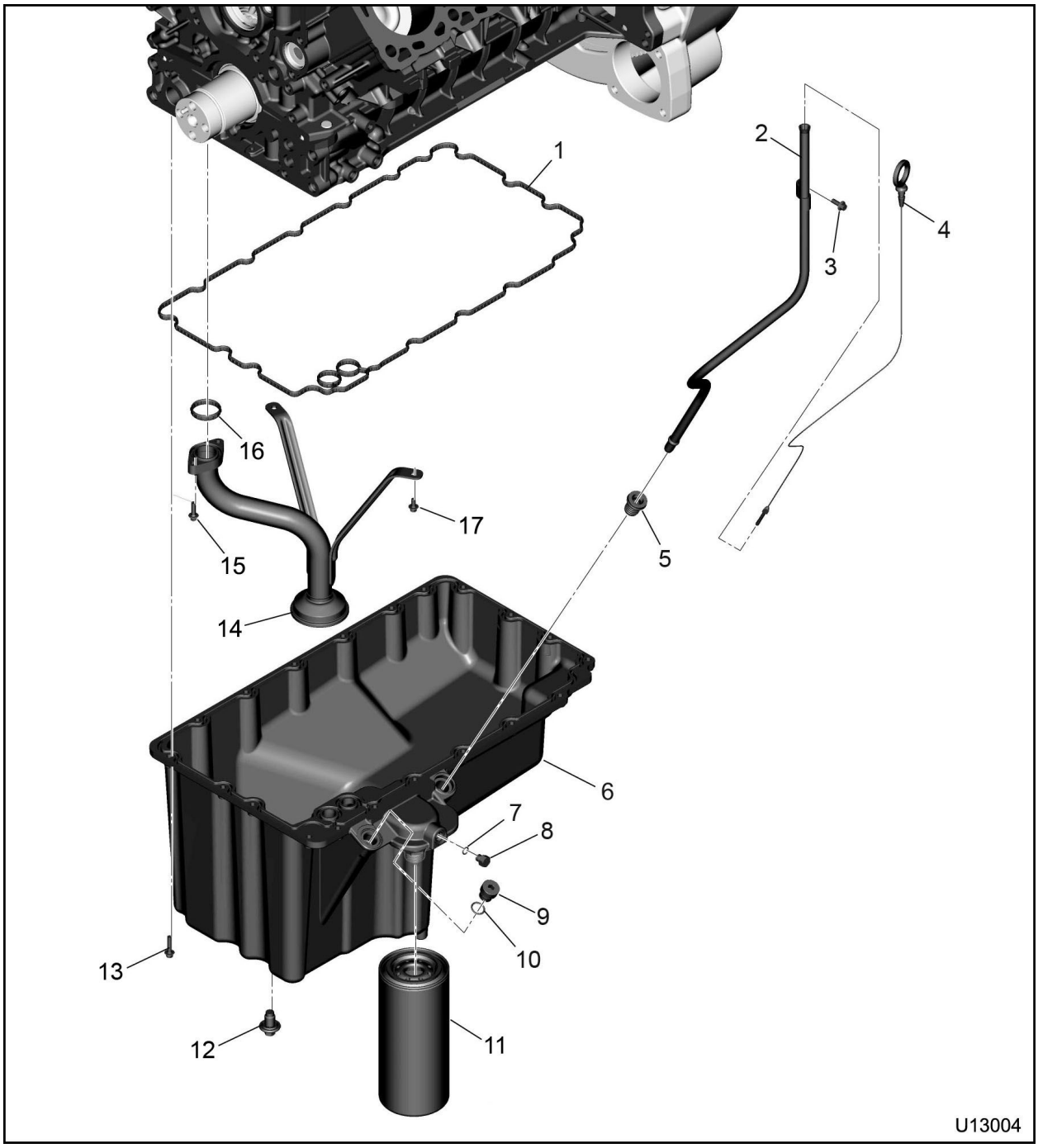


Figure 418 Oil Pan Assembly and Oil Filter

1. Oil pan gasket
2. Oil level gauge tube
3. M6 x 16 bolt
4. Oil level gauge assembly (with O-ring)
5. Oil level gauge tube gasket
6. Oil pan
7. M10 plug O-ring
8. Hex plug assembly
9. M18 plug assembly
10. O-ring seal
11. Oil filter assembly
12. Oil drain plug assembly
13. M6 x 25 bolt (20)
14. Lube oil suction tube assembly
15. M6 x 20 bolt (2)
16. Oil pick up tube gasket
17. M6 x 12 bolt (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 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 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**
- **Dual Turbocharger, Exhaust Manifolds, and Piping**
- **Air Compressor and Power Steering Pump**
- **Fuel System**

Oil Cooler Assembly

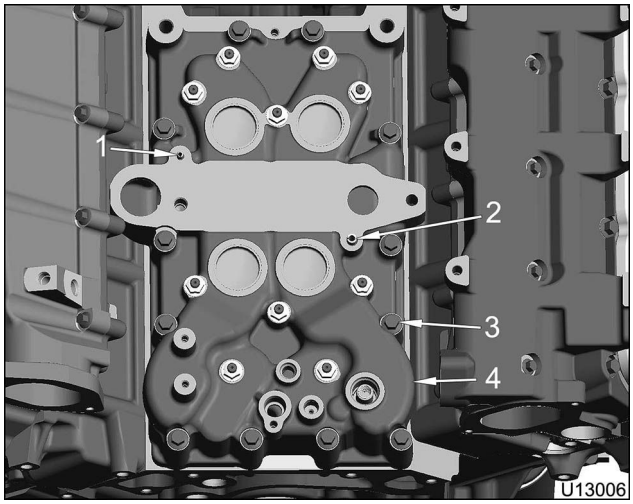


Figure 419 Oil Cooler Assembly

1. M5 x 20 slotted pin
2. M8 x 20 slotted pin
3. M8 x 70 bolt (12)
4. Oil cooler assembly

1. If required, remove M5 x 20 slotted pin and M8 x 20 slotted pin.
2. Remove 12 M8 x 70 bolts.
3. Remove oil cooler assembly.

Oil Cooler Assembly Leak Test (Coolant Side)

Oil Cooler Assembly Leak Test Procedure

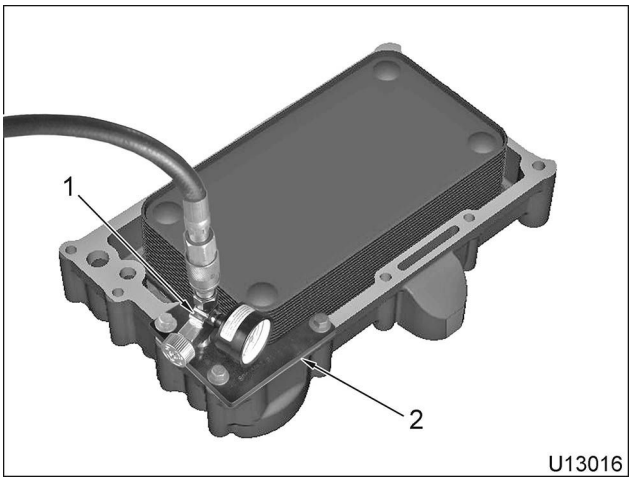


Figure 420 Oil Cooler Assembly Leak Test

1. Air pressure regulator
2. Oil Cooler Block-off Plate

1. Install Oil Cooler Block-off Plate (page 308) on oil 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 (page 308) to Oil Cooler Block-off Plate. Connect to compressed air supply and adjust air pressure to approximately 172 to 207 kPa (25 to 30 psi).
3. Submerge oil cooler assembly in a container of water.
4. Inspect for air bubbles on the oil cooler and between oil cooler and oil cooler cover.

- If leaks are not detected, remove air supply line and air pressure regulator. Dry oil cooler assembly with compressed air and set cooler assembly aside for installation later.
- If leaks are detected, identify the leak. Remove air supply line and air pressure regulator, Oil Cooler Block-off Plate, and disassemble oil cooler assembly.

Disassembly

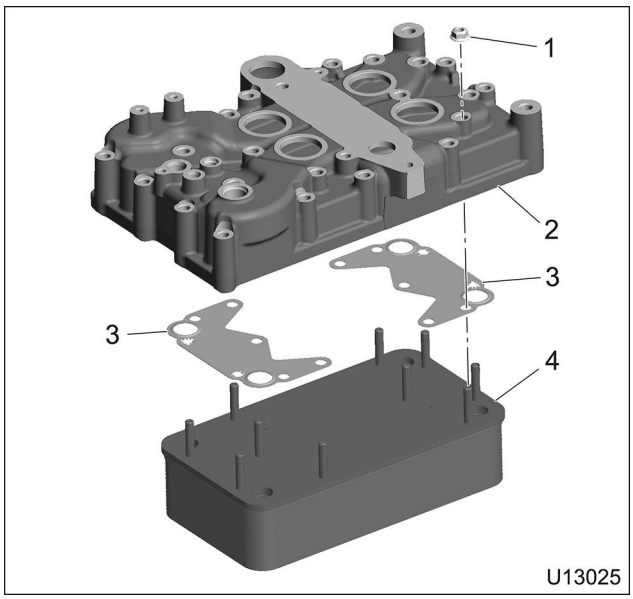


Figure 421 Oil Cooler Cover, Cooler to Cover Gasket, and Oil Cooler

1. Serrated nut (10)
2. Oil cooler cover
3. Cooler to cover gasket (2)
4. Oil cooler

1. Remove 10 serrated nuts.
2. Separate oil cooler cover and oil cooler.
3. Remove and discard two cooler to cover gaskets.
4. Discard defective oil cooler cover or oil cooler, or both.

Service Parts

- If installing new cooler to cover gaskets, clean gasket surfaces on oil cooler cover and oil cooler.
- If installing a new oil cooler, clean gasket surfaces on oil cooler cover.
- If installing a new oil cooler cover, clean gasket surfaces on oil cooler.

Assembly

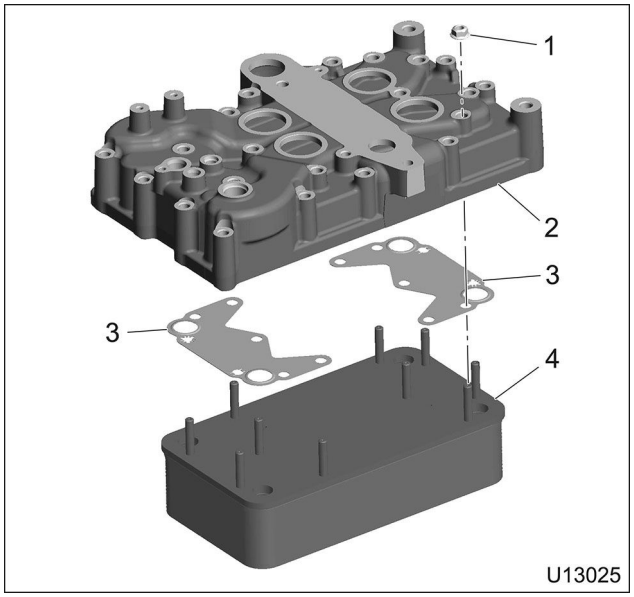


Figure 422 Oil Cooler Cover, Cooler to Cover Gasket, and Oil Cooler

1. Serrated nut (10)
2. Oil cooler cover
3. Cooler to cover gasket (2)
4. Oil cooler

1. Assemble oil cooler cover, two new cooler cover gaskets, and oil cooler.
2. Install 10 serrated nuts.

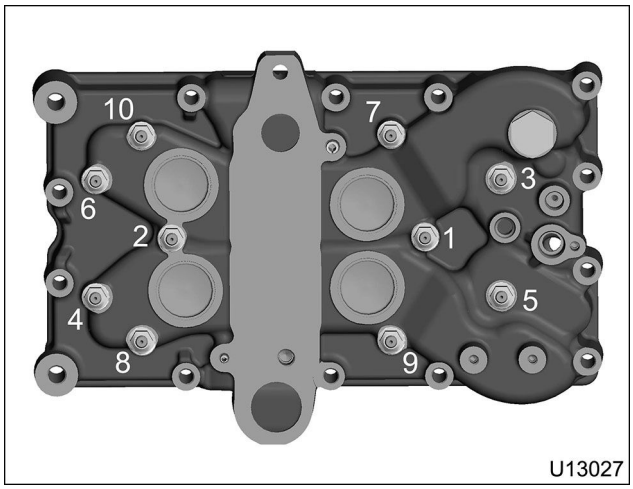


Figure 423 Torque Sequence for Serrated Nuts (Oil Cooler Cover to Oil Cooler)

3. Tighten serrated nuts in torque sequence to 25 N·m (18 lb·ft). Set oil cooler assembly aside for installation later.
4. Repeat Oil Cooler Assembly Leak Test Procedure to confirm that cooler to cover gaskets have sealed.
5. Drain and flush 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. Dry oil cooler cover assembly thoroughly with compressed air.
7. Set oil cooler assembly aside for installation later.

Oil Cooler Cover Assembly

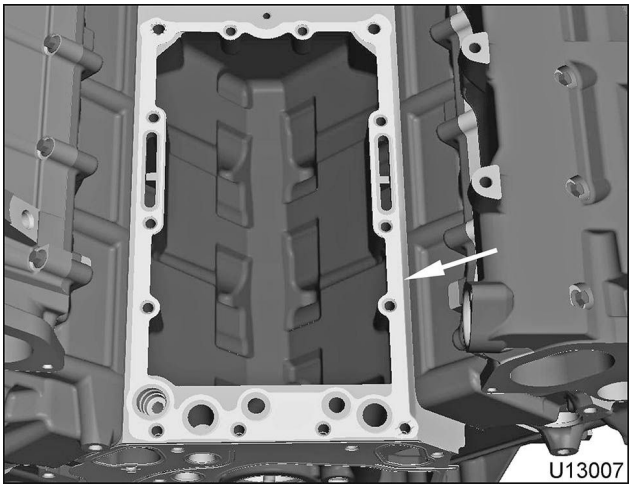


Figure 424 Cover to Crankcase Gasket

1. Remove and discard cover to crankcase gasket.

Front Crankshaft Oil Seal

NOTE: The MaxxForce® 7 is not equipped with a wear sleeve during factory production. Wear sleeves are included with oil seal service kits.

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

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

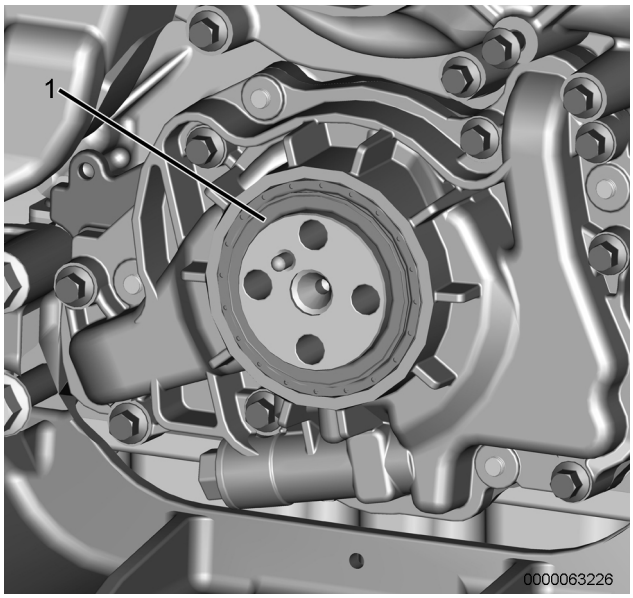


Figure 425 Front Crankshaft Oil Seal

1. Front oil seal

2. Thread a Slide Hammer (page 308) 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, only if engine has a front wear sleeve.

4. Complete following steps to install the Front Wear Sleeve Remover (page 308):

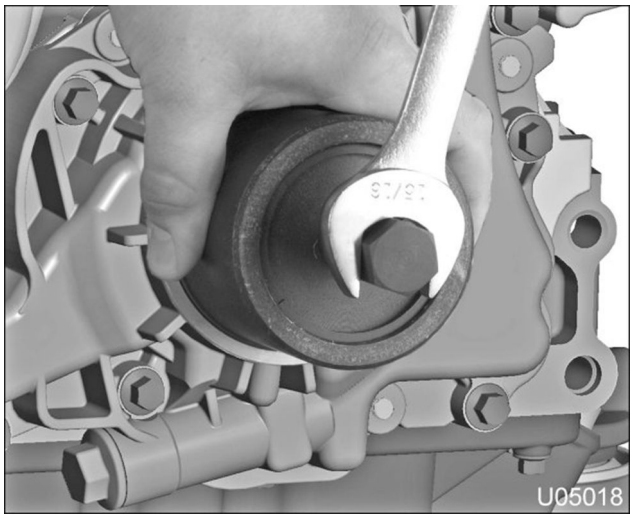


Figure 426 Removal of Front Wear Sleeve

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.

Oil Pump Assembly

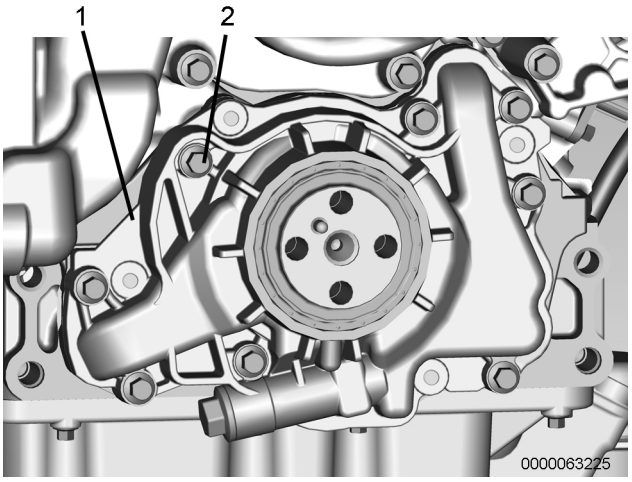


Figure 427 Oil Pump Assembly

1. Oil pump assembly
2. M8 x 45 dog point bolt (8)

1. Remove eight M8 x 45 bolts and oil pump assembly.

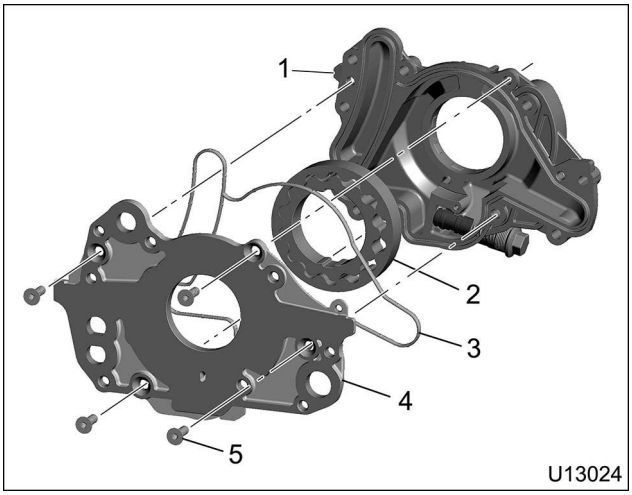


Figure 428 Oil Pump Housing, Rotor Assembly, Housing Gasket, and Plate

1. Oil pump housing
2. Oil pump rotor assembly
3. Oil pump housing gasket
4. Oil pump housing plate
5. M8 x 25 screw (4)

2. Remove four M8 x 25 screws that secure the oil pump housing plate to the oil pump housing.
3. Remove oil pump housing plate.
4. Remove and discard oil pump housing gasket.

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

5. Use a permanent marker to mark the front of the inner and outer oil pump rotor for correct reassembly orientation.
6. See Cleaning, Inspection, and Testing (Oil Pump Rotor Assembly, page 299).
7. See Cleaning, Inspection, and Testing (Oil Pressure Regulator Components, page 300).

CAUTION: To prevent engine damage, cut sealant between oil pump to engine gasket and the joint of the upper and lower crankcase, before removing the oil pump to engine 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.

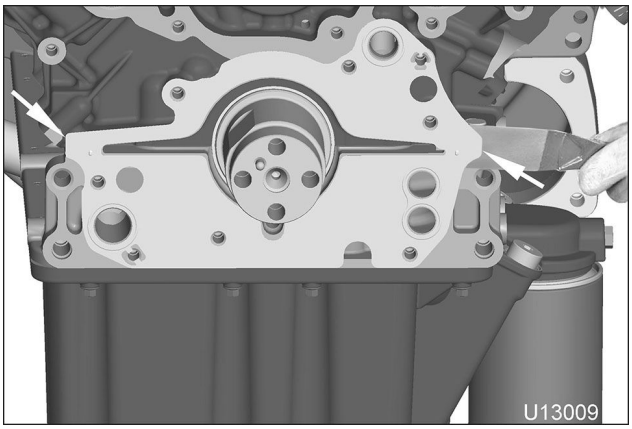


Figure 429 Cutting Sealant Between Oil Pump to Engine Gasket

8. Using a thin, sharp blade scraper, cut through sealant between oil pump to engine gasket at both joints of the upper and lower crankcase.
9. Remove and discard oil pump to engine gasket.

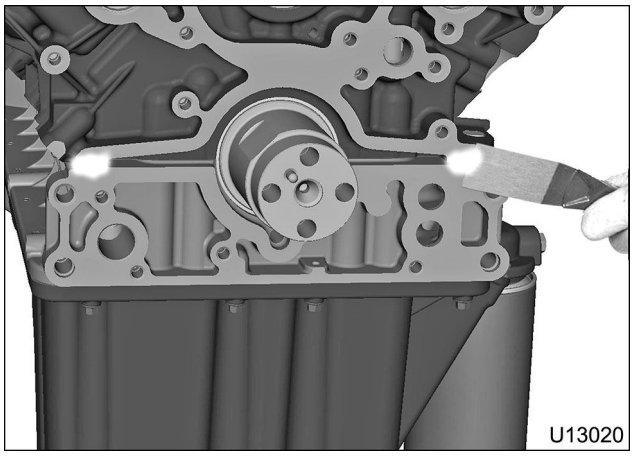


Figure 430 Removal of Sealant

10. If necessary, trim remaining sealant from both joints of the upper and lower crankcase.

Oil Level Tube assembly

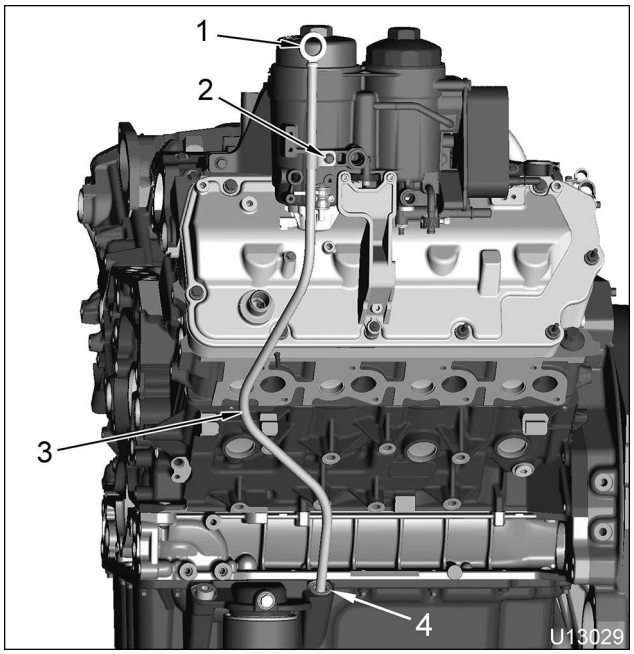


Figure 431 Oil Level Tube Assembly

1. Oil level gauge assembly (with O-ring)
2. M6 x 16 bolt
3. Oil level tube assembly
4. Oil level gauge tube gasket

1. Remove oil level gauge assembly from oil level tube assembly.
2. Remove M6 x 16 bolt that secures oil level tube assembly to fuel filter module housing.
3. Pull up and remove oil level tube assembly.

Oil Pan Plugs and Oil Level Gauge Tube Gasket

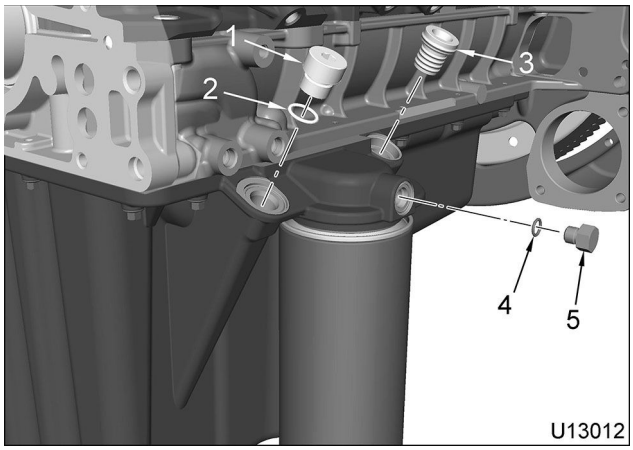


Figure 432 Oil Pan Plugs and Oil Level Gauge Tube Gasket

1. M18 plug assembly
2. O-ring seal
3. Oil level gauge tube gasket
4. M10 plug O-ring
5. Hex plug assembly

1. Remove M18 plug assembly and O-ring seal. Discard O-ring seal.
2. Pull up, remove, and discard oil level gauge tube gasket.
3. Remove hex plug assembly and O-ring. Discard O-ring.

Oil Filter Assembly

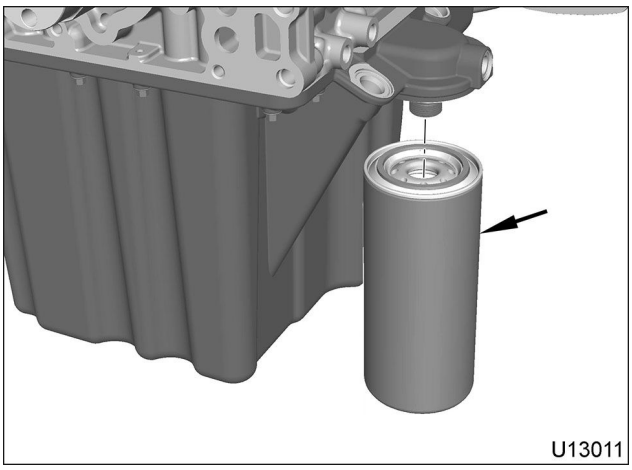


Figure 433 Oil Filter Assembly

1. Remove oil filter assembly.

Oil Pan

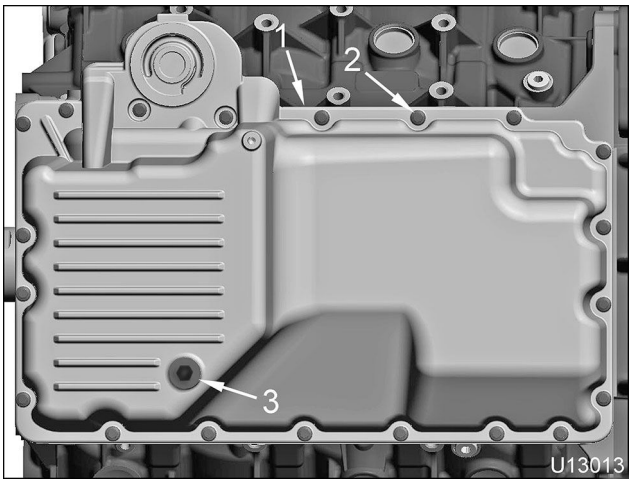


Figure 434 Oil Pan

1. Oil pan
2. M6 x 25 bolt (20)
3. Oil drain plug assembly

1. Remove twenty M6 x 25 bolts.
2. If not previously removed, remove oil drain plug assembly.

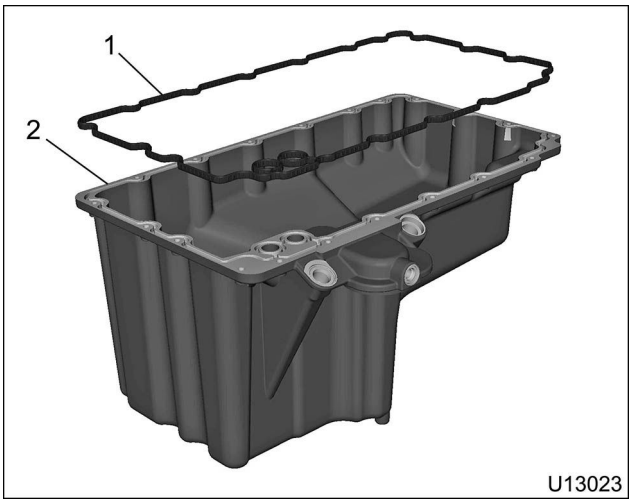


Figure 435 Oil Pan Gasket

1. Oil pan gasket
2. Oil pan

3. Remove oil pan and discard oil pan gasket.

Lube Oil Suction Tube

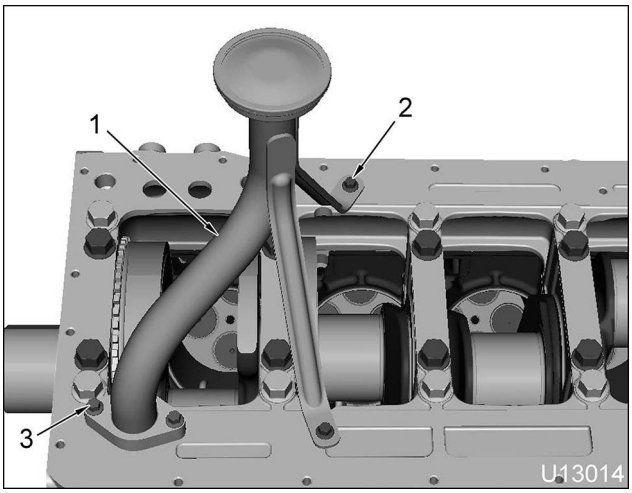


Figure 436 Lube Oil Suction Tube

1. Lube oil suction tube
2. M6 x 12 bolt (2)
3. M6 X 20 bolt (2)

1. Remove M6 x 12 bolts and M6 X 20 bolts.
2. Remove lube oil suction tube.

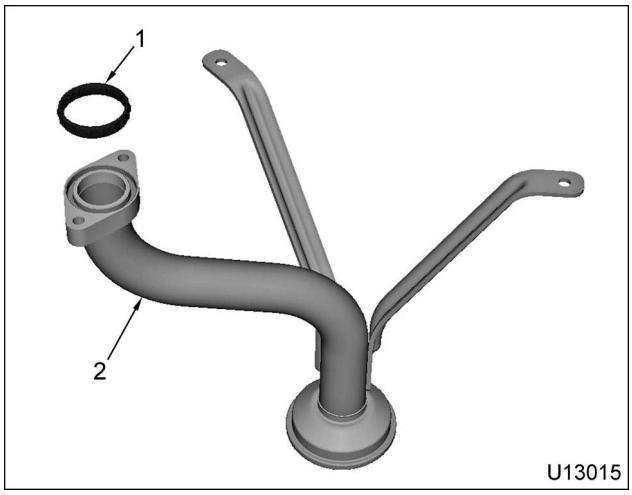


Figure 437 Oil Pickup Tube Gasket

1. Oil pickup tube gasket
2. Lube oil suction tube

3. Remove and discard oil pickup tube gasket.

Cleaning, Inspection, and Measurement

Cleaning and Inspection

1. Wash parts thoroughly in 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).

2. Dry parts with filtered compressed air.
3. Inspect oil pan for warping or cracking. Install a new oil pan, if necessary.
4. Inspect lube oil suction tube and bracket for cracking. Install a new lube oil suction tube and bracket, if necessary.

Oil Pump Rotor Assembly

1. Lay oil pump housing assembly on workbench.
2. Inspect inner and outer oil pump rotors and oil pump housing assembly for nicks, burrs, or scoring.
3. Replace any damaged components.

   NOTE: The inner and outer oil pump rotors are a matched set and cannot be replaced individually.

   NOTE: If installing a new oil pump rotor assembly, correct orientation of rotors to each other or to the engine is not important. If installing a used oil pump rotor assembly, correct orientation of rotors to each other and to the engine is necessary.

4. Apply 15W30 or 10W30 oil to rotor area only.

NOTE: When assembled, rotor pair must rotate freely and smoothly.

5. Install oil pump rotor assembly in oil pump housing. Verify that the rotor assembly rotates freely and smoothly in the oil pump housing.

Figure 438 Outer Oil Pump Gerotor Measurement

6. Use a feeler gauge (page 308) to inspect for wear by measuring radial clearance (page 307) between outer oil pump rotor and oil pump housing assembly.

Figure 439 End Clearance Check for Oil Pump

7. Check oil pump end clearance as follows:
   a. With inner and outer oil pump rotors in place in the oil pump housing, put straightedge across housing.
   b. Insert feeler gauge under straightedge (page 308) at inner and outer oil pump gerotors. Compare end clearance with specifications (page 307).
   c. If measurements are not within specifications, install a new oil pump rotor assembly.

Oil Pressure Regulator Components

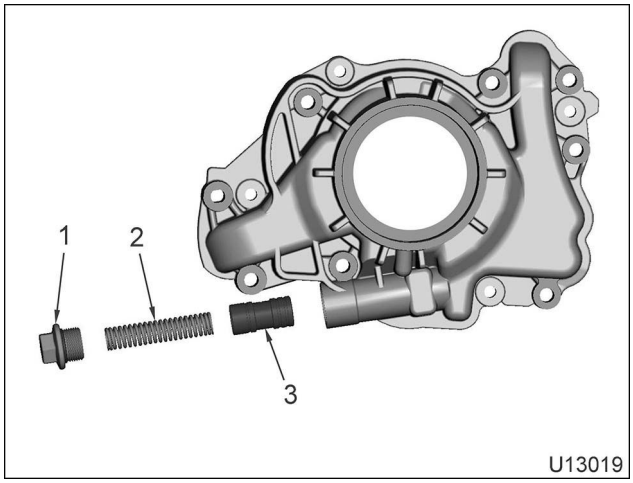


Figure 440 Oil Pressure Regulator Components

1. Relief valve cap and relief valve retainer seal
2. Relief valve spring
3. Relief valve piston

1. Remove oil pressure regulator components.
2. Inspect oil pressure regulator components and bore in oil pump housing for wear. Install new components, if necessary.
3. Tighten relief valve cap to special torque (page 307).

Installation

Lube Oil Suction Tube

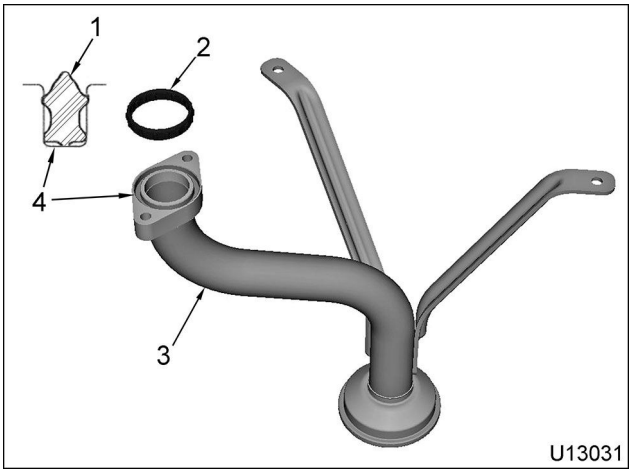


Figure 441 Oil Pickup Tube Gasket

1. Cross-section of oil pickup tube gasket
2. Oil pickup tube gasket
3. Lube oil suction tube
4. Gasket groove in flange of lube oil suction tube

1. Lubricate a new oil pickup tube gasket with clean engine oil.
2. See cross-section of oil pickup tube gasket and install gasket correctly into gasket groove of lube oil suction tube flange.

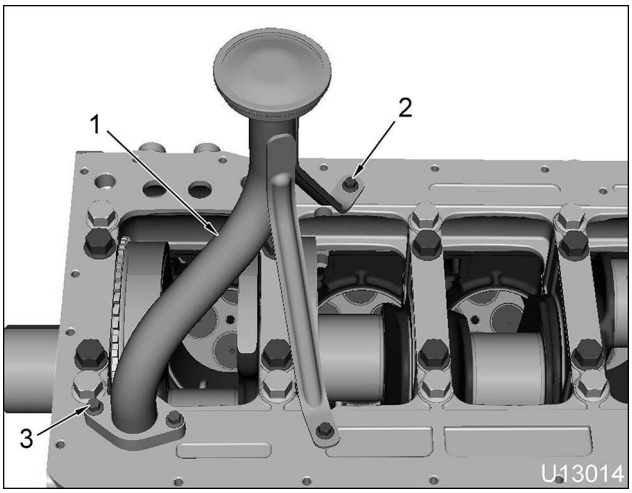


Figure 442 Lube Oil Suction Tube

1. Lube oil suction tube
2. M6 x 12 bolt (2)
3. M6 X 20 bolt (2)

3. Position lube oil suction tube.
4. Install two M6 x 12 bolts, two M6 X 20 bolts, and tighten bolts to standard torque (page 473).

Oil Pan

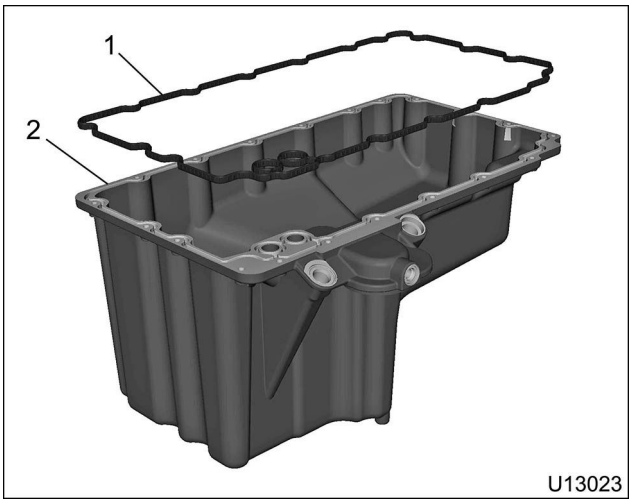


Figure 443 Oil Pan Gasket

1. Oil pan gasket
2. Oil pan

1. Install new oil pan gasket and position oil pan.

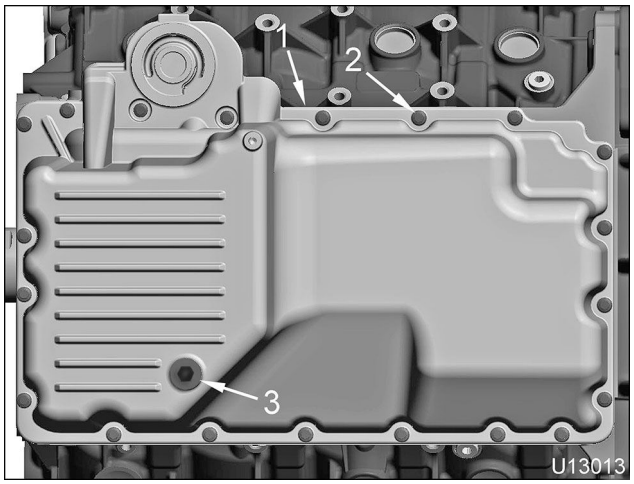


Figure 444 Oil Pan

1. Oil pan
2. M6 x 25 bolt (20)
3. Oil drain plug assembly

2. Install 20 M6 x 25 bolts and tighten to standard torque (page 473).
3. If removed, install oil drain plug assembly and tighten to special torque (page 307).

Oil Pan Plugs and Oil Level Gauge Tube Gasket

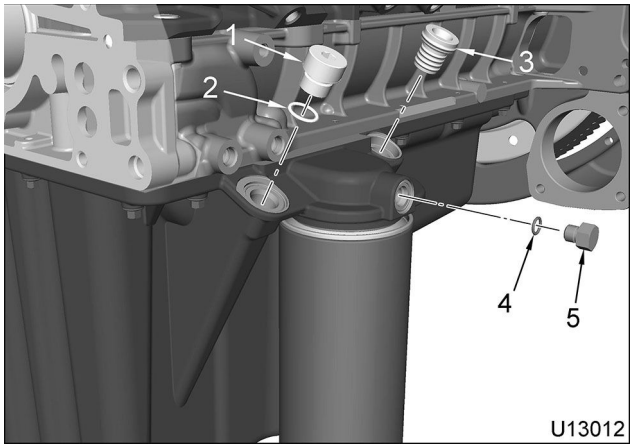


Figure 445 Oil Pan Plugs and Oil Level Gauge Tube Gasket

1. M18 plug assembly
2. O-ring seal
3. Oil level gauge tube gasket
4. M10 plug O-ring
5. Hex plug assembly

1. Lubricate a new O-ring seal with a light coat of clean engine oil and install onto M18 plug assembly.
2. Install plug assembly into oil pan and tighten plug assembly to special torque (page 307).
3. Lubricate a new oil level gauge tube gasket with a light coat of clean engine oil to and press gasket into oil pan.
4. Lubricate a new O-ring with a light coat of clean engine oil and install onto hex plug assembly.
5. Install hex plug into oil pan and tighten to special torque (page 307).

Oil Filter Assembly

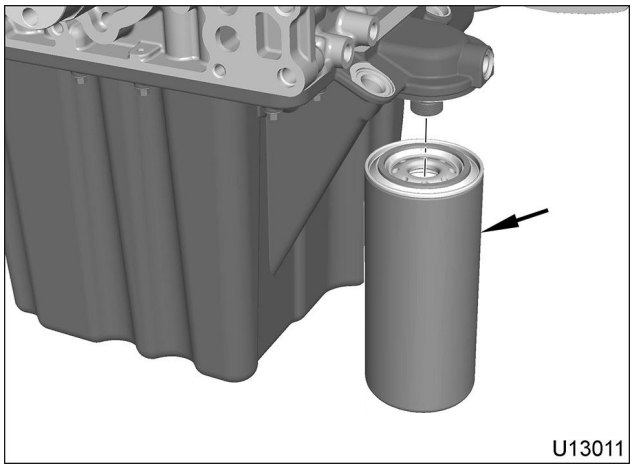


Figure 446 Oil Filter Assembly

1. Lubricate oil filter seal with clean engine oil.
2. Install oil filter assembly hand tight to contact the oil filter housing. Then, turn oil the filter assembly 3/4 to 1 full turn.

Oil Level Tube Assembly

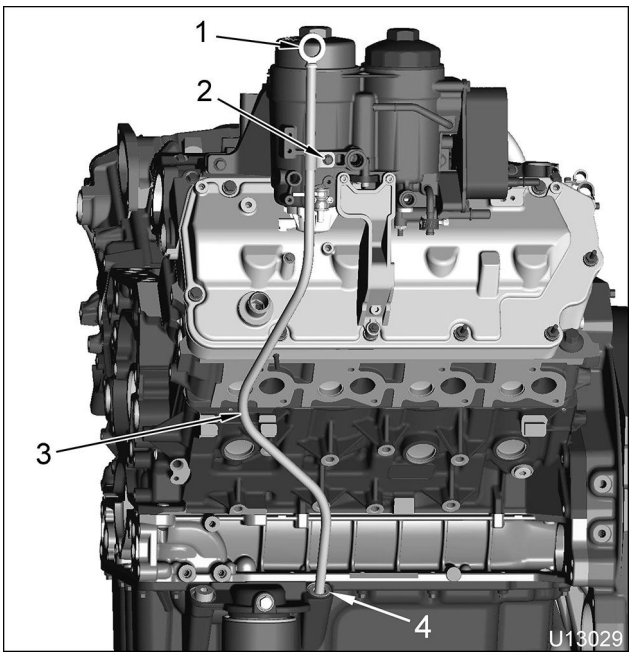


Figure 447 Oil Level Tube Assembly

1. Oil level gauge assembly (with O-ring)
2. M6 x 16 bolt
3. Oil level tube assembly
4. Oil level gauge tube gasket

1. Apply a light coating of P-80® Rubber Lubricant or equivalent (page 308) to bead end of the oil level tube assembly and insert tube into oil level gauge tube gasket until tube bead touches gasket.
2. Install M6 x 16 bolt to secure oil level tube to the fuel filter module. Tighten bolt to standard torque (page 473).
3. Install oil level gauge assembly into oil level tube assembly.

Oil Pump Housing Assembly

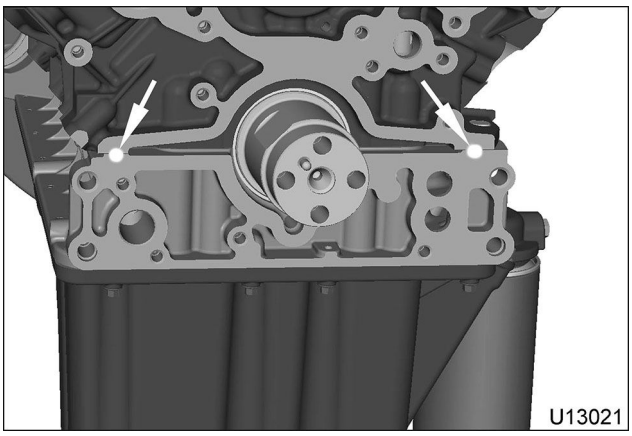


Figure 448 Application of Liquid Gasket (RTV) to Tee joints

CAUTION: To prevent engine damage, do not apply too much Liquid Gasket (RTV) to Tee joints between upper and lower crankcase assemblies.

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 only a dab (.325 cc) of Liquid Gasket (RTV) (page 308) to Tee joints between upper and lower crankcase assemblies.

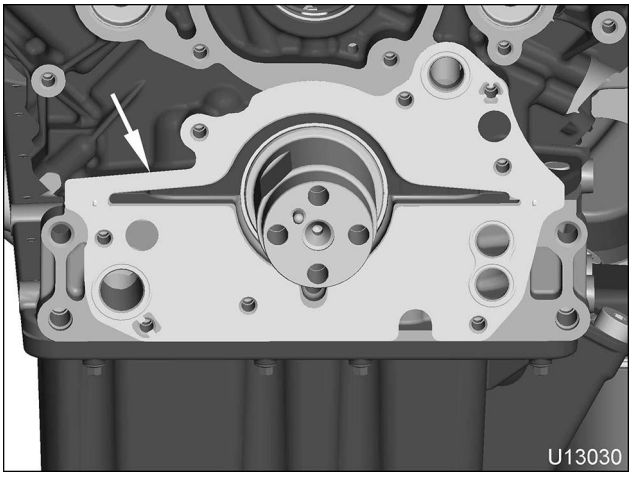


Figure 449 Oil Pump to Engine Gasket

2. Install oil pump engine gasket.

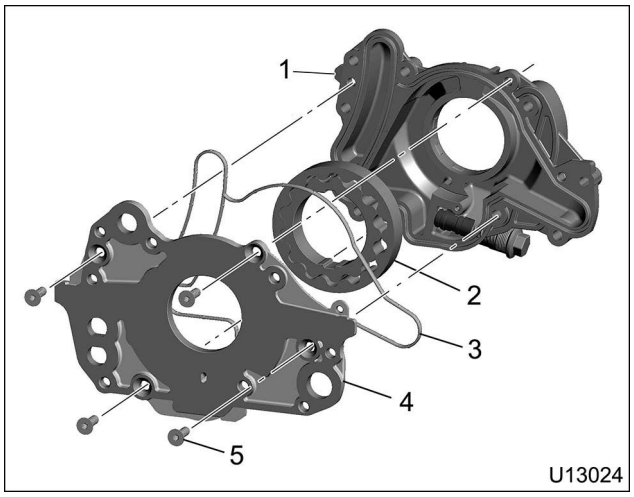


Figure 450 Oil Pump Housing, Rotor Assembly, Housing Gasket, and Plate

1. Oil pump housing
2. Oil pump rotor assembly
3. Oil pump housing gasket
4. Oil pump housing plate
5. M8 x 25 screw (4)

3. Lubricate oil pump housing gasket with clean engine oil and install gasket into oil pump housing.

NOTE: If installing new inner and outer oil pump rotors, correct orientation is not necessary. If installing used inner and outer oil pump rotors, correct orientation is necessary.

4. Install oil pump rotor assembly in the oil pump housing. Ensure correct orientation, if reusing the oil pump rotor assembly.
5. Install oil pump housing plate and four M8 x 25 screws. Tighten screws to special torque (page 307).

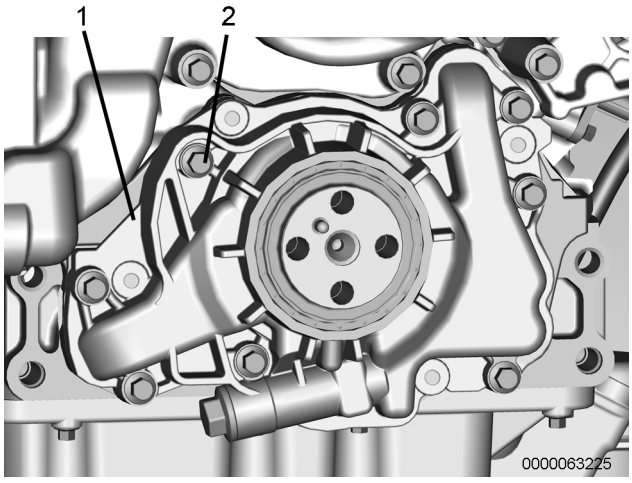


Figure 451 Oil Pump Assembly

1. Oil pump assembly
2. M8 x 45 dog point bolt (8)

6. Install oil pump assembly and loosely install eight M8 x 45 dog point bolts.

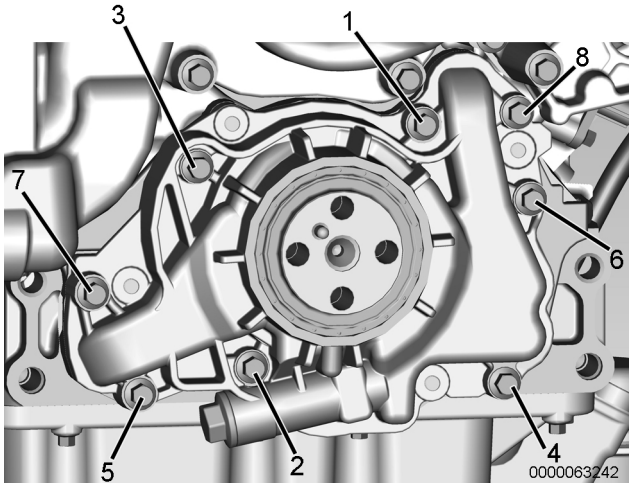


Figure 452 Torque Sequence for Oil Pump Assembly Bolts

7. Tighten eight M8 x 45 dog point bolts in torque sequence to standard torque (page 473).

Front Crankshaft Oil Seal

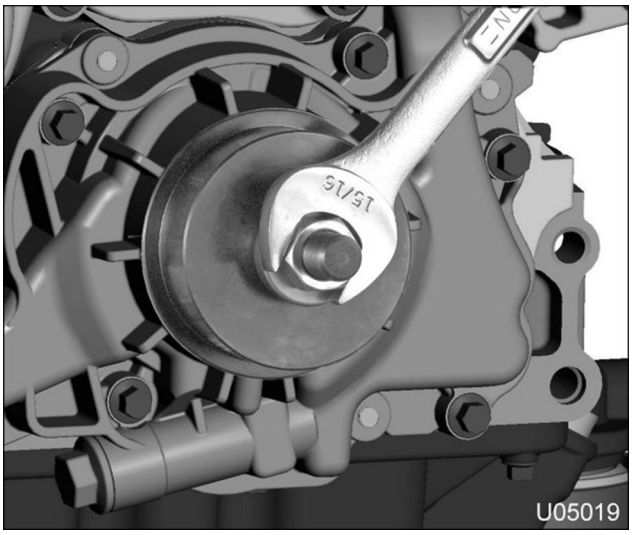


Figure 453 Front Oil Seal Wear Sleeve Installation

1. Put a 360° bead of hydraulic sealant such as Loctite® 569 (page 308) or equivalent on leading edge of crankshaft before wear sleeve installation.

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 308), to drive oil seal and wear sleeve assembly into oil pump housing assembly.

Oil Cooler Assembly

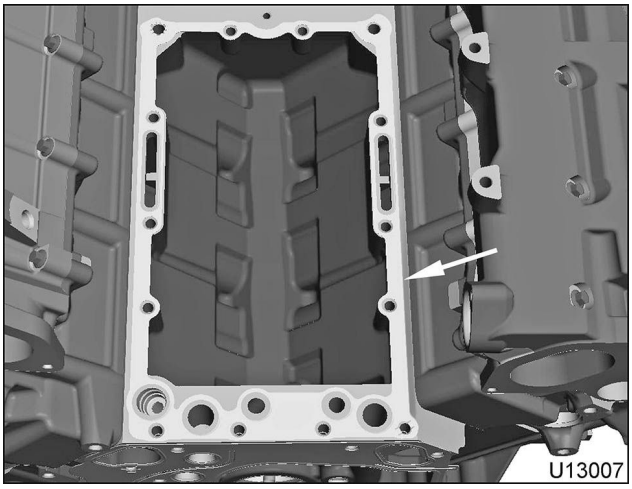


Figure 454 Cover to Crankcase Gasket

1. Install new crankcase cover gasket.

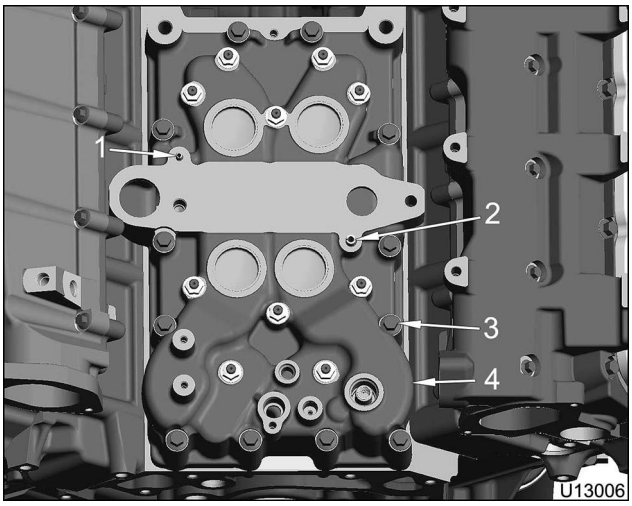


Figure 455 Oil Cooler Assembly

1. M5 x 20 slotted pin
2. M8 x 20 slotted pin
3. M8 x 70 bolt (12)
4. Oil cooler assembly

2. Position oil cooler assembly on crankcase, install 12 M8 x 70 bolts, and tighten bolts to standard torque (page 473).
3. If previously removed, install M5 x 20 slotted pin and M8 x 20 slotted pin.

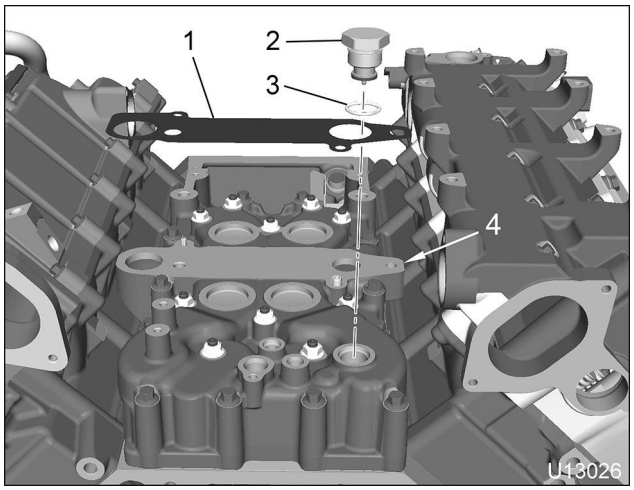


Figure 456 Oil Cooler Cover, Turbocharger Oil Drain Gasket, Bypass Valve Assembly, and Bypass Valve Cap Seal

1. Turbocharger oil drain gasket
2. Oil cooler bypass valve assembly
3. Bypass valve cap seal
4. Oil cooler cover

4. Lubricate a new bypass valve cap seal with a light coat of clean engine oil and install onto bypass valve assembly.
5. Install bypass valve assembly into oil cooler.
6. Tighten bypass valve assembly to special torque (page 307).
7. Install new turbocharger oil drain gasket.

Specifications

Oil Pump Assembly	
Type	Gerotor
Drive	Crankshaft
Location	Oil pump housing assembly
Pressure Regulating Valve: Operates between 5.2 kPa - 6.0 kPa (75 psi - 87 psi)	
End clearance (inner and outer oil pump rotor to oil pump housing assembly)	0.025 to 0.095 mm (0.001 to 0.004 in)
Radial clearance (between outer oil pump rotor and oil pump housing assembly)	0.15 to 0.28 mm (0.006 to 0.011 in)

Oil Cooler Assembly	
Type	Full flow, fin
Location	Engine valley (front)

Oil Filter	
Type	Spin-on, full flow - disposable
Location	Oil pan mounted
Filter bypass location	Oil filter can

Special Torque

Oil cooler bypass valve assembly	71 N·m (52 lb·ft)
Oil cooler cover assembly serrated nuts	See assembly procedure for special torque sequence
Hex plug assembly (oil pan)	25 N·m (18 lb·ft)
Plug assembly, M18 (oil pan)	25 N·m (18 lb·ft)
Oil pan drain plug (M14)	44 N·m (32 lb·ft)
Oil filter adapter (oil pan)	55 N·m (40 lb·ft)
Oil pump housing plate screws, M8 x 25	17 N·m (150 lb·in)
Relief valve cap, oil pump	35 N·m (26 lb·ft)

Special Service Tools

Description	Tool Number
Air pressure regulator	Obtain locally
Feeler gauge	Obtain locally
Front Crankshaft Wear Sleeve Remover / Installer	ZTSE4705
Front Crankshaft Seal Remover / Installer	ZTSE6060
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Loctite® 271	Obtain locally
Loctite® 569 hydraulic sealant or equivalent	Obtain locally
P-80® Rubber Lubricant or equivalent	Obtain locally
Slide hammer	Obtain locally
Oil Cooler Block-off Plate	ZTSE6029
Straightedge	Obtain locally

Table of Contents

Exploded Views.....311

Removal.....315
- **Balance Duct and Balance Tube Flange**.....315
- **Draft Tube Assembly**.....317
- **Lifting Eye and Jet Pump Tube Assembly**.....317
- **Breather Cover Assembly and Filter with variable impactor**.....318
- **Right Valve Cover**.....319
- **Oil Fill Tube Assembly**.....319
- **Left Valve Cover**.....320
- **Left Valve Cover and Intake Manifold Base Assembly**.....322
- **Right Valve Cover and Intake Manifold Base Assembly**.....324
- **Dual Fulcrum Plates Assemblies**.....325
- **Rocker Arm Support, Push Rods, and Valve Bridges**.....326
- **Cylinder Heads**.....326
- **Roller Hydraulic Cam Followers**.....328
- **Valves**.....329
- **Fuel Injector Sleeves**.....329
- **Dual Fulcrum Plate Assemblies**.....331

Cleaning, Inspection, and Testing.....333
- **Cylinder Head and Crankcase Components**.....333
- **Cylinder Head Inspection – Valves Installed**.....333
- **Cylinder Head Inspection – Valves Removed**.....336
- **Valve Seats**.....337
- **Valves**.....337
- **Valve Guides**.....338
- **Valve Springs**.....339
- **Valve Stem Keys**.....340
- **Push Rods**.....340
- **Fuel Injector Sleeve Bore and Gallery**.....340
- **Dual Rocker Fulcrums**.....340

Installation.....341
- **Dual Fulcrum Plate Assemblies**.....341
- **Fuel Injector Sleeves**.....342
- **Valves**.....343
- **Roller Hydraulic Cam Followers**.....344
- **Cylinder Heads**.....345
  - **Installation**.....345
  - **Tightening Sequence for Cylinder Head Bolts**.....348
- **Rocker Arm Supports, Push Rods, and Valve Bridges**.....350
- **Right Valve Cover and Intake Manifold Base Assembly**.....353
- **Left Valve Cover and Intake Manifold Base Assembly**.....355
- **Left Valve Cover**.....357
- **Oil Fill Tube Assembly**.....357

Right Valve Cover.....**358**
Breather Cover Assembly and Variable Impactor.....**358**
Lifting eye and jet pump tube assembly.....**360**
Draft Tube Assembly.....**360**
Balance Duct and Balance Tube Flange.....**361**

Specifications.....**364**

Special Torque.....**365**

Special Service Tools.....**365**

Exploded Views

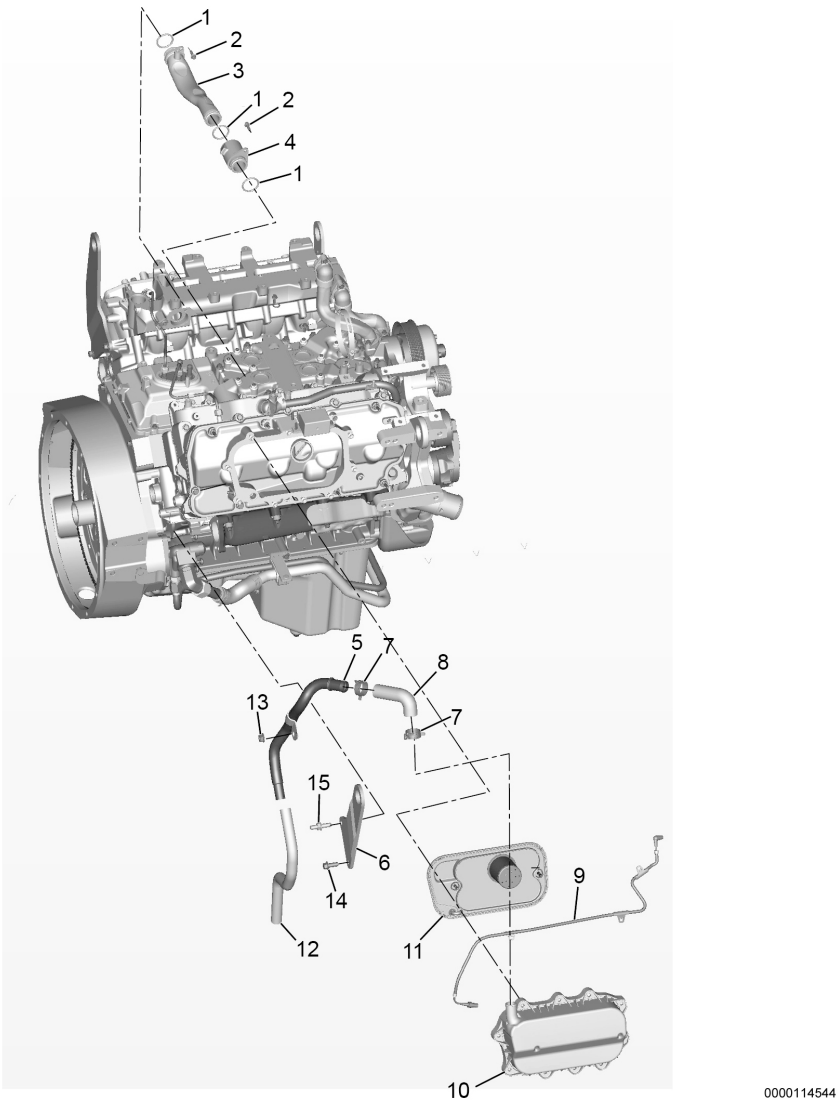


Figure 457 Intake Balance Duct, Crankcase Breather Assembly, and Crankcase Ventilation

1. O-ring (3)
2. M6 x 14 bolt (2)
3. Balance duct
4. Balance tube flange
5. Upper draft tube
6. Lifting eye
7. 1” Worm gear hose clamp (2)
8. 1” 90° elbow
9. Jet pump tube assembly
10. Breather cover
11. Filter with variable impactor
12. Lower draft tube
13. M10 nut
14. M10 x 25 bolt
15. M10 x 25 stud bolt

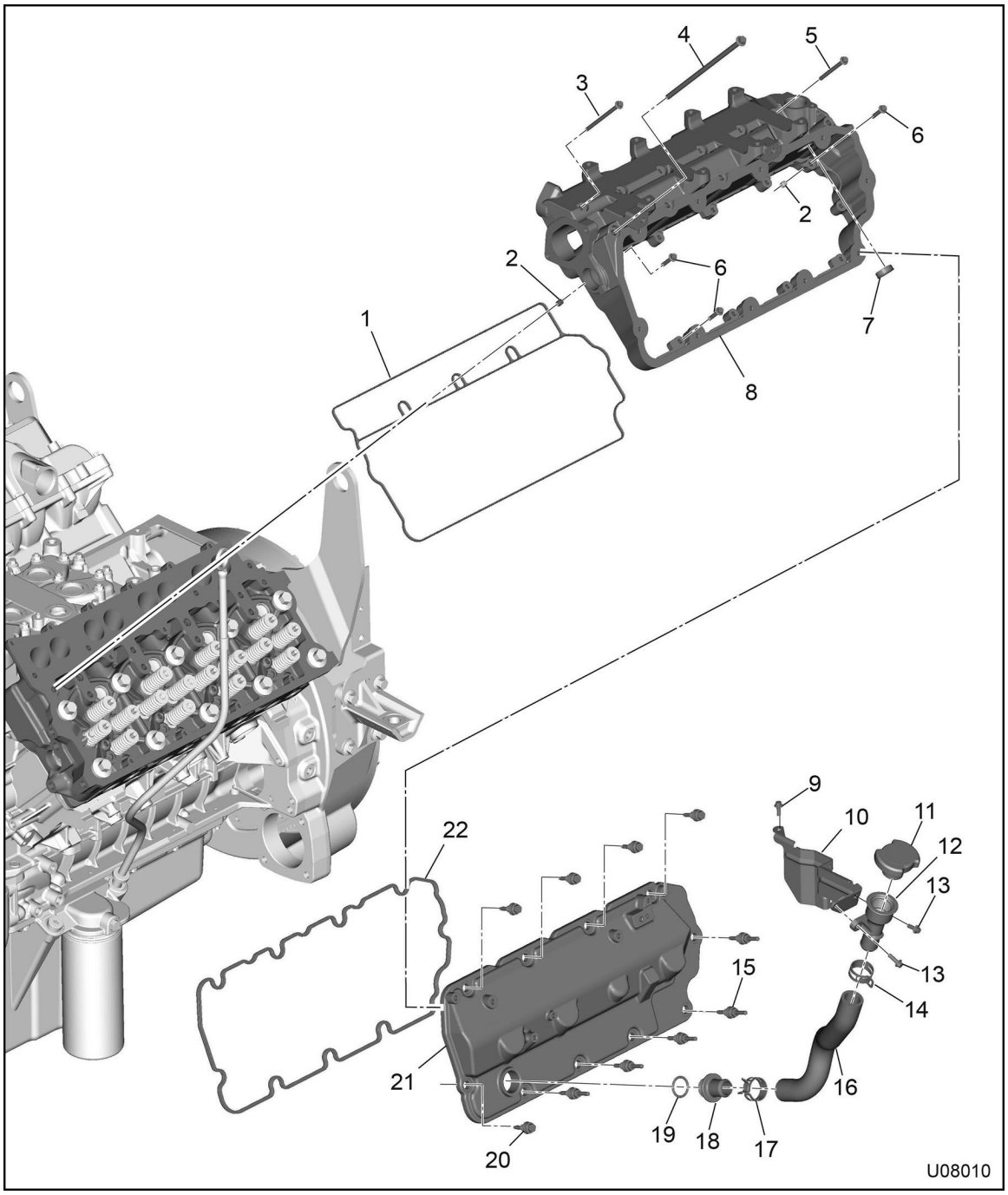


Figure 458 Valve Cover And Valve Cover Base Assemblies (Left)

1. Valve cover base gasket
2. Slotted spring dowel pin (2)
3. M6 x 100 bolt (5)
4. M8 x 225 bolt (5)
5. M6 x 80 bolt
6. M6 x 30 bolt (11)
7. Fuel supply line seal
8. Left valve cover and intake manifold base
9. M6 x 16 hex flange bolt (3)
10. Oil fill support
11. Oil fill cap assembly
12. Oil fill tube assembly
13. M6 x 20 bolt (2)
14. Clamp
15. Valve cover stud bolt assembly (5)
16. Oil fill tube
17. Clamp
18. Oil fill tube
19. Intake manifold O-ring
20. Valve cover bolt assembly (5)
21. Left valve cover
22. Valve cover gasket

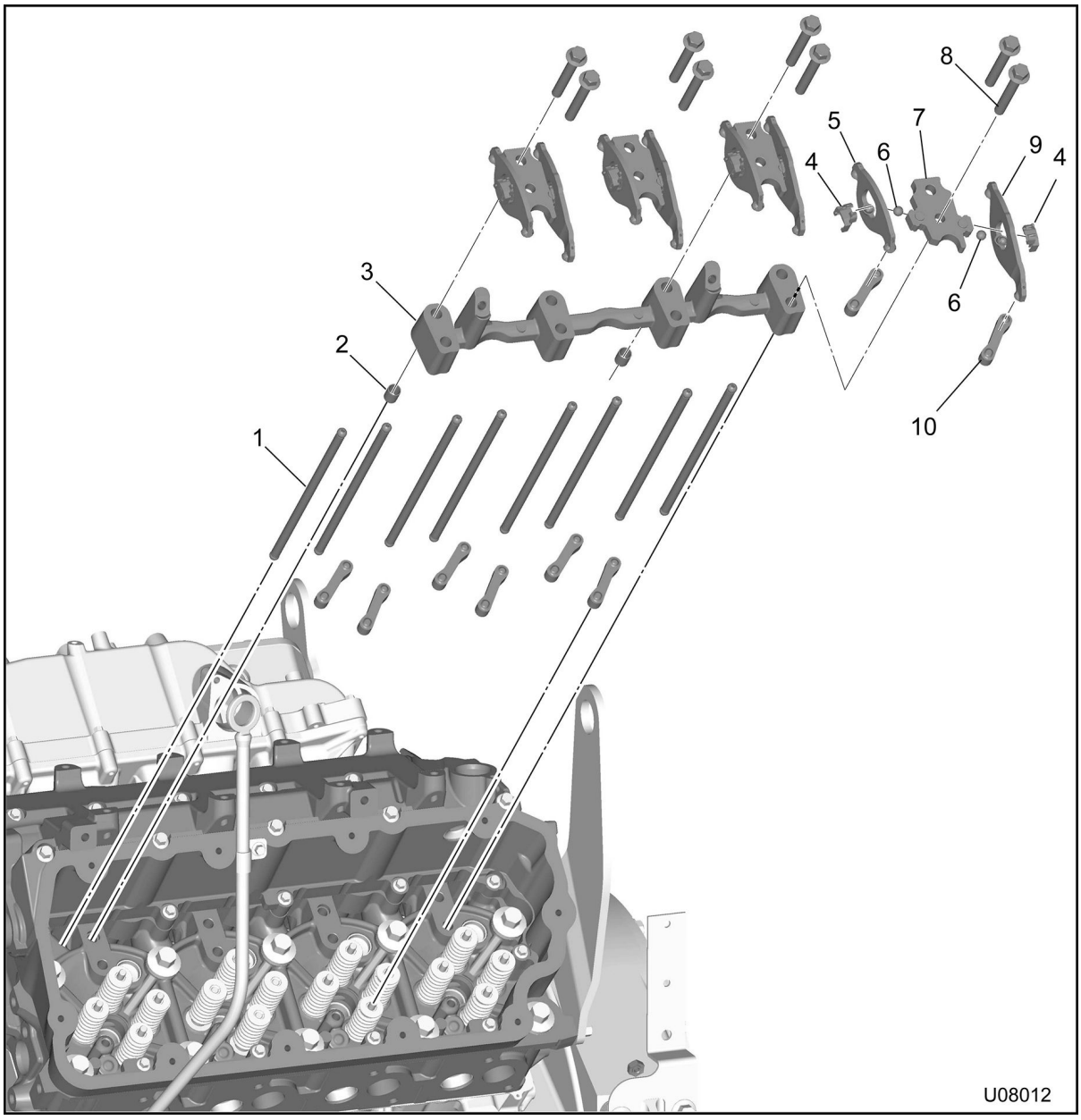


Figure 459 Rocker Arm Support Components (typical)

1. Push rod assembly (8)
2. Dowel sleeve bushing (2)
3. Rocker arm (V8) support
4. Rocker arm clip (8)
5. Intake rocker arm assembly (4)
6. Pivot ball (8)
7. Dual rocker fulcrum plate (4)
8. M10 x 70 hex flange bolt (8)
9. Exhaust rocker arm assembly (4)
10. Valve bridge (8)

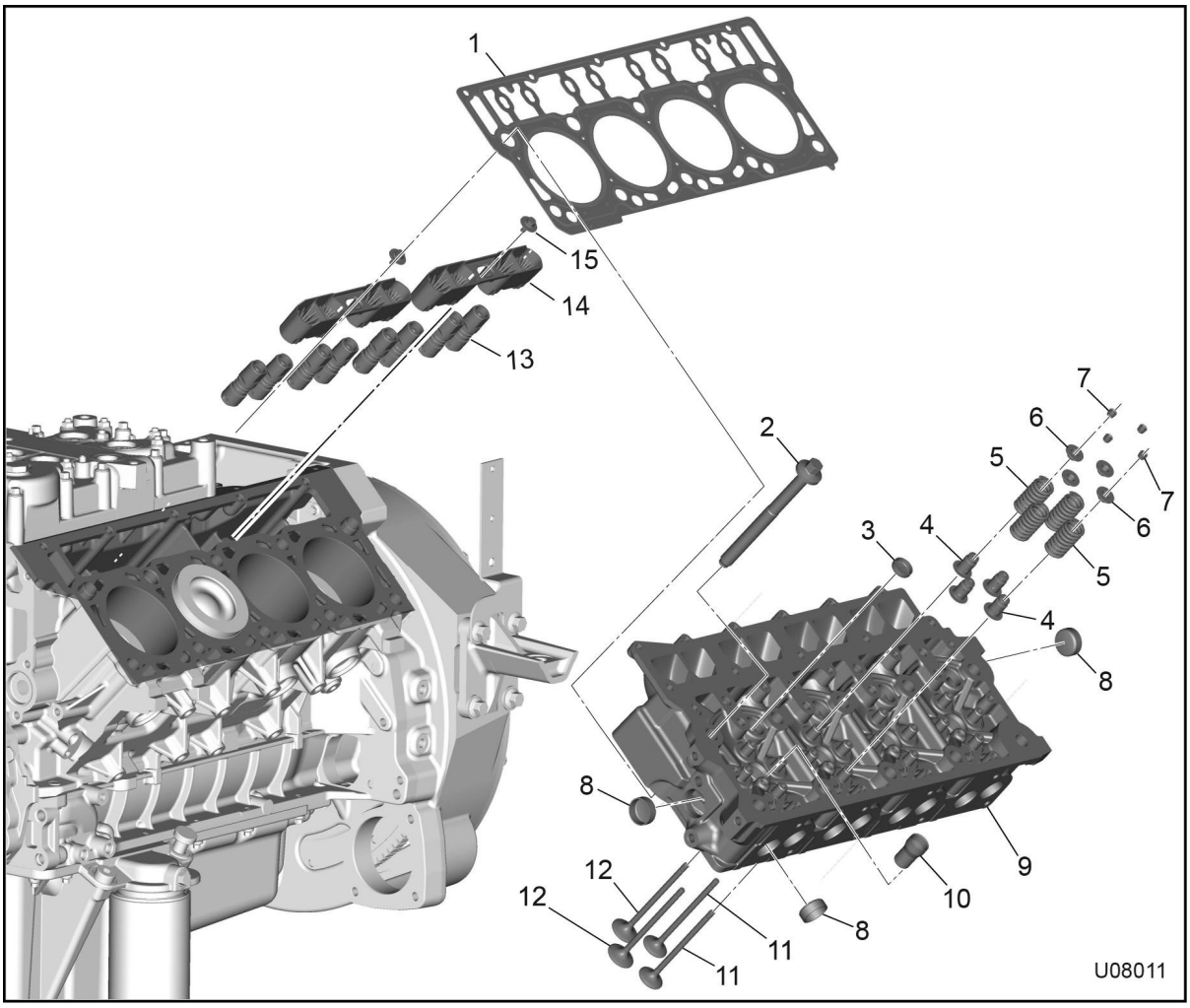


Figure 460 Cylinder Head Components (typical)

1. Cylinder head gasket
2. M16 x 172 cylinder head bolt (10)
3. 25 mm cup plug (4)
4. Valve seal assembly (16)
5. Valve spring (16)
6. Valve spring retainer (16)
7. Valve stem key (32)
8. 32 mm cup plug (6)
9. Cylinder head
10. Injector sleeve (4)
11. Exhaust valve (8)
12. Intake valve (8)
13. Roller hydraulic cam followers (8)
14. Roller follower guide (2)
15. Lifter guide bolt with washer (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: Failure to observe the following warning may cause property damage, personal injury, or death. To prevent personal injury or death, read all safety instructions in the "Safety Information" section of this manual.

WARNING: Failure to observe the following warning may cause property damage, personal injury, or death. 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: Failure to observe the following warning may cause property damage, personal injury, or death. To prevent personal injury or death, disconnect the main battery negative terminal before disconnecting or connecting electrical components.

WARNING: Failure to observe the following warning may cause property damage, personal injury, or death. To prevent personal injury or death, wear safety glasses with side shields. Limit compressed air pressure to 207 kPa (30 psi).

WARNING: Failure to observe the following warning may cause property damage, personal injury, or death. 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: Failure to observe the following warning may cause property damage, personal injury, or death. 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**
- **Dual Stage Turbocharger and Exhaust Manifolds**
- **Air Compressor and Power Steering Pump**
- **Fuel System**
- **Front Cover, Cooling System, and Related components**
- **Oil Cooler, Oil Pump, Oil Filter, and Oil Pan**

Balance Duct and Balance Tube Flange

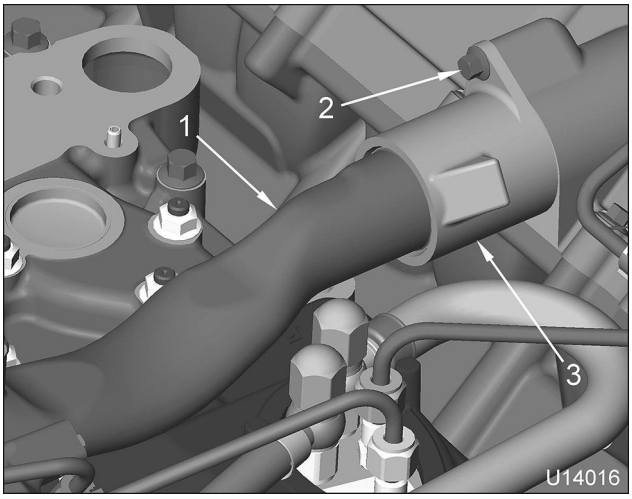


Figure 461 Balance Duct and Balance Tube Flange

1. Balance duct
2. M6 x 14 bolt
3. Balance tube flange

1. Remove M6 x 14 bolt that secures balance tube flange to the right valve cover and intake manifold base assembly.

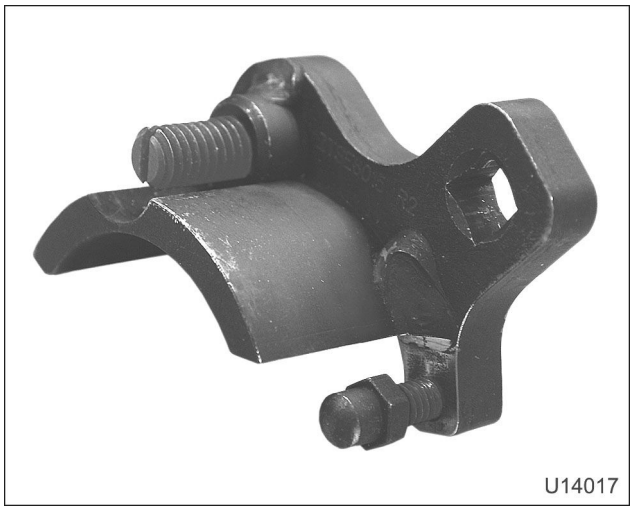


Figure 462 Cross-over Tube Removal Tool

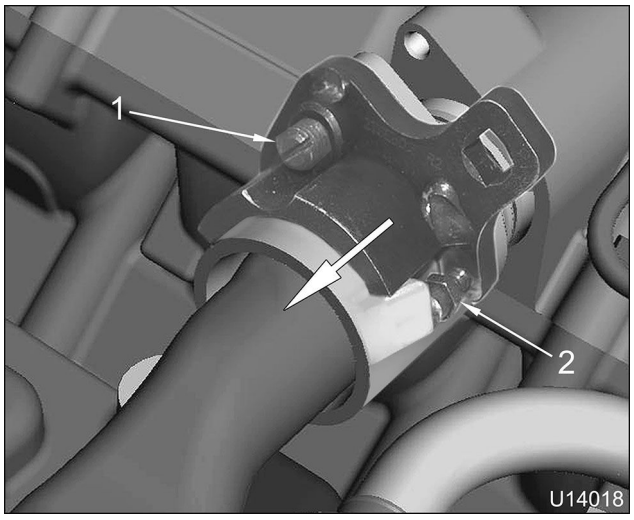


Figure 463 Installation of Cross-over Tube Removal Tool

1. Set screw
2. Adjustment screw

2. Position Cross-over Tube Removal Tool (page 261) onto balance tube flange, turn set screw into hole in balance tube flange, and turn adjustment screw counterclockwise against tab on tube flange.
3. Turn the Cross-over Tube Removal Tool and apply force to move the balance tube flange until the end of the balance tube flange clears the hole in the valve cover and intake manifold base assembly.
4. Remove Cross-over Tube Removal Tool.

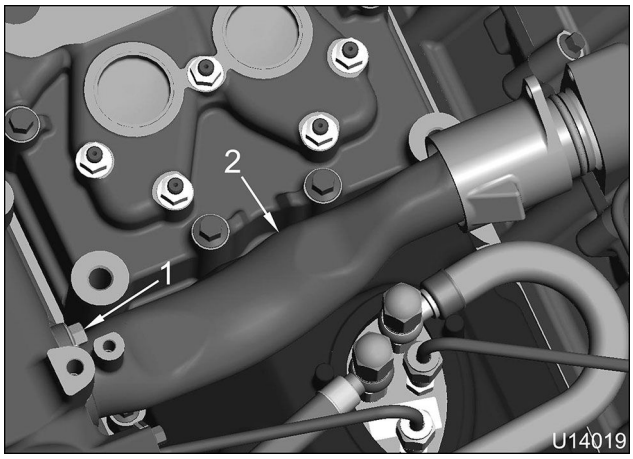


Figure 464 Removal of Balance Duct and Balance Tube Flange

1. M6 x 14 bolt
2. Balance duct

5. Remove M6 x 14 bolt that secures balance duct.
6. Remove balance duct and balance tube flange.

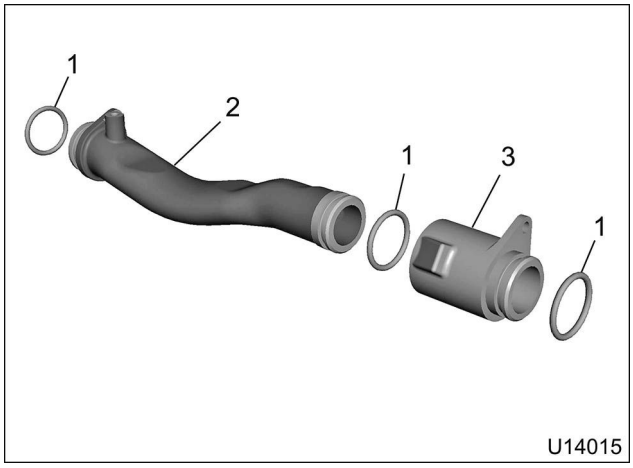


Figure 465 Balance Duct, Balance Tube Flange, and O-Rings

1. O-ring (3)
2. Balance duct
3. Balance tube flange

7. Remove and discard three O-rings gaskets.

Draft Tube Assembly

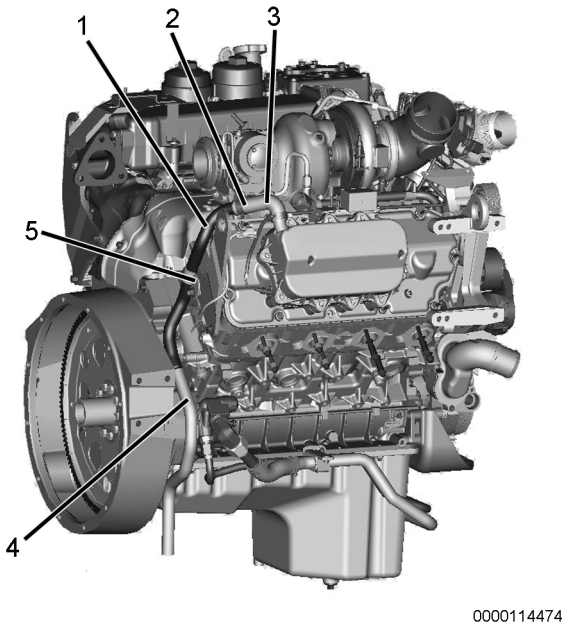


Figure 466 Draft Tube Assembly

1. Upper draft tube
2. 1” worm gear hose clamp (2)
3. 1” 90° elbow
4. Lower draft tube
5. M12 nut

NOTE: New lower draft tube assembly (7091588C1) will be non-serviceable.

1. Loosen worm gear hose clamp connecting 90° elbow to upper draft tube assembly.
2. Remove M12 nut securing upper draft tube assembly to rear crankcase cover.
3. Remove draft tube assembly.
4. Loosen worm gear hose clamp on 90° elbow to breather cover and remove elbow.
5. If necessary, remove worm gear hose clamps from elbow.

Lifting Eye and Jet Pump Tube Assembly

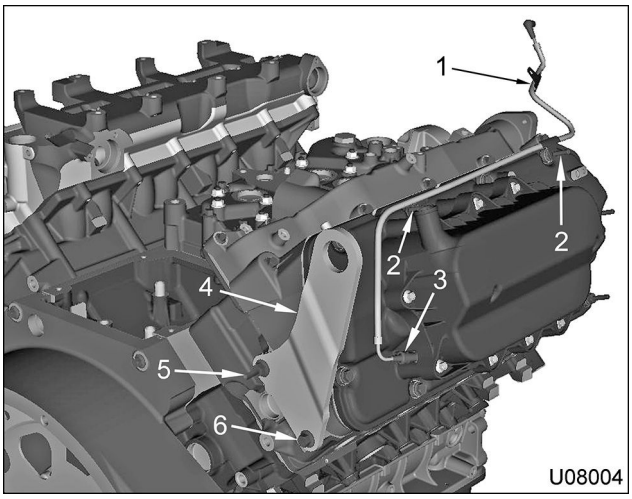


Figure 467 Lifting Eye and Jet Pump Tube Assembly

1. Jet pump tube assembly
2. Valve cover stud bolt assembly (2)
3. Nut
4. Lifting eye
5. M10 x 25 stud bolt
6. M10 x 25 bolt

1. Remove M10 x 25 stud bolt, M10 x 25 bolt, and lifting eye from cylinder head.
2. Disconnect nut on jet pump tube assembly from fitting in right valve cover.
3. Remove jet pump tube assembly from stud bolts in right valve cover, and discard jet pump tube assembly.

Breather Cover Assembly and Filter with variable impactor

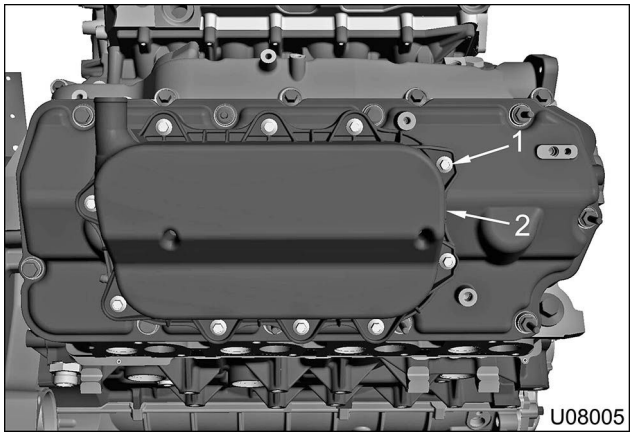


Figure 468 Breather Cover Assembly

1. M6 captive bolt (10)
2. Breather cover assembly

1. Loosen and disengage 10 captive bolts and remove breather cover assembly.

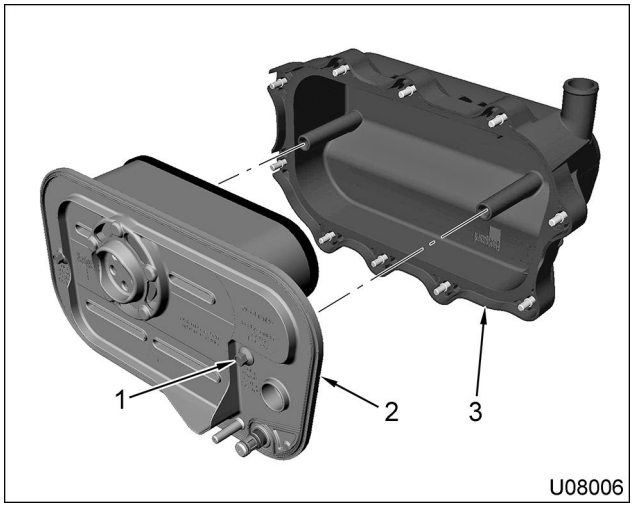


Figure 469 Filter with Variable Impactor (serviceable)

1. M6 captive bolt (2)
2. Filter
3. Breather cover assembly

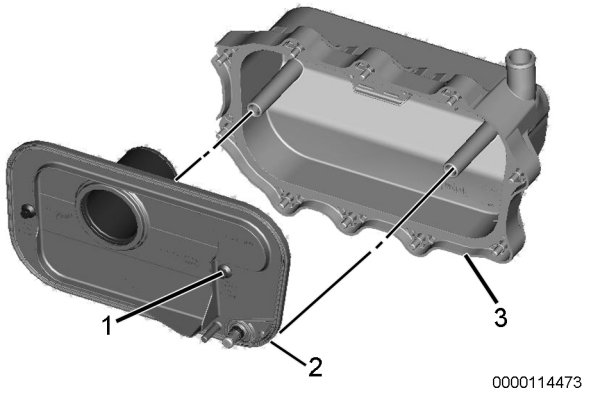


Figure 470 Filter with Variable Impactor (Non-serviceable)

1. M6 captive bolt (2)
2. Filter
3. Breather cover assembly

NOTE: If vehicle is equipped with a Coalescer type serviceable breather, it should be replaced with a non-serviceable variable impactor type breather assembly. When replacing breather assembly, Breather Programmable Parameter will need to be disabled.

2. Disengage two M6 captive bolts, and remove filter with variable impactor from breather cover assembly.

Right Valve Cover

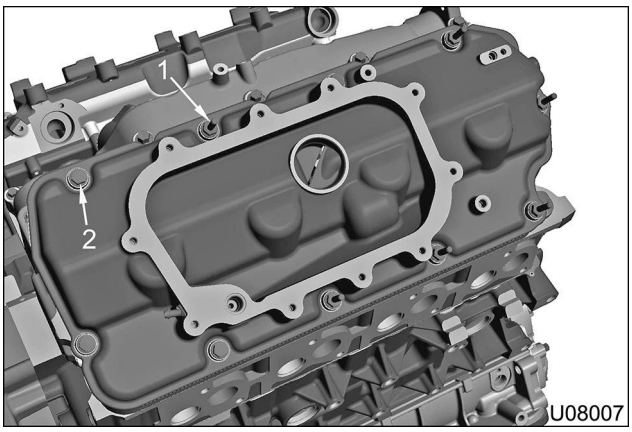


Figure 471 Right Valve Cover

1. Valve cover stud bolt assembly (6)
2. Valve cover bolt assembly (4)

CAUTION: To prevent engine damage, do not use power tools to remove or install valve cover bolts.

1. Disengage four valve cover bolt assemblies and six valve cover stud bolt assemblies.
2. Remove right valve cover.

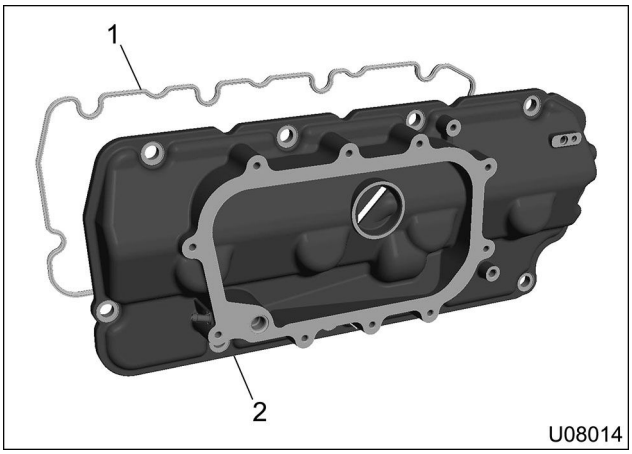


Figure 472 Valve Cover Gasket

1. Valve cover gasket
2. Right valve cover

3. Remove and discard right valve cover gasket.

Oil Fill Tube Assembly

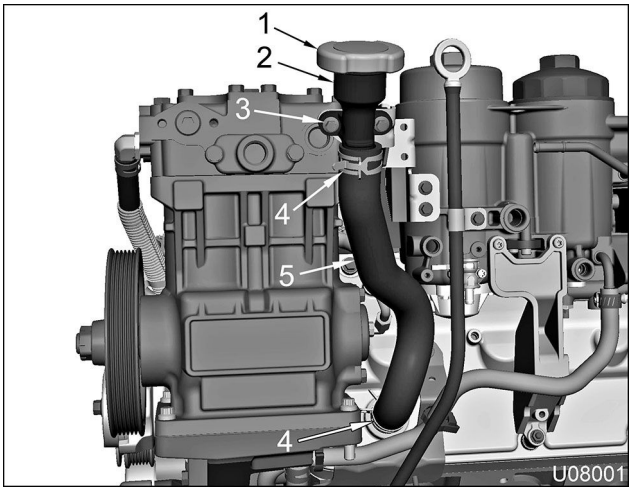


Figure 473 Oil Fill Tube Assembly

1. Oil fill cap assembly
2. Oil fill tube
3. M6 x 20 bolt (2)
4. Clamp (2)
5. Oil fill (hose)

1. Remove two M6 x 20 bolts securing oil fill tube to oil fill support bracket.
2. Loosen lower clamp and remove oil fill tube assembly.

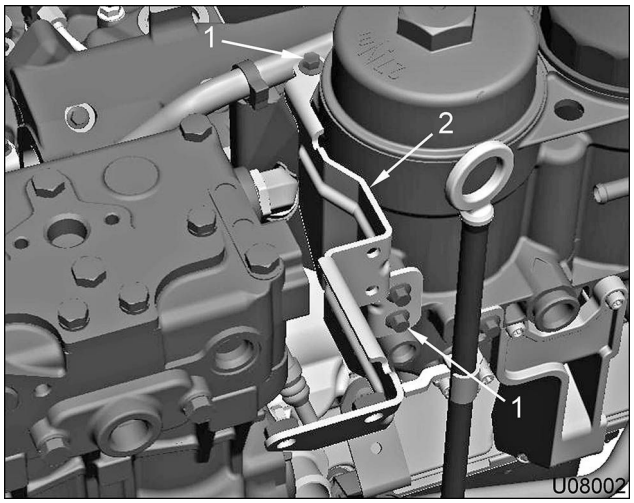


Figure 474 Oil Fill Support

1. M6 x 16 bolt (3)
2. Oil fill support

3. Remove three M6 x 16 bolts that secure the oil support bracket.
4. Remove oil support bracket.

Left Valve Cover

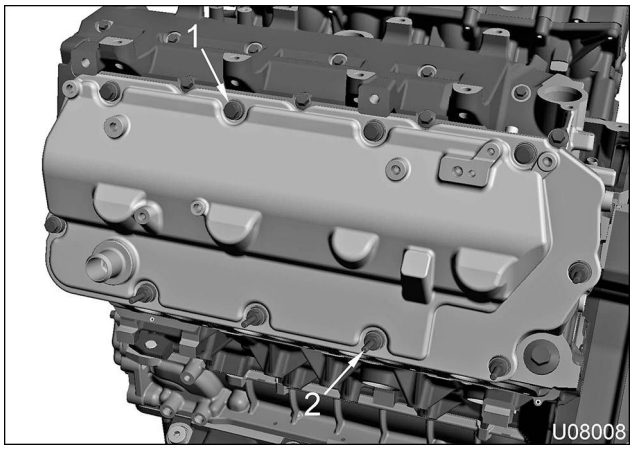


Figure 475 Left Valve Cover

1. Valve cover bolt assembly (5)
2. Valve cover stud bolt assembly (5)

1. Disengage five valve cover bolt assemblies and five valve cover stud bolt assemblies.
2. Remove left valve cover.

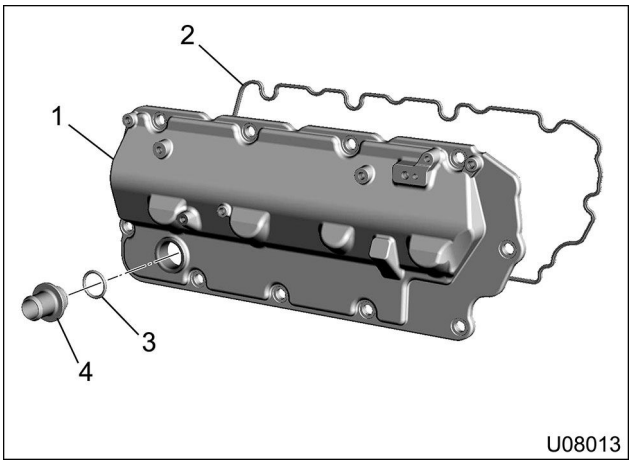


Figure 476 Oil Fill Tube and Valve Cover Gasket

1. Left valve cover
2. Valve cover gasket
3. O-ring
4. Oil fill tube

3. Remove and discard left valve cover gasket.
4. Remove oil fill tube from left valve cover. Discard O-ring.

Left Valve Cover and Intake Manifold Base Assembly

NOTE: Before removing the left valve cover and intake manifold base assembly, and the right valve cover and intake manifold base assembly, see the following procedures:

- Fuel Rail Pressure (FRP) Sensor (page 87)
- Under Valve Cover (UVC) Harnesses (page 88)
- Fuel rail assemblies and fuel Injectors (page 224)

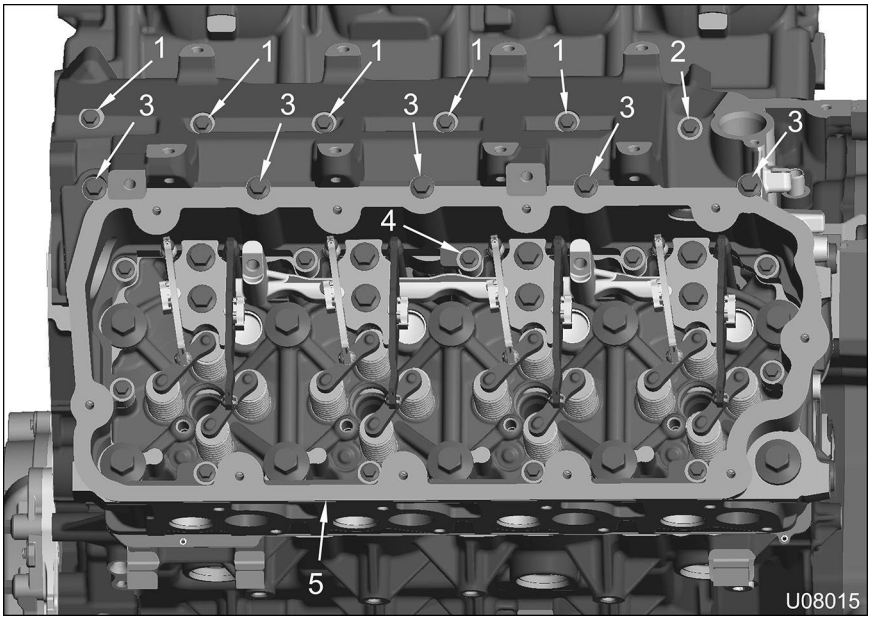


Figure 477 Left Valve Cover and Intake Manifold Base Assembly

1. M6 x 100 bolt (5)
2. M6 x 80 bolt
3. M8 x 225 bolt (5)
4. M6 x 30 bolt (11)
5. Left valve cover and intake manifold base

1. Remove five M6 x 100 bolts.
2. Remove M6 x 80 bolt.
3. Remove five M8 x 225 bolts.
4. Remove 11 M6 x 30 bolts.
5. Remove left valve cover and intake manifold base.

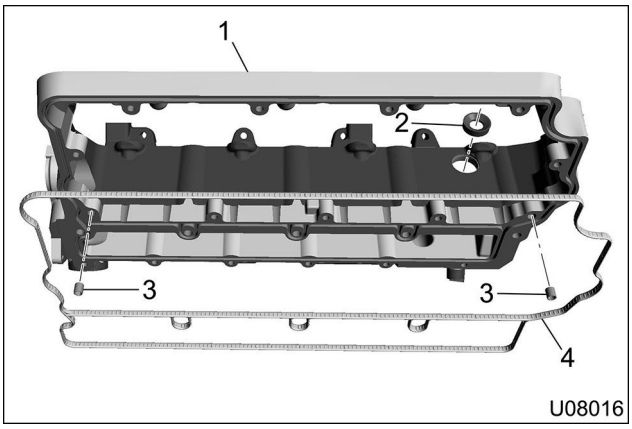


Figure 478 Left Valve Cover, Intake Manifold Base, and Gasket

1. Left valve cover and intake manifold base
2. Fuel supply line seal
3. Slotted spring pin (2)
4. Valve cover and intake manifold base gasket

6. Remove and discard fuel supply line seal.
7. If necessary, remove two slotted spring pins.
8. Remove and discard valve cover and intake manifold base gasket.

Right Valve Cover and Intake Manifold Base Assembly

NOTE: Before removing the left valve cover and intake manifold base assembly, and the right valve cover and intake manifold base assembly, see the following procedures:

- Fuel Rail Pressure (FRP) Sensor (page 87)
- Under Valve Cover (UVC) Harnesses (page 88)
- Fuel rail assemblies and fuel Injectors (page 224)

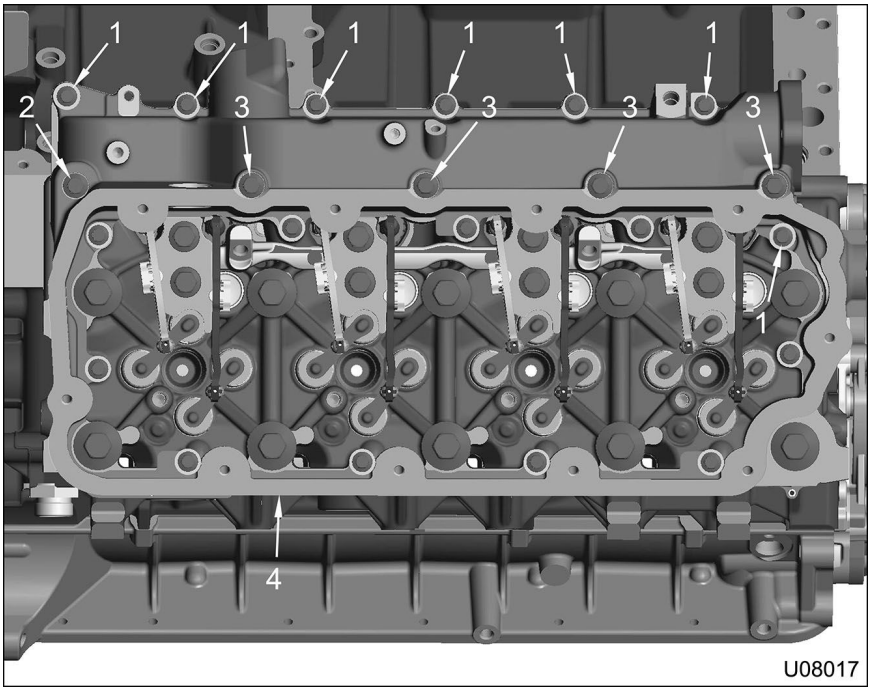


Figure 479 Right Valve Cover and Intake Manifold Base Assembly

1. M6 x 30 bolt (17)
2. M8 x 170 bolt
3. M8 x 225 bolt (4)
4. Right valve cover and intake manifold base

1. Remove 17 M6 x 30 bolts.
2. Remove four M8 x 225 bolts.
3. Remove M8 x 170 bolt.
4. Remove right valve cover and intake manifold base.

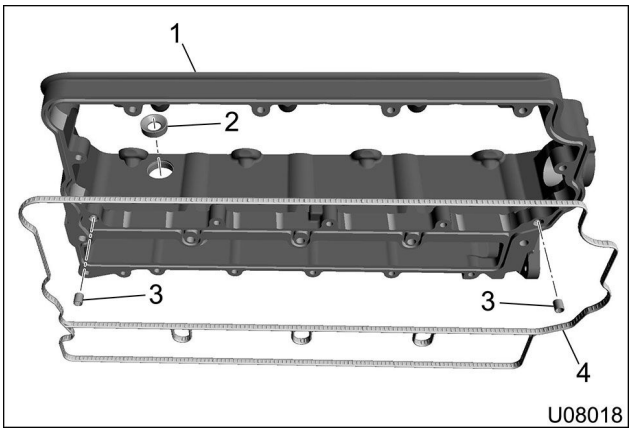


Figure 480 Right Valve Cover and Intake Manifold Base and Gasket

1. Right valve cover and intake manifold base
2. Fuel supply line seal
3. Slotted spring pin (2)
4. Valve cover and intake manifold base gasket

5. Remove and discard fuel supply line seal.
6. If necessary, remove two slotted spring pins.
7. Remove and discard valve cover and intake manifold base gasket.

Dual Fulcrum Plates Assemblies

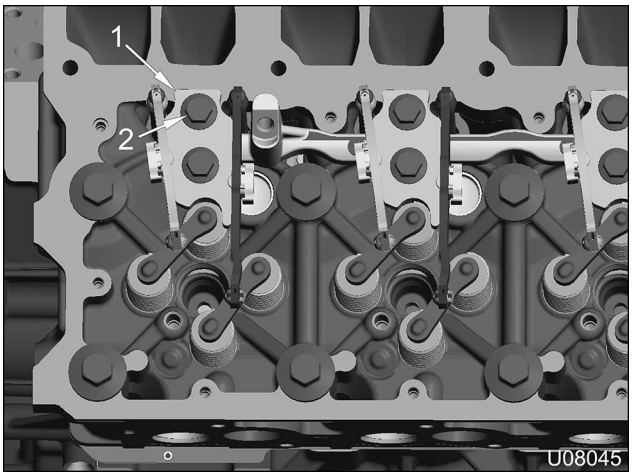


Figure 481 Dual Fulcrum Plates Assemblies (typical)

1. Dual fulcrum plate assembly (4)
2. M10 x 70 bolt (8)

CAUTION: To prevent engine damage, use a permanent marker 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.

Rocker Arm Support, Push Rods, and Valve Bridges

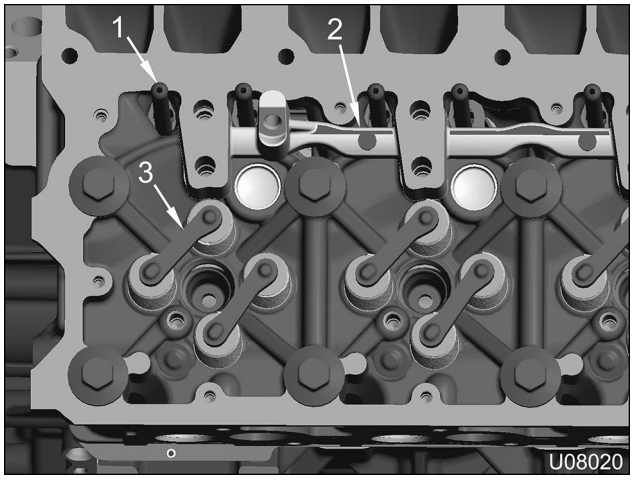


Figure 482 Rocker Arm Support, Push Rods, and Valve Bridges

1. Push rod
2. Rocker arm support
3. Valve bridge

1. Remove rocker arm support.

CAUTION: To prevent engine damage, use a permanent marker 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.

2. Remove and identify each push rod so they can be installed in their original locations.

   Example: 2 - I

   - Cylinder number 2
   - I = Intake, E = Exhaust

NOTE: Identify each valve bridge and corresponding valve set so they can be installed in their original locations.

3. Remove eight valve bridges.

Cylinder Heads

CAUTION: To prevent engine damage, remove injectors before removing cylinder head.

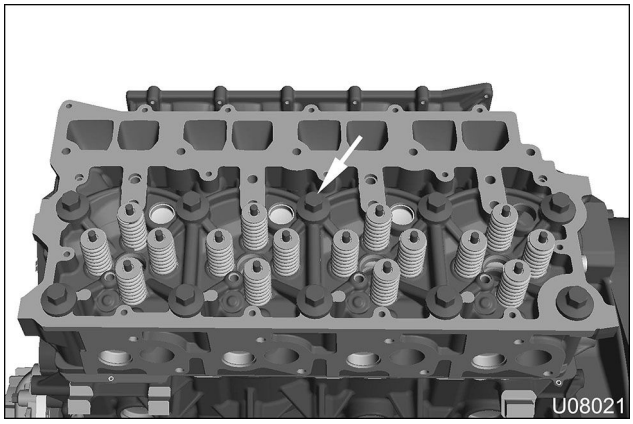


Figure 483 Removal Of M16 X 172 Cylinder Head Bolt (typical)

1. Remove and discard the center M16 x 172 cylinder head bolt, as indicated.

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.

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

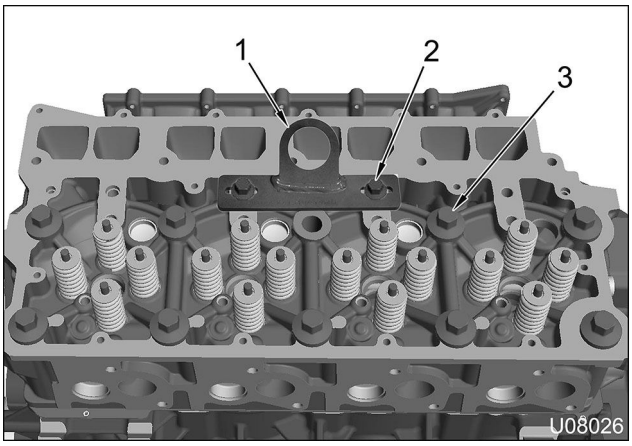


Figure 484 Installation of Cylinder Head Lifting Bracket and Removal Of Cylinder Head Bolts (typical)

1. Cylinder Head Lifting Bracket
2. M10 x 70 bolt (2)
3. M16 x 172 bolts (9)

2. Position Cylinder Head Lifting Bracket (page 365) on cylinder head over the center two threaded holes for the fulcrum plate assemblies and install two M10 x 70 bolts.
3. Tighten two M10 x 70 bolts to standard torque (page 473).
4. Attach a lifting hoist hook or suitable lifting sling to lifting bracket.
5. Using a circular pattern loosen, remove, and discard nine M16 x 172 cylinder head bolts. Begin with the outer bolts and move inward.
6. Lift cylinder head from crankcase.

CAUTION: To prevent engine damage, do not scratch gasket surface of cylinder head.

7. Place cylinder head on a protected surface.
8. Remove and discard cylinder head gasket.

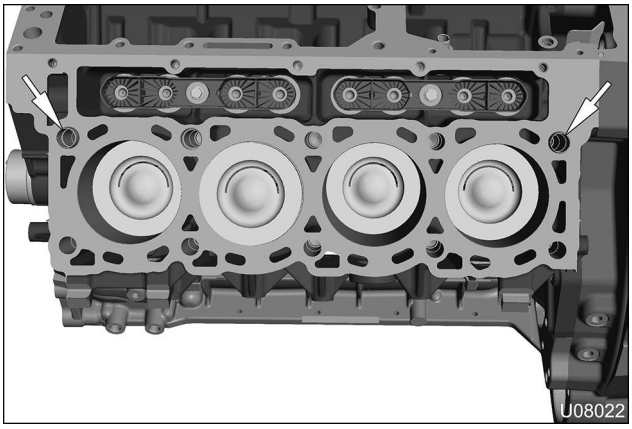


Figure 485 Cylinder Head Spring Dowel Pins (typical)

9. Remove two spring dowel pins.
10. For left 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.

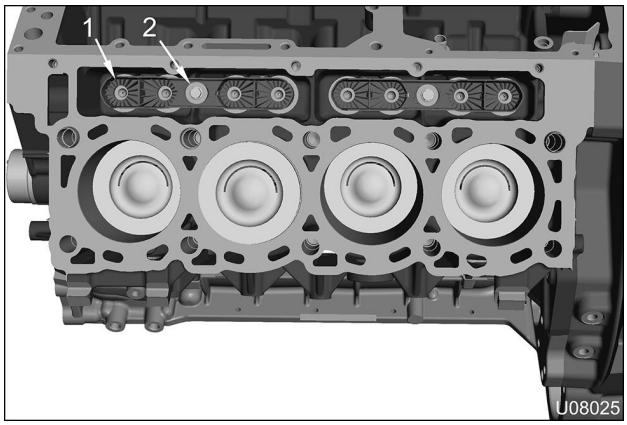


Figure 486 Roller Follower Guides (typical)

1. Roller follower guide (2)
2. Lifter guide bolt with washer (2)

CAUTION: To prevent engine damage, use a permanent marker 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 bolts and two roller follower guides.

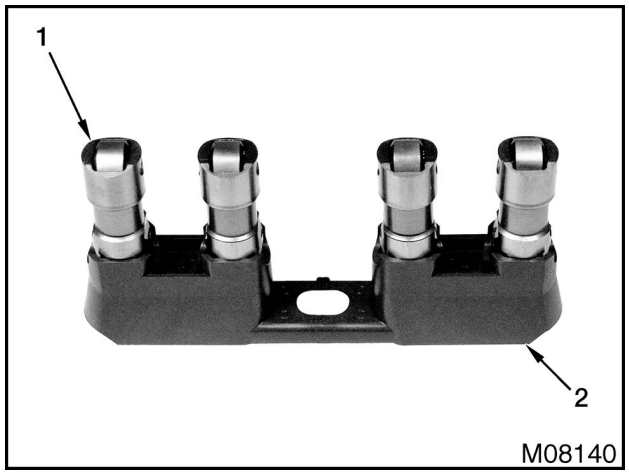


Figure 487 Roller Hydraulic Cam Followers (typical)

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

NOTE: Before removing valves, do inspections for head thickness, valve recession, lower deck cracks, and valve seat leakage. See Cylinder Head Inspection – Valves Installed (page 333).

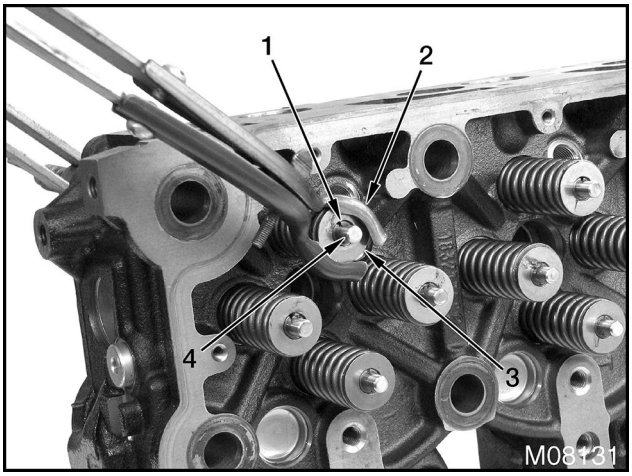


Figure 488 Valve Spring Compression (typical)

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 365), 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.

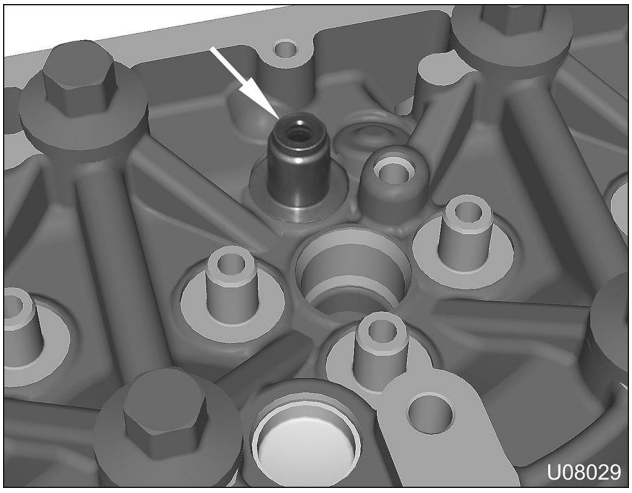


Figure 489 Valve Seal Assembly (typical)

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 365) to remove injector sleeves.

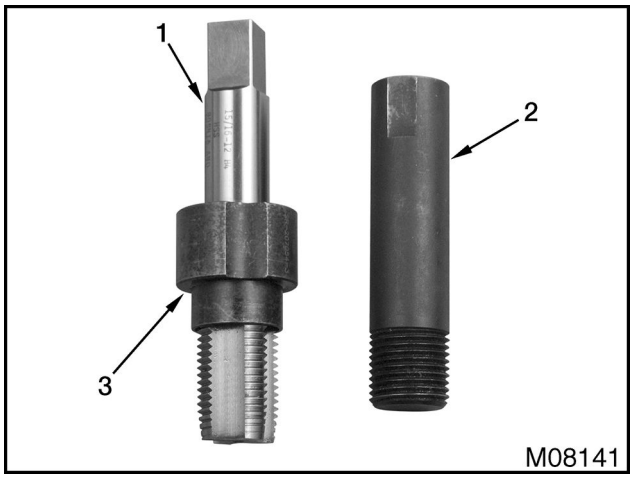


Figure 490 Injector Sleeve Remover

1. Thread tap
2. Injector Sleeve Remover
3. Thread tap guide collar

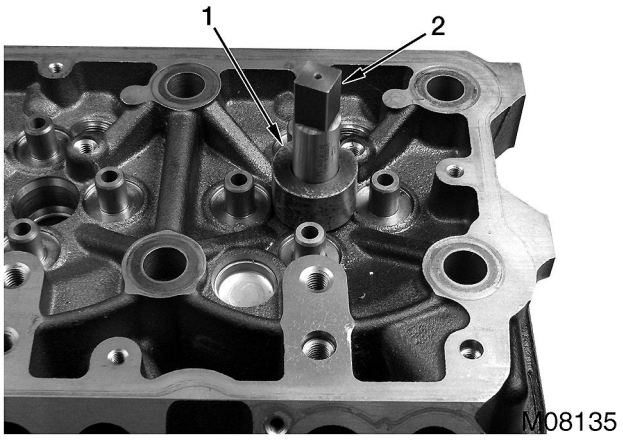


Figure 491 Thread Tap Guide Collar Installed (typical)

1. Thread tap guide collar
2. Thread tap

NOTE: The fuel injector sleeve is made of stainless steel. Lubrication of the thread tap is required.

1. Lubricate thread tap with clean engine oil.
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.

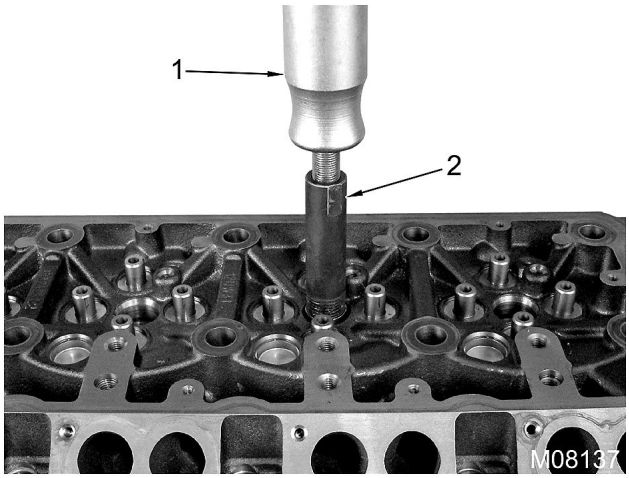


Figure 492 Installation of Injector Sleeve Remover and Slide Hammer (typical)

1. Slide Hammer
2. Injector Sleeve Remover

4. Install and tighten Injector Sleeve Remover (page 365) into fuel injector sleeve.
5. Thread Slide Hammer (page 365) in injector sleeve remover.
6. Remove and discard fuel injector sleeve.

Dual Fulcrum Plate Assemblies

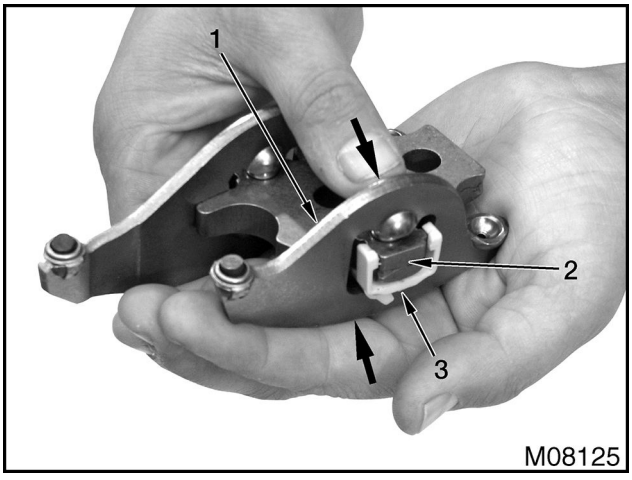


Figure 493 Separation of Rocker Arm Assembly From Dual Rocker Fulcrum Plate (typical)

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.

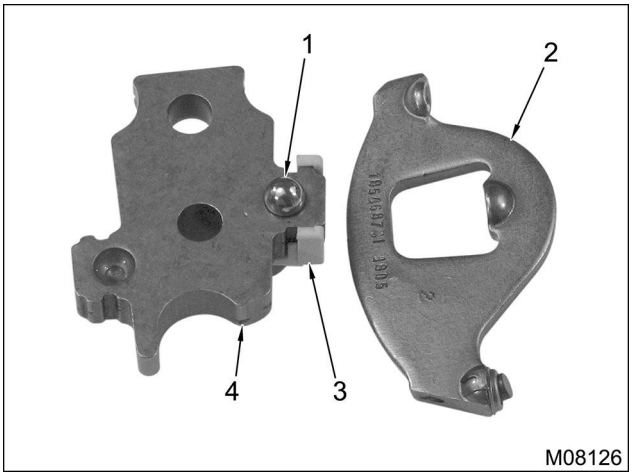


Figure 494 Rocker Arm Assembly Separated (typical)

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.

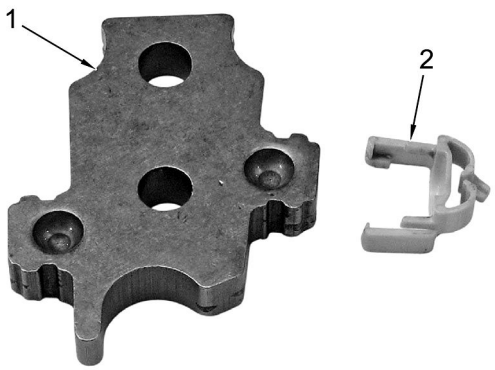


Figure 495 Rocker Arm Clip Removed (typical)

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 in crankcase. 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 suitable 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.

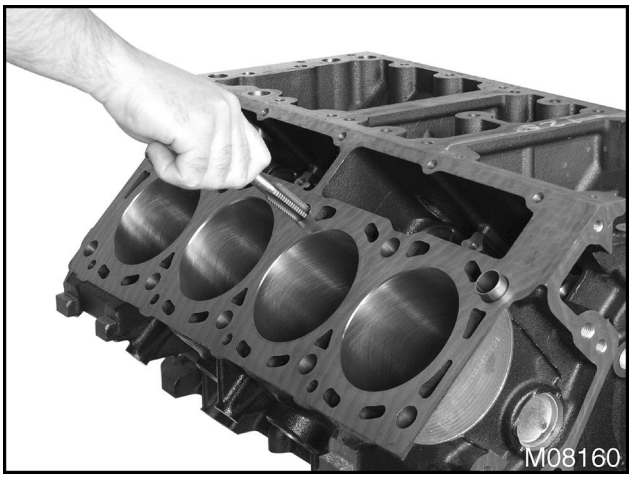


Figure 496 Cylinder Head Bolt Tap

6. Use Cylinder Head Bolt Tap (page 365) 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.

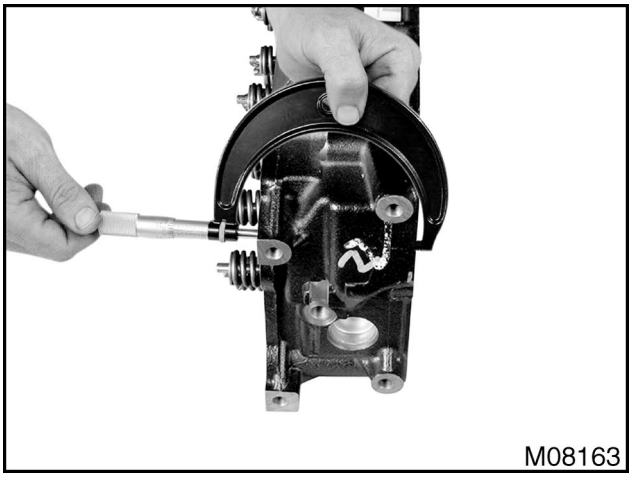


Figure 497 Measurement Of Cylinder Head Thickness

1. Use a 3-4 inch micrometer (page 365) to measure deck thickness of cylinder head at four corner locations. If overall cylinder head thickness (deck-to-deck) specification (page 364) is not met, install new cylinder head.

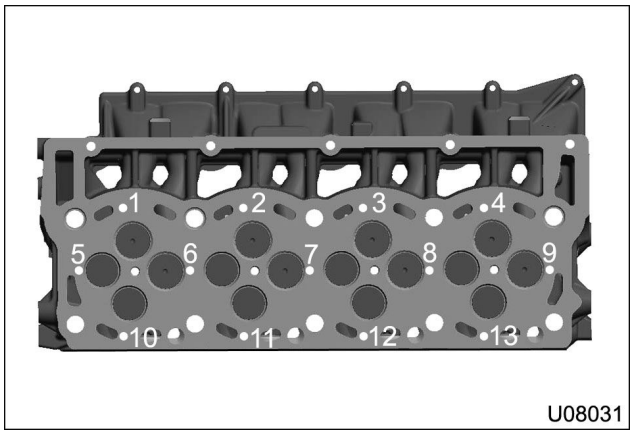


Figure 498 Points To Check For Cylinder Head Flatness

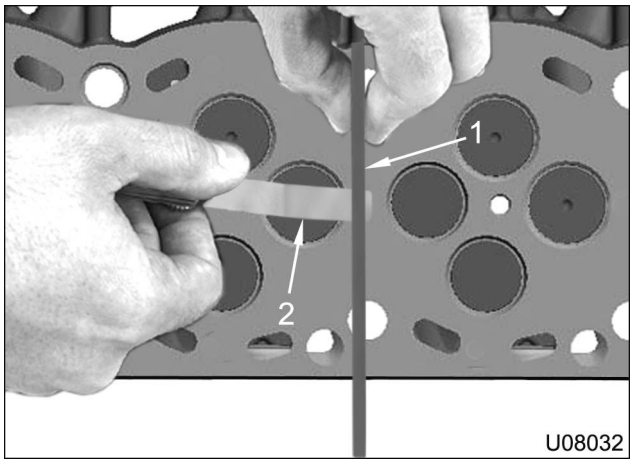


Figure 499 Check Point Inspection

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 in (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 in) blade of the feeler gauge (page 365) on the check point, and place the straight edge (page 365) 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 could be out of flat. Install a new cylinder head.

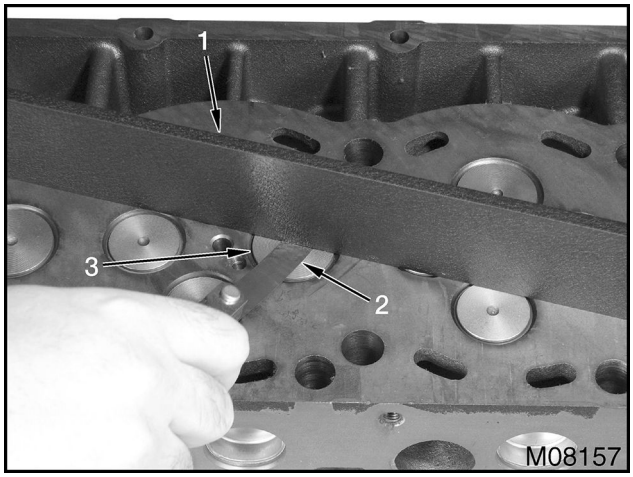


Figure 500 Checking Valve Head Recession

1. Straightedge
2. Feeler gauge
3. Valve head

3. 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 364), replace valve. Repeat step 2 with new valve, and if specifications are still not met, replace cylinder head.
4. Use the Dye Penetrant Kit (page 365), to inspect for cracks in cylinder head.

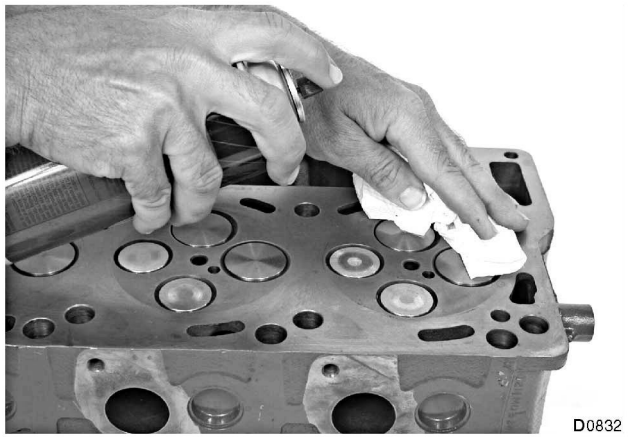


Figure 501 Cleaner Sprayed on Cylinder Head (typical)

5. Spray cleaner on lower deck (gasket surface) of cylinder head and wipe dry.

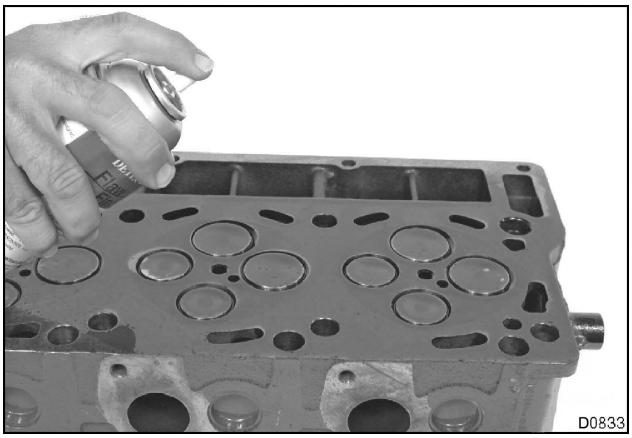


Figure 502 Dye Penetrant Sprayed on Cylinder Head (typical)

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.

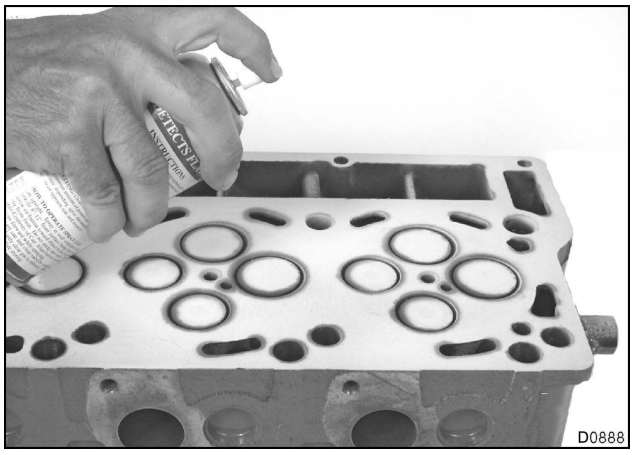


Figure 503 Spraying Developer onto Cylinder Head (typical)

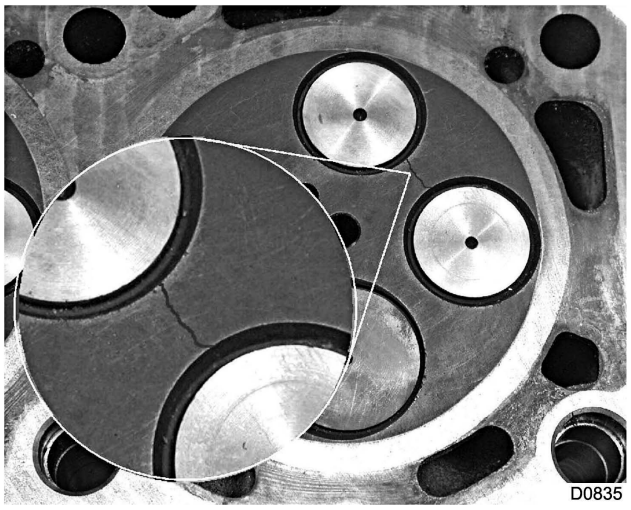


Figure 504 Cylinder Head Crack Between Intake and Exhaust Valves

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: 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.

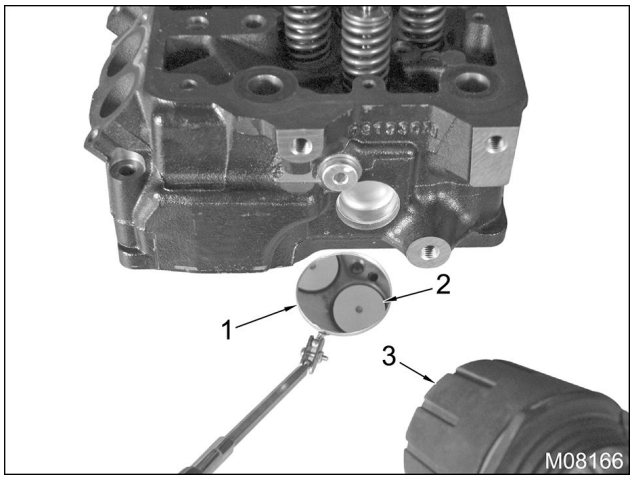


Figure 505 Leak Inspection

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

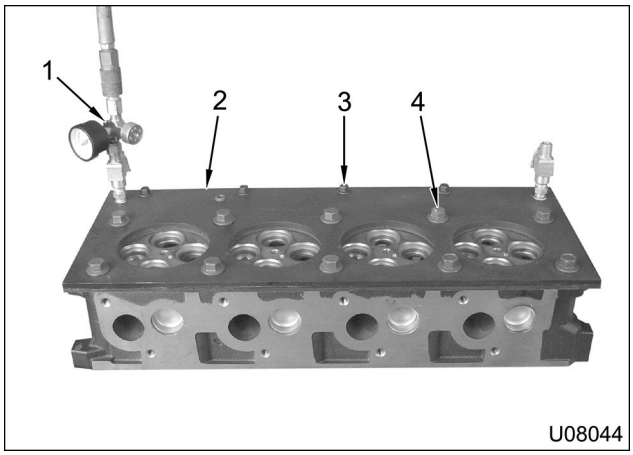


Figure 506 Cylinder Head Pressure Test Plate

1. Pressure Test Regulator and Gauge assembly
2. Cylinder Head Pressure Test Plate
3. M8 bolt (5)
4. M14 mounting bolt (10)

10. Wait five minutes. Use an inspection mirror (page 365) 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 343).

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 365) with rubber gasket attached to gasket side of cylinder head. Secure plate with ten M14 and five M8 mounting bolts.
3. Install the Pressure Test Regulator and Gauge assembly (page 365) to Cylinder Head Pressure Test Plate.
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
5. If leaks are observed, install a new cylinder head.

Valve Seats

1. Clean valve seat area using suitable solvent, before inspection.
2. Inspect exhaust valve seats for burned or cracked conditions. If any of these conditions exist, replace cylinder head.
3. Using a dial caliper (page 365), measure valve seat width. See Specifications (page 364). Replace cylinder head if necessary.

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.

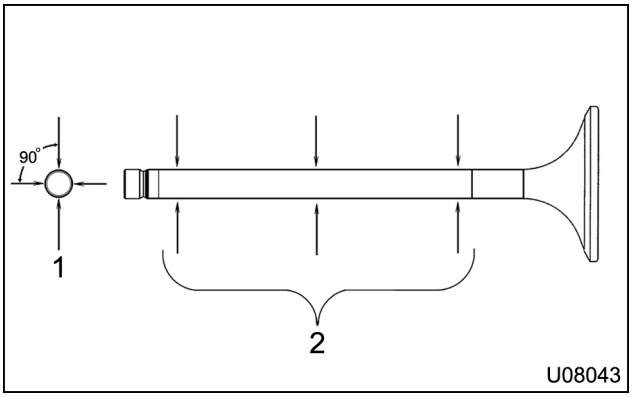


Figure 507 Valve Stem Diameter Measurements

1. Two measurements 90 degrees apart
2. Three valve stem diameter measurements locations

3. Measure valve stem diameter with a 0-1 inch micrometer (page 365) at three locations. At each location, take two measurements 90 degrees apart. Average the two measurements from each location.

   If the average of measurements at any of the three locations is not within valve stem diameter Specification (page 364), replace that valve.

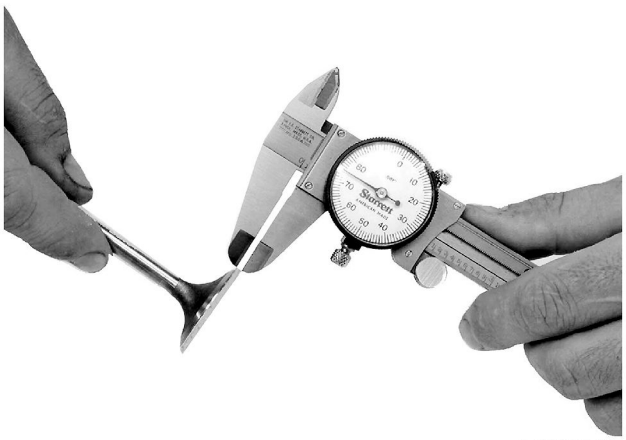


Figure 508 Measurement of Valve Face Margin

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 364).

4. Use a dial caliper (page 365) to measure valve face margin at four locations (90° apart).

Valve Guides

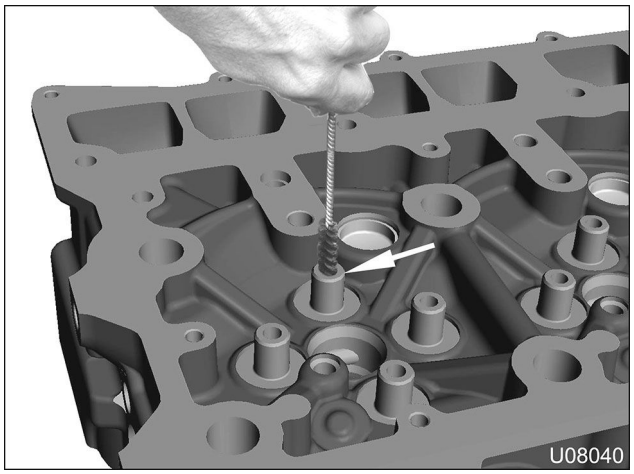


Figure 509 Cleaning Valve Guide Bore

1. Clean all valve guide bores using a nylon brush, soap and water. Blow out any residue with filtered compressed air.
2. 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.

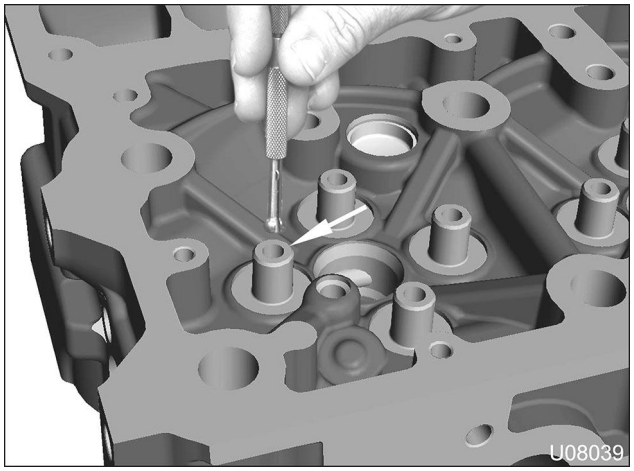


Figure 510 Measuring Valve Guide Bore with Valve Guide Gauge Tool

3. Use Valve Guide Gauge Tool (page 365) to measure each valve guide bore. Measure valve guides within 0.64 mm (0.025 in) of each end and 90° from the crankshaft center line. Record the readings to determine valve stem-to-guide running clearance.

Figure 511 Measurement of Valve Guide Gauge Tool

4. Measure Valve Guide Gauge Tool with a 0-1 inch micrometer (page 365).

NOTE: If valve guide inside diameter exceeds specifications (page 364), install a new cylinder head.

5. Using each valve guide inside diameter and valve stem diameter measurement, determine valve stem-to-guide running clearance for each valve. See Specifications (page 364). Replace valve if necessary.

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 512 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 365).

Figure 513 Measurement of Valve Spring Length Under Load

5. Apply correct test loads to each spring and determine whether specified heights are achieved. See Specifications (page 364). 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.

Push Rods

1. Inspect push rods for wear and deposits that may restrict oil flow into rocker arm assemblies. Replace push rod if necessary.

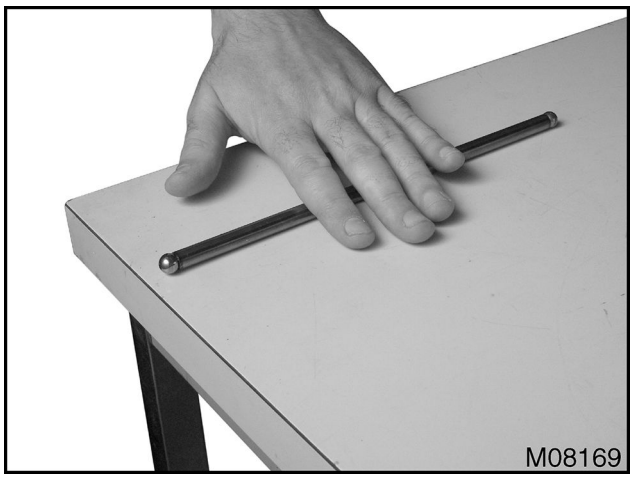


Figure 514 Push Rod Runout

2. Roll push rod on a flat surface to check runout. If a push rod is not straight, see Specifications (page 364) for runout. If specifications are exceeded, replace push rod.

Fuel Injector Sleeve Bore and Gallery

1. Use Injector Sleeve Brushes (page 365) in fuel injector bore to remove deposits and hardened sealant.
2. Remove fuel rail plug assembly and discard seal.

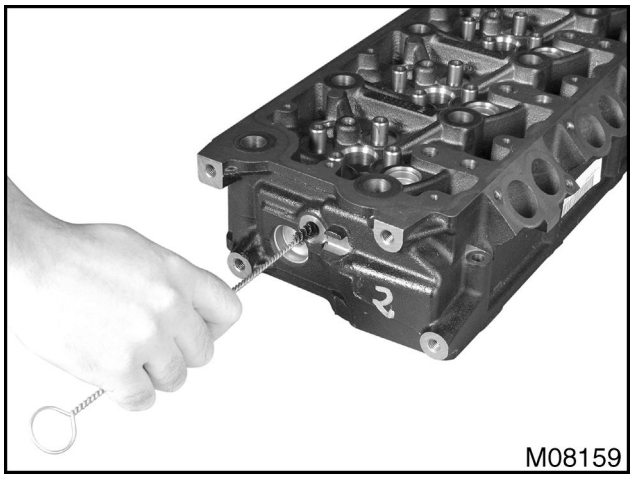


Figure 515 Fuel Gallery

3. Clean fuel gallery with Fuel Gallery Cleaning Brush (page 365).

⚠ 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 365).

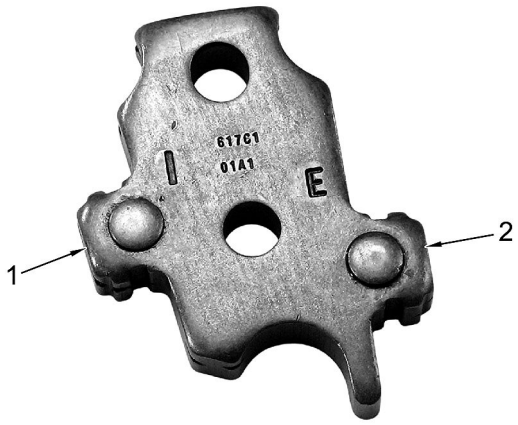
Dual Rocker Fulcrums

⚠ 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

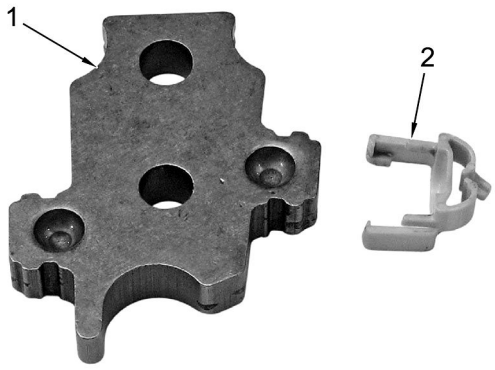
Dual Fulcrum Plate Assemblies



M08128

Figure 516 Dual Rocker Fulcrum Plate (typical)

1. Intake end
2. Exhaust end

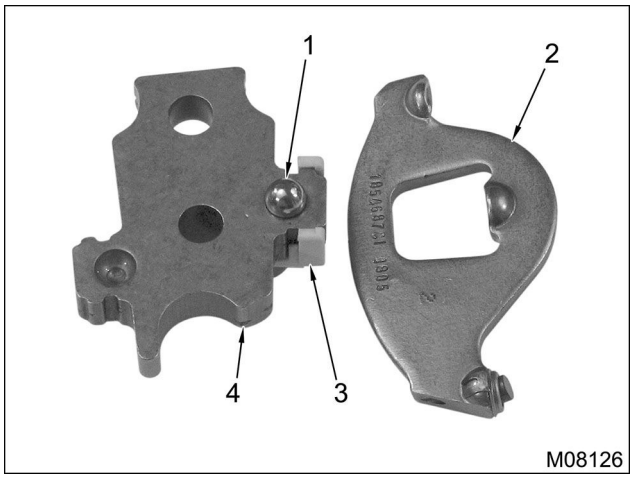


M08127

Figure 517 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.



M08126

Figure 518 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 365) to dual rocker fulcrum plate pockets.
3. Insert 3/8” pivot ball in dual rocker fulcrum plate pockets.

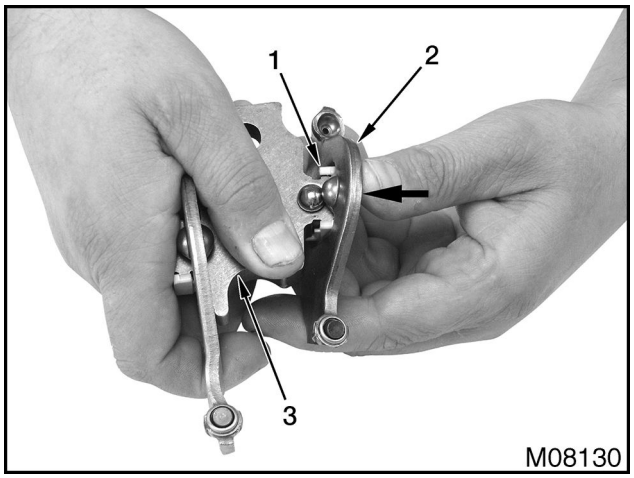


Figure 519 Installation Of Rocker Arm (typical)

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.

Fuel Injector Sleeves

NOTE: Verify injector bore is completely clean and dry.

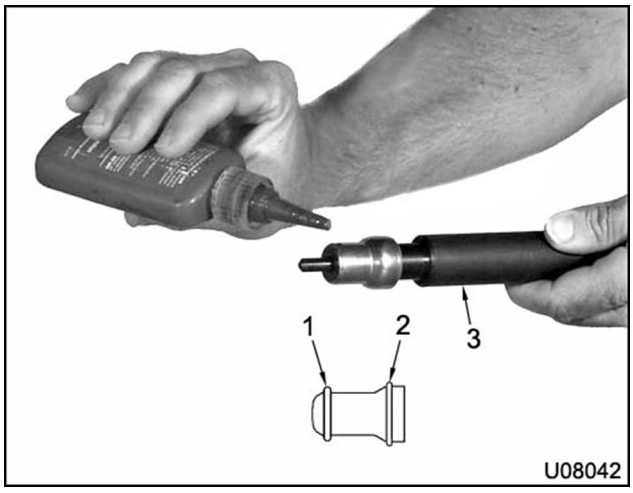


Figure 520 Application of Loctite® 620 Retaining Compound to Fuel Injector Sleeve

1. Wall (end)
2. Upper wall (top)
3. Injector Sleeve Installer

1. Place new fuel injector sleeve on Injector Sleeve Installer (page 365).
2. Apply Loctite® 620 Retaining Compound (page 365) to fuel injector sleeve.
3. Center fuel injector sleeve into injector bore.

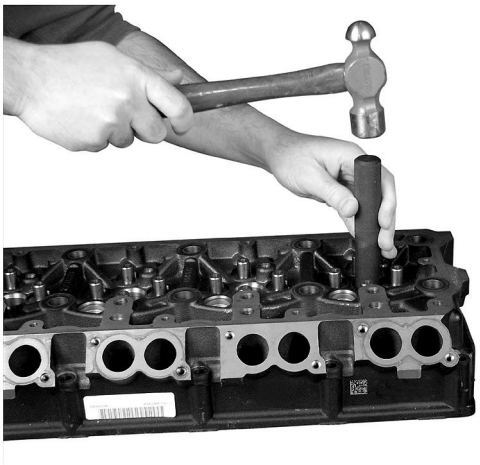


Figure 521 Installation of Fuel Injector Sleeve Into Injector Bore

4. Use a hammer to drive Injector Sleeve Installer (page 365) with fuel injector sleeve into 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. Ensure 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

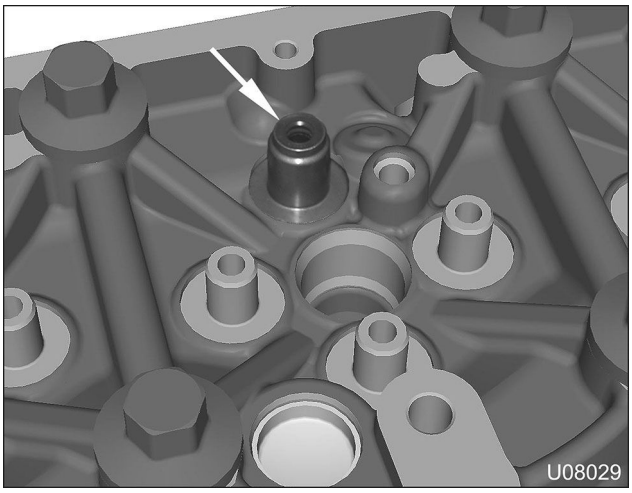


Figure 522 Valve Seal Assembly (typical)

1. Lubricate inside of new valve seal assembly with clean engine oil and put seal onto valve guide.

2. Install valve seal assembly.
3. Lubricate valve stem with clean engine oil and insert valve in cylinder head.
4. Install valve spring over valve seal.
5. Install valve spring retainer on top of valve spring.

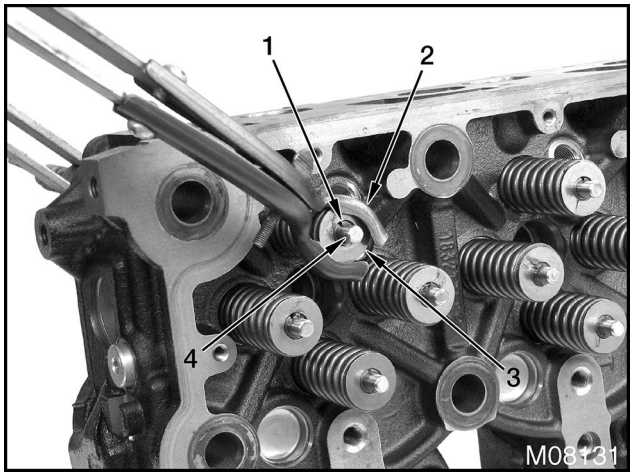


Figure 523 Valve Spring Compression (typical)

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.

6. Compress valve spring with C Type Valve Spring Compressor (page 365), install two valve stem keys, and release spring compressor.
7. After valve replacement, measure valve head recession relative to deck to confirm reconditioning. See Specifications (page 364).

Roller Hydraulic Cam Followers

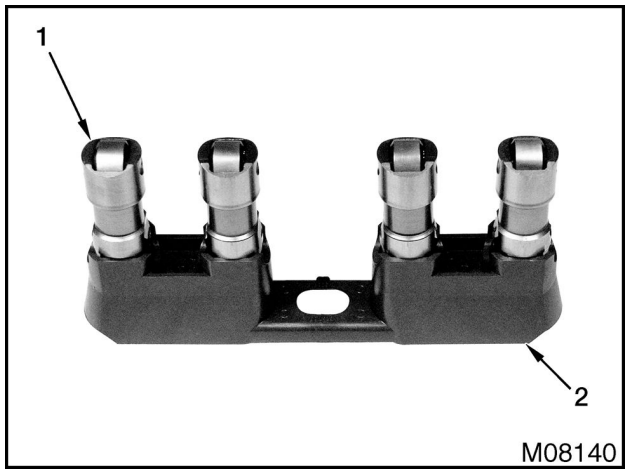


Figure 524 Roller Hydraulic Cam Followers (typical)

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: Install roller 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.

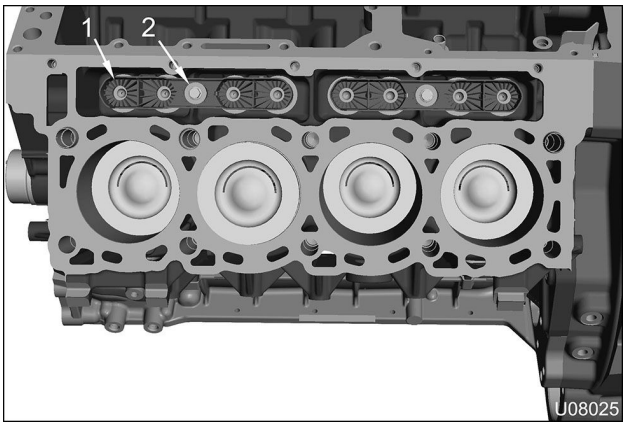


Figure 525 Cam Follower And Guide Assemblies (typical)

1. Cam follower and guide assembly (2)
2. Lifter guide bolt with washer 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 standard torque (page 473).

Cylinder Heads

Installation

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

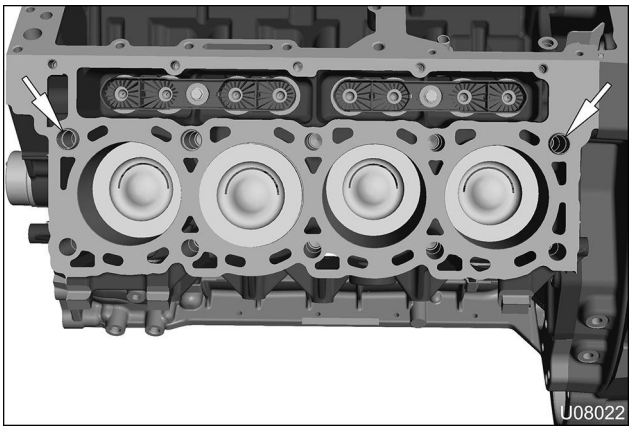


Figure 526 Cylinder Head Spring Dowel Pins In Crankcase (typical)

1. Install two spring dowel pins in upper crankcase assembly.

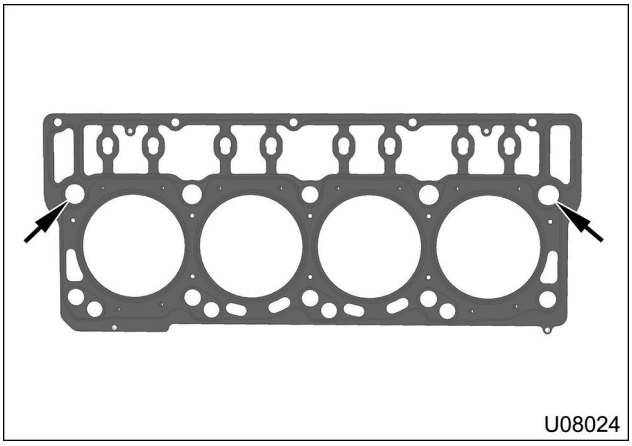


Figure 527 Clearance Holes For Spring Dowel Pins (typical)

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 and contaminates from cylinder head gasket mating surfaces. A faulty seal between the cylinder head, gasket, and crankcase 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.

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

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.

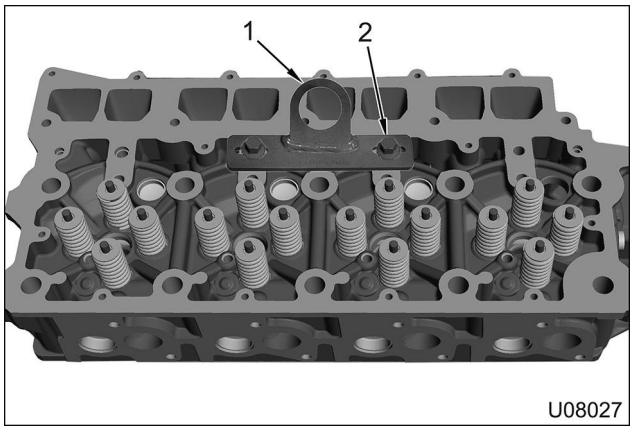


Figure 528 Cylinder Head Lifting Bracket (typical)

1. Cylinder Head Lifting Bracket
2. M10 x 70 bolt (2)

3. Position Cylinder Head Lifting Bracket (page 365) onto center of cylinder head and install two M10 x 70 bolts. Tighten bolts to standard torque (page 473).

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.

4. Attach lifting hoist hook or lifting sling to lifting bracket. Raise cylinder head and align with dowel sleeves previously installed in crankcase.

5. Lower cylinder head onto crankcase.

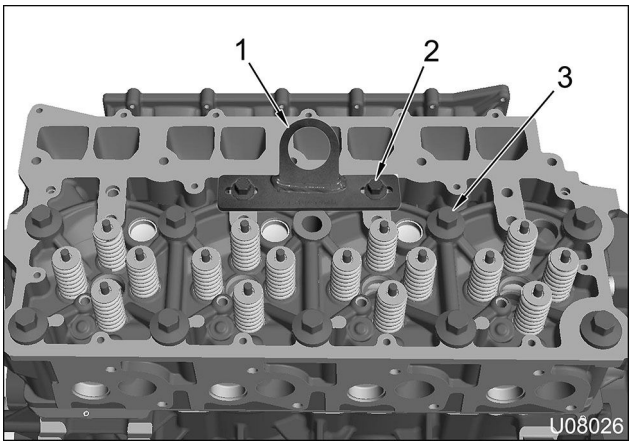


Figure 529 Cylinder Head Lifting Bracket (typical)

1. Cylinder Head Lifting Bracket
2. M10 x 70 bolt (2)
3. M16 x 172 bolt (9)

6. Remove two M10 x 70 bolts and the Cylinder Head Lifting Bracket.

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.

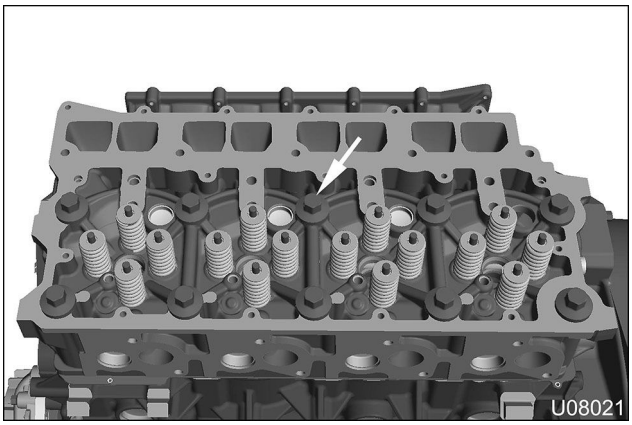


Figure 530 M16 x 172 Cylinder head bolt (10)

7. Lubricate 10 new cylinder head bolts with clean engine oil.
8. Install and hand tighten bolts.

Tightening Sequence for Cylinder Head Bolts

CAUTION: To prevent engine damage, use a permanent ink marker to identify bolt torque orientation.

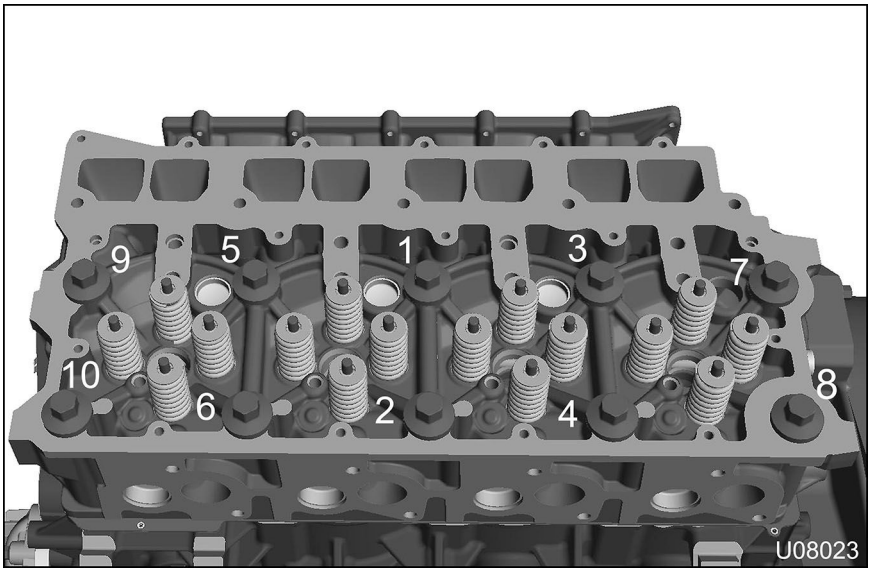


Figure 531 Tightening Sequence For Cylinder Head Bolts (typical)

NOTE: For correct cylinder head surface seating and sealing, follow the procedure and tightening sequence below for new M16 x 172 cylinder head bolts.

1. Tighten cylinder head bolts 1 through 10 to 95 N·m (70 lb·ft) in tightening sequence.
2. Loosen cylinder head bolts 1 through 10 in tightening sequence.
3. Tighten cylinder head bolts 1 through 10 to 163 N·m (120 lb·ft) in tightening sequence.

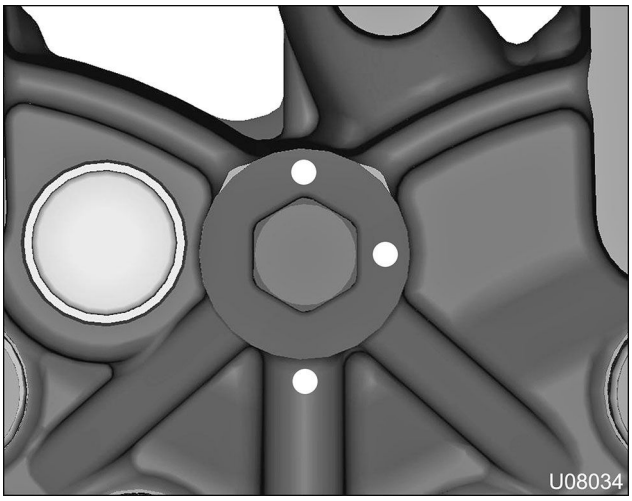


Figure 532 Dots Applied (typical)

4. Apply dots to all cylinder head bolts and dots to cylinder head [after all bolts are tightened to 163 N·m (120 lb·ft)].

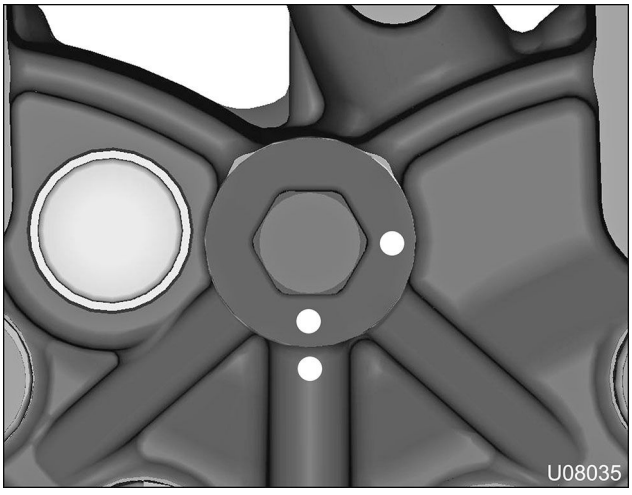


Figure 533 First 90° Turn

5. First, turn cylinder head bolts 1 through 10 clockwise 90° (1/4 turn) in tightening sequence.

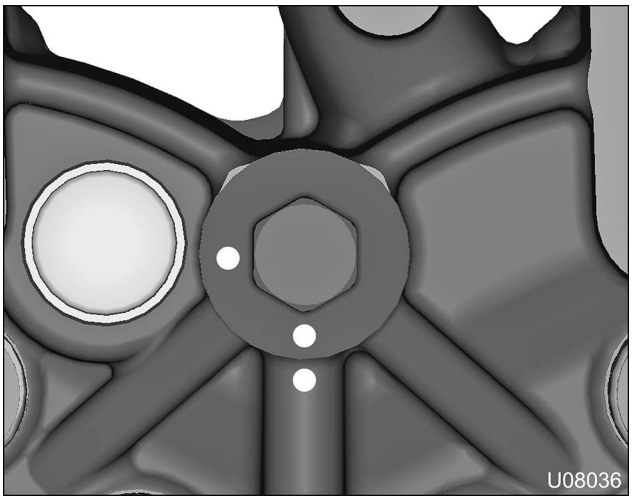


Figure 534 Second 90° Turn

6. Second, turn cylinder head bolts 1 through 10 clockwise 90° (1/4 turn) in tightening sequence.

Rocker Arm Supports, Push Rods, and Valve Bridges

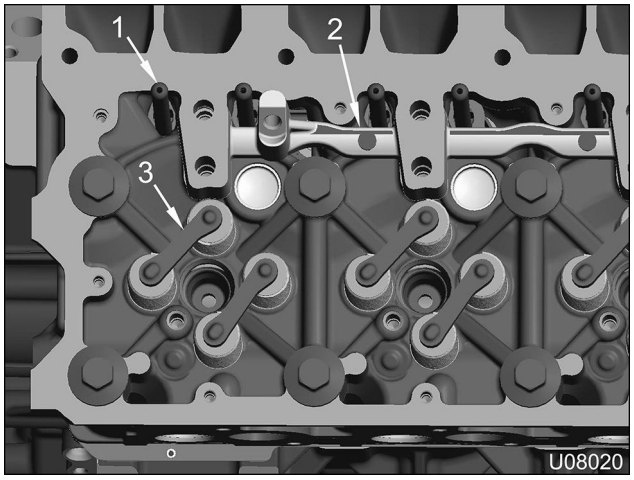


Figure 535 Rocker Arm Support, Push Rods, And Valve Bridges (typical)

1. Push rod
2. Rocker arm support
3. Valve bridge

1. Apply lithium grease (page 365) to valve stem tips and to valve bridge pockets.
2. Place each of the previously marked valve bridges on their respective valve stems.
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.

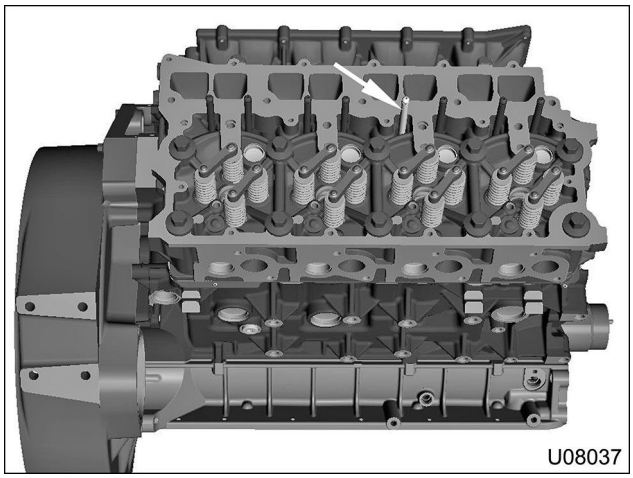


Figure 536 Intake Push Rod (cylinder 3)

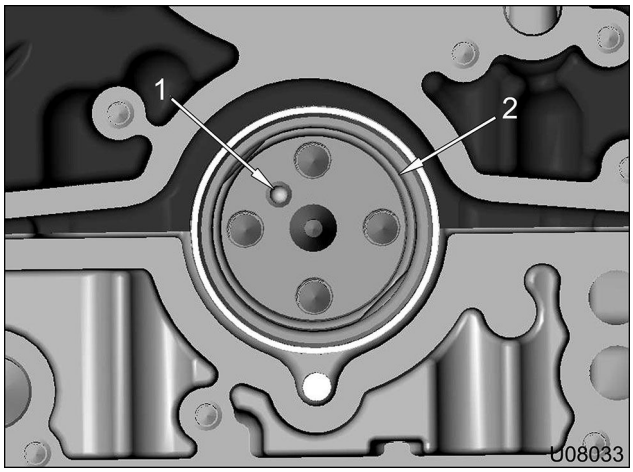


Figure 537 Dowel Pin In Crankshaft At 10:30 Position

1. Dowel pin
2. Crankshaft

NOTE: Rotate crankshaft and observe the intake push rod at number 3 cylinder. Cylinder number 1 is Top Dead Center (TDC) 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 cylinder number 1 is at TDC and in the firing position.

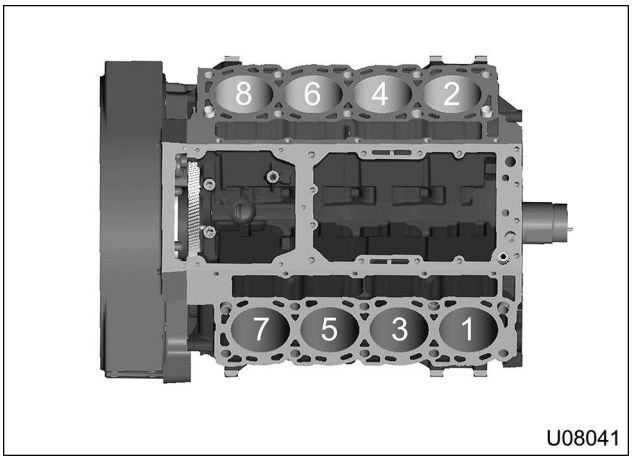


Figure 538 Cylinder Numbers

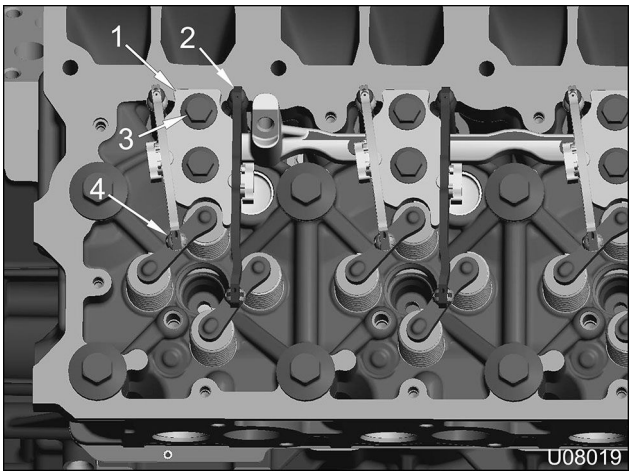


Figure 539 Dual Fulcrum Plate Assemblies (typical)

1. Dual fulcrum plate assembly (4)
2. Rocker arm pocket
3. M10 x 70 bolt (8)
4. Pivot foot

6. Install dual fulcrum plate assemblies for cylinder numbers 1, 2, 7, and 8.

CAUTION: To prevent engine damage, make sure push rods have seated in the rocker arm pocket.

7. Install and tighten M10 x 70 bolts for cylinder numbers 1, 2, 7, and 8 as follows:
    a. Hand tighten all bolts
    b. Make sure pivot foot is centered on valve bridge.
    c. Tighten inboard (upper) bolts to 61 N·m (45 lb·ft).
    d. Tighten outboard (lower) bolts to 61 N·m (45 lb·ft).
    e. Make sure 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.

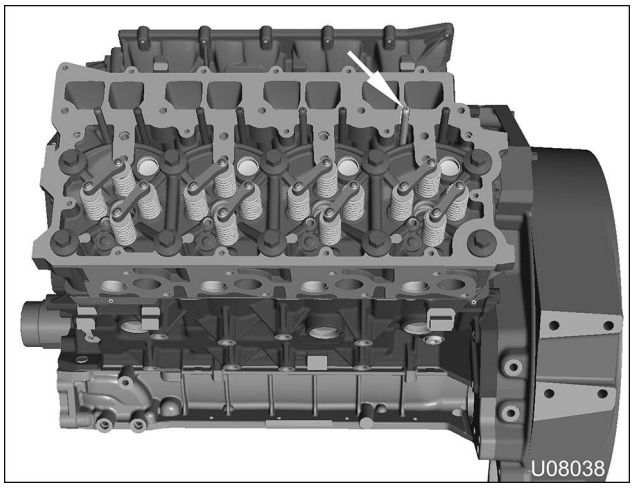


Figure 540 Intake Push Rod (cylinder 8)

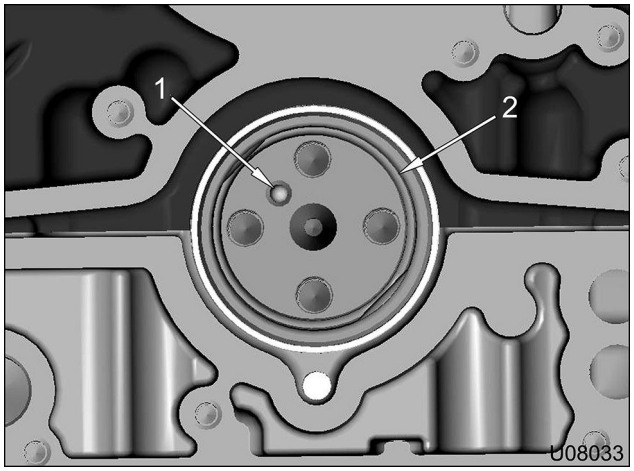


Figure 541 Dowel Pin In Crankshaft At 10:30 Position

1. Dowel pin
2. Crankshaft

NOTE: Rotate crankshaft and observe the intake push rod at number 8 cylinder. Cylinder number 4 is Top Dead Center (TDC) 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 at TDC and in the firing position.

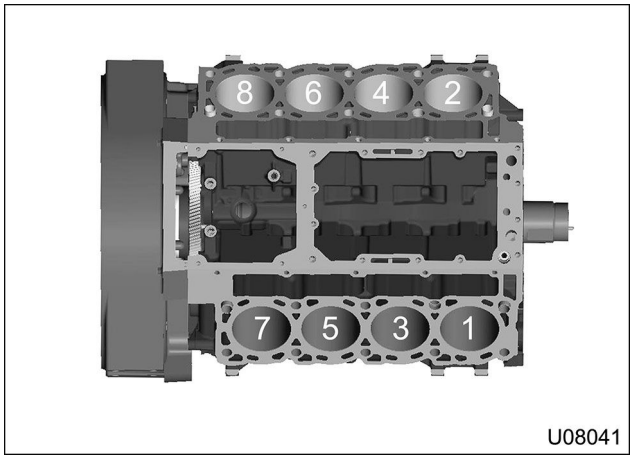


Figure 542 Cylinder Numbers

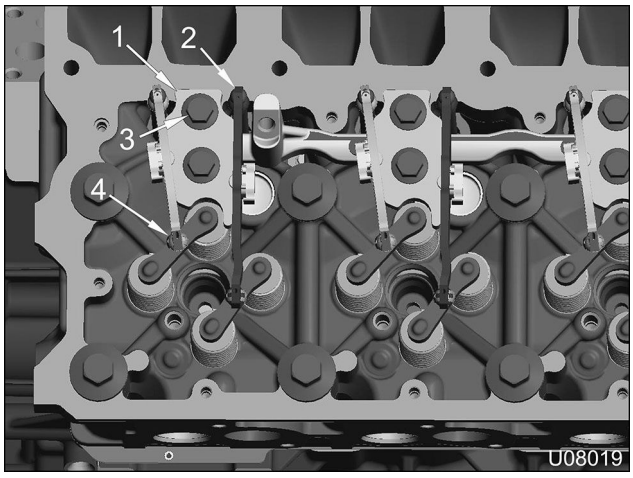


Figure 543 Dual Fulcrum Plate Assemblies (typical)

1. Dual fulcrum plate assembly (4)
2. Rocker arm pocket
3. M10 x 70 bolt (8)
4. Pivot foot

9. Install dual fulcrum plate assemblies for cylinder numbers 3, 4, 5, and 6.

CAUTION: To prevent engine damage, make sure push rods have seated in the rocker arm pocket.

10. Install and tighten M10 x 70 bolts for cylinder numbers 3, 4, 5, and 6 as follows:
    a. Hand tighten all bolts
    b. Make sure pivot foot is centered on valve bridge.
    c. Tighten inboard (upper) bolts to 61 N·m (45 lb·ft).
    d. Tighten outboard (lower) bolts to 61 N·m (45 lb·ft).
    e. Make sure 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.

Right Valve Cover and Intake Manifold Base Assembly

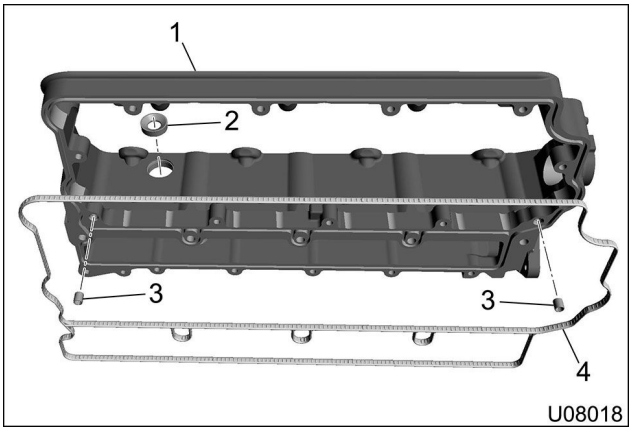


Figure 544 Right Valve Cover and Intake Manifold Base and Gasket

1. Right valve cover and intake manifold base
2. Fuel supply line seal
3. Slotted spring pin (2)
4. Valve cover and intake manifold base gasket

1. Install two slotted spring pins, if previously removed.
2. Install new fuel supply line seal.
3. Install new valve cover and intake manifold base gasket.

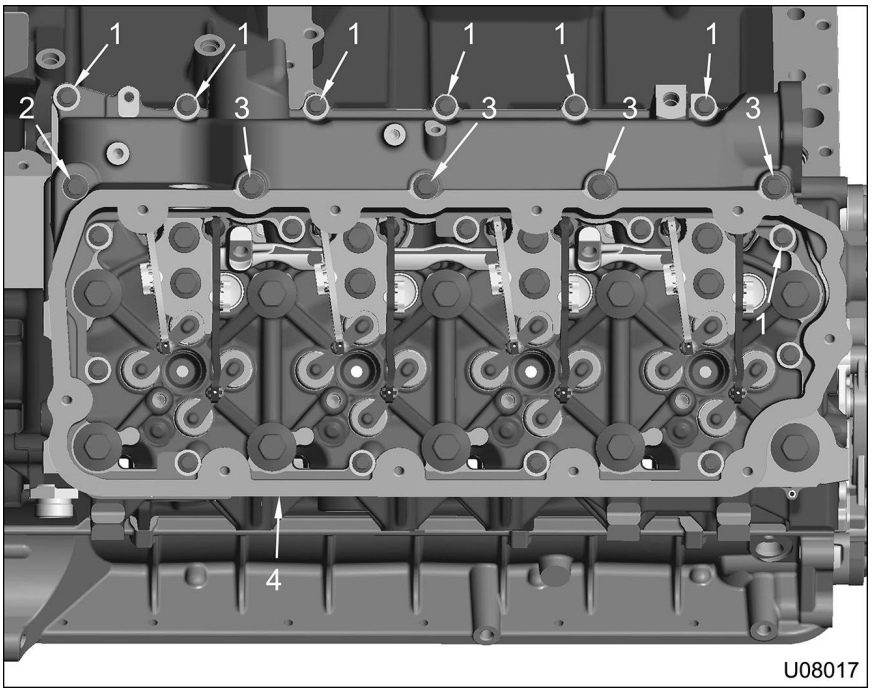


Figure 545 Right Valve Cover and Intake Manifold Base Assembly

1. M6 x 30 bolt (17)
2. M8 x 170 bolt
3. M8 x 225 bolt (4)
4. Right valve cover and intake manifold base

4. Position right valve cover and intake manifold base onto cylinder head.
5. Install 17 M6 x 30 bolts and tighten bolts to standard torque (page 473).
6. Install four M8 x 225 bolts and tighten bolts to standard torque (page 473).
7. Install M8 x 170 bolt and tighten bolt to standard torque (page 473).

NOTE: Before installing the left valve cover and right valve cover, see the following procedures:

- **Fuel rail assemblies and fuel Injectors (page 251)**
- **Under Valve Cover (UVC) Harnesses (page 91)**
- **Fuel Rail Pressure (FRP) Sensor (page 93)**

Left Valve Cover and Intake Manifold Base Assembly

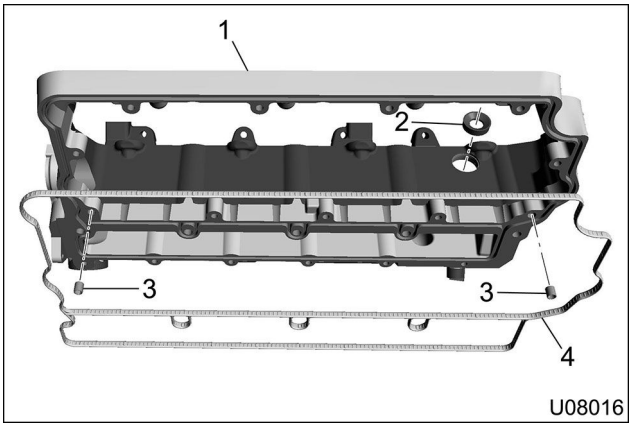


Figure 546 Left Valve Cover and Intake Manifold Base and Gasket

1. Left valve cover and intake manifold base
2. Fuel supply line seal
3. Slotted spring pin (2)
4. Valve cover and intake manifold base gasket

1. Install two slotted spring pins.
2. Install new fuel supply line seal.
3. Install new valve cover and intake manifold base gasket.

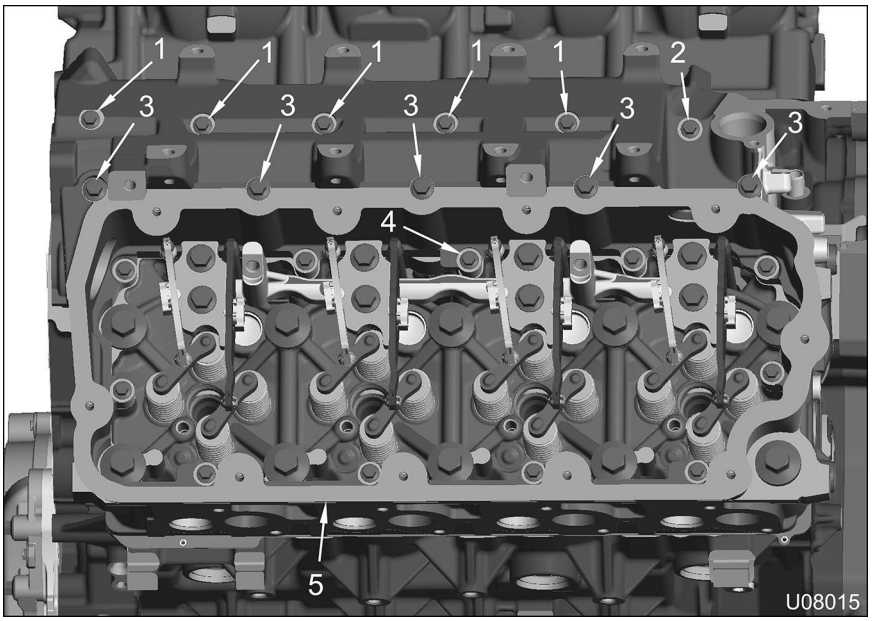


Figure 547 Left Valve Cover and Intake Manifold Base Assembly

1. M6 x 100 bolt (5)
2. M6 x 80 bolt
3. M8 x 225 bolt (5)
4. M6 x 30 bolt (11)
5. Left valve cover and intake manifold base

4. Position left valve cover and intake manifold base onto cylinder head.
5. Install 11 M6 x 30 bolts and tighten bolts to standard torque (page 473).
6. Install five M6 x 100 bolts and tighten bolts to standard torque (page 473).
7. Install five M8 x 225 bolts and tighten bolts to standard torque (page 473).
8. Install M6 x 80 bolt and tighten bolt to standard torque (page 473).

NOTE: Before installing the left valve cover and right valve cover, see the following procedures:

- **Fuel rail assemblies and fuel Injectors (page 251)**
- **Under Valve Cover (UVC) Harnesses (page 91)**
- **Fuel Rail Pressure (FRP) Sensor (page 93)**

Left Valve Cover

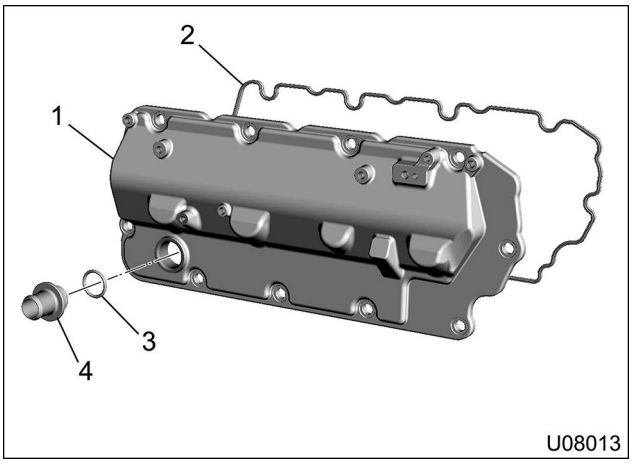


Figure 548 Oil Fill Tube and Valve Cover Gasket

1. Left valve cover
2. Valve cover gasket
3. Intake manifold O-ring
4. Oil fill tube

1. Install new intake manifold O-ring onto oil fill tube.
2. Install oil fill tube into left valve cover.
3. Install new left valve cover gasket.

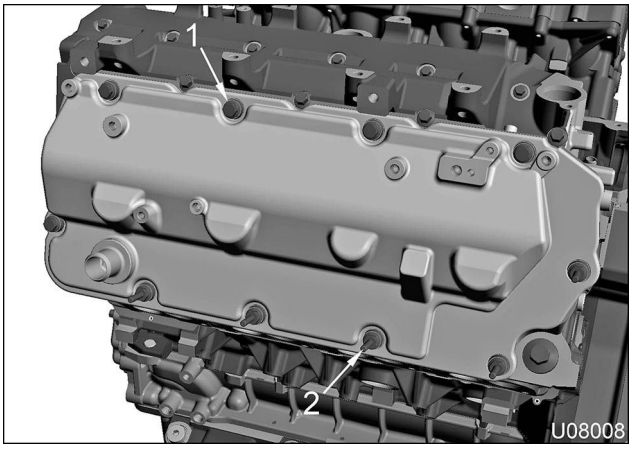


Figure 549 Left Valve Cover

1. Valve cover bolt assembly (5)
2. Valve cover stud bolt assembly (5)

4. Position left valve cover onto valve cover and intake manifold base.
5. Engage five valve cover bolt assemblies and five valve cover stud bolt assemblies. Tighten bolts and stud bolts to special torque (page 365).
6. Install oil fill support bracket and oil fill hose assembly onto fuel filter cooler assembly (page 357).

Oil Fill Tube Assembly

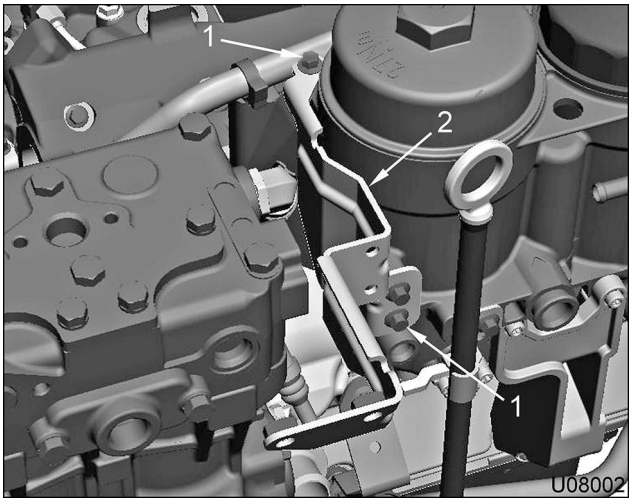


Figure 550 Oil Fill Support

1. M6 x 16 bolt (3)
2. Oil fill support

1. Install oil support bracket and install three M6 x 16 bolts to secure oil support bracket.
2. Tighten bolts to standard torque (page 473).

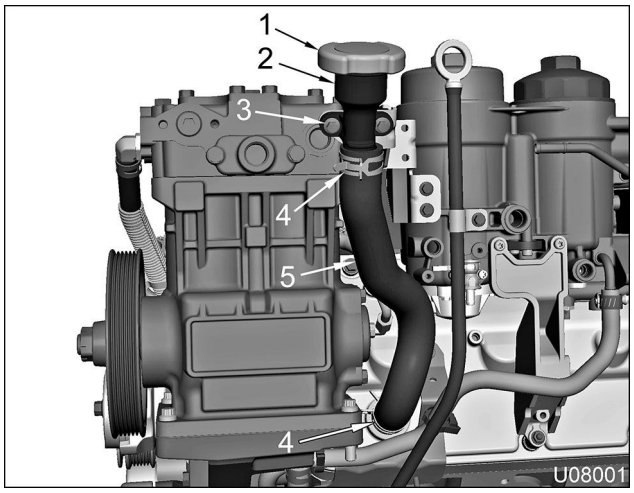


Figure 551 Oil Fill Tube Assembly

1. Oil fill cap assembly
2. Oil fill tube
3. M6 x 20 bolt (2)
4. Clamp (2)
5. Oil fill (hose)

3. Install oil fill tube assembly.
4. Install two M6 x 20 bolts to secure oil fill tube assembly to oil fill support bracket. Tighten bolts to standard torque (page 473).

Right Valve Cover

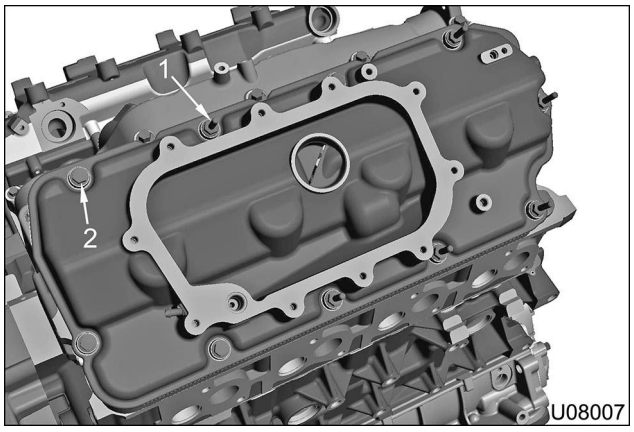


Figure 552 Right Valve Cover

1. Valve cover bolt assembly (4)
2. Valve cover stud bolt assembly (6)

CAUTION: To prevent engine damage, do not use power tools to remove or install valve cover bolts.

1. Install new right valve cover gasket.
2. Position right valve cover onto valve cover and intake manifold base.
3. Engage four valve cover bolt assemblies and six valve cover stud bolt assemblies. Tighten bolts and stud bolts to special torque (page 365).

Breather Cover Assembly and Variable Impactor

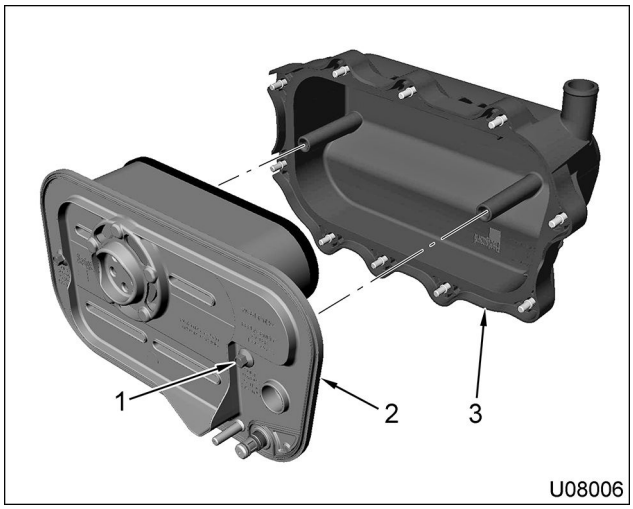


Figure 553 Filter with Variable Impactor (serviceable)

1. M6 captive bolt (2)
2. Filter
3. Breather cover assembly

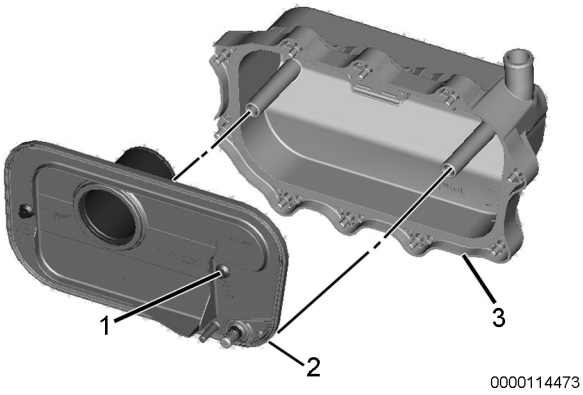


Figure 554 Filter with Variable Impactor (Non-serviceable)

1. M6 captive bolt (2)
2. Filter
3. Breather cover assembly

NOTE: If vehicle is equipped with a Coalescer type serviceable breather, it should be replaced with a non-serviceable variable impactor type breather assembly. When replacing breather assembly, breather programmable parameter will need to be disabled.

1. Join new filter with variable impactor and breather cover assembly.
2. Engage two M6 captive bolts and tighten to special torque (page 365).

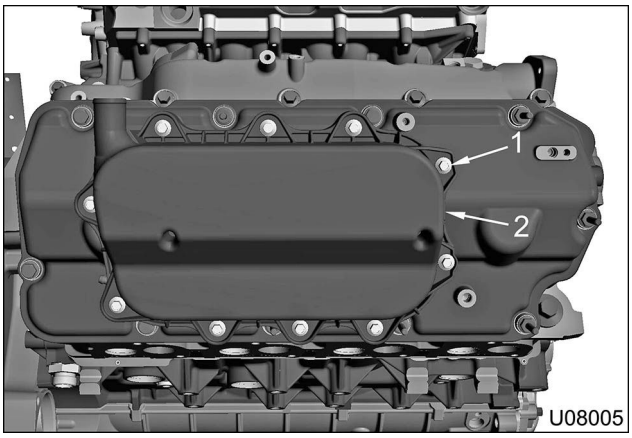


Figure 555 Breather Cover Assembly

1. M6 captive bolt (10)
2. Breather cover assembly

3. Position breather cover assembly onto right valve cover.
4. Engage 10 captive bolts to secure breather cover assembly.

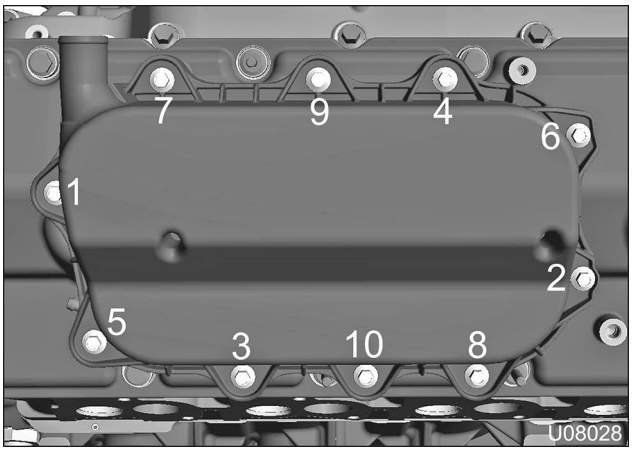


Figure 556 Torque Sequence For Breather Cover Assembly Captive Bolts

5. Tighten M6 captive bolts in sequence to standard torque (page 473).

Lifting eye and jet pump tube assembly

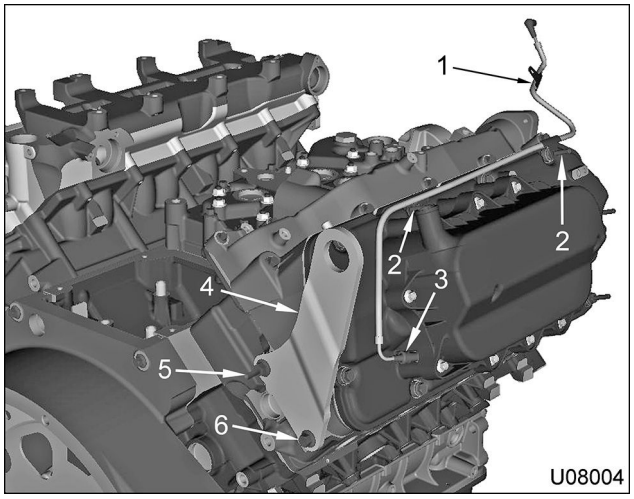


Figure 557 Lifting Eye and Jet Pump Tube Assembly

1. Jet pump tube assembly
2. Valve cover stud bolt assembly (2)
3. Nut
4. Lifting eye
5. M10 x 25 stud bolt
6. M10 x 25 bolt

1. Install a new jet pump tube assembly onto 1/4 hose fitting in breather cover and attach to valve cover stud bolts.
2. Position lifting eye onto cylinder head, install M10 stud bolt and M10 x 25 bolt, and tighten both to standard torque (page 473).

Draft Tube Assembly

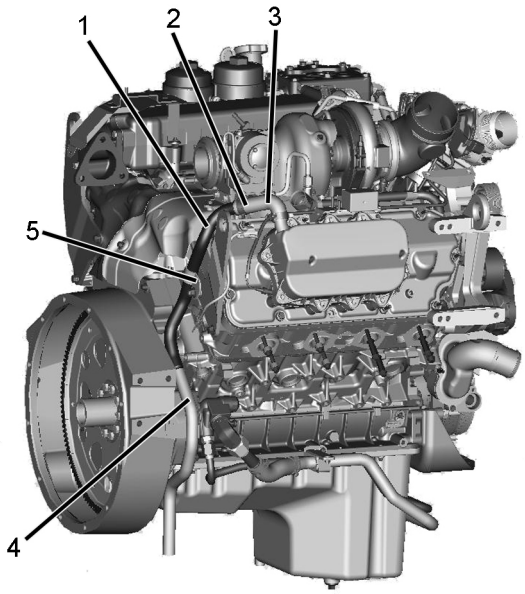


Figure 558 Draft Tube Assembly

1. Upper draft tube
2. 1” worm gear hose clamp (2)
3. 1” 90° elbow
4. Lower draft hose
5. M12 nut

NOTE: Lower draft tube assembly has been redesigned to meet new vehicle clearance requirements. Components of new lower draft tube assembly are not serviceable. Attempting to service draft tube assembly with older components will result in clearance issues.

1. If removed, install worm gear hose clamp onto the 90° elbow and install elbow onto the breather cover.
2. If removed, install worm gear hose clamp that connects the 90° elbow to the draft tube assembly.
3. Install draft tube assembly.
4. Install the M12 nut to secure the draft tube assembly to the rear crankcase cover and tighten to standard torque (page 473).
5. Tighten worm gear hose clamps to special torque (page 365).

Balance Duct and Balance Tube Flange

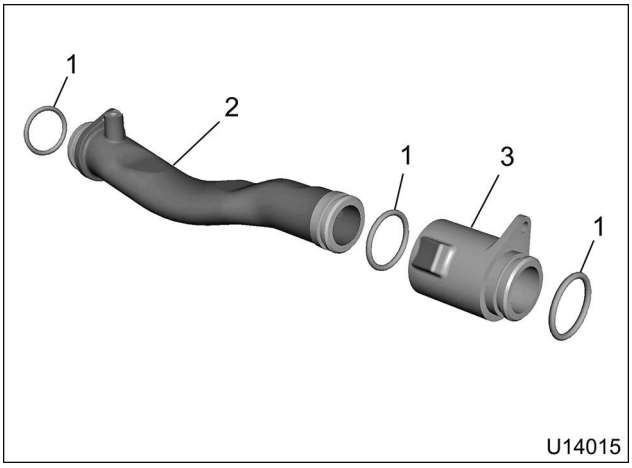


Figure 559 Balance Duct, Balance Tube Flange, and O-Rings

1. O-ring (3)
2. Balance duct
3. Balance tube flange

1. Lubricate a new O-ring with P-80® Rubber Lubricant or equivalent (page 365), position O-ring on end of balance duct, and slide balance tube flange onto balance duct.
2. Lubricate two O-rings with P-80® Rubber Lubricant or equivalent (page 365), and install one O-ring onto end of balance duct and one O-ring onto balance tube flange.

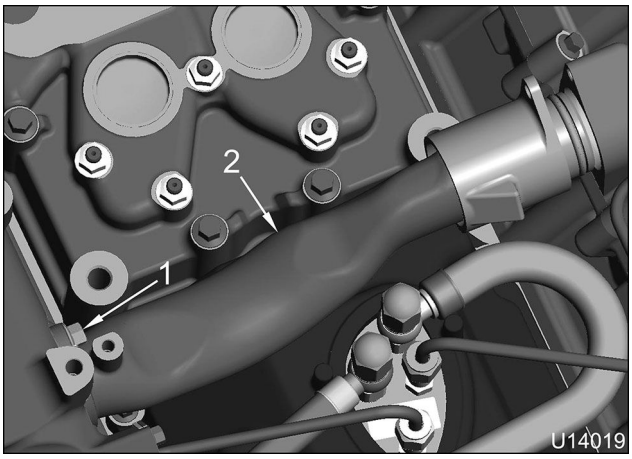


Figure 560 Installation Of Balance Duct and Balance Tube Flange

1. M6 x 14 bolt
2. Balance duct

3. Position balance duct and balance tube flange.
4. Install M6 x 14 bolt finger tight to secure balance duct.

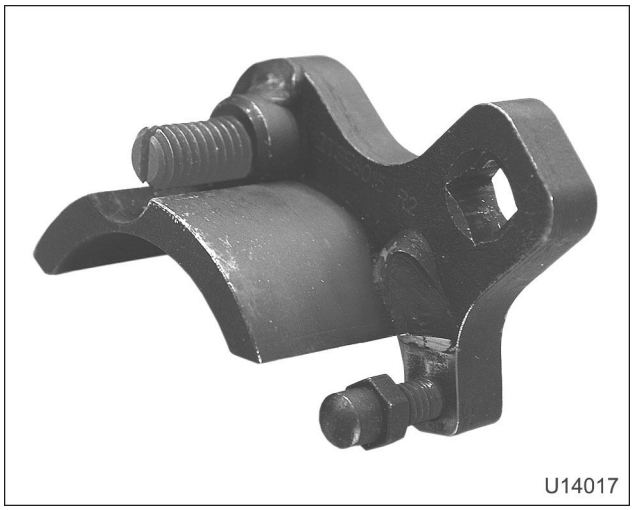


Figure 561 Cross-over Tube Removal Tool

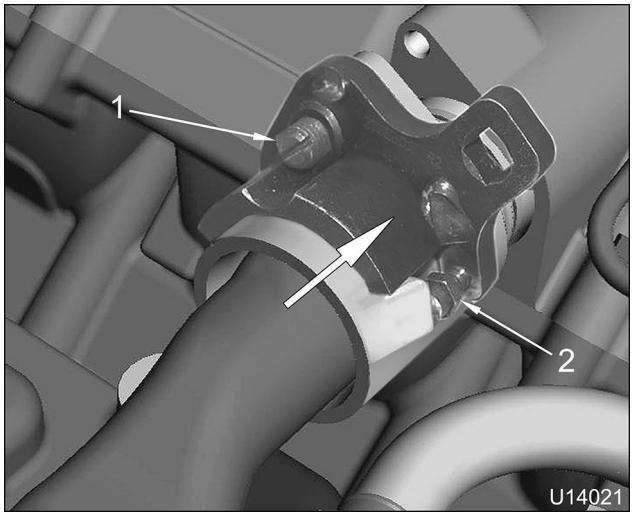


Figure 562 Installation of Cross-over Tube Removal Tool

1. Set screw
2. Adjustment screw

5. Position Cross-over Tube Removal Tool (page 365) onto balance tube flange, turn set screw into hole in balance tube flange, and turn adjustment screw counterclockwise against tab on tube flange.
6. Twist the Cross-over Tube Removal Tool and apply force to move the balance tube flange until the flange contacts the intake manifold valve cover base.
7. Remove Cross-over Tube Removal Tool.

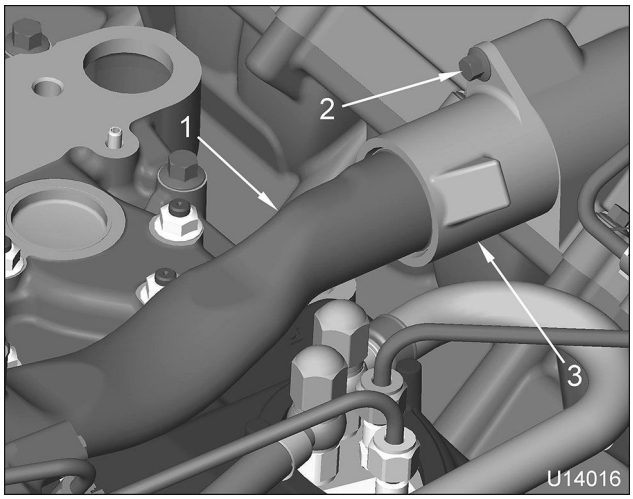


Figure 563 Balance Duct And Balance Tube Flange

1. Balance duct
2. M6 x 14 bolt
3. Balance tube flange

8. Install M6 x 14 bolt finger tight to secure balance tube flange.

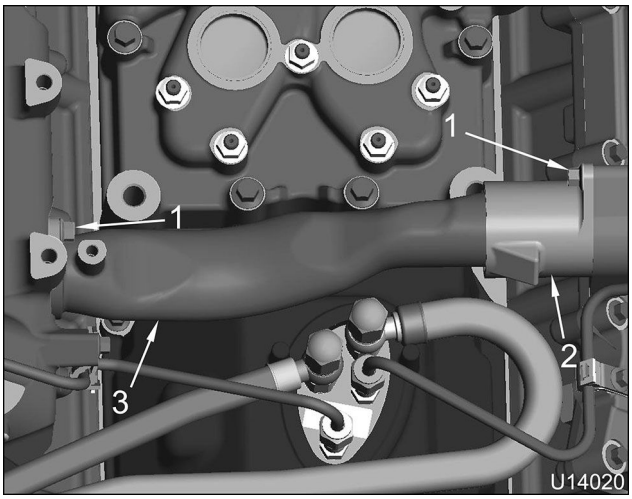


Figure 564 Balance Duct And Balance Tube Flange

1. M6 x 14 bolt (2)
2. Balance tube flange
3. Balance duct

9. Tighten two M6 x 14 bolts to standard torque (page 473).

Specifications

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 to 50.75°
Valve margin (minimum)	1.53 mm (0.060 in)
Valve recession in head	0.37 to 0.73 mm (0.0146 to 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 to 53.25°
Valve margin (minimum)	1.40 mm (0.055 in)
Valve recession in head	0.37 to 0.73 mm (0.0146 to 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 to 52.75°
Valve seat angle (exhaust) from center line of valve guide	50.0 to 50.25°
Overall thickness of cylinder head (deck-to-deck)	95 ± 0.48 mm (3.74 ± 0.018 in)
Valve Springs	
Solid height	36.1 mm (1.42 in)
Compressed*	46.50 mm @ 340 ± 17 N (1.83 in @ 76.5 ± 3.8 lb)
Compressed*	38.30 mm @ 850 ± 43 N (1.51 in @ 191.1 ± 9.7 lb)
* Spring must be compressed to a solid height before checking test loads.	
Push Rods	
Runout (maximum)	0.5 mm (0.02 in)

Special Torque

Cylinder head bolts	See tightening steps in procedure
Draft tube assembly nut, M10	54 N·m (40 lb·ft)
Dual fulcrum plate assembly bolts	See tightening steps in procedure
Filter with jet pump captive bolts, M6	5 N·m (44 lb·in)
Fuel rail plug assembly	27 N·m (20 lb·ft)
Valve cover bolt and stud bolts assemblies	9 N·m (80 lb·in)
Worm gear hose clamps	13 N·m (115 lb·in)

Special Service Tools

Description	Tool Number
C Type Valve Spring Compressor	ZTSE1846
Cylinder Head Bolt Tap	ZTSE4744
Cylinder Head Lifting Bracket	ZTSE6035
Cylinder Head Pressure Test Plate	ZTSE4534
Dial Caliper	Obtain locally
Dye Penetrant Kit	PT-7191
Feeler Gauge	Obtain locally
Fuel Gallery Cleaning Brush	ZTSE4541
Fuel Injector Tip Cleaning Brush	ZTSE4301
Injector Sleeve Brushes	ZTSE4751
Injector Sleeve Installer	ZTSE4733
Injector Sleeve Remover	ZTSE4732
Inspection Mirror	Obtain locally
Lithium Grease	Obtain locally
Loctite® 620 Retaining Compound	Obtain locally
Pressure Test Regulator and Gauge	Obtain locally
P-80® Rubber Lubricant or equivalent	Obtain locally
Slide Hammer Kit	ZTSE4398A
Straightedge	Obtain locally
Valve Guide Gauge Tool	ZTSE4577
Valve Spring Tester	ZTSE2241
0-1 inch Micrometer	Obtain locally
3-4 inch Micrometer	Obtain locally

Table of Contents

Exploded Views.....369

Removal.....375
- **Engine Mount Rear Brackets**.....375
- **Flywheel Assembly (Manual Transmission)**.....376
- **Flex Plate flywheel Assembly (Automatic Transmission)**.....377
- **Crankshaft Rear Oil Seal and Wear Sleeve**.....377
- **Crankshaft Rear Oil Seal Carrier and Power Steering Idler Gear Assembly**.....378
- **Crankshaft Flange**.....379
- **Flywheel Housing and Power Steering Idler Shaft**.....380

Cleaning, Inspection, and Measurement.....382
- **All Components**.....382
- **Flex Plate Flywheel Assembly (Automatic Transmission)**.....382
- **Flywheel Assembly (Manual Transmission)**.....382
- **Flywheel Surface Runout**.....382
- **Flywheel Housing Runout**.....383
- **Backlash Measurement for Power Steering Idler Gear Assembly**.....383

Installation.....384
- **Flywheel Housing**.....384
- **Power Steering Idler Shaft**.....384
- **Crankshaft Flange**.....386
- **Power Steering Idler Gear Assembly and Crankshaft Rear Oil Seal Carrier**.....387
- **Crankshaft Rear Oil Seal and Wear Sleeve**.....388
- **Flex Plate Flywheel Assembly (Automatic Transmission)**.....390
- **Flywheel Assembly (Manual Transmission)**.....391
- **Engine Mount Rear Brackets**.....392

Specifications.....393

Special Torque.....393

Special Service Tools.....393

Exploded Views

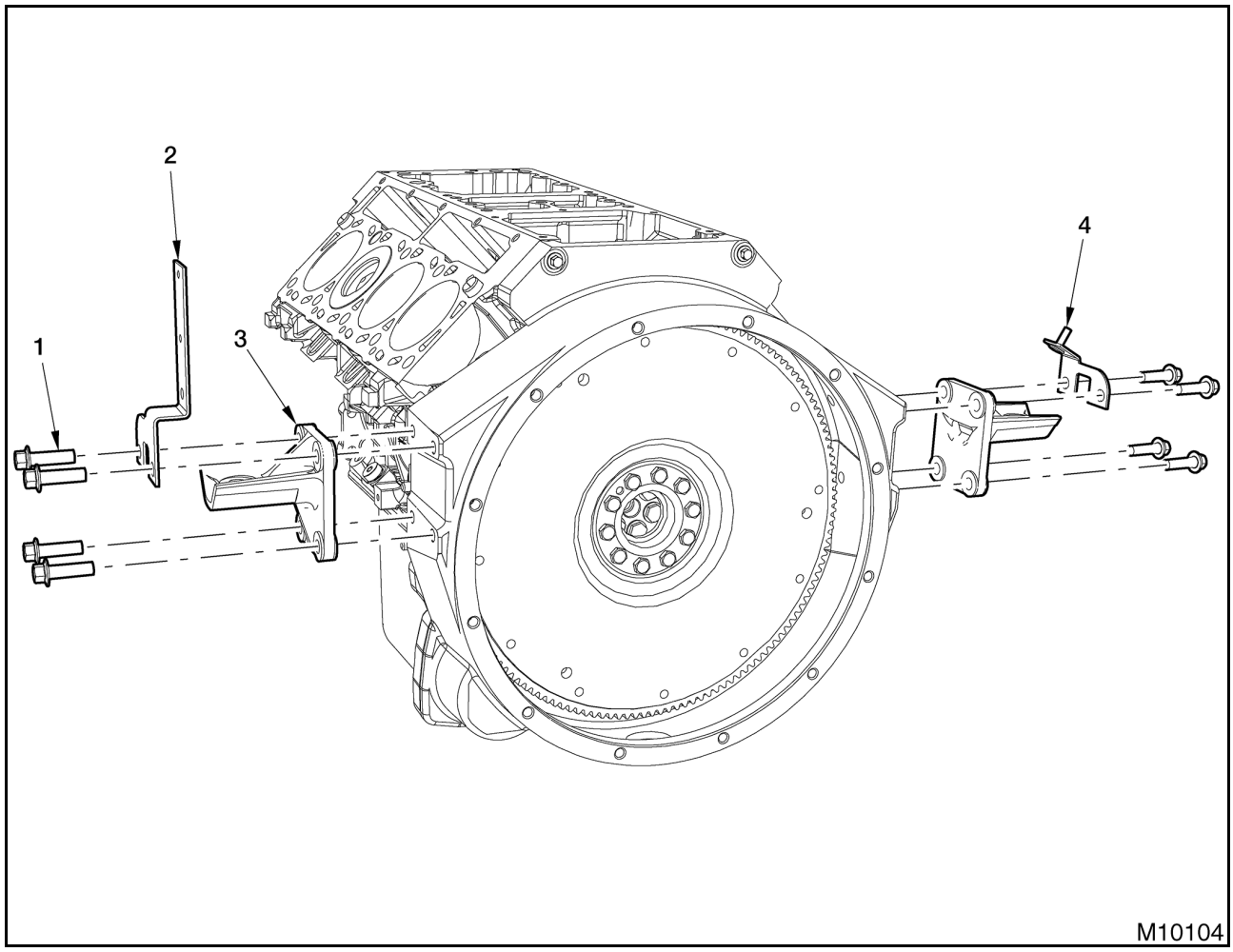


Figure 565 Engine Mount Rear Brackets

1. M12 x 40 bolt (8)
2. Pipe clip bracket
3. Engine mount rear bracket (2)
4. Extension clip

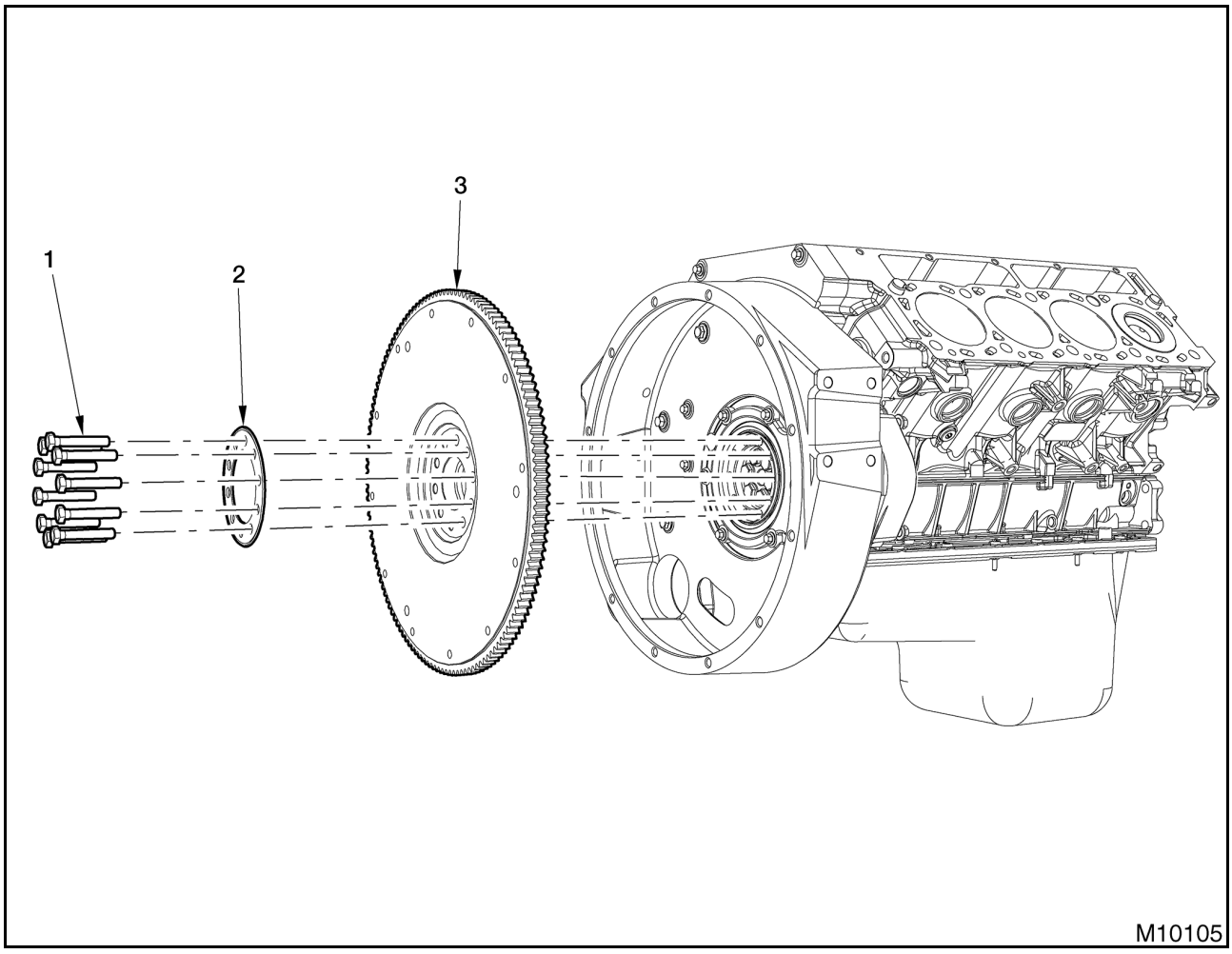


Figure 566 Flywheel Assembly (Manual Transmission)

1. M10 x 55 bolt (10)
2. Reinforcement ring
3. Flywheel assembly

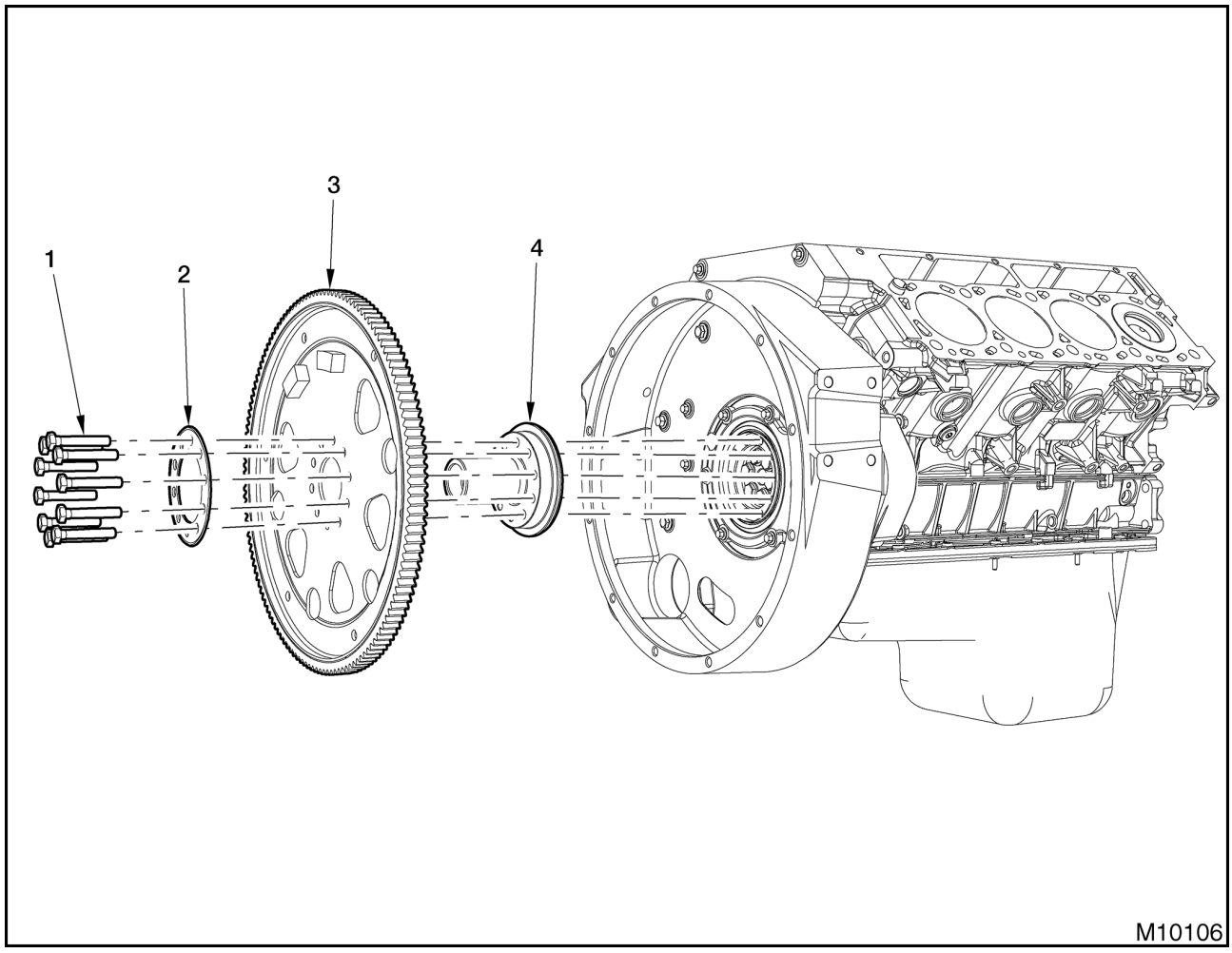


Figure 567 Flex Plate Flywheel Assembly (Automatic Transmission)

1. M10 x 55 bolt (10)
2. Reinforcement ring
3. Flex plate flywheel assembly
4. Adapter hub

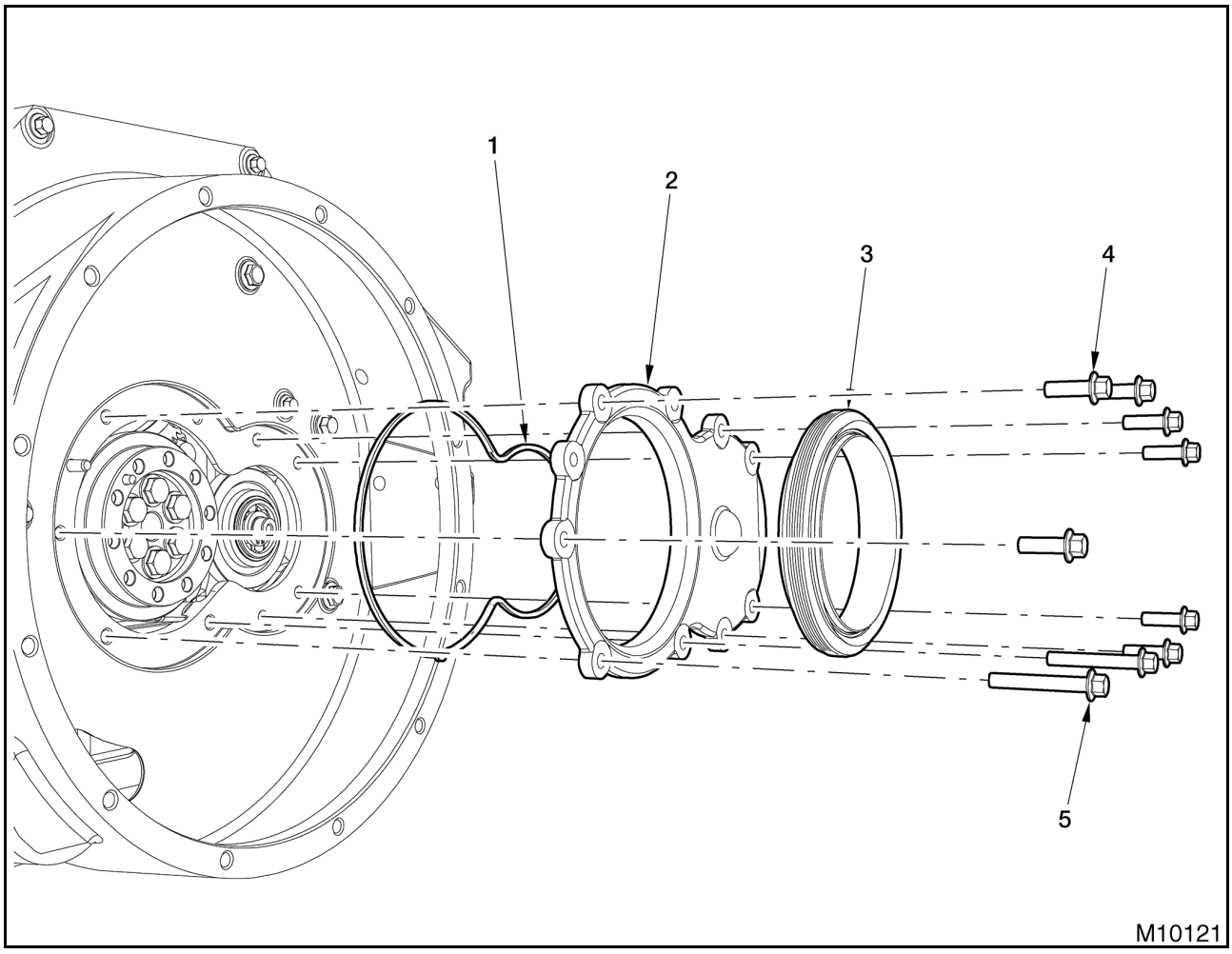


Figure 568 Crankshaft Rear Oil Seal and Crankshaft Rear Oil Seal Carrier

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)

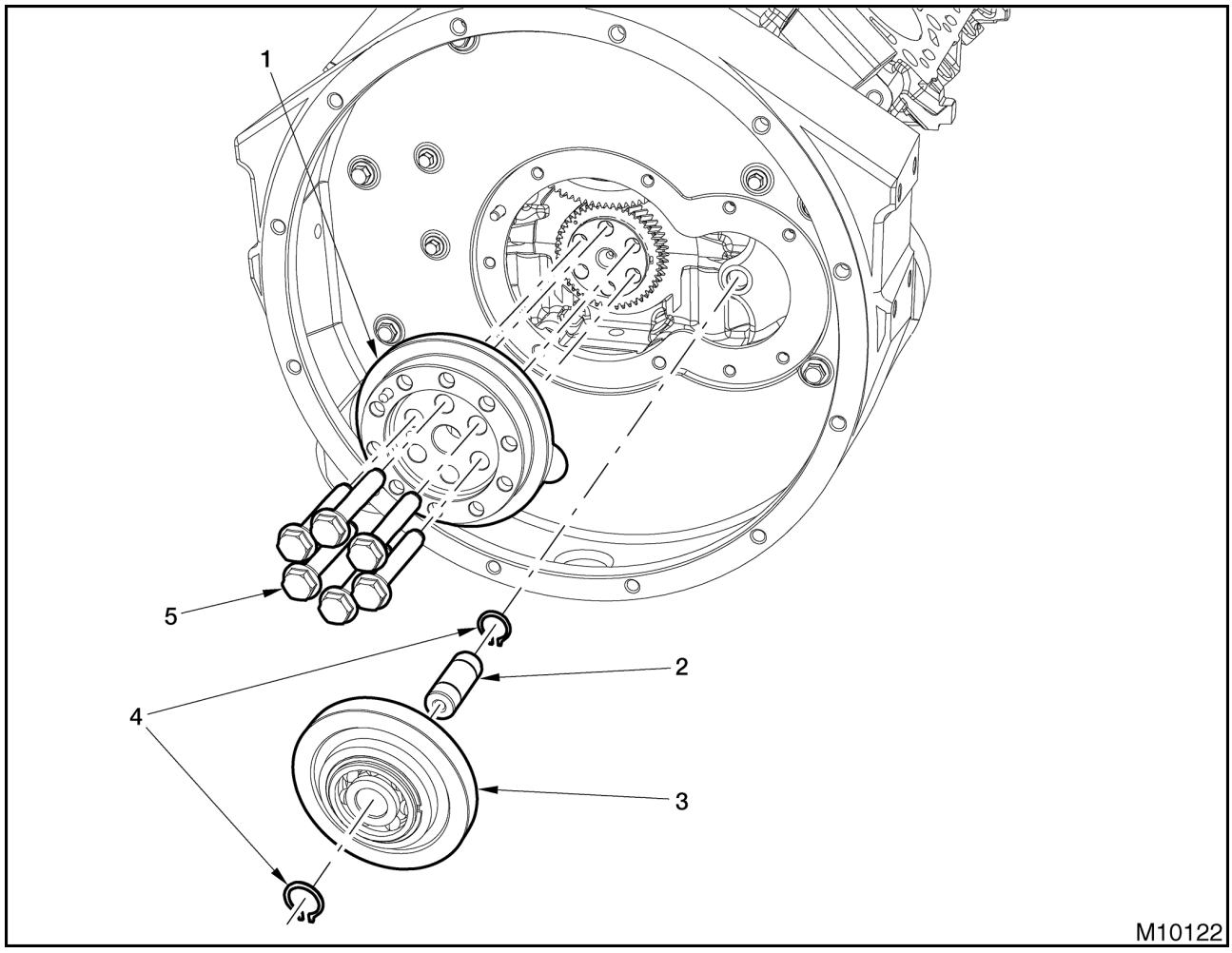
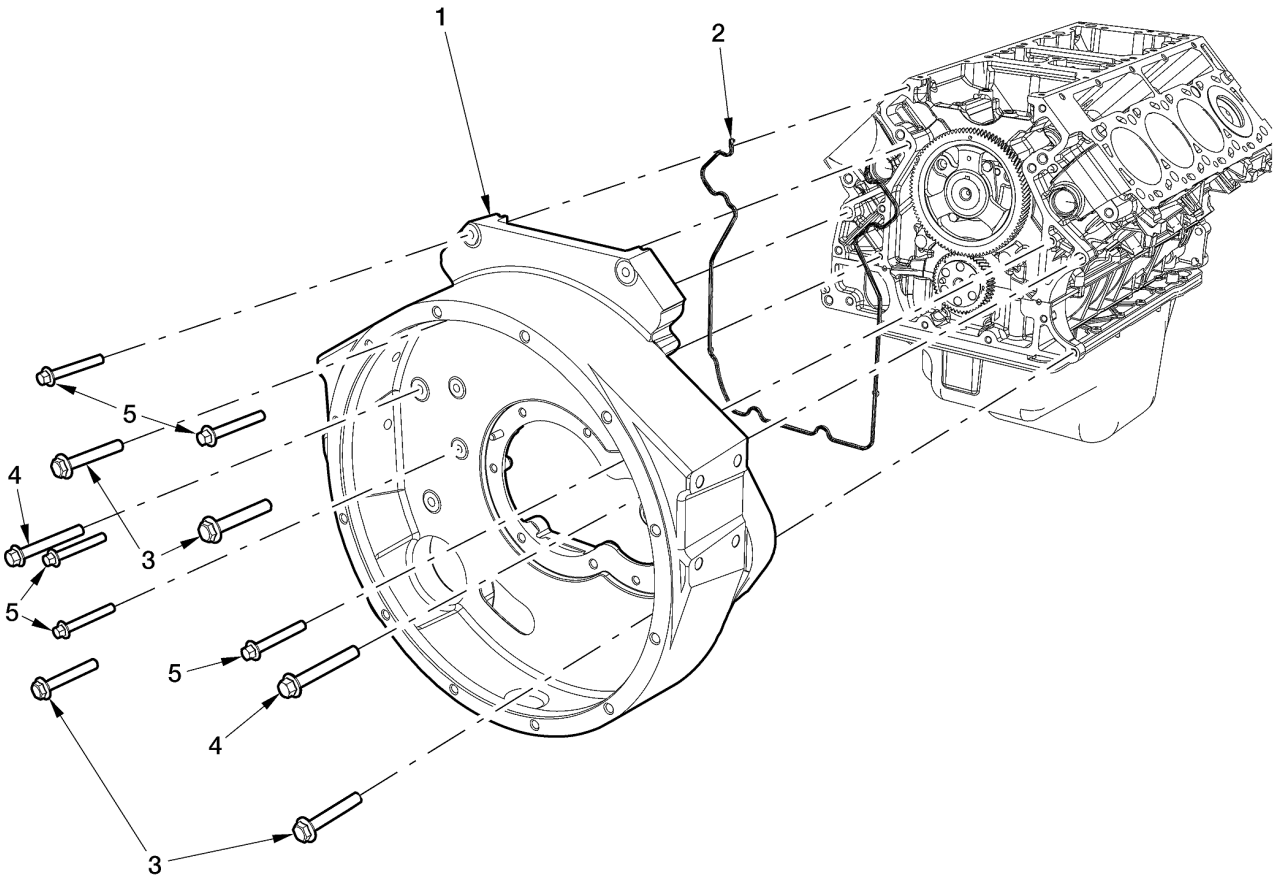


Figure 569 Crankshaft Flange and Power Steering Idler Gear Assembly

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)



M10123

Figure 570 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: See the following service sections for information on removal of components prior to this section.

- **Engine Electrical**
- **Exhaust Gas Recirculation (EGR) System**
- **Dual Stage Turbocharger and Exhaust Manifolds**
- **Air Compressor and Power Steering Pump**
- **Fuel System**
- **Front Cover, Cooling System, and Related components**
- **Oil Cooler, Oil Pump, Oil Filter, and Oil Pan**
- **Cylinder Heads, Valve Covers, and Valve Train**

Engine Mount Rear Brackets

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

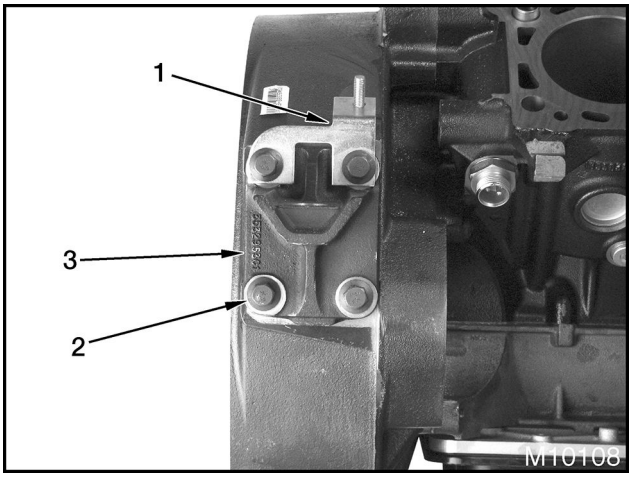


Figure 571 Engine Mount Rear Bracket (Right)

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.

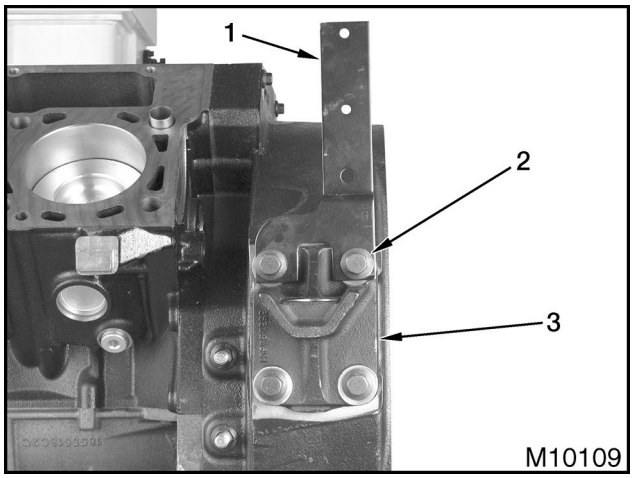


Figure 572 Engine Mount Rear Bracket (Left)

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)

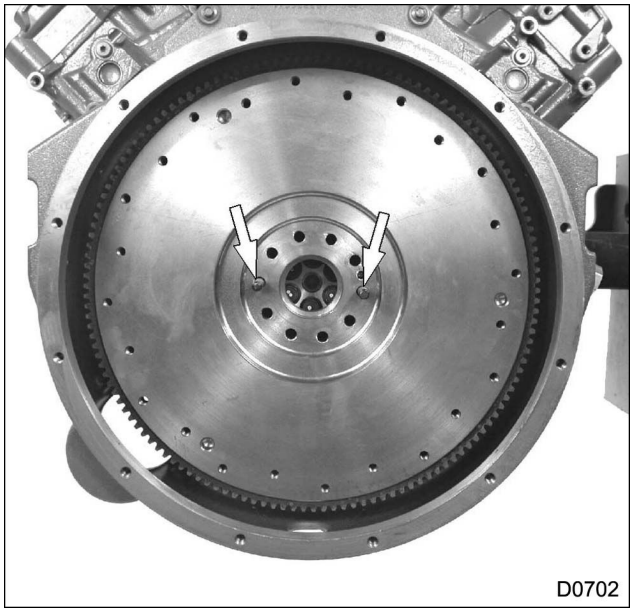


Figure 573 Flywheel Assembly Guide Pins

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.

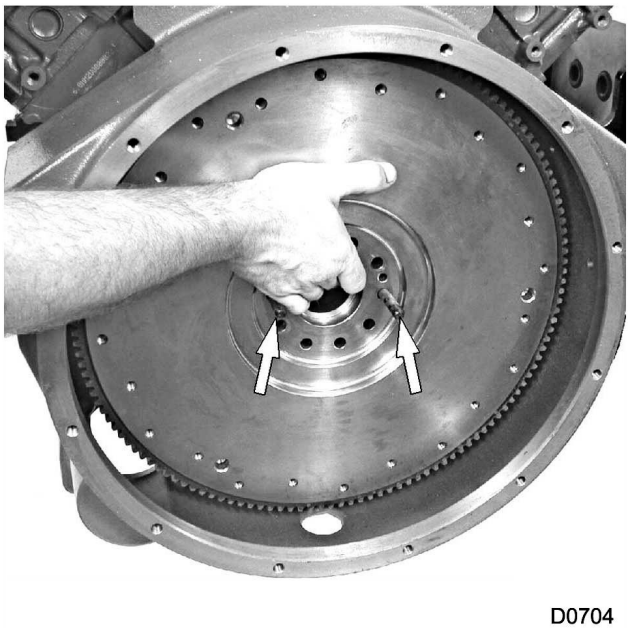
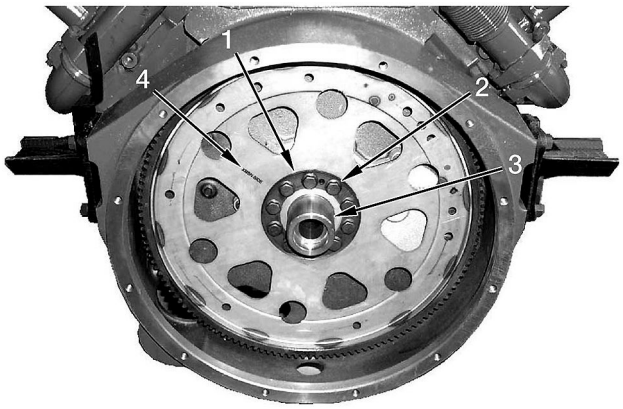


Figure 574 Flywheel Assembly Removal

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)



M10124

Figure 575 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.

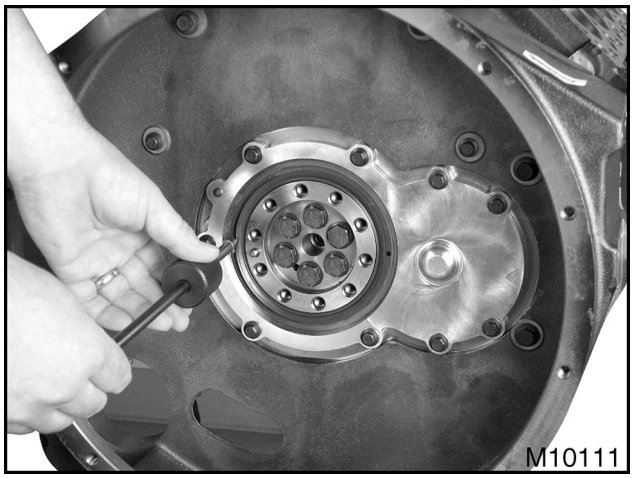


Figure 576 Crankshaft Rear Oil Seal Removal

2. Thread slide hammer (page 393) 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.

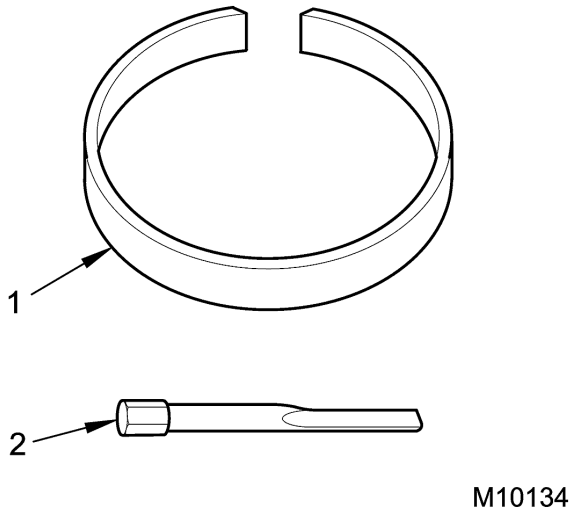


Figure 577 Rear Wear Sleeve Remover

1. Distorter Ring
2. Distorter Shaft

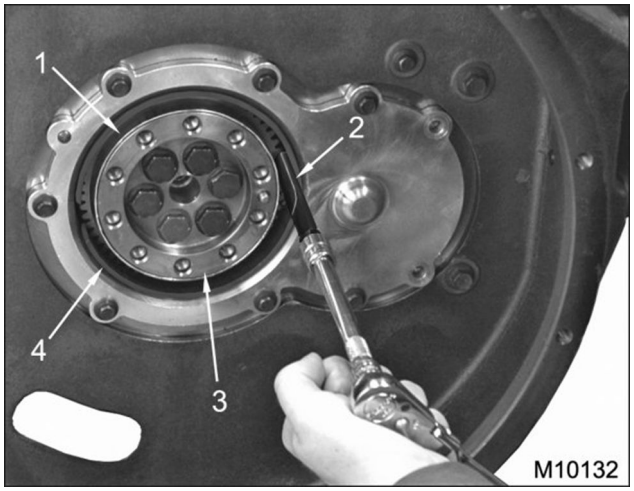


Figure 578 Rear Wear Sleeve Removal

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 393).

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 90° apart.
9. Remove wear sleeve.
10. Remove Distorter Ring.

Crankshaft Rear Oil Seal Carrier and Power Steering Idler Gear Assembly

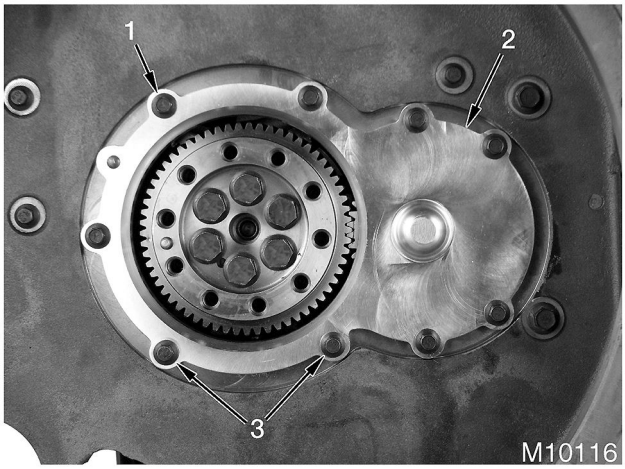


Figure 579 Crankshaft Rear Oil Seal Carrier

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 383).

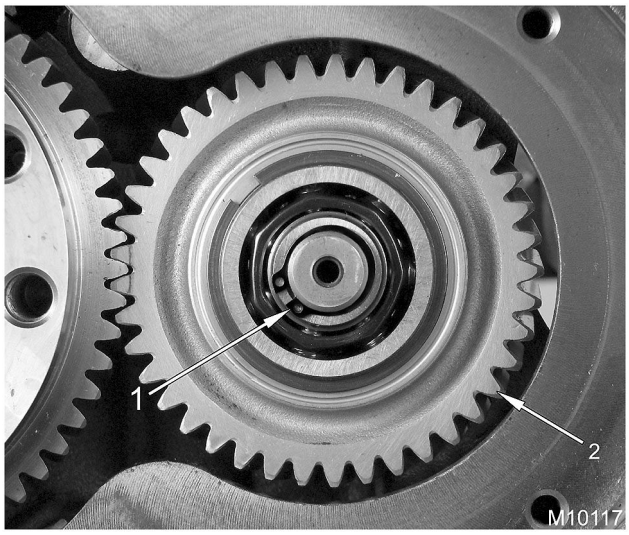


Figure 580 Power Steering Idler Gear Assembly

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 393).
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.

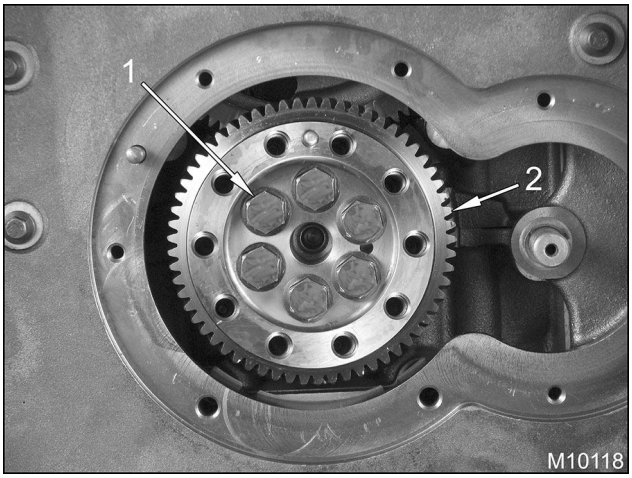


Figure 581 Crankshaft Flange

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 393) 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.

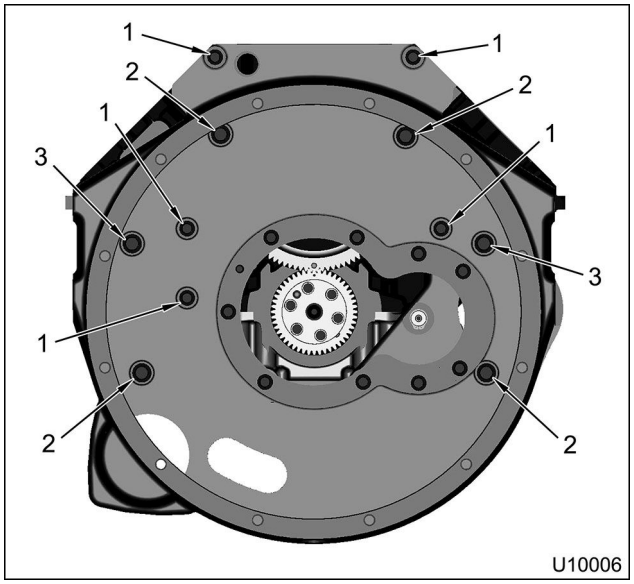


Figure 582 Flywheel Housing Mounting Bolts

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

CAUTION: To prevent engine damage, when removing flywheel housing, do not pull out crankcase lower seals between upper and lower crankcase.

1. Remove 11 mounting bolts from flywheel housing.

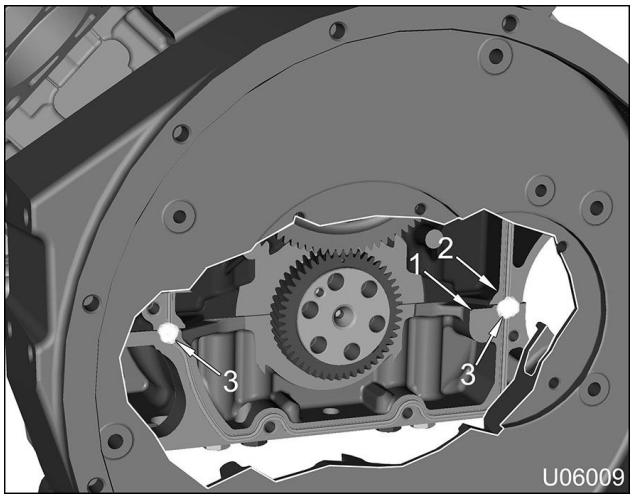


Figure 583 Liquid Gasket (RTV) Sealant (Reference)

1. Lower crankcase
2. Upper crankcase
3. RTV sealant

NOTE: Before removing flywheel housing, do steps 2 and 3 to cut through the Liquid Gasket (RTV) sealant between flywheel housing and upper and lower crankcase joint. This will prevent pulling out the crankcase lower seals, when removing the flywheel housing.

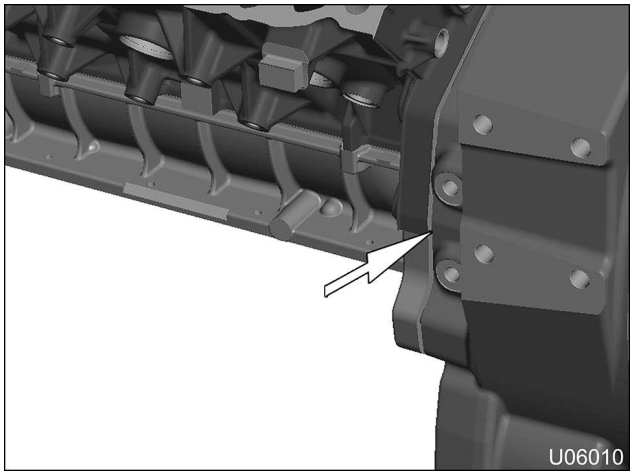


Figure 584 Left Side of Flywheel Housing

2. 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.

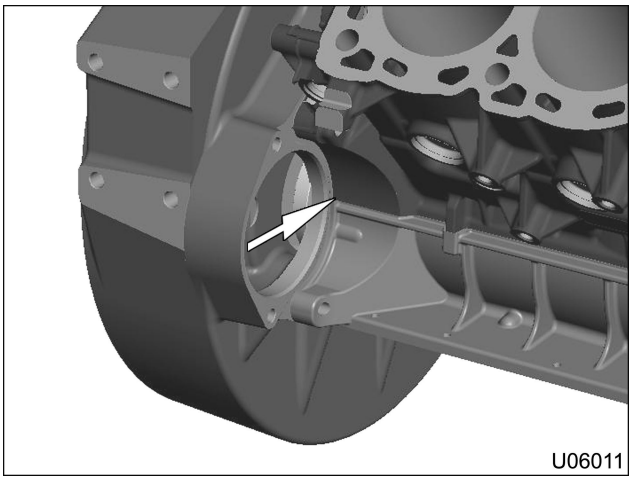


Figure 585 Right Side of Flywheel Housing

3. 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.

4. Remove flywheel housing with aid of an assistant.
5. Remove RTV and clean areas of the flywheel housing.

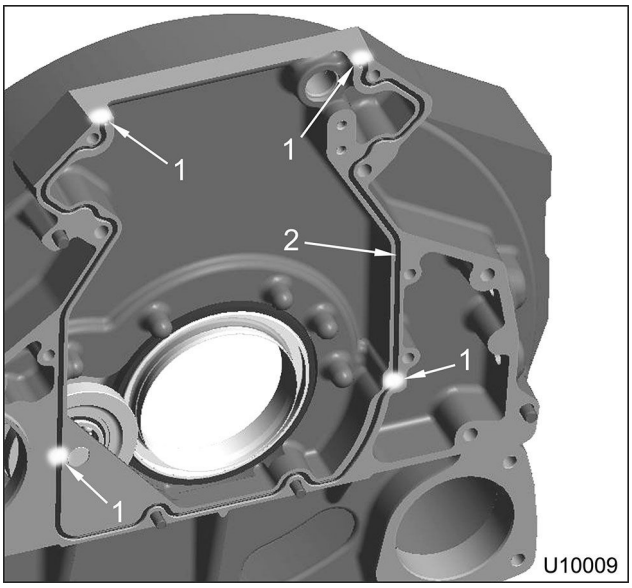


Figure 586 Removal of Rear Cover Gasket and Liquid Gasket (RTV)

1. Liquid Gasket (RTV)
2. Rear cover gasket

6. Remove and discard crankcase rear cover gasket.
7. Remove RTV and clean areas of the flywheel housing.
8. If necessary, use a slide hammer (page 393) to remove power steering idler shaft.

Cleaning, Inspection, and Measurement

All Components

⚠ 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 suitable 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.

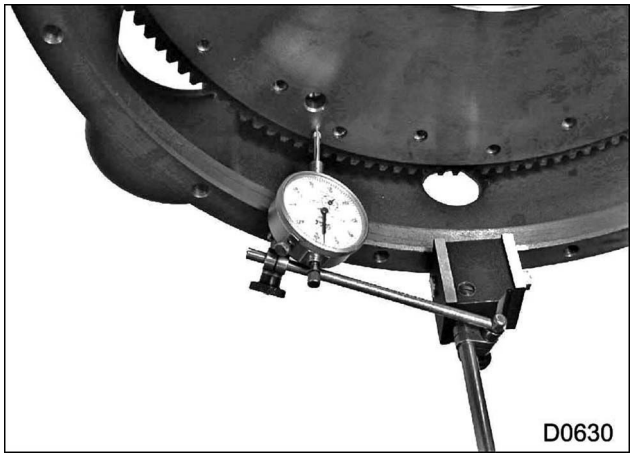


Figure 587 Flywheel Surface Runout

1. Attach dial indicator with magnetic base (page 393) 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 393).

Flywheel Housing Runout

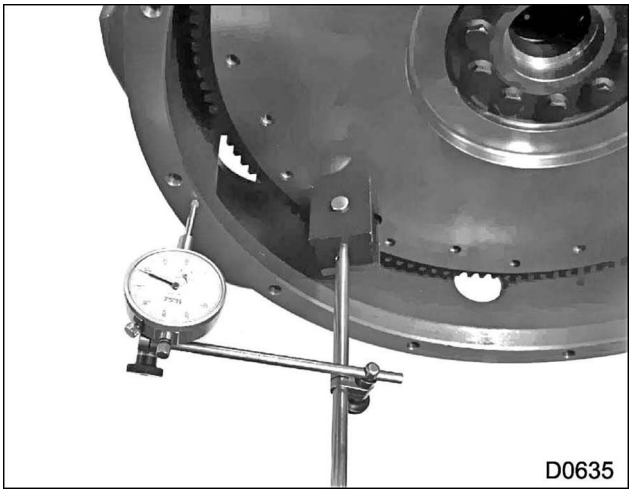


Figure 588 Flywheel Housing Runout

1. Attach dial indicator with magnetic base (page 393) 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 393).

Backlash Measurement for Power Steering Idler Gear Assembly

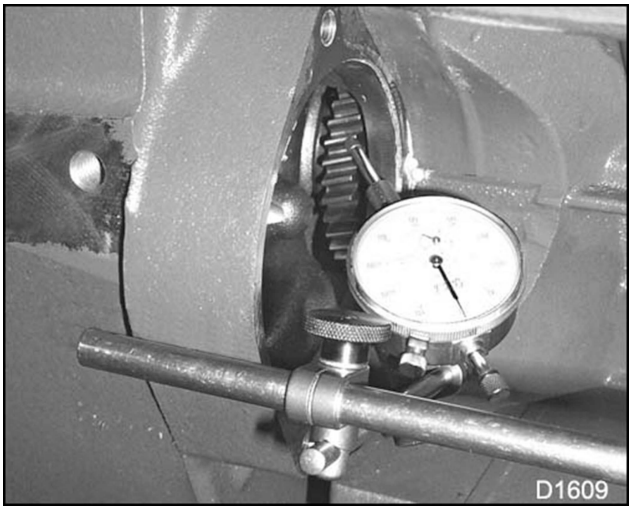


Figure 589 Power Steering Idler Gear Assembly Backlash (Typical)

1. Attach dial indicator with magnetic base (page 393) to flywheel housing.
2. Place indicator tip against power steering idler gear assembly.

NOTE: Lock crankshaft flange for an accurate measurement.

3. Lock crankshaft flange.
4. Zero the dial indicator.
5. Move power steering idler gear assembly and record dial indicator reading. Verify reading is within specification (page 393). If out of inspection, install a new gear.

Installation

Flywheel Housing

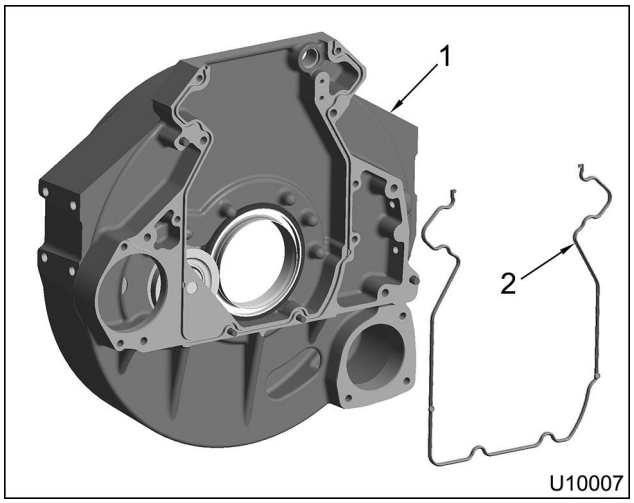


Figure 590 Rear Cover Gasket

1. Rear cover (flywheel housing)
2. Rear cover gasket

1. Install new crankcase rear cover gasket.

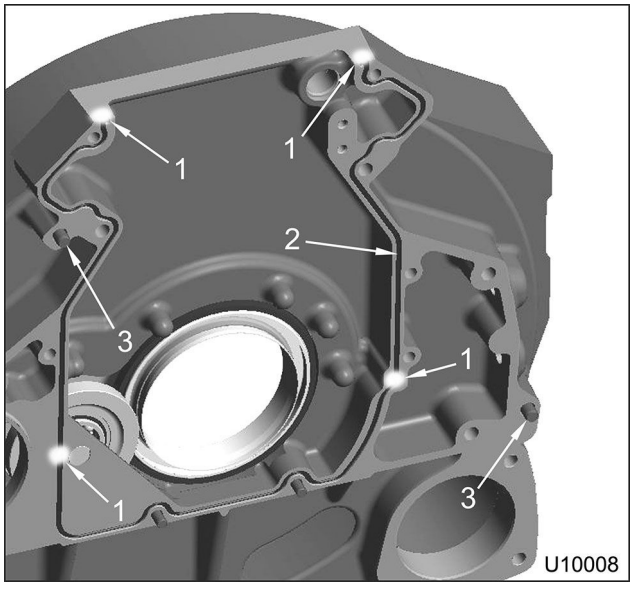


Figure 591 Liquid Gasket (RTV) and Assembly Pins

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 393) 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. Install flywheel housing, with aid from an assistant.

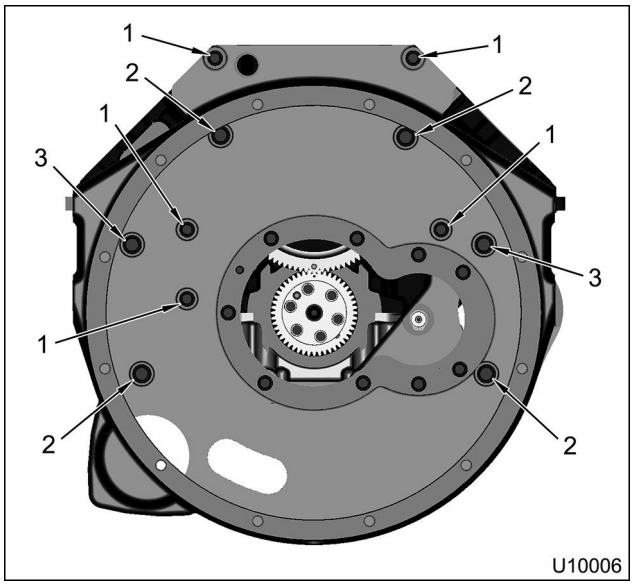


Figure 592 Flywheel Housing Mounting Bolts

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 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.

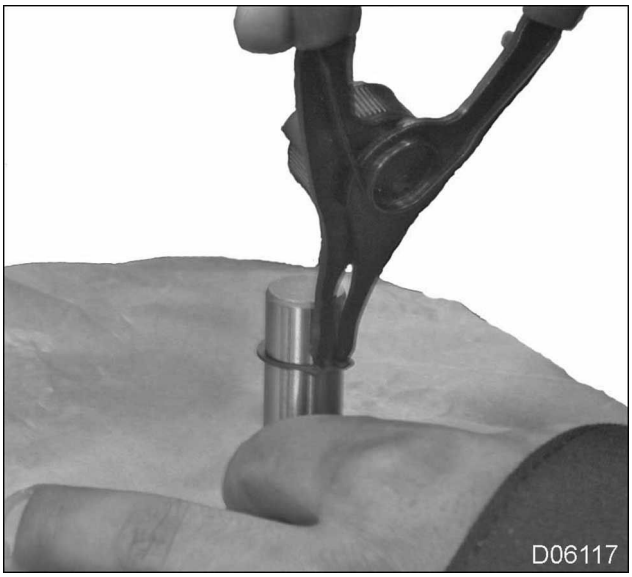


Figure 593 External Retaining Ring on Power Steering Idler Shaft

1. Place external retaining ring on end of power steering idler shaft without threaded hole.

Figure 594 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 393) to set correct shaft height (page 393).

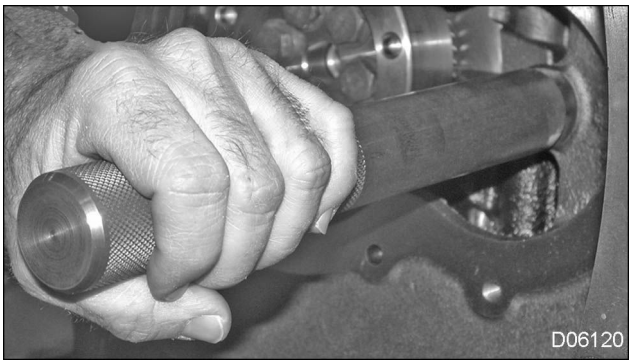


Figure 595 Power Steering Idler Shaft Installation

⚠ 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.

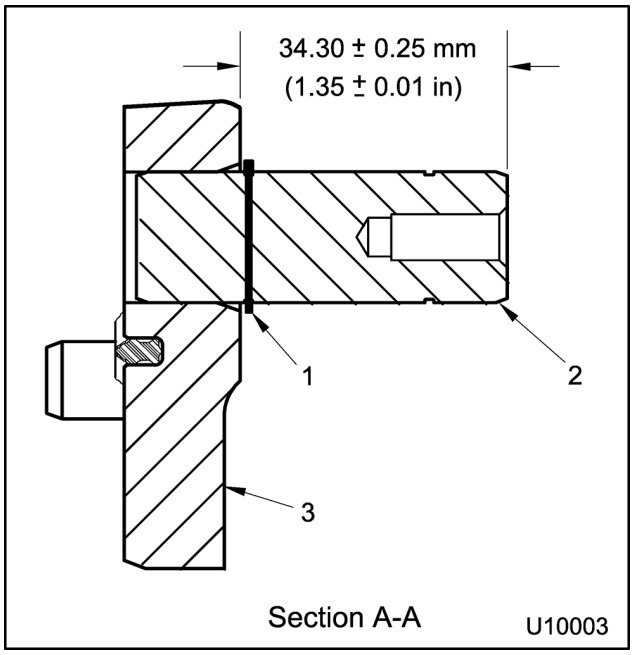


Figure 596 Power Steering Idler Shaft Installation Height

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.

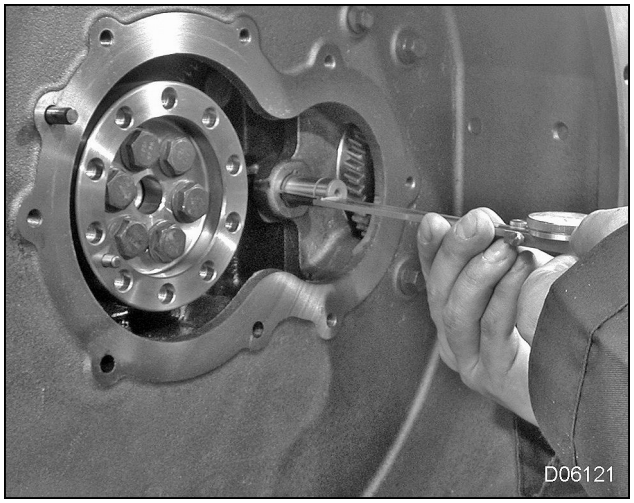


Figure 597 Power Steering Idler Shaft Height Measurement

5. Measure power steering idler shaft height, using a dial caliper (page 393). Power steering idler shaft height should match specification (page 393).

Crankshaft Flange

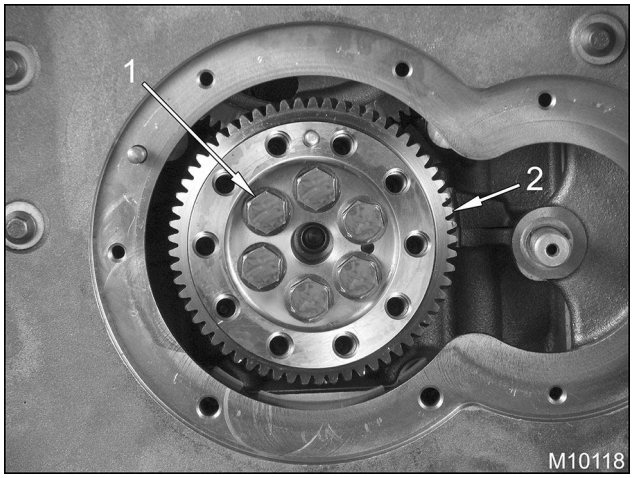


Figure 598 Crankshaft Flange

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 393). If face runout exceeds specification (page 393), 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.

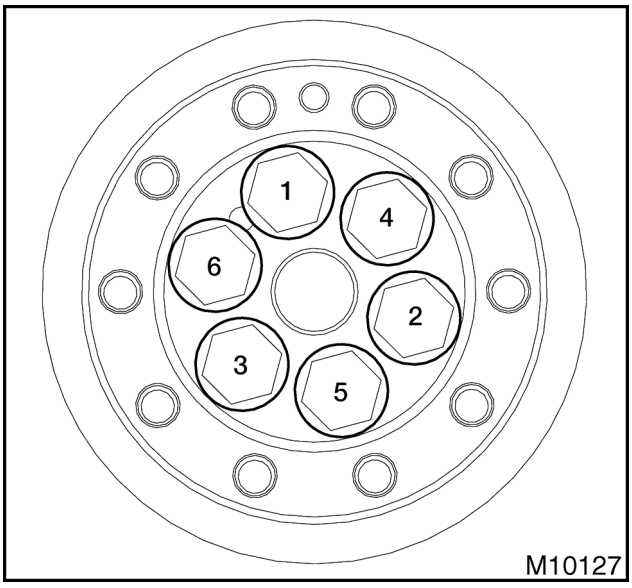


Figure 599 Crankshaft Flange Torque Sequence

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 lb·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. Install power steering idler gear assembly on power steering idler shaft.
2. Verify correct gear orientation and gear tooth engagement.

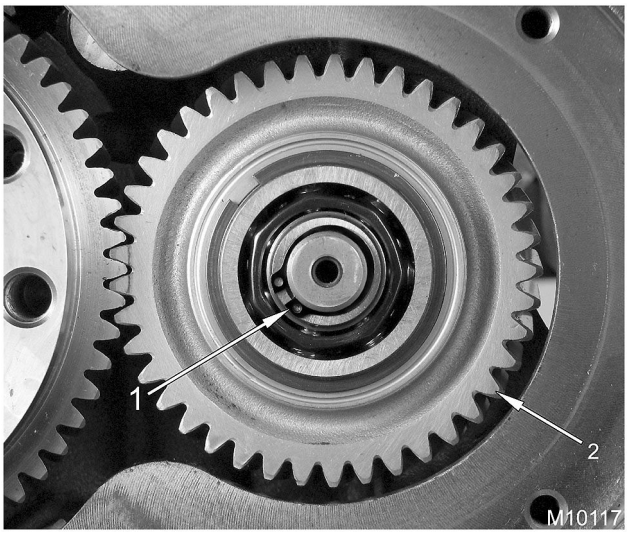


Figure 600 Power Steering Idler Gear Assembly

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 383).
5. Install new rear seal carrier gasket on crankshaft rear oil seal carrier.

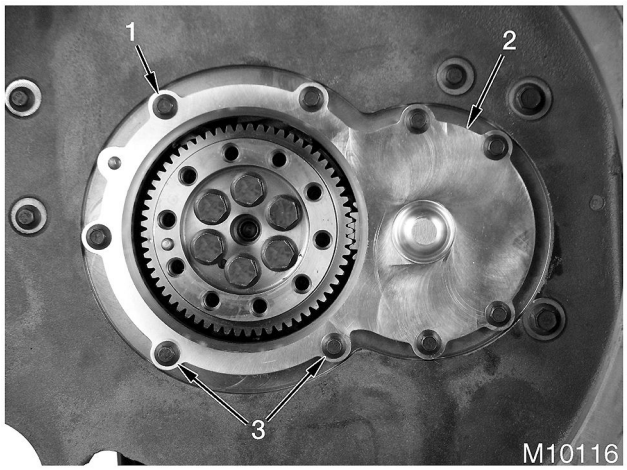


Figure 601 Crankshaft Rear Oil Seal Carrier

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.

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.

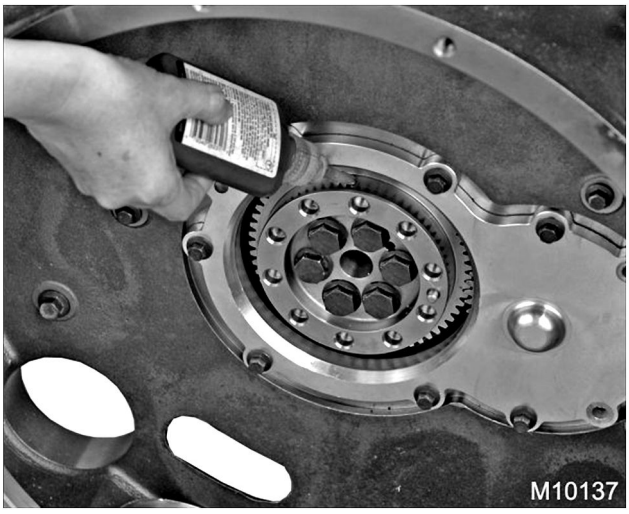


Figure 602 Application of Hydraulic Sealant

2. Apply a 360° bead of Loctite® 569 Hydraulic Sealant (page 393) on rear edge of crankshaft flange.

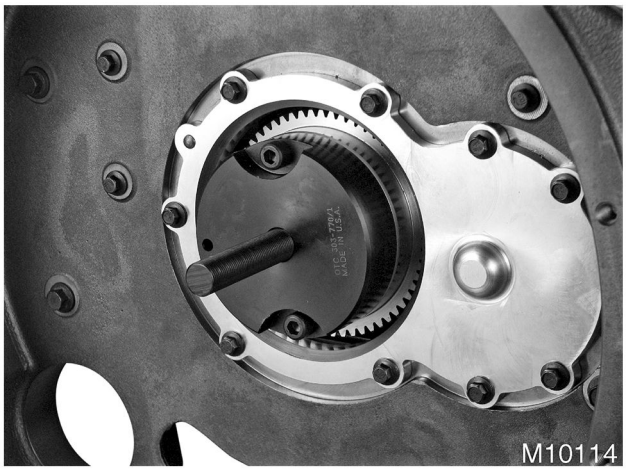


Figure 603 Crankshaft Rear Seal / Wear Sleeve Installer (Base)

3. Align base of Crankshaft Rear Seal / Wear Sleeve Installer (page 393) 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.

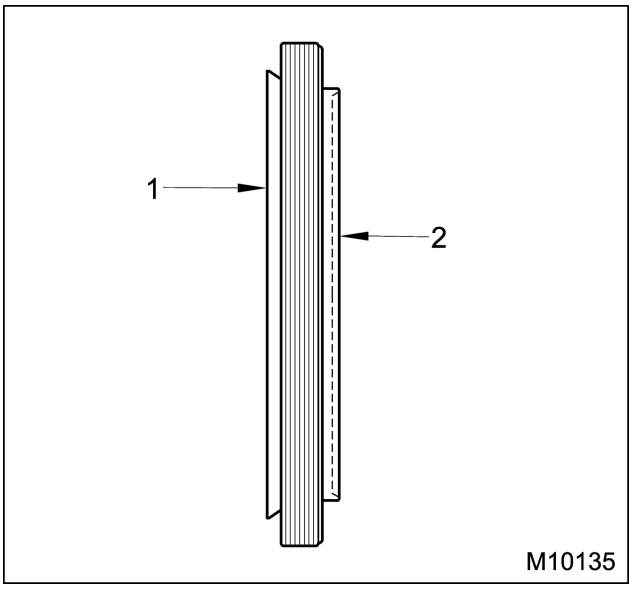


Figure 604 Crankshaft Rear Oil Seal and Wear Sleeve Assembly

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.

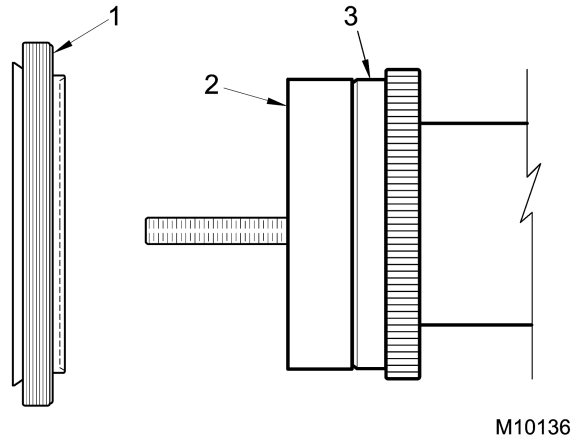


Figure 605 Installation of Crankshaft Rear Oil Seal and Wear Sleeve Assembly

1. Crankshaft rear oil seal and wear sleeve assembly
2. Rear Oil Seal Installer (base)
3. Crankshaft flange

4. Position a new crankshaft rear oil seal and wear sleeve assembly onto hub of Crankshaft Rear Seal / Wear Sleeve Installer (page 393).

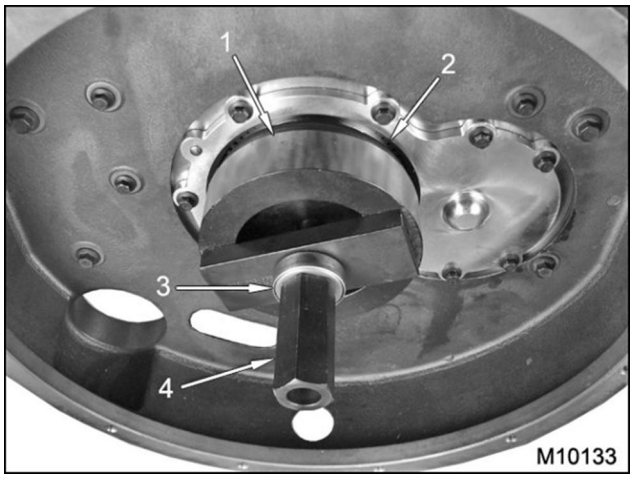


Figure 606 Installation of Crankshaft Rear Oil Seal and Wear Sleeve Assembly

1. Rear Seal Installer with 40 mm Cap Screws (forcing collar)
2. Crankshaft Rear Seal / Wear sleeve Installer
3. Thrust bearing
4. Drive nut

5. Put forcing collar (page 393), 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)

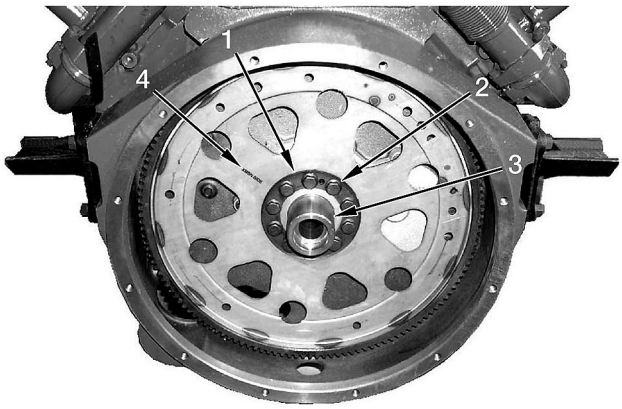


Figure 607 Flex Plate Flywheel Assembly

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.

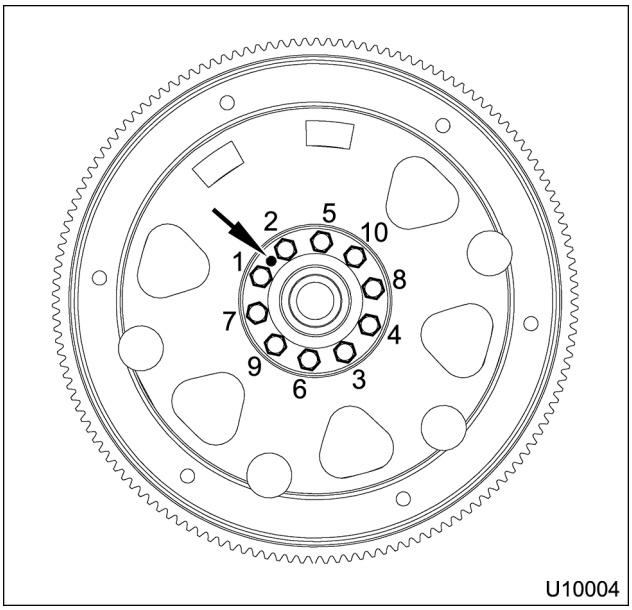


Figure 608 Torque Sequence for Flex Plate Flywheel Assembly Bolts and Dowel Location

NOTE: New phosphate coated bolts do not require oil before torquing.

4. Snug all bolts in sequence shown (Figure 608) to initial torque of 4 N·m (35 lb·in).
5. Tighten all bolts in sequence shown (Figure 608) to final torque of 94 N·m (69 lb·ft).

Flywheel Assembly (Manual Transmission)

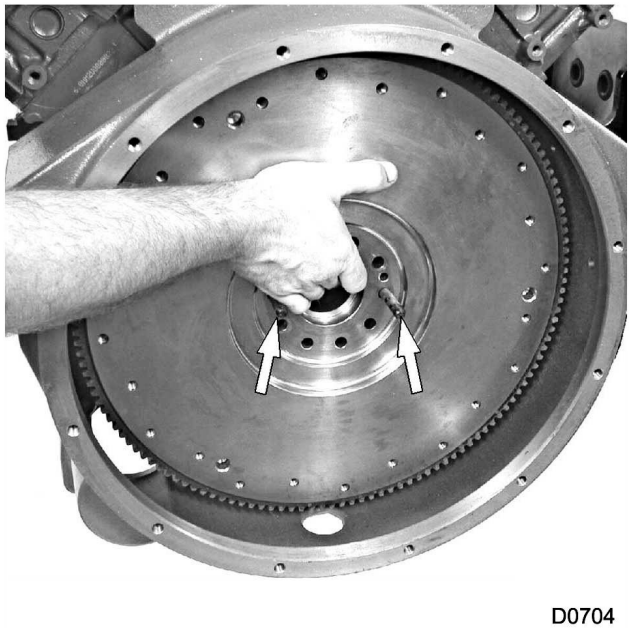


Figure 609 Flywheel Assembly Installation (Typical)

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.

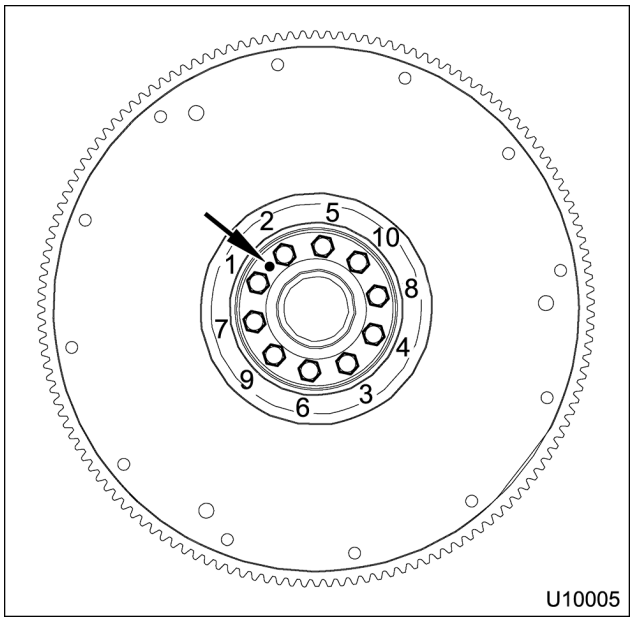


Figure 610 Torque Sequence for Flywheel Assembly Bolts and Dowel Location

NOTE: New phosphate coated bolts do not require oil before torquing.

6. Snug all bolts in sequence shown (Figure 610) to initial torque of 4 N·m (35 lb·in).
7. Tighten all bolts in sequence shown (Figure 610) to final torque of 94 N·m (69 lb·ft).
8. Measure Flywheel Surface Runout. (page 382).

Engine Mount Rear Brackets

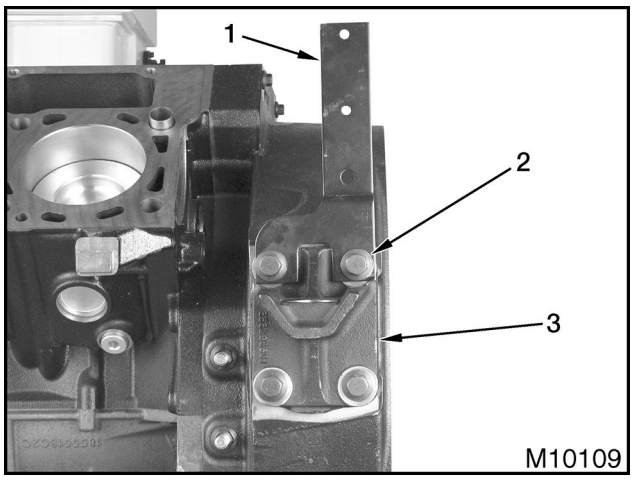


Figure 611 Engine Mount Rear Bracket (Left)

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.

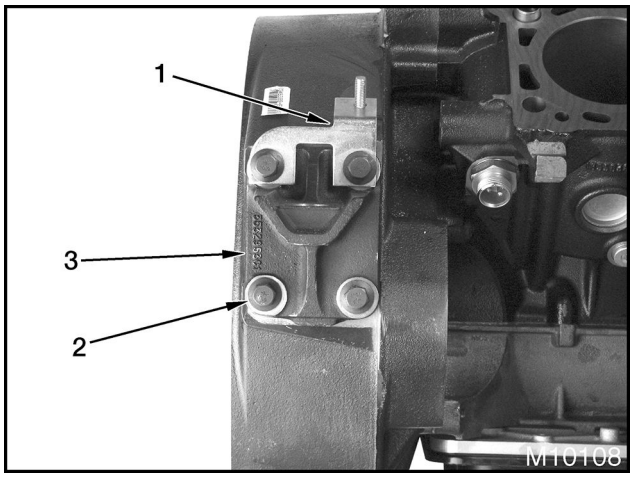


Figure 612 Engine Mount Rear Bracket (Right)

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.

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
Rear Crankshaft Seal and Sleeve Installer	ZTSE4515C
Rear Wear Sleeve Remover (Distorter Ring and Distorter Shaft)	ZTSE4889
Slide hammer	Obtain locally
Heat insulated glove	Obtain locally

Table of Contents

Exploded View.....397

Removal.....398
- **Piston Protrusion Measurement**.....399
- **Connecting Rod Side Clearance Measurement**.....399
- **Connecting Rod and Piston Assembly**.....400
- **Piston Disassembly**.....401

Cleaning, Inspection, and Measurement.....403
- **Cleaning and Inspection**.....403
- **Piston Measurement**.....403
- **Piston Rings**.....405
- **Connecting Rods**.....405
- **Connecting Rod Bore Out-of-round Measurement**.....406
- **Connecting Rod Bearing Fit Measurement**.....407
- **Piston Pin Inspection**.....407

Installation.....409
- **Piston Assembly**.....409
- **Connecting Rod and Piston Assembly**.....411

Specifications.....414

Special Torque.....415

Special Service Tools.....415

Exploded View

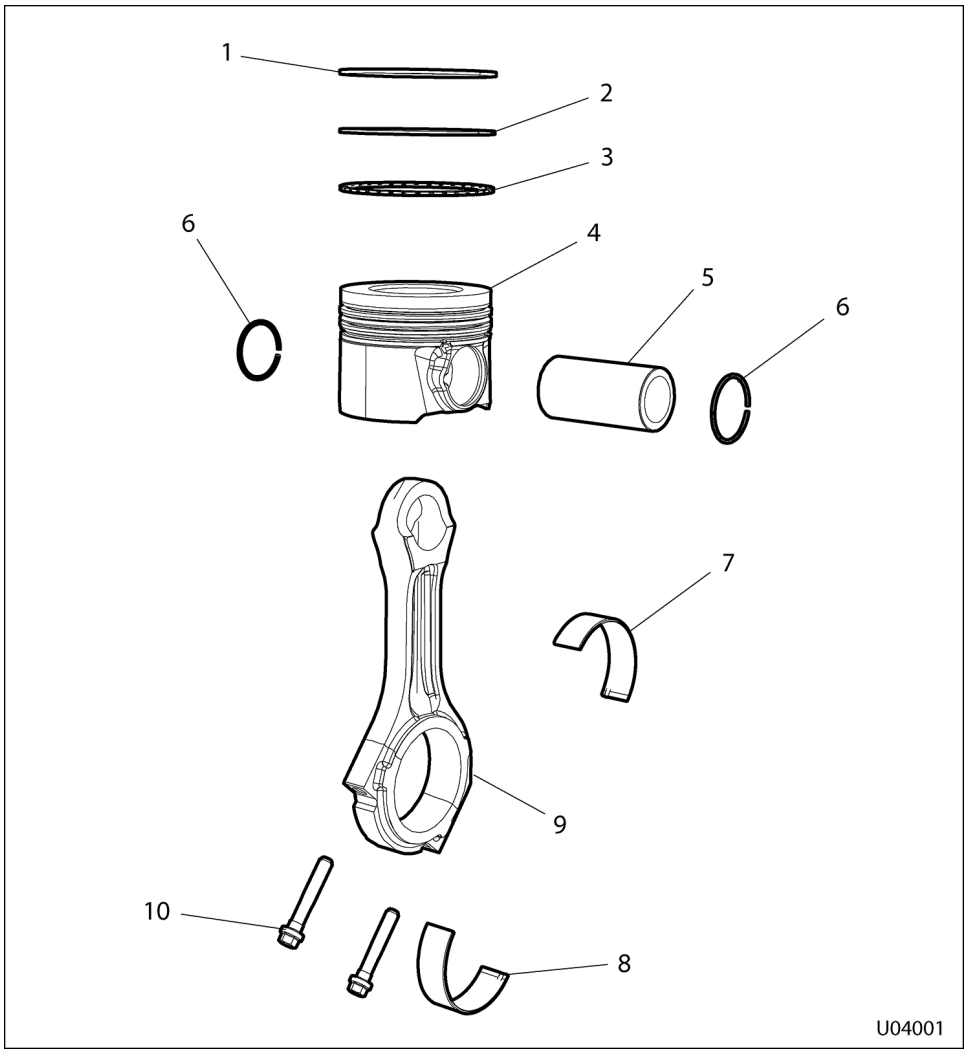


Figure 613 Piston, Piston Pin, and Connecting Rod

1. Top compression ring
2. Intermediate compression ring
3. Oil control ring
4. Piston
5. Piston pin with coating
6. Piston pin retainer ring (2)
7. Upper connecting rod bearing
8. Lower connecting rod bearing
9. Connecting rod assembly (rod and cap)
10. Connecting rod bolt (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, 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.

- **Mounting Engine on Engine Stand**
- **Engine Electrical**
- **Exhaust Gas Recirculation (EGR) System**
- **Dual Turbocharger, Exhaust Manifolds, and Piping**
- **Air Compressor and Power Steering Pump**
- **Fuel System**
- **Front Cover, Cooling System, and Related Components**
- **Cylinder Heads, Valve Covers, and Valve Train**
- **Oil Cooler, Oil Pump, Oil Filter, and Oil Pan**

Piston Protrusion Measurement

CAUTION: To prevent engine damage, do not scratch gasket surface of cylinder head.

NOTE: Evaluate piston protrusion before removing any piston and connecting rod assemblies. This will help identify bent or twisted connecting rods.

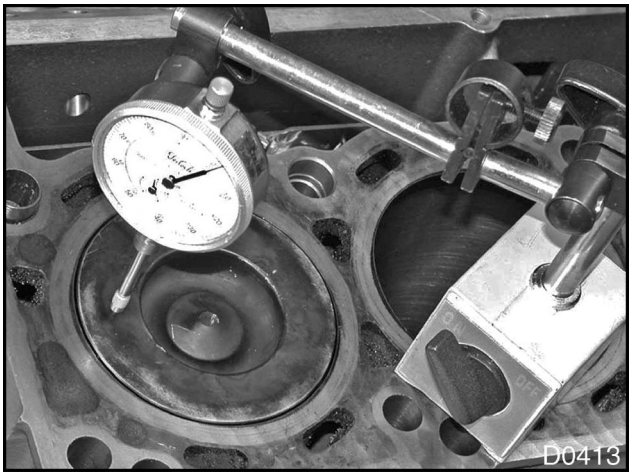


Figure 614 Measuring Piston Protrusion

NOTE: Before checking piston protrusion, make sure upper crankcase assembly deck surface is flat and level. See Crankcase Inspection(page 429).

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

1. Check piston protrusion above upper crankcase assembly as follows:
   a. Zero dial indicator with magnetic base (page 415) on upper crankcase assembly deck surface.
   b. Position dial indicator tip over piston head at 3 o'clock position.
   c. Rotate crankshaft 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 piston height above crankcase deck (protrusion) specifications (page 414).

Connecting Rod Side Clearance Measurement

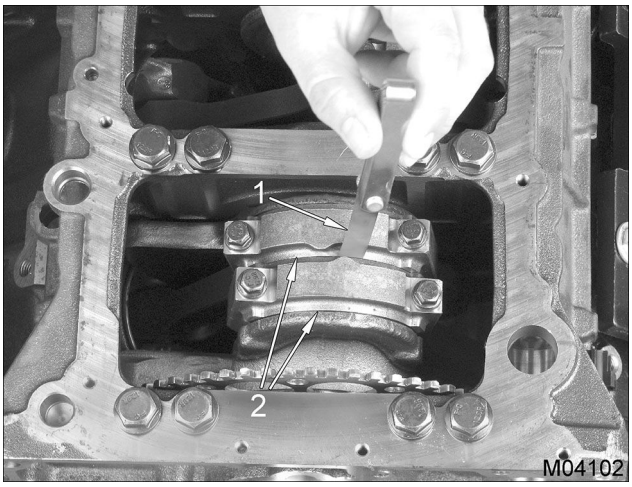


Figure 615 Side Clearance Measurement For Connecting Rod and Cap (typical)

1. Feeler gauge
2. Connecting rod and cap

1. Use a feeler gauge (page 415) 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 connecting rod side clearance specification (page 414).

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

Connecting Rod and Piston Assembly

1. Measure piston protrusion (page 399) and connecting rod side clearance (page 399).

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 connecting rod and piston assemblies.

2. Scrape carbon ridge from top of cylinder bore, if necessary. Use care not to damage cylinder bore surface.

3. Rotate crankshaft to correctly position journals for removal of connecting rod assemblies.

CAUTION: Use permanent markers to identify components or their orientation. Do not use paint or temporary markers.

4. Mark each connecting rod location and connecting rod cap orientation.

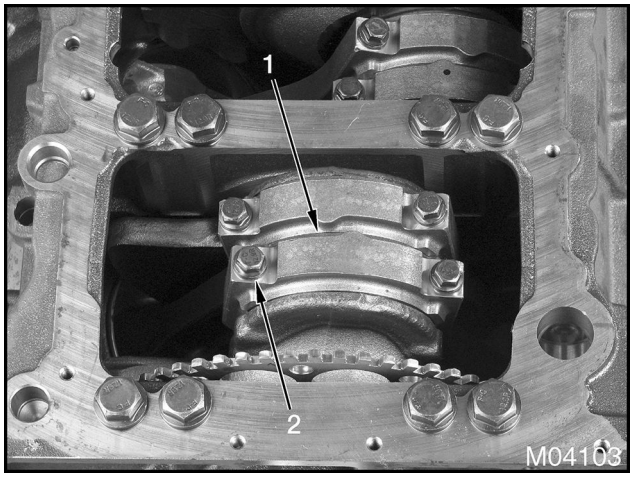


Figure 616 Connecting Rods and Bolts (typical)

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

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.

5. Loosen two connecting rod bolts and remove connecting rod cap.

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

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.

6. 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.

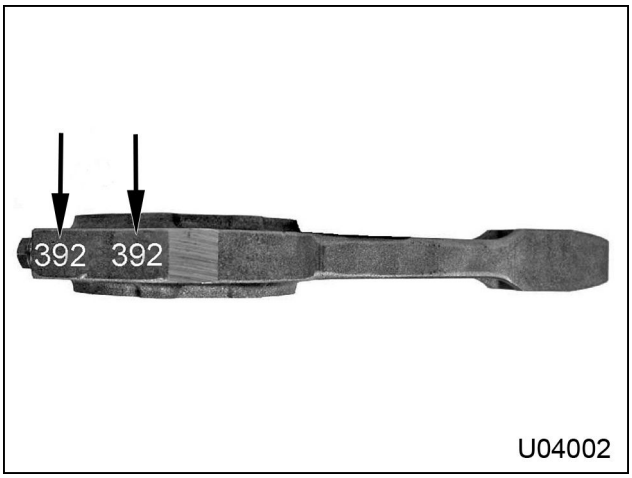


Figure 617 Connecting Rod and Cap Matching Numbers or Symbols

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 damage the mating surfaces, causing incorrect mating of rod and cap.

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, install connecting rod cap and connecting rod with matching serial numbers on the same side. If the rod cap is reversed or not installed on its matching connecting rod, the fractured mating surfaces will be damaged. This can loosen the rod cap. A new connecting rod assembly must be installed.

7. 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.
8. Check the crankshaft crankpin fillets for damage. If crankpin fillets are damaged, replace crankshaft assembly. See Crankshaft Assembly (page 422).

Piston Disassembly

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

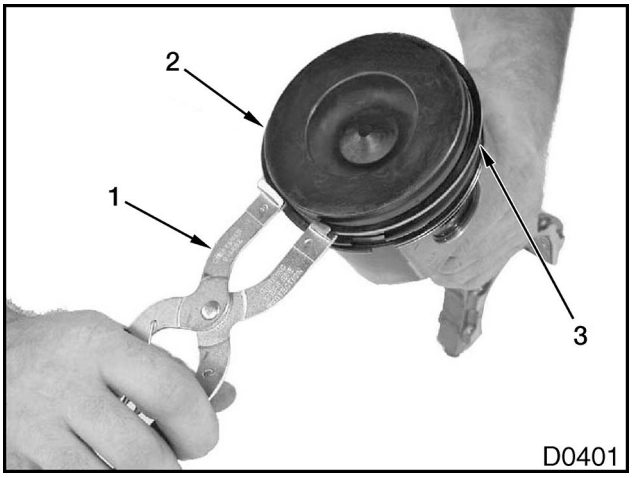


Figure 618 Piston Ring Removal (typical)

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 415) to remove top compression ring, intermediate compression ring, and oil control ring.

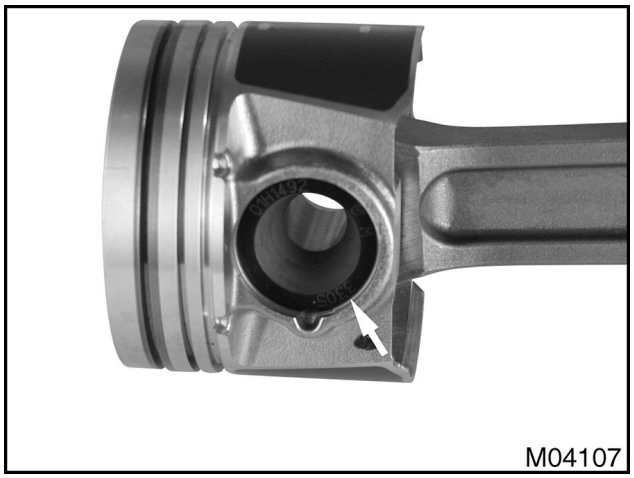


Figure 619 Piston Pin Retainer Ring (typical)

2. Use a small pick to remove both piston pin retainer rings.

CAUTION: Mark piston pin on flat end or tapered inside surface, for cylinder location and orientation. Do not mark on outer diameter.

CAUTION: Use permanent markers to identify components or their orientation. Do not use paint or temporary markers.

3. Remove piston pin from its bore by hand, and separate connecting rod from piston.

Cleaning, Inspection, and Measurement

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 suitable solvent:
   - Piston pins
   - Piston pin retainer rings
4. Thoroughly clean connecting rod bolt holes and threads.

Piston Measurement

1. Inspect pistons for excessively 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.

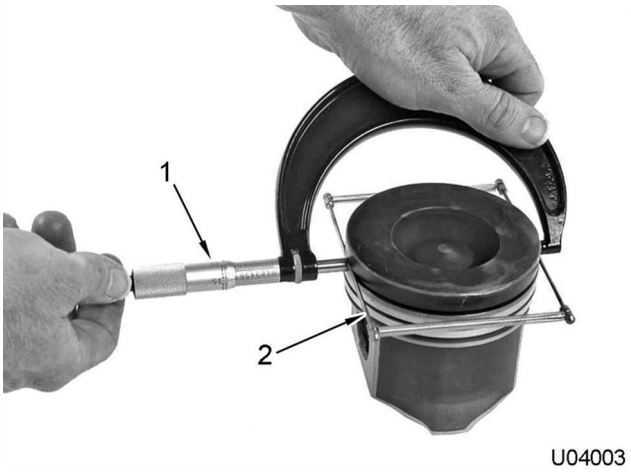


Figure 620 Top Compression Ring Groove Measurement (typical)

1. 3 - 4 inch micrometer
2. Piston Gauge Pins [2.10 mm (0.083 in)]

2. Check top compression ring groove for wear.
   a. Install Piston Gauge Pins [2.10 mm (0.083 in)] (page 415) in the top compression ring groove. Piston Gauge Pins must be parallel.
   b. Use a 3 - 4 inch micrometer (page 415) to measure the diameter over piston gauge pins.
   c. If measurement over gauge pins is not within top compression ring groove width specifications (page 414), excessive piston groove wear exists. Replace piston.

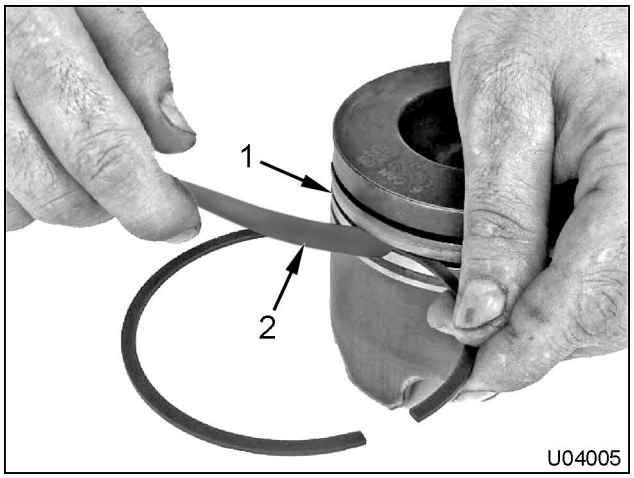


Figure 621 Intermediate and Oil Ring Groove Clearance Measurement (Intermediate Ring Shown, typical)

1. Intermediate compression ring groove
2. Feeler gauge

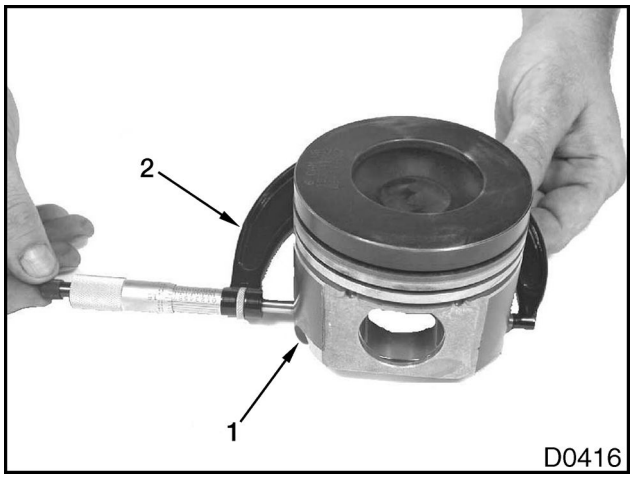


Figure 622 Piston Skirt Diameter Measurement (typical)

1. Piston skirt
2. 3 - 4 inch micrometer

3. Check side clearance of intermediate compression and oil control ring grooves 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 groove.
   c. Use a feeler gauge (page 415) to measure intermediate and oil ring groove side clearance (page 414). Excessive side clearance indicates ring groove wear and requires piston replacement.
4. When considering piston replacement, check cylinder bores. See Crankcase Inspection (page 429). Cylinder boring may be required. Bore reconditioning requires oversize service pistons.
5. Measuring piston skirt diameter under conditions indicated in specifications (page 414).

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)**

6. If cylinder walls have minor surface damage, but are otherwise within specification, 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 415), then reassemble.

NOTE: See Cylinder Deglazing (page 430) for correct procedure.

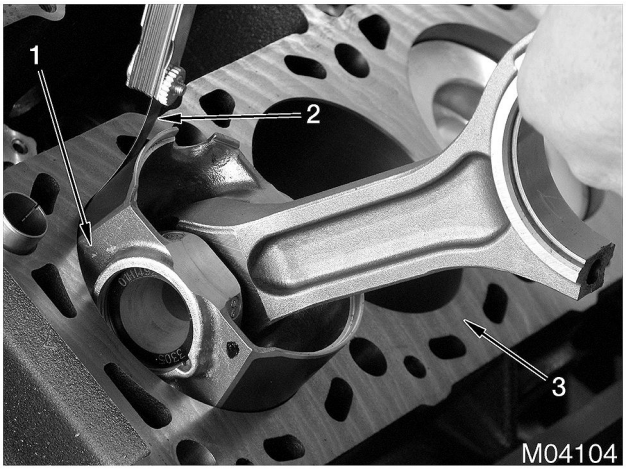


Figure 623 Piston Skirt Clearance Measurement, in Cylinder Bore (typical)

1. Piston
2. Feeler gauge
3. Upper crankcase

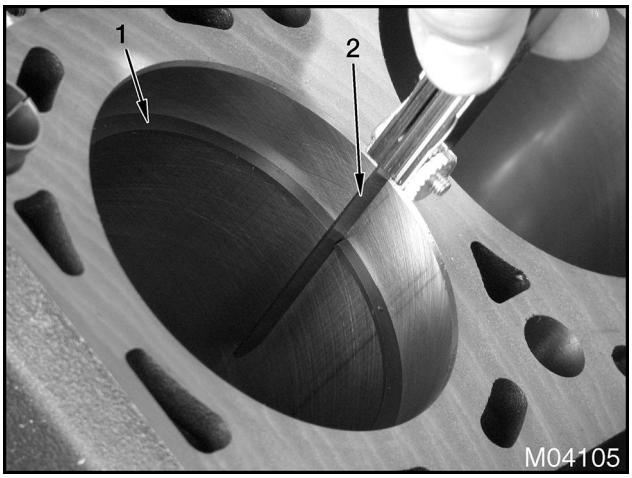


Figure 624 Piston Ring End Gap Clearance in Cylinder Bore

1. Piston ring
2. Feeler gauge

7. Measure piston skirt clearance (page 414). 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 end 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 415) to measure gap between ends of each piston ring.
   c. If gap does not meet specifications (page 414), select another ring or recheck cylinder bore wear.

Connecting Rods

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

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.

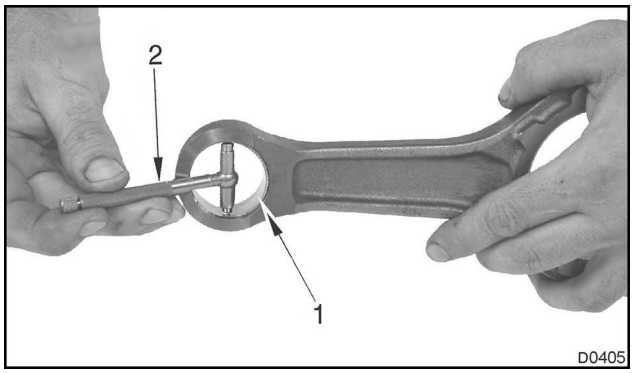


Figure 625 Inside Diameter of Piston Pin Bore

1. Piston pin bore
2. Telescoping gauge

3. Inspect connecting rod piston pin bore for wear as follows:
   a. Use a telescoping gauge (page 415) and a 1-2 inch micrometer (page 415) to measure piston pin bore at two locations 90° apart.
   b. If piston pin bore inside diameter exceeds specification (page 414), replace connecting rod.

Connecting Rod Bore Out-of-round Measurement

CAUTION: To prevent engine damage, do not use power tools to remove or install connecting rod cap bolts. Threads will be damaged if a bolt or nut is rotated too quickly.

1. Lightly lubricate connecting rod bolt threads with clean engine oil. Assemble connecting rod cap to rod without bearing insert. Tighten bolts to special torque (page 415).

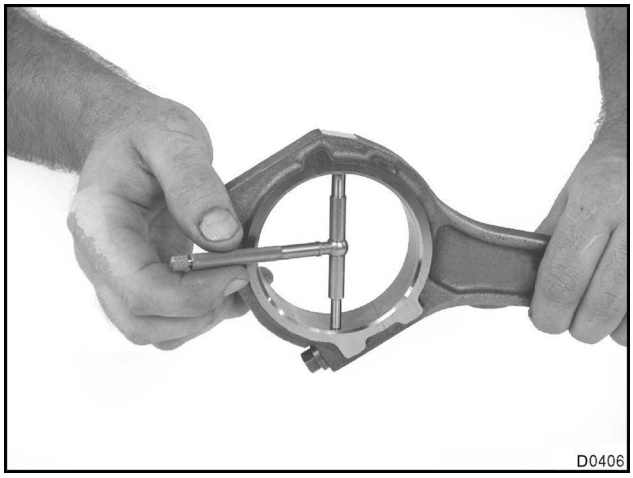


Figure 626 Connecting Rod Bearing Bore Out-of-round Measurement

2. Using a telescoping gauge (page 415), measure connecting rod bearing bore at two locations, 90° apart.
3. If the difference between dimension A and B exceeds bearing bore maximum out-of-round specifications (page 414), 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 Measurement

NOTE: Connecting rod bearings must fit tightly in the bore. When bearings are inserted into the connecting rod and cap, they protrude above parting line. This protrusion is required to achieve bearing crush. Bearing crush forces the ends inward at the parting line when a load is applied by tightening the bolts. Some 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. Lightly lubricate connecting rod bolt threads with clean engine oil. Assemble cap onto connecting rod with new bearings installed. Tighten connecting rod bolts to special torque (page 415).
2. Using a telescoping gauge (page 415), measure inside diameter of connecting rod bearing (big end) at two locations 90° apart. Average the two inside diameters.
3. Using a 2–3 inch micrometer (page 415), 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 and connecting rod.

CAUTION: To prevent engine damage, do not rework bearings or bearing caps to reduce journal-to-bearing running clearances. Grind or install a new crankshaft.

5. If connecting rod bearing running clearances exceed specifications (page 414) because of wear on crankshaft, replace or grind crankshaft and install under-size precision type bearings.

Piston Pin Inspection

NOTE: Some wear of the piston pin coating is 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.

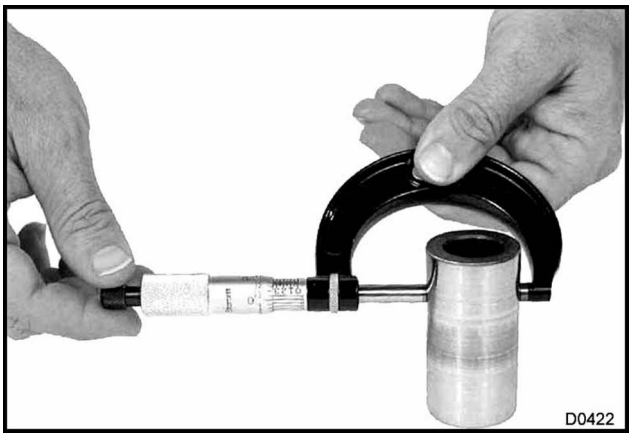


Figure 627 Piston Pin Diameter Measurement (typical)

2. Use a 1-2 inch micrometer (page 415) to measure piston pin outside diameter at two locations 90° apart. Measure each end of the pin.
3. Use a 2-3 inch micrometer to measure piston pin length.
4. If piston pin length or diameter are out of specifications (page 414), replace piston pin.

Figure 628 Inside Diameter Measurement of Piston Pin Bore

5. Using a telescoping gauge and 1–2 inch micrometer, measure each piston pin bore inside diameter, at two locations 90° apart.
6. To check piston pin clearance, subtract outside diameter of piston pin from inside diameter of piston pin bore. If clearance exceeds specifications (page 414), replace piston pin and piston.

Installation

Piston Assembly

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

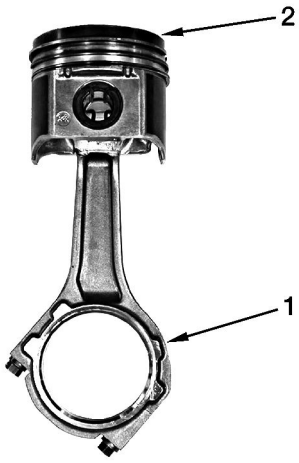


Figure 629 Correct Position of Installed Connecting Rod (typical)

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 in line with the side of the piston showing the CAM SIDE stamp on the piston crown.
   c. Place connecting rod into piston.

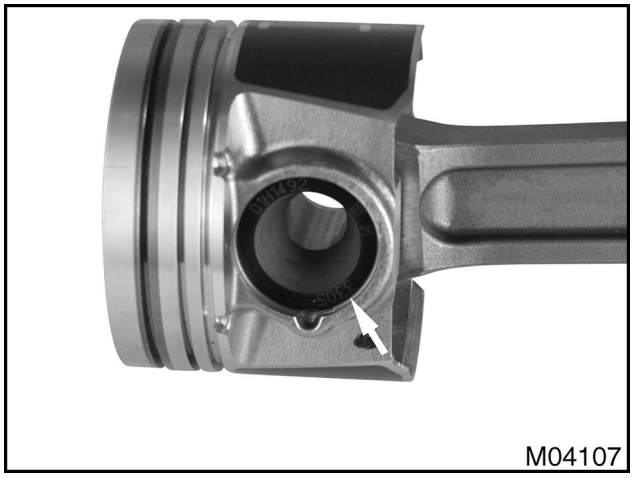


Figure 630 Piston Pin Retainer Ring

   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 piston pin end clearance (page 414).

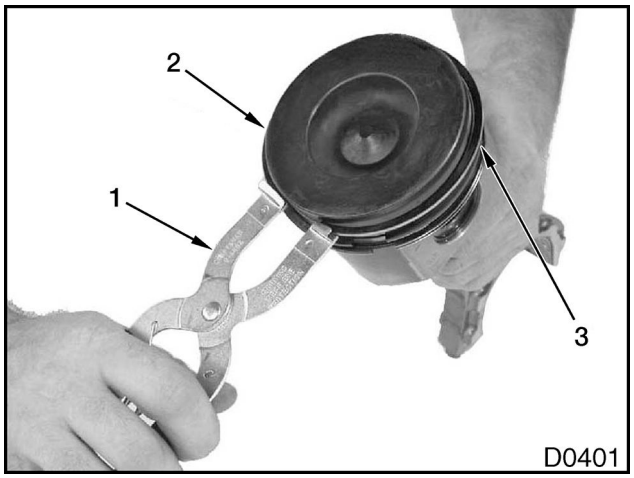


Figure 631 Piston Rings Installation (typical)

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

CAUTION: To prevent engine damage, install piston rings correctly. Both top and intermediate 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 415) to install piston rings.
   a. Install oil control ring into bottom piston groove.

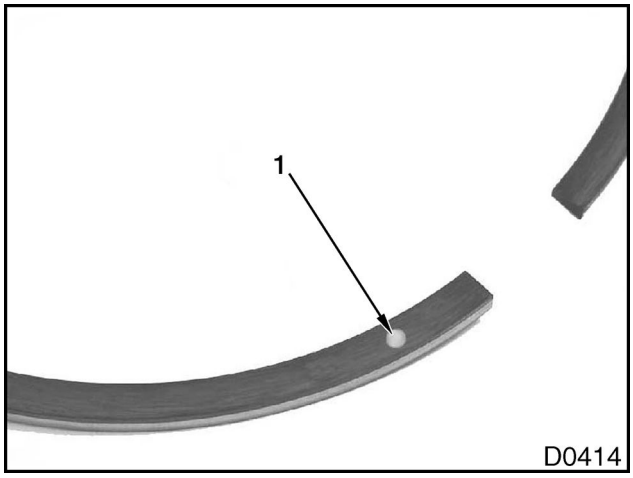


Figure 632 Piston Ring Identification Mark (Top Compression Ring)

1. Identification mark

   b. Install intermediate compression ring into middle piston groove. Make sure ring is installed with identification mark facing up.
   c. 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 the bottom of its stroke.

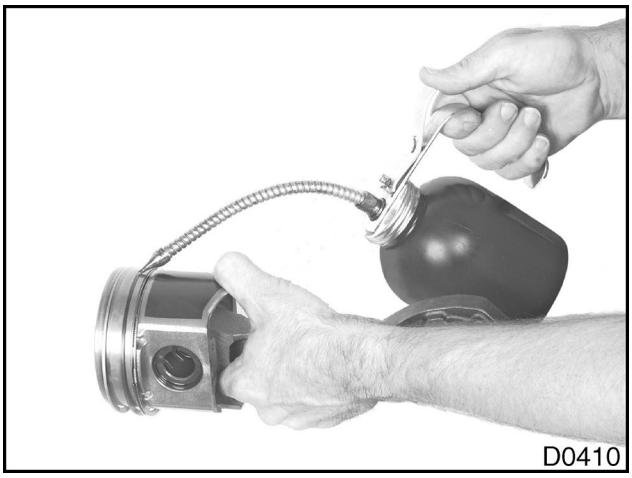


Figure 633 Piston and Piston Ring Lubrication (typical)

2. Lightly coat piston and piston rings with clean engine oil.

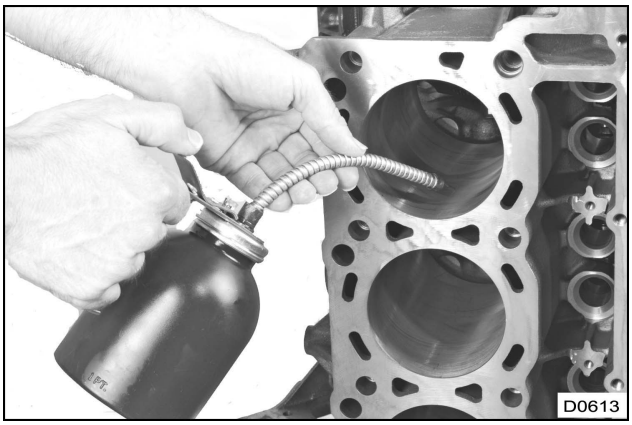


Figure 634 Cylinder Wall Lubrication (typical)

3. Coat cylinder walls, crankshaft journals, and Piston Ring Compressor (Cope) (page 415) with clean engine oil.

Figure 635 Piston Installed in Piston Ring Compressor (Cope)

4. Place piston in Piston Ring Compressor (Cope) (page 415).
5. Install bearings in the connecting rod and cap. Coat bearing in connecting rod with clean engine oil.

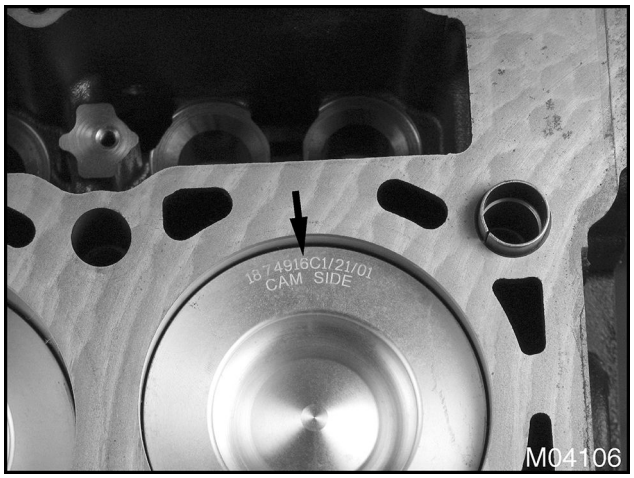


Figure 636 CAM SIDE Stamp on Piston

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 connecting rod and piston assembly into cylinder bore.

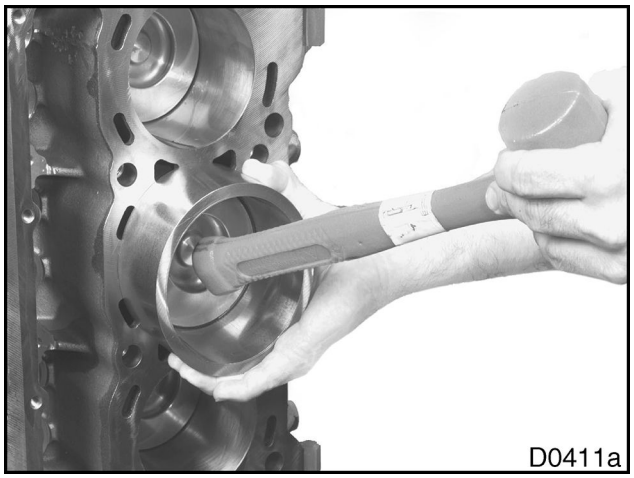


Figure 637 Installation of Piston in Cylinder Bore

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.

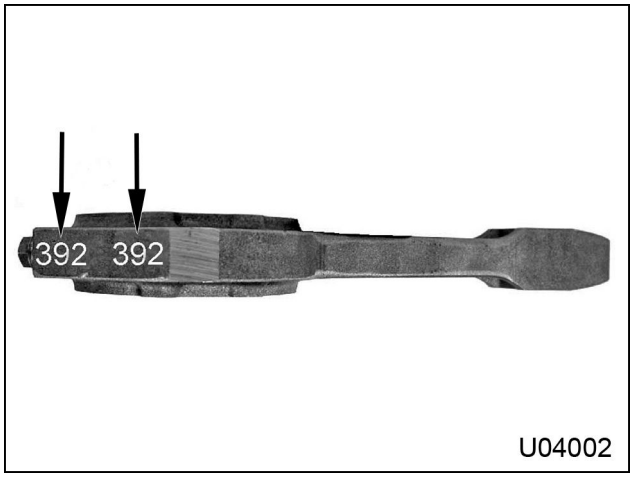


Figure 638 Connecting Rod and Cap Matching Numbers or Symbols

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 connecting rod and cap 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.

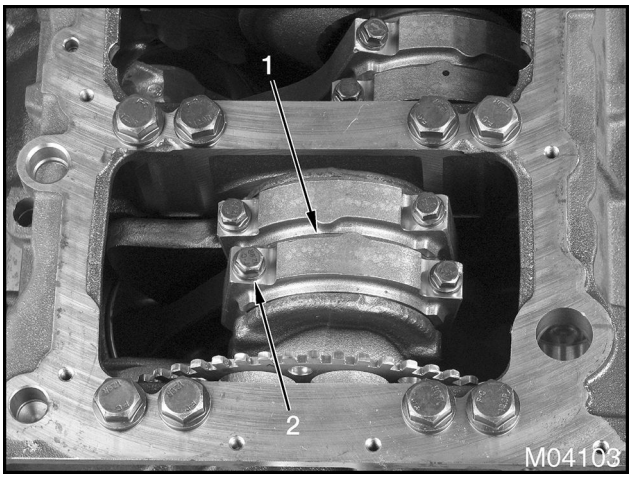


Figure 639 Connecting Rod Cap

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

CAUTION: To prevent engine damage, do not use power tools to remove or install connecting rod cap bolts. Threads will be damaged if a bolt or nut is rotated too quickly.

CAUTION: To prevent engine damage, when torquing connecting rod bolts, use a torque wrench that is known to be accurate. Correct torque of connecting rod cap bolts is important.

10. Install and tighten connecting rod bolts evenly to special torque (page 415).
11. Repeat installation procedure for remaining connecting rod and piston assemblies.
12. Check connecting rod side clearance (page 399) with feeler gauge.

Specifications

Connecting Rods	
Connecting rod length (center to center)	176 mm (6.929 in)
Piston pin bore inside diameter	38.512 to 38.549 mm (1.5162 to 1.5177 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 (2.8352 to 2.8375 in)
Connecting rod bearing running clearance (diameter)	0.027 to 0.097 mm (0.0001 to 0.0038 in)
Connecting rod side clearance	0.230 to 0.730 mm (0.0091 to 0.0287 in)
Weight (complete rod without bearing)	1280.5 to 1301.5 g (2.823 to 2.869 lb)
Pistons	
Material	Aluminum Alloy
Skirt diameter [1]	98.103 to 98.117 mm (3.862 to 3.863 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	98.103 to 98.117 mm (3.862 to 3.863 in)
0.254 mm (0.010 in) oversize	98.357 to 98.371 mm (3.872 to 3.873 in)
0.508 mm (0.020 in) oversize	98.611 to 98.625 mm (3.882 to 3.883 in)
0.762 mm (0.030 in) oversize	98.865 to 98.879 mm (3.892 to 3.893 in)
Top compression ring groove width (measured over 2.10 mm (0.083 in) gauge pins):	
Upper limit	96.541 mm (3.8008 in)
Replacement limit	96.341 mm (3.7929 in)
Ring groove (side clearance):	
Intermediate compression	0.050 to 0.096 mm (0.0020 to 0.0038 in)
Oil control	0.040 to 0.080 mm (0.00157 to 0.00315 in)
Piston height above crankcase deck (protrusion)	0.609 to 0.863 mm (0.0240 to 0.0340 in)
Piston skirt clearance	0.060 to 0.111 mm (0.0024 to 0.0044 in)
Piston Pins	
Length	74.6 to 75.0 mm (2.9371 to 2.9528 in)
Diameter	38.490 to 38.500 mm (1.5154 to 1.5158 in)
Piston pin clearance (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 0.0023 in)

Clearance in piston (piston pin bore)	0.010 to 0.020 mm (0.0004 to 0.0008 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 0.022 in)
Intermediate compression	0.67 to 0.82 mm (0.0263 to 0.0323 in)
Oil control	0.25 to 0.40 mm (0.010 to 0.016 in)

Special Torque

Connecting rod bolts	61 N·m (45 lb·ft)

Special Service Tools

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 (2.10 mm [0.083 in])	ZTSE6062
Piston Ring Compressor (Cope)	ZTSE4714
Piston ring expansion pliers	Obtain locally
Telescoping gauge set	Obtain locally

Table of Contents

Exploded View.....419

Removal.....421
- **Lower Crankcase Assembly**.....421
- **Crankshaft Assembly**.....422
- **Piston Cooling Tubes**.....423
- **Camshaft Assembly**.....423
- **Camshaft Bushings**.....424
- **Coolant Heater**.....425

Cleaning, Inspection, and Measurement.....426
- **Camshaft Gear Backlash Measurement**.....426
- **Camshaft End Play Measurement**.....426
- **Crankshaft End Play Measurement**.....427
- **Crankcase Assembly**.....427
  - **Crankcase Cleaning**.....427
  - **Crankcase Inspection and Measurement**.....429
  - **Cylinder Deglazing**.....430
- **Crankshaft Assembly**.....430
- **Main Bearing Fit Check**.....431
- **Piston Cooling Tubes**.....432
- **Camshaft Assembly**.....432
- **Measuring Camshaft Bushings**.....433
- **Coolant Heater**.....434

Installation.....435
- **Camshaft Bushings**.....435
- **Camshaft Assembly**.....435
- **Piston Cooling Tubes**.....436
- **Crankshaft Assembly**.....436
- **Lower Crankcase Assembly**.....437
- **Coolant Heater**.....440

Specifications.....441

Special Torque.....441

Special Service Tools.....442

Exploded View

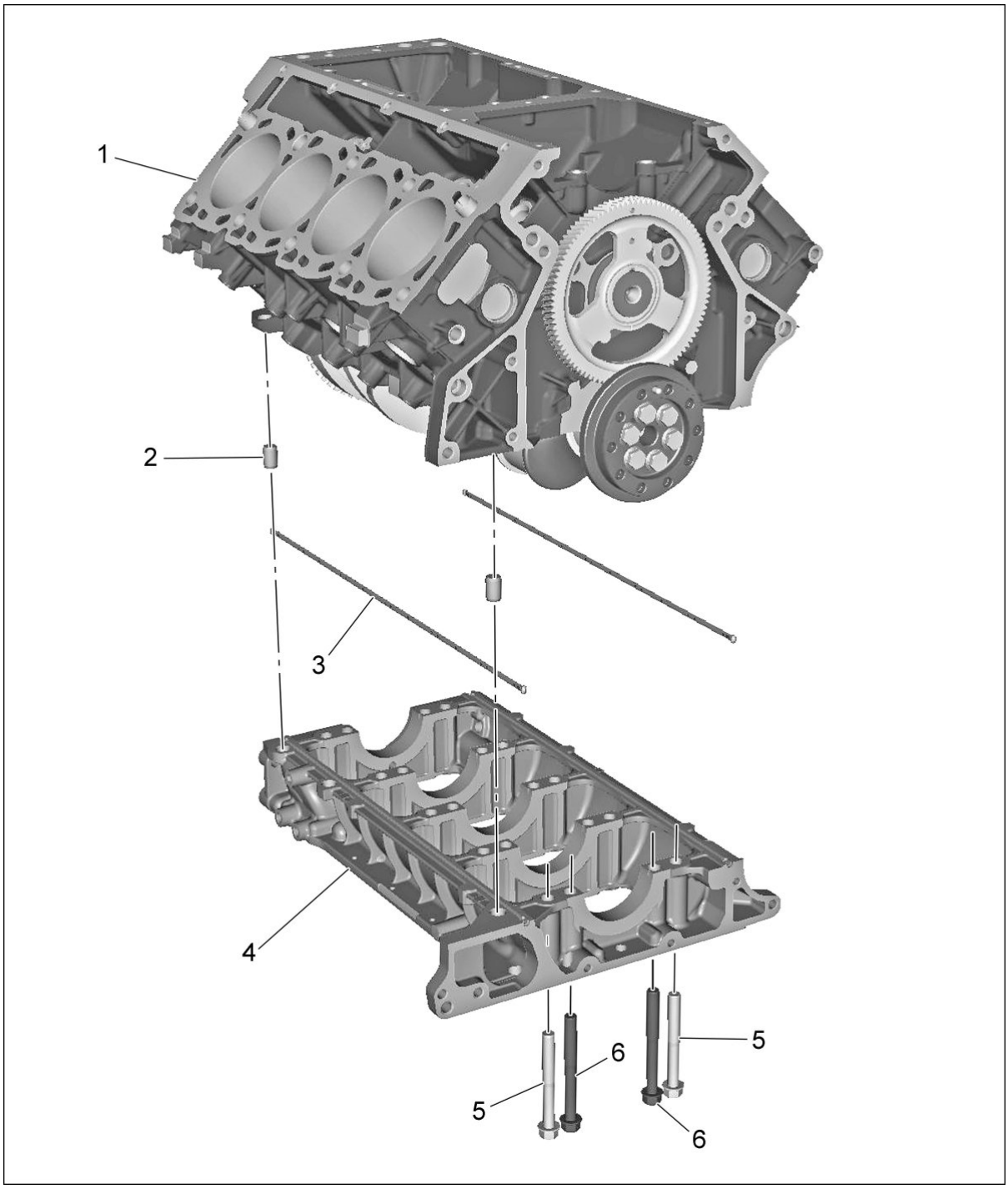


Figure 640 Upper Crankcase and Lower Crankcase

1. Upper crankcase assembly
2. Hardened dowel pin (2)
3. Crankcase lower seal (2)
4. Lower crankcase
5. Main bearing bolt M14 x 114.5 (10)
6. Main bearing bolt M14 x 127.5 (10)

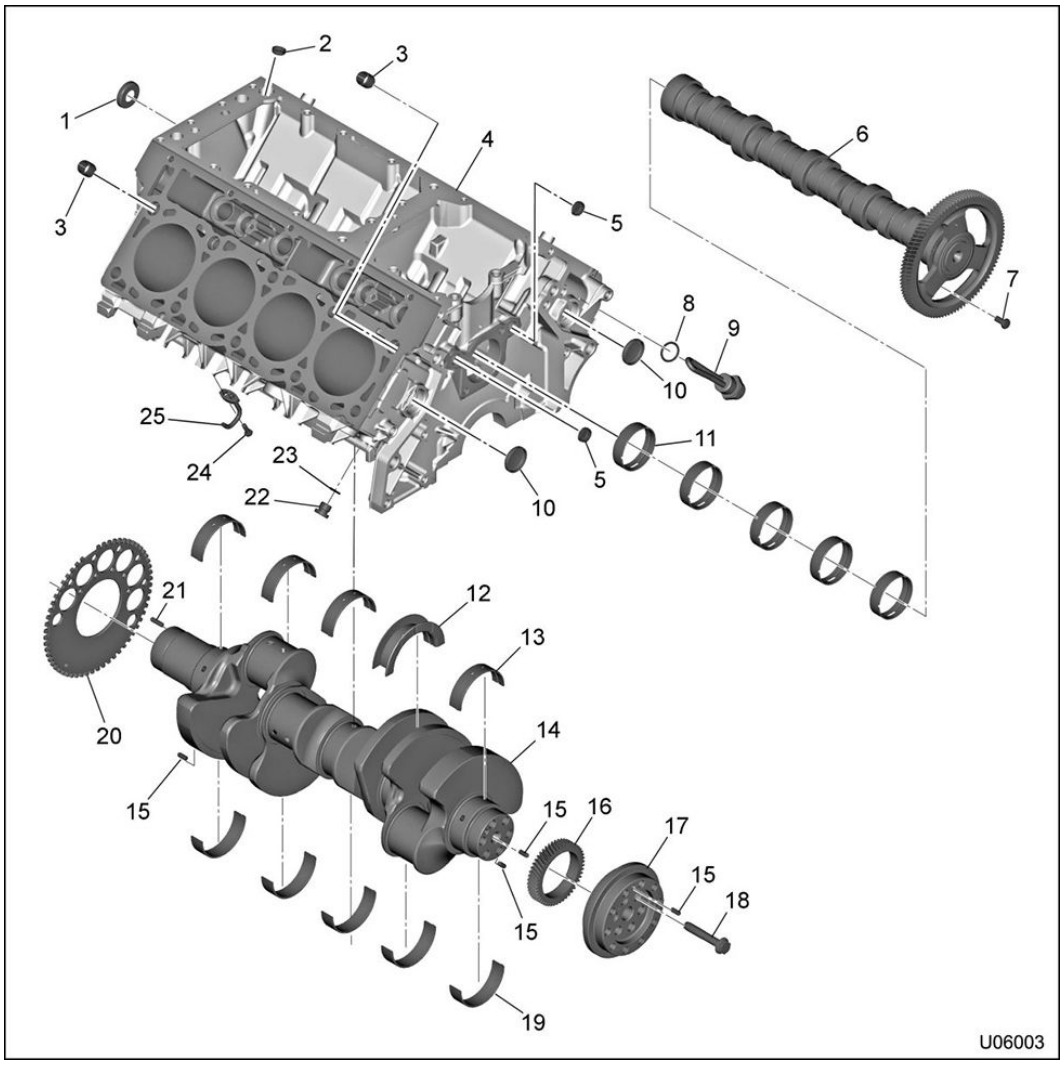


Figure 641 Upper Crankcase, Camshaft Assembly, and Crankshaft Assembly

1. Coolant passage orifice plug (2)
2. Coolant passage orifice plug
3. Spring dowel pin (4)
4. Upper crankcase assembly
5. Cup plug 16 mm (4)
6. Camshaft
7. M8 x 16 bolt (2)
8. O-ring seal
9. Coolant heater
10. Cup plug 38 mm (8)
11. Camshaft bushing (5)
12. Upper thrust bearing
13. Upper main bearing (4)
14. Crankshaft
15. Hardened dowel pin .250 x .625 (4)
16. Crankshaft gear
17. Crankshaft flange
18. M12 x 68 mm bolt (6)
19. Crankshaft lower main bearing (5)
20. Timing disc
21. Hardened dowel pin .250 x .875
22. Plug 16 mm (2)
23. O-ring seal 16 mm (2)
24. M6 x 18 bolt (8)
25. Piston cooling tube assembly (8)

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**
- **Dual Turbocharger, Exhaust Manifolds, and Piping**
- **Air Compressor and Power Steering Pump**
- **Fuel System**
- **Front Cover, Cooling System, and Related Components**
- **Oil Cooler, Oil Pump, Oil Filter, and Oil Pan**
- **Cylinder Heads, Valve Covers, and Valve Train**
- **Flywheel Assembly and Flywheel Housing**
- **Power Cylinders**

Lower Crankcase Assembly

1. Measure camshaft gear backlash, camshaft end play, and crankshaft end play (page 426).

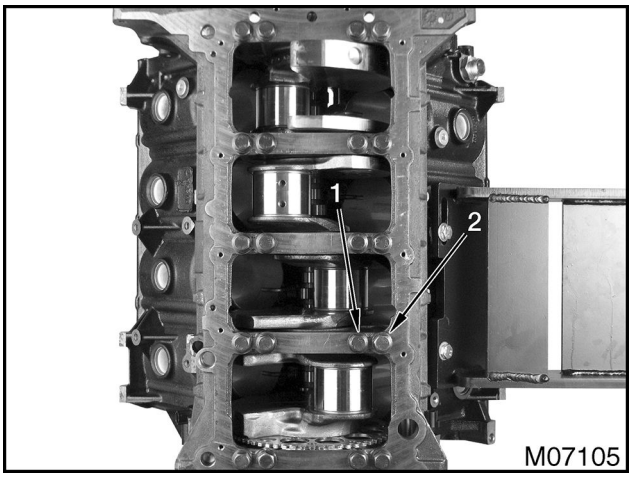


Figure 642 Main Bearing Bolts (Typical)

1. M14 x 127.5 main bearing bolt (10)
2. M14 x 114.5 main bearing bolt (10)

NOTE: Save main bearing bolts to perform main bearing fit check.

2. Remove 10 M14 x 127.5 main bearing bolts.
3. Remove 10 M14 x 114.5 main bearing bolts.

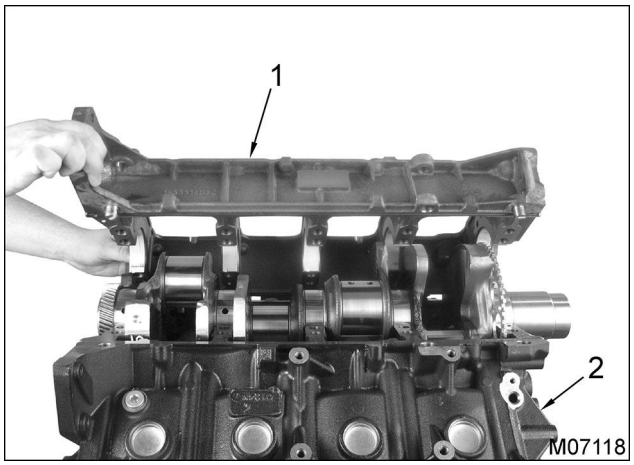


Figure 643 Lower Crankcase Assembly (Typical)

1. Lower crankcase assembly
2. Upper crankcase assembly

CAUTION: To prevent engine damage, do not allow the lower crankcase (at the parting line) to contact the crankshaft journal, when removing the lower crankcase onto upper crankcase.

4. Separate and remove lower crankcase assembly from upper crankcase assembly.

5. Remove and discard crankcase lower seals.

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

6. Beginning from front of engine, remove lower main bearings from lower crankcase by pushing bearings out of bearing saddles. Number main bearings with bearing number (1 to 5) and put aside for inspection.

Crankshaft Assembly

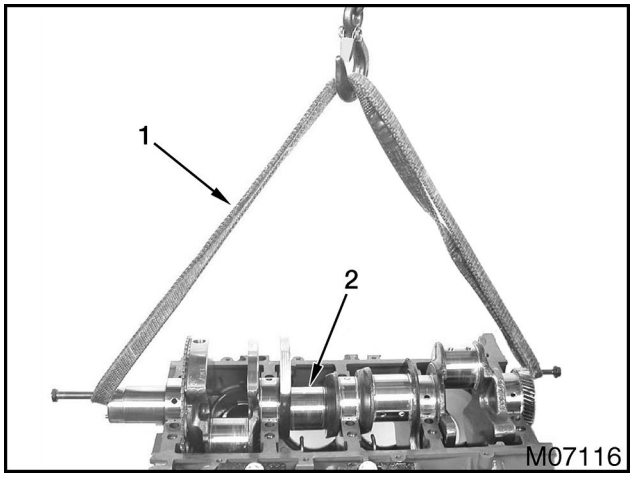


Figure 644 Crankshaft and Lifting Sling

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 the crankshaft.

CAUTION: To prevent engine damage, do not drop or bend the crankshaft.

2. Attach lifting sling (page 486) to crankshaft over bolts installed in crankshaft ends. Lift crankshaft straight up and out of upper crankcase assembly.

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

3. Beginning from front of engine, remove upper main bearings and thrust bearing from upper crankcase by pushing bearings out of bearing saddles. Number bearings with bearing number (1 to 5) and put aside for inspection.

Piston Cooling Tubes

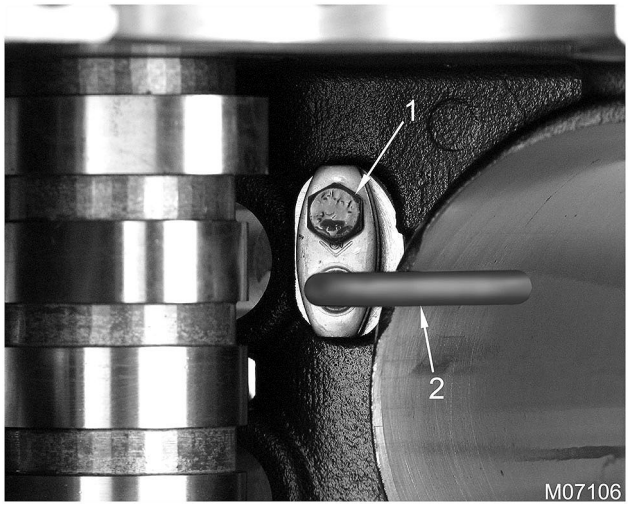


Figure 645 Piston Cooling Tube and Bolt (Typical)

1. M6 x 18 bolt (8)
2. Piston cooling tube assembly (8)

Remove each piston cooling tube by removing its M6 x 18 bolt. The bolts are reusable, providing bolt is cleaned and inspected, and Loctite® 262 is added to bolt threads before installation.

Camshaft Assembly

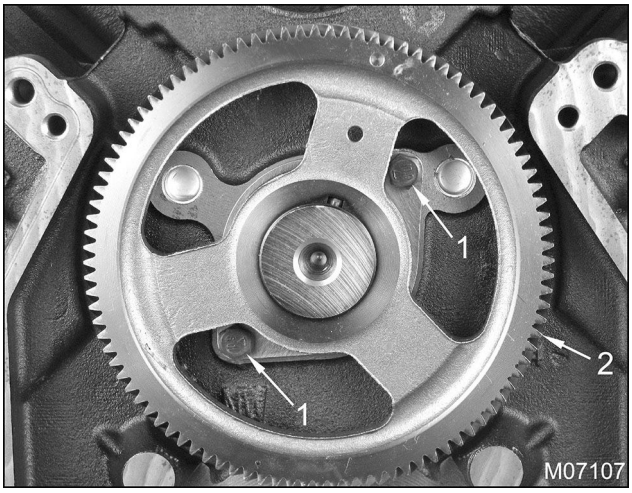


Figure 646 Camshaft Thrust Plate Bolts

1. M8 x 16 bolt (2)
2. Camshaft gear

1. Remove two M8 x 16 camshaft thrust plate bolts.

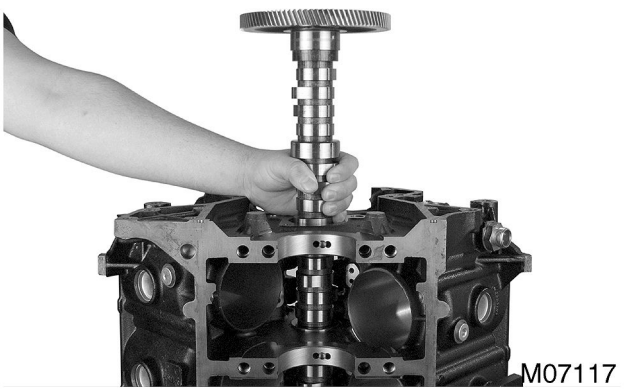


Figure 647 Camshaft Assembly Removal

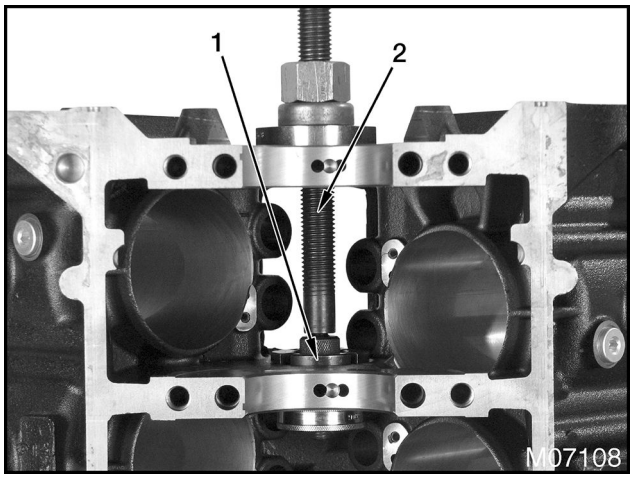


Figure 648 Camshaft Bushing Removal

1. Camshaft Bushing Remover / Installer (Expanding Collet)
2. Pulling screw (from Camshaft Bushing Service Set)

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 camshaft bushings based on camshaft journal and bushing running clearance (page 441). See Camshaft Assembly (page 432) and Measuring Camshaft Bushings (page 433).

2. Use Camshaft Bushing Service Set (page 486) with Camshaft Bushing Remover / Installer (Expanding Collet) (page 486) to remove all camshaft bushings. Install Camshaft Bushing Remover / Installer (Expanding Collet) in collapsed state inside 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 avoid nicks on bushings, be careful when inserting or removing threads of pulling screw.

4. Attach pulling plate, thrust bearing, and drive nut on pulling screw. Tighten nut against thrust bearing and pulling plate. Continue to tighten nut on pulling screw until camshaft bushing is free from upper crankcase assembly. Discard bushings.

Coolant Heater

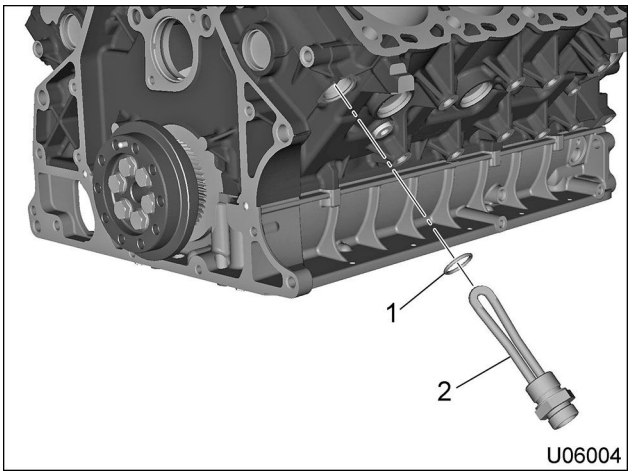


Figure 649 Coolant Heater

1. O-ring seal
2. Coolant heater

1. Remove coolant heater from right rear side of upper crankcase assembly and discard O-ring seal.

Cleaning, Inspection, and Measurement

Camshaft Gear Backlash Measurement

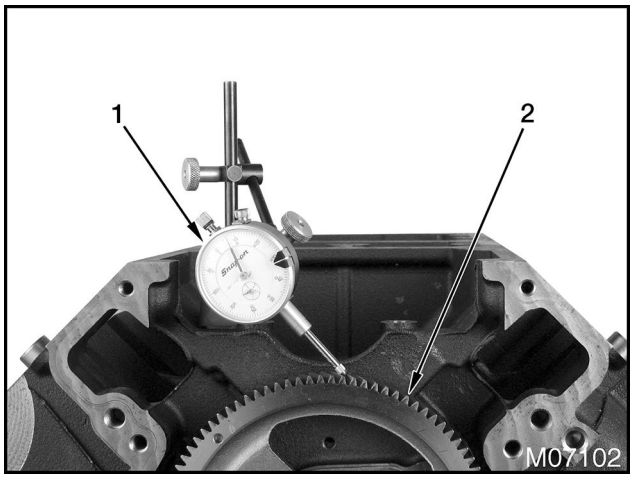


Figure 650 Camshaft Gear Backlash (Camshaft Gear to Crankshaft Gear)

1. Dial indicator with magnetic base
2. Camshaft gear

1. Mount dial indicator with magnetic base (page 486) on upper crankcase.

NOTE: Crankshaft gear must be fixed and not allowed to rotate; the camshaft gear must rotate, for a correct reading.

2. Position dial indicator tip on a gear tooth and remove lash by slowly turning camshaft gear until play is gone.
3. Zero the dial indicator.
4. Turn gear back and forth by hand and read indicator.
5. If camshaft gear backlash exceeds specification (page 441), replace camshaft assembly.

Camshaft End Play Measurement

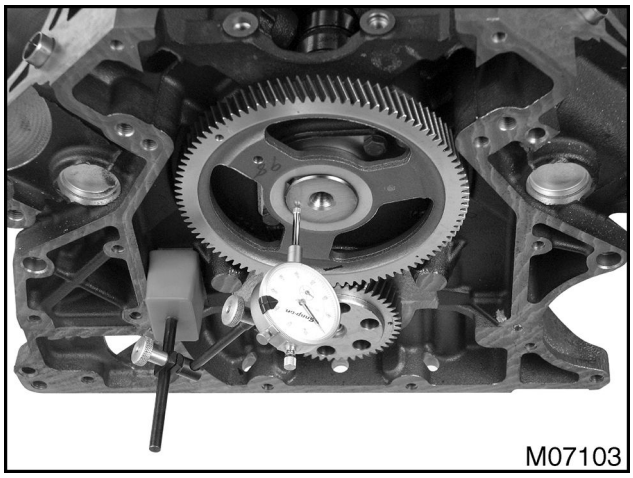


Figure 651 Camshaft End Play

1. Mount dial indicator with magnetic base (page 486) on upper crankcase.
2. Push camshaft to front of engine.
3. Zero the dial indicator.
4. Place a small pry bar between camshaft gear and crankcase and gently pry camshaft away from front of engine. Compare dial indicator reading with camshaft end play specification (page 441).
5. If end play exceeds specified limit, replace camshaft assembly.

Crankshaft End Play Measurement

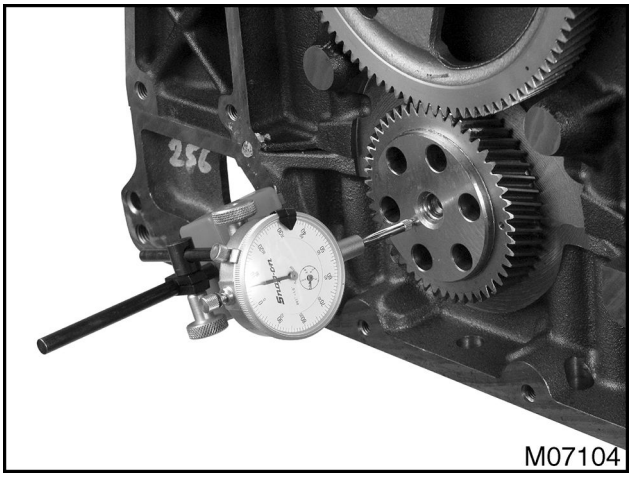


Figure 652 Crankshaft End Play

1. Mount dial indicator with magnetic base (page 486) on lower crankcase. Put indicator tip on end of crankshaft as shown.
2. Move crankshaft forward with pry bar and zero the dial indicator.
3. Move crankshaft back and forth while reading dial indicator. Compare dial indicator reading with Crankshaft end play specifications (page 441).
4. If end play exceeds maximum service specification, replace upper thrust bearing.

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 solvent.
   d. Dry with filtered compressed air.

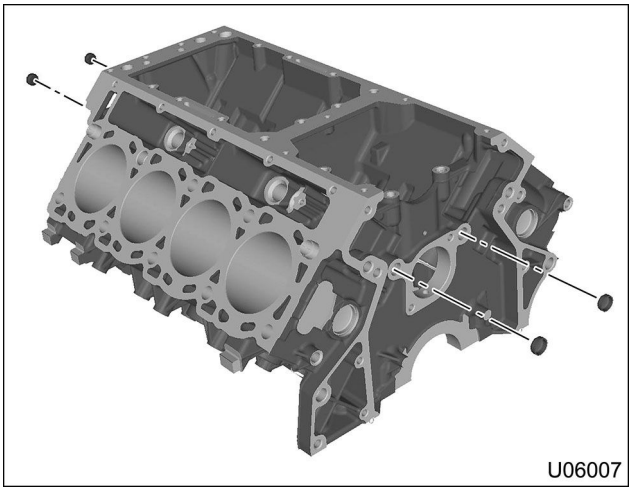


Figure 653 16-mm Cup Plugs (Oil Gallery)

3. Remove four 16 mm cup plugs from upper crankcase assembly (two in front and two in rear of main oil gallery), using a punch and hammer near edge of plug and striking with hammer. Discard plugs.

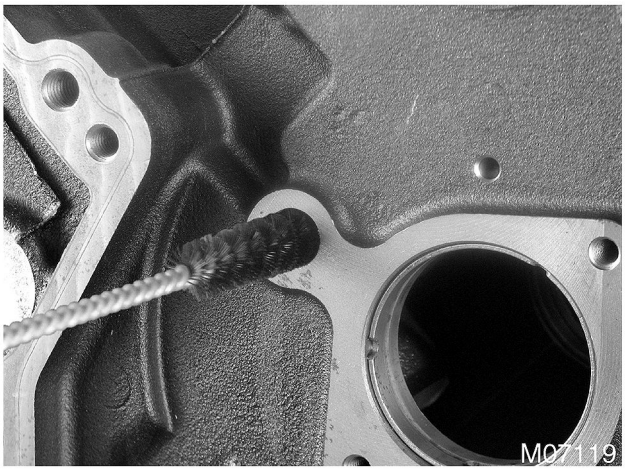


Figure 654 Main Oil Gallery Cleaning

4. Clean main oil galleries with Oil Gallery Cleaning Brush (page 486).
5. Coat edges of new 16 mm cup plugs (oil gallery) with Loctite® 11747 (page 486). Use Oil Gallery Plug Driver (page 486) 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.

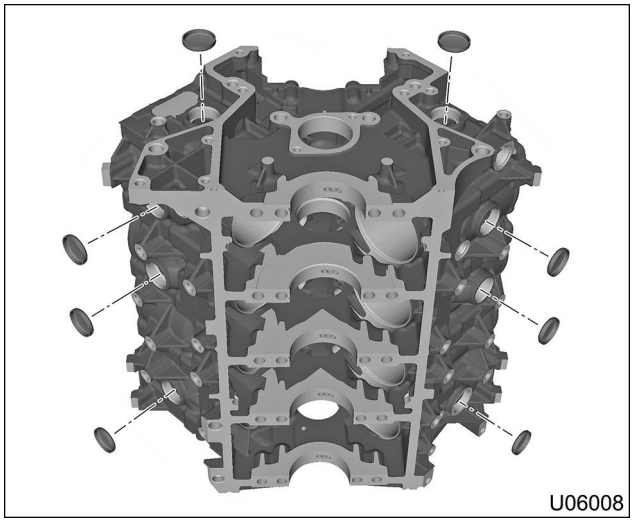


Figure 655 38-mm Cup Plugs

6. Remove eight 38 mm cup plugs from upper crankcase assembly (two in rear and three in each side of upper crankcase assembly), using a punch and hammer near edge of plug and striking with hammer. Discard plugs.
7. Clean the machined bores for the coolant cup plugs
8. Coat edges of new 38 mm cup plugs with Loctite® 11747 (page 486). Use Oil Gallery Plug Driver (page 486) 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.

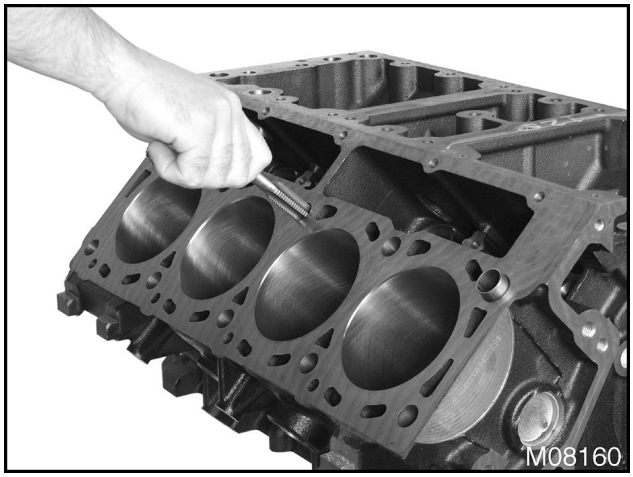


Figure 656 Cylinder Head Bolt Hole Cleaning (Typical)

⚠ 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, clean and blow dry crankcase bolt holes with filtered compressed air. Debris or fluids in bolt holes may cause binding and incorrect bolt torque.

9. Clean cylinder head bolt holes with Head Bolt Bottoming Tap (page 486).
10. Blow out bolt holes with filtered compressed air.

Crankcase Inspection and Measurement

1. After cleaning, inspect upper crankcase assembly for cracks, scoring, roughness or wear at cylinder bores.

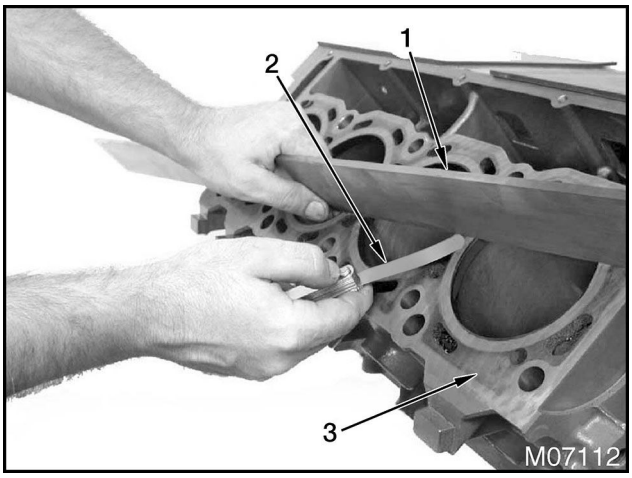


Figure 657 Flatness Check for Top Surface of Upper Crankcase Assembly

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 486) to check top surface of upper crankcase assembly (firing deck) for flatness. Insert a feeler gauge (page 486) between straightedge and upper crankcase assembly head surface.
   a. Measure entire deck surface. If gap exceeds specifications (page 441), replace upper and lower crankcase assembly.

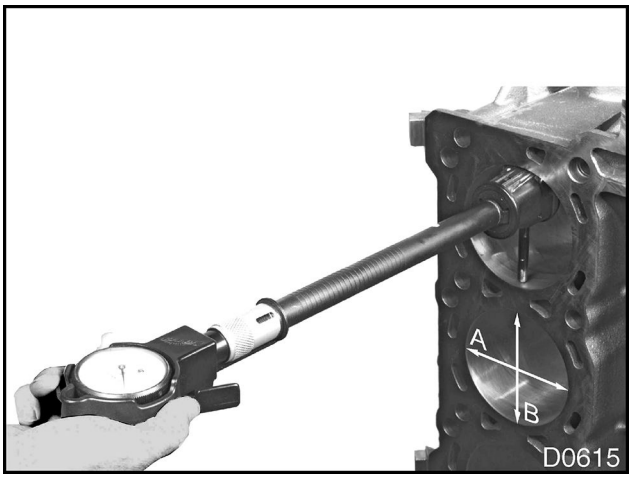


Figure 658 Cylinder Bore Out-of-Round Measurement

CAUTION: To prevent engine damage, if cylinder bores are deeply scored, out-of-round, or exceed diameter 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 430).

3. Use a cylinder bore gauge (page 486) to check each cylinder bore for diameter and 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.
5. If cylinder bore is within standard size specifications (page 441), standard size pistons and rings may be used.

Cylinder Deglazing

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

NOTE: Remove piston cooling tubes before deglazing cylinder bores.

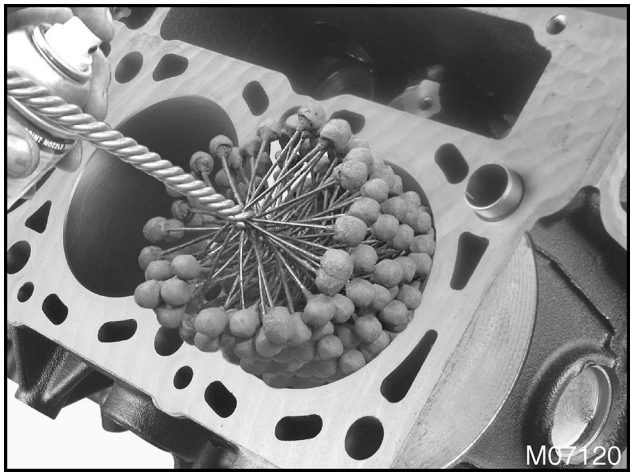


Figure 659 Deglazing Hone (Four-Inch, Typical)

1. Spray cylinder and deglazing hone with penetrating fluid or equivalent.

NOTE: For a successful procedure 100 to 120 rpm is required.

2. Attach deglazing hone (four inch) (page 486) to a variable speed electric or air powered drill. 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.

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.

3. Deglaze each cylinder wall for about 15 seconds. Stroke bore up and down at a rate of one complete up and down stroke per second.
4. 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.

5. Continue deglazing cylinder bore for 10 to 15 seconds or 20 to 25 strokes.
6. Wipe cylinder bore clean and inspect bore for correct 45° crosshatch pattern.
7. After deglazing, thoroughly clean cylinder bores with soft bristle brush, soap and water.
8. Dry with filtered compressed air.
9. Lubricate bores with clean engine oil.

Crankshaft Assembly

⚠ 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 with a suitable solvent.
2. Use a stiff nylon brush to clean oil passages in crankshaft. Loosen accumulated dirt, sludge, and deposits.
3. Flush oil passages with a suitable solvent.
4. Dry with filtered compressed air.
5. Inspect crankshaft journals (main and connecting rod) for scratches, grooves, and scoring.
6. Inspect main bearings for scratches, grooves, scoring, pitting, and inconsistent coloring.

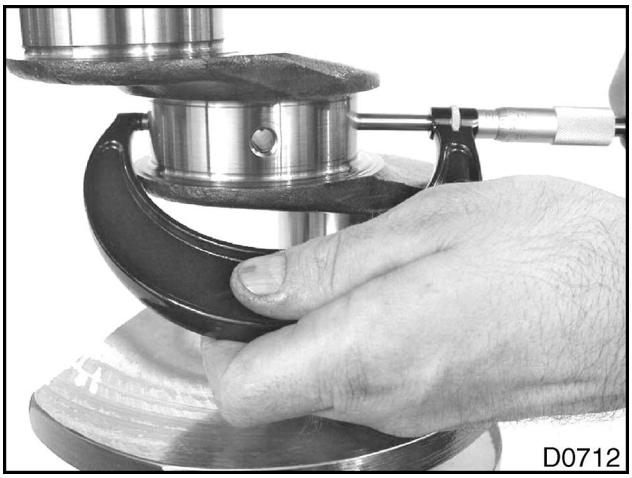


Figure 660 Measurement of Crankshaft Main Journal

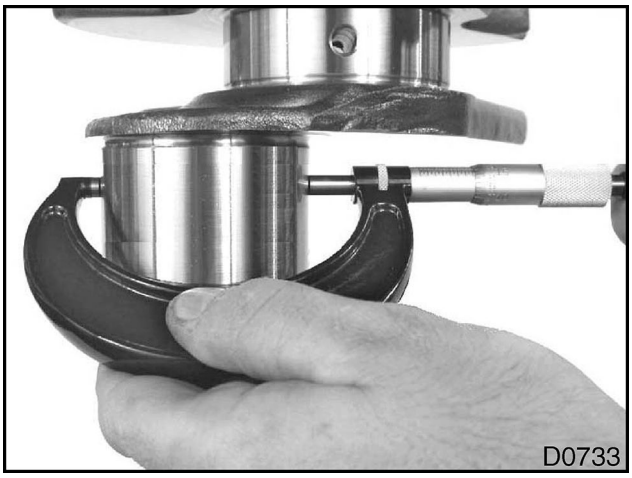


Figure 661 Measurement of Crankshaft Connecting Rod Journal

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.

7. Use a 3-4 inch micrometer (page 486) 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 441), grind or replace crankshaft.

Main Bearing Fit Check

NOTE: Main bearings must fit tightly in the bore. When bearings are inserted into upper and lower crankcase assembly, they protrude above parting line. This protrusion is required to achieve bearing crush.

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

NOTE: If main bearings have scratches, grooves, scoring, pitting, or inconsistent coloring, new main bearings must be installed.

1. Install main bearings into upper crankcase assembly.

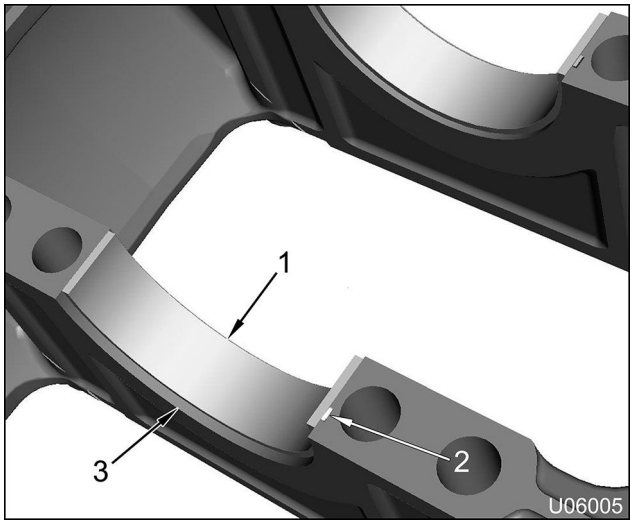


Figure 662 Lower Main Bearings

1. Lower main bearing
2. Locking tab
3. Bearing saddle

2. Install crankshaft lower main bearings in lower crankcase assembly. Make sure locking tab on bearing is snapped into bearing saddle.

CAUTION: To prevent engine damage, do not allow the lower crankcase (at the parting line) to contact the crankshaft journal, when positioning the lower crankcase onto upper crankcase.

3. Position lower crankcase onto upper crankcase.
4. Lubricate old main bearing bolts with clean engine oil.

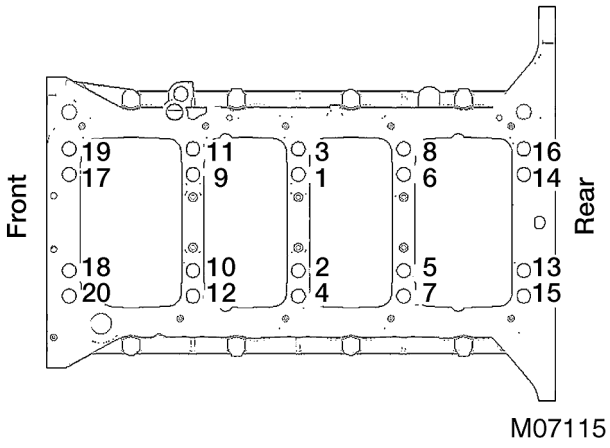


Figure 663 Torque Sequence for Main Bearing Bolts

CAUTION: To prevent engine damage, install longer main cap bolts (M14 x 127.5) inboard and shorter main cap bolts (M14 x 114.5) outboard.

5. Tighten old bolts using above sequence as follows:
   - Tighten bolts to 149 N·m (110 lb·ft).
   - Tighten bolts to 176 N·m (130 lb·ft).
   - Tighten bolts to 231 N·m (170 lb·ft).
6. Using a telescoping gauge (page 486), measure inside diameter of main bearing at two locations 90° apart.
7. If not previously done, use a 3-4 inch micrometer (page 486) to measure each crankshaft main journal diameter. Average the two inside diameter measurements.
8. 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.

9. If bearing-to-crankshaft running clearances exceed specifications (page 441) 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 bearing journals with a micrometer, always take two measurements 90° apart.

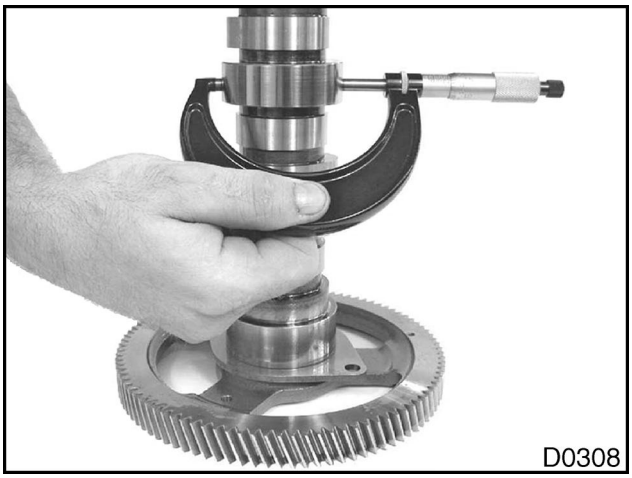


Figure 664 Measurement of Camshaft Bearing Journal

a. Use a 2-3 inch micrometer (page 486) to measure journal diameter of camshaft bearing. If bearing journals are worn beyond specification (page 441), install a new camshaft assembly.

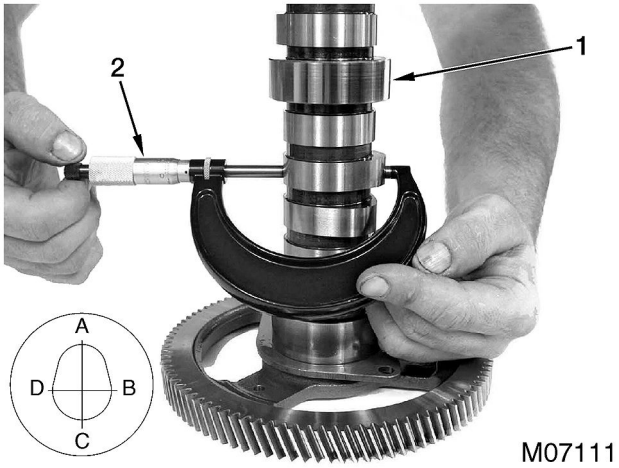


Figure 665 Measurement of Camshaft Intake and Exhaust Lobes

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 441) to obtain cam lobe wear measurement. Replace camshaft assembly if cam lobe wear exceeds specifications (page 441).

3. Inspect thrust plate for wear, cracks or distortion. Use a 0-1 inch micrometer (page 486) to measure thrust plate thickness. If thickness does not meet specification (page 441), 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

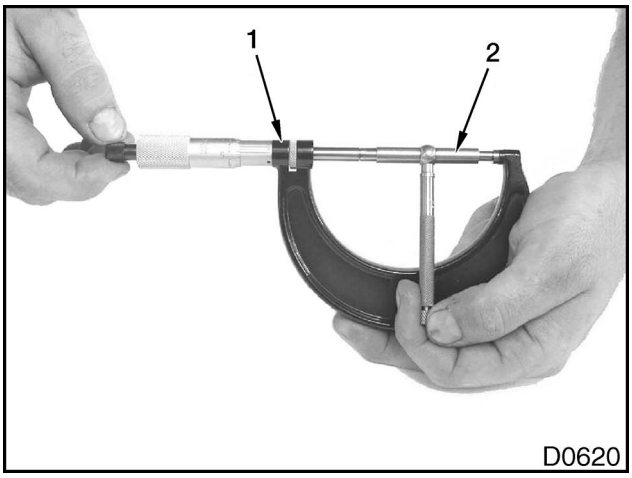


Figure 666 Measurement of Camshaft Bushing Inside Diameter

1. Outside micrometer
2. Telescoping gauge

Measure five camshaft bushings and calculate running clearance as follows:

1. Use a telescoping gauge set (page 486) 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 441), replace camshaft bushings. See Camshaft Bushings removal (page 424) 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.

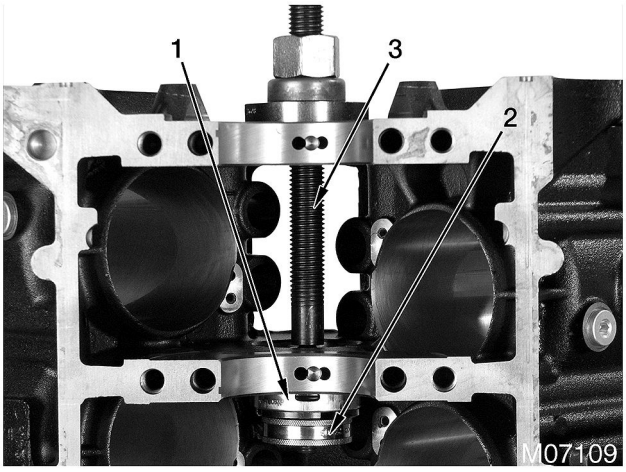


Figure 667 Installation of Cam Bushing

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) (page 486).
3. Thread pulling screw (from Camshaft Bushing Service Set), backup nut, and Camshaft Bushing Remover / Installer (Expanding Collet) (page 486) together.
4. Tighten expanding collet by turning backup nut until bushing is securely held on Camshaft Bushing Remover / Installer (Expanding Collet) (page 486).

CAUTION: To prevent engine damage and ensure correct oil circulation through the crankcase. Align camshaft bushing oil holes with corresponding oil supply holes machined in the crankcase.

5. To aid in alignment of camshaft 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 486) and inspect oil hole alignment.

Camshaft Assembly

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

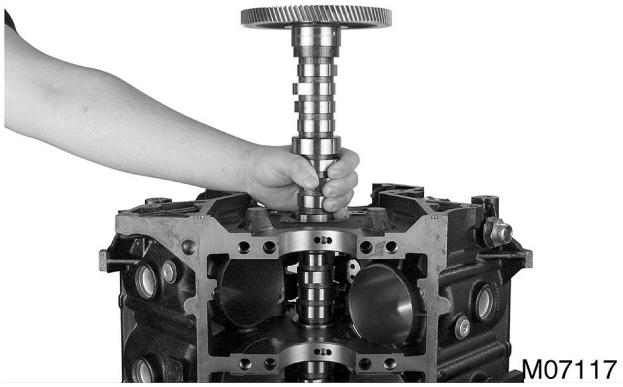


Figure 668 Camshaft Assembly

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 carefully install camshaft assembly.

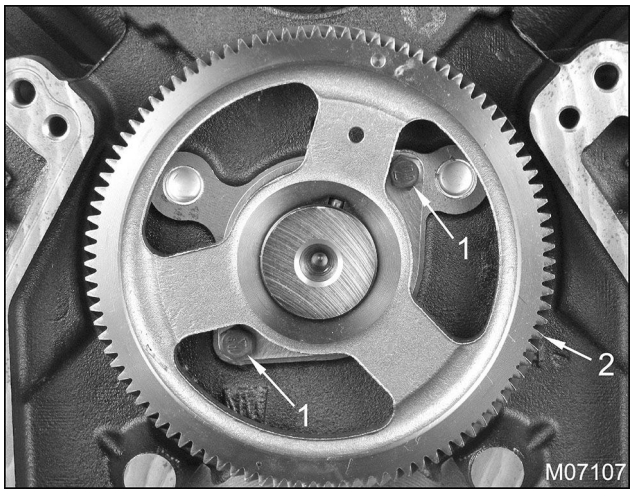


Figure 669 Camshaft Thrust Plate Bolts

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 473).
4. Measure camshaft end play (page 426). Verify camshaft end play is within specifications (page 441).

Piston Cooling Tubes

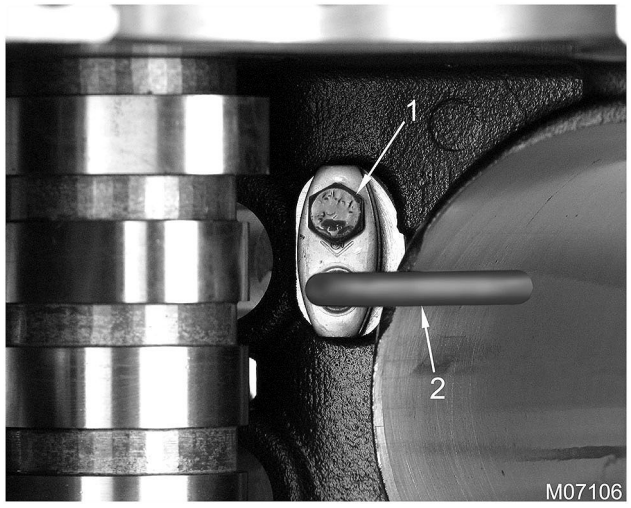


Figure 670 Piston Cooling Tube

1. M6 x 18 bolt (8)
2. Piston cooling tube (8)

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

1. Place piston cooling tubes on upper crankcase assembly mounting pad.
2. Apply Loctite® 262 (page 486) to M6 x 18 bolt threads and install bolts in crankcase.
3. Install and tighten bolts to standard torque (page 473).

Crankshaft Assembly

NOTE: Make sure crankshaft assembly has been inspected and cleaned per instructions on (page 430) before doing the following procedure.

1. Use a lint-free cloth to wipe oil from bearing supports of upper crankcase assembly.

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.

2. 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.

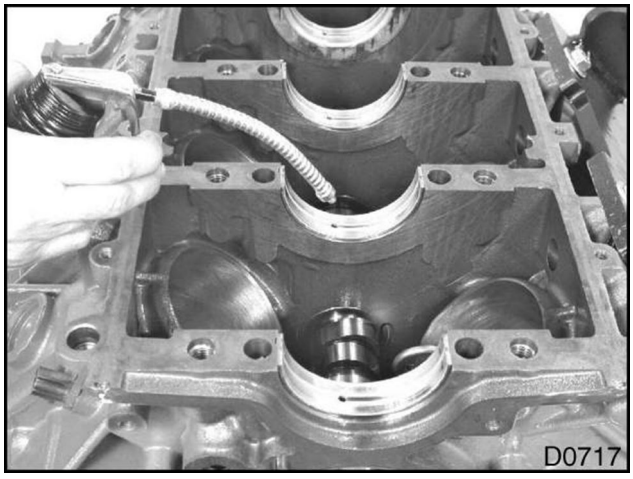


Figure 671 Upper Main Bearings Lubrication

3. Lubricate bearings with clean engine oil.
4. Rotate camshaft so timing mark on camshaft gear is pointing upwards.

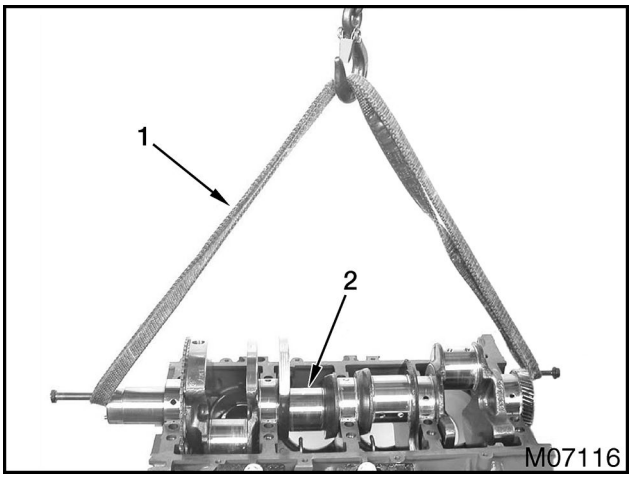


Figure 672 Lifting Sling

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 drop or bend the crankshaft.

5. Install a bolt in each end of the crankshaft assembly (if removed). Attach hoist and lifting sling (page 486) around crankshaft bolts and carefully lower crankshaft onto five main bearings.

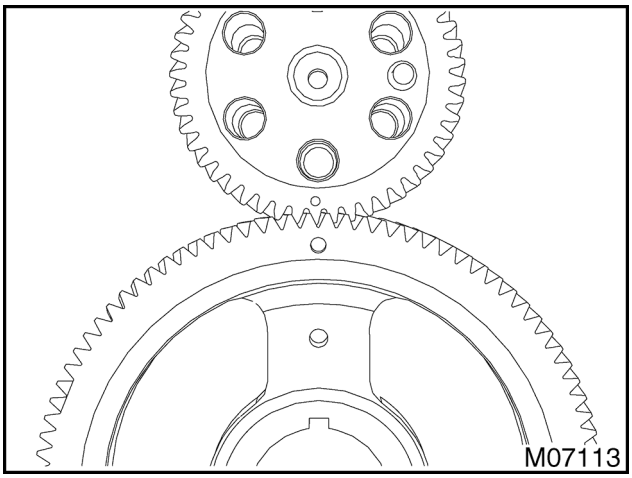


Figure 673 Crankshaft and Camshaft Timing Marks

6. 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 431), 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.

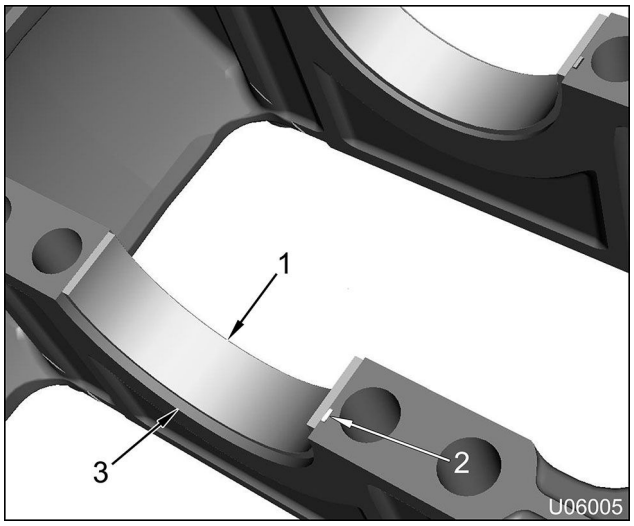


Figure 674 Lower Main Bearings

1. Lower main bearing
2. Locking tab
3. Bearing saddle

1. Install crankshaft lower main bearings in lower crankcase assembly. Make sure locking tab on bearing is snapped into bearing saddle.

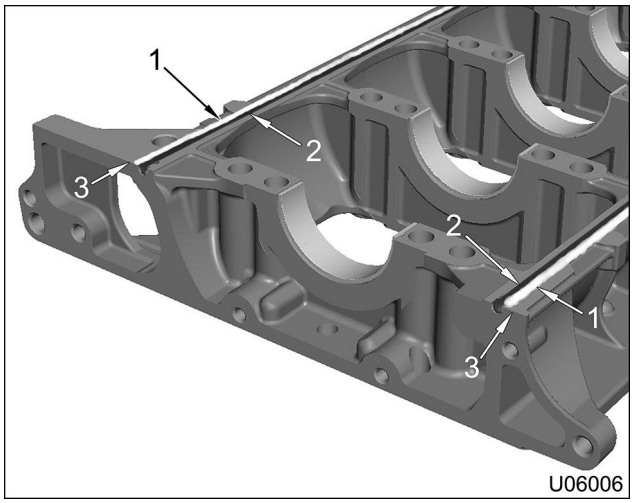


Figure 675 Crankcase Lower Seals and Loctite® 5127 Sealant

1. Loctite® 5127 sealant
2. Crankcase lower seal (2)
3. Outside machined surface of lower crankcase assembly

2. Install new crankcase lower seals.
3. Apply Loctite® 5127 sealant (page 486) onto the full length of outside machined surfaces.
4. Apply clean engine oil to lower bearings, crankshaft journals, and main bearing bolts.

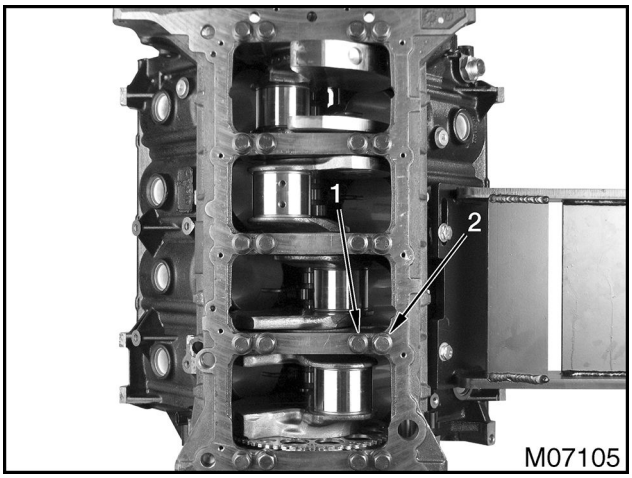


Figure 676 Main Bearing Bolts (Typical)

1. M14 x 127.5 main bearing bolt (10)
2. M14 x 114.5 main bearing bolt (10)

CAUTION: To prevent engine damage, do not allow the lower crankcase (at the parting line) to contact the crankshaft journal, when positioning the lower crankcase onto upper crankcase.

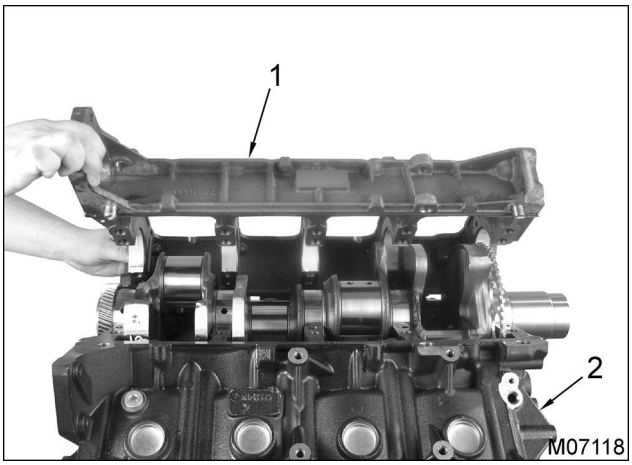


Figure 677 Lower Crankcase Assembly (Typical)

1. Lower crankcase assembly
2. Upper crankcase assembly

5. Position lower crankcase onto upper crankcase.

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 127.5) inboard and shorter main cap bolts (M14 x 114.5) outboard.

6. Install 10 new M14 x 127.5 main bearing bolts.
7. Install 10 new M14 x 114.5 main bearing bolts.

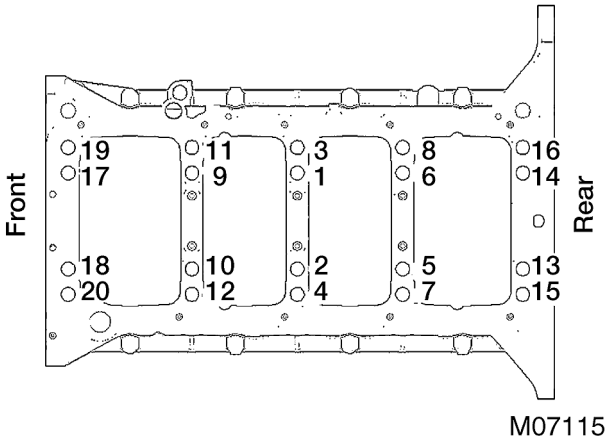


Figure 678 Torque Sequence for Main Bearing Bolts

8. Tighten bolts using above sequence as follows:
   - Tighten bolts to 149 N·m (110 lb·ft).
   - Tighten bolts to 176 N·m (130 lb·ft).
   - Tighten bolts to 231 N·m (170 lb·ft).
9. Measure camshaft gear backlash, camshaft end play, and crankshaft end play (page 426).

Coolant Heater

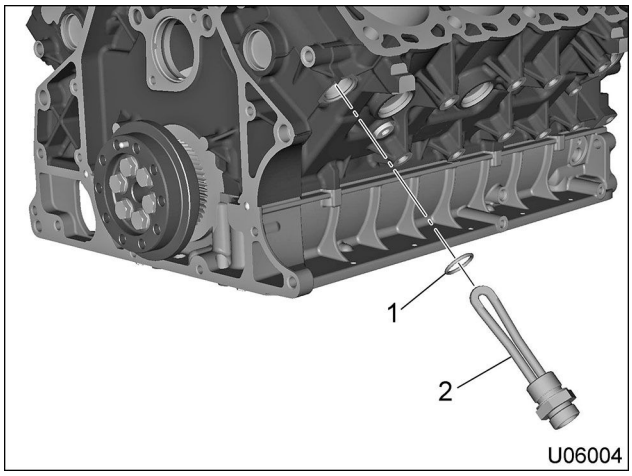


Figure 679 Coolant Heater

1. O-ring seal
2. Coolant heater

1. Lubricate a new O-ring seal with P-80® Rubber Lubricant or equivalent (page 486) and install O-ring seal onto coolant heater.
2. Install coolant heater in upper crankcase assembly and tighten to special torque (page 441).

Specifications

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	80.9873 to 81.0127 mm (3.1885 to 3.1895 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	71.987 to 72.013 mm (2.834 to 2.835 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)
Camshaft lobe lift (maximum):	
Intake	5.820 mm (0.2291 in)
Exhaust	5.906 mm (0.2325 in)

Special Torque

Main bearing bolts	See tightening procedure and sequence
Coolant heater	41 N·m (30 lb·ft)

Special Service Tools

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
Head Bolt Bottoming Tap	ZTSE4508
Lifting sling	Obtain locally
Loctite® 11747	Obtain locally
Loctite® 262	Obtain locally
Loctite® 5127 sealant	Obtain locally
P-80® Rubber Lubricant or equivalent	Obtain locally
Oil Gallery Cleaning Brush	ZTSE4511
Oil Gallery Plug Driver	ZTSE4512
Straightedge	Obtain locally
Telescoping gauge set	Obtain locally

Table of Contents

Abbreviations and Acronyms.....445
Abbreviations and Acronyms.....445

Abbreviations and Acronyms

Abbreviations and Acronyms

A or amp – Ampere
AAT – Ambient Air Temperature
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
ACM – Aftertreatment Control Module
ACT PWR GND – Actuator Power Ground
ACV – Air Control Valve
AF – Air to Fuel ratio
AFT – Aftertreatment
AFTFD – Aftertreatment Fuel Doser
AFTFDH – Aftertreatment Fuel Doser High
AFTFDL – Aftertreatment Fuel Doser Low
AFTFIT – Aftertreatment Fuel Inlet Temperature
AFTFIS – Aftertreatment Fuel Inlet Sensor
AFTFP – Aftertreatment Fuel Pressure
AFTFP1 – Aftertreatment Fuel Pressure 1
AFTFP2 – Aftertreatment Fuel Pressure 2
AFTFSH – Aftertreatment Fuel Shutoff High
AFTFSL – Aftertreatment Fuel Shutoff Low
AFTFSV – Aftertreatment Fuel Shutoff Valve
AIT – Air Inlet Temperature
Amb – Ambient
amp or A – Ampere
AMS – Air Management System
API – American Petroleum Institute
APP – Accelerator Pedal Position
APP1 – Accelerator Pedal Position 1
APP2 – Accelerator Pedal Position 2
ASTM – American Society for Testing and Materials
ATA – American Trucking Association
ATAH – American Trucking Association Link High
ATAL – American Trucking Association Link Low
ATDC – After Top Dead Center
AWG – American Wire Gauge
AWL – Amber Warning Lamp
B+ or VBAT – Battery Voltage
BARO – Barometric Absolute Pressure
BBDC – Before Bottom Dead Center
BC – Body Controller
BDC – Bottom Dead Center
bhp – Brake Horsepower
BOO – Brake On / Off
BPP – Brake Pedal Position
BPS – Brake Pressure Switch
BTDC – Before Top Dead Center
BTU – British Thermal Unit
C – Celsius
CAC – Charge Air Cooler
CACOT – Charge Air Cooler Outlet Temperature
CAN – Controller Area Network
CAP – Cold Ambient Protection
CARB – California Air Resources Board
cc – Cubic centimeter
CCA – Cold Cranking Ampere
CCOSS – Crankcase Oil Separator Speed
CCS – Cruise Control Switches
cfm – Cubic feet per minute
cfs – Cubic feet per second
CFV – Coolant Flow Valve
CID – Cubic Inch Displacement
CKP – Crankshaft Position
CKPH – Crankshaft Position High
CKPL – Crankshaft Position Low
CKPO – Crankshaft Position Out
cm – Centimeter
CMP – Camshaft Position
CMPH – Camshaft Position High
CMPL – Camshaft Position Low
CMPO – Camshaft Position Out
CMV – Coolant Mixer Valve
CO – Carbon Monoxide
COO – Cruise On / Off switch
CPU – Central Processing Unit
CSFI – Cold Start Fuel Igniter
CSFS – Cold Start Fuel Solenoid
CSR – Cold Start Relay
CTC – Coolant Temperature Compensation
Cyl – Cylinder
DB – Decibel
DC – Direct Current
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
DOCIT – Diesel Oxidation Catalyst Inlet Temperature
DOCOT – Diesel Oxidation Catalyst Outlet Temperature
DPF – Diesel Particulate Filter
DPFDP – Diesel Particulate Filter Differential Pressure
DPFIT – Diesel Particulate Filter Inlet Temperature

DPFOT – Diesel Particulate Filter Outlet Temperature
DSI – Down Stream Injection
DT – Diesel Turbocharged
DTC – Diagnostic Trouble Code
DTRM – Diesel Thermo Recirculation Module
EAWD – Engine Assisted Windshield Defrost
EBP – Exhaust Back Pressure
EBPD – Exhaust Back Pressure Desired
EBPV – Exhaust Back Pressure Valve
ECB – Engine Compression Brake
ECB1 – Engine Compression Brake 1
ECB2 – Engine Compression Brake 2
ECBP – Engine Compression Brake Pressure
ECI – Engine Crank Inhibit
ECL – Engine Coolant Level
ECM – Engine Control Module
ECM GND – Engine Control Module Ground
ECM PWR – Engine Control Module Power
ECS – Engine Coolant System
ECSR – Engine Controlled Shutdown Request
ECT – Engine Coolant Temperature
ECT1 – Engine Coolant Temperature 1
ECT2 – Engine Coolant Temperature 2
EFAN – Engine Fan
EFC – Engine Fan Control
EFRC – Engine Family Rating Code
EFS – Engine Fan Speed
EFT – Engine Fuel Temperature
EG – Ethylene Glycol
EGC – Electronic Gauge Cluster
EGBP – Exhaust Gas Back Pressure
EGDP – Exhaust Gas Differential Pressure
EGR – Exhaust Gas Recirculation
EGRC – Exhaust Gas Recirculation Control
EGRH – Exhaust Gas Recirculation High control
EGRL – Exhaust Gas Recirculation Low control
EGROT – Exhaust Gas Recirculation Outlet Temperature
EGRP – Exhaust Gas Recirculation Position
EGRT – Exhaust Gas Recirculation Temperature
EGT – Exhaust Gas Temperature
EGT1 – Exhaust Gas Temperature 1
EGT2 – Exhaust Gas Temperature 2
EGT3 – Exhaust Gas Temperature 3
EMI – Electromagnetic Interference
EMP – Exhaust Manifold Pressure
EMT – Exhaust Manifold Temperature
EOL – Engine Oil Level
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
ETC – Engine Throttle Control
ETCH – Engine Throttle Control High
ETCL – Engine Throttle Control Low
ETP – Engine Throttle Position
ETV – Engine Throttle Valve
EWPS – Engine Warning Protection System
F – Fahrenheit
FCV – Fuel Coolant Valve
FDP – Fuel Delivery Pressure
FEL – Family Emissions Limit
fhp – Friction horsepower
FMI – Failure Mode Indicator
FPC – Fuel Pump Control
FPCV – Fuel Pressure Control Valve
fpm – Feet per minute
FPM – Fuel Pump Monitor
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
HEST – High Exhaust System Temperature
HFCM – Horizontal Fuel Conditioning Module
Hg – Mercury
hp – Horsepower
HPCAC – High-Pressure Charge Air Cooler
HPCR – High-Pressure Common Rail
HPFP – High-Pressure Fuel Pump
hr – Hour
HS – Humidity Sensor
Hyd – Hydraulic
IAH – Inlet Air Heater
IAHC – Inlet Air Heater Control
IAHD – Inlet Air Heater Diagnostic
IAHR – Inlet Air heater Relay
IC – Integrated Circuit

ICP – Injection Control Pressure
ICPR – Injection Control Pressure Regulator
ICG1 – Injector Control Group 1
ICG2 – Injector Control Group 2
ID – Inside Diameter
IGN – Ignition
ILO – Injector Leak Off
IMP – Intake Manifold Pressure
IMT – Intake Manifold Temperature
in – Inch
inHg – Inch of mercury
inH_2O – Inch of water
INJs – Injectors
IPR – Injection Pressure Regulator
IPR PWR – Injection Pressure Regulator Power
ISC – Interstage Cooler
ISIS – International Service Information System
IST – Idle Shutdown Timer
ITP – Internal Transfer Pump
J1939H – J1939 Data Link High
J1939L – J1939 Data Link Low
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
lb – Pounds of force
lb/s – Pounds per second
lb ft – Pounds of force per foot
lb 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
MAF GND – Mass Air Flow Ground
MAG – Magnetic
MAP – Manifold Absolute Pressure
MAT – Manifold Air Temperature
mep – Mean effective pressure
mi – Mile
MIL – Malfunction Indicator Lamp
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
O2S – Oxygen Sensor
O2SH – Oxygen Sensor Heater
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
PDOC – Pre-Diesel Oxidation Catalyst
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
RAPP – Remote Accelerator Pedal Position
RAS – Resume / Accelerate Switch (speed control)
REPTO – Rear Engine Power Takeoff
RFI – Radio Frequency Interference
rev – Revolution
rpm – Revolutions per minute
RPRE – Remote Preset Power Take Off
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 GND – Signal Ground
SIG GNDB – Signal Ground Body
SIG GNDC – Signal Ground Chassis
SIG GNDE – Signal Ground Engine
S/N – Serial Number
SPEEDO – Speedometer
SPN – Suspect Parameter Number
SW – Switch (electrical)
SWBAT – Switch Battery
SYNC – Synchronization
TACH – Tachometer output signal
TBD – To Be Determined
TC2CIS – Turbocharger 2 Compressor Inlet Sensor
TC2CIT – Turbocharger 2 Compressor Inlet Temperature
TC1TOP – Turbocharger 1 Turbine Outlet Pressure
TC2TOP – Turbocharger 2 Turbine Outlet Pressure
TC1WC – Turbocharger 1 Wastegate Control
TC2WC – Turbocharger 2 Wastegate Control
TCAPE – Truck Computer Analysis of Performance and Economy
TCM – Transmission Control Module
TCWC – Turbocharger Wastegate Control
TDC – Top Dead Center
TDE – Transmission Driving Engaged
TOP – Transmission Oil Pressure
TOSS – Transmission Output Shaft Speed
TOT – Transmission Oil Temperature
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
VIGN – Ignition Voltage
VIN – Vehicle Identification Number
VOP – Valve Opening Pressure
VRE – Vehicle Retarder Enable
VREF – Reference Voltage
VREFB – Reference Voltage Body
VREFC – Reference Voltage Chassis
VREFE – Reference Voltage Engine
VSO – Vehicle Speed Output
VSS – Vehicle Speed Sensor
VSSH – Vehicle Speed Sensor High
VSSL – Vehicle Speed Sensor Low
WTSL – Wait to Start Lamp
WEL – Warn Engine Lamp
WIF – Water In Fuel
WIFL – Water In Fuel Lamp
WTEC – World Transmission Electronically Controlled automatic transmissions (Allison)
XCS – Transfercase
XMSN – Transmission

Table of Contents

Terminology.....**451**
Terminology.....**451**
Terms.....**451**

Terminology

Terminology

Terms

Accelerator Pedal Position (APP) sensor – A potentiometer sensor that indicates the position of the throttle pedal.

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.

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.

Aeration – The entrainment of air or combustion gas in coolant, lubricant, or fuel.

Aftercooler (Charge Air Cooler) – See **Charge Air Cooler**.

Aftertreatment (AFT) system – A part of the exhaust system that processes engine exhaust to meet emission requirements and traps particulate matter (soot) to prevent it from leaving the tailpipe.

Aftertreatment Fuel Doser (AFTFD) – A part of the Downstream Injection (DSI) unit that sends pressurized fuel to the Aftertreatment Fuel Injector (AFI) to inject fuel into the exhaust pipe.

Aftertreatment Fuel Inlet Sensor (AFTFIS) – A sensor that monitors fuel temperature in the DSI system and provides constant feedback to the ECM.

Aftertreatment Fuel Pressure 2 (AFTFP2) sensor – A sensor that monitors fuel pressure in the DSI system and provides constant feedback to the ECM.

Aftertreatment Fuel Shutoff Valve (AFTFSV) – A valve used to prevent fuel flow to the Aftertreatment Fuel Injector (AFI), and prevents all uncontrolled fuel delivery for the Aftertreatment system during an AFTFD valve malfunction.

Air Control Valve (ACV) – Contains the LP turbocharger wastegate control port, HP turbocharger wastegate control port, the EBPV control port, and the TC1TOP port. Although these components are integral to the ACV, each circuit is controlled by the ECM. The ACV controls compressed air for each control valve.

Air Inlet Temperature (AIT) sensor – A thermistor sensor that monitors intake air temperature.

Ambient Air Temperature (AAT) sensor – A sensor that sends an ambient air temperature signal to the ECM.

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)

American Trucking Association (ATA) Datalink – A serial datalink specified by the American Trucking Association and the SAE.

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 device in the ECM that converts an analog signal to a digital signal.

Barometric Absolute Pressure (BAP) sensor – A sensor built into the ECM that provides barometric pressure information to the ECM.

Bobtailing – Operating a truck/tractor without a trailer attached.

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)

Brake On/Off (BOO) switch – A switch located on the brake pedal lever, that provides a brake pedal position signal to the ECM.

Brake Pressure Switch (BPS) – A switch located in the brake pressure line that provides a brake pedal position signal to the ECM.

Calibration – ECM programming strategy to solve engine performance 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.

Camshaft Position (CMP) sensor – A magnetic pickup sensor that provides the ECM with a camshaft speed and position signal.

Carbon Monoxide (CO) – A colorless, odorless, highly poisonous gas that is formed by the incomplete combustion of carbon burning diesel engine. It is present in the exhaust gases of diesel engines.

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) – A heat exchanger mounted in the charge air path between the turbocharger and engine intake manifold. The charge air cooler reduces the charge air temperature by transferring heat from the charge air to a cooling medium (usually air).

Charge Air Cooler Outlet Temperature (CACOT) sensor – A thermistor sensor that monitors the temperature of charge air entering the intake air duct.

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 sensors to provide feedback to the ECM. The ECM uses the sensor input to continuously monitor variables and adjust actuators 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.

Cold soak – Allowing engine to remain OFF for a period of eight or more hours.

Cold Start Fuel Ignitor (CSFI) – The CSFI heats the intake air by vaporizing and igniting fuel in the air inlet duct.

Cold Start Fuel Solenoid (CSFS) – As the engine is cranked, the ECM energizes the CSFS valve, introducing fuel into the CSFI, which ignites and warms the air being drawn into the engine.

Cold Start Relay (CSR) – The CSR provides voltage to the CSFI, and is controlled by the ECM.

Continuous Monitor Test – An ECM function that continuously monitors the inputs and outputs to ensure that readings are within set limits.

Controller Area Network (CAN) – A J1939 high speed communication link.

Coolant – A fluid used to transport heat from one point to another.

Coolant Flow Valve (CFV) – The CFV is ECM controlled and redirects coolant through the fuel cooler, based on EFT, when directed.

Coolant level switch – A switch sensor used to monitor coolant level.

Coolant Mixer Valve (CMV) – Controls coolant flow through the low-temperature radiator.

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 Oil Separator Speed (CCOSS) sensor – The CCOSS sensor sends the ECM information about the speed of the crankcase oil separator internal components.

Crankcase pressure – The force of air inside the crankcase against the crankcase housing.

Crankshaft Position (CKP) sensor – A magnetic pickup sensor that determines crankshaft position and speed.

Cruise Control Switches (CCS) – A set of switches used for cruise control, Power Take Off (PTO), and remote hand throttle system.

Current – The flow of electrons passing through a conductor. Measured in amperes.

Cylinder Balance – An ECM control strategy to even-out the power contributions of each power cylinder.

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) – 2010 model year vehicles no longer utilize DTC identification by number. DTCs are now identified using the Suspect Parameter Number (SPN) and Failure Mode Indicator (FMI) identifiers only.

Diamond Logic Builder (DLB) – The diagnostics software for chassis related components and systems.

Diesel Oxidation Catalyst (DOC) – A DOC is part of the diesel exhaust Aftertreatment system. DOCs are devices that use a chemical process to break down pollutants in the exhaust stream into less harmful components. More specifically, DOCs utilize rare metals such as palladium and platinum to reduce hydrocarbon based Soluble Organic Fraction (SOF) and carbon monoxide content of diesel exhaust by simple oxidation. The DOC can be used during an active regeneration to create higher exhaust temperatures, thereby reducing soot in the DPF.

Diesel Oxidation Catalyst Inlet Temperature (DOCIT) sensor – A sensor that provides DOC inlet temperature signal to the ECM.

Diesel Particulate Filter (DPF) – A diesel particulate filter, sometimes called a DPF, is a device designed to remove diesel particulate matter or soot from the exhaust gas of a diesel engine.

Diesel Particulate Filter Differential Pressure (DPFDP) sensor – A sensor that measures pressure difference between the inlet and outlet of the DPF and provides feedback to the ECM.

Diesel Particulate Filter Inlet Temperature (DPFIT) sensor – A sensor that provides DOC inlet temperature signal to the ECM.

Diesel Particulate Filter Outlet Temperature (DPFOT) sensor – A sensor that provides DOC outlet temperature signal to the ECM.

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.

Down Stream Injection (DSI) – The DSI system injects fuel into the exhaust system to increase temperature of the exhaust gases, and is necessary for DPF regeneration.

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.

Dual Stage Turbocharger – An assembly of two turbochargers (low-pressure and high-pressure) in series to provide a wide range of charge air pressures efficiently.

Duty cycle – A control signal that has a controlled on/off time measurement from 0 to 100%. Normally used to control solenoids.

EGR Cooler – A cooler that allows heat to dissipate from the exhaust gasses before they enter the intake manifold.

Engine Back Pressure Valve (EBPV) – The ECM commands the EBPV to control the Exhaust Brake.

Engine Compression Brake (ECB) valve – The ECB valve controls pressure entering the brake oil gallery from the high-pressure oil rail gallery. This activates the brake actuator pistons and opens the exhaust valves.

Engine Compression Brake 1 (ECB1) solenoid – The ECB1 solenoid controls pressure entering the brake oil gallery from the high-pressure oil rail gallery.

Engine Compression Brake 2 (ECB2) solenoid – The ECB2 solenoid controls pressure entering the brake oil gallery from the high-pressure oil rail gallery.

Engine Compression Brake Pressure (ECBP) sensor – A high-pressure sensor that provides a feedback signal to the ECM indicating brake control pressure.

Engine Control Module (ECM) – An electronic processor that monitors and controls the engine.

Engine Coolant Level (ECL) sensor – A switch sensor that monitors coolant level.

Engine Coolant Temperature 1 (ECT1) sensor – A thermistor sensor that detects engine coolant temperature.

Engine Coolant Temperature 2 (ECT2) sensor – A thermistor sensor that detects engine coolant temperature.

Engine Fuel Temperature (EFT) sensor – A thermistor sensor that measures fuel temperature.

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 Oil Pressure (EOP) sensor – A variable capacitance sensor that measures oil pressure.

Engine Oil Temperature (EOT) sensor – A thermistor sensor that measures oil temperature.

Engine rating – Engine rating includes **Rated hp** and **Rated rpm**.

Engine RUNNING tests – Tests done with the engine running.

Engine Throttle Valve (ETV) and Engine Throttle Position Sensor – The ETV valve is used to control airflow during a regeneration process of the aftertreatment system. The ETV valve is also used to ensure a smooth engine shut down by restricting airflow to the engine at shut down.

Engine Warning Protection System (EWPS) – Safeguards the engine from undesirable operating conditions to prevent engine damage and to prolong engine life.

Exhaust Back Pressure (EBP) – The pressure present in the exhaust system during the exhaust period.

Exhaust Back Pressure Valve (EBPV) – A valve that regulates the amount of air pressure applied to the EBPV pneumatic actuator.

Exhaust brake – A brake device using engine exhaust back pressure as a retarding medium.

Exhaust Gas Recirculation (EGR) – A system used to recirculate a portion of the exhaust gases into the power cylinder in order to reduce oxides of nitrogen.

Exhaust Gas Recirculation Temperature (EGRT) sensor – A thermistor sensor that detects the exhaust gas temperature entering the EGR cooler.

Exhaust Gas Recirculation (EGR) valve – The EGRV controls the flow of exhaust gases to the intake manifold. The EGRV is integrated with an EGR Position (EGRP) sensor.

Exhaust Gas Temperature (EGT) – The temperature of exhaust gases.

Exhaust manifold – Exhaust gases flow through the exhaust manifold to the turbocharger exhaust inlet and are directed to the EGR cooler.

Exhaust Manifold Pressure (EMP) sensor – A variable capacitance sensor used to indicate air pressure in the exhaust manifold.

Exhaust Manifold Temperature (EMT) sensor – A thermistor style sensor used to indicate air temperature in the exhaust manifold.

Failure Mode Indicator (FMI) – Identifies the fault or condition effecting the individual component.

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 Cooler Control Valve – A valve used to redirect coolant through the fuel cooler.

Fuel Delivery Pressure (FDP) sensor – A variable capacitance sensor that monitors fuel pressure coming from the fuel tank and sends a signal to the ECM.

Fuel inlet restriction – A blockage, usually from contaminants, that prevents the flow of fluid through the fuel inlet line.

Fuel pressure – The force fuel exerts on the fuel system as it is pumped through the fuel system.

Fuel Pressure Control Valve (FPCV) – The FPCV controls the fuel pressure to the fuel rails and is controlled by the ECM. FPCV control depends on fuel pressure and fuel temperature.

Fuel Rail Pressure (FRP) – The amount of pressure in the fuel rail.

Fuel Rail Pressure (FRP) sensor – A variable capacitance sensor that monitors fuel pressure in the fuel rail and sends a signal to the ECM.

Fuel strainer – A pre-filter in the fuel system that keeps larger contaminants from entering the fuel system.

Fuel Volume Control Valve (FVCV) – The FVCV regulates the volume of flow sent to the HPFP. The FVCV allows a sufficient quantity of fuel to be delivered to the HPFP depending on engine load, speed, injector quantity, fuel temperature, and number of injections per cycle.

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 brake horsepower – The power of a complete basic engine, with air cleaner, without fan, and alternator, and air compressor not charging.

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.

H-Bridge Circuit – An H-Bridge (bipolar) circuit operates like putting a power source on one side of a motor and connecting 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.

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 – Transducer that varies its output voltage in response to changes in a magnetic field. Commonly used to time the speed of wheels and shafts.

High Pressure Fuel Pump (HPFP) assembly – The HPFP is a volumetric pump that supplies fuel at high pressure. The HPFP is mounted in the rear valley on the top of the engine and is driven by the camshaft.

High-pressure Piezo Common Rail (HPCR) – 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.

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.

Humidity Sensor (HS) – A sensor that measures the moisture content of filtered air entering the intake system.

Hydrocarbons – Organic compounds consisting of hydrogen and carbon (fuel and oil).

Hydrocarbon Injector – Injects fuel into the exhaust system to increase temperature of the exhaust gases.

Idle Shutdown Timer (IST) – An engine calibration that allows the ECM to shut down the engine during extended engine idle times.

Injection Control Pressure (ICP) sensor – Provides a feedback signal to the ECM indicating injection control pressure.

Injection Pressure Regulator (IPR) valve – A valve that is used to maintain desired injection control pressure.

Inlet Air Heater (IAH) – The IAH is primarily used to assist in starting the engine during cold weather. In addition, it helps to reduce white smoke emissions by heating the incoming air.

Intake manifold – Engine component that evenly supplies air to each intake port in the cylinder head(s).

Intake Manifold Pressure (IMP) sensor – A variable capacitance sensor used to indicate air pressure in the intake manifold.

Intake Manifold Temperature (IMT) sensor – A thermistor sensor used to indicate air temperature in the intake manifold.

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 HPFP though the Fuel Volume Control Valve (FVCV). The ITP also provides fuel for cooling and lubrication of the HPFP. Fuel is rerouted as pump return flow through the HPFP cooling and lubrication valve. Pressure is maintained at the inlet of the HPFP piston pump by an ITP regulator.

Interstage Cooler (ISC) – Uses cooled coolant to lower the charged air temperature that exits from the turbocharger low-pressure compressor and enters the turbocharger high-pressure compressor.

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).

Low temperature radiator thermostat – Coolant flow to the low temperature radiator is regulated by the low temperature radiator thermostat.

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 run at an overly low RPM for the load being applied.

Magnehelic Gauge – A gauge that measures pressure in inches of water.

Magnetic Pickup Sensor – 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 the gear teeth that disturb the magnetic field.

Malfunction Indicator Lamp (MIL) – An indicator lamp in the Electronic Instrument Cluster that will illuminate when a detected emissions fault occurs.

Manifold Absolute Pressure (MAP) – Boost pressure in the manifold that is a result of the turbocharger.

Manifold Absolute Pressure (MAP) sensor – A variable capacitance sensor that measures boost pressure.

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.

Mass Airflow – The intake airflow in an engine.

Mass Airflow (MAF) sensor – The MAF sensor is used for closed loop control of the EGR valve and ITV. The ECM monitors the MAF signal so that the ECM can control the EGR and intake throttle systems.

Metering unit valve assembly – The Metering unit valve assembly provides a metered amount of fuel to the Aftertreatment Fuel Injector (AFI).

Microprocessor – An integrated circuit in a microcomputer that controls information flow.

Micro Strain Gauge (MSG) Sensor – A MSG sensor measures pressure. Pressure 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.

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 electrical 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 the technician initiates using the EST that is run from a program in the software.

Output Circuit Check (OCC) – An on-demand test done during an Engine OFF self-test to check the continuity of selected actuators.

Output Shaft Speed (OSS) sensor – A sensor mounted to the rear of the transmission that supplies a vehicle speed signal to the ECM. The ECM uses this signal to control PTO, road speed limiting, and cruise control. Automatic transmissions use this signal for shift scheduling.

Oxides of Nitrogen (NOx) – Nitrogen oxides formed by a reaction between nitrogen and oxygen at high temperatures.

Oxygen Sensor (O2S) – A sensor that monitors oxygen levels in the exhaust.

Particulate matter – Particulate matter includes mostly burned particles of fuel and engine oil.

pH – A measure of the acidity or alkalinity of a solution.

Piezometer – An instrument for measuring fluid pressure.

Power – Power is a measure of the rate at which work (force x distance) is done during a specific time. 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).

Pre-DOC – Refers to exhaust gases that have not passed through the DOC.

Pulse Width Modulation (PWM) – Succession of digital electrical pulses, rather than an analog signal. Efficient method of providing power between fully on and fully off.

Radiator Shutter Enable (RSE) – A feature that uses various input signals to open or close radiator shutters by energizing or de-energizing a solenoid that controls an air or hydraulic cylinder.

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.

Regeneration – Oxidation of accumulated soot (carbon-based particulates) in the Diesel Particulate Filter (DPF). The soot is reduced to ash and stored in the DPF.

Reference voltage (V_{REF}) – A 5 volt reference supplied by the ECM to operate the engine sensors.

Remote Accelerator Pedal Position (RAPP) – A feature that allows the operator to set and maintain a constant engine speed from outside the vehicle cab. This feature may also be known as Remote Engine Speed Control (RESC). Control over engine speed is accomplished by using remote mounted switches to turn on the RESC and select the desired engine speed.

Remote Engine Speed Control (RESC) – See **Remote Accelerator Pedal Position**.

Reserve capacity – Time in minutes that a fully charged battery can be discharged to 10.5 volts at 25 amperes.

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.

ServiceMaxx™ software – Diagnostics software for engine related components and systems.

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.

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.

Starter Motor Control (SMC) – An ECM function that prevents starter engagement while the engine is running (above a set calibrated rpm), when the automatic transmission is in gear, or when the manual transmission clutch pedal is not depressed.

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 – The movement of the piston from Top Dead Center (TDC) to Bottom Dead Center (BDC).

Substrate – Material that supports the wash coating or catalytic materials.

Suspect Parameter Number (SPN) – A 19-bit number used to identify the item for which diagnostics are being reported. The SPN is used for multiple purposes, some that are specific to diagnostics are as follows;

- Identify the least repairable subsystem that has failed.
- Identify subsystems or assemblies that may not have hard failures but may be exhibiting abnormal operating performance.
- Identify a particular event or condition that will be reported.
- Report a component and non-standard failure mode.

System restriction (air) – The static pressure differential that occurs at a given airflow 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.

Thermistor Sensor – Changes 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 to form a voltage signal matched with a temperature value.

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) – A computer program that simulates the performance and fuel economy of trucks.

Turbocharger – A turbine driven compressor mounted on the exhaust manifold. The turbocharger increases the pressure, temperature and density of intake air to charge air.

Turbocharger 1 Turbine Outlet Pressure (TC1TOP) sensor – A variable capacitance sensor that monitors exhaust back-pressure.

Turbocharger 2 Compressor Inlet Temperature (TC2CIT) sensor – The TC2ICT sensor is thermistor-based sensor that monitors the temperature of charge air entering the HP turbocharger.

Turbocharger 2 Compressor Inlet (TC2CIS) sensor – The TC2CIS sensor includes a thermistor sensor that monitors the temperature of charge air entering the HP turbocharger. This sensor also monitors boost pressure for the LP turbocharger.

Turbocharger Outlet Temperature (TCOT) sensor – A sensor that provides a turbocharger outlet temperature signal to the ECM.

Turbocharger 1 Wastegate Control (TC1WC) solenoid – Controls the TC1WC actuator by regulating the amount of charge air pressure supplied to the TC1WC actuator. The TC1WC solenoid is controlled by signals from the ECM in response to engine speed, required fuel quantity, boost, exhaust back-pressure, and altitude. The TC1WC actuator is part of the turbocharger assembly.

Turbocharger Wastegate Control (TCWC) solenoid – Controls the TCWC actuator by regulating the amount of charge air pressure supplied to the TCWC actuator. The TCWC solenoid is controlled by signals from the ECM in response to engine speed, required fuel quantity, boost, exhaust back-pressure, and altitude.

Turbocharger 2 Wastegate Control (TC2WC) solenoid – Controls the TC2WC actuator by regulating the amount of charge air pressure supplied to the wastegate actuator. The TC2WC solenoid is controlled by signals from the ECM in response to engine speed, required fuel quantity, boost, exhaust back-pressure, and altitude. The TC2WC actuator is part of the turbocharger assembly.

Variable capacitance sensor – A variable capacitance sensor 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 Output (VSO) – A vehicle speed signal sent to the EGC through the J1939 network.

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.

Water In Fuel (WIF) sensor – A switch sensor that measures the amount of water in the fuel.

Wiggle Test – A test used to detect intermittent faults in harnesses and/or connectors. This test, usually used in conjunction with the ServiceMaxx™ Continuous Monitor Test, involves gently wiggling connectors and wiring without detaching connectors while monitoring signal voltage on the EST. When a voltage spike is noted (either high or low) the technician will have located a potential open, short or high resistance in the circuit.

Table of Contents

Dual Turbocharger, Exhaust Manifolds, and Piping.....463

Air Compressor and Power Steering Pump.....463

Fuel System.....463

Front Cover, Cooling System, and Related Components.....463

Oil Cooler, Oil Pump, Oil Filter, and Oil Pan.....464

Cylinder Head and Valve Train.....465

Flywheel and Flywheel Housing.....466

Power Cylinders.....466

Crankcase, Crankshaft, and Camshaft.....468

Dual Turbocharger, Exhaust Manifolds, and Piping

Dual Turbocharger	
Turbine shaft axial end play	0.05 to 0.10 mm (0.002 to 0.004 in).

Exhaust Manifold	
Maximum allowable warpage	0.08 mm (0.003 in)

Air Compressor and Power Steering Pump

Power Steering Pump	
Backlash: Power steering idler gear assembly	0.066 to 0.290 mm (0.0026 to 0.0114 in).

Fuel System

Primary fuel filter type	10 micron with water separation
Secondary fuel filter type	4 micron with water separation

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)
Thermostat Assembly with Bypass	
Type	Balanced pressure, wax pellet
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
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 (219.2°F)

Oil Cooler, Oil Pump, Oil Filter, and Oil Pan

Oil Pump Assembly	
Type	Gerotor
Drive	Crankshaft
Location	Oil pump housing assembly
Pressure Regulating Valve (operating range)	5.2 to 6.0 kPa (0.75 to 0.87 psi)
End clearance (inner and outer oil pump rotor to oil pump housing assembly)	0.025 to 0.095 mm (0.001 to 0.004 in)
Radial clearance (between outer oil pump rotor and oil pump housing assembly)	0.15 to 0.28 mm (0.006 to 0.011 in)

Oil Cooler Assembly	
Type	Full flow, fin
Location	Engine valley (front)

Oil Filter	
Type	Spin-on, full flow - disposable
Location	Oil pan mounted
Filter bypass location	Oil filter can

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 to 50.75°
Valve margin (minimum)	1.53 mm (0.060 in)
Valve recession in head	0.37 to 0.73 mm (0.0146 to 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 to 53.25°
Valve margin (minimum)	1.40 mm (0.055 in)
Valve recession in head	0.37 to 0.73 mm (0.0146 to 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 to 52.75°
Valve seat angle (exhaust) from center line of valve guide	50.0 to 50.25°
Overall thickness of cylinder head (deck-to-deck)	95 ± 0.48 mm (3.74 ± 0.018 in)
Valve Springs	
Solid height	36.1 mm (1.42 in)
Compressed*	46.50 mm @ 340 ± 17 N (1.83 in @ 76.5 ± 3.8 lb)
Compressed*	38.30 mm @ 850 ± 43 N (1.51 in @ 191.1 ± 9.7 lb)
* Spring must be compressed to a solid height before checking test loads.	
Push Rods	
Runout (maximum)	0.5 mm (0.02 in)

Flywheel 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)

Power Cylinders

Connecting Rods	
Connecting rod length (center to center)	176 mm (6.929 in)
Piston pin bore inside diameter	38.512 to 38.549 mm (1.5162 to 1.5177 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)	0.027 to 0.097 mm (0.0001 to 0.0038 in)
Connecting rod side clearance	0.230 to 0.730 mm (0.0091 to 0.0287 in)
Weight (complete rod without bearing)	1280.5 to 1301.5 g (2.823 to 2.869 lb)
Pistons	
Material	Aluminum Alloy
Skirt diameter [1]	98.103 to 98.117 mm (3.862 to 3.863 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	98.103 to 98.117 mm (3.862 to 3.863 in)
0.254 mm (0.010 in) oversize	98.357 to 98.371 mm (3.872 to 3.873 in)
0.508 mm (0.020 in) oversize	98.611 to 98.625 mm (3.882 to 3.883 in)
0.762 mm (0.030 in) oversize	98.865 to 98.879 mm (3.892 to 3.893 in)

Top compression ring groove width (measured over 2.10 mm (0.083 in) gauge pins):	
Upper limit	96.541 mm (3.8008 in)
Replacement limit	96.341 mm (3.7929 in)
Ring groove (side clearance):	
Intermediate compression	0.050 to 0.096 mm (0.0020 to 0.0038 in)
Oil control	0.040 to 0.080 mm (0.00157 to 0.00315 in)
Piston height above crankcase deck (protrusion)	0.609 to 0.863 mm (0.0240 to 0.0340 in)
Piston skirt clearance	0.060 to 0.111 mm (0.0023 to 0.0044 in)
Piston Pins	
Length	74.6 to 75.0 mm (2.9371 to 2.9528 in)
Diameter	38.490 to 38.500 mm (1.5154 to 1.5158 in)
Piston pin clearance (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 0.0023 in)
Clearance in piston (piston pin bore)	0.010 to 0.020 mm (0.0004 to 0.0008 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 0.022 in)
Intermediate compression	0.67 to 0.82 mm (0.0264 to 0.0323 in)
Oil control	0.25 to 0.40 mm (0.010 to 0.016 in)

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 (0.0005 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	80.9873 to 81.0127 mm (3.1885 to 3.1895 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	71.987 to 72.013 mm (2.834 to 2.835 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 0.1437 in)
Camshaft lobe lift (maximum):	
Intake	5.820 mm (0.2291 in)
Exhaust	5.906 mm (0.2325 in)

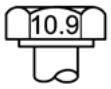
Table of Contents

General Torque.....471
- **Bolt Identification**.....471
- **General Torque Guidelines**.....472
- **Standard Torque Charts**.....473
- **Using a Torque Wrench Extension**.....474

Special Torques.....475
- **Mounting Engine on Stand**.....475
- **Engine Electrical**.....475
- **Exhaust Gas Recirculation (EGR) System**.....475
- **Dual Turbocharger, Exhaust Manifolds, and Piping**.....476
- **Air Compressor and Power Steering Pump**.....476
- **Fuel System**.....477
- **Front Cover, Cooling System, and Related Components**.....477
- **Oil Cooler, Oil pump, Oil Filter, and Oil Pan**.....477
- **Cylinder Heads, Valve Covers, and Valve Train**.....478
- **Flywheel and Flywheel Housing**.....478
- **Power Cylinders**.....478
- **Crankcase, Crankshaft, and Camshaft**.....478

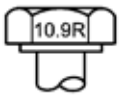
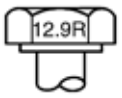
General Torque

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		
8.8	8.8	Medium carbon, Medium carbon Alloy steel or low Carbon boron steel	Quench and tempered		
9.8	–	Medium carbon, Medium carbon Alloy steel or low Carbon boron steel	Quench and tempered		
10.9	10.9	Medium carbon, Medium carbon Alloy steel or low Carbon boron steel	Quench and tempered		

M03100

Figure 680 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		
12.9R	Medium carbon Alloy steel	Quench and tempered, Roll threaded after heat treatment		

M03101

Figure 681 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

CAUTION: To prevent engine damage, do not use this standard torque chart with other International brand engines or engines made by other manufacturers.

Standard torque chart provides tightening values for all hardware that do not require special torque.

Standard Torque Values - Class 10.9 Metric Flange Head Bolts and Studs

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

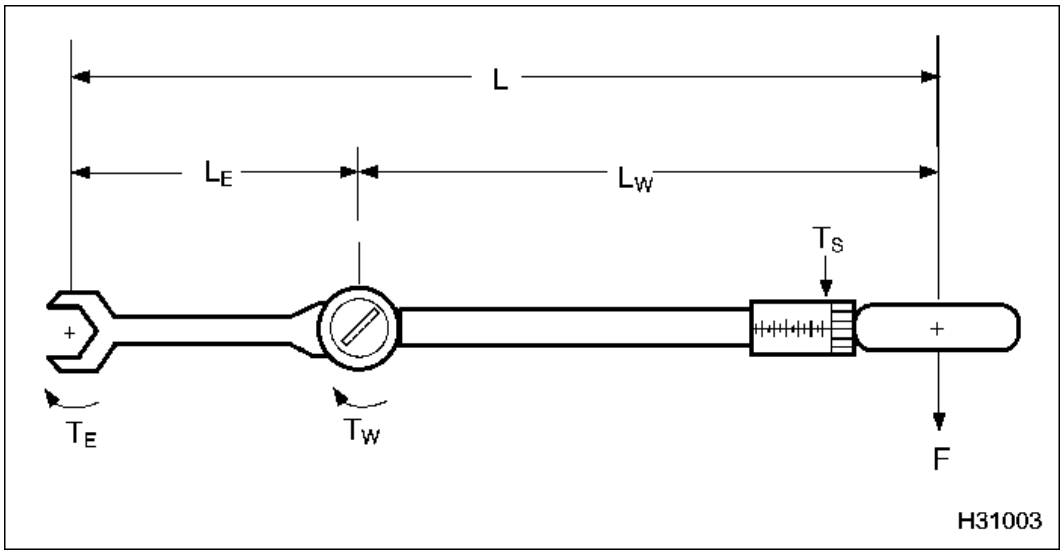


Figure 682 Torque Wrench and Extension

- 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 lb-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 lb-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 lb-ft (12 inches / (12 inches + 6 inches)

T_S = 65 lb-ft (12 inches / (18 inches)

T_S = 65 lb-ft (0.666)

T_S = 43.33 lb-ft

Special Torques

Mounting Engine on Stand

Crankcase coolant drain plug (M16)	20 N·m (15 lb-ft)
Oil pan drain plug (M14)	44 N·m (32 lb-ft)

Engine Electrical

Crankshaft Position (CKP) sensor bolt	10 N·m (89 lb-in)
Camshaft Position (CMP) sensor bolt	10 N·m (89 lb-in)
Engine Coolant Temperature (ECT1) sensor	18 N·m (159 lb-in)
Engine Fuel Temperature (EFT) sensor	18 N·m (159 lb-in)
Exhaust Gas Recirculation Temperature (EGRT) Sensor	38 N·m (30 lb-ft)
Exhaust Gas Temperature (EGT) Sensor	44 N·m (32 lb-ft)
Engine Oil Pressure (EOP) sensor	12 N·m (106 lb-in)
Engine Oil Temperature (EOT) sensor	18 N·m (159 lb-in)
Fuel Delivery Pressure (FDP) Sensor	12 N·m (106 lb-in)
Fuel Rail Pressure (FRP) sensor	7 N·m (62 lb-in), then turn one hex flat
Intake Manifold Temperature (IMT) sensor	18 N·m (159 lb-in)
Intake Manifold Pressure (IMP) sensor	12 N·m (106 lb-in)
MAF/AIT Torx screw	1 N·m (10 lb-in)
Upper harness channel shield bolt, M5 x 10	4 N·m (35 lb-in)
Water In Fuel (WIF) sensor	20 N·m (15 lb-ft)

Exhaust Gas Recirculation (EGR) System

Worm drive clamp	3.5 N·m (31 lb-in)

Dual Turbocharger, Exhaust Manifolds, and Piping

Turbocharger Clamps	
Turbo air inlet duct clamp	5 N·m (48 lb-in)
Turbocharger assembly exhaust outlet V-clamps	See tightening steps in procedure.

Exhaust Manifolds	
Exhaust manifold bolts, M8 x 50	See tightening steps in procedure.
Exhaust manifold stud bolts, M8 x 40	See tightening steps in procedure.
Exhaust manifold heat shield threaded spacers	30 N·m (21 lb-ft)
Heat shield bolts, M8 x 12	30 N·m (21 lb-ft)
Heat shield nut, M8	30 N·m (21 lb-ft)

Air Compressor and Power Steering Pump

Air Compressor and Power Steering Pump	
Air compressor to air compressor bracket bolts, M10 x 30 and M10 x 45	72 N·m (53 lb-ft)
Connector assembly, M18 (for air compressor coolant return and supply hoses)	25 N·m (18 lb-ft)
Elbow assembly, M18 (for air compressor coolant return and supply hoses)	25 N·m (18 lb-ft)
Air compressor oil supply hose fitting nut	20 N·m (177 lb-in)
Air compressor pulley nut	120 N·m (88 lb-ft)
Oil outlet fitting assembly	25 N·m (18 lb-ft)
Power steering suction tube assembly flared tube nut	166 N·m (122 lb-ft)
Power steering pressure tube assembly flared tube nut	87 N·m (64 lb-ft)
45° flare to M10 90° elbow	19 N·m (14 lb-ft)

Fuel System

Banjo bolts, M12	25 N·m (18 lb-ft)
High-pressure pump cap nuts	25 N·m (18 lb-ft)
Diagnostic valve	13 N·m (115 lb-in)
Right high-pressure tube assembly nuts	See tightening steps in procedure.
Left high-pressure tube assembly nuts	See tightening steps in procedure.
Fuel cooler screws, M8 x 20	23 N·m (16 lb-ft)
Fuel housing cover screws, M5 x 18	7 N·m (62 lb-in)
High-pressure fuel pump gear bolt	78 N·m (57 lb-ft)
Fuel rail to injector tube fittings	See tightening steps in procedure
Injector clamp bolts	See tightening steps in procedure
Coolant return hose clamps	3 N·m (26 lb-in)
Primary fuel filter cap	50 N·m (37 lb-ft)
Secondary fuel filter cap	40 N·m (29 lb-ft)
Water drain retainer screws, M5 x18	7 N·m (62 lb-in)
WIF sensor	2 N·m (18 lb-in)
EFT sensor	18 N·m (159 lb-in)
FDP sensor	18 N·m (159 lb-in)

Front Cover, Cooling System, and Related Components

Vibration damper bolts	See Vibration Damper Installation Procedure

Oil Cooler, Oil pump, Oil Filter, and Oil Pan

Oil cooler bypass valve assembly	71 N·m (52 lb-ft)
Oil cooler cover assembly serrated nuts	See assembly procedure for special torque sequence
Hex plug assembly (oil pan)	25 N·m (18 lb-ft)
Plug assembly, M18 (oil pan)	25 N·m (18 lb-ft)
Oil pan drain plug (M14)	44 N·m (32 lb-ft)
Oil filter adapter (oil pan)	55 N·m (40 lb-ft)
Oil pump housing plate screws, M8 x 25	17 N·m (150 lb-in)
Relief valve cap, oil pump	35 N·m (26 lb-ft)

Cylinder Heads, Valve Covers, and Valve Train

Cylinder head bolts	See tightening steps in procedure
Draft tube assembly nut, M10	54 N·m (40 lb-ft)
Dual fulcrum plate assembly bolts	See tightening steps in procedure
Filter with jet pump captive bolts, M6	5 N·m (44 lb-in)
Fuel rail plug assembly	27 N·m (20 lb-ft)
Valve cover bolt and stud bolts assemblies	9 N·m (80 lb-in)
Worm gear hose clamps	13 N·m (115 lb-in)

Flywheel and Flywheel Housing

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.

Power Cylinders

Connecting rod bolts	61 N·m (45 lb-ft)

Crankcase, Crankshaft, and Camshaft

Main bearing bolts	See tightening procedure and sequence
Coolant heater	41 N·m (30 lb-ft)

Table of Contents

Special Tools.....481

Mounting Engine on Stand.....481

Engine Electrical.....481

Exhaust Gas Recirculation (EGR) System.....481

Dual Turbocharger, Exhaust Manifolds, and Piping.....482

Air Compressor and Power Steering Pump.....482

Fuel System.....482

Front Cover, Cooling System, and Related Components.....483

Oil Cooler, Oil Pump, Oil Filter, and Oil Pan.....483

Cylinder Heads, Valve Covers, and Valve Train.....484

Flywheel Assembly and Flywheel Housing.....485

Power Cylinders.....485

Crankcase, Crankshaft, and Camshaft.....486

Special Tools.....487
Essential Tools.....487

Special Tools

Special tools for the MaxxForce® 7 engine can be ordered from the SPX Corporation, 1-800-520-2584.

Mounting Engine on Stand

Description	Tool Number
Engine Stand	OTC1750A
Engine Stand Mounting Bracket	ZTSE4507

Engine Electrical

Description	Tool Number
Injector Connector Release Tool	ZTSE6074
P-80® Rubber Lubricant or equivalent	Obtain locally

Exhaust Gas Recirculation (EGR) System

Description	Tool Number
EGR Leak Detection Kit	KL20040NAV
EGR Coolant Return Tool (Single Hole Seal Air Inlet)	KL20040-1
EGR Turbocharger Inlet Flange Tool (Flange End Seal Leak Detection)	KL20040-2
EGR Cooler Inlet Tool (End Seal {small diameter})	KL20040-3
EGR Gas Outlet Tool (End Seal {large diameter})	KL20040-4
EGR Cooler Vent Tool (Small Port Plug)	KL20040-5
Air Regulator	KL20020-13
EGR Valve Bore Cleaning Brush	ZTSE4753
EGR Valve Puller	ZTSE6010
Intake Manifold Mixing Bowl Covers (Intake Plates Cover)	ZTSE6034
P-80® Rubber Lubricant or equivalent	Obtain locally

Dual Turbocharger, Exhaust Manifolds, and Piping

Description	Tool Number
Cap kit (All)	Obtain locally
Dial indicator with magnetic base	Obtain locally
Turbo Supply Blockoff Plugs (silicone)	ZTSE6012
Turbo Oil Supply Blockoff (Steel)	ZTSE6013
P-80® Rubber Lubricant or equivalent	Obtain locally

Air Compressor and Power Steering Pump

Description	Tool Number
Cap Protector kit (All)	Obtain locally
Dial indicator with magnetic base	Obtain locally
P-80® Rubber Lubricant or equivalent	Obtain locally

Fuel System

Description	Tool Number
Clean Fuel Tank Kit (Clean Fuel Source Tool)	15-637-01
Cross-over Tube Removal Tool	ZTSE6015
Fuel System Caps	ZTSE4710
Fuel Injector Rack Holder	ZTSE4299B
Fuel Injector Tip Cleaning Brush	ZTSE4301
High-pressure Fuel Pump Wrench	ZTSE4959
Injector Cup	ZTSE4709
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
P-80® Rubber Lubricant or equivalent	Obtain locally
Spring lock coupling disconnect tool	Obtain locally

Front Cover, Cooling System, and Related Components

Description	Tool Number
Dial indicator with magnetic base	Obtain locally
P-80® Rubber Lubricant or equivalent	Obtain locally

Oil Cooler, Oil Pump, Oil Filter, and Oil Pan

Description	Tool Number
Air pressure regulator	Obtain locally
Feeler gauge	Obtain locally
Front Wear Sleeve Remover and Installer	ZTSE4705
Front Seal Remover and Installer	ZTSE6060
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Loctite® 271	Obtain locally
Loctite® 569 hydraulic sealant or equivalent	Obtain locally
P-80® Rubber Lubricant or equivalent	Obtain locally
Slide hammer	Obtain locally
Oil Cooler Block-off Plate	ZTSE6029
Straightedge	Obtain locally

Cylinder Heads, Valve Covers, and Valve Train

Description	Tool Number
C Type Valve Spring Compressor	ZTSE1846
Cylinder Head Bolt Tap	ZTSE4744
Cylinder Head Lifting Bracket	ZTSE6035
Cylinder Head Pressure Test Plate	ZTSE4534
Dial Caliper	Obtain locally
Dye Penetrant Kit	PT-7191
Feeler Gauge	Obtain locally
Fuel Gallery Cleaning Brush	ZTSE4541
Fuel Injector Tip Cleaning Brush	ZTSE4301
Injector Sleeve Brushes	ZTSE4751
Injector Sleeve Installer	ZTSE4733
Injector Sleeve Remover	ZTSE4732
Inspection Mirror	Obtain locally
Lithium Grease	Obtain locally
Loctite® 620 Retaining Compound	Obtain locally
Pressure Test Regulator and Gauge	Obtain locally
P-80® Rubber Lubricant or equivalent	Obtain locally
Slide Hammer Kit	ZTSE4398A
Straightedge	Obtain locally
Valve Guide Gauge Tool	ZTSE4577
Valve Spring Tester	ZTSE2241
0-1 inch Micrometer	Obtain locally
3-4 inch Micrometer	Obtain locally

Flywheel Assembly and Flywheel Housing

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
Rear Crankshaft Seal and Sleeve Installer	ZTSE4515C
Rear Wear Sleeve Remover (Distorter Ring and Distorter Shaft)	ZTSE4889
Slide hammer	Obtain locally
Heat insulated glove	Obtain locally

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 (2.10 mm [0.083 in])	ZTSE6062
Piston Ring Compressor (Cope)	ZTSE4714
Piston ring expansion pliers	Obtain locally
Telescoping gauge set	Obtain locally

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
Head Bolt Bottoming Tap	ZTSE4508
Lifting sling	Obtain locally
Loctite® 11747	Obtain locally
Loctite® 262	Obtain locally
Loctite® 5127 sealant	Obtain locally
P-80® Rubber Lubricant or equivalent	Obtain locally
Oil Gallery Cleaning Brush	ZTSE4511
Oil Gallery Plug Driver	ZTSE4512
Straightedge	Obtain locally
Telescoping gauge set	Obtain locally

Special Tools

Essential Tools

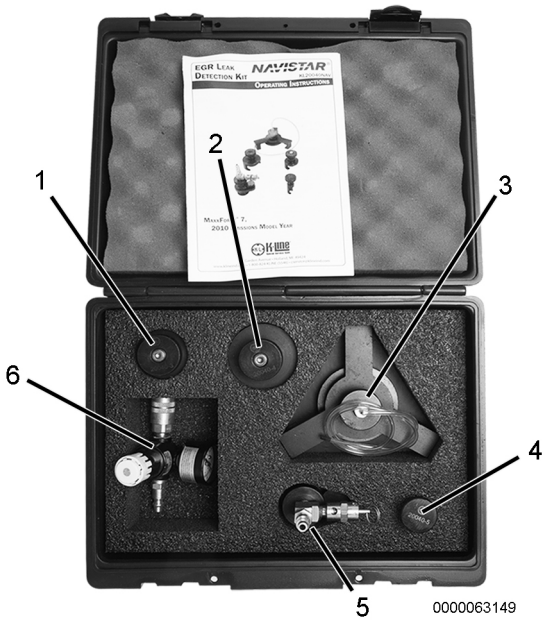


Figure 683 KL20040NAV 2010 MaxxForce® 7 EGR Leak Detection Kit

1. KL20040-3 EGR Cooler Inlet Tool (End Seal [small diameter])
2. KL20040-4 EGR Gas Outlet Tool (End Seal [large diameter])
3. KL20040-2 EGR Turbocharger Inlet Flange Tool (Flange End Seal Leak Detection)
4. KL20040-5 EGR Cooler Vent Tool (small port plug)
5. KL20040-1 EGR Coolant Return Tool (Single Hole Seal Air Inlet)
6. KL20020-13 air regulator

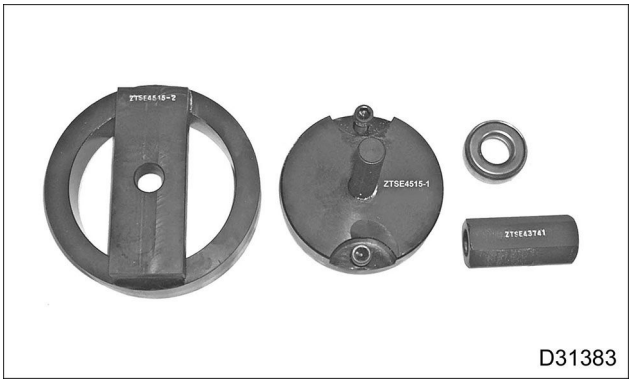


Figure 684 ZTSE4515C Rear Crankshaft Seal and Sleeve Installer

Figure 685 15-637-01 Clean Fuel Tank Kit (Clean Fuel Source Tool)

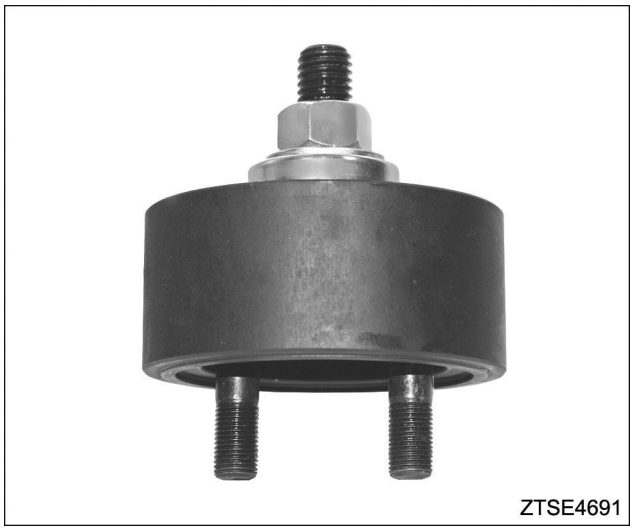


Figure 686 ZTSE4691 Front Seal Installer

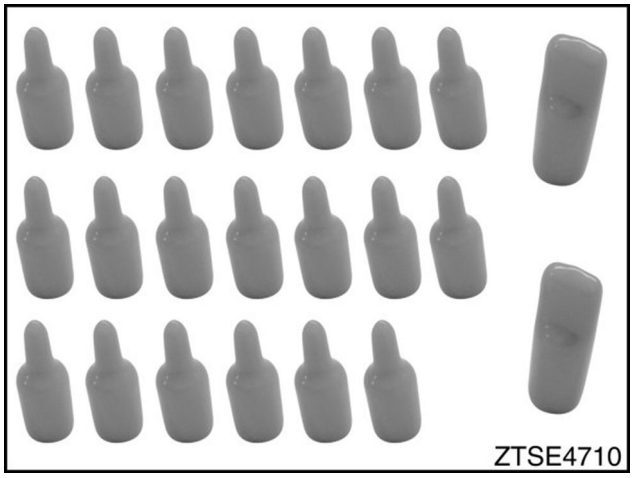


Figure 687 ZTSE4710 Fuel System Caps

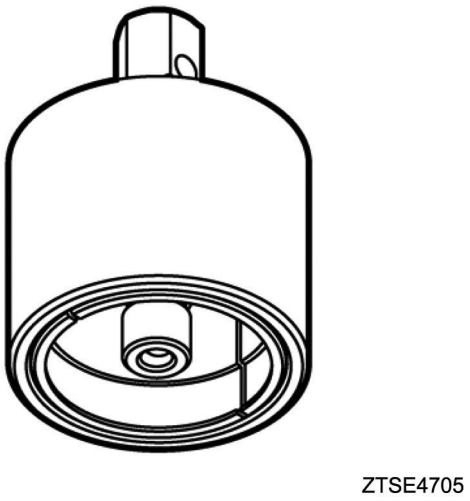


Figure 688 ZTSE4705 Front Wear Sleeve Remover

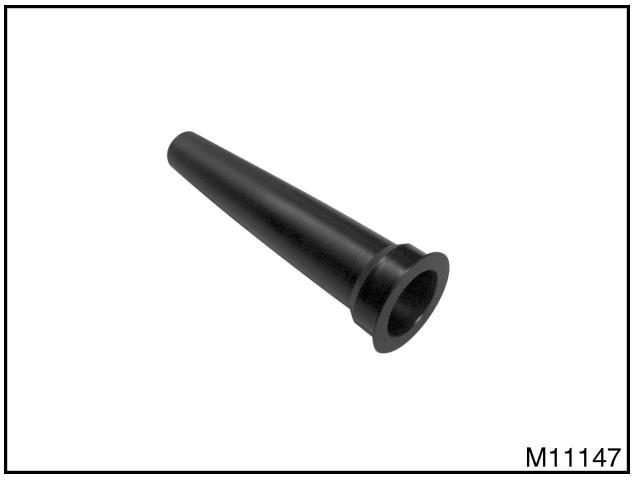


Figure 689 ZTSE4709 Injector Cups for ZTSE4299 (8)

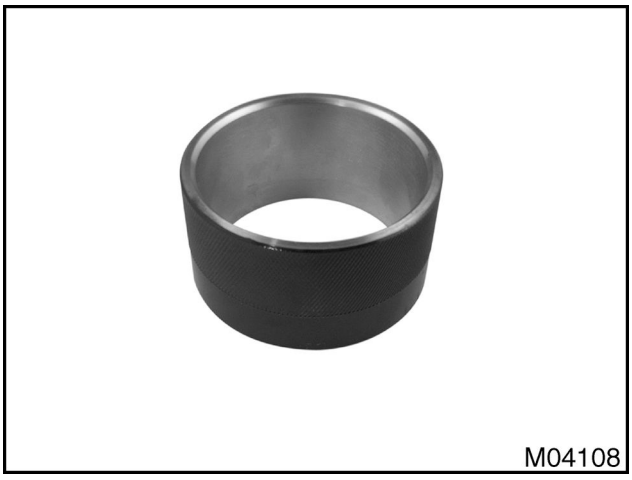


Figure 690 ZTSE4714 Piston Ring Compressor

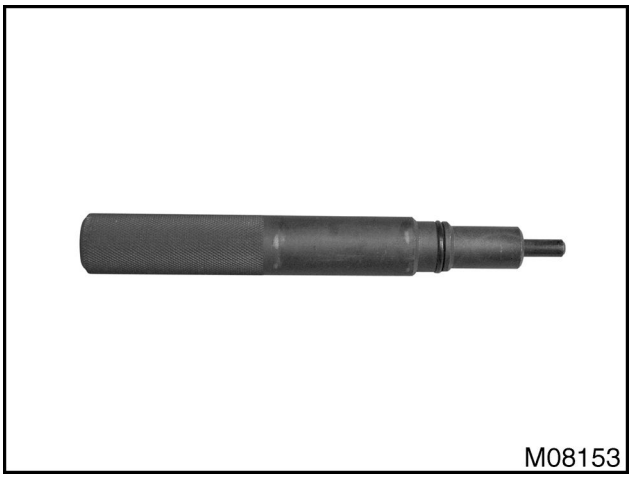


Figure 692 ZTSE4733 Injector Sleeve Installer

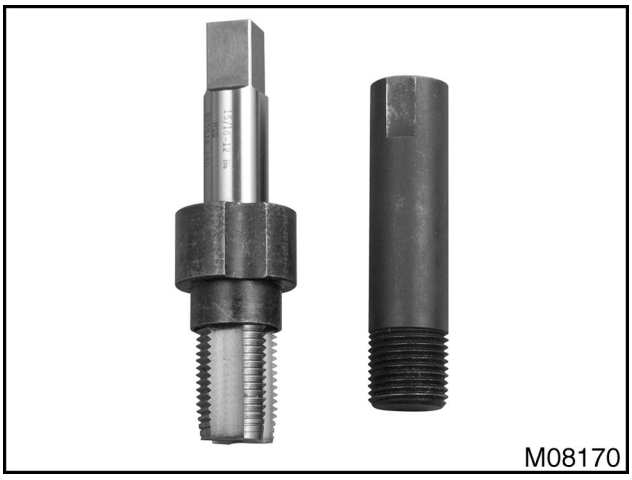


Figure 691 ZTSE4732 Injector Sleeve Remover

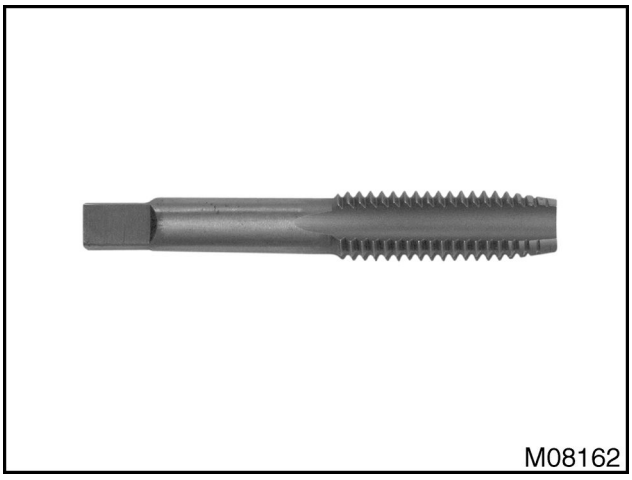
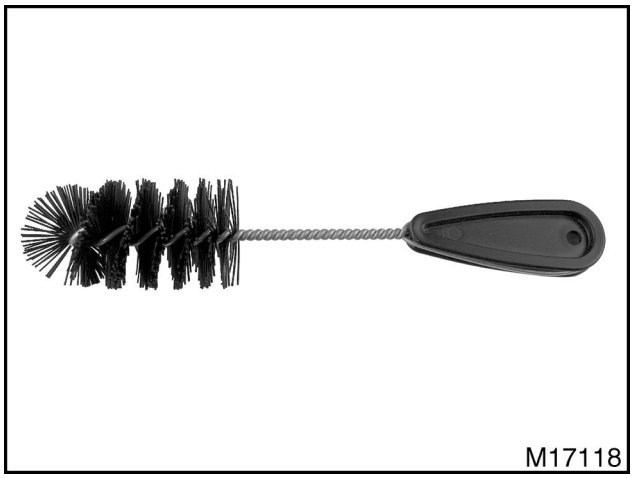


Figure 693 ZTSE4744 Cylinder Head Bolt Tap

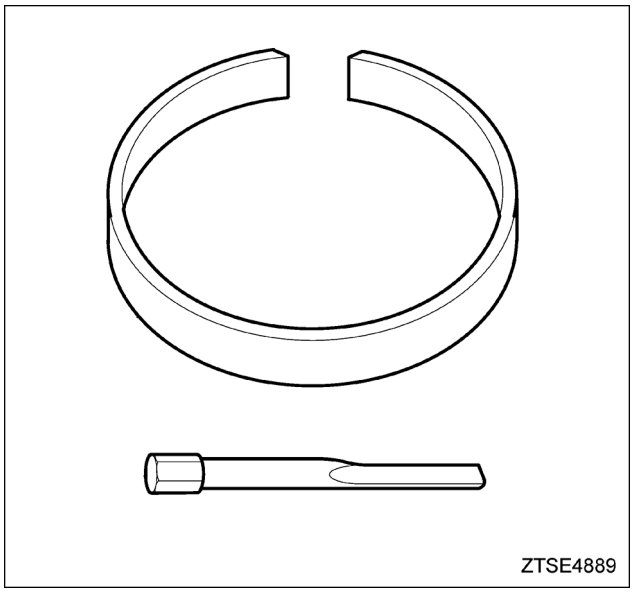
M08152

Figure 694 ZTSE4751 Injector Sleeve Brushes



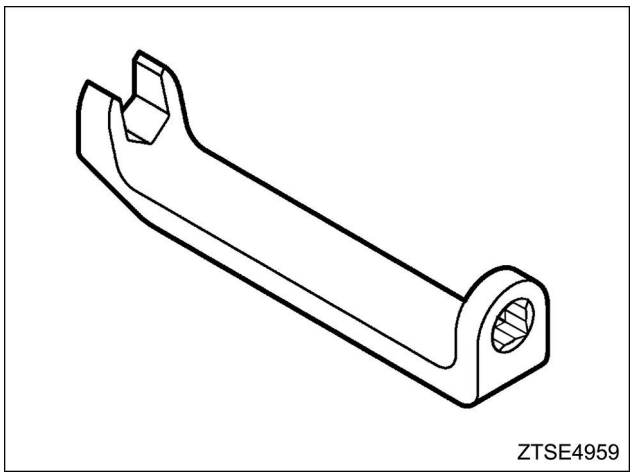
M17118

Figure 695 ZTSE4753 EGR Valve Bore Cleaning Brush



ZTSE4889

Figure 696 ZTSE4889 Rear Wear Sleeve Remover



ZTSE4959

Figure 697 ZTSE4959 High-pressure Fuel Pump Wrench

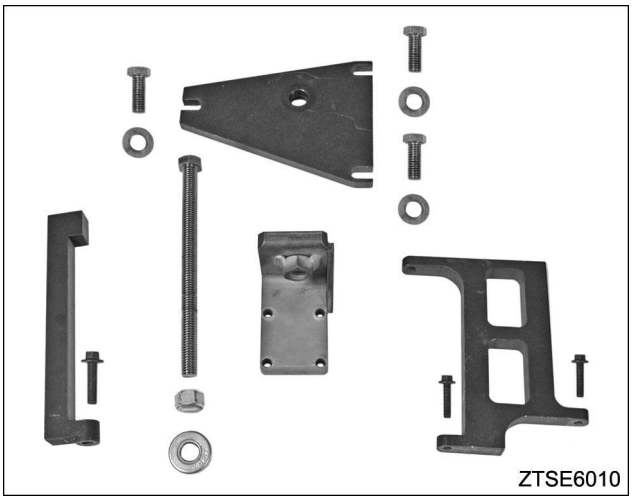


Figure 698 ZTSE6010 EGR Valve Puller

Figure 700 ZTSE6013 Turbo Oil Supply Blockoff (Steel)

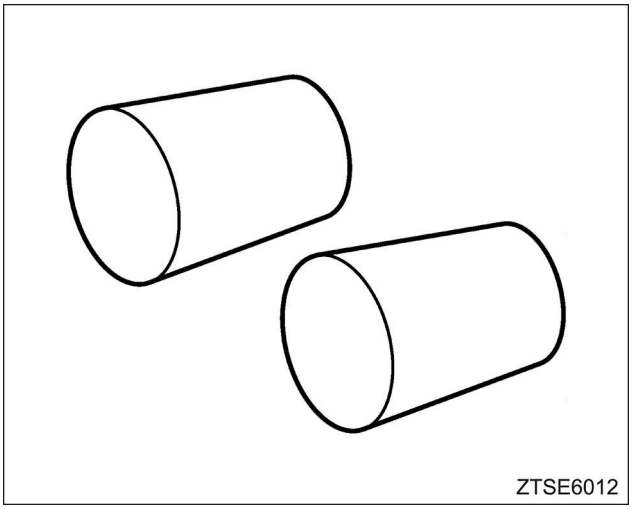


Figure 699 ZTSE6012 Turbo Supply Blockoff Plugs (silicone)

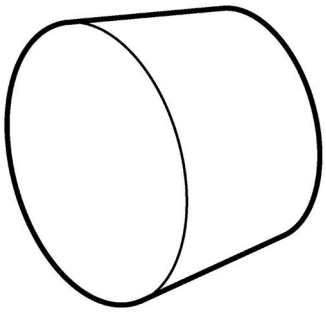


Figure 701 ZTSE6014 Turbo Drain Blockoff Plug (silicone)

Figure 702 ZTSE6015 Cross-over Tube Removal Tool

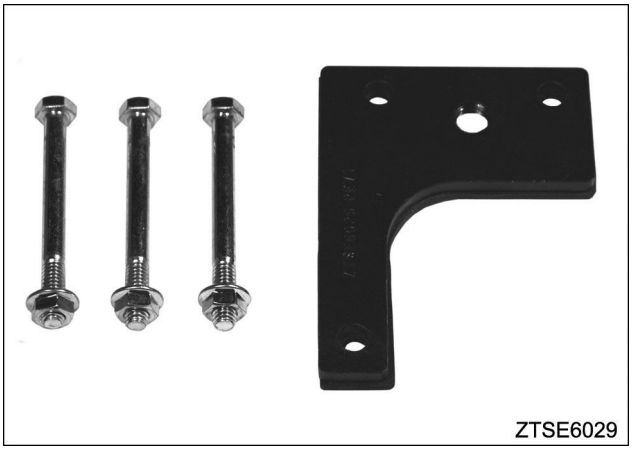


Figure 703 ZTSE6029 Oil Cooler Blockoff Plate

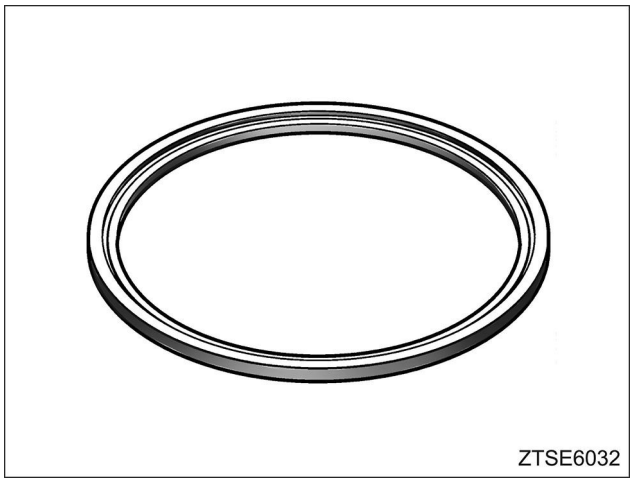


Figure 704 ZTSE6032 Rear Crank Seal Insert Tool

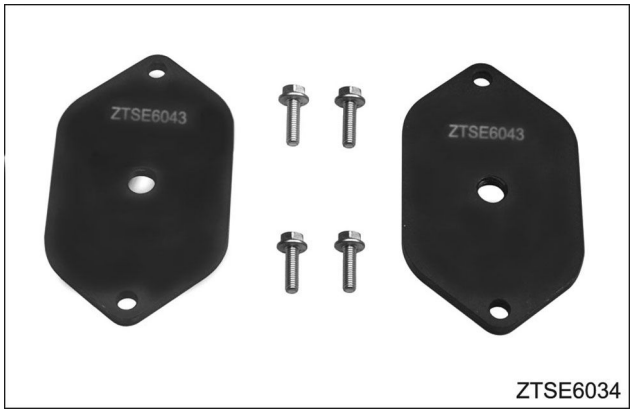


Figure 705 ZTSE6034 Intake Manifold Mixing Bowl Covers (Intake Plate Covers)

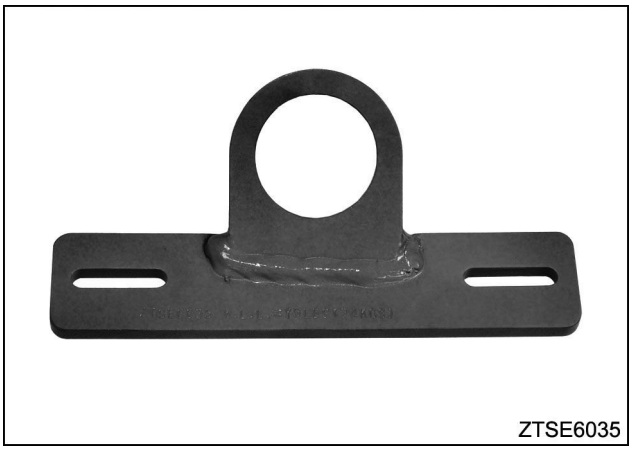


Figure 706 ZTSE6035 Cylinder Head Lifting Bracket

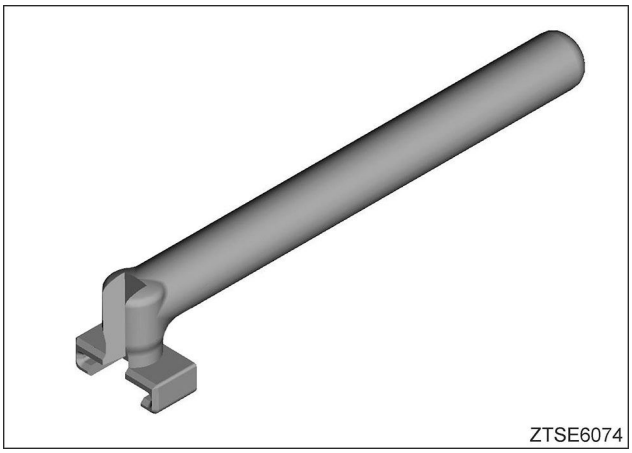


Figure 707 ZTSE6074 Injector Connector Release Tool