ENGINE SERVICE MANUAL

MaxxForce® 11 and 13

Navistar, Inc.

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Highlights

Table 1 Summary of Changes

Location	Reason
Turbochargers section	Removed figure and text regarding inspection of turbocharger on bench

TABLE OF CONTENTS

Foreword....1
Service Diagnosis....2
Safety Information....3
Engine Systems....5
Mounting Engine on Stand....55
Engine Electrical....61
Cold Start Assist....107
Aftertreatment System....119
Exhaust Back Pressure Control....139
Turbochargers....151
Air Compressor and Power Steering....183
Fuel System....197
Oil Cooler, Filter Housing and Crankcase Ventilation....245
Exhaust Gas Recirculation (EGR) System....261
Air Intake Throttle Duct and Exhaust Manifold....297
Front Cover, Fan Drive, Cooling System and Related Components....311
MaxxForce® Engine Brake by Jacobs....341
Cylinder Head, Camshaft and Valve Train....357
Flywheel and Flywheel Housing....391
Oil Pan and Oil Pickup Tube....409
Oil Pump and Timing Gears....425
Power Cylinders....441
Crankcase and Crankshaft....461
Abbreviations and Acronyms....475
Terminology....481

Appendix A – Specifications.....493

Appendix B – Torques.....499

Appendix C – Special Service Tools.....517

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.

MaxxForce® 11 and 13 *Engine Operation and Maintenance Manual*

MaxxForce® 11 and 13 *Engine Service Manual*

MaxxForce® 11 and 13 *Engine Diagnostic Manual*

MaxxForce® 11 and 13 Hard Start and No Start Form

MaxxForce® 11 and 13 Electric Control Systems Diagnostic Form

MaxxForce® 11 and 13 Performance Diagnostic Form

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

NOTE: To order technical service literature, contact your MaxxForce® dealer.

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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 maintenance 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.

Obey Safety Instructions, Warnings, Cautions, and Notes in this manual. Not following warnings, cautions, and notes 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

Work Area

- Keep work area clean, dry, and organized.
- Keep tools and parts off the floor.
- Make sure the work area is ventilated and well lit.
- Make sure a First Aid Kit is available.

Safety Equipment

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

Protective Measures

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

Vehicle

- Shift transmission to park or neutral, set parking brake, and block wheels before doing diagnostic or service procedures.
- Clear the area before starting the engine.

Engine

- The engine should be operated or serviced only by qualified individuals.
- Provide necessary ventilation when operating engine in a closed area.
- Keep combustible material away from engine exhaust system and exhaust manifolds.
- Install all shields, guards, and access covers before operating engine.
- Do not run engine with unprotected air inlets or exhaust openings. If unavoidable for service reasons, put protective screens over all openings before servicing engine.
- Shut engine off and relieve all pressure in the system before removing panels, housing covers, and caps.
- If an engine is not safe to operate, tag the engine and ignition key.

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

- 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 flames or sparks.
- Do not smoke in workplace.

Compressed Air

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

Tools

- Make sure all tools are in good condition.
- Make sure all standard electrical tools are grounded.
- Check for frayed or damaged 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
Engine Emission Label....7
Engine Accessory Labels and Identification Plates....8
Engine Specifications....8
Heavy Duty On Board Diagnostics (HD-OBD)....10
Engine Description....10
Optional Equipment....11
Chassis Mounted Equipment....11
Engine Component Locations....12

Air Management System....16
Airflow....17
Turbochargers....18
Air Control Valve (ACV)....19
Boost Control....19
Low-Pressure Charge Air Cooler (LPCAC)....19
High-Pressure Charge Air Cooler (HPCAC)....19
High-Pressure Boost Pressure (HPBP) Sensor....20
High-Pressure Boost Temperature (HPBT) Sensor....20
Low-Pressure Boost Pressure (LPBP) Sensor and Low-Pressure Boost Temperature (LPBT) Sensor....20
Exhaust Gas Recirculation (EGR) System....21
Aftertreatment (AFT) System....24
Diesel Particulate Filter (DPF)....25
Diesel Oxidation Catalyst (DOC)....25
Aftertreatment (AFT) System Conditions and Responses....25
Downstream Fuel Injection....26
Crankcase Oil Separator....28

Fuel Management System....30
Fuel System....30
Fuel Flow....31
Low-Pressure Fuel System....32
High-Pressure Fuel System....34

Cold Start Assist System....35
Cold Start Assist System Components....35
Cold Start Assist System Operation....36

Oil Flow and Components....37

Engine Cooling System....41
Cooling System Flow....41
Thermostat Operation....42
Coolant Control Valve (CCV) operation....43

Engine Brake System.....44
Engine Brake Control System Components.....44
Engine Brake System Operation.....46

Electronic Control System.....47
Electronic Control System Components.....47
Operation and Function.....47
Reference Voltage (VREF).....47
Signal Conditioner.....47
Microprocessor.....47
Diagnostic Trouble Codes.....47
Microprocessor Memory.....47
Actuator Control.....48
Actuators.....48
Coolant Control Valve (CCV).....48
Exhaust Back Pressure Valve (EBPV) Control.....48
Exhaust Gas Recirculation (EGR) Valve 48
Air Control Valve (ACV).....48
Cold Start Relay (CSR).....48
Cold Start Solenoid (CSS) Valve.....49
Engine Throttle Valve (ETV).....49
Fuel Pressure Control Valve (FPCV).....49
Aftertreatment Fuel Doser (AFTFD).....49
Aftertreatment Shutoff Valve (AFTSV).....49
Engine and Vehicle Sensors.....49
Thermistor Sensors.....49
Variable Capacitance Sensors.....51
Magnetic Pickup Sensors.....52
Potentiometer Sensors.....53
Switches.....54
Additional Sensors.....54
Oxygen Sensor (O2S).....54
Humidity Sensor (HS).....54

Engine Identification

Engine Serial Number

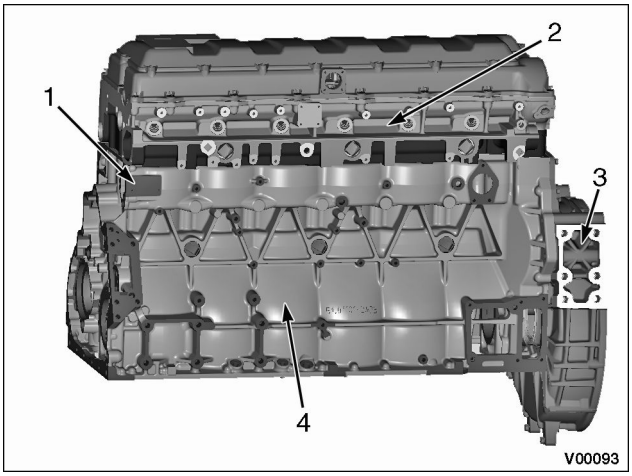


Figure 1 Engine serial number

1. Engine Serial Number (ESN) location
2. Cylinder head
3. Flywheel housing
4. Crankcase

The Engine Serial Number (ESN) is located on the front of the crankcase (left side), below the cylinder head.

Engine Serial Number Examples

MaxxForce® 11: 106HM2XXXXXXX

MaxxForce® 13: 125HM2XXXXXXX

MaxxForce® 11: 106HM2YXXXXXXX

MaxxForce® 13: 125HM2YXXXXXXX

Engine Serial Number Codes

106 – Engine displacement (10.5 L)
125 – Engine displacement (12.4 L)
H – Diesel, turbocharged, Charge Air Cooler (CAC), and electronically controlled
M2 – Motor truck
Y – Huntsville, Alabama
7 digit suffix – Engine serial number sequence

Engine Emission Label

Figure 2 2012 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 valve cover (front left side). The EPA label typically includes the following:

- Model year
- Engine family, model, and displacement
- Advertised brake horsepower and torque rating
- Emission family and control systems
- Valve lash specifications
- ESN
- EPA, Onboard Diagnostics (OBD), EURO, and reserved fields for specific applications

Engine Accessory Labels and Identification Plates

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

- Air compressor
- Air conditioning compressor
- Alternator
- Cooling fan clutch
- Engine Control Module (ECM)
- High-pressure (HP) fuel pump
- Power steering pump
- Starter motor
- Turbochargers

Engine Specifications

MaxxForce® 11 and 13 Diesel Engines	
Engine Configuration	4 stroke, inline six cylinder diesel
Advertised brake horsepower @ rpm	
• MaxxForce® 11	See EPA exhaust emission label
• MaxxForce® 13	See EPA exhaust emission label
Peak torque @ rpm	
• MaxxForce® 11	See EPA exhaust emission label
• MaxxForce® 13	See EPA exhaust emission label
Displacement	
• MaxxForce® 11	10.5 L (641 in^3)
• MaxxForce® 13	12.4 L (758 in^3)
Compression ratio	
• MaxxForce® 11	16.5:1
• MaxxForce® 13	17.0:1
Stroke	
• MaxxForce® 11	155 mm (6.10 in)
• MaxxForce® 13	166 mm (6.54 in)
Bore (sleeve diameter)	
• MaxxForce® 11	120 mm (4.72 in)
• MaxxForce® 13	126 mm (4.96 in)

Total engine weight (dry weight without trim or accessories)	
• MaxxForce® 11	1087 kgs (2392 lbs)
• MaxxForce® 13	1087 kgs (2392 lbs)
Firing order	1-5-3-6-2-4
Engine rotation direction (facing flywheel)	Counterclockwise
Aspiration	Dual turbocharged and charge air cooled
Combustion system	Direct injection turbocharged
Fuel system	High-pressure common rail
Lube system capacity (including filter)	
• MaxxForce® 11	40 L (42 qts)
• MaxxForce® 13	40 L (42 qts)
Lube system capacity (overhaul only, with filter)	
• MaxxForce® 11	44 L (46 qts)
• MaxxForce® 13	44 L (46 qts)
Engine oil pressure at operating temperature with SAE 15W-40 oil	
• Low idle	69 kPa (10 psi) min
• High idle	276-483 kPa (40-70 psi)
Idle speed (no load)	600 rpm, nominal
Thermostat operating temperature	
• Primary	83 °C - 95 °C (181 °F - 203 °F)
• Secondary	87 °C - 102 °C (189 °F - 216 °F)

Heavy Duty On Board Diagnostics (HD-OBD)

The EPA has added new regulations for 2010 to reduce heavy duty vehicle emissions. The HD-OBD system is designed specifically for electronically controlled heavy duty engines. The key goal for HD-OBD regulation is to keep engine emissions in specification for as long as a given vehicle is in use.

HD-OBD is legislated to be implemented in three phases:

- 2010: First engine for each Original Equipment Manufacture (OEM) becomes fully certified.
    - The lead engine is determined by a legislated equation based on projected sales volume and useful life of the engine.
    - For Navistar®, this is the EPA 2010 MaxxForce® 13 engine.
- 2013: One engine in each engine family becomes fully certified.
    - This will be the largest step of the three phases.
- 2016: All engines must be fully HD-OBD certified.

The HD-OBD system continuously monitors for proper engine operation, and will alert the vehicle operator to emission-related faults using the Malfunction Indicator Lamp (MIL).

The MIL is installed in the Electronic Instrument Cluster. When a detected emissions fault occurs, the MIL will be illuminated. Diagnostic information is also stored in the ECM, and may be accessed by the technician for diagnosis and repair of the malfunction. Diagnostic information is accessed by connecting the Electronic Service Tool (EST) to the in-cab Diagnostic Connector.

Engine Description

The MaxxForce® 11 and 13 diesel engines are designed for increased durability, reliability, and ease of maintenance.

The cylinder head has four valves per cylinder for increased airflow. The overhead valve train includes rocker arms and valve bridges to operate the four valves. The fuel injector is centrally located between the four valves, directing fuel over the piston for improved performance and reduced emissions.

The overhead camshaft is supported by seven bearings in the cylinder head. The camshaft gear is driven from the rear of the engine. The overhead valve train includes roller rocker arms and dual valves that open, using a valve bridge. For 2010, the camshaft has been redesigned to incorporate six additional lobes. These new lobes are used with the engine brake housings for operation of the MaxxForce® Engine Brake.

The MaxxForce® 11 engines use aluminum pistons, and the MaxxForce® 13 engines use one piece steel pistons. All pistons use an offset piston axis and centered combustion bowls. Crown markings show correct piston orientation in the crankcase.

The one-piece crankcase uses replaceable wet cylinder liners that are sealed by dual crevice seals.

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

A gerotor lube oil pump is mounted behind the front cover and is driven by the crankshaft. Pressurized oil is supplied to various engine components. All MaxxForce® 11 and 13 engines also use an engine oil cooler and a cartridge-style engine oil filter, which are located in the engine lube oil module.

The low-pressure fuel pump draws fuel from the fuel tank(s) through a chassis mounted filter/water separator. The low-pressure fuel pump provides fuel for the engine mounted fuel module. Conditioned low-pressure fuel is supplied from the engine mounted fuel module to the high-pressure fuel pump, cold start fuel solenoid, and the Downstream Injection (DSI) unit.

The high-pressure fuel system is a direct fuel injected common-rail system. the common-rail includes a high-pressure fuel pump, two fuel rail supply lines, fuel rail, six fuel injectors, and pressure limiting valve.

The fuel injectors are installed in the cylinder head under the valve cover and are electronically actuated by the ECM.

MaxxForce® 11 and 13 engines use a dual stage, fixed geometry turbocharger assembly. The high-pressure (HP) turbocharger includes a

pneumatically operated wastegate. Each stage uses a Charge Air Cooler (CAC). The Low Pressure Charge Air Cooler (LPCAC) is mounted on the lower right side of the engine, and uses the engine cooling system to regulate charge air temperatures. The High Pressure Charge Air Cooler (HPCAC) is mounted in front of the engine cooling package. The HPCAC is an air-to-air type cooler, and requires no connections to the engine's cooling system.

The Exhaust Gas Recirculation (EGR) system circulates cooled exhaust into the stream in the air inlet duct. The dual stage EGR cooler provides regulated cooling of the EGR gases before entering the air intake duct. This cools the combustion process, and reduces Nitrogen Oxides (NO_x) emissions.

The open crankcase breather system uses a centrifugal Crankcase Oil Separator (CCOS) to return oil mist to the crankcase, and vent the cleaned crankcase gasses to the atmosphere. The CCOS is part of the oil module. The breather system has been redesigned, and uses no crankcase breather filter or external piping. Blowby gases enter the CCOS directly through the side of the crankcase.

The cold start assist system warms the incoming air supply prior to and during cranking.

The MaxxForce® Engine Brake by Jacobs® is optional for both MaxxForce® 11 and 13 engine displacements. The engine brake is a compression release system that provides additional vehicle braking performance. The operator can control the engine brake for different operating conditions.

Optional Equipment

Optional cold climate features available are an oil pan heater and a coolant heater. Both heaters use an electric element to warm engine fluids in cold weather.

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

The coolant heater warms the engine coolant surrounding the cylinders. Warmed engine coolant increases fuel economy and aids start-up in cold weather.

Chassis Mounted Equipment

- The chassis mounted fuel filter/water separator removes a majority of the water and foreign particles that may enter the fuel system from the supply tank(s). This filter works with the engine mounted fuel module to eliminate foreign matter and moisture from the fuel before entering the fuel injection system.
- The Low Temperature Radiator (LTR) regulates the temperature of the LPCAC and the low temperature stage of the EGR cooler. The LTR is mounted in front of the radiator cooling package, and requires connections to the engine cooling system.
- The HPCAC lowers the temperature of the after the air is compressed by the turbochargers and has no connections to the engine cooling system. The HPCAC is an air-to-air cooler. The HPCAC is mounted in front of the radiator cooling package.
- The Diesel Oxidation Catalyst (DOC) oxidizes hydrocarbons and carbon monoxide, provides heat for exhaust system warm-up, aids in temperature management for the Diesel Particulate Filter (DPF), and oxidizes NO into NO_2 for passive DPF regeneration. The DOC is monitored by the ECM using one Diesel Oxidation Catalyst Inlet Temperature (DOCIT) sensor positioned at the DOC inlet, and one Diesel Oxidation Catalyst Outlet Temperature (DOCOT) sensor positioned at the DOC outlet.
- The DPF temporarily stores carbon-based particulates, oxidizes stored particulates, stores non-combustible ash, and provides required exhaust back pressure for proper engine performance. The DPF is monitored by the ECM using one Diesel Particulate Filter Outlet Temperature (DPFOT) sensor located at the outlet of the DPF, and one Diesel Particulate Filter Differential Pressure (DPFDP) sensor located on or near the DPF.

Engine Component Locations

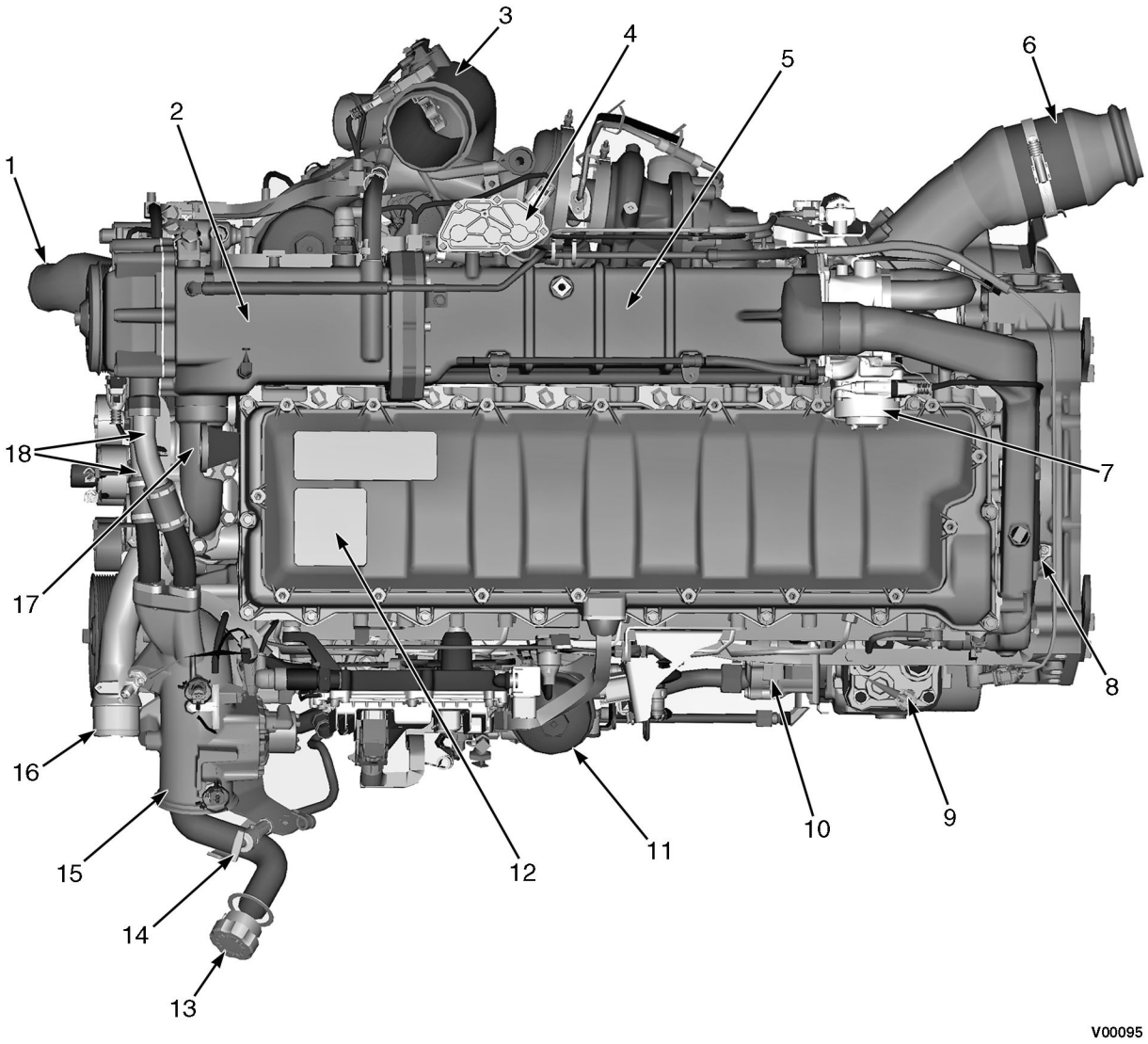


Figure 3 Component location – top view

1. Engine coolant inlet
2. Exhaust Gas Recirculation (EGR) cooler (low temperature stage)
3. Air intake duct
4. Air Control Valve (ACV) assembly
5. EGR cooler (high temperature stage)
6. Pre-DOC assembly (PDOC)
7. EGR Valve (EGRV)
8. Crankshaft Position (CKP) Sensor
9. Air compressor
10. Power steering pump
11. Engine mounted secondary fuel filter access
12. Emission label (location)
13. Engine oil fill
14. Engine oil level gauge
15. Intake throttle duct assy
16. Engine coolant outlet
17. EGR cooler outlet pipe (coolant)
18. EGR cooler outlet tubes (gases)

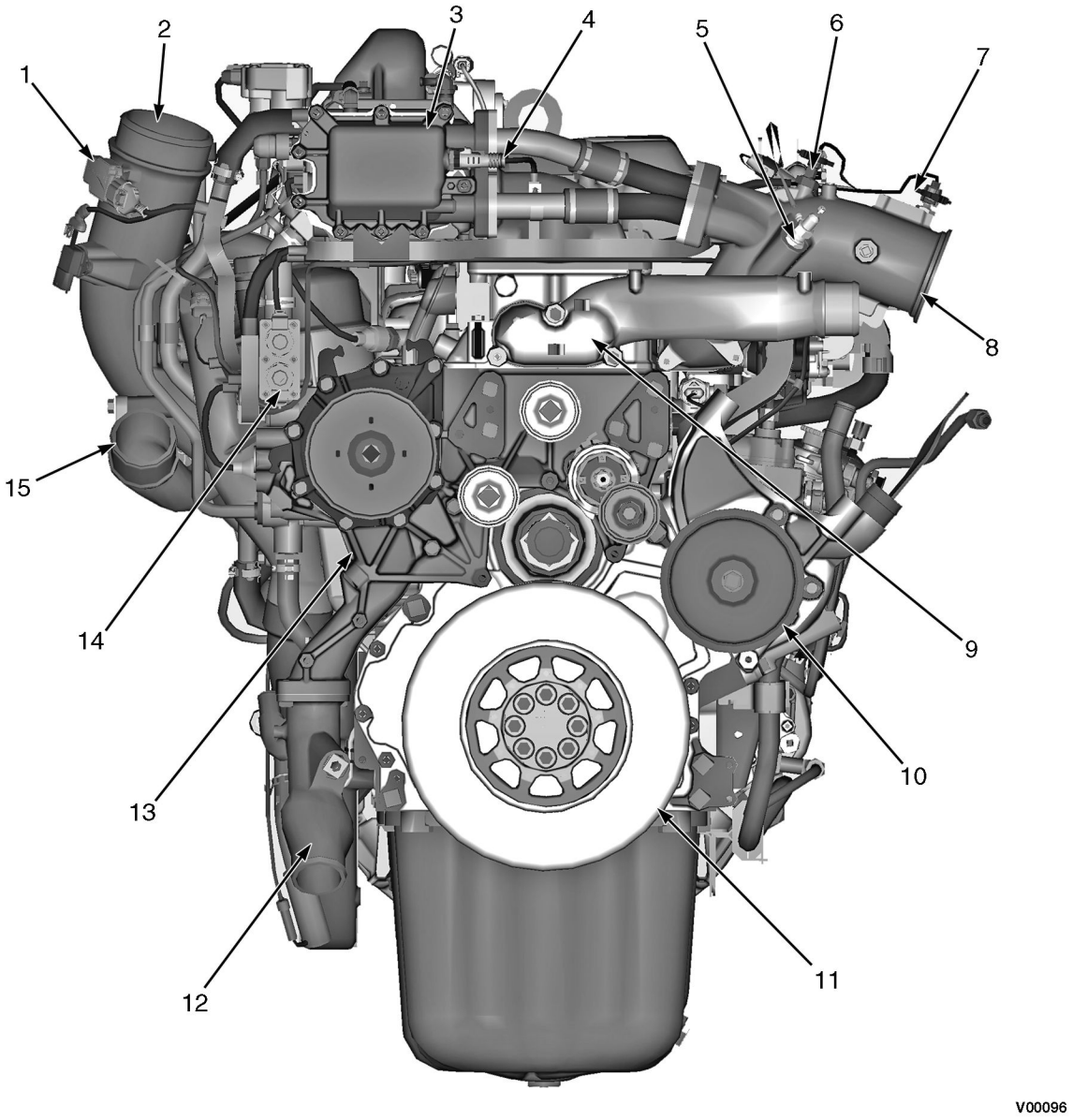


Figure 4 Component location – front view

1. Mass Air Flow (MAF) sensor
2. Air inlet duct
3. EGR cooler
4. EGR Temperature (EGRT) sensor
5. Cold Start Fuel Ignitor (CSFI)
6. Intake Manifold Pressure (IMP) sensor
7. Charge Air Cooler Outlet Temperature (CACOT) sensor
8. Intake throttle duct assy
9. Thermostat housing
10. HP pump pulley
11. Vibration damper
12. Water engine inlet
13. Water distribution housing.
14. Coolant Control Valve (CCV)
15. HP turbocharger compressor outlet

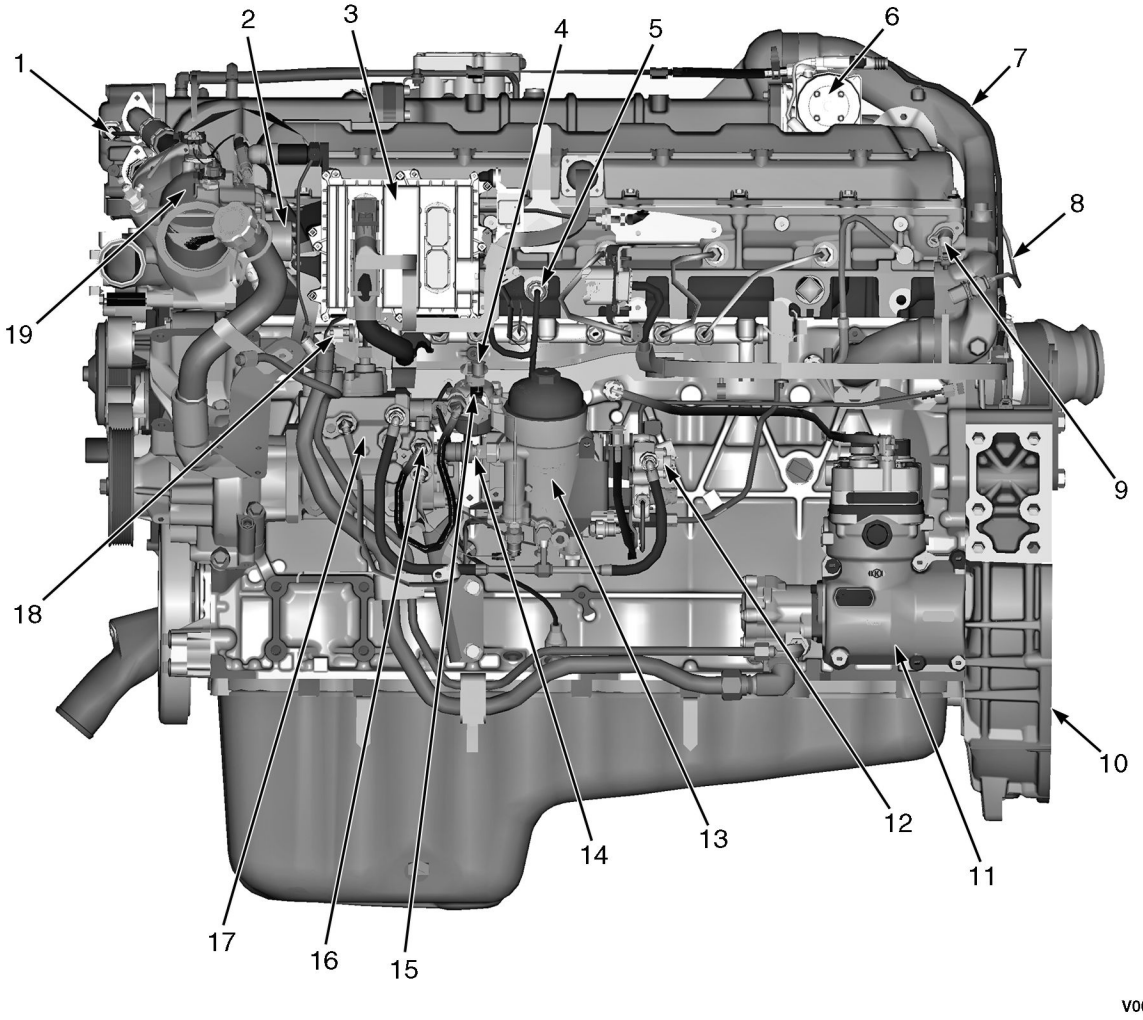


Figure 5 Component location – left view

1. EGRT sensor
2. Engine Throttle Valve (ETV)
3. ECM
4. Low Pressure (LP) fuel pressure test port
5. Intake Manifold Temperature (IMT)
6. EGRV
7. EGR cooler coolant manifold
8. Oxygen Sensor harness
9. Camshaft Position (CMP) sensor
10. Flywheel Housing
11. Air Compressor
12. DSI unit
13. Engine mounted secondary fuel filter access
14. Fuel Delivery Pressure (EDP) sensor
15. Fuel primer pump assembly
16. LP fuel pump
17. HP fuel pump
18. Fuel Rail Pressure (FRP) sensor
19. Intake throttle duct assembly

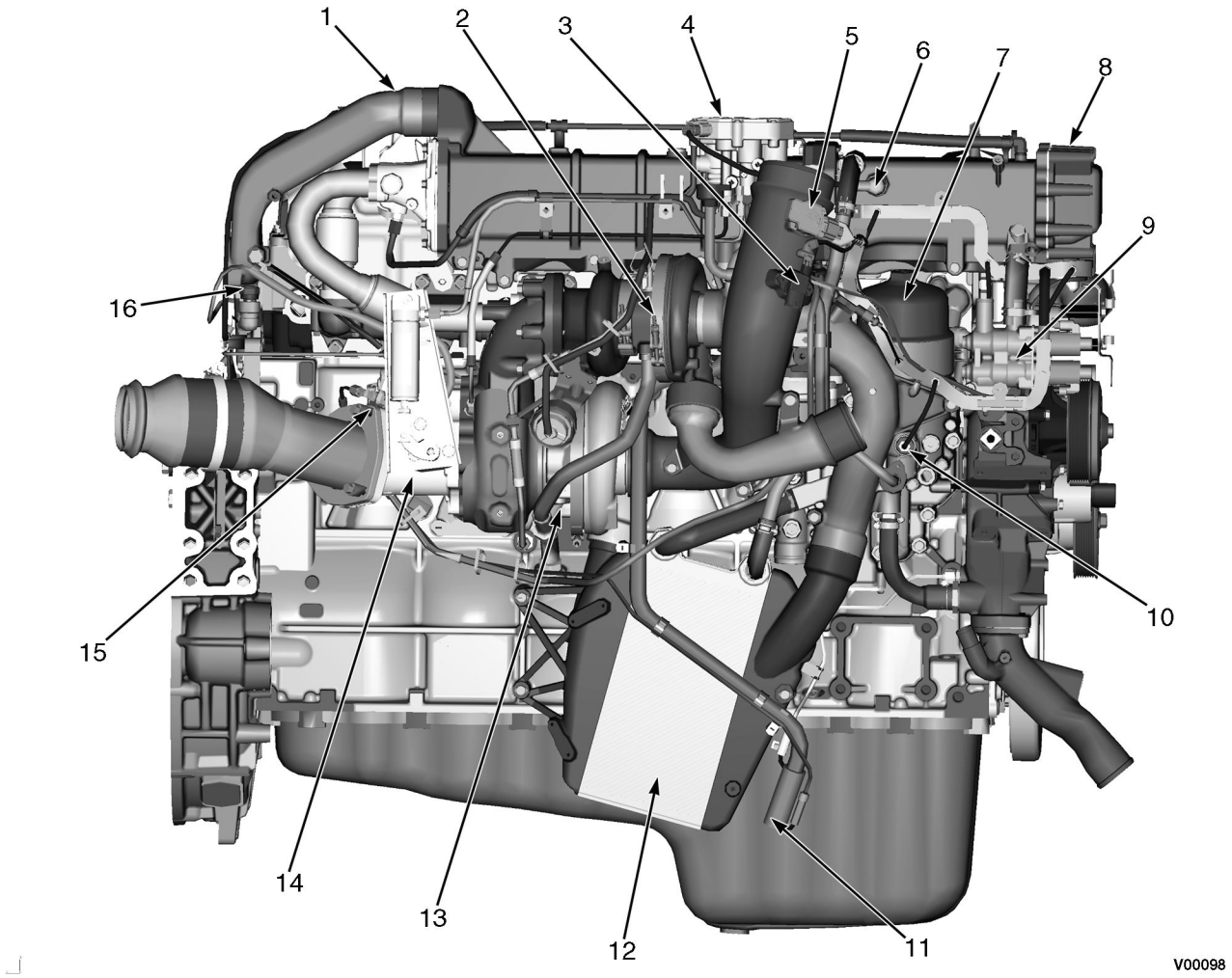


Figure 6 Component location – right view

1. EGR cooler coolant manifold
2. HP turbocharger
3. Humidity Sensor (HS) / Air Inlet Temperature (AIT) sensor
4. Air Control Valve (ACV) assembly
5. MAF sensor (if equipped)
6. Engine Coolant Temperature 2 (ECT2)
7. Oil filter cap
8. EGR Cooler
9. CCV
10. Engine Oil Pressure (EOP) sensor
11. Crankcase Oil Separator (CCOS)
12. Low-Pressure Charge Air Cooler (LPCAC)
13. LP Turbocharger
14. Engine Back Pressure Valve (EBPV)
15. Hydrocarbon Injector (HCI) assembly
16. Engine Coolant Temperature 1 (ECT1) sensor

Air Management System

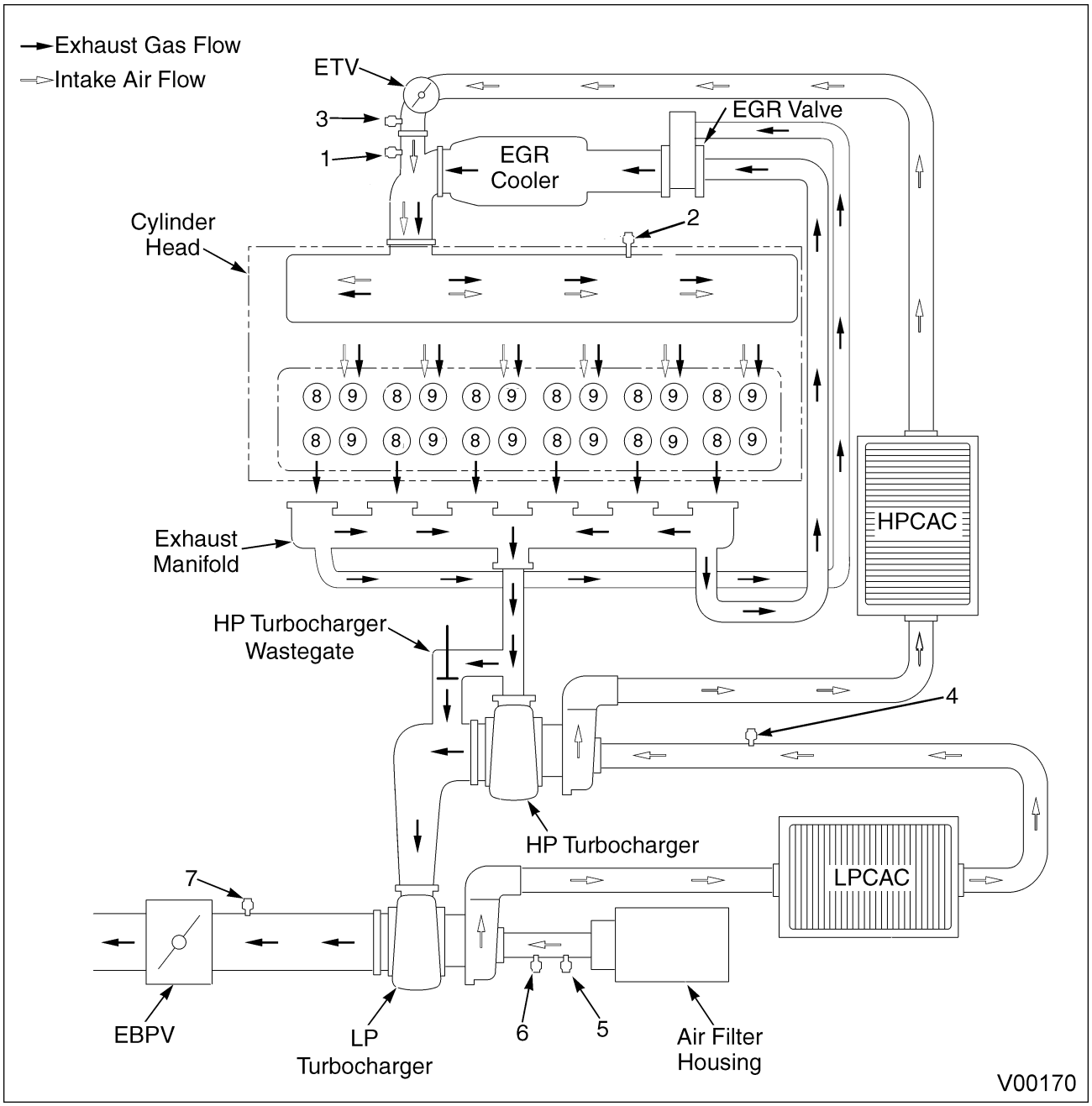


Figure 7 Air Management System

1. EGRT sensor
2. IMP sensor
3. Charge Air Cooler Outlet Temperature (CACOT)
4. LP Boost/LP Temperature sensor
5. MAF sensor (if equipped)
6. Humidity Sensor (HS) / Air Inlet Temperature (AIT) sensor
7. Oxygen Sensor (O2S)
8. Exhaust Valve
9. Intake Valve

Airflow

Air flows through the air filter housing and enters the Low-pressure (LP) turbocharger. The LP turbocharger increases the pressure and temperature of the filtered intake air before it enters the LPCAC. Cooled and compressed air then flows from the LPCAC into the HP turbocharger (compressor inlet). Hot and highly compressed air flows from the HP turbocharger (compressor outlet) into the HPCAC where it is cooled, and into the intake throttle duct, and continues through the Engine Throttle Valve (ETV). The HP and LP turbochargers increase pressures up to 345 kPa (50 psi).

If the EGRV is open, exhaust gases pass through the EGR cooler and into the intake throttle duct where it is mixed with filtered air. This mixture flows into the intake manifold, and then the cylinder head. The intake manifold is an integral part of the cylinder head casting.

During cold weather, the cold start assist system rapidly activates the heater element, vaporizing and igniting small quantities of fuel into the air inlet duct.

After combustion, exhaust gases exit through the cylinder head exhaust valves and ports. The exhaust gas is forced through the exhaust manifold where, depending on EGRV position, it is split between the EGR system and the exit path through the HP turbocharger, LP turbocharger, and EBPV.

The EBPV is operated by a pneumatic actuator. When the ACV is applied, the EBPV restricts flow and increases exhaust back pressure. Operation of the EBPV is controlled by the ECM using the ACV and the Turbocharger 1 Turbine Outlet Pressure (TC1TOP) sensor. When the EBPV is opened, exhaust back pressure is released.

Exhaust gases exiting the engine systems flow through the EBPV, then through the vehicle Aftertreatment (AFT) system, and out the exhaust tail pipe.

Turbochargers

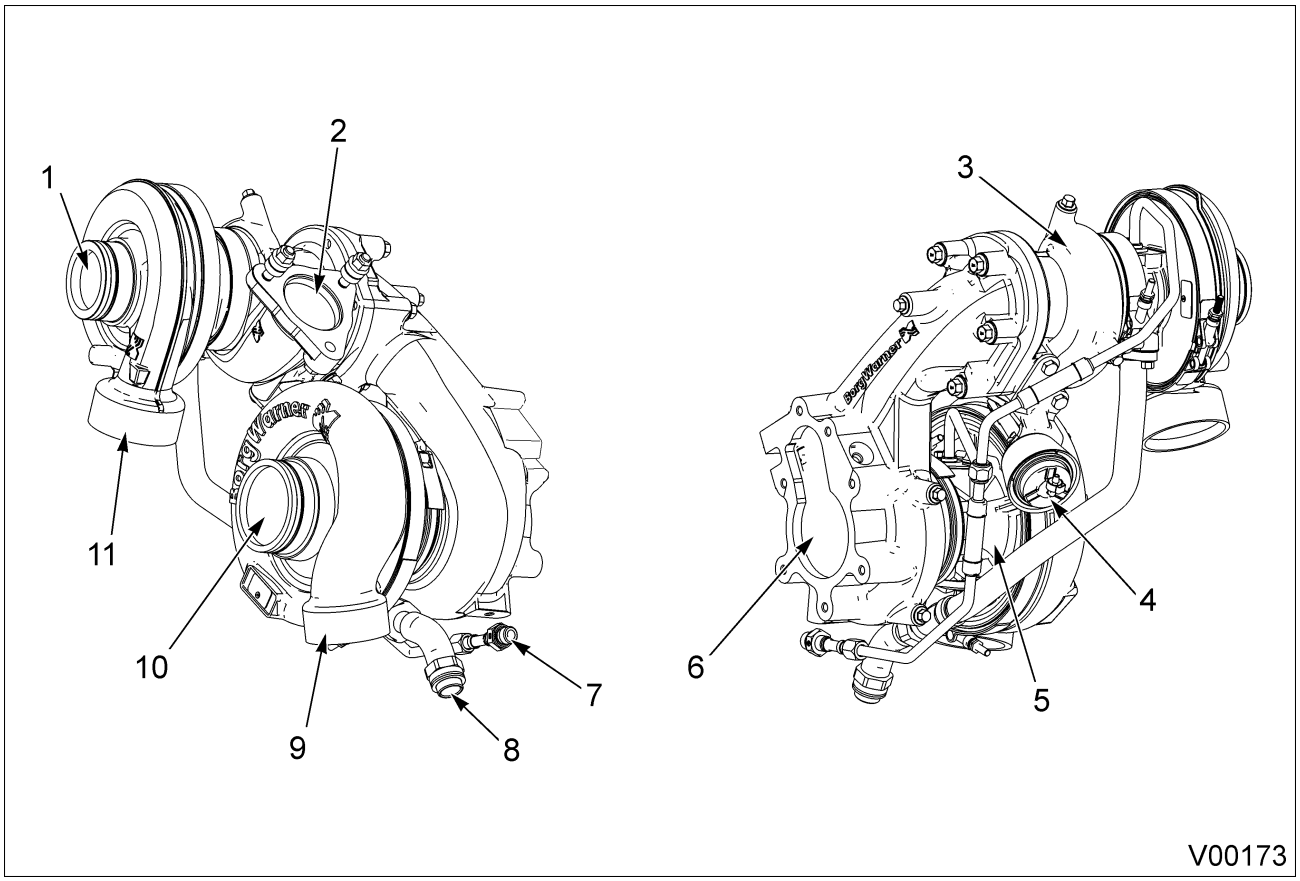


Figure 8 High and low-pressure turbocharger components

1. HP turbocharger compressor inlet
2. HP turbocharger turbine inlet
3. HP turbocharger
4. HP turbocharger wastegate actuator
5. LP turbocharger
6. LP turbocharger turbine outlet
7. Oil supply line
8. Oil return line
9. LP turbocharger compressor outlet
10. LP turbocharger compressor inlet
11. HP turbocharger compressor outlet

MaxxForce® 11 and 13 engines are equipped with a pneumatically regulated two-stage turbocharging system. The HP and LP turbochargers are installed parallel on the right side of the engine.

Intake air flow: Filtered air enters the LP compressor, where it is compressed and directed to the LPCAC. Cooled LP air then enters the HP compressor, where it is further compressed and directed into the HPCAC. Compressed air then goes through the ETV and the intake throttle duct. This system provides high charge air pressure to improve engine performance and to help reduce emissions.

Exhaust gas flow: The HP turbocharger is connected directly to the exhaust manifold through the HP turbine inlet. Exhaust gases exit the HP turbine outlet and are directed to the LP turbine inlet. The HP turbocharger is equipped with a wastegate, controlled by a pneumatic actuator. The wastegate regulates boost by controlling the amount of exhaust gases that bypass the HP turbine. When boost demand is low, the wastegate opens, allowing part of the exhaust gas flow to bypass the HP turbine.

Control system signals associated with the HP and LP turbochargers have been renamed for 2010.

All signals related to the LP turbocharger are designated as Turbocharger 1 (TC1) signals, and are identified below:

- Turbocharger 1 Turbine Outlet Pressure (TC1TOP)

All signals associated with the HP turbocharger are designated as Turbocharger 2 (TC2), and are identified below:

- Turbocharger 2 Wastegate Control (TC2WC)
- Turbocharger 2 Compressor Inlet Pressure (TC2CIP)

Air Control Valve (ACV)

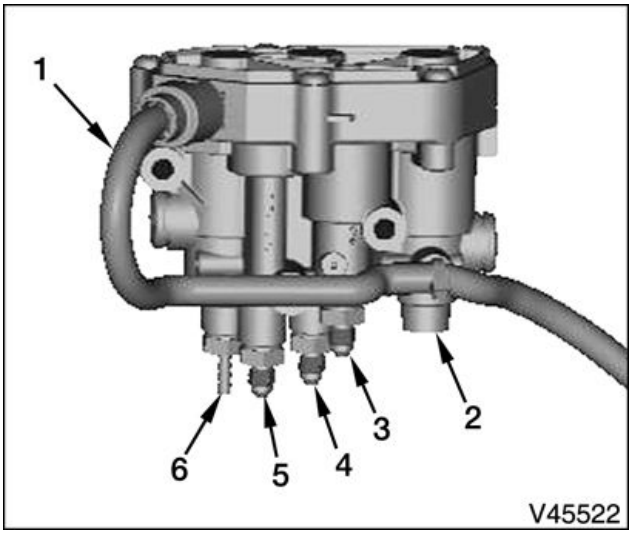


Figure 9 Air Control Valve (ACV) connections

1. Pigtail harness (to engine sensor harness connector)
2. Plug
3. Vehicle air supply port
4. EBPV control port
5. TC1TOP sensor port
6. HP turbocharger wastegate control port

The ACV assembly contains the HP turbocharger wastegate control port, 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. The air supply port is connected to the vehicle's air system.

The ECM provides a Pulse Width Modulate (PWM) signal for operation of the wastegate control valve. With no PWM signal the control valve is closed, and no air is supplied to the wastegate actuator. The wastegate remains closed.

When an increase in boost is required, the ECM supplies PWM voltage to close the control valve. This reduces air pressure to the wastegate control valve causing the watsegate to move in the closed direction, resulting in increased boost.

The TC1TOP sensor and EBPV control valve are in the ACV. The EBPV control valve is also operated by the ECM using PWM, and the TC1TOP sensor is monitored by the ECM. The EBPV control valve operates the EPBV actuator.

Boost Control

The wastegate control valve, in the ACV, provides operation of a pneumatic wastegate actuator for the HP turbocharger. Boost is controlled for the HP turbocharger, by signals sent from the ECM to the ACV. In normal operation the HP wastegate is actuated by the ACV using vehicle compressed air, regulated to 296 kPa (43 psi). Positioning of the wastegate by the ACV is based on boost pressure and temperature signals monitored by the ECM.

Low-Pressure Charge Air Cooler (LPCAC)

The LPCAC is installed between the HP and LP turbochargers, and is mounted to the lower right side of the engine. The LPCAC air inlet is connected to the low-pressure turbocharger compressor outlet, and uses engine coolant to regulate the LP charge air temperature. The LPCAC air outlet is connected to the compressor inlet of the HP turbocharger.

High-Pressure Charge Air Cooler (HPCAC)

The HPCAC is installed between the HP turbocharger and the intake throttle duct. The HPCAC air inlet is connected to the HP compressor outlet, and uses ambient airflow entering the front of the vehicle to reduce the charge air temperature. The HPCAC air outlet is connected directly to the intake throttle duct.

High-Pressure Boost Pressure (HPBP) Sensor

This sensor monitors the pressure of the charge air entering the duct. The primary function of the sensor is to provide information used to ensure proper boost control. It is also used as part of EGR control.

Pressure sensor works by providing an analog voltage output to the ECM which is proportional to pressure being applied to an internal diaphragm in the sensor. The sensor is connected to the control module through the Reference Voltage (VREF), signal, and signal ground wires. A transfer function contained in the ECM software converts the analog voltage to a pressure value which is then used by software strategies requiring the pressure information.

The ECM continuously monitors the pressure sensor output voltage for determination of charge air pressure. High and low diagnostic voltage thresholds are evaluated to ensure that output voltage is within a valid range.

High-Pressure Boost Temperature (HPBT) Sensor

This sensor monitors the temperature of the charge air entering the duct. The temperature measured is an input to the engine coolant control strategy. It also is used for evaluation of on-board diagnostics to ensure proper functionality of the charge air cooling system.

This temperature sensor is a thermistor and has two connections to the ECM. A thermistor varies resistance as temperature changes. When interfaced to the ECM circuitry, a change in sensor resistance results in a voltage change internal to the ECM. A transfer function contained in the ECM software translates the measured voltage to a temperature value.

The ECM continuously monitors the voltage resulting from the thermistor's changing resistance. High and low diagnostic voltage thresholds are evaluated to ensure that the output voltage is within a valid range.

Low-Pressure Boost Pressure (LPBP) Sensor and Low-Pressure Boost Temperature (LPBT) Sensor

This is a combination pressure and temperature sensor.

This sensor is a dual function sensor that detects pressure and temperature of the charge air entering the HP compressor. It is installed in the piping between the LP compressor outlet and the HP compressor inlet. This sensor is used for evaluation by on-board diagnostics to ensure proper functionality of the charge air cooling system.

This sensor consists of a thermistor which varies resistance as temperature changes. When interfaced to the ECM circuitry, a change in sensor resistance results in a voltage change internal to the ECM. An internal diaphragm which deflects due to pressure changes results in an analog voltage output to the ECM which is proportional to the pressure. Transfer functions contained in the ECM software translate the measured voltages into a temperature and a pressure value.

The ECM continuously monitors the voltages resulting from changes in both the temperature and pressure. High and low diagnostic voltage thresholds are evaluated to ensure that the output voltage is within a valid range.

Exhaust Gas Recirculation (EGR) System

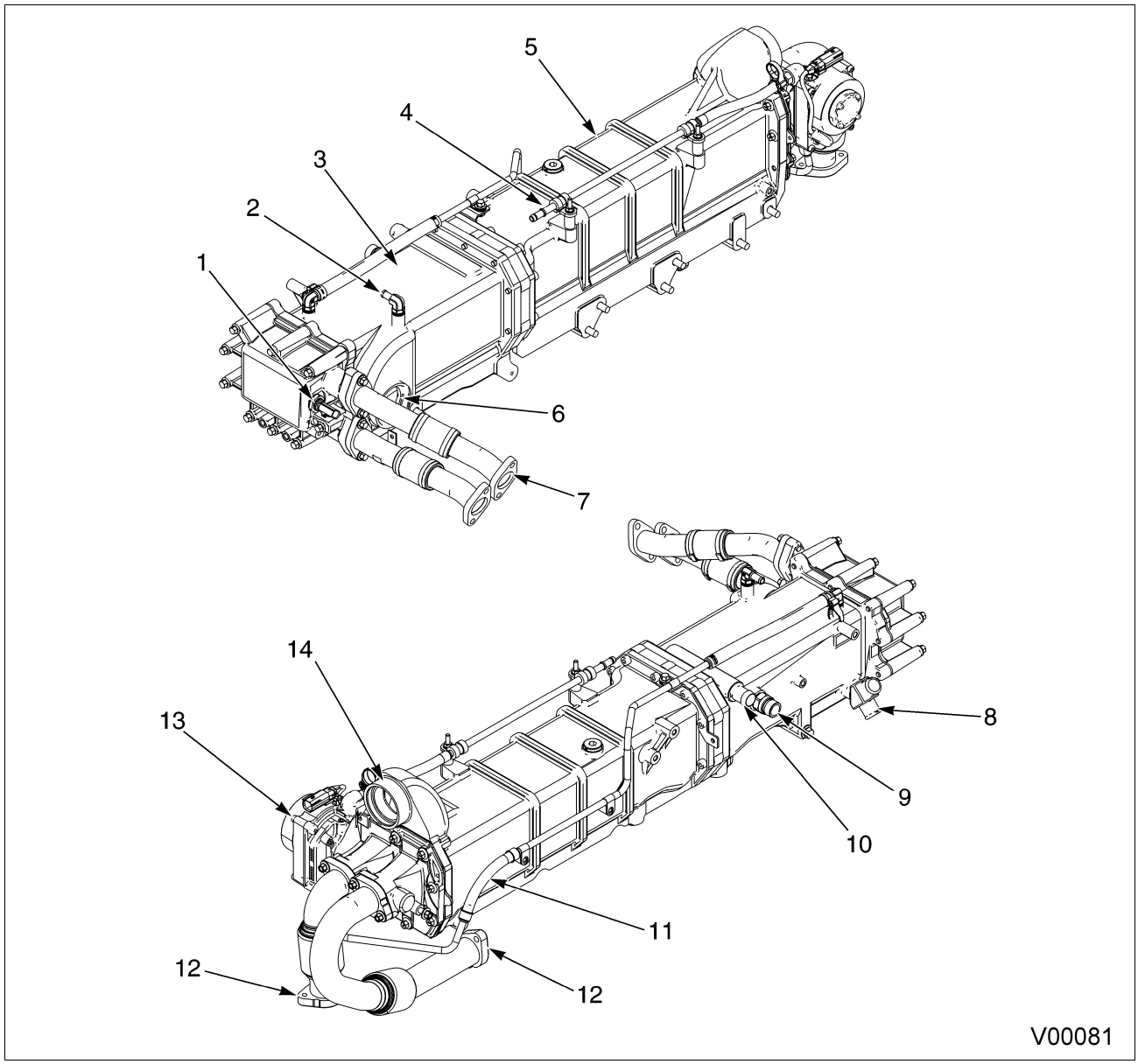


Figure 10 EGR system components

1. EGRT sensor
2. EGR cooler air bleed (to dearation tank)
3. EGR cooler (low temperature stage)
4. EGRV coolant return line (to dearation tank)
5. High temperature EGR cooler
6. Intake Manifold Temperature (IMT)
7. EGR cooler outlet tube (2) (gases)
8. Low temperature EGR cooler inlet (coolant)
9. Engine Coolant Temperature 2 (ECT2) sensor
10. Low temperature EGR cooler outlet (coolant)
11. EGRV coolant supply line
12. EGR cooler inlet tubes (gases)
13. EGRV
14. EGR cooler inlet (coolant)

EGR System Overview

The EGR system reduces NO_x engine emissions by introducing inert cooled exhaust gas into the air inlet duct. NO_x forms during a reaction between nitrogen and oxygen at high temperatures during combustion.

The ECM monitors signals from the CACOT sensor, Oxygen sensor (O2S), Engine Coolant Temperature 1 (ECT1) sensor, EGRT sensor to control the EGR system.

EGR is switched off (EGRV closed) if any of the following conditions are present:

- Engine coolant temperature less than 10 °C (50 °F) will close the EGR valve
- Intake manifold temperatures less than 7 °C (45 °F) will close the EGR valve
- During engine brake operation

EGR Flow

Exhaust gas from the exhaust manifold flows through the EGR inlet tubes to the EGRV. When EGR function is activated, the EGRV opens and allows exhaust gas to enter the EGR cooler. Cooled exhaust gas flows from the front of the EGR cooler, through the EGR outlet tubes, and into the intake throttle duct where it is mixed with filtered air.

EGR System Control

The EGR system consists of the EGRV, ETV, and O2S. The EGRV contains a PWM controlled valve and Exhaust Gas Recirculation Position (EGRP) sensor.

The EGRV is installed at the rear of the EGR cooler, on the right side of engine valve cover. The EGRV limits exhaust gas flow into the EGR cooler.

The ECM commands the EGRV to move and hold position. The EGRP sensor, located inside the EGRV, monitors and provides an EGRV position signal to the ECM.

The O2S is installed in the exhaust, in front of the aftertreatment fuel injector. The O2S has a heater element that heats the sensor to its normal operating temperature of 780 °C (1436 °F). During initial engine warm-up, the O2S heater element is activated only after the engine coolant reaches 40 °C (104 °F) and the exhaust gas temperature DOCIT sensor exceeds 100 °C (212 °F) for more than 30 seconds.

EGRV Control

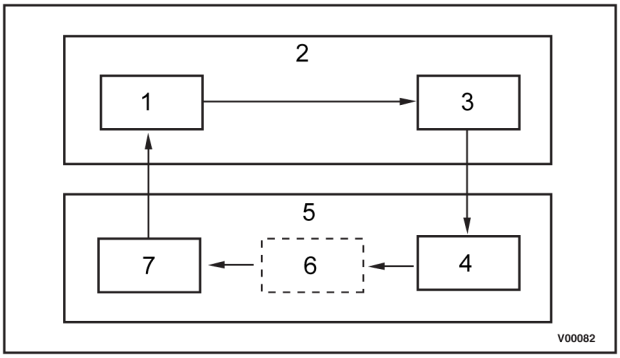


Figure 11 EGRV position control

1. EGR position monitored by ECM
2. ECM
3. ECM commands EGR to desired position
4. EGRV to desired position
5. EGRV
6. EGRV position matches ECM command
7. EGR position sent to ECM

The EGRV has an integrated position sensor, and provides feedback to the ECM indicating EGRV position.

EGR – Open Loop

During the engine warm-up period and before the O2S reaches its normal operating temperature, the EGR system operates in open loop. In open loop, the EGR system is controlled by the ECM based on the charge air temperature, engine coolant temperature, engine speed, and load conditions.

EGR – Closed Loop

After the O2S reaches its operating temperature, the EGR system switches to closed loop operation. In closed loop, the EGR system is controlled by the ECM based on coolant temperature and O2S readings.

EGR Flow Cooling

The EGR system includes a two-stage EGR cooler, allowing the ECM to regulate EGR Cooler temperatures. The ECM monitors intake manifold temperature through the Exhaust Gas Recirculation Temperature 1 (EGRT1) sensor and to regulate EGR flow temperatures, the CCV regulates coolant flow through the LTR. Refer to Cooling System in this section for more information.

Aftertreatment (AFT) System

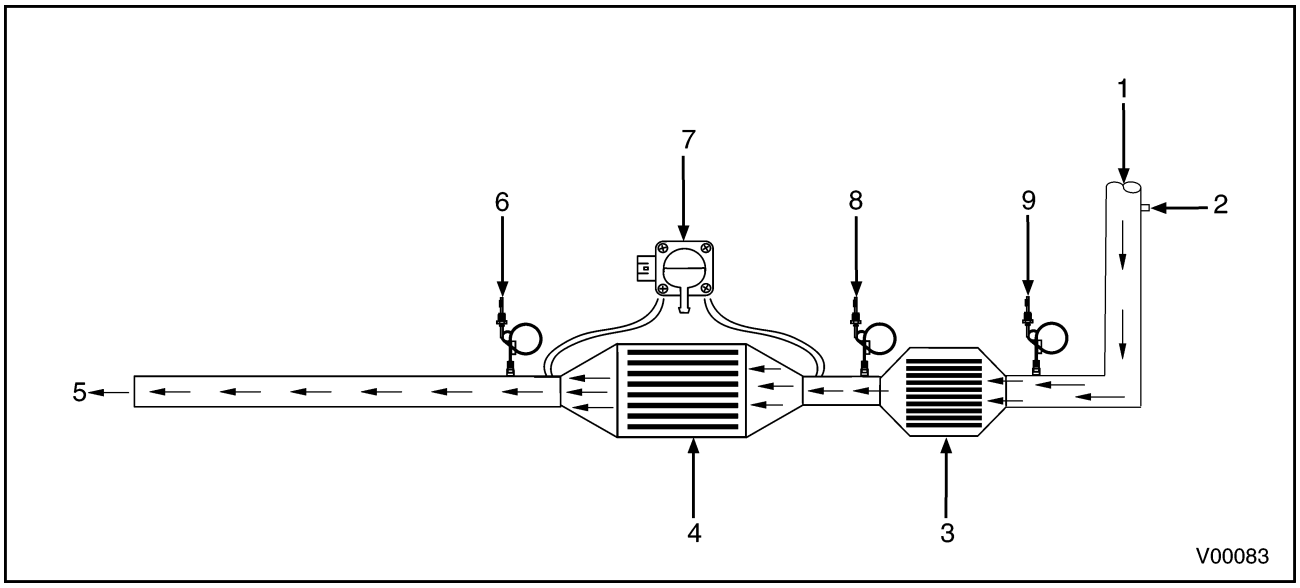


Figure 12 AFT system overview

1. Pre-DOC exhaust flow
2. Hydrocarbon Injector (HCI) assembly
3. DOC
4. DPF
5. Exhaust out to tail pipe
6. DPFOT sensor
7. DPFDP sensor
8. DOCOT sensor
9. DOCIT sensor

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

The AFT system performs the following functions:

- Monitors exhaust gas temperatures DOC in, DOC out, and DPF out temperature and delta pressure across the DPF. It controls engine operating parameters for emission control and failure recognition
- May cancel regeneration in the event of catalyst or sensor failure
- Monitors the level of soot accumulation in the DPF
- AFT control system initiates regeneration automatically when DPF is full with soot and control engine operating parameters to increase temperature to have successful regeneration
- Maintains vehicle and engine performance during 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 (restriction)
- Provides the required exhaust back pressure drop for engine performance
- Stores non-combustible ash

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

Aftertreatment (AFT) System Conditions and Responses

The operator is alerted of system status either audibly or with instrument panel indicators. 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.

Downstream Fuel Injection

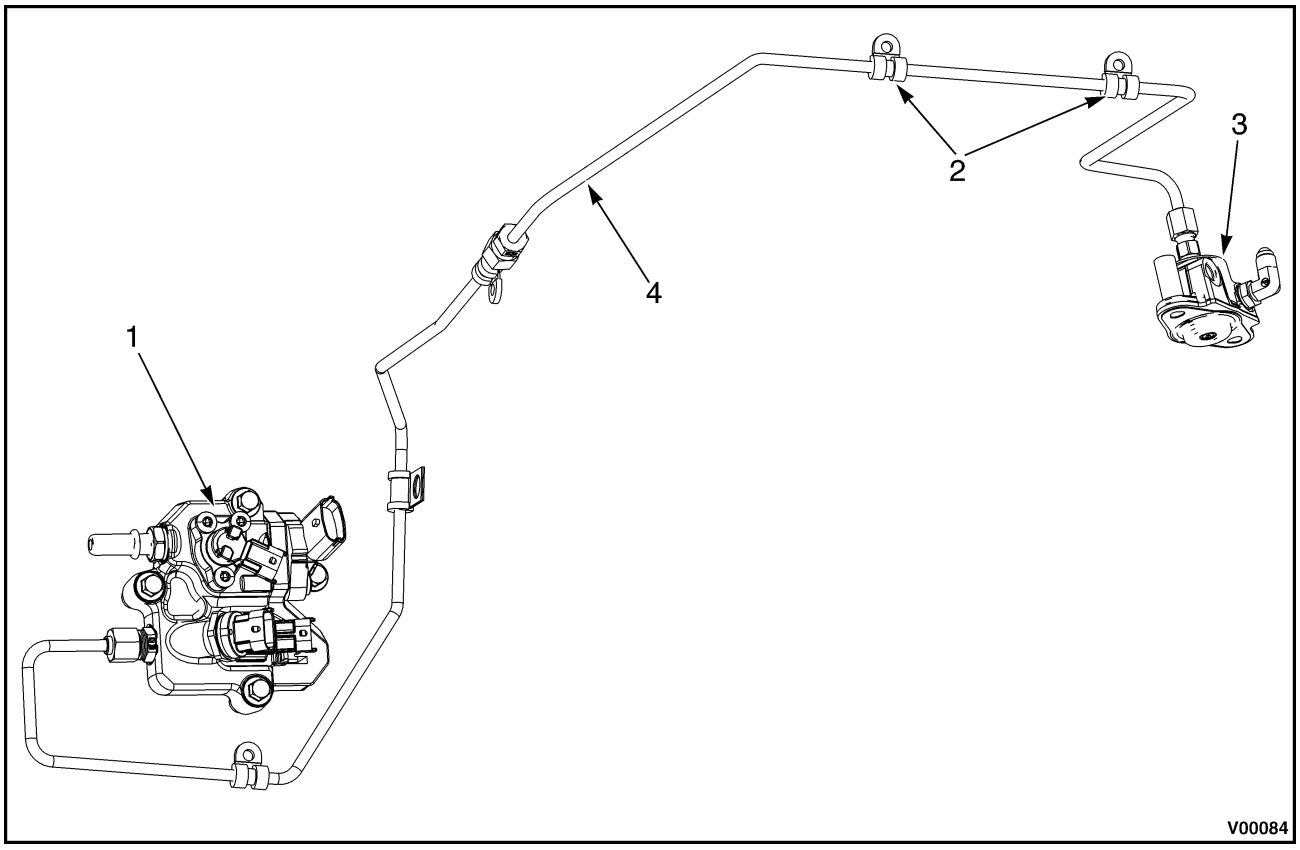


Figure 13 Downstream fuel injection components

1. Downstream Injection (DSI) unit
2. Fuel line retainers (rear of engine block)
3. Hydrocarbon Injector (HCI) assembly
4. HCI fuel pressure line

The DSI system injects fuel into the exhaust system to increase temperature of the exhaust gases, and is necessary for DPF regeneration. DSI is controlled by the ECM. The ECM receives signals from the Aftertreatment Fuel Doser (AFTFD) sensor (in the DSI unit), and controls operation when downstream injection (regeneration) is required. The ECM also controls the Aftertreatment Shutoff Valve (AFTSV) (located in the DSI unit) which controls the volume of fuel sent to the HCI in case of AFTFD malfunction.

Downstream Injection (DSI) Unit

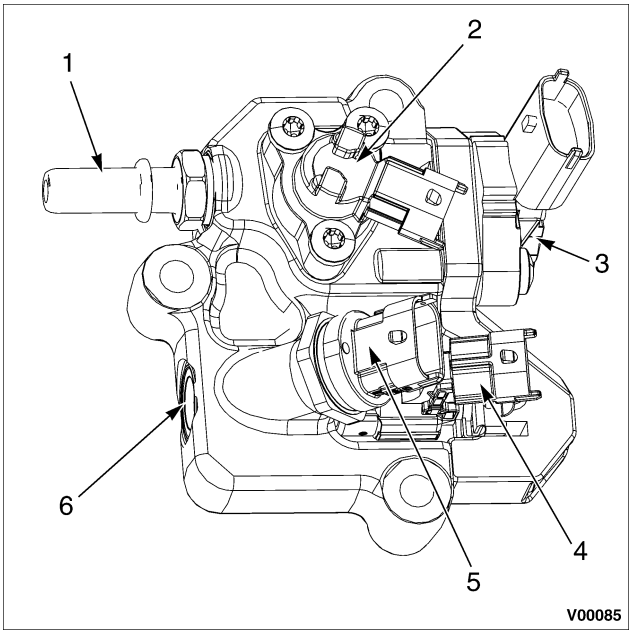


Figure 14 Downstream Injection (DSI) unit

1. Fuel supply from fuel filter assembly
2. Aftertreatment fuel shutoff valve
3. Aftertreatment fuel inlet sensor (dual temperature and pressure)
4. Aftertreatment fuel doser
5. Aftertreatment Fuel Pressure 2 (AFTFP2)
6. Fuel outlet port to HCI

The DSI unit is connected to the clean side of the low-pressure fuel system, and will provide a metered amount of fuel to the Hydrocarbon Injector (HCI) assembly. The DSI unit provides pressurized fuel injection pulses to the HCI. The HCI is a mechanical poppet type injector, and will only inject fuel when fuel line pressure is increased above a specific pressure. The DSI unit is installed on the left side of the engine, to the rear of the fuel module.

The AFTFIS and AFTFP2 sensors monitor fuel pressure and temperature in the DSI system, and provide constant feedback to the ECM.

Hydrocarbon Injector (HCI) Assembly

The HCI is located on the right side of the engine, and is installed in the turbocharger exhaust pipe after the exhaust O2S.

Pressurized fuel is supplied to the injector by the DSI unit using the AFTFD valve. When the conditions required for regeneration are met, the ECM sends a PWM voltage to the AFTFD. During operation, the AFTFD increases fuel pressure to the HCI, causing injection of fuel into the exhaust pipe.

To protect the HCI internal components, continuous engine coolant flow through the HCI is maintained by external coolant supply and return lines.

Crankcase Oil Separator

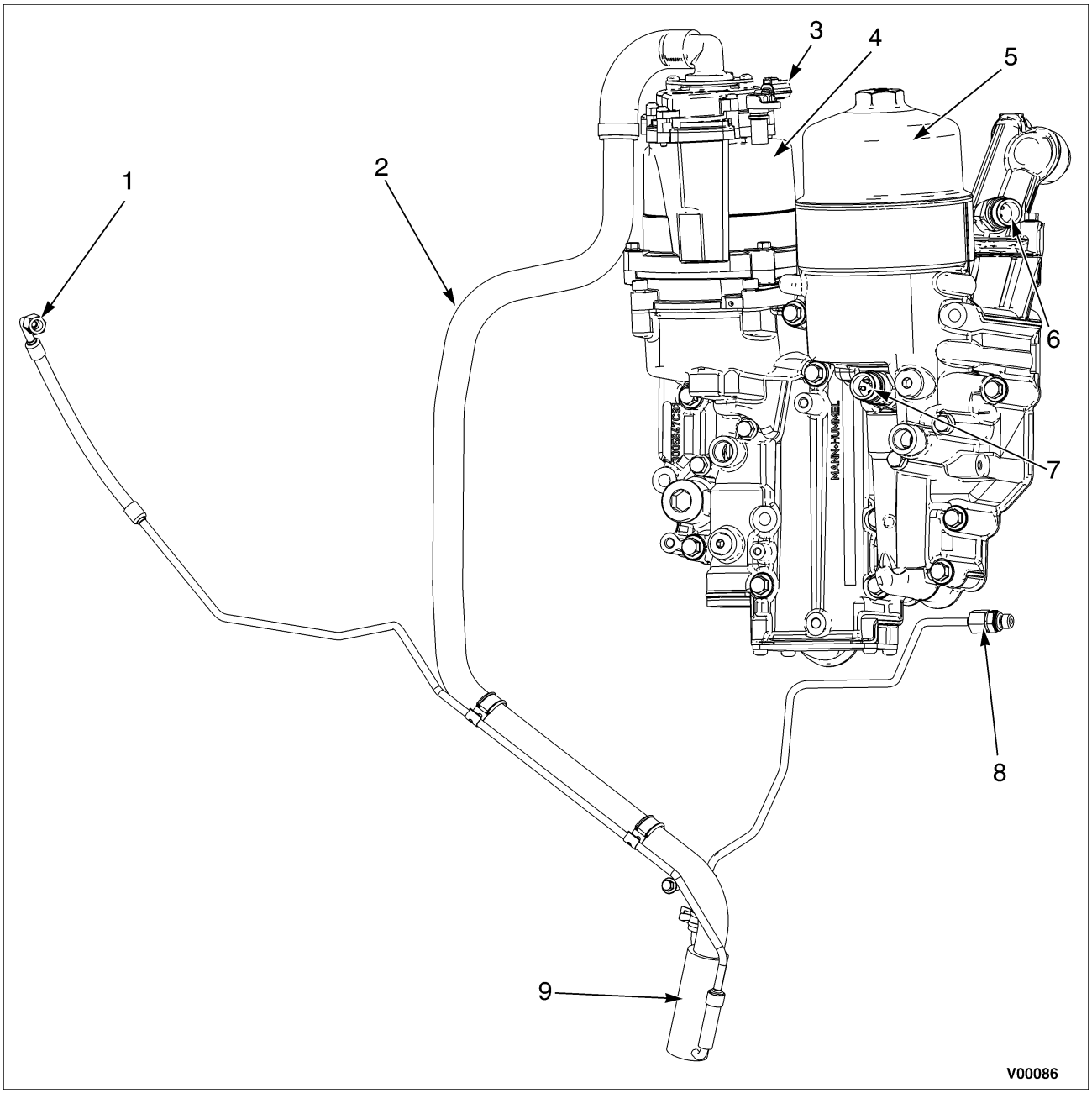


Figure 15 Oil Module w/Crankcase Oil Separator

1. Coolant supply line
2. CCOS vent tube
3. Crankcase Oil Separator Speed (CCOSS) sensor
4. Crankcase Centrifuge Oil Separator (CCOS)
5. Oil filter access cap
6. Engine Oil Temperature (EOT) sensor
7. Engine Oil Pressure (EOP) sensor
8. Coolant return line
9. CCOS ventilation tube heater

Crankcase ventilation is provided using the CCOS. Excess crankcase vapors are filtered by the CCOS, and are then vented to the atmosphere.

A centrifugal oil separator, driven by engine oil pressure, separates and directs oil mist to the side of CCOS housing. The separated oil mist drains from the oil separator, through the crankcase, and into the oil pan. The oil separator is an integral part of the oil module.

Fuel Management System

Fuel System

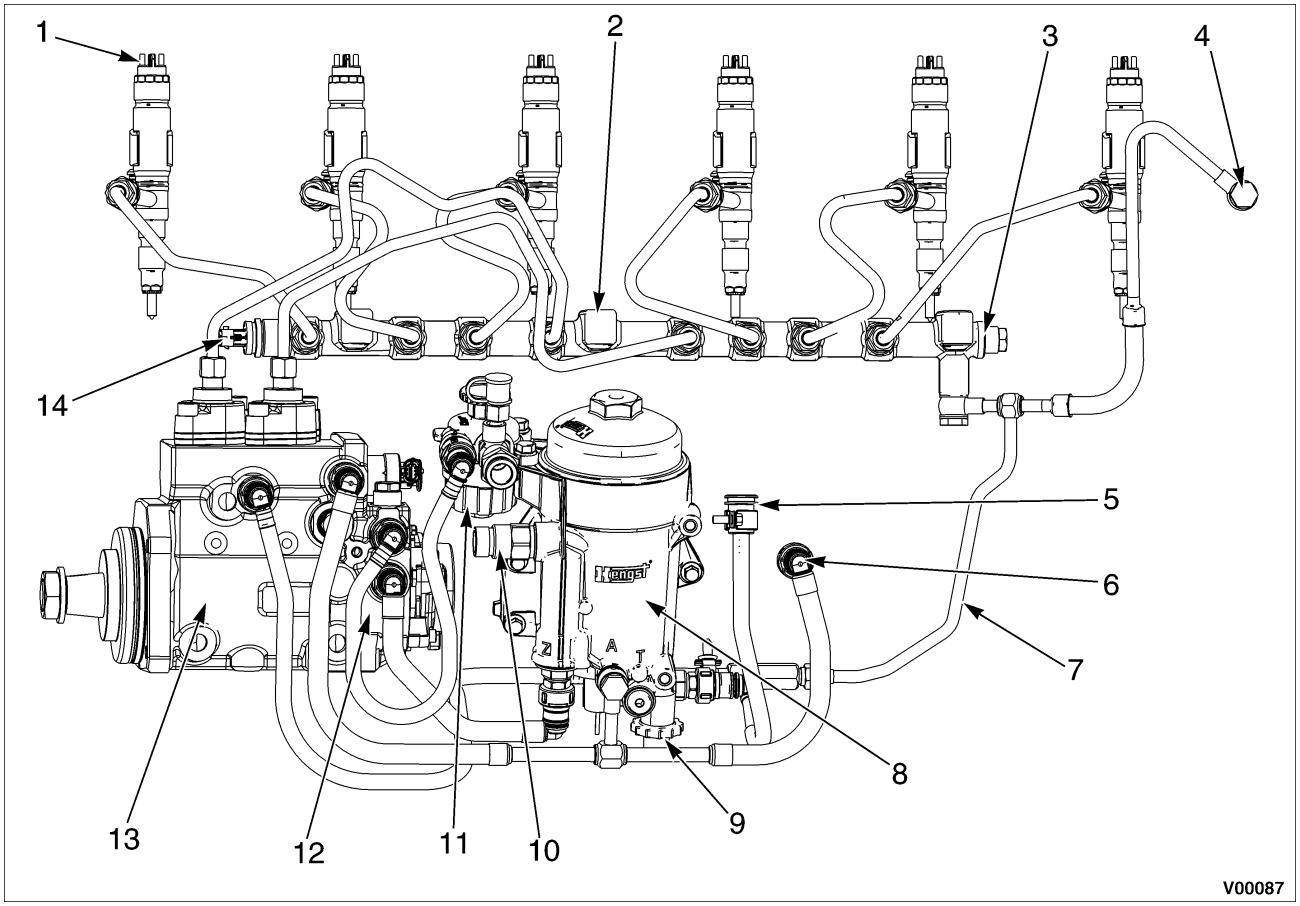


Figure 16 Fuel System

1. Injector (6)
2. Fuel Rail
3. Pressure limiting valve
4. Fuel return from cylinder head
5. Engine fuel return connection (to chassis filter)
6. Fuel supply to DSI unit
7. Fuel return line
8. Fuel filter assembly
9. Drain screw
10. Engine Fuel Pressure (EFP) sensor
11. Fuel primer pump assembly
12. LP fuel pump
13. HP fuel pump
14. Fuel Rail Pressure (FRP) sensor

MaxxForce® 11 and 13 engines are equipped with a high-pressure common rail injection system. The common rail fuel injection system provides pressurized fuel to the fuel injectors for optimal fuel atomization in the combustion chamber.

All excess fuel is returned to the chassis mounted filter separator, before returning to the fuel tank.

The fuel system is controlled by the ECM, various sensors, and the Fuel Pressure Metering Unit (FPMU) located in the HP pump. For additional information, refer to LP Fuel System and HP Fuel System in this section.

Fuel Flow

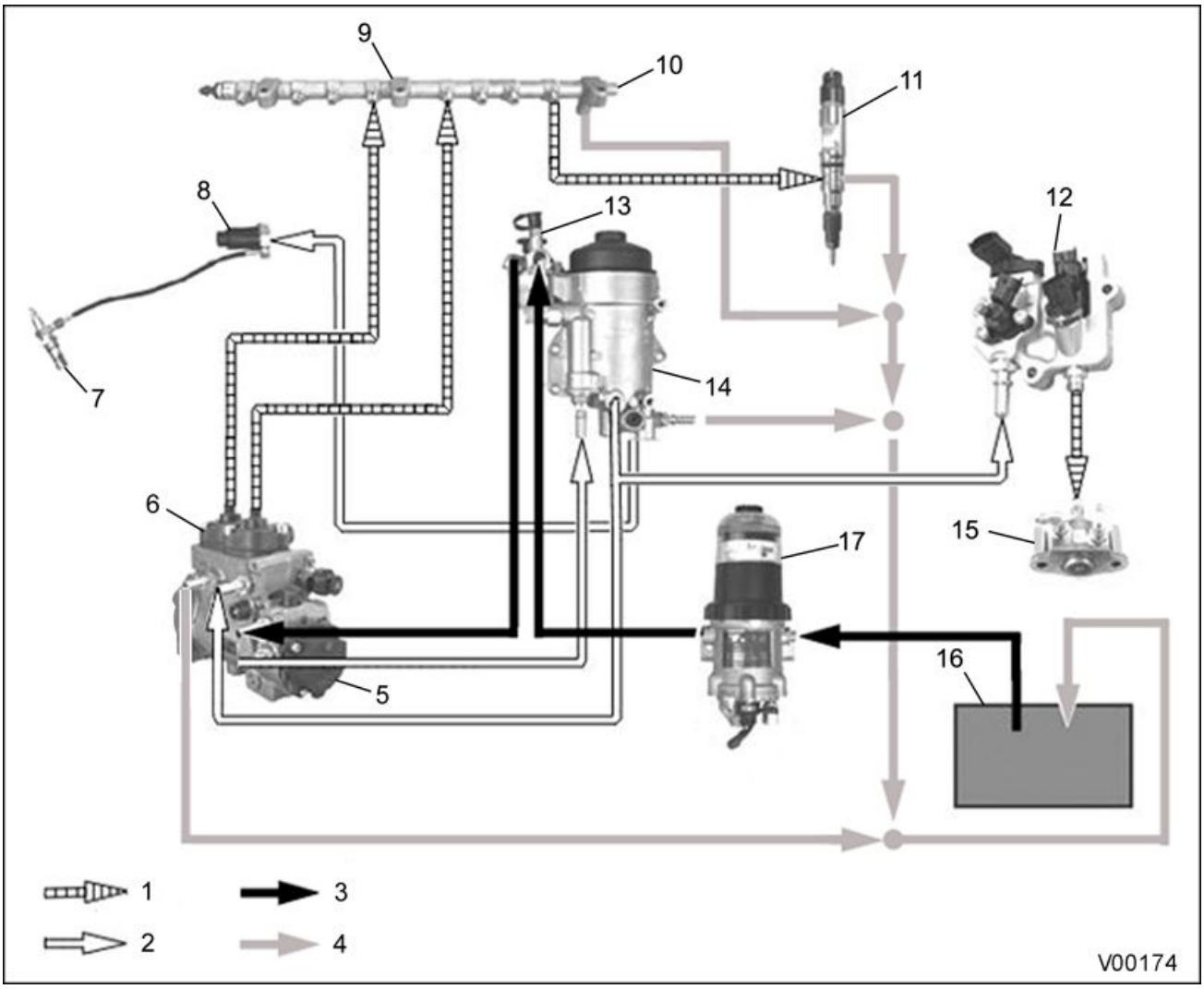


Figure 17 Fuel supply flow diagram

1. High-pressure
2. Low-pressure
3. Fuel supply
4. Fuel Return
5. LP fuel pump
6. HP fuel pump
7. Cold Start Fuel Ignitor (CSFI)
8. Cold Start Fuel Solenoid (CSFS)
9. Fuel rail
10. Pressure limiting valve
11. Fuel injector
12. DSI unit
13. Fuel primer pump assembly w/ fuel strainer element
14. Fuel filter assembly (engine mounted)
15. HCI
16. Fuel tank
17. Chassis mounted fuel filter/water separator

Fuel is pumped from the tank, through the chassis mounted fuel filter/water separator using the LP fuel pump. Fuel is pumped from the LP fuel pump to the engine mounted fuel filter assembly, before being supplied to the HP fuel pump. The high-pressure fuel pump supplies high-pressure fuel to the fuel rail, which feeds the injectors through individual tubes. The LP fuel pump and HP fuel pump are assembled as one gear driven unit, and are serviced as an assembly.

Low-Pressure Fuel System

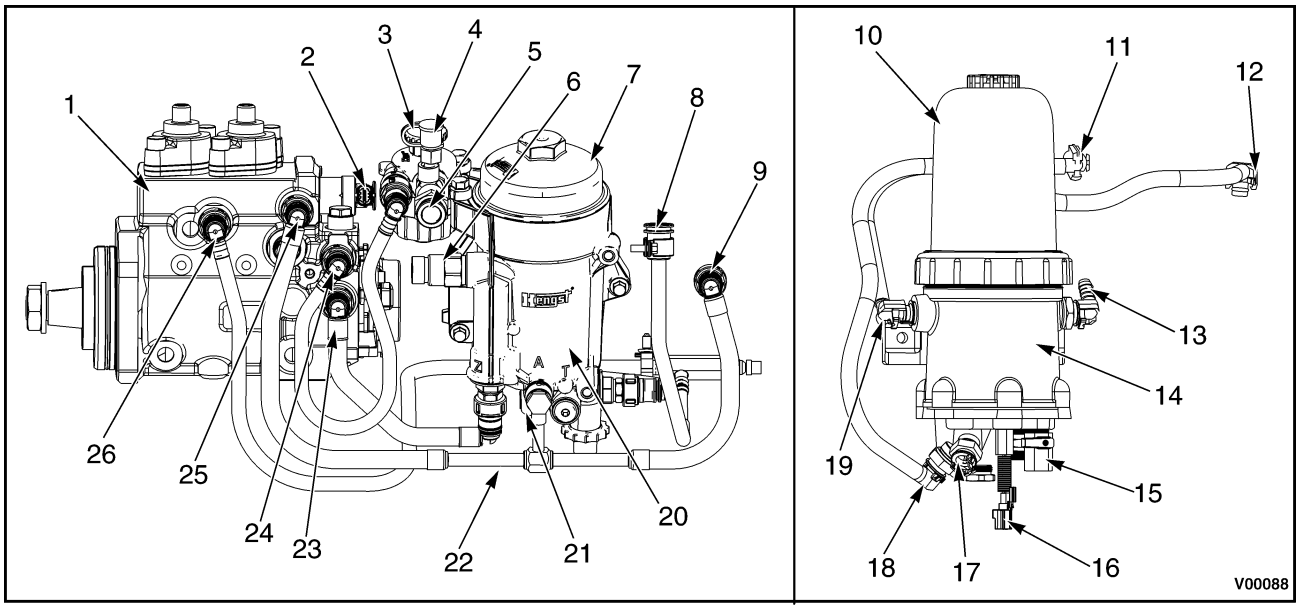


Figure 18 Low-pressure (LP) fuel system

1. HP fuel pump
2. Fuel Pressure Control Valve (FPCV)
3. Fuel primer pump assembly w/ fuel strainer element
4. Fuel pressure test port
5. Engine fuel supply connection
6. EFP sensor
7. Engine mounted secondary fuel filter access
8. Engine fuel return connection
9. Fuel supply to DSI unit
10. Chassis mounted primary fuel filter access
11. Fuel supply to engine
12. Fuel return from engine
13. Fuel supply from tank
14. Chassis mounted fuel filter/water separator
15. Fuel Heater
16. Water In Fuel (WIF) sensor
17. Fuel return to tank
18. Fuel return from engine
19. Fuel supply to engine
20. Engine mounted fuel module
21. Cold start assist port
22. Low pressure fuel supply line
23. LP fuel pump outlet
24. LP fuel pump inlet
25. HP fuel pump inlet
26. HP fuel pump return

The LP fuel pump pumps fuel from the tank through the chassis mounted fuel filter/water separator, fuel strainer element and engine filter element, then to the high-pressure fuel system, cold start assist system, and DSI.

In addition to providing high-pressure fuel to the injectors, the fuel system provides filtered low-pressure fuel to the downstream Injection and cold start assist systems.

Chassis Mounted Filter/Water Separator

The chassis mounted filter/water separator removes debris and water from the fuel before it enters the fuel primer pump and low-pressure fuel pump. The chassis mounted filter/water separator includes a Water In Fuel (WIF) sensor and optional fuel heater. Refer to Section 5 “Chassis Filter/Water Separator Maintenance and Inspection” in this manual for more information.

Fuel Primer Pump Assembly

During fuel system priming, fuel is drawn from the tank through the chassis mounted filter/water separator by the fuel primer pump assembly. The fuel primer pump assembly has an integrated fuel strainer element that can be cleaned. The fuel primer pump assembly is manually operated, and is used to prime the low-pressure fuel system anytime the fuel system has been emptied. The primer pump provides unrestricted fuel flow to the low-pressure pump during normal engine operation.

Low-Pressure (LP) Fuel Pump

The LP fuel pump and the HP fuel pump are housed as one assembly. Fuel is drawn through the fuel primer pump assembly and into the LP fuel pump. The LP pump supplies fuel to the fuel filter housing assembly at pressures varying between 496 kPa (72 psi) at idle, and 896 kPa (130 psi) at rated speed. The LP fuel pump is equipped with an internal pressure regulator that relieves the fuel pressure internally if the pressure exceeds 1300 kPa (189 psi).

Fuel Filter Assembly

The fuel filter assembly is located on the left side of the engine and has a disposable filter element. An EFP sensor is installed on the front side of the fuel filter assembly, which measures fuel pressure between the LP fuel pump and the filter element. The fuel filter assembly also has a drain screw that allows water and dirt to be drained periodically. Because water may accumulate inside the fuel filter assembly, use the drain screw to drain water per maintenance schedule in the *Engine Operation and Maintenance Manual*. An additional function of the fuel filter assembly is fuel system self-deaeration. The air separated from fuel is pushed back into the fuel tanks through the return line. The fuel filter assembly also provides filtered fuel to the DSI and cold start assist system. An orifice regulator is integrated into the fuel filter assembly, and regulates the fuel pressure for the cold start assist system to 70 kPa (10 psi).

High-Pressure Fuel System

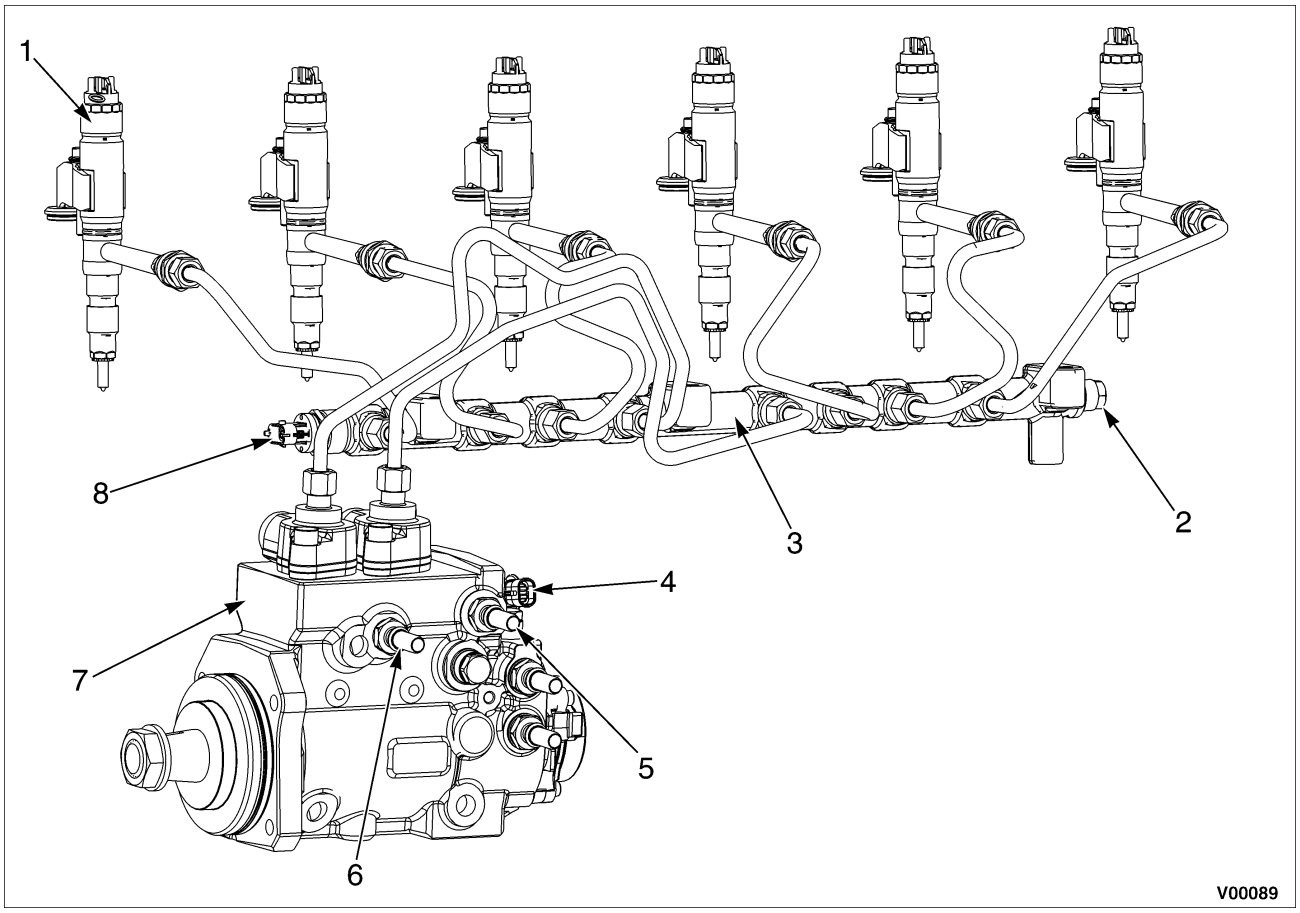


Figure 19 High-pressure (HP) fuel system

1. Injector (6)
2. Pressure limiting valve
3. Fuel Rail
4. Fuel Pressure Control Valve (FPCV)
5. Fuel inlet - HP fuel pump
6. Fuel return - HP fuel pump
7. HP fuel pump
8. FRP sensor

Pressurization and injection are separate in the common rail injection system. The optimal injection pressure is generated by the high-pressure pump at any engine speed. High-pressure fuel quantity from high-pressure pump is controlled by the FPCV. The injection timing and quantity are calculated in the ECM and implemented by solenoid valve controlled injectors. The use of solenoid valve controlled injectors allows three injections per cycle.

The first injection is used to reduce combustion noise and emissions by introducing a small amount of fuel into the cylinder, preventing a rapid rise in cylinder pressure when combustion begins. The second injection is the main injection. This injection allows high temperatures to be maintained during combustion, but not long enough to allow generation of large soot amounts. The third injection is done during the power stroke to maximize cylinder temperature and reduce engine soot generation.

The high-pressure fuel system consists of the high-pressure pump with integrated Fuel Pressure Metering Unit (FPMU), pressure pipe rail, high-pressure fuel lines, injectors, FRP sensor, and pressure limiting valve.

High-Pressure (HP) Pump

The HP pump supplies the necessary quantity of HP fuel for all operating engine modes. The HP pump is gear driven and is fuel lubricated. Fuel from the LP fuel pump is forced through the fuel module assembly, and into the HP pump. The flow of fuel to the suction chamber of the HP pump is controlled by the FPCV, in order to control HP fuel output.

Fuel Pressure Control Valve (FPCV)

The FPCV is a variable position actuator installed on the suction side of the high-pressure pump and controls the output fuel pressure. The ECM sends a PWM signal to control the FPCV. A 100% duty cycle PWM signal corresponds to minimum fuel pressure delivery, while a 0% duty cycle PWM corresponds to maximum fuel pressure delivery.

Fuel Rail

The fuel rail is a HP fuel storage unit. The storage volume of the fuel rail is designed to reduce pressure pulses caused by the HP pump and injectors, and to maintain constant fuel pressure even when large fuel quantities are injected into the cylinders. Connection between the fuel rail and injectors are made through two individual injection lines.

Fuel Rail Pressure (FRP) Sensor

The FRP sensor is a variable resistance sensor that monitors fuel pressure in the HP fuel rail. The FRP sensor is mounted in the front of the fuel rail, on the left side of the engine.

Pressure Limiting Valve

The pressure limiting valve maintains fuel pressure inside the fuel rail below 260,000 kPa (37,710 psi). If HP pump output exceeds 260,000 kPa (37,710 psi), the pressure limiting valve opens and allows fuel to flow into the fuel return line. With the pressure limiting valve open, fuel pressure in the pressure pipe rail drops to approximately 110,000 kPa (15,954 psi).

Injectors

MaxxForce® 11 and 13 engines are equipped with electronically controlled injectors. During engine operation, injectors are supplied at all times with high-pressure fuel, and the injector solenoid valves open up to three times per cycle. The injectors are positioned vertically in the center of the cylinder head and are held in place by brackets. The seal between the injectors and the combustion chamber consists of a copper washer on the tip of each injector.

Cold Start Assist System

Cold Start Assist System Components

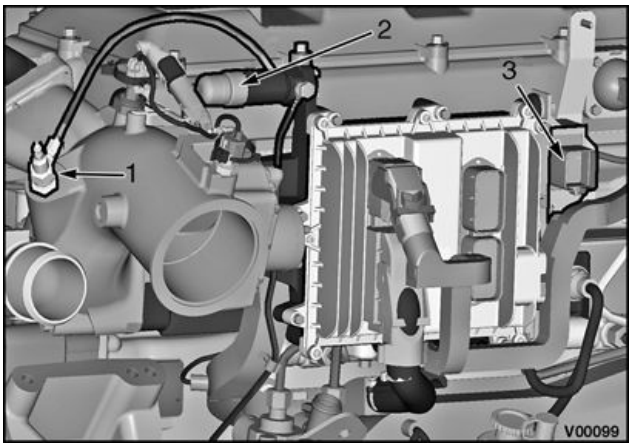


Figure 20 Cold start assist system

1. Cold Start Fuel Ignitor (CSFI)
2. Cold Start Solenoid (CSS) valve
3. Cold Start Relay (CSR)

Cold Start Fuel Ignitor (CSFI)

The cold start assist system rapidly activates the heater element, vaporizing and igniting small quantities of fuel into the air inlet duct.

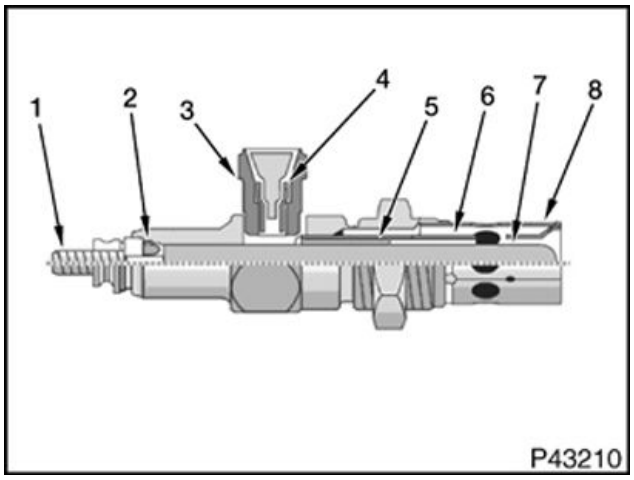


Figure 21 Cold Start Fuel Ignitor (partial cut away view)

1. Electrical connection
2. Insulation
3. CSFI fuel line connection
4. Metering device
5. Vaporizer filter
6. Vaporizer tube
7. Heater element
8. Protective sleeve

The CSFI has an internal fuel metering device, a vaporizer filter, a vaporizer tube, a heater element, and a protective sleeve. The protective sleeve has holes that allow enough air to pass through the CSFI to enable fuel vaporization and combustion.

The CSFI is installed on the left front side of the engine, in the intake throttle duct.

Cold Start Relay (CSR)

The CSR is located on the left side of the engine at the rear of the ECM. The CSR provides voltage to the CSFI, and is controlled by the ECM.

Cold Start Solenoid (CSS) Valve

The CSS valve is located on the left side of the engine and is controlled by the ECM. The CSS valve is supplied with low fuel pressure regulated fuel from the fuel filter assembly.

When the ECM provides battery voltage to the CSS valve, the solenoid opens and allows fuel to flow to the CSFI through the CSFI fuel line.

Cold Start Assist System Operation

The cold start assist system operates only in temperatures lower than 10 °C (50 °F).

When the truck operator turns the ignition switch to ON, the wait-to-start lamp in the instrument cluster illuminates. Based on the temperature readings from the ECT, the ECM activates the CSR heater element. The CSR then energizes the CSFI for approximately 35 seconds.

Once the CSFI is heated to approximately 1000 °C (1832 °F), the wait-to-start lamp starts to flash and the operator needs to crank the engine. When the engine starts rotating, the CSS valve opens and allows fuel to enter the CSFI. Inside the CSFI, fuel passes through the vaporizer tube. The vaporized fuel then mixes with in coming air and ignites in contact with the heater element.

Once the engine starts, the CSFI remains energized and fuel continues to be injected, and the wait-to-start lamp continues to flash for a maximum of four minutes. When the wait-to-start lamp stops flashing, the CSFI and the CSS valve are deactivated. If the operator accelerates while the wait-to-start lamp is flashing, the cold start assist system will shutdown.

Oil Flow and Components

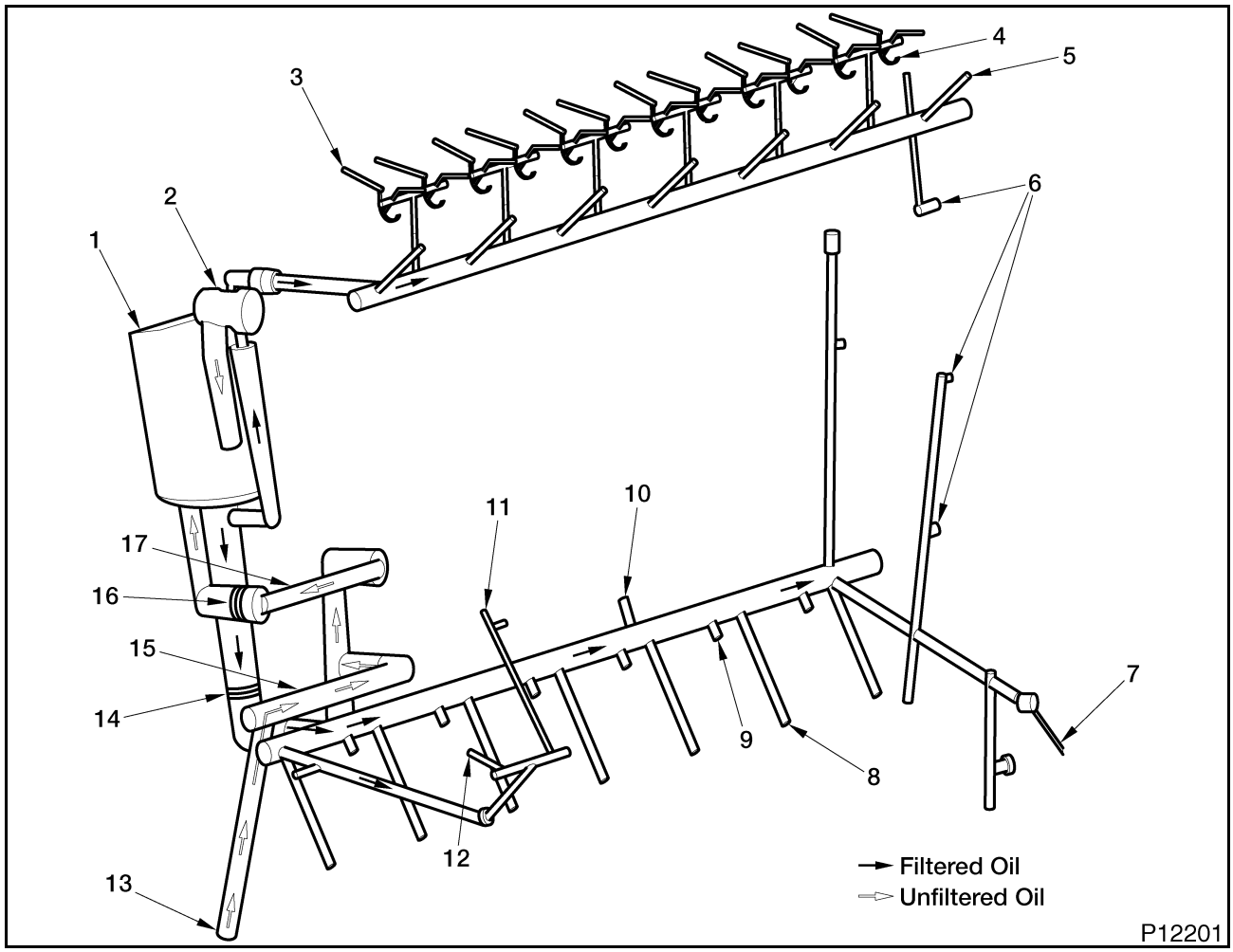


Figure 22 Oil flow

1. Oil filter element
2. Oil return from cylinder head
3. Oil supply to exhaust valve bridge
4. Oil supply to rocker gear
5. Oil supply to camshaft bearings
6. Oil supply to intermediate gears
7. Oil supply to air compressor
8. Oil supply to crankshaft main bearings
9. Oil supply to piston oil sprayer nozzles
10. Oil supply to turbochargers
11. Oil supply to drive housing
12. Oil supply to front cover
13. Oil pump output
14. Oil pressure relief valve
15. Oil supply to oil module
16. Oil return shutoff valve
17. Oil cooler

Unfiltered oil is drawn from the oil pan through the pickup tube and front cover passage by the crankshaft driven gerotor pump. The pressurized oil is moved through a vertical crankcase passage and into the oil module.

Inside the oil module, unfiltered oil flows through plates in the oil cooler heat exchanger. Engine coolant flows around the plates to cool the surrounding oil. An oil return shutoff valve installed at the exit from the oil cooler prevents oil from draining through the oil pump and back into the oil pan when the engine is stopped. If oil pressure coming out of the oil pump is too high, a pressure relief valve allows the excess oil to return through the crankcase and into the oil pan before entering the oil cooler.

Oil that exits the oil cooler flows through a return shutoff valve that prevents the oil from draining back into the oil pan. From the return shutoff valve, oil enters the oil filter element and flows from the outside to the inside of the filter element to remove debris. When the filter is restricted, an oil filter bypass valve opens and allows oil to bypass the filter so engine lubrication is maintained. If the oil pressure inside the oil filter element is too high, an oil pressure relief valve, located at the bottom of the oil filter element housing, allows the excess oil to return to the oil pan.

After passing through the oil filter element, oil flow is directed to the cylinder head and crankcase.

Clean oil enters the cylinder head through an external flange elbow connected directly to the oil module. Inside the cylinder head, oil flows through passages to lubricate the camshaft bearings, rocker arms, exhaust valve bridges, and cylinder intermediate gear.

Clean oil enters the crankcase directly from the oil module to lubricate the crankshaft, high-pressure pump, air compressor, intermediate gears, and turbochargers. The crankshaft has cross-drillings that direct oil to the connecting rods.

Oil sprayer nozzles continuously direct cooled oil to the bottom of the piston crowns.

The turbochargers are lubricated with filtered oil from an external supply tube that connects the main oil gallery from the crankcase to the center housing of each turbocharger. Oil drains back to the oil pan through the low and high-pressure turbocharger oil return pipes connected to the crankcase.

A service oil drain valve, located at the bottom of the filter element cavity, opens automatically when the filter element is lifted for replacement, and allows the oil from the oil filter element cavity to drain into the oil pan.

Oil is also supplied to the MaxxForce® Engine Brake housings (under valve cover) through specially designed rocker mounting bolts.

Crankcase Oil Separator

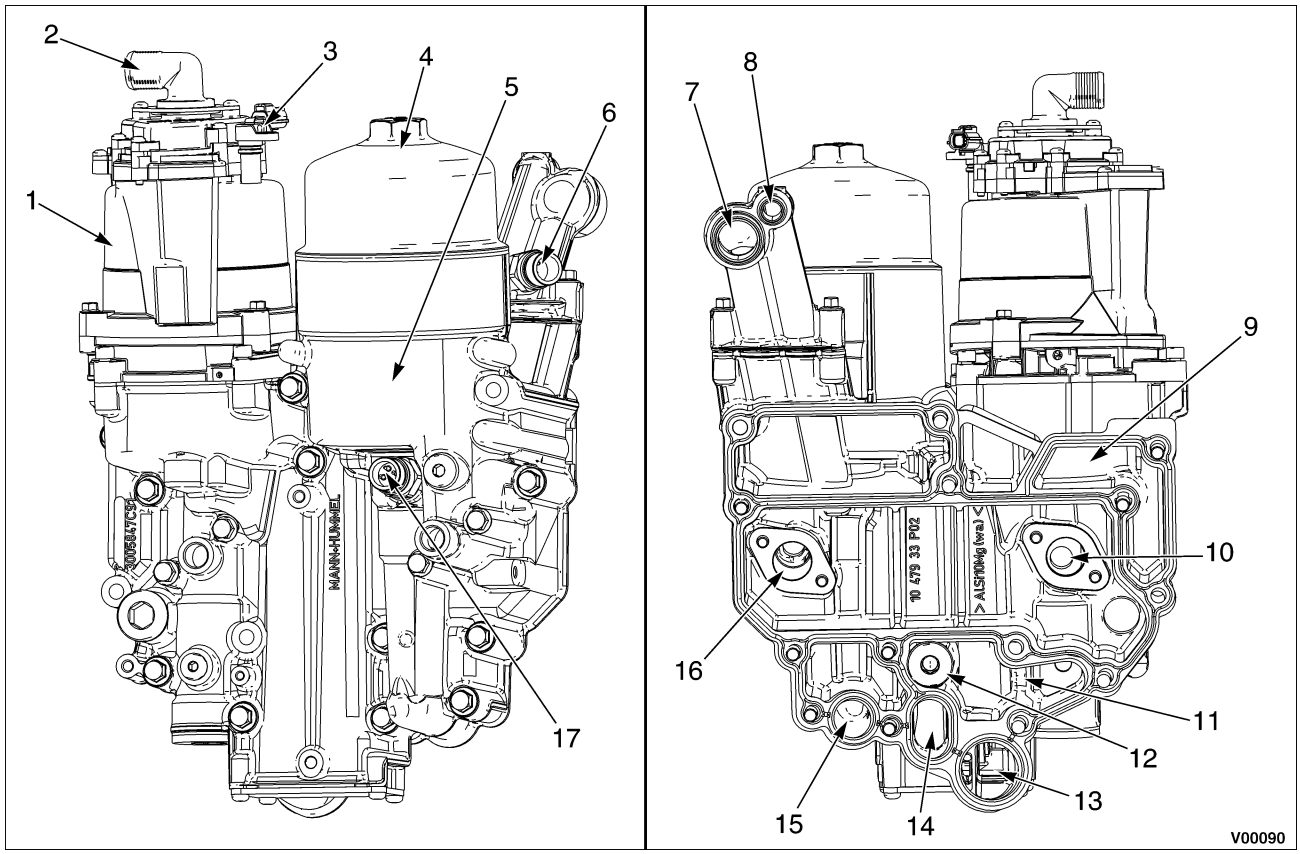


Figure 23 Oil module w/crankcase oil separator assembly (inner and outer views)

1. CCOS
2. CCOS vent outlet
3. CCOSS sensor
4. Filter cover
5. Oil filter assembly
6. EOT sensor
7. Oil return from cylinder head
8. Oil supply to cylinder head
9. Crankcase gas inlet
10. Oil cooler inlet
11. Oil supply from oil pump
12. Regulator
13. CCOS oil return
14. Oil module pressure relief port
15. Oil out to crankcase
16. Oil cooler outlet to crankcase
17. EOP sensor

The oil module contains a canister style filter, oil cooler, EOP and EOT sensors, a pressure relief valve, an oil filter bypass valve, and an oil return shutoff valve. The oil module also collects, and then directs crankcase emissions to the CCOS. The oil that separates from the crankcase emissions, before it reaches the CCOS, is drained back into the oil pan through the oil return port.

Remote Mounted Centrifugal Oil Filter (Optional)

The Remote Mounted Centrifugal Oil Filter is used to remove soot particulates from engine oil, reducing wear and extending engine oil change intervals. During operation, dirty oil enters the oil supply port to a regulator valve. When engine oil pressure exceeds 138 kPa (20 psi), the regulator valve opens, and oil enters the centrifugal element through the center hollow spindle. Inside the element, centrifugal force separates contaminants from oil. Contaminants accumulate on the serviceable rotor surface as a solid cake. Clean oil exits through opposing twin nozzles that power the centrifuge and returns to the crankcase from the oil level control base. Oil level is managed by the oil float. When the oil float raises, compressed air enters the system to force oil back to the crankcase. When the oil float drops, the air supply port is closed.

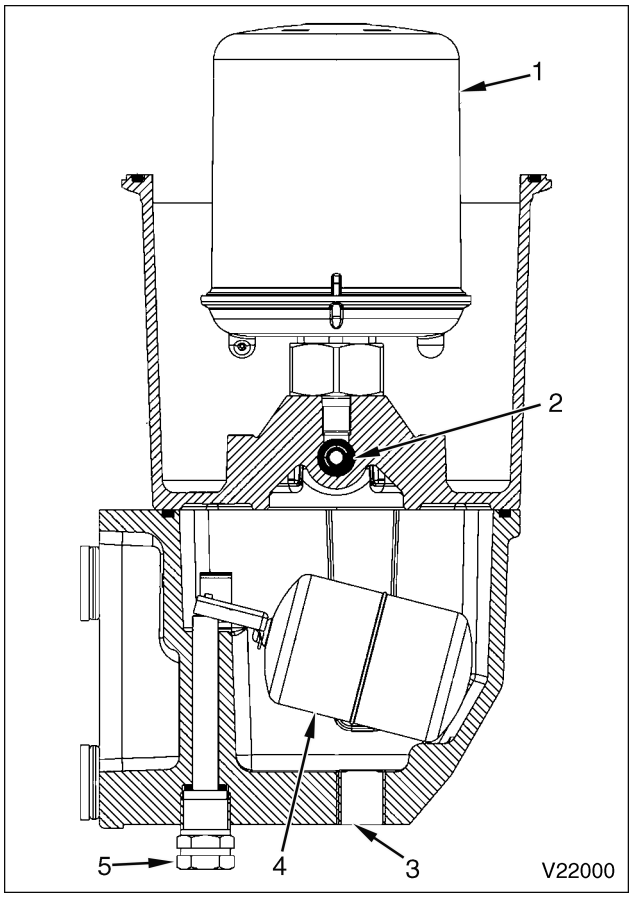


Figure 24 Remote mounted centrifugal oil filter

1. Serviceable rotor
2. Oil supply port (regulator valve)
3. Oil return port
4. Oil float
5. Air supply port (regulator valve)

Engine Cooling System

Cooling System Flow

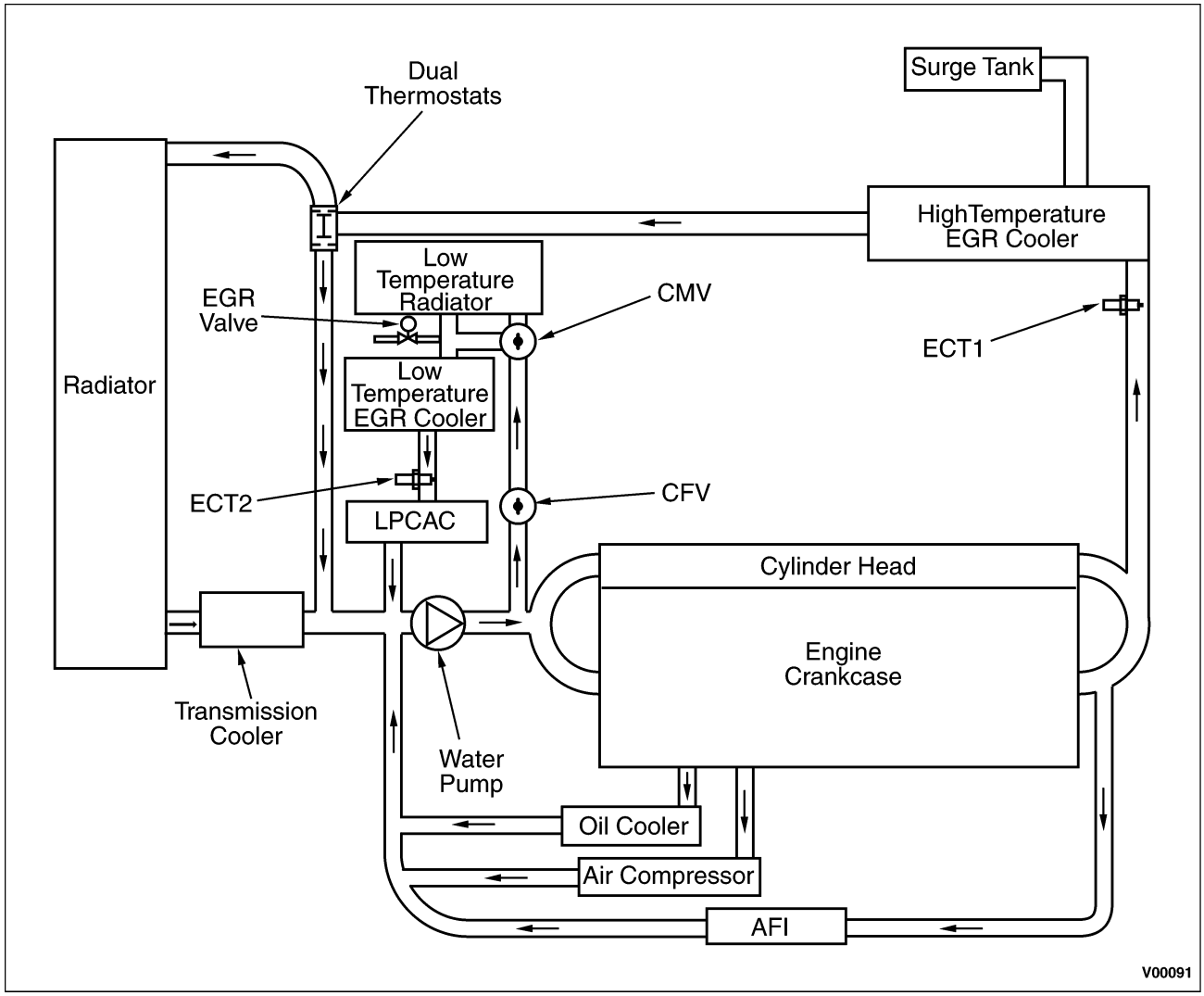


Figure 25 Cooling system flow

The water pump is installed on the water distribution housing and draws coolant from the radiator through the coolant inlet.

MaxxForce® 11 and 13 engines have no coolant passages between the crankcase and cylinder head through the cylinder head gasket. This eliminates the possibility of coolant leaks at the cylinder head gasket. Coolant in and out of the crankcase and cylinder head is directed through external passages. Coolant flows through the crankcase and cylinder head from front to rear. This coolant flows around the cylinder liners and combustion chambers to absorb heat from combustion.

Coolant exiting the crankcase and cylinder head at the rear of the engine is directed through an external coolant pipe to the high temperature stage of the EGR cooler. Coolant passes between the EGR cooler plates, travels parallel to the exhaust flow, travels through a transfer passage in the left side of the low temperature EGR cooler, into the EGR cooler return manifold and into the thermostat housing. A deaeration port on the top of the high temperature EGR cooler directs coolant and trapped air to the coolant surge tank.

Coolant from the water pump also flows through the low temperature EGR Cooler and then through the LPCAC to regulate the charge air temperature. Flow through the low temperature EGR cooler/charge air cooler is controlled by the Coolant Mixer Valve (CMV) and Coolant Flow Valve (CFV). Depending on the coolant flow, CMV sends coolant through the low temperature EGR Cooler, or bypass indirectly to the LPCAC, after going through the LTR located in front of the main coolant radiator. When the charge air temperature is too low, CMV bypasses the LTR and directs all the coolant through the CAC. When the charge air temperature increases, CMV directs a percentage of the coolant to the LTR before it enters the CAC to cool the charge air. If the engine coolant temperature is too high, CMV sends all of the coolant flow through the LTR and through the LPCAC to help cool the engine faster.

Both CMV and CFV are controlled by the ECM based on signals from the Engine Coolant Temperature (ECT) sensor, ECT2 sensor, and the Intake Manifold Pressure (IMP)/Air Inlet Temperature 2 (MAP/AIT2) sensors.

Coolant flow to the radiator is controlled by two thermostats. When the thermostats are closed, coolant flowing out of the EGR cooler is directed through a bypass port inside the front cover into the water pump. When the thermostats are open the bypass port is blocked, and coolant is directed from the engine into the radiator.

Coolant passes through the radiator and is cooled by air flowing through the radiator from ram air and operation of the coolant fan. The coolant returns to the engine first through the transmission cooler, then through the engine coolant inlet elbow.

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

The oil module receives coolant from a passage in the crankcase. Coolant passes between the oil cooler plates and returns back to the water pump suction passage.

Thermostat Operation

MaxxForce® 11 and 13 engines are fitted with two thermostats in a common housing to ensure sufficient coolant flow in all operating conditions. The thermostat housing is installed on top of the water distribution housing.

The thermostat housing assembly has two outlets. One directs coolant to the radiator when the engine is at operating temperature. The second outlet directs coolant to the water pump until the engine reaches operating temperature. The thermostats begin to open at 83 °C (181 °F) and are fully open at 91 °C (196 °F).

When engine coolant is below 83 °C (181 °F), the thermostats are closed, blocking coolant flow to the radiator.

When coolant temperature reaches the opening temperature of 83 °C (181 °F), the thermostats open allowing some coolant to flow to the radiator. When coolant temperature exceeds 91 °C (196 °F), the lower seat blocks the bypass port directing full coolant flow to the radiator.

Coolant Control Valve (CCV) operation

The CCV is installed on the upper right side of the water distribution housing and controls the coolant flow to the CACs.

The CCV has two separate solenoid actuated valves based on the charged air temperature and the two engine coolant temperature sensors; CMV, and CFV. The CMV and the CFV are part of the CCV assembly and cannot be serviced separately. The CMV and CFV solenoids are controlled by two separate PWM signals from the ECM. The PWM signal duty cycles vary between 0% and 100% depending on the coolant and charge air temperature.

Coolant Flow Valve (CFV)

The CFV is installed on the lower side of CCV and controls the amount of coolant flow through the LPCAC. The CFV will close to reduce the coolant flow through the LPCAC when the engine is operating at high speeds.

Coolant Mixer Valve (CMV)

The CMV is installed on the upper side of CCV and controls the coolant flow through the LTR. When the temperature of the charge air and coolant coming out of the LPCAC is low, the CMV directs the coolant through a LTR bypass directly into the LPCAC. This helps the engine reach its normal operating temperature faster. If the temperature of the charge air and coolant coming out of the LPCAC is high, the CMV directs the coolant flow through the LTR. This prevents overheating of the LPCAC, which can result in LPCAC failure.

Engine Brake System

Engine Brake Control System Components

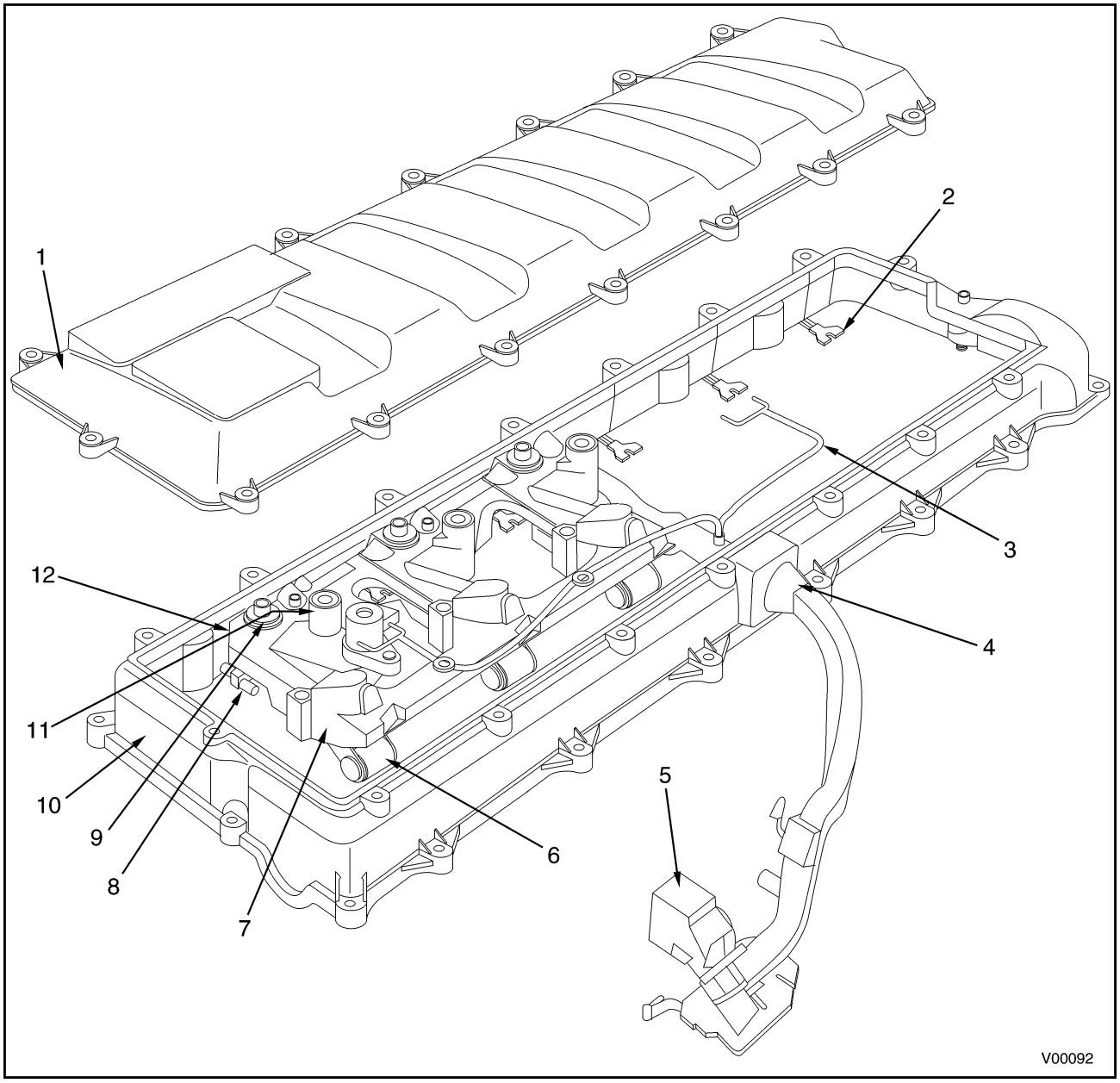


Figure 26 Engine brake control system components

1. Upper valve cover
2. Injector harness connector
3. Engine brake solenoid harness connector lead (2)
4. Pass through harness
5. ECM E1 connector
6. Master piston roller assembly (3 each housing)
7. Engine brake master piston (within housing)
8. Exhaust valve bridge
9. Engine brake slave piston
10. Valve cover base
11. Engine brake solenoid (1 each housing)
12. Engine brake housing assembly (2)

The MaxxForce® Engine Brake by Jacobs® braking system is standard equipment on the PROSTAR® and optional equipment on the TRANSTAR® and WORKSTAR® for the MaxxForce® 11 and 13 engines. The braking system is a hydro-mechanical device that mounts under the engine's valve cover. It turns your power-producing diesel engine into a power-absorbing air compressor.

Here's how: when the driver releases the accelerator pedal, the forward momentum of the truck continues to turn the drivetrain and engine. The pistons continue to move up and down. Once activated, the engine brake opens the exhaust valves near the peak of the compression stroke, releasing the highly compressed air through the exhaust systems. Little energy is returned to the piston, and as the cycle repeats, the energy of the truck's forward motion is now directed toward motoring the diesel engine, thus reducing the forward motion causing the truck to slow down.

Engine Brake System Operation

The engine brake system consists of two hydraulic braking housings, activated using two ECM actuated brake solenoids, and an exhaust bridge (pin). The engine brake depends on engine oil for operation; minimum oil temperature for engine brake activation is 40 °C (104 °F).

The operation of the engine brake is fully automatic once it is turned on by an ON/OFF switch by the operator. When the clutch is fully engaged and you remove your foot completely from the throttle, the engine brake is automatically activated.

NOTE: The operator can select various retarding levels by pressing a HIGH/MEDIUM/LOW switch depending on the retarding performance required.

Activation occurs through the following steps:

1. Engine oil pressure fills the housing passages up to the solenoid.
2. Activation of the engine brake is communicated by the ECM using the J1939 data link. When activated, the energized solenoid valve permits engine lube oil to flow under pressure through the control valve to both the master piston and slave piston circuits.
3. Oil pressure causes the master piston roller assembly to move down, picking up the motion of the cam (dedicated braking lobe) pushing the piston back into the housing creating high-pressure oil.
4. The high-pressure oil flows back through the master piston, slave piston and control valve circuits.
5. The check ball in the control valve seats, trapping oil in the circuit creating a high-pressure link between the slave piston and master piston.
6. Once the high-pressure link is created, the master piston follows the cam profile causing the slave piston to move down, momentarily opening exhaust valve (single valve opening), while the engine piston is near its top dead center position, releasing compressed cylinder air to the exhaust manifold.
7. Compressed air escapes to atmosphere completing compression braking cycle.

NOTE:

1. The MaxxForce® Engine Brake by Jacobs® will disengage during Anti-lock Brake System (ABS) braking.
2. Will interact with the vehicle cruise control for smooth operation during engine braking
3. Will interact with the UltraShift™ Transmission for smooth up-shifts under fueling conditions

Electronic Control System

Electronic Control System Components

MaxxForce® 11 and 13 engines are equipped with one control module; the Engine Control Module (ECM).

Operation and Function

The ECM monitors and controls engine operation to ensure maximum performance and adherence to emissions standards. The ECM, performs the following functions:

- Provide reference voltage (VREF)
- Condition input signals
- Process and store control strategies
- Control actuators

Reference Voltage (VREF)

The ECM supplies 5 volt VREF signals to various 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.

Signal Conditioner

Signal conditioning circuitry in the ECM converts analog signals to digital signals, squares up sine wave signals, and amplifies low intensity signals.

Microprocessor

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

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

Diagnostic Trouble Codes

Diagnostic Trouble Codes (DTCs) are stored by the ECM if inputs or conditions do not comply with expected values. Diagnostic codes for the 2010 MY are communicated using the Suspect Parameter Number (SPN) and Failure Mode Indicator (FMI) identifiers, and are accessed using an electronic service tool with ServiceMaxx® diagnostic software or a generic scan tool as well.

Microprocessor Memory

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

ROM

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

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

RAM

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

- Engine temperature
- Engine rpm
- Accelerator pedal position

Actuator Control

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

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

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

Actuators

The ECM controls engine operation with the following:

- CCV
- EBPV
- EGRV
- ACV
- CSR
- Cold Start Solenoid (CSS) valve
- ETV
- FPCV
- AFTFD
- AFTSV
- CSFI relay

Coolant Control Valve (CCV)

The CMV and CFV are a combined solenoid assembly that regulates coolant flow and temperature through the LPCAC and the low temp EGR cooler. The CMV and CFV are housed in the CCV assembly.

CFV controls the rate of coolant flow through the CAC, and the CMV regulates the temperature of the coolant, by directing the coolant either through the LTR or through an internal bypass. Both valves are controlled by the ECM.

The CCV is installed on the water distribution housing.

Exhaust Back Pressure Valve (EBPV) Control

The EBPV is controlled using the ACV assembly. The ACV assembly contains the EBPV control valve, and the TC1TOP sensor. Both are used by the ECM to control EBPV operation.

The EBPV regulates the amount of air pressure applied to the EBPV pneumatic actuator. The pneumatic cylinder actuates the valve (in the exhaust system) in response to commands by the ECM.

The EBPV actuator is mounted on a bracket, on the right side of the engine, after the turbocharger exhaust connection.

Exhaust Gas Recirculation (EGR) Valve

The EGRV is mounted on the rear of the EGR cooler, on top of the engine. The EGRV assembly receives the desired valve position from the ECM. The EGRV regulates the flow of exhaust gases through the EGR system.

Air Control Valve (ACV)

The ACV contains solenoids used for the control of the HP turbocharger wastegate and EBPV. It also contains the TC1TOP sensor.

ACV solenoids are controlled through pulse width modulated signals sent by the ECM.

The ACV is located on the right side of the engine, mounted near the center of the EGR cooler.

Cold Start Relay (CSR)

The cold start assist system aids cold engine starting by warming the incoming air supply prior to, and during, cranking, and also up to four minutes for cold engine warm-up.

The ECM is programmed to energize the CSFI heater element through the CSR while monitoring certain programmed conditions for engine coolant temperature, air inlet temperature, engine oil temperature, and atmospheric pressure.

The CSR delivers battery voltage (VBAT) to the heater element for a set time, depending on engine coolant temperature and altitude. The ground circuit is supplied directly from the battery ground at all times. The relay is controlled by switching on a voltage source from the ECM, and is installed to the rear of the ECM.

Cold Start Solenoid (CSS) Valve

The CSS valve controls fuel flow to the CSFI during cold start assist operation.

When cold start assist is required, the ECM provides voltage to open the CSS valve during cranking.

The CSS valve is mounted on the intake throttle duct, on the top left side of the engine.

Engine Throttle Valve (ETV)

The ETV controls the flow of fresh air (boosted and cooled) into the engine's air intake path through the CAC to help heat the exhaust aftertreatment during regeneration, and to assist when heavy EGR is requested. The electronic portion of the ETV contains a microprocessor that monitors valve position, electronic chamber temperature, controls the electric motor, and reports diagnostic faults to the ECM. The ETV changes position in response to ECM signals.

The ETV is integrated into the intake throttle duct, on the top left side of the engine.

Fuel Pressure Control Valve (FPCV)

The FPCV is a variable position actuator that controls the flow of fuel to the suction side of the high-pressure pump.

The FPCV changes valve position through pulse width modulated signals from the ECM.

The FPCV is mounted on the upper side of the high-pressure pump. The FPCV and fuel pump are serviced as an assembly.

Aftertreatment Fuel Doser (AFTFD)

The AFTFD is used to provide HP fuel flow to the aftertreatment fuel injector. The AFTFD is controlled through an PWM signal sent by the ECM. The AFTFD is housed in the DSI unit, which is located to the rear of the fuel filter assembly.

Aftertreatment Shutoff Valve (AFTSV)

The AFTSV is used to prevent fuel flow to the Hydrocarbon Injector (HCI) assembly, and prevents all uncontrolled fuel delivery for the aftertreatment system during a AFTFD valve malfunction. The AFTSV is controlled through an on-off signal sent by the ECM. The AFTSV is housed in the DSI unit, which is located to the rear of the fuel filter assembly.

Engine and Vehicle Sensors

Thermistor Sensors

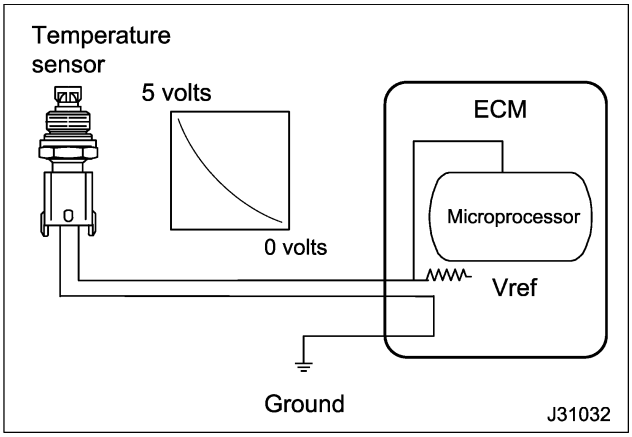


Figure 27 Thermistor

A thermistor sensor changes electrical resistance with changes in temperature. As temperature changes at the thermistor, voltage at the ECM will change accordingly. Thermistors work with the control module to produce a voltage signal directly proportional to temperature values.

A thermistor sensor has two electrical connectors, signal return and ground. The output of a thermistor sensor is a non-linear analog signal.

Thermistor type sensors include the following:

- Aftertreatment temperature sensors
- Engine Coolant Temp sensors
- EOT sensor
- TC2CIS
- CACOT sensor
- IMT sensor
- EGRT
- Ambient Air Temperature (AAT) sensor

Aftertreatment Temperature Sensors

Four sensors used in the Aftertreatment System include the following:

- Aftertreatment Fuel Inlet (AFTFI) sensor
- Diesel Oxidation Catalyst Inlet Temperature (DOCIT)
- Diesel Oxidation Catalyst Outlet Temperature (DOCOT)
- Diesel Particulate Filter Outlet Temperature (DPFOT)

The AFTFI sensor provides a feedback signal to the ECM indicating temperature of the fuel supplied to the downstream Injection DSI unit. The AFTFI is a dual function sensor, and also provides inlet fuel pressure values for DSI unit. The AFTFI sensor is installed in the DSI unit.

The DOCIT sensor provides a feedback signal to the ECM indicating DOC inlet temperature. The DOCIT sensor is the first temperature sensor installed past the turbocharger and just before the main DOC.

The DOCOT sensor provides a feedback signal to the ECM indicating DOC outlet temperature. The DOCOT sensor is the second temperature sensor installed past the turbocharger and just after the main DOC.

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

During a catalyst regeneration, the ECM monitors all three temperature sensors.

Engine Coolant Temperature (ECT) Sensors

The ECT1 and ECT2 sensors are thermistor-type sensors that detect engine coolant temperature.

The ECT1 signal is monitored by the ECM for operation of the instrument panel temperature gauge, coolant temperature compensation, charge air temperature control, EGR system control, optional Engine Warning Protection System (EWPS), and the wait to start lamp. The ECM uses ECT1 sensor input as a backup, if EOT sensor values are out of range.

The ECT1 sensor is installed in the underside of the EGR coolant crossover manifold, at the back of the engine. The ECT2 sensor is installed in the low temperature stage of the EGR cooler, on the right side of the engine.

Engine Oil Temperature (EOT) Sensor

The EOT sensor is a thermistor sensor that detects engine oil temperature. The EOT sensor is installed in the side oil module flange, behind the oil filter cover, on the right side of the engine.

Turbocharger 2 Compressor Inlet Sensor (TC2CIS)

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.

The TC2CIS sensor is monitored by the ECM, and is used for calculating fuel delivery and controlling LP wastegate operation.

The TC2CIS is installed in the piping between the LP compressor outlet and the HP compressor inlet.

Charge Air Cooler Outlet Temp (CACOT) Sensor

The CACOT sensor is a thermistor sensor that monitors the temperature of charge air entering the intake air duct.

The CACOT signal is monitored by the ECM.

The CACOT sensor is installed on the intake air duct, before the ETV.

Intake Manifold Temperature (IMT) Sensor

The IMT sensor is a thermistor sensor that monitors temperature.

The IMT sensor is installed in the intake side of the cylinder head, on the left side of the engine.

Exhaust Gas Recirculation Temperature (EGRT) Sensor

The EGRT sensor is a thermistor sensor that detects the exhaust gas temperature entering the EGR cooler.

The EGRT signal is monitored by the ECM.

The EGRT sensor is installed in the front of the low temp EGR cooler on the left side.

Ambient Air Temperature (AAT) Sensor

The AAT sensor is a thermistor sensor that detects the temperature of ambient.

The AAT signal is monitored by the ECM.

The AAT sensor is installed in various places on the vehicle.

Variable Capacitance Sensors

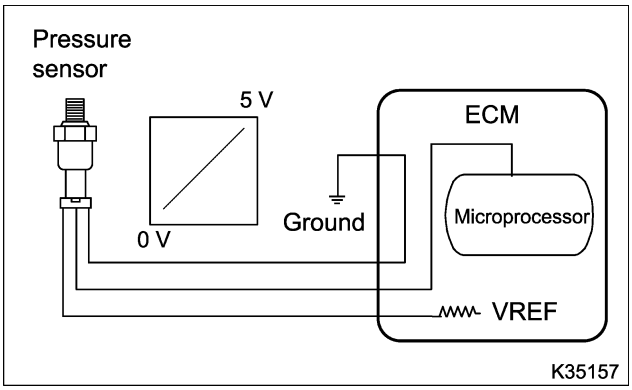


Figure 28 Variable capacitance sensor example

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 control module through the VREF, signal, and signal ground wires.

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

Variable capacitance sensors include the following:

- DPFDP sensor
- EFP sensor
- EOP sensor
- FRP sensor
- IMP sensor
- AFTFI sensor
- AFTFP2 sensor
- TC1TOP

DPF Differential Pressure (DPFDP) Sensor

The DPFDP sensor provides a feedback signal to the ECM indicating the pressure difference between the inlet and outlet of the particulate filter.

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

Engine Fuel Pressure (EFP) Sensor

The EFP sensor is a variable capacitance sensor that measures fuel supply pressure.

The EFP sensor provides feedback to the ECM for the LP fuel system.

The EFP sensor is installed in the front of the fuel filter assembly on the left side of the engine.

Engine Oil Pressure (EOP) Sensor

The EOP sensor is a variable capacitance sensor that detects engine oil pressure.

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

The EOP sensor is installed in the oil module, on the right side of the engine.

Fuel Rail Pressure (FRP) Sensor

The FRP sensor is a variable capacitance sensor that monitors fuel pressure in the HP fuel rail.

The FRP sensor measures fuel pressure just before injection.

The FRP sensor is mounted in the front of the fuel rail on the left side of the engine.

Intake Manifold Pressure (IMP) Sensor

The IMP sensor is a variable capacitance sensor that monitors the pressure of charge air entering the intake air duct.

The IMP signal is monitored by the ECM for control of the EGR system and turbocharger wastegates.

The IMP sensor is installed on the intake air duct, after the ETV.

Aftertreatment Fuel Inlet (AFTFI) Sensor

The AFTFI sensor is a dual function sensor and includes a thermistor sensor that monitors inlet fuel Temperature for the DSI unit.

The AFTFI sensor includes a variable capacitance sensor that measures fuel pressure supplied by the DSI unit, and is used to monitor fuel delivery to the aftertreatment system.

The AFTFI sensor is located in the DSI unit, to the rear of the fuel filter assembly.

Aftertreatment Fuel Pressure 2 (AFP2) sensor

The AFTFP2 sensor is a variable capacitance sensor that monitors fuel pressure after the Aftertreatment Shutoff Valve (ASV).

The AFP2 sensor measures fuel pressure supplied by the ASV to the AFTFD valve, and is used to monitor fuel delivery to the aftertreatment system.

The AFP2 sensor is located in the DSI unit, to the rear of the fuel filter assembly.

Turbocharger 1 Turbine Outlet Pressure (TC1TOP)

The TC1TOP sensor is a variable capacitance sensor that monitors exhaust back pressure.

The sensor measures back pressure in the exhaust system. A tap for the TC1TOP is located in the exhaust, between the LP turbocharger and EBPV.

The TC1TOP sensor is located in the Air Control Valve, on the right side of the engine.

Magnetic Pickup Sensors

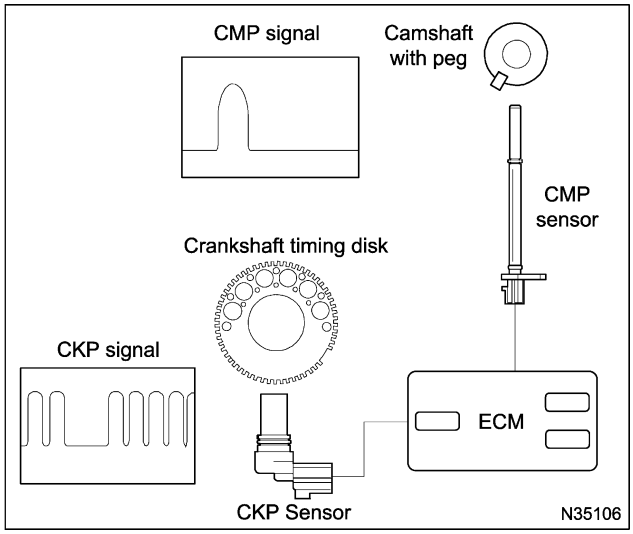


Figure 29 Magnetic pickup sensor example

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

Magnetic pickup sensors used include the following:

- CKP sensor
- CMP sensor
- VSS
- CCOSS sensor

Crankshaft Position (CKP) Sensor

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

The CKP sensor sends a pulsed signal to the Engine Control Module (ECM) as the crankshaft turns. The CKP sensor reacts to holes drilled into the flywheel adjacent to the ring gear. For crankshaft position reference, teeth 59 and 60 are missing. By comparing the CKP signal with the CMP signal, the ECM calculates engine rpm and timing requirements.

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

Camshaft Position (CMP) Sensor

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

The CMP sensor sends a pulsed signal to the ECM as a toothed wheel on the camshaft rotates past the CMP sensor. The ECM calculates camshaft speed and position from CMP signal frequency.

The CMP sensor is installed in the left rear of the cylinder head.

Vehicle Speed Sensor (VSS)

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

Crankcase Oil Separator Speed (CCOSS) sensor

The CCOSS sensor sends the ECM information about the speed of the crankcase oil separator internal components. The detected sine wave signal (AC) received by the ECM is used to monitor proper operation of the cyclonic oil separator, located inside the breather assembly on the engine oil filter assembly.

Potentiometer Sensors

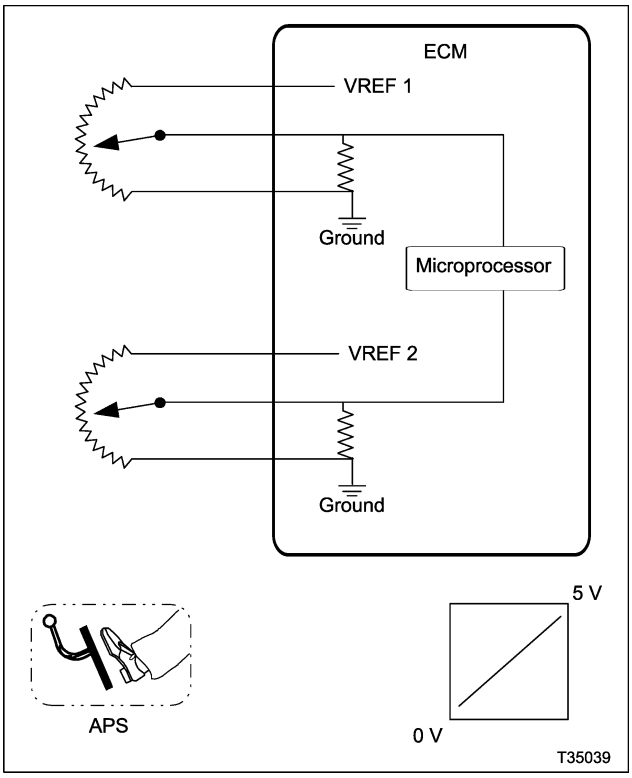


Figure 30 Potentiometer example

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

The engine has two potentiometers, both contained in the Accelerator Pedal Position (APP) Sensor.

Accelerator Pedal Position (APP)

The APP provides the ECM with a dual feedback signal (dual linear analog voltages) that indicate the operator's demand for power. The APP contains two potentiometers, and provides two individual signals (APP and APP2) to the ECM. The APP is installed in the cab on the accelerator pedal assembly.

Switches

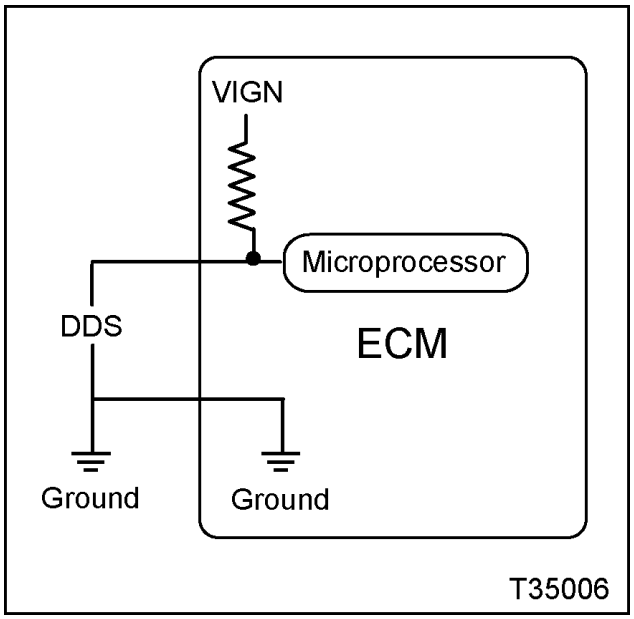


Figure 31 Switch example

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

Switches include the following:

- Driveline Disengagement Switch (DDS)
- Engine Coolant Level (ECL)
- Oil Level Sensor (OLS)

Driveline Disengagement Switch (DDS)

The DDS determines if a vehicle is in gear. For manual transmissions, the clutch switch serves as the DDS. For automatic transmissions, the neutral indicator switch functions as the DDS. The DDS signal is sent to the Body Controller (BC) and transmitted on the J1939 datalink to the engine ECM.

Engine Coolant Level (ECL) Switch

The ECL switch is part of the EWPS. The ECL switch is located on the deaeration tank. When the magnetic switch is open, the tank is considered full of coolant.

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

Oil Level Sensor (OLS)

The OLS is part of the EWPS. The OLS is located on the engine oil pan. The OLS measures the volume of oil in the oil pan and broadcast the percentage volume over J1939 CAN.

If the level of engine lube oil is low, the red ENGINE lamp on the instrument panel is illuminated.

Additional Sensors

Oxygen Sensor (O2S)

The O2S monitors oxygen levels in the exhaust.

The O2S is used to control the EGR flow to a specified air-to-fuel ratio by monitoring the level of unused oxygen in the exhaust stream.

The O2S compares oxygen levels in the exhaust stream with oxygen levels in the outside air. The sensor generates an analog voltage and is monitored by the ECM. The level of voltage generated by the O2S directly corresponds to the oxygen levels in the exhaust stream.

The O2S is installed in the turbocharger exhaust pipe, directly after the EBPV.

Humidity Sensor (HS)

The HS measures the moisture content of filtered air entering the intake system.

Using the HS, the ECM will adjust in order to prevent condensation of airborne water particles (moisture). The HS also houses the AIT sensor, which is used by the ECM for calculating fuel delivery.

Table of Contents

Mounting Engine.....57
Engine Cleaning.....57
Mounting Engine on Stand.....57

Special Torque.....60

Special Service Tools.....60

Mounting Engine

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

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

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

WARNING: To prevent personal injury or death, 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.

Engine Cleaning

1. Using Disposable Air and Fuel Caps (page 60), cover all engine openings to prevent water, degreasing agents or detergents from entering engine.
2. Cover exposed electrical connectors and the Engine Control Module (ECM) using plastic and duct tape.
3. Use an appropriate detergent mixed in the correct ratio as described on the detergent directions and apply to engine using a hot pressure washer or similar cleaning equipment.

Mounting Engine on Stand

NOTE: Before mounting engine on engine stand, do the following.

1. Drain any remaining coolant from individual components as necessary into a suitable container.
2. Remove oil drain plug and drain oil into a suitable container.
3. Inspect oil drain plug O-ring. Discard and replace if damaged.
4. After oil is drained, lubricate oil drain plug O-ring with clean engine oil and install oil drain plug.
5. Tighten oil drain plug to special torque (page 60).

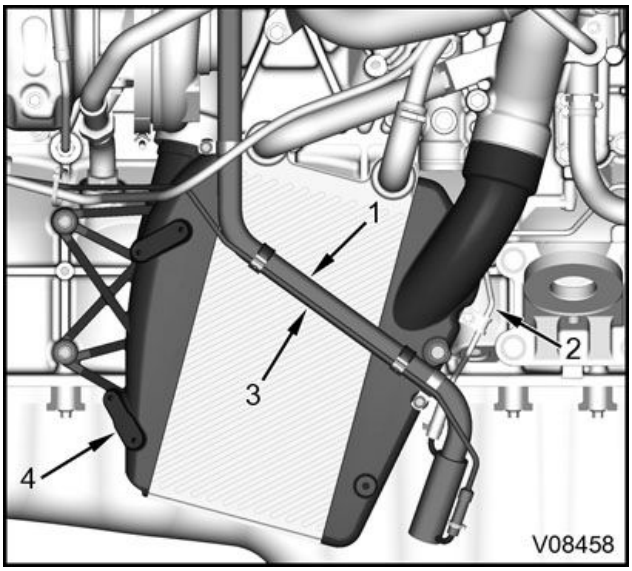


Figure 32 Low-pressure Charge Air Cooler (LPCAC) and tubes

1. Open breather tube assembly
2. Heater hose return tube
3. HCI coolant return tube assembly
4. LPCAC

6. Remove HCI coolant return tube assembly. See HCI Coolant Return Tube Assembly (page 130).
7. Disconnect heater hose return tube from water distribution housing, tube clamp and open breather tube assembly. See Oil Module Assembly (page 251).

8. Remove open breather tube assembly. See Oil Centrifuge (page 250).
9. Remove Low-pressure Charge Air Cooler (LPCAC). See Low-Pressure Charge Air Cooler (LPCAC) (page 160).

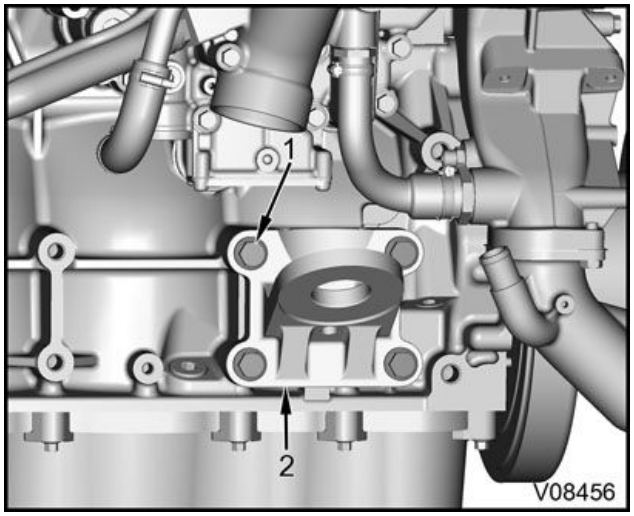


Figure 33 Engine front mount support (right side)

1. M14 x 50 bolt (4)
2. Engine front mount support

NOTE: For reinstallation of engine front mount support, tighten M14 x 50 bolts to special torque (page 60).

10. Remove four M14 x 50 bolts and engine front mount support (right).
11. Remove starter motor assembly.

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.

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

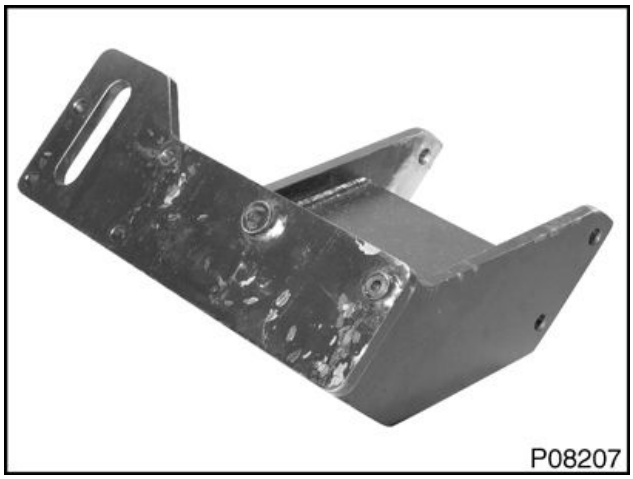


Figure 34 Engine Stand Adapter Plate (mounting bracket)

⚠ WARNING: To prevent personal injury or death, use metric class 10.9 or SAE grade 8 bolts when mounting Engine Stand Adapter Plate to engine and engine stand. See instructions included with engine stand and Engine Stand Adapter Plate.

NOTE: See manufacturer's safety instructions included with engine stand and Engine Stand Adapter Plate.

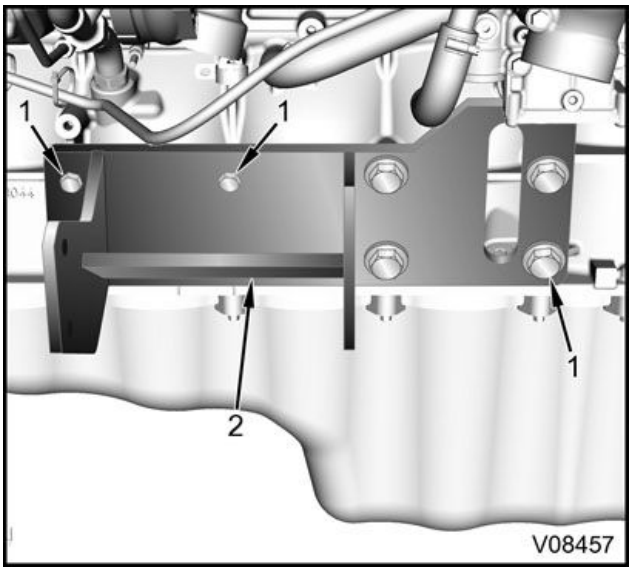


Figure 35 Engine Stand Adapter Plate (mounting bracket)

1. Hex bolt (part of ZTSE4789)
2. Engine Stand Adapter Plate (mounting bracket)

13. Position Engine Stand Adapter Plate (page 60) on right side of engine. Secure adapter plate with six mounting bolts and washers (part of Engine Stand Adapter Plate). Tighten bolts to standard torque (page 503).
14. Mount engine on engine stand using four 5/8 x 1.5 inch grade 8 mounting bolts. Tighten bolts to standard torque (page 503) .

Special Torque

Table 2 Mounting Engine on Stand

M14 x 50 engine front mount support bolts	225 N·m (166 lbf·ft)
Oil drain plug	75 N·m (55 lbf·ft)

Special Service Tools

Table 3 Mounting Engine on Stand

Description	Tool Number
Disposable Air and Fuel Caps	ZTSE4891
Engine Stand Adapter Plate	ZTSE4789

Table of Contents

Electronic Component Location.....63
- **Electronic Components – Right Front**.....63
- **Electronic Components – Left Rear**.....64

Description of Engine Sensors, Valves and Actuators.....65
- **Crankshaft Position (CKP) Sensor**.....65
- **Camshaft Position (CMP) Sensor**.....65
- **Engine Coolant Temperature (ECT) Sensors**.....65
- **Engine Oil Temperature (EOT) Sensor**.....66
- **Engine Oil Pressure (EOP) Sensor**.....66
- **Crankcase Oil Separator Speed (CCOSS) Sensor**.....66
- **Fuel Delivery Pressure (FDP) Sensor**.....67
- **Fuel Pressure Control Valve (FPCV)**.....67
- **Mass Air Flow (MAF) Sensor**.....67
- **Humidity / Air Inlet Temperature (IAT) Sensor**.....68
- **Charge Air Cooler Outlet Temperature (CACOT) Sensor**.....68
- **Intake Manifold Pressure (IMP) Sensor**.....68
- **Fuel Rail Pressure (FRP) Sensor**.....69
- **Intake Manifold Temperature (IMT) Sensor**.....69
- **Oxygen Sensor (O2S)**.....69
- **Engine Throttle Valve (ETV)**.....70
- **Coolant Control Valve (CCV)**.....70
- **Air Control Valve (ACV) Assembly**.....70
- **Exhaust Gas Recirculation (EGR) Valve**.....71
- **Exhaust Gas Recirculation Temperature (EGRT) Sensor**.....71
- **Turbocharger 2 Compressor Inlet Sensor (TC2CIS)**.....72

Removal.....73
- **Warnings and Cautions**.....73
- **Crankshaft Position (CKP) Sensor**.....73
- **Camshaft Position (CMP) Sensor**.....74
- **Engine Coolant Temperature 1 (ECT1) Sensor**.....74
- **Engine Coolant Temperature 2 (ECT2) Sensor**.....74
- **Engine Oil Temperature (EOT) Sensor**.....75
- **Engine Oil Pressure (EOP) Sensor**.....75
- **Crankcase Oil Separator Speed (CCOSS) Sensor**.....76
- **Fuel Delivery Pressure (FDP) Sensor**.....76
- **Fuel Pressure Control Valve (FPCV)**.....76
- **Mass Air Flow (MAF) Sensor (If equipped)**.....77
- **Humidity / Intake Air Temperature (IAT) Sensor**.....77
- **Charger Air Cooler Outlet Temperature (CACOT) Sensor**.....78
- **Intake Manifold Pressure (IMP) Sensor**.....78
- **Fuel Rail Pressure (FRP) Sensor**.....79
- **Intake Manifold Temperature (IMT) Sensor**.....79
- **Oxygen Sensor (O2S)**.....79
- **Engine Throttle Valve (ETV)**.....80

Coolant Control Valve (CCV)....80
Air Control Valve (ACV)....81
Exhaust Gas Recirculation (EGR) Valve....81
Exhaust Gas Recirculation Temperature (EGRT) Sensor....82
Turbocharger 2 Compressor Inlet Sensor (TC2CIS)....82
Wiring Harness ECM Connections....82
Engine Injector (Wiring) Harness....83
Engine Sensor (Wiring) Harness....85
Engine Control Module (ECM) and Support....88

Cleaning and Inspection....89
Engine Injection and Engine Sensor Wiring Harnesses....89
Sensors and Valves....89
Engine Control Module (ECM)....89

Installation....90
Engine Control Module (ECM) and Support....90
Engine Sensor (Wiring) Harness....91
Engine Injector (Wiring) Harness....94
Wiring Harness ECM Connections....96
Turbocharger 2 Compressor Inlet Sensor (TC2CIS)....96
Exhaust Gas Recirculation Temperature (EGRT) Sensor....97
Exhaust Gas Recirculation (EGR) Valve....97
Air Control Valve (ACV)....98
Coolant Control Valve (CCV)....98
Engine Throttle Valve (ETV)....99
Oxygen Sensor (O2S)....99
Intake Manifold Temperature (IMT) Sensor....100
Fuel Rail Pressure (FRP) Sensor....100
Intake Manifold Pressure (IMP) Sensor....100
Charger Air Cooler Outlet Temperature (CACOT) Sensor....101
Humidity / Air Inlet Temperature (IAT) Sensor....101
Mass Air Flow (MAF) Sensor (If equipped)....102
Fuel Pressure Control Valve (FPCV)....102
Fuel Delivery Pressure (FDP) Sensor....102
Crankcase Oil Separator Speed (CCOSS) Sensor....103
Engine Oil Pressure (EOP) Sensor....103
Engine Oil Temperature (EOT) Sensor....104
Engine Coolant Temperature 2 (ECT2) Sensor....104
Engine Coolant Temperature 1 (ECT1) Sensor....105
Camshaft Position (CMP) Sensor....105
Crankshaft Position (CKP) Sensor....105

Special Torque....106

Special Service Tools....106

Electronic Component Location

Electronic Components – Right Front

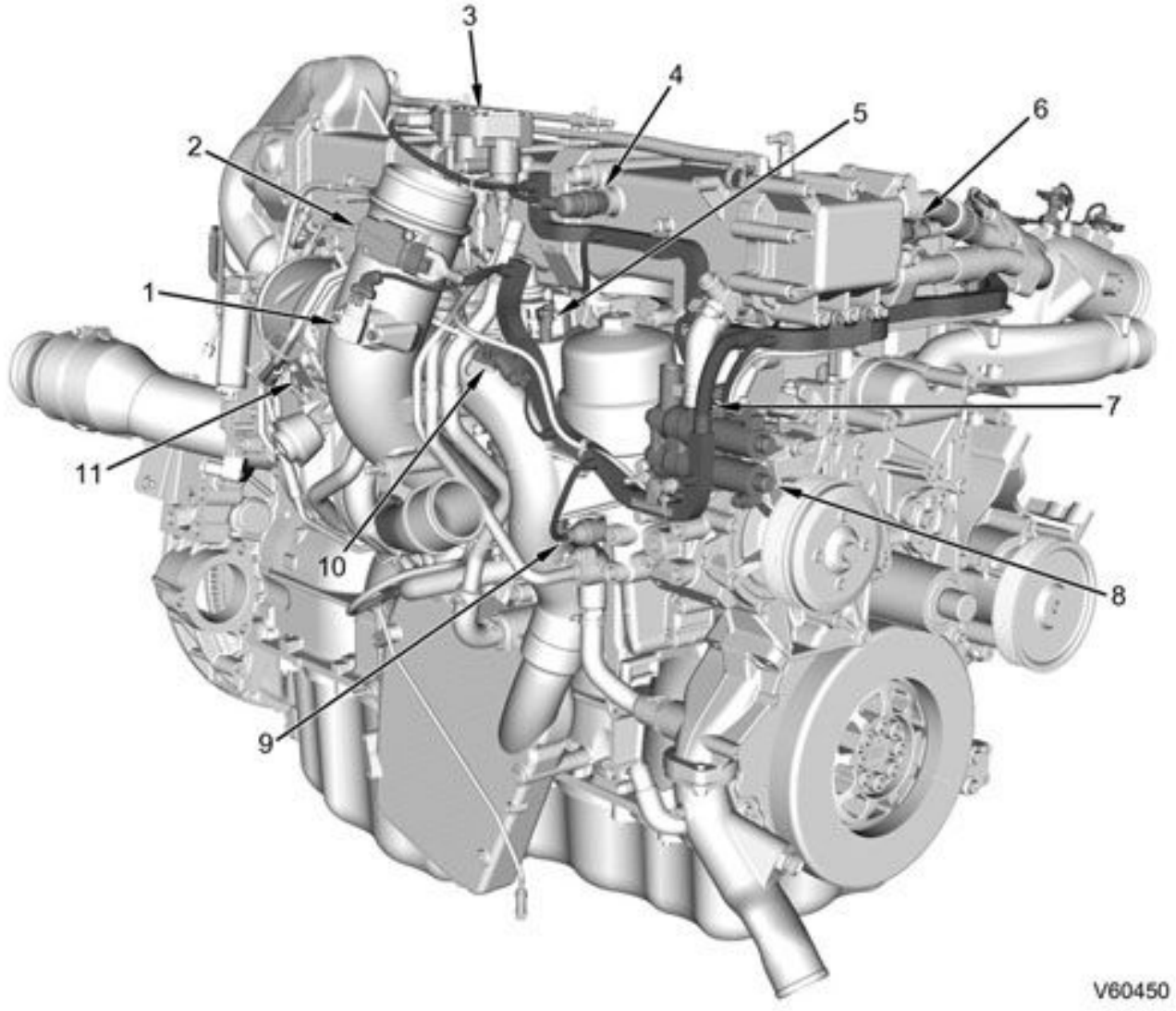


Figure 36 Electronic components – right front

1. Humidity / Air Inlet Temperature (IAT) sensor
2. Mass Air Flow (MAF) sensor (if equipped)
3. Air Control Valve (ACV) assembly
4. Engine Coolant Temperature 2 (ECT2) sensor
5. Crankcase Oil Separator Speed (CCOSS) sensor
6. Exhaust Gas Recirculation Temperature (EGRT) sensor
7. Engine Oil Temperature (EOT) sensor (behind CCV in oil module flange)
8. Coolant Control Valve (CCV) assembly
9. Engine Oil Pressure (EOP) sensor
10. Turbocharger 2 Compressor Inlet Sensor (TC2CIS)
11. Oxygen Sensor (O2S) (in exhaust back pressure valve housing)

Electronic Components – Left Rear

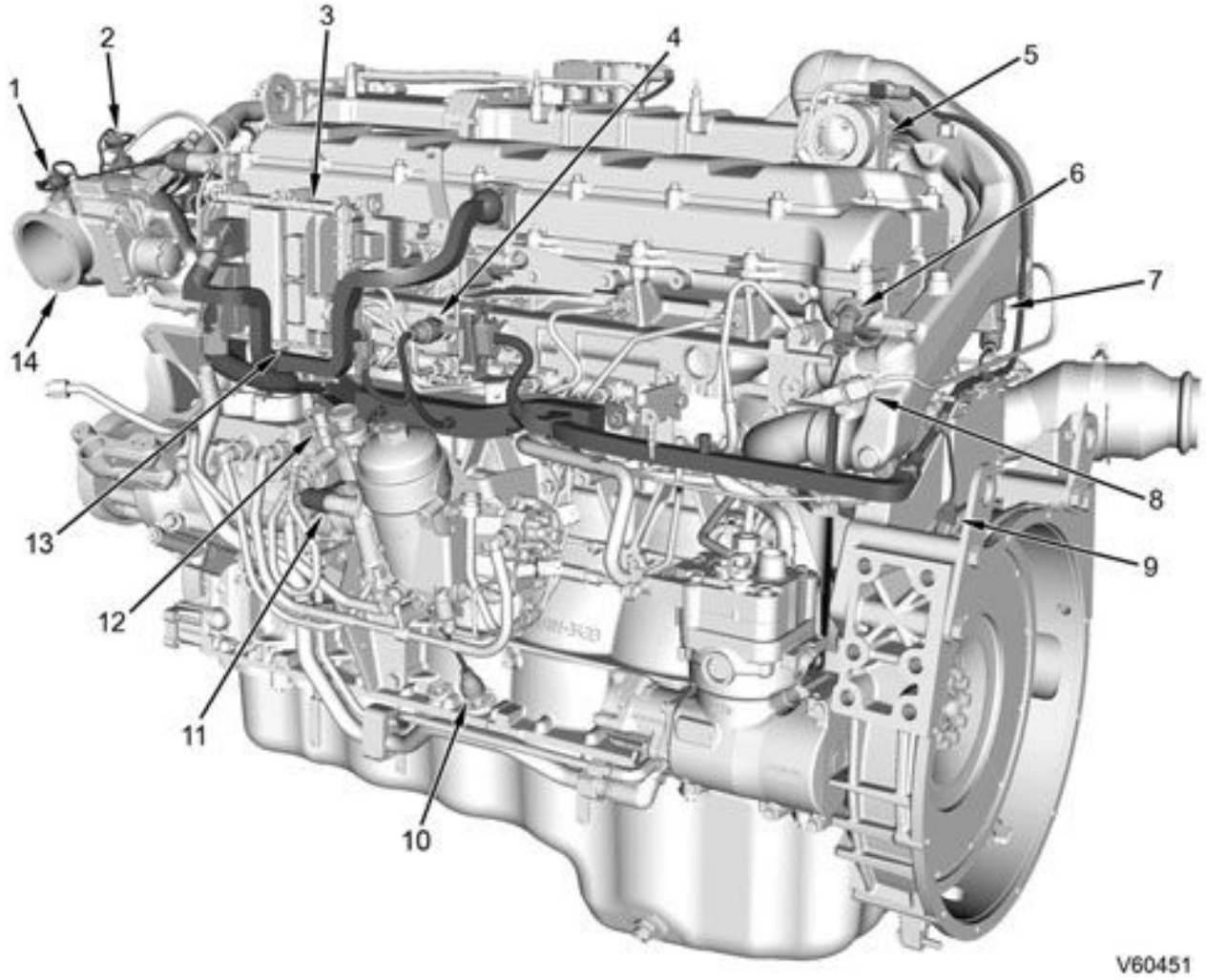


Figure 37 Electronic components – left rear

1. Charger Air Cooler Outlet Temperature (CACOT) sensor
2. Intake Manifold Pressure (IMP) sensor
3. Engine Control Module (ECM)
4. Intake Manifold Temperature (IMT) sensor
5. Exhaust Gas Recirculation (EGR) valve
6. Camshaft Position (CMP) sensor
7. Engine Coolant Temperature (ECT1) sensor
8. Oxygen Sensor (O2S) connector
9. Crankshaft Position (CKP) sensor
10. Engine Oil Level (EOL) sensor
11. Fuel Delivery Pressure (FDP) sensor
12. Fuel Pressure Control Valve (FPCV) (at back of high-pressure fuel pump)
13. Fuel Rail Pressure (FRP) sensor (behind ECM, at front of fuel rail)
14. Engine Throttle Valve (ETV)

Description of Engine Sensors, Valves and Actuators

NOTE: Refer to the following publications for information on diagnostics and troubleshooting:

- EGES-470 MaxxForce® 11 and 13 Engine Diagnostic Form
- EGED-475 MaxxForce® 11 and 13 Engine Diagnostic Form
- EGED-500 MaxxForce® 11 and 13 Electronic Control System Diagnostic Form

Crankshaft Position (CKP) Sensor

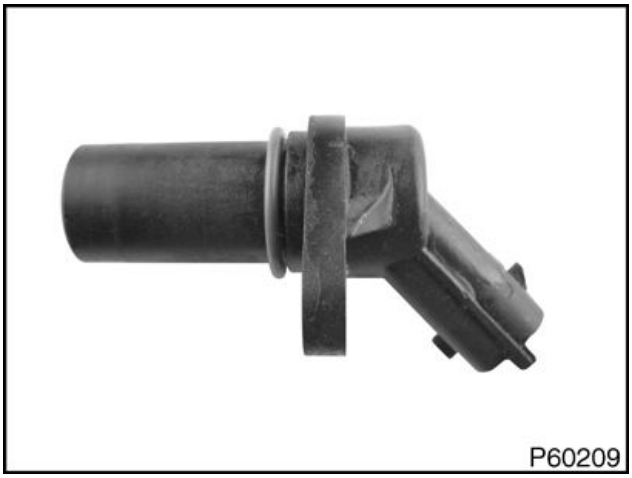


Figure 38 CKP sensor

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

The CKP sensor sends a pulsed signal to the Engine Control Module (ECM) as the crankshaft turns. The CKP sensor reacts to holes drilled into the flywheel adjacent to the ring gear. For crankshaft position reference, 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 top left of the flywheel housing.

Camshaft Position (CMP) Sensor

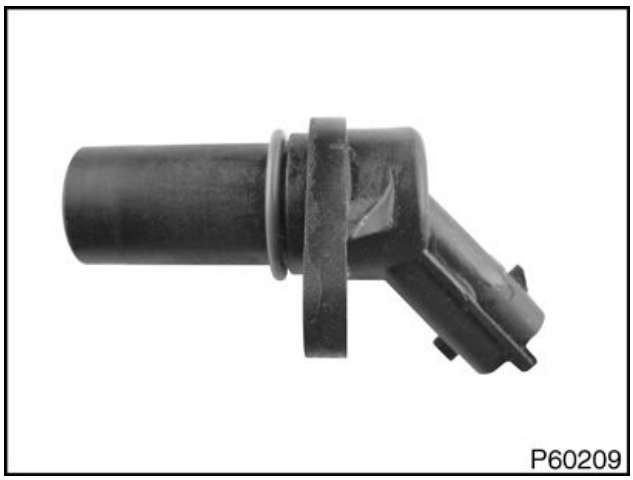


Figure 39 CMP sensor

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

The CMP sensor sends a pulsed signal to the ECM as a toothed wheel on the camshaft rotates past the CMP sensor. The ECM calculates camshaft speed and position from CMP signal frequency.

The CMP sensor is installed in the left rear of the cylinder head.

Engine Coolant Temperature (ECT) Sensors

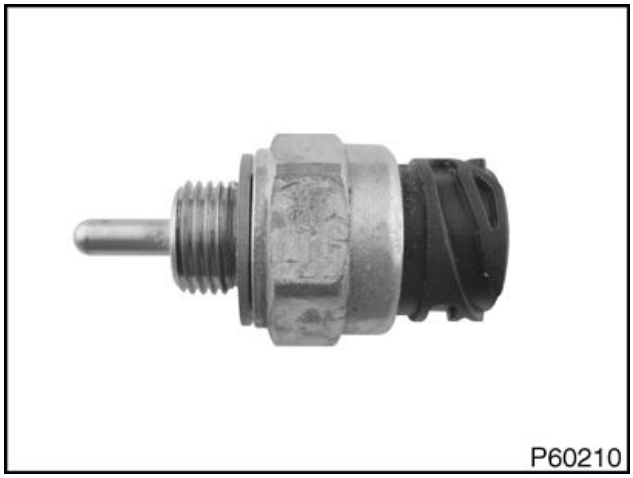


Figure 40 ECT sensor

The ECT1 and ECT2 sensors are thermistor sensors that detect engine coolant temperature.

The ECT1 and ECT2 signals are monitored by the ECM for operation of the instrument panel temperature gauge, coolant temperature compensation, charge air temperature control, Exhaust Gas Recirculation (EGR) system control, optional Engine Warning Protection System (EWPS) and the wait to start lamp. The ECM uses ECT1 sensor input as a backup, if Engine Oil Temperature (EOT) sensor values are out of range.

The ECT1 sensor is installed in the underside of the EGR coolant crossover manifold at the back of the engine. The ECT2 sensor is installed in the low-temperature stage of the EGR cooler on the right side of the engine.

Engine Oil Temperature (EOT) Sensor

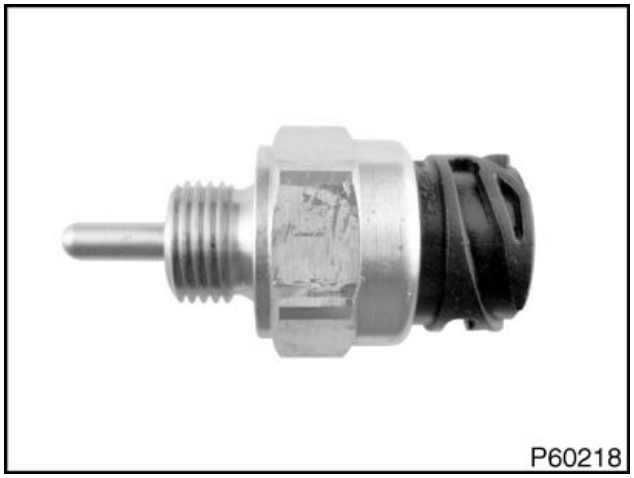


Figure 41 EOT sensor

The EOT sensor is a thermistor sensor that detects engine oil temperature, and is monitored by the ECM for cold start assist. The EOT sensor is installed in the oil module flange, behind the CCV on the right side of the engine.

Engine Oil Pressure (EOP) Sensor

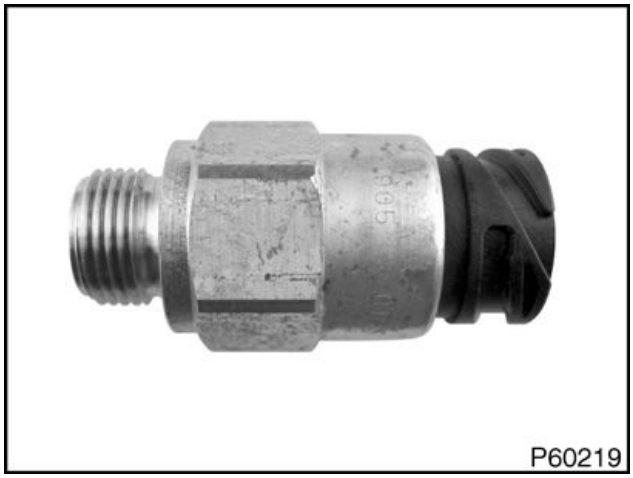


Figure 42 EOP sensor

The EOP sensor is a variable resistance sensor that detects engine oil pressure. The EOP signal is monitored by the ECM for operation of the instrument panel pressure gauge and optional EWPS. The EOP sensor is installed in the oil module, on the right side of the engine.

Crankcase Oil Separator Speed (CCOSS) Sensor

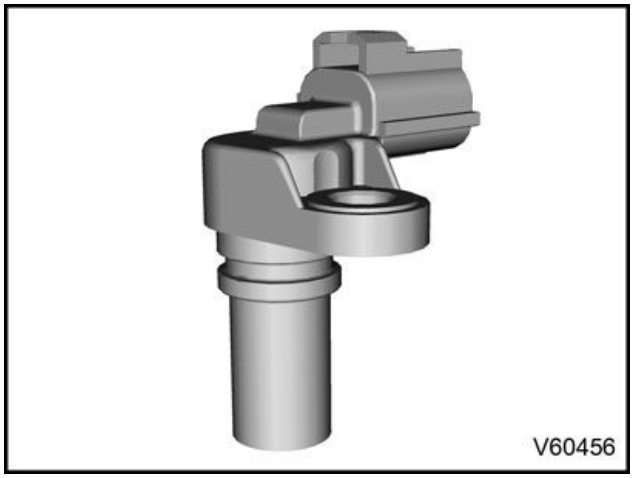


Figure 43 CCOSS sensor

The CCOSS sensor sends the ECM information about the speed of the crankcase oil separator internal components. The detected sine wave signal (AC) is used to monitor proper operation of the cyclonic

oil separator, located on the oil centrifuge on the oil module assembly.

Fuel Delivery Pressure (FDP) Sensor

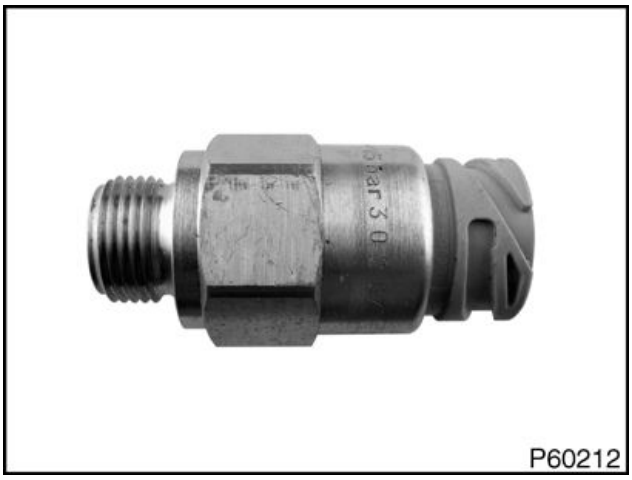


Figure 44 FDP sensor

The FDP sensor is a variable resistance sensor that measures fuel supply pressure, and provides feedback to the ECM for the low-pressure fuel system. The FDP sensor is installed in the front of the fuel filter housing assembly on the left side of the engine.

Fuel Pressure Control Valve (FPCV)

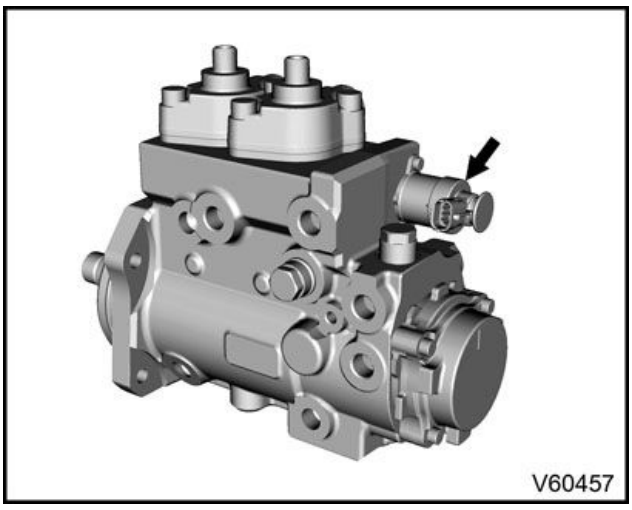


Figure 45 FPCV

The FPCV is a variable-position actuator that controls the flow of fuel to the suction side of the high-pressure fuel pump.

The FPCV changes valve position through pulse-width modulated signals from the ECM.

The FPCV is mounted on the upper side of the high-pressure fuel pump. The FPCV and high-pressure fuel pump are serviced as an assembly.

Mass Air Flow (MAF) Sensor

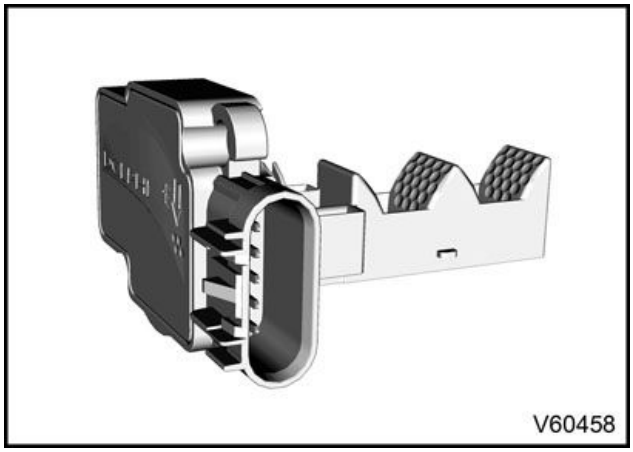


Figure 46 MAF Sensor

The MAF sensor measures the amount of filtered air entering the engine intake system.

The MAF sensor provides a digital signal to the ECM and will vary frequency depending on the amount of air entering the intake.

The MAF sensor is installed in the air inlet duct, before the low-pressure turbocharger compressor inlet.

Humidity / Air Inlet Temperature (IAT) Sensor

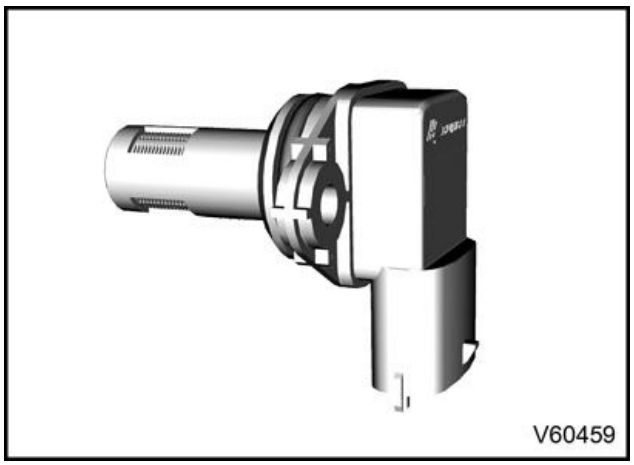


Figure 47 IAT

The IAT measures the moisture content of filtered air entering the intake system.

The IAT is used by the ECM to prevent EGR system component degradation due to moisture contamination. Using the sensor, the ECM will adjust EGR system flow to prevent condensation of airborne water particles. The sensor also measures intake air temperature, which is used by the ECM for calculating fuel delivery.

The IAT is mounted in the air inlet duct at the upper right side of the engine.

Charge Air Cooler Outlet Temperature (CACOT) Sensor

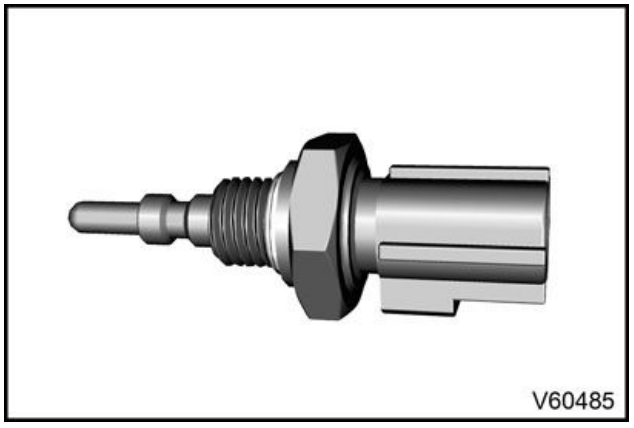


Figure 48 CACOT sensor

The CACOT sensor is a thermistor sensor that monitors the temperature of charge air entering the intake air duct.

The CACOT signal is monitored by the ECM for control of the EGR system.

The CACOT sensor is installed on the air intake throttle duct, before the Engine Throttle Valve (ETV).

Intake Manifold Pressure (IMP) Sensor

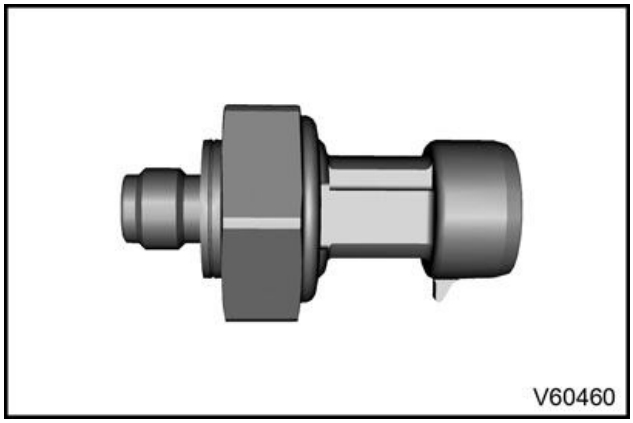


Figure 49 IMP sensor

The IMP sensor is a variable capacitance sensor that monitors the pressure of charge air entering the air intake throttle duct. The IMP signal is monitored by the ECM for control of the EGR system and turbocharger wastegates.

The IMP sensor is installed on the air intake throttle duct after the ETV.

Fuel Rail Pressure (FRP) Sensor

Figure 50 FRP sensor

The FRP sensor is a variable capacitance sensor that monitors the fuel pressure in the high-pressure fuel rail. The sensor measures the fuel pressure just before injection.

The FRP sensor is mounted in the front of the fuel rail on the left side of the engine.

Intake Manifold Temperature (IMT) Sensor

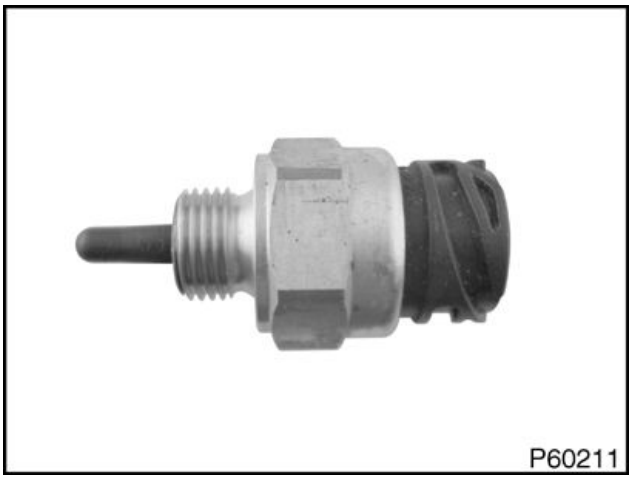


Figure 51 IMT sensor

The IMT sensor is a thermistor sensor that monitors the temperature of the mixture of recirculated exhaust gas and fresh intake air.

EGR system operation is shut down under certain temperature conditions, to prevent acids from condensing under cold charge-air temperatures and to protect the engine from excessively hot intake air in the event of an EGR fault.

The IMT sensor is installed in the intake channel of the cylinder head, on the left side of the engine.

Oxygen Sensor (O2S)

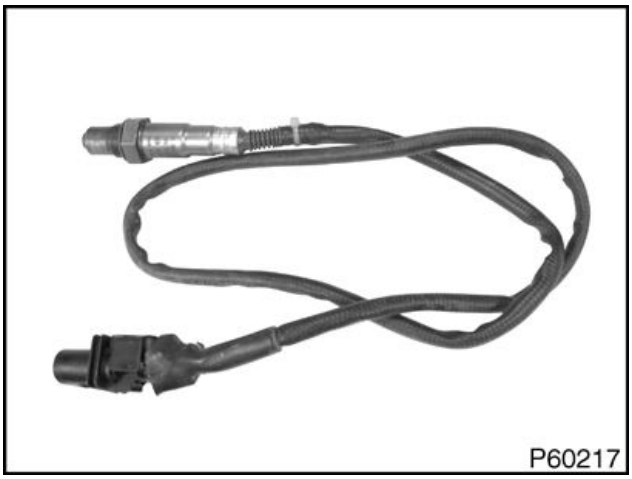


Figure 52 O2S

The O2S monitors oxygen levels in exhaust gases. It is used to tune engine operation by monitoring the level of unused oxygen in the exhaust stream.

The O2S compares oxygen levels in the exhaust stream with oxygen levels in the outside air. The sensor generates an analog voltage and is monitored by the ECM. The level of voltage generated by the O2S corresponds to the oxygen levels in the exhaust stream.

The O2S is installed in the exhaust back pressure valve housing.

NOTE: The Oxygen sensor should only be replaced after a coolant and/or oil loss into the exhaust system has been verified based on the Engine Symptoms Diagnostics in the Engine Diagnostic Manual.

Engine Throttle Valve (ETV)

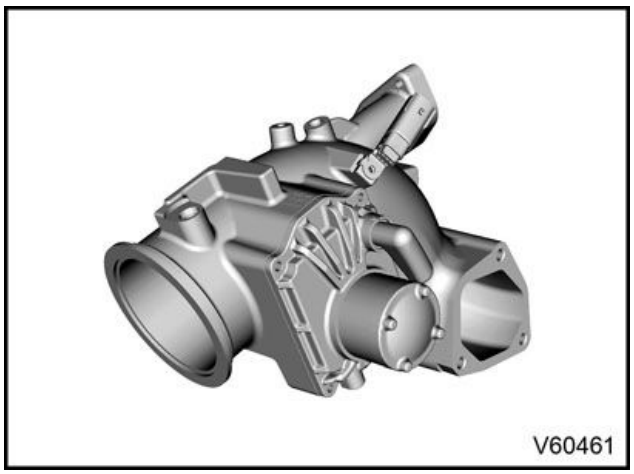


Figure 53 ETV

The ETV controls the flow of filtered air (boosted and cooled) into the engine's air intake through the Charge Air Cooler (CAC) to help heat the exhaust aftertreatment during regeneration, and to assist when heavy EGR is requested. The electronic portion of the ETV contains a microprocessor that monitors valve position, electronic chamber temperature, controls the electric motor and reports diagnostic faults to the ECM. The ETV changes position in response to ECM signals.

The ETV is integrated into the air intake throttle duct at the front top left side of the engine.

Coolant Control Valve (CCV)

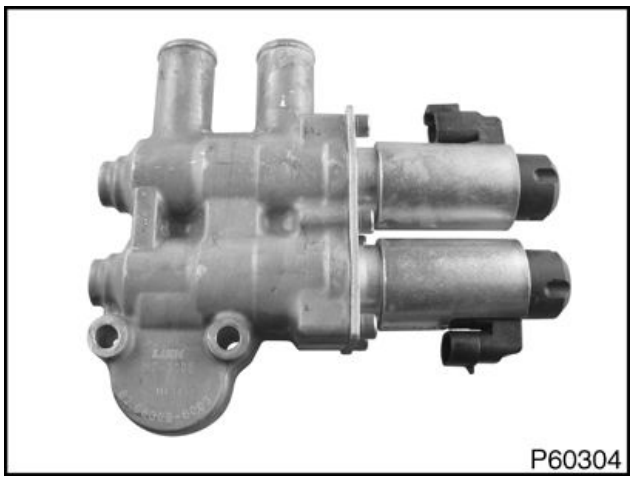


Figure 54 CCV

The Coolant Mixer Valve (CMV) and Coolant Flow Valve (CFV) are a combined solenoid assembly that regulates coolant flow and temperature through the Low-pressure Charge Air Cooler (LPCAC) and the low temperature EGR cooler. The CMV and CFV are housed in the CCV assembly.

The CFV controls the rate of coolant flow through the CAC and the CMV regulates the temperature of the coolant by directing the coolant either through the low temperature radiator or through an internal bypass. Both valves are controlled by the ECM.

The CCV is mounted on the right side of the water distribution housing.

Air Control Valve (ACV) Assembly

NOTE: Various air control valves have been used on this engine. Early production air control valves use two mounting bolts and later production valves use three mounting bolts. Late production valves may also utilize a remote electrical connector attached to a pigtail harness.

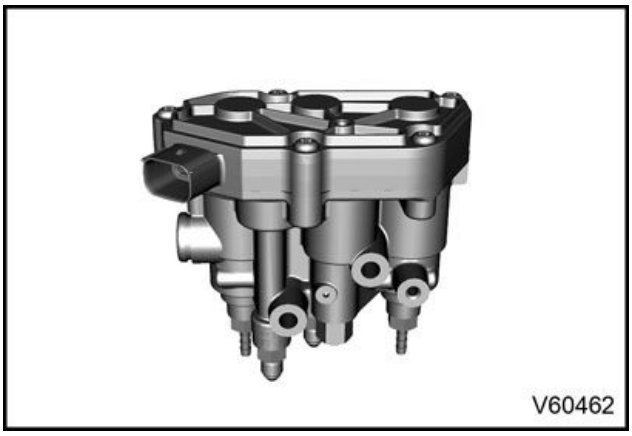


Figure 55 Early production ACV with two mounting bolts

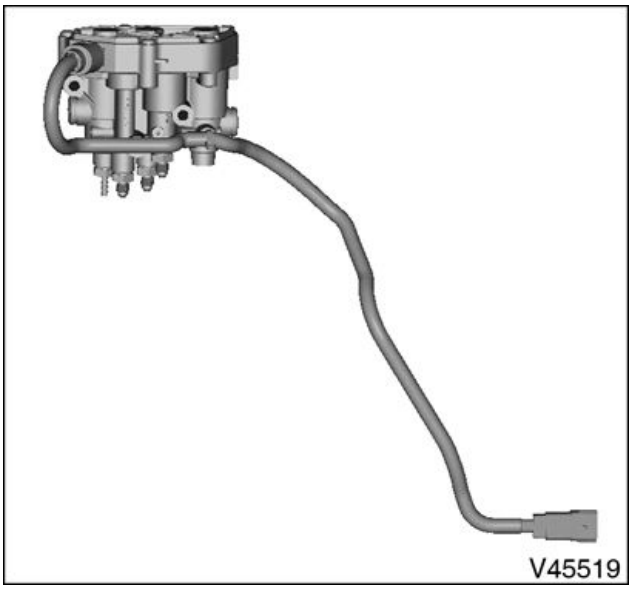


Figure 56 Late production ACV with pigtail

The ACV contains solenoids for the control of the high-pressure turbocharger wastegate and Exhaust Back Pressure Valve (EBPV). It also contains the Turbocharger 1 Turbine Outlet Pressure (TC1TOP) sensor. ACV solenoids are controlled through pulse-width modulated signals sent by the ECM.

The ACV assembly is installed on the right side of the engine, mounted near the center of the EGR cooler.

Exhaust Gas Recirculation (EGR) Valve

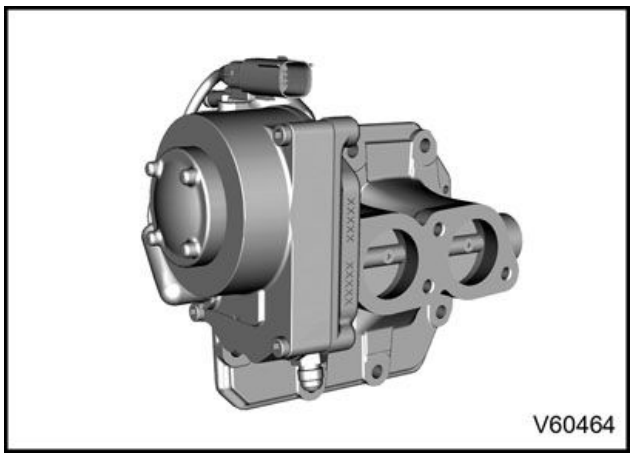


Figure 57 EGR valve

The EGR valve regulates the flow of exhaust gases through the EGR system. The desired valve position is controlled by commands from the ECM.

The EGR valve is mounted on the rear of the EGR cooler on top of the engine.

Exhaust Gas Recirculation Temperature (EGRT) Sensor

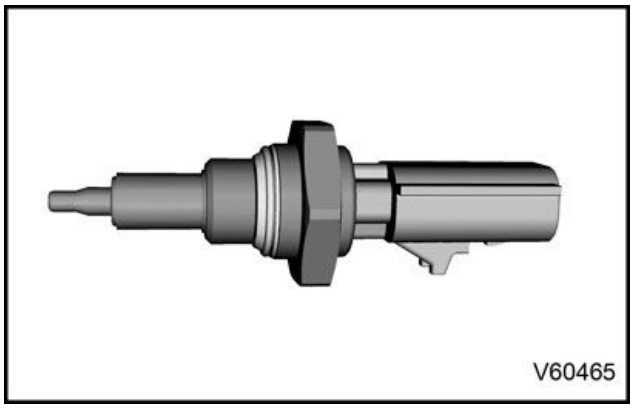


Figure 58 EGRT sensor

The EGRT sensor is a thermistor sensor that detects the exhaust gas temperature exiting the EGR cooler. The sensor signal is monitored by the ECM to control the Coolant Flow Valve (CFV) and Coolant Mixer Valve (CMV), and check for proper EGR cooling.

The EGRT sensor is installed in the front of the low-temperature EGR cooler on the left side.

Turbocharger 2 Compressor Inlet Sensor (TC2CIS)

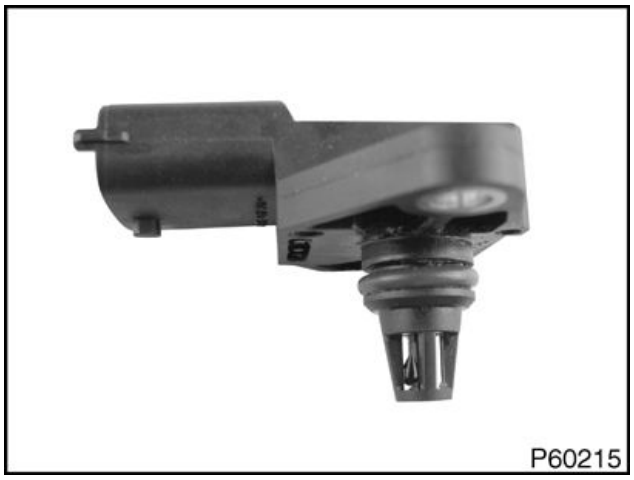


Figure 59 TC2CIS

The TC2CIS sensor includes a thermistor sensor that monitors the temperature of charge air entering the high-pressure turbocharger. This sensor also monitors boost pressure for the low-pressure turbocharger.

The TC2CIS sensor is monitored by the ECM, and is used to check for proper thermostat operation and charge air cooling.

The TC2CIS is installed in the piping between the low-pressure compressor outlet and the high-pressure compressor inlet.

Removal

Warnings and Cautions

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.

Disconnect ground cable (–) from the negative terminal of the battery.

Crankshaft Position (CKP) Sensor

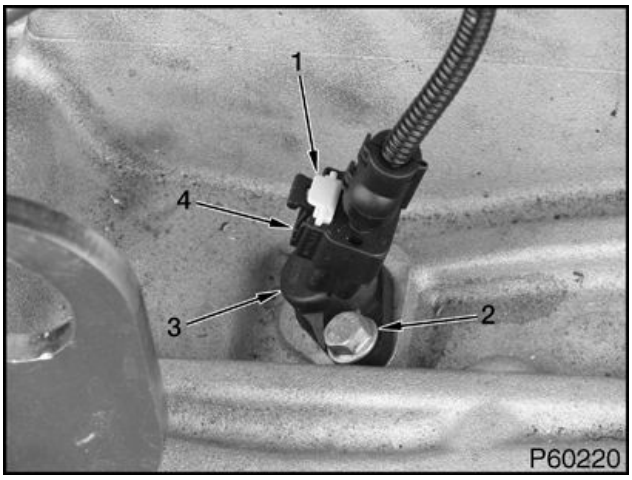


Figure 60 CKP sensor (typical)

1. Locking tab
2. M6 x 16 bolt
3. CKP sensor
4. CKP harness connector

1. Pull out yellow locking tab on CKP sensor harness connector.
2. Press release lever and disconnect harness connector from CKP sensor installed in top left of flywheel housing.
3. Remove M6 x 16 bolt from CKP sensor.
4. Remove CKP sensor and discard O-ring.

Camshaft Position (CMP) Sensor

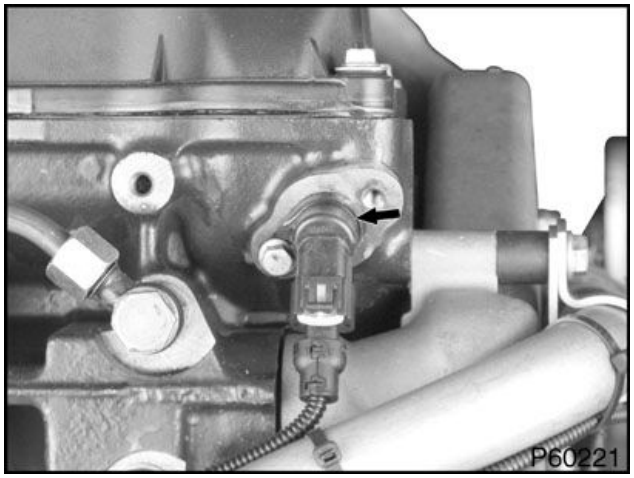


Figure 61 CMP sensor (typical)

1. Pull out yellow locking tab on CMP sensor harness connector.
2. Press release lever and disconnect harness connector from CMP sensor installed in rear left of cylinder head.
3. Remove M6 x 12 bolt from CMP sensor.
4. Remove CMP sensor and discard O-ring.

Engine Coolant Temperature 1 (ECT1) Sensor

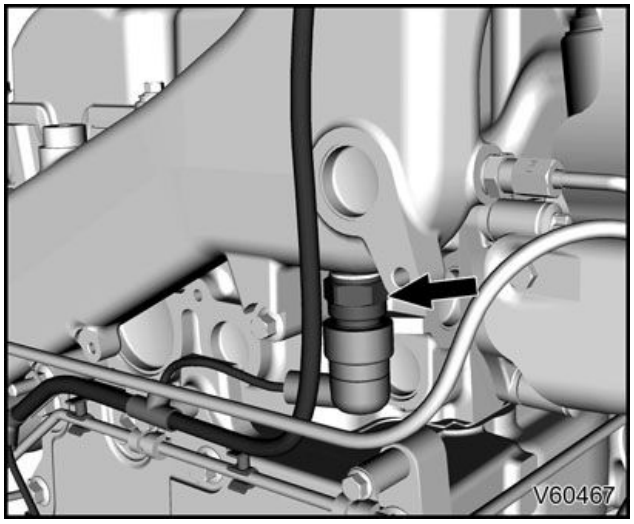


Figure 62 ECT1 sensor

1. Turn ECT1 sensor harness connector locking ring 90° counterclockwise.
2. Disconnect harness connector from ECT1 sensor installed in underside of Exhaust Gas Recirculation (EGR) coolant manifold at rear of engine.
3. Remove ECT1 sensor and discard seal ring.

Engine Coolant Temperature 2 (ECT2) Sensor

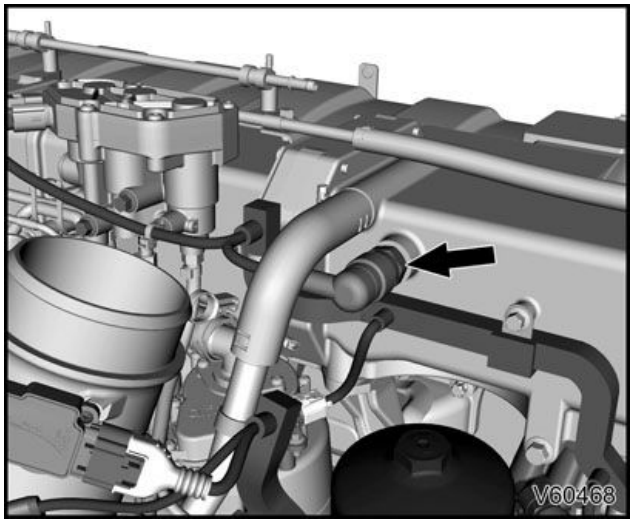


Figure 63 ECT2 sensor connector

1. Turn ECT2 sensor harness connector locking ring 90°counterclockwise.
2. Disconnect harness connector from ECT2 sensor installed in EGR module low-temperature housing on upper right side of engine.
3. Remove ECT2 sensor and discard seal ring.

Engine Oil Temperature (EOT) Sensor

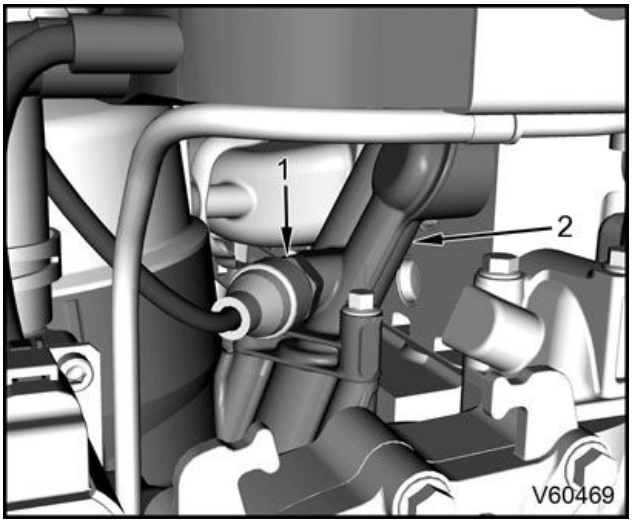


Figure 64 EOT sensor

1. EOT sensor
2. Oil module flange

1. Turn EOT harness connector locking ring 90° counterclockwise.
2. Disconnect harness connector from EOT sensor and remove sensor from oil module flange. Discard seal ring.

Engine Oil Pressure (EOP) Sensor

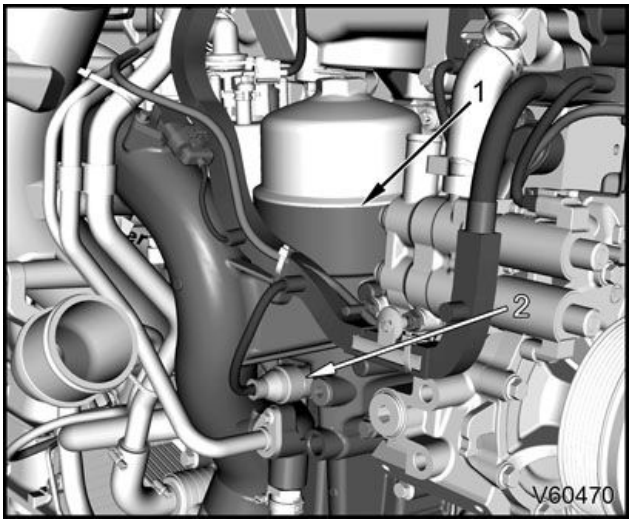


Figure 65 EOP sensor

1. Oil module assembly
2. EOP sensor

1. Turn EOP harness connector locking ring 90° counterclockwise.
2. Disconnect harness connector from EOP sensor and remove sensor from oil module assembly. Discard seal ring.

Crankcase Oil Separator Speed (CCOSS) Sensor

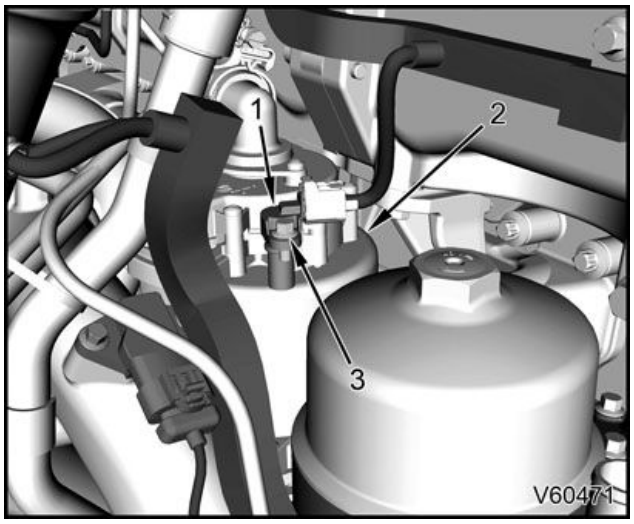


Figure 66 CCOSS sensor

1. CCOSS sensor
2. Oil centrifuge (part of oil module assembly)
3. M6 x 14 bolt and nut

1. Press release tab to disconnect wiring harness connector from CCOSS sensor.
2. Remove M6 x 14 bolt and nut and remove sensor from bracket on oil centrifuge.

Fuel Delivery Pressure (FDP) Sensor

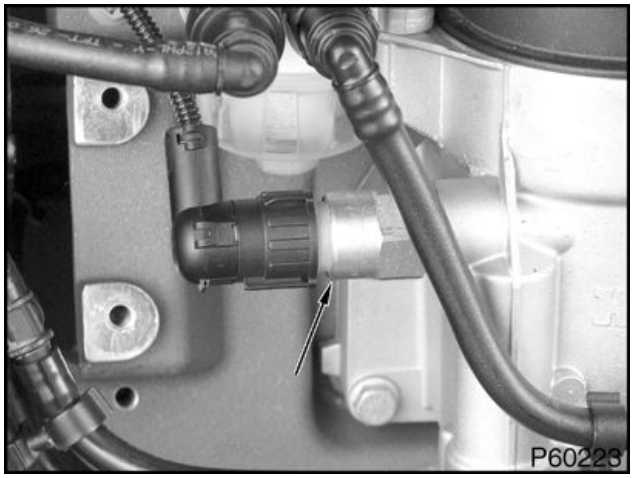


Figure 67 FDP sensor

1. Turn FDP sensor harness connector locking ring 90° counterclockwise.
2. Disconnect harness connector from FDP sensor installed in fuel filter assembly.
3. Remove FDP sensor and discard seal ring.

Fuel Pressure Control Valve (FPCV)

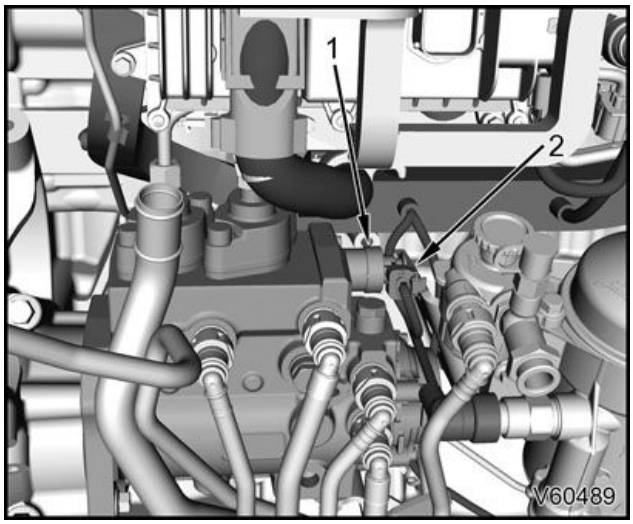


Figure 68 FPCV (on high-pressure fuel pump)

1. FPCV
2. Harness connector

1. Pull out yellow locking tab on FPCV harness connector.
2. Press release tab and disconnect harness connector from FPCV mounted at upper rear of high-pressure fuel pump.
3. See High-pressure Fuel Pump (HPFP) and Drive Housing (page 213) for removal of high-pressure pump with integral FPCV if the FPCV requires replacement.

Mass Air Flow (MAF) Sensor (If equipped)

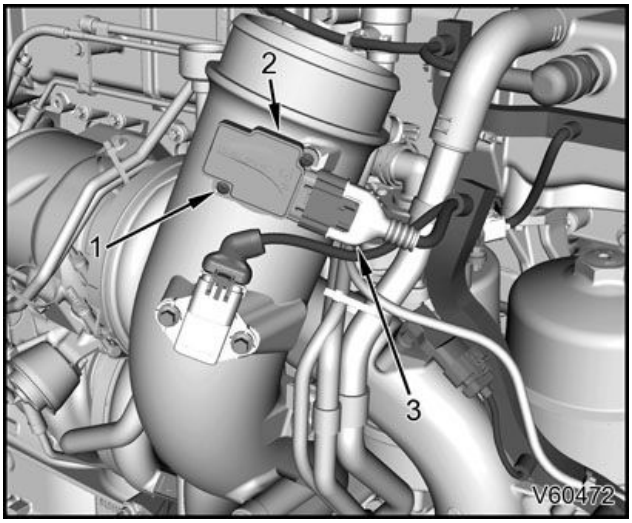


Figure 69 MAF sensor

1. M4 x 0.7 cap screw (2)
2. MAF sensor
3. Harness connector

1. Pull out yellow tab to release wiring harness connector from MAF sensor.
2. Remove two M4 x 0.7 cap screws and remove sensor from air inlet duct.
3. Discard O-ring.

Humidity / Intake Air Temperature (IAT) Sensor

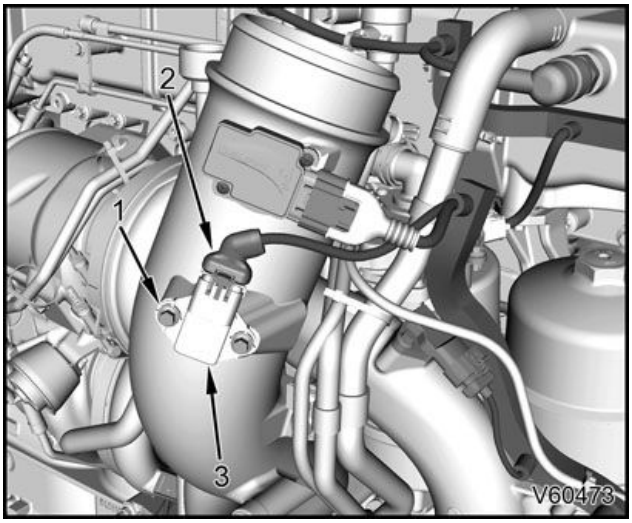


Figure 70 IAT

1. M6 x 16 bolt (2)
2. Harness connector
3. IAT

1. Pull out yellow locking tab on IAT harness connector.
2. Press release tab to disconnect harness connector from IAT sensor.
3. Remove two M6 x 16 bolts and remove sensor from air inlet duct. Discard O-ring.

Charger Air Cooler Outlet Temperature (CACOT) Sensor

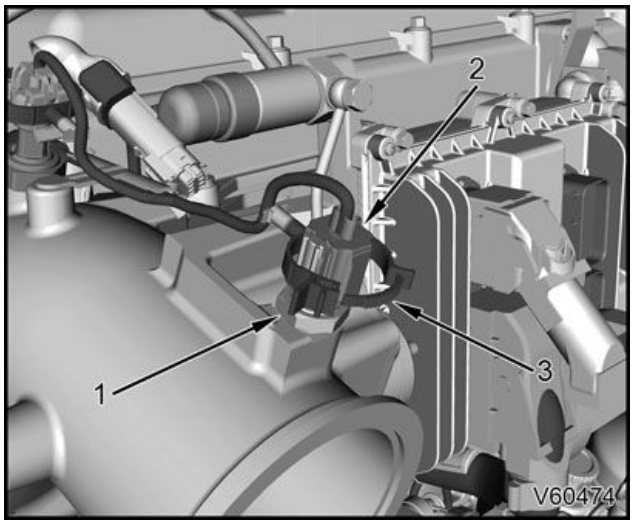


Figure 71 CACOT sensor

1. CACOT sensor
2. Harness connector
3. Standoff tie strap

1. Press release tab to loosen tie strap and remove standoff bracket securing connector harness lead to CACOT sensor.
2. Press release tab to disconnect harness from CACOT sensor.
3. Remove CACOT sensor from throttle valve housing. Discard O-ring.

Intake Manifold Pressure (IMP) Sensor

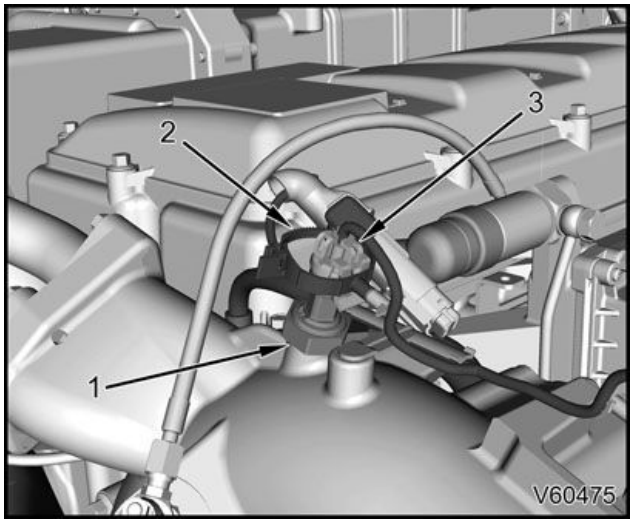


Figure 72 IMP sensor

1. IMP sensor
2. Standoff tie strap
3. Harness connector

1. Press release tab to loosen tie strap and remove standoff bracket securing harness connector lead to IMP sensor.
2. Press release tab to disconnect harness from IMP sensor.
3. Remove IMP sensor from Engine Throttle Valve (ETV) housing. Discard O-ring.

Fuel Rail Pressure (FRP) Sensor

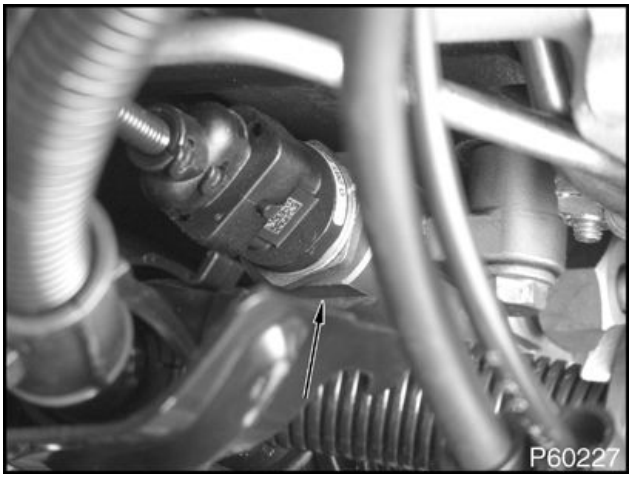


Figure 73 FRP sensor (typical)

1. Pull out yellow locking tab on FRP sensor harness connector.
2. Press release lever and disconnect harness connector from FRP sensor installed in front of fuel rail on left side of engine.
3. Remove FRP sensor from fuel rail.
4. Install plastic protective cap from Disposable Air and Fuel Caps (page 244), to prevent dirt from entering fuel system

Intake Manifold Temperature (IMT) Sensor

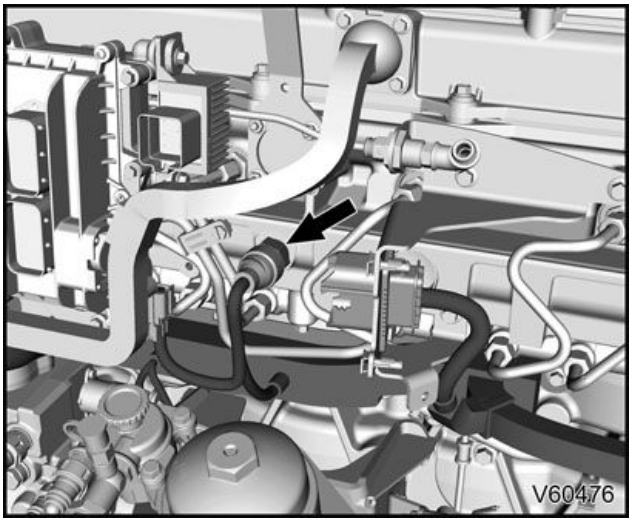


Figure 74 IMT sensor

1. Turn IMT sensor harness connector locking ring 90° counterclockwise.
2. Disconnect harness connector from IMT sensor.
3. Remove IMT sensor from cylinder head and discard seal ring.

Oxygen Sensor (O2S)

NOTE: The Oxygen sensor should only be replaced after a coolant and/or oil loss into the exhaust system has been verified based on the Engine Symptoms Diagnostics in the Engine Diagnostic Manual.

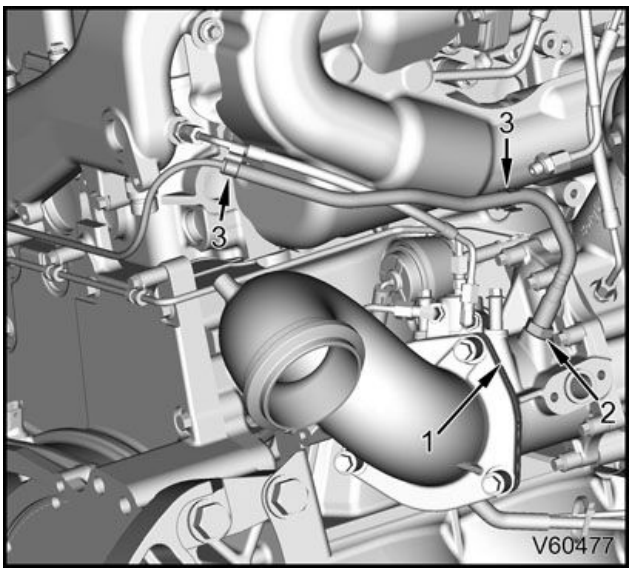


Figure 75 O2S (valve actuator removed for clarity)

1. Exhaust back pressure valve housing
2. O2S (with harness lead)
3. Clip (2)

1. Press release lever and disconnect O2S harness lead from engine electrical harness at left rear of engine.
2. Disconnect clips securing O2S harness lead at right rear of engine to coolant tube and to valve actuator bracket.
3. Only if required, remove O2S from exhaust back pressure valve housing.

Engine Throttle Valve (ETV)

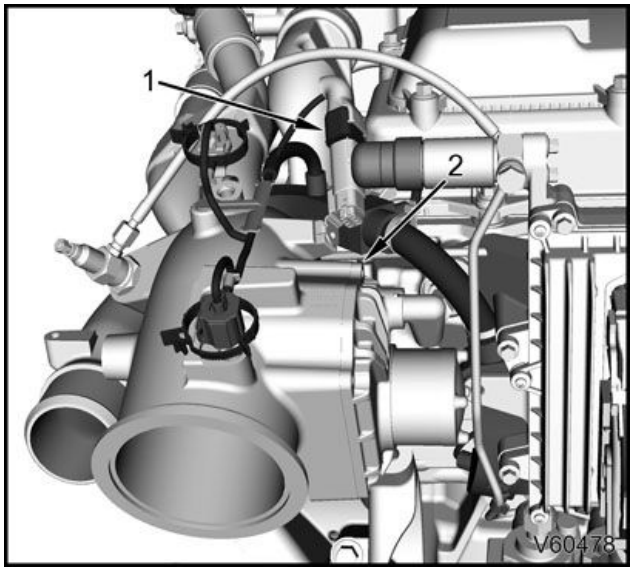


Figure 76 ETV

1. ETV harness connector
2. ETV

1. Press release tab and disconnect harness connector from ETV, located on top left front of engine.
2. See Glow Plug and Fuel Supply Cold Start Hose (page 111) for removal procedure of the fuel supply cold start hose.
3. See Air Intake Throttle Duct (page 303) for removal procedure of duct.

Coolant Control Valve (CCV)

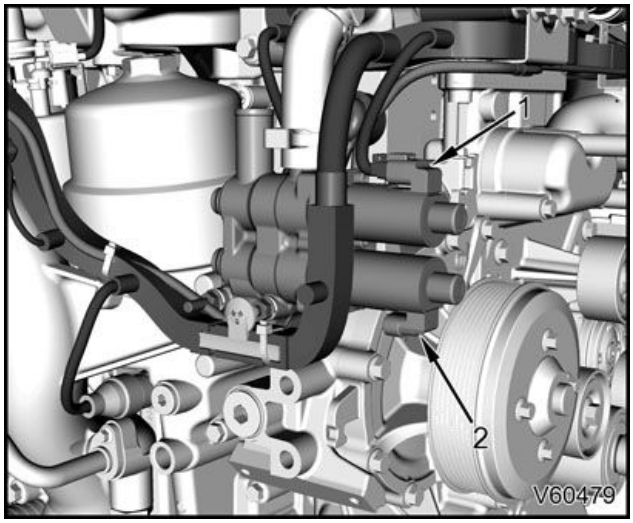


Figure 77 CCV

1. Coolant Mixer Valve (CMV) terminal
2. Coolant Flow Valve (CFV) terminal

NOTE: The coolant mixer and coolant flow valves are not serviced separately. Both valves are an integral part of the CCV assembly which is available as a unit.

1. Press release tab and disconnect harness connector from CMV, installed in the CCV assembly on the right side of the water distribution housing.
2. Lift release tab and disconnect harness connector from CFV, also in the CCV assembly.
3. See Coolant Control Valve (CCV) Assembly (page 326) for removal procedure.

Air Control Valve (ACV)

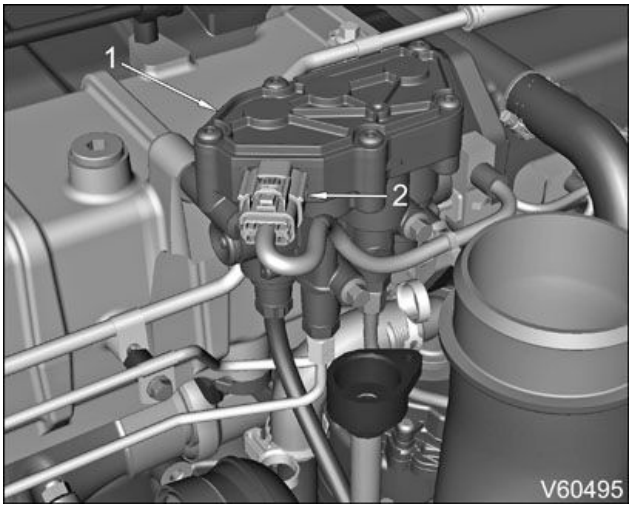


Figure 78 ACV

1. ACV assembly
2. Harness connector

1. Press release tab and disconnect harness connector from ACV mounted on EGR cooler assembly high-temperature housing at top right of engine.
2. Remove ACV. See Air Control Valve (ACV) (page 143).

Exhaust Gas Recirculation (EGR) Valve

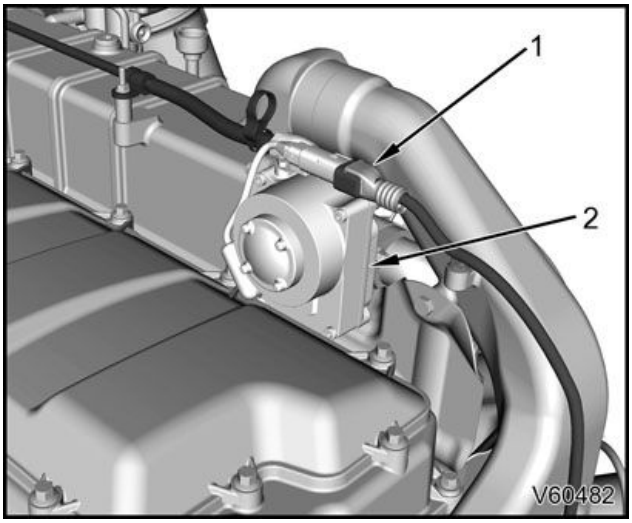


Figure 79 EGR valve harness connector

1. Harness connector
2. EGR valve

1. Press release tab to disconnect wiring harness lead from EGR valve connector.
2. Remove dual flap EGR valve. See EGR Dual Flap Valve (page 272).

Exhaust Gas Recirculation Temperature (EGRT) Sensor

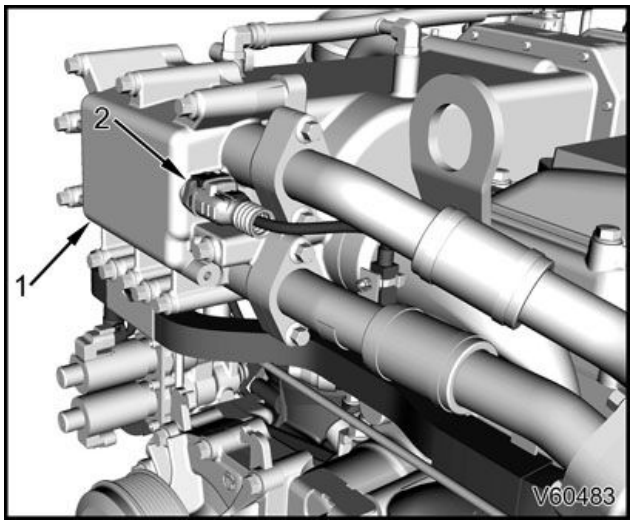


Figure 80 EGRT sensor harness connector

1. EGR module cover
2. EGRT sensor

1. Pull out red locking tab on EGRT sensor connector.
2. Press release tab to disconnect harness connector from EGRT sensor.

NOTE: The EGRT has a non-serviceable crush washer for sealing. If sensor is removed, the complete sensor must be replaced.

3. Only if required, remove EGRT sensor from EGR module cover and discard.

Turbocharger 2 Compressor Inlet Sensor (TC2CIS)

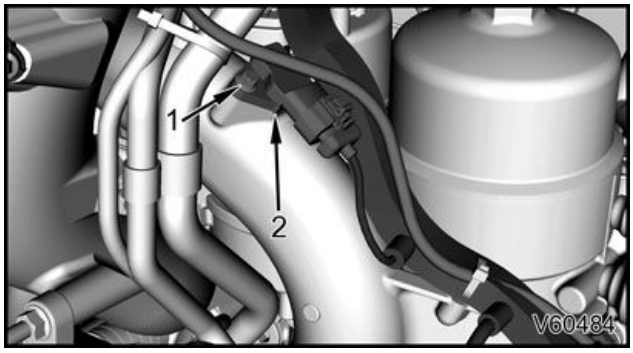


Figure 81 TC2CIS

1. M6 x 16 bolt (2)
2. TC2CIS

1. Pull out yellow lock tab on TC2CIS harness connector.
2. Press release tab and disconnect harness lead from TC2CIS.
3. Remove two M6 x 16 bolts and sensor from high-pressure turbocharger air supply duct. Discard O-ring seal.

Wiring Harness ECM Connections

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. If not done, disconnect ground (–) cable from the negative terminal of the battery.
2. Note location of wire ties for reinstallation. Cut wire ties securing engine injector, engine sensor and chassis harness connector lock levers at ECM.

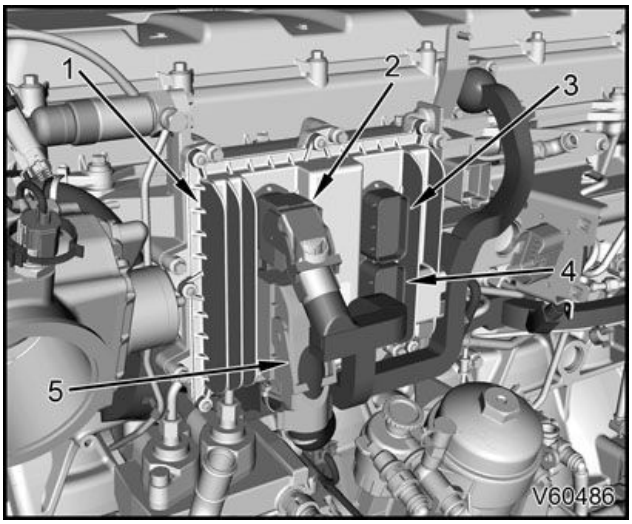


Figure 82 ECM harness connectors

1. ECM
2. Engine injector harness connector (to ECM 16-pin E2 terminal)
3. ECM 58-pin C2 chassis terminal
4. ECM 58-pin C1 chassis terminal
5. Engine sensor harness connector (to ECM 96-pin E1 terminal)

3. If not already done, disconnect chassis wiring harness connectors from ECM 58-pin C1 and C2 terminals.
4. Remove connector clip and lift lock lever to release engine injector harness connector. Pull straight out to remove connector from ECM terminal E2.
5. Lift lock lever to release engine sensor harness connector. Pull straight out to remove connector from ECM terminal E1.

Engine Injector (Wiring) Harness

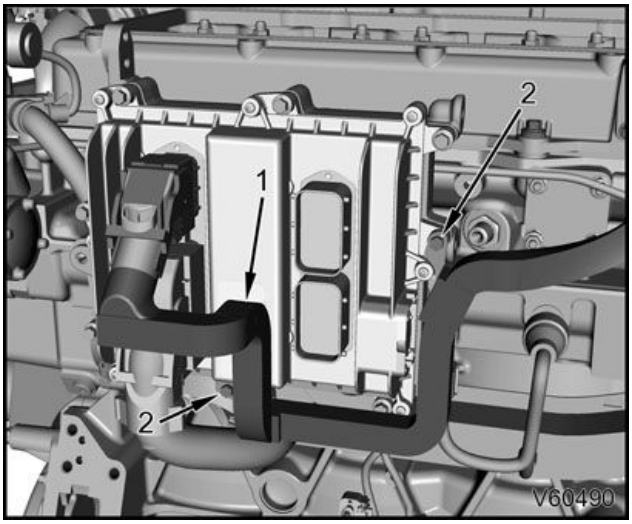


Figure 83 Injector harness attachment points at ECM

1. Injector harness
2. M6 x 30 bolt (2)

1. Remove two M6 x 30 bolts and remove injector harness retainer clips from ECM.
2. Remove upper valve cover from valve cover base. See Upper Valve Cover and Base(page 367) .

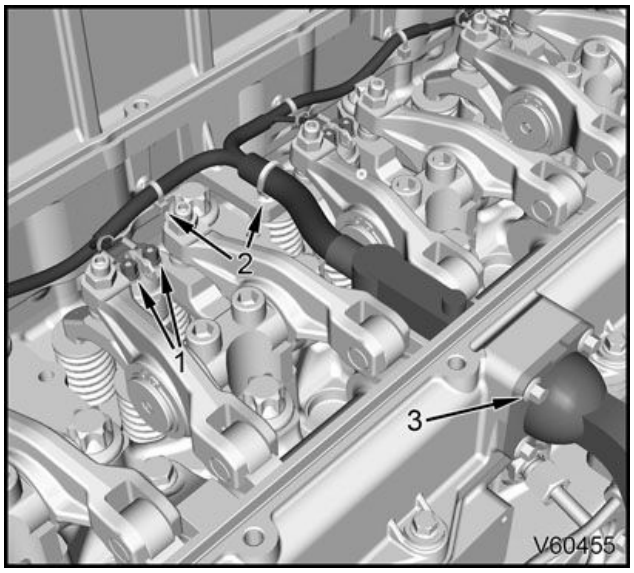


Figure 84 Injector harness attachment points at cylinder head

1. Injector harness nut (12)
2. Tie strap (7)
3. M6 x 16 bolt (4)

3. Loosen 12 harness nuts (two at each injector) and disconnect harness leads from injector terminals.
4. Cut tie straps at six locations securing injector harness to valve cover base.
5. Cut tie strap securing harness at center of cylinder head.
6. Remove four M6 x 16 bolts from injector harness mounting flange.
7. Carefully pull harness through valve cover base opening and remove harness from engine.

Engine Sensor (Wiring) Harness

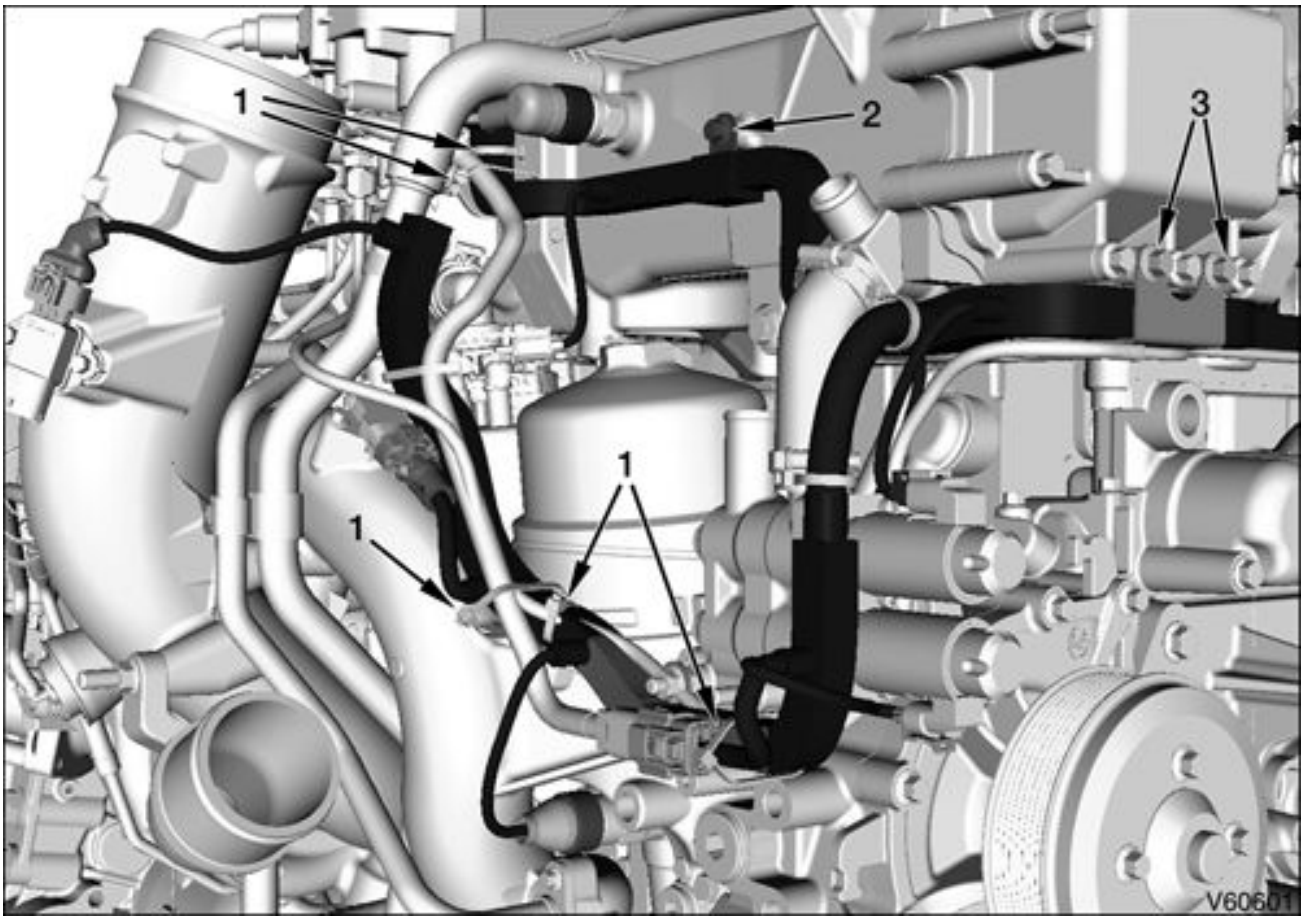


Figure 85 Sensor harness attachment points at right front

1. Tie strap (5)
2. M8 x 12 bolt
3. M8 x 16 bolt (2)

1. Disconnect harness connectors at IAT, MAF (if equipped), TC2CIS, EOP, ACV, ECT2, CCOSS, CCV and EOT terminals.
2. Starting on right side at front, cut tie straps securing sensor harness at ACV, CCV and to air supply tube.
3. Remove M8 x 12 bolt attaching harness clip to EGR cooler low-temperature housing.
4. Remove two M8 x 16 bolts attaching harness clip to EGR module cover.
5. At left front, disconnect harness connectors at EGRT, CACOT, IMP, FRP, FDP and EOL sensors.

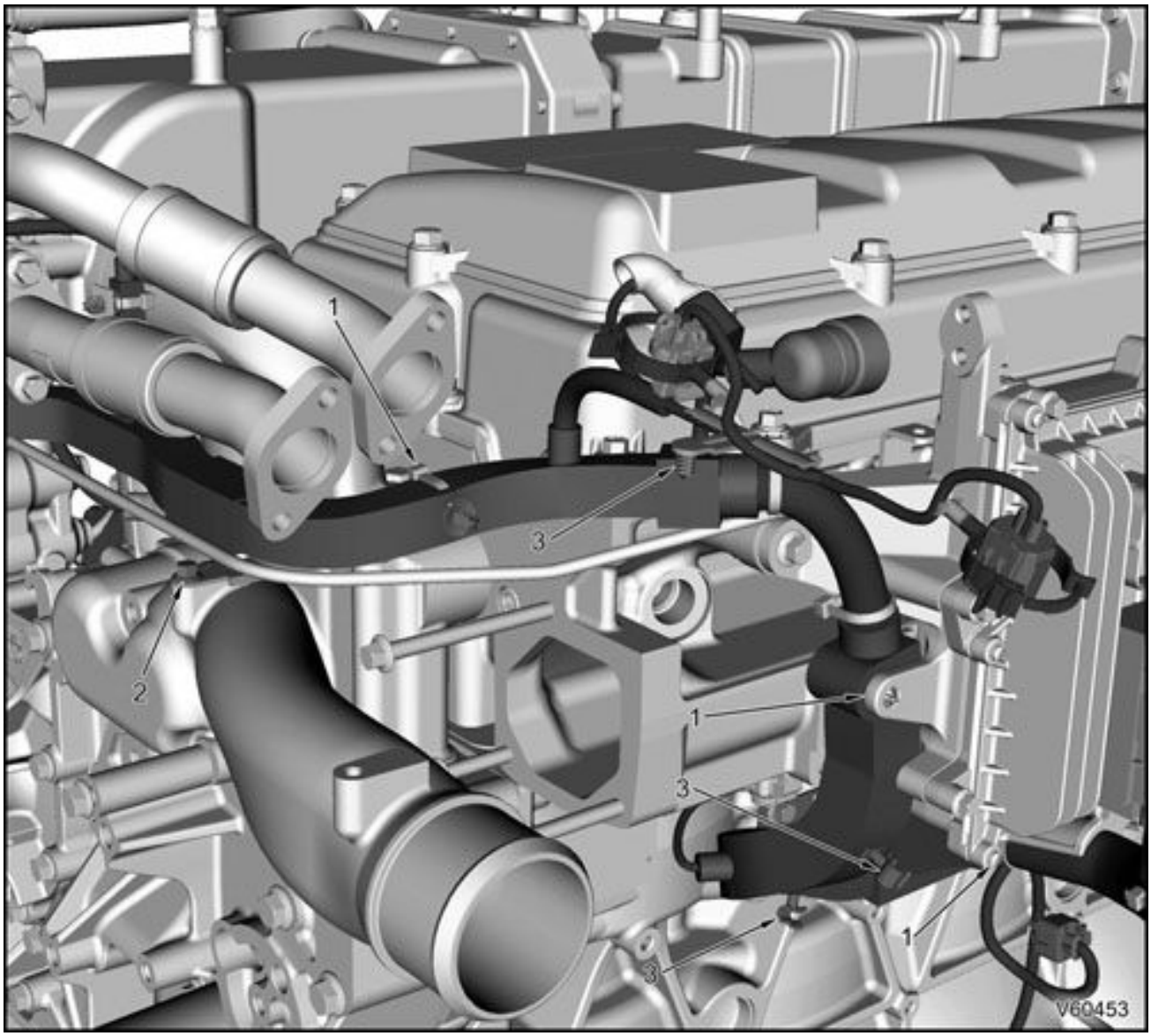


Figure 86 Sensor harness attachment points at left front (air intake throttle duct removed for clarity)

1. Tie strap (3)
2. M6 x 16 bolt
3. Other attachments

6. Cut tie straps securing sensor harness to back of air intake throttle duct and at back and bottom of ECM support.
7. Remove M6 x 16 bolt attaching harness clip to coolant outlet manifold.
8. Remove other attachments as necessary.
9. At left rear, disconnect harness connectors at CMP, CKP, ECT1 sensors and EGR valve.

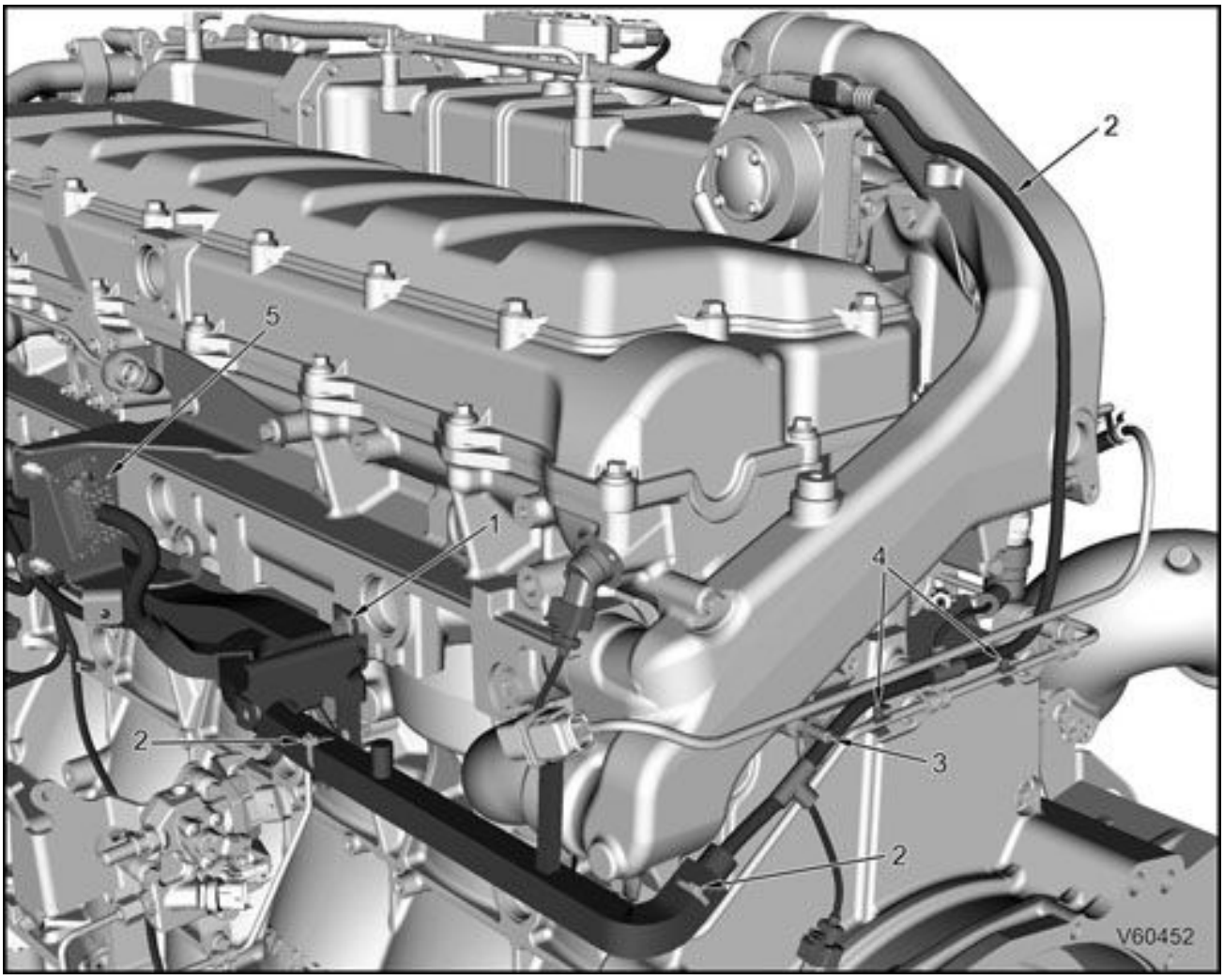


Figure 87 Sensor harness attachment points at left rear

1. M8 x 16 bolt (2)
2. Tie strap (3)
3. M8 stud
4. Harness clips
5. 21-way connector

10. At left side and rear of engine, cut tie straps securing sensor harness to harness support and coolant manifold.
11. Disconnect harness from M8 stud at coolant manifold.
12. At left center of engine, remove two M8 x 16 bolts attaching harness bracket to crankcase.
13. Remove sensor harness from engine using care to avoid damage to harness as it is removed from around components.
14. Remove 21-way connector from harness bracket.

Engine Control Module (ECM) and Support

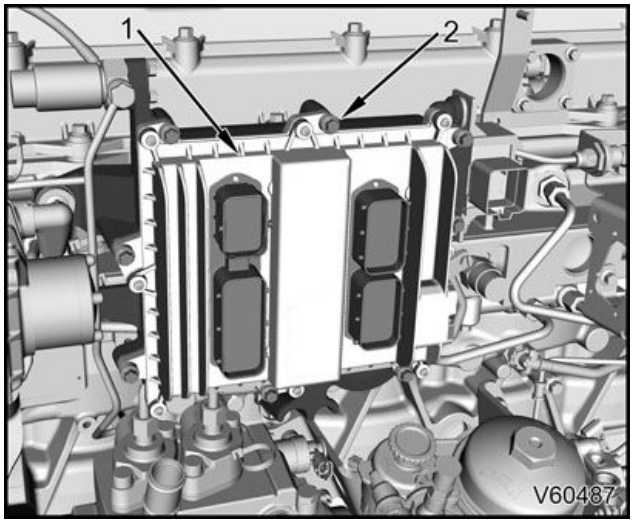


Figure 88 ECM mounting bolts

1. ECM
2. M6 x 30 bolt (8)

1. Remove eight M6 x 30 bolts and remove ECM from support.

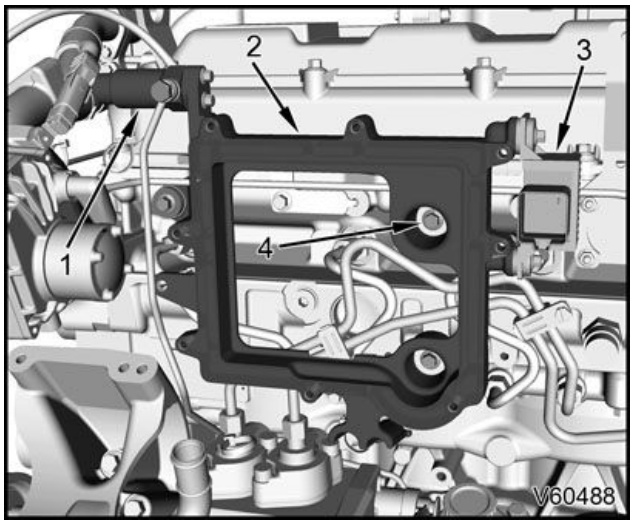


Figure 89 ECM support

1. Cold Start Solenoid (CSS)
2. ECM support
3. Cold Start Relay (CSR)
4. M8 x 40 bolt (3) with EDC bracket insulators (6)

2. Remove CSR from ECM support. See Relay Assembly (page 110).
3. Remove CSS from ECM support. See Fuel Supply Solenoid Hose (page 111).
4. Remove three M8 x 40 bolts, six EDC bracket insulators (three on each side of support) and ECM support from cylinder head.

Cleaning and Inspection

Engine Injection and Engine Sensor Wiring Harnesses

1. Carefully inspect engine injection wiring harnesses for worn conduit, frayed insulation or heat damage to wires. Repair or replace if necessary.
2. Inspect injector terminal ends and ECM terminal connector for cracked connector body, bent or loose pins, chafing and damaged or missing terminal nuts. Replace connector or terminal ends if necessary.
3. Inspect each connector for the following conditions and replace, if necessary:
   - Corroded connectors and green, gray or white deposits on metal terminals.
   - Terminals incorrectly latched in connector body or pushed back relative to other terminals in same connector.
   - Make sure that each connector has its seals in place. During disassembly, a seal may pull off its connector and remain in mating socket of a sensor or actuator. A connector assembled without the correct seals can be contaminated with moisture and have corroded terminals, causing a poor electrical connection.
4. Carefully inspect main engine sensors wiring harness for worn conduit, frayed insulation or heat damage to wires. Repair or replace if necessary.
5. Inspect sensor, actuator and valve connectors for cracked connector bodies, bent or loose pins, chafing and damaged or missing O-rings. Replace connectors if necessary.
6. 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 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.

Sensors and Valves

1. Check all connector pins on sensors and valves. If bent or corroded, replace damaged component.
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 (ECM)

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

Installation

Engine Control Module (ECM) and Support

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

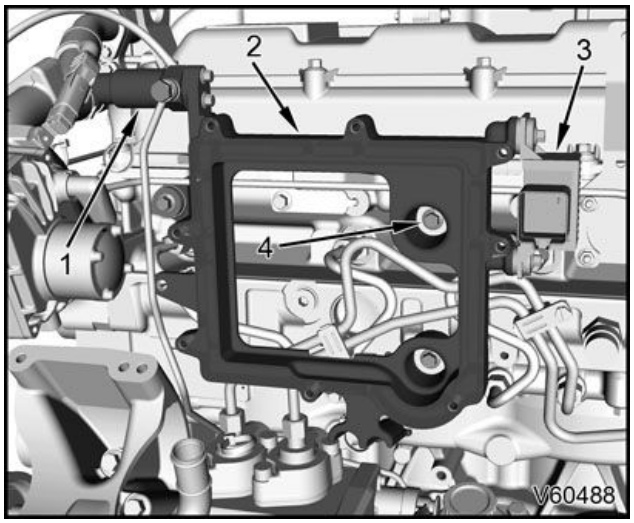


Figure 90 ECM support

1. Cold Start Solenoid (CSS)
2. ECM support
3. Cold Start Relay (CSR)
4. M8 x 40 bolt (3) with EDC bracket insulator (6)

1. Place ECM support in position on engine and install six EDC bracket insulators and three M8 x 40 bolts. Tighten bolts to special torque (page 106).
2. Install CSS on ECM support. See Fuel Supply Solenoid Hose (page 114).
3. Install CSR on ECM support. See Relay Assembly (page 116).

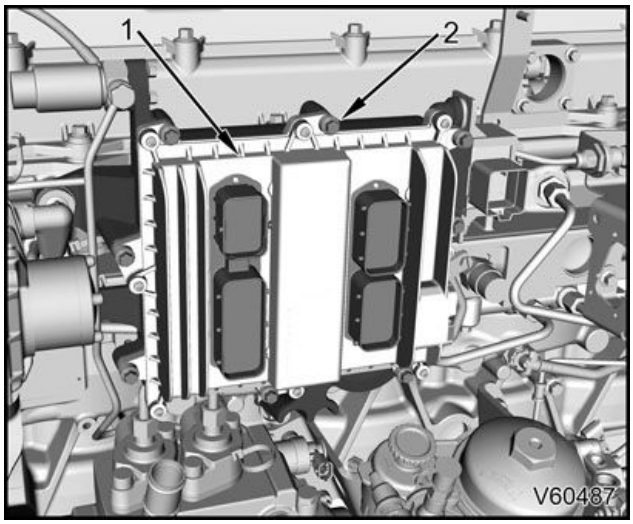


Figure 91 ECM mounting bolts

1. ECM
2. M6 x 30 bolt (8)

4. Place ECM in position on support and install eight M6 x 30 bolts hand tight.

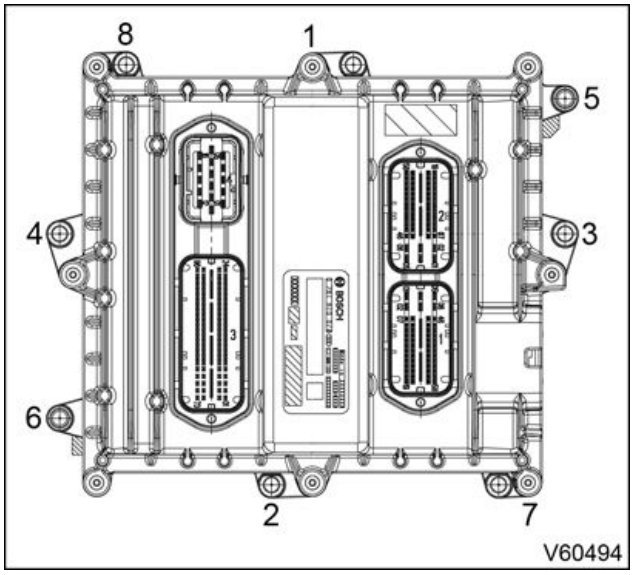


Figure 92 ECM bolt tightening sequence

5. Tighten M6 x 30 bolts in sequence shown to special torque (page 106).

Engine Sensor (Wiring) Harness

1. Place sensor harness in position on engine using care to properly route it around and between components.

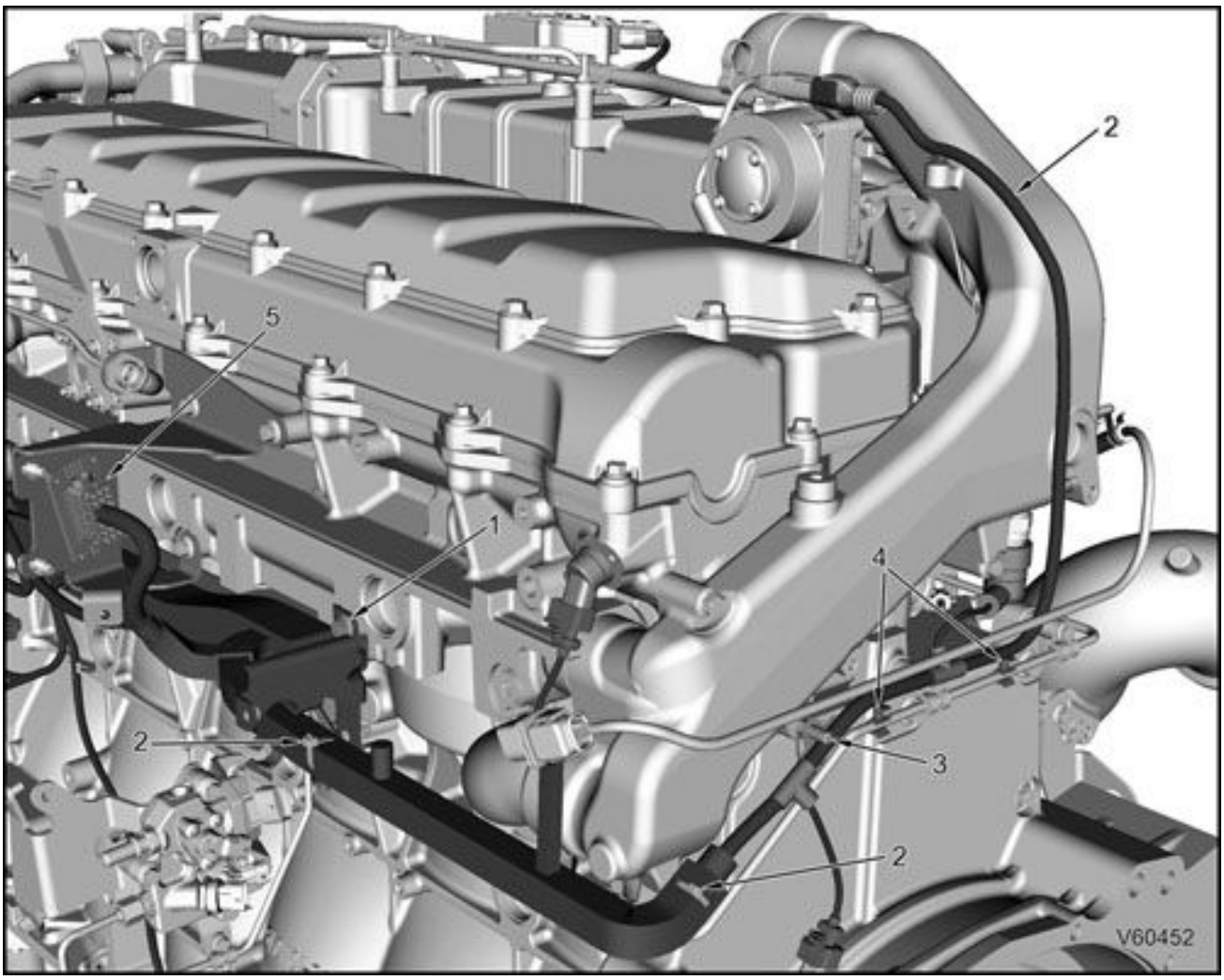


Figure 93 Sensor harness attachment points at left rear

1. M8 x 16 bolt (2)
2. Tie strap (3)
3. M8 stud
4. Harness clips
5. 21-way connector

2. Install two M8 x 16 bolts to attach harness bracket to crankcase. Tighten bolts to special torque (page 106).
3. Attach harness clip to M8 stud at coolant manifold.
4. Install three tie straps to secure sensor harness to harness support and coolant manifold.
5. Attach 21-way connector to harness bracket.
6. At left rear, connect harness connectors at CMP, CKP, ECT1 sensors and EGR valve.

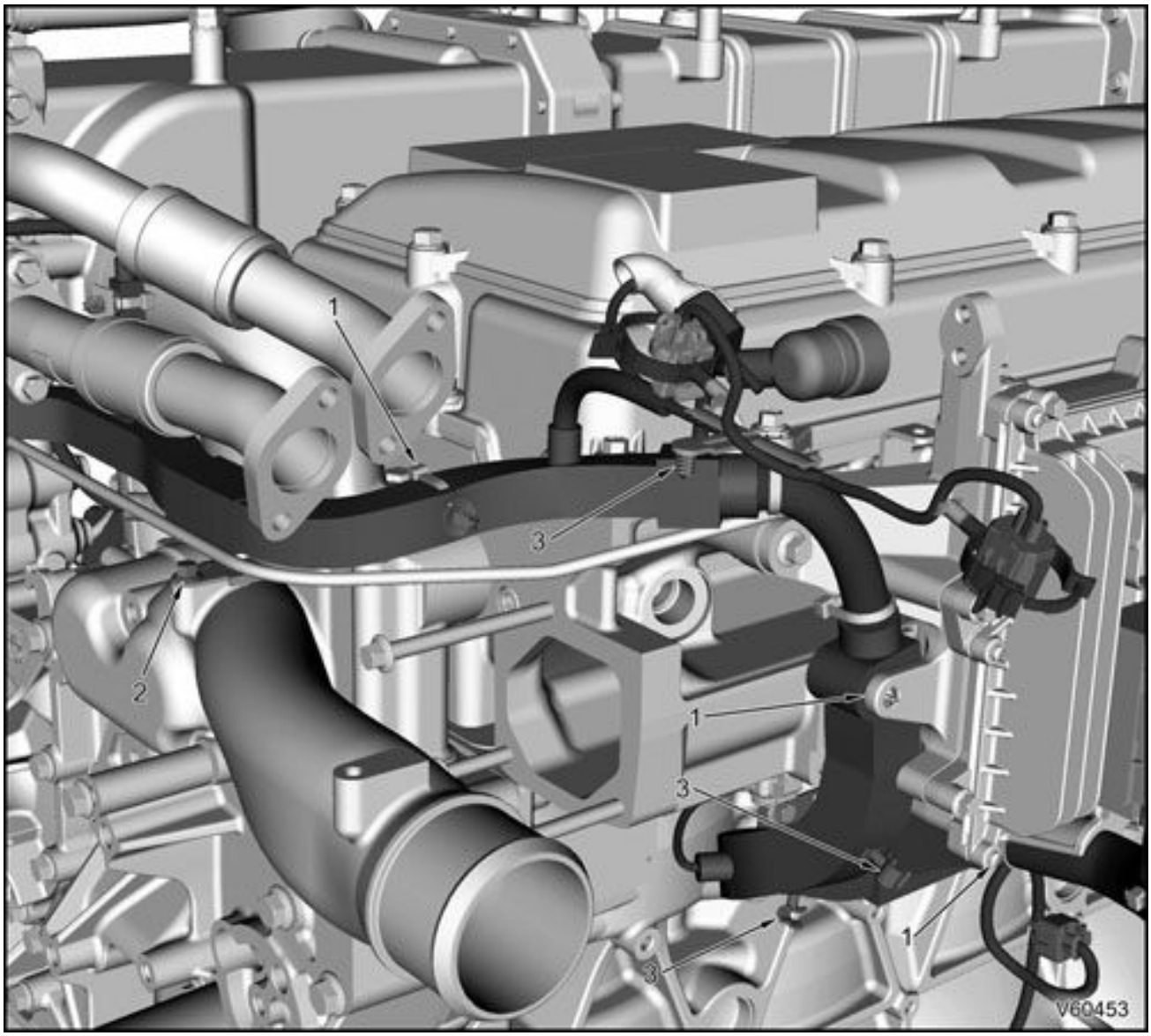


Figure 94 Sensor harness attachment points at left front (air intake throttle duct removed for clarity)

1. Tie strap (3)
2. M6 x 16 bolt
3. Other attachments

7. Install M6 x 16 bolt to attach harness clip to coolant outlet manifold. Tighten bolt to standard torque (page 503).
8. Install three tie straps to secure sensor harness to back of air intake throttle duct and back and bottom of ECM support.
9. Install other attachments as necessary.
10. Connect harness connectors at EGRT, CACOT, IMP, FRP, FDP and EOL sensors.

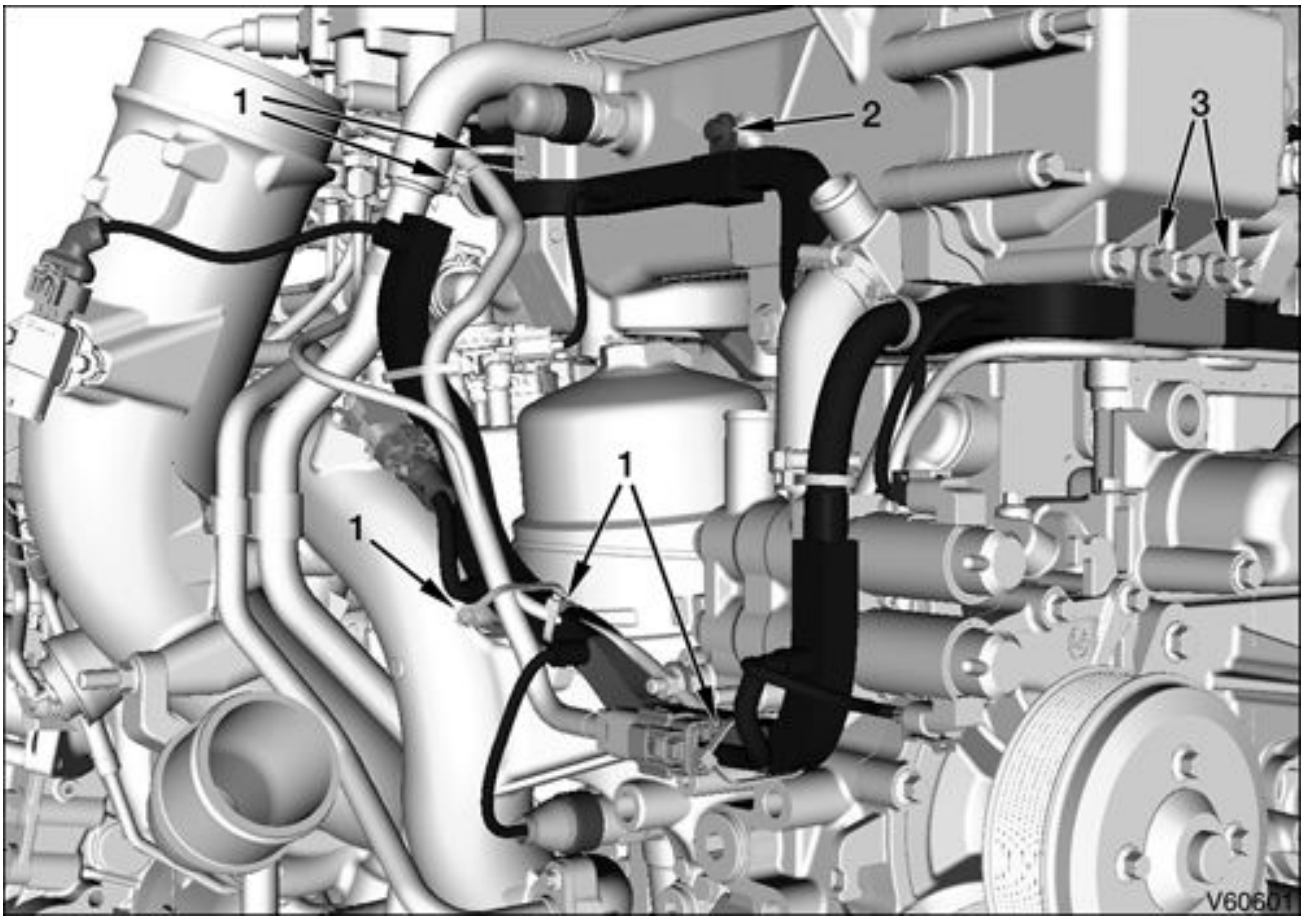


Figure 95 Sensor harness attachment points at right front

1. Tie strap (5)
2. M8 x 12 bolt
3. M8 x 16 bolt (2)

11. Install two M8 x 16 bolts to attach harness clip to EGR module cover. Tighten bolts to special torque (page 106).
12. Install M8 x 12 bolt to attach harness clip to EGR cooler low-temperature housing. Tighten bolt to standard torque (page 503).
13. Install tie straps to secure sensor harness at ACV, EGR cooler, CCV and to air supply tube.
14. Connect harness connectors at IAT, MAF (if equipped), TC2CIS, EOP, ACV, ECT2, CCOSS, CCV and EOT terminals.

Engine Injector (Wiring) Harness

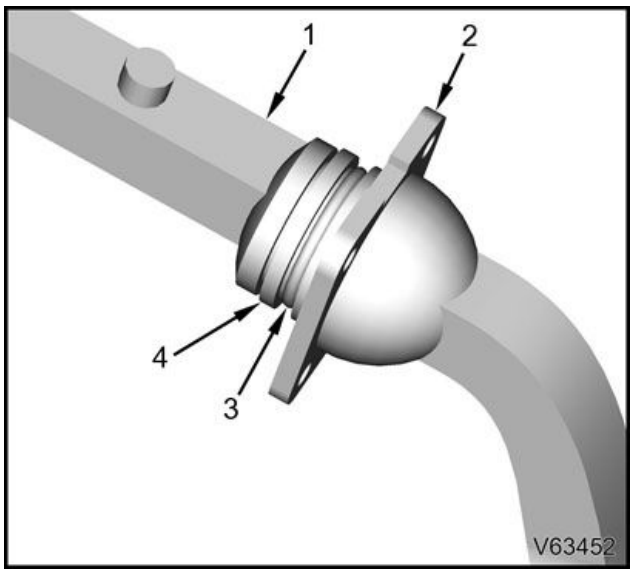


Figure 96 Engine injector (wiring) harness O-ring location

1. Engine injector (wiring) harness
2. Harness mounting flange
3. 32.92 x 3.53 O-ring
4. Harness flange collar

1. Check that 32.92 x 3.53 O-ring is in position on collar of harness mounting flange and in good condition. Replace as necessary.
2. Carefully route injector harness through valve cover base opening and along valve cover base to injectors.

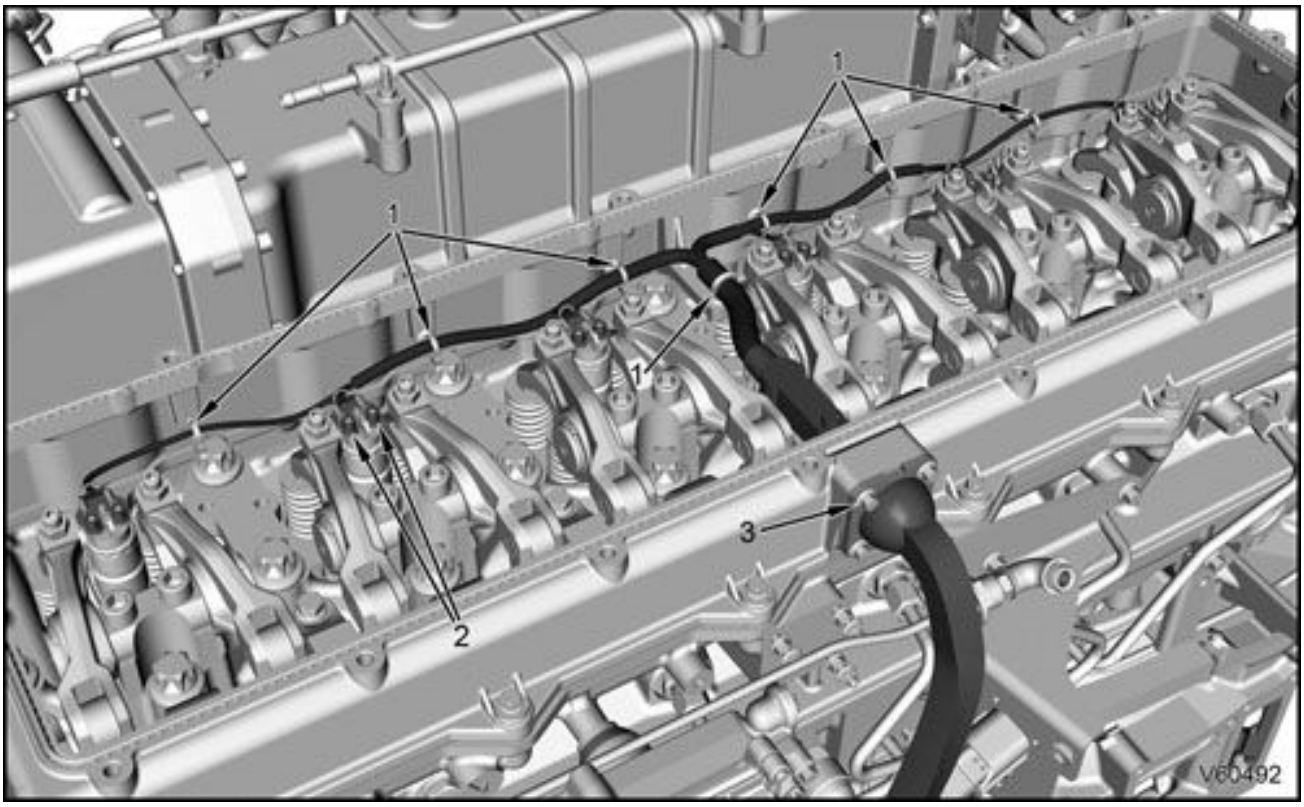


Figure 97 Injector harness attachment points at cylinder head

1. Tie strap (7)
2. Injector harness nut (12)
3. M6 x 16 bolt (4)

3. Install four M6 x 16 bolts to attach injector harness mounting flange to valve cover base. Tighten bolts to standard torque (page 503).
4. Install tie strap to secure injector at center of cylinder head.
5. Install tie straps at six locations to secure injector harness to valve cover base.
6. Install 12 harness nuts to connect harness leads to injector terminals.

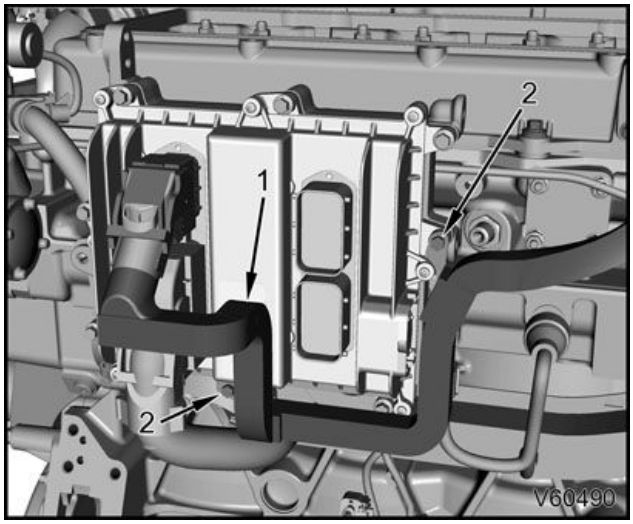


Figure 98 Injector harness attachment points at ECM

1. Injector harness
2. M6 x 30 bolt (2)

7. Install two M6 x 30 bolts to attach engine injector harness retainer clips to ECM. Tighten bolts to special torque (page 106).

Wiring Harness ECM Connections

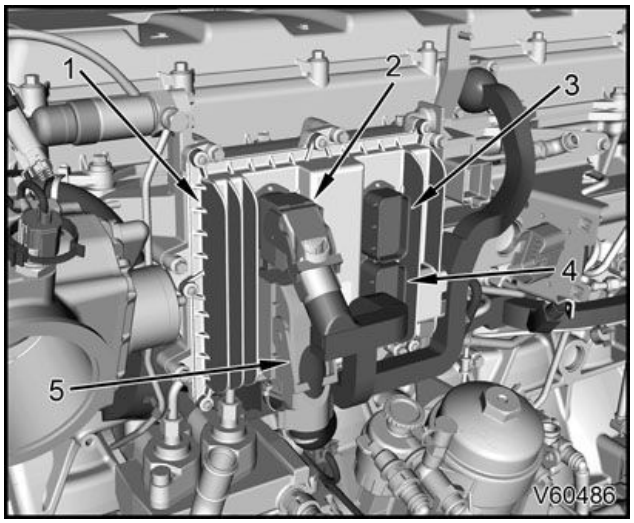


Figure 99 ECM harness connectors

1. ECM
2. Engine injector harness connector (to ECM 16-pin E2 terminal)
3. ECM 58-pin C2 chassis terminal
4. ECM 58-pin C1 chassis terminal
5. Engine sensor harness connector (to ECM 96-pin E1 terminal)

1. Check that ECM E1 and E2 terminal pins are straight and undamaged.
2. Align engine sensor harness connector with ECM E1 terminal and push connector straight in to engage pins. Push down on lock lever to draw in and secure connector.

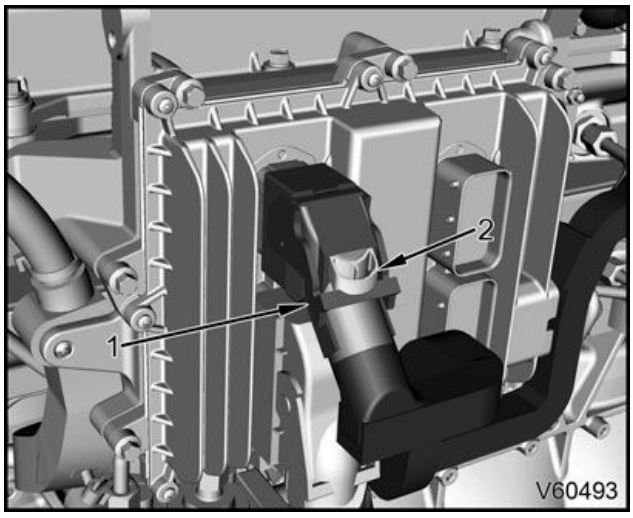


Figure 100 Injector harness connector

1. Lock lever
2. Connector clip

3. Align engine injector harness connector with ECM E2 terminal and push connector straight in to engage pins. Push down on lock lever to draw in and secure connector. Install connector clip.
4. Connect chassis harness connectors to ECM 58–pin C1 and C2 terminals. Lock connectors in place.

Turbocharger 2 Compressor Inlet Sensor (TC2CIS)

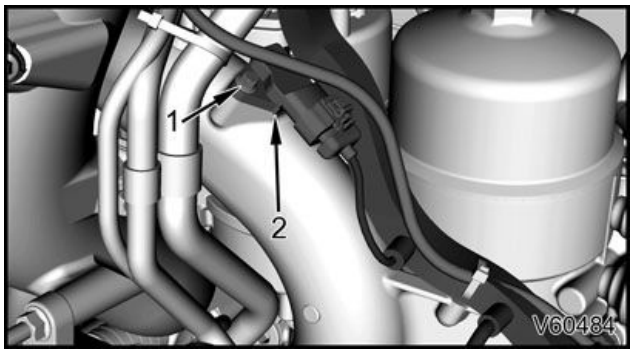


Figure 101 TC2CIS

1. M6 x 16 bolt (2)
2. TC2CIS

1. Place TC2CIS sensor in position on air supply duct and install two M6 x 16 bolts. Tighten bolts to special torque (page 106).
2. Connect harness to TC2CIS terminal by pushing in on connector until a click is heard.
3. Push in yellow tab to lock connector.

Exhaust Gas Recirculation Temperature (EGRT) Sensor

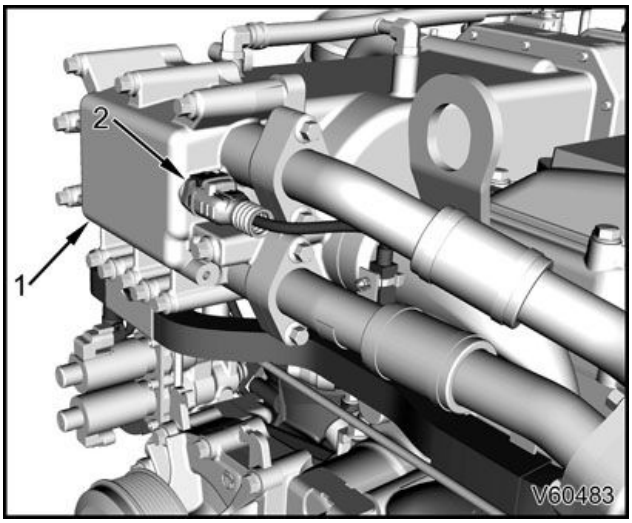


Figure 102 EGRT sensor

1. EGR module cover
2. EGRT sensor

1. Install EGRT sensor in module cover. Tighten sensor to special torque (page 106).
2. Connect harness to EGRT sensor terminal by pushing in on connector until a click is heard.
3. Push in red tab to lock connector.

Exhaust Gas Recirculation (EGR) Valve

1. Install EGR dual flap valve. See EGR Dual Flap Valve (page 289).

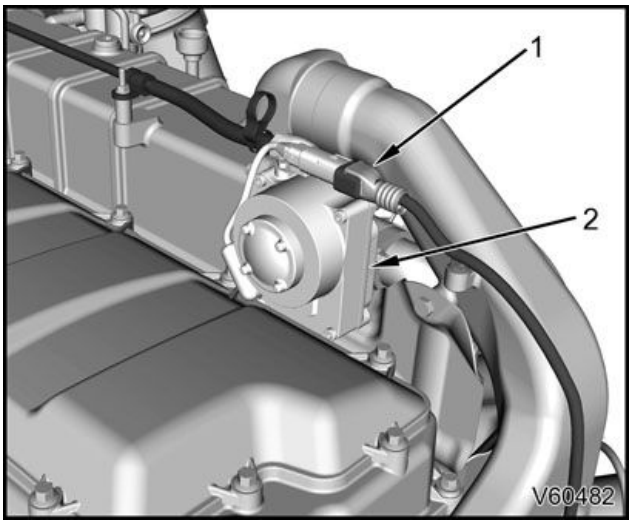


Figure 103 EGR valve harness connector

1. Harness connector
2. EGR valve

2. Connect harness to EGR valve terminal by pushing in on connector until a click is heard.
3. Engage release tab.

Air Control Valve (ACV)

1. Install ACV. See Air Control Valve (ACV) (page 147).

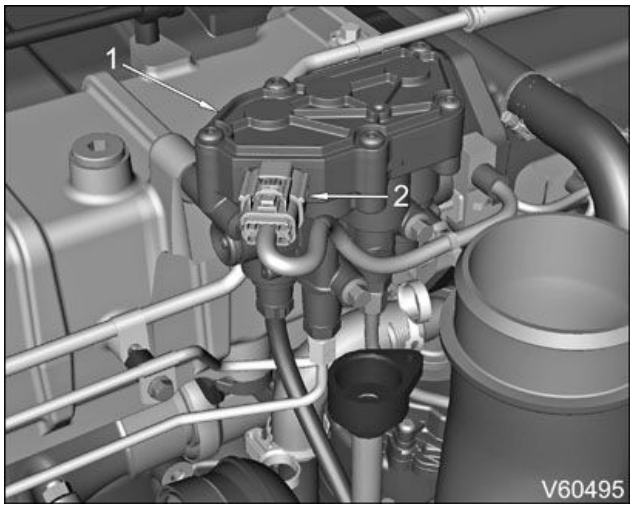


Figure 104 ACV

1. ACV assembly
2. Harness connector

2. Connect harness to ACV terminal by pushing in on connector until a click is heard.

Coolant Control Valve (CCV)

NOTE: The coolant mixer and coolant flow valves are not serviced separately. Both valves are an integral part of the CCV assembly which is available as a unit.

1. See Coolant Control Valve (CCV) (page 334) for installation.

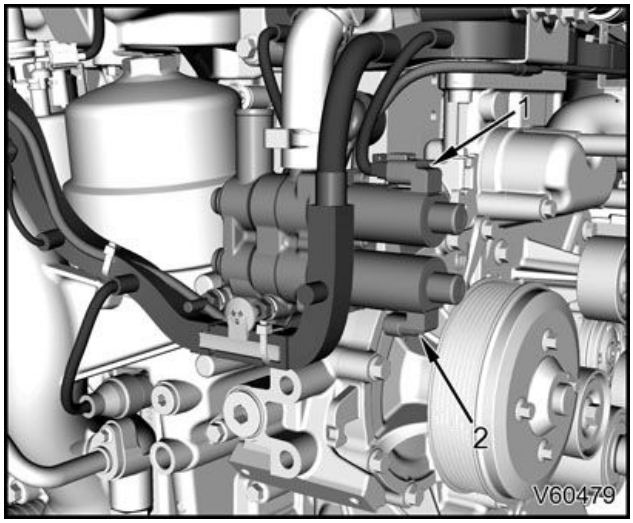


Figure 105 CCV

1. Coolant Mixer Valve (CMV) terminal
2. Coolant Flow Valve (CFV) terminal

2. Connect harness CMV and CFV terminals by pushing in until a click is heard.
3. Engage release tab and secure CMV and CFV terminals to wiring harness.

Engine Throttle Valve (ETV)

1. See Air Intake Throttle Duct (page 306) for installation of air intake throttle duct and ETV as an assembly.

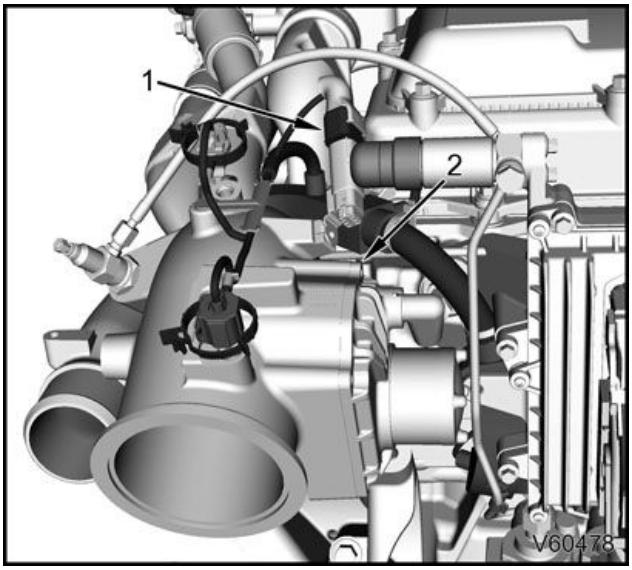


Figure 106 ETV

1. ETV harness connector
2. ETV

2. Connect harness to ETV terminal by pushing in on connector until a click is heard.
3. Engage release tab.
4. See Intake Manifold Pressure (IMP) Sensor (page 100) and Charge Air Cooler Outlet Temperature (CACOT) Sensor (page 101) for installation of ETV-mounted sensors.

Oxygen Sensor (O2S)

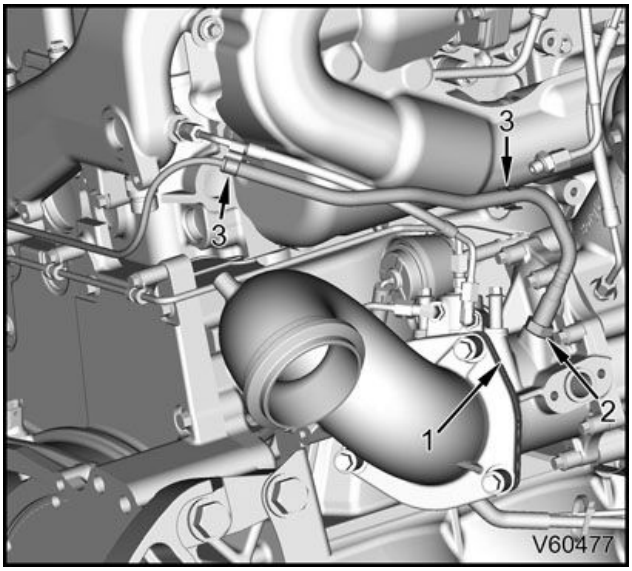


Figure 107 O2S (valve actuator removed for clarity)

1. Exhaust back pressure valve housing
2. O2S (with harness lead)
3. Harness clip (2)

NOTE: The O2S should be reused unless there is damage to the sealing ring and evidence of an exhaust leak.

1. If removed, install O2S. Tighten O2S to special torque (page 106).
2. Attach clips to secure harness lead to coolant tube and valve actuator bracket and at left rear of engine.
3. Connect harness to O2S terminal end by pushing in on connector until a click is heard.
4. Engage release lever.

NOTE: Any time the O2S is replaced, an Oxygen Sensor Calibration Procedure must be done. See MaxxForce® 11 and 13 *Engine Diagnostic Manual* EGES-470 for details.

Intake Manifold Temperature (IMT) Sensor

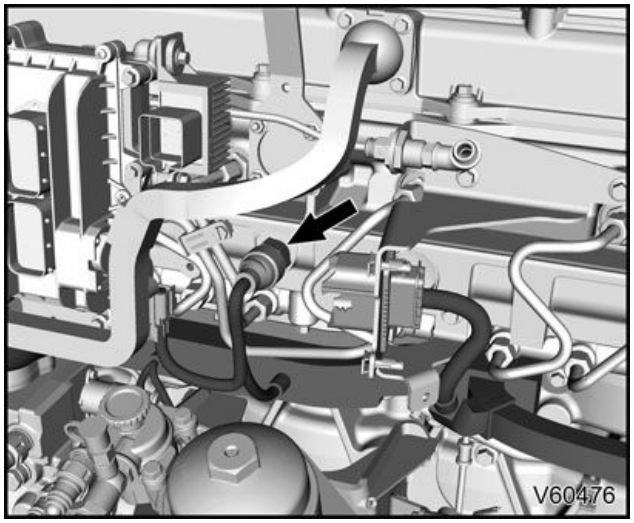


Figure 108 IMT sensor

1. Install new 16.7 x 24 seal ring and IMT sensor. Tighten sensor to special torque (page 106).

NOTE: It may be necessary to rotate the harness connector to ensure the alignment tabs engage properly.

2. Connect harness connector to IMT sensor.
3. Turn IMT sensor harness connector locking ring 90° clockwise.

Fuel Rail Pressure (FRP) Sensor

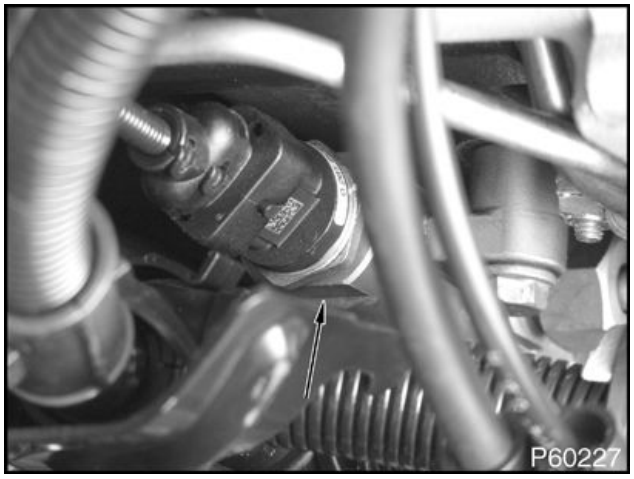


Figure 109 FRP sensor (typical)

1. Apply a thin film of Lubricant F11V27 or equivalent to the threads and seal ring of the FRP sensor.
2. Remove plastic protective cap from the FRP sensor port.
3. Install and hand tighten FRP sensor. Tighten FRP sensor to special torque (page 106).
4. Connect engine harness connector to FRP sensor terminal by pushing in on connector until a click is heard.
5. Push in yellow tab to lock engine harness connector.

Intake Manifold Pressure (IMP) Sensor

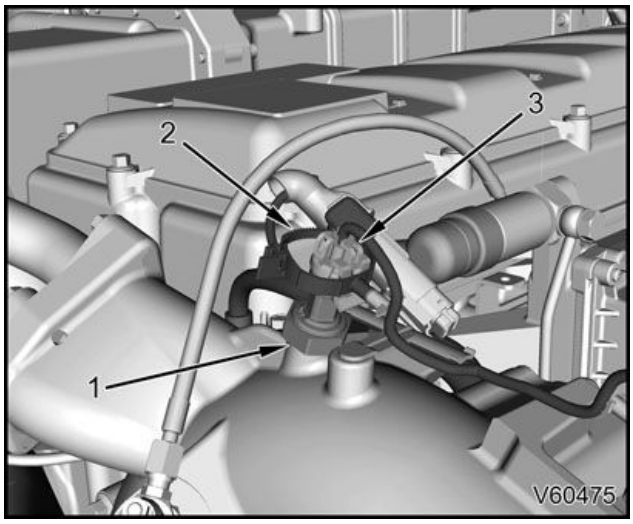


Figure 110 IMP sensor

1. IMP sensor
2. Standoff tie strap
3. Harness connector

1. Install new O-ring and install IMP sensor in Engine Throttle Valve (ETV) housing. Tighten sensor to special torque (page 106).
2. Connect harness to IMP sensor terminal by pushing in on connector until a click is heard.
3. Engage release tab.
4. Attach tie strap to secure harness standoff bracket to IMP sensor.

Charger Air Cooler Outlet Temperature (CACOT) Sensor

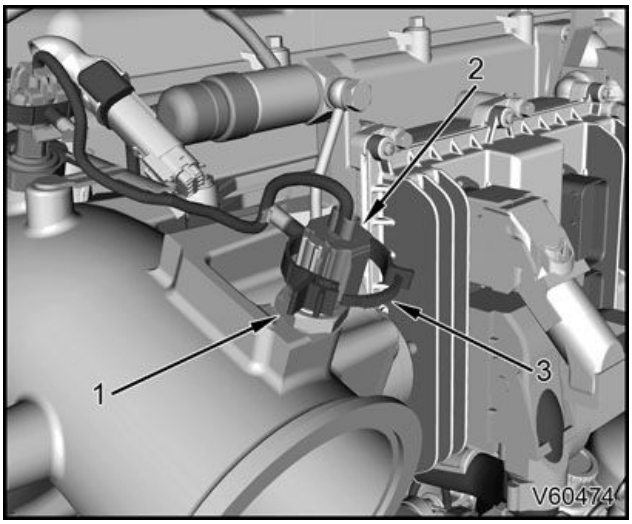


Figure 111 CACOT

1. CACOT sensor
2. Harness connector
3. Standoff tie strap

1. Install new 2.2 x 9.3 ID O-ring and CACOT sensor in throttle valve housing. Tighten sensor to special torque (page 106).
2. Connect harness to CACOT sensor terminal by pushing in on connector until a click is heard.
3. Engage release tab.
4. Attach tie strap to secure harness standoff bracket to CACOT sensor.

Humidity / Air Inlet Temperature (IAT) Sensor

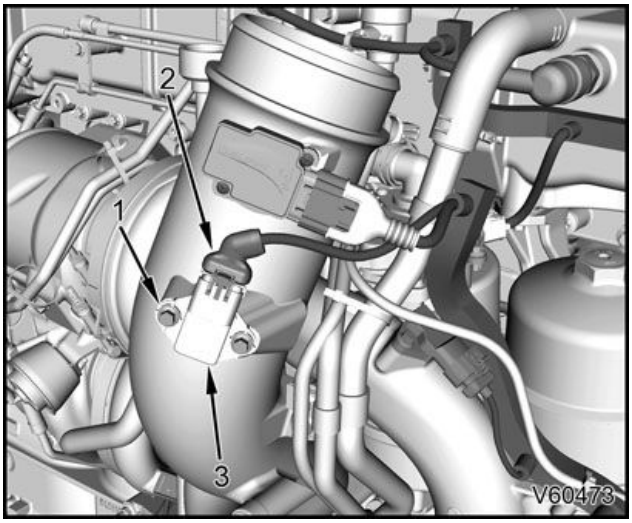


Figure 112 IAT

1. M6 x 16 bolt (2)
2. Harness connector
3. IAT

1. Insert new O-ring and place IAT in position on air inlet duct.
2. Install two M6 x 16 bolts. Tighten bolts to special torque (page 106).
3. Connect harness to IAT terminal by pushing in on connector until a click is heard.
4. Push in yellow tab to lock sensor connector.

Mass Air Flow (MAF) Sensor (If equipped)

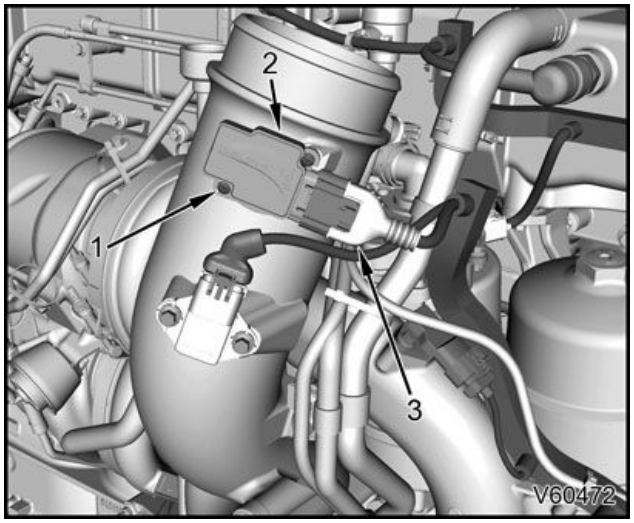


Figure 113 MAF sensor

1. M4 x 0.7 cap screw (2)
2. MAF sensor
3. Harness connector

1. Install new 2.62 x 26.64 ID O-ring and place MAF sensor in position on air inlet duct.
2. Install two M4 x 0.7 cap screws. Tighten cap screws to special torque (page 106).
3. Connect harness to MAF sensor terminal by pushing in on connector until a click is heard.
4. Push in yellow tab to lock sensor connector.

Fuel Pressure Control Valve (FPCV)

1. See High-pressure Fuel Pump (HPFP) and Drive Housing (page 224) for installation of high-pressure fuel pump.

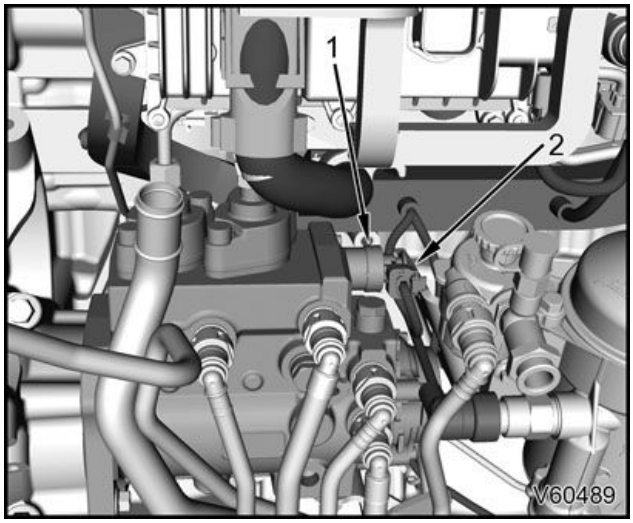


Figure 114 FPCV (on high-pressure fuel pump)

1. FPCV
2. Harness connector

2. Connect harness to FPCV terminal by pushing in on connector until a click is heard.
3. Push in yellow tab to lock sensor connector.

Fuel Delivery Pressure (FDP) Sensor

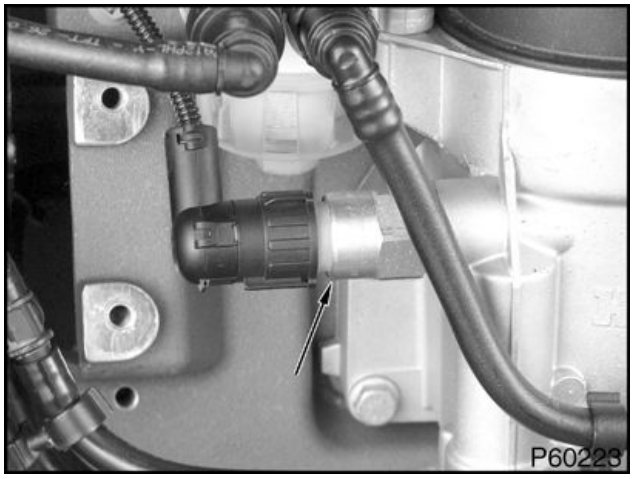


Figure 115 FDP sensor

1. Install FDP sensor and new 18.7 x 26 seal ring. Tighten sensor to special torque (page 106).

NOTE: It may be necessary to rotate the harness connector to ensure the alignment tabs engage properly.

2. Connect harness to FDP sensor.
3. Turn sensor harness connector locking ring 90° clockwise.

Crankcase Oil Separator Speed (CCOSS) Sensor

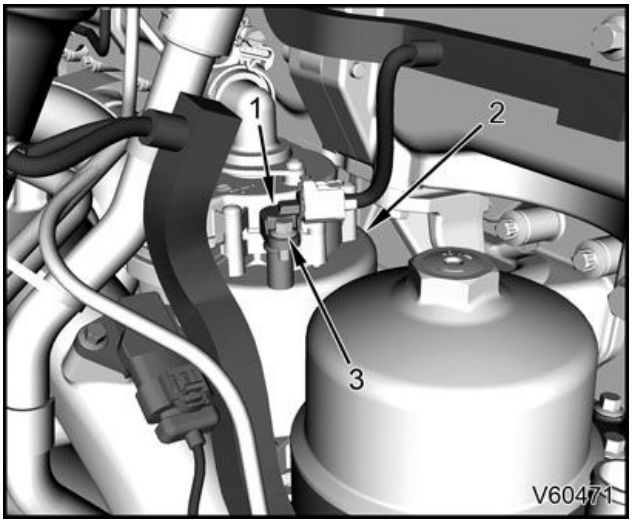


Figure 116 CCOSS sensor

1. CCOSS sensor
2. Oil centrifuge (part of oil module assembly)
3. M6 x 14 bolt and nut

1. Place CCOSS sensor in position on bracket and install M6 x 14 bolt and nut.
2. Tighten bolt to special torque (page 106).
3. Connect harness to CCOSS sensor by pushing in on connector until a click is heard.
4. Push in yellow tab to lock connector in place.

Engine Oil Pressure (EOP) Sensor

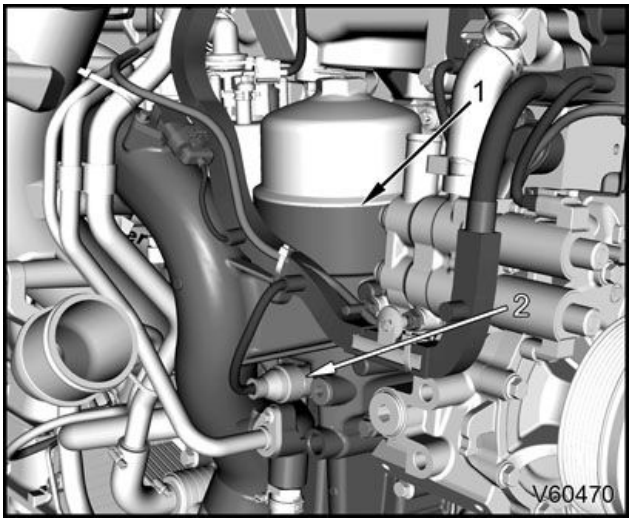


Figure 117 EOP sensor

1. Oil module assembly
2. EOP sensor

1. Install EOP sensor and new 18.7 x 26 seal ring in oil module assembly. Tighten sensor to special torque (page 106).

NOTE: It may be necessary to rotate the harness connector to ensure the alignment tabs engage properly.

2. Connect harness to EOP sensor.
3. Turn sensor connector locking ring 90° clockwise.

Engine Oil Temperature (EOT) Sensor

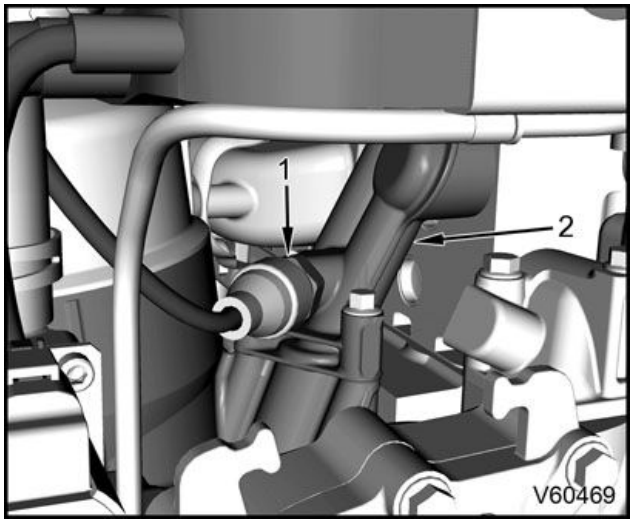


Figure 118 EOT sensor

1. EOT sensor
2. Oil module flange

1. Install EOT sensor and new 16.7 x 24 seal ring in oil module flange. Tighten sensor to special torque (page 106).

NOTE: It may be necessary to rotate the harness connector to ensure the alignment tabs engage properly.

2. Connect harness to EOT sensor.
3. Turn sensor connector locking ring 90° clockwise.

Engine Coolant Temperature 2 (ECT2) Sensor

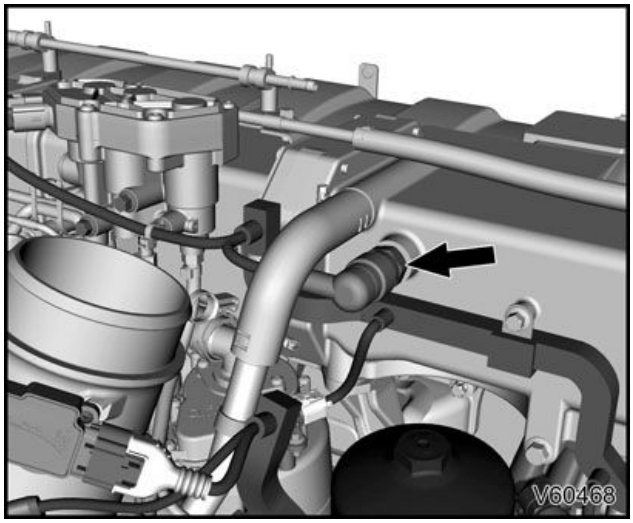


Figure 119 ECT2 sensor

1. Install ECT2 sensor and new 16.7 x 24 seal ring in EGR module low-temperature housing. Tighten sensor to special torque (page 106).

NOTE: It may be necessary to rotate the harness connector to ensure the alignment tabs engage properly.

2. Connect harness to ECT2 sensor.
3. Turn sensor connector locking ring 90° clockwise.

Engine Coolant Temperature 1 (ECT1) Sensor

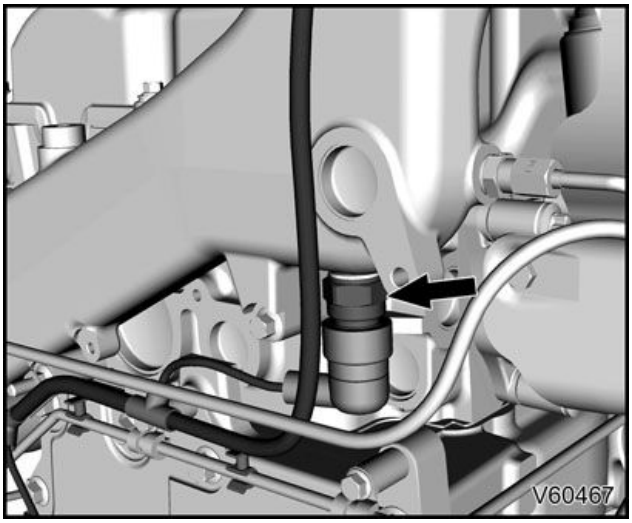


Figure 120 ECT1 sensor

1. Install ECT1 sensor with new 16.7 x 24 seal ring in EGR coolant manifold at rear of engine. Tighten sensor to special torque (page 106).

NOTE: It may be necessary to rotate the harness connector to ensure the alignment tabs engage properly.

2. Connect harness connector to ECT1 sensor.
3. Turn sensor harness connector locking ring 90° clockwise.

Camshaft Position (CMP) Sensor

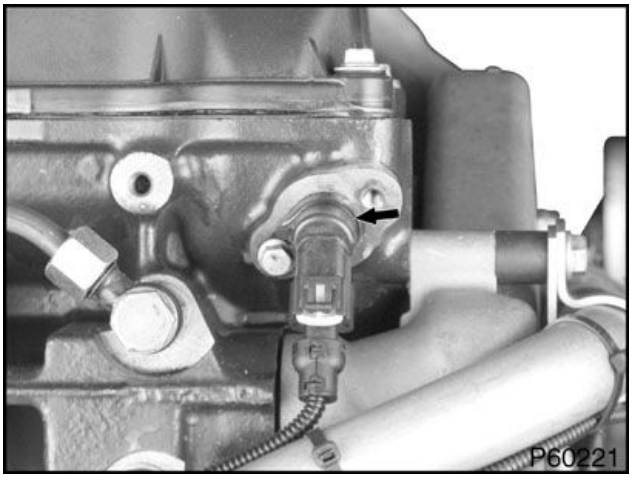


Figure 121 CMP sensor (typical)

1. Lubricate new O-ring with oil-based grease and install on CMP sensor.
2. Insert CMP sensor in port at left rear of cylinder head.
3. Install M6 x 12 bolt to attach CMP sensor to head. Tighten bolt to special torque (page 106).
4. Connect harness to CMP sensor terminal by pushing in on connector until a click is heard.
5. Push in yellow tab to lock sensor connector in place.

Crankshaft Position (CKP) Sensor

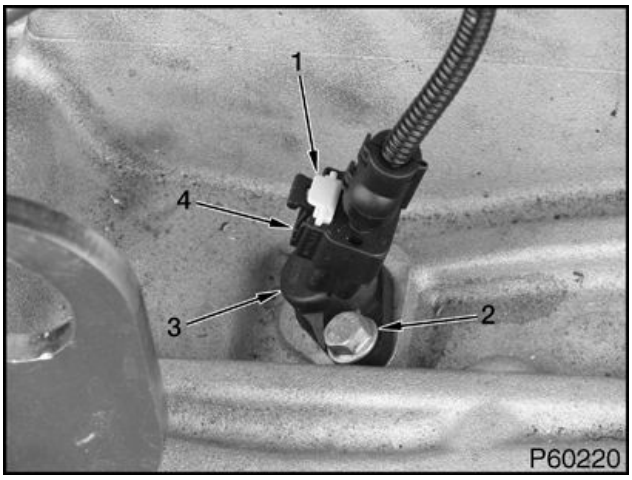


Figure 122 CKP sensor (typical)

1. Locking tab
2. M6 x 16 bolt
3. CKP sensor
4. CKP harness connector

1. Lubricate new O-ring with oil-based grease and install on CKP sensor.
2. Insert CKP sensor in port at top left of flywheel housing.
3. Install M6 x 16 bolt to CKP sensor. Tighten bolt to special torque (page 106).
4. Connect harness to CKP sensor terminal by pushing in on connector until a click is heard.
5. Push in yellow tab to lock connector in place.

Special Torque

Table 4 Engine Electrical

Camshaft Position (CMP) sensor, M6 x 12 bolt	8 N·m (71 lbf·in)
Charger Air Cooler Outlet Temperature (CACOT) sensor	11 N·m (97 lbf·in)
Crankcase Oil Separator Speed (CCOSS) sensor, M6 x 14 bolt	10 N·m (89 lbf·in)
Crankshaft Position (CKP) sensor, M6 x 16 bolt	8 N·m (71 lbf·in)
Engine Control Module (ECM), M6 x 30 bolt	10 N·m (89 lbf·in) See procedure for tightening sequence
Engine Control Module (ECM) support, M8 x 40 bolt	13 N·m (115 lbf·in)
Engine Coolant Temperature 1 (ECT1) sensor	45 N·m (33 lbf·ft)
Engine Coolant Temperature 2 (ECT2) sensor	45 N·m (33 lbf·ft)
Engine injector harness retainer clip, M6 x 30 bolt	10 N·m (89 lbf·in)
Engine Oil Pressure (EOP) sensor	45 N·m (33 lbf·ft)
Engine Oil Temperature (EOT) sensor	45 N·m (33 lbf·ft)
Engine sensor harness bracket/clip, M8 x 16 bolt	35 N·m (26 lbf·ft)
Exhaust Gas Recirculation Temperature (EGRT) sensor	37 N·m (27 lbf·ft)
Fuel Delivery Pressure (FDP) sensor	45 N·m (33 lbf·ft)
Humidity / Air Inlet Temperature (AIT) sensor, M6 x 16 bolt	9 N·m (80 lbf·in)
Intake Manifold Temperature (IMT) sensor	45 N·m (33 lbf·ft)
Intake Manifold Pressure (IMP) sensor	12 N·m (106 lbf·in)
Mass Air Flow (MAF) sensor, M4 x 0.7 cap screw	0.36 N·m (3 lbf·in)
Oxygen Sensor (O2S)	50 N·m (37 lbf·ft)
Fuel Rail Pressure (FRP) sensor	70 N·m (52 lbf·ft)
Turbocharger 2 Compressor Inlet Sensor (TC2CIS), M6 x 16 bolt	9 N·m (80 lbf·in)

Special Service Tools

Table 5 Engine Electrical

Description	Tool Number
Disposable Air and Fuel Caps	ZTSE4891

Table of Contents

Exploded View.....109
Cold Start Assist Components.....109

Removal.....110
Relay Assembly.....110
Glow Plug and Fuel Supply Cold Start Hose.....111
Fuel Supply Solenoid Hose.....111
Glow Plug.....112

Installation.....113
Glow Plug.....113
Fuel Supply Solenoid Hose.....114
Glow Plug and Fuel Supply Cold Start Hose.....115
Relay Assembly.....116

Special Torque.....117

Exploded View

Cold Start Assist Components

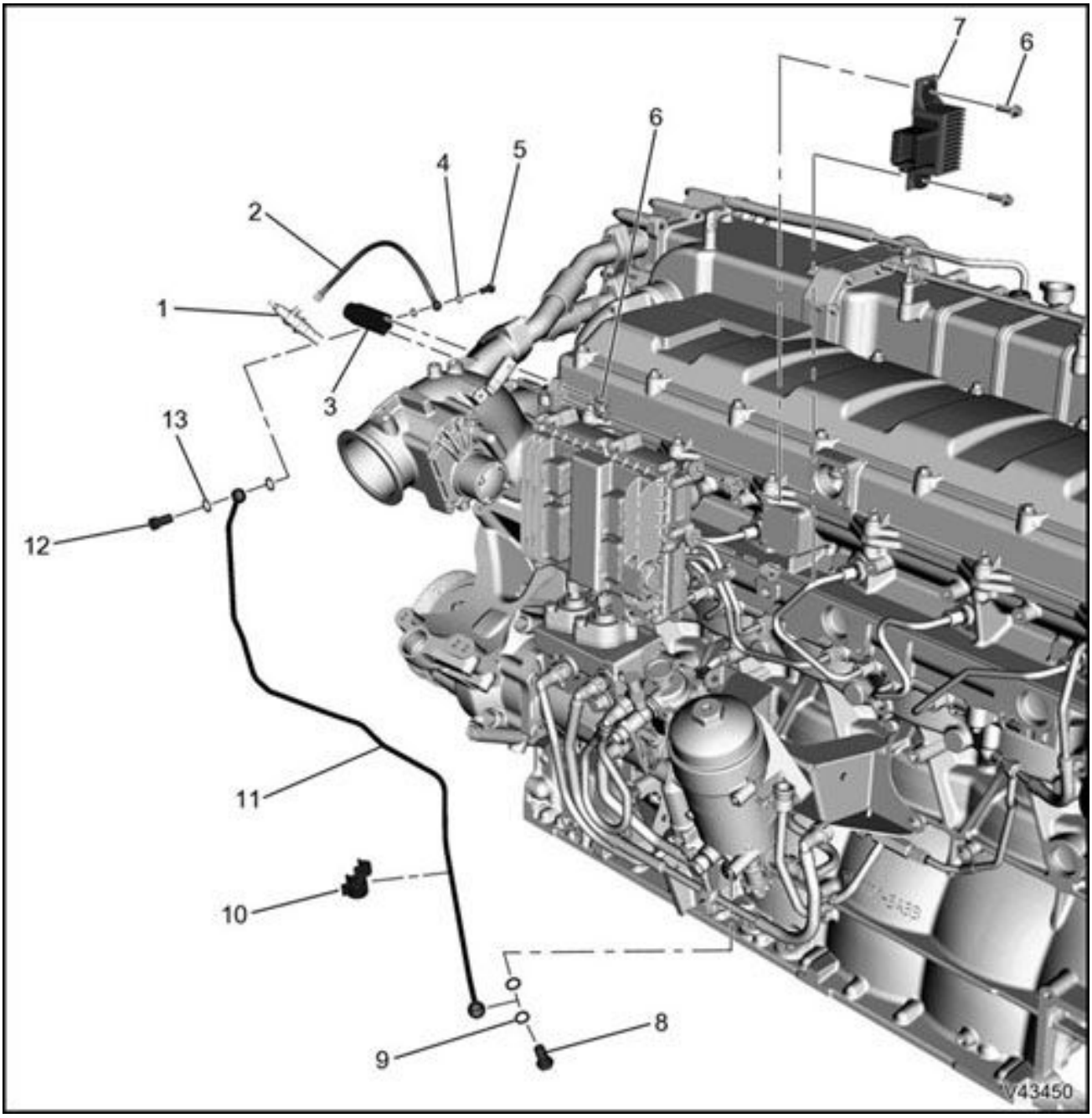


Figure 123 Cold start assist components

1. Glow plug
2. Fuel supply cold start hose
3. Solenoid valve
4. Washer (seal ring) (2)
5. M8 x 1 banjo bolt
6. M6 x 20 bolt (4)
7. Relay assembly
8. Banjo 8 bolt (M12 x 1.5)
9. Seal 12.7 x 18 ring (2)
10. Wiring DMR 11-13 x 6-6.5 clip
11. Fuel supply solenoid hose
12. Banjo 6 bolt (M10 x 1)
13. Seal 10.7 x 16 ring (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 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.

Relay Assembly

1. Disconnect wiring harness connector from relay assembly, if not already done.

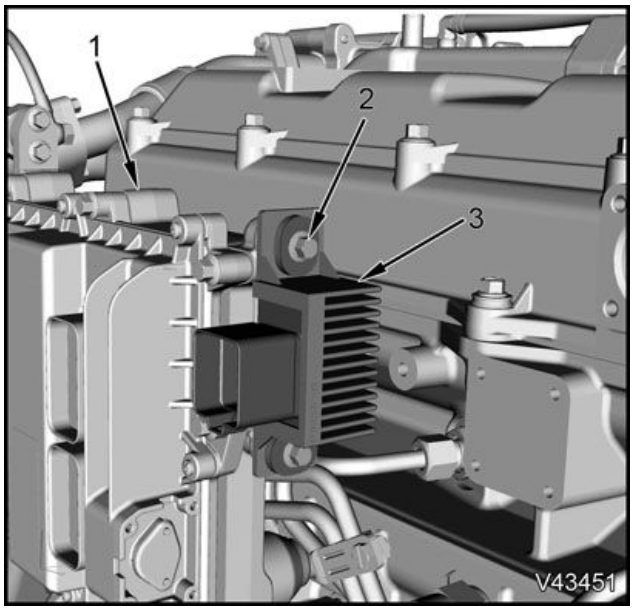


Figure 124 Relay assembly

1. Engine Control Module (ECM) support bracket
2. M6 x 20 bolt (2)
3. Relay assembly

2. Remove two M6 x 20 bolts and remove relay assembly from ECM support bracket.

Glow Plug and Fuel Supply Cold Start Hose

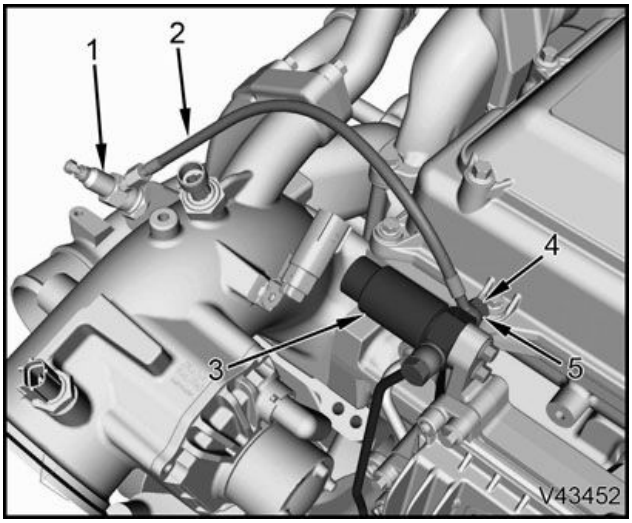


Figure 125 Glow plug and fuel supply cold start hose

1. Glow plug
2. Fuel supply cold start hose
3. Solenoid valve
4. M8 x 1 banjo bolt
5. Washer (seal ring) (2)

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

1. Place suitable container clearly marked DIESEL FUEL under fuel supply cold start hose.
2. Loosen hose fitting nut that attaches to glow plug fitting. Drain fuel into container.
3. Loosen and remove M8 x 1 banjo bolt securing fuel supply cold start hose to solenoid valve. Remove hose and discard two washers (seal rings).

Fuel Supply Solenoid Hose

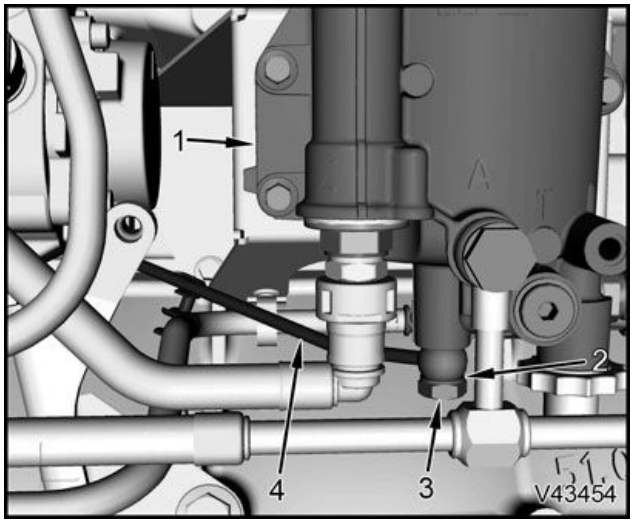


Figure 126 Fuel supply solenoid hose (at fuel filter housing)

1. Fuel filter housing
2. Seal 12.7 x 18 ring (2)
3. Banjo 8 bolt (M12 x 1.5)
4. Fuel supply solenoid hose

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

1. Place suitable container clearly marked DIESEL FUEL under lower end of fuel supply solenoid hose.
2. Remove banjo 8 bolt (M12 x 1.5) from fuel filter housing and drain fuel into container.
3. Remove hose from filter housing and discard two seal 12.7 x 18 rings.

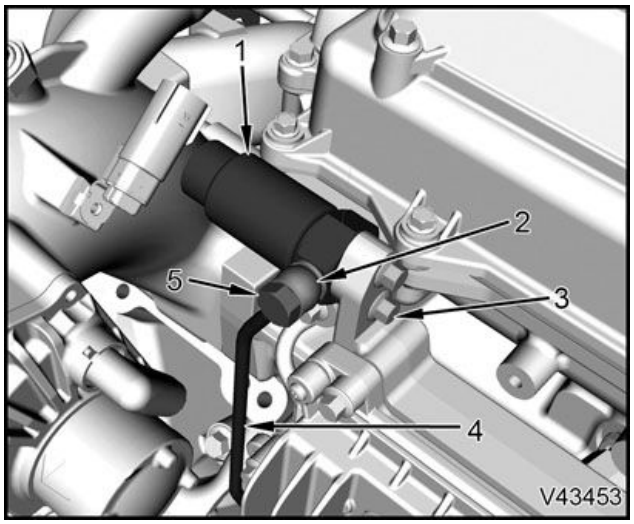


Figure 127 Fuel supply solenoid hose (at solenoid valve)

1. Solenoid valve
2. Seal 10.7 x 16 ring
3. M6 x 20 bolt (2)
4. Fuel supply solenoid hose (tube)
5. Banjo 6 bolt (M10 x 1)

4. Remove banjo 6 bolt (M10 x 1) from solenoid valve.
5. Remove fuel supply solenoid hose from valve and discard two seal 10.7 x 16 rings.

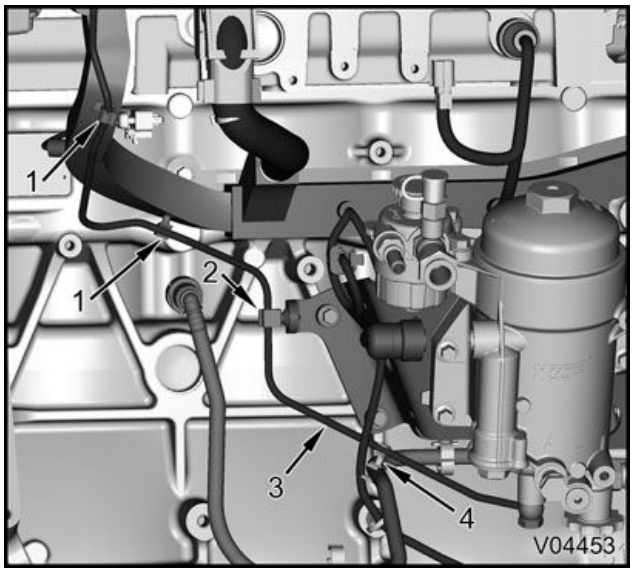


Figure 128 Fuel supply solenoid hose clips

1. Clips on electrical harness (2)
2. Clip on fuel filter bracket
3. Fuel supply solenoid hose (tube)
4. Clip on fuel HP pump drain hose

6. Remove fuel supply solenoid hose from four clips.
7. Remove two M6 x 20 bolts securing the solenoid valve to the ECM bracket. Remove valve.

Glow Plug

1. If not already done, disconnect the wiring harness lead from the glow plug.

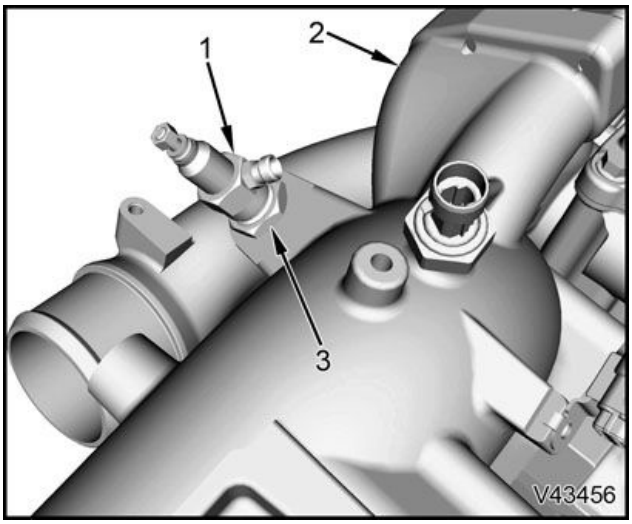


Figure 129 Glow plug

1. Glow plug
2. Air intake throttle duct (horizontal shown)
3. Glow plug locking nut

2. Loosen glow plug locking nut.
3. Remove glow plug from air intake throttle duct by rotating counterclockwise.

Installation

Glow Plug

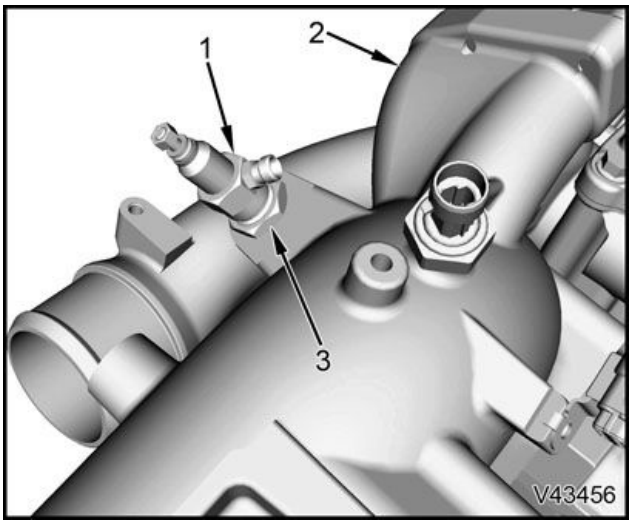


Figure 130 Glow plug

1. Glow plug
2. Air intake throttle duct (horizontal shown)
3. Glow plug locking nut

1. Install glow plug hand tight on air intake throttle duct.
2. Check that glow plug is properly oriented for connection of fuel supply hose and tighten glow plug locking nut to special torque (page 117).

Fuel Supply Solenoid Hose

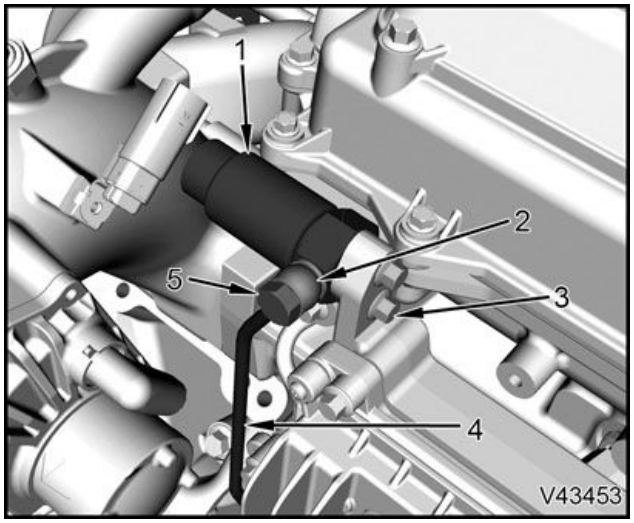


Figure 131 Fuel supply solenoid hose (at solenoid valve)

1. Solenoid valve
2. Seal 10.7 x 16 ring (12)
3. M6 x 20 bolt (2)
4. Fuel supply solenoid hose (tube)
5. Banjo 6 bolt (M10 x 1)

1. Install solenoid valve to ECM support bracket using two M6 x 20 bolts. Finger-tighten bolts.
2. Tighten M6 x 20 bolts to special torque (page 117).
3. Position fuel supply solenoid hose banjo fitting on solenoid valve port. Install two new seal 10.7 x 16 rings and banjo 6 bolt (M10 x 1) into solenoid valve.

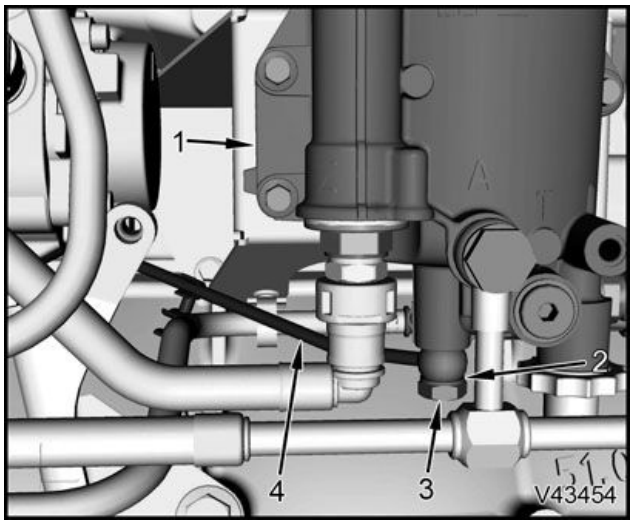


Figure 132 Fuel supply solenoid hose (at fuel filter housing)

1. Fuel filter housing
2. Seal 12.7 x 18 ring (2)
3. Banjo 8 bolt (M12 x 1.5)
4. Fuel supply solenoid hose (tube)

4. Position fuel supply solenoid hose banjo fitting on port at bottom of fuel filter housing. Install two new seal 12.7 x 18 rings and banjo 8 bolt into fuel filter housing.
5. Tighten banjo 6 (M10 x 1) and 8 (M12 x 1.5) bolts to special torque (page 117).

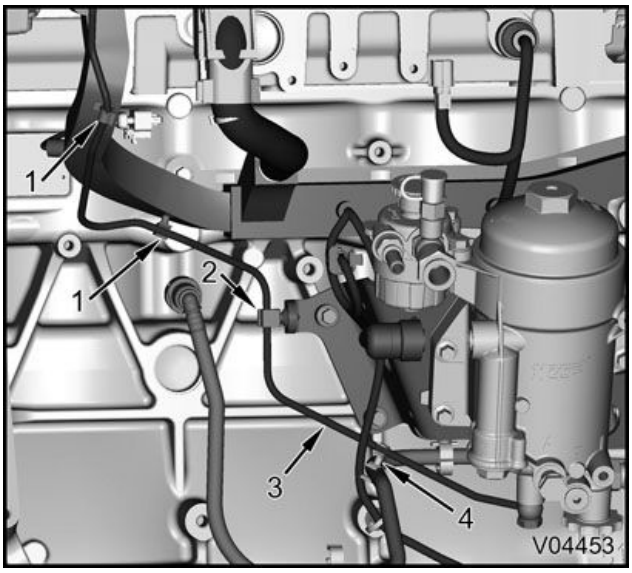


Figure 133 Fuel supply solenoid hose clips

1. Clips on electrical harness (2)
2. Clip on fuel filter bracket
3. Fuel supply solenoid hose
4. Clip on fuel HP pump drain hose

6. Install fuel supply solenoid hose to four clips.

Glow Plug and Fuel Supply Cold Start Hose

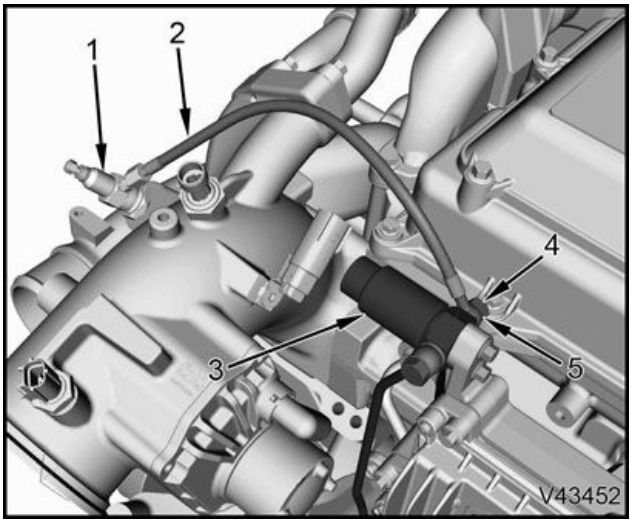


Figure 134 Glow plug and fuel supply cold start hose

1. Glow plug
2. Fuel supply cold start hose
3. Solenoid valve
4. M8 x 1 banjo bolt
5. Washer (seal ring) (2)

1. Position fuel supply cold start hose onto solenoid valve port.
2. Install two new washers (seal rings) and M8 x 1 banjo bolt. Tighten banjo bolt to special torque (page 117).
3. Install fuel supply cold start hose onto glow plug fitting. Tighten fitting nut to special torque (page 117).

Relay Assembly

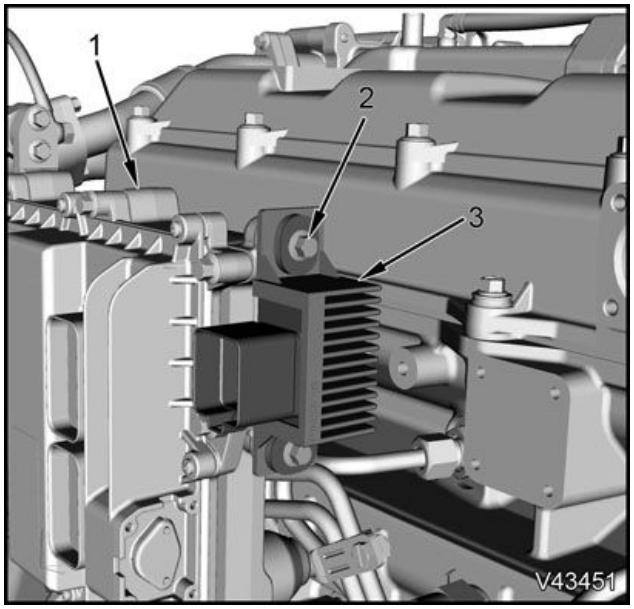


Figure 135 Relay assembly

1. ECM support
2. M6 x 20 bolt (2)
3. Relay assembly

1. Position relay assembly on mounting pad at rear of ECM support.
2. Install two M6 x 20 bolts. Tighten bolts to special torque (page 117).

Special Torque

Table 6 Cold Start Assist

Banjo 6 (M10 x 1) and 8 (M12 x 1.5) bolts	15 N·m (11 lbf·ft)
Banjo M8 x 1 bolt	8 N·m (71 lbf·in)
Fuel supply cold start hose fitting nut	10 N·m (11 lbf·ft)
Glow plug locking nut	25 N·m (18 lbf·ft)
Relay assembly M6 x 20 bolts	10 N·m (89 lbf·in)
Solenoid valve M6 x 20 bolts	6 N·m (53 lbf·in)

Table of Contents

Illustrations.....121
- **Catalyst and Aftertreatment System Fuel Supply Components**.....121

Removal.....124
- **Supply Fuel After Filter Hose and Tubes**.....124
- **Metering Unit Valve Assembly**.....126
- **Pre-Diesel Oxidation (PDOC) Catalyst**.....128
- **HCI Coolant Supply Tube Assembly**.....129
- **HCI Coolant Return Tube Assembly**.....130
- **Hydrocarbon Injector (HCI) Assembly**.....131

Cleaning and Inspection.....131
- **Hydrocarbon Injector Cleaning**.....131

Installation.....132
- **Metering Unit Valve Assembly**.....132
- **Hydrocarbon Injector (HCI) Assembly**.....133
- **HCI Coolant Return Tube Assembly**.....134
- **HCI Coolant Supply Tube Assembly**.....135
- **Pre-Diesel Oxidation (PDOC) Catalyst**.....135
- **HCI Fuel Tube Assembly**.....136

Special Torque.....138

Special Service Tools.....138

Illustrations

Catalyst and Aftertreatment System Fuel Supply Components

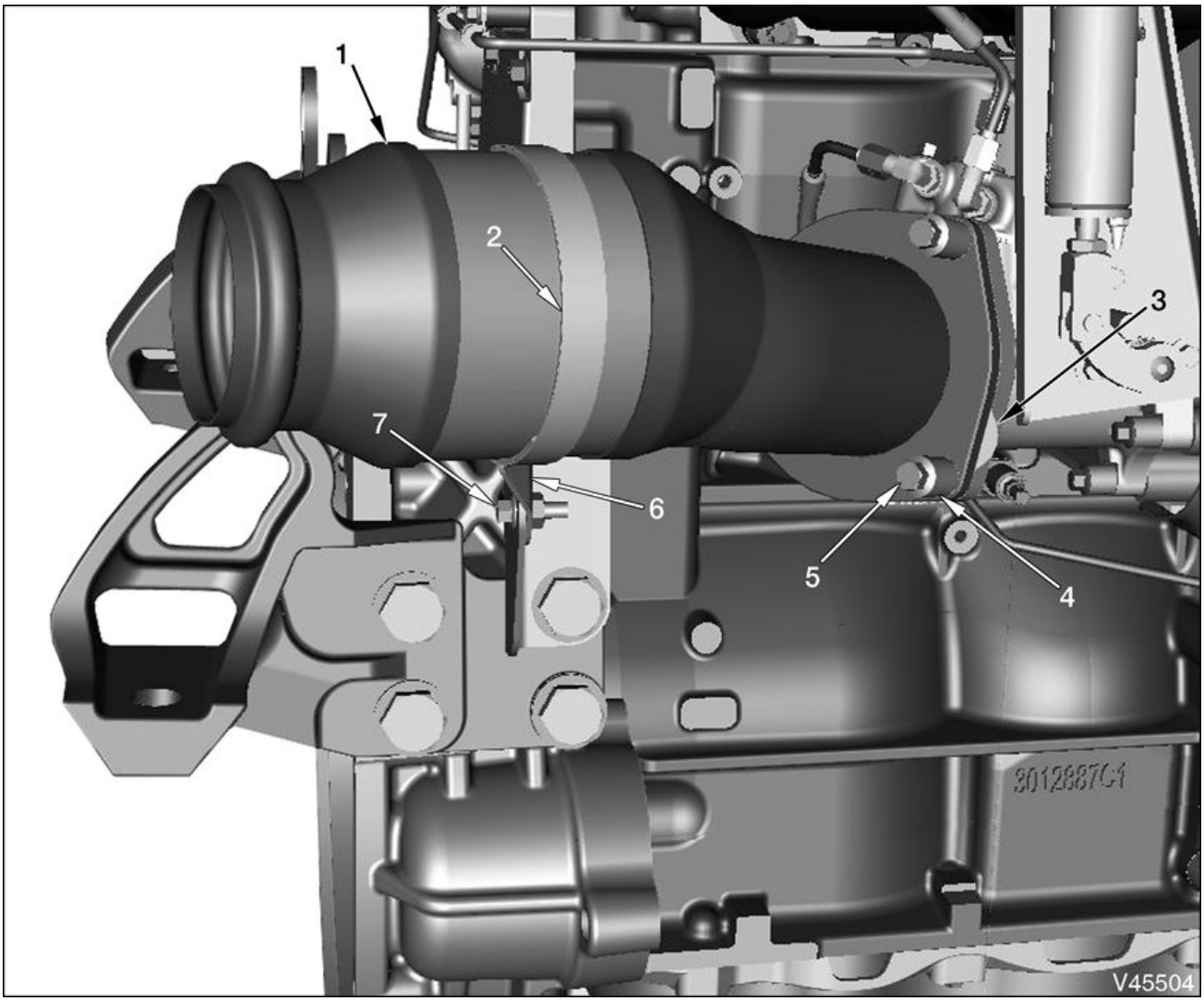


Figure 136 Pre-Diesel Oxidation (PDOC) Catalyst Components

1. Pre-Diesel Oxidation (PDOC) catalyst
2. Clamp
3. Engine brake gasket
4. 11 x 20 x 24 Spacer (3)
5. M10 x 50 bolt (3)
6. PDO bracket
7. M8 x 25 bolt (3)

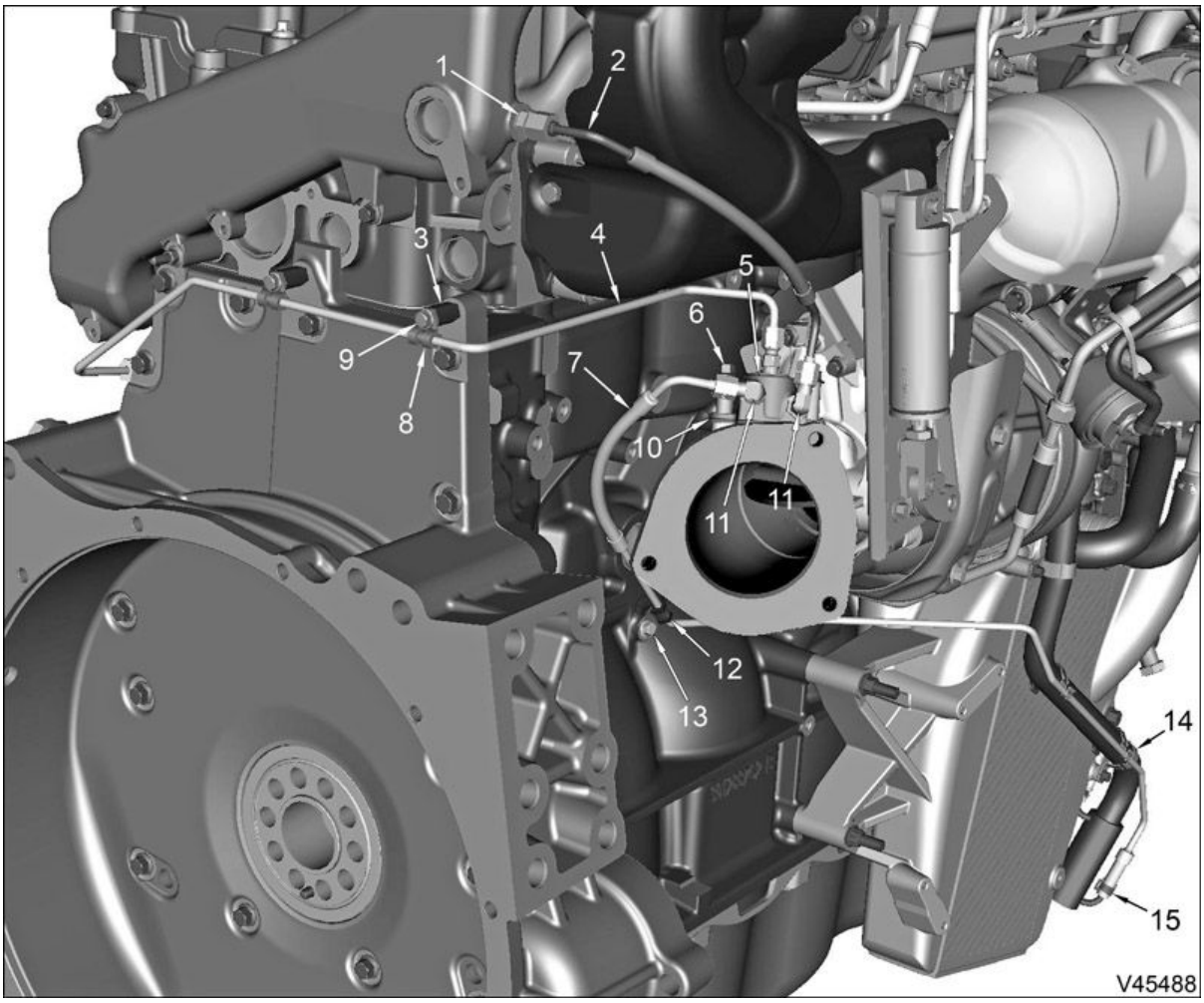


Figure 137 Aftertreatment system components

1. Straight fitting
2. HCI coolant supply tube assembly
3. Spacer (2)
4. HCI fuel 2 tube assembly
5. Hydrocarbon Injector (HCI) assembly
6. M8 x 45 bolt (2)
7. HCI coolant return tube
8. P6 x 15 clamp (2)
9. M6 x 40 bolt (2)
10. Hydrocarbon injector gasket
11. Tube M10 elbow fitting (coolant supply and return) (2)
12. Pipe single cushioned clamp
13. M8 x 16 bolt
14. Tube clamp (2)
15. Hose clamp (spring type)

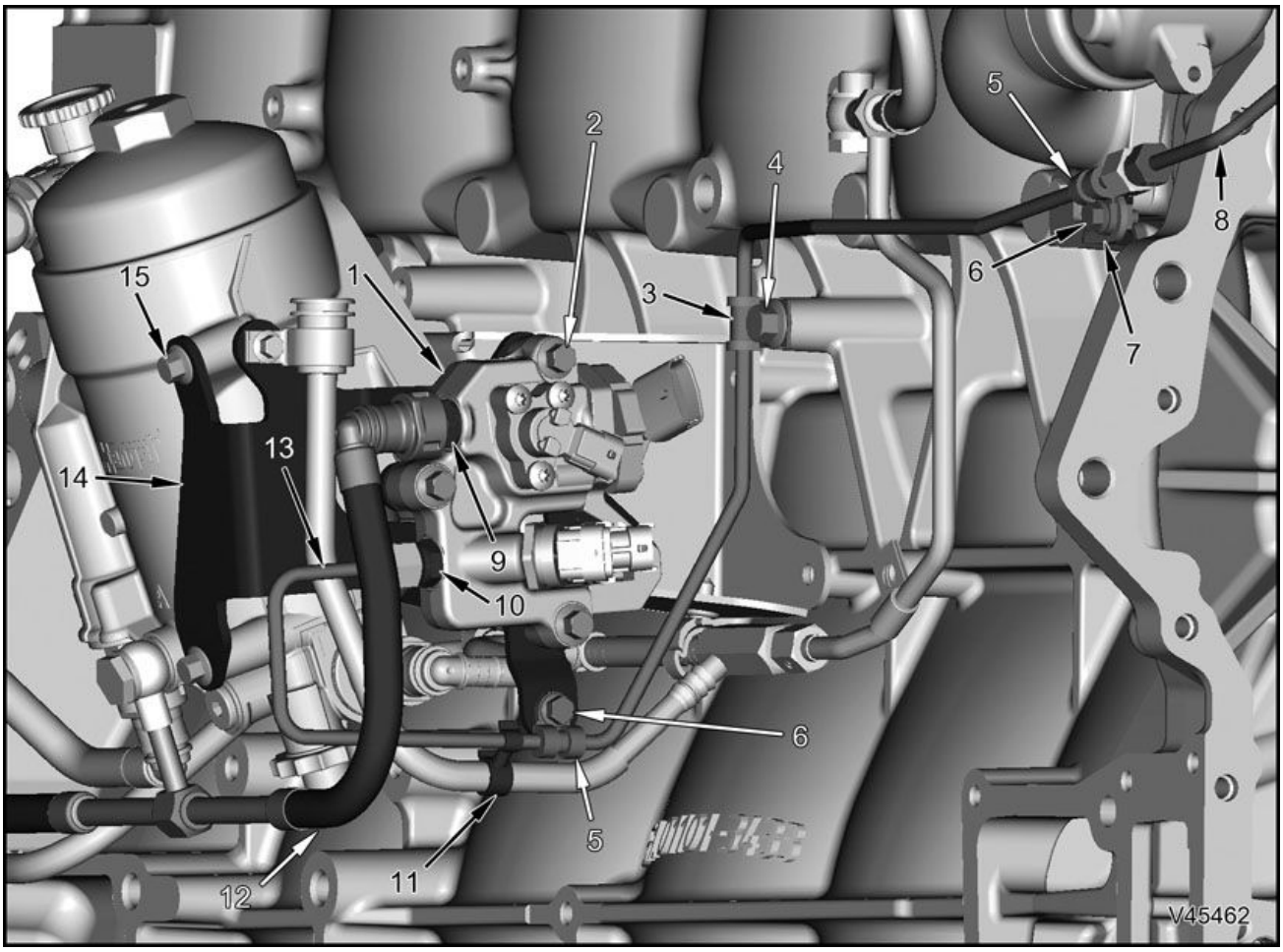


Figure 138 Aftertreatment system fuel supply

1. Metering unit valve assembly
2. M8 x 35 bolt (3)
3. Cushioned 1/4 inch diameter clamp
4. M10 x 16 bolt
5. P 6 x 15 clamp (2)
6. M6 x 16 bolt (2)
7. HCI fuel tube bracket assembly
8. HCI fuel 2 tube assembly
9. Fitting (quick-connect adapter) (contains port O-ring seal)
10. Fitting (straight union orifice) (contains port and fitting O-rings)
11. Clamp (to fuel drain tube)
12. Supply fuel after filter hose
13. HCI fuel 1 tube assembly
14. Metering unit bracket
15. M8 x 16 bolt (4)

Removal

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

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

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

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

Supply Fuel After Filter Hose and Tubes

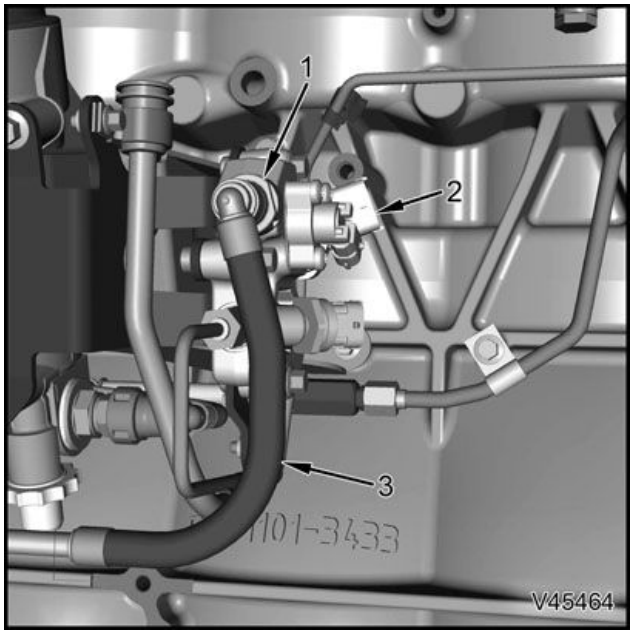


Figure 139 Supply fuel after filter hose connection

1. Fitting (quick-connect adapter)
2. Metering unit valve assembly
3. Supply fuel after filter hose

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

CAUTION: To prevent engine damage, all fuel exposed O-rings and O-ring seals must be replaced with biodiesel compatible O-rings and O-ring seals. The specific Navistar P/N must be used for service.

1. Place suitable container clearly marked DIESEL FUEL under metering unit valve assembly.

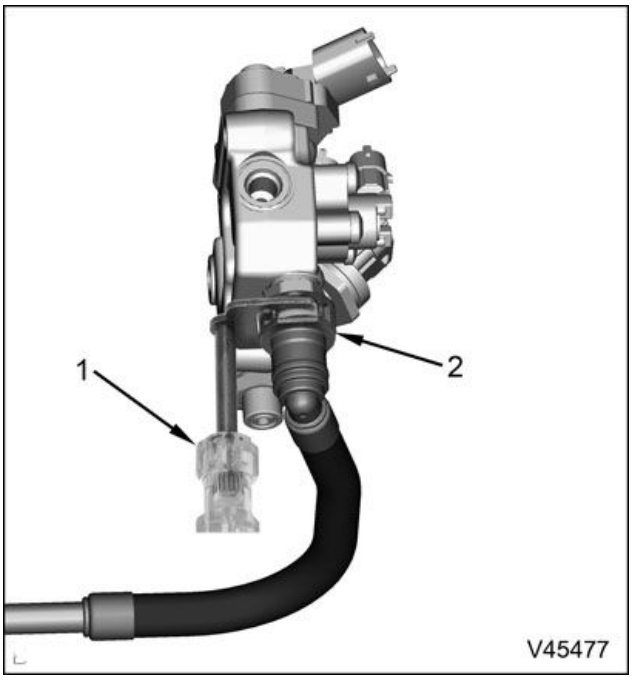


Figure 140 Fuel Line Disconnect Tool 11.8 mm on fuel supply hose

1. Fuel Line Disconnect Tool 11.8 mm
2. Supply fuel after filter hose quick-connect fitting

2. Using Fuel Line Disconnect Tool 11.8 mm (page 138), disconnect supply fuel after filter hose from metering unit valve assembly.

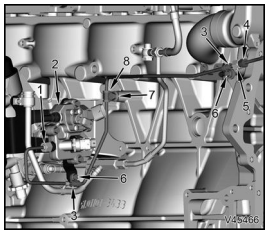


Figure 141 Hydrocarbon injector (HCI) fuel 1 and 2 tube assemblies

1. HCI fuel 1 tube assembly nut
2. Metering unit valve assembly
3. P-clamp (2)
4. HCI fuel 2 tube assembly fitting (brazed to tube)
5. HCI fuel 1 tube assembly nut
6. M6 x 16 bolt (2)
7. M10 x 16 bolt
8. Cushioned 1/4 inch diameter clamp

3. Loosen HCI fuel 1 tube assembly nut and disconnect tube from fitting assembly at metering unit valve assembly.
4. Remove M6 x 16 bolt, M10 x 16 bolt, P-clamp and cushioned 1/4 inch diameter clamp from HCI fuel 1 tube assembly.

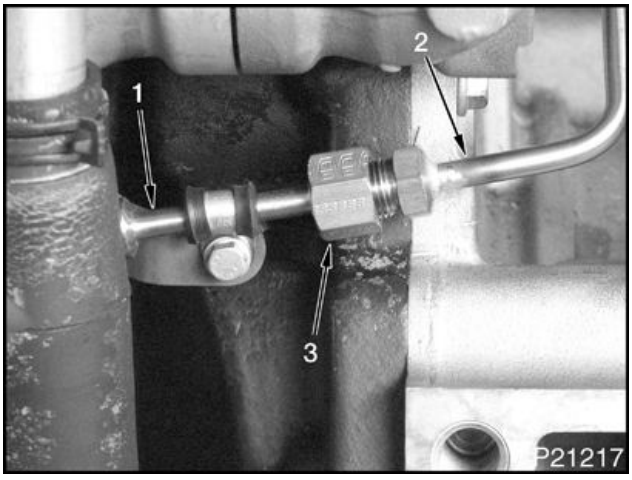


Figure 142 HCI fuel 1 tube assembly connection

1. HCI fuel 1 tube assembly
2. HCI fuel 2 tube assembly
3. HCI fuel 1 tube assembly nut
4. M6 x 16 bolt

5. Loosen HCI fuel 1 tube assembly nut and disconnect fuel tube from HCI fuel 2 tube assembly.
6. Remove M6 x 16 bolt, P-clamp and HCI fuel 1 tube assembly.

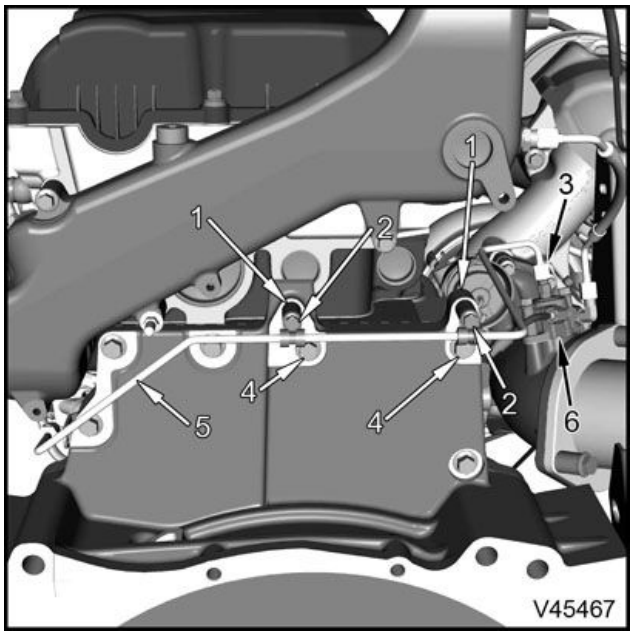


Figure 143 HCI fuel 2 tube assembly

1. 6.6 x 15 x 23 spacer (2)
2. M6 x 40 bolt (2)
3. HCI fuel 2 tube assembly nut
4. P 6 x 15 clamp (2)
5. HCI fuel 2 tube assembly
6. Hydrocarbon Injector (HCI) assembly

7. Loosen HCI fuel 2 tube assembly nut and disconnect tube from hydrocarbon injector assembly.
8. Remove two M6 x 40 bolts, two 6.6 x 15 x 23 spacers and remove HCI fuel 2 tube assembly.

Metering Unit Valve Assembly

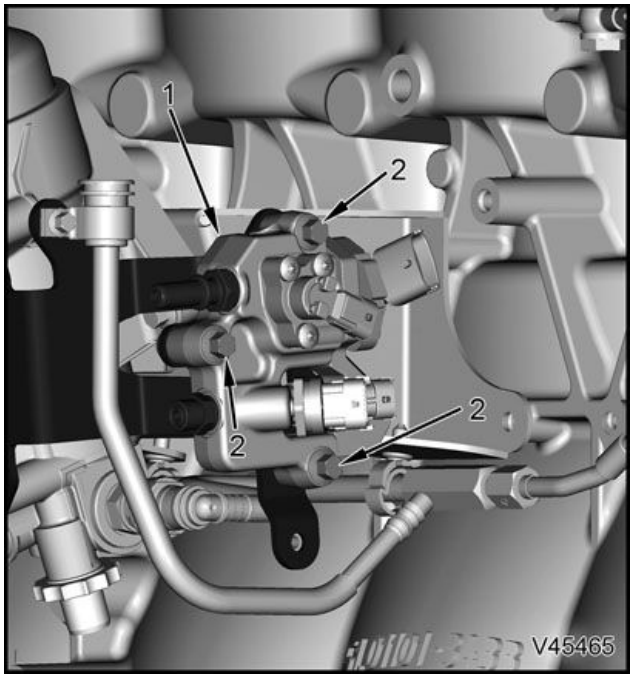


Figure 144 Metering unit valve assembly

1. Metering unit valve assembly
2. M8 x 35 bolt (3)

CAUTION: To prevent component damage, keep metering unit valve assembly and related components clean and protected from damage until ready to install. Do not let dirt or other debris, lubricants or water get into fuel passages. Do not blow compressed air into fuel passages. If protection caps are used, they should be new, or ultrasonically cleaned before using.

CAUTION: To prevent component damage, do not drop metering unit valve assembly onto a hard surface. If this happens, replace the valve.

1. Remove three M8 x 35 bolts and metering unit valve assembly.
2. If necessary, remove four M8 x 16 bolts and metering unit bracket. (Figure 138).

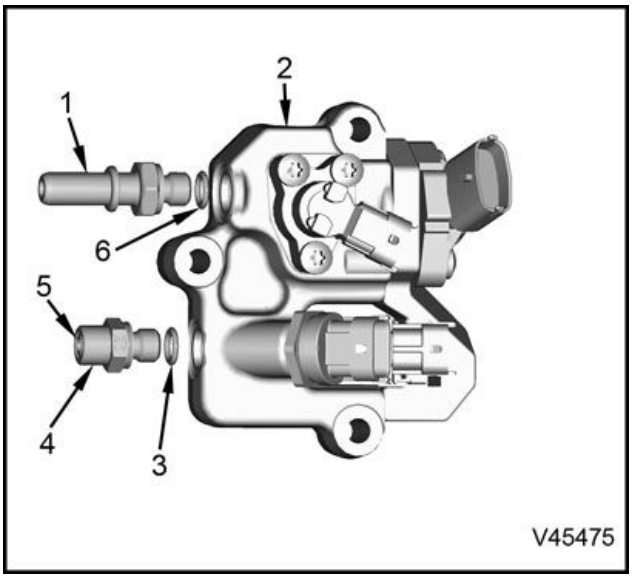


Figure 145 Metering unit valve assembly (adapter/unions)

1. Fitting (quick-connect adapter)
2. Metering unit valve assembly
3. O-ring seal (orifice fitting)
4. Fitting (straight union orifice)
5. O-ring (# 011)
6. O-ring seal (adapter)

NOTE: Do steps 3 and 4 only if metering unit valve assembly adapter or union fitting are leaking or if unit is being replaced. Use adapter and fitting on replacement unit.

CAUTION: To prevent engine damage, all fuel exposed O-rings and O-ring seals must be replaced with biodiesel compatible O-rings and O-ring seals. The specific Navistar P/N must be used for service.

3. Remove fitting (quick-connect adapter) from metering unit valve assembly. Remove and discard O-ring seal.
4. Remove fitting (straight union orifice) from metering unit. Remove and discard O-ring (# 011) and O-ring seal.

Pre-Diesel Oxidation (PDOC) Catalyst

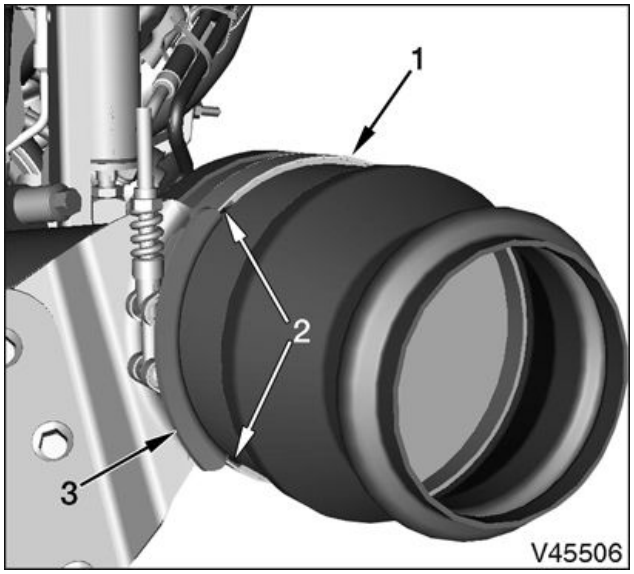


Figure 146 PDOC catalyst clamp

1. Clamp
2. 8 – 10 mm space
3. PDO bracket

1. Remove clamp securing PDOC to PDO bracket.

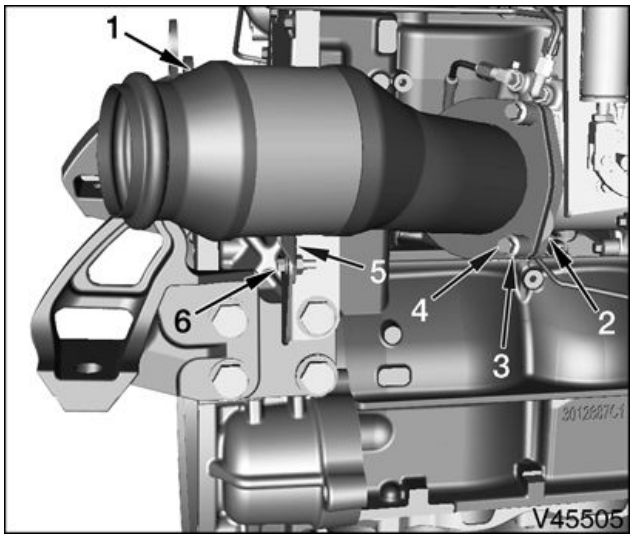


Figure 147 PDOC

1. PDOC
2. Engine brake gasket
3. 11 x 20 x 24 spacer (3)
4. M10 x 50 bolt (3)
5. PDO bracket
6. M8 x 25 bolt (3)

2. Remove three M10 x 50 bolts and three 11 x 20 x 24 spacers.
3. Remove PDOC and engine brake gasket.
4. Remove three M8 x 25 bolts and the PDO bracket.

HCI Coolant Supply Tube Assembly

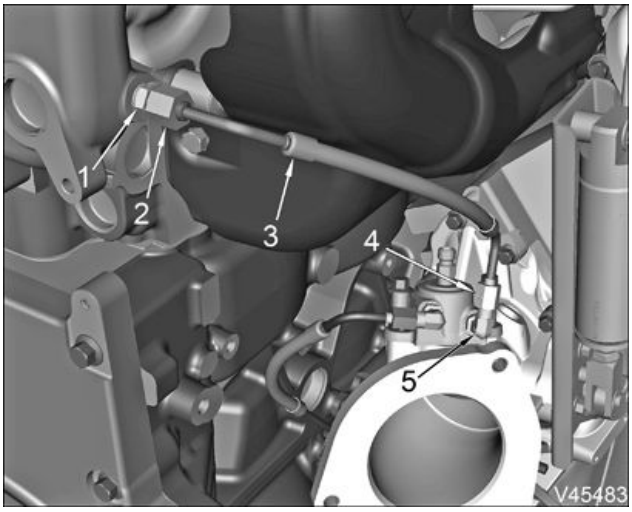


Figure 148 HCI coolant supply tube assembly

1. Straight fitting
2. HCI coolant supply tube nut (connection to straight fitting)
3. HCI coolant supply tube assembly
4. HCI coolant supply tube assembly nut (connection to tube M10 elbow fitting)
5. Tube M10 elbow fitting

1. Loosen the HCI coolant supply tube assembly nut and disconnect tube from tube M10 elbow fitting.
2. Loosen coolant supply tube nut and disconnect tube from straight fitting at coolant manifold. Remove HCI coolant supply tube.
3. If necessary, remove straight fitting from coolant manifold.

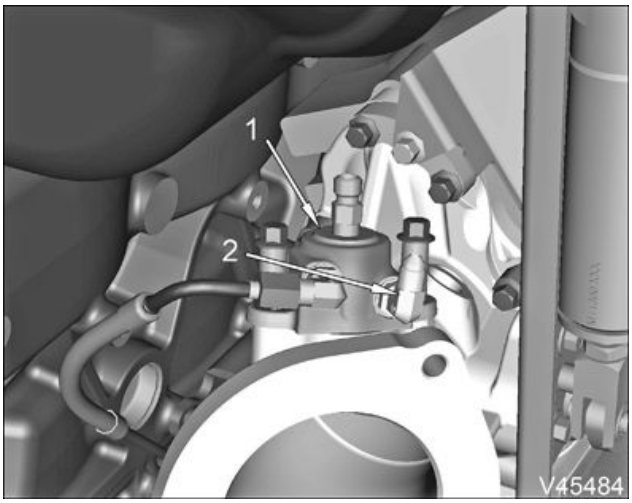


Figure 149 Hydrocarbon injector connection

1. Hydrocarbon Injector (HCI) assembly
2. Tube M10 elbow fitting

NOTE: Perform step 4 only if tube M10 elbow fitting is leaking or if hydrocarbon injector assembly is being replaced.

4. Remove tube M10 elbow fitting from hydrocarbon injector assembly.

HCI Coolant Return Tube Assembly

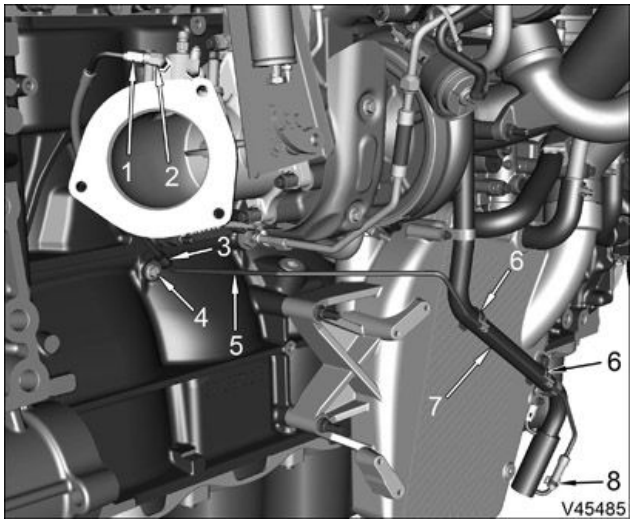


Figure 150 HCI coolant return tube assembly

1. HCI coolant return tube nut
2. Tube M10 elbow fitting
3. Pipe single cushion clamp
4. M8 x 16 bolt
5. HCI coolant return tube assembly
6. Tube clamp (2)
7. Open breather tube
8. Hose clamp (spring type)

1. Loosen HCI coolant return tube assembly nut and disconnect tube from tube M10 elbow fitting.
2. Remove M8 x 16 bolt from pipe single cushion clamp. Separate clamp from tube as necessary.
3. Release HCI coolant return tube from two tube clamps at open breather tube.
4. Loosen hose clamp (spring type). Separate HCI coolant return tube from open breather tube. Remove from engine.

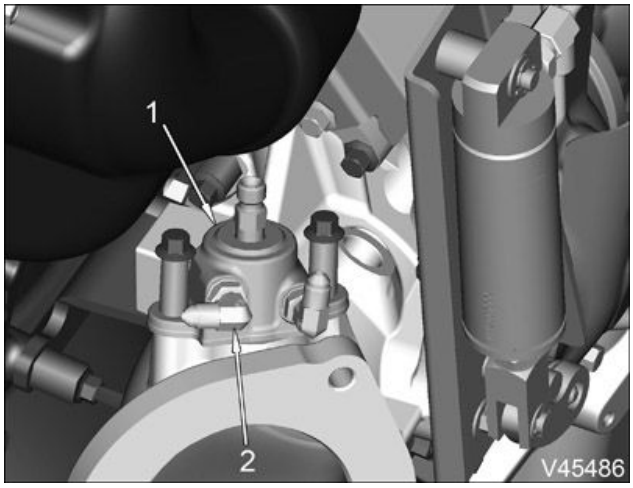


Figure 151 Hydrocarbon injector tube M10 elbow fitting

1. Hydrocarbon Injector (HCI) assembly
2. Tube M10 elbow fitting

NOTE: Do step 5 only if tube M10 elbow fitting is leaking or if hydrocarbon injector assembly is being replaced.

5. Remove tube M10 elbow fitting from hydrocarbon injector assembly.

Hydrocarbon Injector (HCI) Assembly

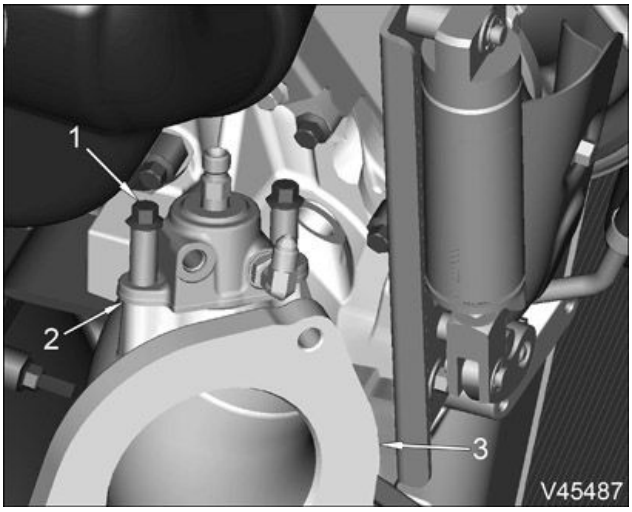


Figure 152 Hydrocarbon injector assembly

1. M8 x 45 bolt (2)
2. Hydrocarbon injector gasket
3. Thermal management valve housing

CAUTION: To prevent component damage, keep hydrocarbon injector and related components clean and protected from damage until ready to install. Make sure to protect the injector nozzle tip as well as sealing and threaded surfaces. Do not let dirt or other debris, lubricants or water get into fuel or coolant passages. Do not blow compressed air into injector fuel passage. If protection caps are used, they should be new, or ultrasonically cleaned before using.

CAUTION: To prevent component damage, do not drop hydrocarbon injector (especially nozzle tip) onto a hard surface. If this happens, replace the injector.

1. Remove two M8 x 45 bolts and hydrocarbon injector from valve thermal management valve housing. Discard bolts.
2. Remove hydrocarbon injector gasket and save the used gasket for reuse during the hydrocarbon injector flow test.

Cleaning and Inspection

Hydrocarbon Injector Cleaning

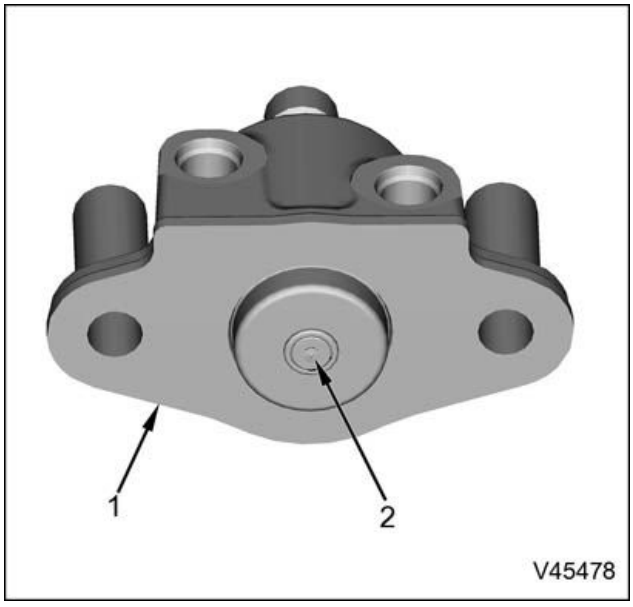


Figure 153 Hydrocarbon injector assembly

1. Hydrocarbon Injector (HCI) assembly
2. Injector nozzle tip

CAUTION: To prevent component damage, cleaning of the hydrocarbon injector using carb and choke cleaner, other solvents or using any brush is NOT recommended. It is not considered a regular maintenance procedure, nor is the injector considered a serviceable item. Do not blast the injector with compressed air. Do not pull or otherwise manipulate the injector nozzle tip. There is no acceptable cleaning method for the hydrocarbon injector. If in doubt, do not clean the injector, replace it.

Installation

Metering Unit Valve Assembly

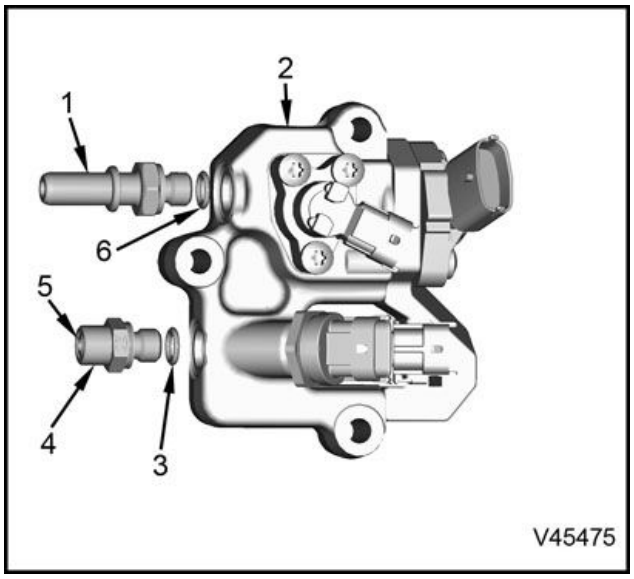


Figure 154 Metering unit valve assembly (adapter/unions)

1. Fitting (quick-connect adapter)
2. Metering unit valve assembly
3. O-ring seal
4. Fitting (straight union orifice)
5. O-ring (# 011)
6. O-ring seal

NOTE: Do steps 1 and 2 only if fitting (quick-connect adapter) or fitting (straight union orifice) are removed or metering unit valve assembly is replaced.

CAUTION: To prevent engine damage, all fuel exposed O-rings and O-ring seals must be replaced with biodiesel compatible O-rings and O-rings seals. The specific Navistar P/N must be used for service.

1. Lubricate a new O-ring seal with P-80® rubber lubricant or equivalent (page 138) and install onto fitting (quick-connect adapter). Install fitting to metering unit valve assembly. Tighten to special torque (page 138).
2. Lubricate a new O-ring (#011) with P-80® rubber lubricant or equivalent (page 138) and install into new fitting (straight union orifice).
3. Lubricate a new O-ring seal with P-80® rubber lubricant or equivalent (page 138) and install onto new fitting (straight union orifice) to metering unit valve assembly. Tighten to special torque (page 138).
4. If removed, position metering unit bracket and install four M8 x 16 bolts. Tighten bolts to standard torque (page 503)

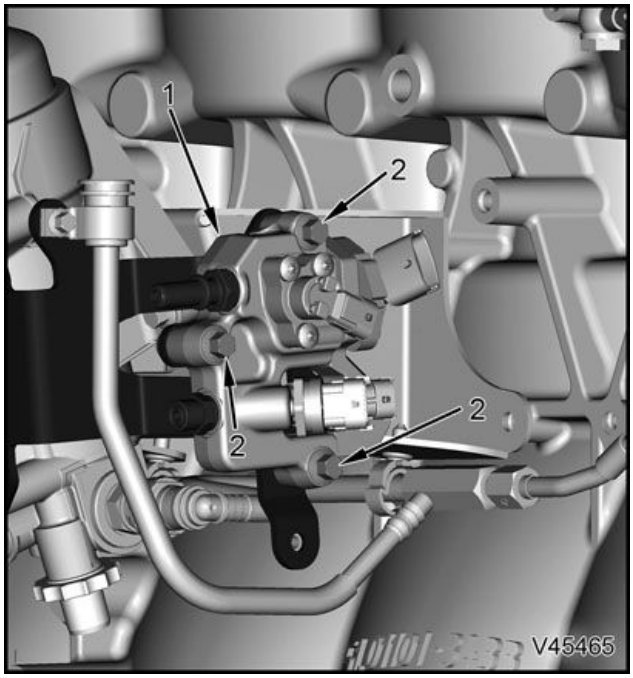


Figure 155 Metering unit valve assembly

1. Metering unit valve assembly
2. M8 x 35 bolt (3)

5. Install metering unit valve assembly and three M8 x 35 bolts. Tighten bolts to standard torque (page 503).

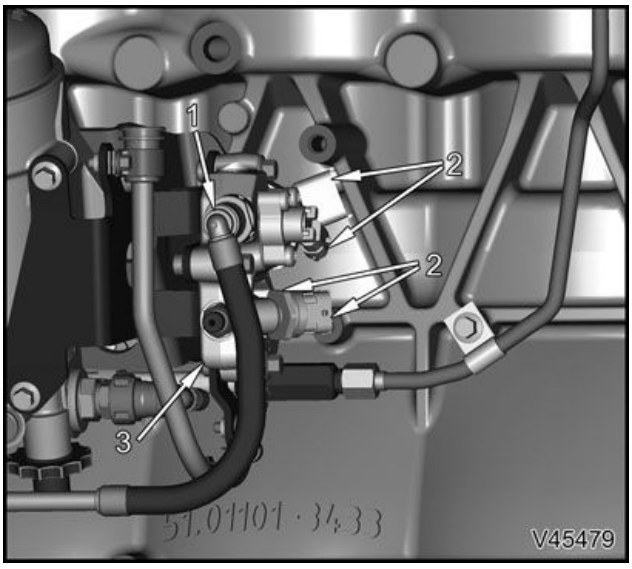


Figure 156 Metering unit valve assembly connections

1. Supply fuel after filter hose quick-connect fitting
2. Electrical connections (4)
3. Metering unit valve assembly

6. Position supply fuel after filter hose onto fitting (quick-connect adapter) and push on until click is heard or felt.
7. Reconnect wiring harness to four electrical connections.

Hydrocarbon Injector (HCI) Assembly

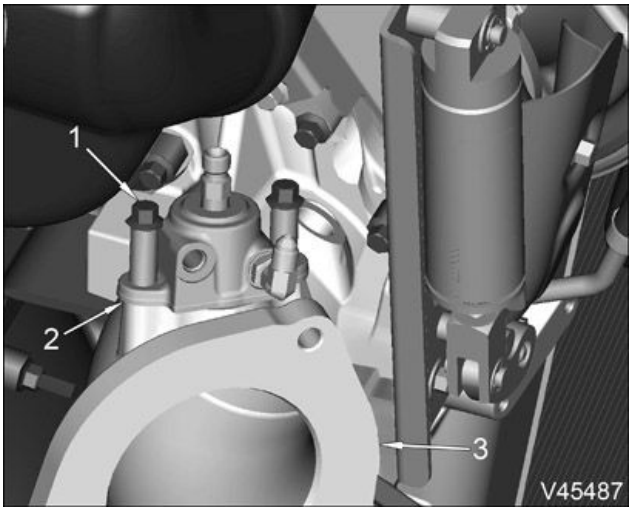


Figure 157 Hydrocarbon injector assembly

1. M8 x 45 bolt (2)
2. Hydrocarbon injector gasket
3. Exhaust back pressure valve housing

1. Position hydrocarbon injector and gasket onto the exhaust back pressure valve housing. Install two new M8 x 45 bolts and tighten as follows.
   a. Pre-tighten bolts to 11 N·m (97 lbf·in).
   b. Final-tighten bolts to 25 N·m (18 lbf·ft). Do not over tighten.

NOTE: Do steps 2 and 3 only if fittings were removed or if hydrocarbon injector assembly was replaced.

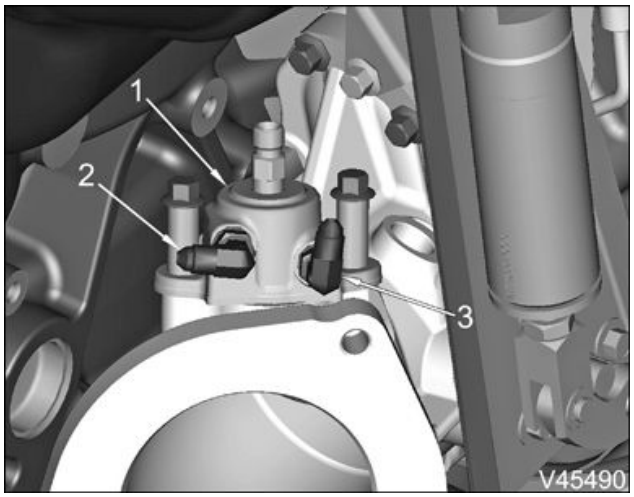


Figure 158 Hydrocarbon injector tube M10 elbow fittings

1. Hydrocarbon Injector (HCI) assembly
2. Tube M10 elbow fitting (coolant out)
3. Tube M10 elbow fitting (coolant in)

2. Install tube M10 elbow fitting (coolant in) into hydrocarbon injector assembly and finger-tighten.
3. Install tube M10 elbow fitting (coolant out) into hydrocarbon injector assembly and finger-tighten.

HCI Coolant Return Tube Assembly

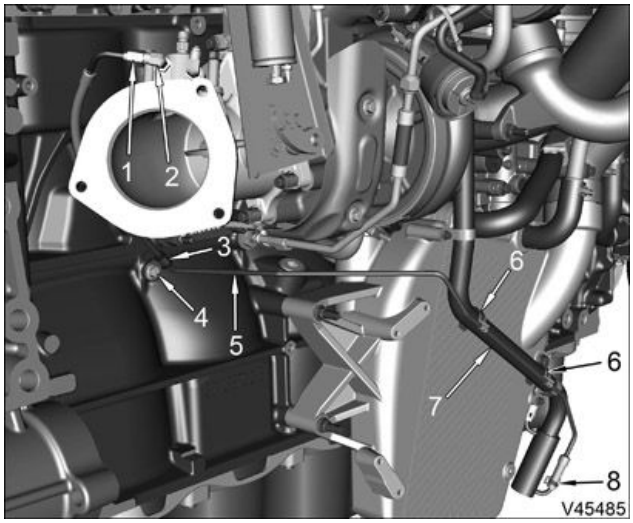


Figure 159 HCI coolant return tube assembly

1. HCI coolant return tube nut
2. Tube M10 elbow fitting
3. Pipe single cushion clamp
4. M8 x 16 bolt
5. HCI coolant return tube assembly
6. Tube clamp (2)
7. Open breather tube
8. Hose clamp (spring type)

NOTE: Do steps 1 and 2 if tube M10 elbow fitting was removed or if hydrocarbon injector assembly was replaced. Otherwise, skip to step 3.

1. Install tube M10 elbow fitting onto hydrocarbon injector assembly and tighten fitting to maintain orientation and clearance for HCI coolant return tube assembly.
2. Tighten tube M10 elbow fitting to special torque (page 138).
3. Position HCI coolant return tube assembly onto open breather tube nipple, two tube clamps on open breather tube and pipe single cushion clamp.
4. Install M8 x 16 bolt through pipe single cushion clamp and tighten to standard torque (page 503).
5. Snap HCI coolant return tube into two tube clamps and install hose clamp (spring type) to secure tube to open breather tube.

6. Tighten HCI coolant return tube assembly nut onto tube M10 elbow fitting (orient fitting as needed to reduce tube stress and to not contact other components) and tighten tube nut and elbow fitting each to special torque (page 138).

HCI Coolant Supply Tube Assembly

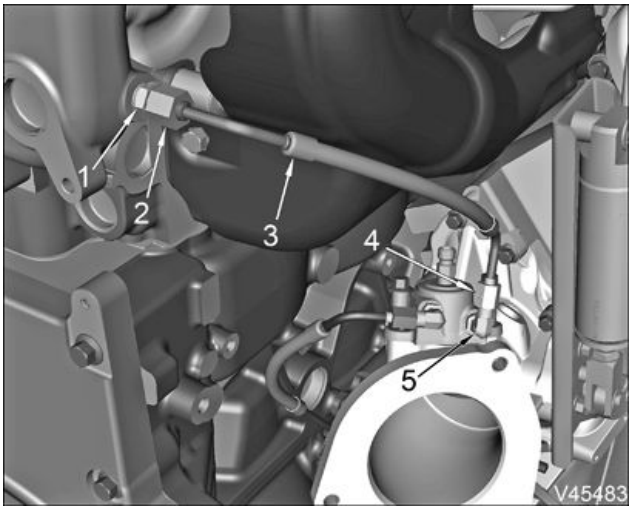


Figure 160 HCI coolant supply tube assembly

1. Straight fitting
2. HCI coolant supply tube nut (connection to straight fitting)
3. HCI coolant supply tube assembly
4. HCI coolant supply tube assembly nut (connection to tube M10 elbow fitting)
5. Tube M10 elbow fitting

1. If previously removed, install straight fitting into coolant manifold and tighten to special torque (page 138).
2. Loosely install HCI coolant supply tube nut onto straight fitting at coolant manifold.

NOTE: Do steps 3 and 4 if tube M10 elbow fitting was removed or if hydrocarbon injector assembly was replaced. Otherwise, skip to step 5.

3. Install tube M10 elbow fitting onto hydrocarbon injector assembly and tighten fitting to maintain orientation and clearance for HCI coolant supply tube assembly. Tighten tube M10 elbow fitting to special torque (page 138).
4. Loosely install HCI coolant supply tube nut onto tube M10 elbow fitting (orient fitting as needed) on hydrocarbon injector assembly.
5. Tighten two HCI coolant supply tube nuts to special torque (page 138).

Pre-Diesel Oxidation (PDOC) Catalyst

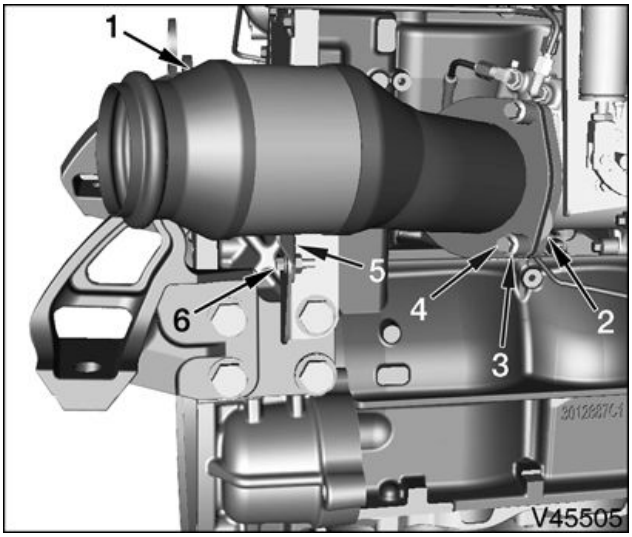


Figure 161 PDOC

1. PDOC
2. Engine brake gasket
3. 11 x 20 x 24 spacer (3)
4. M10 x 50 bolt (3)
5. PDO bracket
6. M8 x 25 bolt (3)

1. Install PDO bracket with three M8 x 25 bolts. Install bolts finger tight.
2. Install PDOC and new engine brake gasket to thermal management valve housing.
3. Install three M10 x 50 bolts and three 11 x 20 x 24 spacers. Tighten bolts to special torque (page 138).

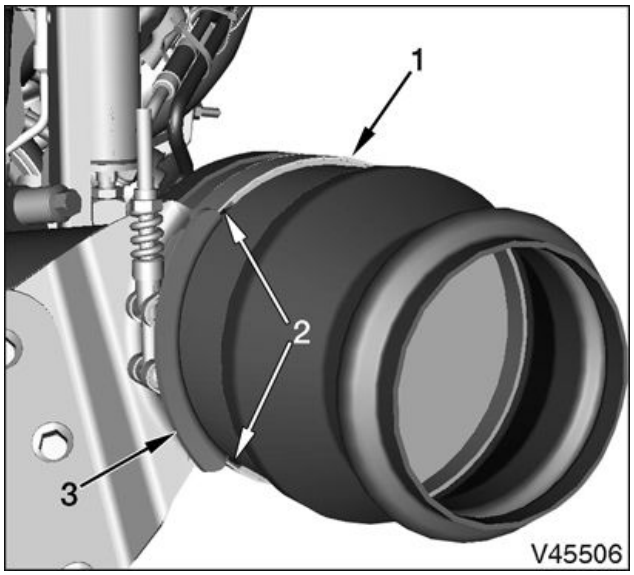


Figure 162 PDOC clamp

1. Clamp
2. 0.315 – 0.393 in (8 – 10 mm) space
3. PDO bracket

NOTE: The clamp has three spacers welded to the inside surface which are intended to distribute the load equally. Ensure there is equal space of at least 0.315 in (8 mm) between the PDO bracket and the spacer on the inside of the clamp on either side of the bracket.

4. Secure PDOC to PDO bracket with clamp. Ensure the spacers are an equal distance of at least 0.315 in (8 mm) at either side of the PDO bracket, and tighten clamp to special torque (page 138).
5. Tighten three M8 x 25 bolts to standard torque (page 503)

HCI Fuel Tube Assembly

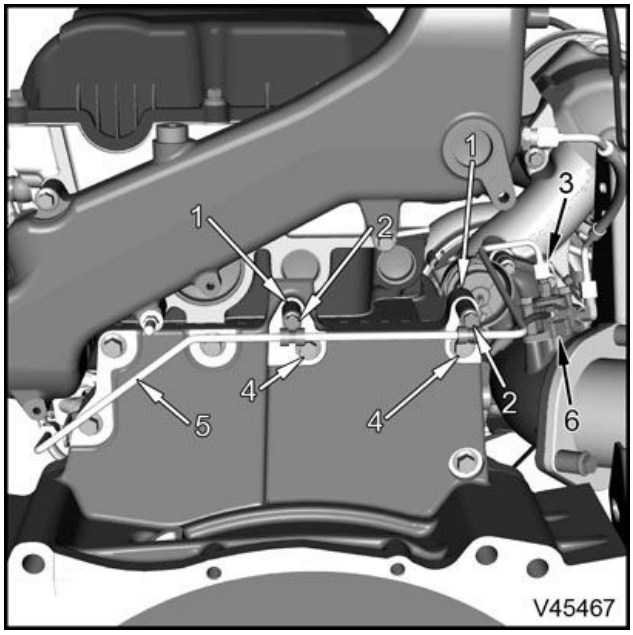


Figure 163 HCI fuel 2 tube assembly

1. 6.6 x 15 x 23 spacer (2)
2. M6 x 40 bolt (2)
3. HCI fuel 2 tube assembly nut
4. P 6 x 15 clamp (2)
5. HCI fuel 2 tube assembly
6. Hydrocarbon Injector (HCI) assembly

1. Position HCI fuel 2 tube assembly onto engine.
2. Connect HCI fuel 2 tube assembly onto hydrocarbon injector assembly.
3. Install two M6 x 40 bolts, 2 clamps and two 6.6 x 15 x 23 spacers. Tighten bolts to standard torque (page 503).
4. Using a wrench, hold the hydrocarbon injector assembly hex to keep it from rotating. Tighten HCI fuel 2 tube nut to special torque (page 138), while holding the injector body hex.

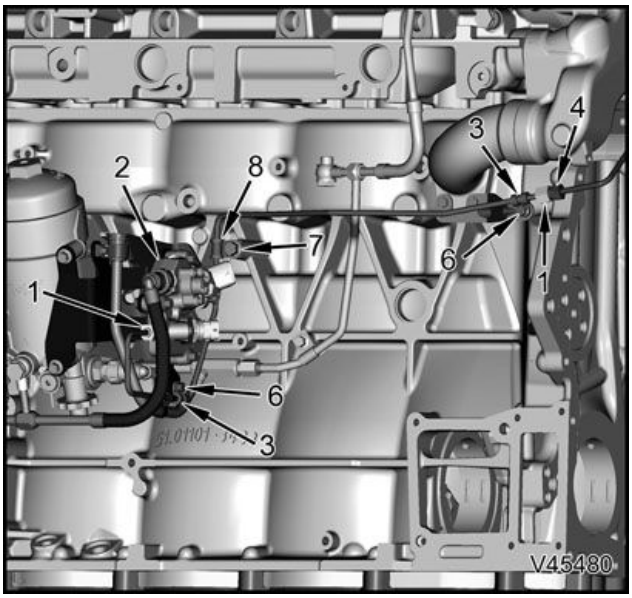


Figure 164 HCI fuel 1 and 2 tube assemblies

1. HCI fuel 1 tube assembly nut (2)
2. Metering unit valve assembly
3. P 6 x 15 clamp (2)
4. HCI fuel 2 tube assembly fitting (brazed to tube)
5. M6 x 16 bolt (2)
6. M10 x 16 bolt
7. Cushioned 1/4 inch diameter clamp

5. Position HCI fuel 1 tube assembly to engine. Loosely connect fuel 1 tube with fuel 2 tube and metering unit valve assembly.
6. Install two M6 x 16 bolts, one M10 x 16 bolt, two P 6 x 15 clamps and cushioned 1/4 inch diameter clamp. Tighten bolts to standard torque (page 503) .

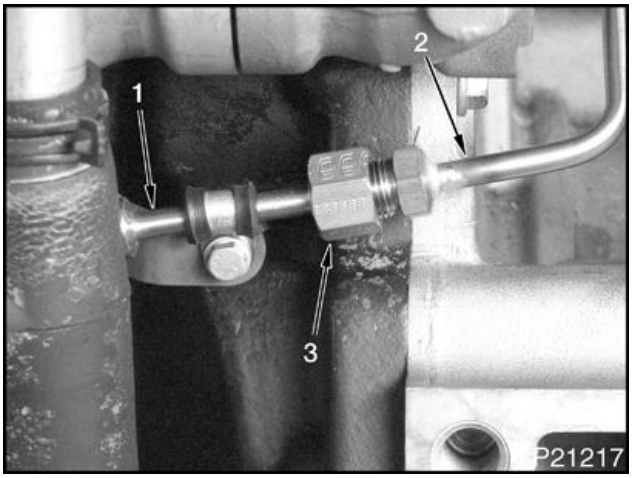


Figure 165 Fuel supply assembly connection

1. HCI fuel 1 tube assembly
2. HCI fuel 2 tube assembly
3. HCI fuel 1 tube assembly nut
4. M6 x 16 bolt

7. Tighten HCI fuel 1 tube assembly nut at HCI fuel 2 tube nut (brazed) to special torque (page 138).
8. Tighten HCI fuel 1 tube assembly nut at metering unit valve assembly to special torque (page 138).
9. Connect clamp from fuel drain tube to HCI fuel 1 tube assembly.

Special Torque

Table 7 Aftertreatment System

Coolant supply (straight) fitting at coolant manifold	35 N·m (26 lbf·ft)
Fitting (quick-connect adapter) at metering unit valve assembly	35 N·m (26 lbf·ft)
Fitting (straight union orifice) at metering unit valve assembly	35 N·m (26 lbf·ft)
HCI coolant supply and return tube nut at tube M10 elbow fittings	15 N·m (11 lbf·ft)
HCI coolant supply tube nut at coolant manifold	25 N·m (18 lbf·ft)
HCI fuel 1 tube assembly nut at HCI fuel 2 tube fitting (brazed)	25 N·m (18 lbf·ft)
HCI fuel 1 tube assembly nut at metering unit valve assembly	25 N·m (18 lbf·ft)
HCI fuel 2 tube assembly nut at hydrocarbon injector assembly	18 N·m (13 lbf·ft)
Hydrocarbon injector assembly M8 x 45 bolt	See tightening steps in procedure.
Hydrocarbon injector assembly body to assembly (if accidentally loosened during fuel tube nut service)	20 N·m (15 lbf·ft)
PDOC clamp	3 N·m (26 lbf·in)
PDOC M10 x 50 bolts	36 N·m (27 lbf·ft)
Tube M10 elbow fittings at hydrocarbon injector assembly	17.5 N·m (13 lbf·ft)

Special Service Tools

Table 8 Aftertreatment System

Description	Tool Number
Fuel Line Disconnect Tool 11.8 mm	ZTSE4773
P-80® rubber lubricant or equivalent	Obtain locally

Table of Contents

Exploded Views.....141
- **Control System**.....141

Removal.....142
- **Warnings**.....142
- **Air Control Valve (ACV)**.....143
- **Exhaust Back Pressure Valve Actuator and TC1 Turbine Outlet Pressure Sensor Tubes**.....144
- **Exhaust Back Pressure Valve Assembly**.....145

Installation.....145
- **Exhaust Back Pressure Valve Assembly**.....145
- **Air Control Valve (ACV)**.....146
- **Exhaust Back Pressure Valve Actuator and TC1 Turbine Outlet Pressure Sensor Tubes**.....147

Special Torque.....150

Special Service Tools.....150

Exploded Views

Control System

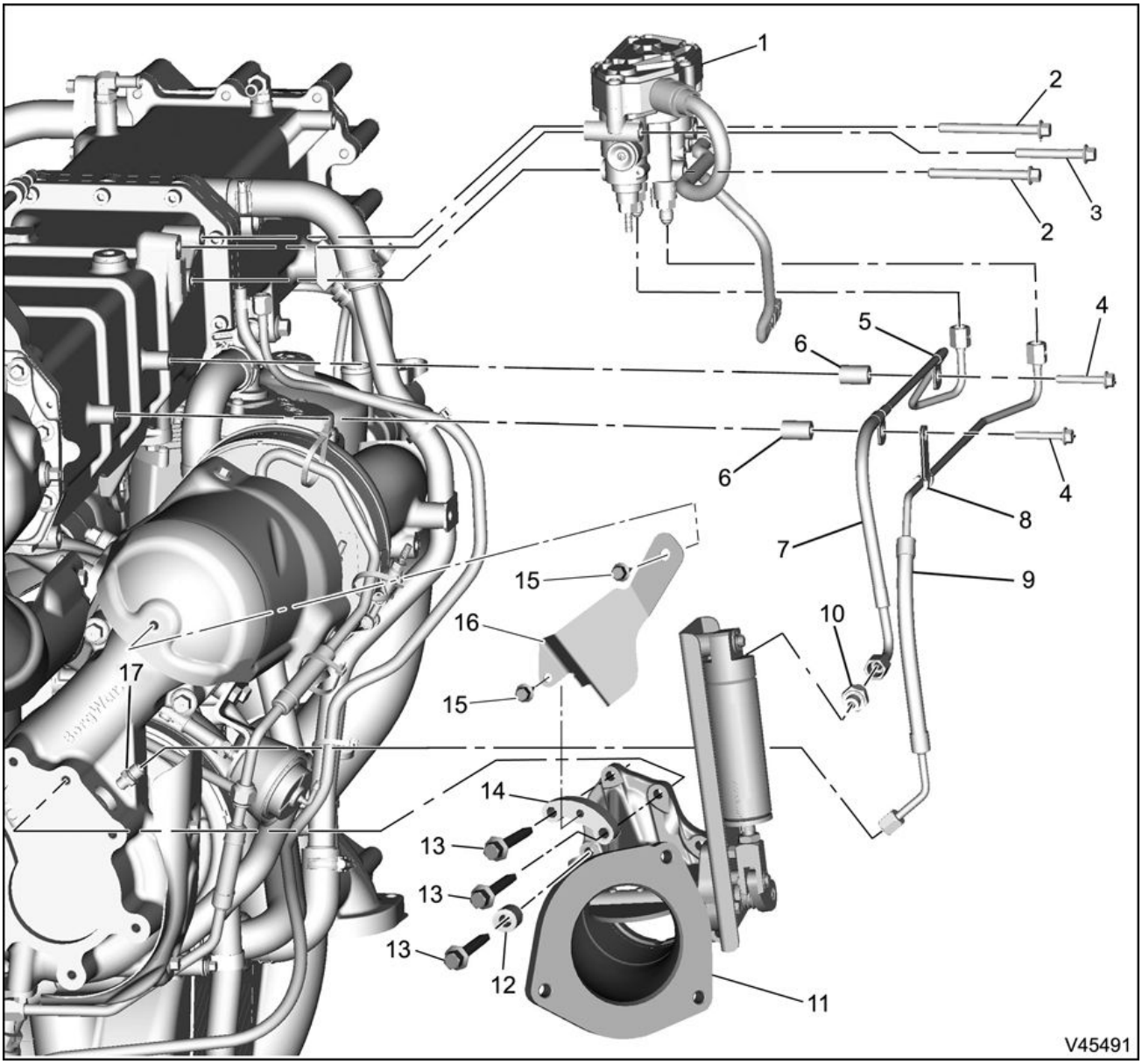


Figure 166 Exhaust back pressure control system

1. Air control valve (ACV) [updated]
2. M8 x 85 bolt (2)
3. M8 x 65 bolt (if equipped)
4. M6 x 40 bolt
5. Exhaust back pressure valve tube bracket (2)
6. Spacer
7. Exhaust back pressure valve tube assembly
8. Tube bracket
9. TC1 turbine outlet pressure (TC1TOP) sensor tube assembly
10. Flare M10 x 1.5 (37 degree) fitting
11. Exhaust back pressure valve assembly
12. Spacer (5)
13. M8 x 45 bolt (7)
14. Heat shield spacer
15. M8 x 16 bolt
16. Heat shield
17. Flare M10 x M12 (24 degree) fitting

Removal

Warnings

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.

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

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

- Engine Electrical
- Aftertreatment System

Air Control Valve (ACV)

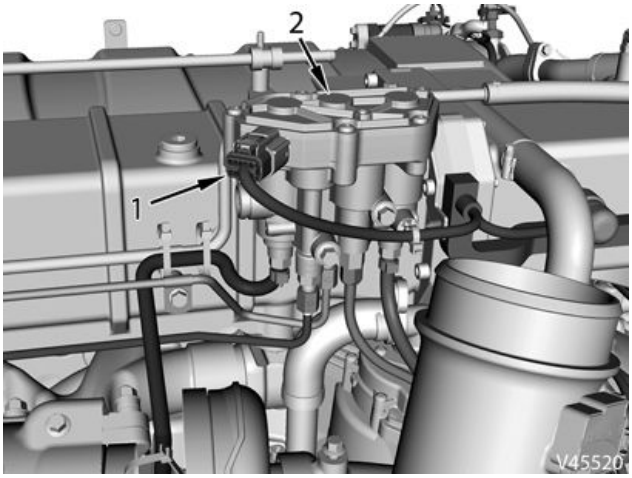


Figure 167 Early production ACV

1. Air Control Valve (ACV)
2. 10-way electrical connector

Figure 168 Updated ACV with pigtail harness

1. Air Control Valve (ACV)
2. Pigtail harness

NOTE: Various Air Control Valves (ACV) have been used on this engine. Early production ACVs have the 10-way electrical connector on the ACV housing (Figure 167), and updated 3-bolt ACVs have a pigtail harness that relocates the 10-way pigtail connector (Figure 168).

1. If engine has an early production ACV with the 10-way electrical connector on the ACV housing (Figure 167), install an updated ACV, also obtain Harness Boost Control Solenoid Exhaust Back Pressure Kit and install a new ACV 10-way connector pigtail on the engine harness.

NOTE: If engine has an early production 2-bolt EGRV coolant supply tube (Figure 175), install a new 3-bolt EGRV coolant supply tube (Figure 176).

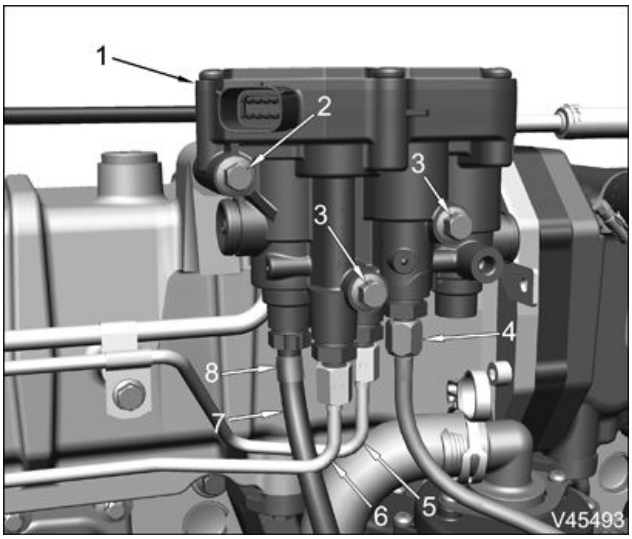


Figure 169 Early production 3-bolt Air Control Valve (ACV), bolts, and tube connections

1. ACV (early production)
2. M8 x 65 bolt (if equipped)
3. M8 x 85 bolt (2)
4. Air supply tube nut
5. Exhaust back pressure valve tube
6. TC1 turbine outlet pressure (TC1TOP) sensor tube
7. High-pressure wastegate actuator hose
8. Crimp clamp

CAUTION: Relieve system pressure before loosening air supply tube valve.

2. Loosen air supply tube nut from air control valve. Disconnect air supply tube ACV.
3. Remove crimp clamps that secures High-pressure (HP) and Low-pressure (LP) (if equipped) wastegate actuator hoses. Discard crimp clamps and disconnect hoses from the ACV.
4. Loosen TC1TOP sensor tube nut and exhaust back pressure tube nut. Disconnect tubes from control valve.

NOTE: The LP wastegate actuator is installed only on early production models, is not functional, and the hose can be removed and left off.

5. If equipped, remove and discard the LP wastegate actuator hose.
6. Remove one M8 x 65 bolt (if equipped), two M8 x 85 bolts and control valve.

Exhaust Back Pressure Valve Actuator and TC1 Turbine Outlet Pressure Sensor Tubes

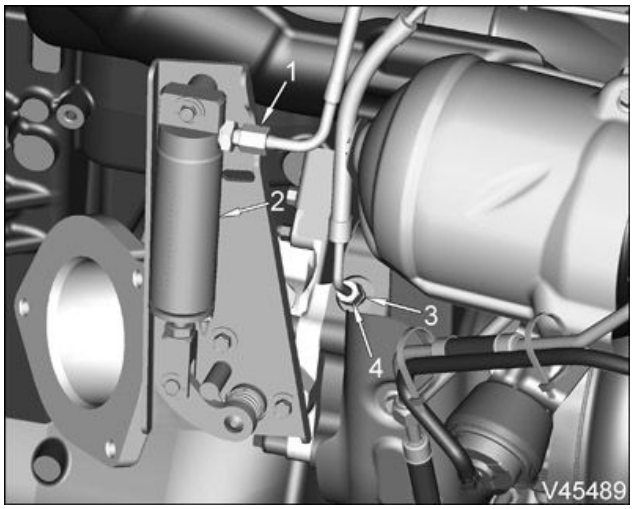


Figure 170 Exhaust back pressure valve actuator and TC1 turbine outlet pressure (TC1TOP) sensor tubes

1. Exhaust back pressure valve tube nut
2. Exhaust back pressure valve actuator
3. TC1TOP sensor tube nut
4. M10 x M12 flare fitting (24 degree)

1. Loosen exhaust back pressure valve tube nut from exhaust back pressure valve actuator and disconnect tube.
2. Loosen TC1TOP sensor tube nut from low-pressure turbocharger housing flare M10 x M12 (24 degree) fitting and disconnect tube.
3. If necessary, remove M10 x M12 flare fitting (24 degree).

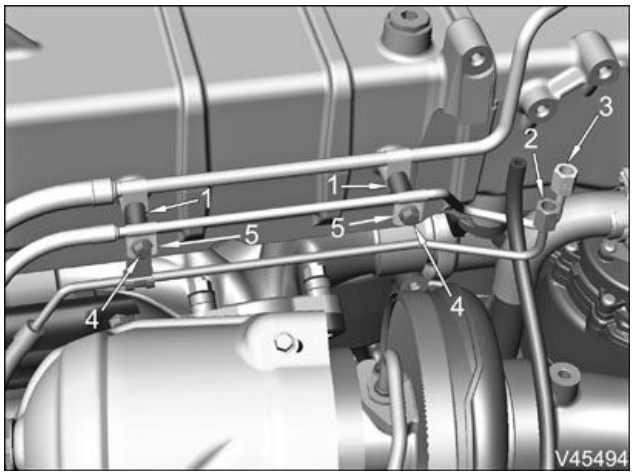


Figure 171 TC1TOP sensor tube and exhaust back pressure valve tube (typical)

1. TC1TOP sensor tube bracket
2. TC1TOP sensor tube
3. Exhaust back pressure valve tube
4. M6 x 40 bolt (2)
5. Exhaust back pressure valve tube bracket (2)

4. Remove two M6 x 40 bolts, exhaust back pressure valve tube and TC1TOP sensor tube.

Exhaust Back Pressure Valve Assembly

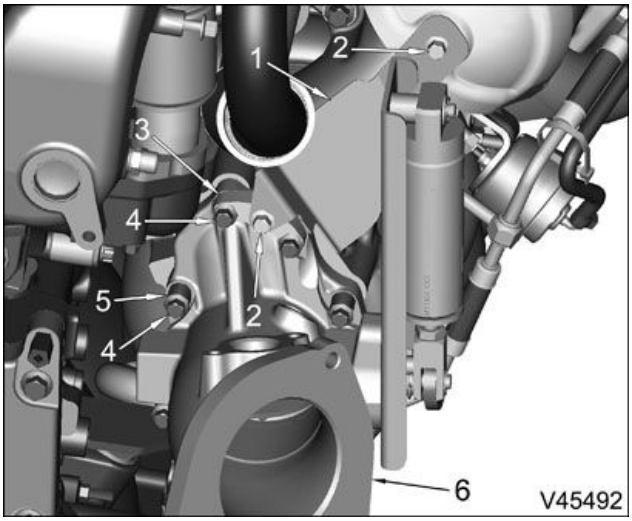


Figure 172 Exhaust back pressure valve Assembly

1. Heat shield
2. M8 x 16 bolt (2)
3. Heat shield spacer
4. M8 x 45 bolt (7)
5. Spacer (5)
6. Exhaust back pressure valve assembly

1. Remove two M8 x 16 bolts that secure the heat shield to the HP turbocharger and exhaust back pressure valve assembly.
2. Remove heat shield.
3. Remove seven M8 x 45 bolts, the heat shield spacer, five spacers, and exhaust back pressure valve assembly.

Installation

Exhaust Back Pressure Valve Assembly

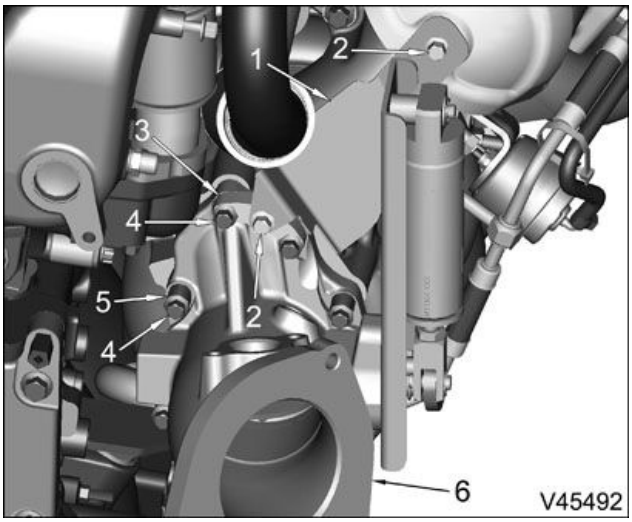


Figure 173 Exhaust back pressure valve Assembly

1. Heat shield
2. M8 x 16 bolt (2)
3. Heat shield spacer
4. M8 x 45 bolt (7)
5. Spacer (5)
6. Exhaust back pressure valve assembly

1. Position the exhaust back pressure valve assembly, install five spacers, the heat shield spacer, and seven M8 x 45 bolts.
2. Tighten M8 x 45 bolts to standard torque (page 503).
3. Position heat shield, and install two M8 x 16 bolts. Tighten M8 x 16 bolts to standard torque (page 503).

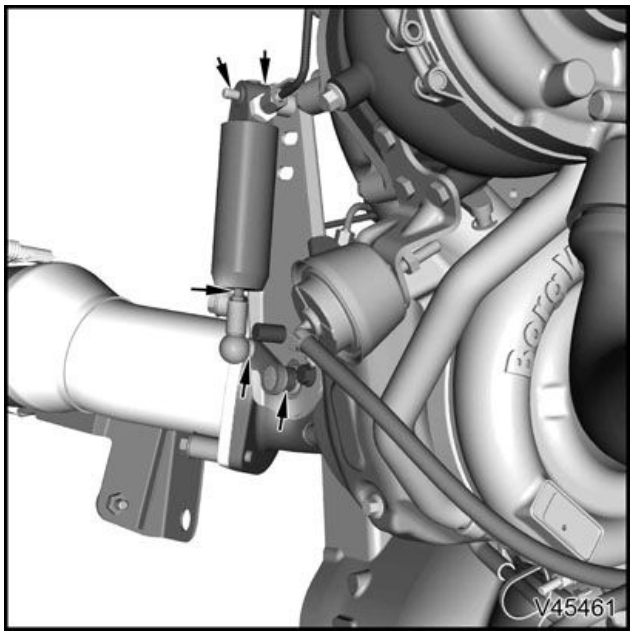


Figure 174 Exhaust back pressure valve actuator lubrication points

4. Apply Superlub™ synthetic high heat lubricant (page 150) or equivalent to areas indicated.

Air Control Valve (ACV)

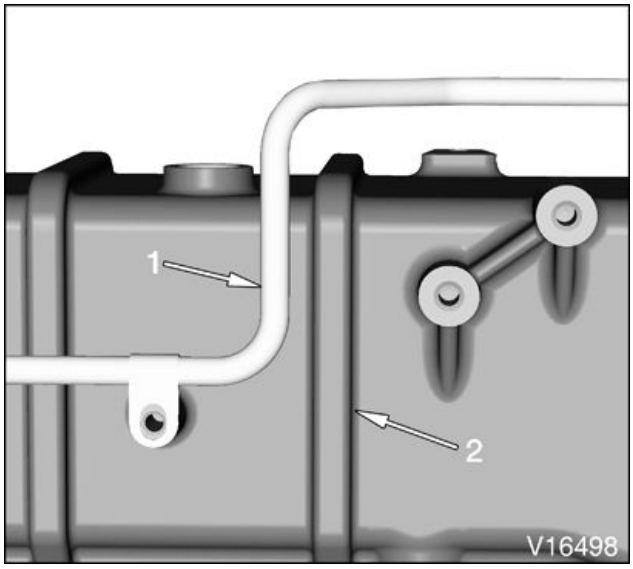


Figure 175 EGRV coolant supply tube and EGR cooler (2-bolt early production)

1. EGRV coolant supply tube assembly (Early production)
2. EGR cooler casting rib

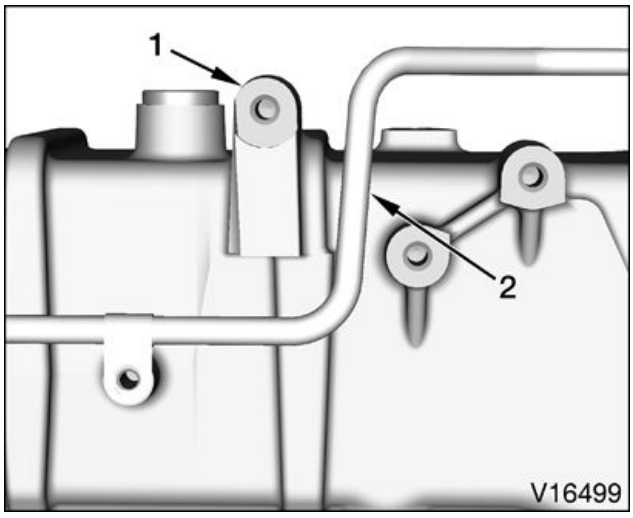


Figure 176 EGRV coolant supply tube and EGR cooler (Updated 3-bolt version)

1. EGR cooler third ACV mounting bolt boss (if equipped)
2. EGRV coolant supply tube assembly (updated version)

1. Determine if the EGRV coolant supply tube assembly is the early production 2-bolt version with the vertical portion to the left of the EGR cooler casting rib (Figure 175) or the updated 3-bolt version that has the vertical on the right side of the third ACV mounting bolt boss of the EGR cooler (Figure 176).

   - If engine has an early production 2-bolt EGRV coolant supply tube assembly (Figure 175), obtain EGRV Coolant Supply Tube Kit and install a new updated 3-bolt EGRV coolant supply tube assembly.

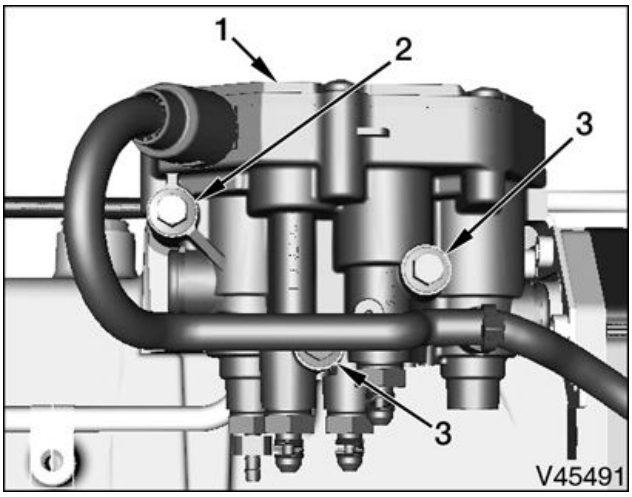


Figure 177 Air control valve tubes and hoses

1. Air Control Valve (ACV)
2. M8 x 65 bolt
3. M8 x 85 bolt (2)

2. Position new ACV onto the EGR cooler and install two saved M8 x 85 bolts finger tight. Tighten bolts to standard torque (page 503).

   - If EGR cooler has a third ACV mounting bolt boss, install new M8 x 65 bolt. Tighten bolt to standard torque (page 503)
   - If EGR cooler does not have a third ACV mounting bolt boss, the M8 x 65 bolt is not used.

Exhaust Back Pressure Valve Actuator and TC1 Turbine Outlet Pressure Sensor Tubes

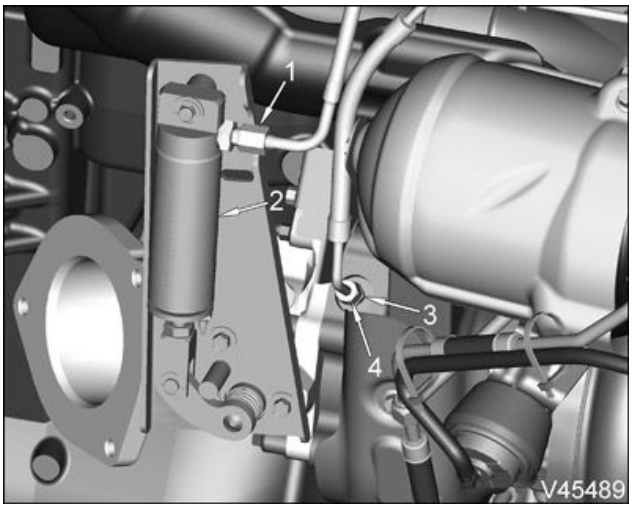


Figure 178 Exhaust back pressure valve actuator and TC1 turbine outlet pressure (TC1TOP) sensor tubes

1. Exhaust back pressure valve tube nut
2. Exhaust back pressure valve actuator
3. TC1TOP sensor tube nut
4. M10 x M12 flare fitting (24 degree)

1. Install exhaust back pressure valve tube nut onto exhaust back pressure valve actuator. Leave loose at this time.
2. If removed, install and tighten M10 x M12 flare fitting (24 degree) to special torque (page 150).
3. Position TC1TOP sensor tube nut to low-pressure turbocharger housing M10 x M12 flare fitting (24 degree). Leave loose at this time.

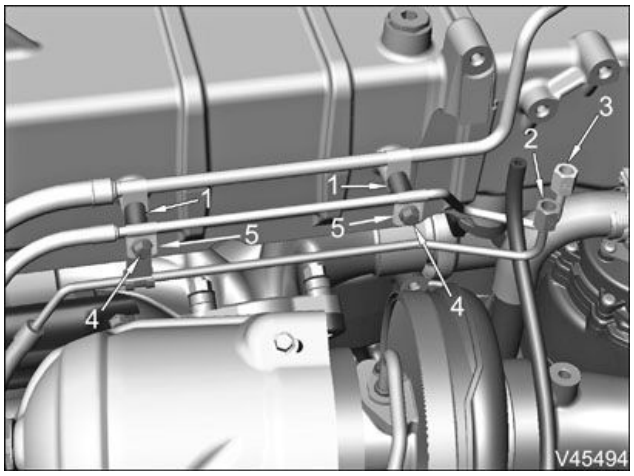


Figure 179 TC1TOP sensor tube and exhaust back pressure valve tube (typical)

1. TC1TOP sensor tube bracket
2. TC1TOP sensor tube
3. Exhaust back pressure valve tube
4. M6 x 40 bolt (2)
5. Exhaust back pressure valve tube bracket (2)

4. Position exhaust back pressure valve tube and TC1TOP sensor tube against EGR cooler. Using two M6 x 40 bolts and two spacers, secure tubes to EGR cooler. Tighten bolts to standard torque (page 503).

Figure 180 Air control valve tubes and hoses

1. M8 x 65 bolt
2. M8 x 85 bolt (2)
3. Low-pressure wastegate actuator port (not used)
4. Air supply (from air tank)
5. Exhaust back pressure valve tube
6. High-pressure (HP) wastegate actuator hose
7. Pressure sensor tube assembly [Turbocharger 1 Turbine Outlet Pressure (TC1TOP)]

5. Connect exhaust back pressure valve tube and pressure sensor tube assembly to ACV. Tighten tube nuts to special torque (page 150).
6. Connect air supply hose to ACV. Tighten nut to special torque (page 150).
7. Slide a new crimp clamp onto HP wastegate actuator hose and connect hose to ACV. Secure hose with crimp clamp using Clamp Pliers (LIS30800).

NOTE: The LP wastegate actuator is installed only on early production models, is not functional, and the hose can be removed and left off.

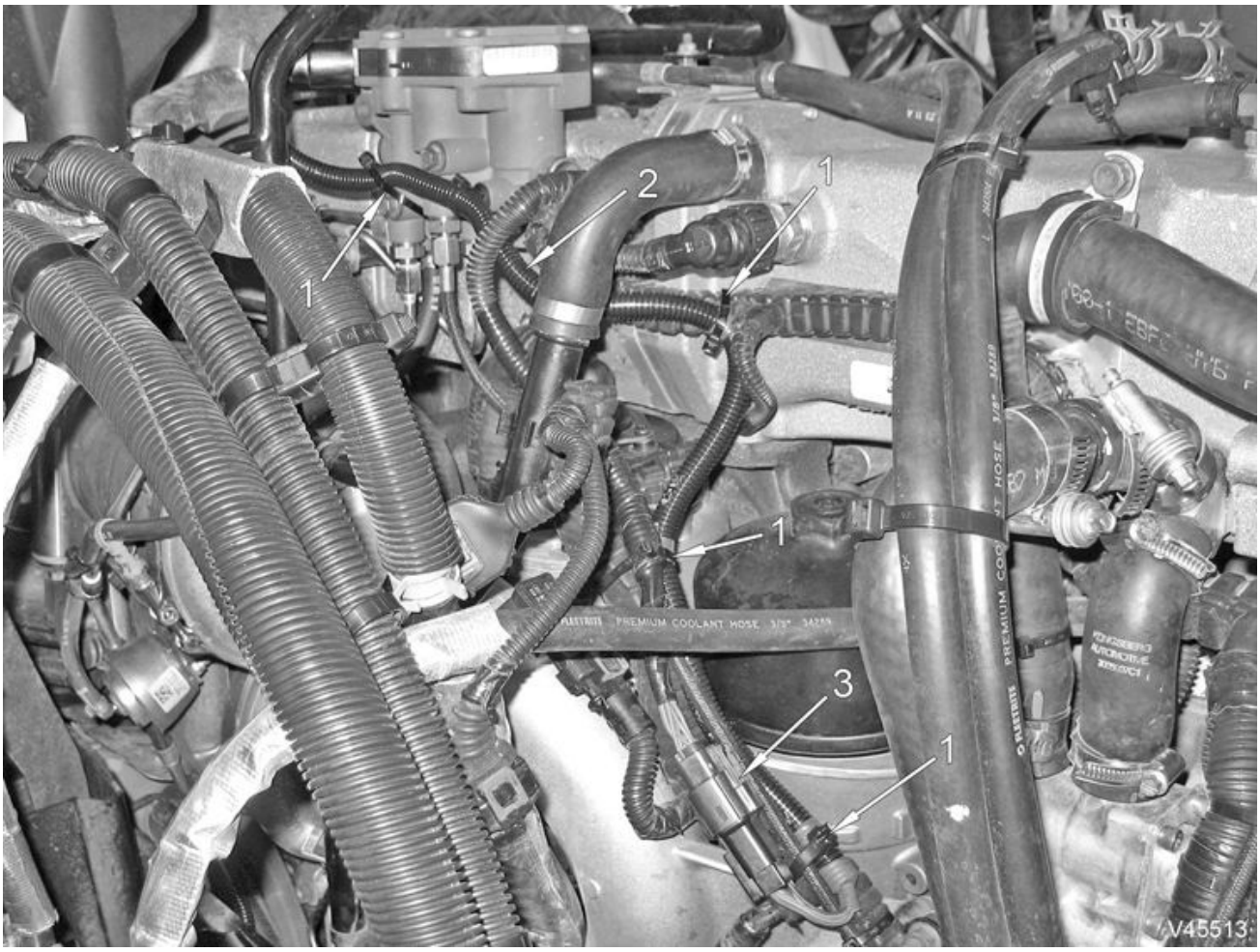


Figure 181 ACV harness routing and tie strap locations

1. Tie straps
2. ACV harness
3. 10-way connector

8. Push ACV harness 10-way connector onto the engine harness 10-way connector until a click is heard, and pull gently to verify that the 10-way connector is securely latched.
9. Secure ACV harness and engine harness with tie straps as shown in (Figure 181).

Special Torque

Table 9 Exhaust Back Pressure Control

Air supply tube (at bulkhead fitting)	17.5 N·m (13 lbf·ft)
Air supply tube nut (at air control valve)	12 N·m (106 lbf·in)
Exhaust back pressure valve tube nut (at actuator)	15 N·m (11 lbf·ft)
Exhaust back pressure valve tube nut (at air control valve)	15 N·m (11 lbf·ft)
Flare M10 x M12 (24 degree) fitting	17.5 N·m (13 lbf·ft)
TC1TOP sensor tube nut (at air control valve)	15 N·m (11 lbf·ft)
TC1TOP sensor tube nut at flare M10 x M12 (24 degree) fitting	15 N·m (11 lbf·ft)

Special Service Tools

Table 10 Exhaust Back Pressure Control

Description	Tool Number
Crimping pliers	Obtain locally
Superlub™ synthetic high heat lubricant	Obtain locally

Table of Contents

Exploded Views.....153
- **Turbochargers and Charge Air Cooler Assembly**.....153
- **Coolant Tube, Coolant Hoses and Low-pressure Charge Air Cooler (LPCAC)**.....154
- **Turbocharger Oil Supply Tube and Support Bracket**.....155
- **Turbocharger Oil Return Tubes**.....156
- **Air Inlets, Wastegate High-Pressure Actuator, and Air Control Valve**.....157
- **Turbochargers**.....158

Removal.....159
- **High-pressure (HP) Wastegate Hose**.....159
- **Low-pressure Charge Air Cooler (LPCAC)**.....160
- **Low-pressure Charge Air Cooler (LPCAC) Coolant Tube and Hoses**.....161
- **High-pressure (HP) Compressor Out Duct and Air Inlet Duct**.....163
- **High-pressure Turbocharger Air Supply Duct**.....163
- **Turbocharger Oil Return and Oil Supply Tubes**.....164
- **Turbocharger Heat Shields**.....165
- **Turbocharger Support Bracket**.....166
- **High-pressure (HP) Turbocharger Wastegate Actuator**.....166
- **Turbocharger Mounting**.....167

Disassembly.....168
- **Turbochargers**.....168

Cleaning and Inspection.....169
- **Turbochargers and Related Parts Cleaning**.....169
- **Turbocharger Inspection**.....169
- **Low-pressure Charge Air Cooler (LPCAC) Pressure Test**.....169

Installation.....171
- **Turbocharger Mounting**.....171
- **Turbocharger Support Bracket**.....173
- **High-pressure (HP) Turbocharger Wastegate Actuator**.....173
- **Turbocharger Heat Shields**.....174
- **Turbocharger Oil Return and Oil Supply Tubes**.....174
- **High-pressure Turbocharger Air Supply Duct**.....176
- **High-pressure (HP) Compressor Out Duct and Air Inlet Duct**.....176
- **Low-pressure Charge Air Cooler (LPCAC) Coolant Tube and Hoses**.....177
- **Low-pressure Charge Air Cooler (LPCAC)**.....179
- **High-pressure (HP) Wastegate Hose**.....180

Special Torque.....181

Special Service Tools.....181

Exploded Views

Turbochargers and Charge Air Cooler Assembly

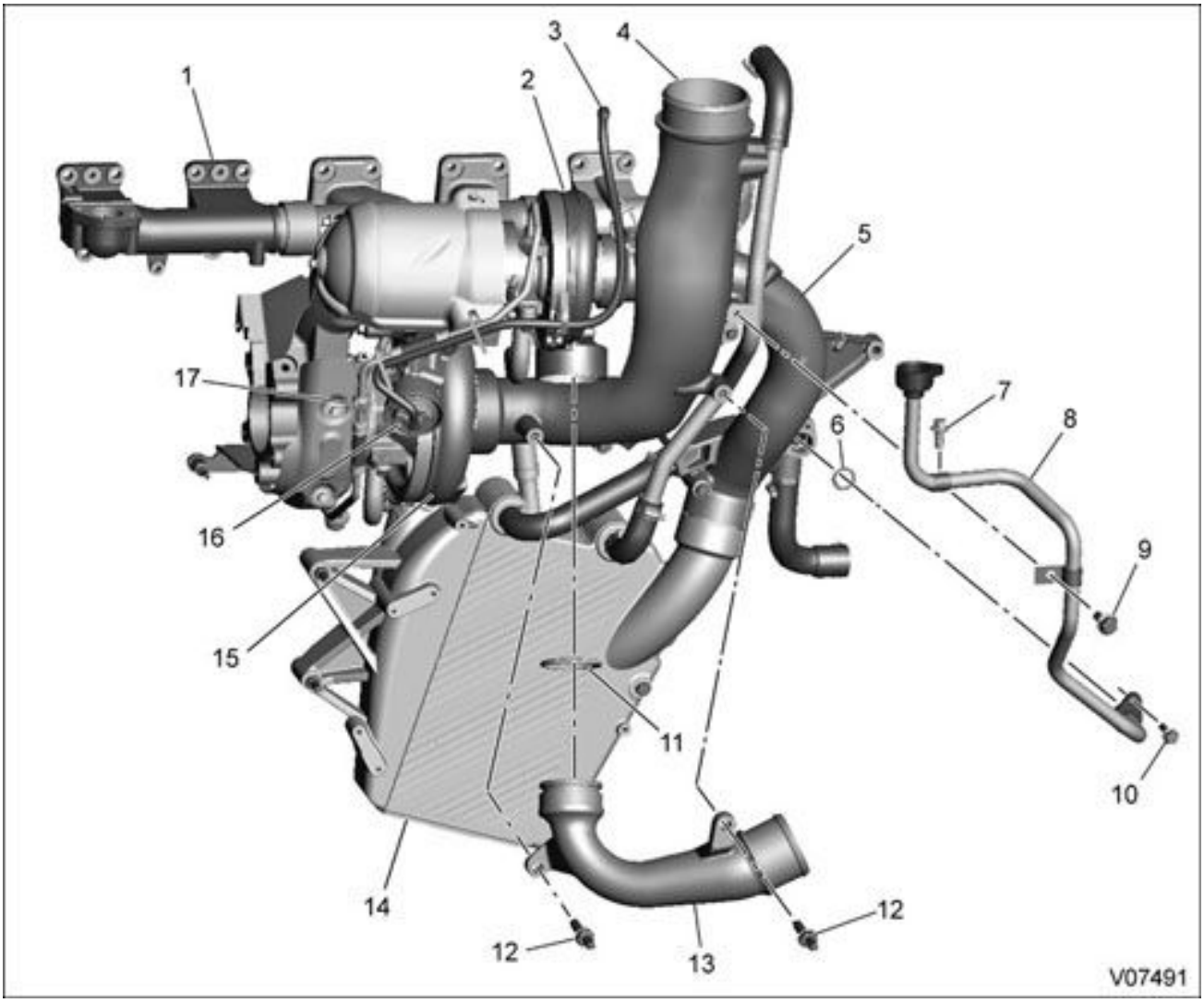


Figure 182 Turbochargers and charge air cooler assembly

1. Rear exhaust manifold
2. High-pressure turbocharger assembly
3. High-pressure wastegate hose
4. Air inlet duct
5. Air supply high-pressure turbocharger duct
6. O-ring
7. M8 x 16 bolt
8. Cab heater return tube assembly
9. M8 x 20 bolt
10. M6 x 20 bolt
11. Inlet (and outlet) high-pressure compressor seal
12. M10 x 20 x 40 stud bolt (2)
13. High-pressure compressor out duct
14. Low-pressure charge air cooler
15. Low-pressure turbocharger assembly
16. High-pressure wastegate actuator
17. Turbocharger oil supply tube assembly

Coolant Tube, Coolant Hoses and Low-pressure Charge Air Cooler (LPCAC)

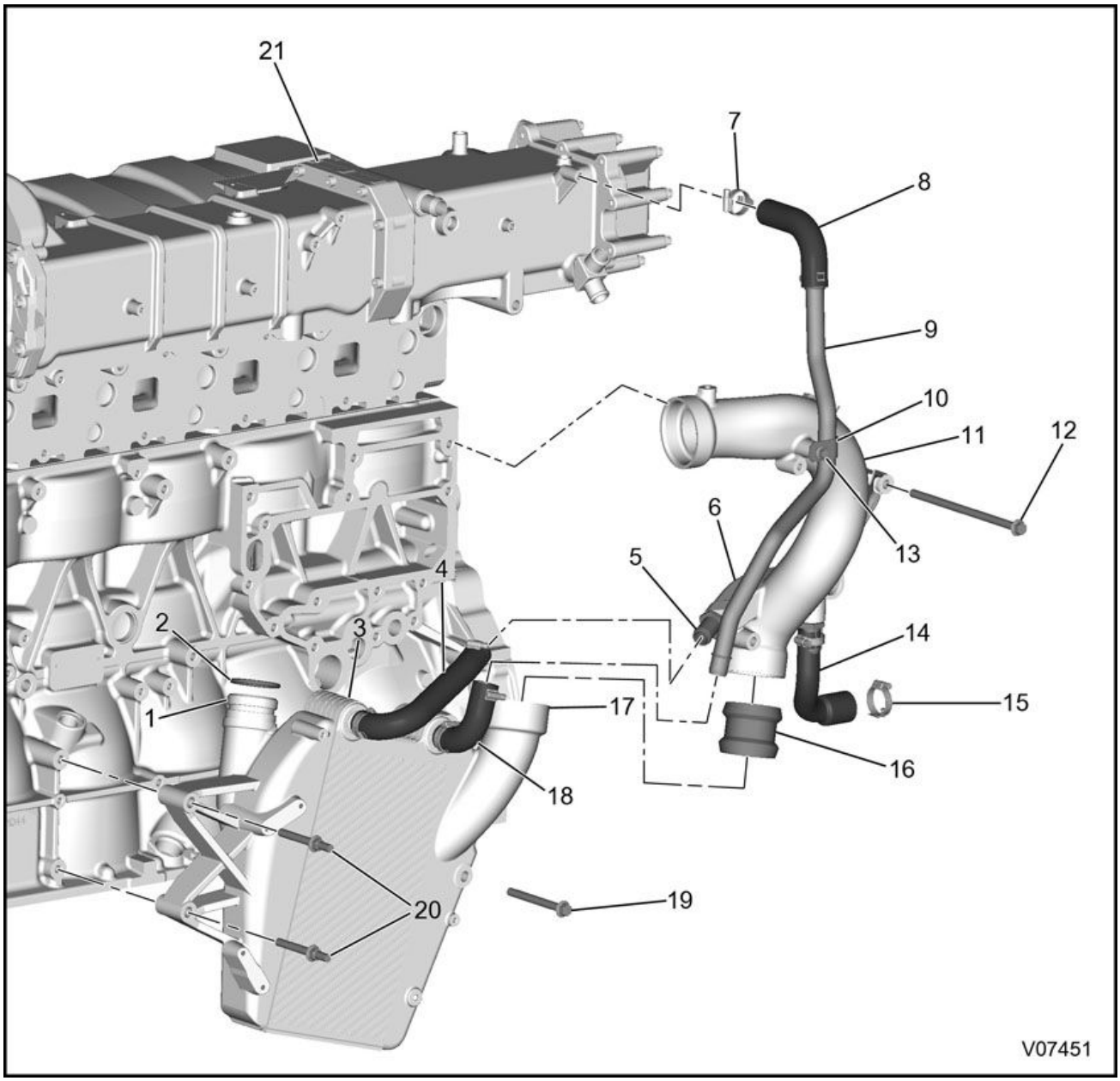


Figure 183 Coolant tube, coolant hoses and low-pressure charge air cooler (LPCAC)

1. LPCAC air inlet
2. Intake O-ring (low-pressure turbocharger to LPCAC)
3. Low-pressure charge air cooler
4. Coolant return hose (CAC to coolant return duct)
5. M24 x 1.5 threaded fitting (2)
6. Coolant return duct (integral with air supply duct)
7. 3/4 inch constant torque hose clamp (7)
8. Coolant return hose (at EGR cooler)
9. Coolant tube (EGR cooler to LPCAC)
10. Tube support
11. Air supply high-pressure turbocharger duct
12. M10 x 200 bolt (2)
13. M8 x 20 bolt
14. Coolant return hose (to water distribution housing)
15. Hose clamp (1 inch worm gear)
16. 72.2 x 60 (DMR) tube seal (extension tube)
17. LPCAC air outlet (to air supply high-pressure turbocharger duct)
18. Coolant hose (coolant tube to CAC water inlet)
19. M10 x 100 bolt
20. Ground stud bolt (2)
21. EGR cooler assembly

Turbocharger Oil Supply Tube and Support Bracket

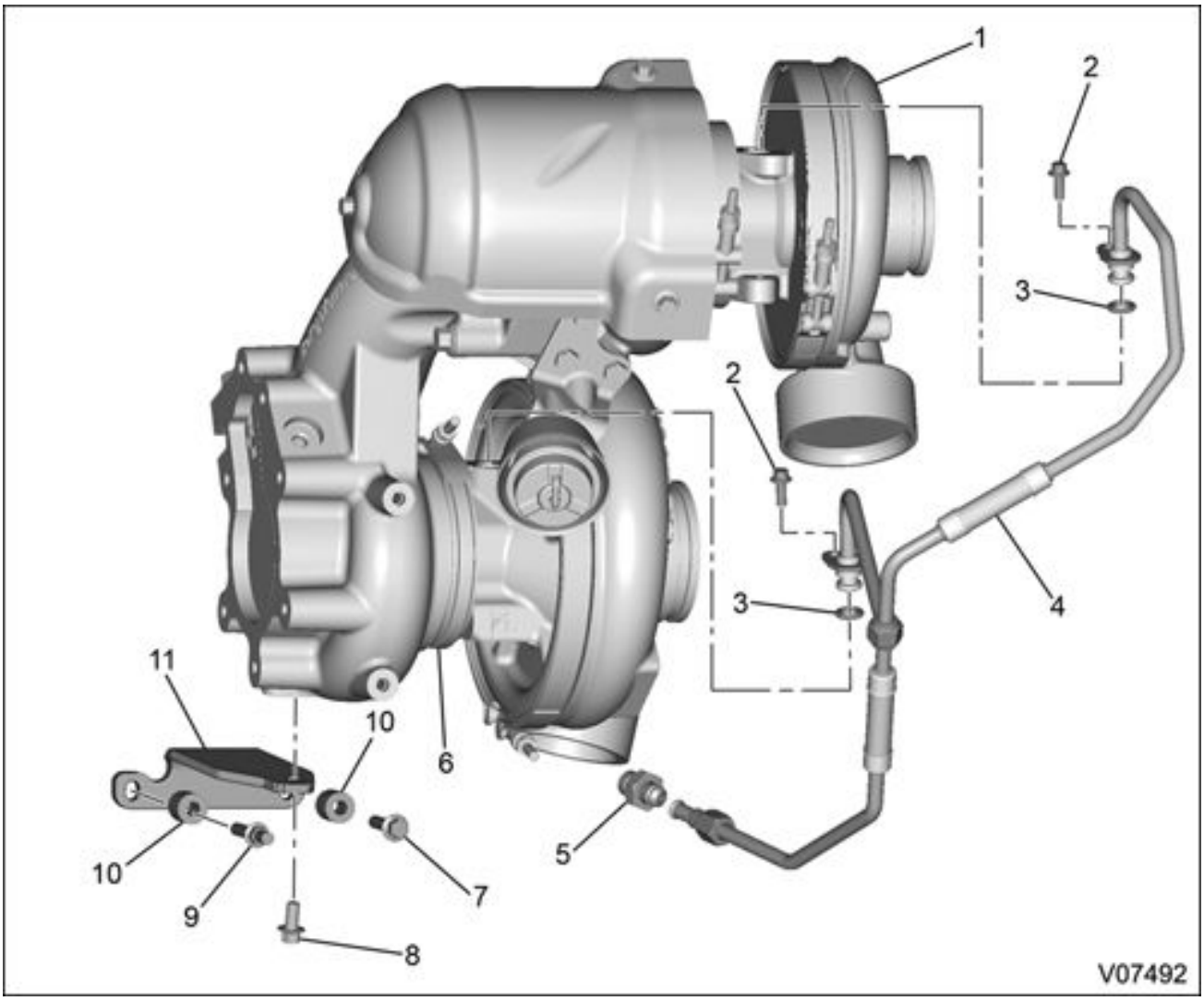


Figure 184 Turbocharger oil supply tube and support bracket

1. High-pressure turbocharger assembly
2. M6 x 16 bolt (2)
3. Turbocharger supply seal (2)
4. Turbocharger oil supply tube assembly
5. Male stud connector (on crankcase)
6. Low-pressure turbocharger assembly
7. M8 x 40 bolt
8. M8 x 16 bolt
9. M8 x 40 x 15 stud bolt
10. 19 x 20 spacer (2)
11. Turbocharger support bracket

Turbocharger Oil Return Tubes

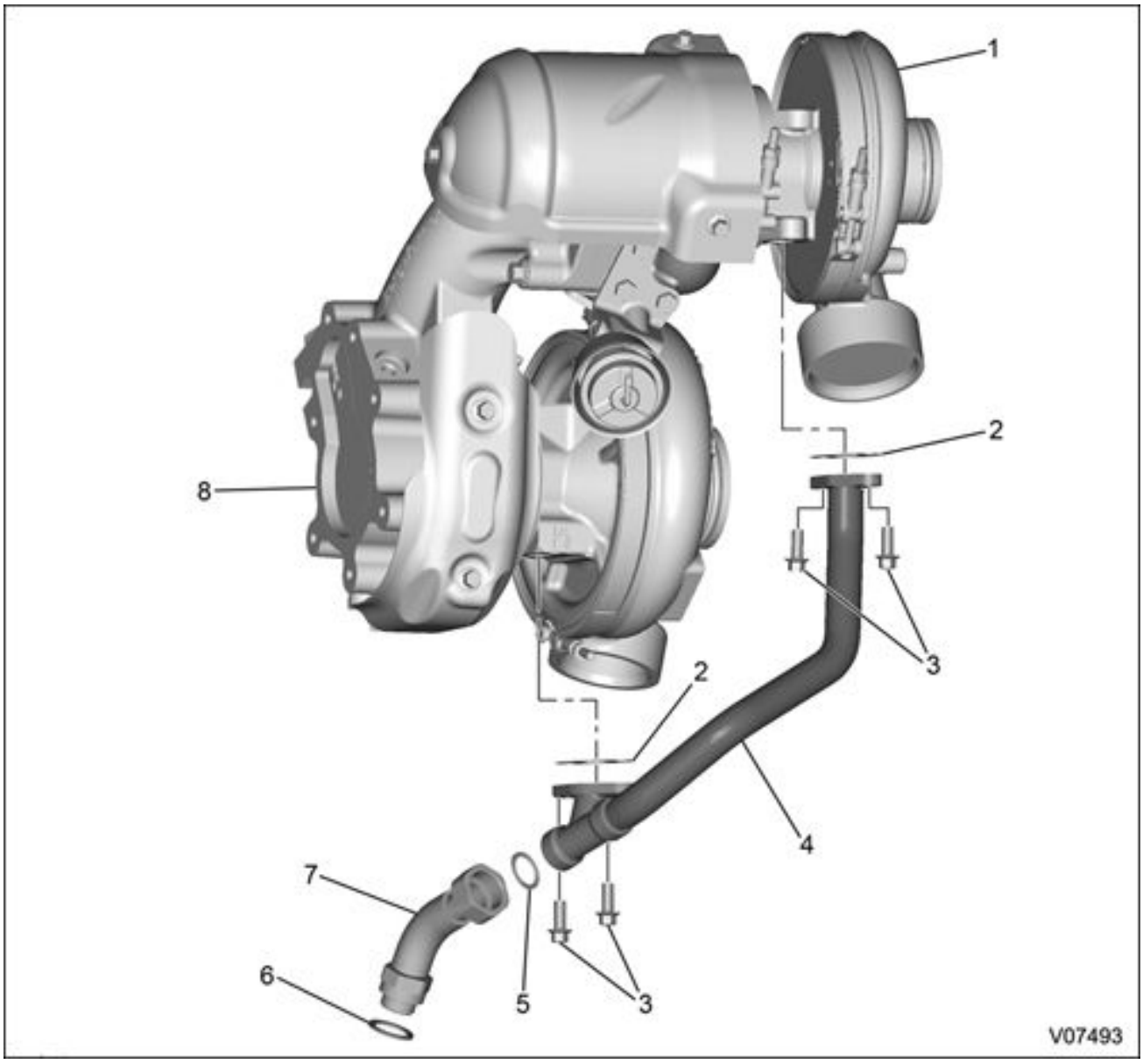


Figure 185 Turbocharger oil return tubes

1. High-pressure turbocharger assembly
2. Turbocharger oil drain gasket (2)
3. M8 x 20 bolt (4)
4. Oil return high-pressure turbocharger tube
5. Metric bonded seal washer
6. 24.7 x 32 seal ring
7. Oil return low-pressure turbocharger tube
8. Low-pressure turbocharger assembly

Air Inlets, Wastegate High-Pressure Actuator, and Air Control Valve

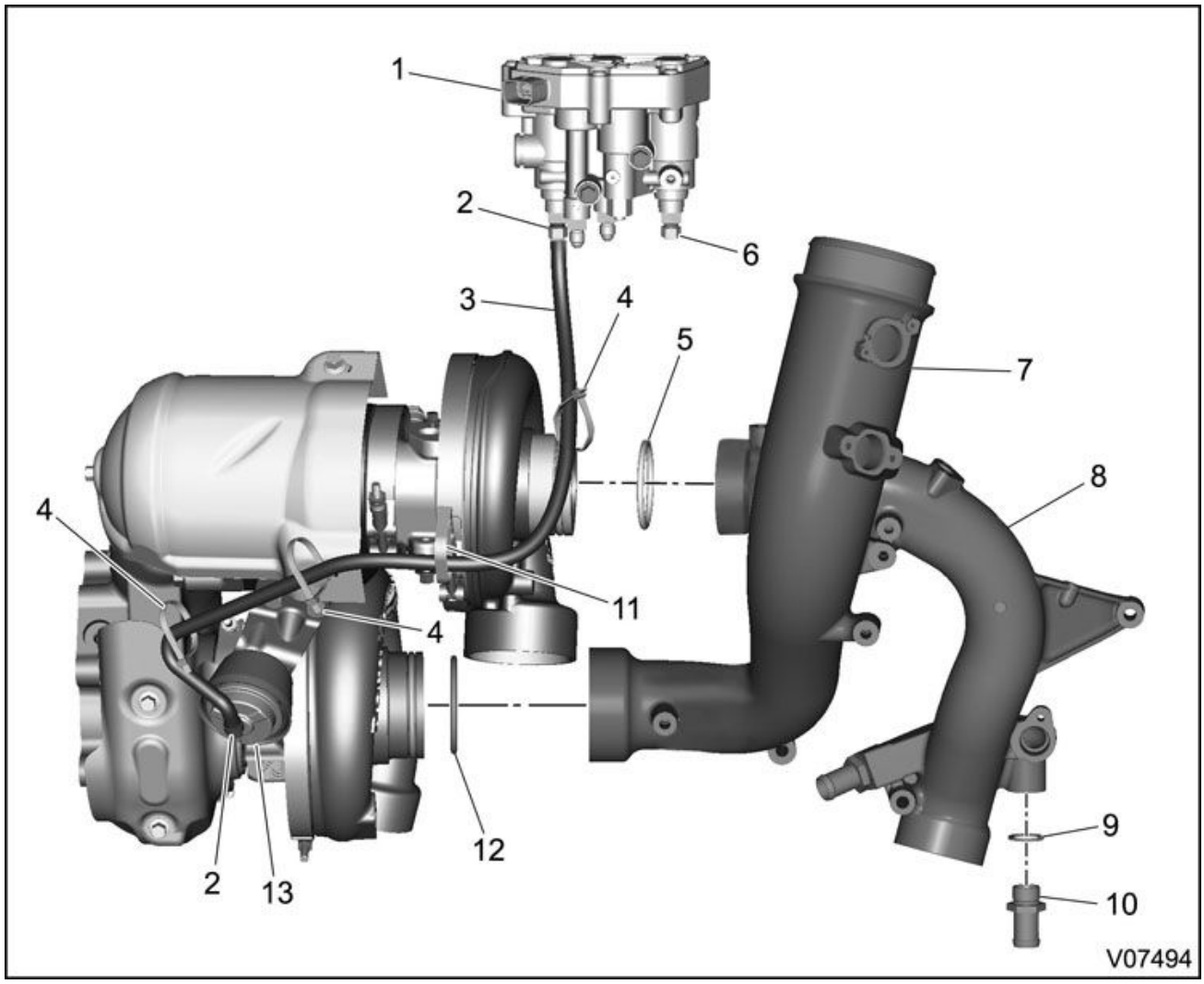


Figure 186 Air inlets, wastegate high-pressure actuator, and air control valve

1. Air control valve assembly
2. 12.3 x 7 crimp clamp (2)
3. High-pressure wastegate hose
4. Cable lock strap (3)
5. Inlet high-pressure compressor seal
6. Plug (if equipped)
7. Air inlet duct
8. Air supply high-pressure turbocharger duct
9. Seal ring (2)
10. M24 threaded fitting (2)
11. Tie strap
12. Inlet low-pressure compressor seal
13. High-pressure (HP) turbocharger wastegate actuator

Turbochargers

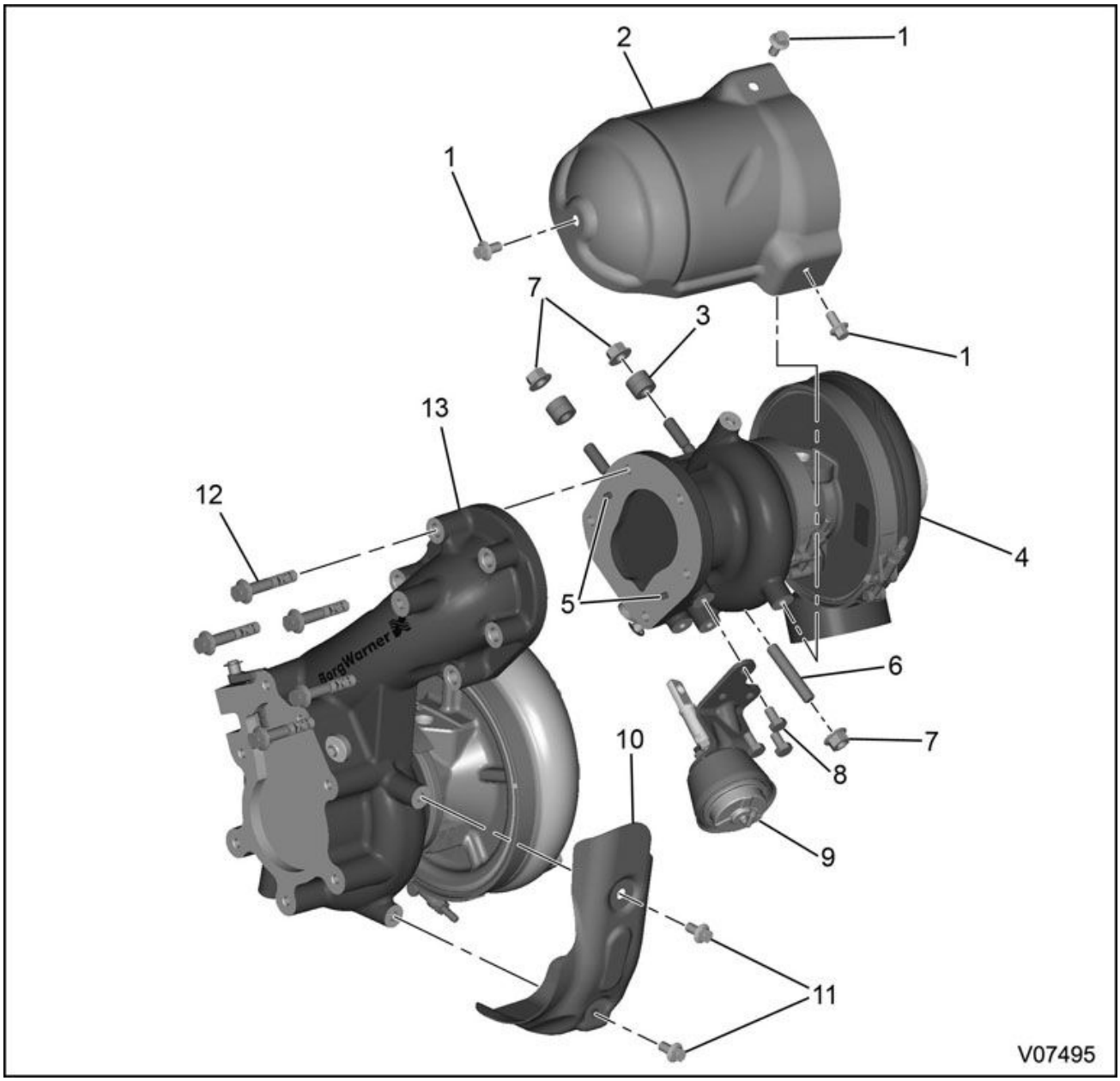


Figure 187 Turbochargers

1. M8 x 16 bolt (3)
2. High-pressure turbocharger heat shield
3. 10.5 x 20 x 15 sleeve (2)
4. High-pressure turbocharger assembly
5. Dowel pin (2)
6. M10 x 45 stud
7. M10 nut (3)
8. M8 x 14 bolt (6)
9. High-pressure turbocharger wastegate actuator
10. Turbocharger heat shield
11. M8 x 16 bolt (2)
12. M10 x 55 bolt (5)
13. Low-pressure turbocharger assembly

Removal

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

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

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

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

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

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

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

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

- Engine Electrical
- Aftertreatment System
- Exhaust Back Pressure Control
- Oil Cooler, Filter Housing and Crankcase Ventilation

High-pressure (HP) Wastegate Hose

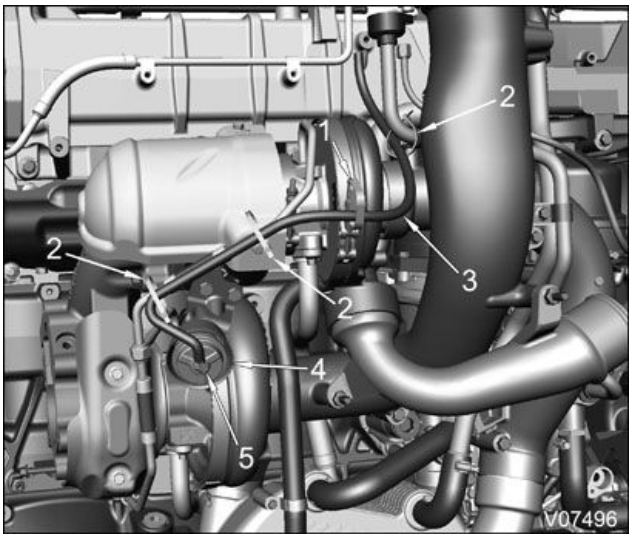


Figure 188 High-pressure (HP) wastegate Hose

1. Tie strap
2. Cable lock strap (3)
3. High-pressure (HP) wastegate hose
4. High-pressure (HP) wastegate
5. 12.3 x 7 crimp clamp

1. Cut and remove crimp clamp on HP wastegate hose on HP wastegate actuator and discard crimp clamp.
2. Cut and discard three cable lock straps.
3. Note routing of HP wastegate hose for later reassembly. Remove HP wastegate hose.
4. Inspect HP wastegate hose for damage or deformation and replace if necessary.

Low-pressure Charge Air Cooler (LPCAC)

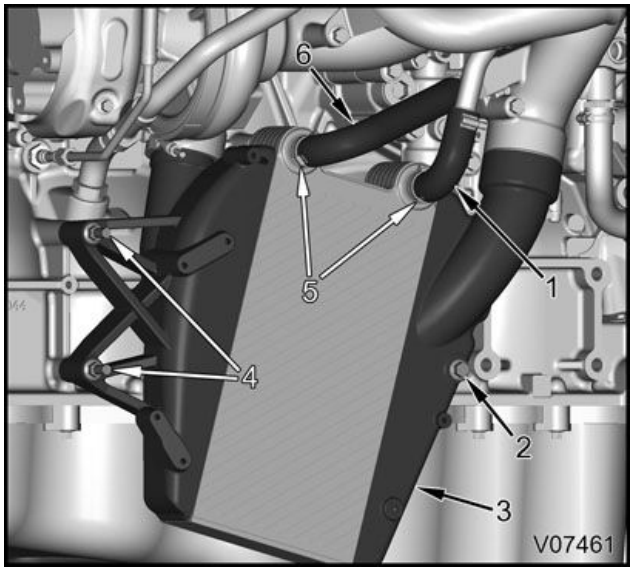


Figure 189 LPCAC and coolant hose connections

1. Coolant hose (supply)
2. M10 x 100 bolt
3. Low-pressure charge air cooler
4. Ground stud bolt (2)
5. 3/4 inch constant torque hose clamp (2)
6. Coolant return hose

NOTE: See Oil Centrifuge (page 250) for removal of the open breather tube assembly and related components.

1. Loosen 3/4 inch hose clamp and disconnect coolant hose (supply) from LPCAC.
2. Loosen 3/4 inch hose clamp and disconnect coolant return hose from LPCAC.
3. Remove M10 x 100 bolt from LPCAC.
4. Remove two M10 stud bolts from LPCAC.
5. Pull down to separate LPCAC from LP turbocharger and air supply HP turbocharger duct.

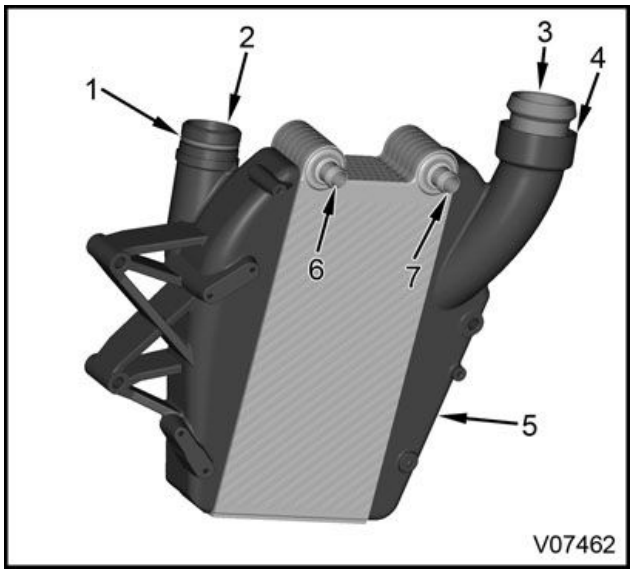


Figure 190 LPCAC

1. O-ring seal
2. LPCAC air inlet
3. 72.2 x 60 (DMR) tube seal (extension tube)
4. LPCAC air outlet
5. Low-pressure charge air cooler
6. Coolant return
7. Coolant supply

6. Remove LPCAC from engine.

CAUTION: To prevent engine damage, do not remove extension tube by grabbing sealing surface.

7. Remove 72.2 x 60 (DMR) tube seal (extension tube) from LPCAC. Do so by inserting pry bar handle (or wooden dowel) into tube seal and carefully prying side-to-side to lift tube from LPCAC. Inspect sealing surfaces of tube seal (extension tube) and LPCAC. Discard if damaged.
8. Remove O-ring seal from LPCAC and discard.

Low-pressure Charge Air Cooler (LPCAC) Coolant Tube and Hoses

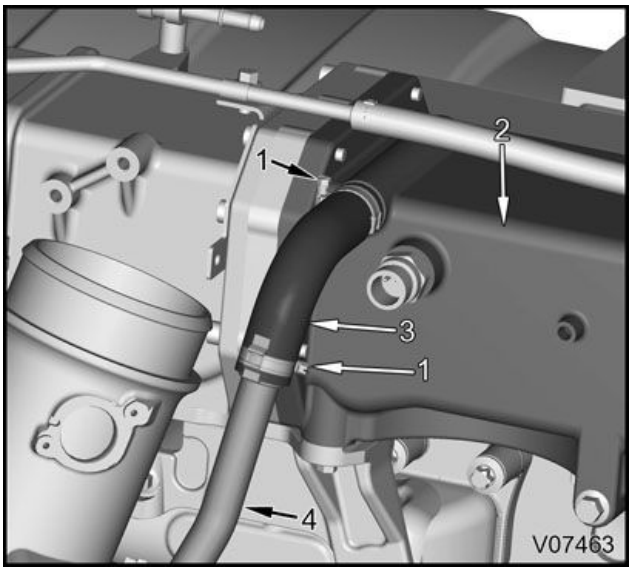


Figure 191 Coolant return hose

1. 3/4 inch constant torque hose clamp (2)
2. Low temperature housing (EGR cooler)
3. Coolant return hose
4. Coolant tube

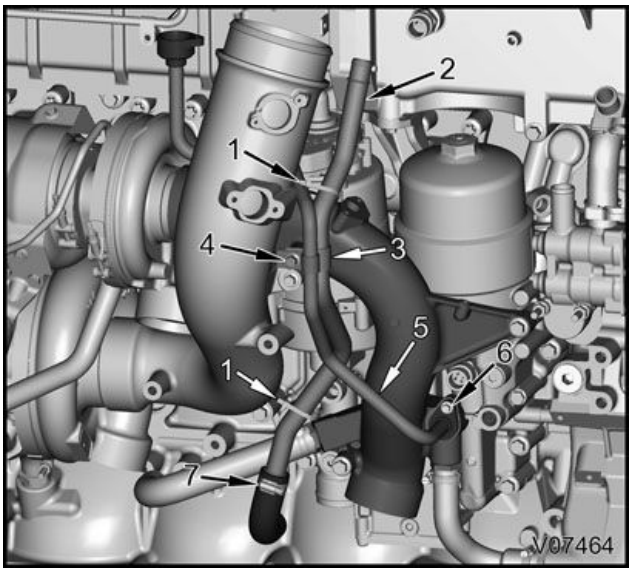


Figure 192 Coolant and cab heater tubes

1. Cable lock strap (2)
2. Coolant tube
3. Tube support
4. M8 x 20 bolt
5. Cab heater return tube assembly
6. M6 x 20 bolt
7. 3/4 inch constant torque hose clamp

1. Loosen two 3/4 inch hose clamps.
2. Disconnect coolant return hose from low temperature housing and coolant tube.
3. Cut two cable lock straps from coolant tube.
4. Remove M8 x 20 bolt to release coolant tube support and cab heater return tube assembly retainer.
5. Remove M8 x 16 bolt and tube support behind air inlet duct. Remove M6 x 20 bolt to release cab heater return tube assembly and remove tube. Remove and discard O-ring.
6. Loosen 3/4 inch hose clamp and disconnect coolant tube from coolant hose. Remove coolant tube.

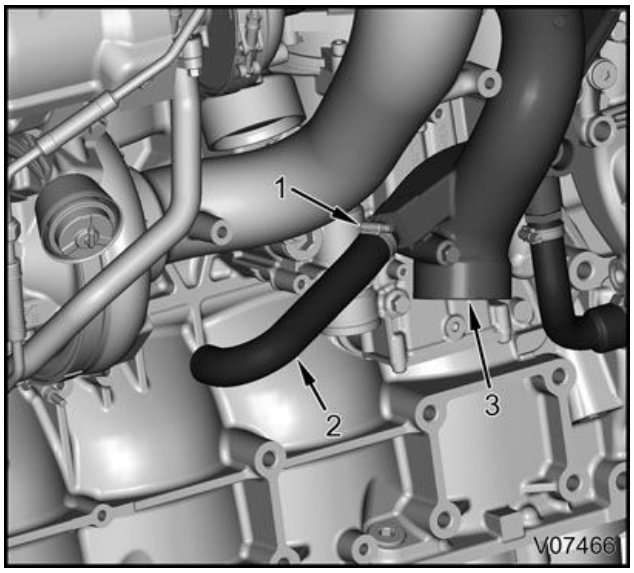


Figure 193 Coolant return hose (at air supply high-pressure turbocharger duct)

1. 3/4 inch constant torque hose clamp
2. Coolant return hose
3. Air supply high-pressure turbocharger duct (coolant return integral with duct)

7. Loosen 3/4 inch hose clamp and disconnect coolant hose from air supply high-pressure turbocharger duct.

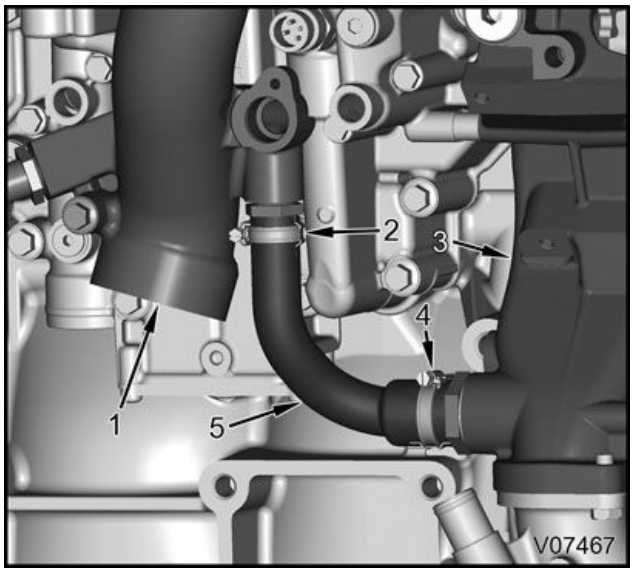


Figure 194 Coolant return hose (air supply duct to water distribution housing)

1. Air supply high-pressure turbocharger duct (coolant return integral with duct)
2. 3/4 inch constant torque hose clamp
3. Water distribution housing
4. 1 inch worm gear hose clamp
5. Coolant return hose

8. Loosen 3/4 inch hose clamp, 1 inch hose clamp and disconnect coolant return hose from air supply duct and water distribution housing.

High-pressure (HP) Compressor Out Duct and Air Inlet Duct

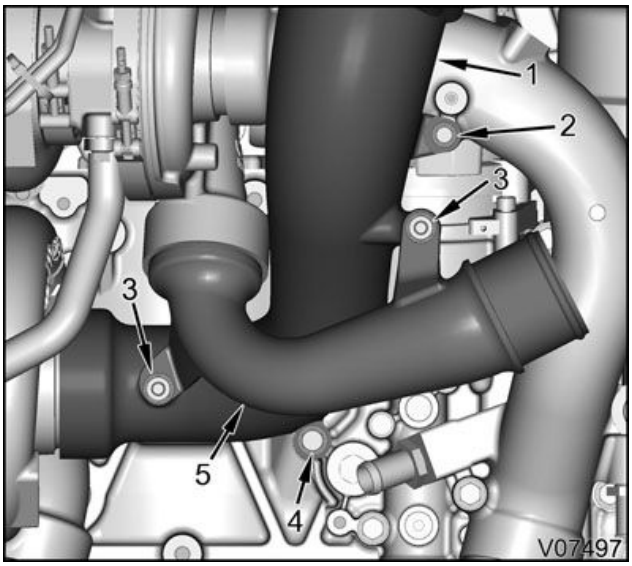


Figure 195 HP compressor out duct and air inlet duct

1. Air inlet duct
2. M8 x 45 bolt
3. M10 x 20 x 40 stud bolt (2)
4. M10 x 140 bolt
5. HP compressor out (outlet) duct

1. Remove two M10 x 20 x 40 stud bolts.
2. Disconnect HP compressor out duct from HP turbocharger compressor outlet. Remove from engine.

NOTE: The high-pressure compressor inlet seal is used in two places on the high-pressure compressor including both compressor inlet and outlet.

3. Remove high-pressure compressor inlet seal from compressor out duct and discard.
4. Remove M8 x 45 bolt and M10 x 140 bolt. Remove air inlet duct from low-pressure turbocharger.
5. Remove LP compressor inlet seal from LP turbocharger compressor inlet and discard.

High-pressure Turbocharger Air Supply Duct

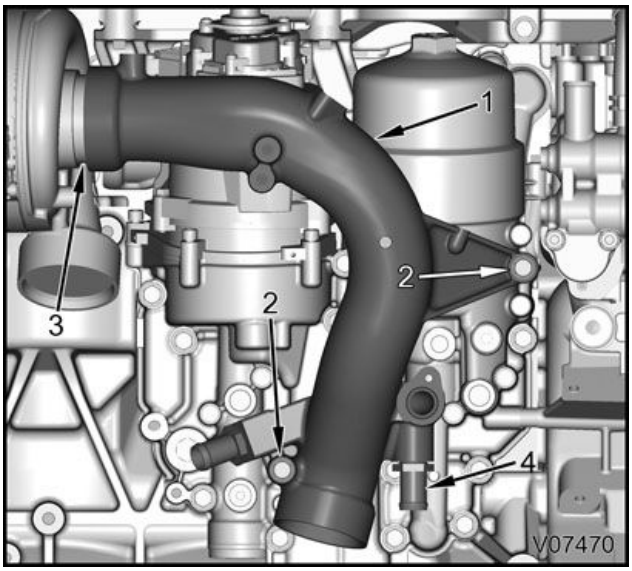


Figure 196 High-pressure (HP) turbocharger air supply duct

1. HP turbocharger air supply duct
2. M10 x 200 bolt (2)
3. High-pressure compressor inlet seal
4. M24 threaded fitting

1. Remove two M10 x 200 bolts and HP turbocharger air supply duct from HP turbocharger.
2. Remove HP compressor inlet seal and discard.
3. Only if required, remove M24 threaded fitting and discard seal ring.

Turbocharger Oil Return and Oil Supply Tubes

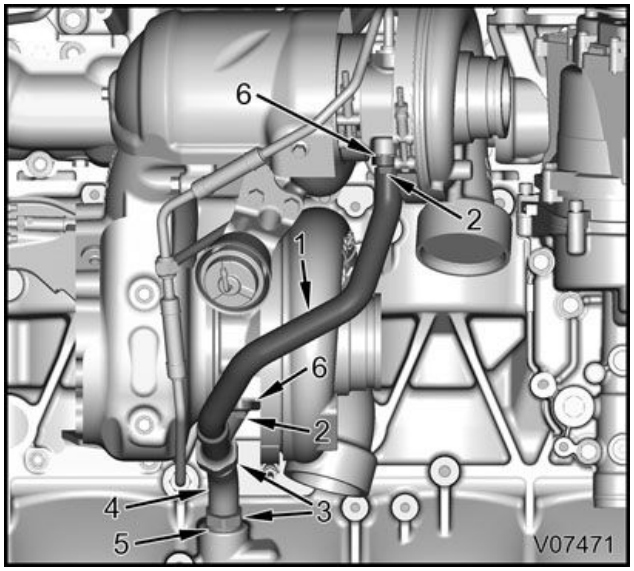


Figure 197 Turbocharger oil return tubes

1. High-pressure (HP) turbocharger oil return tube
2. M8 x 20 bolt (4)
3. Oil return tube fittings (2)
4. Low-pressure (LP) turbocharger oil return tube
5. 24.7 x 32 seal ring
6. Turbocharger oil drain gasket (2)

1. Loosen LP turbocharger oil return tube fitting nut from HP turbocharger oil return tube.
2. Remove four M8 x 20 bolts and disconnect HP oil return tube from HP and LP turbocharger and LP oil return tube.
3. Remove and discard two turbocharger oil drain gaskets.
4. Remove and discard bonded seal washer between HP and LP turbocharger oil return tubes.
5. Remove LP turbocharger oil return tube from crankcase and discard 24.7 x 32 seal ring.

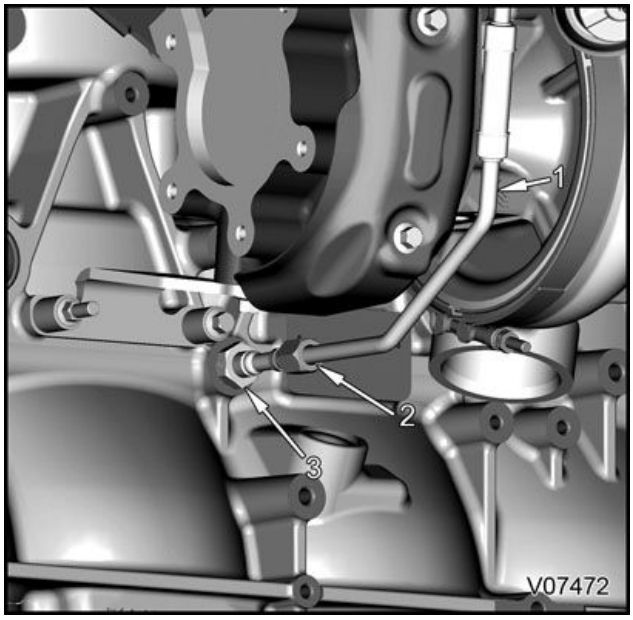


Figure 198 Turbocharger oil supply tube fitting

1. Turbocharger oil supply tube assembly
2. Oil supply tube fitting
3. Male stud connector

6. Loosen turbocharger oil supply tube fitting at male stud connector on crankcase. Disconnect tube fitting from crankcase connector.

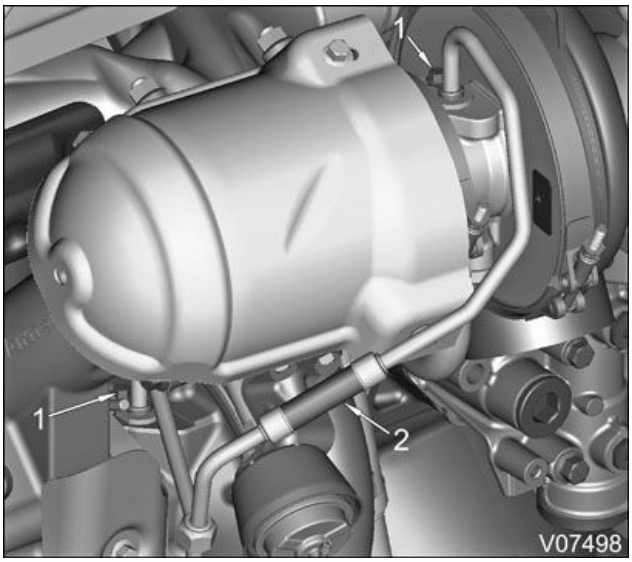


Figure 199 Turbocharger oil supply tube

1. M6 x 16 bolt (2)
2. Turbocharger oil supply tube assembly

7. Remove two M6 x 16 bolts from turbocharger oil supply tube at LP and HP turbochargers. Disconnect oil supply tube.
8. Remove and discard turbocharger supply seals from LP and HP turbocharger oil supply tube ends. Clean and inspect sealing surfaces.

Turbocharger Heat Shields

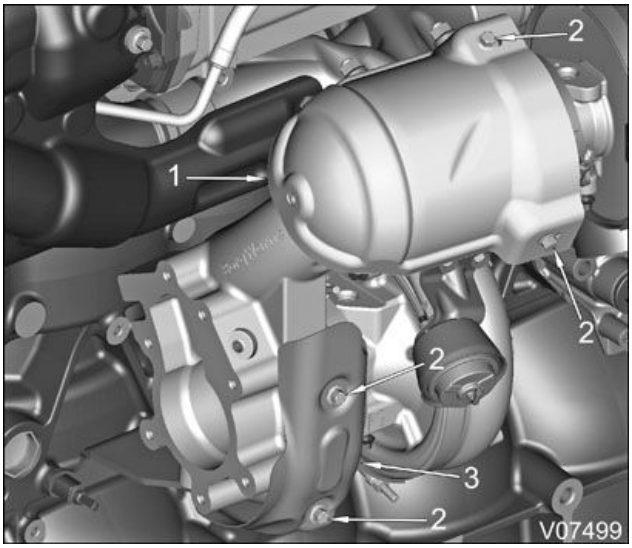


Figure 200 Turbocharger heat shields

1. HP turbocharger heat shield
2. M8 x 16 bolt (4)
3. Turbocharger heat shield

1. Remove two M8 x 16 bolts and HP turbocharger heat shield.
2. Remove two M8 x 16 bolts and turbocharger heat shield.

Turbocharger Support Bracket

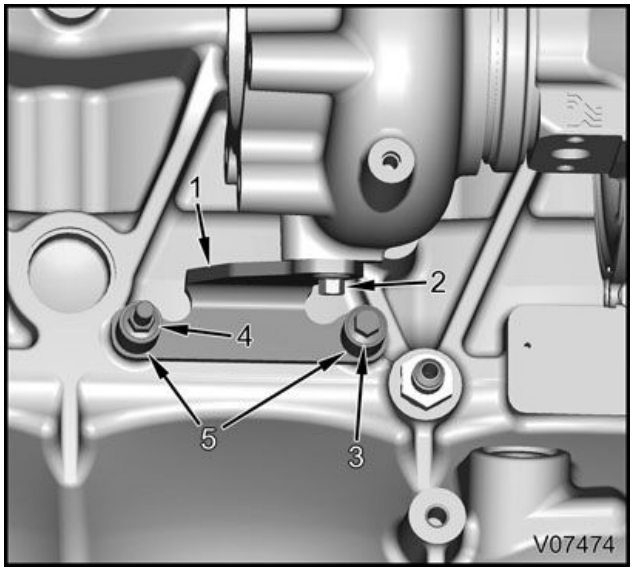


Figure 201 Turbocharger support bracket

1. Turbocharger support bracket
2. M8 x 16 bolt
3. M8 x 40 bolt
4. M8 x 40 x 15 stud bolt
5. 19 x 20 spacer (2)

1. Remove M8 x 16 bolt at bottom of LP turbocharger.
2. Remove M8 x 40 bolt, M8 x 40 x 15 stud bolt, two spacers and support bracket.

High-pressure (HP) Turbocharger Wastegate Actuator

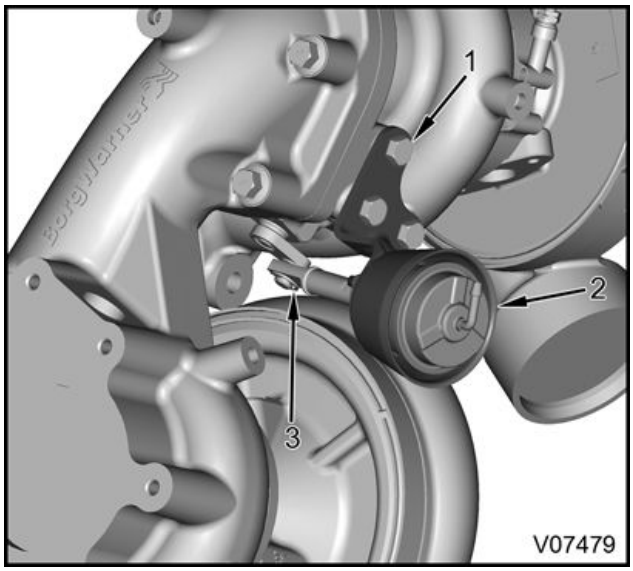


Figure 202 High-pressure (HP) wastegate actuator

1. M8 x 14 bolt (3)
2. HP wastegate actuator
3. C-clip

NOTE: It is not necessary to remove the HP wastegate actuator to remove the turbocharger. The turbocharger and HP wastegate actuator can be removed as an assembly.

1. Remove C-clip from HP actuator wastegate linkage.
2. Remove three M8 x 14 bolts.
3. Remove HP wastegate actuator.

Turbocharger Mounting

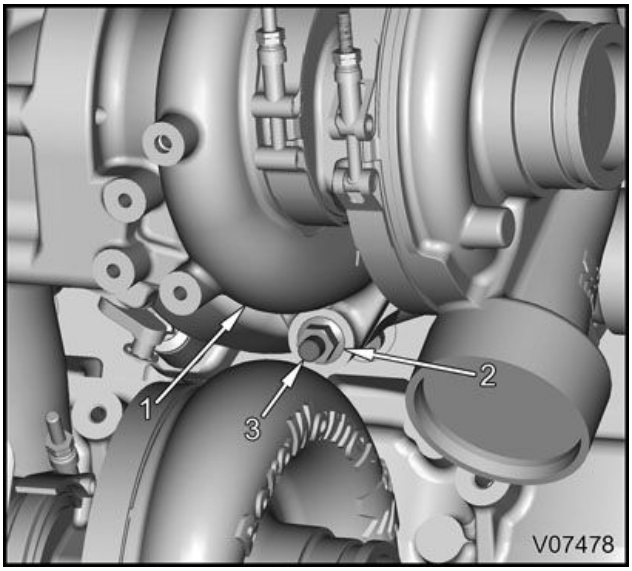


Figure 203 HP turbocharger mounting (lower nut)

1. HP turbocharger assembly
2. M10 nut
3. M10 x 45 stud

WARNING: To prevent personal injury or death, use suitable lifting equipment and get help to remove or install the turbochargers.

1. Get help from an assistant to support turbochargers during removal. Remove M10 nut.

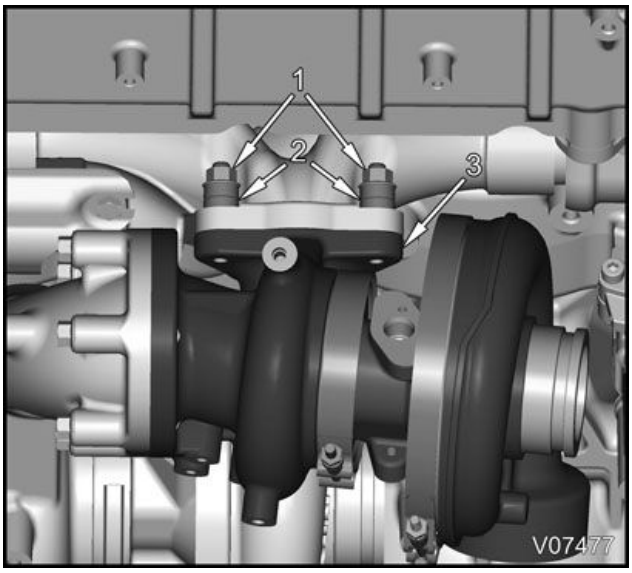


Figure 204 High-pressure (HP) turbocharger mounting (upper nuts and sleeves)

1. M10 nut (2)
2. 10.5 x 20 x 15 sleeve (2)
3. HP turbocharger mounting flange

2. Remove two M10 nuts and two 10.5 x 20 x 15 sleeves.
3. Remove turbochargers from middle exhaust manifold.

Disassembly

Turbochargers

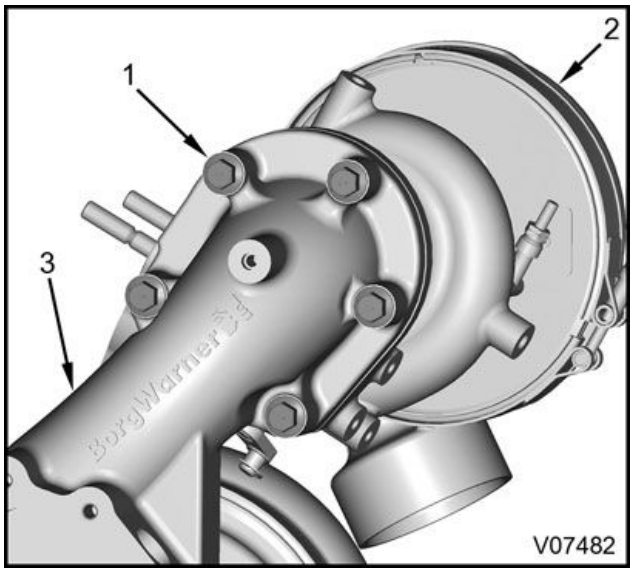


Figure 205 High-pressure (HP) and low-pressure (LP) turbocharger connection

1. M10 x 55 bolt (5)
2. HP turbocharger assembly
3. LP turbocharger assembly

1. Remove five M10 x 55 bolts and separate HP turbocharger from LP turbocharger.
2. Inspect mating flanges and two dowel pins for damage. Replace if necessary.

Cleaning and Inspection

Turbochargers and Related Parts Cleaning

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

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

1. Clean ducting between air inlet duct and air cleaner assembly with soap and then, steam clean. Dry all ducting with filtered compressed air.
2. Clean Low-pressure Charge Air Cooler (LPCAC), air inlet duct, and air supply high-pressure turbocharger duct with filtered compressed air.
3. Clean turbocharger oil supply tube assembly and oil return turbocharger tubes with a nonchlorinated solvent and a nylon brush. Dry tubes with filtered compressed air. Replace any damaged tubes.
4. Clean all gasket and O-ring sealing surfaces.

Turbocharger Inspection

CAUTION: To prevent engine damage, do not damage compressor impeller or turbine wheel. If either is damaged, a new turbocharger must be installed.

1. Inspect turbochargers for cracks. Replace if necessary.
2. Inspect compressor impellers and turbine wheels for blade erosion, bends, breakage, or deposits. Replace turbochargers if damaged.

NOTE: Replace turbochargers if blades are bent. Do not attempt to straighten bent impeller or turbine wheel blades.

3. Turn shafts by hand and check for impeller and wheel rub in the housings.

   The shaft, impeller, and turbine must rotate freely. If there is any rubbing or interference, replace turbocharger.

Low-pressure Charge Air Cooler (LPCAC) Pressure Test

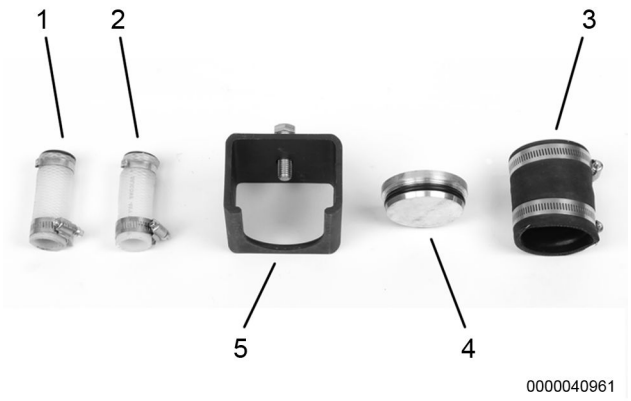


Figure 206 LPCAC pressure test kit ZTSE6042

1. ZTSE6042-1, Coolant Port Plug (with 1/4” NPT hole)
2. ZTSE6042-2, Coolant Port Plug (solid)
3. ZTSE6042-3, Air Inlet Plug (with 1/4” NPT hole)
4. ZTSE6042-4, Air Outlet Disc Plug
5. ZTSE6042-4A, Air Outlet Disc Plug Retaining Bracket

In LPCAC Pressure Test Kit ZTSE6042, the quantity of each component is one (1).

1. Remove Low-pressure Charge Air Cooler (LPCAC) from engine.

⚠ WARNING: To prevent personal injury or death, ensure that components are tightened properly; otherwise, they can project while LPCAC is under pressure.

⚠ WARNING: To prevent personal injury or death, ensure that at LPCAC air inlet and outlet, the O-rings are removed and that no lubricant is on sealing surface areas. O-ring and lubricant can cause the pressure test kit components to project while LPCAC is under pressure.

2. Attach the Pressure Test Kit to LPCAC.
   - Obtain 3-inch couplers and clamps locally.
   - Cover LPCAC air outlet with Air Outlet Disc Plug ZTSE6042-4.

- Install Air Outlet Disc Plug Retaining Bracket ZTSE6042-4A on top of ZTSE6042-4. Tighten clamping bolt to make sure LPCAC air outlet is sealed.
- Attach Air Inlet Plug (with 1/4″ NPT hole) ZTSE6042-3 to LPCAC air inlet, and tighten clamps.
- Attach Coolant Port Plug (solid) ZTSE6042-2 to LPCAC coolant return port. Tighten clamp.
- Attach Coolant Port Plug (with 1/4″ NPT hole) ZTSE6042-1 to LPCAC coolant supply port. Tighten clamp.

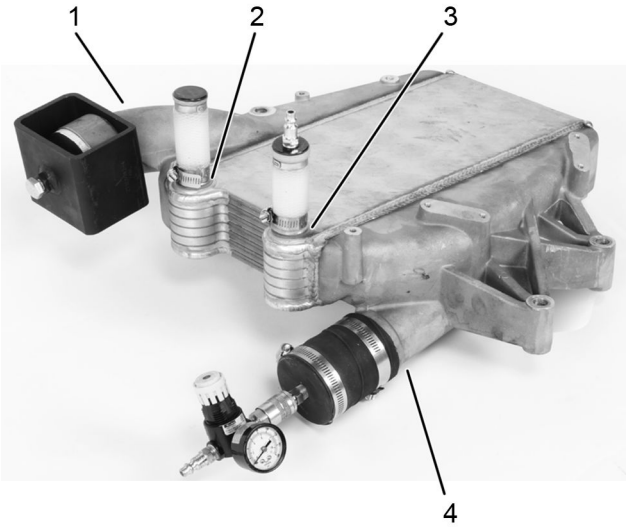


Figure 207 Pressure test on the air side of LPCAC

1. LPCAC air outlet
2. LPCAC coolant return port
3. LPCAC coolant supply port
4. LPCAC air inlet

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

3. Connect locally obtained regulator with shop air source, and pressurize the air side of LPCAC to 30 psi (207 kPa).
4. Spray a soapy water solution on LPCAC. Look for leaks from hose connections, LPCAC, or test components.
5. If a leak is detected on LPCAC or test gauge pressure drops, the test is complete. Replace LPCAC.

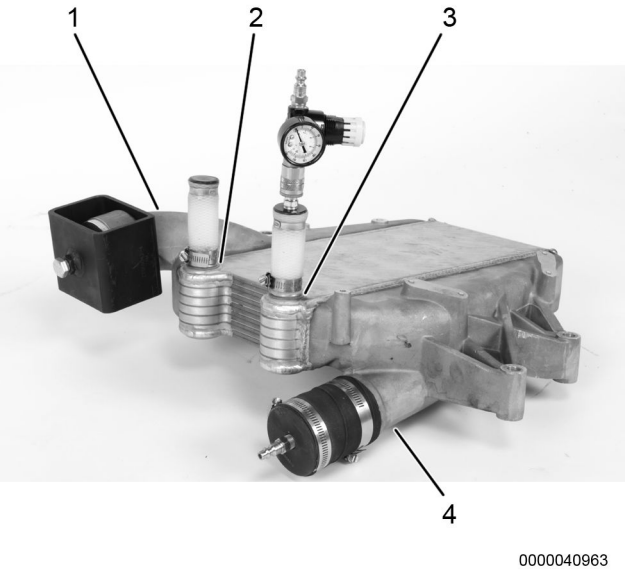


Figure 208 Pressure test on the coolant side of LPCAC

1. LPCAC air outlet
2. LPCAC coolant return port
3. LPCAC coolant supply port
4. LPCAC air inlet

6. Connect locally obtained regulator with shop air source, and pressurize the coolant side of LPCAC to 30 psi (207 kPa).
7. Spray a soapy water solution on LPCAC. Look for leaks from hose connections, LPCAC, or test components.
8. If a leak is detected on LPCAC or test gauge pressure drops, the test is complete. Replace LPCAC.
9. Remove Low-pressure Charge Air Cooler Test Kit from LPCAC.

Installation

Turbocharger Mounting

WARNING: To prevent personal injury or death, use suitable lifting equipment and get help to remove or install the turbochargers.

WARNING: To prevent personal injury or death, do not allow the turbochargers to hang by the lower stud and nut alone. Support the assembly until the upper sleeves and nuts are installed.

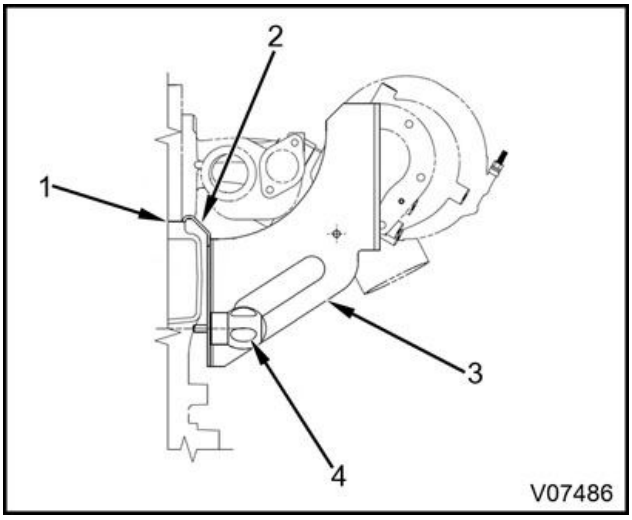


Figure 209 Turbocharger alignment tool installation

1. Crankcase-to-cylinder head deck
2. Tab
3. Turbo Alignment Bracket (ZTSE6041)
4. Hand screw

1. Install Turbo Alignment Bracket ZTSE6041 on engine with tabs seated on crankcase-to-cylinder head deck. Thread tool hand screw into crankcase boss and tighten to secure bracket in place.

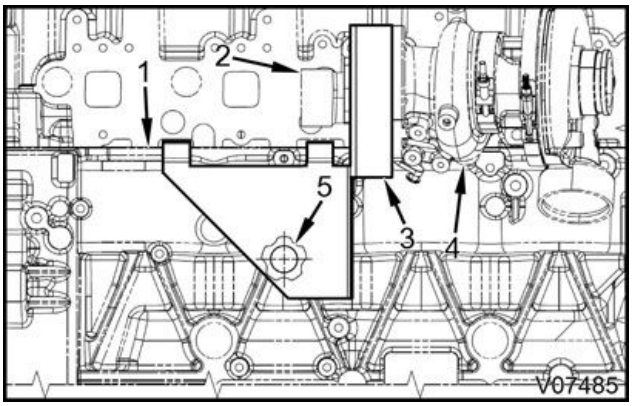


Figure 210 HP turbocharger alignment check

1. Crankcase-to-cylinder head deck
2. Middle exhaust manifold
3. Turbo Alignment Bracket (ZTSE6041)
4. HP turbocharger
5. Hand screw

2. With help of an assistant, align three studs and position HP turbocharger to middle exhaust manifold. Check that turbine exhaust outlet flange is aligned square with Turbo Alignment Bracket.

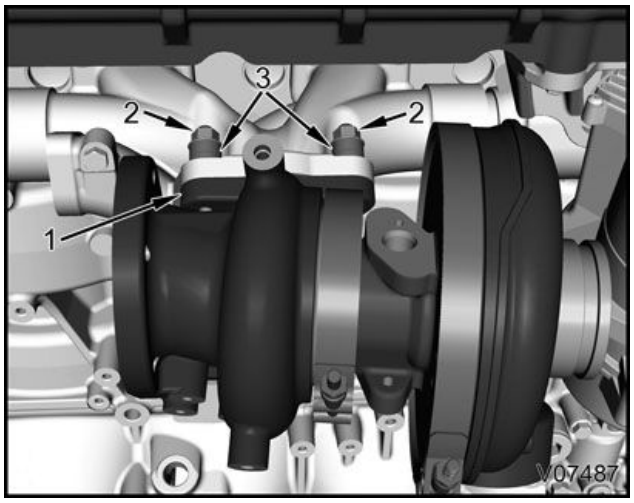


Figure 211 HP turbocharger mounting (upper nuts and sleeves)

1. HP turbocharger mounting flange
2. M10 nut (2)
3. 10.5 x 20 x 15 sleeve (2)

3. With turbocharger supported in place, install two 10.5 x 20 x 15 sleeves and two new M10 nuts on upper mounting studs. Finger-tighten nuts.

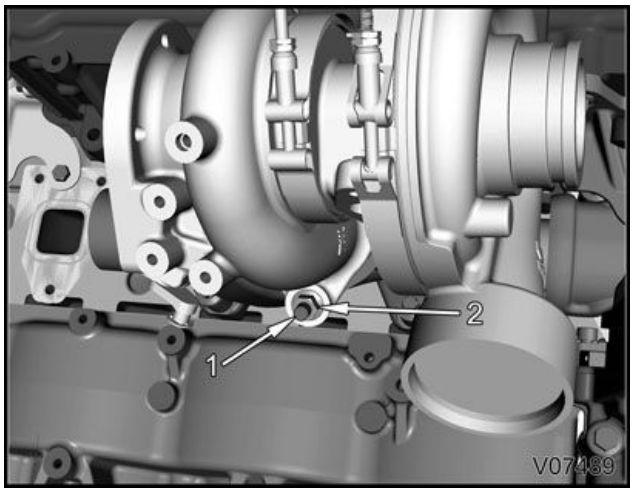


Figure 212 HP turbocharger mounting (lower nut)

1. M10 x 45 stud
2. M10 nut

4. Install new M10 nut on lower mounting stud, finger tight.
5. With turbine exhaust outlet flange aligned square with Turbo Alignment Bracket, tighten three M10 nuts to standard torque (page 503).
6. Remove Turbo Alignment Bracket (ZTSE6041) from engine.

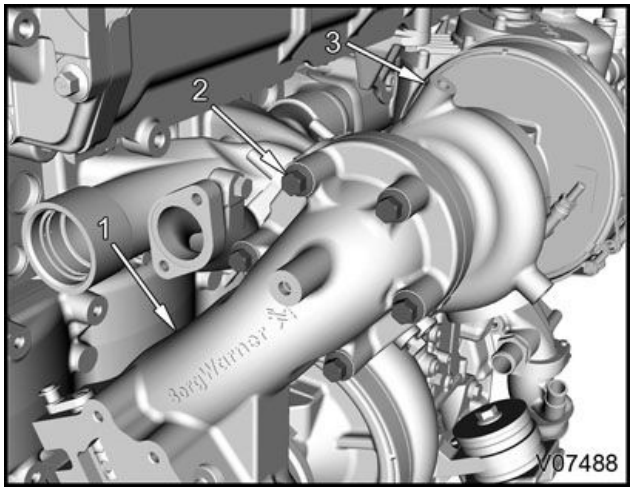


Figure 213 LP turbocharger installation

1. LP turbocharger assembly
2. M10 x 55 bolt (5)
3. HP turbocharger assembly

7. Align two dowel pins and support LP turbocharger in position on HP turbocharger turbine outlet flange.
8. Install five new M10 x 55 bolts and tighten to special torque (page 181).

Turbocharger Support Bracket

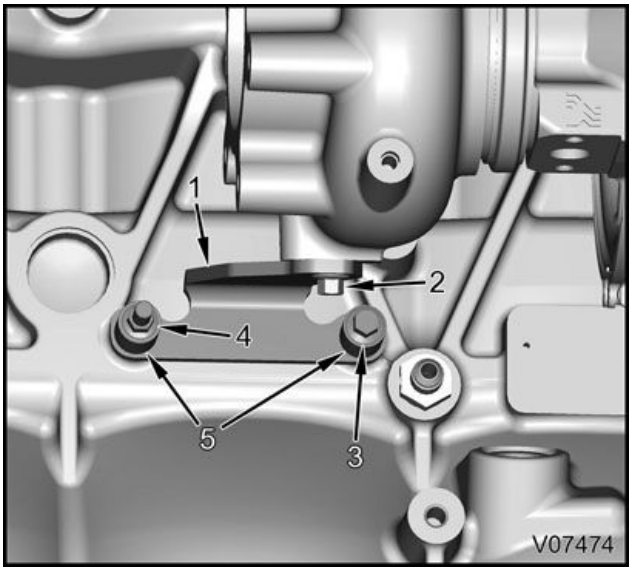


Figure 214 Turbocharger support bracket

1. Turbocharger support bracket
2. M8 x 16 bolt
3. M8 x 40 bolt
4. M8 x 40 x 15 stud bolt
5. 19 x 20 spacer (2)

CAUTION: The turbocharger support bracket must be installed; if the bracket is not installed, the turbochargers or exhaust manifold could crack.

1. Position turbocharger support bracket and install two 19 x 20 spacers, M8 x 40 x 15 stud bolt and M8 x 40 bolt.
2. Install M8 x 16 bolt into bottom of turbocharger. Tighten three bolts to standard torque (page 503).

High-pressure (HP) Turbocharger Wastegate Actuator

NOTE: If HP wastegate actuator was removed from turbocharger, do the following:

⚠ WARNING: To prevent personal injury or death, wear safety glasses with side shields.

NOTE: Check linkage movement for the HP wastegate actuator, using a hand pump or shop air regulated to no more than 345 kPa (50 psi).

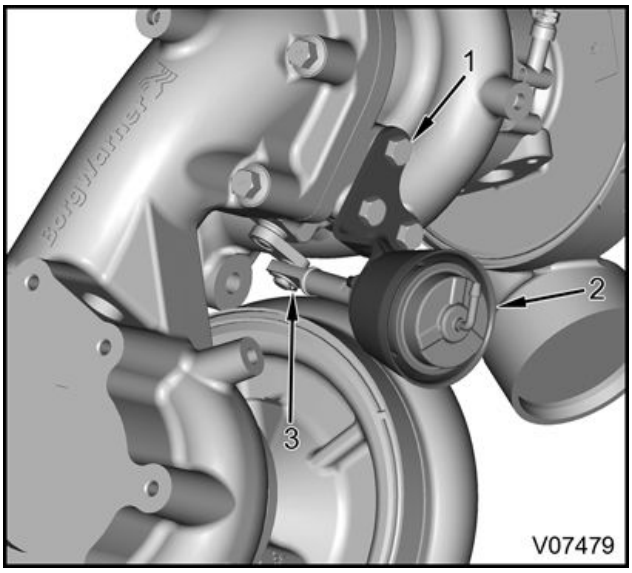


Figure 215 High-pressure (HP) wastegate actuator

1. M8 x 14 HP bolt (3)
2. HP wastegate actuator
3. C-clip

1. Position HP wastegate actuator with hose port facing up and install three M8 x 14 bolts.
2. Tighten three bolts to special torque (page 181).
3. Position wastegate HP actuator linkage on wastegate lever pin.
4. Install actuator linkage C-clip on wastegate lever pin.

⚠ WARNING: To prevent personal injury or death, wear safety glasses with side shields.

NOTE: Check linkage movement for the HP wastegate actuator, using a hand pump or shop air regulated to no more than 345 kPa (50 psi).

5. Attach air source to HP wastegate actuator and operate actuator through full range and check for free movement. There should be smooth operation without binding. If operation is not smooth, loosen pushrod jam nut and retighten. Recheck movement.

Turbocharger Heat Shields

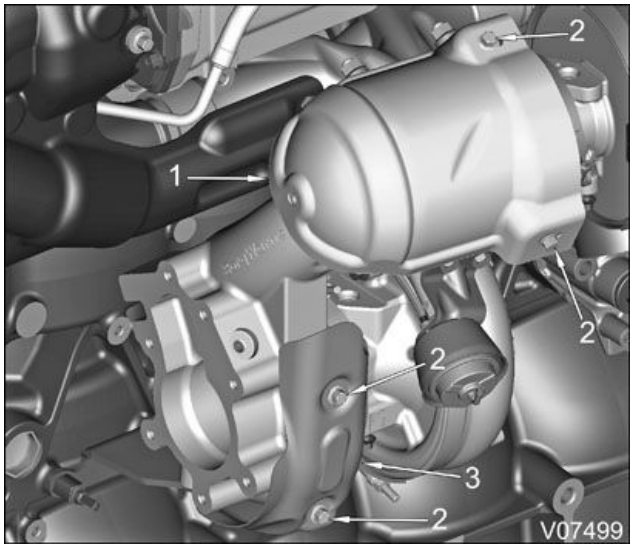


Figure 216 Turbocharger heat shields

1. HP turbocharger heat shield
2. M8 x 16 bolt (4)
3. Turbocharger heat shield

1. Position turbocharger heat shield and install two M8 x 16 bolts. Tighten bolts to standard torque (page 503).
2. Install HP turbocharger heat shield and three M8 x 16 bolts. Tighten bolts to standard torque (page 503).

Turbocharger Oil Return and Oil Supply Tubes

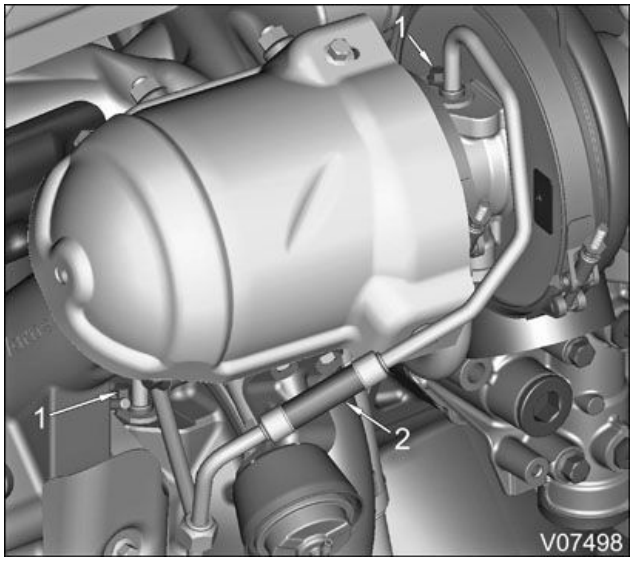


Figure 217 Turbocharger oil supply tube

1. M6 x 16 bolt (2)
2. Turbocharger oil supply tube assembly

1. Lubricate two turbocharger supply seals (Figure 3, item 3) with P-80® rubber lubricant or equivalent (page 181).
2. Install new turbocharger supply seals on ends of the oil supply tube.
3. Position turbocharger oil supply tube onto turbochargers and install two M6 x 16 bolts. Tighten bolts to standard torque (page 503).

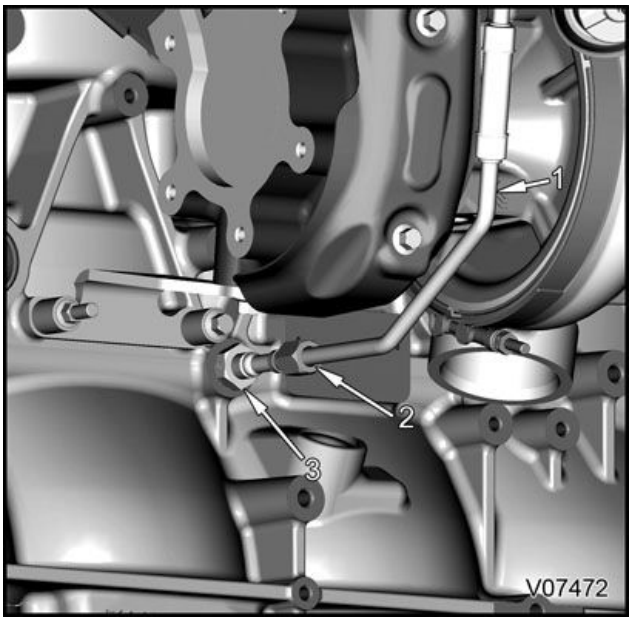


Figure 218 Turbocharger oil supply tube fitting

1. Turbocharger oil supply tube assembly
2. Oil supply tube fitting
3. Male stud connector

4. If removed, install male stud connector and tighten to special torque (page 181).
5. Position turbocharger oil supply tube fitting nut onto male stud connector on crankcase. Tighten fitting nut to special torque (page 181).

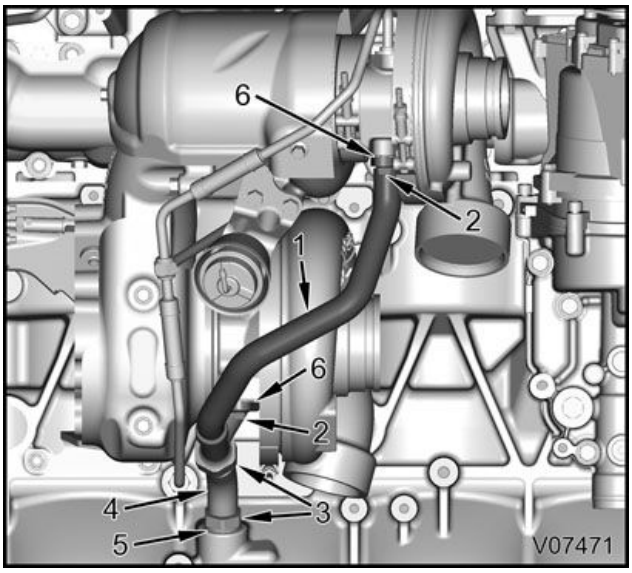


Figure 219 Turbocharger oil return tubes

1. High-pressure (HP) turbocharger oil return tube
2. M8 x 20 bolt (4)
3. Oil return tube fittings (2)
4. Low-pressure (LP) turbocharger oil return tube
5. 24.7 x 32 seal ring
6. Turbocharger oil drain gasket (2)

6. Install LP turbocharger oil return tube with new 24.7 x 32 seal ring into crankcase. Snug fitting only until final tightening.
7. Connect HP turbocharger oil return tube to LP turbocharger oil return tube with new bonded seal washer. Snug fitting only until final tightening.
8. Position HP turbocharger oil return tube with new oil drain gaskets to oil return outlet flanges of LP turbocharger and HP turbocharger.
9. Install four M8 x 20 bolts and tighten bolts to standard torque (page 503).
10. Final tighten LP turbocharger oil return tube fitting nut at crankcase fitting as follows:
    a. Tighten fitting nut to 10 N·m (89 lbf·in).
    b. Turn fitting nut an additional 90°.
11. Final tighten HP turbocharger oil return tube fitting nut at LP turbocharger oil return tube as follows:
    a. Tighten fitting nut to 10 N·m (89 lbf·in).
    b. Turn fitting nut an additional 90°.

High-pressure Turbocharger Air Supply Duct

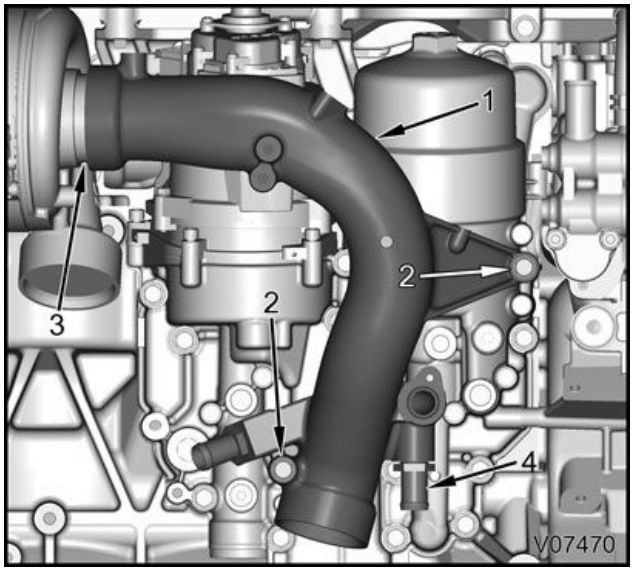


Figure 220 High-pressure (HP) turbocharger air supply duct

1. HP turbocharger air supply duct
2. M10 x 200 bolt (2)
3. High-pressure compressor inlet seal
4. M24 threaded fitting

1. Lubricate new high-pressure compressor inlet seal with P-80® rubber lubricant or equivalent (page 181) and install over HP turbocharger compressor inlet groove.
2. Install HP turbocharger air supply duct along with two M10 x 200 bolts. Tighten bolts to standard torque (page 503).
3. If previously removed, install new seal ring and M24 threaded fitting and tighten to special torque (page 181).

High-pressure (HP) Compressor Out Duct and Air Inlet Duct

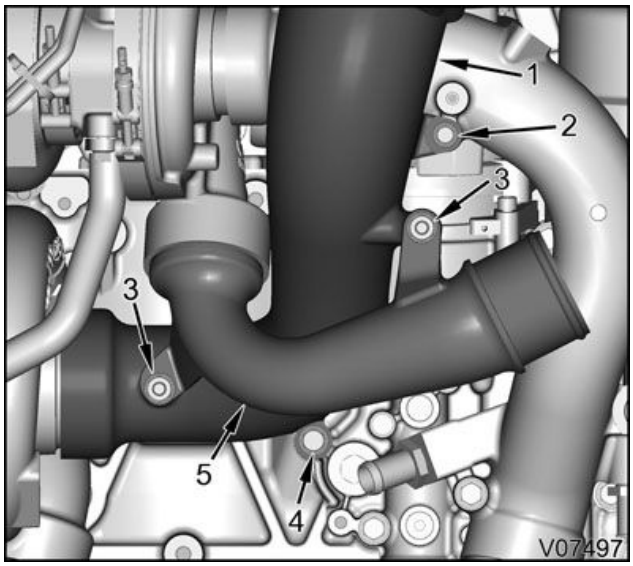


Figure 221 HP compressor out duct and air inlet duct

1. Air inlet duct
2. M8 x 45 bolt
3. M10 x 20 x 40 stud bolt (2)
4. M10 x 140 bolt
5. HP compressor out (outlet) duct

1. Lubricate a new LP compressor inlet seal with P-80® rubber lubricant or equivalent (page 181) and install seal over LP turbocharger compressor inlet.
2. Install air inlet duct to LP turbocharger. Install M8 x 45 bolt and M10 x 140 bolt. Tighten bolts to standard torque (page 503).

NOTE: The high-pressure compressor inlet seal is used in two places on the high-pressure turbocharger compressor including both compressor inlet and outlet.

3. Lubricate new HP compressor inlet seal with P-80® rubber lubricant or equivalent (page 181) and install into groove in compressor out duct.
4. Install HP compressor out duct into HP turbocharger air outlet, install two M10 x 20 x 40 stud bolts and tighten to standard torque (page 503).

Low-pressure Charge Air Cooler (LPCAC) Coolant Tube and Hoses

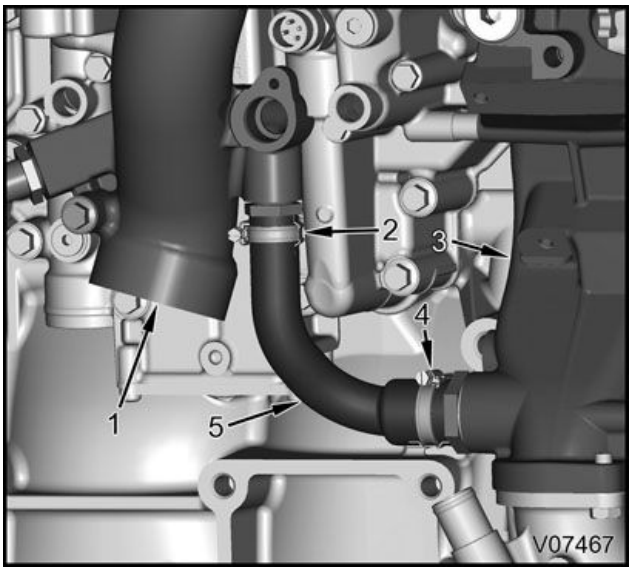


Figure 222 Coolant return hose (air supply duct to water distribution housing)

1. Air supply high-pressure (HP) turbocharger duct (coolant return integral with duct)
2. 3/4 inch worm gear hose clamp
3. Water distribution housing
4. 1 inch worm gear hose clamp
5. Coolant return hose

1. Install coolant return hose to water distribution housing and air supply duct. Install 3/4 inch hose clamp and 1 inch hose clamp. Tighten 3/4 inch and 1 inch hose clamps to special torque (page 181).

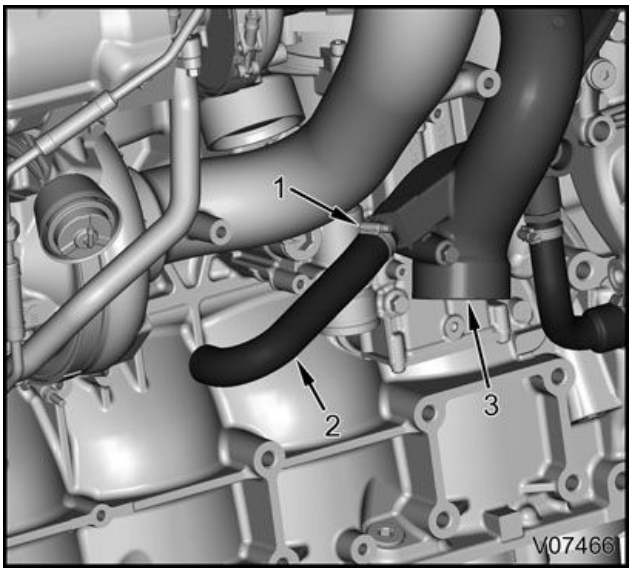


Figure 223 Coolant return hose (air supply high-pressure turbocharger duct)

1. 3/4 inch worm gear hose clamp
2. Coolant return hose
3. Air supply HP turbocharger duct (coolant return integral with duct)

2. Install coolant return hose to air supply HP turbocharger duct. Install 3/4 inch hose clamp and loosely tighten at this time.

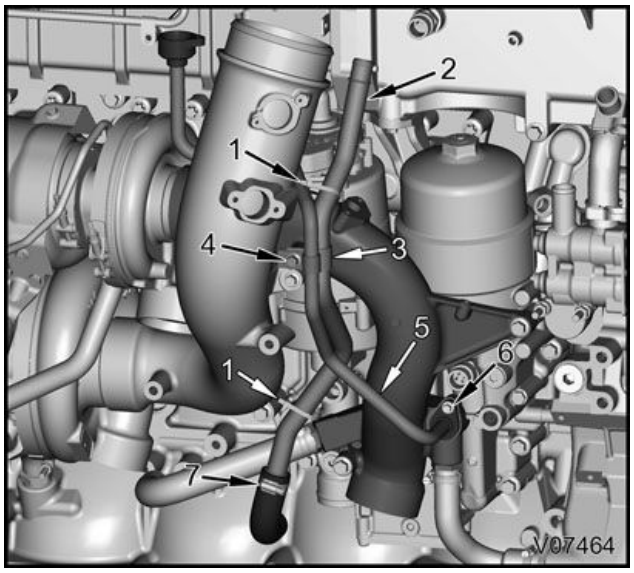


Figure 224 Coolant and cab heater tubes

1. Cable lock strap (2)
2. Coolant tube
3. Tube support
4. M8 x 20 bolt
5. Cab heater return tube assembly
6. M6 x 20 bolt
7. 3/4 inch constant torque hose clamp

3. Lubricate new cab heater return tube O-ring with P-80® rubber lubricant or equivalent (page 181).
4. Install a new O-ring onto cab heater return tube assembly.
5. Position cab heater return tube assembly and install M6 x 20 bolt and M8 x 20 bolt through tube support behind air inlet duct. Tighten bolts to standard torque (page 503).
6. Install coolant hose onto lower end of coolant supply tube. Install 3/4 inch hose clamp onto hose and loosely tighten at this time.
7. Position coolant tube support and cab heater return tube assembly retainer and install M8 x 20 bolt. Tighten bolt to standard torque (page 503).

NOTE: Two cable lock straps are installed later after LP wastegate hose is installed to secure hose to coolant tube.

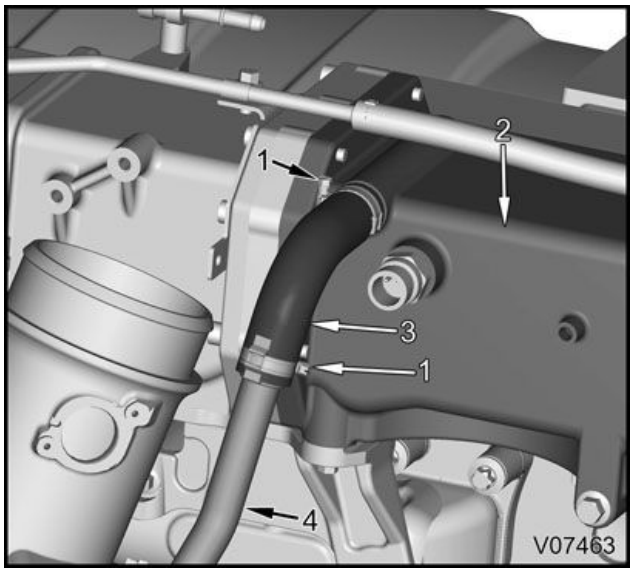


Figure 225 Coolant return hose

1. 3/4 inch worm gear hose clamp (2)
2. Low-temperature housing (EGR cooler)
3. Coolant return hose
4. Coolant tube

8. Install coolant hose and two 3/4 inch hose clamps between coolant tube and low-temperature housing (EGR cooler).
9. Tighten clamps to special torque (page 181).

Low-pressure Charge Air Cooler (LPCAC)

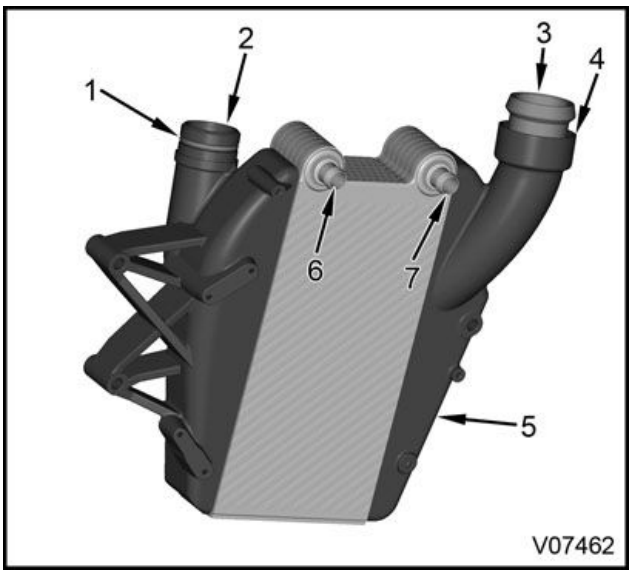


Figure 226 LPCAC

1. O-ring seal
2. LPCAC air inlet
3. 72.2 x 60 (DMR) tube seal (extension tube)
4. LPCAC air outlet
5. Low-pressure charge air cooler
6. Coolant return
7. Coolant supply

1. Lubricate 72.2 x 60 (DMR) tube seal (extension tube) with P-80® rubber lubricant or equivalent (page 181) and install into LPCAC using Extension Tube Installer (page 181).
2. Lubricate new O-ring seal with P-80® rubber lubricant or equivalent (page 181) and install O-ring at LPCAC air inlet.

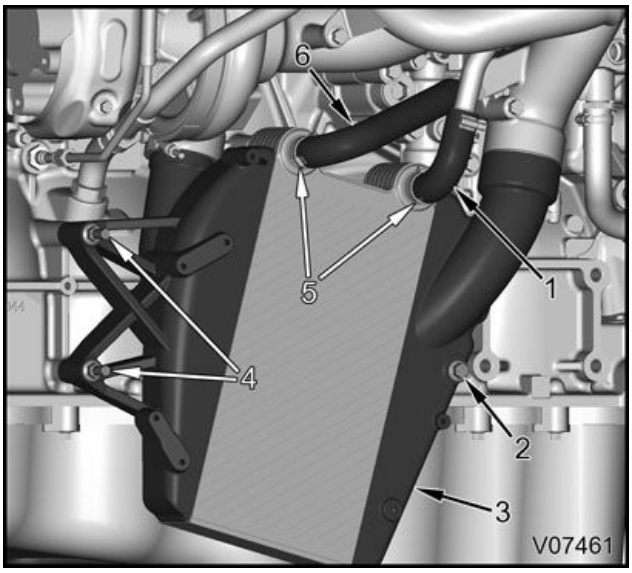


Figure 227 LPCAC and coolant hose connections

1. Coolant hose (supply)
2. M10 x 100 bolt
3. Low-pressure charge air cooler
4. Ground stud bolt (2)
5. 3/4 inch worm gear hose clamp (2)
6. Coolant return hose

3. Install LPCAC to engine until tube seal (extension tube) and O-ring are fully engaged with air duct and LP turbocharger.
4. Install two M10 stud bolts and M10 x 100 bolt. Tighten bolts to standard torque(page 503).
5. Connect coolant return hose to LPCAC and install 3/4 inch hose clamp.
6. Tighten two coolant return hose clamps to special torque (page 181).
7. Connect coolant (supply) hose to LPCAC and install 3/4 inch hose clamp.
8. Tighten two coolant (supply) hose clamps to special torque (page 181).

High-pressure (HP) Wastegate Hose

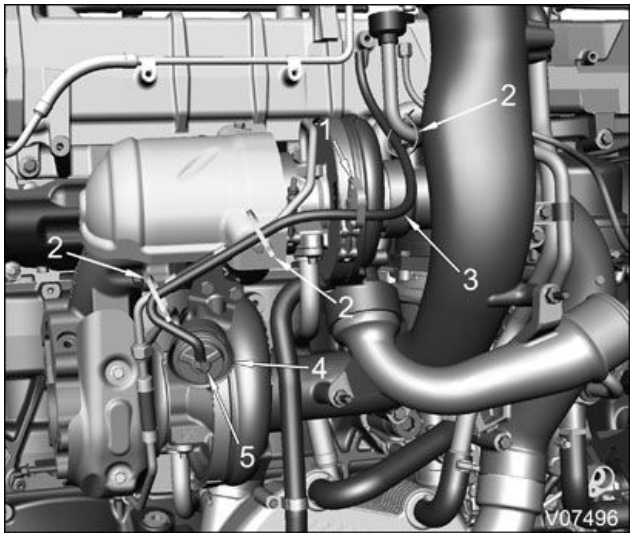


Figure 228 High-pressure (HP) wastegate hose

1. Tie strap
2. Cable lock strap (3)
3. High-pressure (HP) wastegate hose
4. High-pressure (HP) wastegate
5. 12.3 x 7 crimp clamp

NOTE: Replace HP wastegate hose if damaged or deformed.

1. Route HP hose onto engine as noted during removal.
2. Slip crimp clamp over hose and connect HP wastegate hose to HP wastegate actuator fitting.
3. Install three cable lock straps and tie strap to secure HP wastegate hose to turbocharger oil supply tube and EGRV coolant supply tube.
4. Slip crimp clamp over hose and connect HP wastegate hose to air control valve. See "Exhaust Back Pressure Control" for procedure.
5. Using crimping pliers (page 181), tighten the crimp clamps on each end of HP wastegate hose.

Special Torque

Table 11 Turbochargers

3/4 inch and 1 inch worm gear hose clamps	3.5 N·m (31 lbf·in)
High-pressure-to-low-pressure turbine bolts, M10 x 55	47 N·m (35 lbf·ft)
High-pressure wastegate actuator bolts, M8 x 14	16 N·m (12 lbf·ft)
Male stud connector	70 N·m (52 lbf·ft)
M24 threaded fitting	60 N·m (44 lbf·ft)
Oil return low-pressure turbocharger tube (at crankcase)	See tightening steps in procedure.
Oil return low-pressure turbocharger tube fitting nut	See tightening steps in procedure.
Turbocharger oil supply tube assembly fitting nut to male stud connector	27 N·m (20 lbf·ft)

Special Service Tools

Table 12 Turbochargers

Description	Tool Number
3-inch couplers and clamps	Obtain locally
Charge Air Cooler Test Kit	ZTSE6042
Crimping pliers	Obtain locally
Extension Tube Installer	ZTSE6043
P-80® rubber lubricant or equivalent	Obtain locally
Turbo Alignment Bracket	ZTSE6041

Table of Contents

Exploded Views.....185
- **Power Steering and One-Cylinder Air Compressor.....185**
- **Power Steering and Two-Cylinder Air Compressor.....186**

Removal.....187
- **Power Steering Pressure Tubes.....187**
- **Power Steering Elbows.....188**
- **Power Steering Pump.....189**
- **Air Compressor Coolant Hoses.....189**
- **Air Compressor.....190**

Cleaning.....190
- **All components.....190**

Installation.....191
- **Air Compressor 191**
- **Air Compressor Coolant Hoses.....191**
- **Power Steering Pump.....192**
- **Power Steering Elbows.....193**
- **Power Steering Pressure Tubes.....193**

Special Torque.....195

Special Service Tools.....195

Exploded Views

Power Steering and One-Cylinder Air Compressor

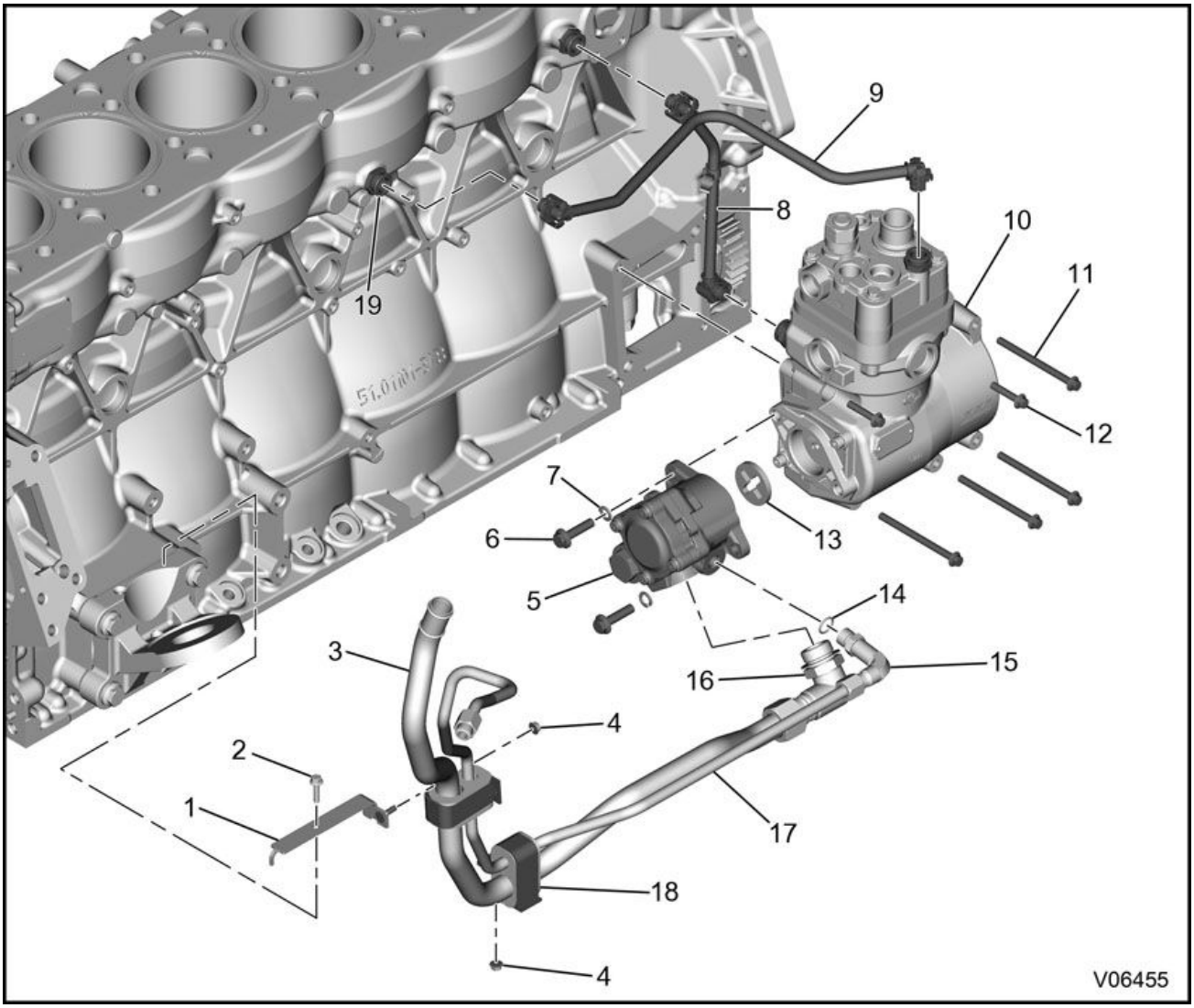


Figure 229 One-cylinder air compressor and power steering system (typical)

1. Extension clip
2. M6 x 25 bolt
3. Power steering (low-pressure) tube assembly
4. M6 x 1.0 nut (2)
5. Power steering pump
6. M10 x 40 bolt (2)
7. Lock washer (10 mm) (2)
8. Return coolant tube assembly
9. Return coolant hose assembly
10. Air compressor
11. M8 x 110 bolt (4)
12. M8 x 40 bolt (2)
13. Power steering pump adapter
14. O-ring seal
15. 1/2” 90 degree tube elbow
16. 1-1/16” 90 degree elbow
17. Power steering (high-pressure) tube assembly
18. Support bracket
19. M16 straight union (2)

Optional two-cylinder compressors are available. Although compressor housings are longer, compressor and power steering line connections to crankcase and chassis are similar to one-cylinder compressors.

Power Steering and Two-Cylinder Air Compressor

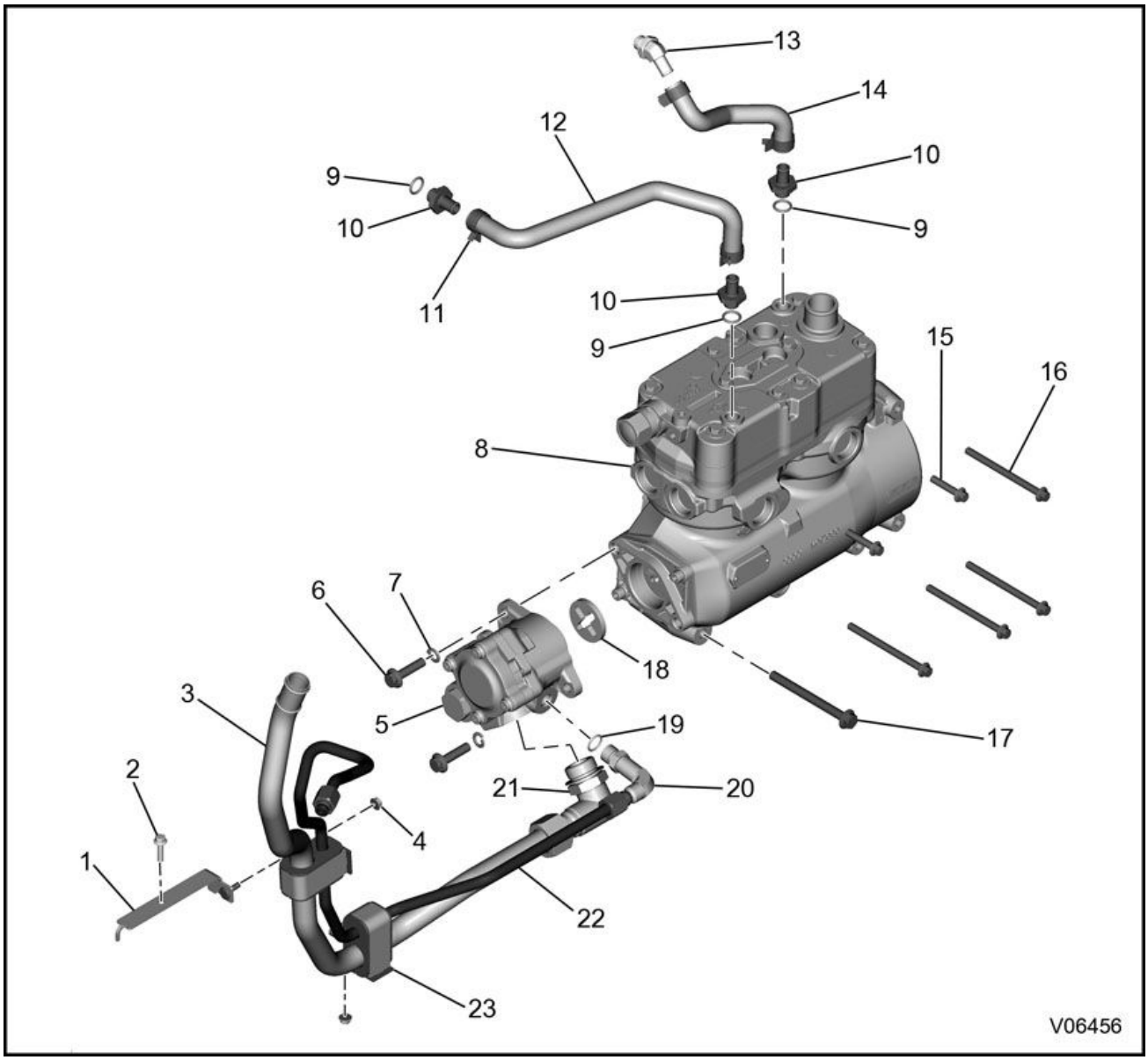


Figure 230 Optional two-cylinder air compressor and power steering system (typical)

1. Extension clip
2. M6 x 25 bolt
3. Power steering (low-pressure) tube assembly
4. M6 x 1.0 nut (2)
5. Power steering pump
6. M10 x 40 bolt (2)
7. Lock washer (10 mm) (2)
8. Air compressor
9. O-ring seal (3)
10. M16 straight fitting (3)
11. 21 mm constant-tension clamp (4)
12. Coolant return hose
13. M16 45 degree fitting
14. Coolant supply hose
15. M8 x 40 bolt (2)
16. M8 x 110 bolt (4)
17. M10 x 110 bolt
18. Power steering pump adapter
19. O-ring seal
20. 1/2” tube 90 degree elbow
21. 1-1/16”-12ST 90 degree elbow
22. Power steering (high-pressure) tube assembly
23. Support bracket

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, 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.

Power Steering Pressure Tubes

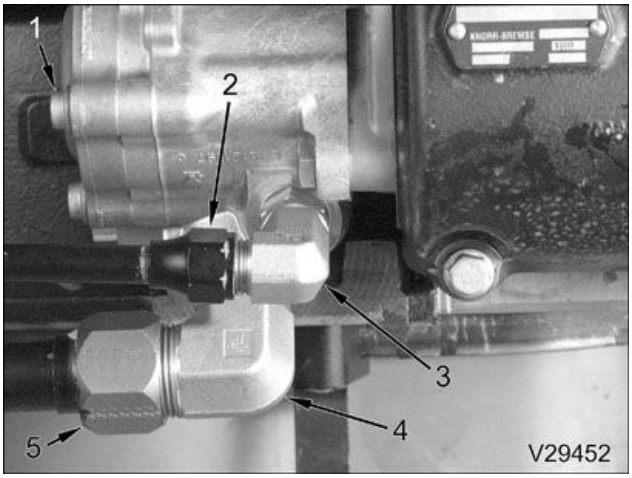


Figure 231 Power steering pump and Pressure tubes

1. Power steering pump
2. High-pressure tube fitting nut
3. 1/2" 90 degree tube elbow
4. 1-1/6" 90 degree tube elbow
5. Low-pressure tube fitting nut

1. Place a drain pan under the power steering pump to catch any fluid.
2. Loosen high-pressure tube fitting nut and disconnect tube from 1/2" 90 degree tube elbow.
3. Loosen low-pressure tube fitting nut and disconnect tube from 1-1/16" 90 degree elbow.

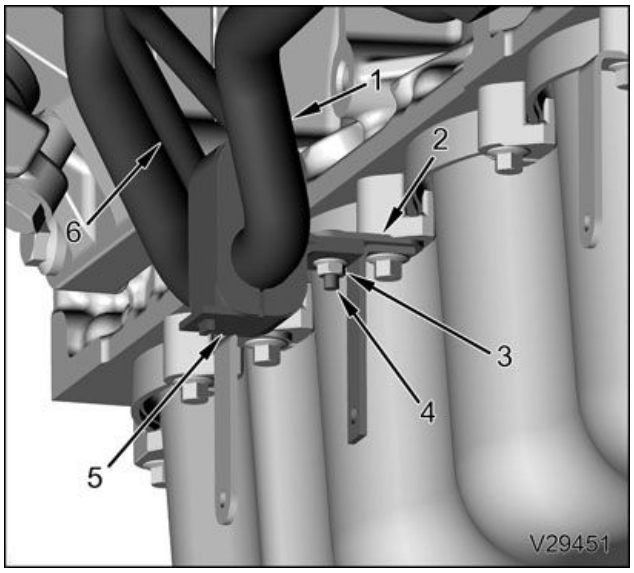


Figure 232 Pressure tubes support bracket

1. Power steering (low-pressure) tube assembly
2. Extension clip
3. M6 nut
4. M6 x 20 stud
5. Rear support bracket
6. Power steering (high-pressure) tube assembly

4. Remove rear support bracket M6 nut from extension clip stud at the oil pan.
5. If equipped, remove front support bracket M6 nut from support bracket.
6. Remove high-pressure and low-pressure tubes as an assembly.

NOTE: If replacing high-pressure and low-pressure tubes, do steps 7 and 8.

7. Remove the rear support brackets and rubber isolator from the high-pressure and low-pressure tubes.
8. If equipped, remove front support brackets and rubber isolator from the high-pressure and low-pressure tubes.

Power Steering Elbows

NOTE: This procedure should be completed only if replacing power steering pump, or if one or both of the elbows are leaking.

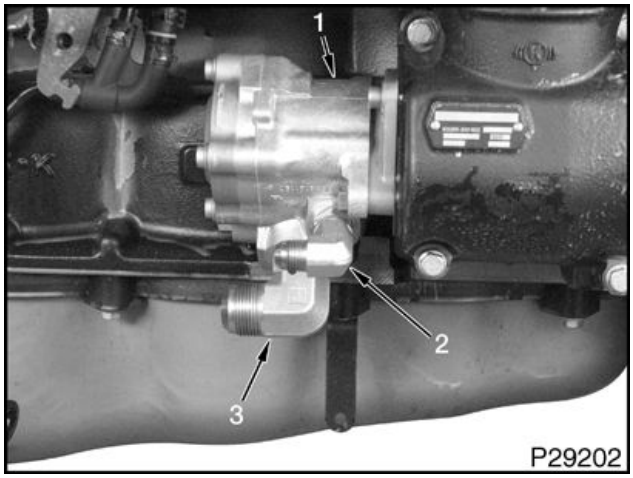


Figure 233 Power steering pump and 90 degree elbows

1. Power steering pump
2. 1/2” 90 degree tube elbow
3. 1-1/16” 90 degree elbow

1. Loosen the lock nut and rotate the 1/2” 90 degree tube elbow counterclockwise to remove from power steering pump.
2. Loosen the lock nut and rotate the 1-1/16” 90 degree elbow counterclockwise to remove from power steering pump.

Power Steering Pump

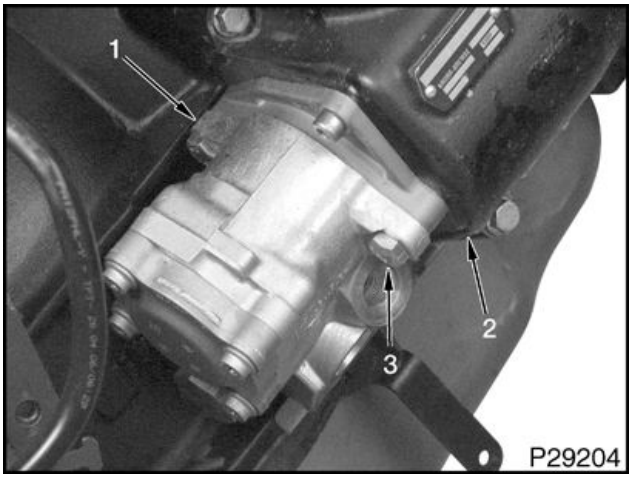


Figure 234 Power steering pump

1. Power steering pump
2. Air compressor
3. M10 x 40 bolt and lock washer (2)

1. Remove two M10 x 40 bolts, lock washers and power steering pump.
2. Check pump collar O-ring for damage and replace as necessary.

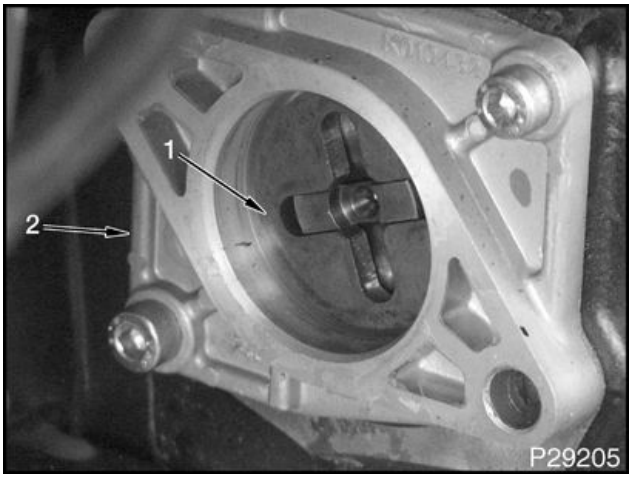


Figure 235 Power steering pump adapter

1. Power steering pump adapter
2. Air compressor

3. Remove power steering pump adapter from air compressor bore.

Air Compressor Coolant Hoses

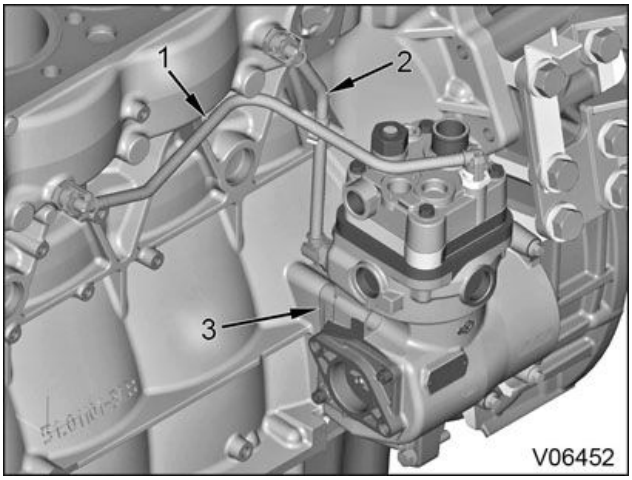


Figure 236 Air compressor coolant hoses

1. Coolant return hose
2. Coolant return tube (one cylinder air compressor) or Coolant supply hose (two cylinder air compressor)
3. Air compressor

1. Place suitable container under air compressor to collect any residual coolant.

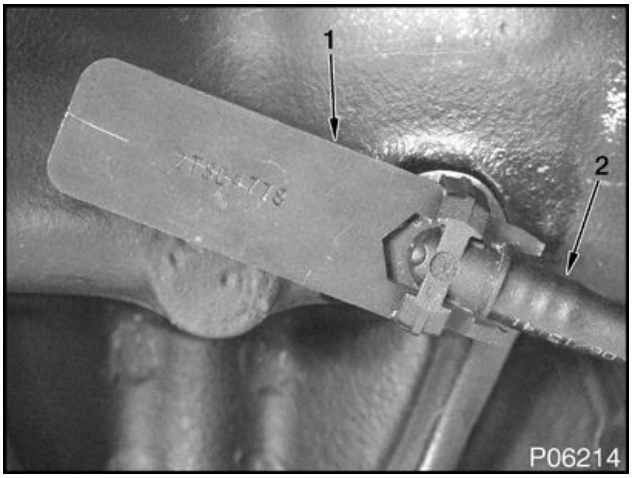


Figure 237 Air compressor coolant hose removal

1. Coolant Line Release Tool
2. Coolant hose

2. Insert Coolant Line Release Tool (page 195) into retaining clips of air compressor coolant hose and remove from crankcase.

3. Using Coolant Line Release Tool, release and remove air compressor coolant tube from air compressor.
4. Recycle or dispose of any coolant according to applicable regulations.

Air Compressor

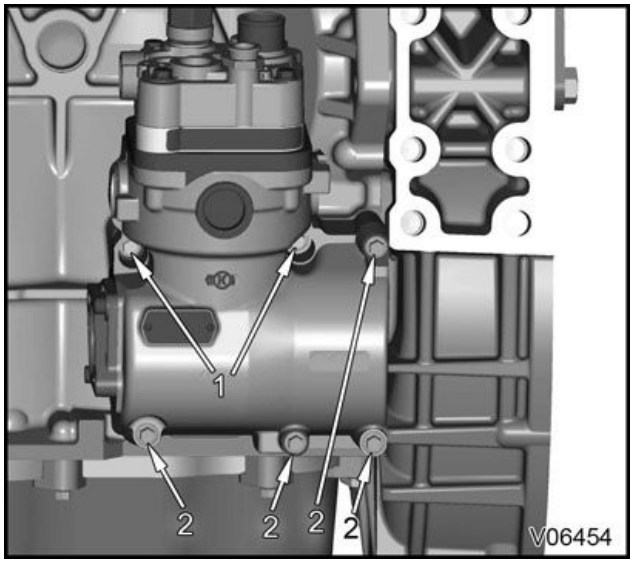


Figure 238 Air compressor (typical)

1. M8 x 40 bolt (2)
2. M8 x 110 bolt (4)

⚠ WARNING: To prevent personal injury or death, get assistance to remove and install the air compressor and power steering pump assembly.

NOTE: For two-cylinder air compressor only, an additional M10 x 110 bolt is located in the air compressor mounting hole next to the power steering pump.

1. For one-cylinder air compressor, remove two M8 x 40 bolts and four M8 x 110 bolts.
2. For two-cylinder air compressor, remove two M8 x 40 bolts, four M8 x 110 bolts and M10 x 110 bolt.
3. Remove air compressor from alignment dowels.

Cleaning

All components

1. Cover coolant, fluid and air openings to ensure dirt does not enter air compressor and power steering pump.
2. Clean foreign material from sealing surfaces of air compressor. Use a scraper to clean sealing material from the sealing surfaces.
3. Use only hot water to clean all hoses and tubes.

Installation

Air Compressor

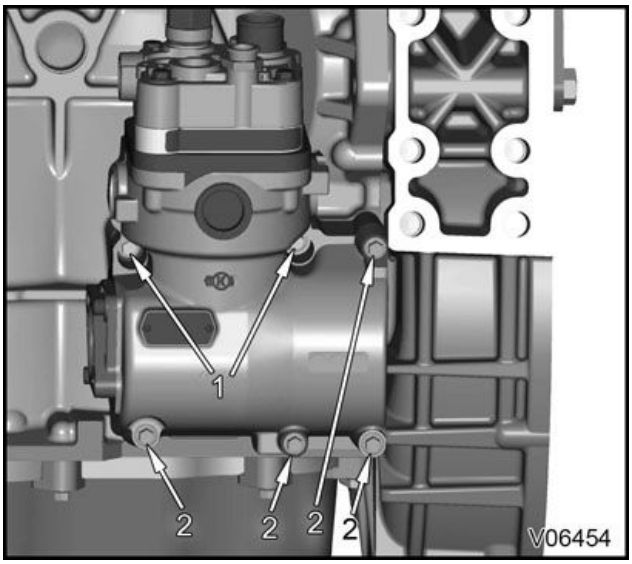


Figure 239 Air compressor (typical)

1. M8 x 40 bolt (2)
2. M8 x 110 bolt (4)

WARNING: To prevent personal injury or death, get assistance to remove and install the air compressor and power steering pump assembly.

CAUTION: To prevent engine damage, install component within 5 minutes of sealant application to inhibit the formation of a skin and ensure a leak-proof joint.

NOTE: For two-cylinder air compressor only, an additional M10 x 110 bolt is located in the mounting hole next to the power steering pump.

1. Apply Loctite® 5900 sealant or Wacker® A-442 RTV (page 195) to crankcase and air compressor mating surface.
2. For one-cylinder air compressor, position air compressor and install two M8 x 40 bolts and four M8 x 110 bolts. Tighten bolts to special torque (page 195).
3. For two-cylinder air compressor, position air compressor and install two M8 x 40 bolts, four M8 x 110 bolts and M10 x 110 bolt. Tighten bolts to special torque (page 195).

Air Compressor Coolant Hoses

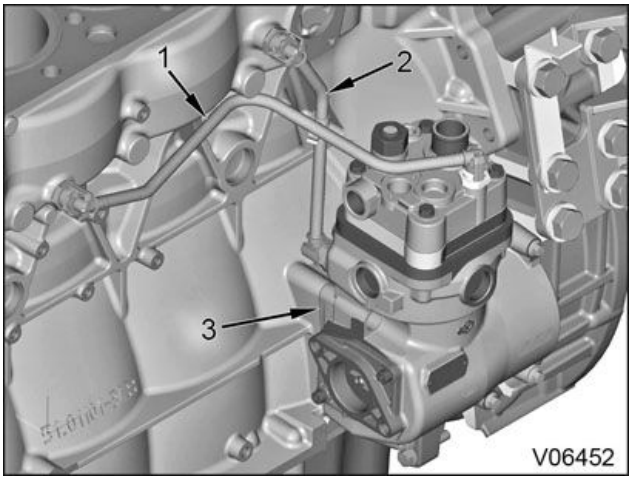


Figure 240 Air compressor coolant hoses

1. Coolant return hose
2. Coolant return tube (one-cylinder air compressor) or Coolant supply hose (two-cylinder air compressor)
3. Air compressor

1. Depending on compressor model, straight and 45° coolant fittings are used. If loosened, tighten fittings as follows:

One-cylinder compressors

- Tighten M16 straight fittings (at crankcase or air compressor) to special torque (page 195).
- If equipped, tighten M16 45° fitting (at crankcase) to special torque (page 195).
- If equipped, tighten M18 straight fittings (at air compressor) to special torque (page 195).

Two-cylinder compressors

- Tighten M16 straight fittings (at crankcase or air compressor) to special torque (page 195).
- If equipped, tighten M16 45° fitting (at crankcase or air compressor) to special torque (page 195).

2. Check air compressor coolant supply and return hose O-rings before installation. Replace O-rings as needed.
3. Place coolant supply hose in position between crankcase and air compressor coolant fittings.

4. Press down on quick-connect fittings until a click is heard to install hose. Lightly pull on hose to make sure it is locked.
5. Repeat steps 3 and 4 to install air compressor coolant return hose.

Power Steering Pump

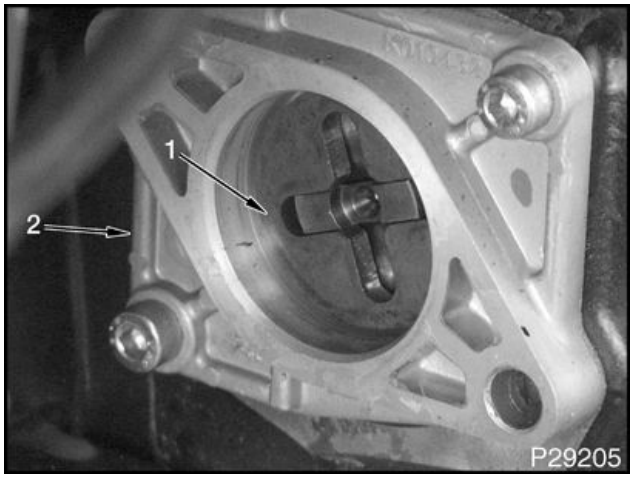


Figure 241 Power steering pump adapter

1. Power steering pump adapter
2. Air compressor

1. Install power steering pump adapter to air compressor bore.

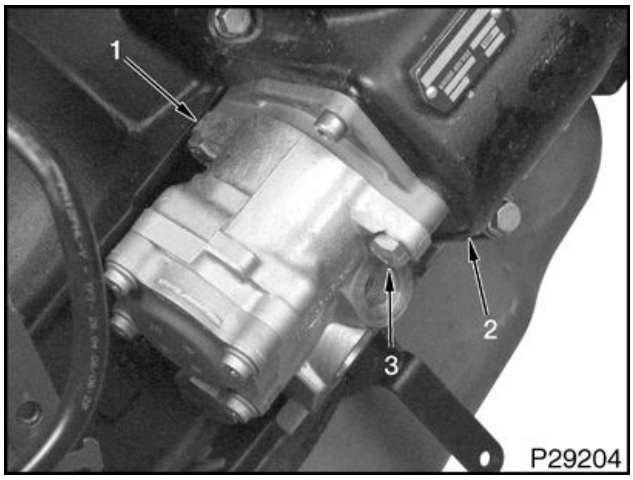


Figure 242 Power steering pump (typical)

1. Power steering pump
2. Air compressor
3. M10 x 40 bolt (2)

2. If pump collar O-ring was removed or damaged, install a new O-ring. Lubricate the new O-ring with P80® rubber lubricant (page 195) or equivalent.
3. Install power steering pump and two M10 x 40 bolts. Tighten bolts to special torque (page 195).

Power Steering Elbows

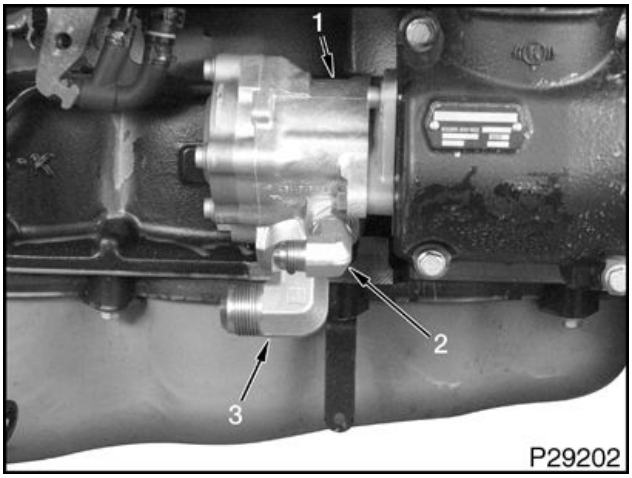


Figure 243 Power steering elbows

1. Power steering pump
2. 1/2” 90 degree tube elbow
3. 1-1/16” 90 degree elbow

NOTE: This procedure should be completed only if replacing power steering pump, or if one or both of the elbows were removed.

1. Check seals on elbow for damage. Replace as necessary.
2. Install 1/2” 90 degree tube elbow to power steering pump. Lock nuts should not be tightened until power steering lines are installed for proper orientation.
3. Install 1-1/16” 90 degree elbow to power steering pump. Lock nuts should not be tightened until power steering lines are installed for proper orientation.

Power Steering Pressure Tubes

NOTE: If high-pressure and low-pressure tubes were replaced, do steps 1 and 2.

1. If equipped and removed, install front support brackets and rubber isolator onto the high- and low-pressure tubes.
2. If removed, install rear support brackets and rubber isolator onto the high- and low-pressure tubes.

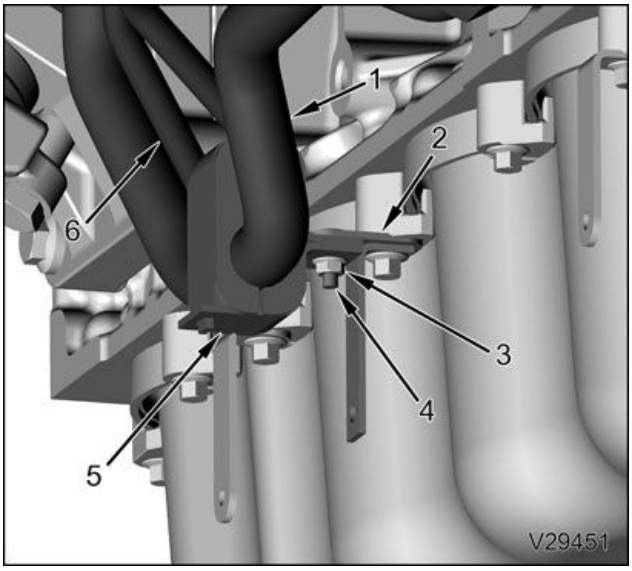


Figure 244 Pressure tubes support bracket

1. High- and low-pressure tube assembly
2. Extension clip
3. M6 x 1.0 nut
4. M6 x 20 bolt
5. Rear support bracket
6. Power steering (high-pressure) tube assembly

3. Position high-pressure and low-pressure tube as an assembly. Install M6 x 1.0 nut onto extension clip stud to secure rear support bracket at the oil pan. Tighten nut to standard torque (page 503).
4. If equipped, install front support bracket to extension clip stud on front engine support and secure with M6 x 1.0 flange nut. Tighten nut to standard torque (page 503).

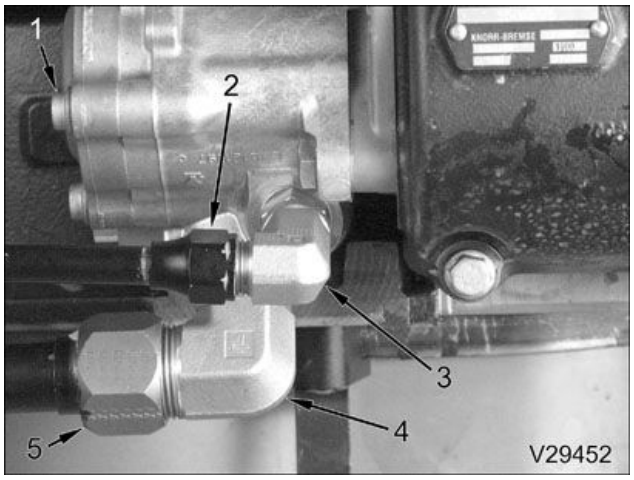


Figure 245 Pressure tubes

1. Power steering pump
2. High-pressure tube
3. 1/2” 90 degree tube elbow
4. 1-1/16” 90 degree elbow
5. Low-pressure tube

NOTE: Do the following steps if fittings were removed or if power steering pump was replaced.

5. Loosely install the high-pressure tube fitting nut to the elbow. Using an appropriate size wrench to hold the elbow, tighten 1/2" 90 degree tube elbow lock nut to special torque (page 195).
6. Loosely install the low-pressure tube fitting nut to the elbow. Using an appropriate size wrench to hold the elbow, tighten 1-1/16" 90 degree elbow lock nut to special torque (page 195).
7. Tighten the high-pressure and low-pressure tube fitting nuts to special torque (page 195).

Special Torque

Table 13 Air Compressor and Power Steering/Fuel Pump

1-1/16" 90 degree elbow lock nut	55 N·m (40 lbf·ft)
1/2" 90 degree tube elbow lock nut	45 N·m (33 lbf·ft)
Air compressor M8 x 40, M8 x 110 bolt (one cylinder)	35 N·m (26 lbf·ft)
Air compressor M8 x 40, M8 x 110 bolt (two cylinder)	31 N·m (23 lbf·ft)
(Two cylinder) Air compressor M10 x 110 bolt	67 N·m (49 lbf·ft)
High-pressure tube fitting nut	62 N·m (45 lbf·ft)
M16 straight fitting	35 N·m (26 lbf·ft)
M16 45° fitting	17.5 N·m (13 lbf·ft)
M18 straight fitting	37.5 N·m (28 lbf·ft)
Low-pressure tube fitting nut	164 N·m (120 lbf·ft)
Power steering pump M10 x 40 bolt	67 N·m (49 lbf·ft)

Special Service Tools

Table 14 Air Compressor

Description	Tool Number
Coolant Line Release Tool	ZTSE4778
Loctite® 5900 sealant or Wacker® A-442 RTV	Obtain locally
P80® rubber lubricant or equivalent	Obtain locally

Table of Contents

Exploded Views.....199
- **High-pressure Fuel Lines**.....199
- **Fuel Supply and Drain (Return) Lines**.....200
- **Fuel Filter Housing Assembly**.....201
- **High-pressure Fuel Pump and Drive Housing**.....202

Removal.....203
- **High-pressure Fuel Lines**.....204
- **Injector and Fuel Drain (Return) Lines**.....206
- **Fuel Rail Assembly**.....207
- **Fuel Primer Pump Assembly**.....207
- **Fuel Supply and Drain (Return) Lines**.....208
- **Fuel Primer Pump Assembly**.....210
- **Fuel Filter Housing Assembly**.....211
- **Fuel Filter Stand Pipe Replacement**.....211
- **High-pressure Pump (Drive Belt) Pulley**.....212
- **High-pressure Pump (Drive Belt) Pulley Housing and Radial Shaft Seal**.....213
- **High-pressure Fuel Pump (HPFP) and Drive Housing**.....213
- **Fuel Injectors**.....216

Cleaning and Inspection.....219
- **Low-pressure and High-pressure Fuel System Components**.....219
- **Fuel Injector Bore**.....219
- **Fuel Injector Harness**.....219

Installation.....220
- **Fuel Injectors**.....220
- **High-pressure Fuel Pump (HPFP) and Drive Housing**.....224
- **High-Pressure Pump (Drive Belt) Pulley Housing and Radial Shaft Seal**.....226
- **High-Pressure Pump (Drive Belt) Pulley**.....227
- **Fuel Filter Housing Assembly**.....227
- **Fuel Primer Pump Assembly**.....228
- **Fuel Supply and Drain (Return) Lines**.....229
- **Fuel Rail Assembly**.....231
- **Injector and Fuel Drain (Return) Lines**.....232
- **High-pressure Fuel Lines**.....232
- **Filter and Fuel Strainer Element**.....235
- **Fuel System Priming**.....235
  - **Fuel System Priming Tool Method**.....235
  - **Hand Primer Pump Method**.....240

Specifications.....242

Special Torque.....243

Special Service Tools.....244

Exploded Views

High-pressure Fuel Lines

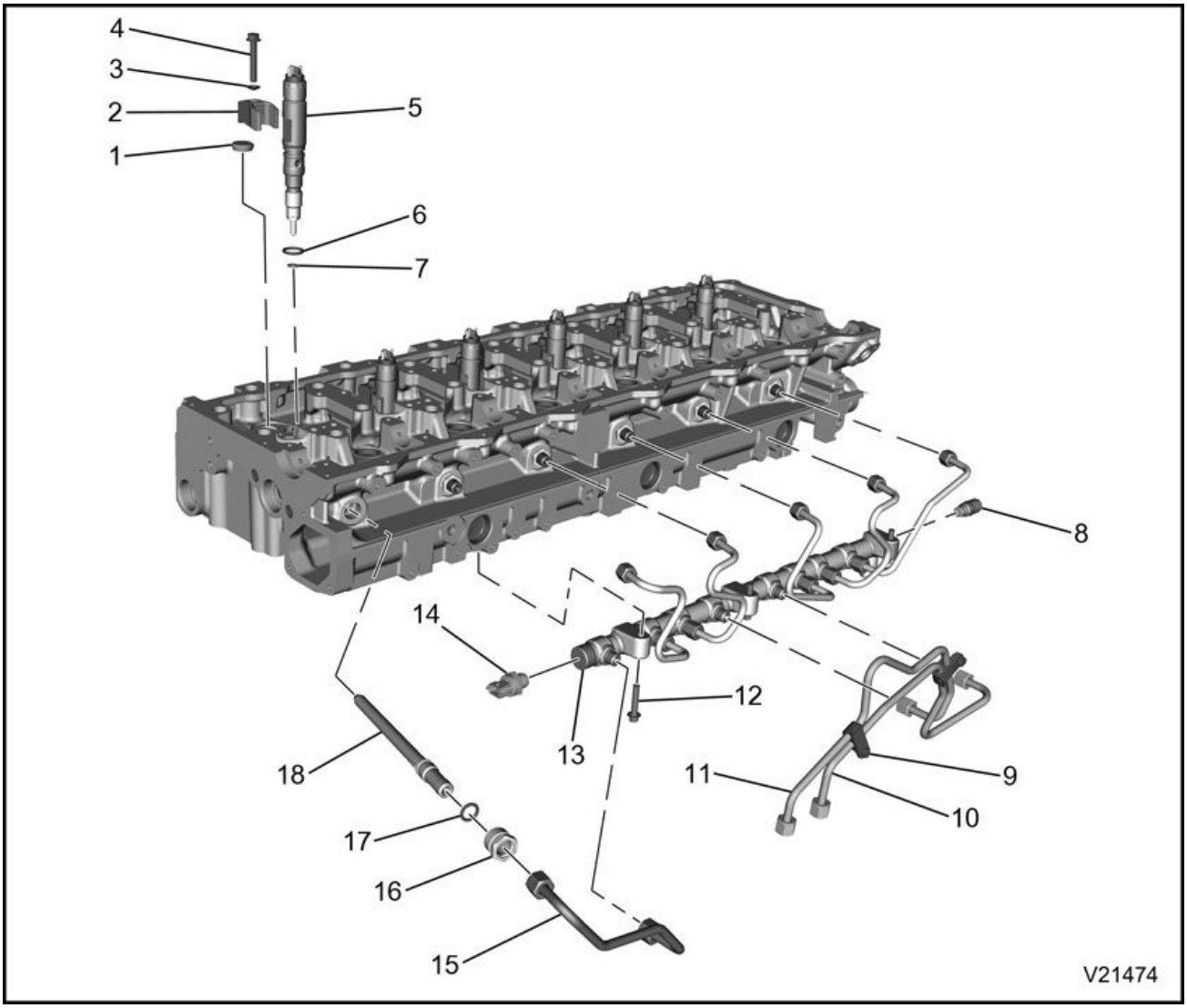


Figure 246 High-pressure fuel lines

1. Thrust washer (6)
2. Injector hold-down clamp (6)
3. Rounded washer (6)
4. M8 x 50 bolt (6)
5. Injector (6)
6. 3 x 20.9 ID O-ring (6)
7. Combustion washer (6)
8. Pressure limiting valve (fuel rail)
9. Fuel to rail supply clamp assembly (2)
10. High-pressure pump to rail tube assembly 2
11. High-pressure pump to rail tube assembly 1
12. M8 x 40 bolt (3)
13. Fuel rail
14. Fuel rail pressure sensor
15. High-pressure rail to injector tube assembly (6)
16. High-pressure connector retaining nut (6)
17. 13.5 x 3 O-ring (6)
18. High-pressure connector body (6)

Fuel Supply and Drain (Return) Lines

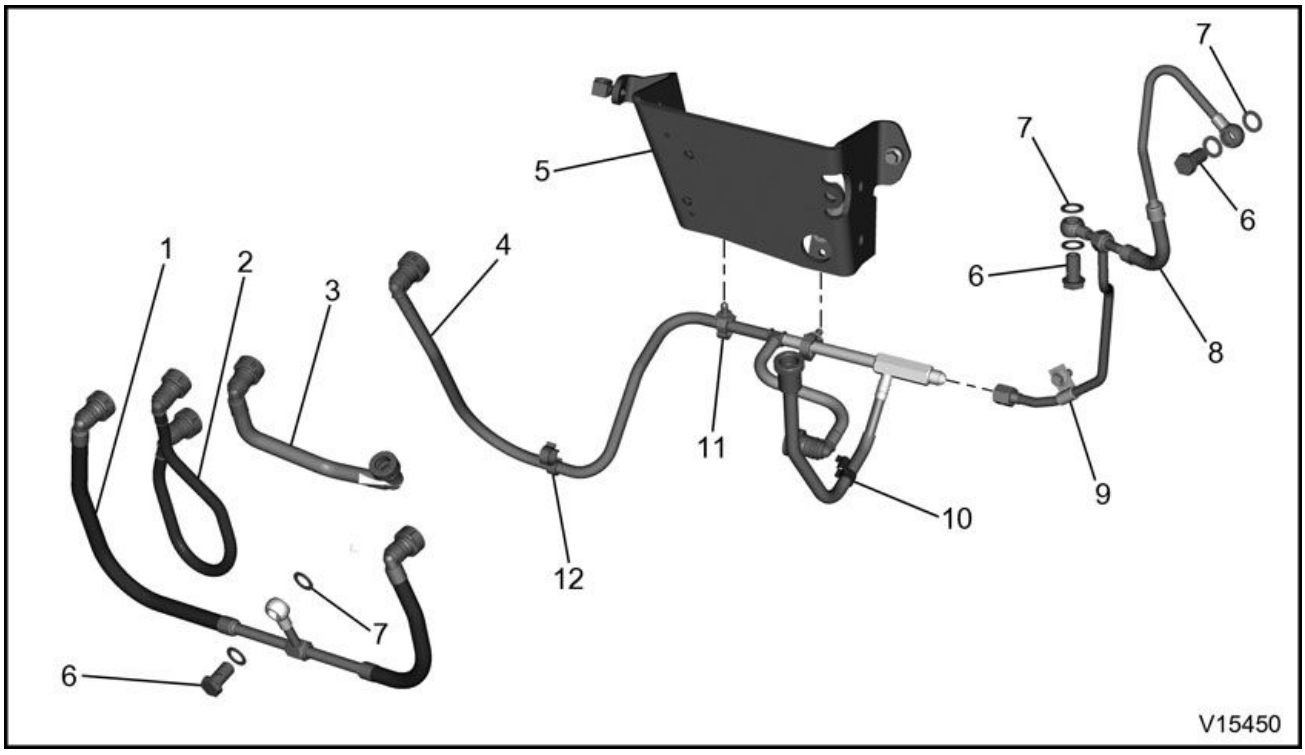


Figure 247 Fuel supply and drain (return) lines

1. After-filter fuel supply hose (assembly)
2. Pre-pump fuel supply hose assembly
3. Pre-filter fuel supply hose (assembly)
4. Fuel drain (return) hose assembly
5. Fuel filter bracket assembly with brace
6. M14 banjo bolt (3)
7. Seal ring, 14.7 x 22 (6)
8. Fuel drain (return) tube assembly
9. Closed (P) clamp and 8 x 16 bolt
10. Wiring clip
11. 8 x 13 single retainer
12. C-clip

Fuel Filter Housing Assembly

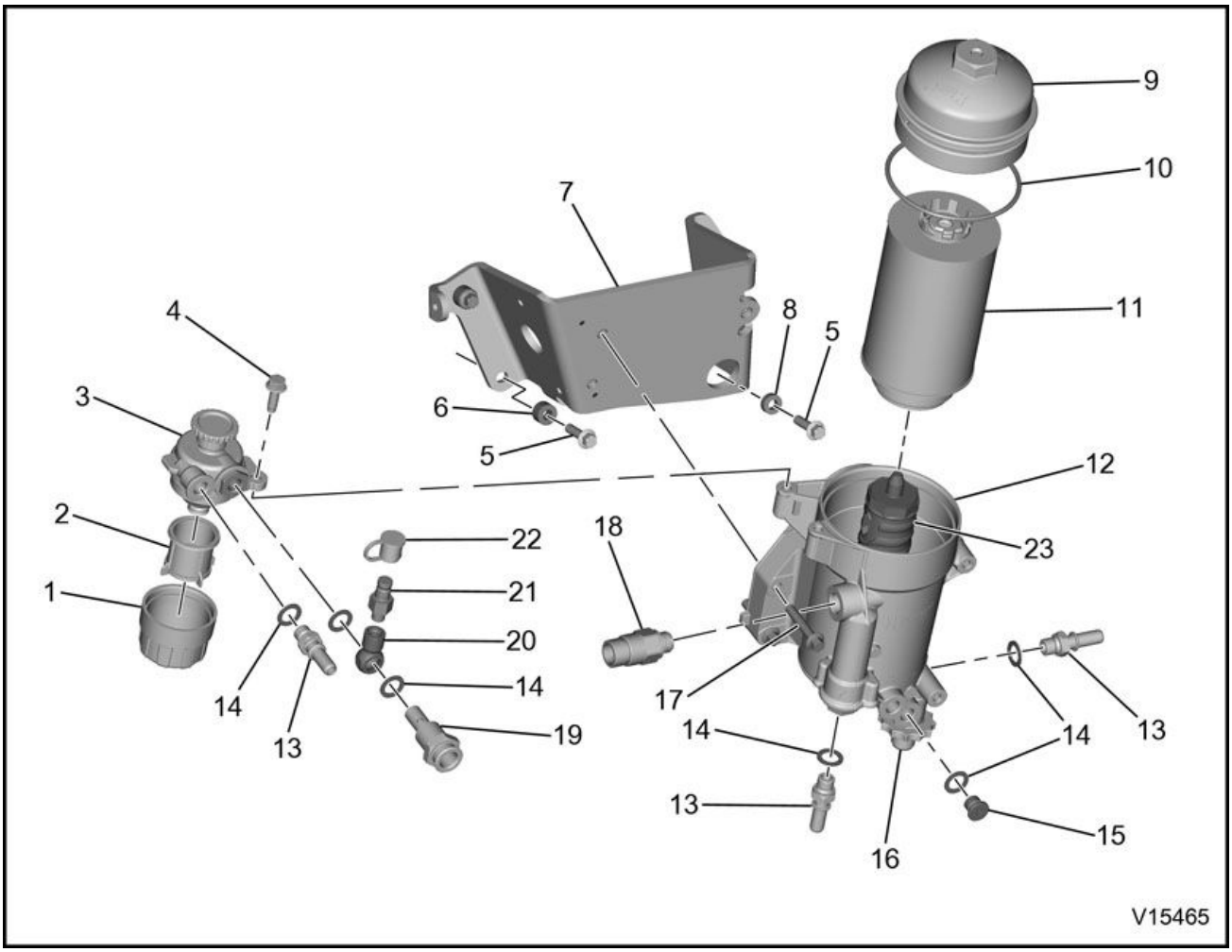


Figure 248 Fuel filter housing assembly

1. Priming cup cap
2. Priming element
3. Fuel primer pump assembly
4. M8 x 25 bolt (2)
5. M8 x 30 bolt (4)
6. 9 ID x 18 OD x 10.5 spacer (3)
7. Fuel filter bracket assembly with brace
8. 9 ID x 17 OD x 6.5 spacer
9. Fuel filter cap
10. Fuel filter cap O-ring
11. Fuel filter element
12. Fuel filter housing assembly
13. Threaded union (3)
14. Seal ring, 14.7 x 22 (12)
15. M14 x 1.5 hex socket plug
16. Fuel filter drain plug
17. M8 x 45 bolts (3)
18. Fuel Delivery Pressure (FDP) sensor
19. Fuel supply adapter
20. Banjo fitting
21. Check valve (quick connect)
22. Dust cap
23. Fuel filter stand pipe

High-pressure Fuel Pump and Drive Housing

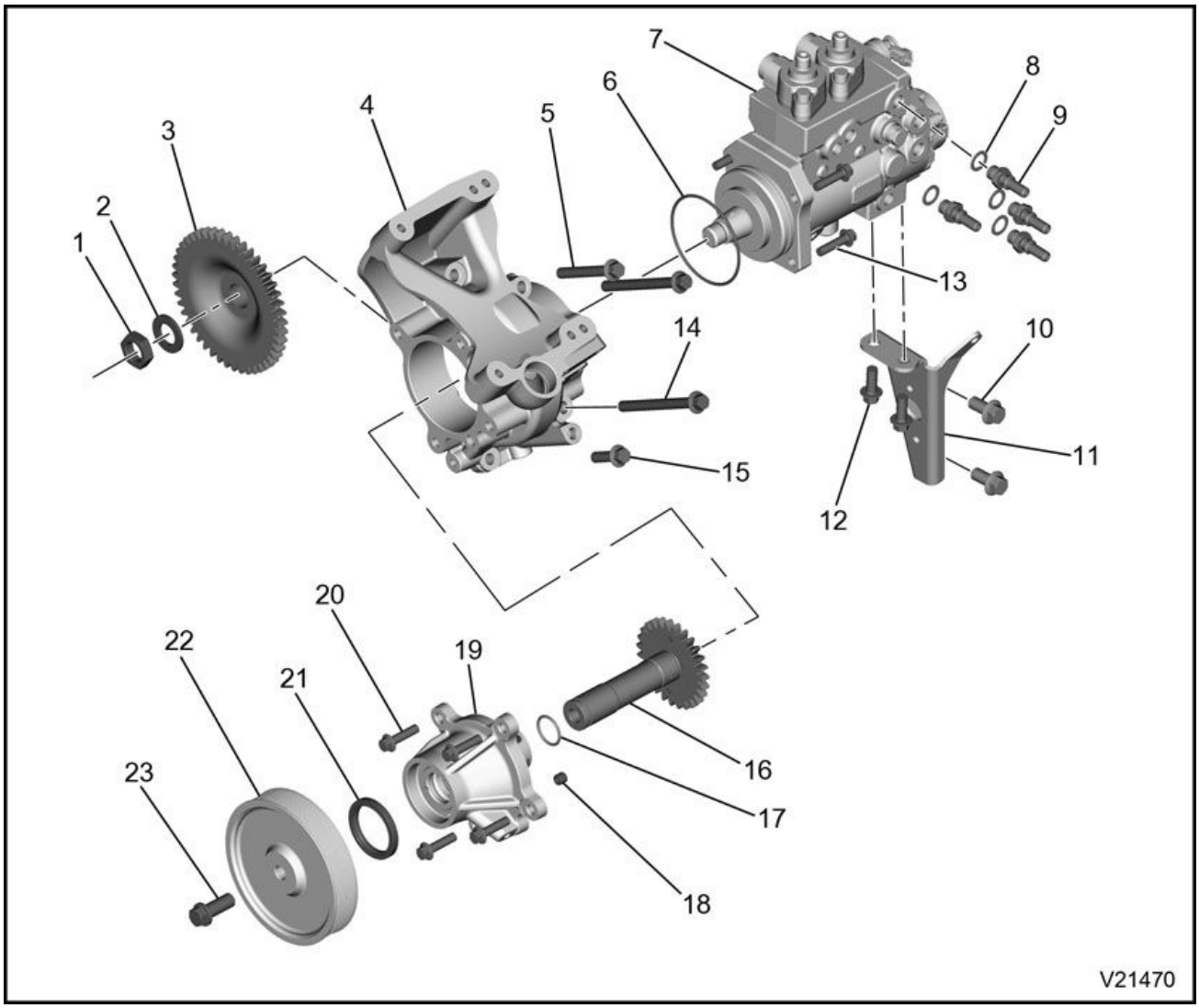


Figure 249 High-pressure fuel pump and drive housing

1. M24 jam nut
2. Washer, 25 x 44 x 4
3. High-pressure (fuel) pump gear
4. High-pressure (fuel) pump drive housing
5. M12 x 90 bolt
6. 100 x 3.349 O-ring
7. High-pressure fuel pump
8. Seal ring, 16.7 x 24 (4)
9. Quick-connect M16 x 1.5 connector (4)
10. M14 x 30 bolt (2)
11. High-pressure (fuel) pump support
12. M12 x 30 bolt (2)
13. M10 x 40 bolt (4)
14. M12 x 130 bolt (2)
15. M12 x 40 bolt
16. Drive belt shaft
17. 30.2 x 3 O-ring
18. Sleeve
19. High-pressure pump (drive belt) pulley housing
20. M10 x 40 bolt (4)
21. 55 x 70 x 8 radial shaft seal
22. High-pressure pump (drive belt) pulley
23. M16 x 40 LH bolt (left-hand thread)

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, remove ground cable from the 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.

WARNING: To prevent personal injury or death, do not turn ignition key to ON if fuel system parts are removed or disconnected. Activation of the fuel pump could spill fuel and create a fire.

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

- Engine Electrical
- Cold Start Assist
- Aftertreatment System
- Turbochargers

High-pressure Fuel Lines

WARNING: To prevent personal injury or death, engine must be stationary for at least 5 minutes before doing any work on high-pressure fuel system to allow for system depressurization.

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.

CAUTION: To prevent engine damage, plug component connections immediately after each fuel line is removed.

1. If not already done, disconnect air supply line from harness 21-way connector bracket.

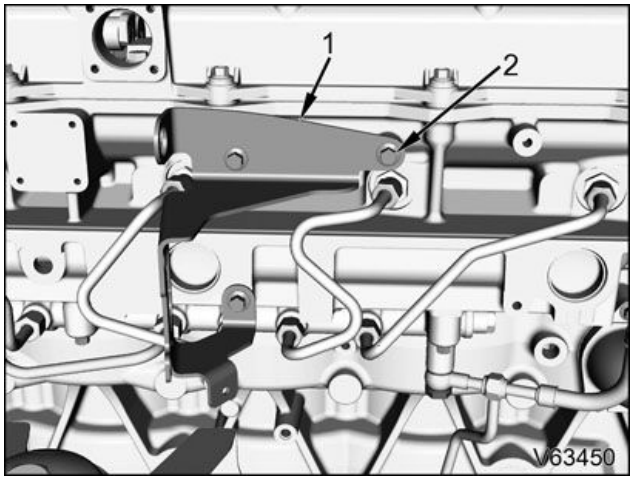


Figure 250 Harness connector bracket

1. Harness 21-way connector bracket
2. M8 x 16 bolt (3)

2. Remove three M8 x 16 bolts and harness 21-way connector bracket.

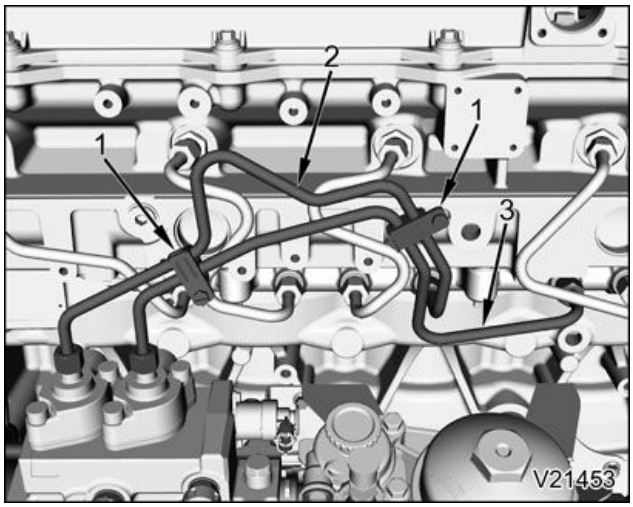


Figure 251 Fuel to rail supply clamp assembly

1. Fuel to rail supply clamp assembly (2)
2. High-pressure pump to rail tube assembly 1
3. High-pressure pump to rail tube assembly 2

NOTE: It is necessary to remove tube clamps (step 3) from high-pressure fuel pump to fuel rail assemblies if only one tube (tube 1 or 2) is to be removed. Tube clamps can remain installed if both pump to rail tubes are removed as an assembly.

3. Remove two clamps from high-pressure fuel pump to fuel rail tube assemblies 1 and 2.

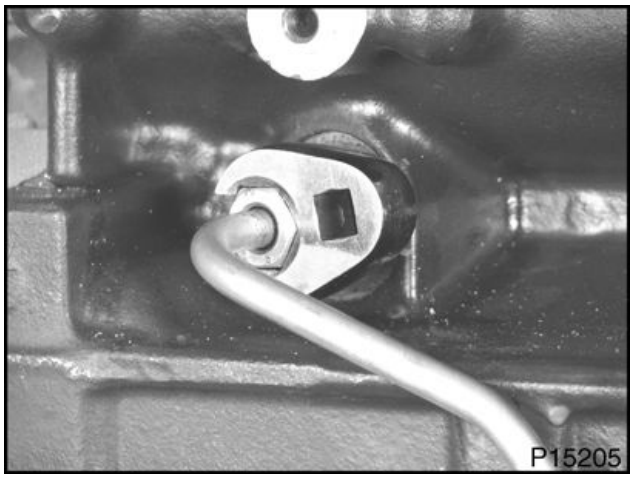


Figure 252 Crowfoot wrench (typical)

4. Obtain a crowfoot wrench (page 244) for removal of all high-pressure fuel lines.

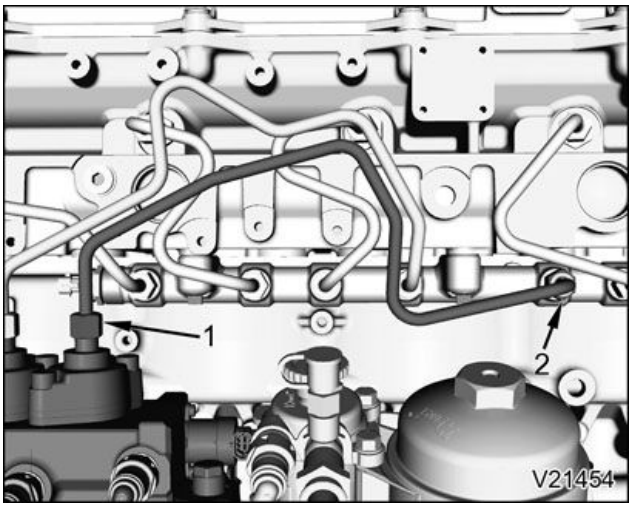


Figure 253 High-pressure pump to rail tube assembly 2

1. Line fitting nut at high-pressure fuel pump
2. Line fitting nut at fuel rail

5. Loosen line fitting nuts at fuel pump and fuel rail and remove high-pressure pump to rail tube assembly 2. Cap open fuel pump and fuel rail connections with clean Disposable Air and Fuel Caps (page 244).

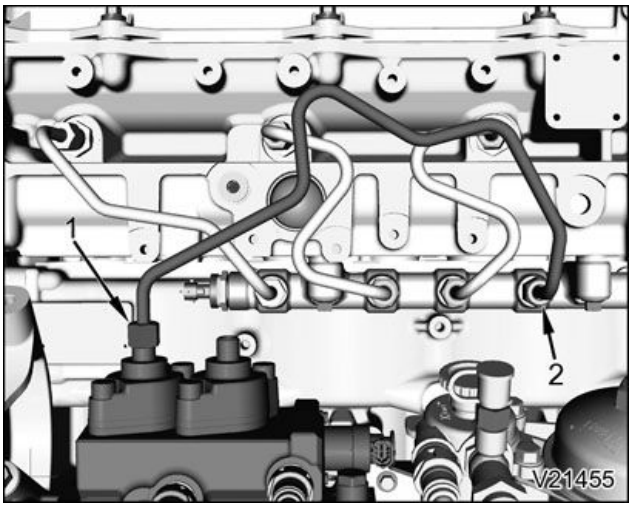


Figure 254 High-pressure pump to rail tube assembly 1

1. Line fitting nut at high-pressure fuel pump
2. Line fitting nut at fuel rail

6. Loosen line fitting nuts at fuel pump and fuel rail and remove high-pressure pump to rail tube assembly 1. Cap open fuel pump and fuel rail connections.

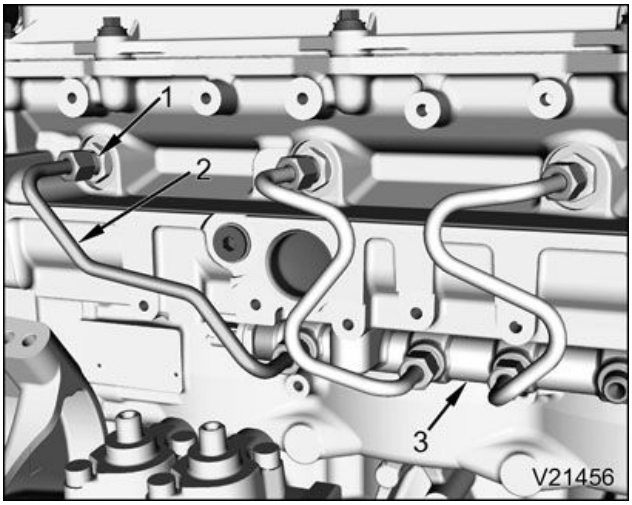


Figure 255 High-pressure rail to injector tube assembly

1. Cylinder 1 high-pressure connector body and retaining nut
2. Cylinder 1 high-pressure rail to injector tube assembly
3. Fuel rail

7. Loosen injector 1 high-pressure rail to injector tube assembly fitting nuts at cylinder head and fuel rail.

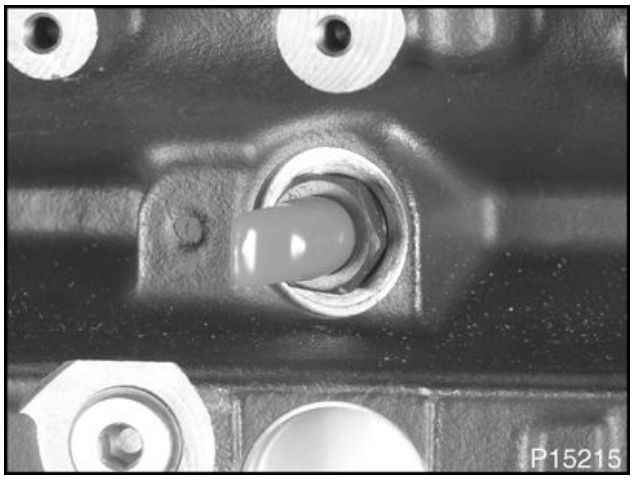


Figure 256 Fuel cap on high-pressure connector body (typical)

8. Remove and discard cylinder 1 high-pressure rail to injector tube assembly. Cap open high-pressure connector body and fuel rail connections with clean Disposable Air and Fuel Caps (page 244).

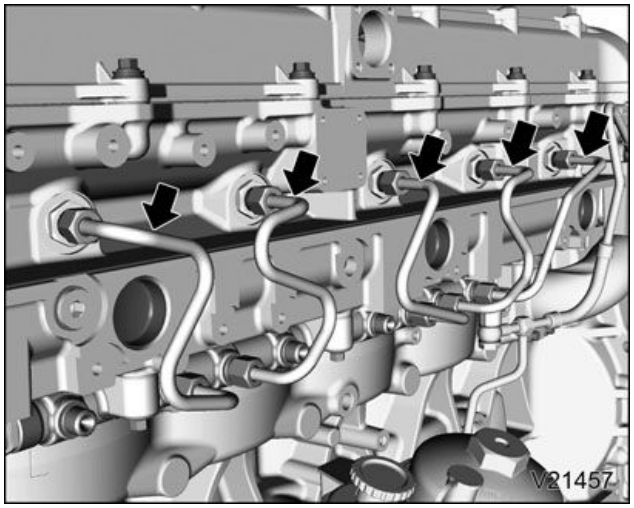


Figure 257 Cylinders 2-6 high-pressure rail to injector tubes

9. Remove high-pressure rail to injector tube assemblies for cylinders 2 through 6. Cap open high-pressure connector body and fuel rail connections.

Injector and Fuel Drain (Return) Lines

NOTE: It is not necessary to disassemble the fuel drain lines unless individual components are leaking or damaged.

CAUTION: To prevent engine damage, plug component connections immediately after each fuel line is removed.

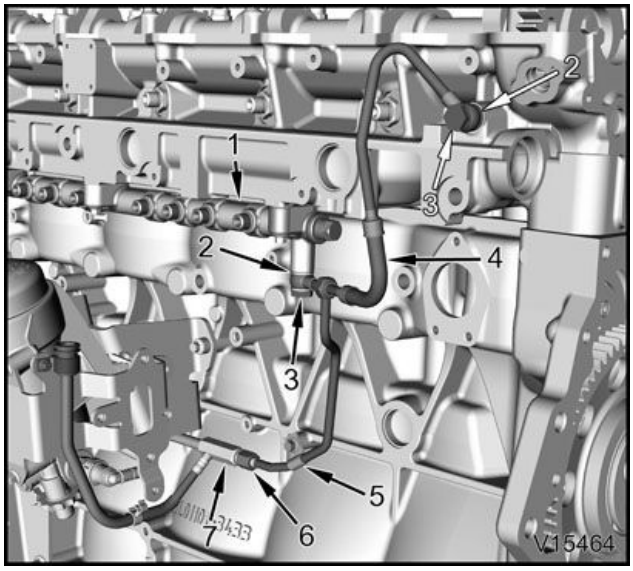


Figure 258 Fuel drain (return) tube

1. Fuel rail
2. 14.7 x 22 seal ring (4)
3. M14 banjo bolt (2)
4. Fuel drain tube
5. M8 x 16 bolt and closed (P) clamp assembly
6. Line fitting nut
7. Fuel drain hose (hex manifold tee)

1. Remove M8 x 16 bolt and closed (P) clamp securing fuel drain tube to crankcase.
2. Loosen fuel drain line fitting nut at the fuel return hex manifold tee and disconnect tube from fuel return line.
3. Remove M14 banjo bolt and two 14.7 x 22 seal rings to disconnect fuel drain tube at fuel rail. Discard seal rings.
4. Remove M14 banjo bolt and 14.7 x 22 seal rings connecting fuel drain tube at cylinder head. Remove fuel drain tube and discard seal rings.

Fuel Rail Assembly

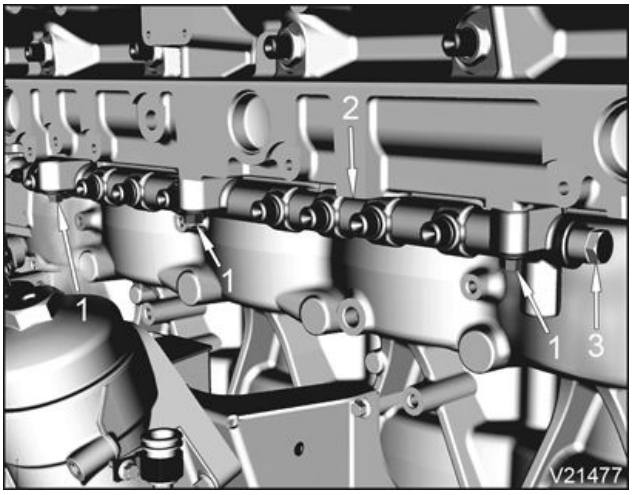


Figure 259 Fuel rail and pressure limiting valve

1. M8 x 40 bolt (3)
2. Fuel rail assembly
3. Pressure limiting valve

WARNING: To prevent personal injury or death, the engine must be stationary for at least 5 minutes to allow for system depressurization, before doing work on the high-pressure fuel system.

NOTE: The pressure limiting valve should not be removed from the fuel rail assembly. Replace the entire fuel rail assembly if the pressure limiting valve is defective. Use ServiceMaxx®to verify fuel pressure following the procedure in the *Engine Diagnostic Manual* .

1. Support fuel rail to prevent it from falling during removal.
2. Remove three M8 x 40 bolts and remove fuel rail from cylinder head.

Fuel Primer Pump Assembly

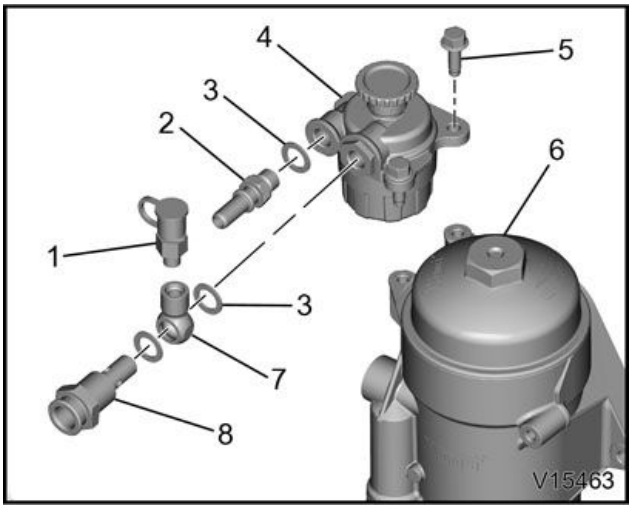


Figure 260 Fuel primer pump assembly

1. Check valve
2. Threaded union
3. 14.7 x 22 seal ring (3)
4. Fuel primer pump assembly
5. M8 x 25 bolt (2)
6. Fuel filter housing
7. Banjo fitting
8. Fuel supply adapter

1. If removed from fuel filter housing, install fuel primer pump assembly and two M8 x 25 bolts. Tighten bolts to special torque (page 243).

NOTE: If fuel primer pump assembly was replaced or fittings were previously removed, continue with step 2.

2. Install banjo fitting with two new 14.7 x 22 seal rings and fuel supply adapter in fuel primer pump assembly inlet port. Tighten adapter to special torque (page 243).
3. Install check valve on banjo fitting. Tighten check valve to special torque (page 243) and install dust cap.
4. Install threaded union and 14.7 x 22 seal ring in fuel primer pump assembly outlet port. Tighten threaded union to special torque (page 243).

Fuel Supply and Drain (Return) Lines

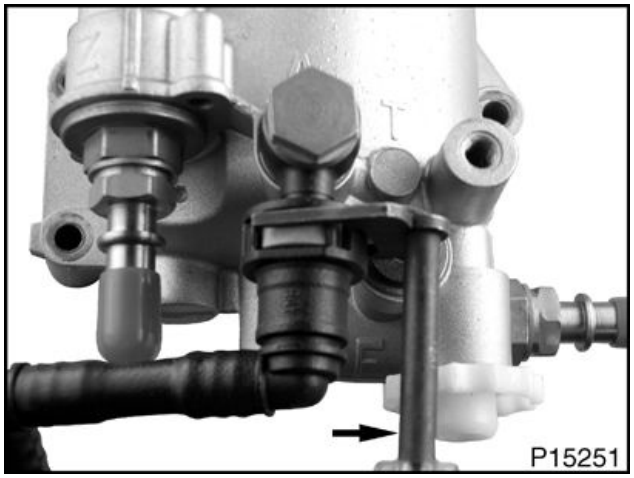


Figure 261 Fuel Line Disconnect Tool 11.8 mm (typical)

CAUTION: To prevent engine damage, plug component connections immediately after each fuel line is removed.

NOTE: Use Fuel Line Disconnect Tool 11.8 mm (page 244) to disconnect all low-pressure fuel line quick-connect fittings.

a. Slide tool over release buttons on quick-connect fitting.

b. Pull quick-connect fitting to disconnect.

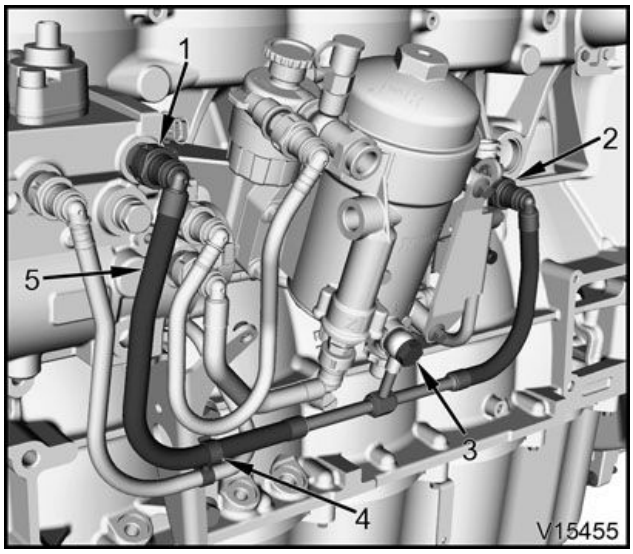


Figure 262 After-filter fuel supply hose connections

1. Quick-connect 90° fitting (at high-pressure fuel pump)
2. Quick-connect 90° fitting (at metering unit valve)
3. M14 banjo bolt
4. Clip
5. After-filter fuel supply hose

1. Disconnect after-filter fuel supply hose assembly quick-connect 90° fittings at high-pressure fuel pump and metering unit valve assembly. Immediately cap openings using clean Disposable Air and Fuel Caps (page 244).
2. Remove M14 banjo bolt and 14.7 x 22 mm seal rings at fuel filter housing and remove after-filter fuel supply hose assembly. Discard seal rings.

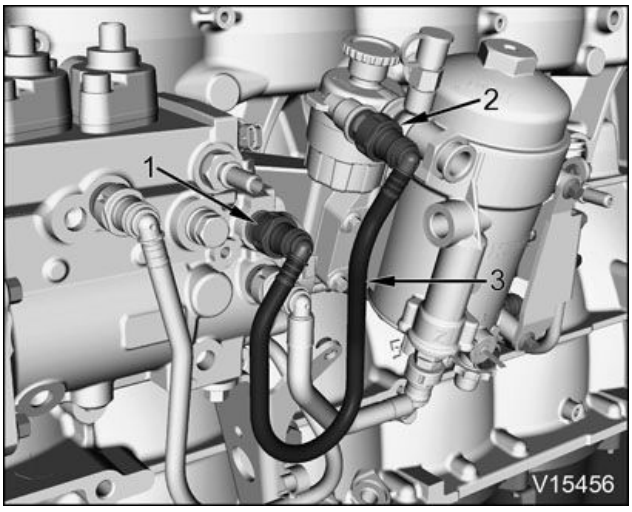


Figure 263 Pre-pump fuel supply hose connections

1. Quick-connect 90° fitting (at high-pressure fuel pump)
2. Quick-connect 90° fitting (at primer pump)
3. Pre-filter fuel supply hose

3. Disconnect pre-pump fuel supply hose assembly quick-connect 90° fittings at high-pressure fuel pump and at fuel primer pump assembly. Remove hose and cap openings.

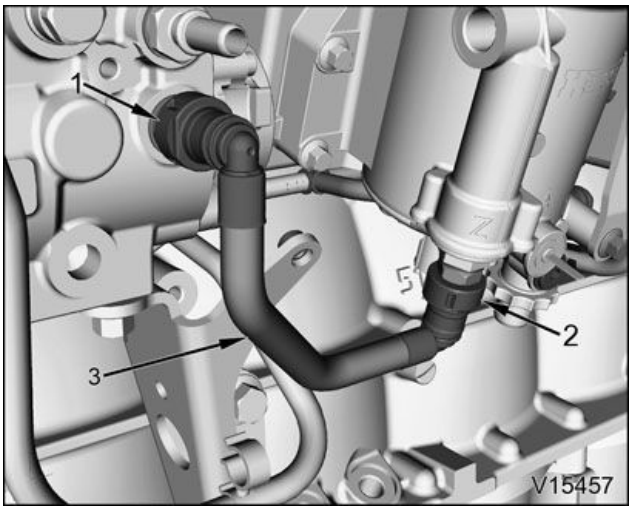


Figure 264 Pre-filter fuel supply hose connections

1. Quick-connect 90° fitting (at high-pressure fuel pump)
2. Quick-connect 90° fitting (at filter housing)
3. Pre-filter fuel supply hose

4. Disconnect pre-filter fuel supply hose assembly quick-connect 90° fittings at high-pressure fuel pump and at fuel filter housing. Remove hose and cap openings.

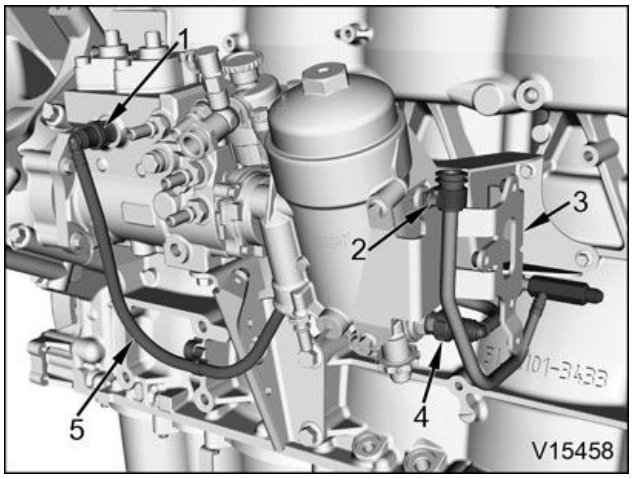


Figure 265 Fuel drain hose connections

1. Quick-connect 90° fitting (at high-pressure fuel pump)
2. M6 x 16 bolt and closed (P) clamp
3. Metering unit bracket
4. Quick-connect 90° fitting (at filter housing)
5. Fuel drain hose

5. Remove M6 x 16 bolt and closed (P) clamp attaching fuel drain hose to metering unit bracket.
6. Disconnect fuel drain hose assembly quick-connect 90° fittings at high-pressure fuel pump and at fuel filter housing. Cap openings.

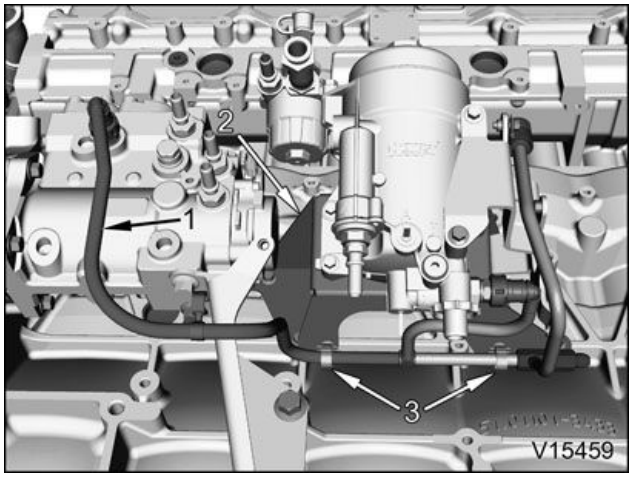


Figure 266 Fuel drain hose retainers

1. Fuel drain hose
2. Fuel filter bracket
3. 8 x 13 single retainer (2)

7. Disconnect 8 x 13 single retainers and remove fuel drain hose from engine.

Fuel Primer Pump Assembly

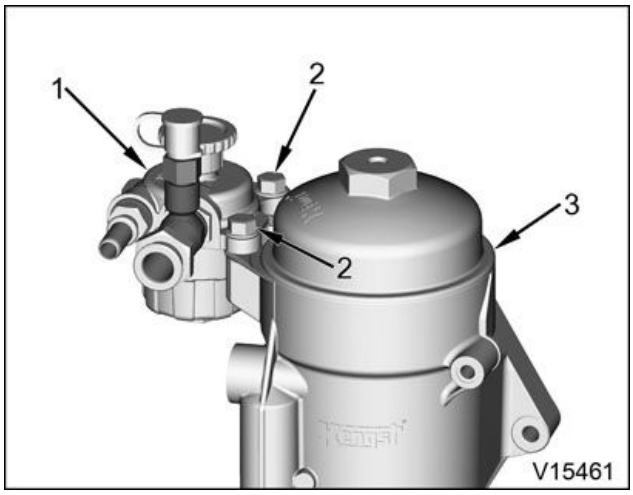


Figure 267 Fuel primer pump assembly

1. Fuel primer pump assembly
2. M8 x 25 bolt (2)
3. Fuel filter housing

NOTE: The fuel primer pump assembly can be removed as an assembly along with the fuel filter housing. If the fuel primer pump assembly is to be replaced, remove two M8 x 25 bolts and remove pump assembly from filter housing.

1. Remove two M8 x 25 bolts.
2. Remove fuel primer pump assembly from fuel filter housing.

Fuel Filter Housing Assembly

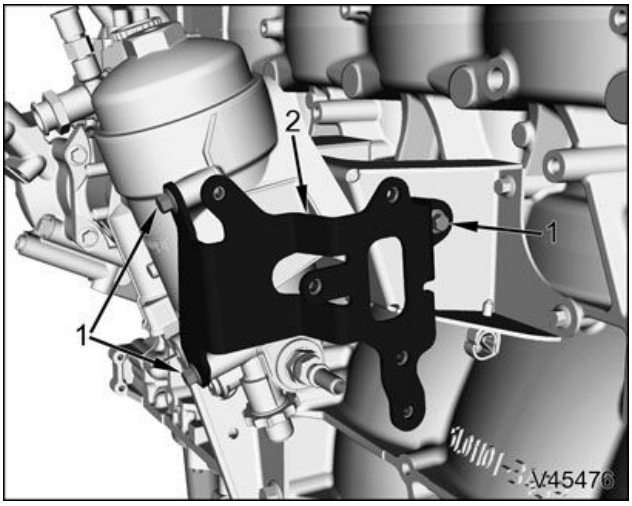


Figure 268 Metering unit bracket

1. M8 x 16 bolts (3)
2. Metering unit bracket

1. Remove three M8 x 16 bolts and remove metering unit bracket.

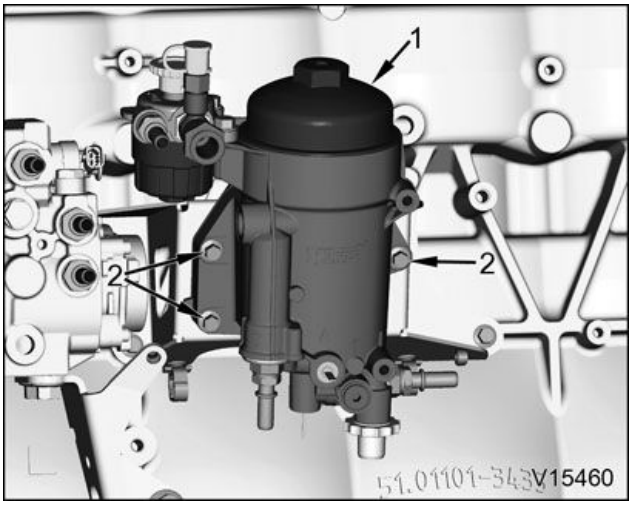


Figure 269 Fuel filter housing assembly

1. Fuel filter housing assembly
2. M8 x 45 bolt (3)

2. Remove three M8 x 45 bolts and remove fuel filter housing assembly.

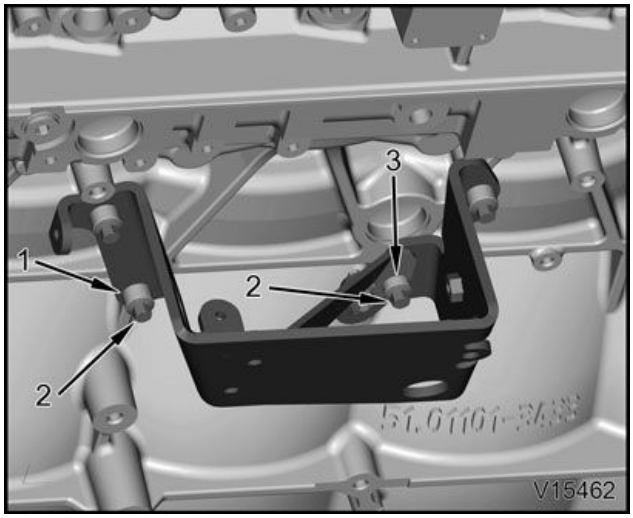


Figure 270 Fuel filter bracket assembly

1. 9 ID x 18 OD x 10.5 spacer (3)
2. M8 x 30 bolt (4)
3. 9 ID x 17 OD x 6.5 spacer

3. Remove four M8 x 30 bolts and spacers; remove fuel filter bracket from crankcase.

Fuel Filter Stand Pipe Replacement

If diagnostic testing indicated replacement of the fuel filter stand pipe, remove the stand pipe and replace with new following this procedure.

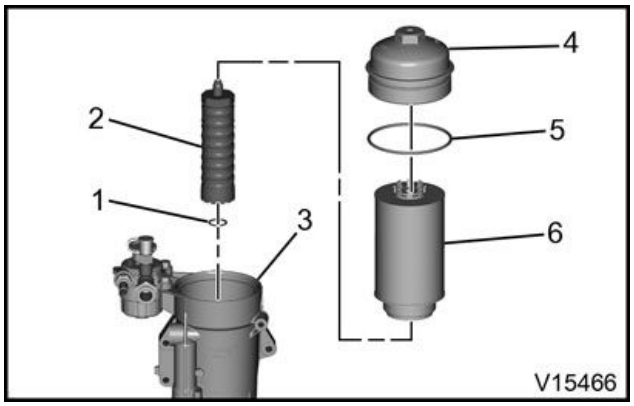


Figure 271 Fuel Filter Stand Pipe

1. Stand pipe O-ring
2. Stand pipe
3. Fuel filter housing
4. Fuel filter cap
5. Fuel filter cap O-ring
6. Fuel filter element

1. Remove fuel filter cap and O-ring
2. Using an appropriate wrench, loosen and remove stand pipe from housing.
3. Remove O-ring from center tube at bottom of stand pipe
4. Apply P-80® rubber lubricant or equivalent (page 244) to new O-ring and install O-ring on center tube in bore at bottom of stand pipe.
5. Insert stand pipe into housing assembly and carefully thread pipe into bore in bottom of housing.
6. Tighten the stand pipe to special torque (page 243).
7. Apply P-80® rubber lubricant or equivalent (page 244) to filter cap o-ring and place in position in housing O-ring groove.
8. Insert new filter element in filter housing.
9. Install filter cap and tighten to special torque (page 243).

High-pressure Pump (Drive Belt) Pulley

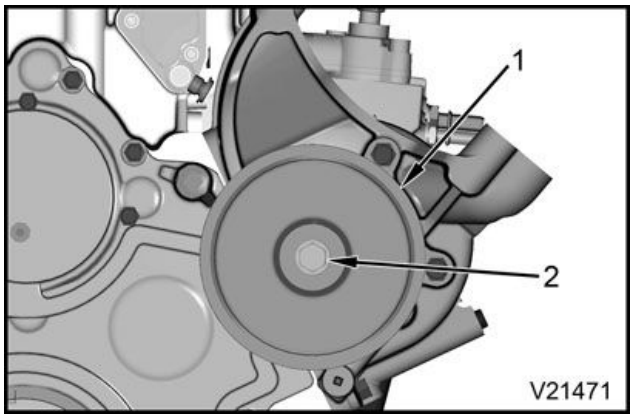


Figure 272 High-pressure pump pulley

1. High-pressure pump pulley
2. M16 x 40 LH bolt (left-hand thread)

1. Remove M16 x 40 LH bolt. Clean any sealer off of bolt threads.
2. Remove high-pressure pump pulley from drive belt shaft assembly. Clean any sealer from shaft and pulley.

High-pressure Pump (Drive Belt) Pulley Housing and Radial Shaft Seal

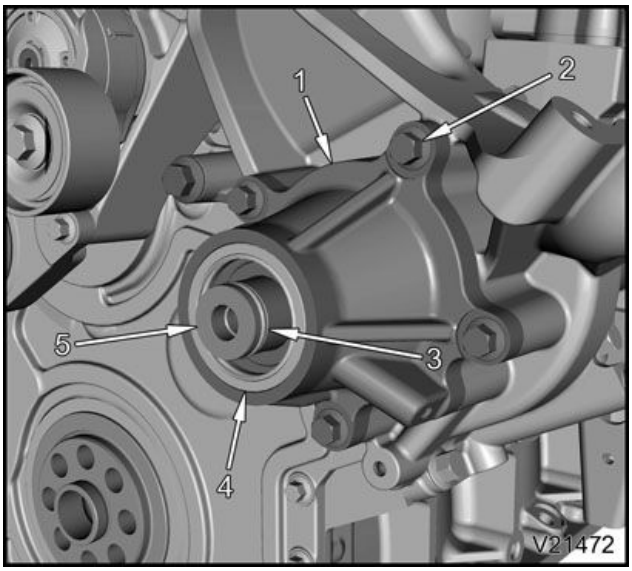


Figure 273 High-pressure pump pulley housing and seal

1. High-pressure pump pulley housing
2. M10 x 40 bolt (4)
3. 30.2 x 3 O-ring
4. 55 x 70 x 8 radial shaft seal
5. Drive belt shaft

1. With an awl and hammer, punch two holes 180° apart in radial shaft seal.
2. Thread a slide hammer (page 244) with correct size screw into one of the two holes.
3. Slide hammer until one side of seal begins to pull out of housing. Move slide hammer to other hole and repeat until radial shaft seal is removed.
4. Remove four M10 x 40 drive belt pulley housing bolts.
5. Remove drive belt pulley housing assembly off high-pressure fuel pump drive housing. Check that (alignment) sleeve remains in place on pulley housing mounting flange.
6. Clean all RTV from sealing surfaces.
7. Remove drive belt shaft from high-pressure fuel pump drive housing.
8. Remove and discard drive belt shaft 30.2 x 3 O-ring.

High-pressure Fuel Pump (HPFP) and Drive Housing

NOTE: The high-pressure fuel pump and drive housing can be removed as an assembly without removing the fuel filter assembly.

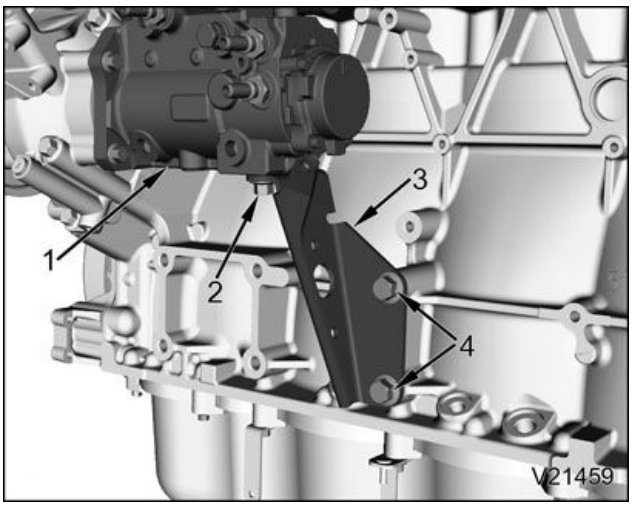


Figure 274 High-pressure fuel pump support bracket

1. High-pressure fuel pump
2. M12 x 30 bolt (2)
3. Support bracket
4. M14 x 30 bolt (2)

1. Remove two M12 x 30 and two M14 x 30 bolts and remove support bracket from below high-pressure fuel pump.

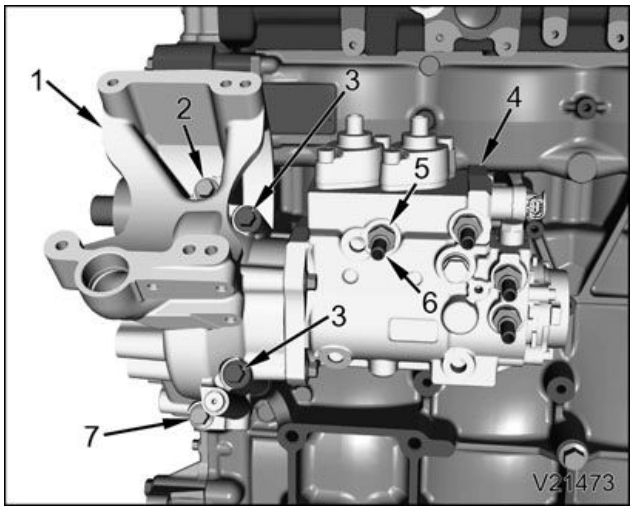


Figure 275 High-pressure fuel pump and drive housing

1. High-pressure fuel pump drive housing
2. M12 x 90 bolt
3. M12 x 130 bolt (2)
4. High-pressure fuel pump
5. 16.7 x 24 seal ring (4)
6. Quick-connect M16 x 1.5 connector (4)
7. M12 x 40 bolt

2. Remove M12 x 40, M12 x 90 and two M12 x 130 bolts and remove high-pressure fuel pump and drive housing assembly from crankcase.

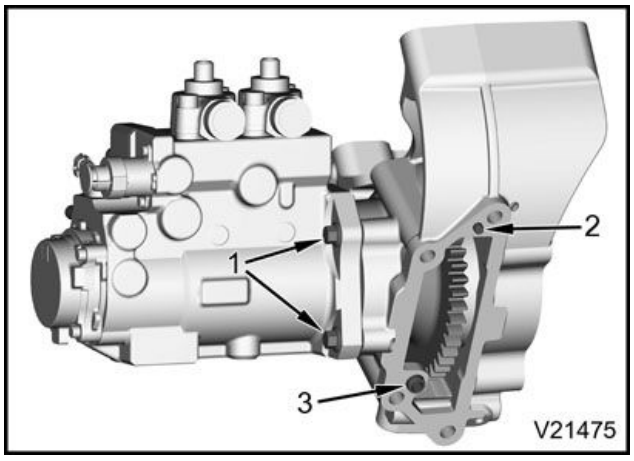


Figure 276 Dowel pin and sleeve

1. M10 x 40 bolt (4)
2. Dowel pin
3. Sleeve

NOTE: A dowel pin and sleeve is used to ensure correct placement of drive housing on the engine block. Holding Plate (page 244) may be bolted to the drive housing with the dowel pin and sleeve in place.

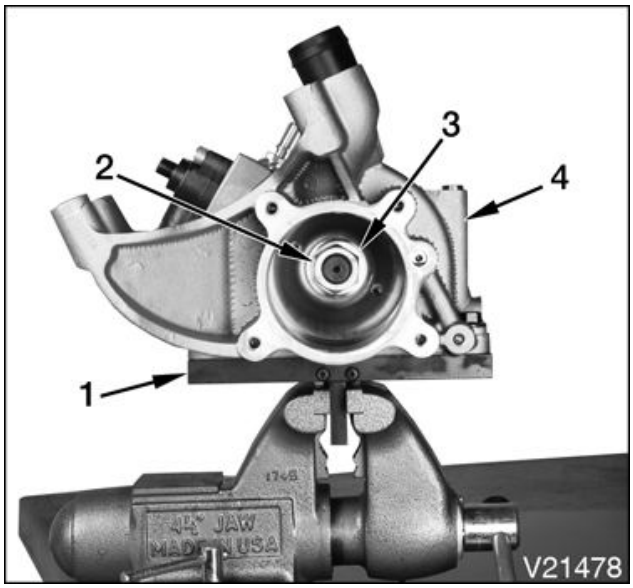


Figure 277 Holding Plate and drive housing

1. Holding Plate
2. M24 jam nut
3. 25 x 44 x 4 washer
4. Drive housing and high-pressure pump

3. Secure Holding Plate (page 244) in a vise.
4. Install drive housing and high-pressure pump to Holding Plate with M12 x 40, M12 x 90 and two M12 x 130 bolts. Tighten bolts to special torque (page 243). Holding Plate will prevent the pump gear from turning while loosening the M24 jam nut.
5. Remove the M24 jam nut and 25 x 44 x 4 washer securing pump gear to pump shaft.

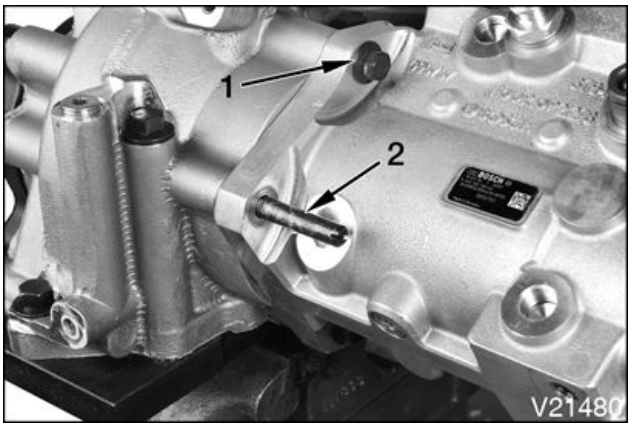


Figure 278 HPP Guide studs

1. M10 x 40 bolt (4)
2. Guide Stud (2)

6. Remove four M10 x 40 bolts. Install two Guide Studs (page 244) in two upper mounting bolt holes of the high-pressure pump.

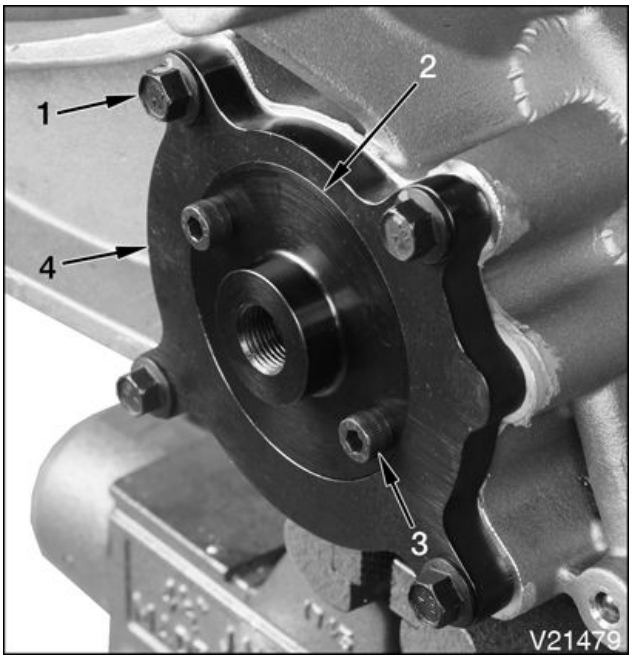


Figure 279 High-Pressure Pump Removal Tool on drive housing

1. M10 x 40 bolt (4)
2. Forcing Screw Adapter (flush with Forcing Screw Adapter Holding Plate)
3. Socket Head Bolt (2)
4. Forcing Screw Adapter Holding Plate

7. Install Forcing Screw Adapter Holding Plate (page 244) on drive housing with four M10 x 40 bolts removed in step 6. Tighten M10 x 40 bolts to special torque (page 243).
8. Place two Socket Head Bolts (page 244) through Forcing Screw Adapter (page 244) and thread them into holes in pump gear. Tighten bolts only until Forcing Screw Adapter is flush with Forcing Screw Adapter Holding Plate.

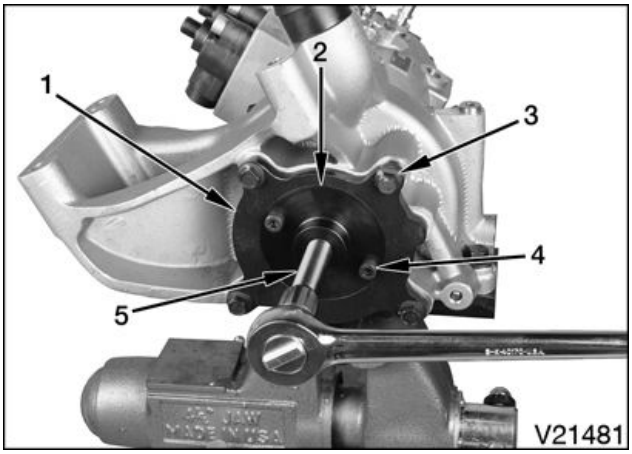


Figure 280 HPP removal

1. Forcing Screw Adapter Holding Plate
2. Forcing Screw Adapter
3. M10 x 40 bolt (4)
4. Socket Head Bolt (2)
5. Forcing Screw

9. Screw Forcing Screw (page 244) by hand into Forcing Screw Adapter until it contacts high-pressure pump shaft.
10. Turn Forcing Screw clockwise until high-pressure pump is removed from drive housing.
11. Remove Socket Head Bolts, Forcing Screw Adapter, and Forcing Screw Adapter Holding Plate from drive housing.
12. Remove drive housing from Holding Plate and remove pump gear from drive housing.
13. Remove and discard 100 x 3.349 O-ring from high-pressure pump.
14. If required, remove four M16 x 1.5 quick-connect connectors and discard seal rings.

Fuel Injectors

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.

CAUTION: To prevent engine damage, install new injector O-ring and combustion washer before installing injector.

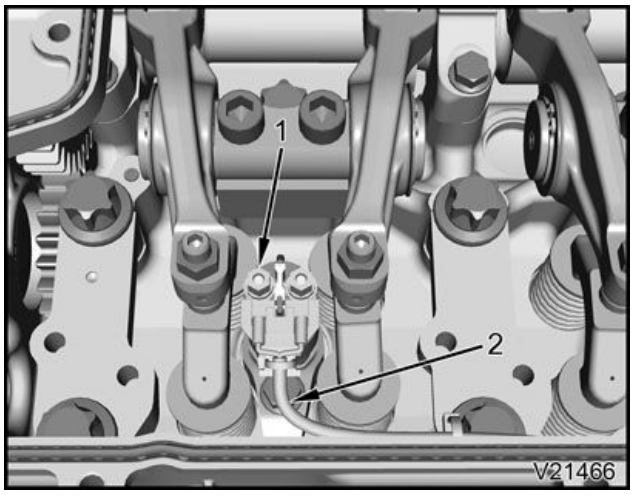


Figure 281 Fuel injector connections

1. Injector harness nuts (12)
2. Engine injector harness

NOTE: The injector harness nuts are part of the injector harness and cannot be separated.

1. Loosen 12 injector harness nuts and position injector harness aside.

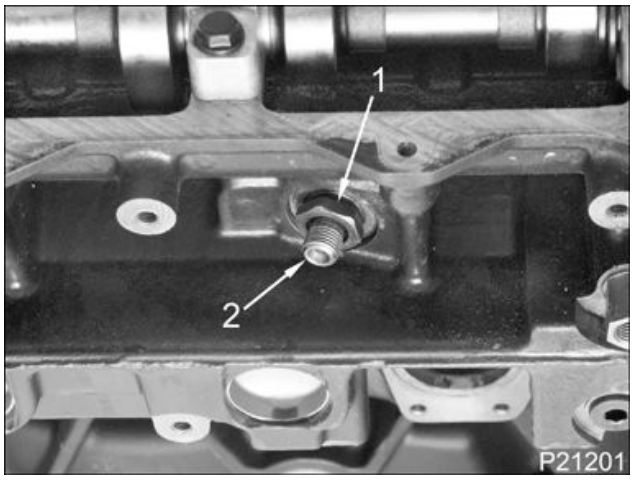


Figure 282 High-pressure connector body (typical)

1. Retaining high-pressure connector nut (6)
2. High-pressure connector body (6)

2. Remove six retaining high-pressure connector nuts.
3. Remove and discard six high-pressure connector bodies.
4. Cover cylinder head high-pressure connector body bores with appropriate size plugs from Disposable Air and Fuel Caps (page 244).

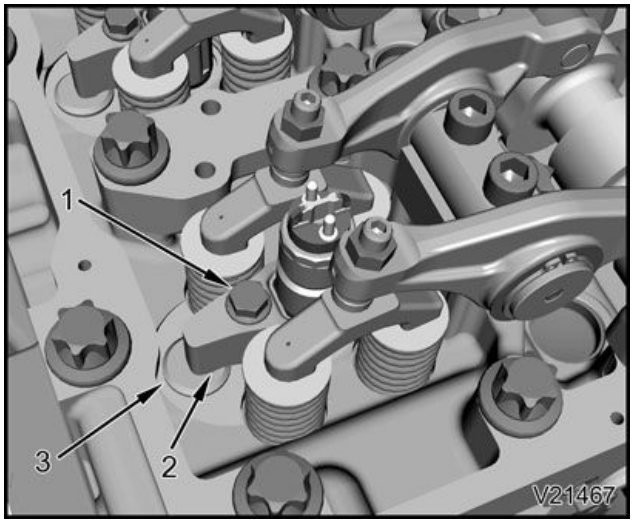


Figure 283 Injector hold-down clamp

1. M8 x 50 bolt (6) and rounded washer (6)
2. Injector hold-down clamp (6)
3. Thrust washer (6)

5. Remove six M8 x 50 hold-down clamp bolts and rounded washers.
6. Remove six thrust washers.

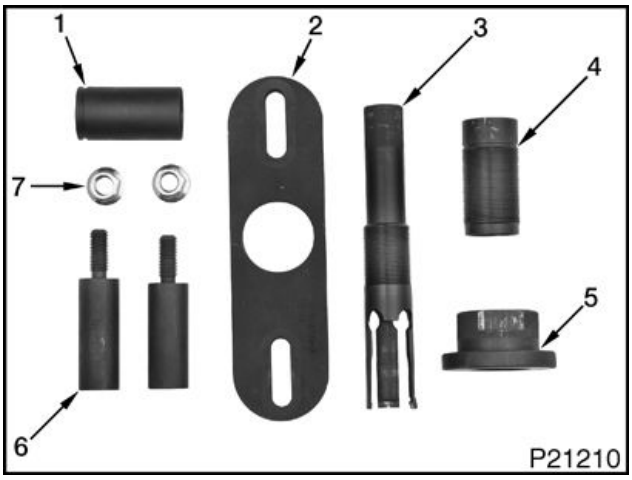


Figure 284 Injector Puller

1. Clamping sleeve
2. Extractor plate
3. Extractor
4. Knurled nut
5. Extractor nut
6. Plate column (2)
7. Plate column nuts (2)

7. Use Injector Puller (page 244) to remove injectors.

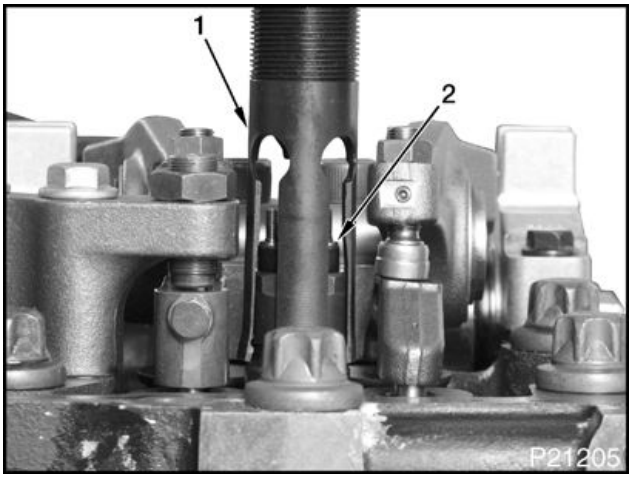


Figure 285 Injector extractor (typical)

1. Extractor (part of Injector Puller)
2. Injector

8. Install extractor on injector.

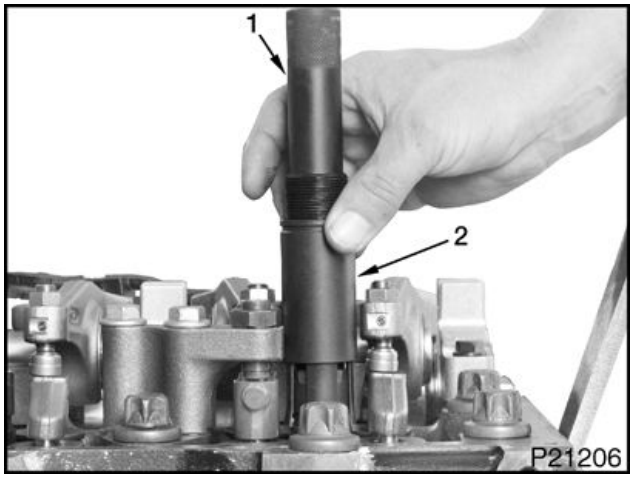


Figure 286 Clamping sleeve on extractor (typical)

1. Extractor
2. Clamping sleeve

9. Slide clamping sleeve over extractor.

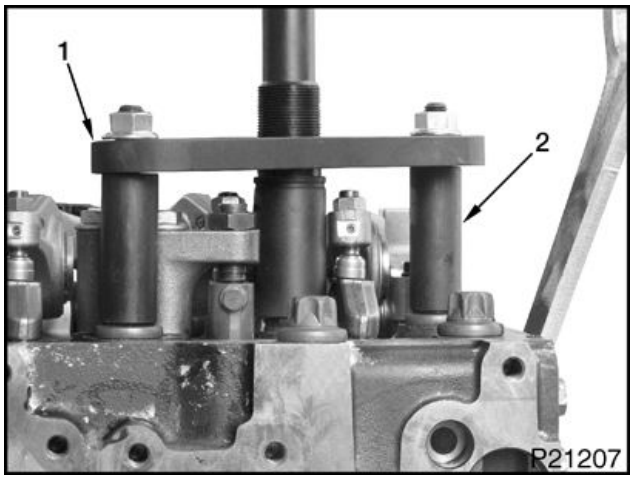


Figure 287 Extractor plate and plate columns (typical)

1. Extractor plate
2. Plate column (2)

10. Position two plate columns on two opposite cylinder head bolts, and slide extractor plate over extractor and plate columns.

11. Install and finger-tighten plate column nuts on plate columns.

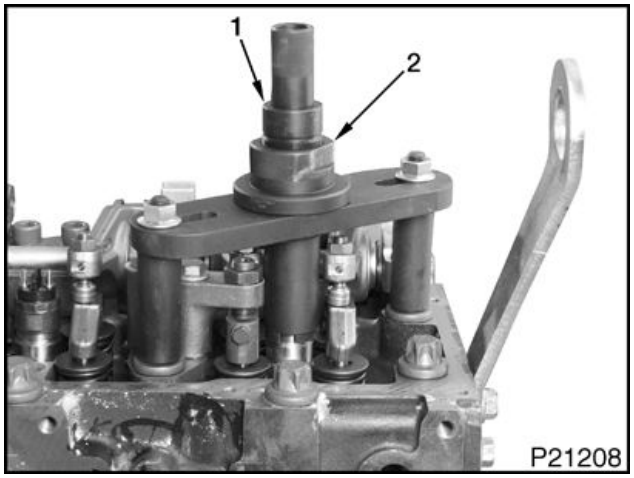


Figure 288 Extractor nut (typical)

1. Knurled nut
2. Extractor nut

12. Install knurled nut and extractor nut, with the extractor nut backed out.
13. Hold knurled nut and tighten extractor nut to remove injector, combustion washer and hold-down clamp.

NOTE: Make sure that no combustion washer remains in the injector bore after the injector is removed.

14. Cover cylinder head injector bore with appropriate size plugs from Disposable Air and Fuel Caps (page 244).

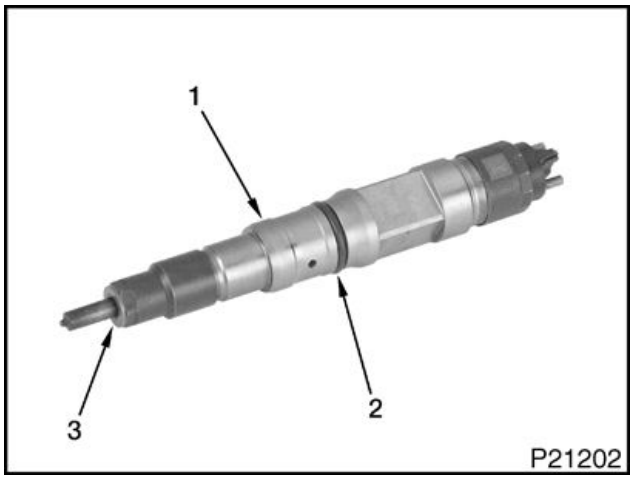


Figure 289 Injector seals (typical)

1. Injector assembly
2. 3 x 20.9 ID O-ring
3. Combustion washer

15. Using a small non-metallic hand tool, carefully remove and discard combustion washer and O-ring. Wipe injector nozzle with a lint-free cloth.

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

16. Clean injector tip with Fuel Injector Tip Cleaning Brush (page 244).
17. Insert injector into Fuel Injector Cup (page 244), and place in Fuel Injector Rack Holder (page 244).

Cleaning and Inspection

Low-pressure and High-pressure Fuel System Components

1. Inspect low-pressure fuel lines for kinks, obstructions or other damage. Replace if necessary.
2. Inspect low-pressure fuel line quick-connect fitting O-ring seals for damage. Replace low-pressure fuel lines if necessary.
3. Inspect fuel filter housing assembly and fuel primer pump assembly for damage. Replace if necessary.
4. Inspect high-pressure pump input shaft and driving sleeve splines for wear or damage. Replace if necessary.

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

5. Clean outside surfaces of low-pressure fuel lines, fuel filter housing assembly and fuel primer pump assembly with a suitable non-caustic solvent. Dry with filtered compressed air.

Fuel Injector Bore

1. Use Injector Sleeve Brushes (page 244) in injector bore to remove deposits.

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

2. Use filtered compressed air to clean out debris from injector bores.

Fuel Injector Harness

Inspect injector wiring harness for kinked wires or terminals. Replace harness if kinks are found. Kinked wires can result in oil leaking in between the harness protective foam covering and the wires.

Installation

Fuel Injectors

CAUTION: To prevent engine damage, remove protective plugs and cups only before immediate installation of components.

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.

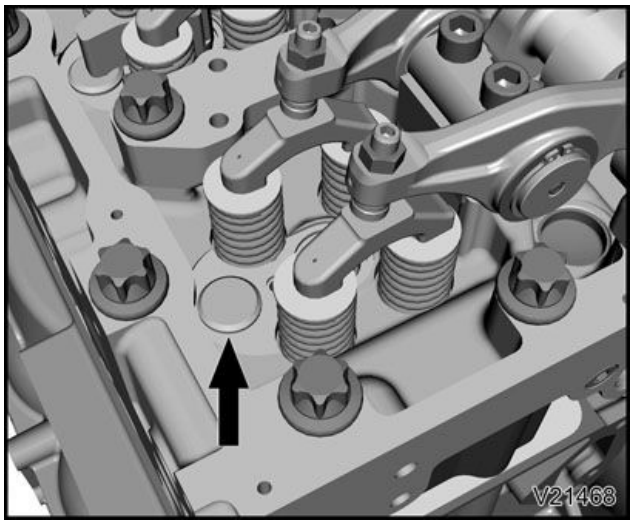


Figure 290 Thrust washer

1. Install six thrust washers on cylinder head.

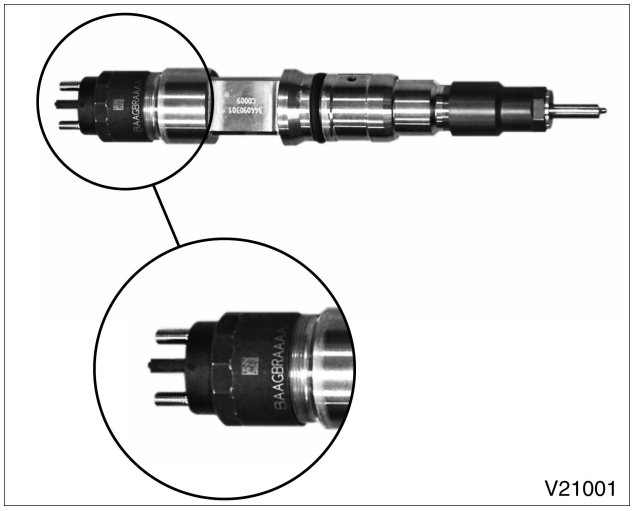


Figure 291 Injection Quantity Adjustment (IQA) code

NOTE: The Injection Quantity Adjustment (IQA) code is printed in capital letters and numbers near the top of the fuel injector.

2. Record the IQA code of each new fuel injector and its corresponding cylinder number so the new code can be programed into the ECM, after fuel injectors are installed.

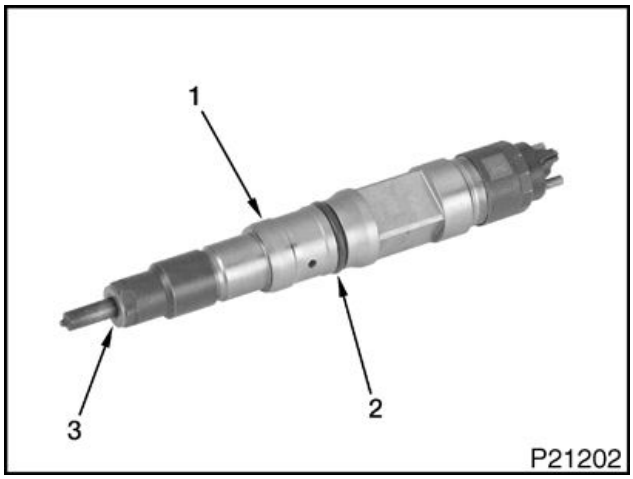


Figure 292 Injector seals (typical)

1. Injector assembly
2. 3 x 20.9 ID O-ring
3. Combustion washer

CAUTION: To prevent engine damage, install new injector O-ring and combustion washer before installing injector.

3. Install a new combustion washer onto injector tip.
4. Lubricate a new 3 x 20.9 ID O-ring with clean engine oil and install in recess at mid-point of injector.

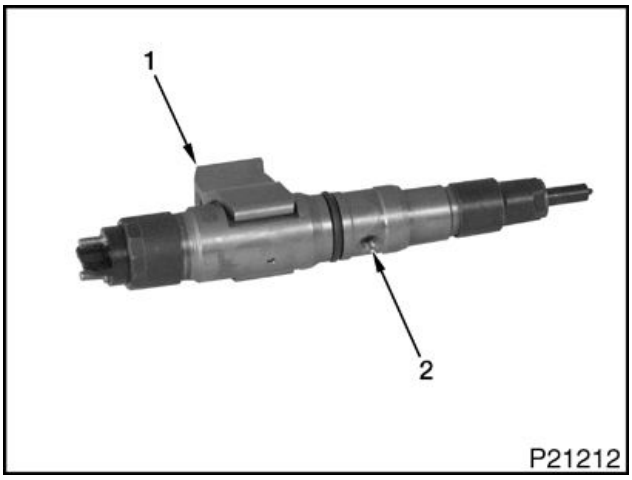


Figure 293 Injector and injector hold-down clamp orientation (typical)

1. Injector hold-down clamp
2. Injector fuel inlet opening

5. Slide injector into hold-down clamp with injector fuel inlet opening on opposite side of hold-down clamp.

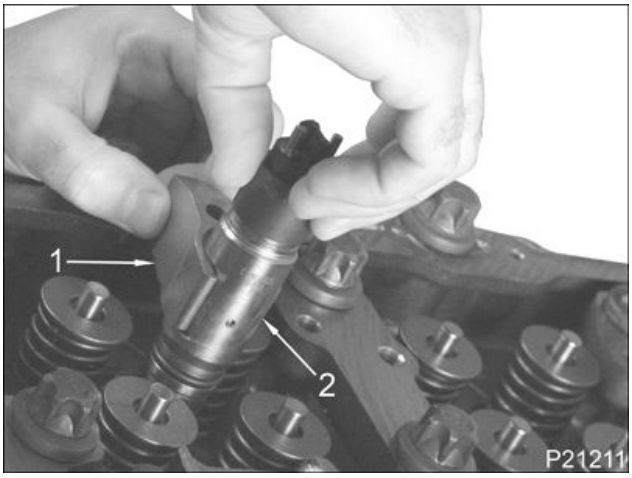


Figure 294 Injector and injector hold-down clamp installation (typical)

1. Injector hold-down clamp
2. Injector

CAUTION: To prevent engine damage, align injector and hold-down clamp correctly with cylinder head; do not twist injector when inserting injector into cylinder head.

NOTE: Make sure injector bore in cylinder head is clean and no old combustion washer remains inside the bore.

6. Install injector by lowering injector and hold-down clamp as one unit into injector bore.
7. Using Injector Installer (page 244), firmly press injector and hold-down clamp and make sure injector is fully seated into cylinder head.

CAUTION: To prevent engine damage, six new high-pressure connector bodies must be installed and aligned before tightening M8 x 50 bolts for six fuel injectors.

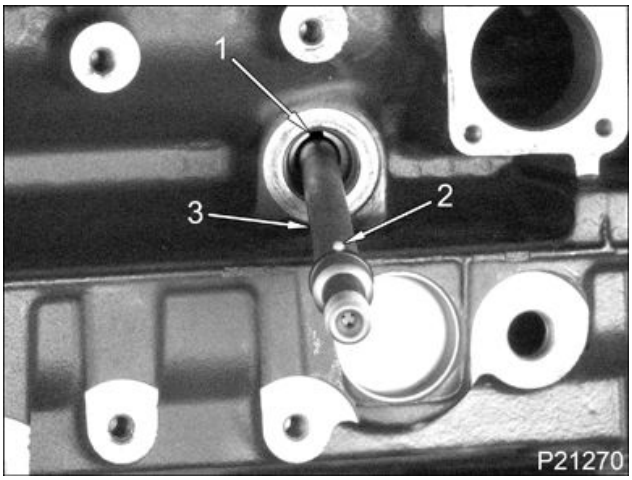


Figure 295 Alignment of high-pressure connector body (typical)

1. Notch in cylinder head
2. Locating ball
3. High-pressure connector body

8. Align locating ball on each new high-pressure connector body with notch in cylinder head and install six new high-pressure connector bodies.

Injector hold-down clamp (M8 x 50 bolts)

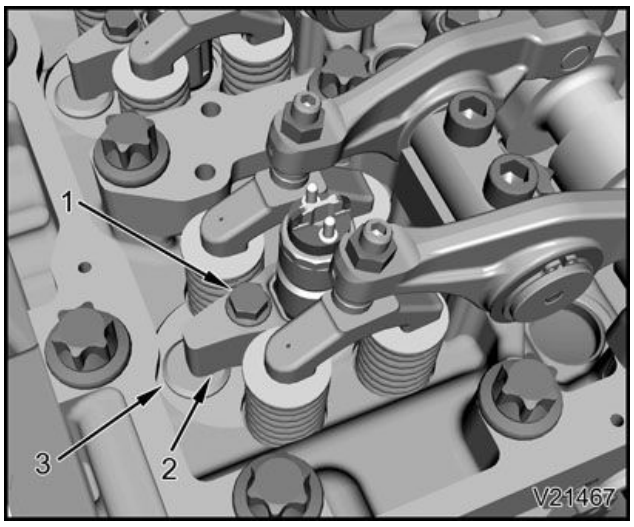


Figure 296 Injector hold-down clamp bolt

1. M8 x 50 bolt (6) and rounded washer (6)
2. Injector hold-down clamp (6)
3. Thrust washer (6)

9. Install six rounded washers and M8 x 50 bolts finger tight.

High-pressure connector body (retaining nuts)

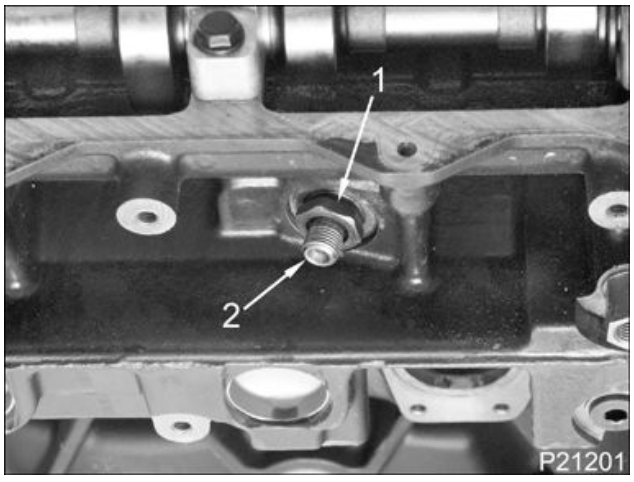


Figure 297 High-pressure connector body (typical)

1. High-pressure connector retaining nut (6)
2. High-pressure connector body (6)

10. Install six high-pressure connector retaining nuts and tighten nuts to 55 N·m (41 lbf·ft).
11. Completely loosen six high-pressure retaining nuts; then, retighten nuts to 10 N·m (89 lbf·in).

Injector hold-down clamp (Final torque of M8 x 50 bolts)

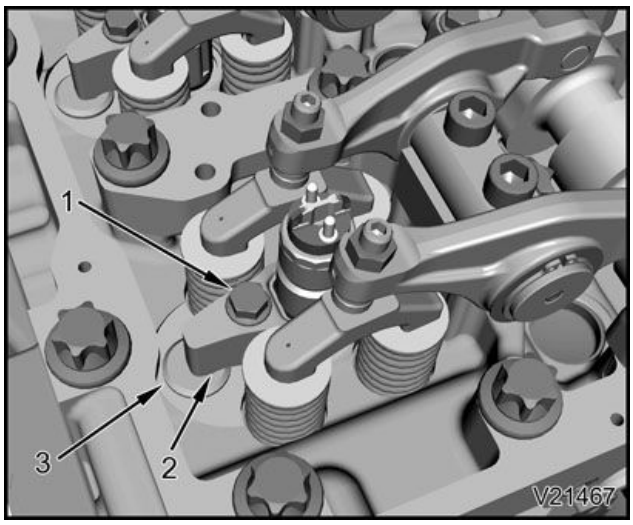


Figure 298 Injector hold-down clamp bolt

1. M8 x 50 bolt (6) and rounded washer (6)
2. Injector hold-down clamp (6)
3. Thrust washer (6)

12. Tighten six M8 x 50 injector hold-down clamp bolts to 25 N·m (18 lbf·ft).
13. Tighten six M8 x 50 injector hold-down clamp bolts an additional 90°.

High-pressure connector body (Final torque of retaining nuts)

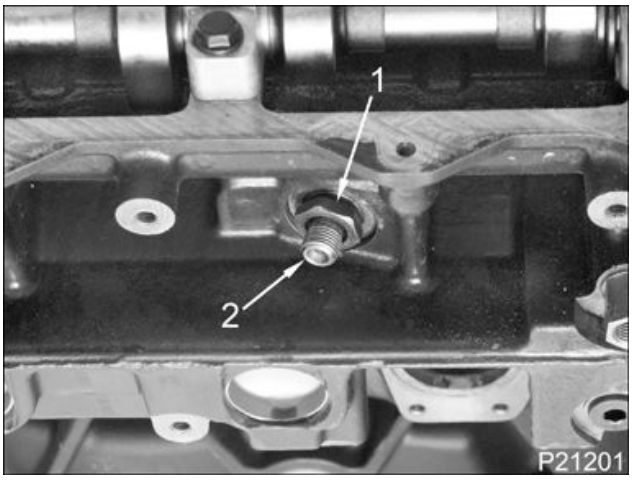


Figure 299 High-pressure connector body (typical)

1. High-pressure connector retaining nut (6)
2. High-pressure connector body (6)

14. Tighten six high-pressure connector retaining nuts to 20 N·m (15 lbf·ft).
15. Tighten six high-pressure connector retaining nuts an additional 32°.

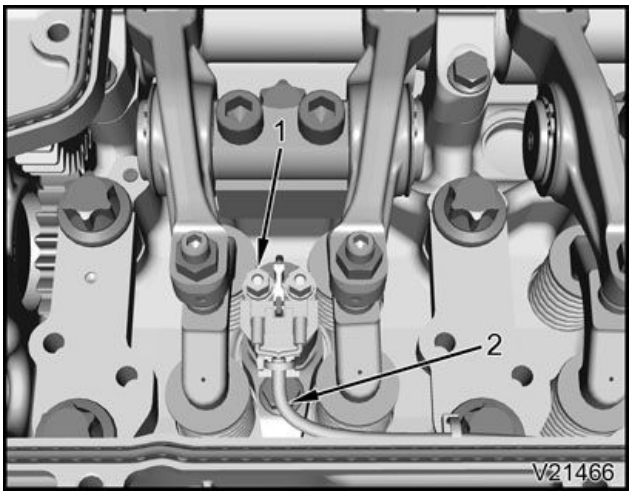


Figure 300 Injector connections

1. Injector harness nuts (12)
2. Engine injector harness

CAUTION: To prevent engine damage, hold injector harness terminals to prevent twisting or turning while tightening the injector harness nuts. Kinked harness terminals can result in an oil leak path between the protective cover and the wire.

CAUTION: To prevent engine damage, use a torque wrench to tighten injector harness nuts to 1.5 N·m (13 lbf·in).

16. Connect injector harness to injectors. Make sure harness terminals are in straight alignment with harness. Hold terminals stationary to avoid twisting and tighten nuts to special torque (page 243).
17. See MaxxForce® 11 and 13 *Engine Diagnostic Manual* EGES-470 Performance Diagnostics section, for instructions on how to program the Engine Control Module (ECM), using ServiceMaxx™, with Injection Quantity Adjustment (IQA) codes for fuel injectors being replaced.

High-pressure Fuel Pump (HPFP) and Drive Housing

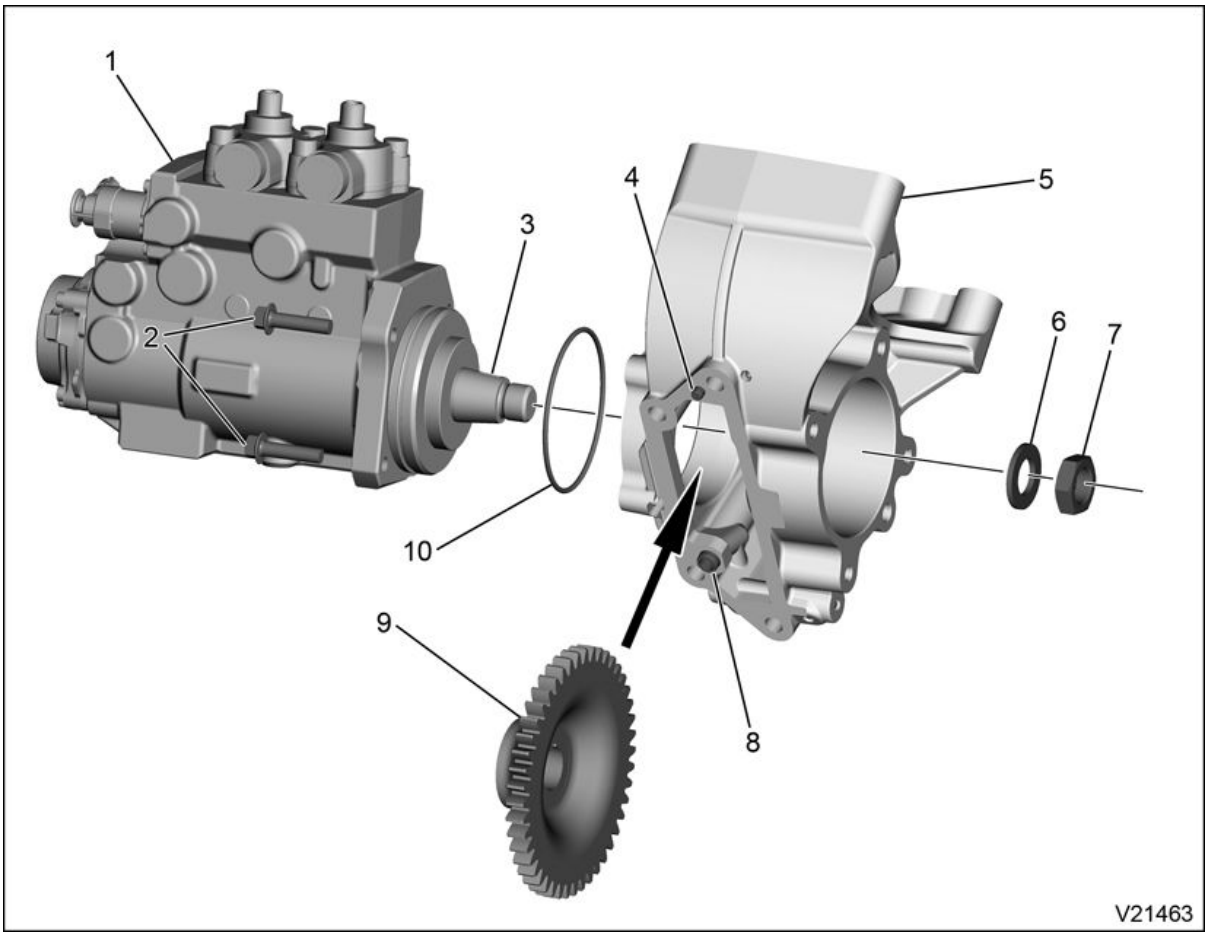


Figure 301 High-pressure fuel pump and drive housing assembly

1. High-pressure fuel pump
2. M10 x 40 bolts (4)
3. Key
4. Dowel pin
5. Drive housing
6. 25 x 44 x 4 washer
7. M24 jam nut
8. Sleeve
9. High-pressure pump gear
10. 100 x 3.349 O-ring

1. Press key into slot on high-pressure fuel pump shaft.
2. Install a new 100 x 3.349 O-ring on fuel pump mounting flange collar.
3. Position high-pressure pump on drive housing. Install four M10 x 40 bolts, hand-tight, to attach high-pressure fuel pump to drive housing.
4. Place high-pressure fuel pump gear into pump drive housing and assemble drive housing to pump. Check that key slot in gear is aligned with key on shaft and push gear onto shaft.
5. Install 25 x 44 x 4 washer and M24 jam nut, hand-tight, to secure gear on high-pressure fuel pump shaft.

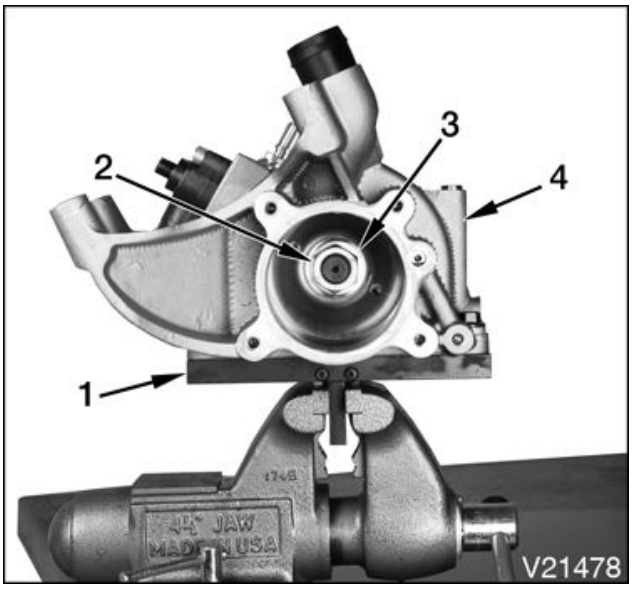


Figure 302 Holding Plate and drive housing mounted in vise

1. Holding Plate
2. M24 jam nut
3. 25 x 44 x 4 washer
4. Drive housing and high-pressure pump

6. Secure Holding Plate (page 244) in a vise.
7. Install drive housing and high-pressure pump to Holding Plate with M12 x 40, M12 x 90 and two M12 x 130 bolts. Tighten bolts to special torque (page 243). Holding Plate will prevent the pump gear from turning while tightening the M24 jam nut.
8. Tighten M24 jam nut to special torque (page 243).
9. Tighten four M10 x 40 bolts to special torque (page 243) to secure high-pressure fuel pump to drive pump housing.
10. Remove drive housing and high-pressure pump from Holding Plate.

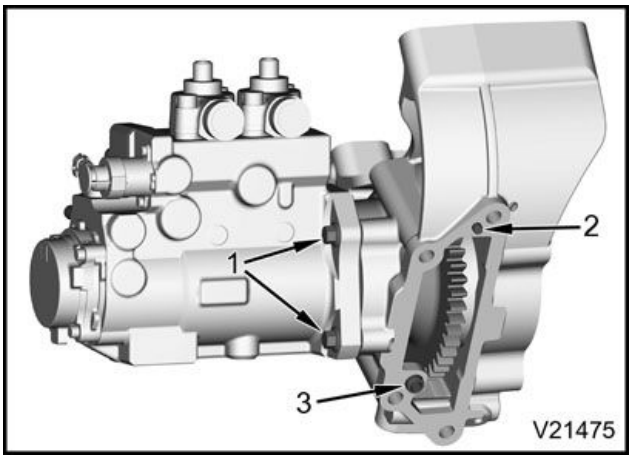


Figure 303 Dowel pin and sleeve placement

1. M10 x 40 bolt (4)
2. Dowel pin
3. Sleeve

11. Check that dowel pin and sleeve are properly seated in drive housing or crankcase.

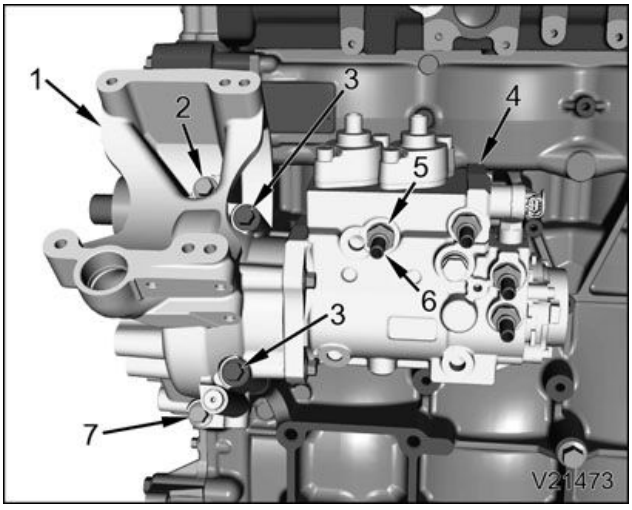


Figure 304 High-pressure fuel pump and drive housing

1. Drive housing
2. M12 x 90 bolt
3. M12 x 130 bolt (2)
4. High-pressure fuel pump
5. 16.7 x 24 seal ring
6. Quick-connect M16 x 1.5 connector
7. M12 x 40 bolt

12. If required, install four M16 x 1.5 quick-connect connectors with new seal rings. Tighten connectors to special torque (page 243).

CAUTION: Install components and tighten bolts within five minutes of Wacker® A-442 RTV sealant or equivalent application.

13. Apply Wacker® A-442 RTV sealant (page 244) or equivalent to mating surfaces of drive housing and crankcase.

14. Position high-pressure fuel pump and drive housing assembly on crankcase using care to align pump drive gear with idler gear. Install M12 x 40, M12 x 90 and two M12 x 130 bolts and tighten bolts to special torque (page 243).

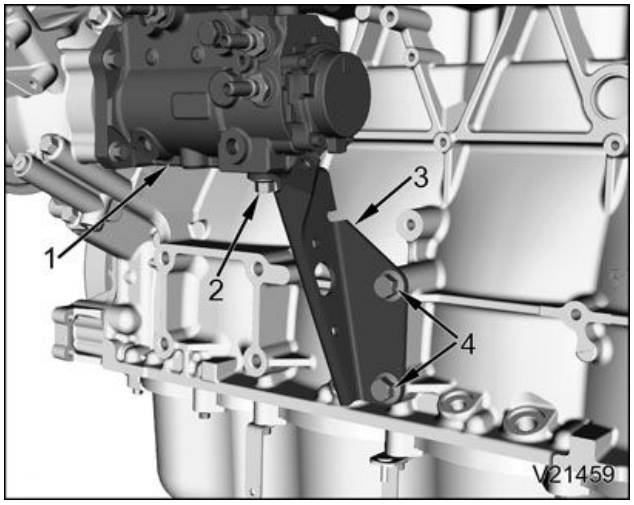


Figure 305 High-pressure fuel pump and support (bracket)

1. High-pressure fuel pump
2. M12 x 30 bolt (2)
3. Support (bracket)
4. M14 x 30 bolt (2)

15. Place support bracket in position below high-pressure fuel pump and install two M12 x 30 and two M14 x 30 bolts.
    - Tighten two M12 x 30 bolts to standard torque (page 503).
    - Tighten two M14 x 30 bolts to special torque (page 243).

CAUTION: To prevent damage to the high-pressure fuel pump, do not start the engine until the fuel system is properly primed. The Fuel System Priming Tool should be used to prime the fuel system. If the Fuel System Priming Tool is not available, prime the fuel system using the hand primer pump method. See Fuel System Priming (page 235).

High-Pressure Pump (Drive Belt) Pulley Housing and Radial Shaft Seal

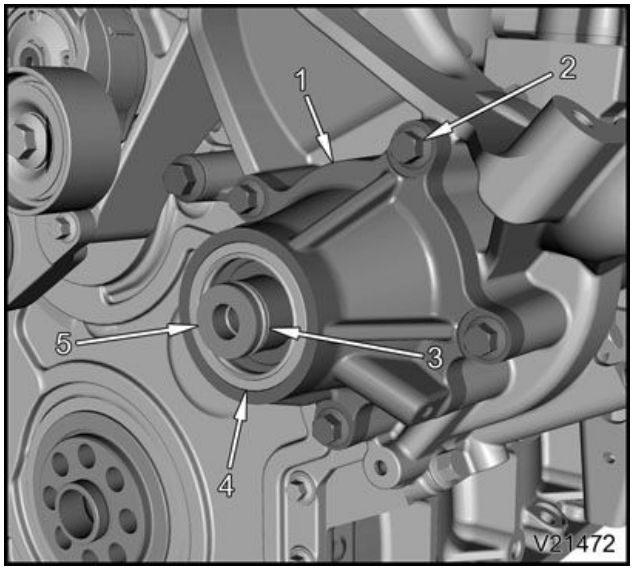


Figure 306 High-pressure pump pulley housing and seal

1. High-pressure pump pulley housing
2. M10 x 40 bolt (4)
3. 30.2 x 3 O-ring
4. 55 x 70 x 8 radial shaft seal
5. Drive belt shaft

1. Lubricate drive belt shaft with clean engine oil and insert shaft into high-pressure pump pulley housing bushing bore.
2. Install new 30.2 x 3 O-ring in groove on drive belt shaft.
3. Check that (alignment) sleeve is in place on pulley housing mounting flange.

CAUTION: To prevent engine damage, install component within 5 minutes of sealant application to inhibit the formation of a skin and ensure a leak proof joint.

4. Apply Wacker® A-442 RTV sealant (page 244) or equivalent to joining surfaces of pulley housing and high-pressure fuel pump drive housing.
5. Place pulley housing assembly with drive belt shaft in position on high-pressure fuel pump drive housing, using care to mesh drive belt shaft gear with idler gear in crankcase.
6. Install four M10 x 40 bolts and tighten to special torque (page 243).
7. Using Fan Hub/High Pressure Drive Seal Installer (page 244), drive new radial shaft seal into housing. Seal is fully installed when tool bottoms out on housing.

High-Pressure Pump (Drive Belt) Pulley

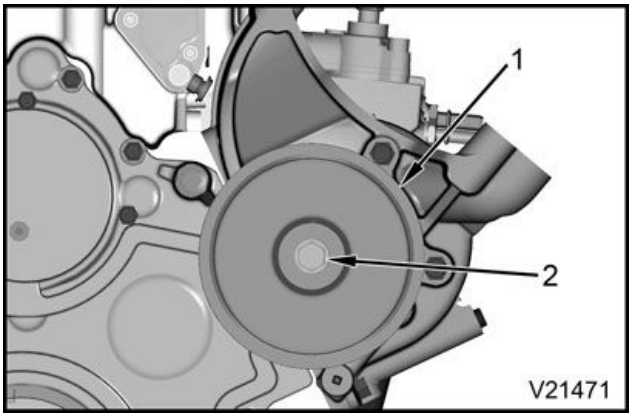


Figure 307 High-pressure pump pulley

1. High-pressure pump pulley
2. M16 x 40 LH bolt (left-hand thread)

1. Install high-pressure pump pulley onto drive belt shaft.
2. Install M16 x 40 LH bolt. Tighten bolt to special torque (page 243).

Fuel Filter Housing Assembly

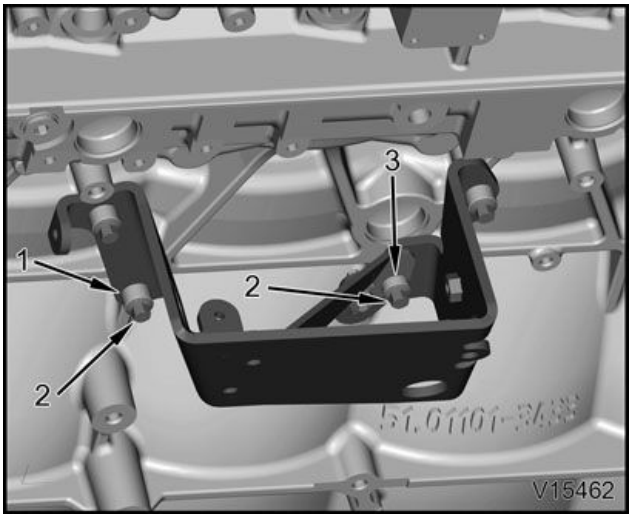


Figure 308 Fuel filter bracket assembly

1. 9 ID x 18 OD x 10.5 spacer (3)
2. M8 x 30 bolt (4)
3. 9 ID x 17 OD x 6.5 spacer

1. If removed, position fuel filter bracket assembly with brace on crankcase and install four M8 x 30 bolts and spacers. Tighten bolts to special torque (page 243).

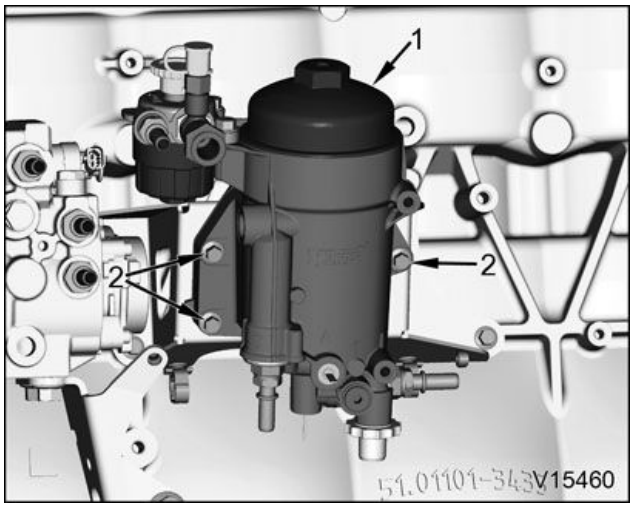


Figure 309 Fuel filter housing assembly

1. Fuel filter housing assembly
2. M8 x 45 bolts (3)

2. Install fuel filter housing assembly and three M8 x 45 bolts. Tighten bolts to special torque (page 243).

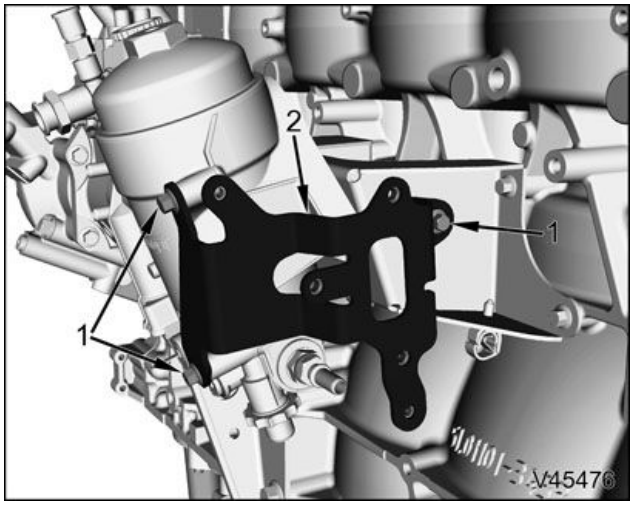


Figure 310 Metering unit (valve) bracket (typical)

1. M8 x 16 bolts (3)
2. Metering unit (valve) bracket

3. Position metering unit bracket on filter housing and install three M8 x 16 bolts. Tighten bolts to standard torque (page 503).

Fuel Primer Pump Assembly

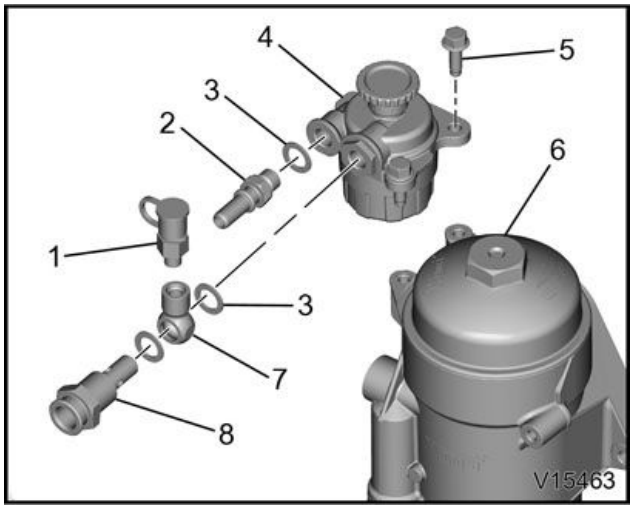


Figure 311 Fuel primer pump assembly

1. Check valve
2. Threaded union
3. 14.7 x 22 seal ring (3)
4. Fuel primer pump assembly
5. M8 x 25 bolt (2)
6. Fuel filter housing
7. Banjo fitting
8. Fuel supply adapter

1. If removed from fuel filter housing, install fuel primer pump assembly and two M8 x 25 bolts. Tighten bolts to special torque (page 243).

NOTE: If fuel primer pump assembly was replaced or fittings were previously removed, continue with step 2.

2. Install banjo fitting with two new 14.7 x 22 seal rings and fuel supply adapter in fuel primer pump assembly inlet port. Tighten adapter to special torque (page 243).
3. Install check valve on banjo fitting. Tighten check valve to special torque (page 243) and install dust cap.
4. Install threaded union and 14.7 x 22 seal ring in fuel primer pump assembly outlet port. Tighten threaded union to special torque (page 243).

Fuel Supply and Drain (Return) Lines

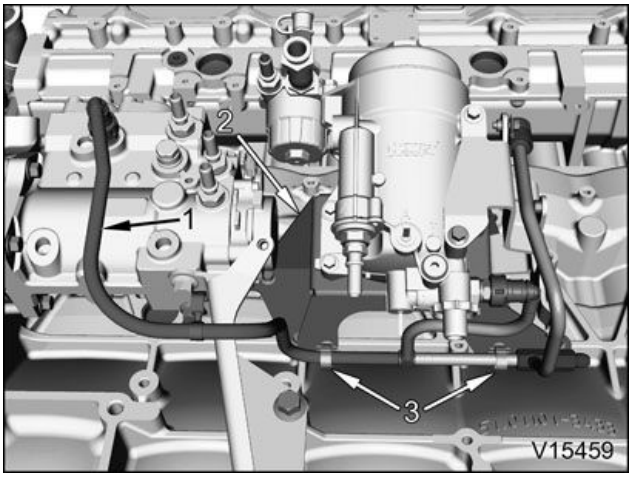


Figure 312 Fuel drain hose retainers (typical)

1. Fuel drain hose
2. Fuel filter bracket
3. 8-13 single retainer (2)

1. Check that O-rings are in place in fuel drain quick-connect 90° fittings and not damaged. Replace as necessary.
2. Place fuel drain hose in position at bottom of fuel filter bracket and attach to bracket with two 8-13 single retainers.

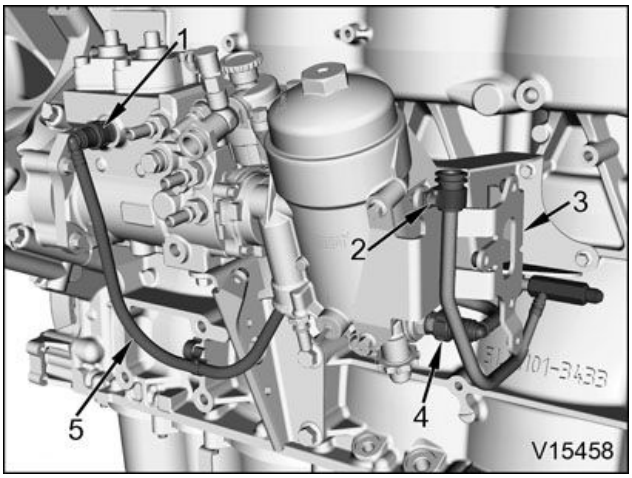


Figure 313 Fuel drain hose connections

1. Quick-connect 90° fitting (at high-pressure fuel pump)
2. M6 x 16 bolt and closed (P) clamp
3. Metering unit (valve) bracket
4. Quick-connect 90° fitting (at filter housing)
5. Fuel drain hose

3. Connect fuel drain hose to high-pressure fuel pump by pushing on quick-connect fitting until an audible click is heard. Pull quick-connect fitting to make sure it is seated.
4. Connect fuel drain hose to fuel filter housing by pushing on quick-connect fitting until an audible click is heard. Pull quick-connect fitting to make sure it is seated.
5. Install closed (P) clamp and M6 x 16 bolt to attach end fitting of fuel drain hose from hex manifold tee to metering unit bracket. Tighten bolt to standard torque (page 503).
6. Cap unconnected end of hex manifold tee using Disposable Air and Fuel Caps (page 244), to prevent dirt from entering fuel system until final connection with injector and fuel rail drain tube is made.

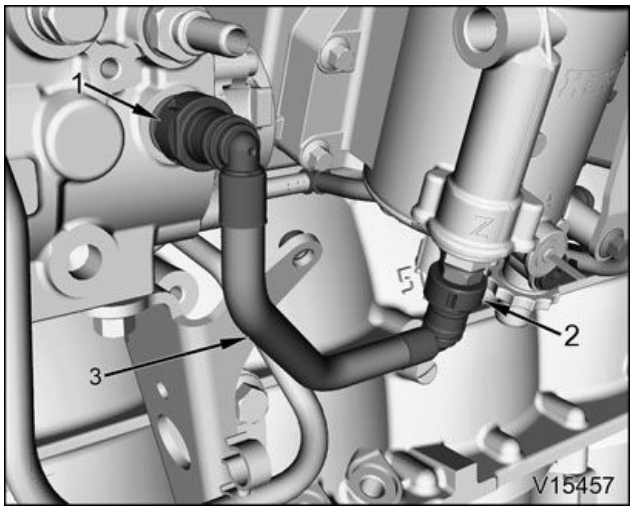


Figure 314 Pre-filter fuel supply hose assembly

1. Quick-connect 90° fitting (at high-pressure fuel pump)
2. Quick-connect 90° fitting (at filter housing)
3. Pre-filter fuel supply hose

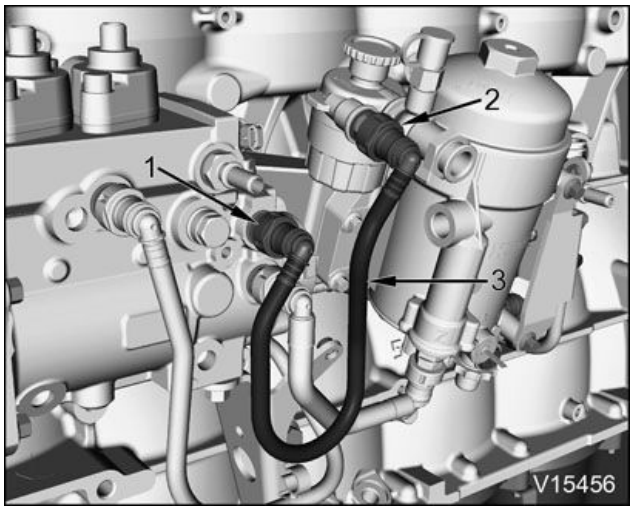


Figure 315 Pre-pump fuel supply hose assembly

1. Quick-connect 90° fitting (at high-pressure fuel pump)
2. Quick-connect 90° fitting (at primer pump)
3. Pre-pump fuel supply hose

7. Check that O-rings are in place in pre-filter fuel supply quick-connect 90° fittings and not damaged. Replace as necessary.
8. Install pre-filter fuel supply hose. Push on quick-connect 90° fitting at high-pressure fuel pump until an audible click is heard. Pull quick-connect fitting to make sure it is seated. Repeat the procedure for the quick-connect 90° fitting at fuel filter housing.
9. Check that O-rings are in place in pre-pump fuel supply hose quick-connect 90° fittings and not damaged. Replace as necessary.
10. Install pre-pump fuel supply hose. Push on quick-connect 90° fitting at high-pressure fuel pump until an audible click is heard. Pull quick-connect fitting to make sure it is seated. Repeat the procedure for the quick-connect 90° fitting at fuel primer pump assembly.

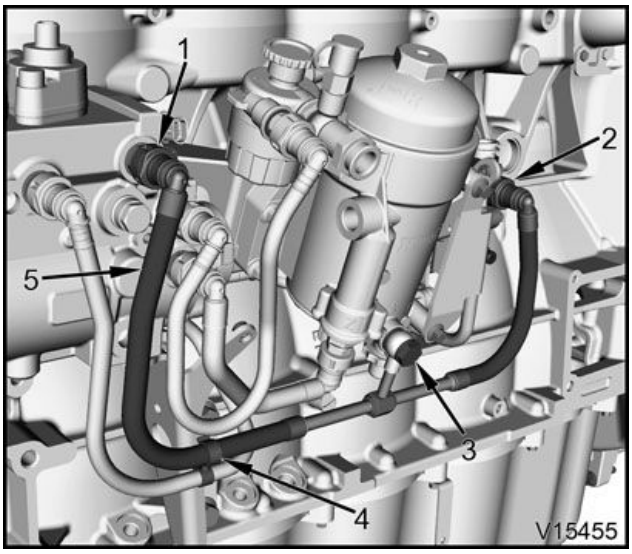


Figure 316 After-filter fuel supply hose connections

1. Quick-connect 90° fitting (at high-pressure fuel pump)
2. Quick-connect 90° fitting (at metering unit)
3. M 14 banjo bolt with two 14.7 x 22 seal rings
4. C-clip
5. After-filter fuel supply hose

11. Install after-filter fuel supply hose as follows:
    a. Check that O-rings are in place in after-filter fuel supply hose quick-connect 90° fittings and not damaged. Replace as necessary.
    b. Position banjo fitting with two new 14.7 x 22 seal rings at filter housing and install M14 banjo bolt. Tighten banjo bolt to special torque (page 243).
    c. Push on quick-connect 90° fitting at high-pressure pump until an audible click is heard. Pull quick-connect fitting to make sure it is seated.
    d. Install C-clip between after filter fuel supply hose and fuel drain hose.
    e. Cap quick-connect 90° connector to fuel metering valve assembly to prevent dirt from entering fuel system until final connection to metering valve can be made.

Fuel Rail Assembly

NOTE: The pressure limiting valve should not be removed from the fuel rail assembly. Replace the entire fuel rail assembly if the pressure limiting valve is defective. Use ServiceMaxx® to verify fuel pressure following the procedure in the *Engine Diagnostic Manual* .

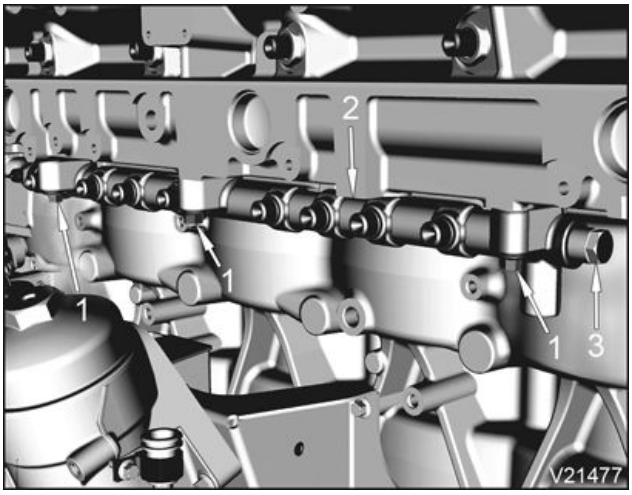


Figure 317 Fuel rail and pressure limiting valve

1. M8 x 40 bolt (3)
2. Fuel rail assembly
3. Pressure limiting valve

1. Support fuel rail assembly in position against underside of cylinder head. Install, and hand tighten three M8 x 40 bolts.
2. Tighten bolts to special torque (page 243).

Injector and Fuel Drain (Return) Lines

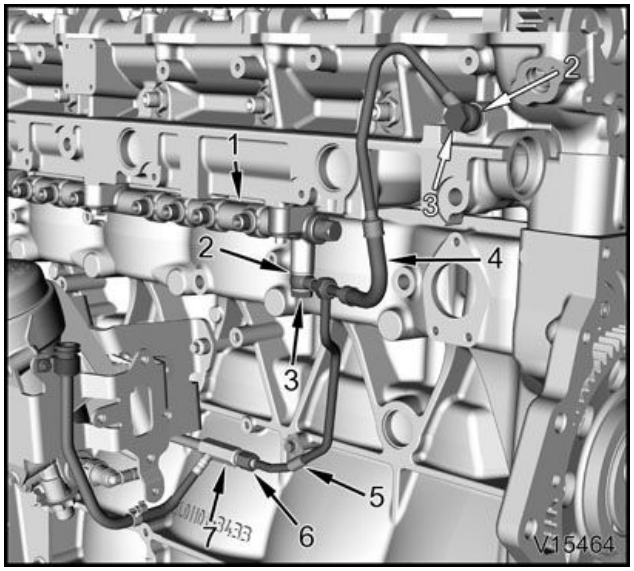


Figure 318 Fuel drain tube connections

1. Fuel rail
2. 14.7 x 22 seal ring (4)
3. M14 banjo bolt (2)
4. Fuel drain tube
5. M8 x 16 bolt and closed (P) clamp assembly
6. Line fitting nut
7. Fuel drain hose (hex manifold tee)

1. Install M14 banjo bolt with two new 14.7 x 22 seal rings to connect fuel drain tube to cylinder head. Do not tighten at this time.
2. Install M14 banjo bolt with two new 14.7 x 22 seal rings to connect fuel drain tube to fuel rail. Do not tighten at this time.

NOTE: Use a backup wrench when tightening fitting nut on hex manifold tee.

3. Connect fuel drain tube to fuel return hex manifold tee at fuel filter bracket. Tighten drain line fitting nut to special torque (page 243).
4. Tighten fuel drain tube M14 banjo bolts at fuel rail and cylinder head to special torque (page 243).
5. Install closed (P) clamp and M8 x 16 bolt to secure drain tube to crankcase. Tighten bolt to standard torque (page 503).

High-pressure Fuel Lines

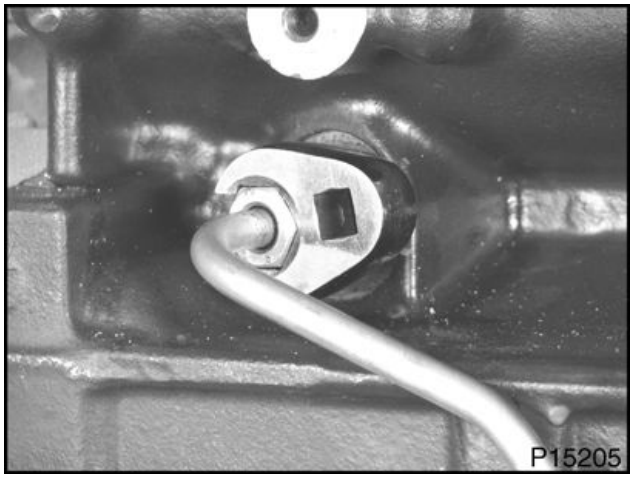


Figure 319 Crowfoot wrench (typical)

1. Obtain a crowfoot wrench (page 244) to connect all high-pressure fuel line fittings. When using a crowfoot wrench to tighten fittings, calculate the torque compensation to match specific wrench configuration. See Using a Torque Wrench Extension (Using a Torque Wrench Extension, page 504)

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.

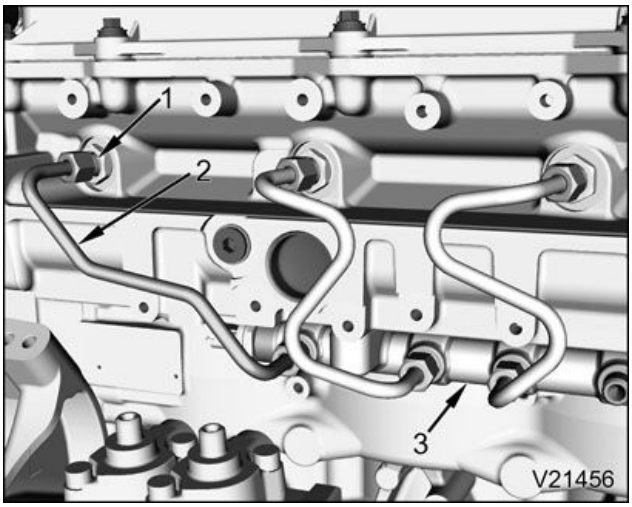


Figure 320 Cylinder 1 high-pressure rail to injector tube assembly

1. Cylinder 1 high-pressure connector body and retaining nut
2. Cylinder 1 high-pressure rail to injector tube assembly
3. Fuel rail

2. Install new high-pressure rail to injector tube assembly for cylinder 1 between fuel rail and cylinder head. Hand tighten line fitting nut at fuel rail and high-pressure connector body.

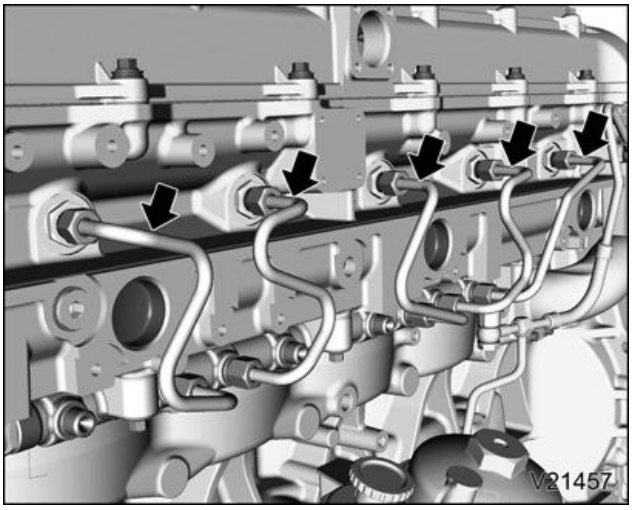


Figure 321 Cylinders 2-6 high-pressure fuel tubes

3. Repeat step 2 to install new high-pressure rail to injector tube assemblies for cylinders 2 through 6.

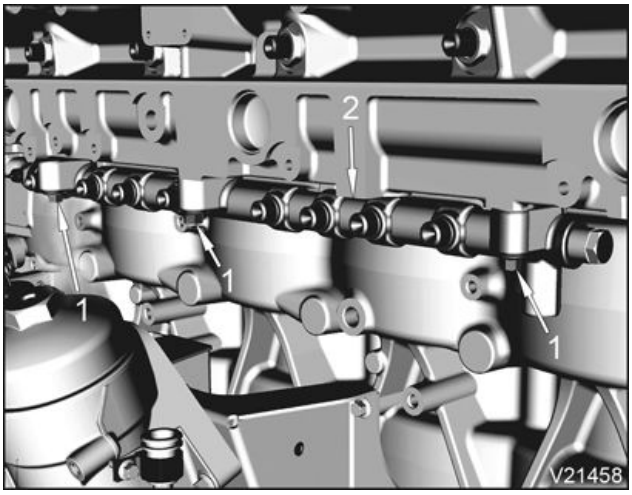


Figure 322 Fuel rail assembly

1. M8 x 40 bolt (3)
2. Fuel rail

Fuel rail assembly (M8 x 40 bolts)

4. Tighten three M8 x 40 bolts to 35 N·m (26 lbf·ft).

High-pressure rail to injector tube assemblies (fittings)

5. Tighten fittings (cylinders 1–6) to 23 N·m (17 lbf·ft).
6. Tighten fittings, an additional 60°.

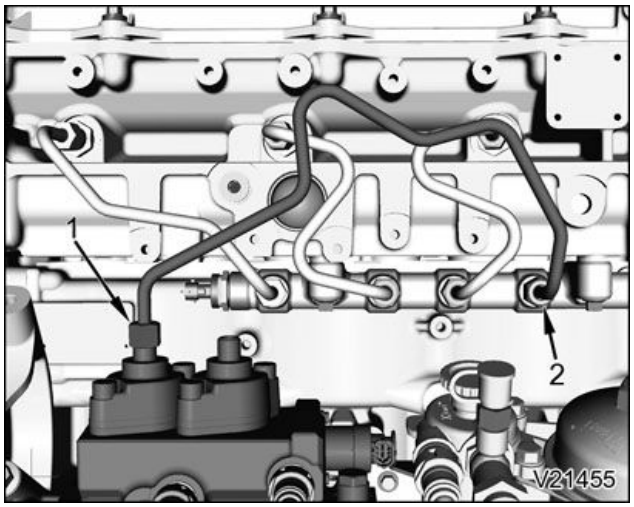


Figure 323 High-pressure pump to rail tube assembly 1

1. Line fitting nut (at high-pressure fuel pump)
2. Line fitting nut (at fuel rail)

7. Install new high-pressure pump to rail tube assembly 1 between high-pressure fuel pump and fuel rail. Hand tighten line fitting nuts.

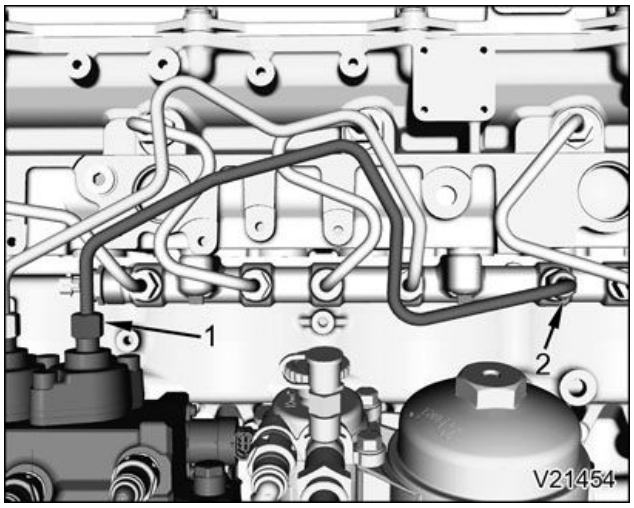


Figure 324 High-pressure (fuel) pump to (fuel) rail tube assembly 2

1. Line fitting nut (at high-pressure fuel pump)
2. Line fitting nut (at fuel rail)

8. Install new high-pressure pump to rail tube assembly 2 between high-pressure fuel pump and fuel rail. Tighten line fitting nuts.

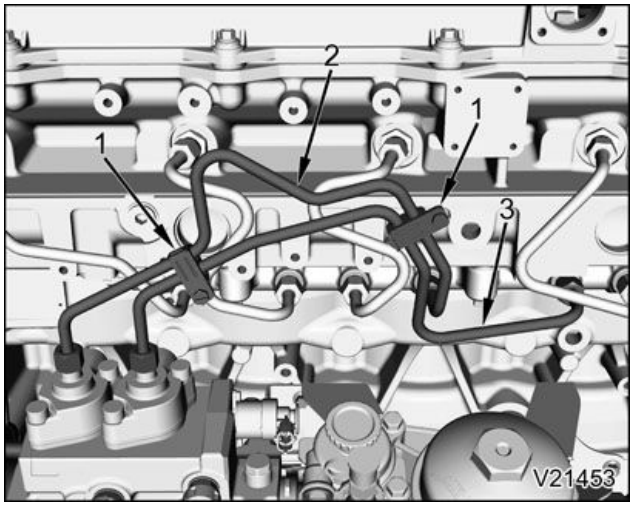


Figure 325 Fuel to rail supply clamp assembly

1. Fuel to rail supply clamp assembly (2)
2. High-pressure pump to rail tube assembly 1
3. High-pressure pump to rail tube assembly 2

High-pressure pump to rail tube assemblies (fittings)

9. Tighten fittings to 23 N·m (17 lbf·ft).
10. Tighten fittings, an additional 60°.

Fuel to rail supply clamps

11. Install two closed (P) clamps to tie high-pressure pump to rail tube assemblies 1 and 2 together. Tighten clamp screws to special torque (page 243).

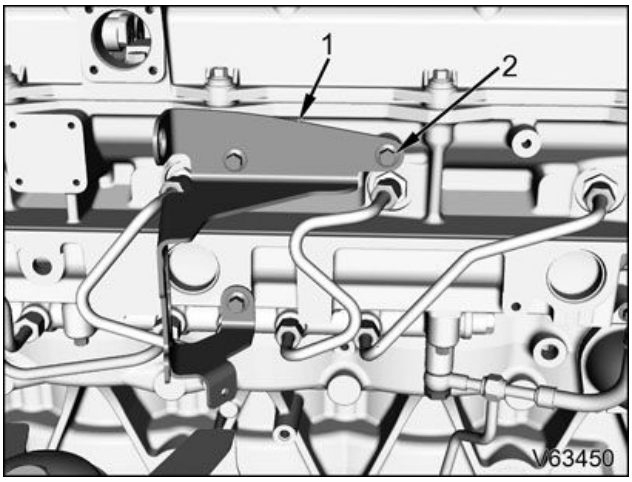


Figure 326 Harness 21-way connector bracket

1. Harness 21-way connector bracket
2. M8 x 16 bolt (3)

12. Install harness 21-way connector bracket and three M8 x 16 bolts. Tighten bolts to standard torque (page 503)
13. Connect air supply line to harness 21-way connector bracket.

Filter and Fuel Strainer Element

Refer to MaxxForce® 11 and 13 *Engine Operation and Maintenance Manual* for filter element and fuel strainer element service procedures.

Fuel System Priming

Fuel System Priming Tool Method

CAUTION: To prevent damage to the high-pressure fuel pump, do not start the engine until the fuel system is properly primed. The Fuel System Priming Tool should be used to prime the fuel system. If the Fuel System Priming Tool is not available, prime the fuel system using the hand primer pump method.

1. Obtain Fuel System Priming Tool (page 244).

NOTE: Fuel System Priming Tool ball valves should be in the closed position, unless suction and pressure hoses are connected to the vehicle fuel system.

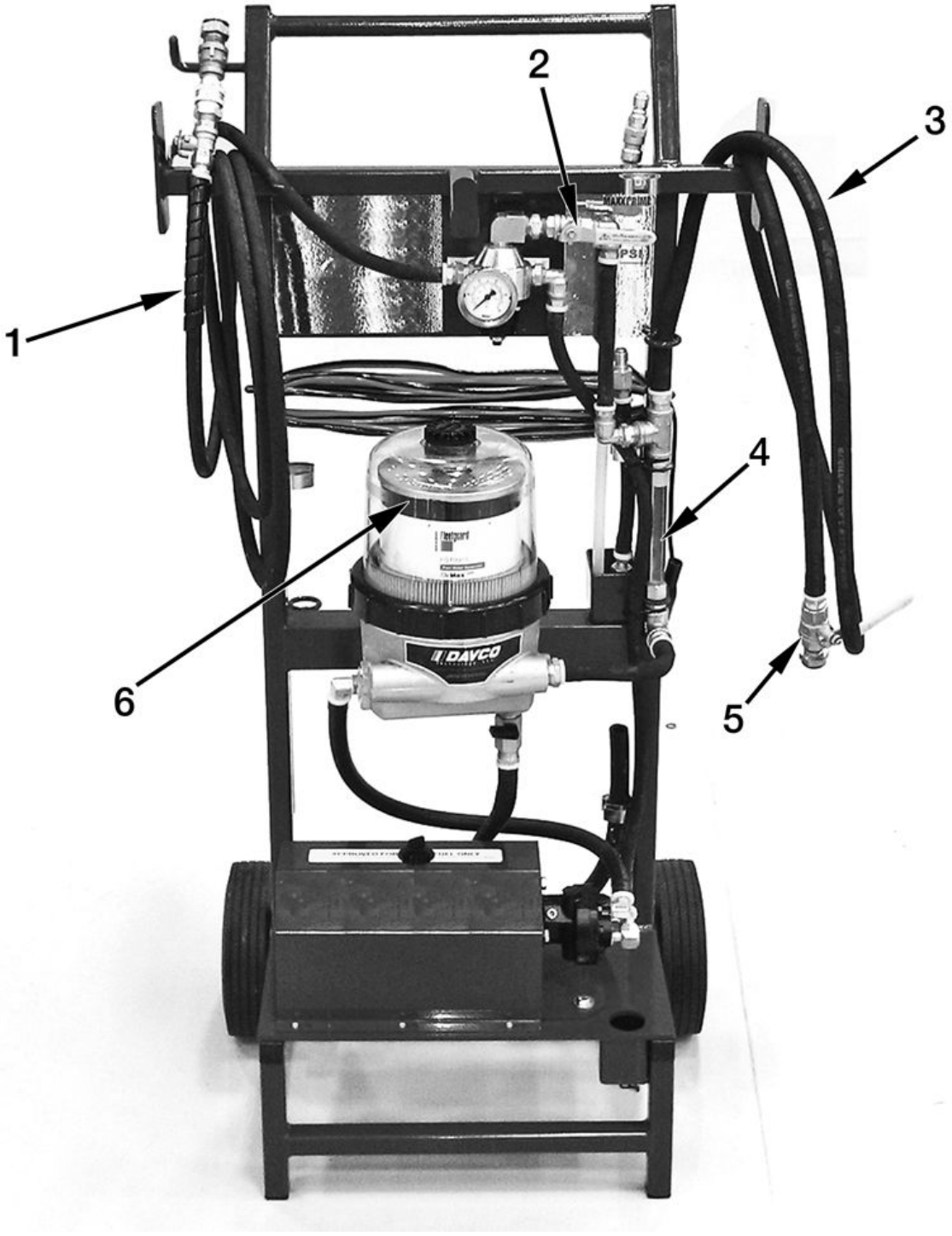


Figure 327 Fuel System Priming Tool

1. Pressure hose
2. Pressure regulator selector lever
3. Suction hose
4. Sight glass
5. Ball valve (2)
6. Filler cap (filter housing)

CAUTION: To prevent damage to fuel system components, make sure pressure regulator handle is in the 50 psi (345 kPa) position (as shown) when servicing MaxxForce® engines.

2. Fill Fuel System Priming Tool fuel filter housing with clean diesel fuel, the first time the tool is used and any time there is no diesel fuel in the filter housing.
3. Put a fuel drain pan under the chassis mounted primary fuel filter / water separator.
4. If necessary, fill the chassis mounted fuel filter with clean diesel fuel. Fill the cartridge type filter from the top or pump the hand primer button for the spin-on type filter.

NOTE: For different vehicles the chassis mounted primary fuel filter / water separator is mounted in different locations than what is shown in (Figure 329) and (Figure 330).

NOTE: The Fuel System Priming Tool will work with either of the primary fuel filter / water separators shown in (Figure 328) or (Figure 329).

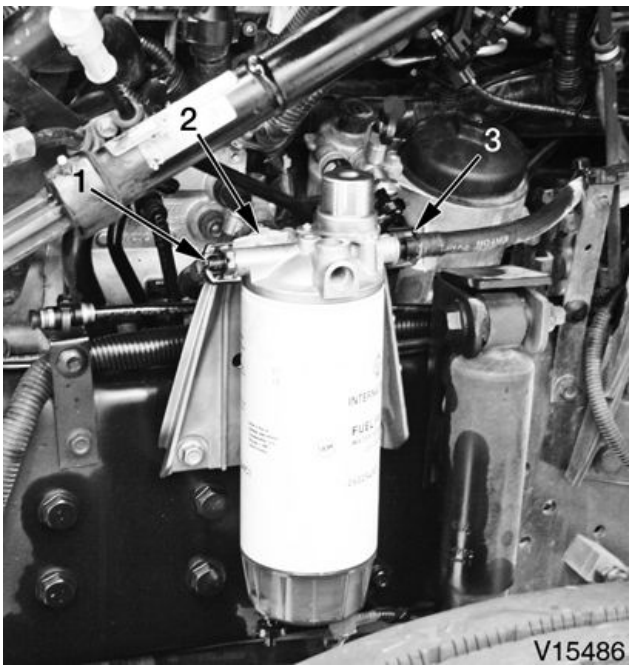


Figure 328 Chassis mounted primary fuel filter / water separator (optional)

1. Fuel output to engine
2. Chassis mounted primary fuel filter / water separator
3. Fuel input from tank

Figure 329 Chassis mounted primary fuel filter / water separator (typical)

1. Chassis mounted primary fuel filter / water separator
2. Fuel input from tank
3. Fuel output to engine

5. Disconnect fuel supply line to engine (fuel output to engine) by pushing red release tab and pulling line off the primary fuel filter housing (Figure 330).

Figure 330 Chassis mounted primary fuel filter / water separator (typical)

1. Fuel supply line to engine
2. Red release tab

6. Connect Fuel System Priming Tool suction hose to the primary fuel filter output (Figure 331).

Figure 331 Fuel Priming Tool suction hose connected to primary fuel filter output

1. Fuel supply line to engine
2. Fuel System Priming Tool suction hose
3. Ball valve (closed)

7. Connect Fuel System Priming Tool pressure hose to the fuel supply line to engine (Figure 332).

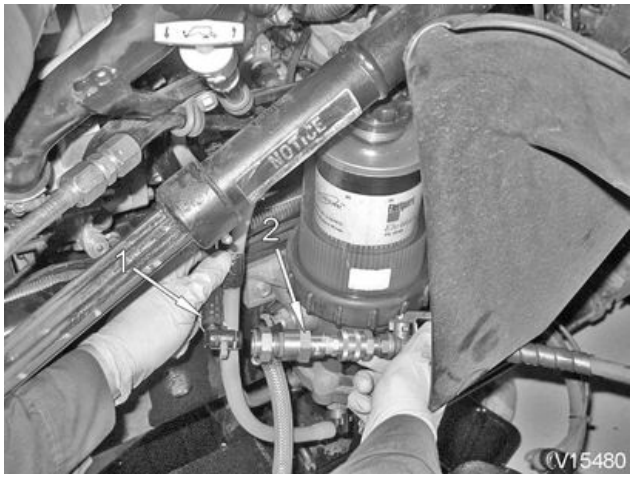


Figure 332 Connecting Fuel System Priming Tool pressure hose to the fuel supply line to engine

1. Fuel supply line to engine
2. Fuel System Priming Tool pressure hose

Figure 333 Ball valves closed

1. Pressure hose ball valve closed
2. Suction hose ball valve closed

8. Open pressure and suction hose ball valves (Figure 334) .

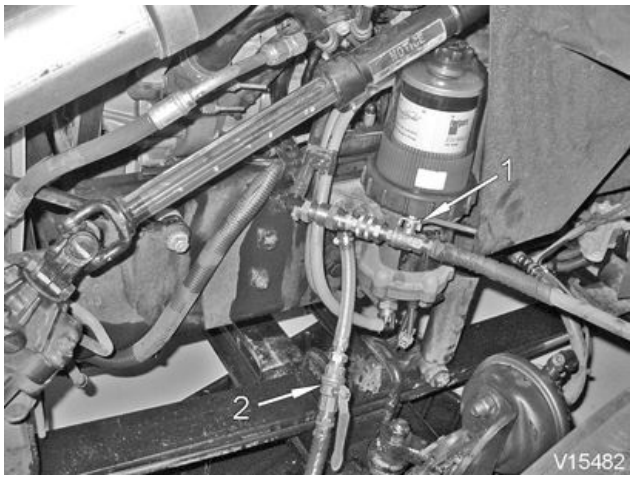


Figure 334 Ball valves open

1. Pressure hose ball valve open
2. Suction hose ball valve open

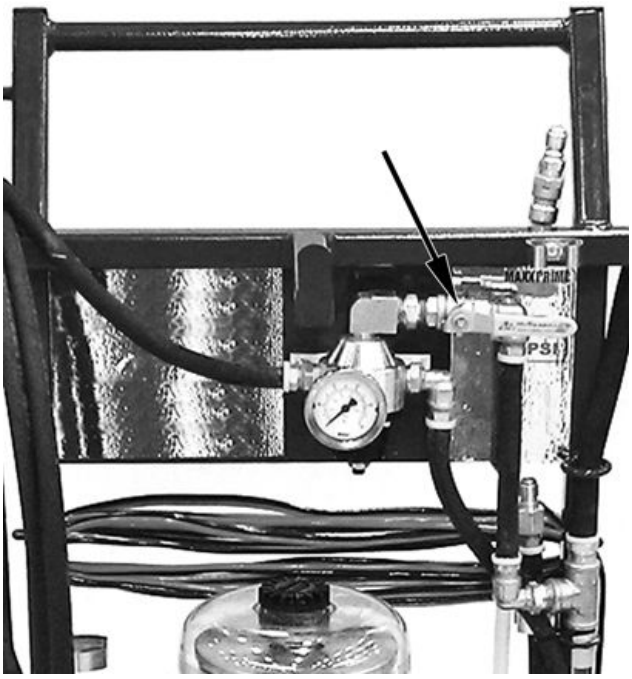


Figure 335 Pressure regulator selector lever

9. Set Fuel System Priming Tool pressure regulator selector lever to 50 psi (345 kPa) (Figure 335).

Figure 336 Fuel System Priming Tool connected to vehicle and electrical power

10. Connect electrical power and press the Fuel System Priming Tool power button (Figure 336).
11. Run Fuel System Priming Tool for a minimum of 2 minutes after no bubbles are visible in the sight glass (Figure 337).

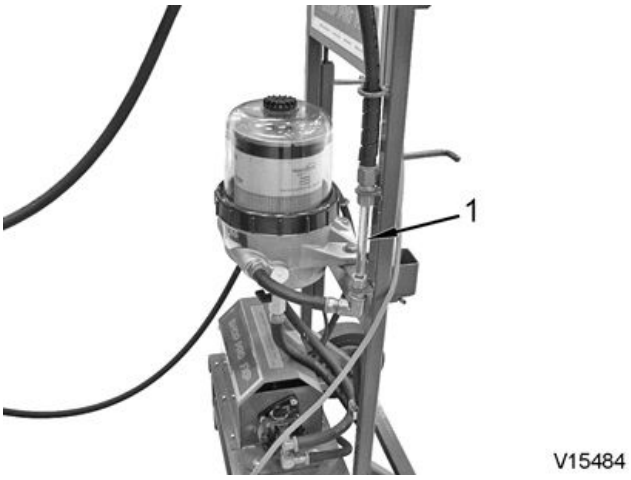


Figure 337 Fuel System Priming Tool sight glass

1. Sight glass

12. Turn Fuel System Priming Tool off.
13. Close pressure and suction hose ball valves (Figure 333).

Figure 338 Ball valves closed

1. Pressure hose ball valve closed
2. Suction hose ball valve closed

14. Disconnect Fuel System Priming Tool pressure and suction hoses.
15. Connect fuel supply line to engine to the chassis mounted primary fuel filter / water separator (Figure 339).

Figure 339 Chassis mounted primary fuel filter / water separator

1. Fuel supply line to engine
2. Red release tab

16. Install left front fender assembly and bracket.

Hand Primer Pump Method

NOTE: Priming the fuel system by hand is not necessary if the Fuel System Priming Tool was used to prime the fuel system.

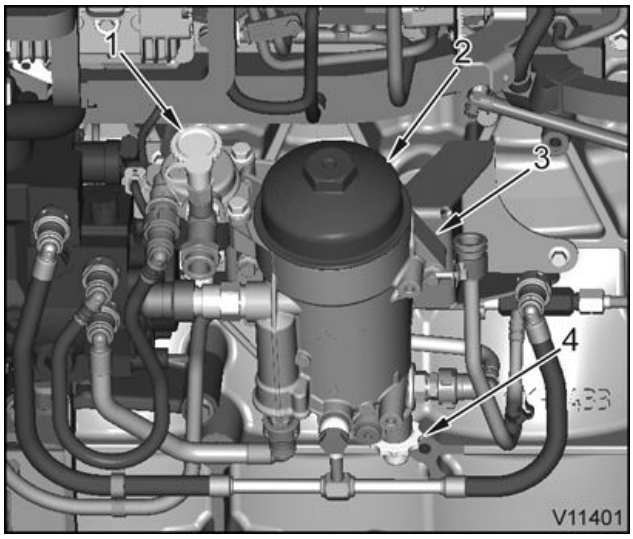


Figure 340 Fuel primer pump

1. Fuel primer pump
2. Fuel filter cover
3. Fuel filter housing
4. Water drain valve (closed)

1. Prime engine at hand primer pump:
   A. Turn the fuel primer pump knob counterclockwise to unlock the pump stem.
   B. Pump the fuel priming pump a minimum of 250 times (approximately 2 minutes). Continue pumping even after higher pumping force is required. Make sure to raise and lower the knob completely on each stroke.
   C. After priming, depress the fuel primer pump knob fully and turn the fuel primer pump knob clockwise until tight to secure the pump stem.

CAUTION: To prevent engine damage, if engine fails to start after 20 seconds of cranking, stop cranking engine and wait two minutes to allow the starter motor to cool.

2. Start engine and check for fuel leaks. Let engine run for 2 minutes. If engine does not start after 20 seconds of cranking, wait 2 minutes before trying to start the engine again. If the engine does not start, reprime the low-pressure fuel system using the above procedure.

3. Install left front fender assembly and bracket.
4. Flip up and secure front bumper (if equipped).
5. Close and secure hood.
6. Remove wheel chocks.

Specifications

Table 15 Fuel System

Fuel strainer filtration	300 microns
Fuel filter element filtration	3-5 microns

Special Torque

Table 16 Fuel System

Banjo bolt, M14	30 N·m (22 lbf·ft)
Check valve	35 N·m (26 lbf·ft)
Forcing Screw Adapter Holding Plate M10 x 40 bolts	27 N·m (20 lbf·ft)
Fuel drain line fitting nut	26 N·m (19 lbf·ft)
Fuel filter bracket M8 x 30 bolt	35 N·m (26 lbf·ft)
Fuel filter housing assembly M8 x 45 bolt	35 N·m (26 lbf·ft)
Fuel filter cap	25 N·m (18 lbf·ft)
Fuel filter stand pipe	12 N·m (106 lbf·in)
Fuel primer pump assembly M8 x 25 bolt	30 N·m (22 lbf·ft)
Fuel rail M8 x 40 bolt	35 N·m (26 lbf·ft)
Fuel strainer cover	10 N·m (89 lbf·in)
Fuel supply adapter	30 N·m (22 lbf·ft)
Fuel to rail supply clamp assembly screws	5 N·m (44 lbf·in)
High-pressure connector (body) retaining nut	See tightening steps in procedure
High-pressure fuel pump drive housing M12 x 40, M12 x 90, M12 x 130 bolt	105 N·m (77 lbf·ft)
High-pressure fuel pump M10 x 40 bolt	62 N·m (46 lbf·ft)
High-pressure fuel pump M24 jam nut	285 N·m (210 lbf·ft)
High-pressure fuel pump support M14 x 30 bolt	172 N·m (126 lbf·ft)
High-pressure pump to rail tube assembly line fitting nuts	See tightening steps in procedure
High-pressure rail to injector line fitting nut	See tightening steps in procedure
High-pressure pump pulley housing M10 x 40 bolt	62 N·m (46 lbf·ft)
High-pressure pump pulley M16 x 40 LH bolt	280 N·m (207 lbf·ft)
Holding plate M12 bolts	47 N·m (35 lbf·ft)
Injector harness nut	1.5 N·m (13 lbf·in)
Injector hold-down clamp M8 x 50 bolt	See tightening steps in procedure
Pressure limiting valve	110 N·m (81 lbf·ft)
Quick-connect M16 x 1.5 connector	30 N·m (22 lbf·ft)
Threaded unions (M14 x 1.5)	30 N·m (22 lbf·ft)

Special Service Tools

Table 17 Fuel System

Description	Tool Number
Crowfoot wrench	Obtain locally
Disposable Air and Fuel Caps	ZTSE4891
Fan Hub/High Pressure Drive Seal Installer	ZTSE6066
Forcing Screw	12-454-01-05
Forcing Screw Adapter	12-454-01-04
Forcing Screw Adapter Holding Plate	12-454-01-01
Fuel Injector Cups	ZTSE4892
Fuel Injector Rack Holder	ZTSE4299B
Fuel Injector Tip Cleaning Brush	ZTSE4301
Fuel Line Disconnect Tool 11.8 mm	ZTSE4773
Fuel System Priming Tool	15-922-01
Guide Stud	12-454-01-02
High-Pressure Pump Removal Tool	12-454-01
Holding Plate	ZTSE6440
Injector Installer	ZTSE4777
Injector Puller	ZTSE4770
Injector Sleeve Brushes	ZTSE4751
P80® Rubber Lubricant or equivalent	Obtain locally
Socket Head Bolt	12-454-01-03
Wacker® A-442 RTV sealant or equivalent	Obtain locally
Slide hammer	Obtain locally

Table of Contents

Exploded Views.....247
- **Oil Module Assembly.....247**
- **Oil Module.....248**

Removal.....249
- **Oil Filter Cover and Filter.....249**
- **Oil Centrifuge.....250**
- **Oil Module Assembly.....251**
- **Oil Cooler.....253**
- **Oil Pressure Relief Valve.....253**

Cleaning, Inspection and Testing.....254
- **Oil Cooler.....254**
- **Oil Cooler Leak Test.....254**
- **Extension Tubes.....254**
- **Oil Centrifuge.....254**

Installation.....255
- **Oil Pressure Relief Valve.....255**
- **Oil Cooler.....255**
- **Oil Module Assembly.....256**
- **Oil Centrifuge.....258**
- **Oil Filter Cover and Filter.....258**

Special Torque.....260

Special Service Tools.....260

Exploded Views

Oil Module Assembly

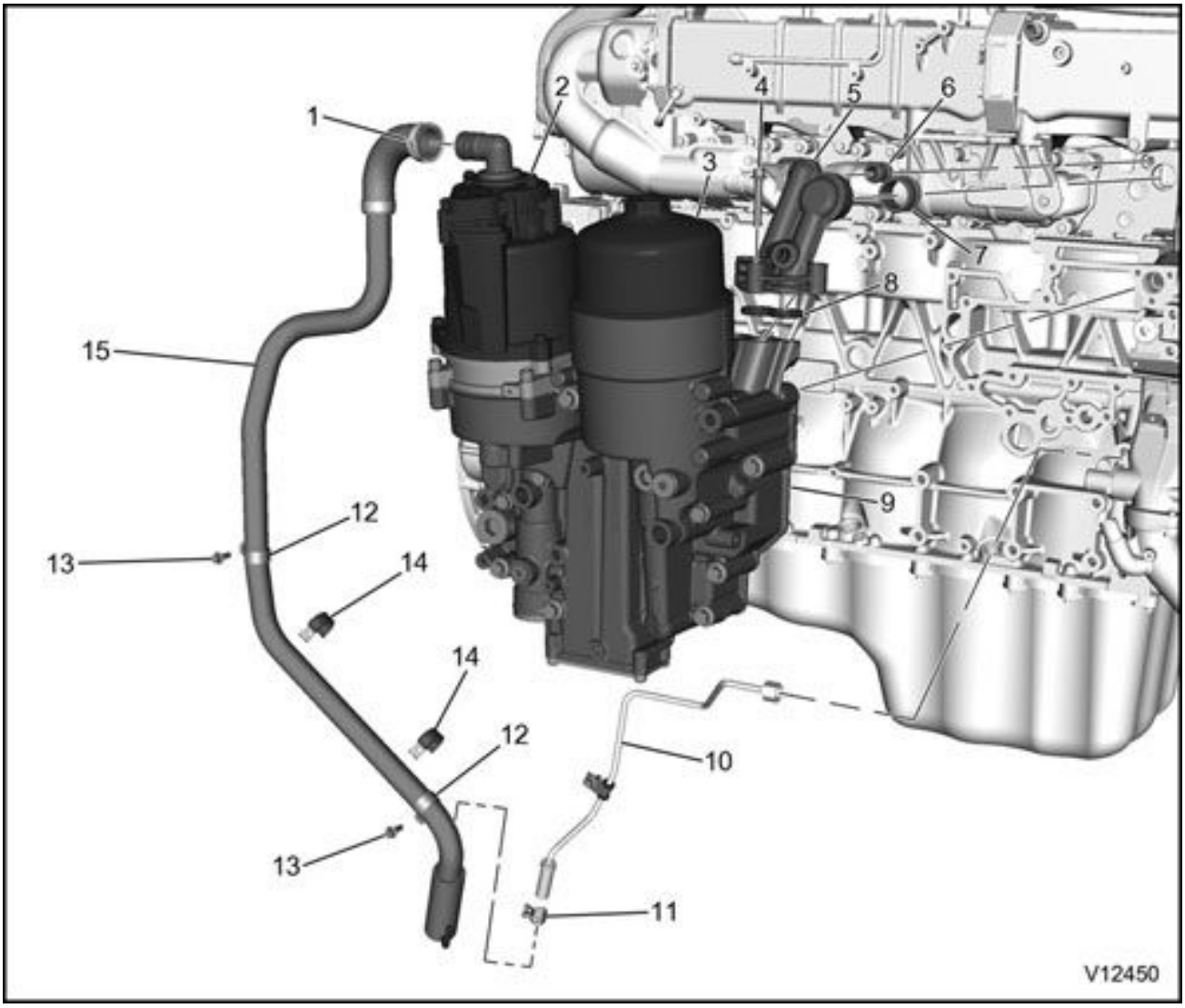


Figure 341 Oil module assembly

1. Clamp (spring)
2. Oil centrifuge
3. Filter cover
4. M8 x 45 bolt (3)
5. Oil module flange
6. Extension tube (DMR20 x DN14)
7. Extension tube (DMR37 x DN29)
8. Seal (formed)
9. Oil module assembly
10. Heater return tube assembly
11. Hose clamp (spring)
12. Tube clamp (2)
13. M6 x 16 bolt (2)
14. Tube clamp (2)
15. Open breather tube assembly

Oil Module

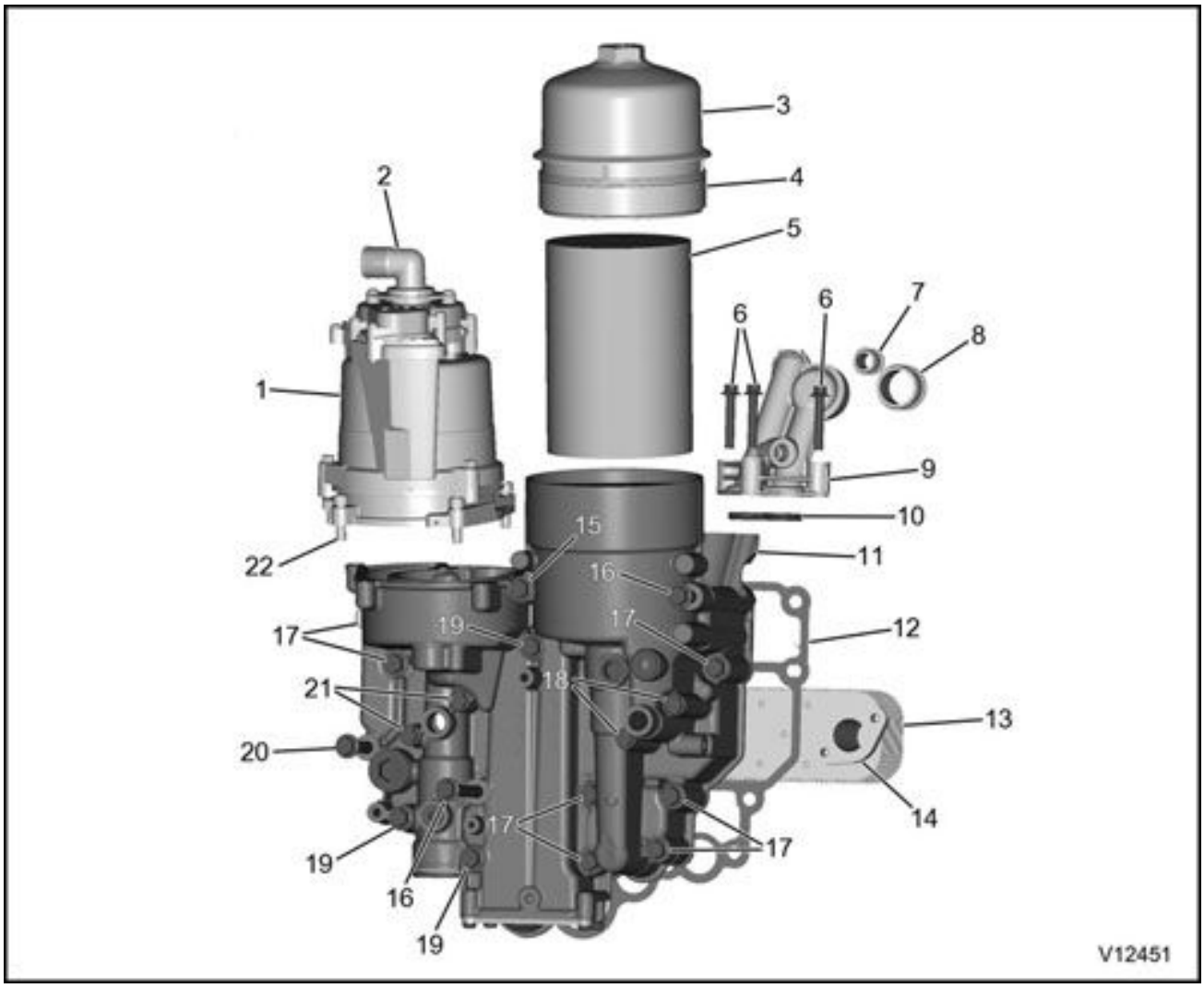


Figure 342 Oil module

1. Oil centrifuge
2. Open breather tube connection
3. Filter cover
4. O-ring seal
5. Oil filter
6. M8 x 45 bolt (3)
7. Extension tube (DMR20 x DN14)
8. Extension tube (DMR37 x DN29)
9. Oil module flange
10. Seal (formed)
11. Oil module assembly
12. Oil module gasket
13. Oil cooler
14. Oil cooler gasket (2)
15. M10 x 170 bolt
16. M10 x 200 bolt (2)
17. M10 x 80 bolt (7)
18. M8 x 90 bolt (2)
19. M10 x 110 bolt (3)
20. M10 x 140 bolt
21. M8 x 45 bolt (2)
22. M6 socket head bolt (4)

Removal

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

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

WARNING: To prevent personal injury or death, shift 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, 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: Refer to the following service sections for information on removal of components prior to this section.

- Engine Electrical
- Turbochargers
- Fuel System

Oil Filter Cover and Filter

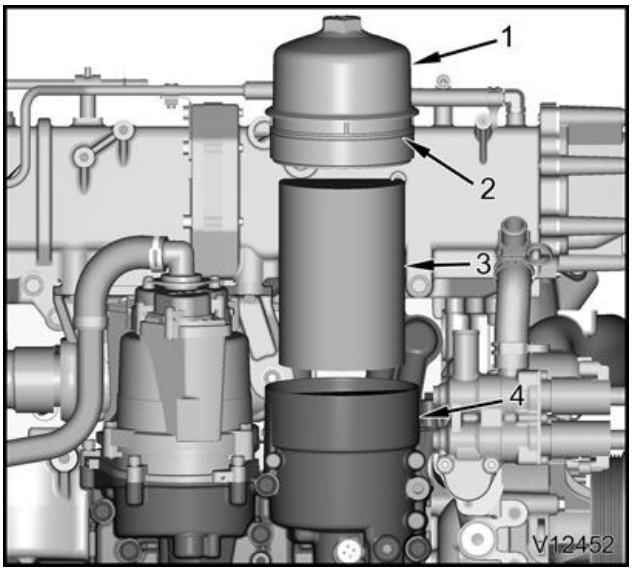


Figure 343 Oil filter cover

1. Filter cover
2. O-ring seal
3. Oil filter
4. Oil module assembly

1. Place absorbent material under the engine and oil module assembly.
2. Unscrew oil filter cover from oil module using a 36 mm wrench.
3. Rotate oil filter element slightly and remove oil filter from filter cover.
4. Remove and discard O-ring seal from exterior of oil filter cover.
5. Dispose of oil filter according to local regulations.

Oil Centrifuge

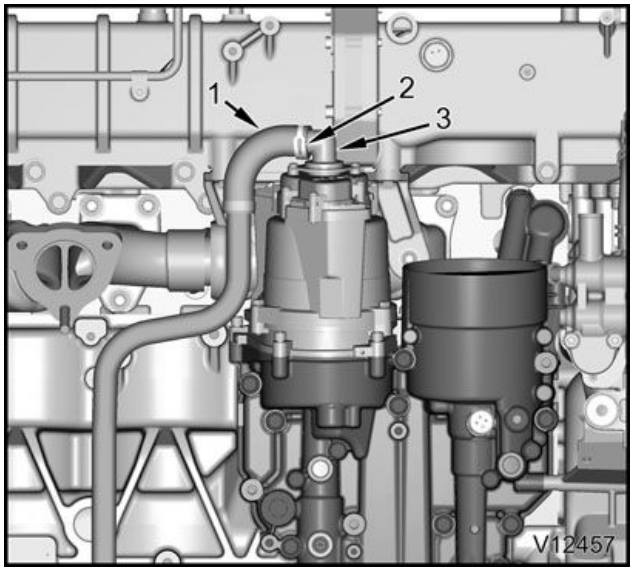


Figure 344 Open breather tube assembly

1. Open breather tube assembly
2. Clamp (spring)
3. Oil centrifuge outlet

1. Release spring clamp and disconnect open breather tube assembly from oil centrifuge outlet.

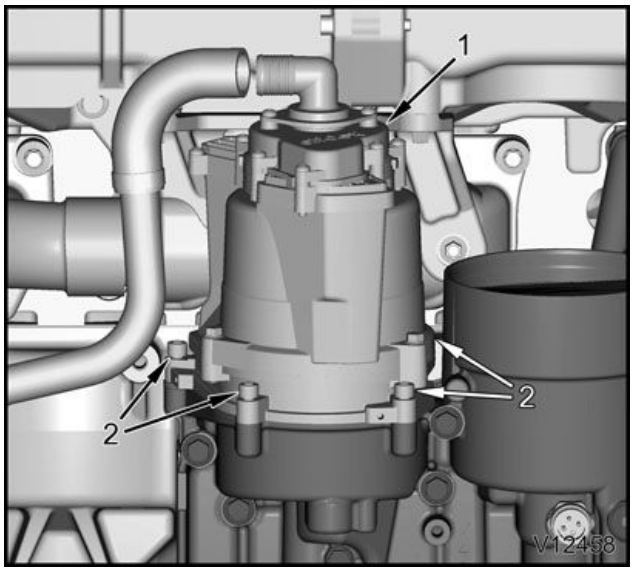


Figure 345 Oil centrifuge

1. Oil centrifuge
2. M6 socket head bolt (4)

2. Remove four M6 socket head bolts from oil centrifuge base and remove oil centrifuge and base as an assembly.
3. Remove seal ring from oil centrifuge base. Discard ring if damaged or leaking.

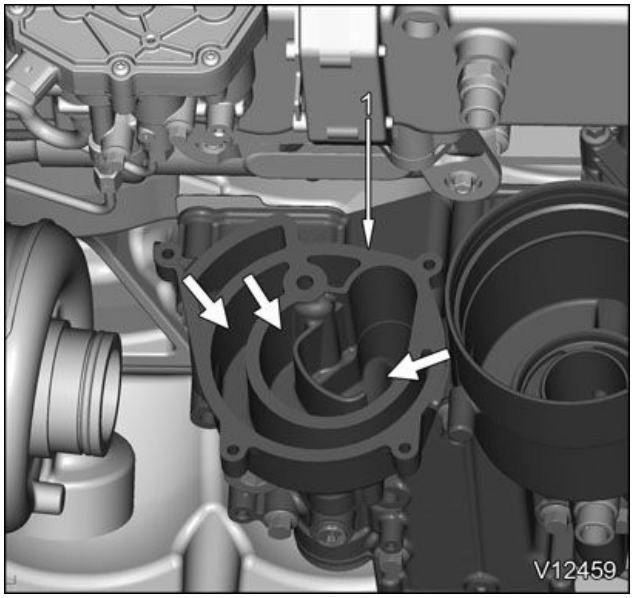


Figure 346 Oil module assembly oil passageways

1. Oil module assembly

4. Inspect oil module assembly oil passageways. Clean any obstructions or dirt as necessary.

Oil Module Assembly

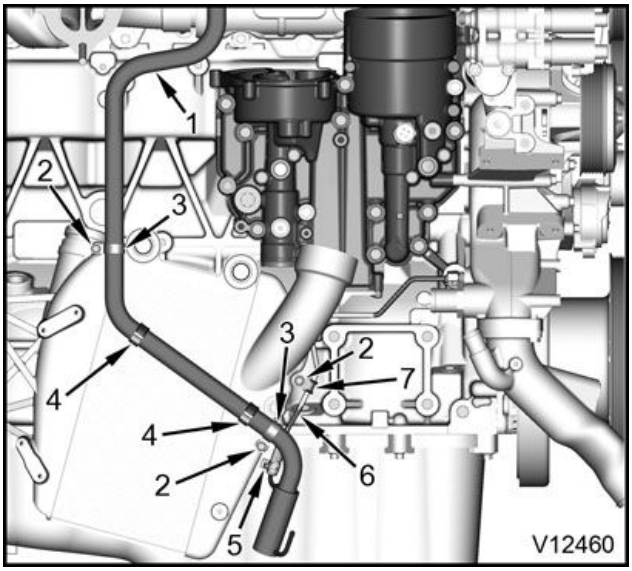


Figure 347 Open breather tube and heater return tube

1. Open breather tube assembly
2. M6 x 16 bolt (3)
3. Tube clamp (2)
4. Tube clamp (2) (for hydrocarbon injector (HCI) coolant return tube assembly)
5. Hose clamp (spring type)
6. Heater return tube assembly
7. Pipe single cushioned clamp

1. Remove two tube clamp M6 x 16 bolts securing open breather tube to low-pressure charge air cooler (LPCAC).
2. If not previously done, unclip two tube clamps securing HCI coolant return tube assembly to open breather tube assembly.

CAUTION: To prevent engine damage, when manipulating the open breather tube assembly, do not create a severe bend to the elbow hose that connects the tube to the oil module centrifuge outlet. The hose can crack.

3. If not previously done, release hose clamp (spring type) securing HCI coolant return tube assembly and disconnect tube from open breather tube.
4. Remove hose clamp (spring type) securing heater return tube to open breather tube assembly. Remove open breather tube assembly.
5. Remove M6 x 16 bolt and pipe single cushioned clamp securing heater return tube to LPCAC.
6. Loosen tube nut securing heater return tube to straight fitting on water distribution housing. Remove heater return tube.

CAUTION: To prevent engine damage, drain all coolant from the engine through the radiator when removing the oil module assembly. Coolant can enter the oil sump and contaminate the engine oil. Engine oil must be drained and replaced after oil module removal and installation, before the engine is started.

7. Drain coolant from engine through radiator.

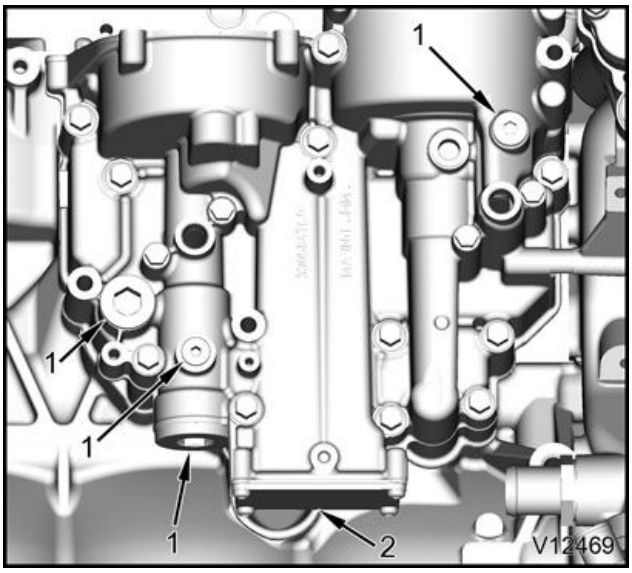


Figure 348 Oil module assembly (non-servicable items)

1. Plug (with seal)
2. Bottom cover

CAUTION: To prevent engine damage, do not remove oil module assembly plugs, seals or bottom cover to drain the coolant or oil. These parts are not serviceable.

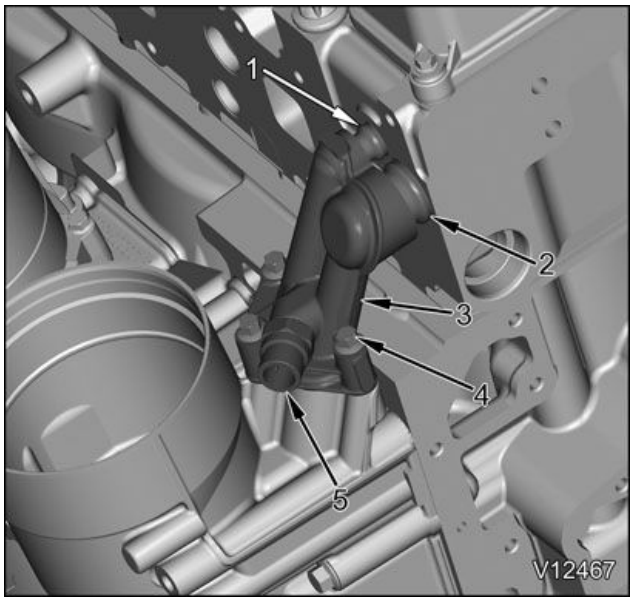


Figure 349 Oil module flange

1. Extension tube (DMR20 x DN14)
2. Extension tube (DMR37 x DN29)
3. Oil module flange
4. M8 x 45 bolt (3)
5. Engine oil temperature sensor

8. If not previously done, disconnect engine oil temperature sensor connector. Remove engine oil temperature sensor from oil module flange if needed. See "ENGINE ELECTRICAL" for procedure.
9. Remove three M8 x 45 bolts then remove oil module flange by pulling away from cylinder head to disengage extension tubes. Discard the oil module flange seal (formed).

CAUTION: To prevent engine damage, do not remove extension tubes by grabbing sealing surfaces.

10. Remove DMR20 x DN14 and DMR37 x DN29 extension tubes. Inspect for damage. Replace as necessary.

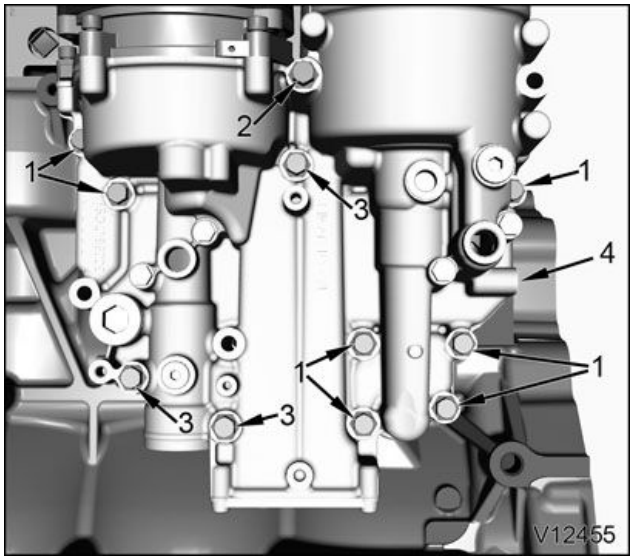


Figure 350 Oil module assembly

1. M10 x 80 bolt (7)
2. M10 x 170 bolt
3. M10 x 110 bolt (3)
4. M8 x 150 bolt location (from water pump) includes 9 x 16 x 15 spacer

11. Remove seven M10 x 80 bolts, three M10 x 110 bolts, M10 x 170 bolt, M8 x 150 bolt (from water pump into front side of oil module assembly) and 9 x 16 x 15 spacer (between oil module assembly and water distribution housing).
12. Remove oil module assembly and gasket from engine. Discard oil module assembly gasket.

Oil Cooler

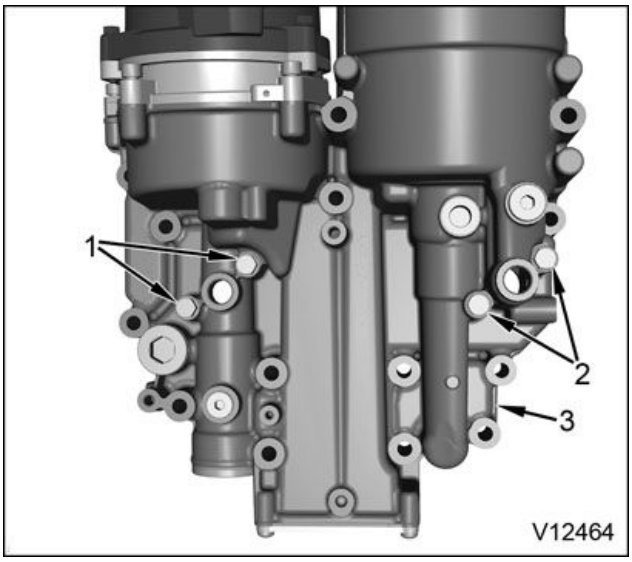


Figure 351 Oil cooler bolts

1. M8 x 45 bolt (2)
2. M8 x 90 bolt (2)
3. Oil module assembly

1. Remove two M8 x 45 and two M8 x 90 bolts.

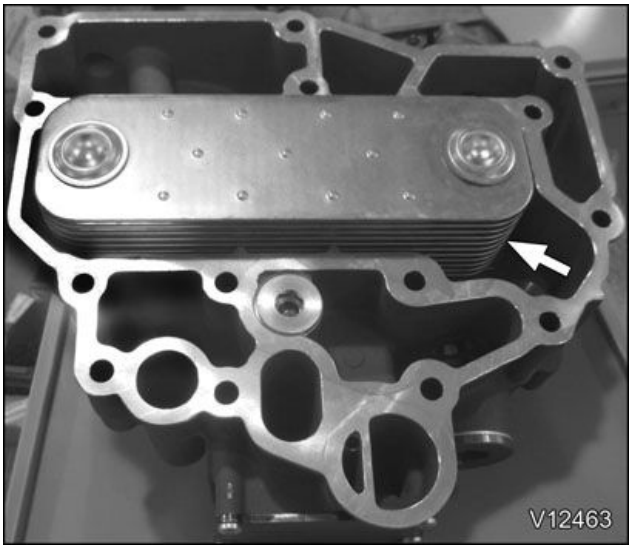


Figure 352 Oil cooler

2. Remove oil cooler from oil module assembly.

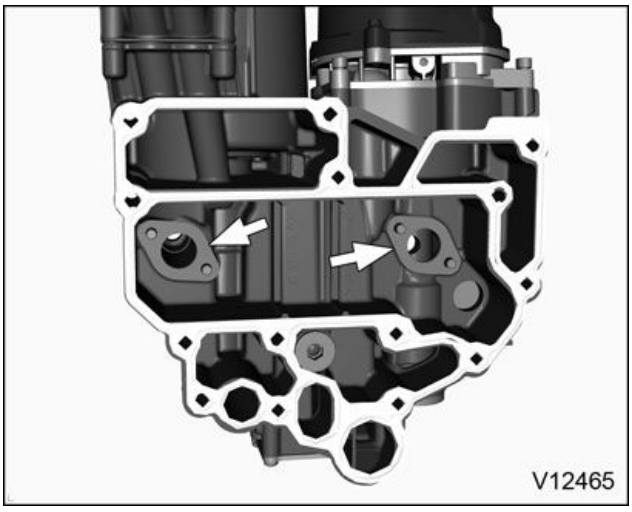


Figure 353 Oil cooler gaskets

3. Remove two oil cooler gaskets from oil module assembly. Discard gaskets.

Oil Pressure Relief Valve

NOTE: Perform this procedure if replacing oil pressure relief valve for oil pressure-related issues.

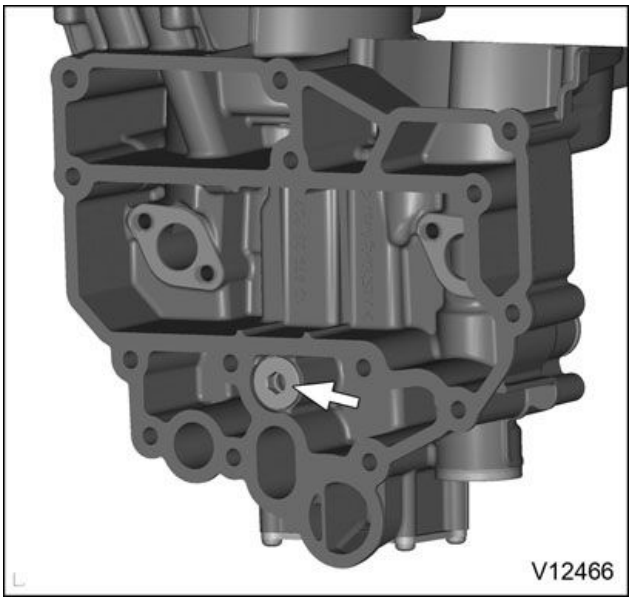


Figure 354 Oil pressure relief valve

1. Remove oil pressure relief valve. Clean and inspect oil pressure relief valve. Replace if necessary.

Cleaning, Inspection and Testing

Oil Cooler

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, replace the oil cooler if an engine bearing fails. Bearing debris can not be removed from the oil cooler.

1. The oil cooler can be cleaned in solvent and dried with filtered compressed air.
   - Clean oil cooler in suitable solvent.
   - Flush and drain oil cooler to remove any residue. Dry components with filtered compressed air.

Oil Cooler Leak Test

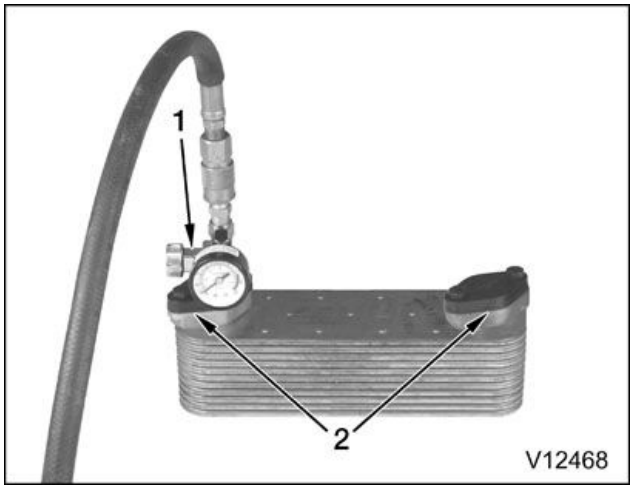


Figure 355 Engine oil cooler pressure test

1. Air pressure regulator
2. Engine Oil Cooler Pressure Test Plate

1. Install Engine Oil Cooler Pressure Test Plate (page 260) onto oil cooler.

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 260) to Engine Oil Cooler Pressure Test Plate. Connect to compressed air supply and adjust air pressure to approximately 172 to 207 kPa (25 to 30 psi).
3. Immerse oil cooler in large container of clean water.
4. Inspect oil cooler and test plate for leaks. If test plate fittings leak, tighten fittings and continue looking for leaks. Air bubbles at any location from oil cooler indicate leaks. Replace oil cooler if leaking.
5. Dry oil cooler using filtered compressed air.

Extension Tubes

1. Wipe extension tubes clean and inspect for tears, cuts or other damage to sealing surfaces. Replace as necessary.

Oil Centrifuge

1. Clean the oil centrifuge and inspect for damage. Replace as necessary.

Installation

Oil Pressure Relief Valve

NOTE: Perform this procedure if oil pressure relief valve is removed.

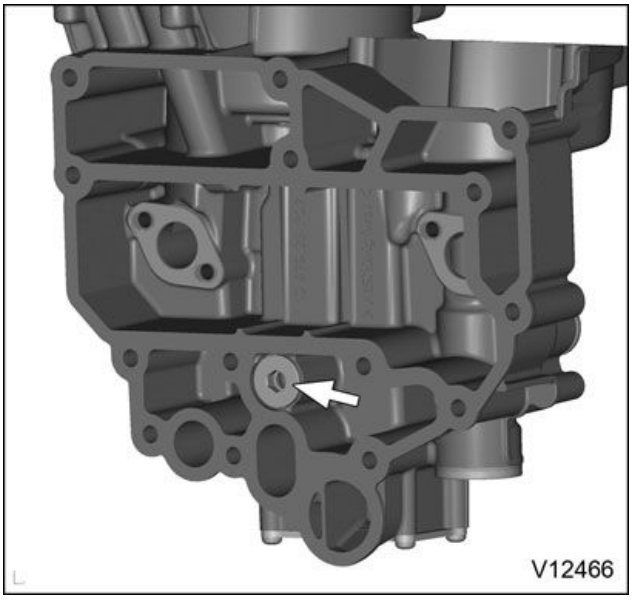


Figure 356 Oil pressure relief valve

1. Install oil pressure relief valve. Tighten valve to special torque (page 260).

Oil Cooler

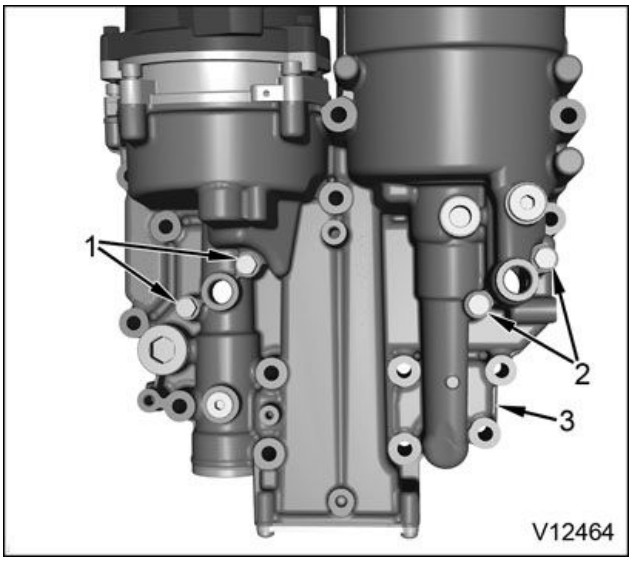


Figure 357 Oil cooler bolts

1. M8 x 45 bolt (2)
2. M8 x 90 bolt (2)
3. Oil module assembly

1. Install two M8 x 45 and two M8 x 90 bolts through oil module assembly.

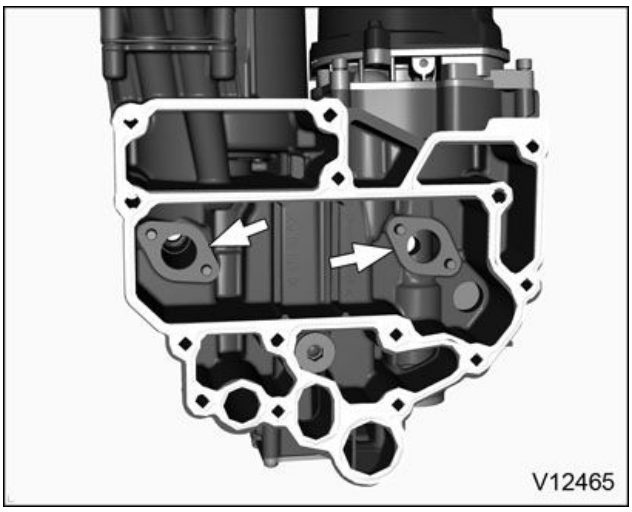


Figure 358 Oil cooler gaskets

2. Install new oil cooler gaskets over threads of installed bolts.

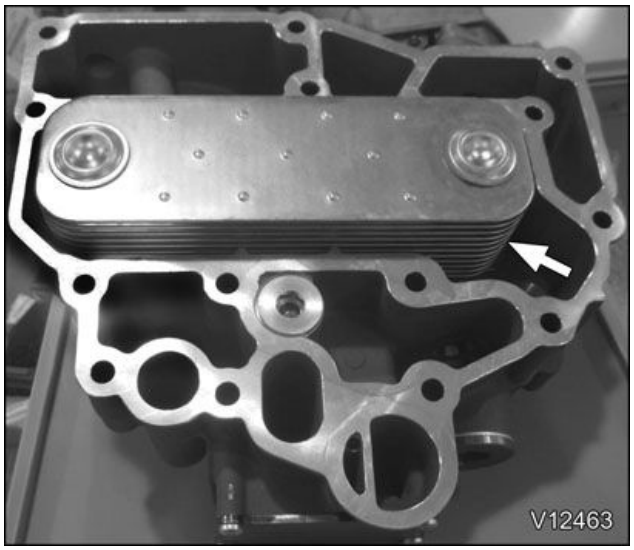


Figure 359 Oil cooler installation

3. Install oil cooler over gaskets and into oil module. Hand-tighten bolts.

   NOTE: Ensure gaskets remain in place during cooler installation.

   Tighten two M8 x 45 and two M8 x 90 bolts to special torque (page 260).

Oil Module Assembly

1. Position new gasket onto oil module assembly.

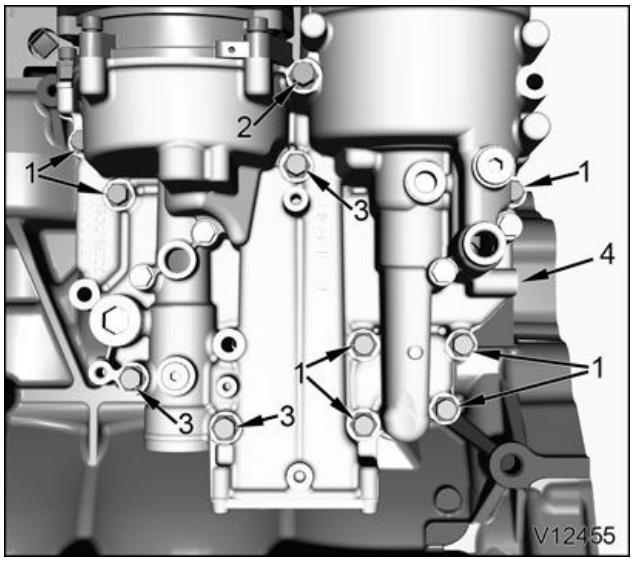


Figure 360 Oil module assembly

1. M10 x 80 bolt (7)
2. M10 x 170 bolt
3. M10 x 110 bolt (3)
4. M8 x 150 bolt location (from water pump) includes 9 x 16 x 15 spacer

CAUTION: To prevent engine damage, do not use any silicone or other sealant when installing oil module assembly.

2. Position oil module assembly and install seven M10 x 80 bolts, M10 x 170 bolt and three M10 x 110 bolts.
3. Tighten oil module bolts to special torque (page 260).
4. Place 9 x 16 x 15 spacer between water distribution housing and oil module assembly.
5. Install M8 x 150 bolt through water pump assembly, water distribution housing, spacer and into front side of oil module assembly. Tighten M8 x 150 bolt to special torque (page 260).

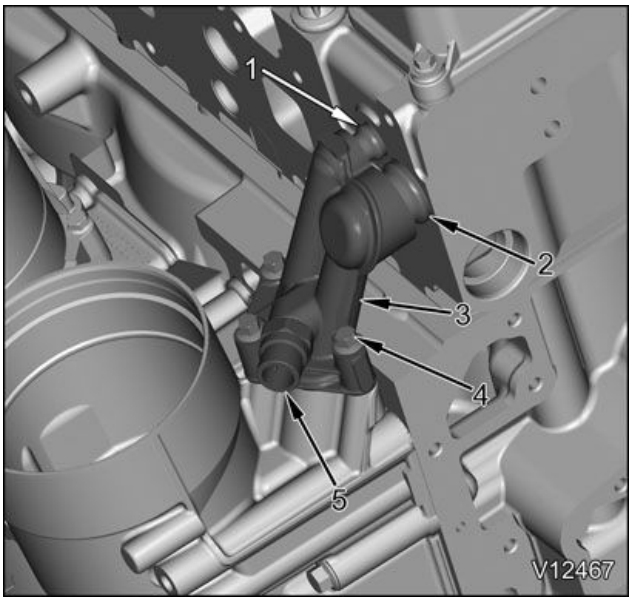


Figure 361 Oil module flange

1. Extension tube (DMR20 x DN14)
2. Extension tube (DMR37 x DN29)
3. Oil module flange
4. M8 x 45 bolt (3)
5. Engine oil temperature sensor

6. Lubricate sealing surfaces of DMR20 x DN14 and DMR37 x DN29 extension tubes with P-80® rubber lubricant or equivalent (page 260) and insert into oil module flange.
7. Install extension tubes into oil module flange using Extension Tube Installer Large and Extension Tube Installer Small (page 260).
8. Position oil module with new formed seal onto oil module while gently pushing extension tubes into cylinder head. Install three M8 x 45 bolts. Tighten bolts to special torque (page 260).
9. If not previously done, install engine oil temperature sensor into oil module flange if needed. See "ENGINE ELECTRICAL" for procedure. Connect temperature sensor electrical connector.

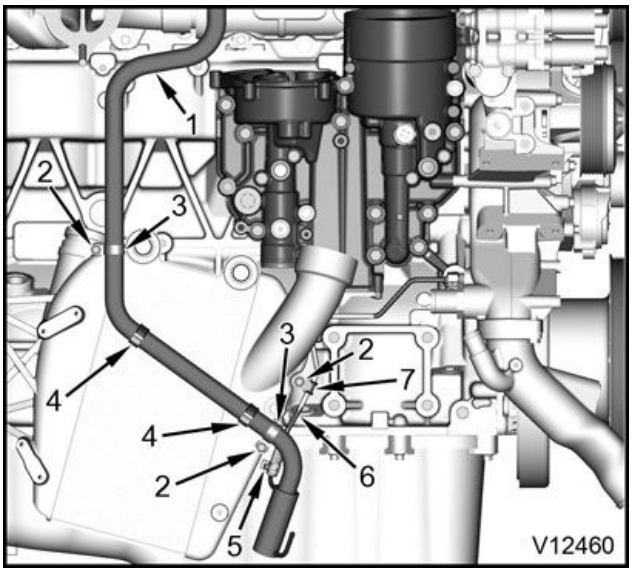


Figure 362 Open breather tube and heater return tube

1. Open breather tube assembly
2. M6 x 16 bolt (3)
3. Tube clamp (2)
4. Tube clamp (2) (for HCI coolant return tube assembly)
5. Hose clamp (spring type)
6. Heater return tube assembly
7. Pipe single cushioned clamp

10. Install two tube clamps onto open breather tube. Position open breather tube assembly to LPCAC and install two M6 x 16 bolts. Tighten bolts to special torque (page 260).
11. If not previously done, snap two tube clamps over open breather tube assembly and HCI coolant return tube assembly.
12. If not previously done, install HCI coolant return tube onto open breather tube assembly and install hose clamp (spring type). See HCI Coolant Return Tube (page 134).
13. Position heater return tube assembly to straight fitting on water distribution housing and loosely tighten tube nut.
14. Install pipe single cushioned clamp onto heater return tube assembly and install M6 x 16 bolt into LPCAC and tighten to special torque (page 260).

15. Install heater return tube assembly hose onto open breather tube and install hose clamp (spring type).
16. Tighten heater return tube assembly tube nut to special torque (page 260).

Oil Centrifuge

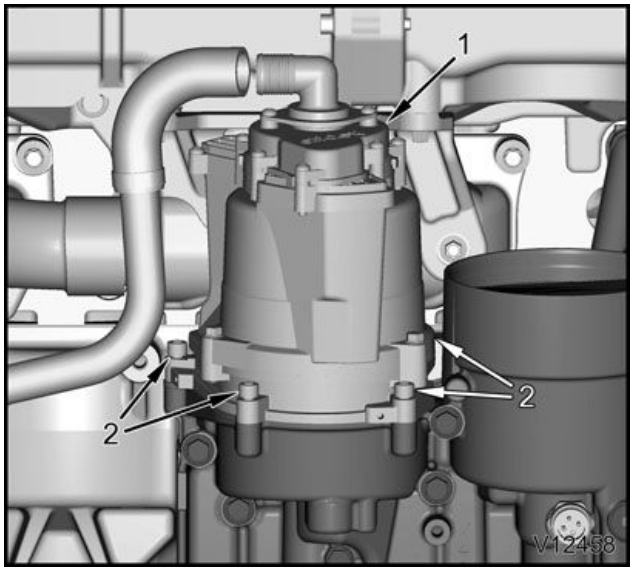


Figure 363 Oil centrifuge

1. Oil centrifuge
2. M6 socket head bolt (4)

1. Install centrifuge with base and new formed seal. Lubricate new formed seal with clean engine oil.
2. Install four M6 socket head bolts. Tighten bolts to standard torque (page 503).

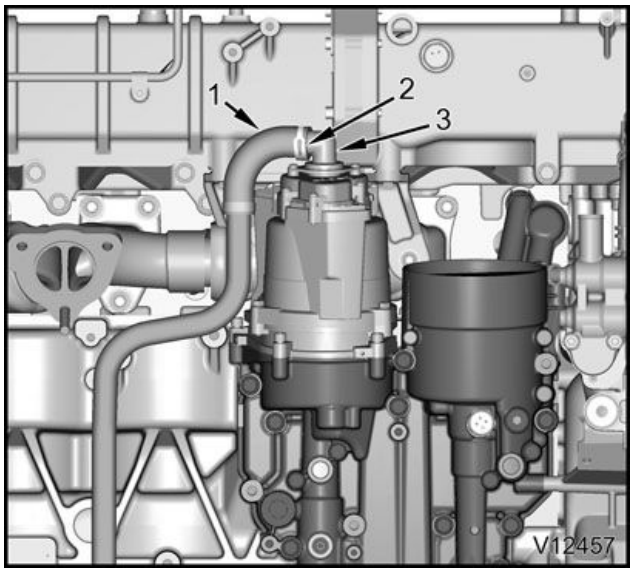


Figure 364 Open breather tube assembly

1. Open breather tube assembly
2. Clamp (spring)
3. Oil centrifuge outlet

3. Slide spring clamp over open breather tube assembly.
4. Connect open breather tube assembly to centrifuge outlet.
5. Install spring clamp and tighten.

Oil Filter Cover and Filter

1. Lubricate new O-ring with clean engine oil and install onto exterior of oil filter cover.
2. Install oil filter into oil filter cover.

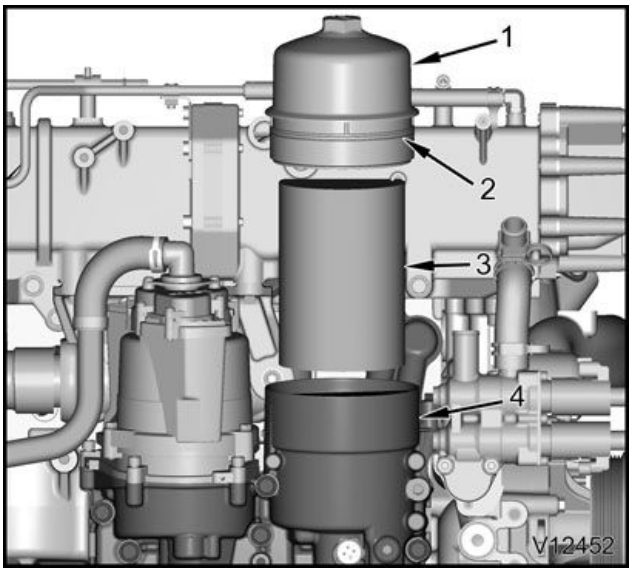


Figure 365 Oil filter cover

1. Filter cover
2. O-ring seal
3. Oil filter
4. Oil module assembly

3. Install oil filter, O-ring seal and oil filter cover as an assembly into oil module. Tighten 36mm cover hex to special torque (page 260).

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 start or allow engine to run until first changing engine oil.

4. Drain and replace engine oil with recommended type and amount. See *Engine Operation and Maintenance Manual* for oil type, capacity and fill procedure.

5. Replace engine coolant with recommended type and amount. See *Engine Operation and Maintenance Manual* for coolant type, capacity and fill procedure.

NOTE: Three additional bolts secure the oil module assembly. These bolts are installed along with the HP turbo air supply duct (two M10 x 200 bolts) and the air inlet duct for the LP turbocharger (one M10 x 140 bolt). See "TURBOCHARGERS" for procedures.

Special Torque

Table 18 Oil Module Assembly

Heater return tube assembly bolt, M6 x 16	13 N·m (115 lbf·in)
Heater return tube assembly tube nut	11 N·m (97 lbf·in)
Oil cooler bolts, M8 x 45 and M8 x 90	25 N·m (18 lbf·ft)
Oil filter cover	40 N·m (30 lbf·ft)
Oil module assembly bolts, M10 x 80, M10 x 170 and M10 x 110	65 N·m (48 lbf·ft)
Oil module flange bolts, M8 x 45	24 N·m (18 lbf·ft)
Oil pressure relief valve	40 N·m (30 lbf·ft)
Open breather tube assembly bolt, M6 x 16	13 N·m (115 lbf·in)
Water pump bolt, M8 x 150 (front side of oil module)	35 N·m (26 lbf·ft)

Special Service Tools

Table 19 Oil Cooler

Description	Tool Number
Air pressure regulator	Obtain locally
Extension Tube Installer Large	ZTSE6051-1
Extension Tube Installer Small	ZTSE6051-2
Engine Oil Cooler Pressure Test Plate	ZTSE6063
P-80® rubber lubricant or equivalent	Obtain locally

Table of Contents

Exploded Views.....263
EGR Coolant Manifold and Elbow.....263

Removal.....268
Coolant Manifold.....268
Coolant Elbow 269
EGR Cooler Bracket.....269
EGR Outlet Tubes.....270
EGR Module Cover.....270
Heat Protection (Cylinders 4-6) Shield.....271
EGR Inlet Tubes.....271
Heat Protection EGR Shield.....272
EGR Dual Flap Valve.....272
EGR Cooler Assembly.....274

Disassembly and Assembly of EGR Cooler.....275
EGR Cooler High-Temperature or Low-Temperature Side Replacement.....275

Cleaning, Inspection and Testing.....281
EGR System Components Cleaning.....281
EGR Cooler Assembly Cleaning.....281
EGR Cooler Assembly Leak Test.....288

Installation.....289
EGR Cooler Assembly.....289
EGR Dual Flap Valve.....289
Heat Protection EGR Shield.....291
EGR Inlet Tubes.....291
Heat Protection (Cylinders 4-6) Shield.....292
EGR Module Cover.....293
EGR Outlet Tubes.....293
EGR Cooler Bracket.....294
Coolant Elbow.....294
Coolant Manifold.....295

Special Torque.....296

Special Service Tools.....296

Exploded Views

EGR Coolant Manifold and Elbow

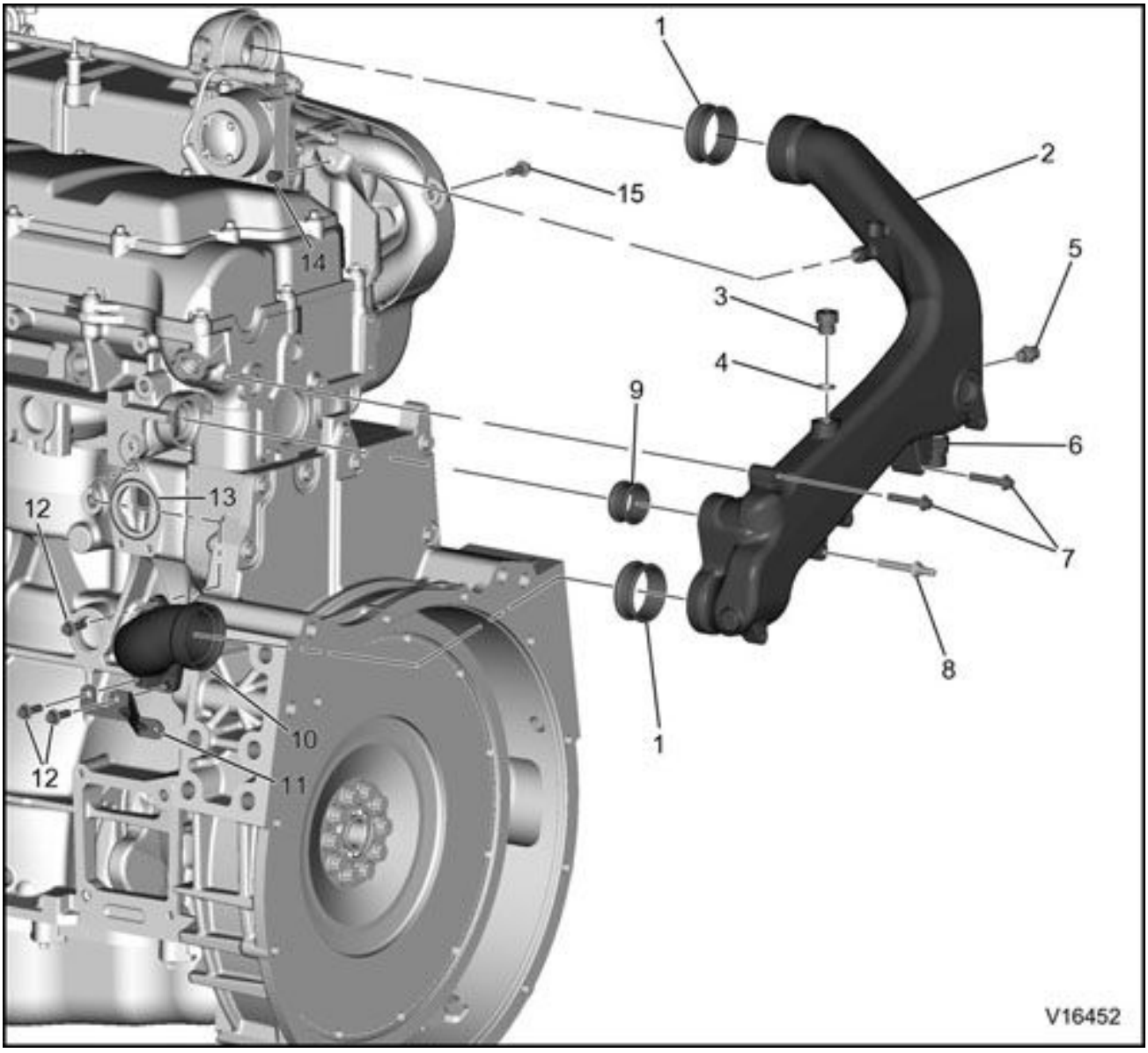


Figure 366 EGR coolant manifold and elbow

1. Extension tube (DMR62 x 51) (2)
2. Coolant manifold
3. M18 O-ring boss plug
4. Seal
5. Coolant supply fitting (to hydrocarbon injector)
6. Engine Coolant Temperature (ECT1) sensor
7. M8 x 45 bolt (2)
8. M8 x 50 x 16 stud bolt
9. Extension tube (DMR44 x 35)
10. Coolant elbow
11. Hydrocarbon injector fuel supply (tube) bracket
12. M8 x 25 bolt (3)
13. 60 x 3 O-ring
14. M8 x 18 bolt
15. M8 x 25 heat-resistant bolt

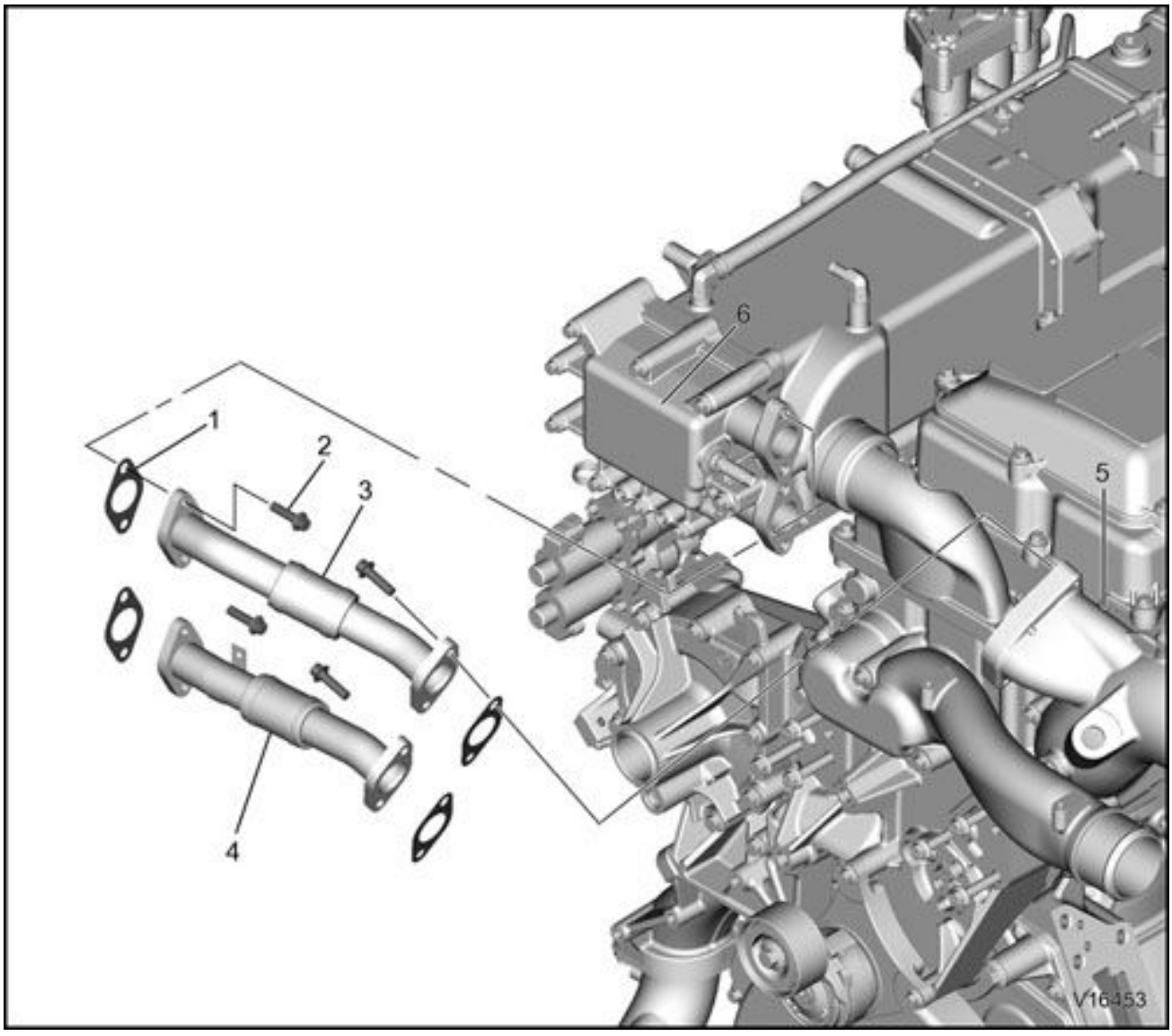


Figure 367 EGR outlet tubes (cylinders 1-3 and cylinders 4-6)

1. EGR outlet gasket (4)
2. M8 x 30 bolt (8)
3. EGR outlet (cylinders 1-3) tube
4. EGR outlet (cylinders 4-6) tube
5. Air intake throttle duct (horizontal)
6. EGR module cover

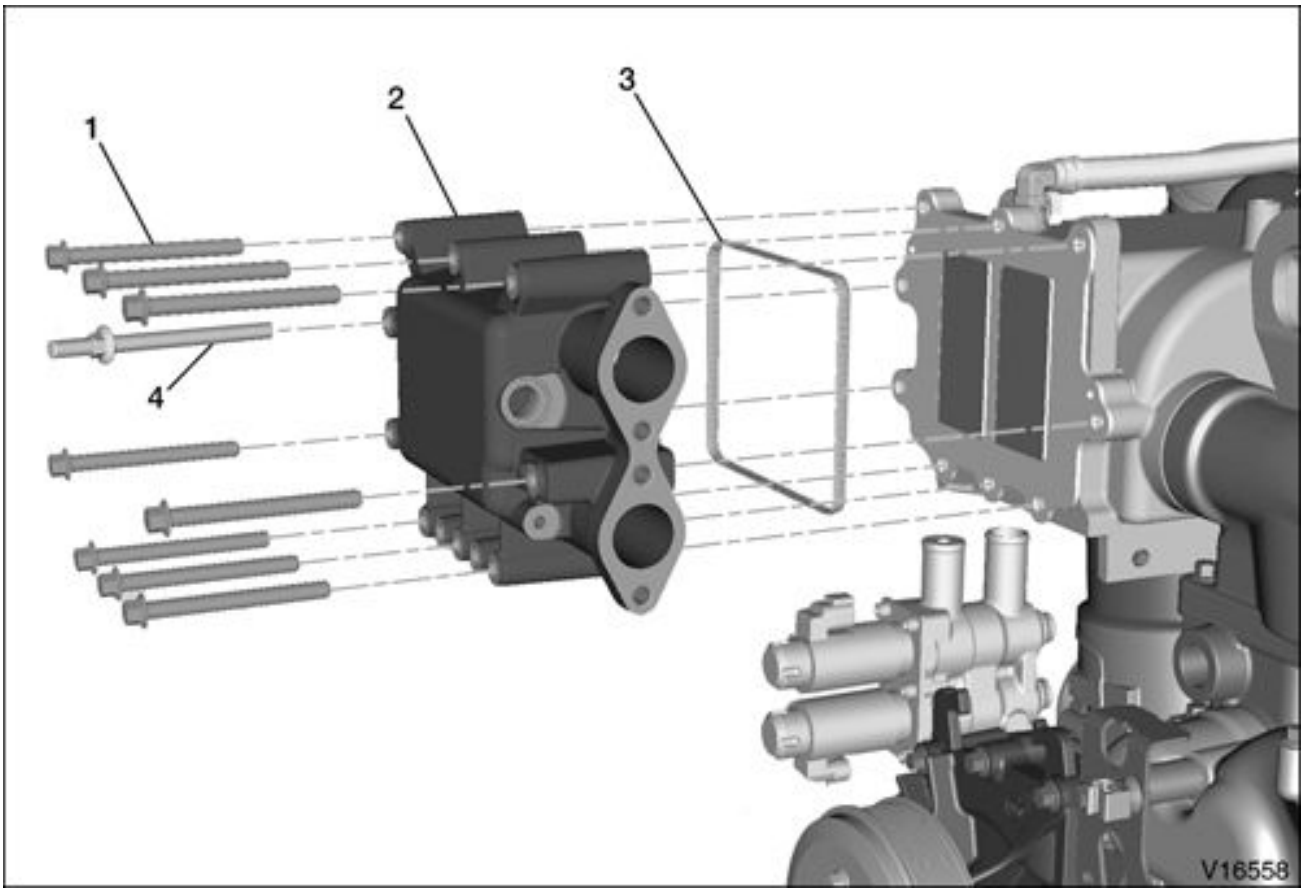


Figure 368 EGR module cover

1. M8 x 85 bolt (9)
2. EGR module cover
3. EGR cover outlet seal
4. M8 x 90 stud bolt

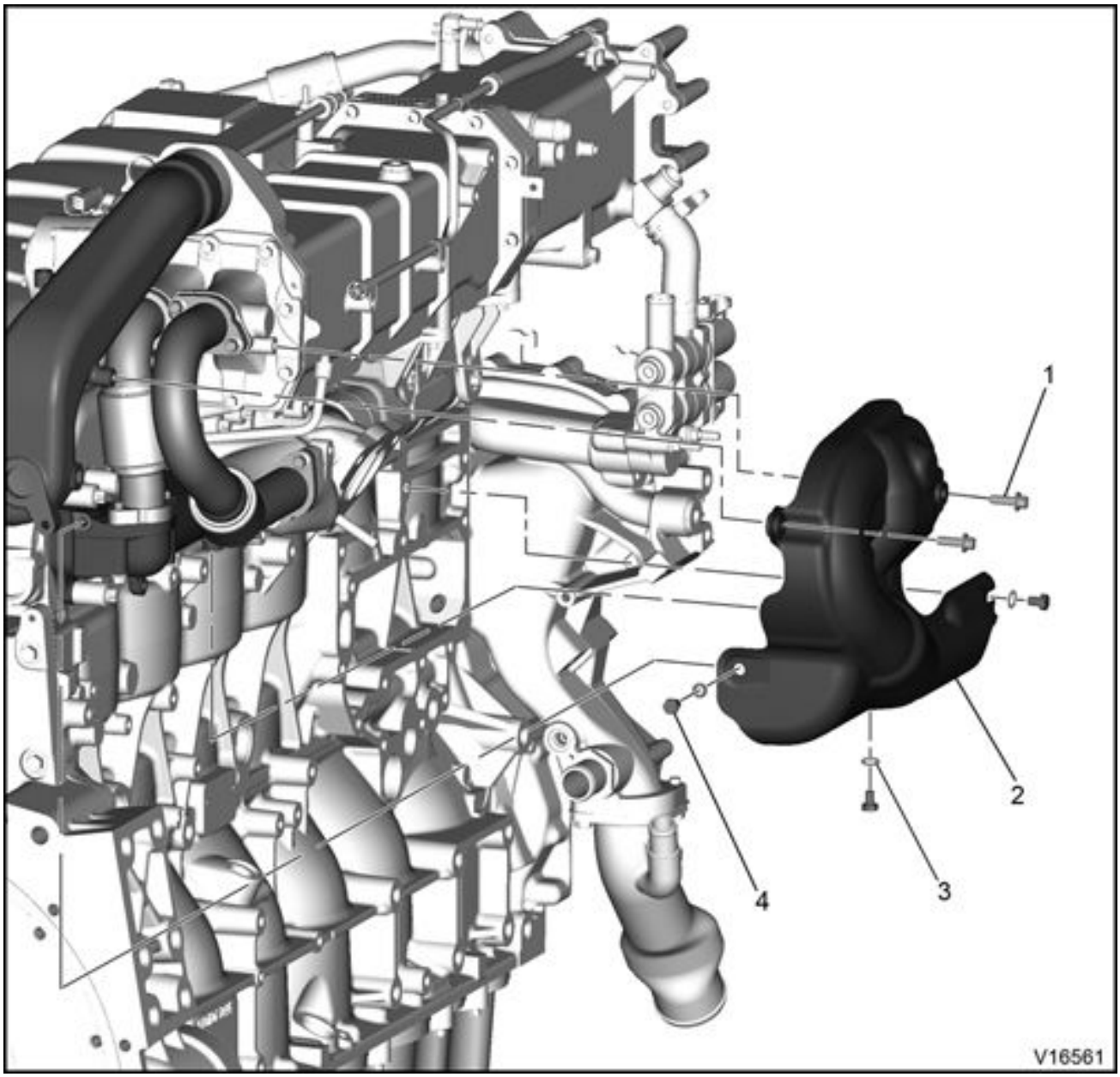


Figure 369 EGR inlet tube heat protection shield

1. M8 x 25 heat-resistant bolt (2)
2. Heat protection (cylinders 4-6) shield
3. 8.4 x 16 x 1.6 washer (3)
4. M8 x 12 bolt (3)

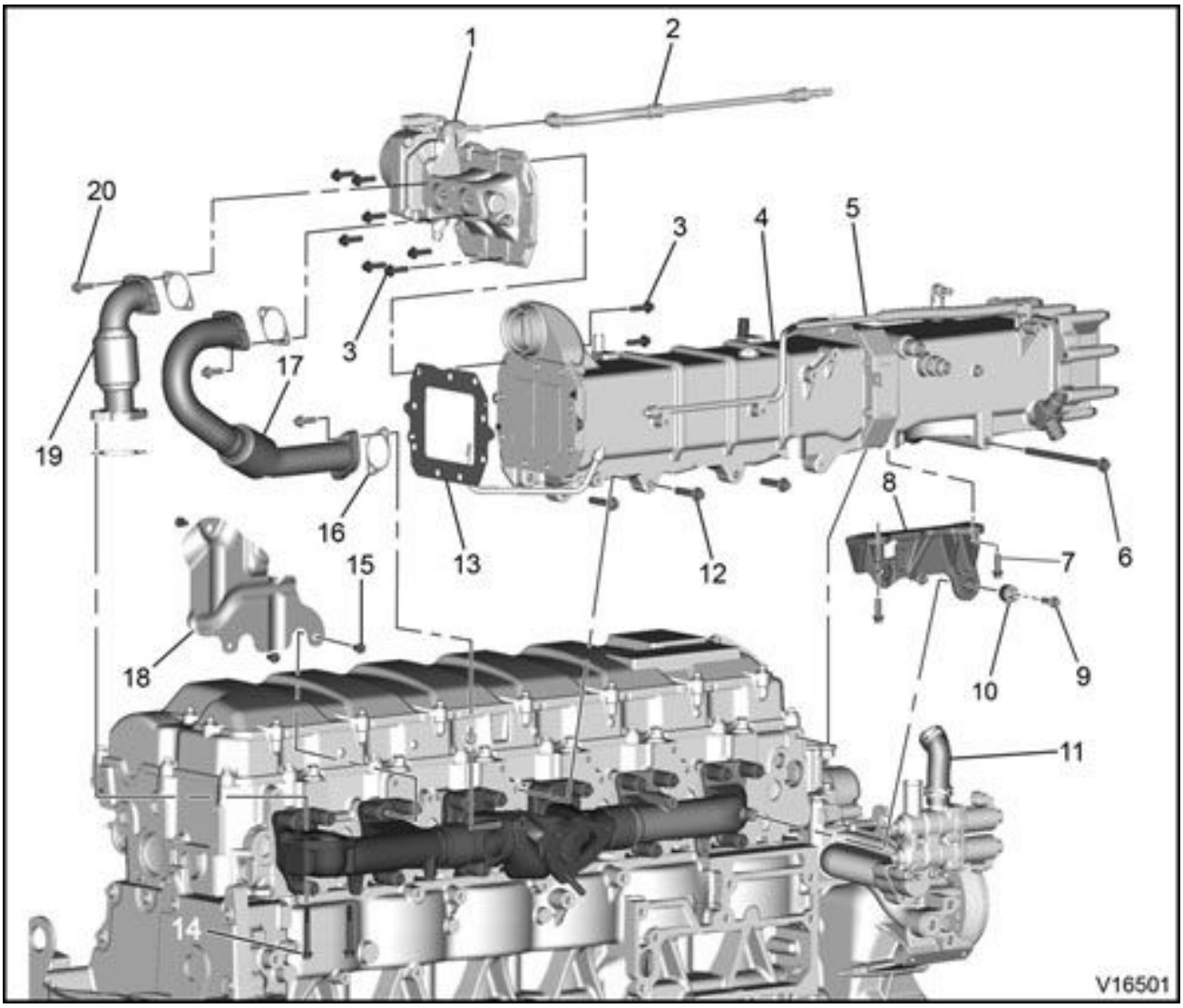


Figure 370 EGR system components

1. EGR dual flap valve
2. EGR valve coolant return tube assembly
3. M8 x 30 heat-resistant bolt (9)
4. EGR cooler assembly
5. EGR valve coolant supply tube assembly
6. M10 x 170 bolt
7. M8 x 25 heat-resistant bolt (2)
8. EGR cooler bracket
9. M8 x 25 heat-resistant bolt (2)
10. Spacer
11. Low-temperature EGR hose assembly
12. M10 x 45 bolt (6)
13. EGR dual flap valve gasket
14. M8 x 65 heat-resistant bolt (2)
15. M8 x 12 bolt (3)
16. Tube EGR gasket (4)
17. Inlet EGR (cylinders 1-3) tube
18. Heat protection EGR shield
19. Inlet EGR (cylinders 4-6) tube
20. M8 x 25 heat-resistant bolt (6)

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

- Engine Electrical
- Front Cover, Fan Drive, Cooling System and Related Components
- Turbochargers
- Oil Cooler, Filter Housing and Crankcase Ventilation

Coolant Manifold

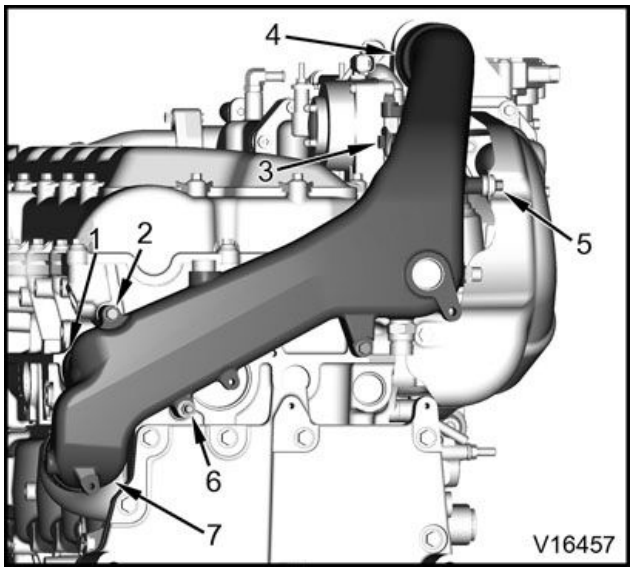


Figure 371 Coolant manifold

1. Extension tube (DMR44 x 35)
2. M8 x 45 bolt (2)
3. M8 x 12 bolt
4. Extension tube (DMR62 x 51)
5. M8 x 25 heat-resistant bolt
6. M8 x 50 x 16 stud bolt
7. Extension tube (DMR62 x 51)

1. Remove M8 x 12 bolt securing heat protection EGR shield to coolant manifold.
2. Remove heat protection (cylinders 4-6) shield M8 x 25 heat-resistant bolt.
3. Remove two M8 x 45 bolts, one M8 x 50 x 16 stud bolt and coolant manifold.

CAUTION: To prevent engine damage, do not remove extension tubes by grabbing sealing surface.

4. Remove two DMR62 x 51 and one DMR44 x 35 extension tubes. Pry the tubes out using a wood or plastic hammer handle or similar tool. Inspect extension tube sealing surfaces for damage. Replace as needed.

Coolant Elbow

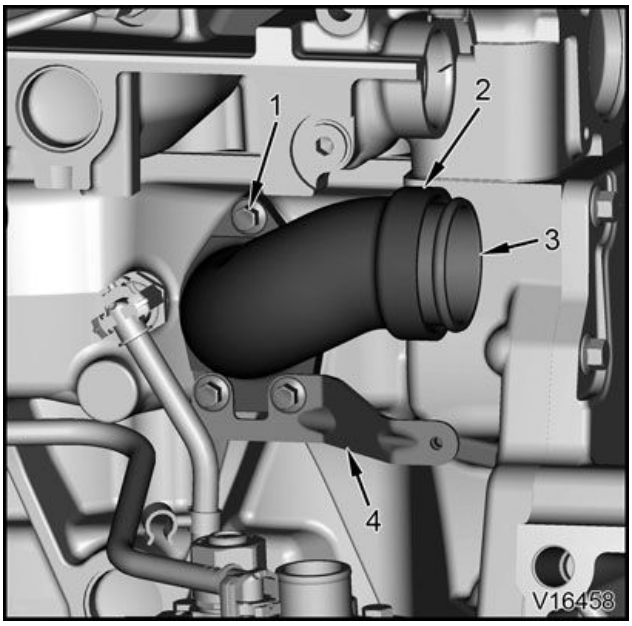


Figure 372 Coolant elbow

1. M8 x 25 bolt (3)
2. Coolant elbow
3. Extension tube (DMR62 x 51)
4. Hydrocarbon injector fuel supply (tube) bracket

CAUTION: To prevent engine damage, do not remove extension tubes by grabbing sealing surface.

1. Remove DMR62 x 51 extension tube from coolant elbow. Pry the tubes out using a wood or plastic hammer handle or similar tool. Inspect extension tube sealing surfaces for damage. Replace as needed.
2. Remove two lower M8 x 25 bolts and hydrocarbon injector fuel supply (tube) bracket.
3. Remove upper M8 x 25 bolt and coolant elbow. Remove and discard 60 x 3 O-ring.

EGR Cooler Bracket

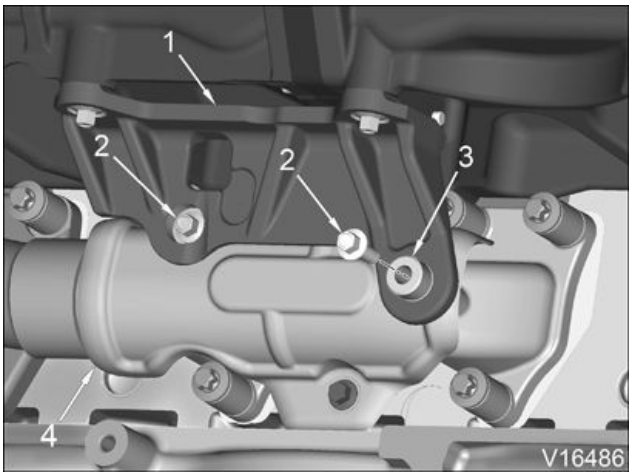


Figure 373 EGR cooler bracket

1. EGR cooler bracket
2. M8 x 25 heat-resistant bolt (2)
3. Spacer
4. Heat protection shield (at front exhaust manifold)

1. Remove and discard two M8 x 25 heat-resistant bolts that secure the EGR cooler bracket to front exhaust manifold.
2. Remove spacer.
3. Leave cooler bracket attached to EGR cooler.

EGR Outlet Tubes

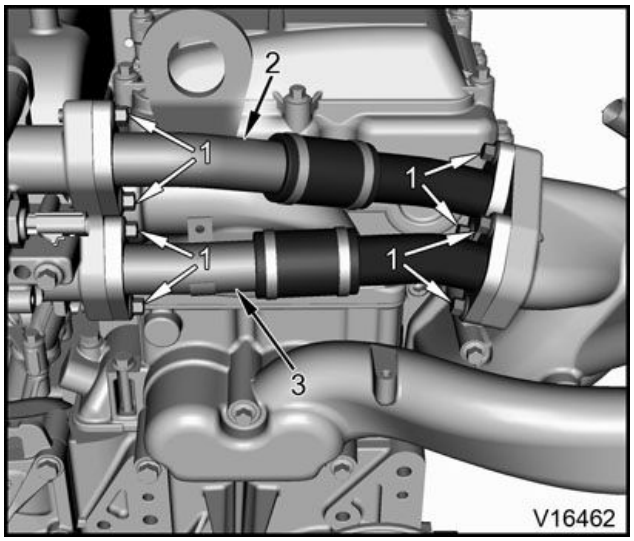


Figure 374 EGR outlet tubes

1. M8 x 30 bolt (8)
2. EGR outlet (cylinders 1-3) tube
3. EGR outlet (cylinders 4-6) tube

1. Remove four M8 x 30 bolts securing the EGR outlet (cylinders 4-6) tube.
2. Remove EGR outlet (cylinders 4-6) tube and discard tube gaskets.
3. Remove four M8 x 30 bolts securing the EGR outlet (cylinders 1-3) tube.
4. Remove EGR outlet (cylinders 1-3) tube and discard tube gaskets.

EGR Module Cover

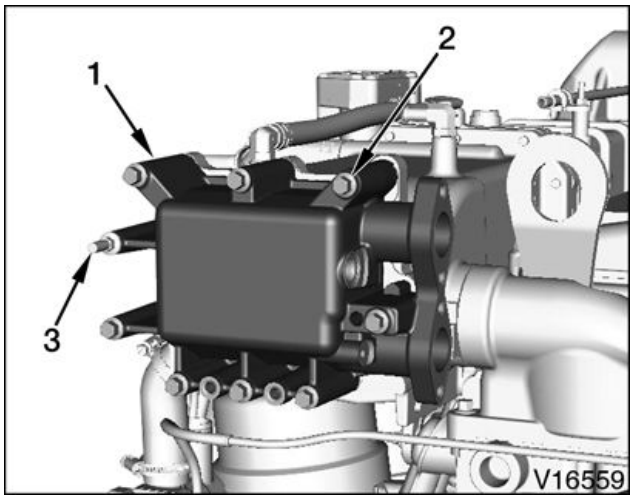


Figure 375 Front of EGR module

1. EGR module cover
2. M8 x 85 bolt (8)
3. M8 x 90 stud bolt

1. Remove eight M8 x 85 bolts and one M8 x 90 stud bolt. Remove EGR module cover.

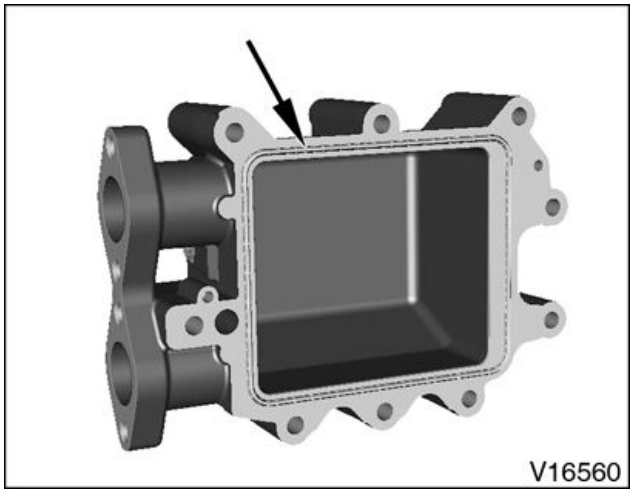


Figure 376 EGR cover outlet seal

2. Remove EGR cover outlet seal from EGR module cover. Save seal for installation.

Heat Protection (Cylinders 4-6) Shield

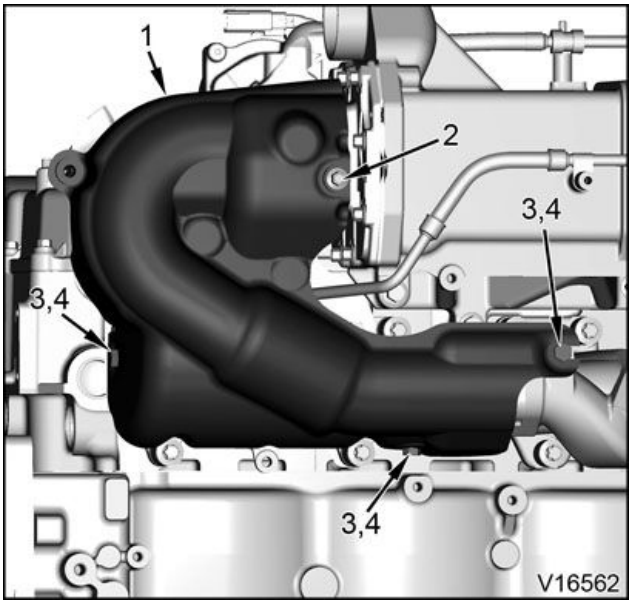


Figure 377 Heat protection (cylinders 4-6) shield

1. Heat protection (cylinders 4-6) shield
2. M8 x 25 heat-resistant bolt
3. M8 x 12 bolt (3)
4. 8.4 x 16 x 1.6 washer (3)

1. Remove M8 x 25 heat-resistant bolt.
2. Remove three M8 x 12 bolts, and three 8.4 x 16 x 1.6 washers. Remove heat protection shield.

EGR Inlet Tubes

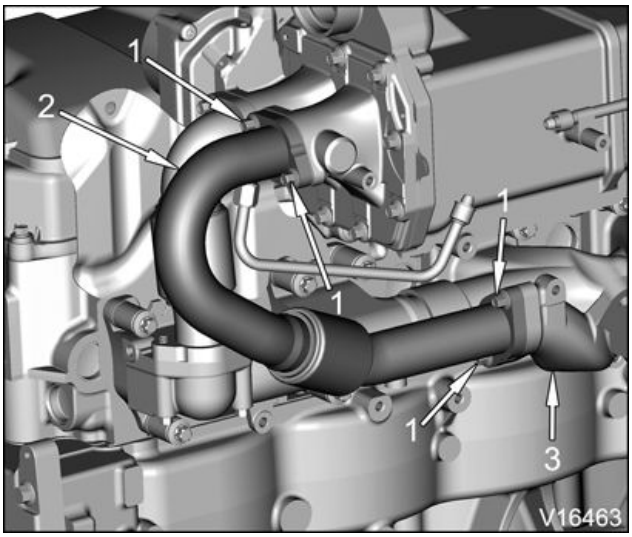


Figure 378 EGR inlet (cylinders 1-3) tube

1. M8 x 25 heat-resistant bolt (4)
2. EGR inlet (cylinders 1-3) tube
3. Middle exhaust manifold

1. Remove four M8 x 25 heat-resistant bolts.
2. Remove EGR inlet tube (cylinders 1-3) and two gaskets. Discard gaskets.

CAUTION: To prevent engine damage, cover opening in the rear manifold to prevent dirt, debris, and objects from entering rear manifold.

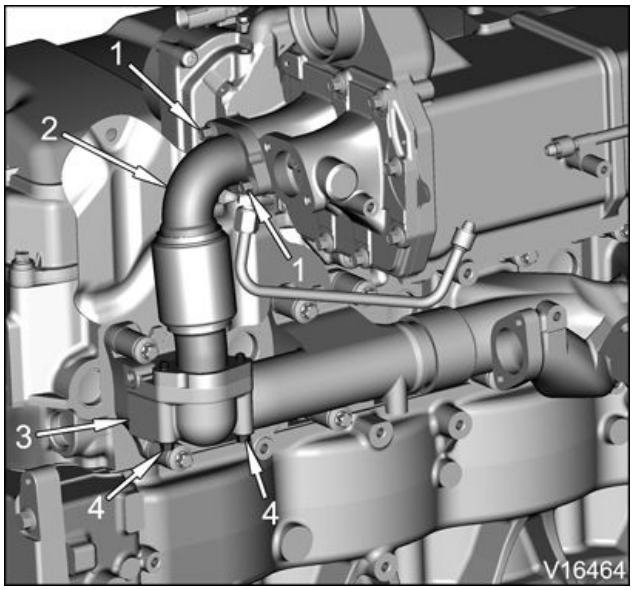


Figure 379 EGR inlet (cylinders 4-6) tube

1. M8 x 25 heat-resistant bolt (2)
2. EGR inlet (cylinders 4-6) tube
3. Rear exhaust manifold
4. M8 x 65 heat-resistant bolt (2)

3. Remove two M8 x 25 heat-resistant bolts.
4. Remove two M8 x 65 heat-resistant bolts.
5. Remove EGR inlet (cylinders 4-6) tube and two tube gaskets. Discard gaskets.

CAUTION: To prevent engine damage, cover opening in the rear manifold to prevent dirt, debris, and objects from entering rear manifold.

Heat Protection EGR Shield

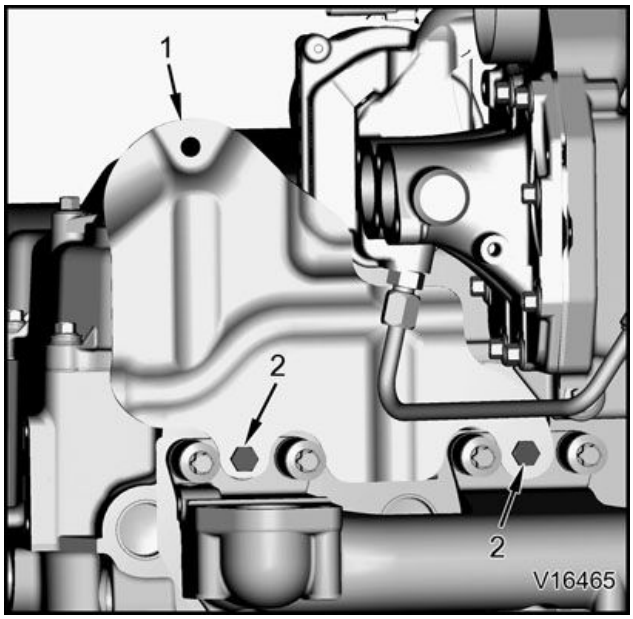


Figure 380 Heat protection EGR shield

1. Heat protection EGR shield
2. M8 x 12 bolt (2)

1. Remove two M8 x 12 bolts at rear exhaust manifold.
2. Remove heat protection EGR shield.

EGR Dual Flap Valve

NOTE: If removing complete EGR cooler assembly for disassembly of engine, removal of EGR dual flap valve is not required.

NOTE: The EGR dual flap valve can be removed as an in-vehicle service.

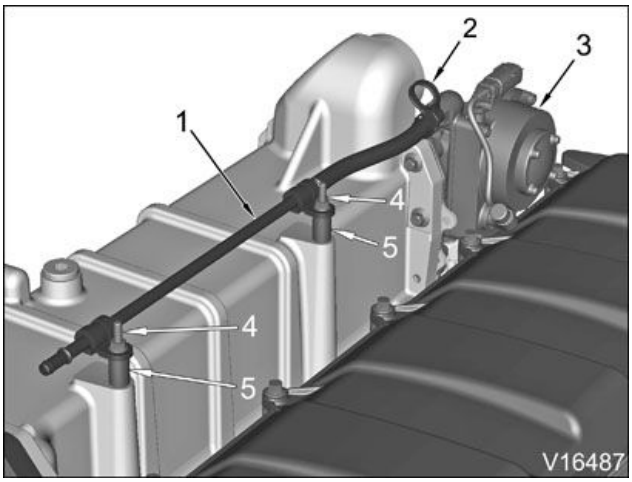


Figure 381 EGR valve coolant return tube assembly and EGR dual flap valve

1. EGR valve coolant return tube assembly
2. Spring clamp
3. EGR dual flap valve
4. M6 x 45 x 15 stud (2)
5. 6 x 15 x 23 spacer (2)

NOTE: Drain coolant from EGR cooler assembly before removal.

1. Remove two M6 x 45 x 15 stud bolts and two 6 x 15 x 23 spacers.
2. Disconnect coolant return tube spring clamp and EGR valve coolant return tube assembly from EGR dual flap valve.

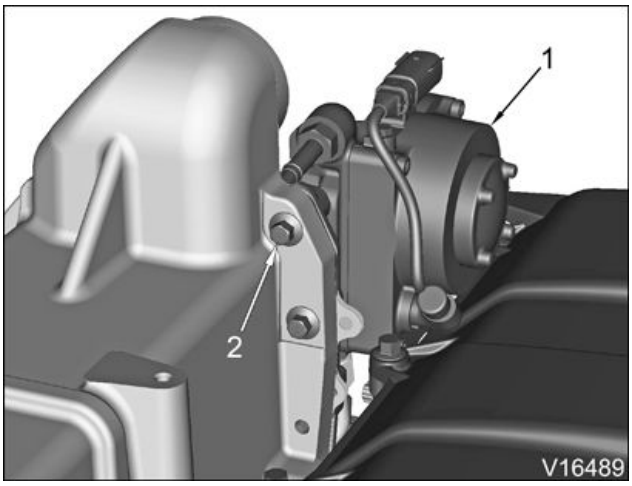


Figure 382 EGR dual flap valve and rear mounting bolts

1. EGR dual flap valve
2. M8 x 30 heat-resistant bolt (2)

3. Remove and discard two M8 x 30 heat-resistant bolts.

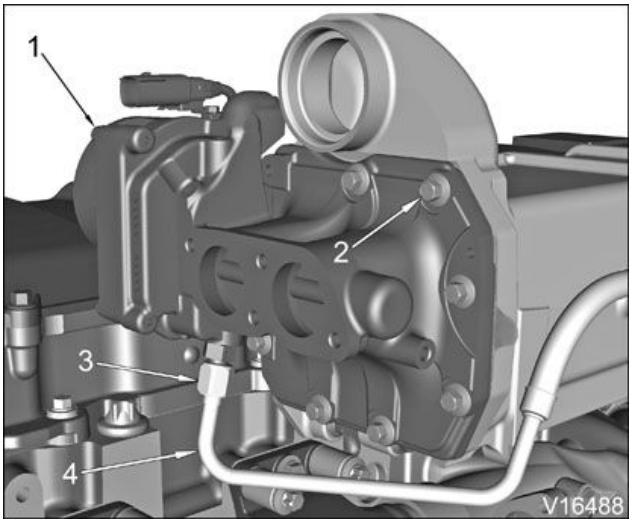


Figure 383 EGR dual flap valve, front mounting bolts, and EGR valve coolant supply tube assembly

1. EGR dual flap valve
2. M8 x 30 heat-resistant bolt (7)
3. EGR valve coolant supply tube nut
4. EGR valve coolant supply tube assembly

4. Loosen tube nut and disconnect EGR dual flap valve coolant supply tube from bottom of EGR dual flap valve.
5. Remove and discard seven M8 x 30 heat-resistant bolts.
6. Remove EGR dual flap valve.
7. Remove and discard EGR dual flap valve gasket.

EGR Cooler Assembly

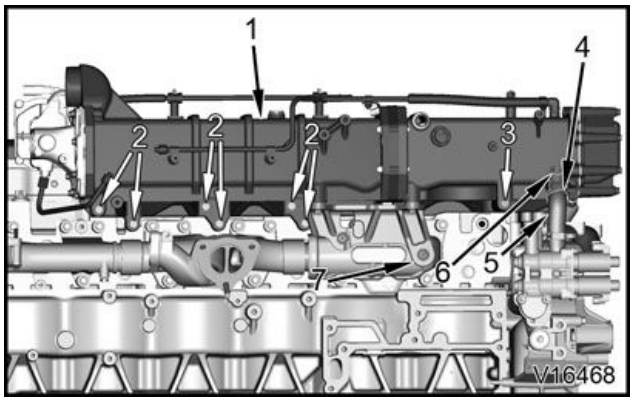


Figure 384 EGR cooler assembly

1. EGR cooler assembly
2. M10 x 45 bolt (6)
3. M10 x 170 bolt
4. Spring clamp
5. Low-temperature EGR hose assembly
6. Y-fitting (to deaeration port hoses)
7. EGR cooler bracket

1. Disconnect low-temperature EGR hose assembly spring clamp and hose from EGR cooler assembly.
2. Remove six M10 x 45 bolts, one M10 x 170 bolt and EGR cooler assembly.

Disassembly and Assembly of EGR Cooler

EGR Cooler High-Temperature or Low-Temperature Side Replacement

1. Obtain EGR Cooler Alignment Tool (page 296) .

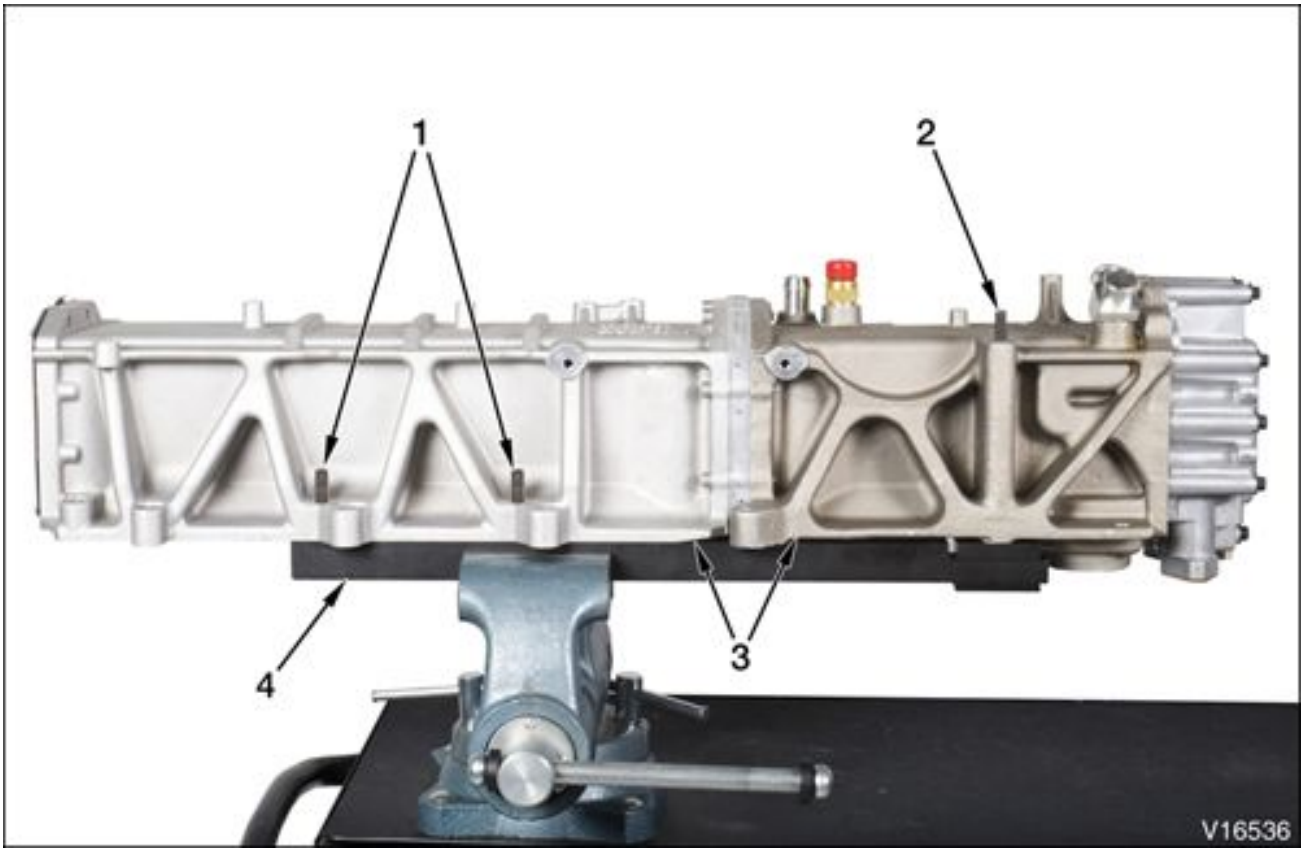


Figure 385 EGR cooler assembly

1. High-Temperature (HT) EGR cooler mounting stud
2. Low-Temperature (LT) EGR cooler mounting stud
3. Notch in tool
4. EGR Cooler Alignment Tool

2. Install EGR Cooler Alignment Tool into a suitable bench vise
3. Install the EGR cooler assembly onto the EGR Cooler Alignment Tool with two shorter mounting studs through High-Temperature (HT) EGR cooler and longer mounting stud through Low-Temperature (LT) EGR cooler.

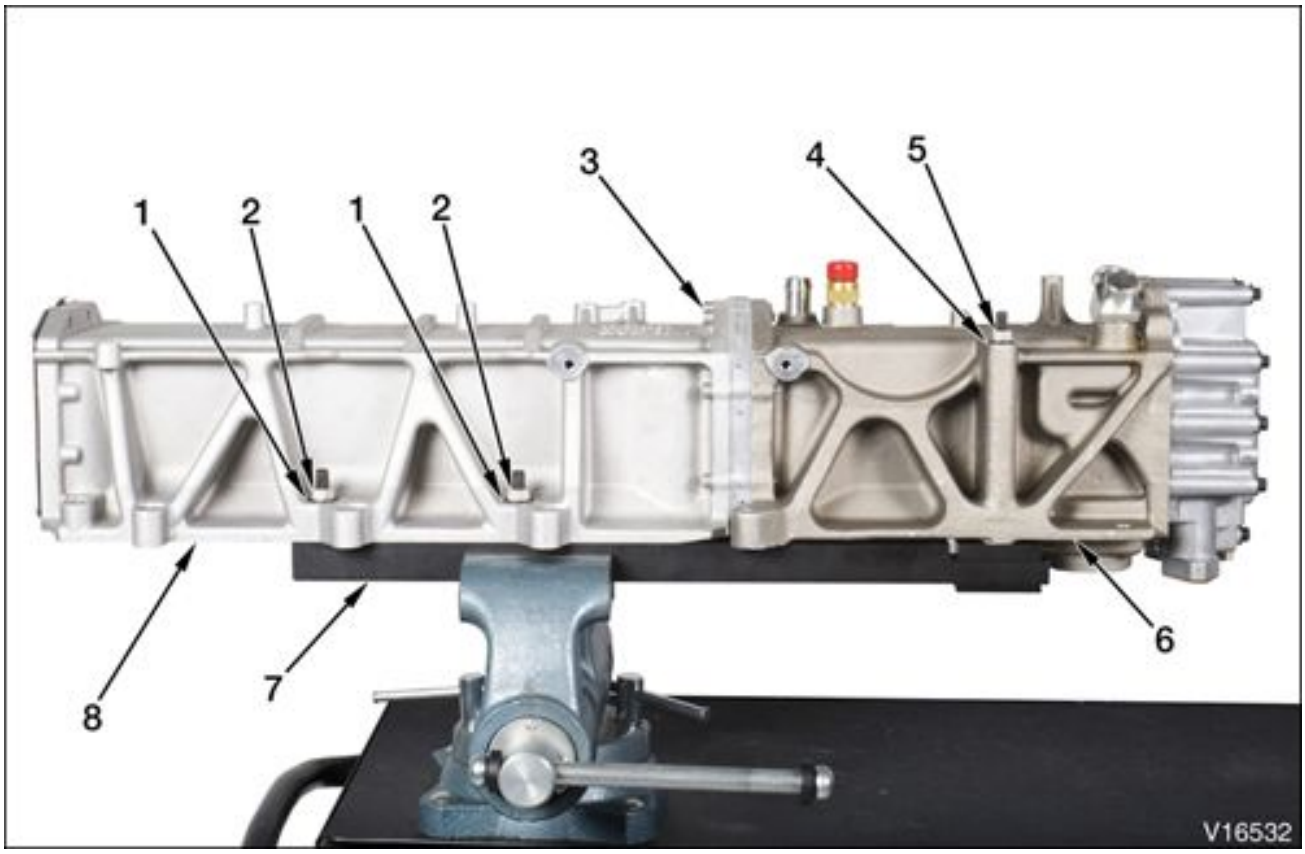


Figure 386 EGR cooler assembly

1. 1. 7/16 SAE flat washer
2. 7/16-14 nut
3. M8 x 50 hex socket screw (9)
4. 3/8 SAE flat washer
5. 3/8-16 nut
6. LT EGR cooler
7. EGR Cooler Alignment Tool
8. HT EGR cooler

4. Install two 7/16 SAE flat washers and two 7/16-14 nuts onto two HT EGR cooler mounting studs of the EGR Cooler Alignment Tool. Tighten nuts to special torque (page 296).
5. Install 3/8 SAE flat washer and 3/8-16 nut onto LT EGR mounting stud of the EGR Cooler Alignment Tool. Tighten nuts to special torque (page 296).
6. Remove nine M8 x 50 hex socket screws. Discard screws.

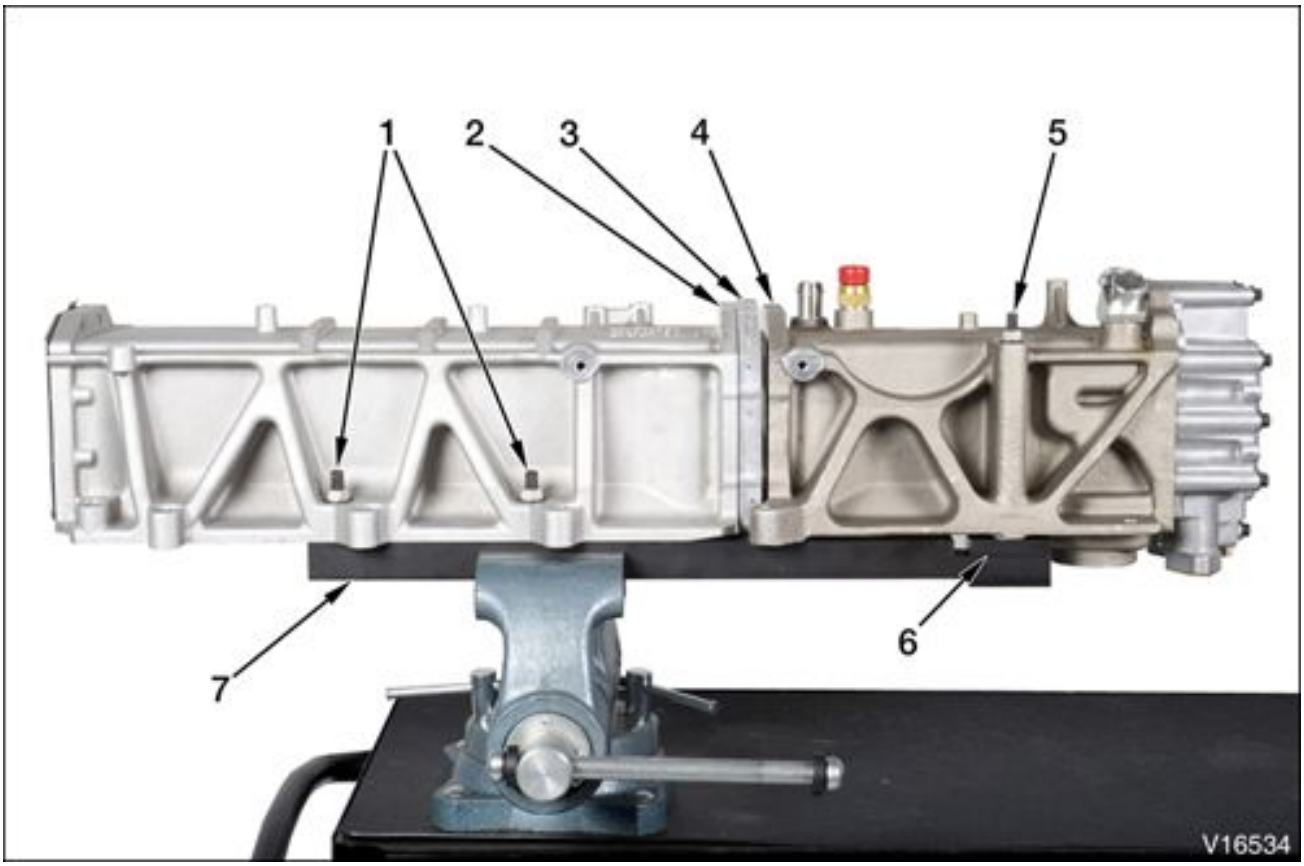


Figure 387 EGR cooler assembly

1. HT EGR cooler mounting stud
2. HT EGR cooler
3. LT EGR cooler
4. 3/8 SAE flat washer
5. LT EGR cooler mounting stud
6. Slider
7. EGR Cooler Alignment Tool

NOTE: Do not remove the mid-plate from the HT EGR cooler. Disturbing the sealing surfaces could cause a leak.

WARNING: To prevent personal injury or death, be sure bench vise is clamped sufficiently to keep EGR Alignment Tool and EGR Cooler Assembly from falling.

7. Separate LT EGR cooler from mid-plate along the slider of EGR Cooler Alignment Tool.
8. Remove the two 7/16-14 nuts, and two 7/16 SAE flat washers, or the 3/8-16 nut and 3/8 SAE flat washer (Figure 386) from mounting stud(s) through the cooler half to be replaced.
9. Loosen but do not remove fasteners on mounding stud(s) on the other cooler half.
10. Remove the cooler half to be replaced from EGR Cooler Alignment Tool.

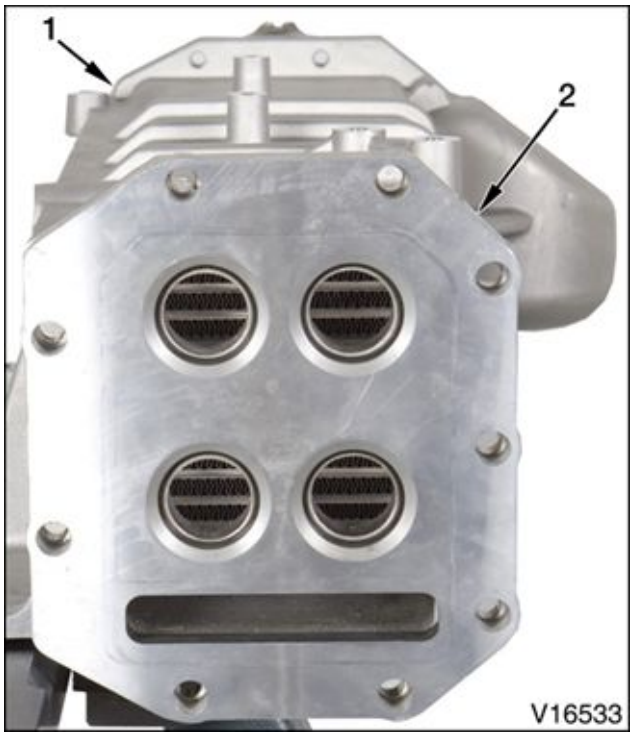


Figure 388 HT EGR cooler and mid-plate

1. HT EGR cooler
2. Mid-plate

11. Clean mating surfaces on HT EGR Cooler and LT EGR Cooler of any debris and contaminants.
12. Install replacement cooler half over the appropriate mounting stud(s) of EGR Cooler Alignment Tool.
13. Install the two 7/16-14 nuts and two 7/16 SAE flat washers, or the 3/8-16 nut and 3/8 SAE flat washer (Figure 386) to mounting studs (Figure 387). Tighten nut(s) finger tight.

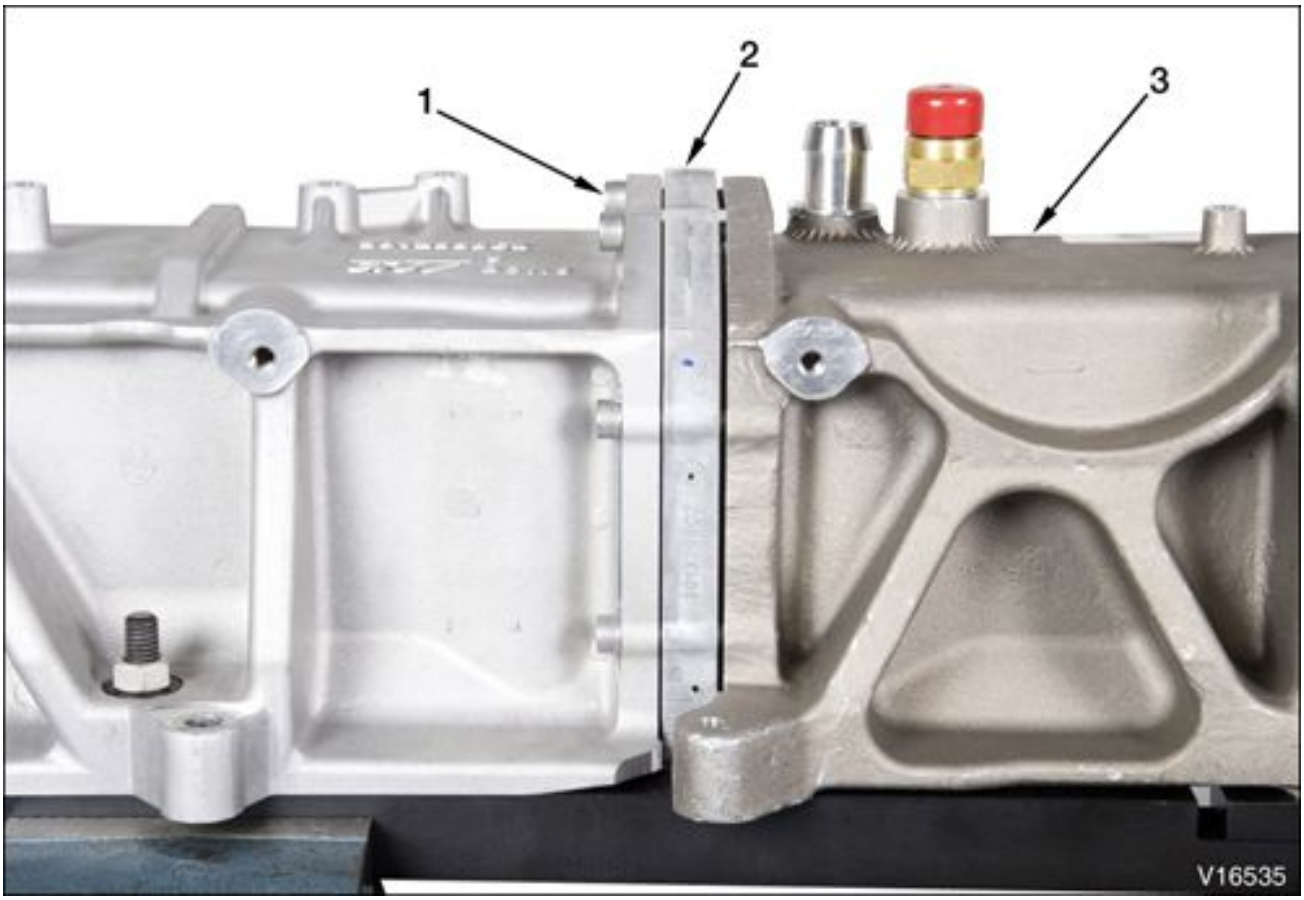


Figure 389 Center of EGR cooler assembly

1. 1. M8 x 50 hex cap screw (9)
2. Mid-plate
3. LT EGR cooler

14. Slide the LT EGR cooler along the EGR Cooler Alignment Tool slider (Figure 387) until the LT EGR cooler seal contacts flush with the mid-plate surface.

NOTE: Be sure any EGR cooler assembly brackets are installed during assembly of HT EGR cooler and LT EGR cooler.

15. Install EGR cooler assembly bracket(s) and nine new M8 x 50 hex socket screws. Tighten screws finger tight.
16. Tighten two 7/16-14 nuts (Figure 386) on HT EGR cooler mounting studs to special torque (page 296).
17. Tighten 3/8-16 nut (Figure 386) on LT EGR cooler mounting stud to special torque (page 296).

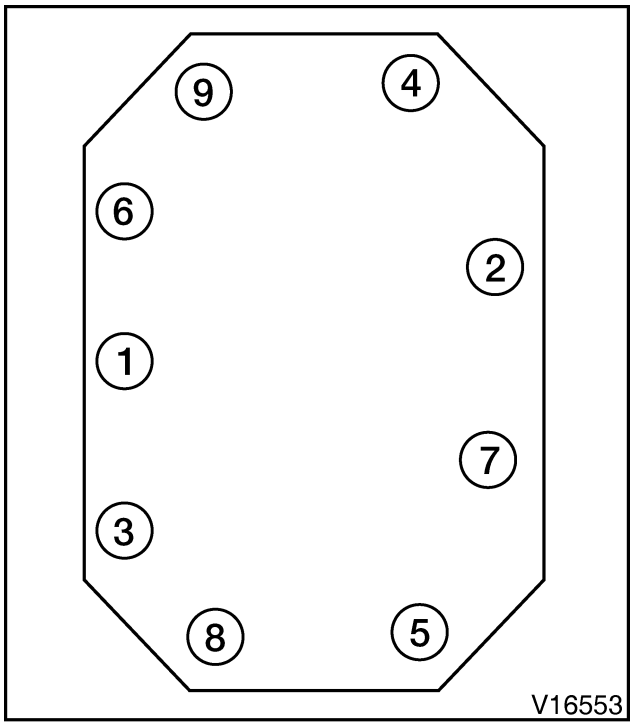


Figure 390 Hex socket screw torque sequence

18. Tighten nine M8 x 50 hex socket screws using the following two step torque sequence:
    A. Tighten M8 x 50 hex socket screws in sequence 1 through 9 to 20 N·m (15 lbf·ft).
    B. Tighten M8 x 50 hex socket screws in sequence 1 through 9 to 31 N·m (23 lbf·ft).
19. Remove two 7/16-14 nuts, two 7/16 SAE flat washers, 3/8-16 nut, and 3/8 SAE flat washer (Figure 386) from mounting studs of EGR Cooler Alignment Tool. Save fasteners.
20. Remove the EGR cooler assembly from the EGR Cooler Alignment Tool.
21. Remove EGR Cooler Alignment Tool from bench vise.
22. Store fasteners with EGR Cooler Alignment Tool for reuse.

Cleaning, Inspection and Testing

EGR System Components Cleaning

1. Using steam, clean all carbon from ends of EGR dual flap valve, coolant manifold and coolant elbow at rear.

CAUTION: To prevent engine damage, do not use steam to clean EGR cooler assembly heat exchanger cores.

2. Using steam, clean EGR cooler coolant return manifold at front. Clean all EGR cooler assembly coolant ports.
3. Inspect EGR system components for cracks and damage. Replace worn or damaged parts.

EGR Cooler Assembly Cleaning

Figure 391 Cleaning Management System 12-353-01 components

1. Timer 12–353–01–1
2. Heater 12–353–01–8
3. FLOW FROM PUMP hose 12–353–01–2
4. Front EGR cooler cleaning adapter 12–353–01–4
5. Cam-lock cap 12–353–01–6
6. Rear EGR cooler cleaning adapter 12–353–01–5
7. FLOW RETURN hose 12–353–01–3
8. Air blower 12–353–01–7
9. Container 12–353–01–17
10. HEATER / PUMP Switch Assembly 12–353–01–9

1. Make sure container is clean.
2. Inspect and clean the filter sock. Replace as needed.
    a. Loosen coupler on flow return tube
    b. Remove filter from coupler
    c. Install filter in coupler
    d. Tighten coupler on flow return tube. Torque only needs to be hand tight

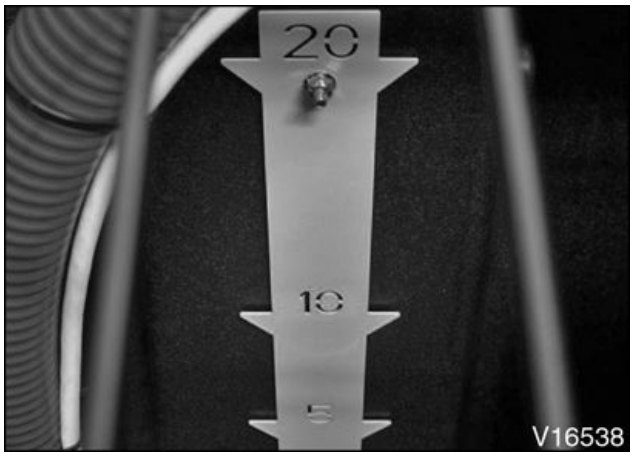


Figure 392 Level gauge

3. Add 5 US gal (19 L) of EGR Cooler Cleaning Solution and 5 US gal (19 L) of tap water to the container.

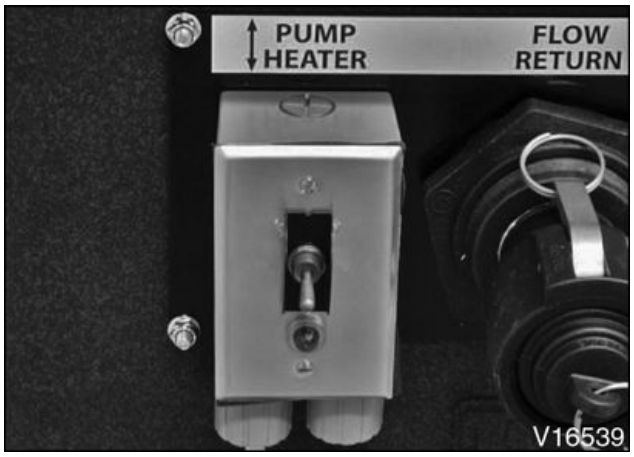


Figure 393 PUMP / HEATER switch

4. Turn on the heating element by simultaneously pulling the HEATER / PUMP Switch Assembly outward and moving to heater position.

NOTE: The heating element has a thermostat that will regulate the temperature. When the amber light on the switch housing goes out, the fluid is up to temperature.

5. Disassemble the truck to gain access to the front and rear of the EGR cooler assembly.
6. Allow engine to cool and use the Coolant Management Tool (page 296) to drain engine coolant to a level below the EGR cooler assembly.
7. Remove coolant manifold from EGR cooler assembly and thermostat housing. See Coolant Manifold (page 268).
8. Remove heat protection (cyclinders 4-6) shield. See Heat Protection (cyclinders 4-6) Shield (page 271)
9. Remove EGR inlet tubes. See EGR Inlet Tubes (page 271)
10. Remove EGR dual flap valve from EGR cooler assembly. See EGR Dual Flap Valve (page 272).
11. Remove EGR outlet (cylinders 4-6) tube, and EGR outlet (cylinders 1-3) tube from EGR cooler assembly and intake throttle duct assembly. See EGR Outlet (cylinders 4-6) Tube, and EGR Outlet (cylinders 1-3) Tube (page 270)
12. Disconnect EGRT sensor electrical connector.
13. Remove EGR module cover from EGR cooler assembly. See EGR Module Cover (page 270).
14. Inspect the O-rings on the front and rear EGR cooler cleaning adapters to be sure there is no damage that would cause a leak.

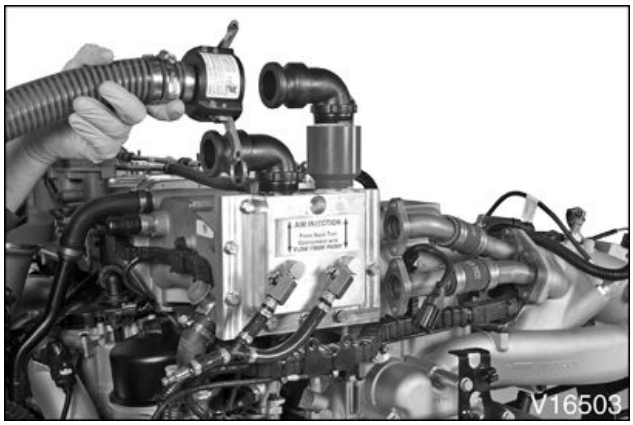


Figure 394 Front EGR cooler cleaning adapter

15. Install the front EGR cooler cleaning adapter. Tighten bolts to special torque (page 296).

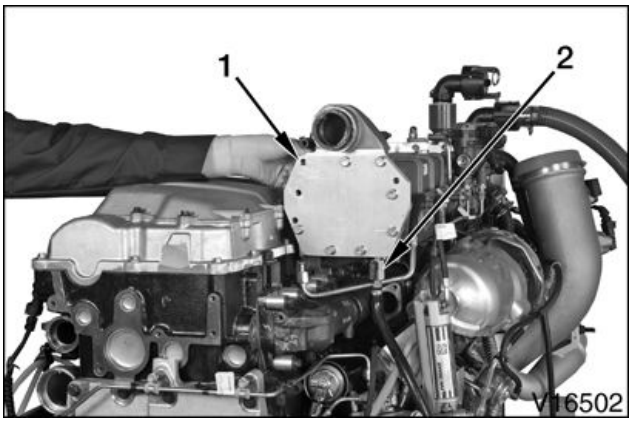


Figure 395 Rear EGR cooler cleaning adapter

1. Rear EGR cooler cleaning adapter
2. Drain valve

16. Install the rear EGR cooler cleaning adapter. Tighten bolts to special torque (page 296).
17. Be sure the drain valve is in the closed position.

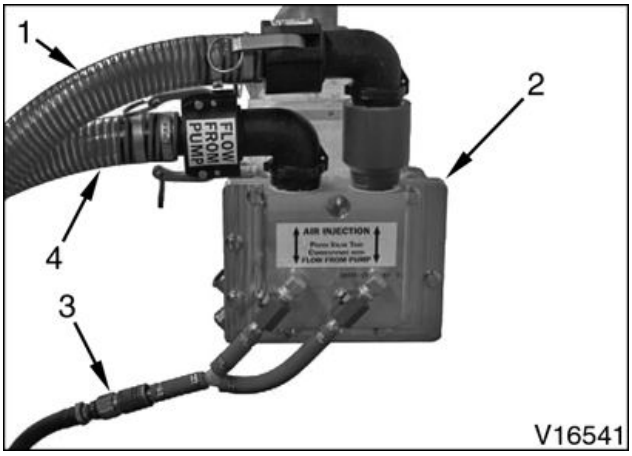


Figure 396 Front of EGR cooler

1. FLOW RETURN hose
2. Front cooler cleaning adapter
3. Air injection fitting
4. FLOW FROM PUMP hose

18. Connect one end of the FLOW FROM PUMP hose to the respective hose connection of the container and the opposite hose end to the front EGR cooler cleaning adapter hose connection.
19. Connect one end of the FLOW RETURN hose to the respective hose connection of the container and the opposite hose end to the remaining front EGR cooler cleaning adapter hose connection.
20. Connect air line to air injection fitting.

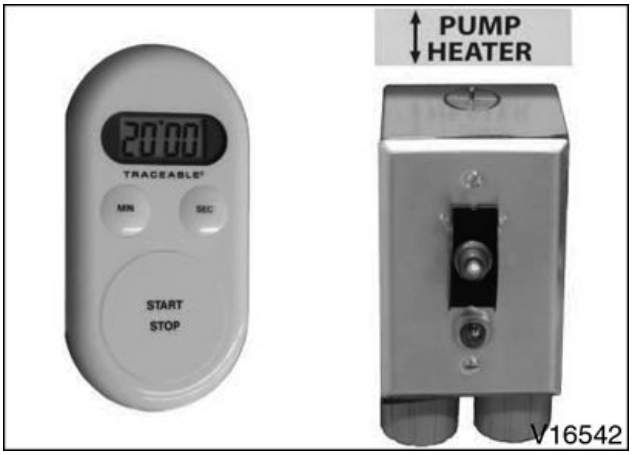


Figure 397 Timer and HEATER/PUMP switch

21. Set the timer for 20 minutes, start timer and turn on pump by moving the HEATER / PUMP switch to PUMP.

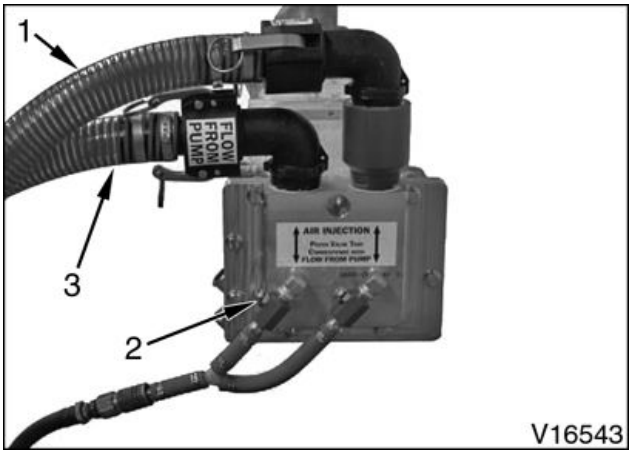


Figure 398 Front of EGR cooler

1. FLOW RETURN hose
2. Front EGR cooler cleaning adapter
3. Air injection button valve

NOTE: Be sure to push only the air injection button valve that corresponds with the FLOW FROM PUMP hose.

22. At the 5, 10, and 15 minute mark, press the air injection button valve on the front EGR cooler

cleaning adaptor to introduce bursts of air at a one second on, two seconds off interval. Be sure to push the air injection button valve that corresponds with the FLOW FROM PUMP hose.

23. After 20 minutes has expired, turn off the pump by moving the PUMP / HEATER switch to the middle position.

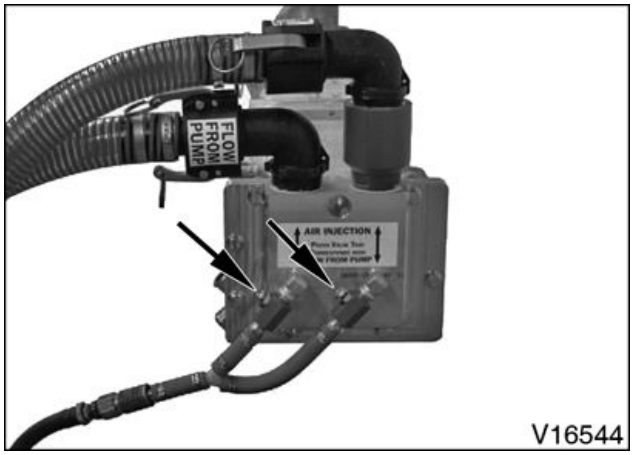


Figure 399 Air injection button valves

24. Press the air injection button valves on both sides independently to purge some of the EGR Cooler Cleaning Solution from the hoses. This will minimize spills when disconnecting the hoses.

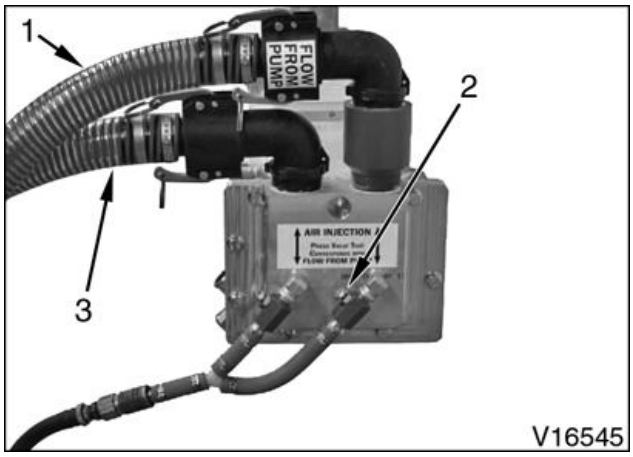


Figure 400 Front of EGR cooler

1. FLOW FROM PUMP hose
2. Air injection button valve
3. FLOW RETURN hose

25. Disconnect and reverse the hose connections at the front EGR cooler cleaning adaptor and repeat steps 21 through 24.

26. Verify pump and heater are switched off. PUMP / HEATER switch should be in the middle position.

Flushing Procedure

Figure 401 Draining used EGR Cooler Cleaning Solution

27. Remove the FLOW RETURN hose from the container and place hose end into a suitable drain or disposal container.

⚠ WARNING: The hose running to the drain will be under pressure. Be sure it is secure before proceeding.

28. Turn on pump by moving the HEATER / PUMP switch to PUMP to remove as much of the used EGR Cooler Cleaning Solution as possible.
29. Turn off pump by moving the HEATER / PUMP switch to the middle position.
30. Remove the FLOW FROM PUMP hose from the container.
31. Using the attached caps, cap each hose connection on the Cleaning Management System.
32. Clean the container by spraying it with clean tap water while the unit is tipped onto its front face. Be sure all the EGR Cooler Cleaning Solution is out of the reservoir.

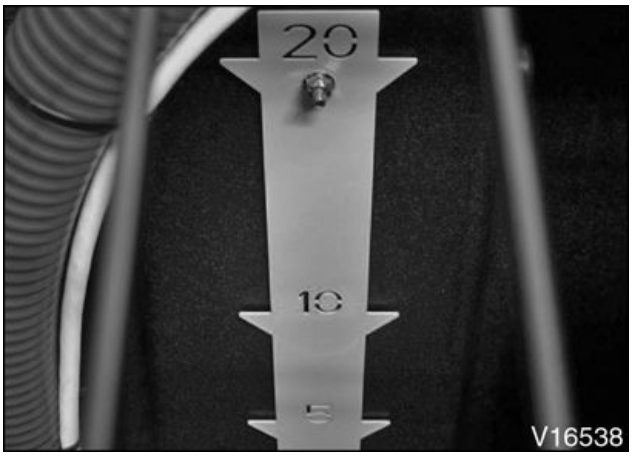


Figure 402 Cleaning Management System volume gauge

33. Fill the container with clean tap water to the 20 gallon mark on the volume gauge.
34. Reconnect the FLOW FROM PUMP hose to the container with the FLOW RETURN hose still in a suitable drain or disposal container.

⚠ WARNING: The hose running to the drain will be under pressure. Be sure it is secure before proceeding.

35. Turn on pump by simultaneously pulling the HEATER / PUMP Switch Assembly outward and moving to PUMP position until all of the clean water has been flushed through the EGR cooler.
36. Turn off pump by moving the HEATER / PUMP switch to the middle position.

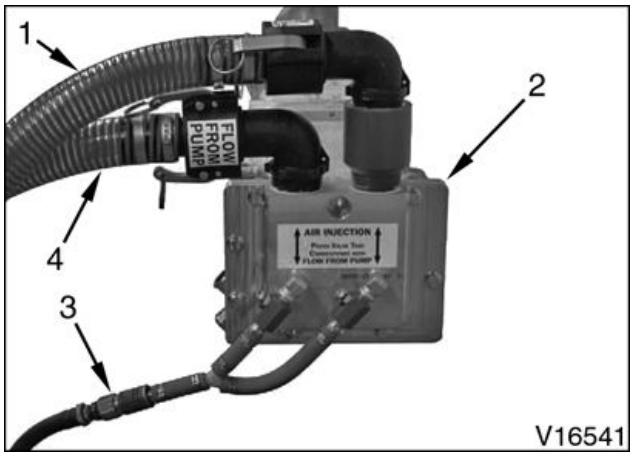


Figure 403 Front of EGR cooler

1. FLOW RETURN hose
2. Front cooler cleaning adapter
3. Air injection fitting
4. FLOW FROM PUMP hose

37. Reverse the FLOW FROM PUMP and FLOW RETURN hoses on the front EGR cooler cleaning adapter
38. Repeat steps 32 through 36.
39. Disconnect the FLOW RETURN hose from the front EGR cooler cleaning adapter.
40. Disconnect the FLOW FROM PUMP hose from the container.

Purging Fluids / Equipment Removal Instructions

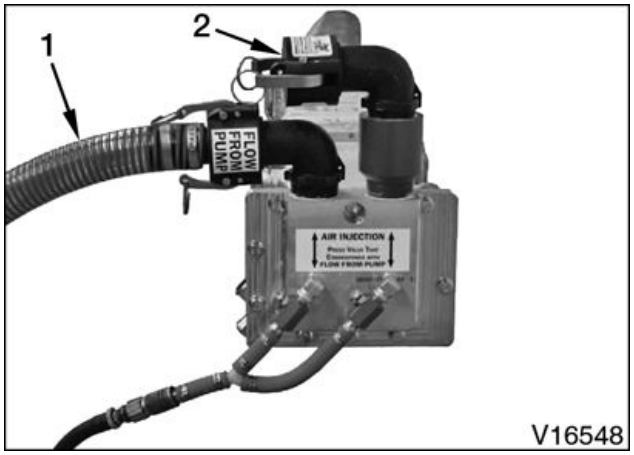


Figure 404 Front of EGR cooler

1. FLOW FROM PUMP hose
2. Cam-lock cap

NOTE: Be sure the cam-lock cap is installed properly to prevent discharge of fluid.

41. Install a cam-lock cap on the open port of the front EGR cooler cleaning adapter.

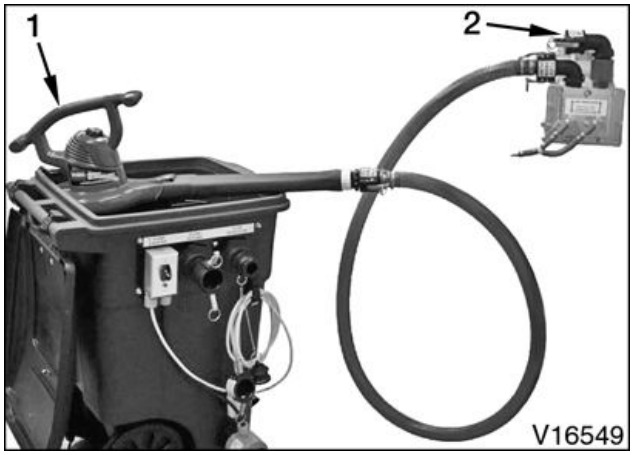


Figure 405 Air blower connection

1. Air blower
2. Cam-lock cap

42. Attach the air blower to the FLOW FROM PUMP hose.

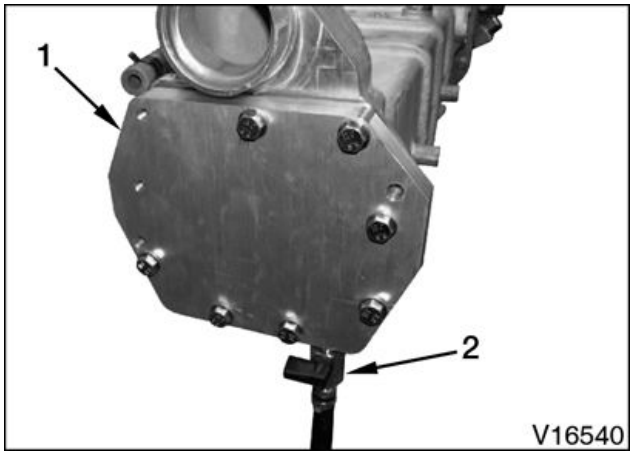


Figure 406 Rear of EGR cooler

1. Rear EGR cooler cleaning adaptor
2. Drain valve

43. Open the drain valve on the rear EGR cooler cleaning adaptor.

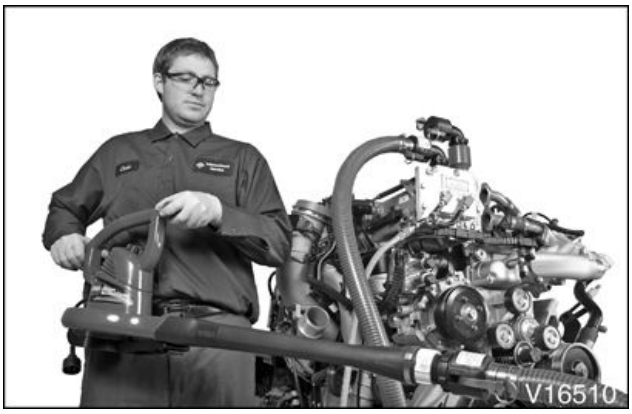


Figure 407

44. Run the blower on maximum power until the water coming out of the drain valve of rear EGR cooler cleaning adapter is at a dripping state.

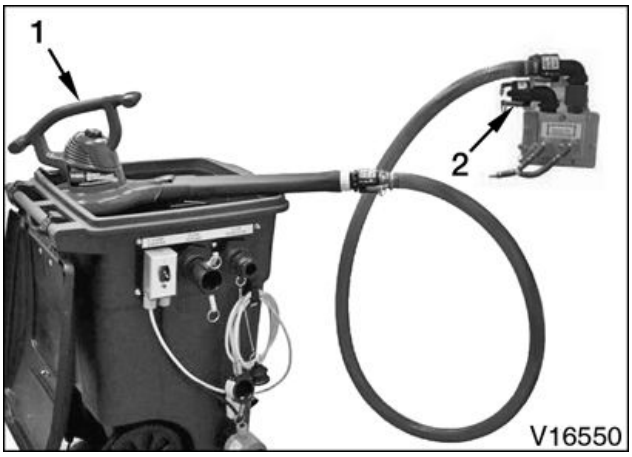


Figure 408

1. Air blower
2. Cam-lock cap

45. Reverse the cam-lock cap and the FLOW FROM PUMP hose and repeat step 44.

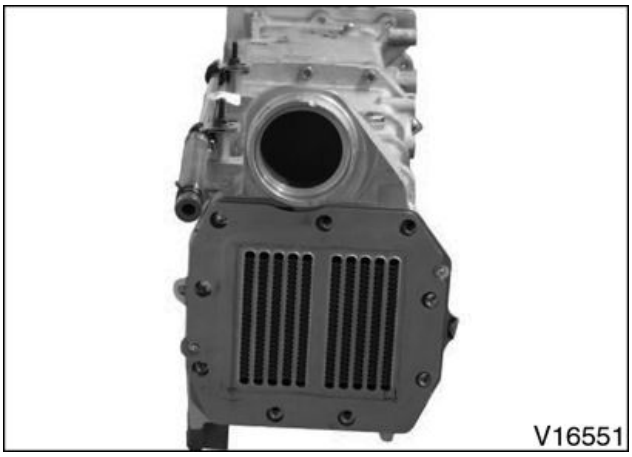


Figure 409 Rear of EGR cooler

NOTE: Protect the inside of the truck from spray coming from the end of the EGR Cooler for the following steps.

46. Remove the rear EGR cooler cleaning adaptor.

47. Run the air blower on maximum power until there is no EGR Cooler Cleaning Solution coming from the rear of the EGR cooler assembly.

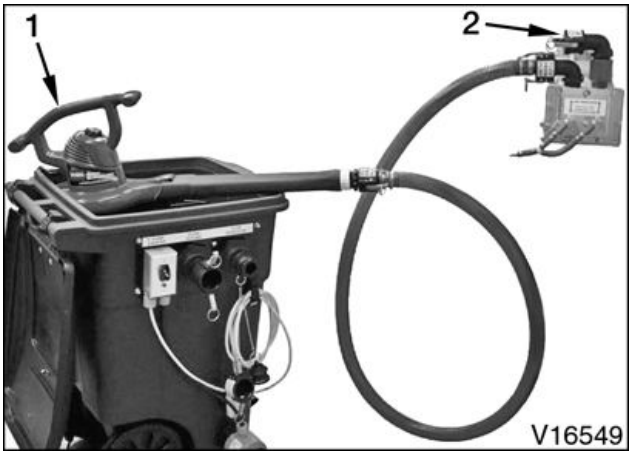


Figure 410

1. Air blower
2. Cam-lock cap

48. Reverse the cam-lock cap and the FLOW FROM PUMP hose on the front EGR cooler cleaning adaptor (Figure 410).

49. Run the air blower on maximum power until there is no EGR Cooler Cleaning Solution coming from the rear of the EGR cooler assembly.
50. The cleaning of the EGR cooler assembly is now complete. Remove the front EGR cooler cleaning adaptor.
51. Install EGR module cover on EGR cooler assembly. See EGR Module Cover (page 293).
52. Connect EGRT sensor electrical connector.
53. Install EGR outlet (cylinders 4-6) tube, and EGR outlet (cylinders 1-3) tube (page 293) to EGR cooler assembly and intake throttle duct assembly.
54. Check EGR outlet tube hose clamps for looseness. Tighten tube hose clamps to special torque (page 296).
55. Install EGR dual flap valve on EGR cooler assembly. See EGR Dual Flap Valve (page 289).
56. Install EGR inlet tubes. See EGR Inlet Tubes (page 291).
57. Install heat protection (cyclinders 4-6) shield. See Heat Protection (cyclinders 4-6) Shield (page 292).
58. Install coolant manifold to EGR cooler assembly and thermostat housing. See Coolant Manifold (page 295).

EGR Cooler Assembly Leak Test

1. Obtain Exhaust Gas Recirculation (EGR) Cooler Leak Detection Tool (page 296).
2. Follow the directions included with the tool to determine if the EGR cooler assembly has any leaks.
3. If any leaks are found, replace the defective part of the EGR cooler assembly. See EGR Cooler High-Temperature or Low-Temperature Side Replacement (page 275).

Installation

EGR Cooler Assembly

NOTE: Install or connect exterior components to the EGR cooler as necessary. When installing a replacement EGR cooler assembly, transfer necessary components from the cooler being replaced.

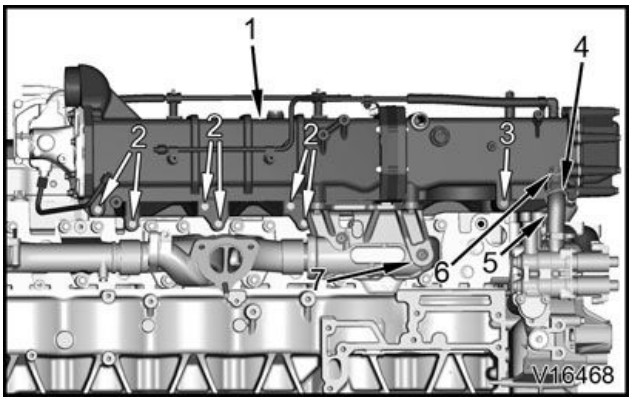


Figure 411 EGR cooler assembly

1. EGR cooler assembly
2. M10 x 45 bolt (6)
3. M10 x 170 bolt
4. Spring clamp
5. Low-temperature EGR hose assembly

1. Install EGR cooler assembly, six M10 x 45 bolts and M10 x 170 bolt. Tighten bolts to special torque (page 296).
2. Connect low-temperature EGR hose assembly to EGR cooler assembly. Position and install spring clamp to secure hose.

EGR Dual Flap Valve

NOTE: Complete this procedure only if the EGR dual flap valve was removed from EGR cooler assembly.

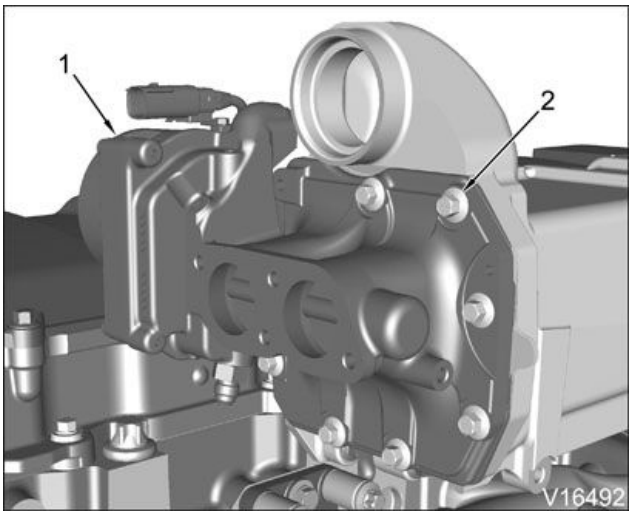


Figure 412 EGR dual flap valve

1. EGR dual flap valve
2. M8 x 30 heat-resistant bolt (7)

1. Install a new gasket.
2. Position EGR dual flap valve and install seven new M8 x 30 heat-resistant bolts. Tighten bolts finger tight.

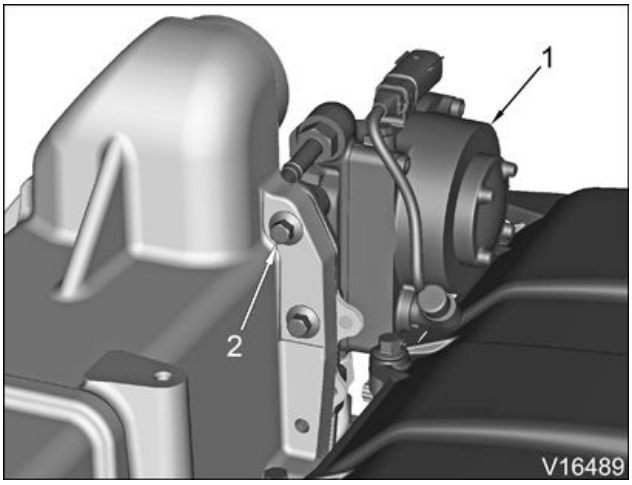


Figure 413 EGR dual flap valve and rear mounting bolts

1. EGR dual flap valve
2. M8 x 30 heat-resistant bolt (2)

3. Install two new M8 x 30 heat-resistant bolts. Tighten bolts finger tight.

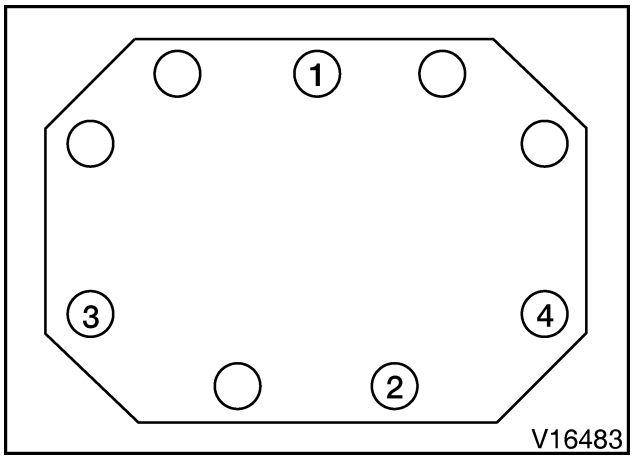


Figure 414 EGR dual flap valve bolt torque sequence (step 1)

4. Tighten the four new M8 x 30 heat resistant bolts in sequence to 5 N·m (45 lbf·in).

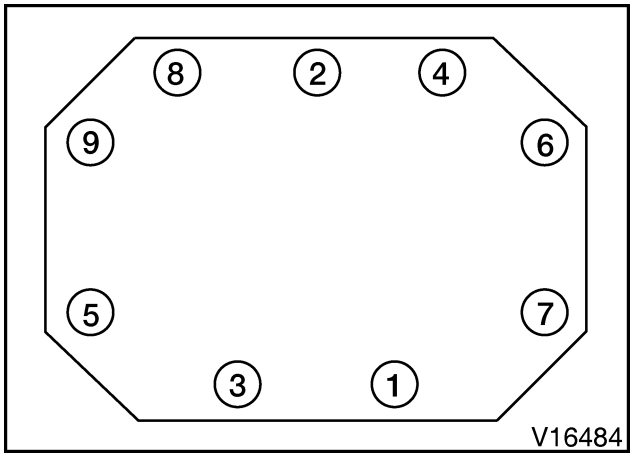


Figure 415 EGR dual flap valve bolt torque sequence (step 2 and 3)

5. Install remaining five new M8 x 30 heat resistant bolts. Tighten nine new M8 x 30 heat resistant bolts in sequence as follows:
   - Tighten bolts to 16 N·m (12 lbf·ft).
   - Tighten bolts to 24 N·m (18 lbf·ft).

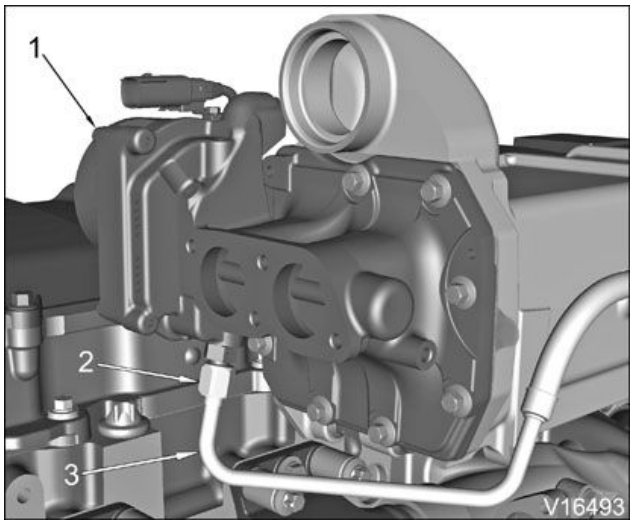


Figure 416 EGR dual flap valve and EGR valve coolant supply tube assembly

1. EGR dual flap valve
2. EGR valve coolant supply tube nut
3. EGR valve coolant supply tube assembly

6. Attach EGR valve coolant supply tube nut to EGR valve and tighten to special torque (page 296).

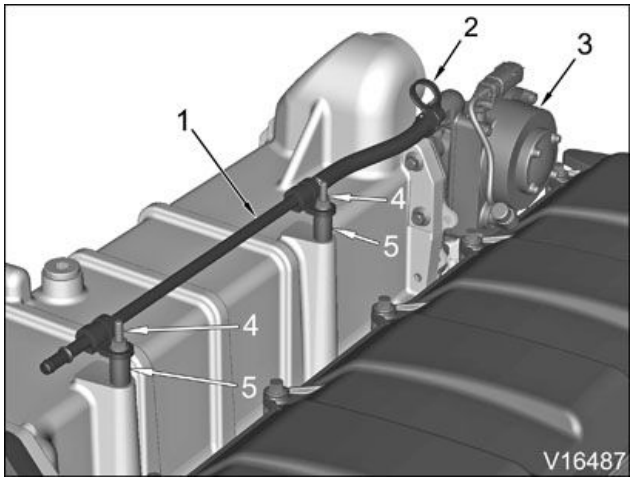


Figure 417 EGR valve coolant return tube assembly and EGR dual flap valve

1. EGR valve coolant return tube assembly
2. Spring clamp
3. EGR dual flap valve
4. M6 x 45 x 15 stud (2)
5. 6 x 15 x 23 spacer (2)

7. Attach EGR valve coolant return tube to EGR valve and secure tube with spring clamp.
8. Install two 6 x 15 x 23 spacers and two M6 x 45 x 15 stud bolts.
9. Tighten M6 x 45 x 15 stud bolts to standard torque (page 503).

Heat Protection EGR Shield

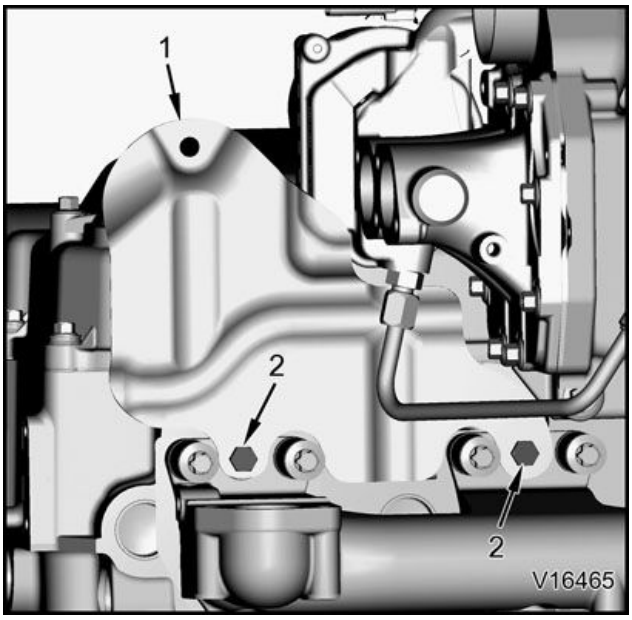


Figure 418 Heat protection EGR shield

1. Heat protection EGR shield
2. M8 x 12 bolt (2)

1. Install heat protection EGR shield and two M8 x 12 bolts at rear exhaust manifold. Tighten bolts to standard torque (page 503).

EGR Inlet Tubes

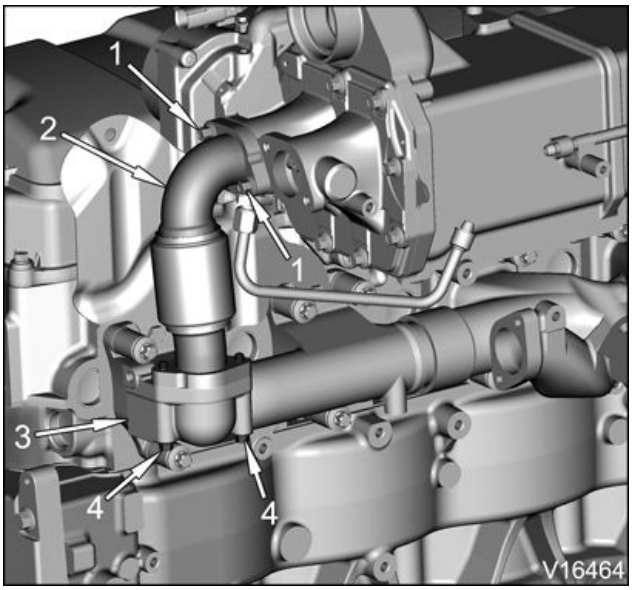


Figure 419 EGR inlet (cylinders 4-6) tube

1. M8 x 25 heat-resistant bolt (2)
2. EGR inlet (cylinders 4-6) tube
3. Rear exhaust manifold
4. M8 x 65 heat-resistant bolt (2)

1. Position two new EGR inlet (cylinders 4-6) tube gaskets, one to EGR valve and one to rear exhaust manifold.
2. Install EGR inlet (cylinders 4-6) tube, two M8 x 25 and two M8 x 65 heat-resistant bolts. Tighten bolts to 16 N·m (12 lbf·ft).

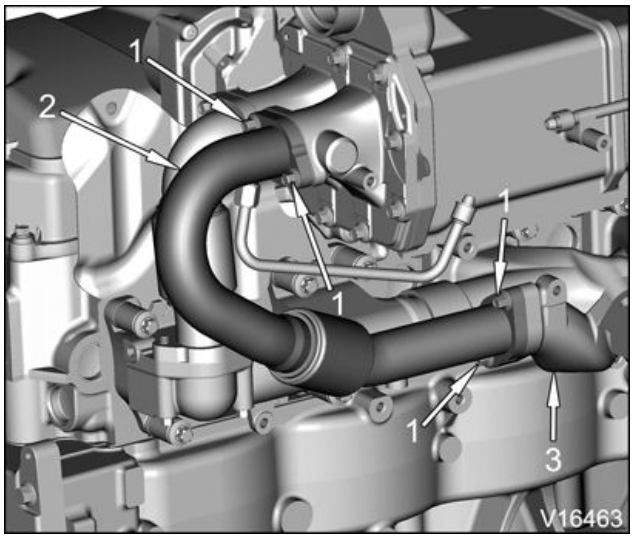


Figure 420 EGR inlet (cylinders 1-3) tube

1. M8 x 25 heat-resistant bolt (4)
2. EGR inlet (cylinders 1-3) tube
3. Middle exhaust manifold

3. Position two new EGR inlet (cylinders 1-3) tube gaskets, one to EGR valve and one to middle exhaust manifold.
4. Install EGR inlet (cylinders 1-3) tube and four M8 x 25 heat-resistant bolts. Tighten bolts to 16 N·m (12 lbf·ft).

EGR Inlet (cylinders 4-6) Tube and EGR Inlet (cylinders 1-3) Tube

5. Tighten eight heat-resistant bolts to 24 N·m (18 lbf·ft).

Heat Protection (Cylinders 4-6) Shield

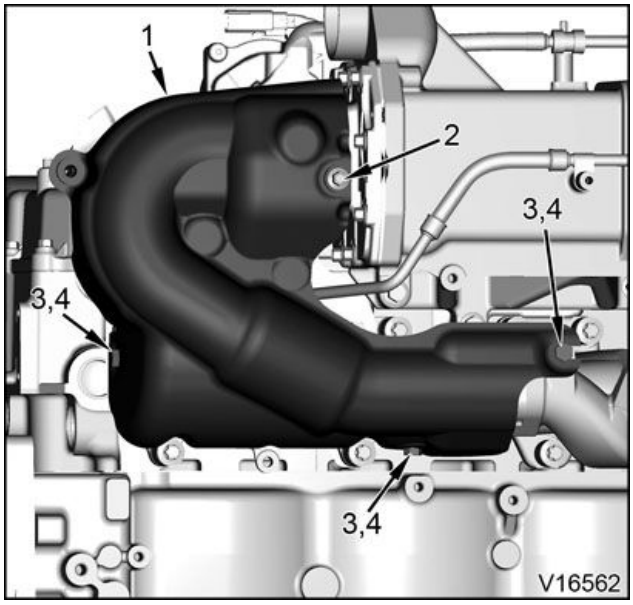


Figure 421 Heat protection (cylinders 4-6) shield

1. Heat protection (cylinders 4-6) shield
2. M8 x 25 heat-resistant bolt
3. M8 x 12 bolt (3)
4. 8.4 x 16 x 1.6 washer (3)

1. Install heat protection shield with three M8 x 12 bolts, and three 8.4 x 16 x 1.6 washers. Tighten bolts finger tight.
2. Install M8 x 25 heat-resistant bolt finger tight.
3. Tighten M8 x 12 bolts, and M8 x 25 heat-resistant bolts to special torque (page 296).

EGR Module Cover

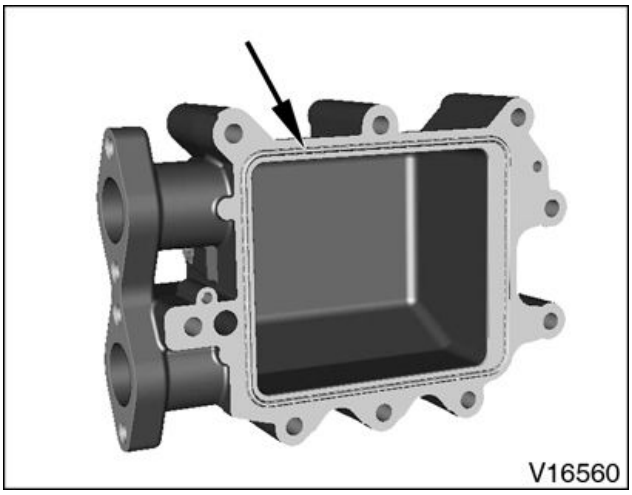


Figure 422 EGR cover outlet seal

1. Install EGR cover outlet seal into EGR module cover.

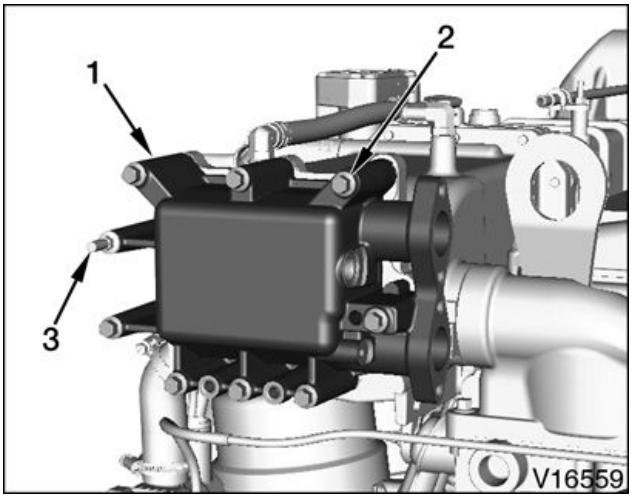


Figure 423 Front of EGR module

1. EGR module cover
2. M8 x 85 bolt (8)
3. M8 x 90 stud bolt

2. Install eight M8 x 85 bolts and one M8 x 90 stud bolt. Tighten bolts in a crisscross pattern to special torque (page 296).

EGR Outlet Tubes

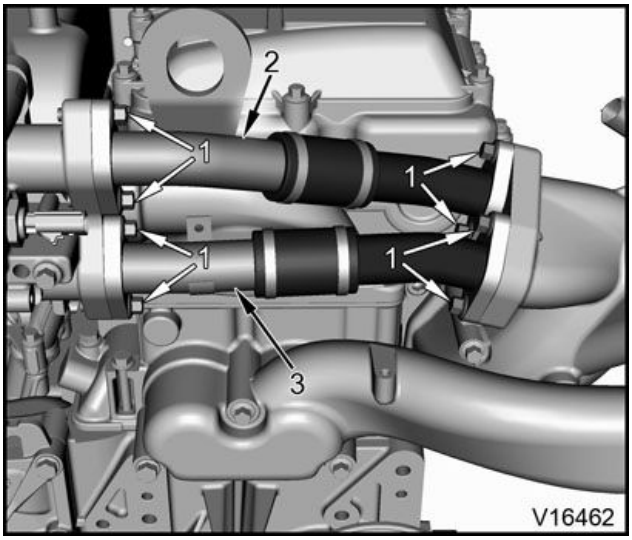


Figure 424 EGR outlet tubes

1. M8 x 30 bolt (8)
2. EGR outlet (cylinders 1-3) tube
3. EGR outlet (cylinders 4-6) tube

1. Install EGR outlet (cylinders 4-6) tube, two new tube gaskets and four M8 x 30 bolts. Tighten bolts to standard torque (page 503).
2. Install EGR outlet (cylinders 1-3) tube, two new tube gaskets and four M8 x 30 bolts. Tighten bolts to standard torque (page 503).
3. Check EGR outlet tube hose clamps for looseness. Tighten tube hose clamps to special torque (page 296).

EGR Cooler Bracket

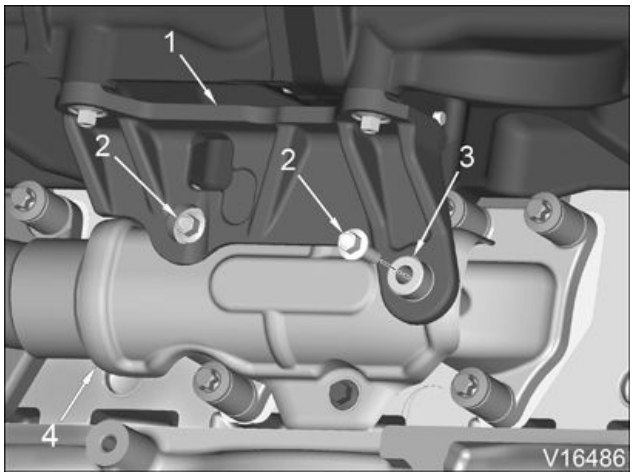


Figure 425 EGR cooler bracket

1. EGR cooler bracket
2. M8 x 25 heat-resistant bolt (2)
3. Spacer
4. Heat protection shield (at front exhaust manifold)

1. Install two EGR cooler bracket M8 x 25 lower heat-resistant bolts.
2. Tighten bolts to standard torque (page 503).

Coolant Elbow

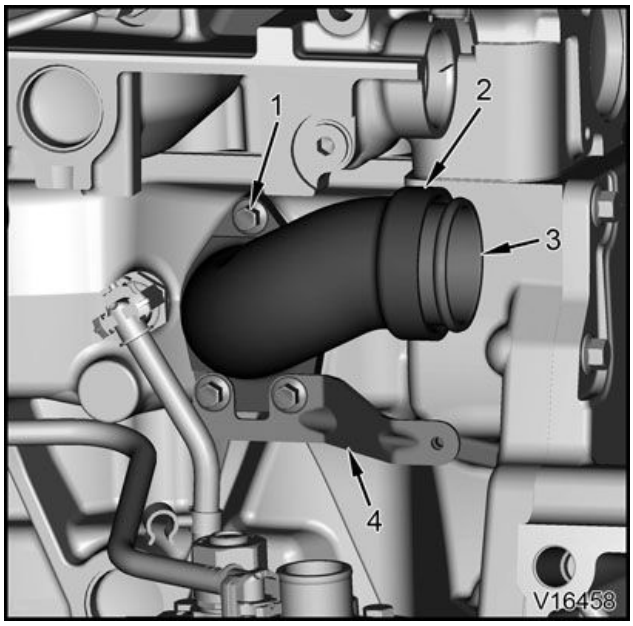


Figure 426 Coolant elbow

1. M8 x 25 bolt (3)
2. Coolant elbow
3. Extension tube (DMR62 x 51)
4. Hydrocarbon injector fuel supply (tube) bracket

1. Install new 60 x 3 O-ring. Install coolant elbow and loosely install upper M8 x 25 bolt.
2. Install HCI supply bracket and loosely install two lower M8 x 25 bolts.
3. Tighten three coolant elbow bolts to standard torque (page 503).
4. Lubricate sealing surfaces of extension tube (DMR62 x 51) with P-80® rubber lubricant or equivalent (page 296). Install extension tube (DMR62 x 51) to coolant elbow using Extension Tube Installer Large (page 296).

NOTE: Alternatively, install extension tube (DMR62 x 51) into coolant manifold.

Coolant Manifold

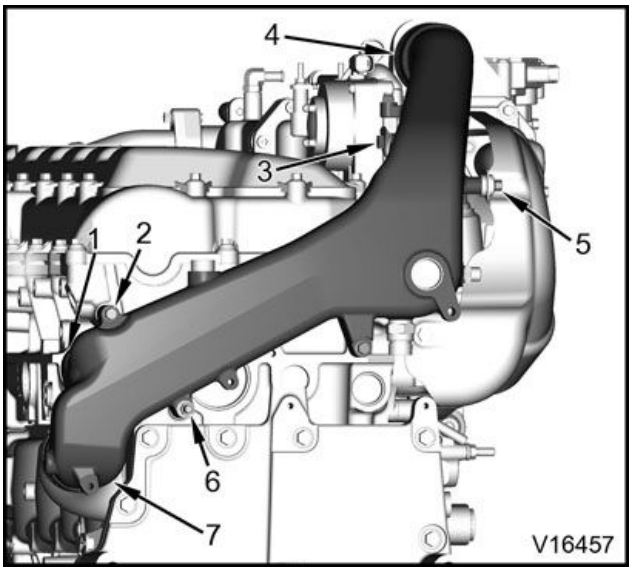


Figure 427 Coolant manifold

1. Extension tube (DMR44 x 35)
2. M8 x 45 bolt (2)
3. M8 x 18 bolt
4. Extension tube (DMR62 x 51)
5. M8 x 25 heat-resistant bolt
6. M8 x 50 x 16 stud bolt
7. Extension tube (DMR62 x 51)

1. Lubricate two extension tubes (DMR62 x 51 and DMR44 x 35) sealing surfaces with P-80® rubber lubricant or equivalent (page 296).
2. Install extension tube (DMR62 x 51) and extension tube (DMR44 x 35) into coolant manifold using Extension Tube Installer Large and Extension Tube Installer Small (page 296).
3. Install coolant manifold using two M8 x 45 bolts, one M8 x 50 x 16 stud bolt and one M8 x 25 heat-resistant bolt (at heat protection (cylinder 4-6) shield). Tighten M8 x 25 heat-resistant bolt to special torque (page 296). Tighten two M8 x 45 bolts and one M8 x 50 x 16 stud bolt to special torque (page 296).
4. Install one M8 x 18 bolt and tighten to special torque (page 296).

Special Torque

Table 20 EGR System

Coolant manifold, M8 x 18 bolt	22 N·m (16 lbf·ft)
Coolant manifold, M8 x 25 heat–resistant bolt	24 N·m (18 lbf·ft)
Coolant manifold, M8 x 45 bolt and M8 x 50 x 16 stud bolt	35 N·m (26 lbf·ft)
EGR dual flap valve, M8 x 30 heat-resistant bolt	See tightening steps in procedure.
EGR inlet (cylinders 1-3) tube, M8 x 25 heat-resistant bolt	See tightening steps in procedure.
EGR inlet (cylinders 4-6) tube, M8 x 25 heat-resistant bolt	See tightening steps in procedure.
EGR module cover, M8 x 85 bolts and M8 x 90 stud bolt	24 N·m (18 lbf·ft)
EGR outlet tube hose clamps	5 N·m (45 lbf·in)
EGR valve coolant supply tube nut	26 N·m (19 lbf·ft)
Front EGR cooler cleaning adapter M8 bolts	24 N·m (18 lbf·ft)
Heat protection (cylinders 4–6) shield, M8 x 25 heat–resistant bolts	24 N·m (18 lbf·ft)
HT EGR cooler mounting studs 7/16 - 14 nuts	41 N·m (30 lbf·ft)
Leak Detection Plate KL20060-4 M8 x 30 bolts	24 N·m (18 lbf·ft)
Low-temperature and high-temperature EGR coolers, M8 x 55 hex socket screws	See tightening steps in procedure.
LT EGR cooler mounting studs 3/8 - 14 nuts	41 N·m (30 lbf·ft)
Rear EGR cooler cleaning adapter M8 bolts	24 N·m (18 lbf·ft)

Special Service Tools

Table 21 EGR System

Description	Tool Number
Cleaning Management System	12-353-01
Coolant Management Tool	KL5007NAV
EGR Cooler Alignment Tool	12-892-01A
Exhaust Gas Recirculation (EGR) Cooler Leak Detection Tool	KL 20060 NAV
Extension Tube Installer Large	ZTSE6046
Extension Tube Installer Small	ZTSE6047
P-80® rubber lubricant or equivalent	Obtain locally

Table of Contents

Exploded Views.....299
- **Exhaust Manifold.....299**
- **Air Intake Throttle Horizontal Duct.....300**
- **Air Intake Throttle Vertical Duct.....301**

Removal.....302
- **Exhaust Manifold.....302**
- **Air Intake Throttle Duct.....303**

Cleaning, Inspection and Testing.....304
- **Air Intake Throttle Duct and Exhaust Manifolds.....304**
- **Manifold Warp Test for Exhaust Manifolds.....304**

Installation.....306
- **Air Intake Throttle Duct.....306**
- **Exhaust Manifold.....306**

Specifications.....309

Special Torque.....309

Special Service Tools.....309

Exploded Views

Exhaust Manifold

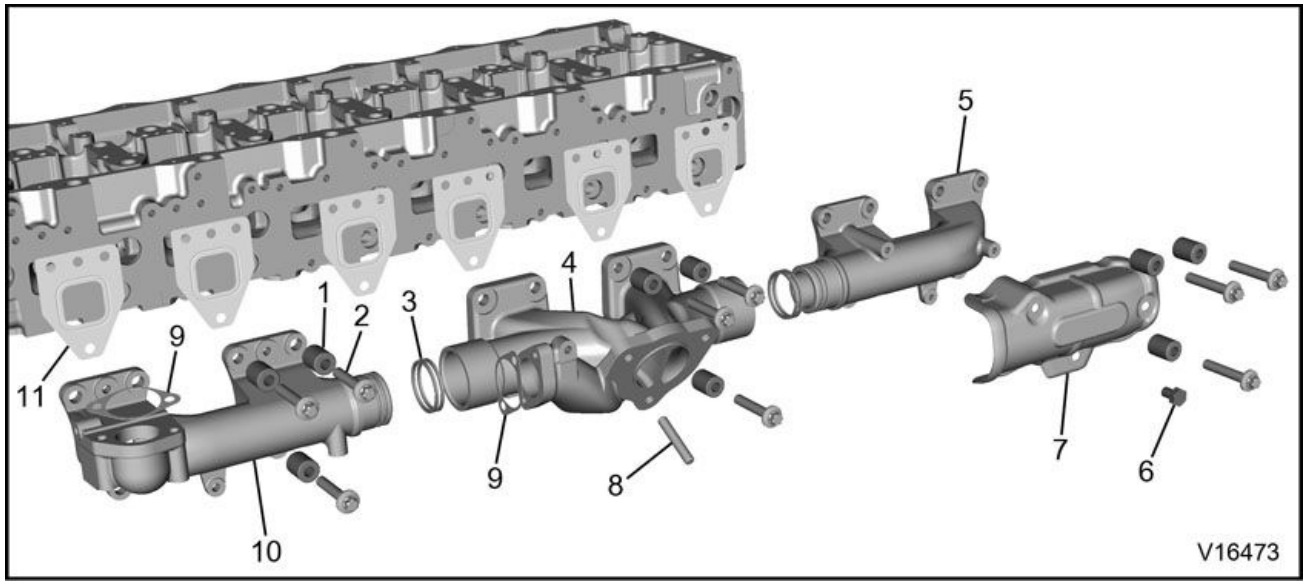


Figure 428 Exhaust manifold

1. Sleeve spacer (18)
2. M10 x 57 Torx® bolt (18)
3. Multipiece oil (FEY) ring (4)
4. Middle exhaust manifold
5. Front exhaust manifold
6. M8 x 12 bolt
7. Heat protection shield
8. M10 x 45 stud
9. Exhaust gas recirculation tube gasket (2)
10. Rear exhaust manifold
11. Exhaust manifold gasket (6)

Air Intake Throttle Horizontal Duct

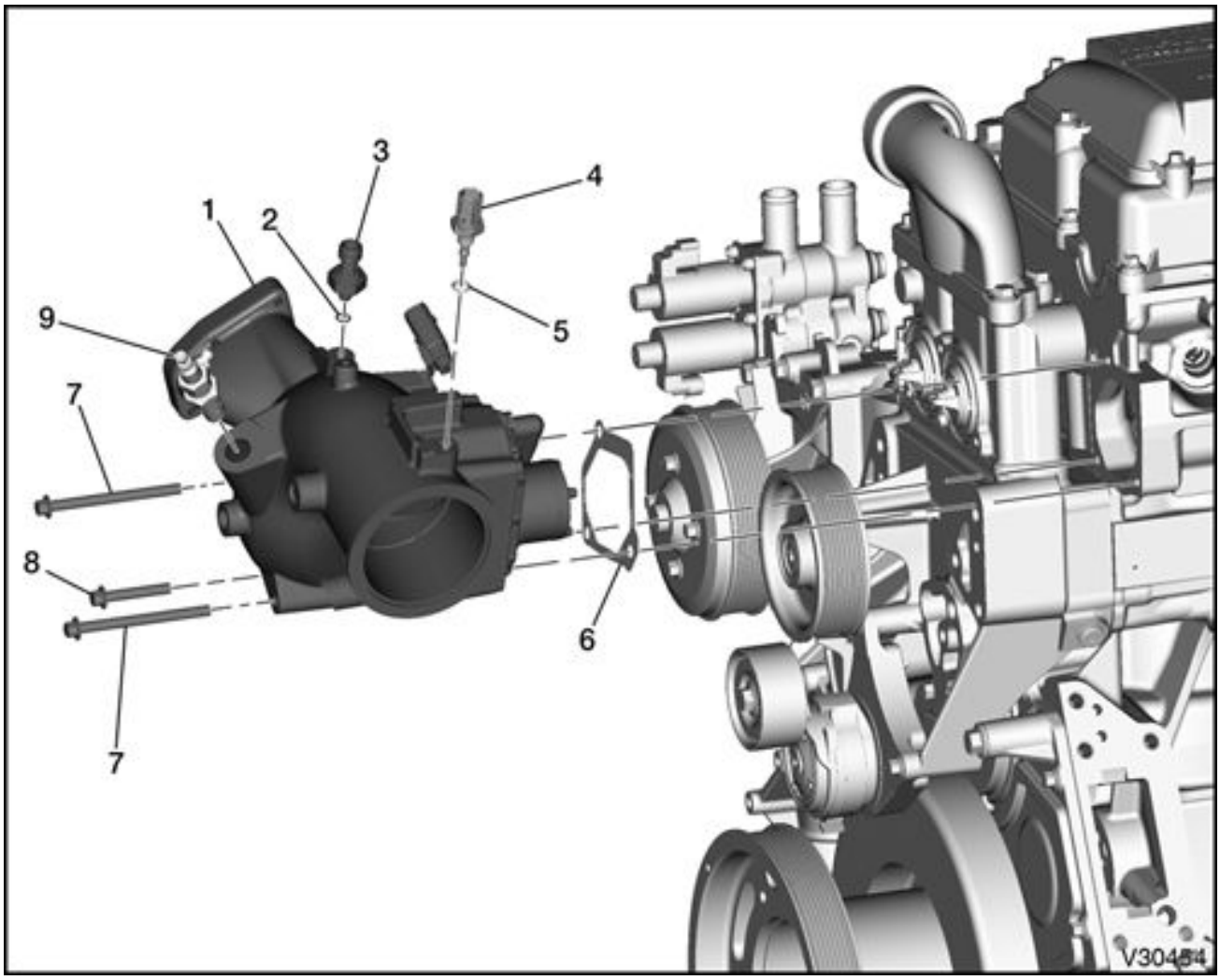


Figure 429 Air intake throttle horizontal duct

1. Air intake throttle horizontal duct
2. Sensor O-ring
3. Intake manifold pressure sensor
4. Charge air cooler outlet temperature sensor
5. O-ring
6. Intake throttle gasket
7. M8 x 100 bolt (2)
8. M8 x 50 bolt
9. Cold start fuel ignitor (glow plug)

Air Intake Throttle Vertical Duct

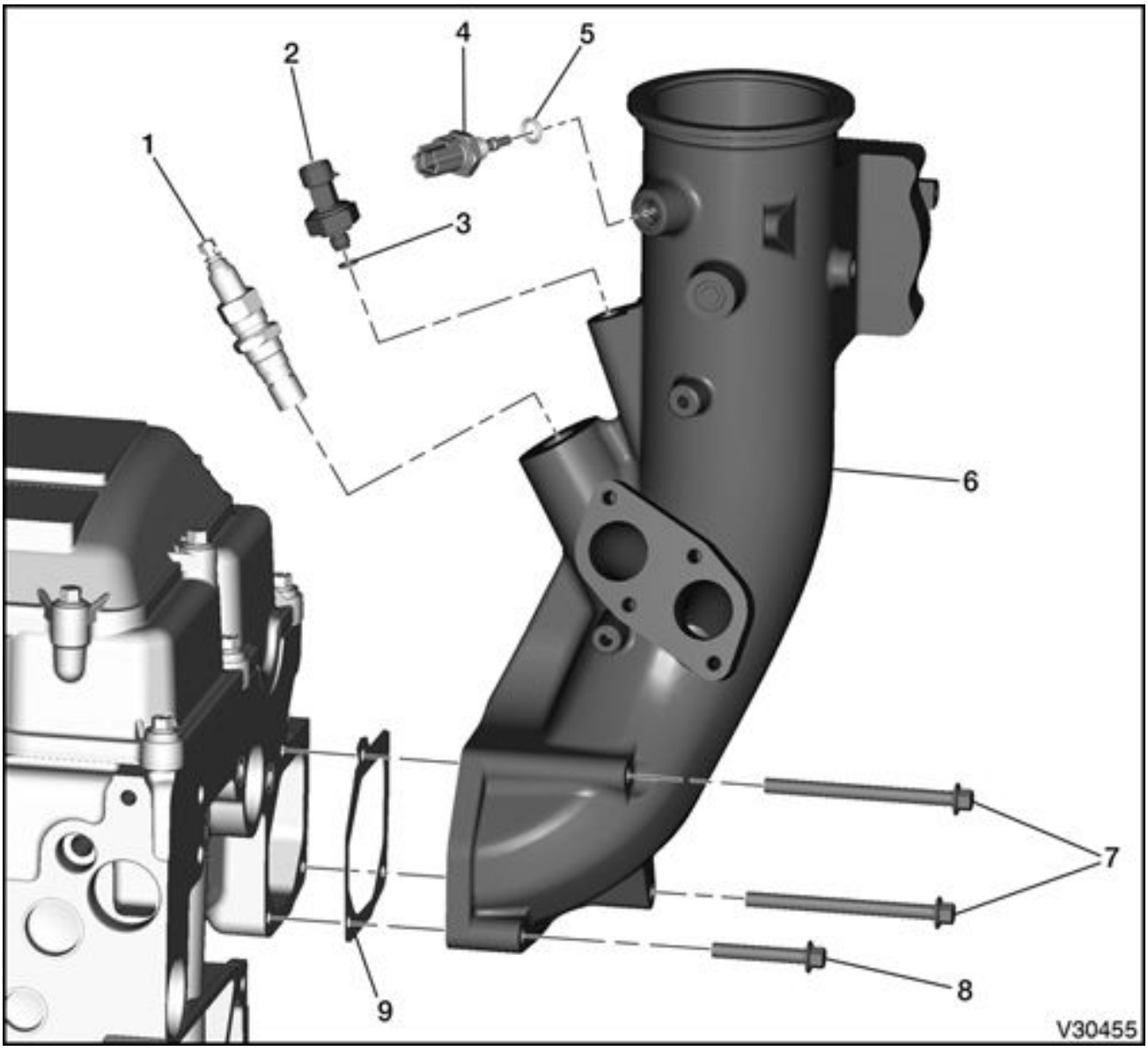


Figure 430 Air intake throttle vertical duct

1. Cold start fuel ignitor (glow plug)
2. Intake manifold pressure sensor
3. O-ring
4. Charge air cooler outlet temperature sensor
5. Sensor O-ring
6. Air intake throttle vertical duct
7. M8 x 100 bolt (2)
8. M8 x 50 bolt
9. Intake throttle gasket

Removal

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

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

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

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

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

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

- Engine Electrical
- Cold Start Assist
- Aftertreatment System
- Exhaust Back Pressure Control
- Turbochargers
- Oil Cooler, Filter Housing and Crankcase Ventilation
- Exhaust Gas Recirculating (EGR) System
- Front Cover, Fan Drive, Cooling System and Related Components

Exhaust Manifold

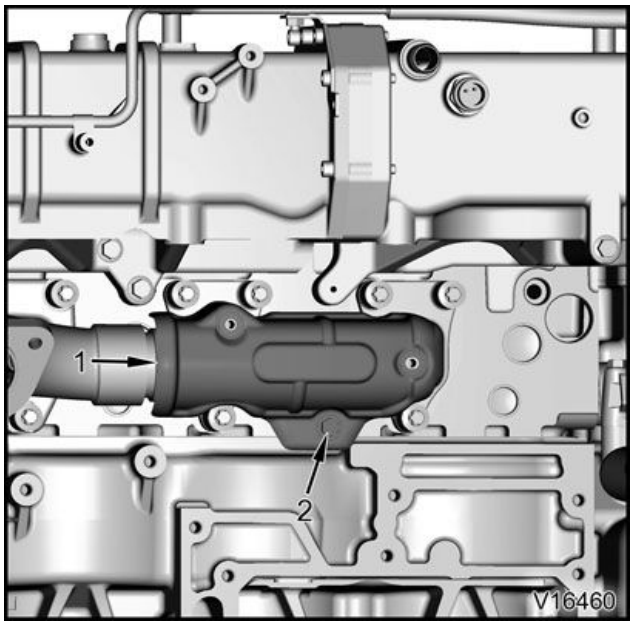


Figure 431 Heat protection shield

1. Heat protection shield (at front exhaust manifold)
2. M8 x 12 bolt

1. Remove M8 x 12 bolt that secures the heat protection shield to the front exhaust manifold and remove heat protection shield.

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

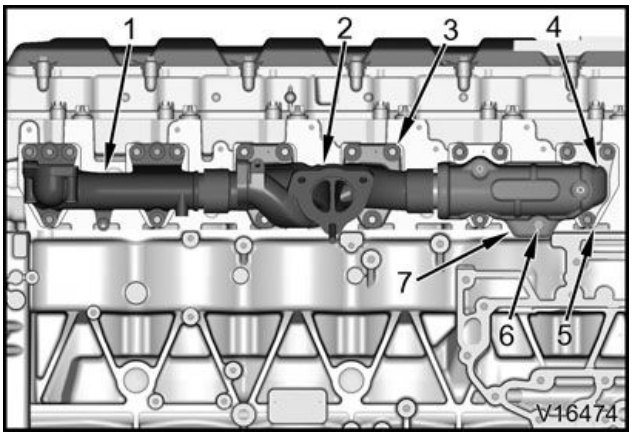


Figure 432 Exhaust manifold (typical)

1. Rear exhaust manifold
2. Middle exhaust manifold
3. M10 x 57 Torx® bolt and sleeve spacer (18)
4. Front exhaust manifold
5. Exhaust manifold gasket (6)
6. M8 x 12 bolt
7. Heat protection shield

2. Remove 18 M10 x 57 Torx® bolts and 18 sleeve spacers. Discard bolts and spacers after removal.
3. Remove exhaust manifold assembly and discard six exhaust manifold gaskets.

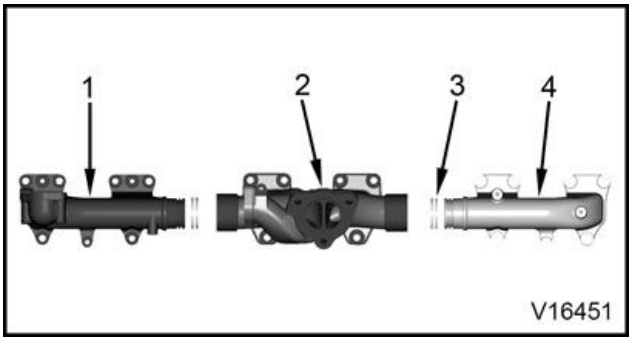


Figure 433 Exhaust manifolds

1. Rear exhaust manifold
2. Middle exhaust manifold
3. Multipiece oil (FEY) ring (4)
4. Front exhaust manifold

4. Separate front and rear exhaust manifold sections from middle exhaust manifold.
5. Remove and discard multipiece oil (FEY) rings from front and rear exhaust manifolds.

Air Intake Throttle Duct

CAUTION: To prevent engine damage, make sure gasket debris and dirt do not enter cylinder head opening.

1. Remove glow plug from air intake throttle duct. See “COLD START ASSIST” for procedure.
2. Remove temperature sensor and air pressure sensor from air intake throttle duct. See “ENGINE ELECTRICAL” for procedures.

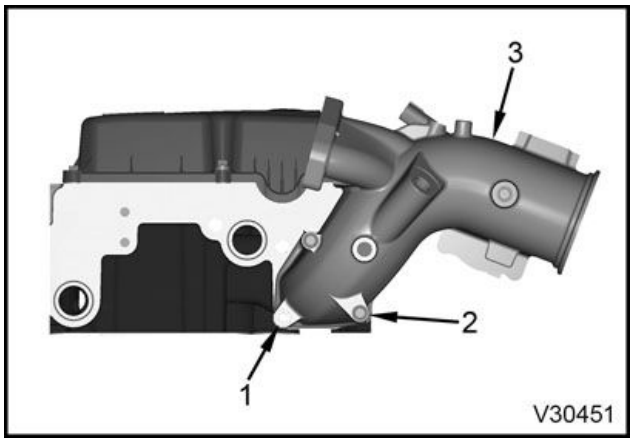


Figure 434 Air intake throttle horizontal duct

1. M8 x 50 bolt
2. M8 x 100 bolt (2)
3. Air intake throttle horizontal duct

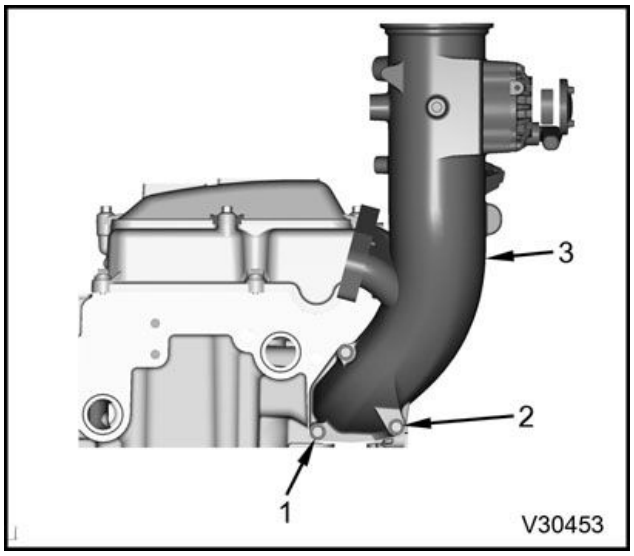


Figure 435 Air intake throttle vertical duct

1. M8 x 50 bolt
2. M8 x 100 bolt (2)
3. Air intake throttle vertical duct

3. Remove M8 x 50 bolt and two M8 x 100 bolts. Depending on application, remove either air intake throttle horizontal or vertical duct.
4. Remove and discard intake throttle gasket.

Cleaning, Inspection and Testing

Air Intake Throttle Duct and Exhaust Manifolds

NOTE: Do not use air tools or abrasive pads to clean aluminum parts.

Air intake throttle duct and three exhaust manifold sections are castings and may be cleaned with steam or suitable non-caustic solvents.

1. Clean cylinder head, air intake throttle duct and exhaust manifold gasket sealing surfaces.
2. Clean multipiece oil (FEY) ring grooves and sealing surfaces of the exhaust manifold sections.

Manifold Warp Test for Exhaust Manifolds

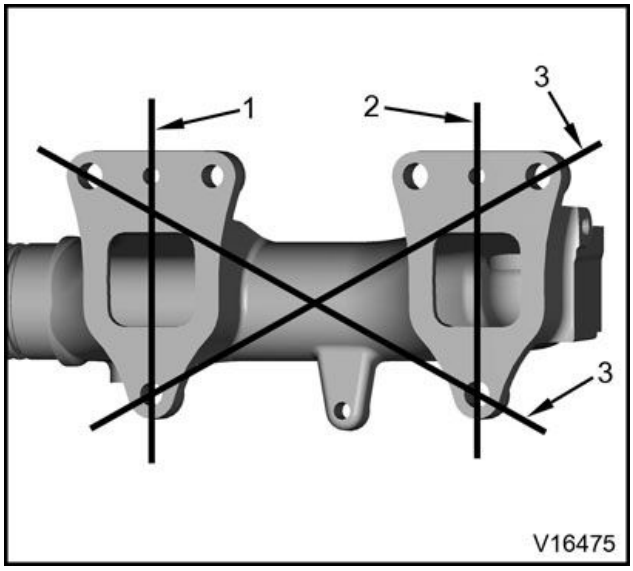


Figure 436 Exhaust manifold section warp test

1. Left
2. Right
3. Diagonally

1. Use a straightedge and feeler gauge (page 309) to check seating surface flatness of three exhaust manifold sections.
2. Check for flatness across left, right and diagonally of each exhaust manifold section individually. See Specification (page 309).
3. If specification is not met, replace individual exhaust manifold section. Do not resurface.

Installation

Air Intake Throttle Duct

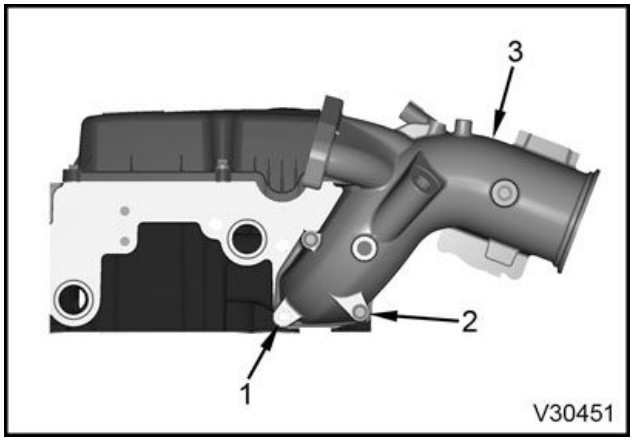


Figure 437 Air intake throttle horizontal duct

1. M8 x 50 bolt
2. M8 x 100 bolt (2)
3. Air intake throttle horizontal duct

1. If equipped with horizontal air intake throttle duct, install intake throttle gasket (Figure 429) (item 6), horizontal air intake throttle duct, M8 x 50 bolt and two M8 x 100 bolts. Tighten bolts to standard torque (page 503).

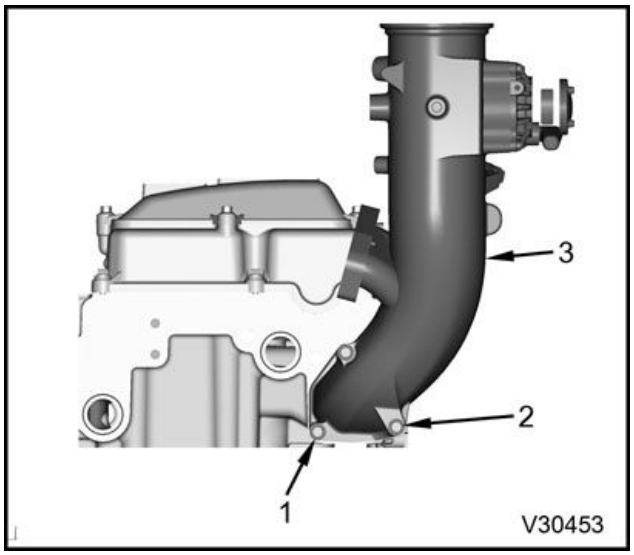


Figure 438 Air intake throttle vertical duct

1. M8 x 50 bolt
2. M8 x 100 bolt (2)
3. Air intake throttle vertical duct

2. If equipped with vertical air intake throttle duct, install intake throttle gasket (Figure 430) (item 9), vertical air intake throttle duct, M8 x 50 bolt, and two M8 x 100 bolts. Tighten bolts to standard torque (page 503).
3. Install charge air cooler outlet temperature sensor and intake manifold pressure sensor to air intake throttle duct. See Charge Air Cooler Outlet Temperature (CACOT) Sensor (page 101) and Intake Manifold Pressure (IMP) Sensor (page 100).
4. Install glow plug to air intake throttle duct. See Glow Plug (page 113).

Exhaust Manifold

CAUTION: To prevent engine damage, hand torque all fasteners 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 sleeve spacers or exhaust manifold bolts.

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

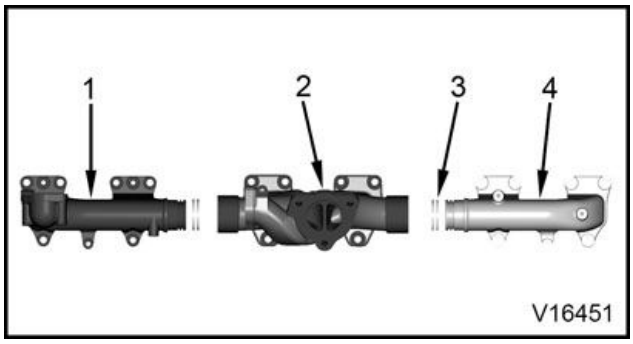


Figure 439 Exhaust manifold

1. Rear exhaust manifold
2. Middle exhaust manifold
3. Multipiece oil (FEY) ring (4)
4. Front exhaust manifold

NOTE: Each multipiece oil (FEY) ring replacement comes as four individual rings. There are two multipiece oil rings (two sets of four rings) for each front and rear exhaust manifold section. This results in four sets of four individual rings or 16 total individual rings for a complete exhaust manifold assembly. Each set of four rings in an exhaust manifold groove must have the ring gaps indexed 180 degrees apart (6 and 12 o'clock positions).

1. Install four new multipiece oil (FEY) rings, two to the front exhaust manifold and two to the rear exhaust manifold, using FEY Rings Installation Tools (page 309). Refer to the tool kit installation instructions. Each multipiece oil ring (four individual rings) must be positioned with the four individual ring gaps alternating at 6 and 12 o'clock positions within each exhaust manifold ring groove.
2. Install the front and rear exhaust manifolds into the middle exhaust manifold.

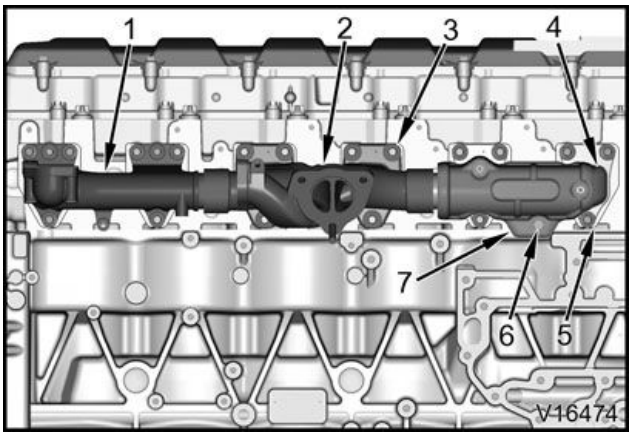


Figure 440 Exhaust manifold

1. Rear exhaust manifold
2. Middle exhaust manifold
3. M10 x 57 Torx® bolt and sleeve spacers (18)
4. Front exhaust manifold
5. Manifold exhaust gasket (6)
6. M8 x 12 bolt
7. Heat protection shield

NOTE: Ensure that raised part of exhaust manifold gasket is facing out towards exhaust manifold.

3. Position six new exhaust manifold gaskets and install exhaust manifold assembly.

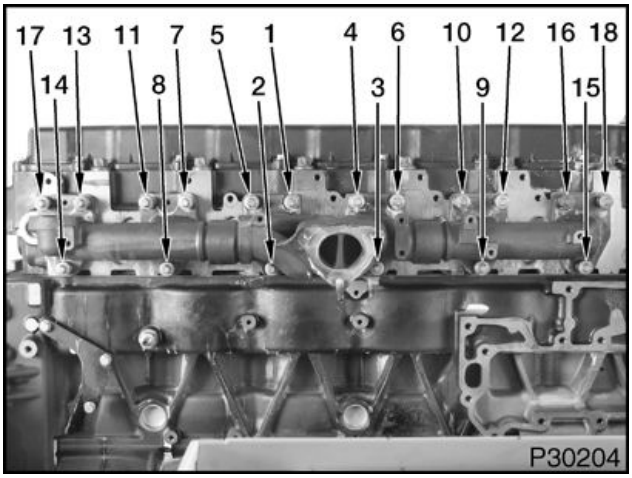


Figure 441 Exhaust manifold tightening sequence

4. Install 18 new M10 x 57 Torx® bolts and 18 new sleeve spacers.
   a. Tighten all bolts to 40 N·m (30 lbf·ft) using tightening sequence shown.
   b. Turn all bolts an additional 90° using tightening sequence shown.

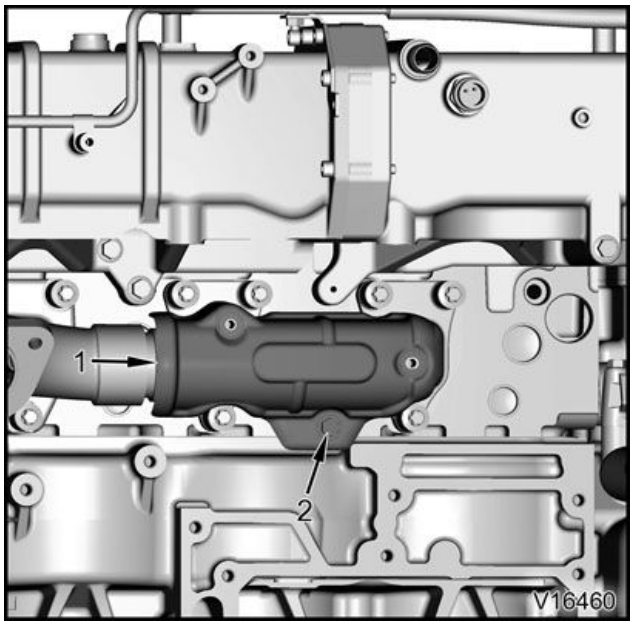


Figure 442 Heat protection shield

1. Heat protection shield (at front exhaust manifold)
2. M8 x 12 bolt

5. Install heat protection shield to exhaust manifold.
6. Install M8 x 12 bolt. Tighten bolt to standard torque(page 503).

Specifications

Table 22 Exhaust Manifolds

Exhaust manifold maximum allowable warpage	0.1 mm (0.003 in)

Special Torque

Table 23 Air Intake Throttle Duct and Exhaust Manifolds

Exhaust manifold Torx® bolts, M10 x 57	(Installation, page 306)

Special Service Tools

Table 24 Air Intake Throttle Duct and Exhaust Manifolds

Description	Tool Number
Feeler gauge	Obtain locally
FEY Rings Installation Tools	ZTSE6030
Straightedge	Obtain locally

Table of Contents

Exploded Views.....313
- **High Mount Fan Drive System and Vibration Damper**.....313
- **Accessory Drive System (Typical)**.....314
- **Thermostat Assembly and Coolant Outlet Manifold (Low Mount Fan)**.....315
- **Thermostat Assembly and Coolant Outlet Manifold (High Mount Fan)**.....316
- **Water Pump Assembly, Coolant Control Valve (CCV), Water Distribution Housing, Thermostat Housing and EGR Cooler Return Manifold**.....317
- **Front Belt-Driven Fan Cover (High Mount Fan)**.....318
- **Front Gear-driven Fan Cover (Low Mount Fan)**.....319
- **Fan Low Mount Drive (Typical)**.....320

Removal.....321
- **Pulley (High Mount Fan)**.....321
- **Tensioner Bracket (High Mount Fan)**.....322
- **High Mount Fan Drive**.....322
- **Coolant Outlet Manifold and Thermostat Assembly**.....323
- **Automatic Belt Tensioner and Idler Pulleys**.....324
- **Water Pump Assembly and Pulley**.....324
- **Vibration Damper**.....325
- **Coolant Control Valve (CCV) Assembly**.....326
- **Thermostat Housing**.....326
- **Water Distribution Housing**.....327
- **Front Belt- or Gear-Driven Fan Cover Radial Shaft Seal**.....328
- **Front Belt- or Gear-Driven Fan Cover**.....328
- **Radial Shaft Seal (Fan Low Mount Drive)**.....329
- **Fan Low Mount Drive Assembly**.....329

Cleaning, Inspection and Testing.....330

Installation.....331
- **Fan Low Mount Drive Assembly**.....331
- **Radial Shaft Seal (Fan Low Mount Drive)**.....331
- **Front Belt- or Gear-Driven Fan Cover**.....332
- **Front Belt- or Gear-Driven Fan Cover Radial Shaft Seal**.....332
- **Water Distribution Housing**.....333
- **Thermostat Housing**.....333
- **Coolant Control Valve (CCV) Assembly**.....334
- **Vibration Damper**.....335
- **Water Pump Assembly and Pulley**.....336
- **Automatic Belt Tensioner and Idler Pulley**.....336
- **Coolant Outlet Manifold and Thermostat Assembly**.....337
- **High Mount Fan Drive**.....338
- **Tensioner Bracket (High Mount Fan)**.....339
- **Pulley (High Mount Fan)**.....339

Special Torque.....340

Special Service Tools……340

Exploded Views

High Mount Fan Drive System and Vibration Damper

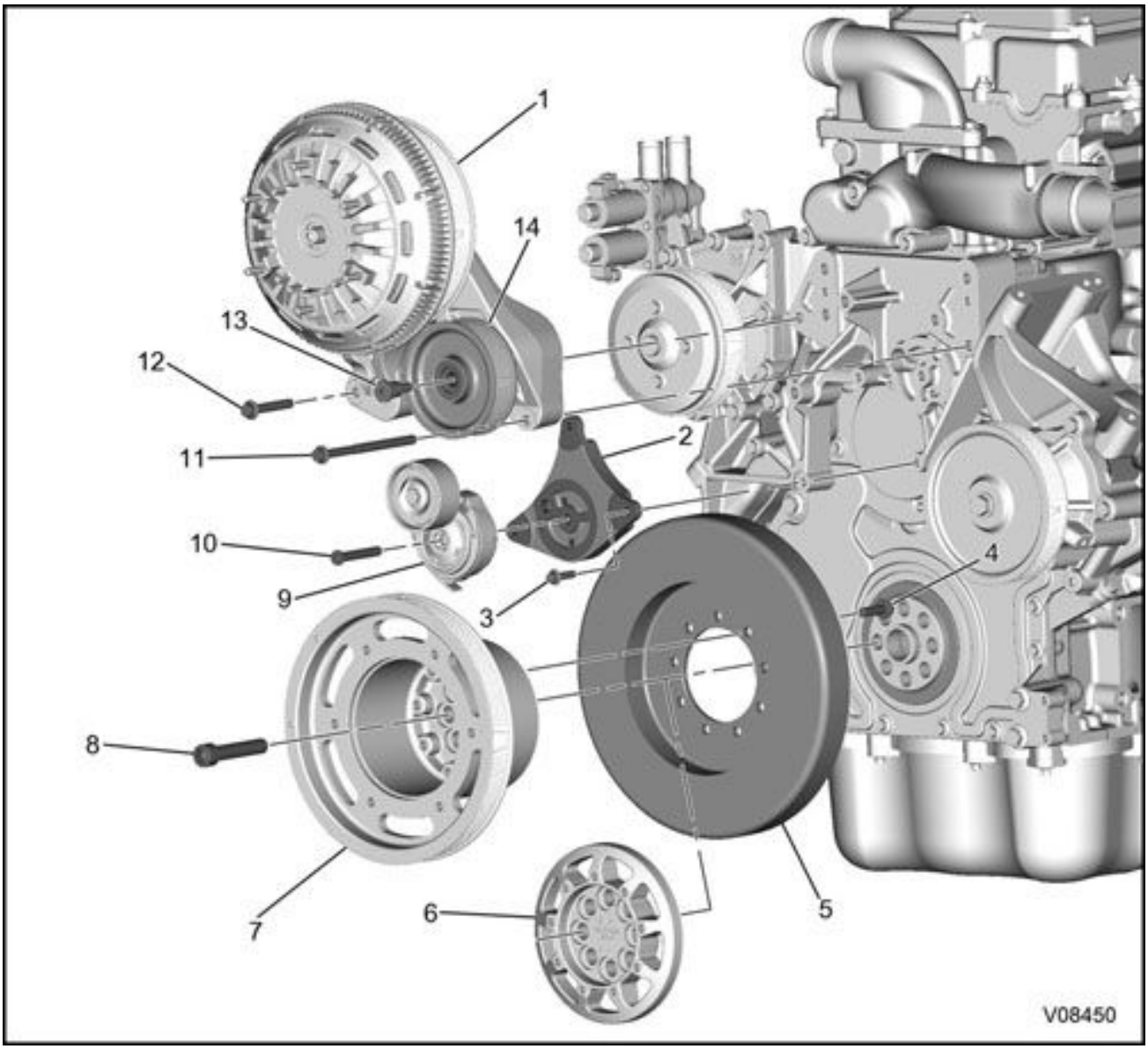


Figure 443 High mount fan drive system and vibration damper

1. Fan drive clutch assembly
2. Tensioner bracket
3. M8 x 30 bolt (3)
4. M10 x 35 bolt (9)
5. Vibration damper
6. Damper hub (low mount fan only)
7. Fan drive pulley (high mount fan only)
8. M16 x 85 socket-head screw (8)
9. Fan drive tensioner assembly
10. M10 x 70 countersunk screw
11. M10 x 150 bolt - 12.9 (5)
12. M10 x 65 bolt
13. Shoulder bolt
14. Pulley assembly

Accessory Drive System (Typical)

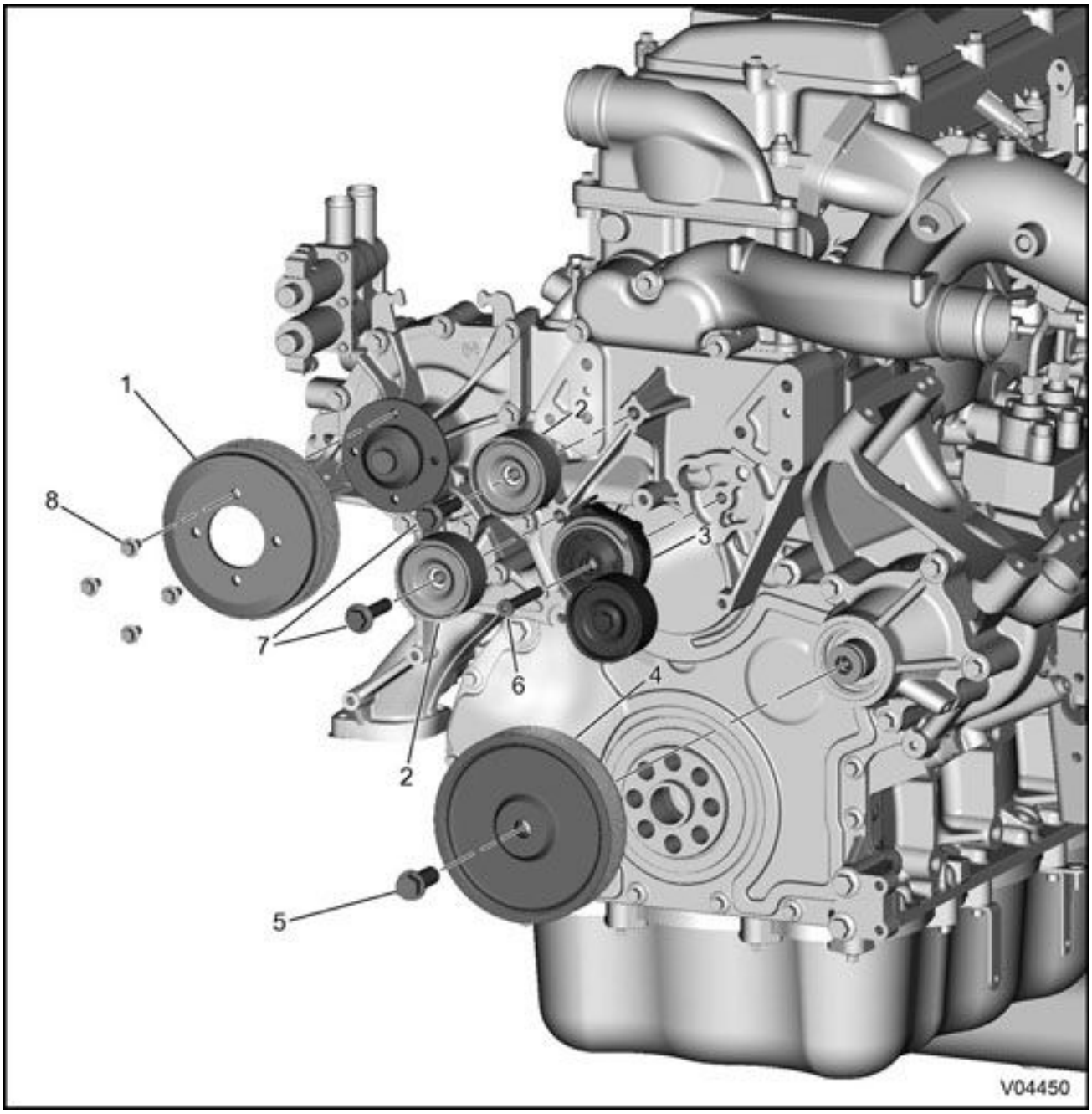


Figure 444 Accessory drive system (typical)

1. Water pump pulley
2. Idler pulley (2)
3. Automatic belt tensioner
4. High-pressure pump pulley (accessory belt drive)
5. M16 x 40 bolt
6. M10 x 70 countersunk screw
7. M12 x 55 bolt (2)
8. M8 x 16 bolt (4)

Thermostat Assembly and Coolant Outlet Manifold (Low Mount Fan)

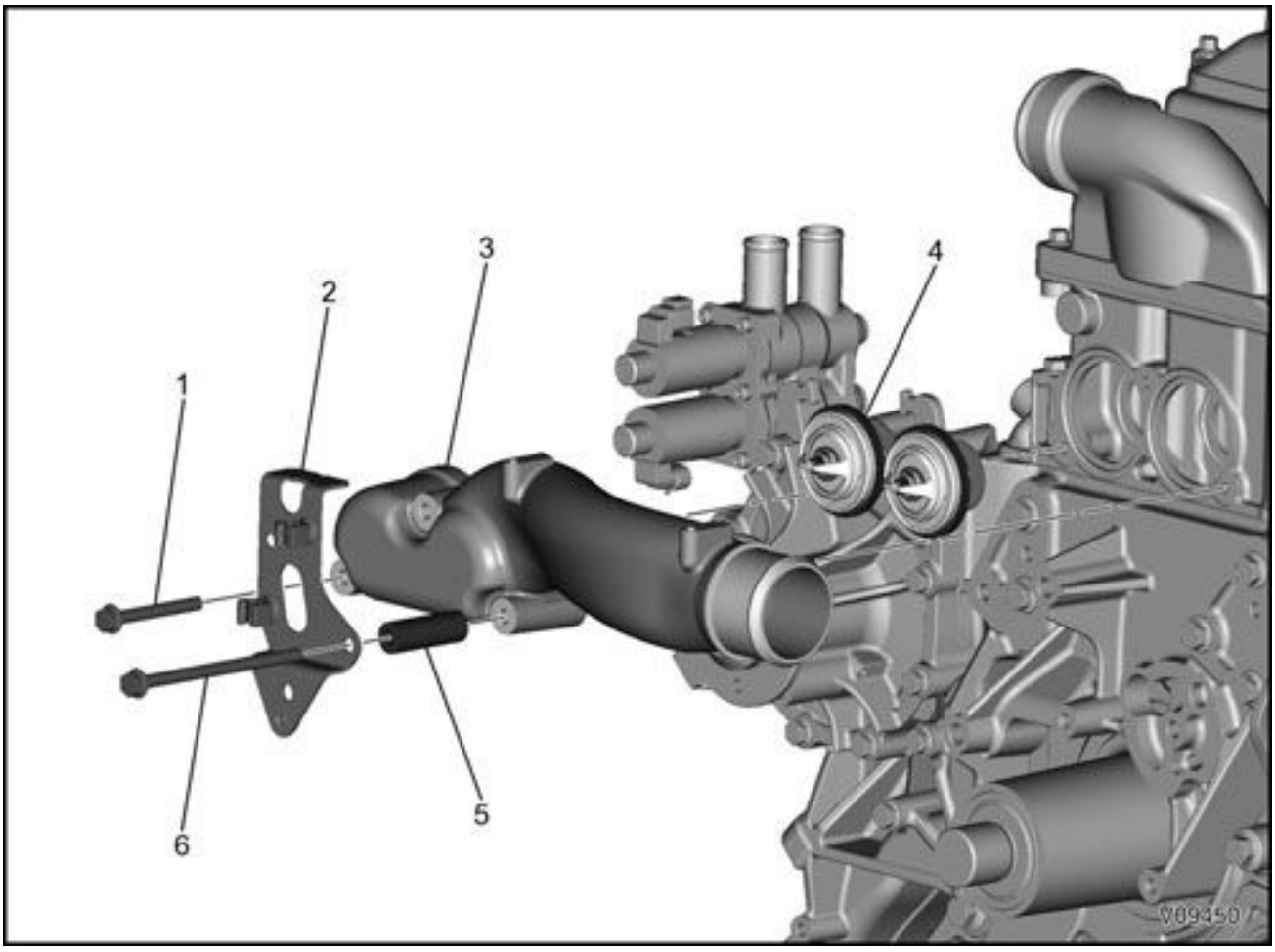


Figure 445 Thermostat assembly and coolant outlet manifold (low mount fan)

1. M8 x 70 bolt
2. Fan coupling bracket assembly
3. Coolant outlet manifold
4. Thermostat assembly (2)
5. Bushing (2)
6. M8 x 130 bolt (2)

Thermostat Assembly and Coolant Outlet Manifold (High Mount Fan)

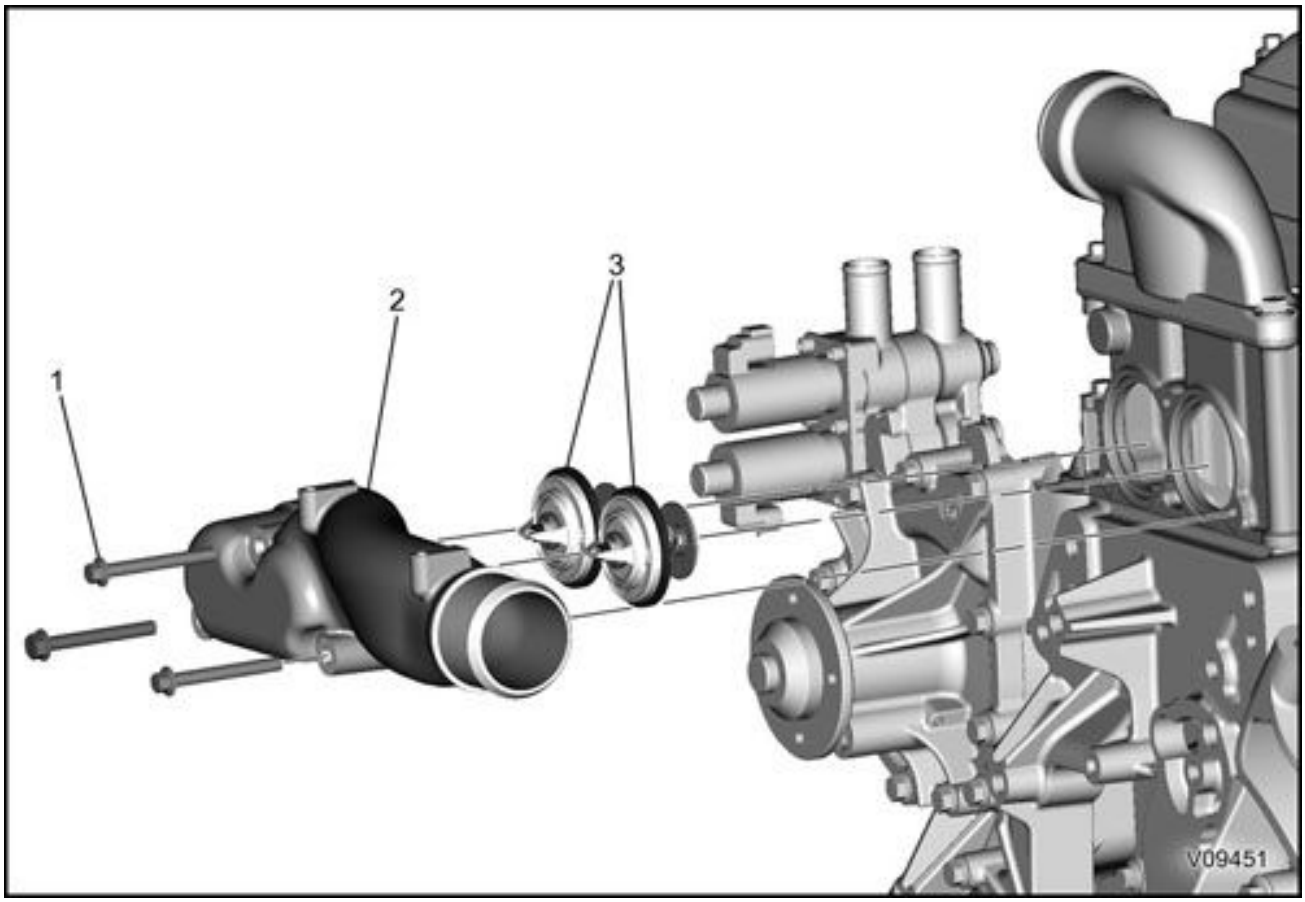


Figure 446 Thermostat assembly and coolant outlet manifold (high mount fan)

1. M8 x 70 bolt (3)
2. Coolant outlet manifold (to radiator)
3. Thermostat assembly (2)

Water Pump Assembly, Coolant Control Valve (CCV), Water Distribution Housing, Thermostat Housing and EGR Cooler Return Manifold

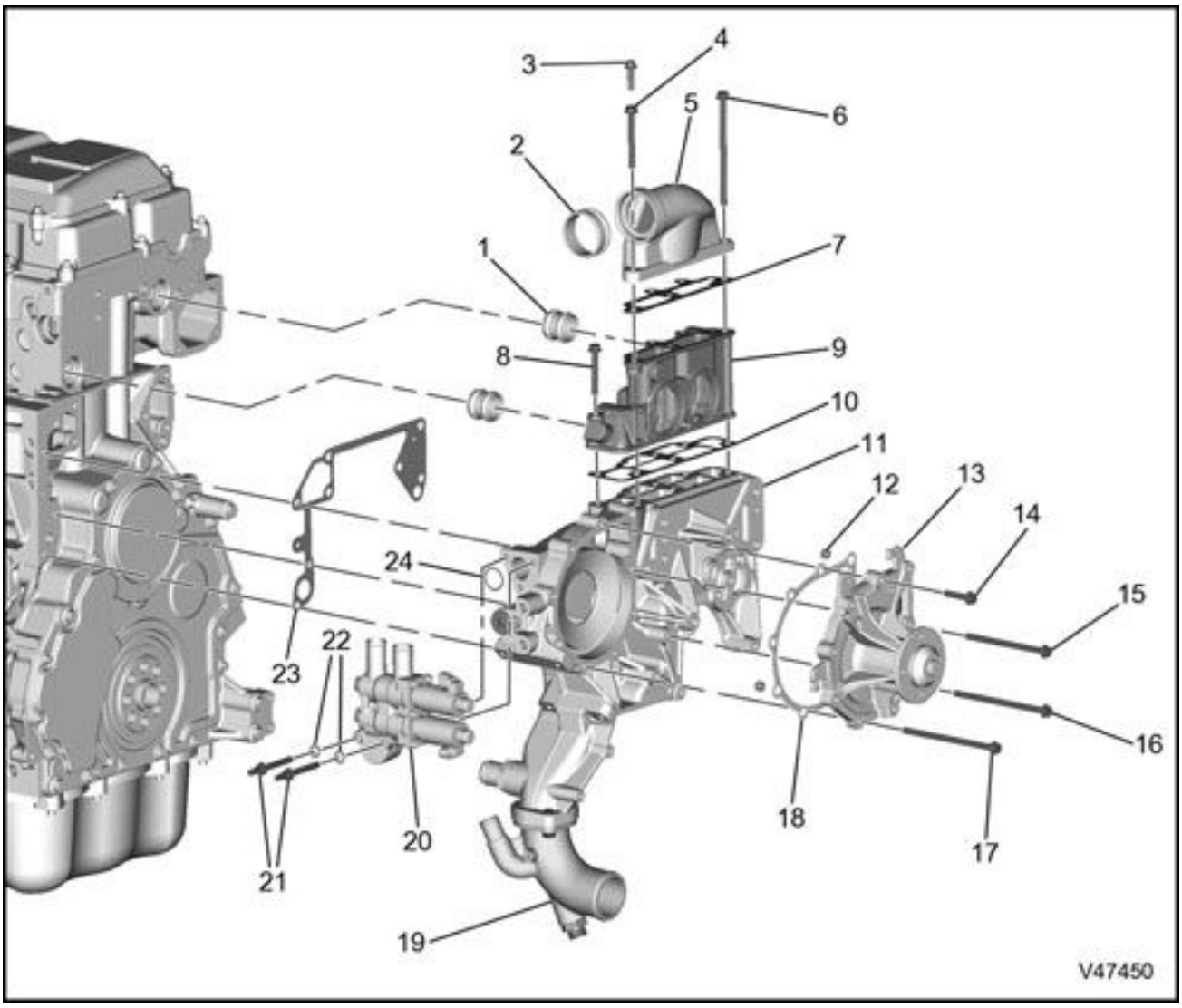


Figure 447 Water pump assembly, Coolant Control Valve (CCV), water distribution housing, thermostat housing and EGR cooler return manifold

1. Extension tube (DMR40 / DN32F) (2)
2. Extension tube (DMR62 / 51)
3. M8 x 30 bolt
4. M8 x 75 bolt
5. EGR cooler return manifold
6. M8 x 145 bolt (4)
7. Housing thermostat gasket
8. M8 x 60 bolt
9. Thermostat housing
10. Gasket
11. Water distribution housing
12. Dowel (2)
13. Water pump assembly
14. M8 x 40 bolt (7)
15. M8 x 130 bolt
16. M8 x 150 bolt (2)
17. M8 x 150 bolt (tightens into oil module assembly)
18. Water pump gasket
19. Engine water inlet
20. CCV assembly
21. M8 x 60 stud bolt (2)
22. Lock washer (2)
23. Housing coolant distribution gasket
24. O-ring

Front Belt-Driven Fan Cover (High Mount Fan)

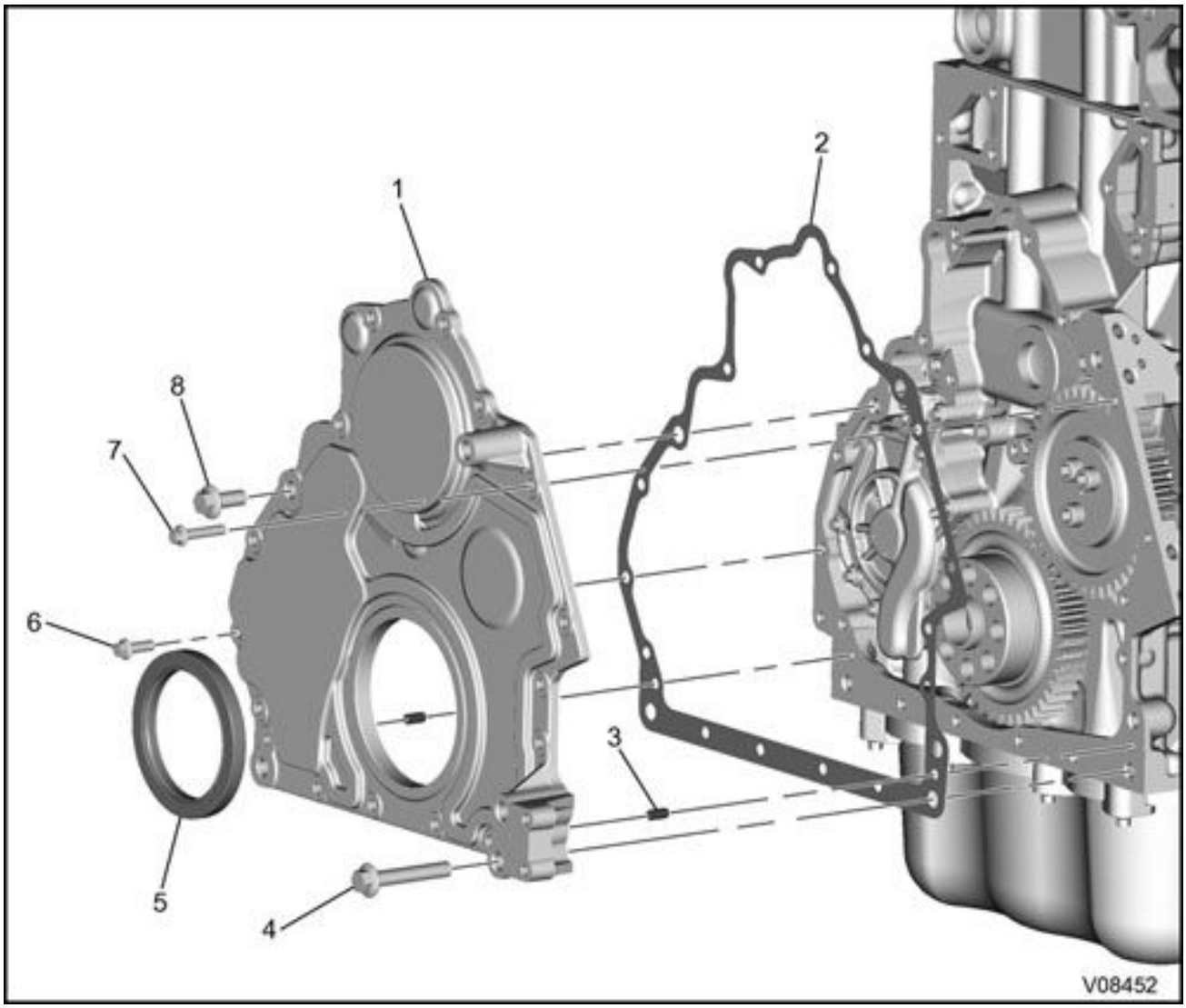


Figure 448 Front belt-driven fan cover (high mount fan)

1. Front belt driven fan cover
2. Front cover gasket
3. Dowel pin (2)
4. M12 x 75 bolt (3)
5. Radial shaft seal
6. M8 x 25 bolt (13)
7. M8 x 40 bolt (2)
8. M12 x 30 bolt (2)

Front Gear-driven Fan Cover (Low Mount Fan)

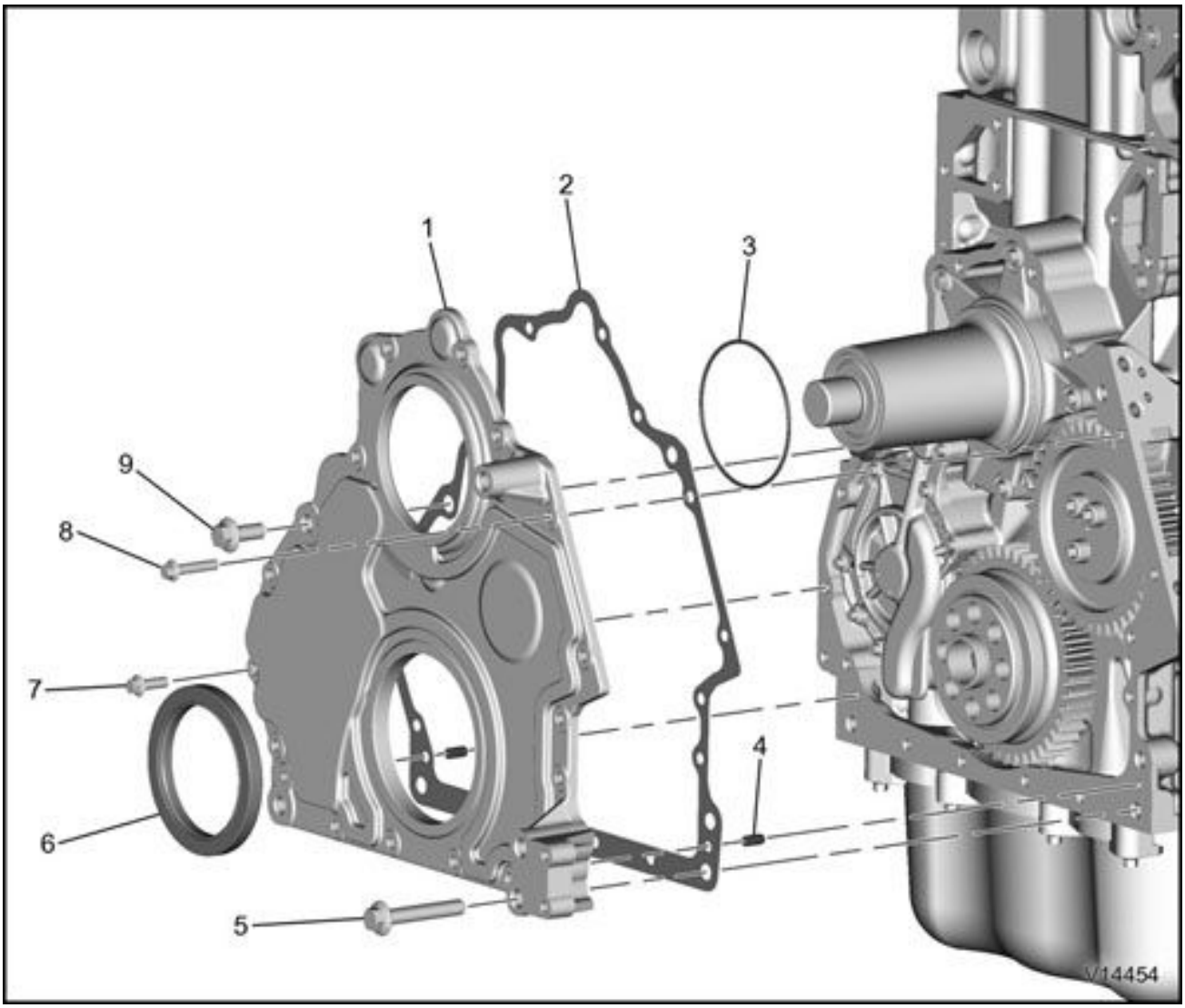


Figure 449 Front gear-driven fan cover (low mount fan)

1. Front gear driven fan cover
2. Front cover gasket
3. O-ring 108 x 3
4. Dowel pin (2)
5. M12 x 75 bolt (3)
6. Radial shaft seal
7. M8 x 25 bolt (13)
8. M8 x 40 bolt (2)
9. M12 x 30 bolt (2)

Fan Low Mount Drive (Typical)

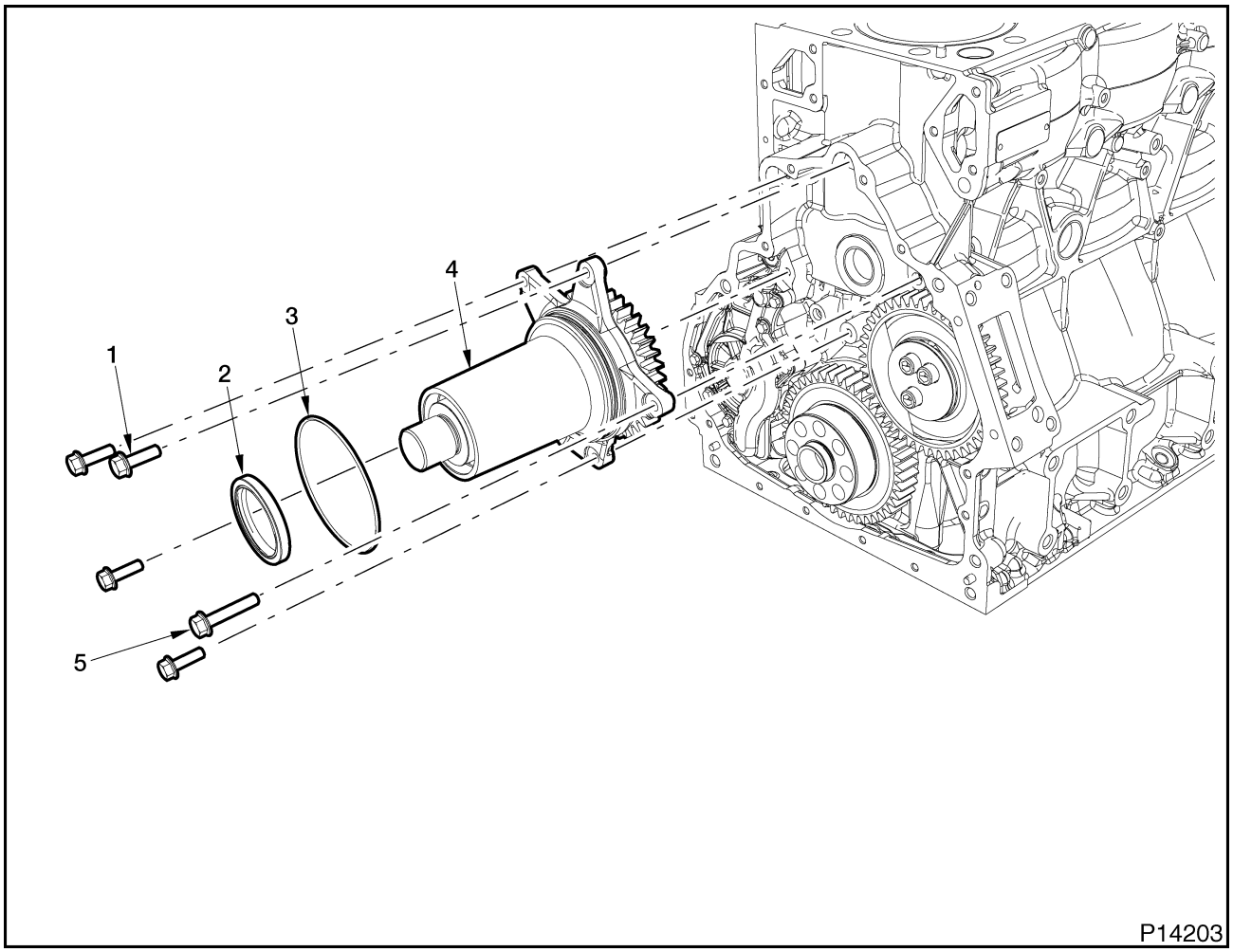


Figure 450 Fan low mount drive (typical)

1. M8 x 25 bolt (4)
2. Radial shaft seal
3. O-ring 108 x 3
4. Fan low mount drive assembly
5. M8 x 40 bolt

Removal

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

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

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

WARNING: To prevent personal injury or death, 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: Refer to the following service sections for information on removal of components prior to this section.

- Engine Electrical
- Exhaust Gas Recirculation (EGR) System

Pulley (High Mount Fan)

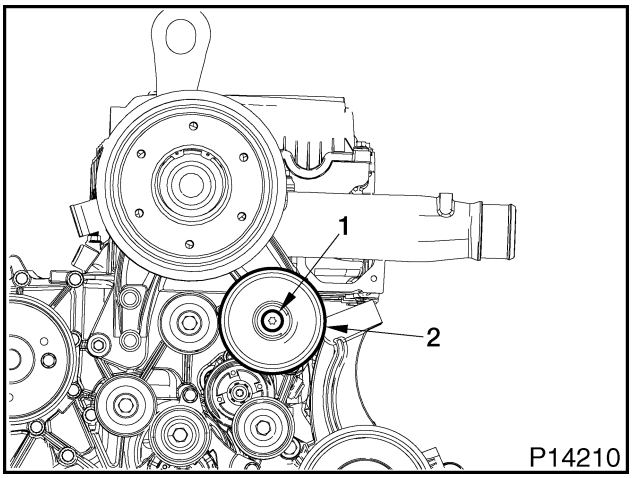


Figure 451 Pulley assembly

1. Shoulder bolt
2. Pulley assembly

1. Remove shoulder bolt and pulley assembly.

Tensioner Bracket (High Mount Fan)

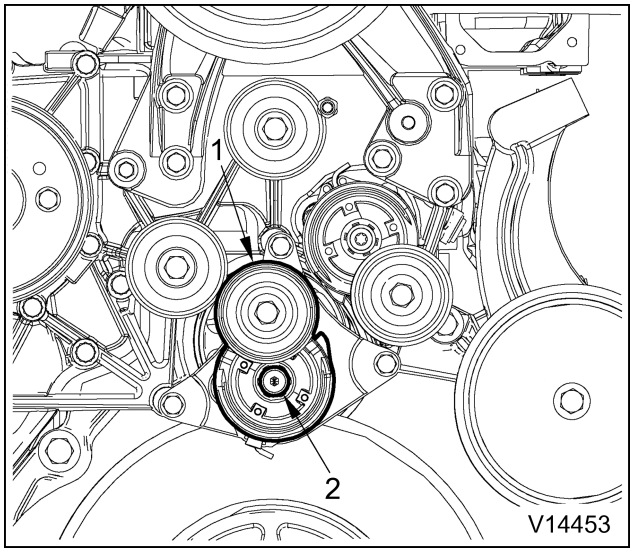


Figure 452 Fan drive tensioner assembly (high mount)

1. Fan drive tensioner assembly
2. M10 x 70 countersunk screw

1. Remove M10 x 70 countersunk screw and fan drive tensioner.

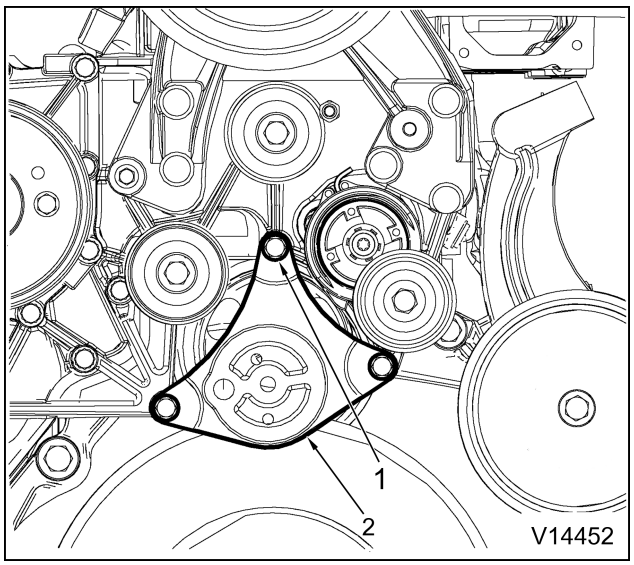


Figure 453 Tensioner bracket

1. M8 x 30 bolt (3)
2. Tensioner bracket

2. Remove three M8 x 30 bolts and tensioner bracket.

High Mount Fan Drive

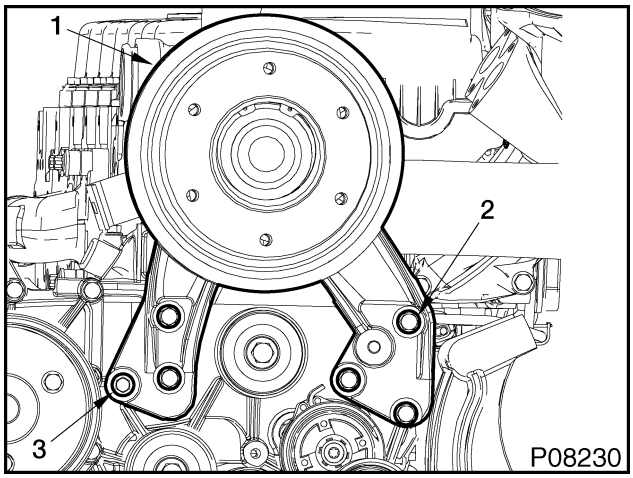


Figure 454 Fan drive clutch assembly (typical)

1. Fan drive clutch assembly
2. M10 x 150 - 12.9 bolt (5)
3. M10 x 65 bolt

1. Disconnect air line from back of fan drive clutch assembly.
2. Remove five M10 x 150 - 12.9 bolts and M10 x 65 bolt. Remove fan drive clutch.
3. Discard six M10 bolts.

Coolant Outlet Manifold and Thermostat Assembly

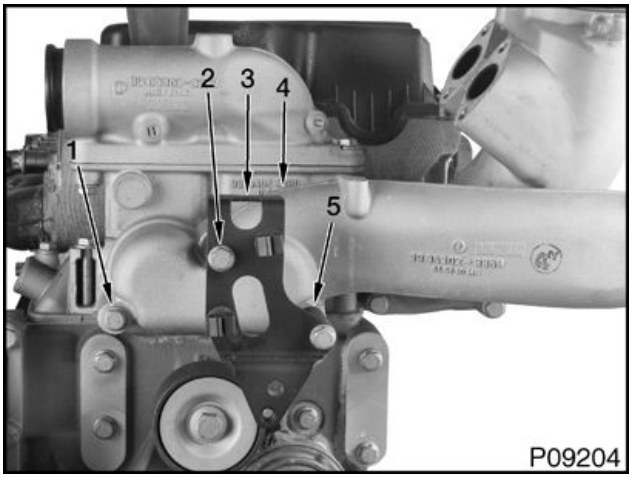


Figure 455 Coolant outlet manifold (low mount fan)

1. M8 x 70 bolt
2. M8 x 130 bolt (2)
3. Fan coupling bracket
4. Coolant outlet manifold
5. Bushing (2)

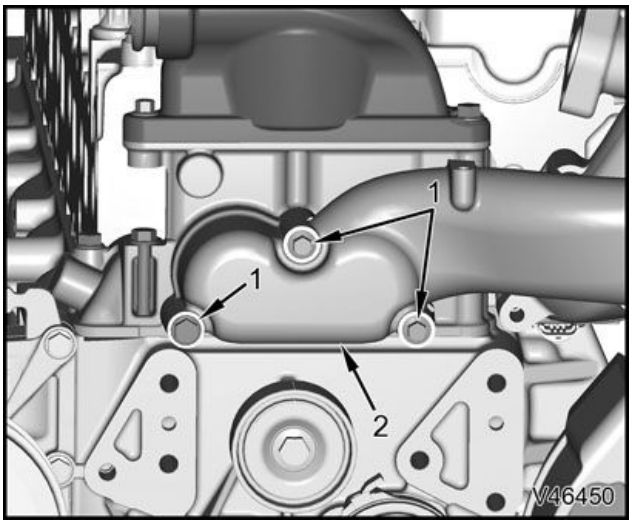


Figure 456 Coolant outlet manifold (high mount fan)

1. M8 x 70 bolt (3)
2. Coolant outlet manifold

1. Remove coolant outlet manifold bolts as follows.
   a. If equipped with low mount fan, remove M8 x 70 bolt, two M8 x 130 bolts, bracket and two bushings.
   b. If equipped with high mount fan, remove three M8 x 70 bolts.
2. Remove coolant outlet manifold.

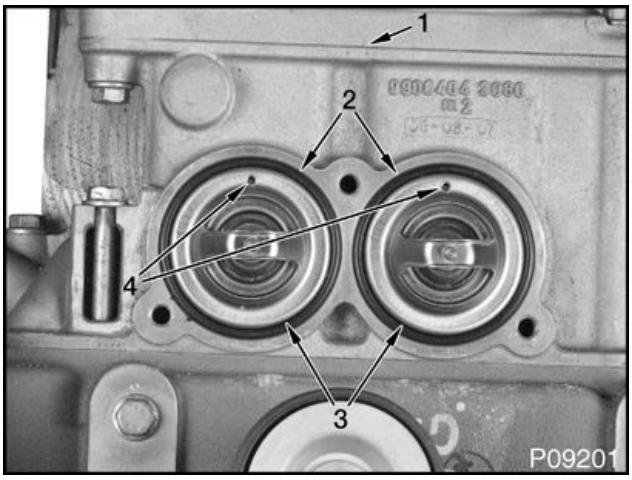


Figure 457 Thermostat assembly

1. Thermostat housing
2. Seals (part of thermostat assembly) (2)
3. Thermostat assembly (2)
4. Ball valves (part of thermostat assembly)

3. Remove two thermostat assemblies from thermostat housing.

Automatic Belt Tensioner and Idler Pulleys

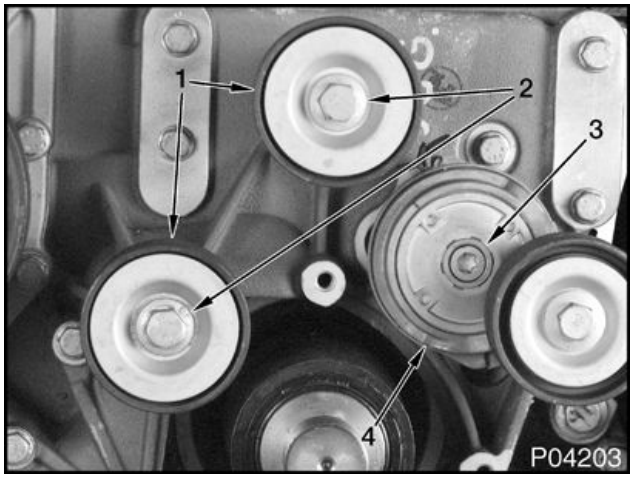


Figure 458 Automatic belt tensioner and idler pulleys (typical)

1. Idler pulley (2)
2. M12 x 55 bolt (2)
3. M10 x 70 countersunk screw
4. Automatic belt tensioner

1. Remove two M12 x 55 bolts and idler pulleys.

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

2. Remove M10 x 70 countersunk screw and automatic belt tensioner.

Water Pump Assembly and Pulley

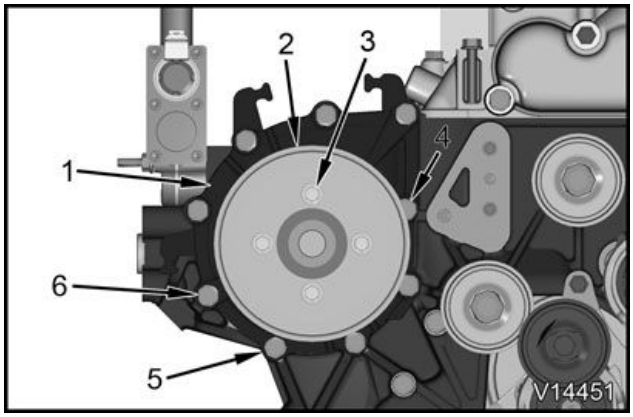


Figure 459 Water pump assembly and pulley

1. Water pump assembly
2. Water pump pulley
3. M8 x 16 bolt (4)
4. M8 x 130 bolt
5. M8 x 150 bolt
6. M8 x 40 bolt (7)

1. Remove four M8 x 16 bolts and water pump pulley.

NOTE: If the oil module is removed, the M8 x 150 bolt is also removed.

2. Remove M8 x 130, M8 x 150 and seven M8 x 40 bolts.

CAUTION: To prevent engine damage, do not drop water pump impeller or hit impeller with hard objects.

3. Remove water pump assembly and discard water pump gasket.

Vibration Damper

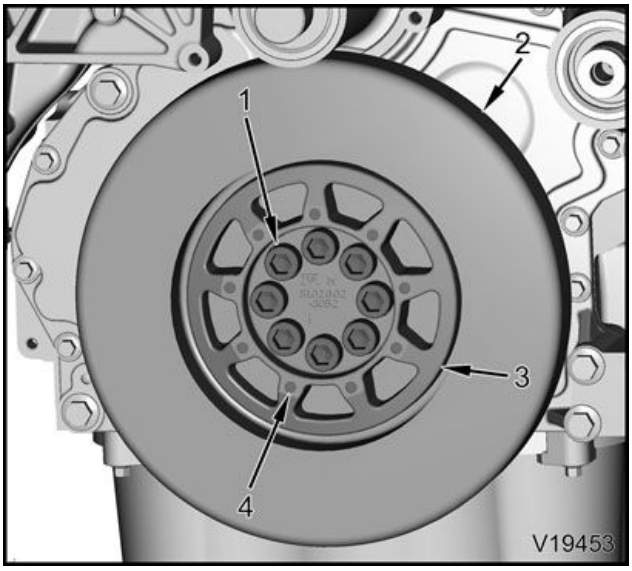


Figure 460 Vibration damper (low mount fan with damper hub)

1. M16 x 85 socket-head cap screw (8)
2. Vibration damper
3. Damper hub
4. M10 x 35 bolt (9)

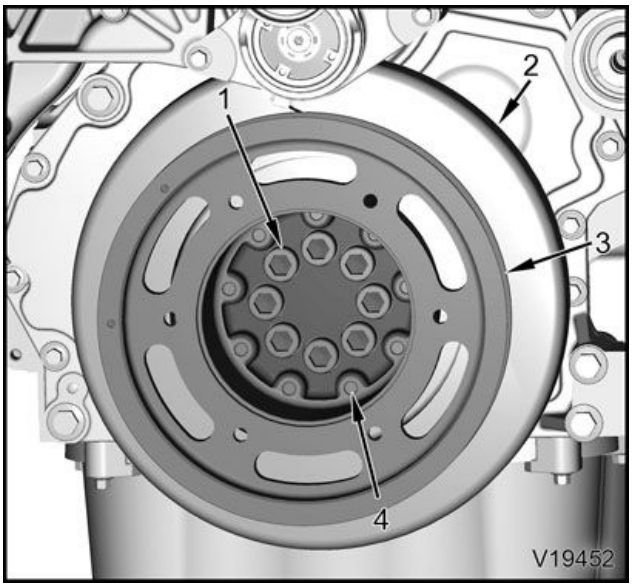


Figure 461 Vibration damper (high mount fan with fan drive pulley)

1. M16 x 85 socket-head cap screw (8)
2. Vibration damper
3. Fan drive pulley
4. M10 x 35 bolt (9)

⚠ WARNING: To prevent personal injury or death, support the vibration damper when removing bolts. The damper can easily slide off the crankshaft.

NOTE: If equipped with high mount fan, remove fan drive pulley and vibration damper together. If equipped with low mount fan, remove damper hub and vibration damper together.

1. Remove eight M16 x 85 socket-head cap screws.
2. Remove vibration damper with damper hub or fan drive pulley as an assembly.
3. For vibration damper replacement only, remove damper hub or fan drive pulley by removing nine M10 x 35 bolts.

Coolant Control Valve (CCV) Assembly

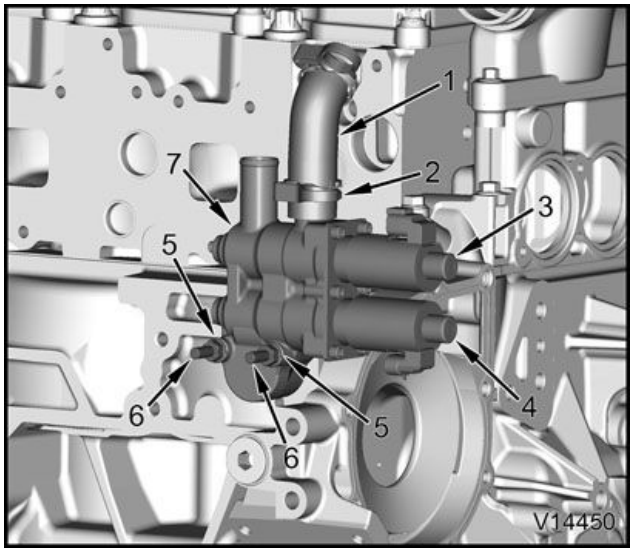


Figure 462 CCV assembly

1. Low temperature hose assembly
2. Hose clamp (spring type)
3. Coolant Mixer Valve (CMV)
4. Coolant Flow Valve (CFV)
5. Lock washer (2)
6. M8 x 60 stud bolt (2)
7. CCV assembly

1. Release hose clamp (spring type) and remove low temperature hose assembly from CCV assembly.
2. Remove two M8 x 60 stud bolts, two lock washers, CCV assembly and O-ring. Discard O-ring.

Thermostat Housing

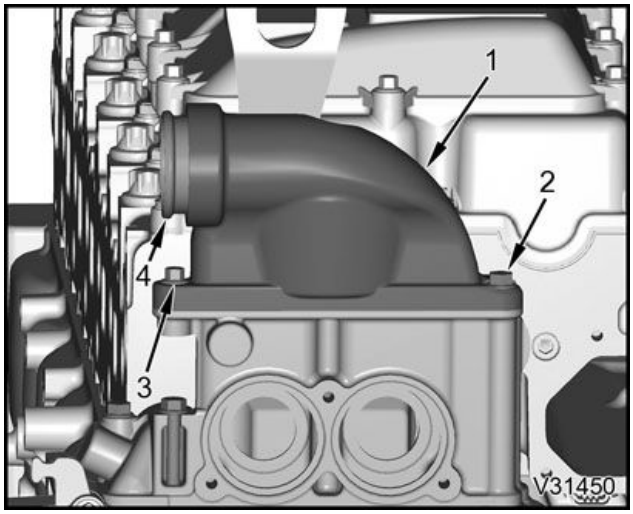


Figure 463 EGR cooler return manifold

1. EGR cooler return manifold
2. M8 x 145 bolt (4)
3. M8 x 30 bolt
4. Extension tube (DMR62 / 51)

CAUTION: To prevent engine damage, do not remove extension tubes by grabbing sealing surface.

1. Remove extension tube (DMR62 / 51) from manifold. Inspect extension tube for damage, replace as needed.
2. Remove four M8 x 145 bolts and one M8 x 30 bolt.
3. Remove EGR cooler return manifold and discard gasket.

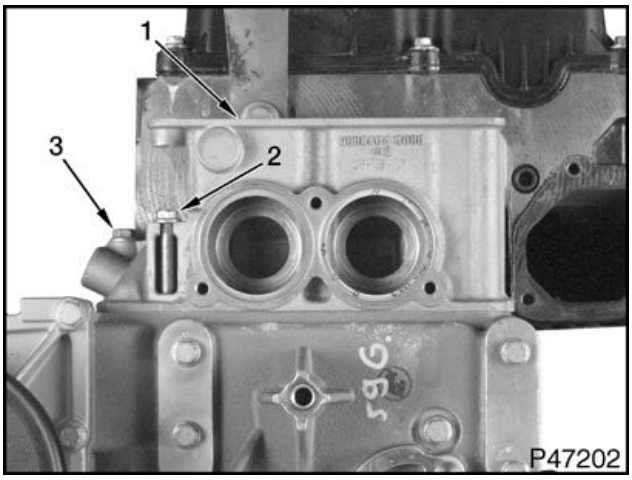


Figure 464 Thermostat housing

1. Thermostat housing
2. M8 x 75 bolt
3. M8 x 60 bolt

4. Remove M8 x 75 bolt and M8 x 60 bolt.
5. Remove thermostat housing and discard gasket.

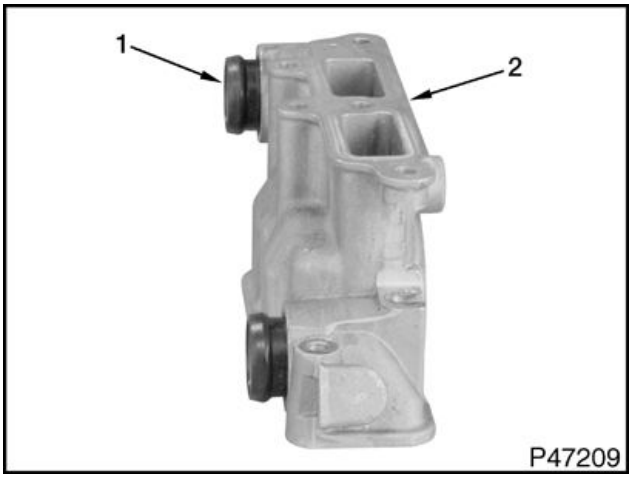


Figure 465 Thermostat housing

1. Extension tube (DMR40 / DN32F) (2)
2. Thermostat housing

CAUTION: To prevent engine damage, do not remove extension tubes by grabbing sealing surface with pliers or other tools that can mar the surface.

6. Remove two extension tubes (DMR40 / DN32F) from thermostat housing using a wood-handled tool. Gently pry the extension tubes out until removed. Inspect extension tubes for damage, replace as needed.

Water Distribution Housing

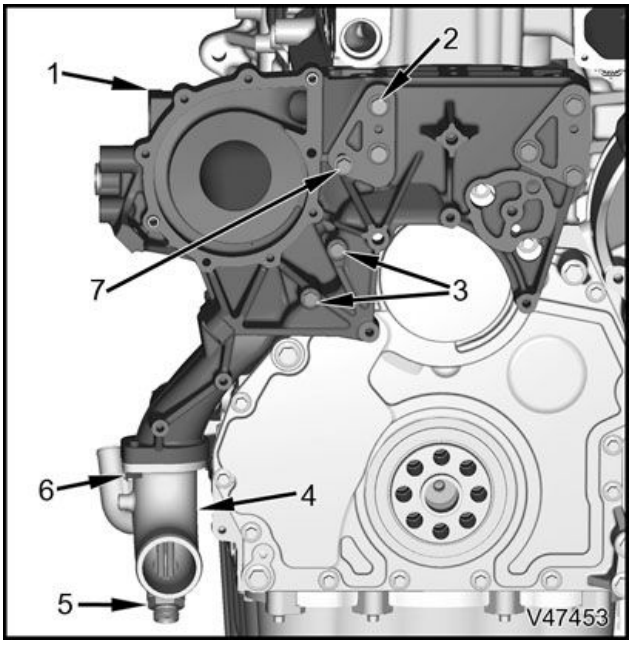


Figure 466 Water distribution housing

1. Water distribution housing
2. M10 x 110 bolt with low mount fan drive or M10 x 150 - 12.9 bolt with high mount fan drive (5)
3. M8 x 150 bolt (2)
4. Engine water inlet (94°)
5. Coolant heater
6. M10 x 30 bolt (2)
7. M10 x 65 bolt (only with high mount fan)

1. Remove two M8 x 150 bolts.
   - If equipped with low mount fan drive, five M10 x 110 bolts.
   - If equipped with high mount fan drive, five M10 x 150 - 12.9 bolts and one M10 x 65 bolt. (These bolts are removed with high mount fan drive clutch assembly removal.)
2. Remove water distribution housing and discard gasket.

3. Remove two M10 x 30 bolts and separate engine water inlet from water distribution housing. Remove and discard gasket.
4. Remove coolant heater from engine water inlet as needed.

Front Belt- or Gear-Driven Fan Cover Radial Shaft Seal

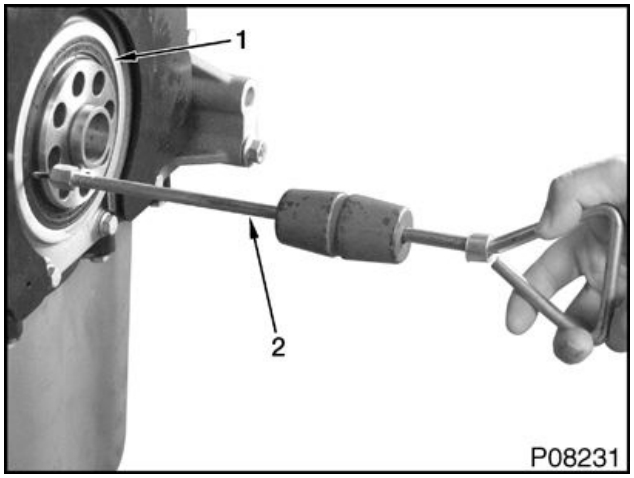


Figure 467 Radial shaft seal removal

1. Radial shaft seal
2. Slide hammer

WARNING: To prevent personal injury or death, wear safety glasses with side shields when doing the following procedure.

1. With an awl and hammer, punch two holes 180° apart in front oil seal.
2. Thread a slide hammer (page 340) with correct size screw in one of the two holes.
3. Slide hammer until one side of seal begins to pull out of cover. Move slide hammer to other hole and repeat until front oil seal is removed.

Front Belt- or Gear-Driven Fan Cover

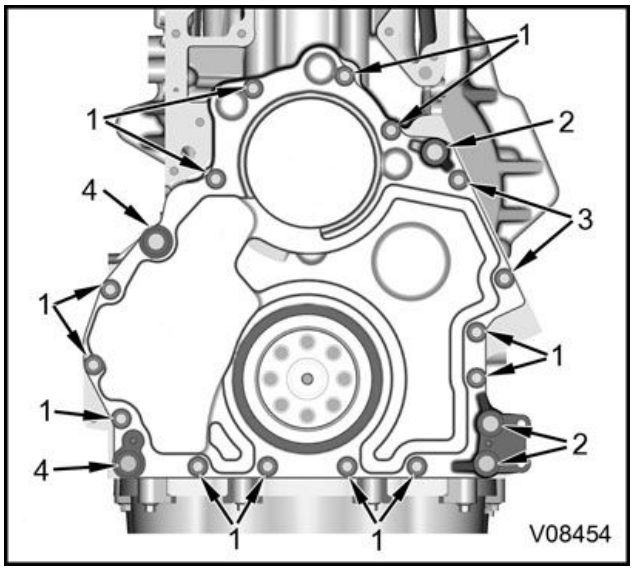


Figure 468 Front belt- or gear-driven fan cover bolts (high mount cover shown)

1. M8 x 25 bolt (13)
2. M12 x 75 bolt (3)
3. M8 x 40 bolt (2)
4. M12 x 30 bolt (2)

WARNING: To prevent personal injury or death, use a suitable lifting device and get help when removing, lowering and installing the front cover.

1. Remove two M8 x 40 bolts, two M12 x 30 bolts, three M12 x 75 bolts and 13 M8 x 25 bolts.
2. Remove front belt- or gear-driven fan cover and front cover gasket from crankcase dowels. Discard front cover gasket.

Radial Shaft Seal (Fan Low Mount Drive)

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 radial shaft seal.

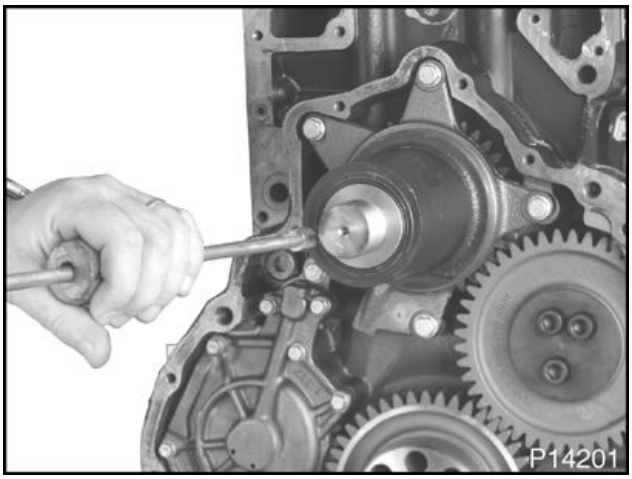


Figure 469 Radial shaft seal removal

2. Thread a slide hammer (page 340) with correct size screw in one of the two holes.
3. Slide hammer until one side of seal begins to pull out of fan drive. Move slide hammer to other hole and repeat until radial shaft seal is removed. Discard radial shaft seal.

Fan Low Mount Drive Assembly

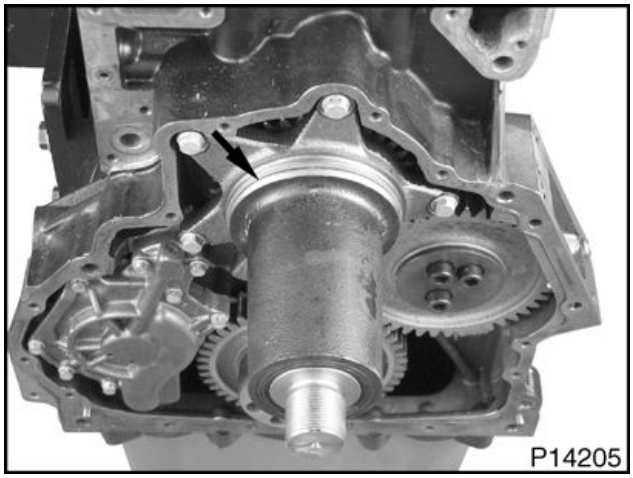


Figure 470 O-ring 108 x 3

1. Remove and discard O-ring 108 x 3.

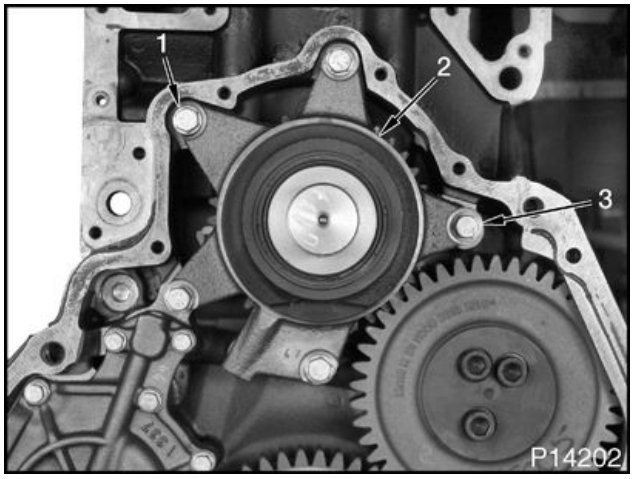


Figure 471 Fan low mount drive assembly

1. M8 x 25 bolt (4)
2. Fan low mount drive assembly
3. M8 x 40 bolt

2. Remove four M8 x 25 bolts, one M8 x 40 bolt and fan low mount drive assembly.

Cleaning, Inspection and Testing

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

1. Clean water distribution housing, water pump, coolant outlet manifold, thermostat housing and front belt- or gear-driven fan cover with a suitable non-caustic solvent.
2. Blow parts dry using filtered compressed air.
3. Clean coolant and oil seal mating surfaces on the crankcase, cylinder head, water distribution housing, water pump assembly, coolant outlet manifold, thermostat housing and front belt- or gear-driven fan cover.
4. Inspect water distribution housing, coolant outlet manifold, vibration damper and front belt- or gear-driven fan cover for damage, contamination or excessive wear. Replace parts if required.
5. Inspect belt automatic tensioners and pulleys to make sure tensioner arms and pulleys are properly in line with the fan drive belt and accessory drive belt and not coming apart. Make sure tensioner arms are not binding and pulley bearings are not loose. Replace belt tensioners if required.
6. Inspect idler pulleys to make sure pulleys are properly in line with the fan drive belt and accessory drive belt and not coming apart. Replace idler pulleys if required.
7. Inspect thermostat assemblies. If thermostat assembly elements are stuck open, damaged, cracked or not opening properly, replace thermostat assemblies.
8. Inspect water pump assembly. Wiggle water pump assembly hub and shaft. If water pump assembly bearing has excess play, replace water pump assembly. Inspect water distribution housing and water pump assembly for coolant leaks. Replace if leaking.

Installation

Fan Low Mount Drive Assembly

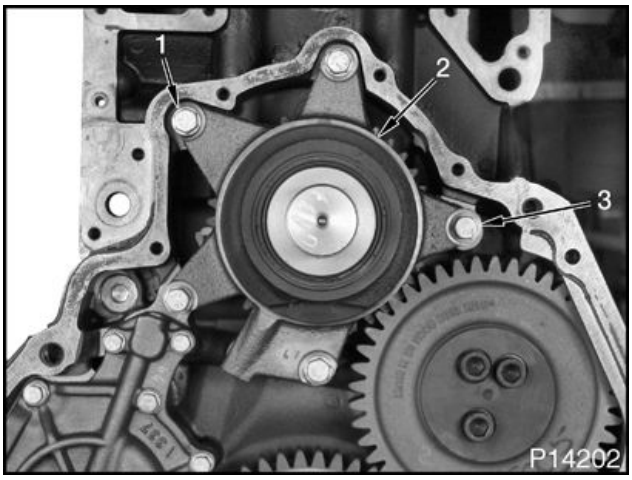


Figure 472 Fan low mount drive assembly

1. M8 x 25 bolt (4)
2. Fan low mount drive assembly
3. M8 x 40 bolt

1. Install fan low mount drive, M8 x 40 bolt and four M8 x 25 bolts. Tighten bolts to standard torque (page 503).

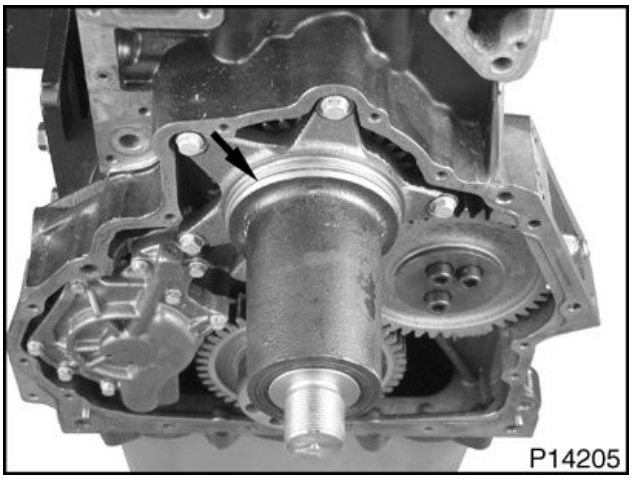


Figure 473 O-ring 108 x 3

2. Lubricate new O-ring 108 x 3 with clean engine oil and install on fan low mount drive assembly.

Radial Shaft Seal (Fan Low Mount Drive)

1. Lubricate radial shaft seal with clean engine oil.

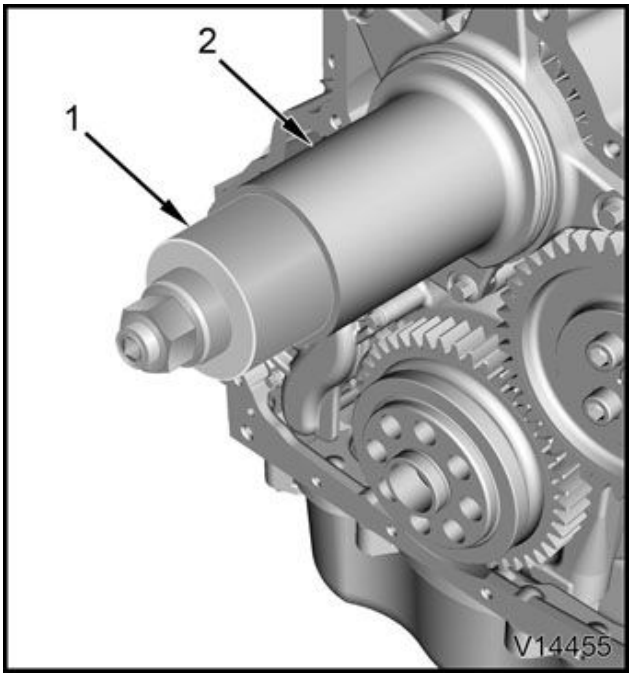


Figure 474 Radial shaft seal installation

1. Fan Seal Installer
2. Fan low mount drive assembly

2. Using Fan Seal Installer (page 340), install new radial shaft seal until fully seated.

Front Belt- or Gear-Driven Fan Cover

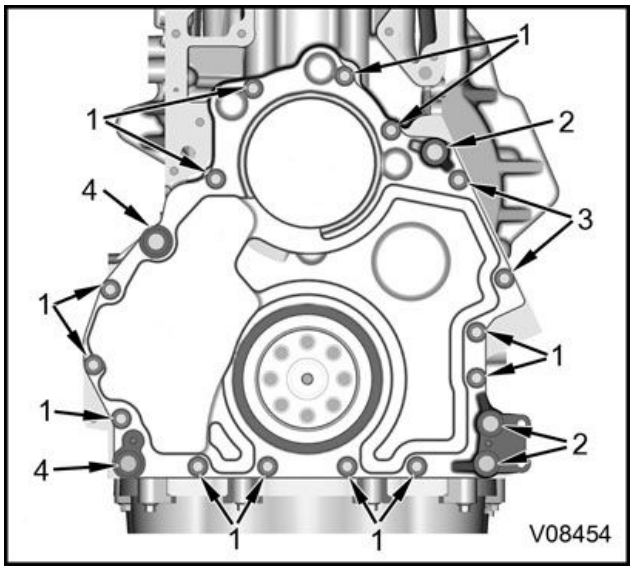


Figure 475 Front belt- or gear-driven fan cover bolts (typical)

1. M8 x 25 bolt (13)
2. M12 x 75 bolt (3)
3. M8 x 40 bolt (2)
4. M12 x 30 bolt (2)

WARNING: To prevent personal injury or death, use a suitable lifting device and get help when removing, lowering and installing the front cover.

1. Position a new front cover gasket on crankcase dowels.
2. Install front cover on crankcase dowels.
3. Install two M8 x 40 bolts, two M12 x 30 bolts, three M12 x 75 bolts and 13 M8 x 25 bolts in locations shown. Tighten M8 bolts to standard torque (page 503). Tighten M12 bolts to special torque (page 340).

Front Belt- or Gear-Driven Fan Cover Radial Shaft Seal

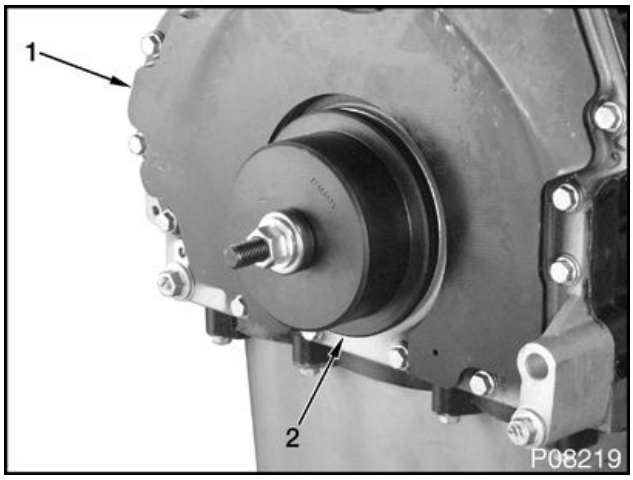


Figure 476 Radial shaft seal installation (typical)

1. Front belt- or gear-driven fan cover
2. Front Crankshaft Seal Installer

CAUTION: To avoid damage to the radial shaft seal, do not touch inner seal lip, allow oil or grease on any part of the seal during installation.

1. Using Front Crankshaft Seal Installer (page 340), install a new radial shaft seal into the front cover.
   a. Install inner hub of tool to crankshaft flange. Use two bolts provided to secure tool.
   b. Install radial shaft seal to inner hub of tool.
   c. Install pressing hub and nut and tighten to install radial shaft seal. When tool bottoms out, seal is fully installed.

Water Distribution Housing

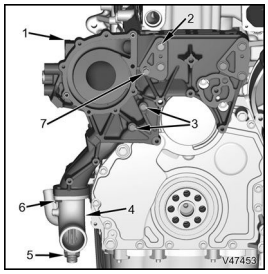


Figure 477 Water distribution housing

1. Water distribution housing
2. M10 x 110 bolt with low mount fan drive or M10 x 150 bolt - 12.9 with high mount fan drive (5)
3. M8 x 150 bolt (2)
4. Engine water inlet (94°)
5. Coolant heater
6. M10 x 30 bolt (2)
7. M10 x 65 bolt (only with high mount fan)

1. Install coolant heater into engine water inlet as needed. Tighten to special torque (page 340).
2. Install new gasket and install engine water inlet and two M10 x 30 bolts to water distribution housing. Tighten bolts to special torque (page 340).
3. Lubricate a new water distribution housing gasket with clean coolant and install into water distribution housing.
4. Install water distribution housing and secure as follows:
   - If equipped with low mount fan drive, use five M10 x 110 bolts.
   - If equipped with high mount fan drive, use five M10 x 150 - 12.9 bolts and one M10 x 65 bolt. (These bolts are installed with high mount fan drive clutch assembly installation.)

   Tighten low mount fan drive bolts to special torque (page 340).

Thermostat Housing

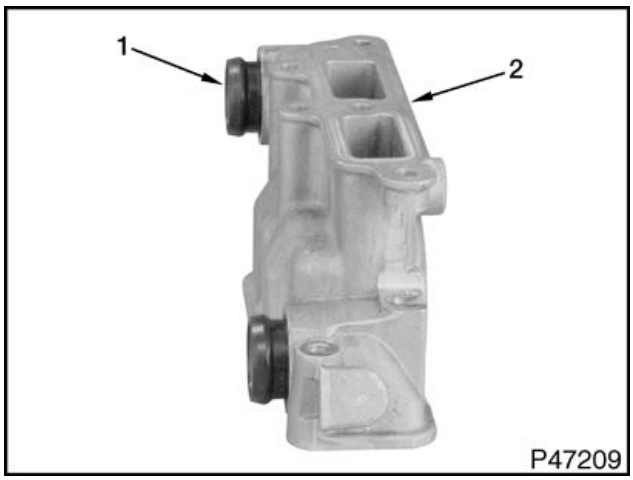


Figure 478 Thermostat housing

1. Extension tube (DMR40 / DN32F) (2)
2. Thermostat housing

1. Lubricate sealing surfaces of two extension tubes (DMR40 / DN32F) with P-80® rubber lubricant or equivalent (page 340) and install into thermostat housing using Extension Tube Installer Small (page 340).

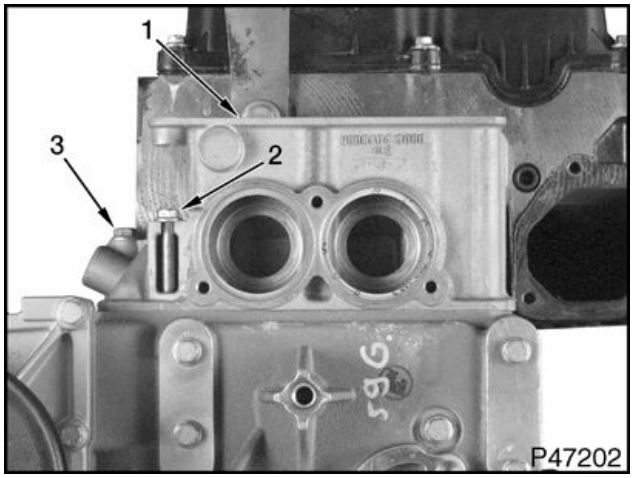


Figure 479 Thermostat housing

1. Thermostat housing
2. M8 x 75 bolt
3. M8 x 60 bolt

2. Install new gasket and thermostat housing.

3. Install M8 x 75 bolt and M8 x 60 bolt. Do not tighten bolts until EGR cooler return manifold is installed.

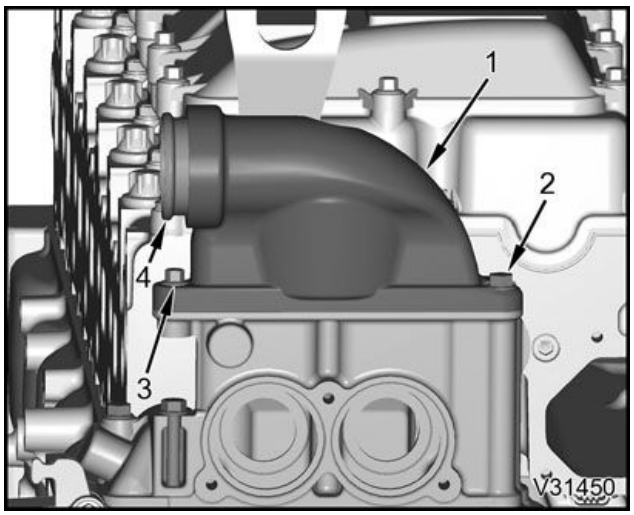


Figure 480 EGR cooler return manifold

1. EGR cooler return manifold
2. M8 x 145 bolt (4)
3. M8 x 30 bolt
4. Extension tube (DMR62 / 51)

4. Install new thermostat housing gasket and EGR cooler return manifold.
5. Install four M8 x 145 bolts and one M8 x 30 bolt. Tighten bolts to special torque (page 340).
6. Tighten M8 x 75 and M8 x 60 thermostat housing bolts to standard torque (page 503).
7. Lubricate sealing surfaces of extension tube (DMR62 / 51) with P-80® rubber lubricant or equivalent (page 340) and install into EGR cooler return manifold using Extension Tube Installer Large (page 340).

Coolant Control Valve (CCV) Assembly

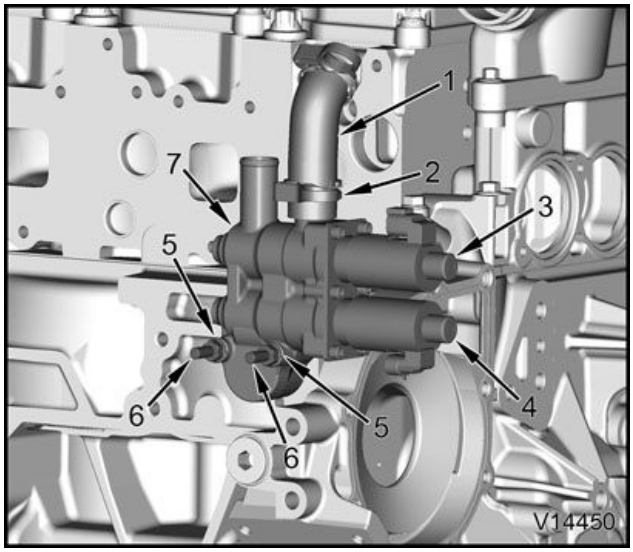


Figure 481 CCV assembly

1. Low temperature EGR hose assembly
2. Hose clamp (spring type)
3. Coolant Mixer Valve (CMV)
4. Coolant Flow Valve (CFV)
5. Lock washer (2)
6. M8 x 60 stud bolt (2)
7. CCV assembly

1. Install a new O-ring on the CCV assembly.
2. Install CCV assembly, two lock washers and two M8 x 60 stud bolts. Tighten stud bolts to special torque (page 340).
3. Install low temperature hose assembly and secure with hose clamp (spring type).

Vibration Damper

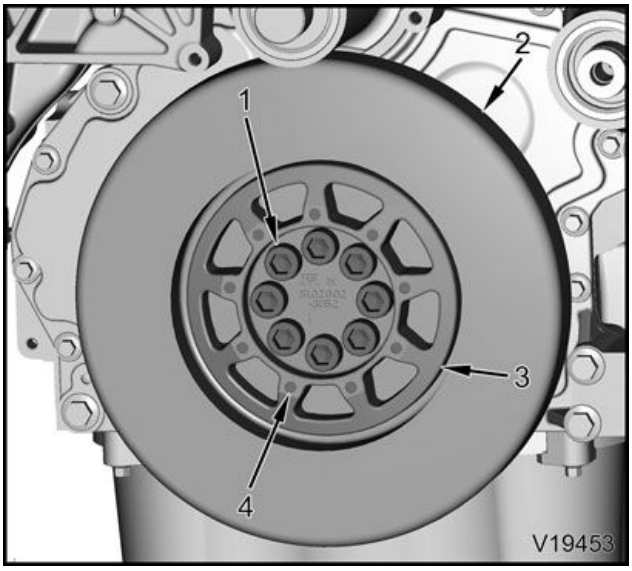


Figure 482 Vibration damper (low mount fan with damper hub)

1. M16 x 85 socket-head cap screw (8)
2. Vibration damper
3. Damper hub
4. M10 x 35 bolt (9)

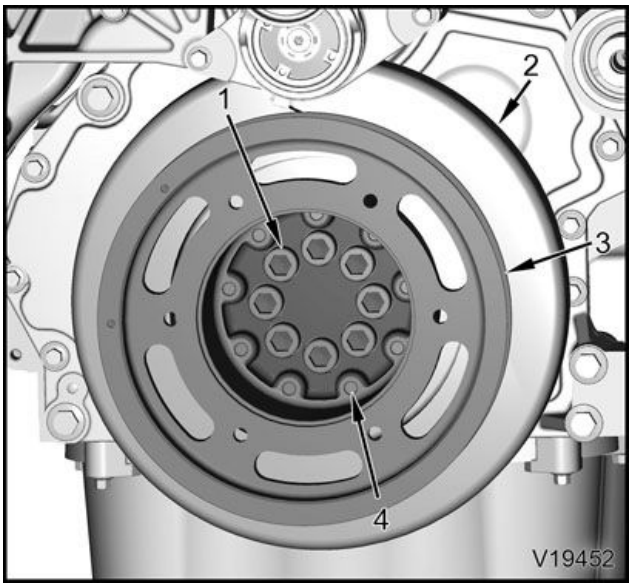


Figure 483 Vibration damper (high mount fan with fan drive pulley)

1. M16 x 85 socket-head cap screw (8)
2. Vibration damper
3. Fan drive pulley
4. M10 x 35 bolt (9)

NOTE: Install damper hub or fan drive pulley and vibration damper together as an assembly.

1. If previously disassembled, assemble damper hub or fan drive pulley to vibration damper with nine M10 x 35 bolts. Tighten bolts to special torque (page 340).
2. Install vibration damper assembly.
3. Install eight M16 x 85 socket-head cap screws. Using a crisscross pattern, tighten screws as follows.
   a. Tighten socket-head cap screws to 150 N·m (111 lbf·ft).
   b. Angle-tighten socket-head cap screws an additional 90°.

Water Pump Assembly and Pulley

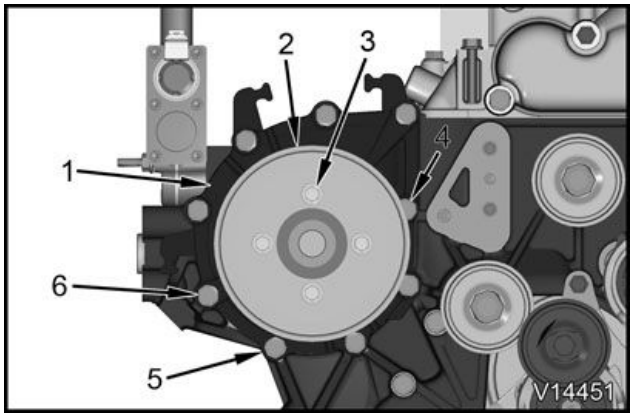


Figure 484 Water pump assembly and pulley

1. Water pump assembly
2. Water pump pulley
3. M8 x 16 bolt (4)
4. M8 x 130 bolt
5. M8 x 150 bolt
6. M8 x 40 bolt (7)

NOTE: If the oil module is removed, the M8 x 150 bolt is installed along with oil module.

1. Lubricate a new water pump gasket with clean coolant and install onto water pump.
2. Install water pump and secure with one M8 x 130, one M8 x 150 and seven M8 x 40 bolts in location shown. Tighten M8 bolts to special torque (page 340).
3. Install water pump pulley and four M8 x 16 bolts. Tighten bolts to special torque (page 340).

Automatic Belt Tensioner and Idler Pulley

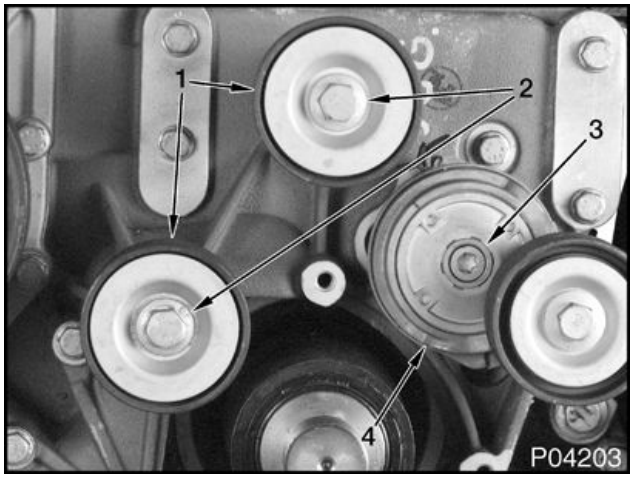


Figure 485 Automatic belt tensioner and idler pulley (typical)

1. Idler pulley (2)
2. M12 x 55 bolt (2)
3. M10 x 70 countersunk screw
4. Automatic belt tensioner

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

1. Install automatic belt tensioner and M10 x 70 countersunk screw. Make sure locating pin is placed into locating hole. Tighten countersunk screw to special torque (page 340).
2. Install two idler pulleys and two M12 x 55 bolts. Tighten bolts to special torque (page 340).

Coolant Outlet Manifold and Thermostat Assembly

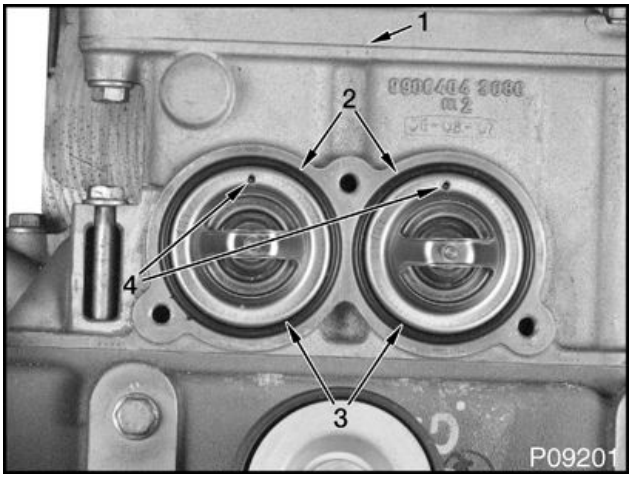


Figure 486 Thermostat assembly

1. Thermostat housing
2. Seals (part of thermostat assembly) (2)
3. Thermostat assembly (2)
4. Ball valves (part of thermostat assembly)

1. Install two thermostat assemblies into thermostat housing with ball valves at 12 o'clock position.

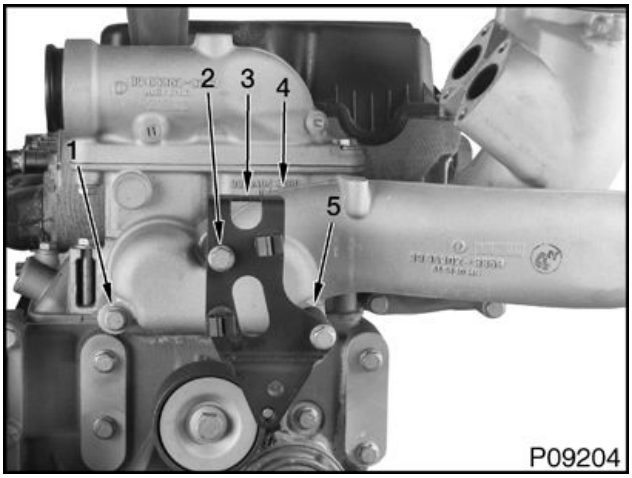


Figure 487 Coolant outlet manifold (low mount fan)

1. M8 x 70 bolt
2. M8 x 130 bolt (2)
3. Fan coupling bracket
4. Coolant outlet manifold
5. Bushing (2)

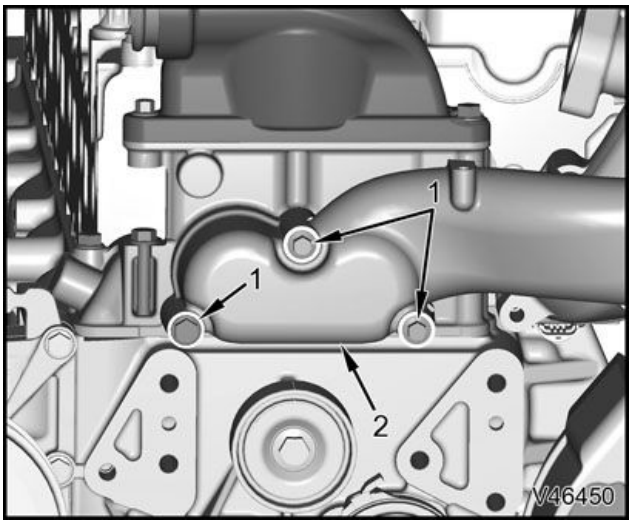


Figure 488 Coolant outlet manifold (high mount fan)

1. M8 x 70 bolt (3)
2. Coolant outlet manifold

2. Install coolant outlet manifold.
3. If equipped with low mount fan, install bracket and two bushings.
4. Install coolant outlet manifold bolts as follows.
   a. If equipped with low mount fan, install one M8 x 70 bolt and two M8 x 130 bolts. Tighten bolts to special torque (page 340).
   b. If equipped with high mount fan, install three M8 x 70 bolts. Tighten bolts to special torque (page 340).

High Mount Fan Drive

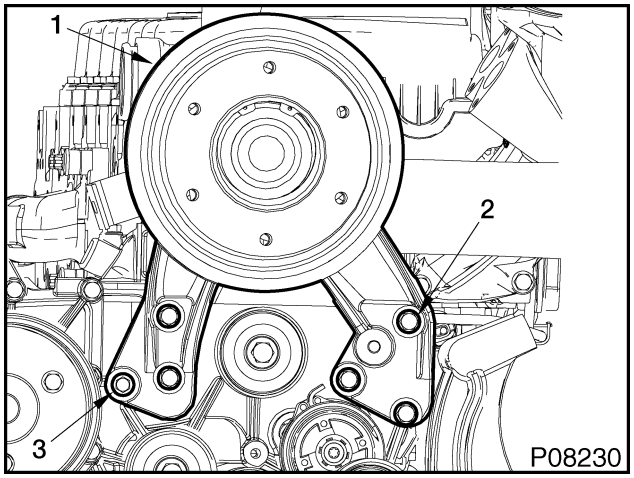


Figure 489 Fan drive clutch assembly (typical)

1. Fan drive clutch assembly
2. M10 x 150 - 12.9 bolt (5)
3. M10 x 65 bolt

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.

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

1. Using filtered compressed air, clean thread holes of fan drive clutch assembly.
2. Install fan drive clutch assembly and five new M10 x 150 - 12.9 and one new M10 x 65 bolt with engine oil lightly applied to threads.

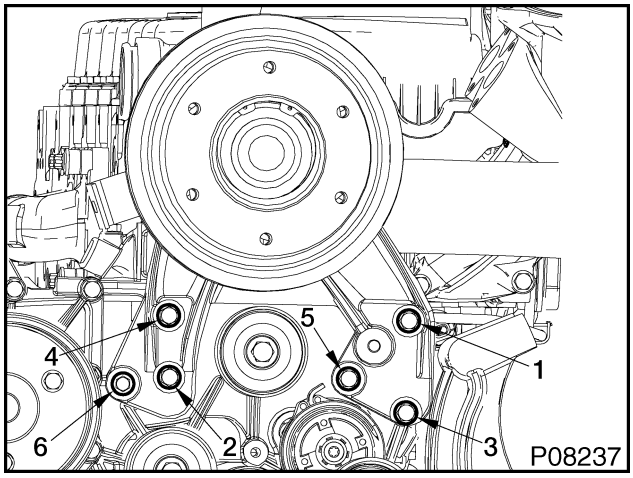


Figure 490 High mount fan drive bolt tightening sequence

3. Tighten M10 bolts using sequence indicated above as follows.
   a. Tighten six M10 bolts to 37 N·m (27 lbf·ft).
   b. Re-tighten six bolts to 37 N·m (27 lbf·ft).
   c. Angle-tighten five M10 x 150 - 12.9 bolts an additional 90° in sequence.
   d. Tighten M10 x 65 bolt to 62 N·m (46 lbf·ft).
4. Connect air line to back of fan drive clutch assembly.

Tensioner Bracket (High Mount Fan)

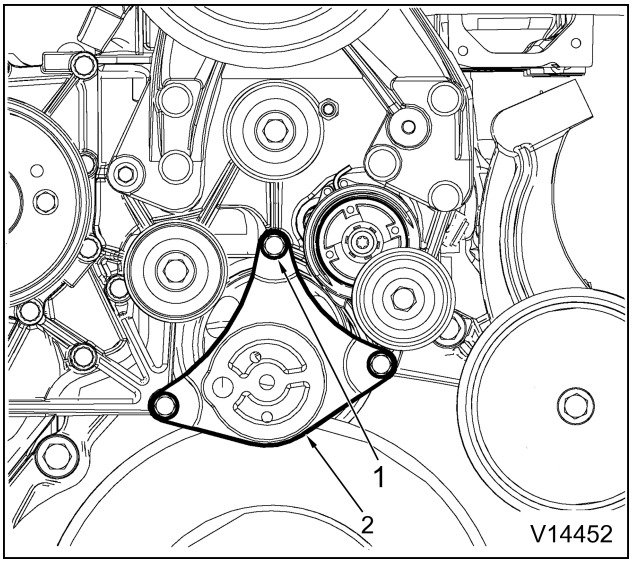


Figure 491 Tensioner bracket

1. M8 x 30 bolt (3)
2. Tensioner bracket

1. Install tensioner bracket and three M8 x 30 bolts. Tighten bolts to standard torque (page 503).

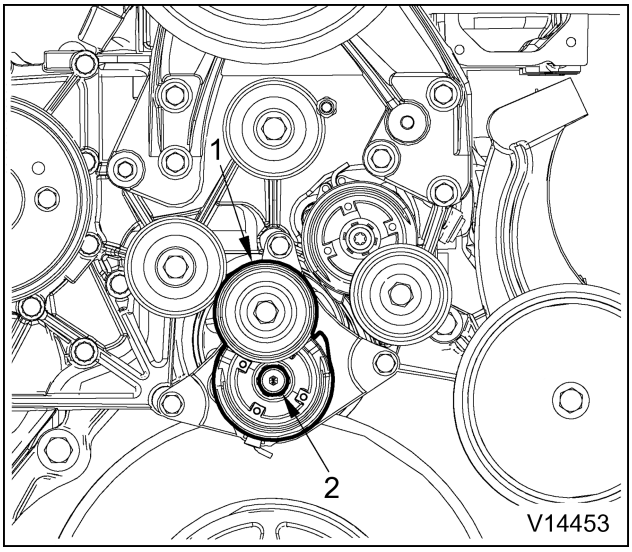


Figure 492 Fan drive tensioner assembly (high mount)

1. Fan drive tensioner assembly
2. M10 x 70 countersunk screw

2. Install fan drive tensioner and M10 x 70 countersunk screw. Make sure locating pin is placed into locating hole. Tighten countersunk screw to special torque (page 340).

Pulley (High Mount Fan)

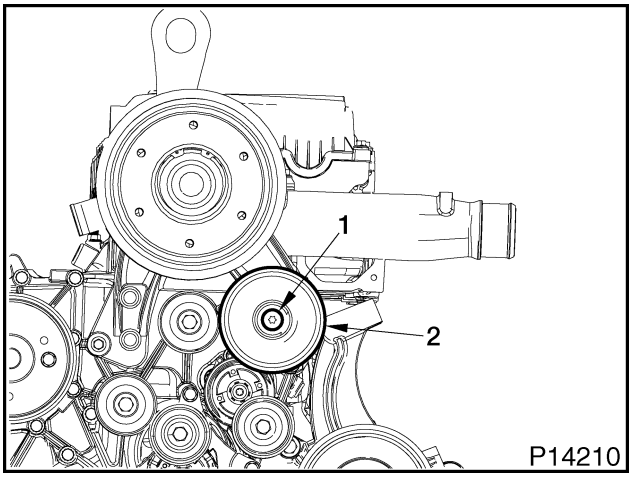


Figure 493 Pulley assembly

1. Shoulder bolt
2. Pulley assembly

1. Install pulley assembly and shoulder bolt. Tighten shoulder bolt to special torque (page 340).

Special Torque

Table 25 Front Cover, Fan Drive, Cooling System and Related Components

Automatic belt tensioner countersunk screw, M10 x 70	47 N·m (35 lbf·ft)
CCV assembly stud bolts (with lock washers), M8 x 60	35 N·m (26 lbf·ft)
Coolant heater	41 N·m (30 lbf·ft)
Coolant outlet manifold bolts, M8	35 N·m (26 lbf·ft)
Damper hub and fan drive pulley bolts to vibration damper, M10 x 35	45 N·m (33 lbf·ft)
EGR cooler return manifold bolts, M8	35 N·m (26 lbf·ft)
Engine water inlet bolts, M10 x 30	29 N·m (21 lbf·ft)
Front belt- or gear-driven fan cover bolts,	
• M12 x 75	115 N·m (85 lbf·ft)
• M12 x 30	115 N·m (85 lbf·ft)
High mount fan drive clutch assembly bolts, M10	See tightening steps in procedure
High mount fan drive tensioner countersunk screw, M10 x 70	47 N·m (35 lbf·ft)
High mount fan pulley assembly shoulder bolt	62 N·m (46 lbf·ft)
Idler pulley bolt, M12 x 55	60 N·m (44 lbf·ft)
Low mount fan drive bolt, M10 x 110	37 N·m (27 lbf·ft)
Vibration damper socket-head cap screws, M16 x 85	See tightening steps in procedure
Water distribution housing bolts, M8	35 N·m (26 lbf·ft)
Water pump assembly bolts, M8	35 N·m (26 lbf·ft)
Water pump pulley bolts, M8 x 16	17 N·m (13 lbf·ft)

Special Service Tools

Table 26 Front Cover, Fan Drive, Cooling System and Related Components

Description	Tool Number
Extension Tube Installer Large	ZTSE6046
Extension Tube Installer Small	ZTSE6047
Fan Seal Installer	ZTSE6066
Front Crankshaft Seal Installer	ZTSE4873
P-80® rubber lubricant or equivalent	Obtain locally
Slide hammer	Obtain locally

Table of Contents

Exploded Views.....343
- **MaxxForce® Engine Brake Housing Assembly**.....344
- **Engine Injector Wiring Harness With Engine Brake Solenoid Leads**.....345

Removal.....346
- **Engine Brake Housing Assembly**.....346

Disassembly.....346
- **Solenoid**.....347
- **Control Valve**.....347
- **Master Piston**.....348
- **Slave Piston**.....348

Cleaning and Inspection.....350
- **Solenoid Assembly Check**.....350

Assembly.....351
- **Slave Piston**.....351
- **Master Piston**.....352
- **Control Valve**.....353
- **Solenoid**.....353

Installation.....354
- **Engine Brake Housing Assembly**.....354
- **Engine Brake Lash Adjustment**.....355

Specifications.....356

Special Torque.....356

Special Service Tools.....356

Exploded Views

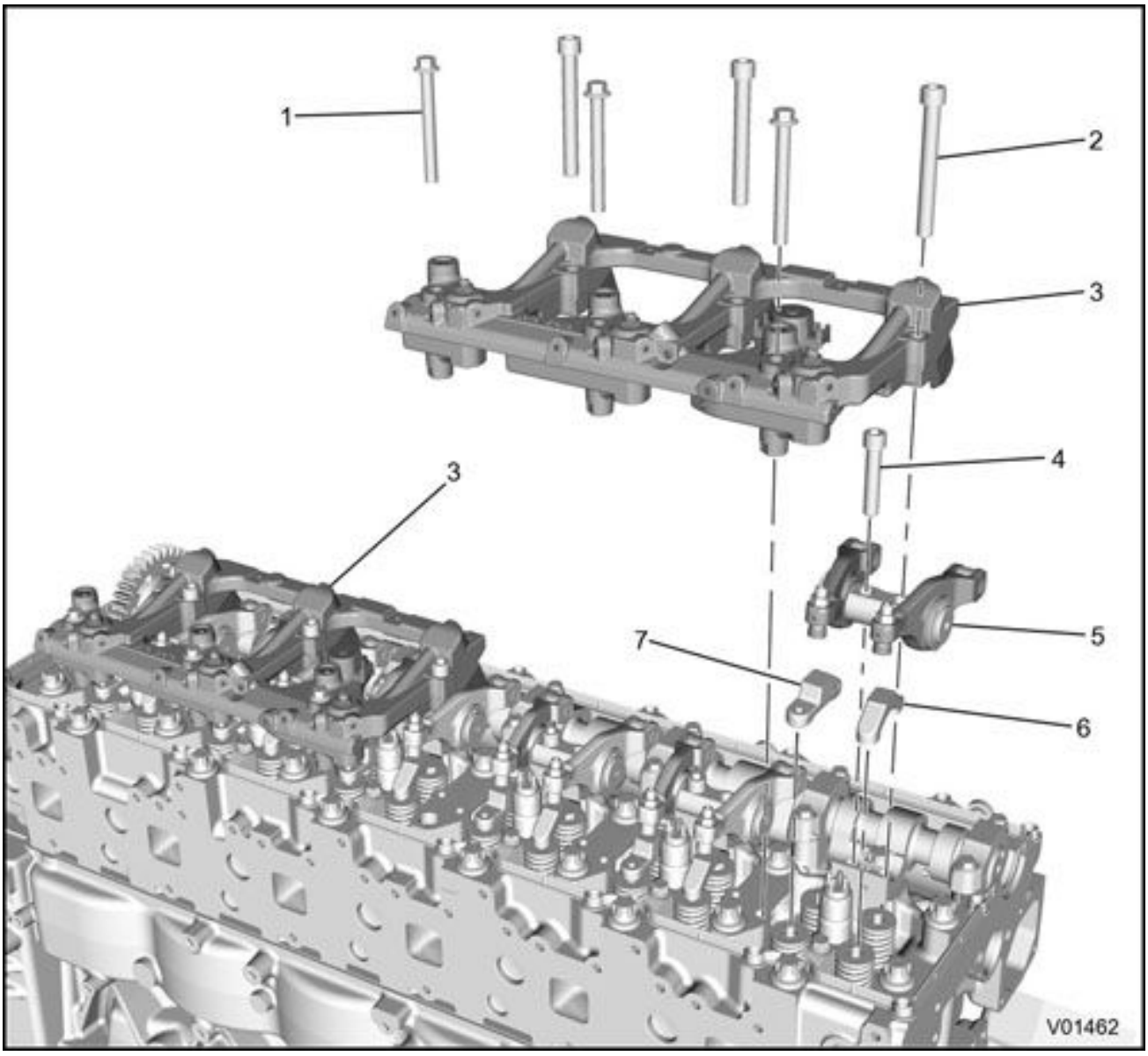


Figure 494 MaxxForce® engine brake assembly installation

1. M10 x 90 bolt (6)
2. M12 x 100 (socket-head) screw (6)
3. Engine brake housing assembly (2)
4. M12 x 60 (socket-head) screw (6)
5. Intake and exhaust rocker arm assembly (6)
6. Valve bridge (intake) (6)
7. Valve bridge (exhaust) (6)

MaxxForce® Engine Brake Housing Assembly

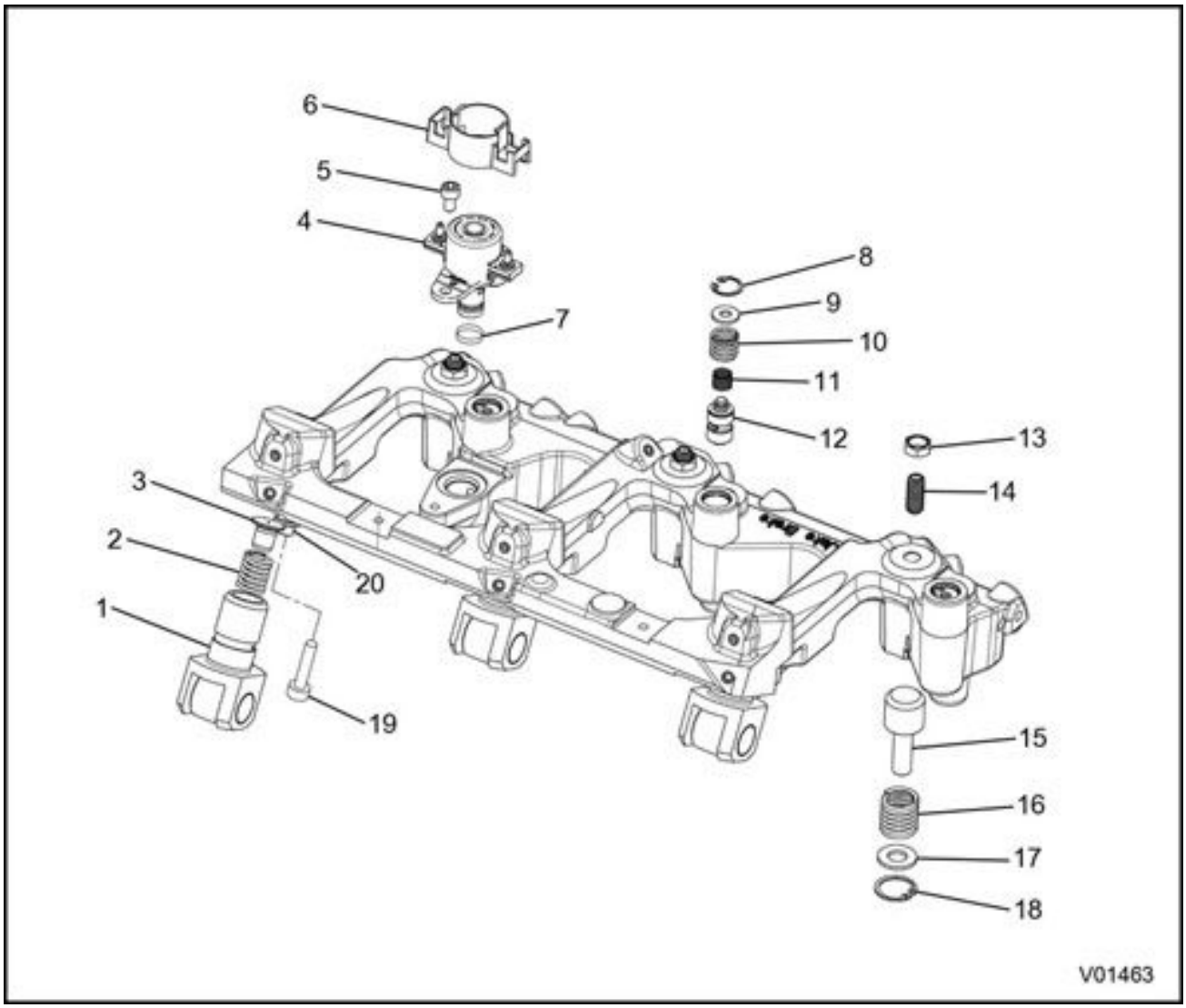


Figure 495 MaxxForce® engine brake housing assembly

1. Master piston roller assembly
2. Master piston roller spring
3. Master piston spring guide
4. Solenoid assembly
5. M6 x 10 socket-head cap screw
6. Solenoid cover
7. Solenoid screen
8. Control valve retaining ring
9. Control valve cover
10. Outer spring
11. Inner spring
12. Control valve assembly
13. M10 (jam) nut
14. Slave piston adjusting screw
15. Slave piston
16. Slave piston spring
17. Slave piston washer
18. Slave piston retaining ring
19. M6 x 30 master piston guide bolt
20. Master piston guide sleeve

Engine Injector Wiring Harness With Engine Brake Solenoid Leads

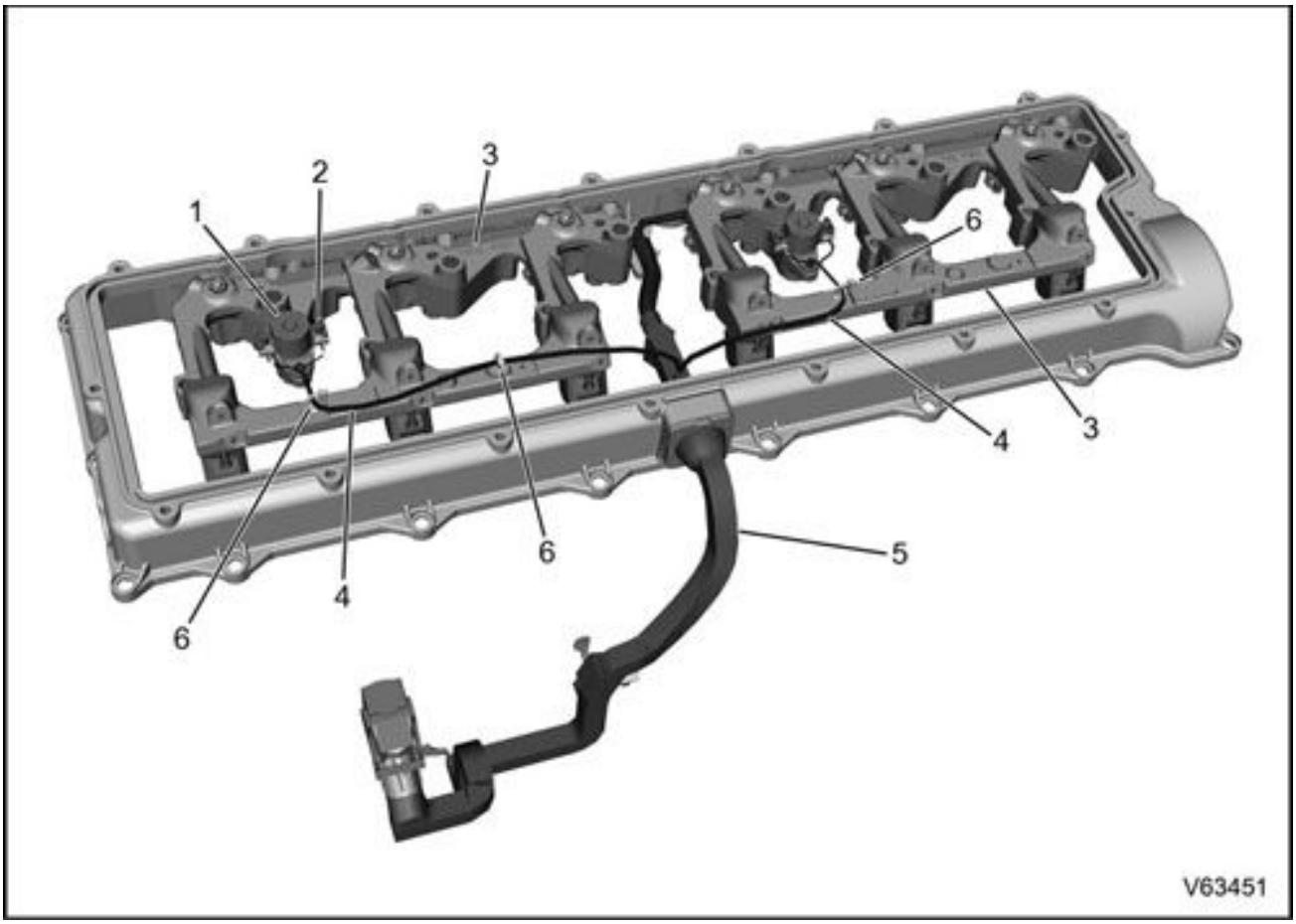


Figure 496 Engine injector wiring harness with engine brake solenoid leads

1. Solenoid assembly (2)
2. Solenoid connector nut (part of harness connector) (4)
3. Engine brake assembly (2)
4. Engine brake solenoid harness connector lead (2)
5. Engine injector harness assembly
6. Tie strap (3)

Removal

Engine Brake Housing Assembly

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, 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, disconnect the main battery negative terminal before disconnecting or connecting electrical components.

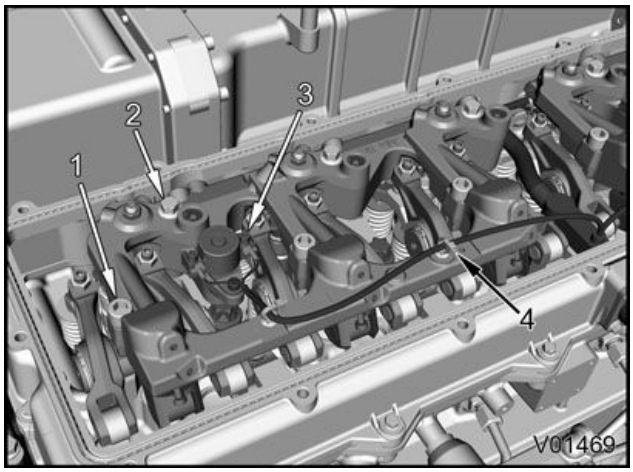


Figure 497 Engine brake assembly

1. M12 x 100 (socket-head) screw (6)
2. M10 x 90 bolt (6)
3. Solenoid connector nut (4)
4. Tie strap (3)

1. Remove upper valve cover. See Upper Valve Cover and Base (page 367).
2. Disconnect brake wiring harness connector leads from solenoid by disengaging two connector nuts on each front and rear engine brake housing assemblies. The connector nuts are retained by the harness connectors.
3. Cut tie straps securing solenoid harness connector leads on front and rear brake housings. Position leads out of the way.
4. Mark housings to indicate front and rear to insure they are reinstalled later in the correct locations.
5. Remove three M12 x 100 socket-head screws and three M10 x 90 bolts and remove front engine brake housing assembly from cylinder head.
6. Repeat step 5 to remove rear brake housing assembly.

Disassembly

NOTE: When disassembling the engine brake housing, keep all component parts together in sets and if reused, reinstall each set back in its original location.

Solenoid

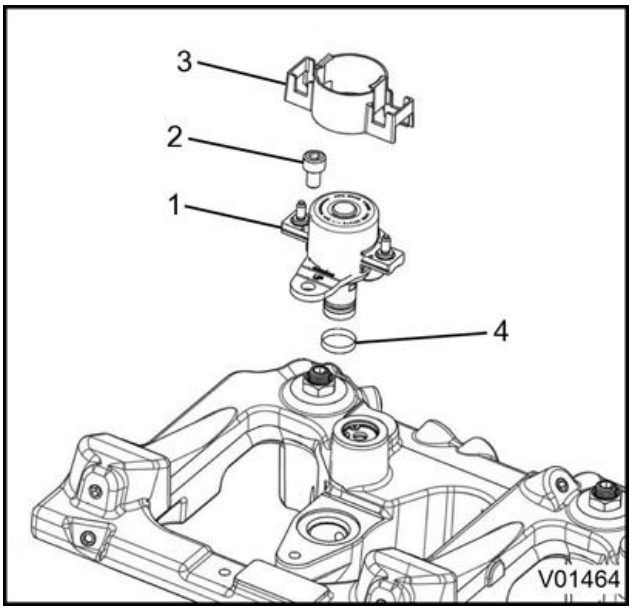


Figure 498 Solenoid

1. Solenoid assembly
2. M6 x 10 socket-head cap screw
3. Solenoid cover
4. Solenoid screen

1. If not already done, loosen connector nuts and disconnect harness connector leads from solenoid.
2. Remove M6 x 10 socket-head cap screw.

NOTE: Cover slides over solenoid and locks onto terminal ends. Cover is removed with solenoid as an assembly.

3. Remove solenoid and cover from brake housing.
4. Remove upper and lower seal rings from solenoid stem. Discard seal rings.
5. Remove and discard solenoid screen.

Control Valve

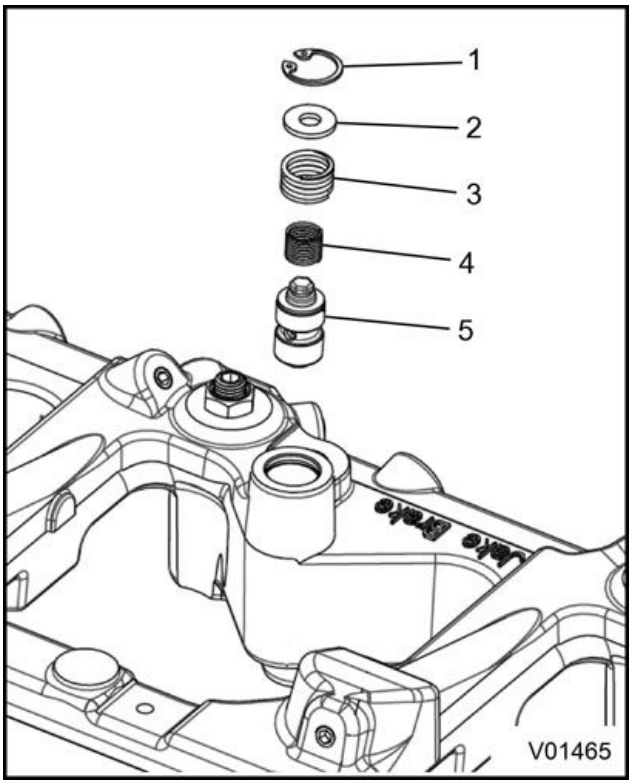


Figure 499 Control valve

1. Control valve retaining ring
2. Control valve cover
3. Outer spring
4. Inner spring
5. Control valve assembly

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

NOTE: Use same procedure to remove all control valves from engine.

1. Push down on control valve cover and hold to remove spring pressure from control valve retaining ring. Using suitable snap-ring pliers, remove control valve retaining ring from housing control valve bore. Slowly release control valve cover to relieve spring pressure.
2. Remove control valve cover from valve bore.
3. Using a pick, carefully remove inner and outer springs from bore.

4. Using a magnet or needle-nose pliers, remove control valve from housing bore.

Master Piston

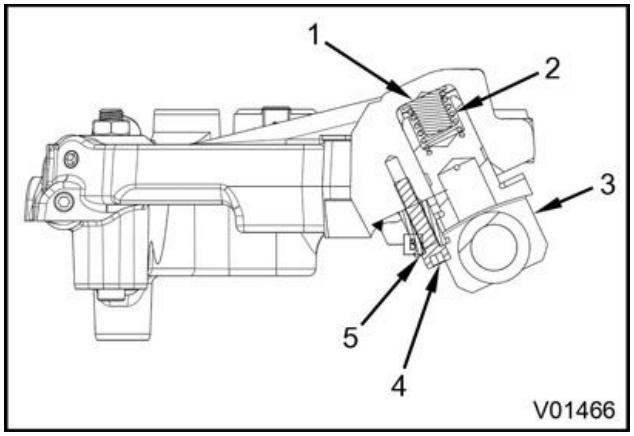


Figure 500 Master piston

1. Master piston spring guide
2. Master piston roller spring
3. Master piston roller assembly
4. M6 x 30 master piston guide bolt
5. Master piston guide sleeve

The master piston group currently is not a serviceable part. If a fault condition is traced to a malfunctioning master piston, replace brake housing assembly.

Slave Piston

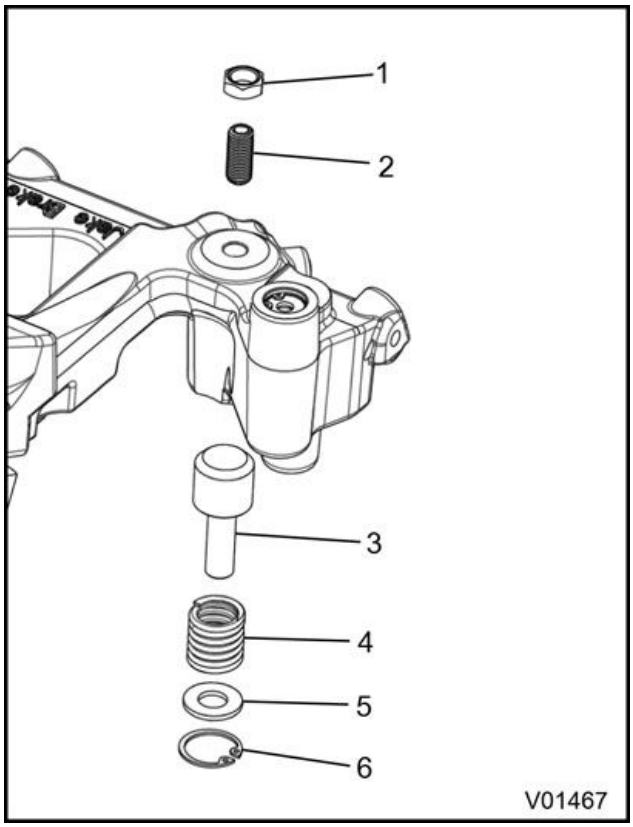


Figure 501 Slave piston

1. M10 (jam) nut
2. Slave piston adjusting screw
3. Slave piston
4. Slave piston spring
5. Slave piston washer
6. Slave piston retaining ring

WARNING: To prevent personal injury or death, use Jacobs® Slave Piston Removal Tool to remove or install slave piston. Slave piston springs are under heavy compression.

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

1. Remove M10 jam nut and back out slave piston adjusting screw until slave piston is fully retracted.

Use same procedure to remove all slave pistons from the engine.

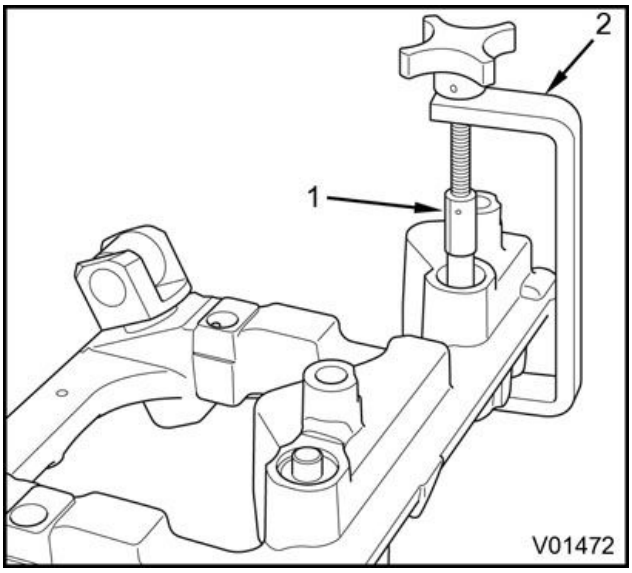


Figure 502 Slave Piston Removal Tool

1. Clamp screw collar
2. Slave Piston Removal Tool

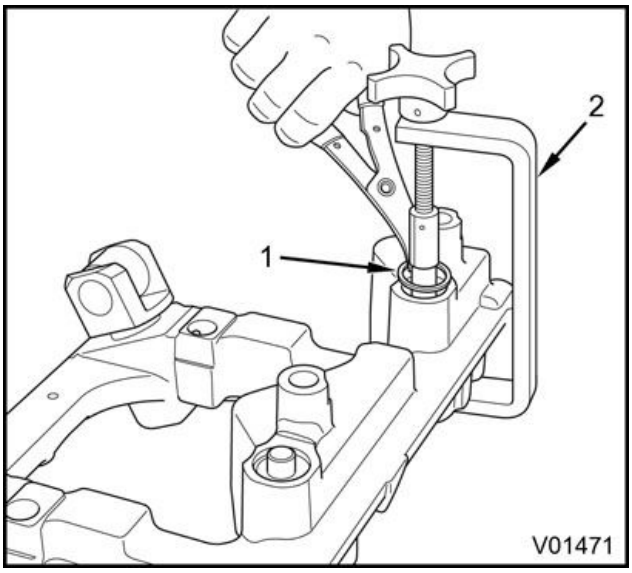


Figure 503 Slave piston retaining ring

1. Slave piston retaining ring
2. Slave Piston Removal Tool

2. Place Jacobs® Slave Piston Removal Tool in position with hole in tool clamp bracket over slave piston adjusting screw and clamp screw collar over slave piston stem.
3. Slowly tighten clamp screw until collar contacts slave piston washer. Continue tightening clamp screw to compress slave piston spring and relieve spring pressure against slave piston retaining ring.

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

4. Using snap-ring pliers, remove slave piston retaining ring from piston bore.
5. Slowly loosen tool clamp screw to release slave piston spring pressure and remove tool.
6. Grasp piston stem and remove slave piston, spring and washer.
7. Remove slave piston adjusting screw.

Cleaning and Inspection

Solenoid Assembly Check

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

1. Clean brake housings, control valve assemblies, master piston rollers, slave pistons and springs with a suitable non-caustic solvent.
2. Blow parts dry using filtered compressed air.
3. Inspect brake housings for cracks. Replace as required.
4. Check for missing or loose pipe plugs at sides and ends of brake housings. If pipe plugs are missing or loose, replace brake housing assembly.
5. Inspect master piston rollers and associated camshaft lobes for excessive wear, spalling and galling. Replace complete brake housing assembly if any master piston roller is determined unacceptable to reuse. If camshaft lobes for engine brake have excessive wear, spalling or galling, replace camshaft.
6. Inspect slave pistons, springs and control valve assembly for worn or damaged parts. Replace parts that are broken or deformed.
7. Inspect slave piston bores in brake housing. Insert slave pistons in respective bores and check for free movement without binding. If there is binding, replace brake housing assembly.
8. Inspect control valve assembly bores in brake housing. Insert control valve assemblies in respective bores and check for free movement without binding. If there is binding, replace brake housing assembly.

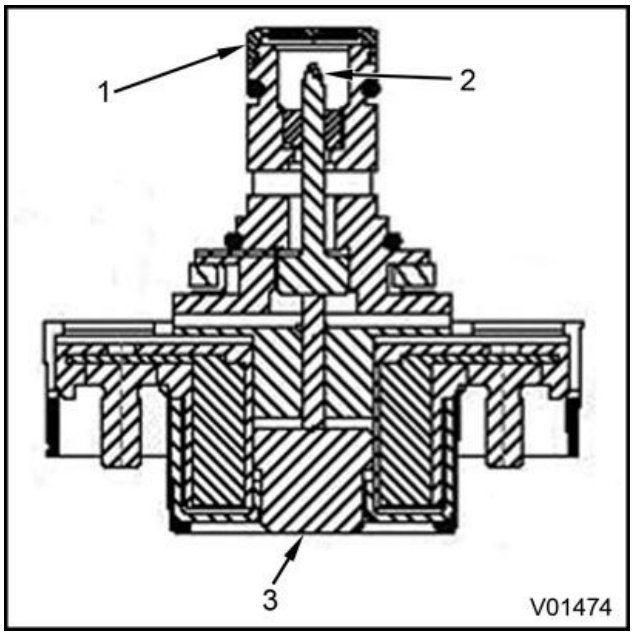


Figure 504 Solenoid assembly check

1. Solenoid screen (removed for check)
2. Pin
3. Button of armature

9. Hold solenoid assembly upside down in hand so you can look into the end where the solenoid screen was removed. Move button of armature with finger while looking into the open end to verify pin moves freely within the solenoid assembly. If pin does not move freely, replace solenoid.
10. Using an ohmmeter, check solenoid assembly resistance per the following steps:
    - Check resistance across the two terminals. If resistance is out of specification (page 356), replace solenoid assembly.
    - Check resistance from each terminal to the solenoid can. This should be an “open circuit.” If a resistance is measured, replace solenoid assembly.

Assembly

Slave Piston

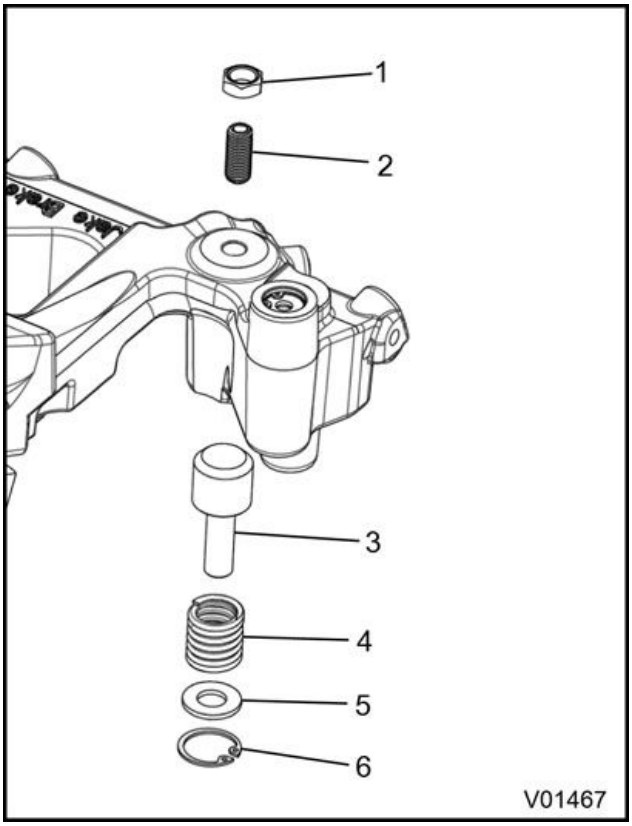


Figure 505 Slave piston

1. M10 (jam) nut
2. Slave piston adjusting screw
3. Slave piston
4. Slave piston spring
5. Slave piston washer
6. Slave piston retaining ring

1. Check that housing slave piston bore is clean, free of any residue and debris.
2. Lubricate slave piston, spring and washer with clean engine oil.
3. Assemble slave piston spring, washer and retaining ring on slave piston stem.
4. Insert slave piston, spring and washer assembly into housing bore.

NOTE: Retaining ring with proper orientation must be placed on stem before using Jacobs® Slave Piston Removal Tool to compress spring in housing bore.

WARNING: To prevent personal injury or death, use Jacobs® Slave Piston Removal Tool to remove or install slave piston. Slave piston springs are under heavy compression.

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

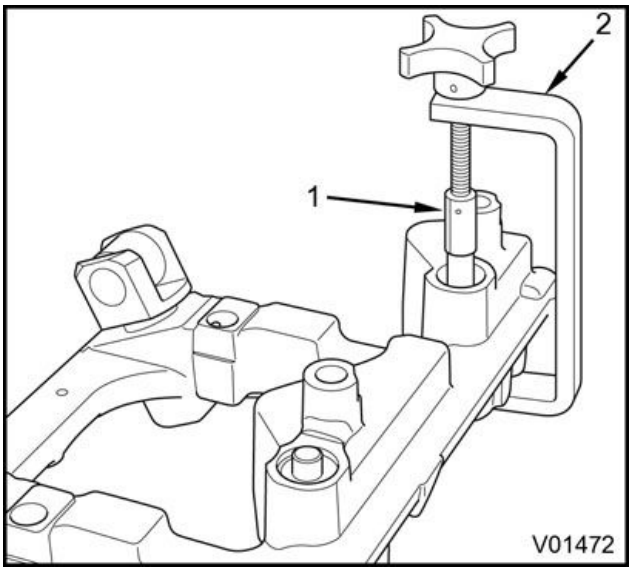


Figure 506 Slave Piston Removal Tool

1. Clamp screw collar
2. Slave Piston Removal Tool

5. Place slave piston retaining ring, oriented with sharp side up (away from washer), in position over slave piston stem. Install Jacobs® Slave Piston Removal Tool with clamp screw collar on slave piston stem.
6. Slowly tighten clamp screw until screw collar contacts slave piston washer. Continue tightening clamp screw to compress piston spring until washer is approximately 1/32 inch below retaining ring groove.

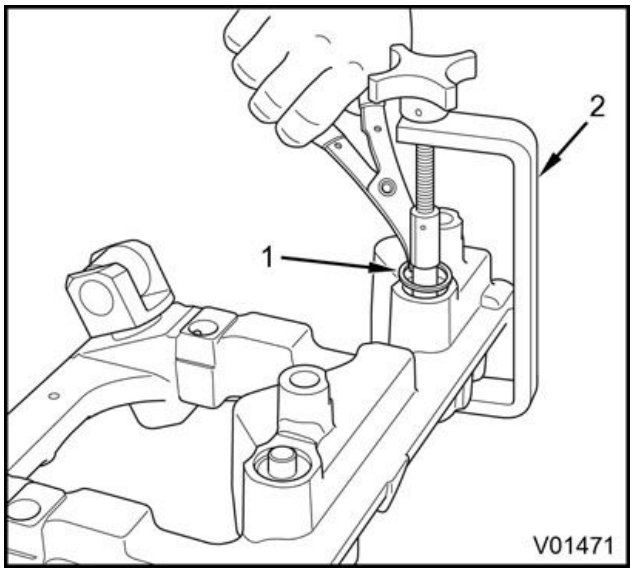


Figure 507 Slave Piston Removal Tool

1. Slave piston retaining ring
2. Slave Piston Removal Tool

7. Using snap-ring pliers, install slave piston retaining ring in bore ring groove. Ensure retaining ring is oriented with sharp side up (away from washer). Rotate retaining ring to ensure that it is properly seated in groove.
8. Slowly loosen tool clamp screw to release piston spring pressure and remove tool.
9. Install slave piston adjusting screw and jam nut. Do not tighten jam nut.

Master Piston

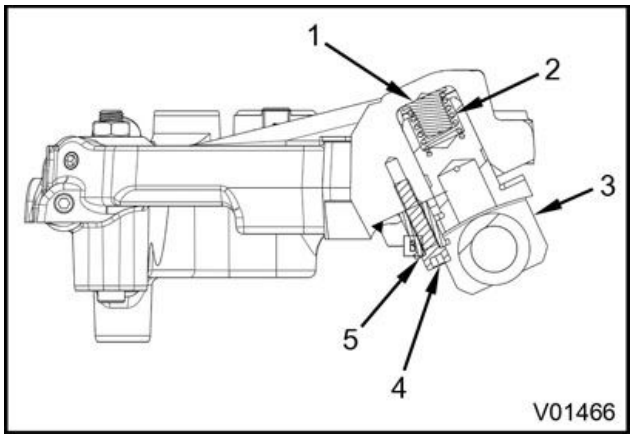


Figure 508 Master piston

1. Master piston spring guide
2. Master piston roller spring
3. Master piston roller assembly
4. M6 x 30 master piston guide bolt
5. Master piston guide sleeve

The master piston group currently is not a serviceable part. If a fault condition is traced to a malfunctioning master piston, replace brake housing assembly.

Control Valve

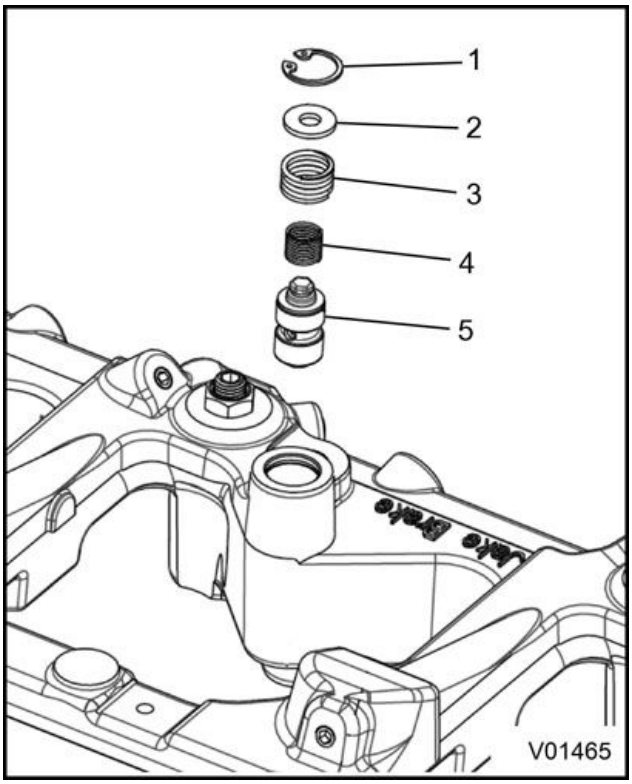


Figure 509 Control valve

1. Control valve retaining ring
2. Control valve cover
3. Outer spring
4. Inner spring
5. Control valve assembly

1. Check that housing control valve bore is clean, free of any residue and debris.
2. Lubricate control valve assembly and springs with clean engine oil.
3. With hex stud end up, insert control valve assembly into housing bore. Ensure control valve assembly moves smoothly and freely down bore.
4. Insert inner and outer springs into bore. Make sure that springs are properly seated with inner spring on control valve and outer spring on step of control valve bore.
5. Install control valve cover over springs.

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

6. Using snap-ring pliers, install control valve retaining ring in housing bore to contain control valve assembly. Ensure retaining ring is installed with sharp side up (away from control valve cover). Rotate retaining ring to insure that it is properly seated in groove.

Solenoid

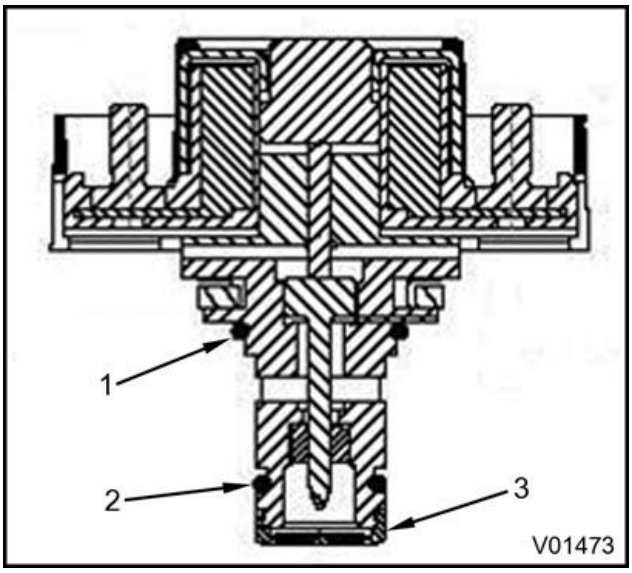


Figure 510 Solenoid seal rings

1. Upper seal ring
2. Lower seal ring
3. Solenoid screen

1. Install new upper and lower seal rings in ring grooves on solenoid stem. Lubricate seal rings with clean engine oil.
2. Clip solenoid screen on bottom of solenoid stem.

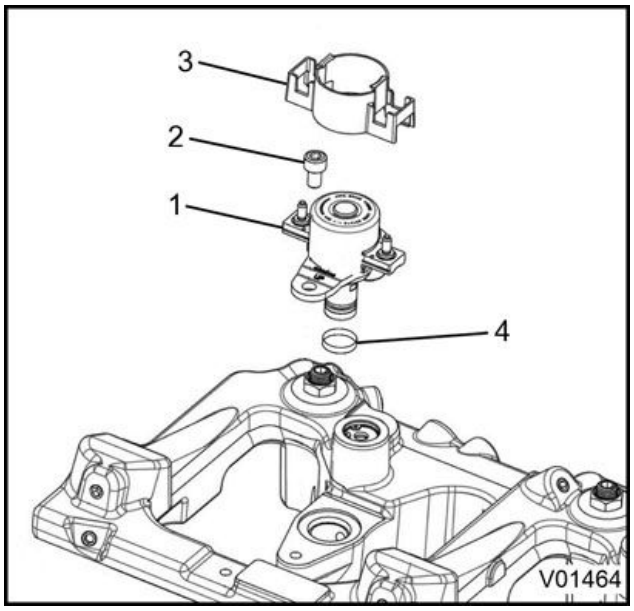


Figure 511 Solenoid

1. Solenoid assembly
2. M6 x 10 socket-head cap screw
3. Solenoid cover
4. Solenoid screen

3. Place solenoid in position on brake housing. Using hand pressure, press solenoid into bore until it snaps into place.
4. If removed, install solenoid cover on solenoid.
5. Install M6 x 10 socket-head cap screw. Tighten screw to special torque (page 356).

Installation

Engine Brake Housing Assembly

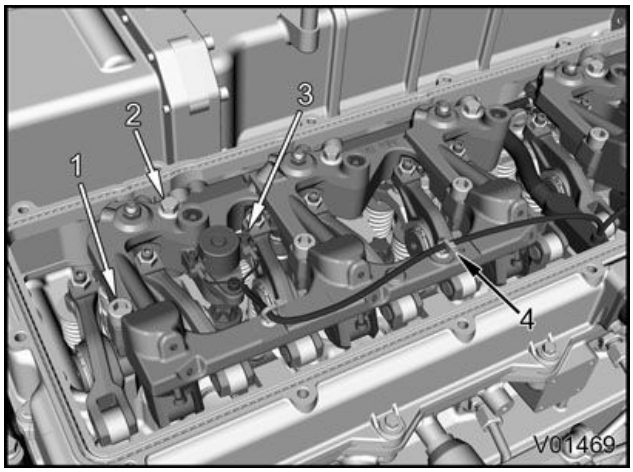


Figure 512 Engine brake assembly

1. M12 x 100 (socket-head) screw (6)
2. M10 x 90 bolt (6)
3. Solenoid connector nut (4)
4. Tie strap (3)

1. Carefully place previously marked front engine brake housing assembly in front position over camshaft and valve train.
2. Install three M12 x 100 socket-head screws and three M10 x 90 bolts. Tighten bolts to special torque (page 356).
3. Repeat steps 1 and 2 to install previously marked rear engine brake housing assembly in rear position over camshaft and valve train.

CAUTION: To prevent engine damage, do not over torque nuts on wiring harness connector leads. Too much torque will damage solenoid terminals.

4. Connect brake wiring harness connector leads to solenoid on front and rear engine brake housing assemblies. Make sure harness terminal connectors are in straight alignment with harness. Hold terminal connectors stationary to avoid twisting and tighten connector nuts to special torque (page 356).
5. Install two tie straps to secure solenoid harness connector lead on front brake housing and one tie strap to secure harness connector lead on rear brake housing.

6. Adjust engine brake lash. See Engine Brake Lash Adjustment (page 355).
7. Install upper valve cover. See Upper Valve Cover and Base (page 386).

Engine Brake Lash Adjustment

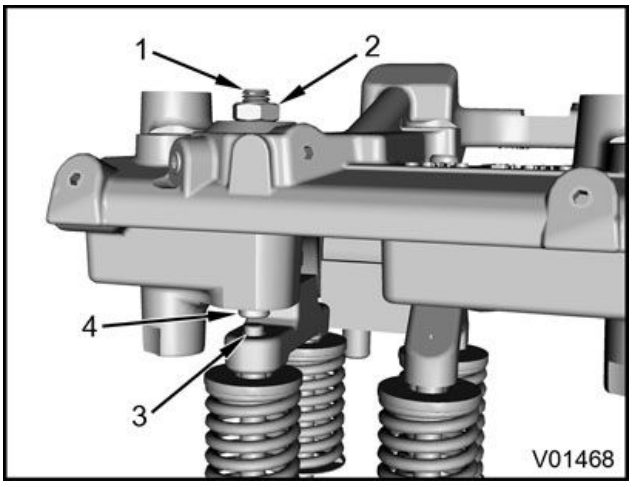


Figure 513 Engine brake lash adjustment

1. Slave piston adjusting screw
2. M10 (jam) nut
3. Actuator pin (in exhaust valve bridge)
4. Slave piston

See Valve Lash Adjustment (page 365) for procedure covering both valve lash and engine brake lash adjustments on engines so equipped.

Specifications

Table 27 Engine Brake

Solenoid resistance:	
Cold — 25 ° C (77 ° F)	8.7–10 ohms
Hot — 121 ° C (250 ° F)	12–15.5 ohms

Special Torque

Table 28 Engine Brake

Brake housing M10 x 90 bolt	75 N·m (55 lbf·ft)
Brake housing M12 x 100 (socket-head) screw	105 N·m (77 lbf-ft)
Brake housing solenoid harness connector nut	3.5 N·m (31 lbf·in)
Slave piston adjusting screw M10 (jam) nut	25 N·m (18 lbf·ft)
Solenoid M6 x 10 socket-head cap screw	12.5 N·m (110 lbf·in)

Special Service Tools

Table 29 Engine Brake

Description	Tool Number
Jacobs® Slave Piston Removal Tool	ZTSE6068

Table of Contents

Exploded Views.....359
- **Valve Cover and Base.....359**
- **Non-Brake Rocker Arm Assembly And Valve Bridges.....360**
- **Camshaft and Cylinder Head Idler Gear.....361**
- **Cylinder Head.....362**

Periodic Service.....363
- **Crankshaft Rotation Procedure.....363**
- **Cylinder No. 1 TDC Procedure.....363**
- **Valve Overlap Procedure.....364**
- **Valve Lash Adjustment Procedure.....364**

Removal.....367
- **Upper Valve Cover and Base.....367**
- **Rocker Arm Assembly (Non-Brake Engine).....368**
- **Camshaft.....369**
- **Cylinder Head.....372**
- **Cylinder Head Idler Gear.....374**

Cleaning, Inspection, and Testing.....376
- **Cylinder Head and Crankcase Components.....376**
- **Camshaft Bearings.....376**
- **Fuel Injector Bore.....377**
- **Valves Leak Test.....377**

Installation.....379
- **Cylinder Head Idler Gear.....379**
- **Cylinder Head.....379**
- **Camshaft.....383**
- **Rocker Arm Assembly (Non-Brake Engine).....385**
- **Upper Valve Cover and Base.....386**

Specifications.....388

Special Torque.....388

Special Service Tools.....389

Exploded Views

Valve Cover and Base

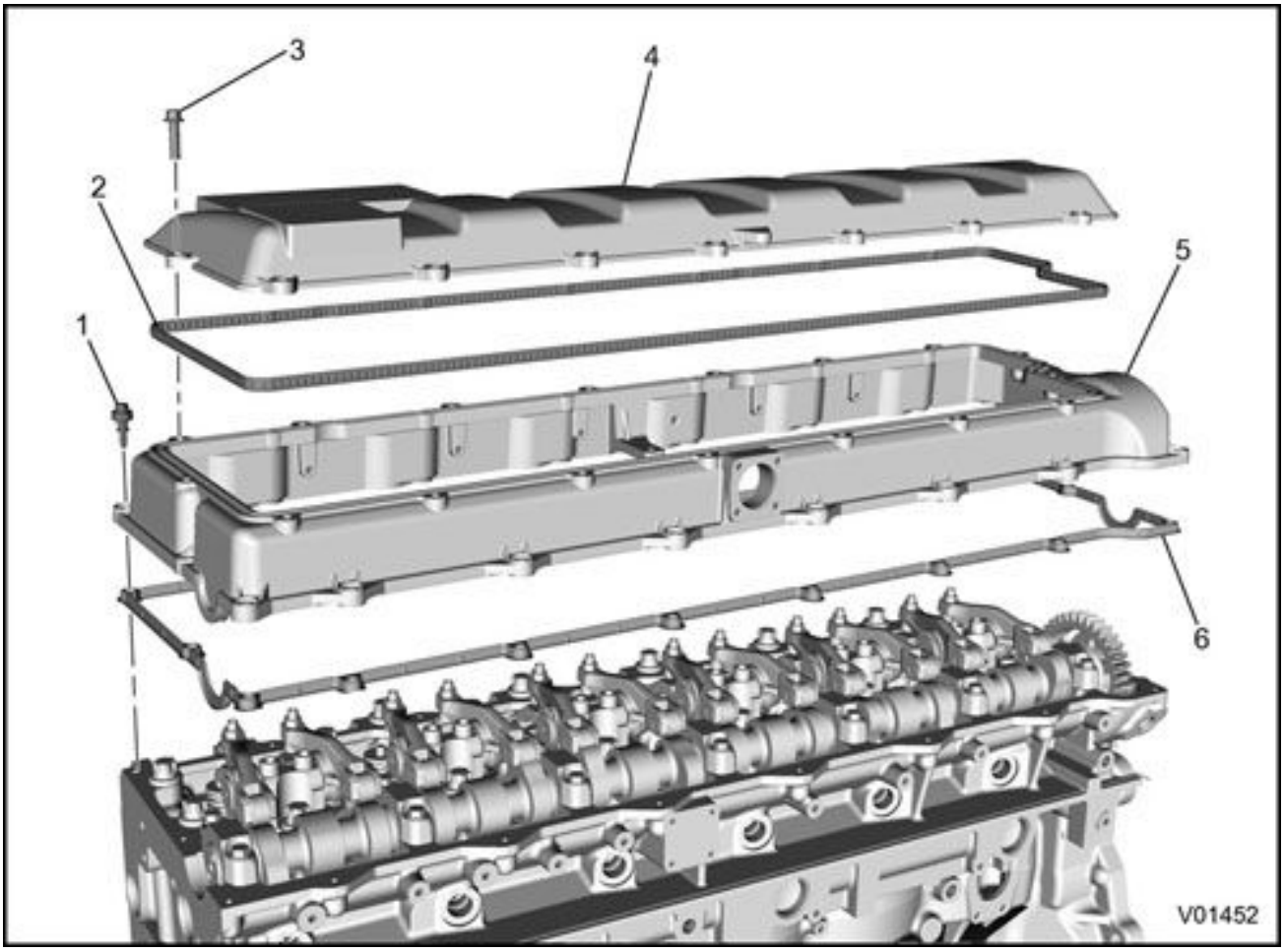


Figure 514 Valve cover and base

1. Screw with damper (18)
2. Upper valve (cover) gasket
3. M8 x 30 bolt (17)
4. Upper valve cover
5. Valve cover base
6. Valve cover (base) gasket

Non-Brake Rocker Arm Assembly And Valve Bridges

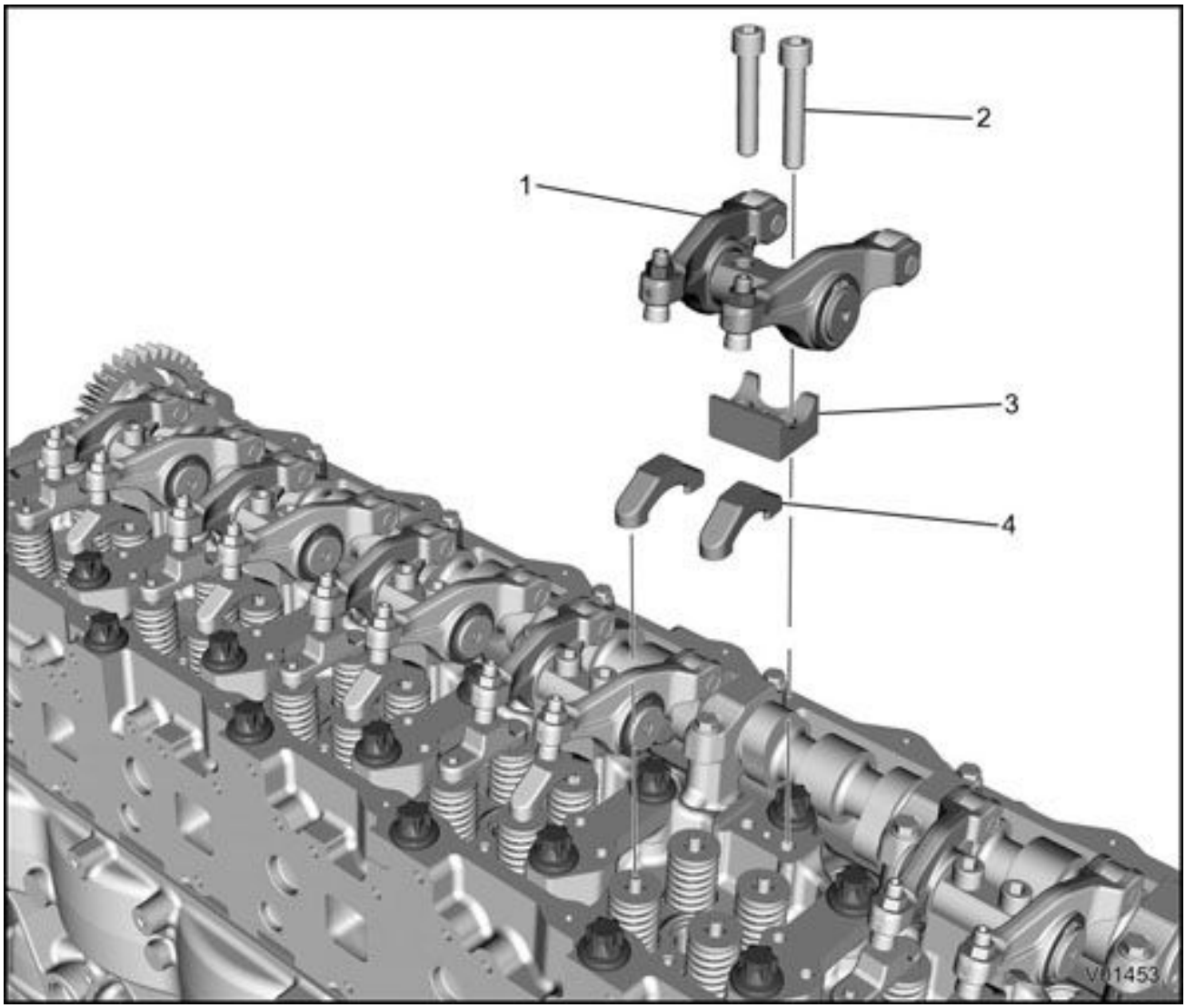


Figure 515 Non-brake rocker arm assembly and valve bridges

1. Intake and exhaust rocker arm assembly (6)
2. M12 x 60 (socket-head) screw (12)
3. Rocker bearing block (6)
4. Valve bridge (intake and exhaust) (12)

NOTE: Rocker arm assemblies and valve bridges shown and covered in this section represent the standard non-brake engine configuration. For engines with optional engine brake, refer to MaxxForce® Engine Brake by Jacobs section for procedures.

Camshaft and Cylinder Head Idler Gear

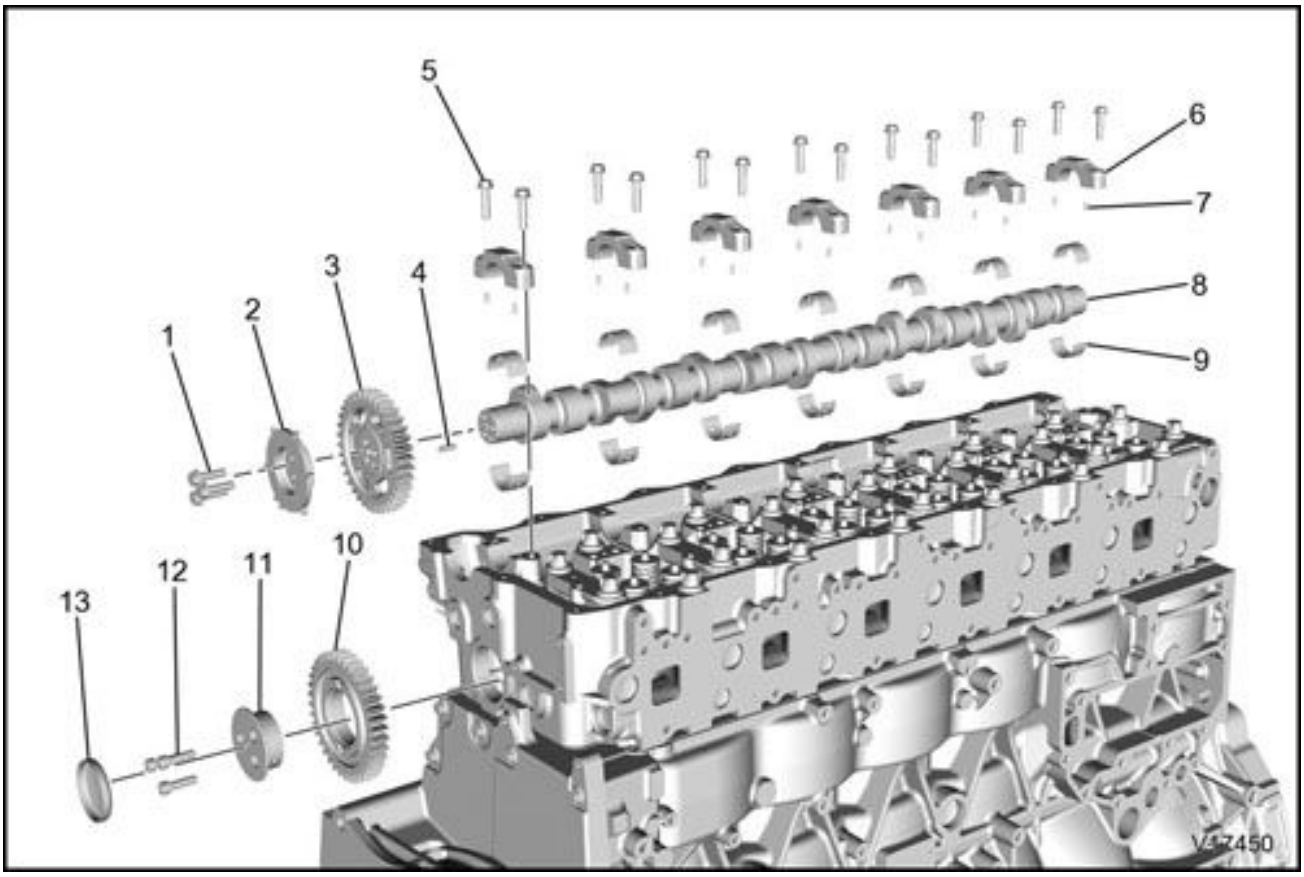


Figure 516 Camshaft and cylinder head idler gear

1. M8 x 30 bolt (3)
2. Camshaft timing disc (pulse wheel)
3. Camshaft gear
4. Timing (M6 x 20 dowel) pin
5. M8 x 35 bolt (14)
6. (Camshaft) bearing cap (7)
7. 4H x 8 x 10 dowel pin (14)
8. Camshaft
9. Bearing shell (14)
10. Cylinder head idler gear
11. Small gear shaft
12. M8 x 30 socket-head cap screw (3)
13. DMR 63.10 cup plug

Cylinder Head

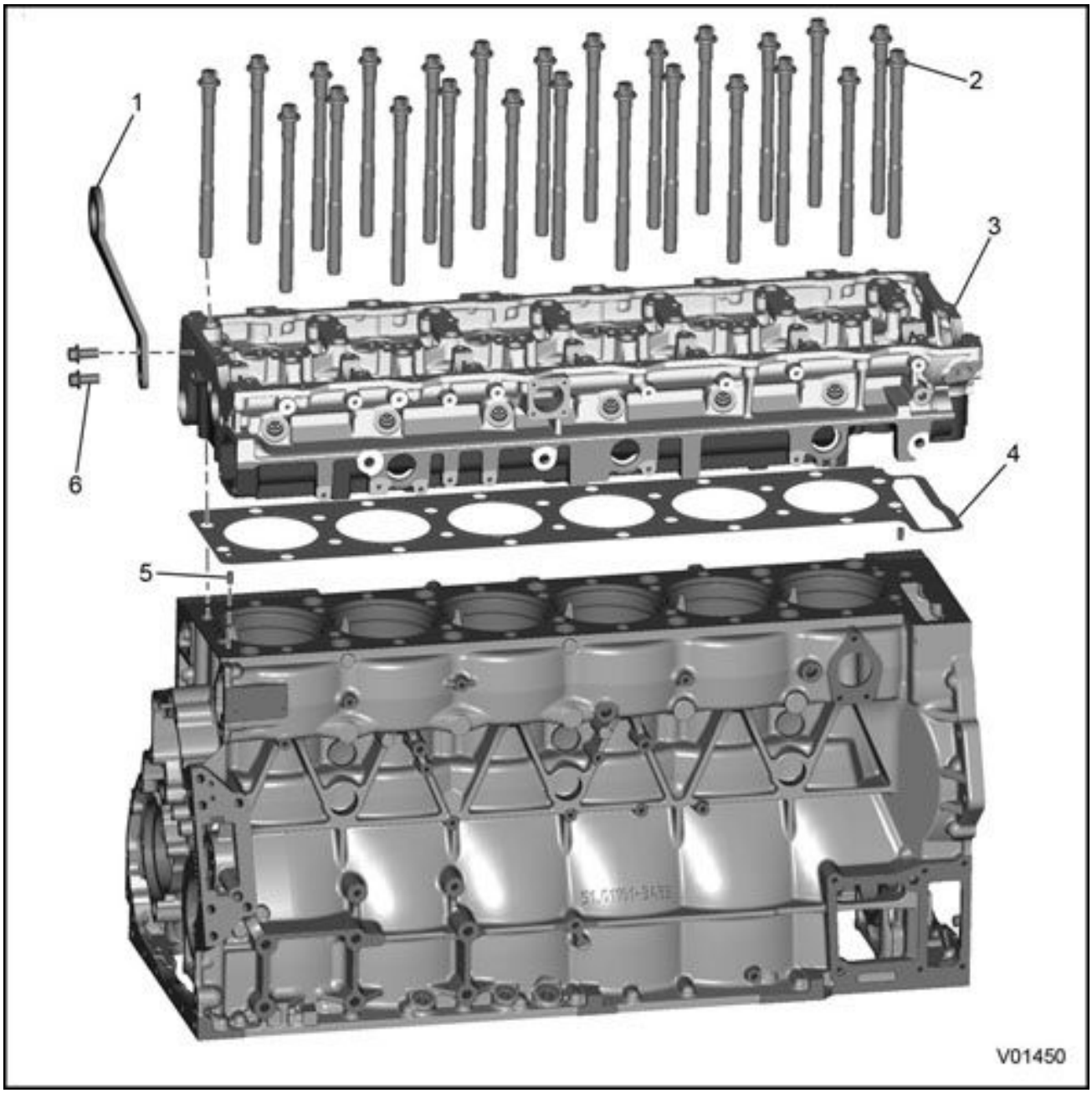


Figure 517 Cylinder head

1. Front lifting eye
2. M18 x 2 x 246 Torx® bolt (26)
3. Cylinder head
4. Cylinder head gasket
5. Dowel pin (2)
6. M12 x 25 bolt (2)

Periodic Service

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 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, 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.

Crankshaft Rotation Procedure

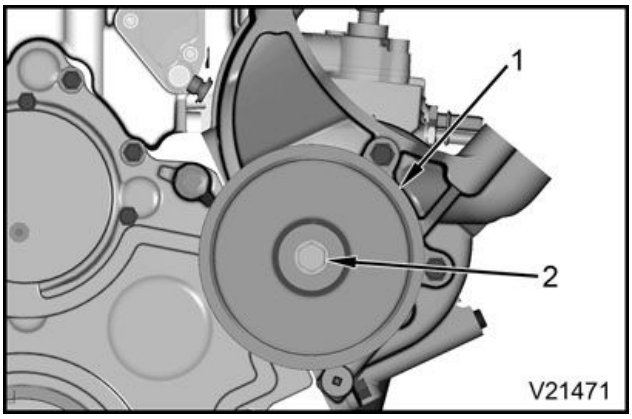


Figure 518 High-pressure pump pulley

1. High-pressure pump pulley
2. M16 x 40 LH bolt (left-hand thread)

NOTE: The crankshaft can be rotated using the M16 x 40 LH bolt (left-hand thread) on the high-pressure pump pulley. Care must be used to ensure the bolt is not loosened while the crankshaft is rotated.

1. Adjust a torque wrench to 162 N·m (120 lbf-ft).
2. Place a 19 mm socket on the torque wrench.
3. Slowly rotate the M16 x 40 LH bolt (left-hand thread) bolt clockwise. Stop pulling if the torque wrench clicks. Torque in excess of 162 N·m (120 lbf-ft) may cause the bolt to loosen. Continue rotating to desired position when compression leaks down and less force is needed to rotate the crankshaft.

Cylinder No. 1 TDC Procedure

1. Remove the upper valve cover and base. See Upper Valve Cover and Base(page 367).

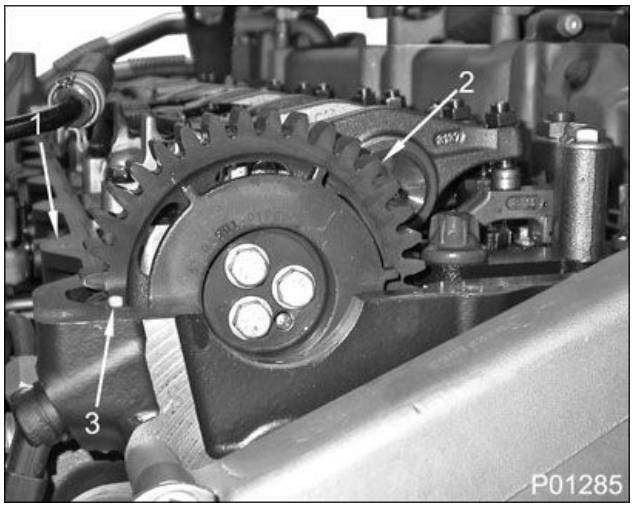


Figure 519 Camshaft gear timing mark

1. Valve cover surface
2. Camshaft gear
3. Timing mark

2. Rotate crankshaft in direction of engine rotation until the camshaft timing gear mark aligns with the valve cover surface on the intake side of the engine. See Crankshaft Rotation Procedure (page 363).

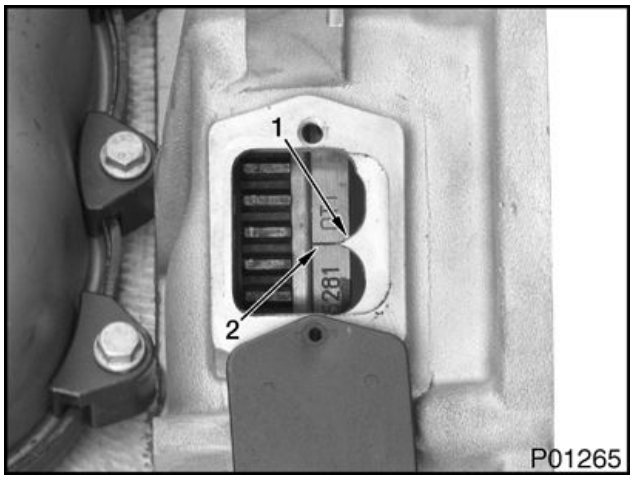


Figure 520 Flywheel housing timing index (typical)

1. Flywheel housing timing index
2. Flywheel timing mark

3. Remove timing hole cover from lower side of flywheel housing.

4. Rotate crankshaft in direction needed to align the flywheel timing mark with flywheel housing timing index.

5. Recheck that the timing mark on camshaft gear is aligned with the valve cover gasket surface (on intake side of cylinder head). If flywheel and camshaft gear marks are in agreement, the engine is at TDC for cylinder 1. Skip step 6 and proceed to Valve Overlap Procedure below.

CAUTION: To prevent engine damage, a new large idler gear must be installed, if the large idler gear has slipped.

6. If flywheel and camshaft gear marks are not in agreement, the large idler gear has slipped. See Rear Timing Gears (page 436) for procedure to install a new large idler gear.

Valve Overlap Procedure

NOTE: Valve lash adjustments are done in firing order sequence (1, 5, 3, 6, 2, 4), using the valve overlap method. Valve overlap happens on the companion cylinder near the end of the exhaust stroke and the beginning of the intake stroke, when both valves are open for a short period of time.

NOTE: Valve lash must be set with engine cold and cylinder head assembled to crankcase.

1. Starting with cylinder 1 at TDC compression, set valve lash for cylinder 1, according to Valve Lash Adjustment Procedure below.

2. After valves for cylinder 1 have been adjusted, rotate crankshaft slowly and watch valves for cylinder 2; watch the exhaust valve as it closes, and watch for intake valve to start opening. When cylinder 2 intake and exhaust valves are open equally, adjust valves on cylinder 5 according to the Valve Lash Adjustment Procedure below.

3. Repeat Valve Overlap Procedure, in order for remaining cylinders 3,6,2, and 4. See Table 29 (page 366).

Valve Lash Adjustment Procedure

NOTE: Valve lash must be set with engine cold and cylinder head assembled to crankcase.

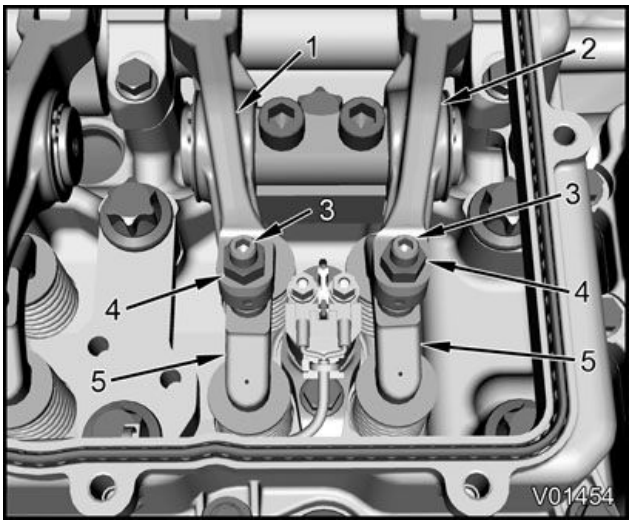


Figure 521 Valve lash adjustment (typical)

1. Exhaust rocker arm
2. Intake rocker arm
3. Adjusting screw
4. M10 nut
5. Valve bridge (intake/exhaust)

1. Loosen intake valve lash adjustment M10 nut.
2. Insert a Lash Gauge 0.5 mm (0.020 in) (page 389) between intake valve bridge and adjusting screw and tighten adjusting screw until a slight drag on feeler gauge is felt.
3. Hold adjusting screw in position and tighten intake valve lash adjustment M10 x 1 nut to special torque (page 388).

NOTE: If equipped with MaxxForce® engine brake, go to step 5 to adjust exhaust valve lash and engine brake lash. If no engine brake, continue with on with step 4.

4. For engine without brake, adjust exhaust valve lash as follows:
   a. Loosen exhaust valve lash adjustment M10 nut.
   b. Insert a Lash Gauge 0.8 mm (0.031 in) (page 389) between exhaust valve bridge and adjusting screw and tighten adjusting screw until a slight drag on feeler gauge is felt.
   c. Hold adjusting screw in position and tighten exhaust valve lash adjustment M10 nut to special torque (page 388).
   d. Go to step 6 to complete adjustments.

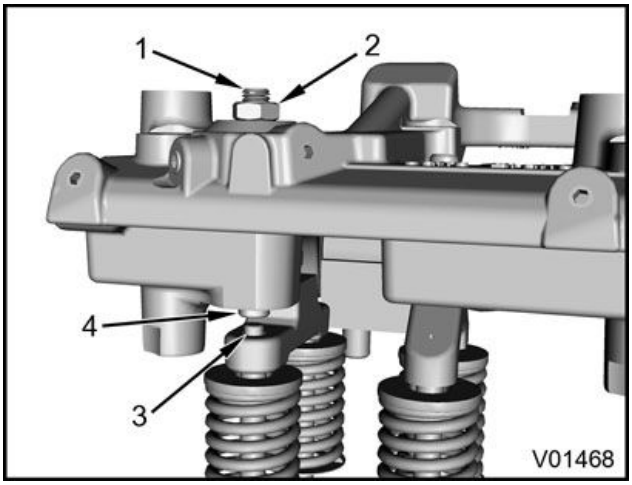


Figure 522 Valve lash adjustment (typical)

1. Slave piston adjusting screw
2. M10 (jam) nut
3. Actuator pin (in exhaust valve bridge)
4. Slave piston

5. For engine with MaxxForce® engine brake, adjust exhaust valve lash and engine brake lash as follows:
   a. Loosen M10 (jam) nut and back out engine brake slave piston adjusting screw so that it no longer makes contact with valve bridge.
   b. Loosen exhaust valve lash adjustment M10 nut.
   c. Insert a 0.8 mm (0.031 in) feeler gauge (page 389) between exhaust valve bridge and adjusting screw and tighten adjusting screw until a slight drag on feeler gauge is felt.
   d. Hold adjusting screw in position and tighten exhaust valve lash adjustment M10 nut to special torque (page 388).
   e. Insert a 0.8 mm (0.031 in) feeler gauge (Jacobs® 96–020949 or equivalent) (page 389) between engine brake slave piston and bridge actuator pin.
   f. Turn adjusting screw in until slave piston contacts feeler gauge and a slight drag on feeler gauge is felt.

g. Using a 5 mm Allen wrench, hold adjusting screw to prevent it from turning and tighten jam nut to special torque (page 388).

6. Turn crankshaft in direction of engine rotation to position next cylinder in firing order at TDC compression (one at a time) and adjust lash for the respective cylinder. See (Crankshaft Rotation Procedure, page 363). For each cylinder positioned at TDC compression, the companion cylinder will be in valve overlap as shown in following table.

Table 30

Cylinder at TDC compression	Companion cylinder in valve overlap
1	6
5	2
3	4
6	1
2	5
4	3

Removal

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

- Engine Electrical
- Turbochargers
- Air Compressor and Power Steering
- Fuel System
- Oil Cooler, Filter Housing and Crankcase Ventilation
- Exhaust Gas Recirculation (EGR) System
- Air Intake Throttle Duct and Exhaust Manifold
- Front Cover, Fan Drive, Cooling System and Related Components

Upper Valve Cover and Base

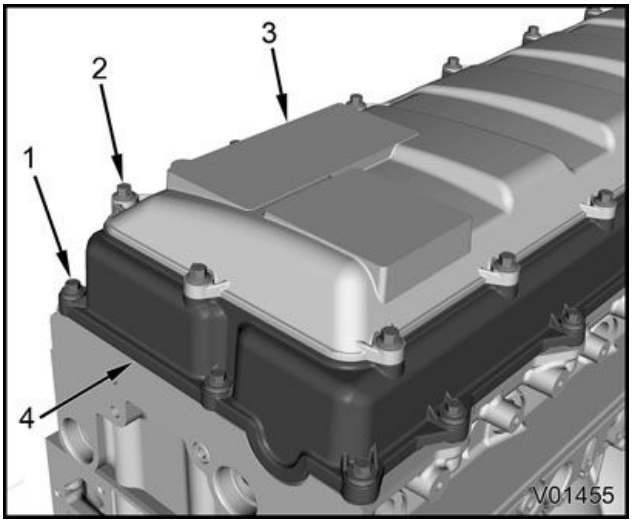


Figure 523 Upper valve cover and base

1. Screw with damper (18)
2. M8 x 30 bolt (17)
3. Upper valve cover
4. Valve cover base

CAUTION: To prevent engine damage, do not use power tools to remove or install valve cover bolts. Threads will be damaged if a bolt or nut is rotated too quickly.

NOTE: The upper valve cover can be removed separately or as an assembly with the valve cover base depending on service work being performed. If it is being removed as an assembly, start with step 2.

1. Remove 17 M8 x 30 bolts and remove upper valve cover from base.

NOTE: The valve cover base screws can only be removed from valve cover as assemblies with the dampers. The screws and dampers should only be completely removed from cover if replacing the valve cover gasket.

2. Release 18 screws with dampers from cylinder head. Do not completely remove screws from valve cover at this time.
3. Remove valve cover base (or assembly) from cylinder head.

NOTE: Valve cover gaskets can be reused and do not require removal from valve cover base unless damaged.

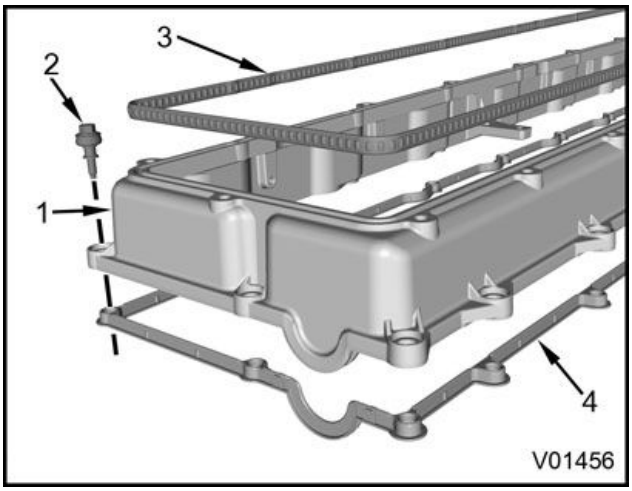


Figure 524 Valve cover gaskets

1. Valve cover base
2. Screw with damper (18)
3. Upper valve cover gasket
4. (Lower) valve cover gasket

4. Inspect upper and lower valve cover gaskets for damage. If damaged, replace as follows:
   a. Upper gasket — remove from groove in upper surface of valve cover base and discard gasket.

b. Lower gasket — completely remove 18 screws with dampers to release gasket from bottom of valve cover base. Discard gasket.

Rocker Arm Assembly (Non-Brake Engine)

CAUTION: To prevent engine damage, use permanent marker to identify internal engine components and their orientation. Do not use paint or temporary markers.

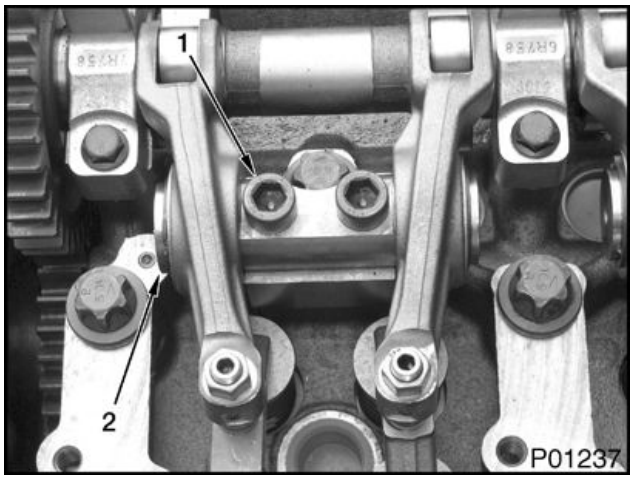


Figure 525 Rocker arm assembly (typical)

1. M12 x 60 (socket-head) screw (12)
2. Rocker arm assembly (6)

1. Mark rocker arm assemblies 1 through 6 so each assembly can be installed in its original cylinder location.
2. Remove 12 M12 x 60 socket-head screws.
3. Remove six rocker arm assemblies.

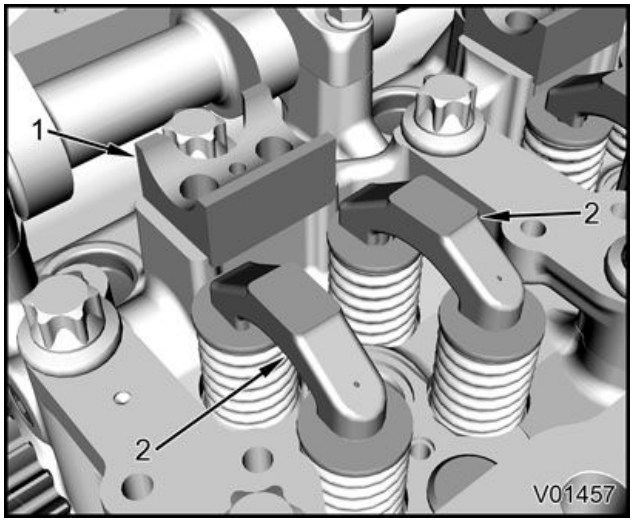


Figure 526 Rocker bearing block and valve bridges

1. Rocker bearing block (6)
2. Valve bridge (12)

4. Mark rocker bearing blocks 1 through 6 so each block can be installed in its original cylinder location.
5. Remove six rocker bearing blocks.
6. Mark valve bridges so each bridge can be installed in its original location and orientation.
7. Remove 12 valve bridges.

Camshaft

CAUTION: To prevent engine damage, use permanent marker to identify internal engine components and their orientation. Do not use paint or temporary markers.

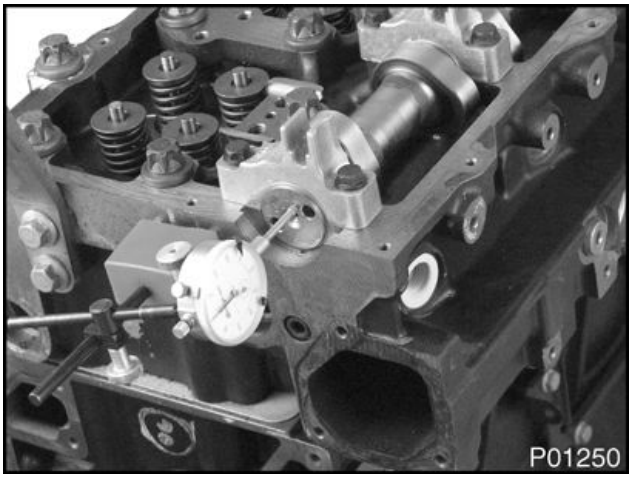


Figure 527 Camshaft end play check (typical)

1. Check camshaft end play as follows:
   a. Mount dial indicator with magnetic base (page 389) on cylinder head with indicator tip on end of camshaft as shown.
   b. Move camshaft toward rear of engine and zero the dial indicator.
   c. Move camshaft back and forth while reading dial indicator. Compare dial indicator reading with camshaft end play specification (page 388).
   d. If end play exceeds specified limits, install a new camshaft.

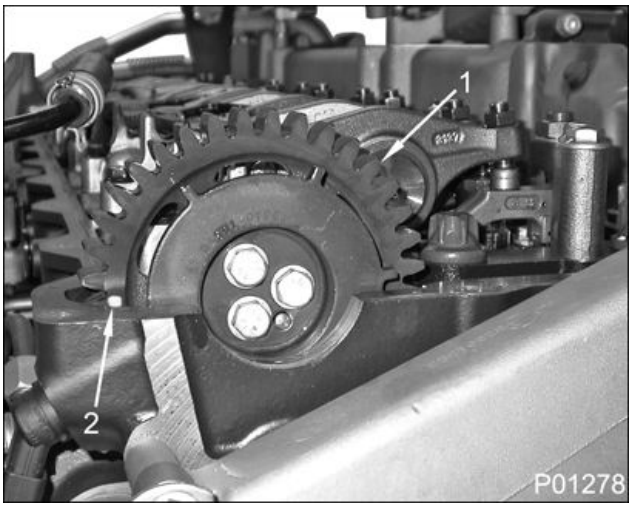


Figure 528 Camshaft timing mark (typical)

1. Camshaft gear
2. Timing mark

2. Turn engine crankshaft in direction of engine rotation, until timing mark on camshaft gear is aligned with cylinder head surface.

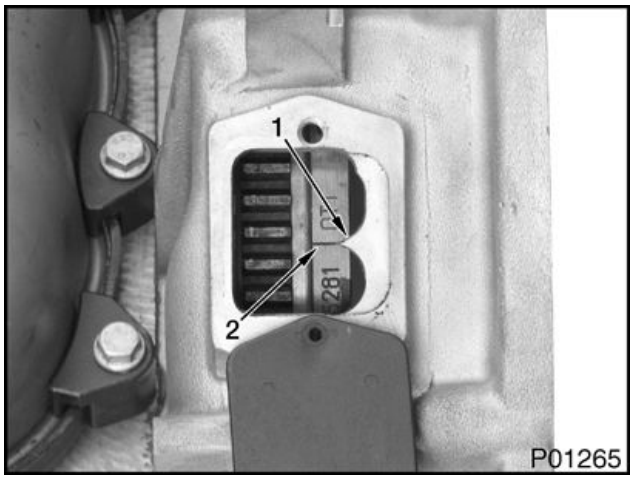


Figure 529 Flywheel housing timing index (typical)

1. Flywheel housing timing index
2. Flywheel timing mark

3. Remove timing hole cover from lower side of flywheel housing and verify timing mark on flywheel is aligned with flywheel housing timing index.
   - If timing mark on flywheel is out of alignment, then the timing has slipped due to large idler gear slippage. Install a new large idler gear. See Rear Timing Gears (page 436) section of this manual for procedures to replace large idler gear.
   - If timing mark on flywheel is aligned with flywheel housing timing index, continue to next step.

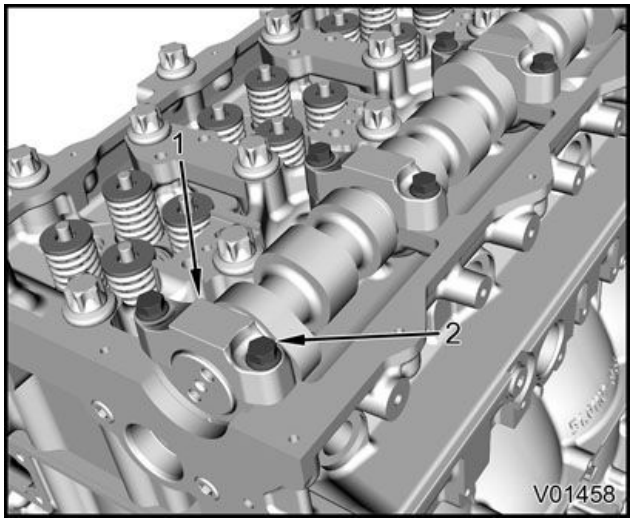


Figure 530 Camshaft bearing caps

1. Camshaft bearing cap (7)
2. M8 x 35 bolt (14)

4. Remove 14 M8 x 35 bolts.
5. Remove seven camshaft bearing caps from the cylinder head. Mark each bearing cap with location number and orientation.

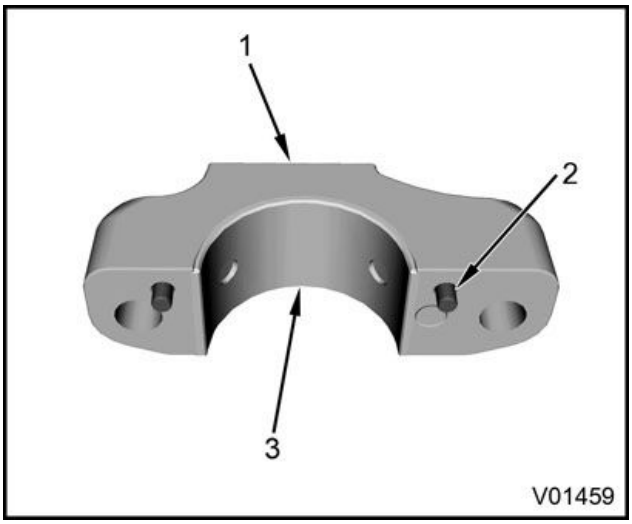


Figure 531 Camshaft bearing cap and bearing shell (typical)

1. Camshaft bearing cap
2. 4H x 8 x 10 dowel pin (2)
3. Bearing shell

6. Remove seven bearing shells from camshaft bearing caps. Mark each bearing shell with camshaft bearing cap number and orientation.
7. If damaged, remove 14 – 4H x 8 x 10 dowel pins from seven camshaft bearing caps.
8. Remove camshaft.
9. Remove seven lower bearing shells from cylinder head. Mark each bearing shell with camshaft bearing cap number and orientation.

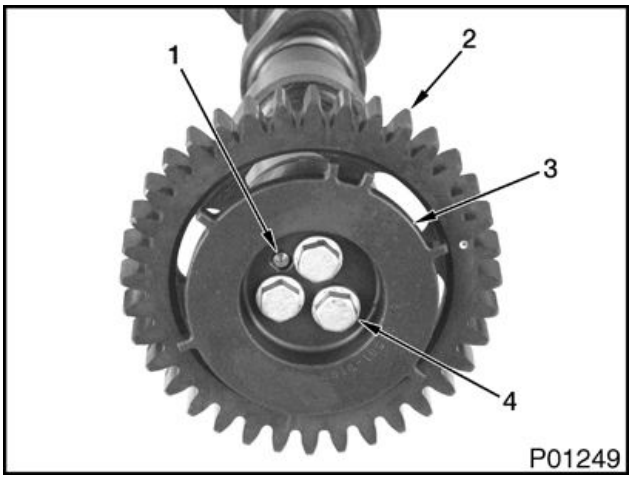


Figure 532 Camshaft gear and camshaft timing disc (pulse wheel)

1. Timing (M6 x 20 dowel) pin
2. Camshaft gear
3. Camshaft timing disc (pulse wheel)
4. M8 x 30 bolt (3)

10. Remove three M8 x 30 bolts.
11. Remove camshaft timing disc and camshaft gear.
12. If damaged, remove timing pin from camshaft.

Cylinder Head

CAUTION: To prevent engine damage, remove fuel injectors before removing cylinder head.

1. Remove six fuel injectors. See Fuel Injectors (page 216).

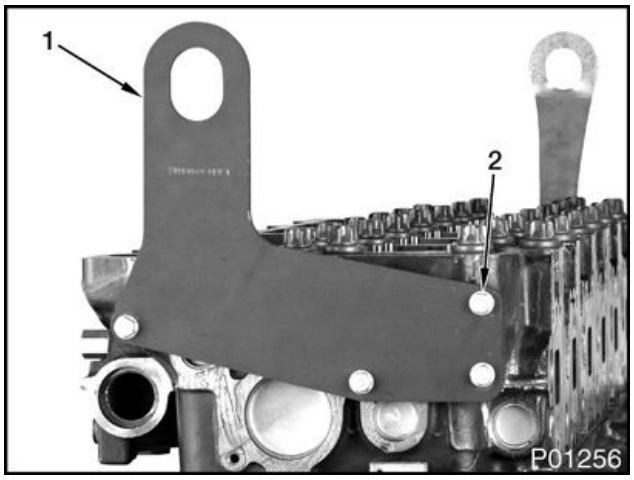


Figure 533 Cylinder Head Lifting Bracket

1. Cylinder Head Lifting Bracket
2. M8 x 20 class 10.9 bolt (4)

2. Position Cylinder Head Lifting Bracket (page 389) on rear end of cylinder head.
3. Install four M8 x 20 class 10.9 bolts (page 389). Tighten bolts to standard torque (page 503).

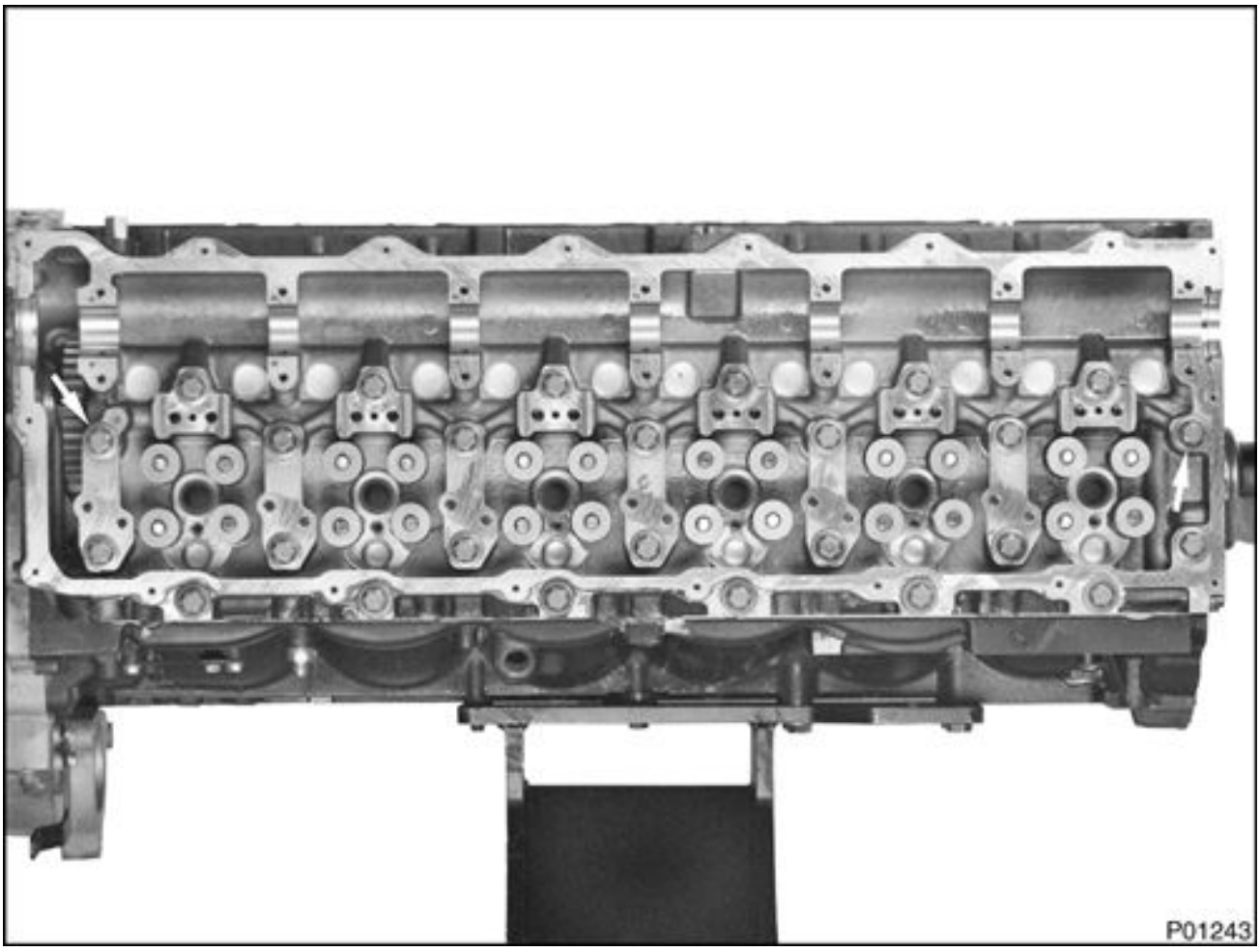


Figure 534 Cylinder head bolts

4. Use Head Bolt Torx® Socket (page 389) and working in a circular pattern, loosen, remove and discard 26 M18 x 246 Torx® bolts. Begin with the outer bolts and move inward.

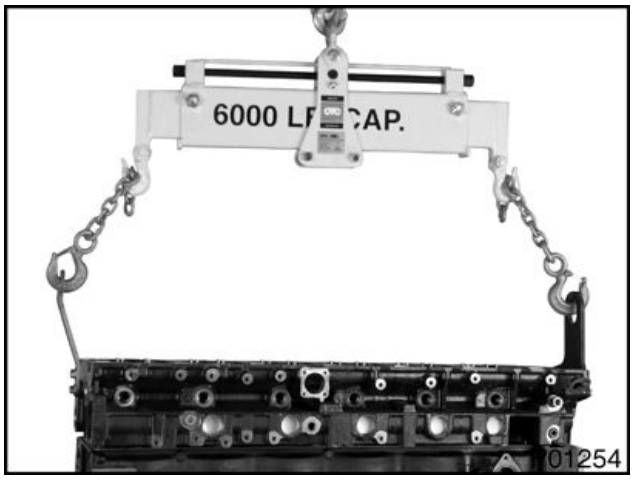


Figure 535 Cylinder head removal

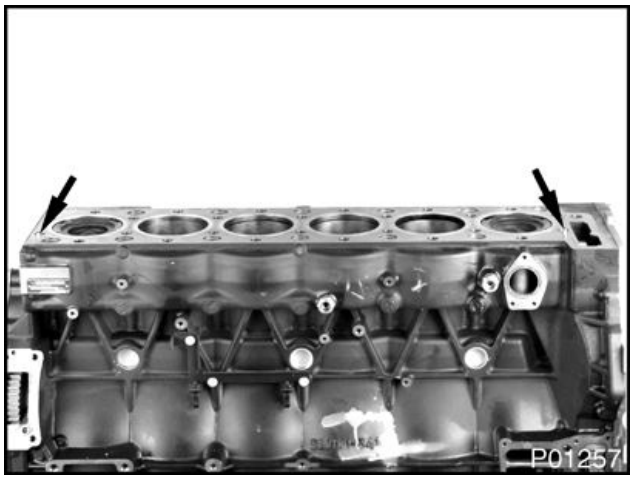


Figure 536 8 mm dowel pin (2)

5. Lift cylinder head using a suitable lifting device.

WARNING: To prevent personal injury or death, use a hoist rated for the weight of the cylinder head and follow the manufacturer's operative and safety instructions. Attach safety lifting hooks to the cylinder head lifting bracket and lifting eye.

CAUTION: To prevent engine damage, do not scratch gasket surface of cylinder head.

CAUTION: To prevent engine damage, carefully set cylinder head on wooden blocks to protect the cylinder head idler gear.

6. Place cylinder head on a clean, non-metallic surface.
7. Remove four M8 x 20 class 10.9 bolts and Cylinder Head Lifting Bracket (page 389).
8. Remove and discard cylinder head gasket.
9. If damaged, remove two 8 mm dowel pins.

Cylinder Head Idler Gear

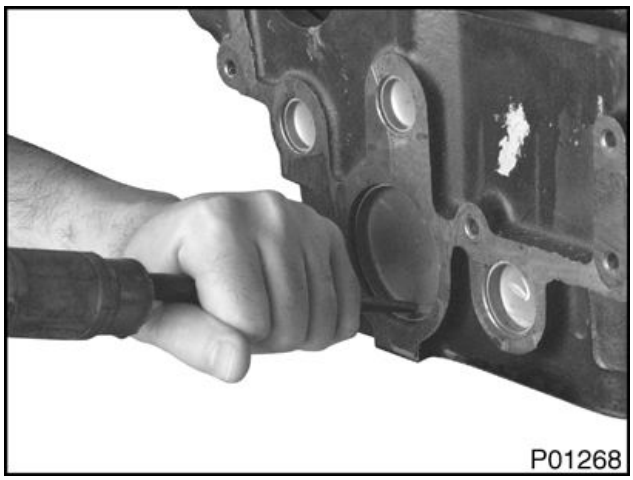


Figure 537 DMR 63.10 cup plug removal

1. Use a punch to knock in bottom of DMR 63.10 cup plug. Remove and discard cup plug.

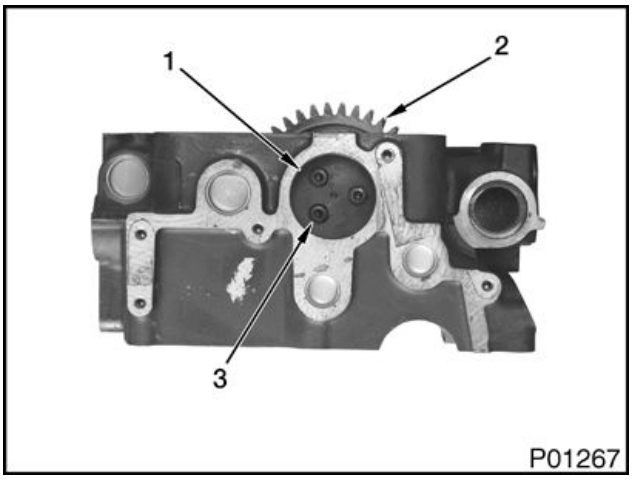


Figure 538 Cylinder head idler gear

1. Small gear shaft
2. Cylinder head idler gear
3. M8 x 30 socket-head cap screw (3)

2. Remove three M8 x 30 socket-head cap screws, small gear shaft and cylinder head idler gear.

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: Do not use chlorinated solvents on cylinder head bolts. If parts are not cleaned thoroughly, parts will corrode over time. Be sure parts are clean, dry and free of chemicals other than engine oil.

CAUTION: To prevent engine damage, do not scratch gasket surface of cylinder head.

1. Use a scraper and wire brush to remove deposits and gasket material from valve heads and gasket surface.
2. Use a suitable solvent to remove dirt, grease and deposits from removed parts.
3. Clean all bolt holes. Make sure gasket surfaces are clean. Clean all surfaces and ports with steam, and then 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.

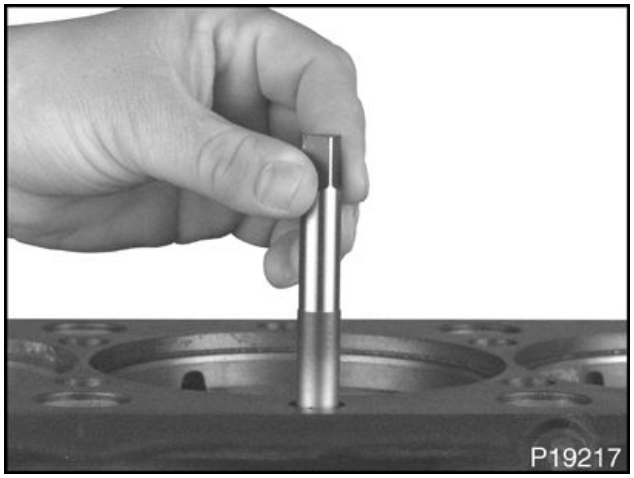


Figure 539 Head bolt bottoming tap (typical)

5. Clean cylinder head bolt holes in crankcase with Head Bolt Bottoming Tap (page 389).
6. Clean out debris with filtered compressed air.

Camshaft Bearings

1. With camshaft removed, install previously marked bearings and camshaft bearing caps. Tighten M8 x 35 bolts to special torque (page 388).

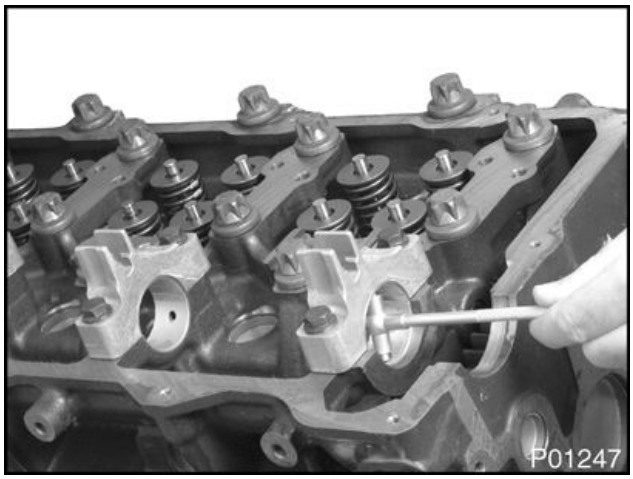


Figure 540 Camshaft bearing check (typical)

2. Use a telescoping gauge set (page 389) and a 1 - 2 inch micrometer (page 389) to measure camshaft bearing inside diameter. If inside diameter does not meet specification (page 388), install new camshaft bearings.

Fuel Injector Bore

1. Use Injector Sleeve Brushes (page 389) in injector bore to remove deposits.

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

2. Use filtered compressed air to clean out debris from injector bores.

Valves Leak Test

NOTE: Position wooden blocks so the view of all the intake and exhaust valve heads and valve seat areas is not restricted.

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

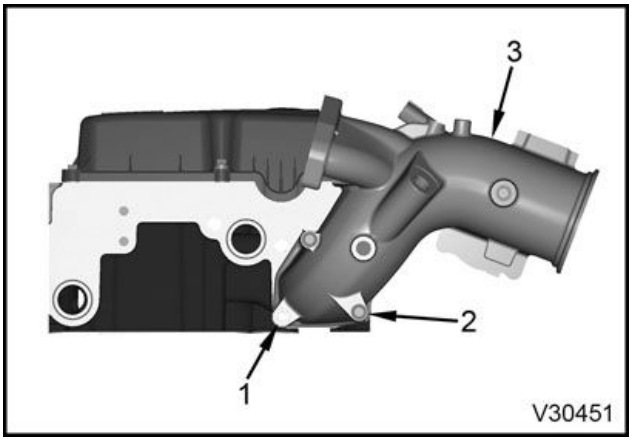


Figure 541 Air intake throttle duct (typical)

1. M8 x 50 bolt
2. M8 x 100 bolt (2)
3. Air intake throttle duct

2. Apply Loctite® 5900 sealant or equivalent (page 389) to joining surfaces of air intake throttle duct and cylinder head.
3. Install air intake throttle duct.
4. Install M8 x 50 bolt and two M8 x 100 bolts. Tighten bolts to standard torque (page 503).
5. Spray mineral spirits into exhaust ports.
6. Pour mineral spirits into air intake throttle duct until intake manifold inside cylinder head is filled.

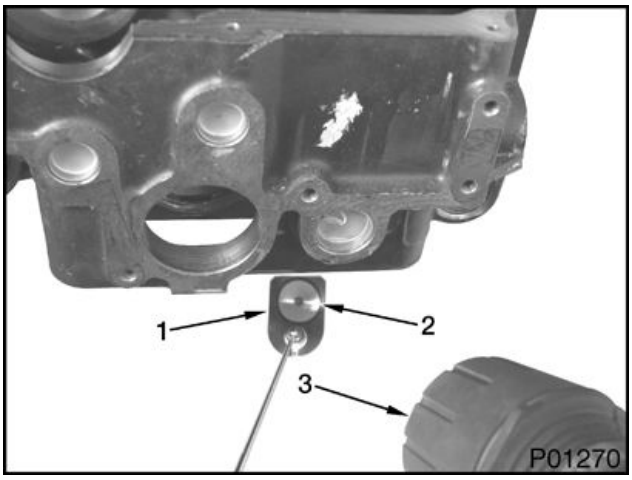


Figure 542 Leak inspection

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

NOTE: Valve seats must not leak. If valve seats leak, install a new cylinder head. Cylinder head replacement is not required if the cylinder head passes the valves leak test using mineral spirits.

7. Wait five minutes. Use an inspection mirror to inspect valve seat area for leakage of mineral spirits. If there is no leakage of mineral spirits through the intake or exhaust valves, the cylinder head is acceptable for reinstallation.

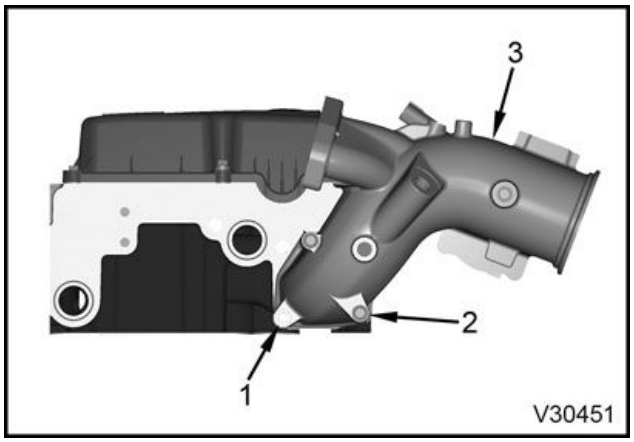


Figure 543 Air intake throttle duct

1. M8 x 50 bolt
2. M8 x 100 bolt (2)
3. Air intake throttle duct

8. Position a suitable container under air intake throttle duct to catch mineral spirits. M8 x 50 bolt and two M8 x 100 bolts.
9. Remove air intake throttle duct.
10. Lift rear end of cylinder head to drain all remaining mineral spirits out of the intake manifold.

Installation

Cylinder Head Idler Gear

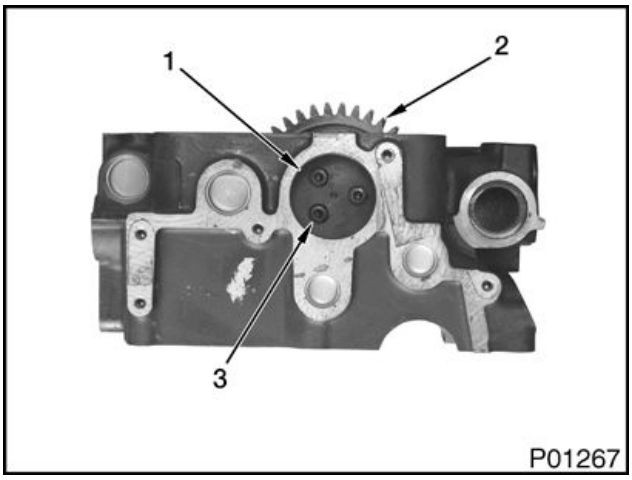


Figure 544 Cylinder head idler gear

1. Small gear shaft
2. Cylinder head idler gear
3. M8 x 30 socket-head cap screw (3)

1. Install small gear shaft and cylinder head idler gear.
2. Install three M8 x 30 socket-head cap screws. Tighten screws to special torque (page 388).
3. Clean cylinder head mating surfaces for cylinder head idler gear DMR 63.10 cup plug.
4. Apply Loctite® 262™ Threadlocker (page 389) to the outside edge of new cylinder head idler gear cup plug.

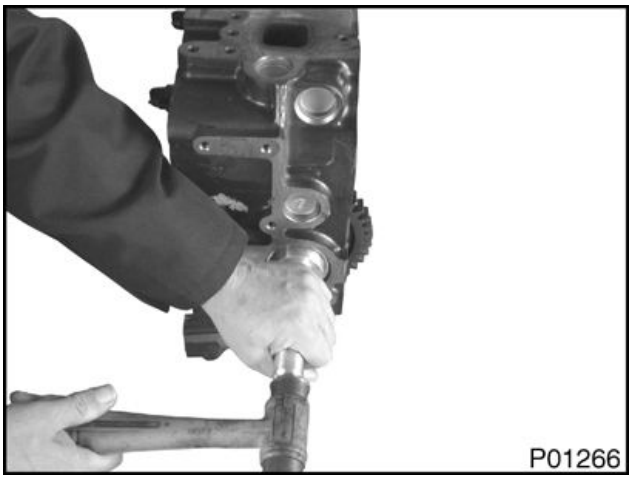


Figure 545 DMR 63.10 cup plug installation

5. Drive new cup plug into the hole using a Bearing Installer (page 389) approximately 6 mm (0.25 in) smaller in diameter than the cup plug.
6. Recess cup plug 2.3 mm (0.9 in) below the machined surface.

Cylinder Head

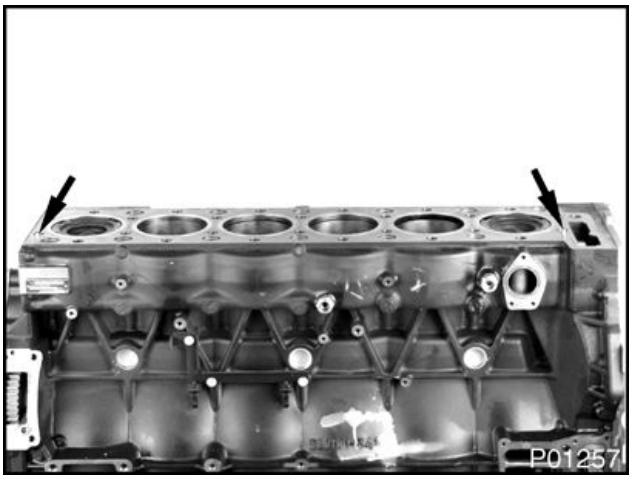


Figure 546 8 mm dowel pin (2)

1. If previously removed, install two 8 mm dowel pins in crankcase.

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

CAUTION: Do not use chlorinated solvents on cylinder head bolts. If parts are not cleaned thoroughly, parts will corrode over time. Be sure parts are clean, dry and free of chemicals other than engine oil.

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 contaminants from cylinder head gasket mating surfaces. If debris is not removed, 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.

2. Install a new cylinder head gasket on crankcase, over dowel pins.

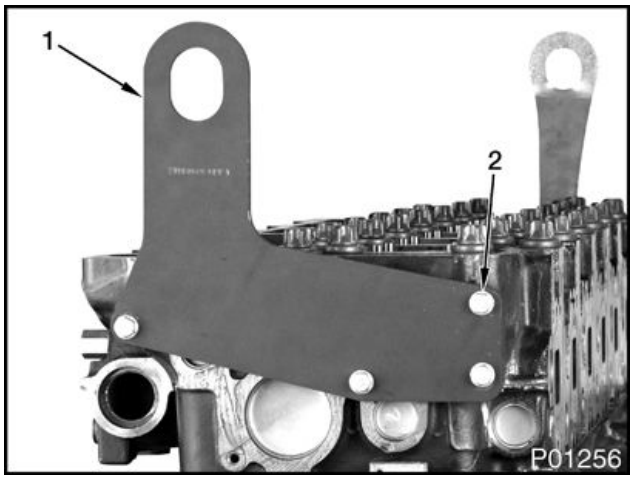


Figure 547 Cylinder Head Lifting Bracket

1. Cylinder Head Lifting Bracket
2. M8 x 20 class 10.9 bolt (4)

3. Position Cylinder Head Lifting Bracket (page 389) on rear end of cylinder head.
4. Install four M8 x 20 class 10.9 bolts (page 389). Tighten bolts to standard torque (page 503).

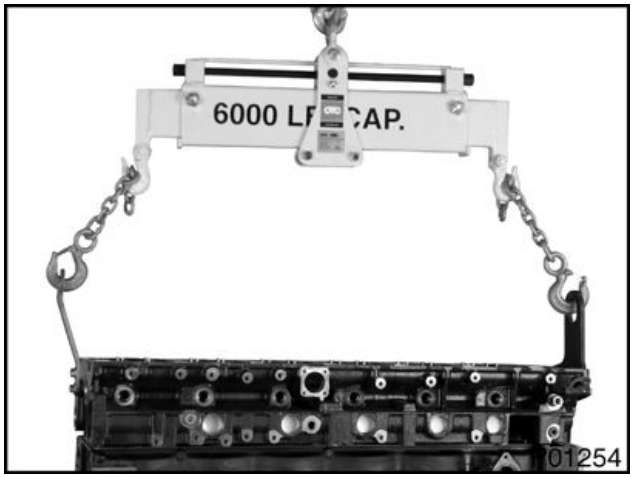


Figure 548 Cylinder head installation

WARNING: To prevent personal injuries or death, use a hoist rated for the weight of the cylinder head and follow the manufacturer's operation and safety instructions. Attach safety lifting hooks to the cylinder head lifting bracket and lifting eye.

CAUTION: To prevent engine damage, do not drop or slide cylinder head on cylinder head gasket. This can damage the cylinder head gasket, dowel pins and the cylinder head idler gear.

5. Attach an appropriate hoist and lifting hooks to cylinder head lifting bracket and lifting eye.
6. Lower cylinder head onto crankcase and align cylinder head alignment dowels in the crankcase with dowel holes in the cylinder head.

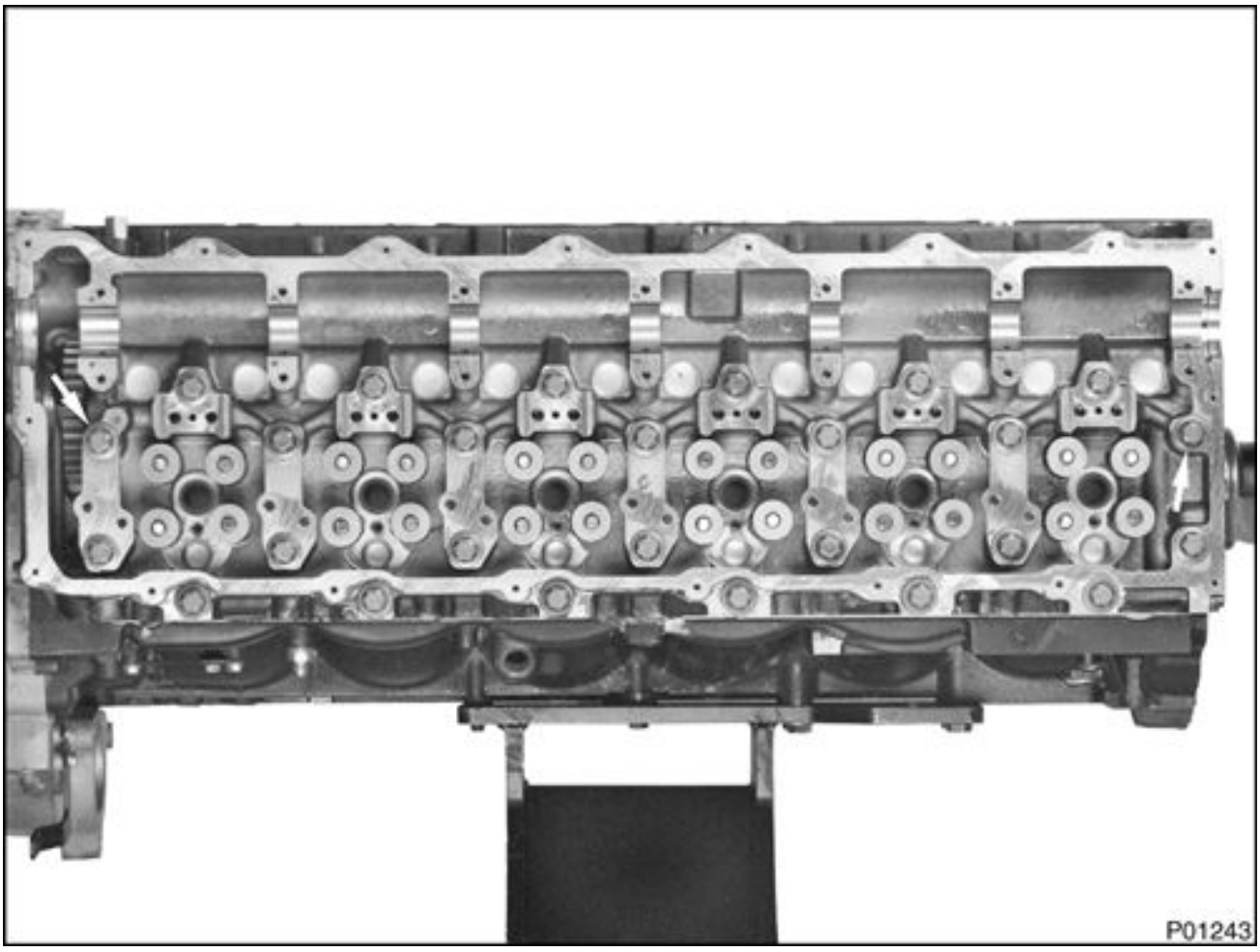


Figure 549 Cylinder head bolts

CAUTION: To prevent engine damage, install new cylinder head bolts when installing cylinder head. Apply a light coat of clean engine oil to new bolt threads and under bolt head. Too much oil will cause hydrostatic lock and give incorrect torque reading. Do not use anti-seize compound, grease, or any other lubricant on cylinder head bolt threads.

7. Install 26 new lightly lubricated M18 x 246 Torx® bolts. Do not tighten bolts at this time.
8. Remove four M8 x 20 class 10.9 bolts and Cylinder Head Lifting Bracket (page 389).

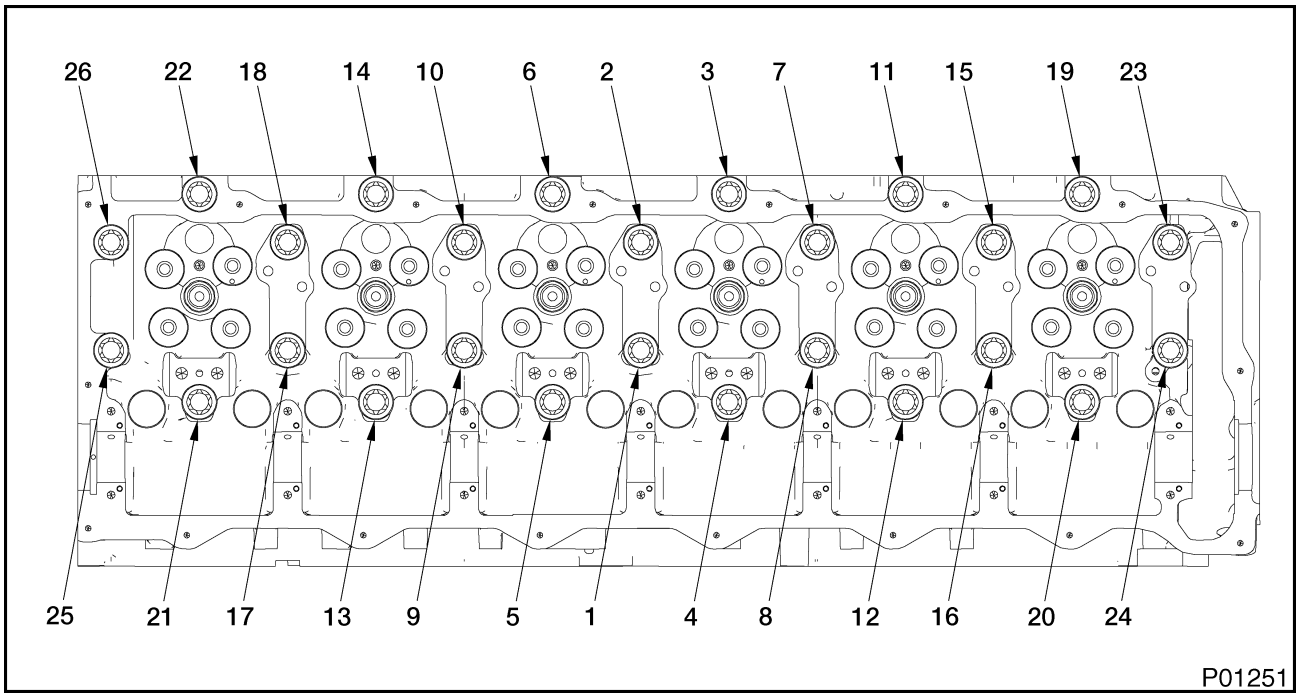


Figure 550 Cylinder head bolt tightening sequence

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

CAUTION: To prevent engine damage, use a torque wrench to tighten cylinder head bolts; do not use an impact wrench.

NOTE: For proper cylinder head surface seating and sealing, follow the correct tightening sequence.

9. Use Head Bolt Torx® Socket (page 389) to tighten the M18 x 246 Torx® bolts in sequence indicated above as follows:
    1. Hand-tighten Torx® bolts.
    2. Tighten Torx® bolts numbered 1 through 26 to 10 N·m (89 lbf·in) in numerical sequence as shown.
    3. Tighten Torx® bolts numbered 1 through 26 to 150 N·m (111 lbf·ft) in numerical sequence.
    4. Tighten Torx® bolts numbered 1 through 26 to 300 N·m (221 lbf·ft) in numerical sequence.
    5. Rotate Torx® bolts numbered 1 through 26 an additional 90° (1/4 turn) clockwise in numerical sequence.
    6. Rotate Torx® bolts numbered 1 through 26 an additional 90° (1/4 turn) clockwise in numerical sequence for second time.
    7. Rotate Torx® bolts numbered 1 through 26 an additional 90° (1/4 turn) clockwise in numerical sequence for third time.

Camshaft

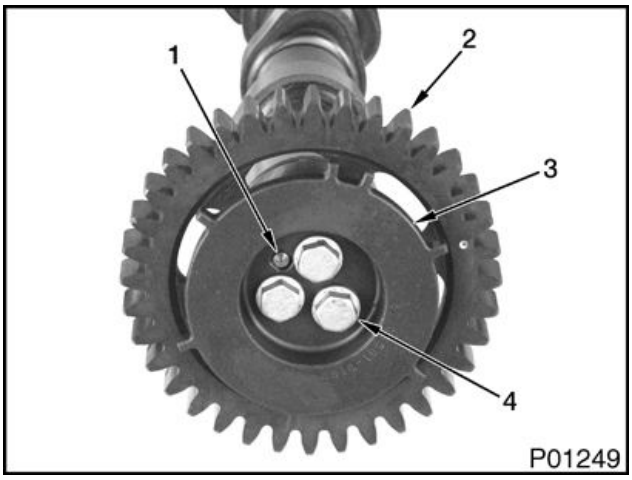


Figure 551 Camshaft gear and camshaft timing disc (pulse wheel)

1. Timing (M6 x 20 dowel) pin
2. Camshaft gear
3. Camshaft timing disc (pulse wheel)
4. M8 x 30 bolt (3)

1. If previously removed, install timing (M6 x 20 dowel) pin into camshaft.
2. Align camshaft gear with timing pin and install on camshaft.
3. Align camshaft timing disc with timing pin and install on camshaft.
4. Install and finger-tighten three M8 x 30 bolts.

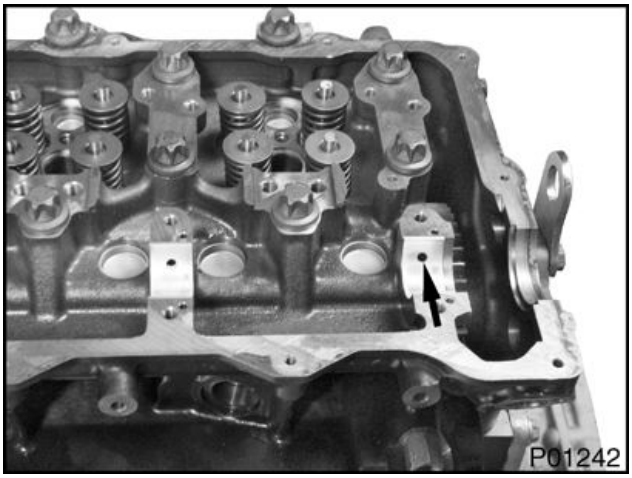


Figure 552 Camshaft lower bearing shell oil hole alignment (typical)

NOTE: If original camshaft bearings are installed, make sure to place them as previously marked in their original location and orientation.

5. Install seven new or previously marked camshaft lower bearings on cylinder head. Make sure oil holes in bearings are aligned with oil holes in cylinder head bearing support.
6. Rotate crankshaft so that cylinder number 1 is positioned at TDC. See Crankshaft Rotation Procedure (page 363).

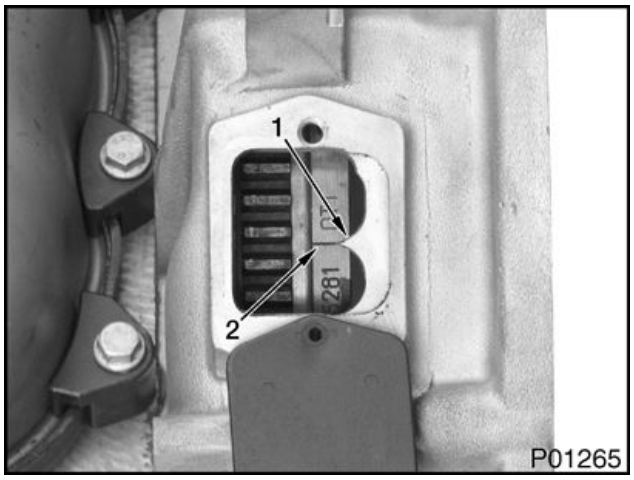


Figure 553 Flywheel housing timing index (typical)

1. Flywheel housing timing index
2. Flywheel timing mark

7. Verify timing mark on flywheel is aligned with flywheel housing timing index at bottom of flywheel housing.

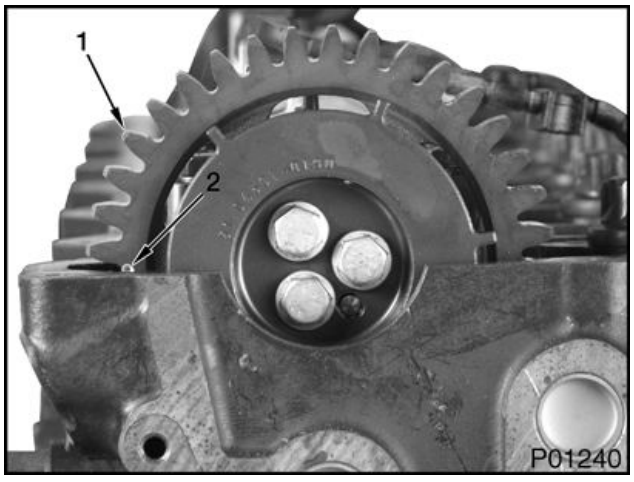


Figure 554 Camshaft timing mark (typical)

1. Camshaft gear
2. Timing mark

8. Lower camshaft on cylinder head and make sure timing mark on camshaft gear is aligned with cylinder head surface.

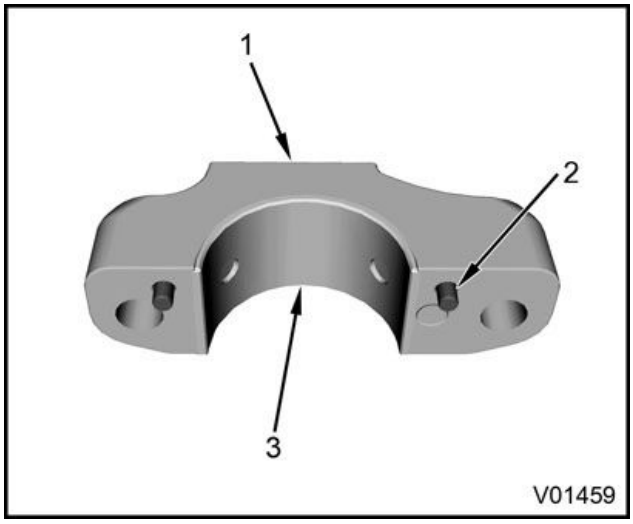


Figure 555 Camshaft bearing cap and bearing shell

1. Camshaft bearing cap
2. 4H x 8 x 10 dowel pin (2)
3. Bearing shell

NOTE: Make sure that each bearing cap has the two dowel pins installed.

9. If previously removed, install 14 – 4H x 8 x 10 dowel pins into seven camshaft bearing caps.

NOTE: If original bearings are installed, make sure each is placed as previously marked in its original location and orientation.

10. Install seven new or previously marked bearing shells on camshaft bearing caps.

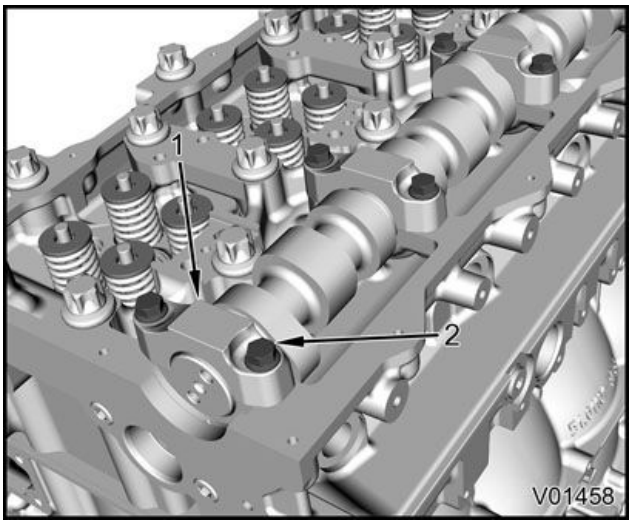


Figure 556 Camshaft bearing caps

1. Camshaft bearing cap (7)
2. M8 x 35 bolt (14)

11. Install seven previously marked camshaft bearing caps with each placed in its original location and orientation.
12. Install 14 M8 x 35 bolts. Tighten bolts to special torque (page 388).

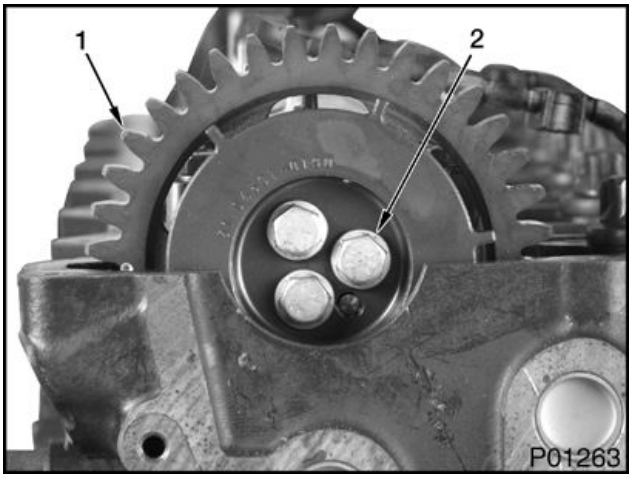


Figure 557 Camshaft gear bolts tightening

1. Camshaft gear
2. M8 x 30 bolt (3)

13. Tighten three M8 x 30 bolts to 15 N·m (133 lbf·in).
14. Tighten three M8 x 30 bolts an additional 90° (1/4 turn).

Rocker Arm Assembly (Non-Brake Engine)

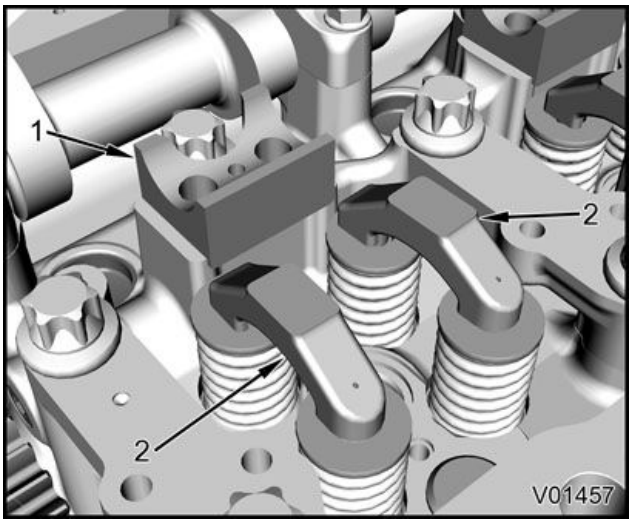


Figure 558 Rocker bearing block and valve bridges

1. Rocker bearing block (6)
2. Valve bridge (12)

NOTE: If original valve bridges are installed, make sure each is placed as previously marked in its original location.

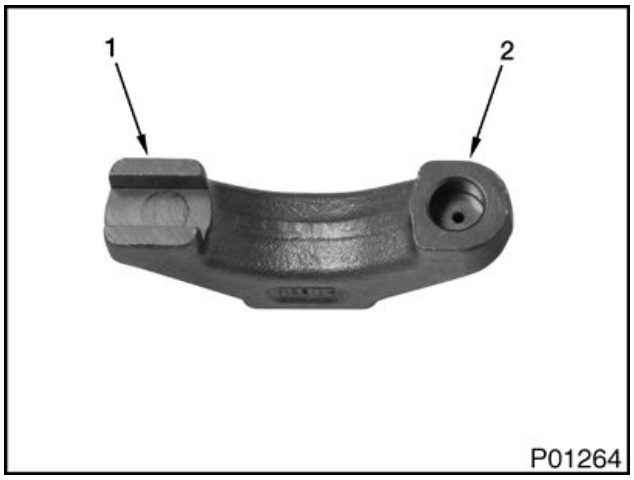


Figure 559 Valve bridge orientation (typical)

1. Camshaft side
2. Exhaust manifold side

1. Place 12 new or previously marked valve bridges on intake and exhaust valves with milled end oriented toward camshaft.

NOTE: If original rocker bearing blocks are installed, make sure each is placed as previously marked in its original location.

2. Install six new or previously marked rocker bearing blocks.

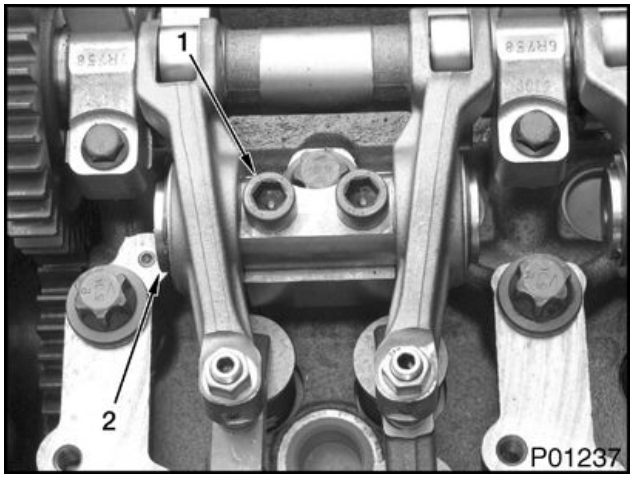


Figure 560 Rocker arm assembly (typical)

1. M12 x 60 (socket-head) screw (12)
2. Rocker arm assembly (6)

NOTE: If original rocker arm assemblies are installed, make sure each is placed as previously marked in its original location.

3. Install six new or previously marked rocker arm assemblies.
4. Install 12 M12 x 60 socket-head screws. Tighten screws to special torque (page 388).
5. Adjust valve lash. See Cylinder No. 1 TDC Procedure (page 363).

Upper Valve Cover and Base

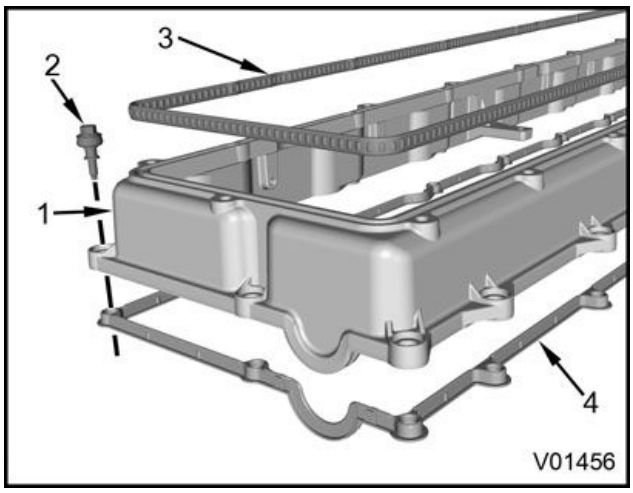


Figure 561 Valve cover gaskets

1. Valve cover base
2. Screw with damper (18)
3. Upper valve cover gasket
4. (Lower) valve cover gasket

1. If necessary, install a new upper and/or lower valve cover gasket.
2. If previously removed, install 18 screws with dampers in valve cover base and through valve cover base gasket.

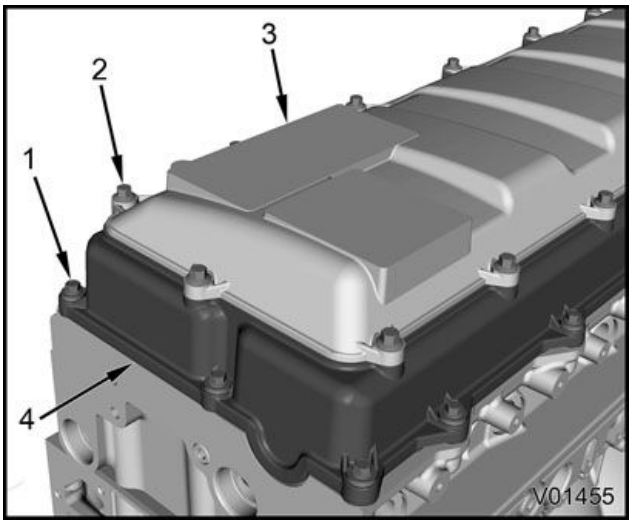


Figure 562 Upper valve cover and base

1. Screw with damper (18)
2. M8 x 30 bolt (17)
3. Upper valve cover
4. Valve cover base

CAUTION: To prevent engine damage, do not use power tools to remove or install valve cover bolts. Threads will be damaged if a bolt or nut is rotated too quickly.

3. Place valve cover base on cylinder head.
4. Tighten 18 screws with dampers to special torque (page 388).
5. If removed, place upper valve cover on valve cover base.
6. Install 17 M8 x 30 bolts and tighten to special torque (page 388).

Specifications

Table 31 Cylinder Head, Camshaft and Valve Train

Camshaft	
Camshaft bearing inside diameter	39.925 – 39.950 mm (1.57185 – 1.57283 in)
Camshaft end play	0.25 – 0.85 mm (0.0098 – 0.0334 in)
Valve Lash Adjustment	
Exhaust valve clearance	0.8 mm (0.0315 in)
Intake valve clearance	0.5 mm (0.0197 in)
Cylinder Head Idler Gear Cup Plug	
Cup plug, DMR 63.10	Recess 2.3 mm (0.9 in)

Special Torque

Table 32 Cylinder Head, Camshaft and Valve Train

Camshaft gear M8 x 30 bolt	See tightening steps in procedure
(Camshaft) bearing cap M8 x 35 bolt	25 N·m (18 lbf·ft)
Cylinder head idler gear M8 x 30 socket-head cap screw	30 N·m (22 lbf·ft)
Cylinder head M18 x 246 Torx® bolt	See tightening steps in procedure
Rocker arm assembly M12 x 60 (socket-head) screw	105 N·m (77 lbf·ft)
Upper valve cover M8 x 30 bolt	10 N·m (89 lbf·in)
Valve cover base screw with damper	11 N·m (97 lbf·in)
Valve lash adjustment M10 nut	45 N·m (33 lbf·ft)

Special Service Tools

Table 33 Cylinder Head, Camshaft and Valve Train

Description	Tool Number
1 - 2 inch micrometer	Obtain locally
Bearing installer	Obtain locally
Connecting Rod Bolt Torx® Socket	ZTSE4835
Cylinder Head Lifting Bracket	ZTSE4869
Dial indicator with magnetic base	Obtain locally
Feeler gauge (standard)	Obtain locally
Feeler gauge (Jacobs® 96-020949)	Obtain from Jacobs
Head Bolt Bottoming Tap	ZTSE4855
Head Bolt Torx® Socket	ZTSE4787
Injector Sleeve Brushes	ZTSE4751
Lash Gauge 0.5 mm (0.020 in)	ZTSE6076-5
Lash Gauge 0.8 mm (0.031 in)	ZTSE6076-7
Loctite® 262™ Threadlocker	Obtain locally
Loctite® 5900 sealant or equivalent	Obtain locally
M8 x 20 class 10.9 bolts	Obtain locally
Telescoping gauge set	Obtain locally

Table of Contents

Exploded Views.....393
- **Flywheel Housing and Flywheel (Manual Transmission)**.....393
- **Flywheel and flexplate assembly (automatic transmission)**.....394
- **Rear Engine Mounts**.....395

Removal.....396
- **Preliminary Checks and Measurements**.....396
  - **Flywheel Assembly (Manual Transmission)**.....396
  - **Flywheel Surface Runout**.....396
- **Pilot Bearing**.....397
- **Flywheel (Manual Transmission)**.....397
- **Flywheel and Flexplate Assembly (Automatic Transmission)**.....398
- **Radial Shaft Ring Seal**.....398
- **Lifting Eyes**.....399
- **Flywheel Housing**.....399

Cleaning and Inspection.....401
- **All Components**.....401
- **Flywheel and Flexplate Assemblies**.....401

Recondition.....401
- **Flywheel**.....401

Installation.....403
- **Flywheel Housing**.....403
- **Lifting Eyes**.....404
- **Radial Shaft Ring Seal**.....405
- **Flywheel Assembly (Manual Transmission)**.....405
- **Pilot Bearing (Flywheel)**.....406

Flywheel and Flexplate Assembly (Automatic Transmission).....406

Specifications.....408

Special Torque.....408

Special Service Tools.....408

Exploded Views

Flywheel Housing and Flywheel (Manual Transmission)

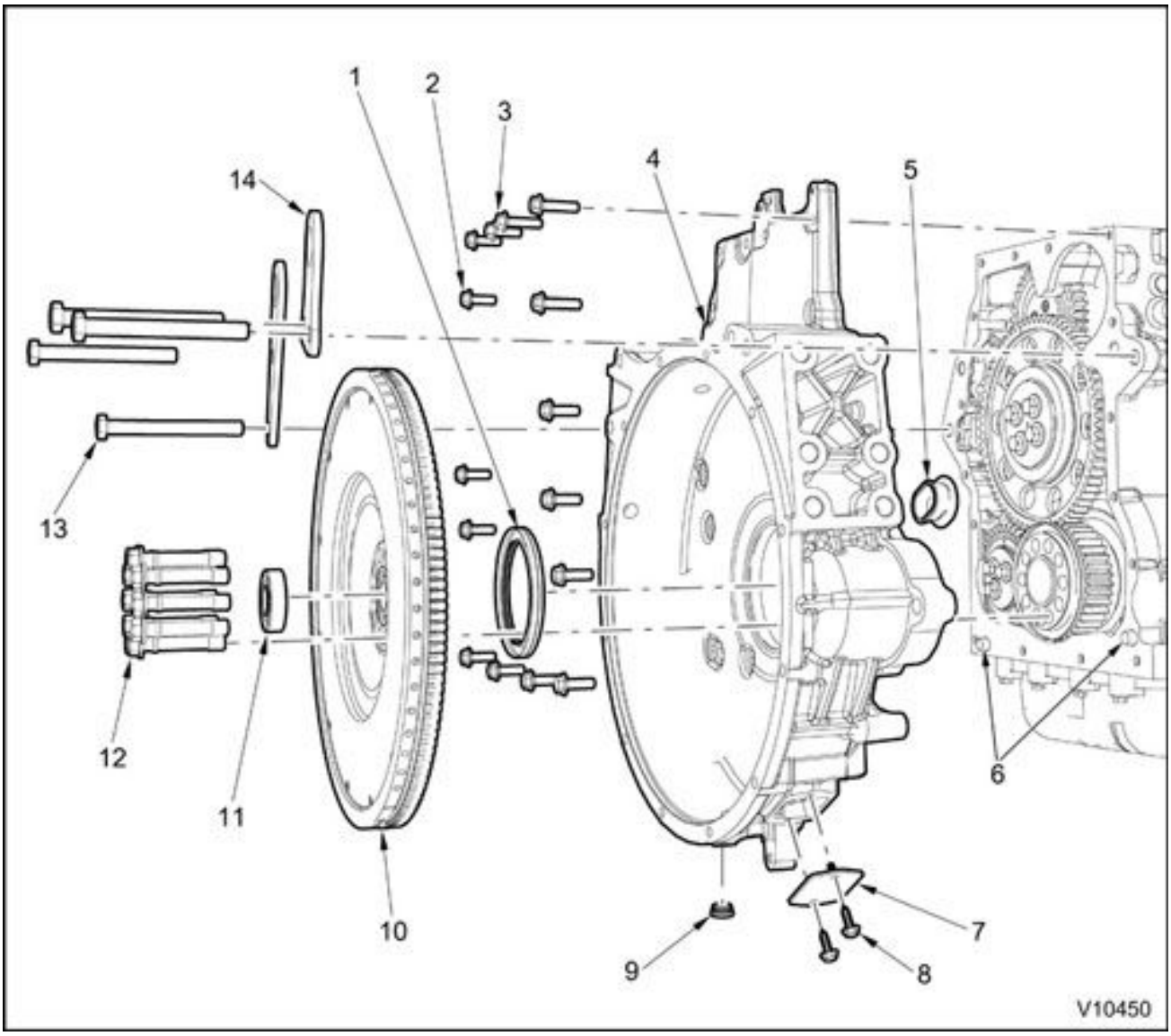


Figure 563 Flywheel housing and flywheel (manual transmission)

1. Radial shaft ring seal
2. M10 x 30 bolt (12)
3. M10 x 40 bolt (3)
4. Flywheel housing
5. 56/48 x 19 plug (converter bolt access)
6. Dowel pin (2)
7. Timing hole cover
8. Tapping screw (2)
9. Plug
10. Flywheel assembly
11. Pilot bearing
12. 12PT flange bolt (10)
13. M16 x 150 bolt (4)
14. Lifting eye (2)

Flywheel and flexplate assembly (automatic transmission)

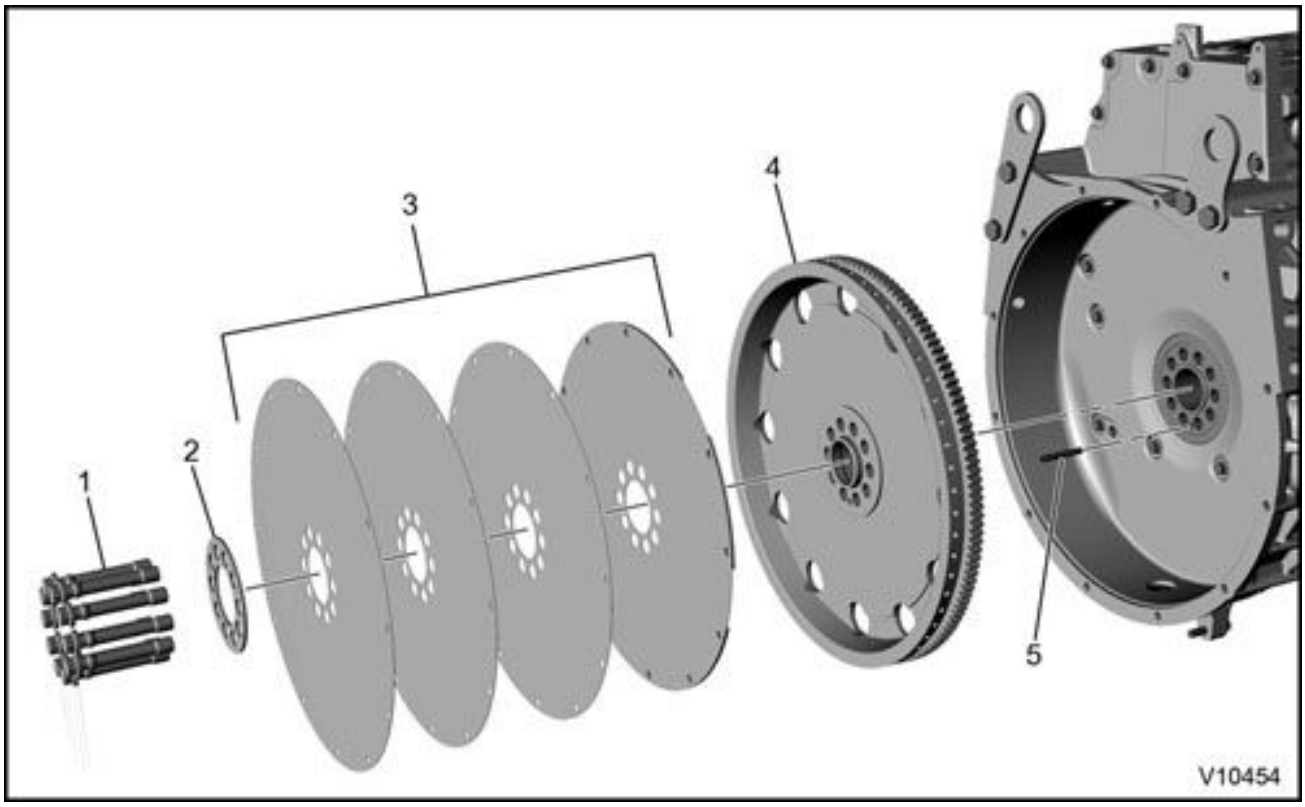


Figure 564 Flywheel and flexplate assembly (automatic transmission)

1. 12PT flange bolt (10)
2. Wear plate (reinforcement ring)
3. Flexplate assembly
4. Flywheel assembly
5. 8 x 60-ST pin

Rear Engine Mounts

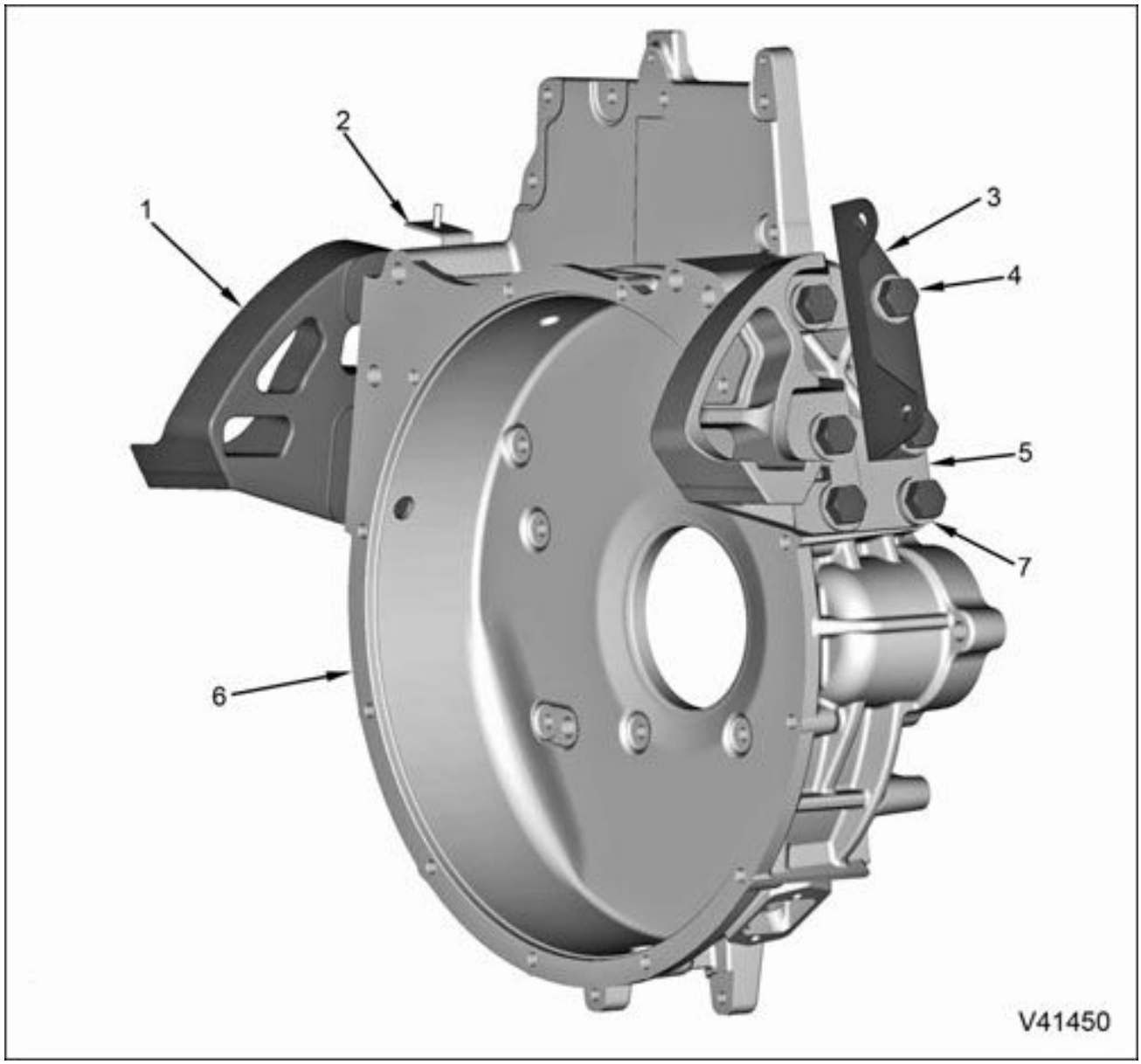


Figure 565 Rear engine mounts

1. Left offset engine mounting support
2. Extension assembly
3. PDO base bracket
4. 3/4” x 2” bolt (12)
5. Right offset engine mounting support
6. Flywheel housing
7. 3/4” washer (12)

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: Refer to the following service section for information on removal of components prior to this section.

- Aftertreatment System

Preliminary Checks and Measurements

Flywheel Assembly (Manual Transmission)

1. Inspect flywheel for cracks around webbing and bolt holes.
2. Inspect flywheel for heat cracks and extensive scoring.
3. Inspect all ring gear teeth for starter pinion damage.
4. Replace flywheel 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 clutch or transmission.

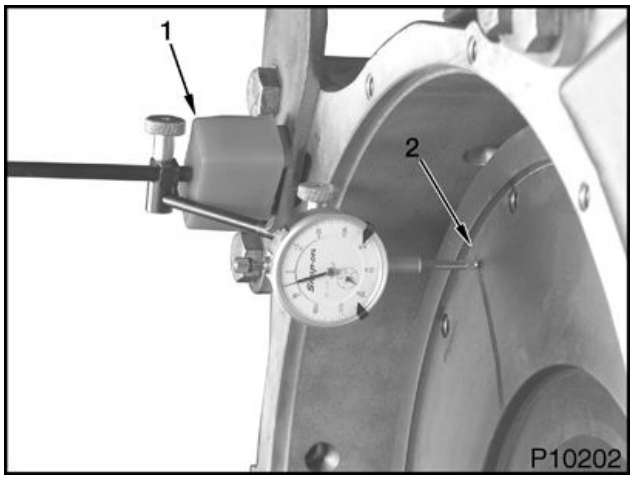


Figure 566 Flywheel surface runout

1. Dial indicator with magnetic base
2. Flywheel

1. Attach dial indicator with magnetic base (page 408) to surface of lifting eye. Place indicator tip against flywheel.

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

2. Push the flywheel inward to eliminate crankshaft end play, zero dial indicator.
3. While pushing inward on the flywheel to eliminate crankshaft end play, slowly rotate crankshaft one complete revolution. See Crankshaft Rotation Procedure (page 363). Compare total dial indicator variation (highest - lowest reading) to specification (page 408).

Pilot Bearing

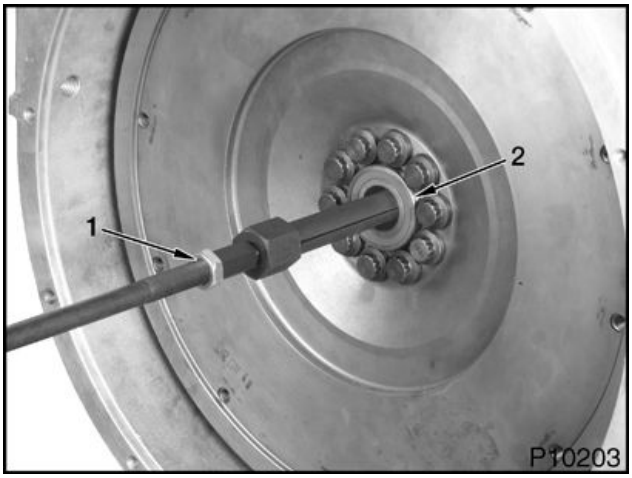


Figure 567 Pilot bearing removal (typical)

1. Slide hammer and blind hole puller
2. Pilot bearing

1. Using a slide hammer (page 408), install blind hole puller (page 408), into pilot bearing.
2. Tap slide hammer and remove pilot bearing.

Flywheel (Manual Transmission)

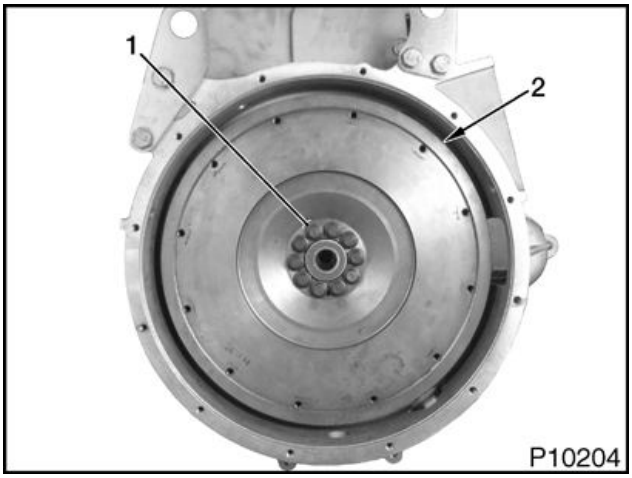


Figure 568 Flywheel removal

1. 12PT flange bolt (10)
2. Flywheel assembly

1. Remove transmission and torque converter assembly. (See transmission manufacturer's service publications.)
2. Remove and discard two 12PT flange bolts at approximately 3 o'clock and 9 o'clock position.
3. Install two guide pins (make locally) into crankshaft flange.
4. Remove and discard remaining eight 12PT flange bolts.
5. Slide wear plate (reinforcement ring) and four flexplates off guide pins.
6. Slide flywheel assembly off guide pins and out of flywheel housing.
7. Remove guide pins from crankshaft flange.

Flywheel and Flexplate Assembly (Automatic Transmission)

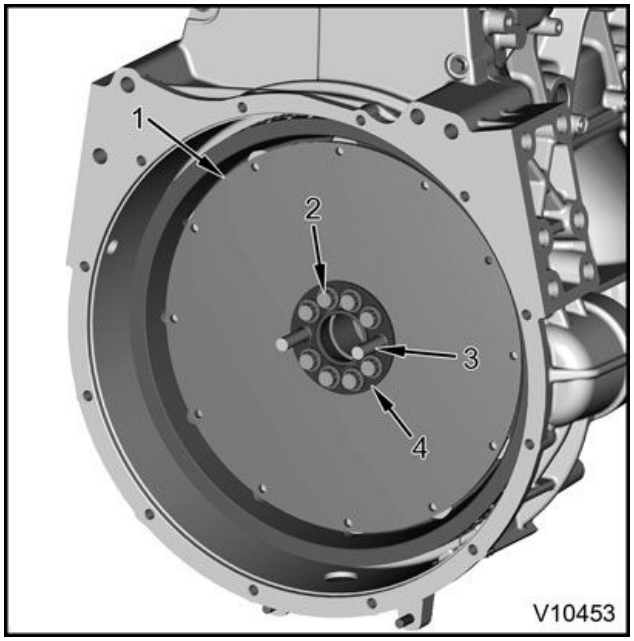


Figure 569 Flywheel and flexplate assembly

1. Flexplate and flywheel assembly
2. 12PT flange bolt (10)
3. Guide pin (2)
4. Wear plate (reinforcement ring)

1. Remove transmission and torque converter assembly. (See transmission manufacturer's service publications.)
2. Remove and discard two 12PT flange bolts, 180 degrees from each other (approximately 3 o'clock and 9 o'clock positions).
3. Install two guide pins (made locally) in place of two removed 12PT flange bolts.
4. Remove and discard the remaining eight 12PT flange bolts.

NOTE: The individual components of the flexplate assembly are non-servicable. Replace the flexplate as an assembly.

5. Slide wear plate (reinforcement ring) and four flexplates off guide pins.
6. Slide flywheel assembly off guide pins and out of flywheel housing.
7. Remove guide pins from crankshaft flange.

Radial Shaft Ring Seal

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

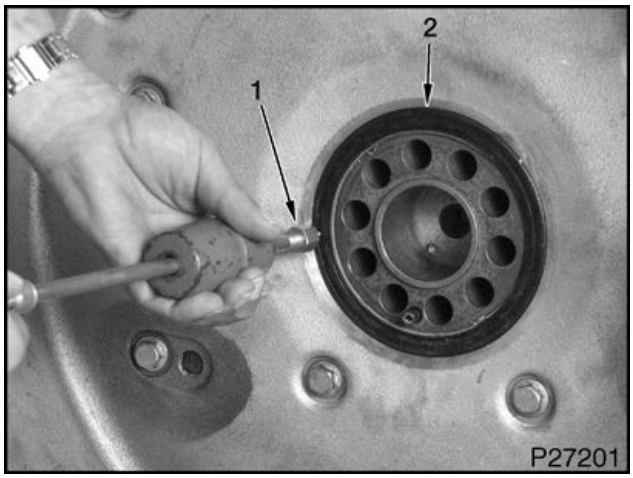


Figure 570 Radial shaft ring seal removal

1. Slide hammer
2. Radial shaft ring seal

1. With an awl and hammer, punch two holes 180° apart in radial shaft ring seal.
2. Thread a slide hammer (page 408) with correct size screw into one of the two holes.
3. Slide hammer until one side of seal begins to pull out of flywheel housing. Move slide hammer to other hole and repeat until seal is completely removed.

Lifting Eyes

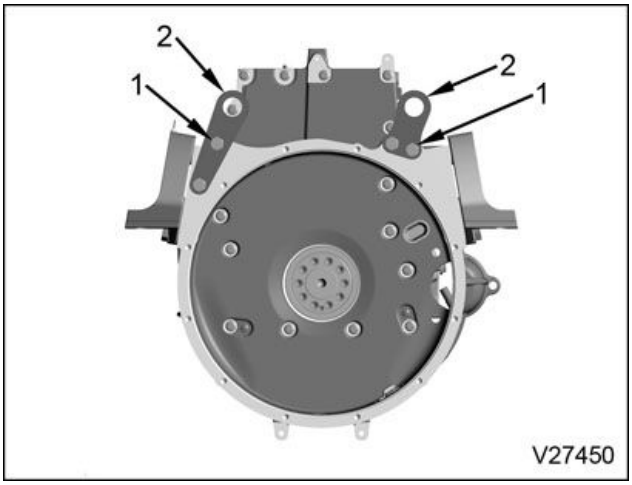


Figure 571 Lifting eye

1. M16 x 150 bolt (4)
2. Lifting eye (2)

1. Remove four M16 x 150 bolts.
2. Remove two lifting eyes.

Flywheel Housing

WARNING: To prevent personal injury or death, support the flywheel housing before removing bolts and breaking sealant bond between flywheel housing and crankcase.

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

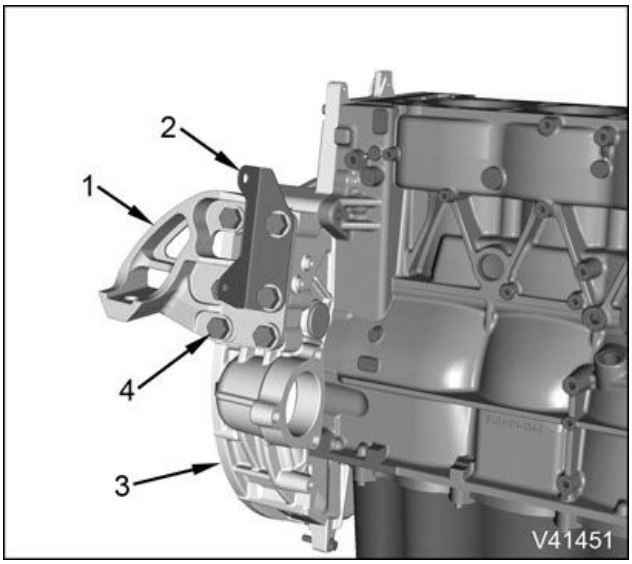


Figure 572 Right offset engine mounting support assembly

1. Right offset engine mounting support
2. PDO base bracket
3. Flywheel housing
4. 3/4" x 2” bolt with 3/4” washer (6)

1. Remove six 3/4" x 2” bolts with washers, PDO base bracket and engine mounting support from right side of flywheel housing.
2. Remove 3/4" x 2” bolts with washers, extension bracket and engine mounting support from the left side of flywheel housing.

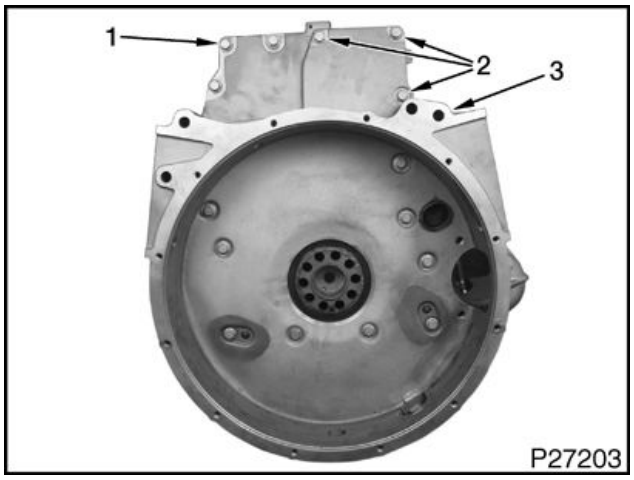


Figure 573 Flywheel housing (typical)

1. M10 x 30 bolt (12)
2. M10 x 40 bolt (3)
3. Flywheel housing

WARNING: To prevent personal injury or death, support the flywheel housing before removing bolts and breaking sealant bond between housing and crankcase.

3. Remove 12 M10 x 30 and three M10 x 40 bolts from flywheel housing.
4. Use a thin gasket scraper to separate sealant between flywheel housing and crankcase.

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

5. Remove flywheel housing with aid of an assistant.

Cleaning and Inspection

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 crankcase 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 crankcase and flywheel housing.
3. Wash flywheel, flexplate (if equipped) and flywheel housing. Dry all with filtered compressed air.
4. Wash crankshaft timing gear with a stiff brush and suitable solvent. Dry all with filtered compressed air.

Flywheel and Flexplate Assemblies

1. Inspect flywheel for cracks around webbing and bolt holes.
2. Inspect flywheel for extensive heat cracks and scoring.
3. If equipped, inspect flexplate for cracks, damage or warpage. Replace if required.
4. Inspect all ring gear teeth for starter pinion damage.
5. Replace flywheel if necessary.

Recondition

Flywheel

NOTE: Flywheels used with manual transmissions may be resurfaced to correct minor wear and scoring. If flywheel meets the following requirements it can be resurfaced.

WARNING: To prevent personal injury or death, do not machine flywheel beyond minimum thickness specified for flywheel resurfacing.

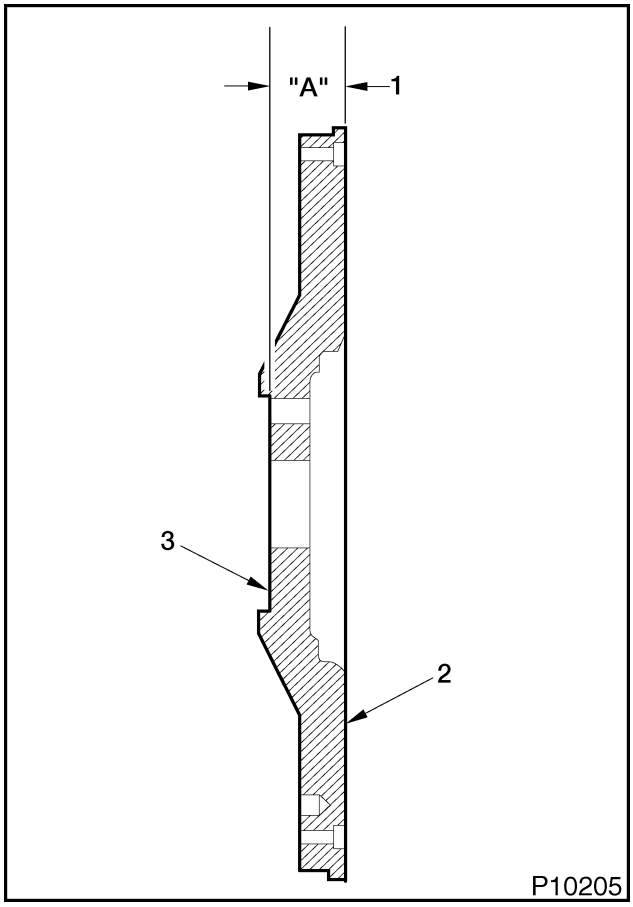


Figure 574 Flywheel surface dimension (typical)

1. Flywheel thickness (dimension “A”)
2. Clutch disc mounting face
3. Crankshaft timing gear face

NOTE: Flywheel resurfacing information is provided for guidance only. Navistar, Inc. assumes no responsibility either for the results of any work performed in accordance with this information or for the ability of service personnel to detect cracks.

WARNING: To prevent personal injury or death, carefully examine flywheel for any cracks or heat checks before and after resurfacing. Cracks in the flywheel can cause it to separate. If there are any questions, do not reuse the flywheel.

1. Check flywheel for cracks and damage. Replace flywheel if required.
2. Using 1-2 inch micrometer (page 408), measure flywheel thickness and compare to minimum required thickness specification (dimension “A”) (page 408). Discard flywheel if below minimum thickness specification or if flywheel will be below minimum thickness after resurfacing.
3. Resurface flywheel. See Flywheel Resurfacing Machine operators manual for instructions on flywheel resurfacing procedure.
4. Check flywheel for cracks and damage after resurfacing. Replace flywheel if required.
5. Measure flywheel thickness after resurfacing and compare to minimum required thickness specification. Discard flywheel if below minimum thickness specification.

Installation

Flywheel Housing

CAUTION: To prevent engine damage, apply Liquid Gasket and component within 5 minutes of application to inhibit the formation of a skin and ensure a leak proof joint.

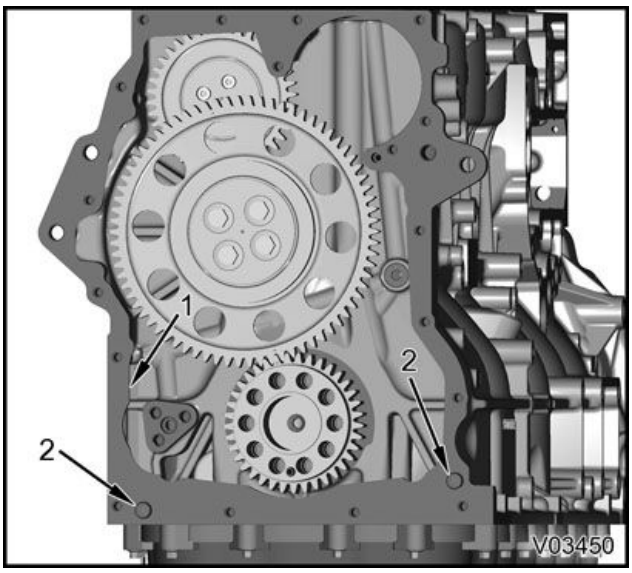


Figure 575 Flywheel housing to crankcase alignment dowel pins

1. Flywheel housing to crankcase mating surface
2. Flywheel housing to crankcase dowel pin (2)

1. Verify flywheel housing alignment dowels are installed into the crankcase and are not damaged. Replace as necessary.

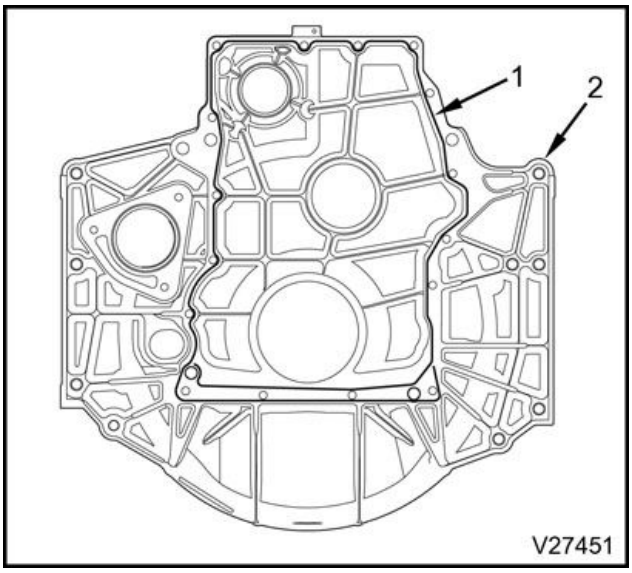


Figure 576 Flywheel housing sealant application

1. Apply sealant on mating surface
2. Front of flywheel housing

2. Apply Loctite 5900 or Wacker® A–442 RTV sealant (page 408) to mating surfaces of flywheel housing and crankcase.

⚠ WARNING: To prevent personal injury or death, get help when removing or installing the flywheel housing.

3. Install flywheel housing to crankcase with the aid of an assistant.

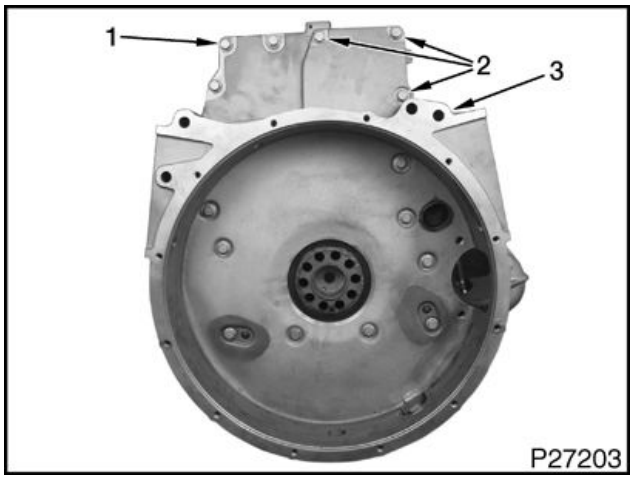


Figure 577 Flywheel housing (typical)

1. M10 x 30 bolt (12)
2. M10 x 40 bolt (3)
3. Flywheel housing

4. Install 12 M10 x 30 and three M10 x 40 flywheel housing bolts. Tighten bolts to special torque (page 408).

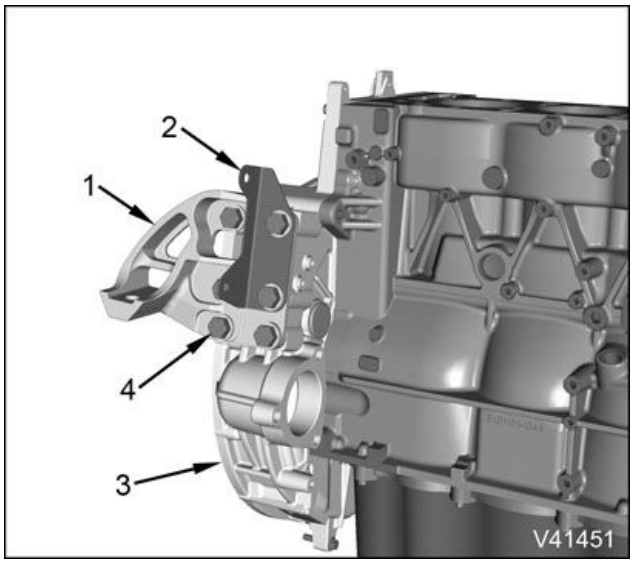


Figure 578 Right offset engine mounting support assembly

1. Right offset engine mounting support
2. PDO base bracket
3. Flywheel housing
4. 3/4" x 2” bolt with 3/4” washer (6)

5. Install 3/4" x 2” bolts, washer, extension bracket and rear engine mount on left side of flywheel housing. Tighten to standard torque (page 503).
6. Install 3/4" x 2” bolts, washer, PDO base bracket and engine mounting support on right side of flywheel housing. Tighten to standard torque (page 503).

Lifting Eyes

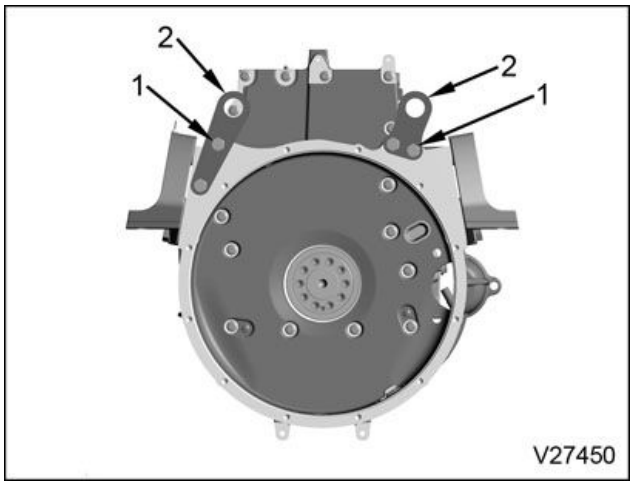


Figure 579 Lifting eyes

1. M16 x 150 bolt (4)
2. Lifting eye (2)

1. Install two lifting eyes.
2. Install four M16 x 150 lifting eye bolts. Tighten bolts to special torque (page 408).

Radial Shaft Ring Seal

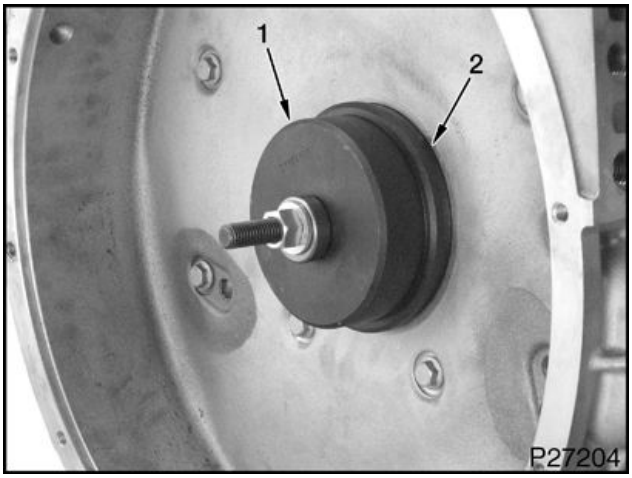


Figure 580 Radial shaft ring seal installation (typical)

1. Rear Oil Seal Installer
2. Radial shaft ring seal

CAUTION: To avoid damage to the radial shaft ring seal, do not touch inner seal lip or allow oil or grease on any part of the seal during installation.

1. Using Rear Oil Seal Installer (page 408), install ring radial shaft seal into flywheel housing.
   a. Install inner hub of tool to crankshaft flange. Use two bolts provided with tool.
   b. Install radial shaft seal to inner hub of tool.
   c. Install pressing hub and nut and tighten to install seal. When tool bottoms out, seal is fully installed.

Flywheel Assembly (Manual Transmission)

1. Install two guide pins (made locally) into crankshaft flange at approximately 3 o'clock and 9 o'clock position.

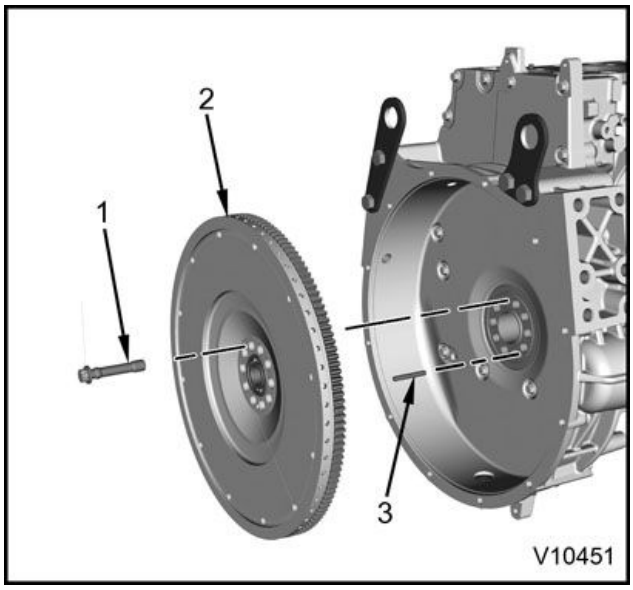


Figure 581 Flywheel assembly and bolts

1. 12PT flange bolt (10)
2. Flywheel assembly
3. 8 x 60-ST pin

2. Align crankshaft timing gear pin hole in flywheel assembly with crankshaft timing gear pin and slide flywheel onto guide pins.

CAUTION: To prevent engine damage, always install new flywheel mounting bolts.

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

3. Loosely install eight new 12PT flange bolts to secure flywheel assembly to crankshaft.
4. Remove both guide pins and loosely install two remaining new 12PT flange bolts.

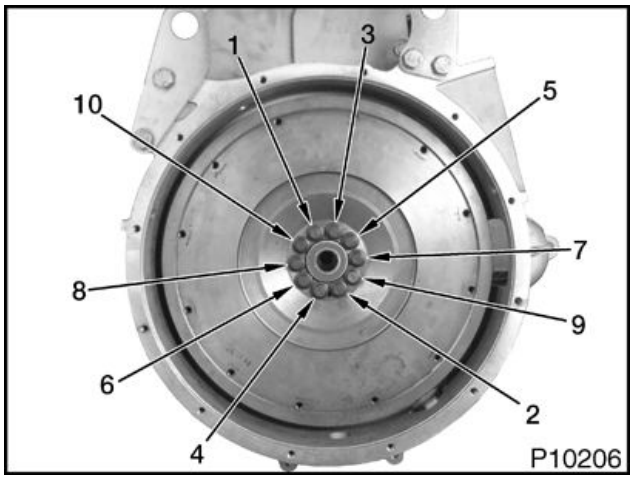


Figure 582 Flywheel bolt tightening sequence

NOTE: For proper flywheel installation, follow the correct tightening sequence while keeping the crankshaft from turning.

5. Tighten 12PT flange bolts using sequence indicated above as follows:
   a. Tighten bolts to 110 N·m (81 lbf·ft).
   b. Angle tighten bolts 90°.
   c. Angle tighten bolts an additional 90°.

Pilot Bearing (Flywheel)

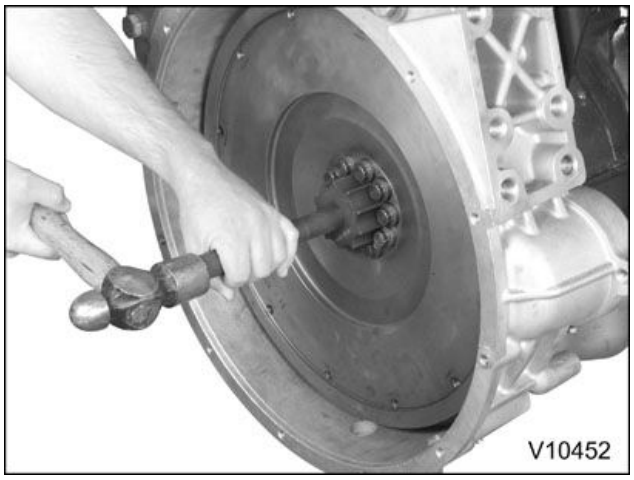


Figure 583 Pilot Bearing Installation Tool

1. Place pilot bearing in flywheel bore.
2. Using Pilot Bearing Installation Tool (page 408), tap pilot bearing into flywheel. When tool bottoms out, pilot bearing is fully installed.

Flywheel and Flexplate Assembly (Automatic Transmission)

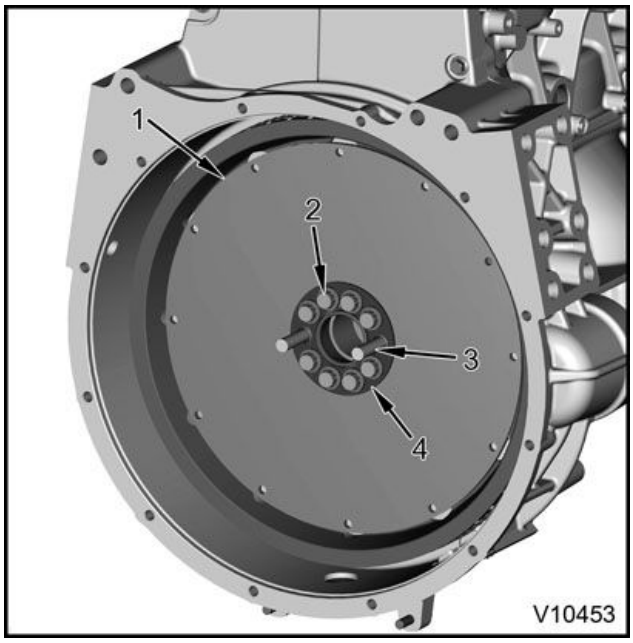


Figure 584 Flywheel and flexplate assembly

1. Flexplate and flywheel assembly
2. 12PT flange bolt (10)
3. Guide pin (2)
4. Wear plate (reinforcement ring)

1. Install two guide pins (made locally) into crankshaft flange 180° apart (approximately 3 o'clock and 9 o'clock positions).
2. Align crankshaft timing gear pin hole in flywheel assembly with crankshaft gear pin and slide flywheel onto guide pins.

CAUTION: To prevent engine damage, always install new flywheel mounting bolts.

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

NOTE: The individual components of the flexplate assembly are non-servicable. Replace the flexplate as an assembly.

3. Slide flexplate assembly over guide pins.
4. Slide wear plate (reinforcement plate) over guide pins with logo and part number visible towards rear and install eight new 12PT flange bolts hand tight.
5. Remove guide pins and install remaining two 12PT flange bolts.

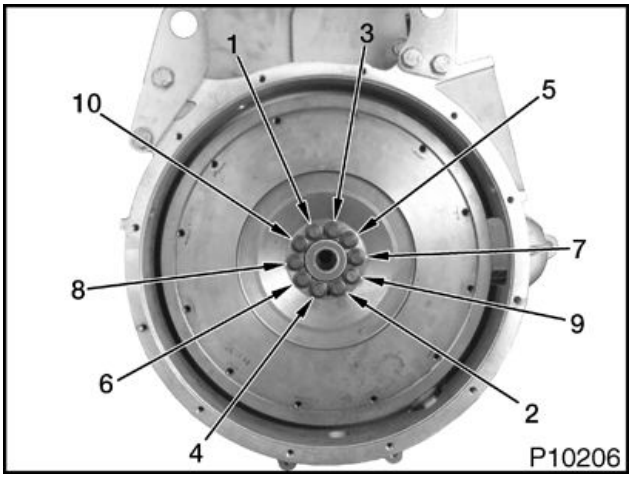


Figure 585 Flywheel and flexplate assembly bolt tightening sequence (typical)

NOTE: For proper flywheel installation, follow the correct tightening sequence while keeping the crankshaft from turning.

6. Tighten 12PT flange bolts using sequence above as follows:
   a. Tighten bolts to 110 N•m (81 lbf·ft).
   b. Angle tighten bolts 90°
   c. Angle tighten bolts an additional 90°.

Specifications

Table 34 Flywheel and Flywheel Housing

Flywheel minimum thickness (dimension “A”)	46 mm (1.811 in)
Flywheel maximum surface runout	0.20 mm (0.0079 in)

Special Torque

Table 35 Flywheel and Flywheel Housing

12PT flange bolts	See tightening steps in procedure.
Flywheel housing bolts, M10 x 30 and M10 x 40	65 N·m (48 lbf·ft)
Lifting eye bolts, M16 x 150	280 N·m (207 lbf·ft)
Timing hole cover screws	2 N·m (18 lbf·in)

Special Service Tools

Table 36 Flywheel and Flywheel Housing

Description	Tool Number
1-2 inch micrometer	Obtain locally
Blind hole puller	Obtain locally
Brake cleaner (non-caustic)	Obtain locally
Dial indicator with magnetic base	Obtain locally
Loctite 5900®	Obtain locally
Wacker® A–442 RTV sealant	Obtain locally
Pilot Bearing Installation Tool	ZTSE4898
Rear Oil Seal Installer	ZTSE4875
Slide hammer	Obtain locally

Table of Contents

Exploded Views.....411
- **Oil Pan (Front Sump Shown, Rear Sump Similar, Typical)**.....411
- **Oil Pickup Tube - Front Sump (Typical)**.....412

Removal.....413
- **Oil Pan**.....413
- **Oil Pickup Tube — Front Sump**.....414
- **Oil Recovery**.....415
- **Oil Pickup Tube — Rear Sump**.....416

Cleaning and Inspection.....417
- **Oil Pan**.....417
- **Oil Pickup Tube**.....417

Installation.....418
- **Oil Pickup Tube — Front Sump**.....418
- **Oil Pickup Tube — Rear Sump**.....418
- **Oil Recovery**.....419
- **Oil Pan**.....422

Special Torque.....424

Exploded Views

Oil Pan (Front Sump Shown, Rear Sump Similar, Typical)

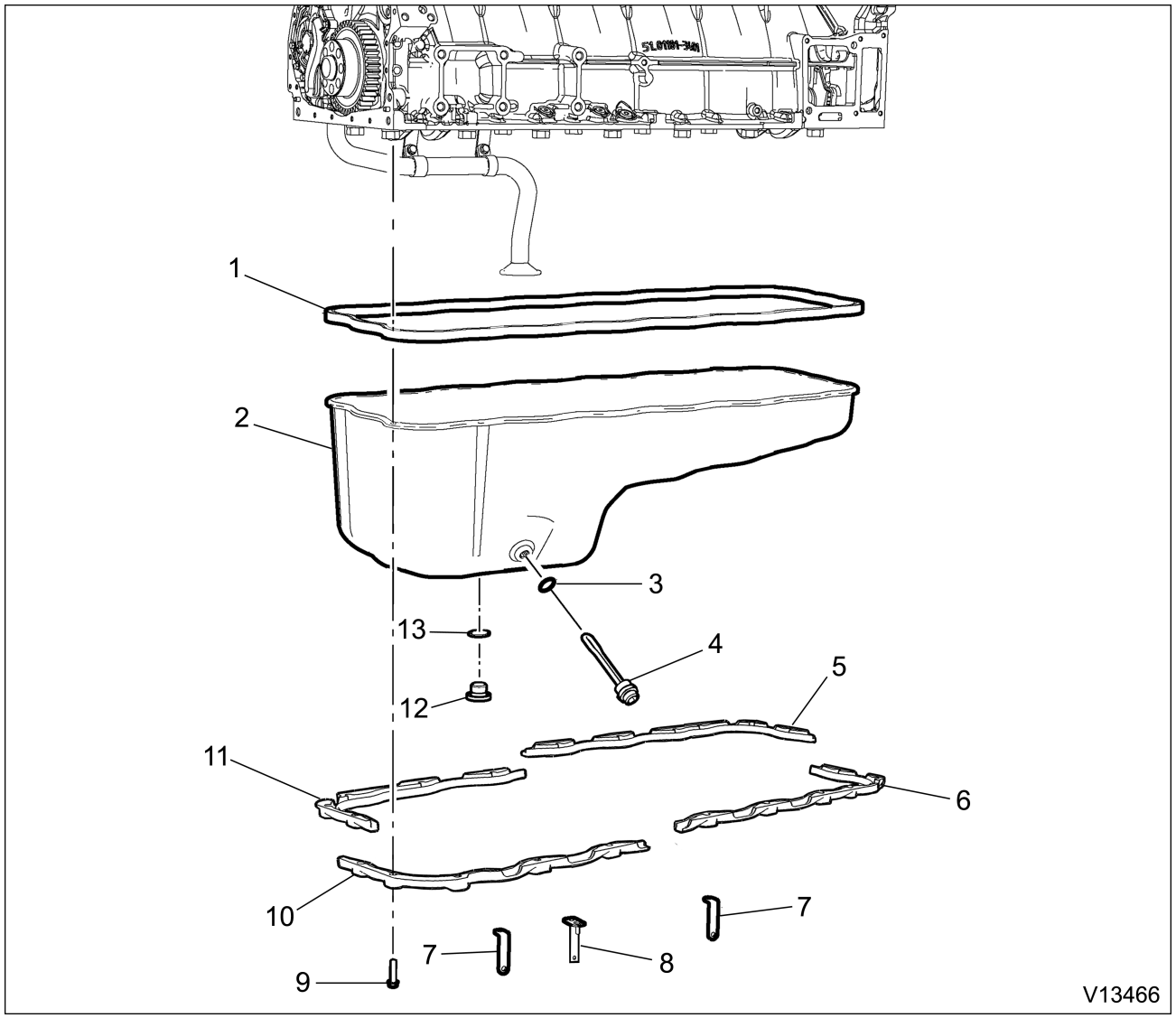


Figure 586 Oil pan (front sump shown, rear sump similar, typical)

1. Oil pan gasket
2. Oil pan (front sump)
3. O-ring (heater, optional)
4. Oil pan heater element (optional)
5. Oil pan clamp – rear right 461 mm (18 in)
6. Oil pan clamp – rear left 461 mm (18 in)
7. Cooling tube bracket (2) (right angle)
8. Extension bracket support (T-bracket)
9. M8 x 40 bolt (22)
10. Oil pan clamp – front left 599 mm (23.5 in)
11. Oil pan clamp – front right 599 mm (23.5 in)
12. Oil drain M27 x 2 plug
13. O-ring (32.92 x 3.53)

Oil Pickup Tube - Front Sump (Typical)

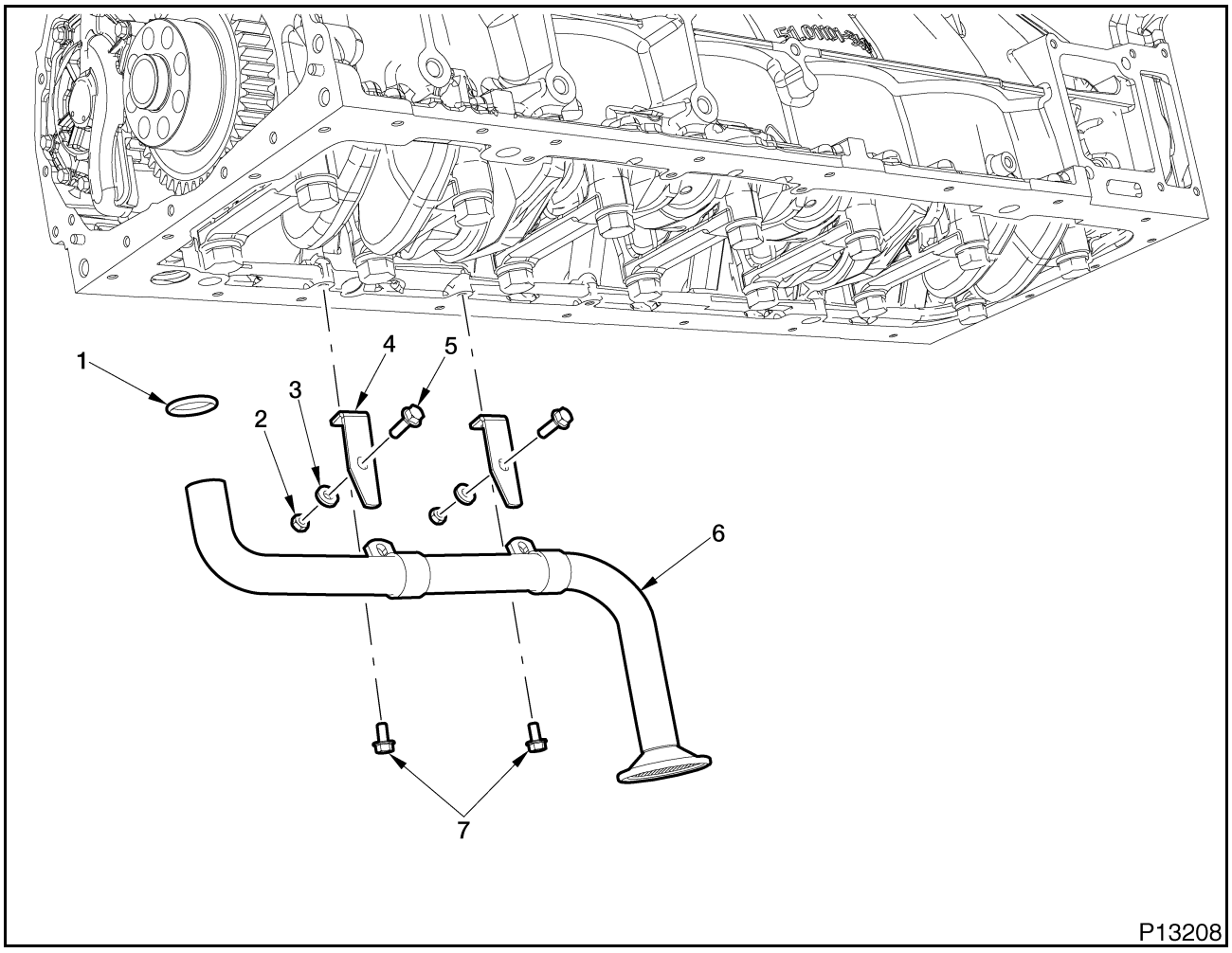


Figure 587 Oil pickup tube - Front sump (typical)

1. O-ring, 32 x 5
2. Prevailing torque nut (M8) (2)
3. D9/19/4 washer (2)
4. Oil pickup tube support (2)
5. M8 x 25 bolt (2)
6. Pickup oil tube
7. M8 x 16 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, 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: Refer to the following service section for information on removal of components prior to this section.

- Engine Electrical — required for preheater removal.

Oil Pan

1. Remove oil drain plug and O-ring and drain oil into a suitable container.
2. If equipped, remove oil pan heater element and discard O-ring.
3. Recycle or dispose of oil according to applicable regulations.

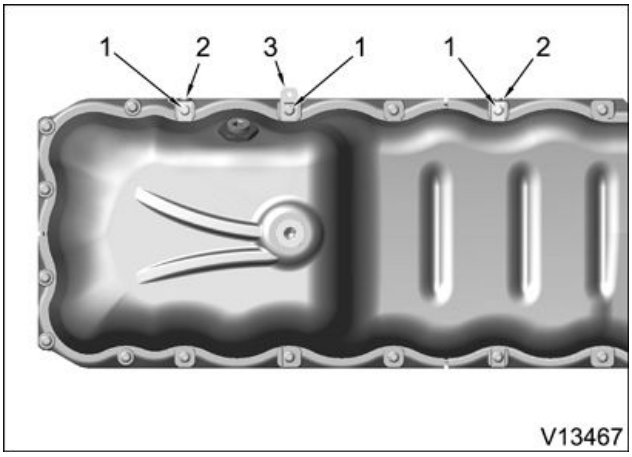


Figure 588 Cooling tube brackets and extension bracket support (typical)

1. M8 x 40 bolt (3)
2. Cooling tube bracket (right angle) (2)
3. Extension bracket support (T-bracket)

4. Remove three M8 x 40 bolts, two cooling tube brackets, and one extension bracket support.

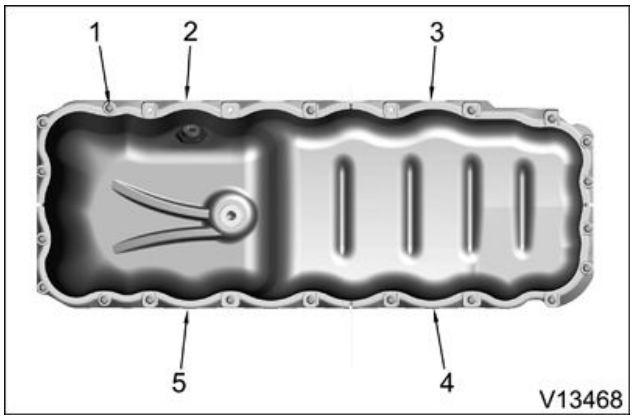


Figure 589 Oil pan clamps (typical)

1. M8 x 40 bolt (19)
2. Oil pan clamp – front left 599 mm (23.5 in)
3. Oil pan clamp – rear left 461 mm (18 in)
4. Oil pan clamp – rear right 461 mm (18 in)
5. Oil pan clamp – front right 599 mm (23.5 in)

5. Remove 19 M8 x 40 bolts.
6. Remove four oil pan clamps.
7. Remove oil pan and oil pan gasket as an assembly.
8. Clean and inspect the oil pan gasket. Discard gasket if damaged.

Oil Pickup Tube — Front Sump

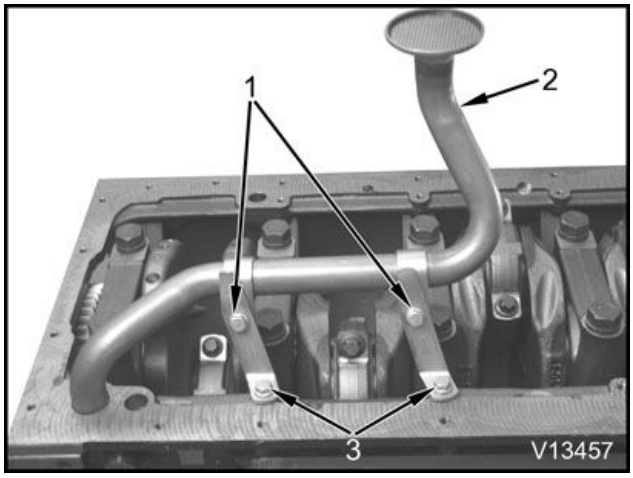


Figure 590 Oil pickup tube (front sump, typical)

1. M8 x 25 bolt (2)
2. Oil pickup tube
3. M8 x 16 bolt (2)

1. Remove two M8 x 16 bolts and pickup tube with supports as an assembly.
2. Only if required, remove the two M8 x 25 bolts, prevailing torque nuts, D9/19/4 washers and oil pickup tube supports.

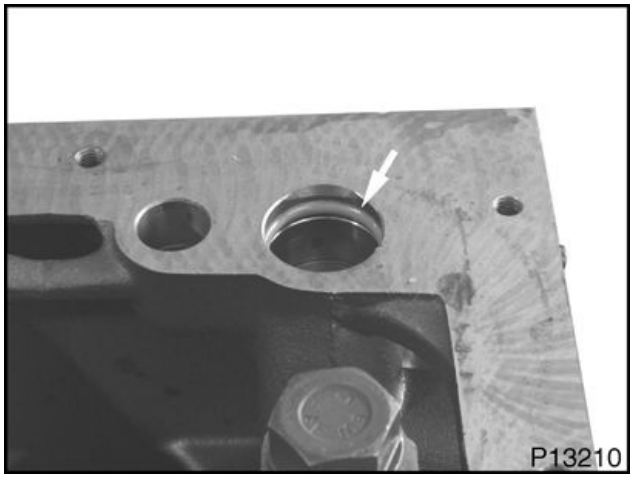


Figure 591 Oil pickup tube O-ring

3. Remove and discard oil pickup tube O-ring.

Oil Recovery

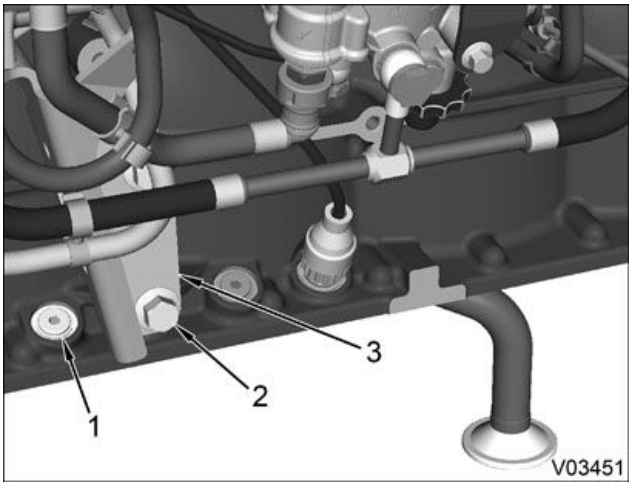


Figure 592 High-pressure pump support and plug

1. Plug
2. M14 x 30 bolt (2)
3. High-pressure pump support

1. Remove and save two M14 x 30 bolts that secure the high-pressure pump support.
2. Remove and save two M12 x 30 bolts that secure the high-pressure pump support. to the bottom of high-pressure pump.
3. Remove and save the high-pressure support.
4. Remove plug from crankcase. Discard plug and seal ring.

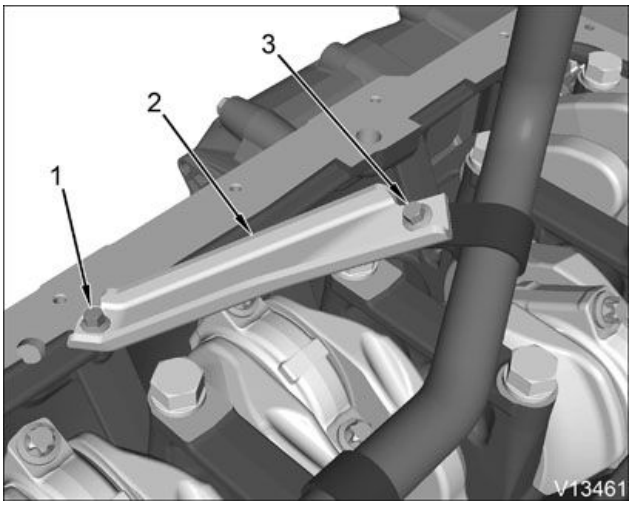


Figure 593 Oil pickup tube

1. M8 x 16 bolt
2. Oil pickup tube support
3. M8 x 25 bolt and M8 nut

5. Remove M8 x 25 bolt and M8 nut that secure the oil pickup tube support to the clamp on the oil pickup tube. Discard M8 x 25 bolt; save M8 nut.
6. Remove and discard M8 x 16 bolt that secures other end of oil pickup tube support .
7. Remove and save oil pickup tube support.

Oil Pickup Tube — Rear Sump

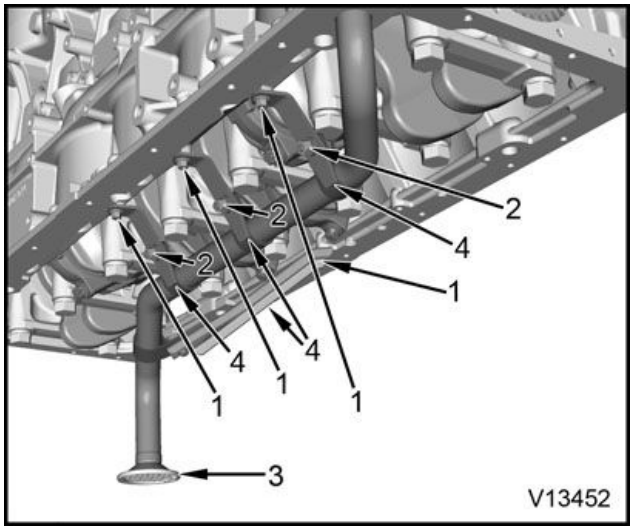


Figure 594 Oil pickup tube (rear sump)

1. M8 x 16 bolt (4)
2. M8 x 25 bolt (3)
3. Oil pickup tube
4. Tube support

1. Remove four M8 x 16 bolts holding oil pickup tube supports to crankcase.
2. Remove oil pickup tube and supports as an assembly.
3. Only if required, remove M8 x 25 bolts, prevailing torque nuts and D9/19/4 washers and supports.

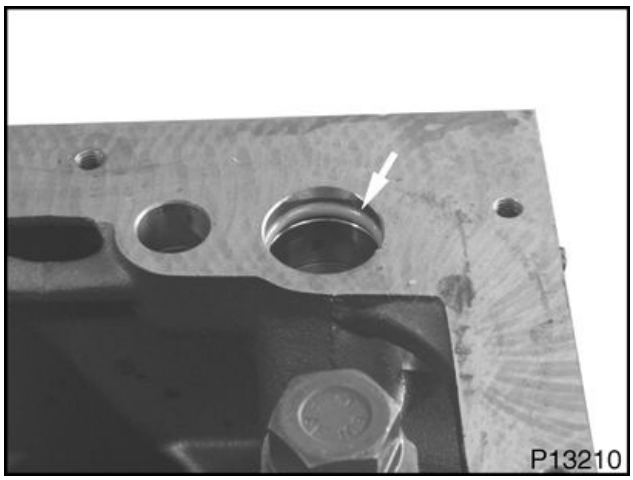


Figure 595 Oil pickup tube O-ring

4. Remove and discard oil pickup tube O-ring.

Cleaning and Inspection

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

Oil Pan

1. Inspect bottom of oil pan for metallic debris or other evidence of engine damage. Investigate any abnormalities as required.
2. Clean oil pan with a suitable solvent.
3. Dry with filtered compressed air.
4. Inspect oil pan for warping, dents and cracks. Replace the oil pan if necessary.

Oil Pickup Tube

1. Clean oil pickup tube and supports with a suitable solvent.
2. Dry with filtered compressed air.
3. Inspect oil pickup tube and supports for cracks, damage or pickup screen blockage. Replace if necessary.

Installation

Oil Pickup Tube — Front Sump

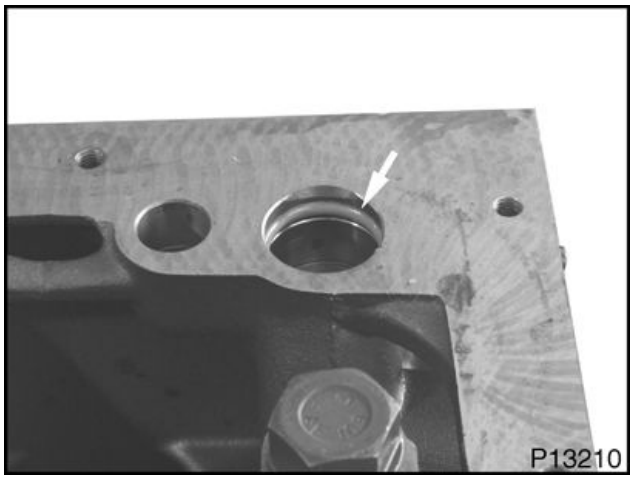


Figure 596 Oil pickup tube O-ring

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

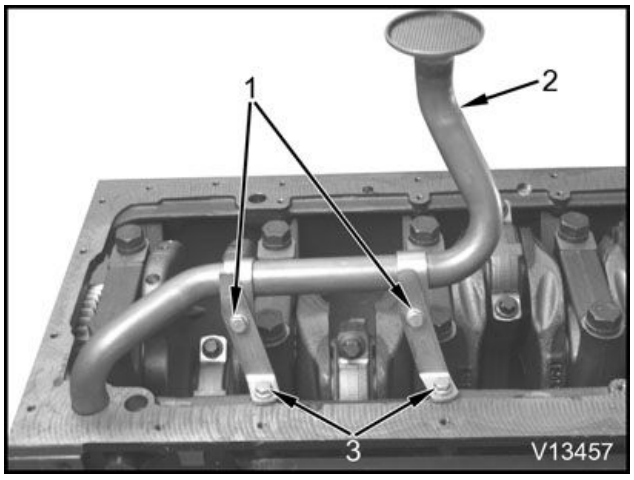


Figure 597 Oil pickup tube (front sump, typical)

1. M8 x 25 bolt (2)
2. Oil pickup tube
3. M8 x 16 bolt (2)

2. If required, position two oil pickup tube supports and loosely install two M8 x 25 bolts, prevailing torque nuts and D9/19/4 washers.
3. Install oil pickup tube and two M8 x 16 bolts.
4. Tighten two M8 x 16 bolts to standard torque (page 503).
5. Tighten two prevailing torque nuts (M8) and M8 x 25 bolts to standard torque (page 503).

Oil Pickup Tube — Rear Sump

1. Lubricate a new oil pickup tube O-ring with clean engine oil and install onto tube.

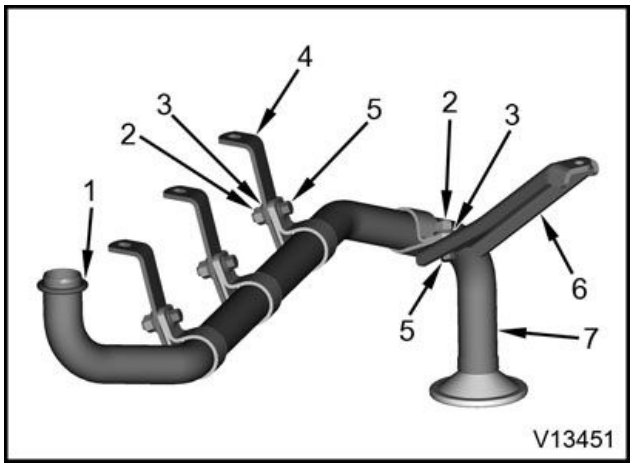


Figure 598 Rear sump oil tube assembly

1. O-ring, 32 x 5
2. Prevailing torque nut (4)
3. D9/19/4 washers (4)
4. Supports (short) (3)
5. M8 x 25 bolt (4)
6. Support (long)
7. Oil pickup tube

2. If oil pickup tube supports were removed, loosely install with four M8 x 25 bolts, D9/19/4 washers and prevailing torque nuts.
3. Install oil pickup tube and supports as an assembly.

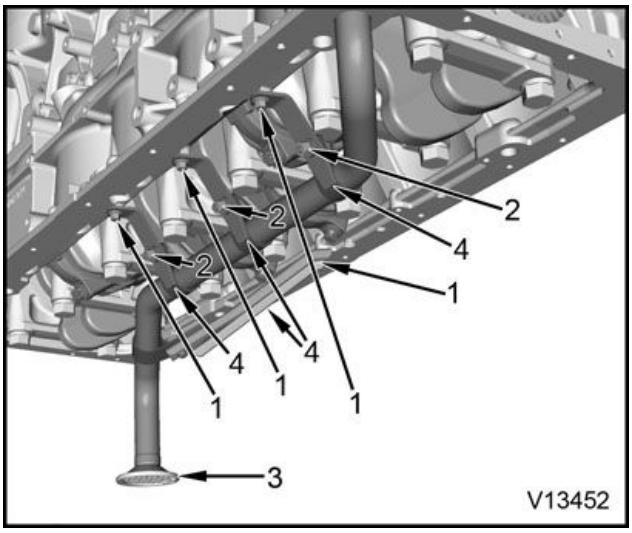


Figure 599 Oil pickup tube

1. M8 x 16 bolts (4)
2. M8 x 25 bolts (3)
3. Oil pickup tube
4. Tube support

4. Install four M8 x 16 bolts through oil pickup tube supports.
5. Tighten four M8 x 16 bolts to standard torque (page 503).
6. Tighten three M8 x 25 bolts and prevailing torque nuts to standard torque (page 503).

Oil Recovery

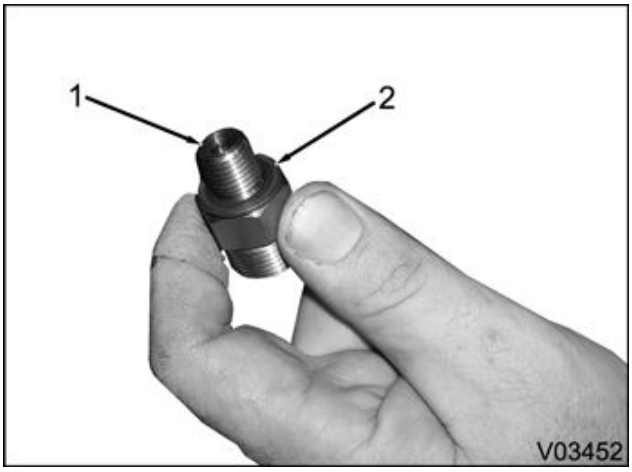


Figure 600 Straight fitting assembly and seal ring

1. Straight fitting assembly
2. Seal ring

1. Lubricate new seal ring with clean engine oil and put ring onto new straight fitting assembly.

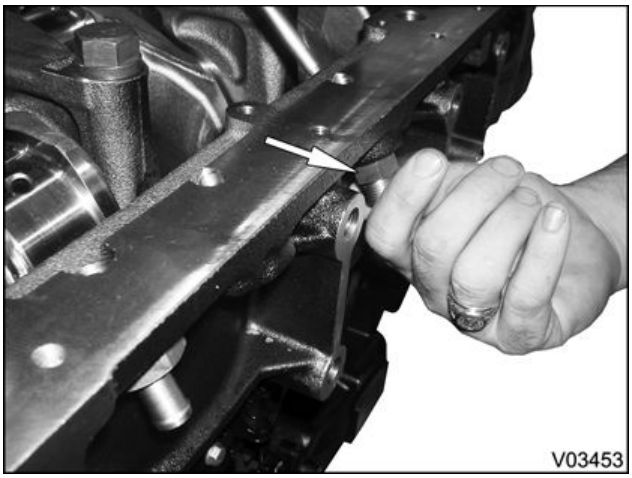


Figure 601 Straight fitting assembly

1.

2. Thread straight fitting assembly into the crankcase (where plug was removed in Figure 1) and tighten fitting to 55 N·m (40 lbf·ft).

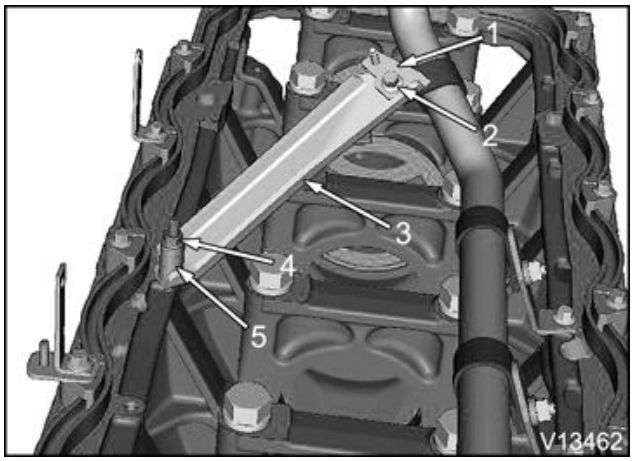


Figure 602 Oil recovery support assembly and oil pickup tube

1. Oil recovery support assembly (includes M6 x 20 stud)
2. M8 x 30 bolt and M8 nut
3. Oil pickup tube support
4. M8 x 50 stud bolt
5. Spacer (30 mm)

3. Position new oil recovery support assembly onto saved oil pickup tube support. Secure by installing a new M8 x 30 bolt and saved M8 nut. Tighten nut to 13 N·m (115 lbf·in).
4. Position new 30 mm spacer onto other end of oil pickup tube support and install new M8 x 50 stud bolt. Tighten bolt to 31 N·m (23 lbf·ft).

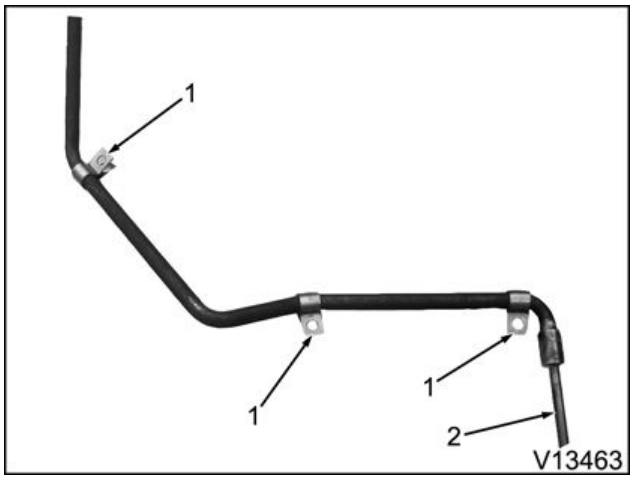


Figure 603 P-clamps on oil recovery tube

1. P-clamp (3)
2. Brazed end

5. Position three new P-clamps onto mew oil recovery tube as shown.

Figure 604 Oil recovery tube (brazed end)

6. Coat brazed end of oil recovery tube with P80® rubber lubricant or equivalent.
7. Insert brazed end of oil recovery tube into straight fitting assembly in crankcase; position P-clamp onto M6 x 20 stud in oil recovery support and P-clamp onto M8 x 50 stud bolt.

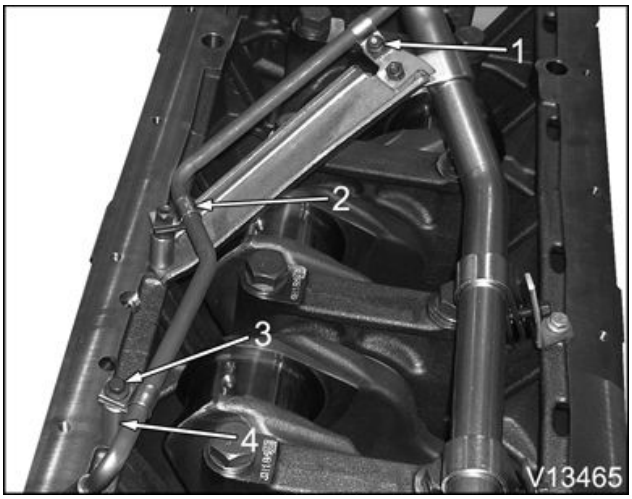


Figure 605 P-clamps

1. M6 nut
2. M8 nut
3. M8 x 60 bolt
4. Spacer (43 mm)

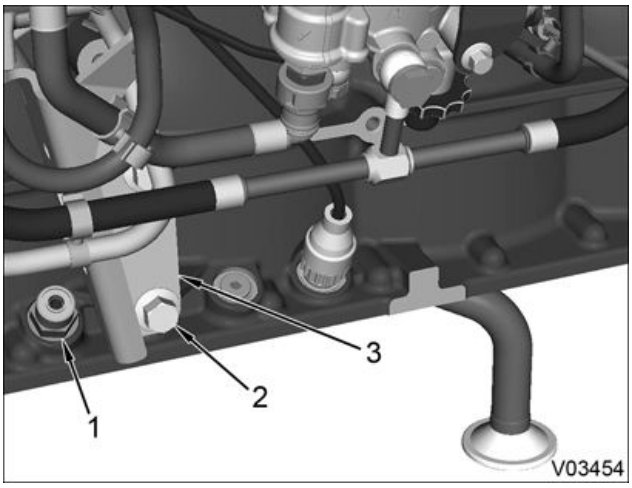


Figure 606 High-pressure pump support and straight fitting assembly

1. Straight fitting assembly
2. M14 x 30 bolt (2)
3. High-pressure pump support

8. Install new M6 nut onto M6 x 20 stud on oil recovery support.
9. Install new M8 nut onto M8 x 50 stud bolt.
10. Position new 43 mm spacer under P-clamp and install new M8 x 60 bolt.
11. Tighten M8 nut and M8 x 60 bolt to 31 N·m (23 lbf·ft).
12. Tighten M6 nut to 13 N·m (115 lbf·in).
13. Install high-pressure pump support.
14. Secure the high-pressure pump support to the bottom of the high-pressure pump using the previously saved M12 x 30 bolts. Hand tighten bolts.
15. Secure the high-pressure pump support to the crankcase using the previously saved M14 x 30 bolts. Hand tighten bolts.
16. Tighten M12 x 30 bolts to 105 N·m (77 lbf·ft).
17. Tighten M14 x 30 bolts to 172 N·m (126 lbf·ft).

Oil Pan

1. Lubricate new or old oil pan gasket with clean engine oil and Install oil pan gasket onto oil pan.
2. Position oil pan and oil pan gasket as an assembly onto the crankcase.

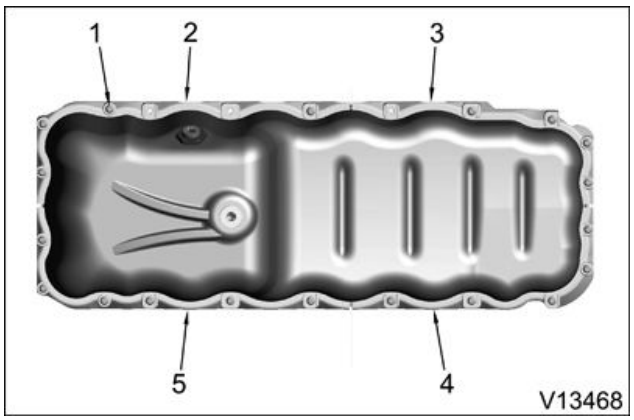


Figure 607 Oil pan clamps (typical)

1. M8 x 40 bolt (19)
2. Oil pan clamp – front left 599 mm (23.5 in)
3. Oil pan clamp – rear left 461 mm (18 in)
4. Oil pan clamp – rear right 461 mm (18 in)
5. Oil pan clamp – front right 599 mm (23.5 in)

3. Install four oil pan clamps and 19 M8 x 40 bolts. Do not install two cooling tube brackets, one extension bracket support, and three M8 x 40 bolts. See (Figure 608).
4. Hand tighten 19 M8 x 40 bolts.

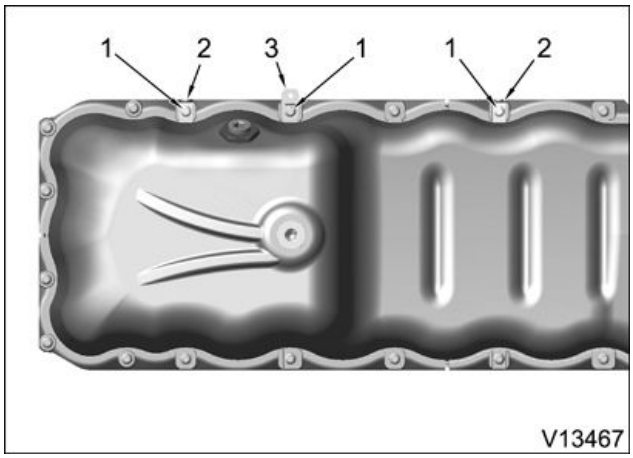


Figure 608 Cooling tube brackets and extension bracket support (typical)

1. M8 x 40 bolt (3)
2. Cooling tube bracket (right angle bracket) (2)
3. Extension bracket support (T-bracket)

5. Position two cooling tube brackets, and one extension bracket, install and hand tighten three M8 x 40 bolts.

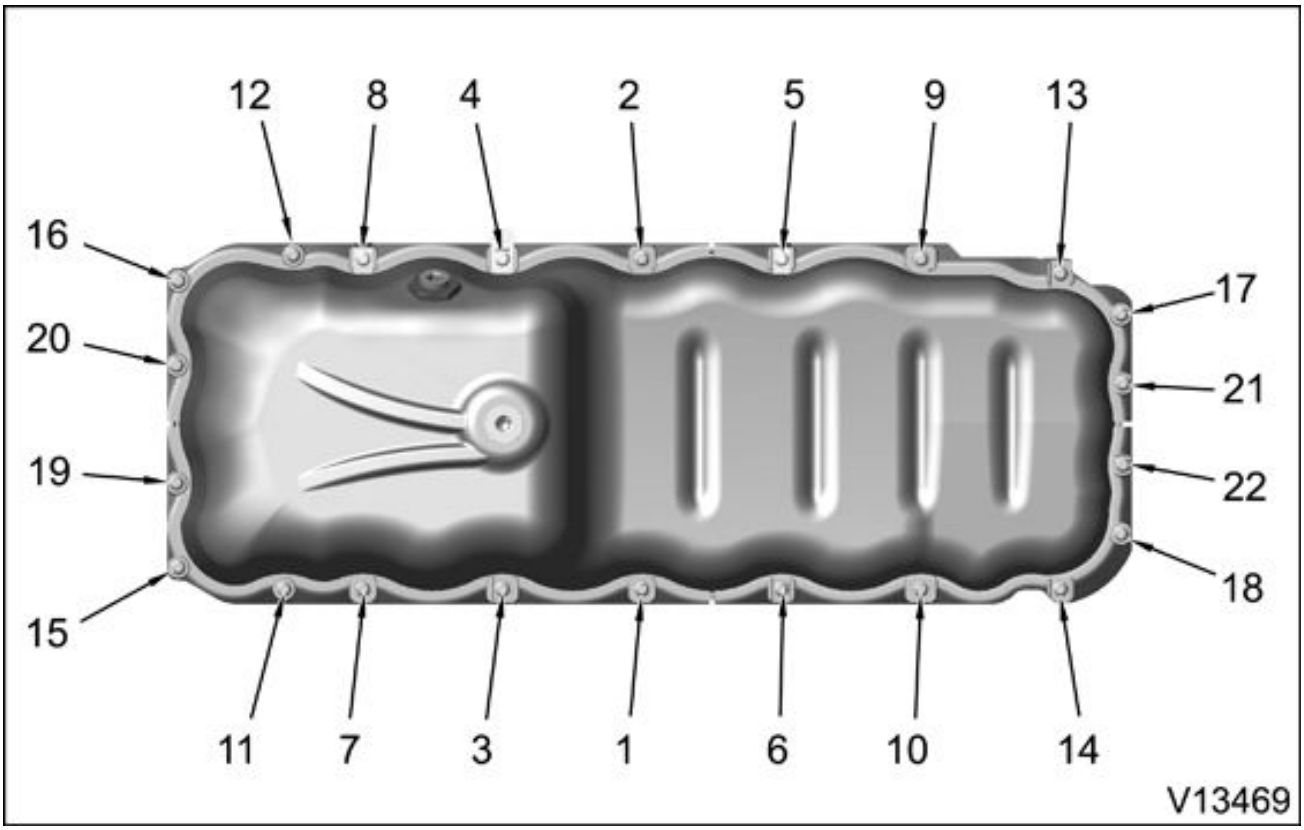


Figure 609 Torque sequence for oil pan bolts

6. Follow the torque sequence and tighten 22 M8 x 40 bolts to 10 N·m (89 lbf·in).
7. Tighten 22 M8 x 40 bolts in sequence to 35 N·m (26 lbf·ft).
8. Retighten 22 M8 x 40 bolts in sequence to 35 N·m (26 lbf·ft).
9. If engine is equipped with oil pan heater element, lubricate a new O-ring with clean engine oil and install heater element into the oil pan. Tighten heater element to special torque (page 424).

   If engine is not equipped with an oil pan heater element, install (oil pan heater drain plug) with a new O-ring lubricated with clean engine oil. Tighten plug to special torque (page 424).
10. Lubricate a new oil pan drain plug O-ring with clean engine oil and put O-ring on the M27 x 2 drain plug.
11. Install M27 x 2 drain plug and tighten to special torque (page 424).

Special Torque

Table 37 Oil Pan Components

Drain plug, M27 x 2	75 N·m (55 lbf·ft)
Oil pan bolts, M8 x 40	See tightening steps in procedure.
Oil pan heater element or replacement drain plug	75 N·m (55 lbf·ft)

Table of Contents

Exploded Views.....427
- **Oil Pump.....427**
- **Front Timing Gears (Typical).....428**
- **Rear Timing Gears.....429**

Removal.....430
- **Preliminary Checks.....430**
- **Oil Pump.....431**
- **Front Crank Gears.....432**
- **Rear Timing Gears.....433**

Cleaning and Inspection.....435
- **Timing Gears.....435**
- **Oil Pump.....435**

Installation.....436
- **Rear Timing Gears.....436**
- **Front Timing Gears.....438**
- **Oil Pump.....438**

Specifications.....440

Special Torque.....440

Special Service Tools.....440

Exploded Views

Oil Pump

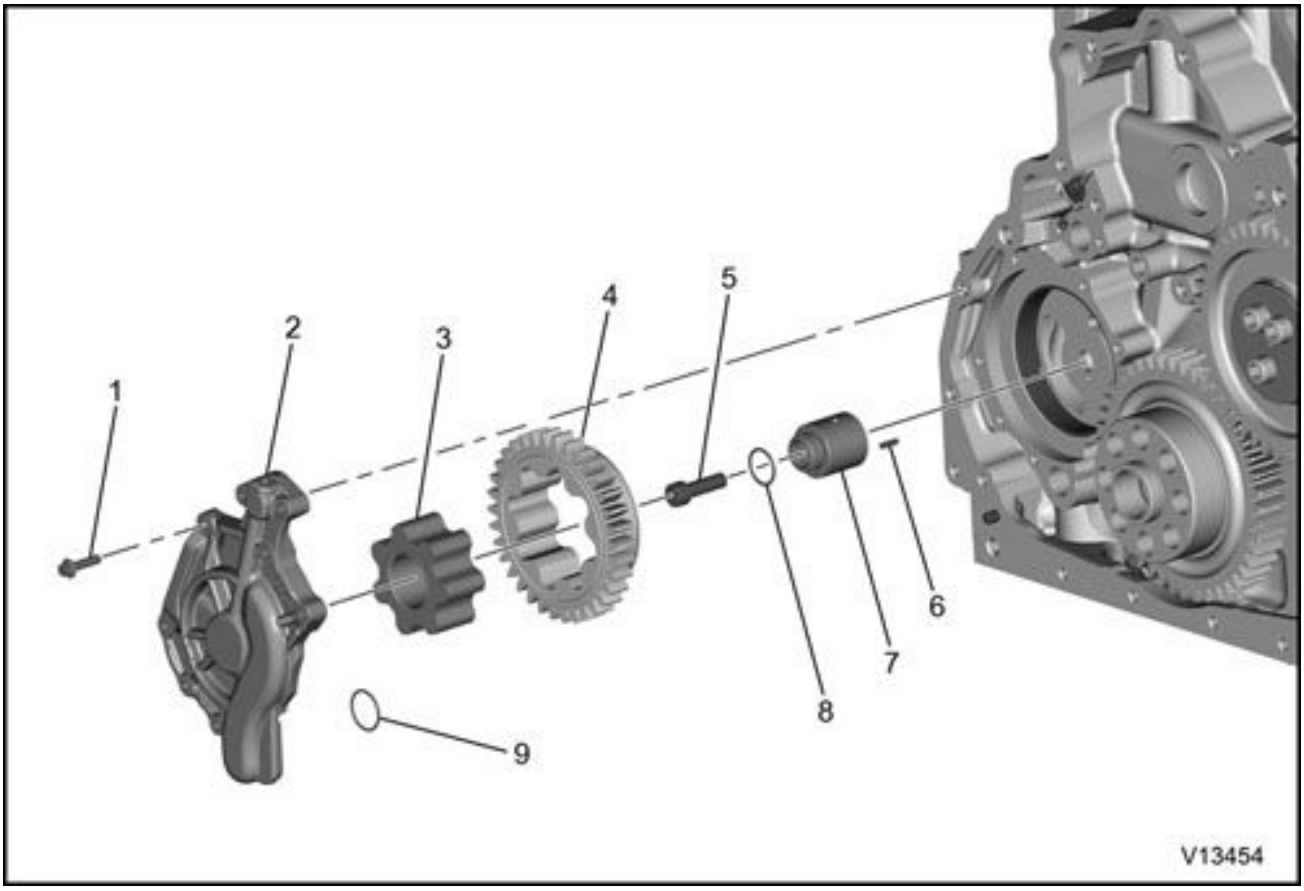


Figure 610 Oil pump

1. M6 x 20 (8) (MaxxForce® 11), or M6 x 25 bolt (8) (MaxxForce® 13)
2. Oil pump cover
3. Pinion (gear) for oil pump
4. (Oil pump) ring gear
5. M10 x 35 socket-head cap screw
6. Spring pin 4 x 14 ST
7. Axle for pinion (oil pump)
8. O-ring 22 x 2
9. O-ring 25.12 x 1.78

Front Timing Gears (Typical)

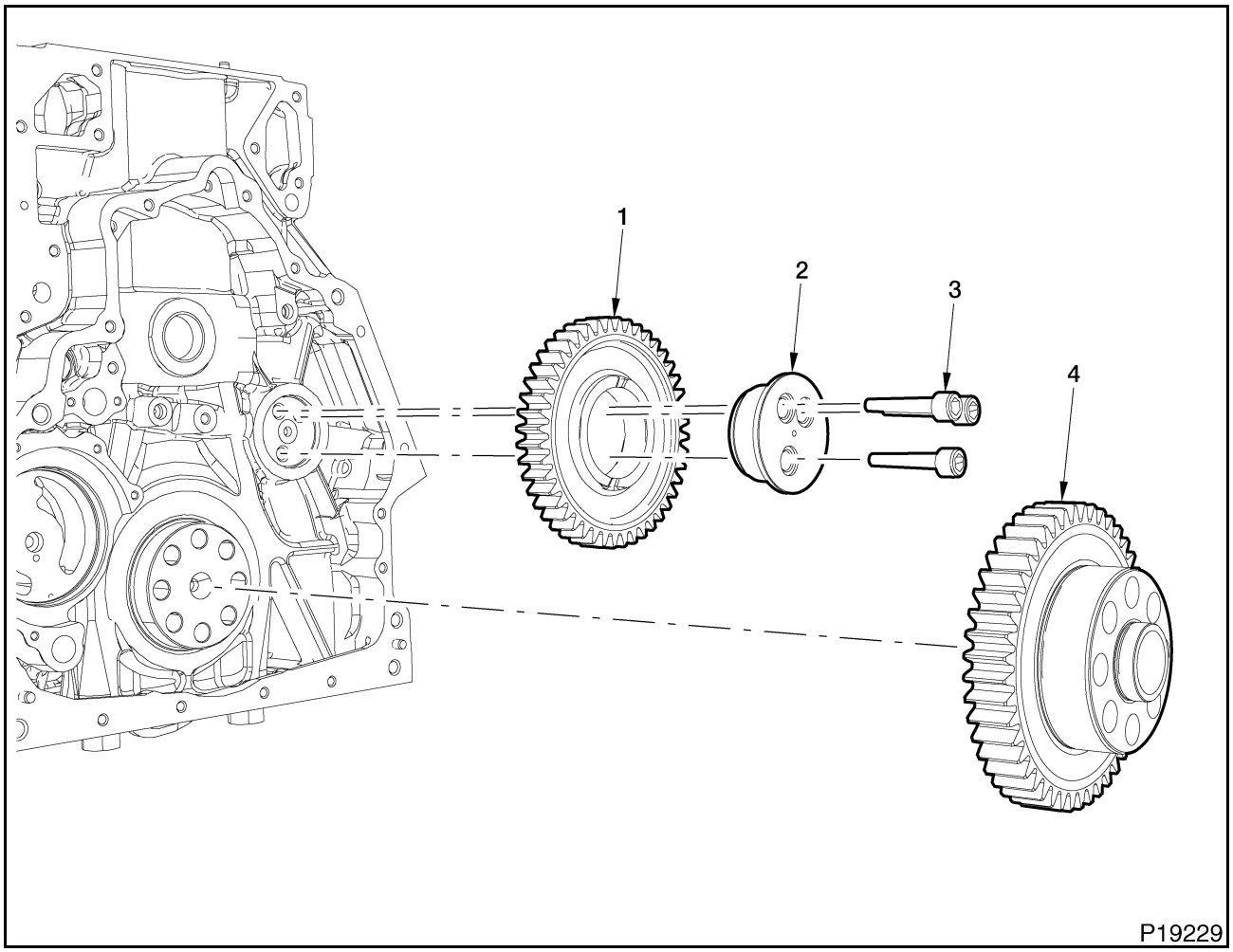


Figure 611 Front timing gears (typical)

1. (Front) idler gear
2. Gear stud (not flywheel side)
3. M12 x 50 socket-head cap screw (3)
4. Front crank gear

Rear Timing Gears

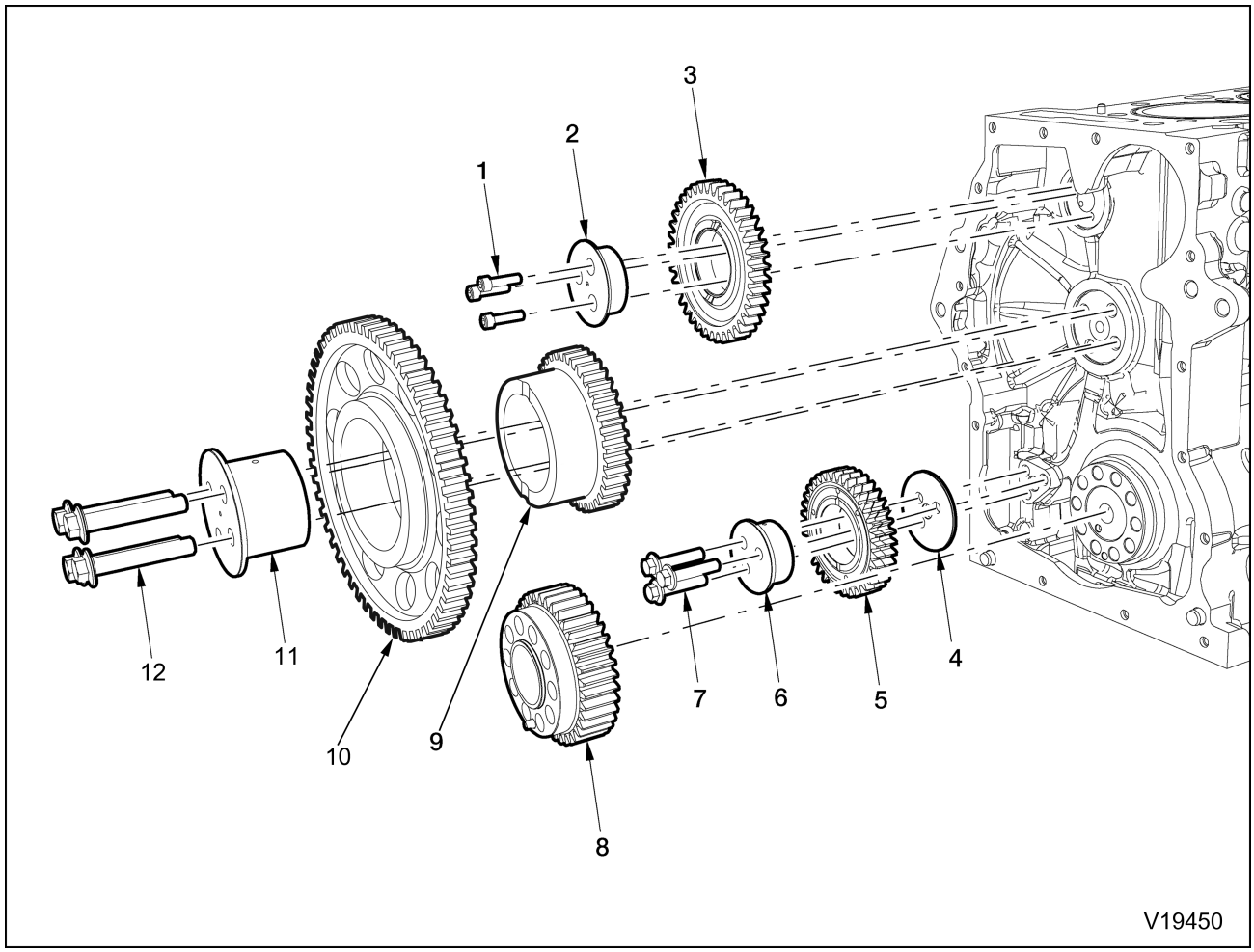


Figure 612 Rear timing gears

1. M8 x 30 socket-head cap screw (3)
2. Gear stud small
3. Crankcase idler gear
4. Thrust washer (for gear stud air compressor)
5. Air compressor coupled idler gear assembly
6. Air compressor gear stud
7. M12 x 55 bolt (3)
8. Rear crank gear assembly
9. Small idler gear
10. Large idler gear
11. Gear stud big
12. M14 x 80 bolt (4)

Removal

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

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

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

WARNING: To prevent personal injury or death, 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: Refer to the following service sections for information on removal of components prior to this section.

- Front Cover, Fan Drive, Cooling System and Related Components
- Cylinder Head, Camshaft and Valve Train
- Flywheel and Flywheel Housing

Preliminary Checks

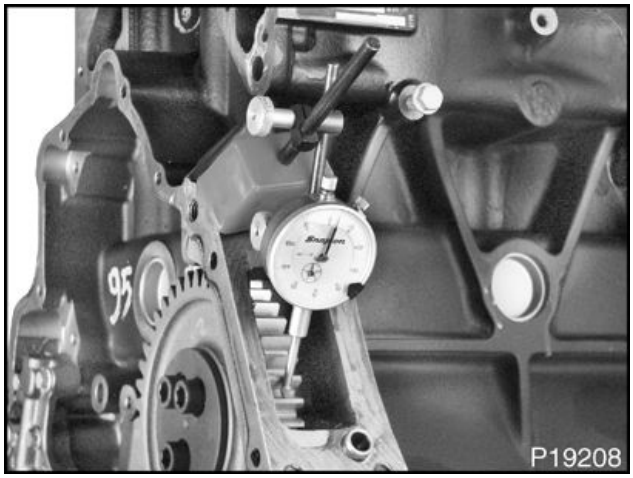


Figure 613 (Front) idler gear backlash measurement (typical)

1. Rotate engine and look for any damaged gear teeth. See Crankshaft Rotation Procedure(page 363). Replace damaged gears as necessary.
2. Place dial indicator with magnetic base (page 440) on front of crankcase with indicator tip on front idler gear. Position dial indicator tangent (90°) relative to plane of gear tooth.
3. Turn front idler gear clockwise and zero dial indicator.
4. Turn front idler gear back and forth while reading dial indicator. Compare dial indicator reading with specifications (page 440).
5. If front idler gear backlash exceeds specification, replace gear.

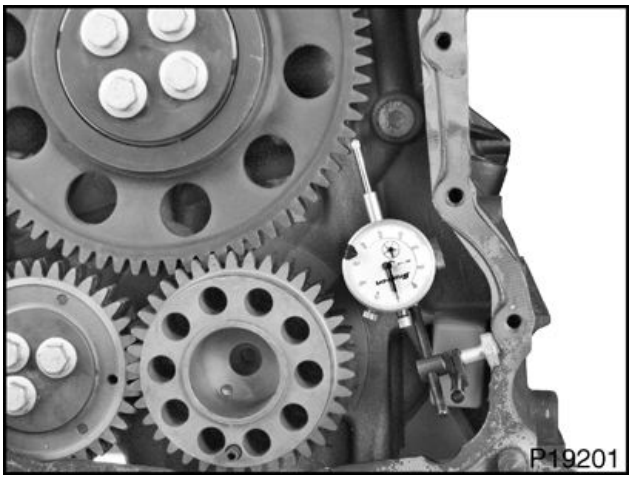


Figure 614 (Rear) large idler gear backlash measurement (typical)

6. Place dial indicator with magnetic base (page 440) on rear of crankcase with indicator tip on large idler gear tooth. Position dial indicator tangent (90°) relative to plane of gear tooth.
7. Turn large idler gear clockwise and zero dial indicator.
8. Turn large idler gear back and forth while reading dial indicator. Compare dial indicator reading with specifications (page 440).
9. If backlash exceeds specification, replace large idler gear.

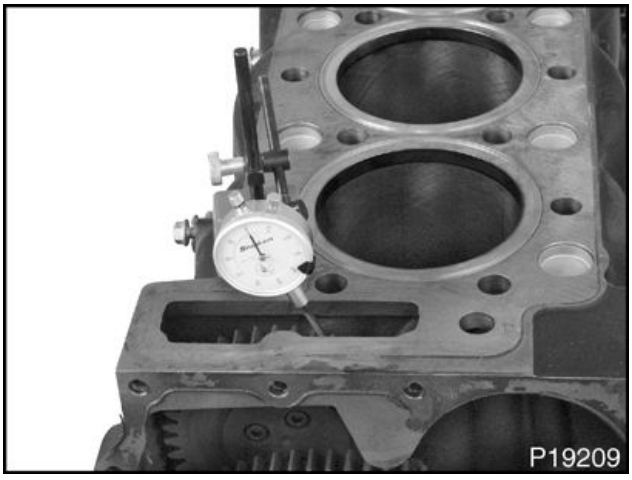


Figure 615 Crankcase idler gear backlash measurement (typical)

10. Place dial indicator with magnetic base (page 440) on top rear of crankcase with indicator tip on crankcase idler gear. Position dial indicator tangent (90°) relative to plane of gear tooth.
11. Turn crankcase idler gear clockwise and zero dial indicator.
12. Turn crankcase idler gear back and forth while reading dial indicator. Compare dial indicator reading with specifications (page 440).
13. If crankcase idler gear backlash exceeds specification, replace crankcase idler gear.

Oil Pump

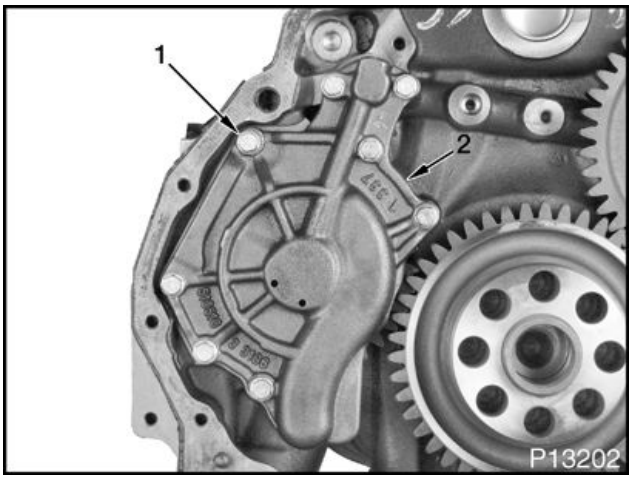


Figure 616 Oil pump cover (typical)

1. M6 x 20 (8) (MaxxForce® 11), or M6 x 25 bolt (8) (MaxxForce® 13)
2. Oil pump cover

1. Remove eight M6 x 20 bolts or M6 x 25 bolts.
2. Remove oil pump cover.
3. Remove and discard O-ring.

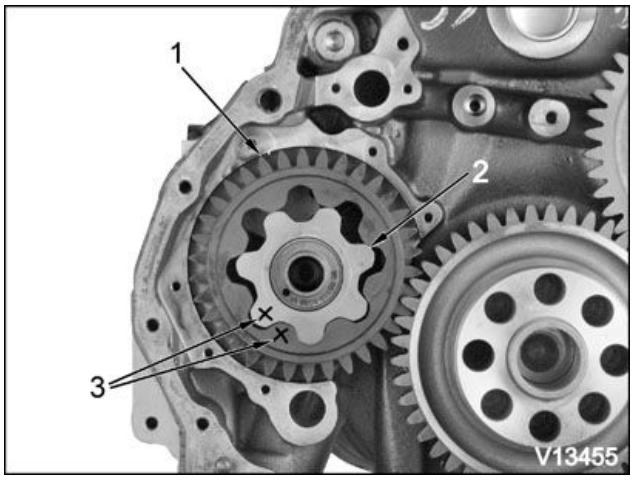


Figure 617 Oil pump pinion (gear) and ring gear

1. (Oil pump) ring gear
2. Oil pump pinion (gear)
3. Marks for reassembly (towards front)

CAUTION: To prevent engine damage, use permanent marker to identify internal engine components and their orientation. Do not use paint or temporary markers.

4. Use a permanent marker to mark the front of oil pump pinion (gear) and ring gear for correct assembly orientation.
5. Remove oil pump pinion gear and ring gear.

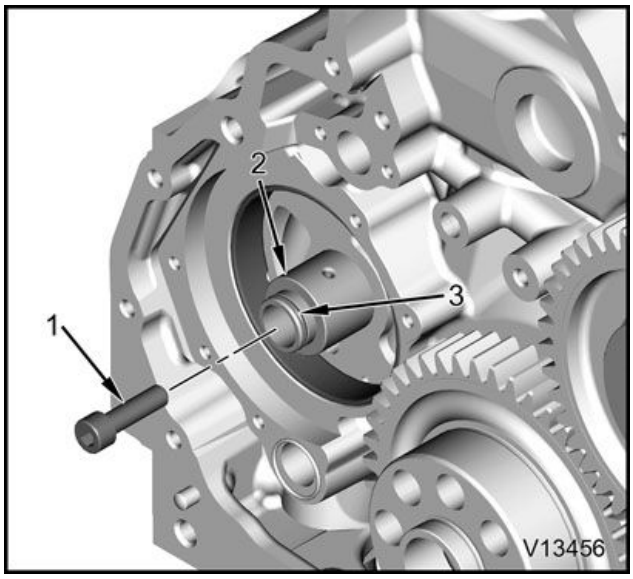


Figure 618 (Oil pump) pinion axle

1. M10 x 35 socket-head cap screw
2. (Oil pump) pinion axle
3. O-ring 22 x 2

6. Remove M10 x 35 socket-head cap screw and oil pump pinion axle.
7. Remove and discard O-ring 22 x 2.

Front Crank Gears

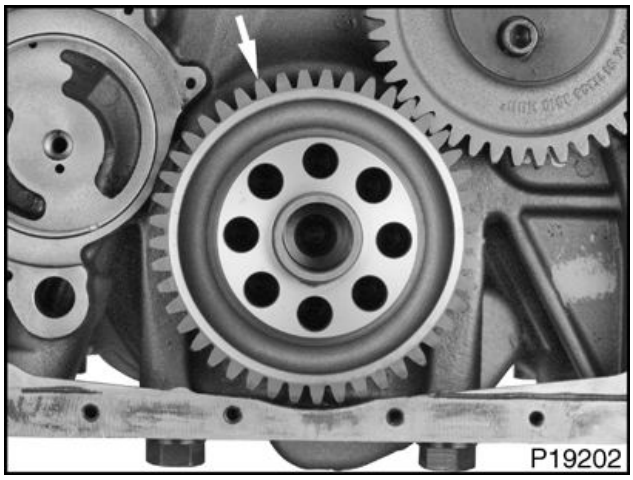


Figure 619 Front crank gear (typical)

1. Using a gear puller (page 440), remove front crank gear.

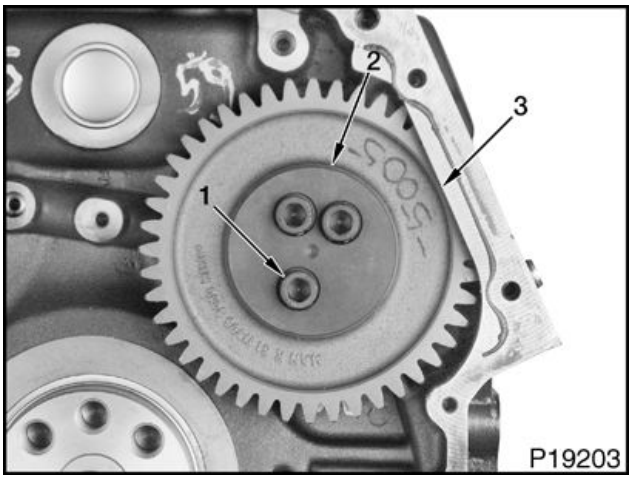


Figure 620 (Front) idler gear (typical)

1. M12 x 50 socket-head cap screw (3)
2. Gear stud (front idler)
3. Idler gear

2. Remove three M12 x 50 cap screws, gear stud and idler gear.

Rear Timing Gears

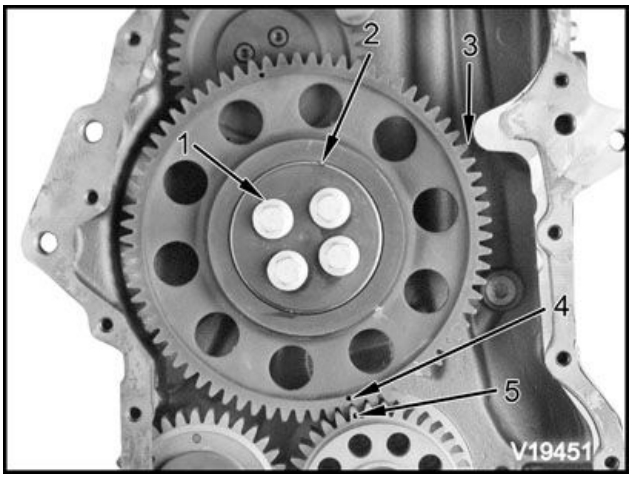


Figure 621 Idler gear assembly and timing marks

1. M14 x 80 bolt (4)
2. Big gear stud
3. Large idler gear
4. Timing mark (large idler gear)
5. Timing mark (rear crank gear)

1. Remove four M14 x 80 bolts, big gear stud and idler gear assembly.

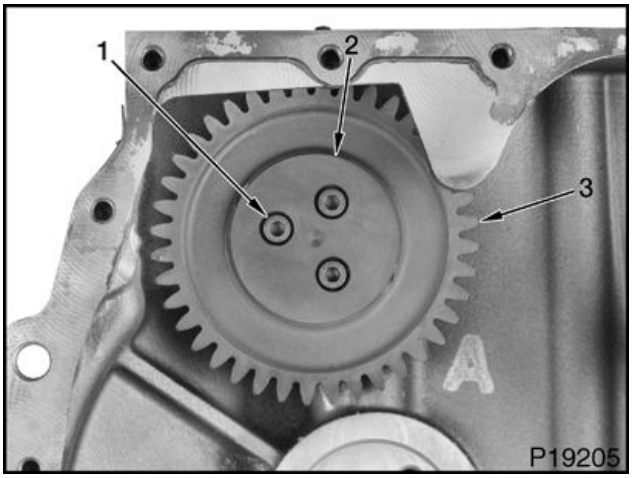


Figure 622 Crankcase idler gear (typical)

1. M8 x 30 socket-head cap screw (3)
2. Small gear stud
3. Crankcase idler gear

2. Remove three M8 x 30 cap screws, small gear stud and crankcase idler gear.

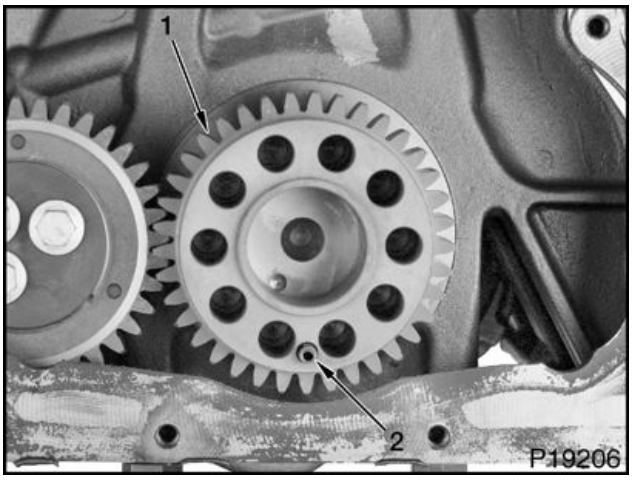


Figure 623 Rear crank gear assembly (typical)

1. Rear crank gear
2. Pin 8 x 60-ST

3. Using a gear puller (page 440), remove rear crank gear assembly.

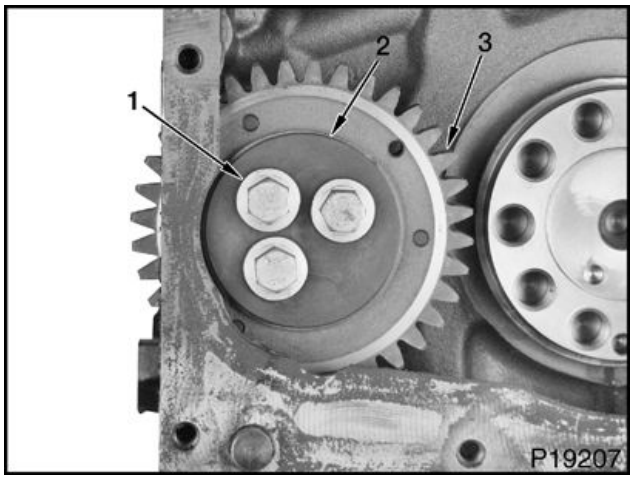


Figure 624 Air compressor coupled idler gear assembly (typical)

1. M12 x 55 bolt (3)
2. Air compressor gear stud
3. Air compressor idler gear assembly

4. Remove three M12 x 55 bolts and air compressor gear stud, air compressor idler gear assembly and thrust washer for air compressor gear stud (not shown, behind gear assembly).

Cleaning and Inspection

Timing Gears

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

1. Wash timing gears and gear pins with a stiff brush and suitable solvent. Dry all with filtered compressed air.
2. Inspect timing gears for irregular wear pattern and worn or damaged teeth. Replace as necessary.
3. Inspect timing gear shafts for worn or damaged bearing surfaces. Replace as necessary.

Oil Pump

1. Wash all parts thoroughly in a suitable solvent.
2. Dry with filtered compressed air.
3. Inspect pinion (gear) for oil pump, oil pump ring gear and oil pump cover for nicks, burrs or scoring.
4. Replace any damaged components.
5. Temporarily install oil pump components in crankcase without O-ring and tighten M6 x 20 (MaxxForce® 11) or M6 x 25 bolts (MaxxForce®13) to standard torque (page 503). See Oil Pump (page 438).

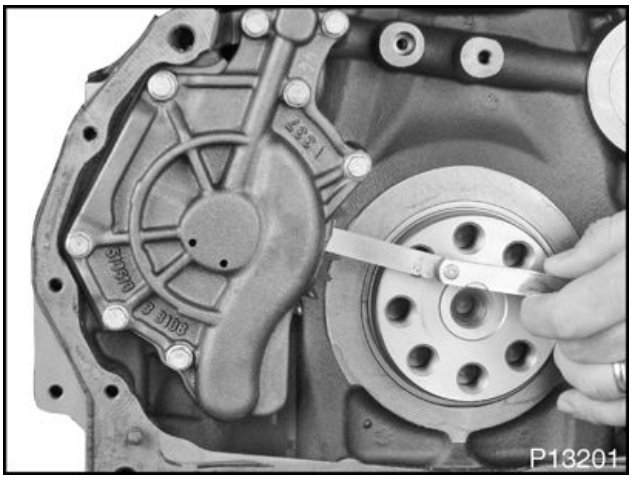


Figure 625 Pinion (gear) for oil pump and ring gear end play measurement (typical)

6. Using a feeler gauge (page 440), measure end play between oil pump cover and oil pump gears.

NOTE: There are two oil pump assemblies. When replacing oil pump parts, be sure you are ordering the correct set.

7. If end play exceeds specification (page 440), replace oil pump cover, pinion (gear) for oil pump and ring gear as a set.
8. Remove oil pump components for final assembly.

Installation

Rear Timing Gears

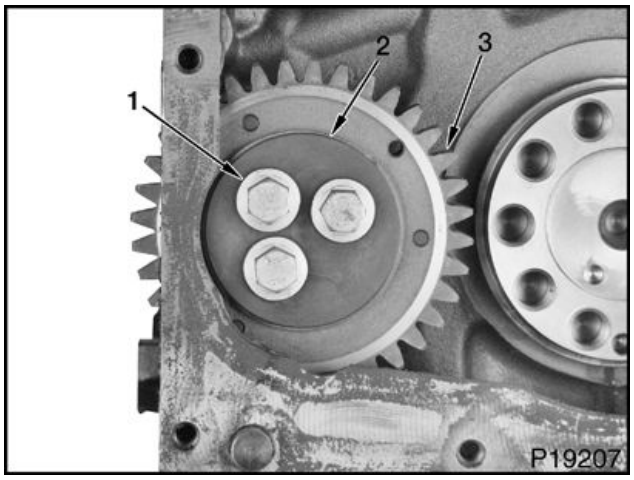


Figure 626 Air compressor coupled idler gear assembly (typical)

1. M12 x 55 bolt (3)
2. Air compressor gear stud
3. Air compressor idler gear assembly

CAUTION: To prevent engine damage, install thrust washer for air compressor gear stud with larger chamfer side facing crankcase.

1. Install air compressor thrust washer (with larger chamfer side facing crankcase), air compressor gear stud and air compressor coupled idler gear assembly.
2. Install three M12 x 55 bolts. Tighten bolts to special torque (page 440).

Figure 627 Crankshaft alignment pin hole (typical)

3. Rotate crankshaft so that alignment pin hole is at 6 o'clock position. See Crankshaft Rotation Procedure (page 363). This positions cylinder No. 1 at Top Dead Center (TDC).

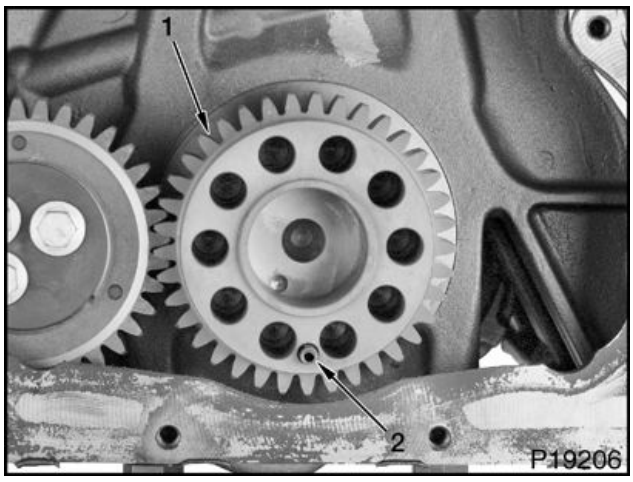


Figure 628 Rear crank gear assembly (typical)

1. Rear crank gear
2. Pin 8 x 60-ST

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

4. Using a hammer and brass drift, install rear crank gear so pin in gear engages crankshaft alignment pin hole.

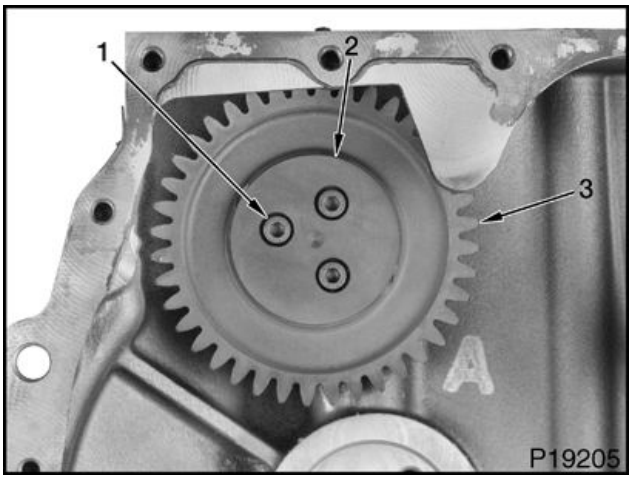


Figure 629 Crankcase idler gear (typical)

1. M8 x 30 socket-head cap screw (3)
2. Small gear stud
3. Crankcase idler gear

CAUTION: To prevent engine damage, insert the crankcase idler gear into the crankcase with the flatter contact surface facing outwards.

5. Install crankcase idler gear and small gear stud.
6. Install three crankcase idler gear M8 x 30 socket-head cap screws. Tighten cap screws to special torque (page 440).

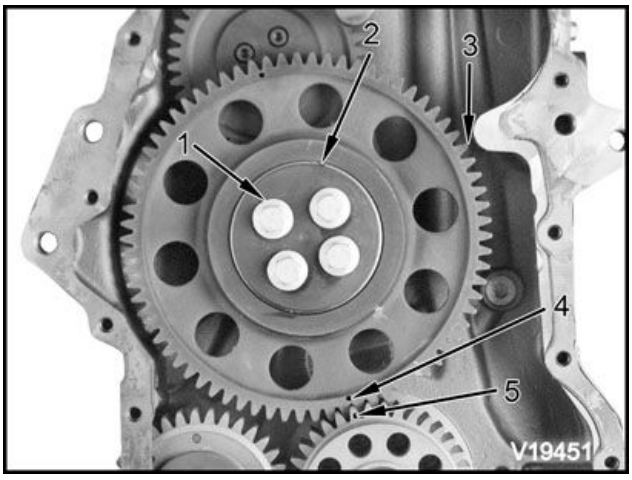


Figure 630 Large Idler gear assembly and timing marks

1. M14 x 80 bolt (4)
2. Big gear stud
3. Large idler gear
4. Timing mark (large idler gear)
5. Timing mark (rear crank gear)

NOTE: Large idler gear has two timing marks 180° apart; either may be used.

7. Install big gear stud and large idler gear, aligning timing mark with timing mark on rear crank gear (flywheel side).
8. Install four M14 x 80 bolts. Tighten bolts to special torque (page 440).

Front Timing Gears

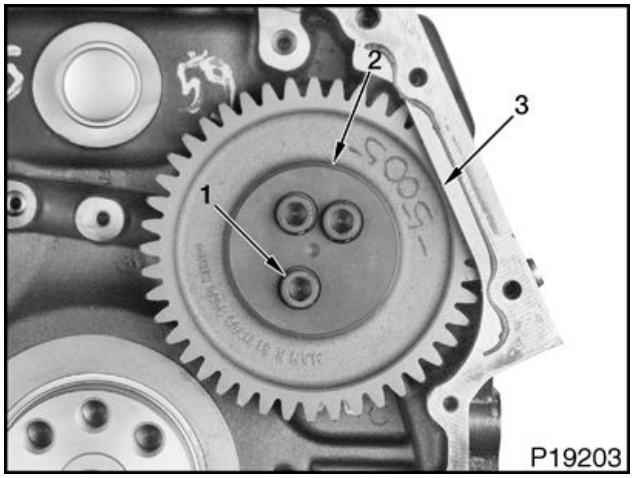


Figure 631 (Front) idler gear (typical)

1. M12 x 50 socket-head cap screw (3)
2. Gear stud (not flywheel side)
3. Idler gear

1. Install idler gear and gear stud.
2. Install three front idler gear M12 x 50 cap screws. Tighten screws to special torque (page 440).

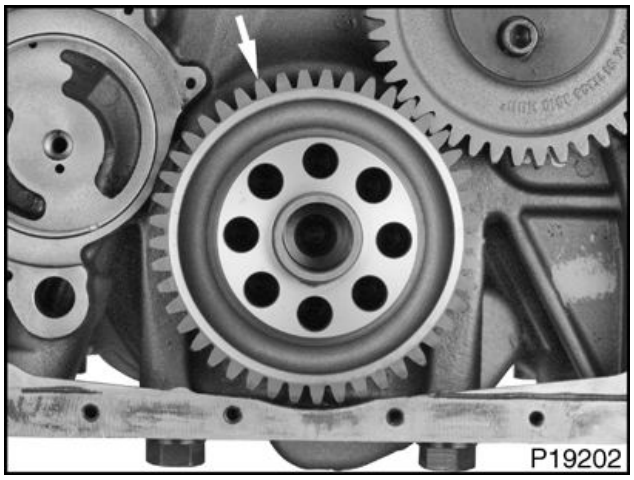


Figure 632 Front crank gear (typical)

3. Install two suitable alignment bolts 180° apart through front crank gear into front of crankshaft.

⚠ WARNING: To prevent personal injury or death, wear safety glasses with side shields.

4. Using a hammer and brass drift, carefully install front crank gear.
5. Remove two alignment bolts.

Oil Pump

1. Lubricate new O-ring 22 x 2 with clean engine oil and install oil pump pinion axle.

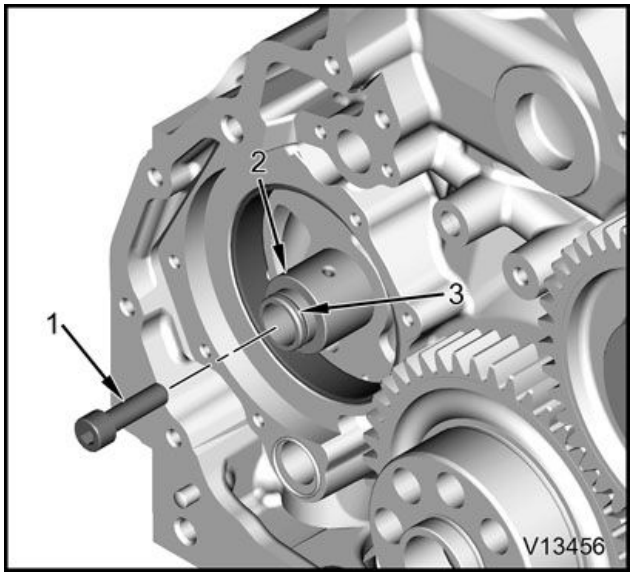


Figure 633 Pinion axle (oil pump)

1. M10 x 35 socket-head cap screw
2. Pinion axle (oil pump)
3. O-ring 22 x 2

2. Install oil pump pinion axle and M10 x 35 cap screw. Tighten screw to special torque (page 440).

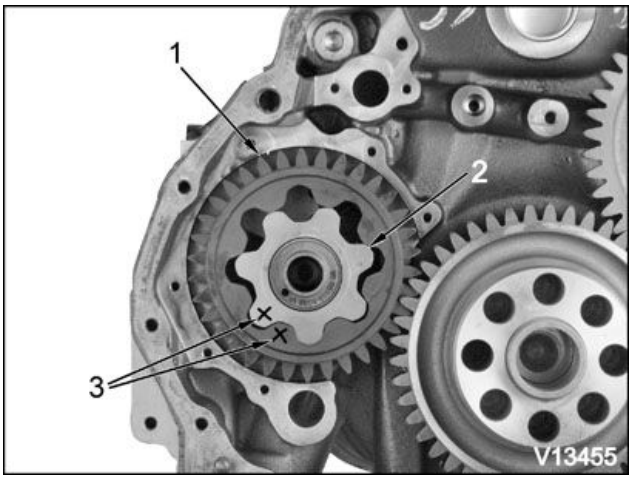


Figure 634 Pinion (gear) for oil pump and ring gear

1. (Oil pump) ring gear
2. Pinion (gear) for oil pump
3. Marks for reassembly (toward front)

3. Lubricate pinion (gear) for oil pump and ring gear with clean engine oil.
4. Install pinion gear and ring gear with previously made index marks facing towards front.
5. Lubricate new oil pump cover O-ring with clean engine oil and install on cover.

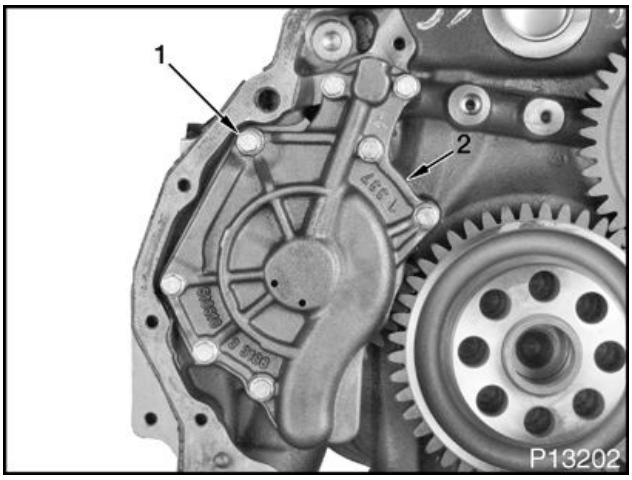


Figure 635 Oil pump cover (typical)

1. M6 x 20 (8) (MaxxForce® 11), or M6 x 25 bolt (8) (MaxxForce® 13)
2. Oil pump cover

6. Install oil pump cover.
7. Install eight M6 x 20 or M6 x 25 bolts. Tighten bolts to standard torque (page 503).

Specifications

Table 38 Oil Pump and Timing Gears

Front Timing Gears	
(Front) idler gear backlash	0.057 - 0.183 mm (0.0022 - 0.0072 in)
Oil Pump	
Oil pump pinion (gear) and ring gear end play	0.030 - 0.120 mm (0.0012 - 0.0047 in)
Rear Timing Gears	
Idler larger gear backlash	0.052 - 0.176 mm (0.0020 - 0.0069 in)
Large idler gear backlash	0.052 - 0.176 mm (0.0020 - 0.0069 in)

Special Torque

Table 39 Oil Pump and Timing Gears

Air compressor coupled idler gear, M12 x 55 bolts	107 N·m (79 lbf·ft)
Crankcase idler gear, M8 x 30 socket-head cap screws	30 N·m (22 lbf·ft)
(Front) idler gear, M12 x 50 socket-head cap screws	105 N·m (77 lbf·ft)
Larger idler gear, M14 x 80 bolts	175 N·m (129 lbf·ft)
Oil pump pinion axle, M10 x 35 socket-head cap screw	65 N·m (48 lbf·ft)

Special Service Tools

Table 40 Oil Pump and Timing Gears

Description	Tool Number
Dial indicator with magnetic base	Obtain locally
Feeler gauge	Obtain locally
Gear puller	Obtain locally

Table of Contents

Exploded Views.....443
- **Piston and Connecting Rod (Typical) and Cylinder Sleeve**.....443

Removal.....445
- **Preliminary Checks**.....445
- **Piston and Connecting Rod**.....446
- **Piston Disassembly**.....447
- **Cylinder Sleeves**.....448

Cleaning and Inspection.....449
- **Cleaning**.....449
- **Piston Inspection**.....449
- **Piston Ring Inspection**.....450
- **Connecting Rod Inspection**.....450
- **Connecting Rod Bore Check**.....451
- **Piston Pin Inspection**.....452
- **Cylinder Sleeve Inspection**.....452

Installation.....454
- **Cylinder Sleeves**.....454
- **Piston Assembly**.....454
- **Piston and Connecting Rod**.....455

Engine Run-in Procedure.....457

Specifications.....458

Special Torque.....459

Special Service Tools.....459

Exploded Views

Piston and Connecting Rod (Typical) and Cylinder Sleeve

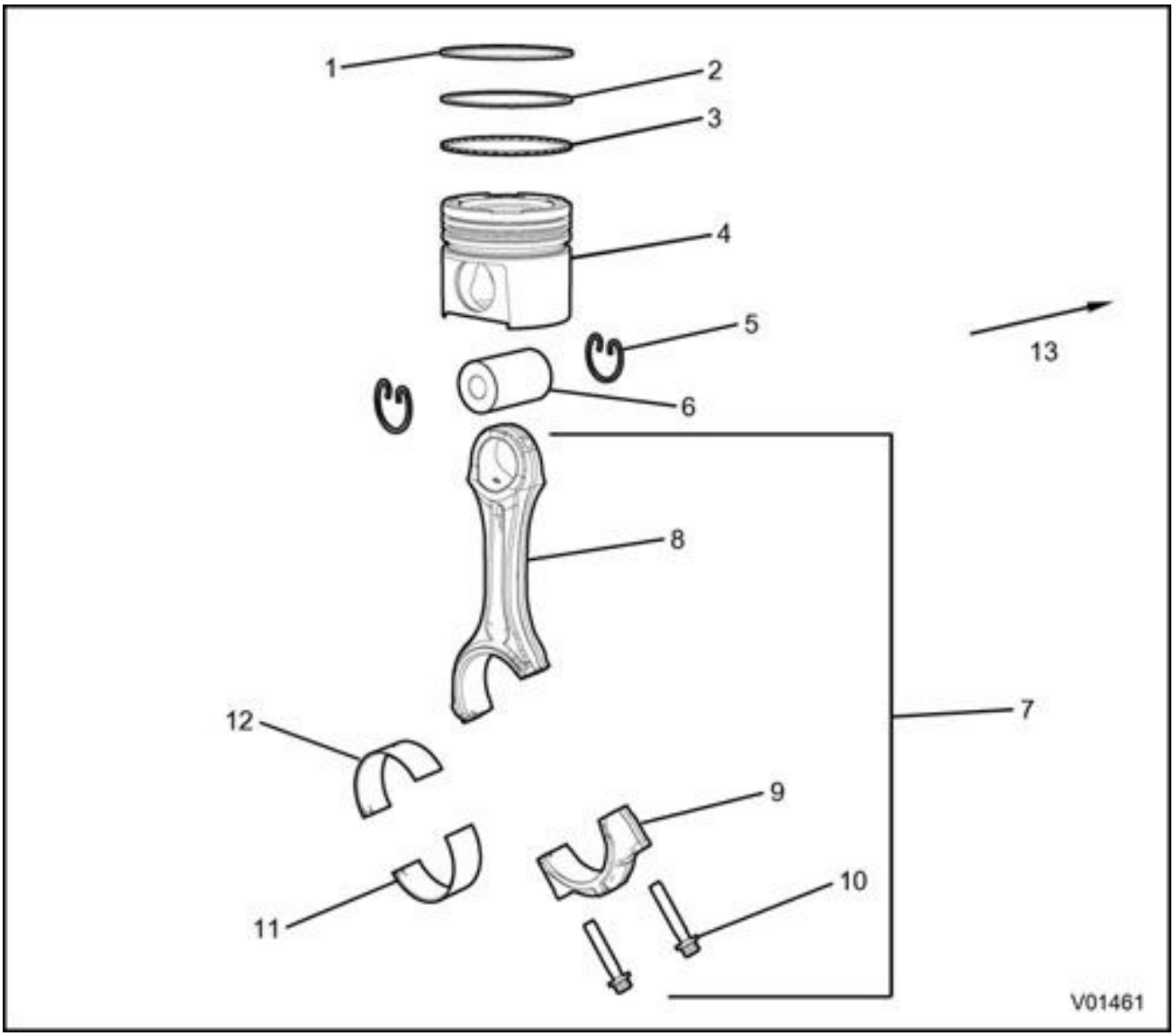


Figure 636 Piston and connecting rod (typical)

1. Compression top ring (6)
2. Taper face compression ring (6)
3. Bevelled oil ring (6)
4. Piston (6)
5. Piston pin retainer (12)
6. Piston pin (6)
7. Connecting rod assembly (6) (includes items 8, 9, 10)
8. Connecting rod
9. Connecting rod cap
10. Connecting rod bolt (2 each assembly)
11. Connecting rod bearing, lower (6)
12. Connecting rod bearing, upper (6)
13. Front of engine

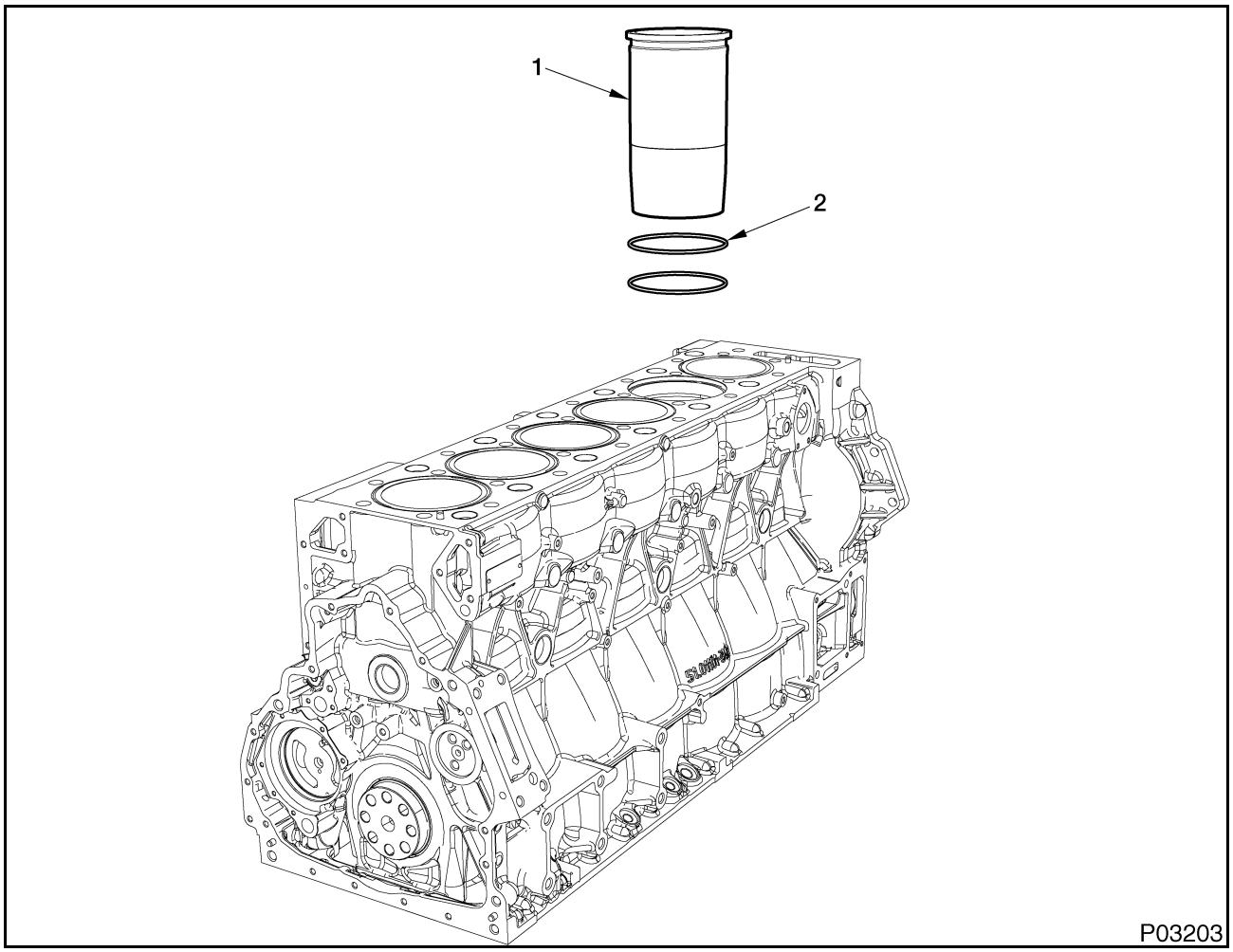


Figure 637 Cylinder sleeve

1. Cylinder sleeve (6)
2. Cylinder sleeve O-ring (12)

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

- Engine Electrical
- Cold Start Assist
- Aftertreatment System
- MaxxForce® Engine Brake by Jacobs
- Turbochargers
- Fuel System
- Oil Cooler, Filter Housing and Crankcase Ventilation
- Exhaust Gas Recirculating (EGR) System
- Air Intake Throttle Duct and Exhaust Manifold
- Cylinder Head, Camshaft and Valve Train
- Flywheel and Flywheel Housing (as needed)
- Oil Pan and Oil Suction Tube

Preliminary Checks

NOTE: Evaluate piston protrusion before removing any piston and connecting rod assemblies. This helps identify bent or twisted connecting rods.

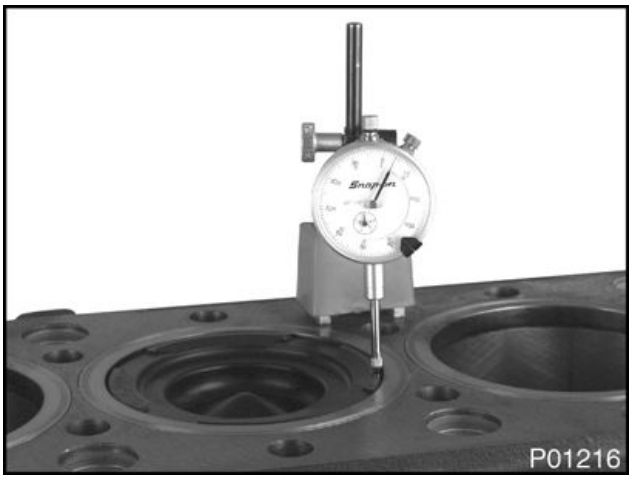


Figure 638 Piston protrusion check

NOTE: Piston protrusion readings are done in line with piston pin, eliminating rocking movement of piston at any other position of measurement.

1. Check piston protrusion as follows:
   a. Make sure crankcase deck surface is clean.

b. Zero dial indicator with magnetic base (page 459) on crankcase deck surface.

c. Position dial indicator tip over piston head at 3 o'clock position.

d. Rotate crankshaft in direction of normal rotation to raise piston to its maximum outward protrusion at cylinder Top Dead Center (TDC). Push down on piston crown before taking reading. Read this maximum protrusion on dial indicator.

e. Reposition dial indicator tip on piston head at 9 o'clock position.

f. Rotate crankshaft to raise piston to its maximum protrusion. Push down on piston crown before taking reading. Read maximum protrusion on dial indicator.

g. Average the two readings. Replace piston and connecting rod if protrusion is not within specification (page 458).

Piston and Connecting Rod

CAUTION: To prevent engine damage, check for a carbon ridge on top of cylinder sleeves. If found, remove carbon ridge with a suitable tool before removing rod and piston assemblies.

1. Scrape carbon ridge from top of cylinder bore, if necessary. Use care not to damage sleeve bore surface.

CAUTION: To prevent engine damage, mark with permanent marker or tag each connecting rod and cap with the correct cylinder number. This engine has “cracked” (fractured) type connecting rods. Do not alter or damage fractured mating surfaces of the rod and cap. A cap from one connecting rod is NOT interchangeable with another connecting rod. The matching connecting rod and cap numbers or symbols indicate a matched set.

CAUTION: To prevent engine damage, 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. A new connecting rod assembly must be installed. Do NOT attempt to reuse a rod that has been misassembled to its cap, assembled with the wrong cap or has been cross-threaded while attempting assembly. Serious engine damage can result.

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

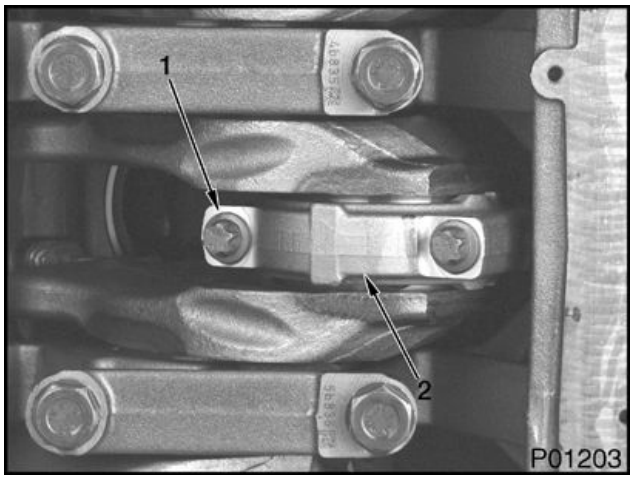


Figure 639 Connecting rod cap

1. Connecting rod bolt M12 x 64 (2)
2. Connecting rod cap

CAUTION: To prevent engine damage, assemble connecting rod cap and connecting rod with their fractured mating surfaces in the original orientation. Matching numbers must be next to each other.

NOTE: 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.

3. Using Exhaust Manifold Bolt Torx® Socket (page 459), remove two connecting rod bolts and connecting rod cap. Save bolts for reuse during connecting rod bore check procedure.

CAUTION: To prevent engine damage, do not push on fractured surface of connecting rod.

CAUTION: To prevent engine damage, do not damage piston cooling jet when removing connecting rod and piston assembly. If jet is bent during piston assembly or removal, replace jet.

4. Remove piston and connecting rod assemblies from cylinder sleeves 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 sleeve.
   c. Once piston rings are free of cylinder bore, remove piston and connecting rod assembly from cylinder sleeve.
   d. Mark each piston and rod assembly with cylinder number from which each was removed, using a permanent marker.

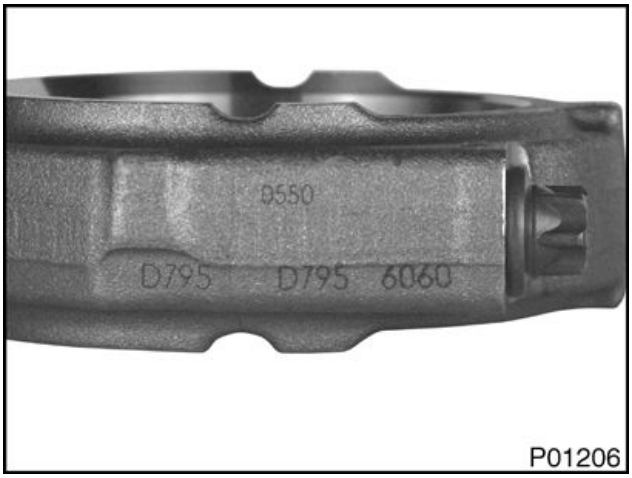


Figure 640 Correct connecting rod and cap joint fit

CAUTION: To prevent engine damage, use permanent markers to identify internal engine components and their orientation. Do not use paint or temporary markers.

NOTE: Upper connecting rod bearings have an oil hole and lower connecting rod bearings do not.

5. Remove connecting rod upper and lower bearings by pushing out. Mark connecting rod bearings for position and orientation and set aside for inspection.

Piston Disassembly

⚠ WARNING: To prevent personal injury or death, wear safety glasses with side shields.

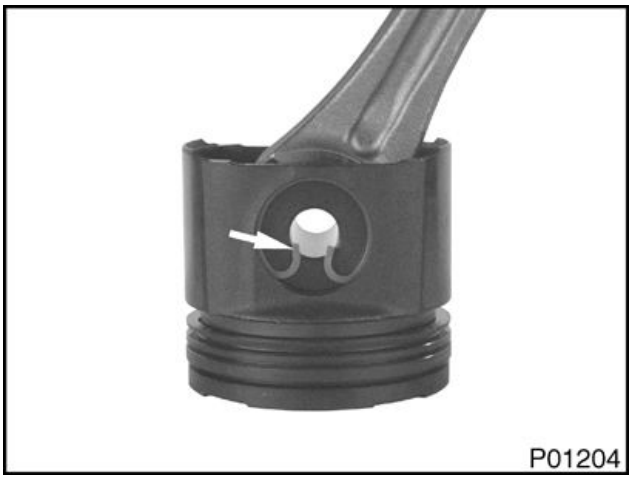


Figure 641 Piston pin retainer (typical)

1. Using a pair of pliers, remove two piston pin retainers.

CAUTION: To prevent engine damage, do not mark piston pin for cylinder and location on outer diameter; place mark only on flat end or tapered inside surface.

2. Remove piston pin from its bore by hand and separate connecting rod from piston.

Figure 642 Piston ring removal (typical)

NOTE: Only expand piston rings enough to fit over top of piston.

NOTE: Keep piston rings organized for each cylinder.

3. Using piston ring expansion pliers (page 459), remove top compression ring, taper face compression ring and bevelled oil ring.

Cylinder Sleeves

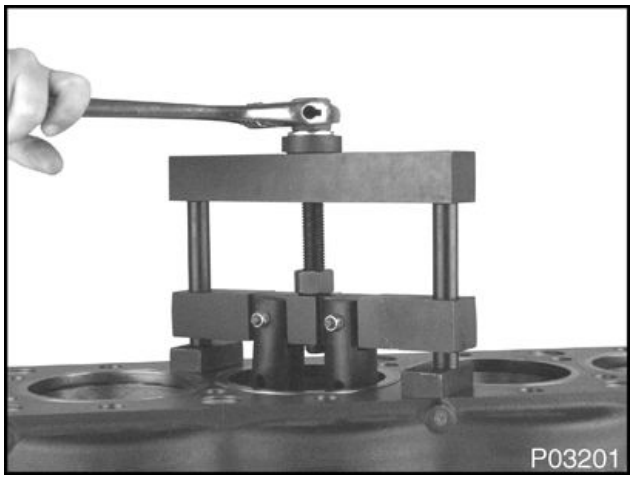


Figure 643 Cylinder sleeve removal

CAUTION: To prevent engine damage, use permanent markers to identify internal engine components and their orientation. Do not use paint or temporary markers.

NOTE: Care must be taken not to damage piston cooling jets during cylinder sleeve removal.

1. Remove six cylinder sleeves from crankcase as follows:
   a. Insert Cylinder Sleeve Puller (page 459) into cylinder sleeve.
   b. Engage removal tool hooks under bottom edge of cylinder sleeve.
   c. Position removal tool feet diagonally on crankcase deck surface.
   d. Turn threaded shaft clockwise to extract cylinder sleeve.
   e. Mark cylinder sleeves for position and set aside for inspection.
2. Remove and discard two cylinder sleeve O-rings from each crankcase cylinder sleeve.

Cleaning and Inspection

Cleaning

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 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 retainers
4. Thoroughly clean connecting rod bolt holes and threads.

Piston Inspection

1. Inspect pistons for scuffed or scored skirts, cracked or worn ring lands and cracked or scuffed pin bores. Replace damaged pistons.

Figure 644 Second and third ring groove clearance check (typical)

NOTE: It is not possible to measure side clearance of top compression ring groove.

2. Check side clearance of taper face compression ring groove as follows:
   a. Place edge of a new taper face compression ring in its respective ring groove. Roll taper face compression ring all around ring groove to ensure ring is free in its groove.
   b. With edge of taper face compression ring in taper face compression ring groove, use a feeler gauge (page 459) to measure side clearance between ring and groove.
   c. Compare taper face compression ring side clearance to specification (page 458). Excessive side clearance indicates ring groove wear and requires piston replacement.
3. Check side clearance of bevelled oil ring groove as follows:
   a. Place edge of a new bevelled oil ring in its respective ring groove. Roll bevelled oil ring all around ring groove to ensure ring is free in its groove.
   b. With edge of bevelled oil ring in the bevelled oil ring groove, use a feeler gauge (page 459) to measure side clearance between ring and groove.
   c. Compare bevelled oil ring side clearance to specification (page 458). Excessive side clearance indicates ring groove wear and requires piston replacement.

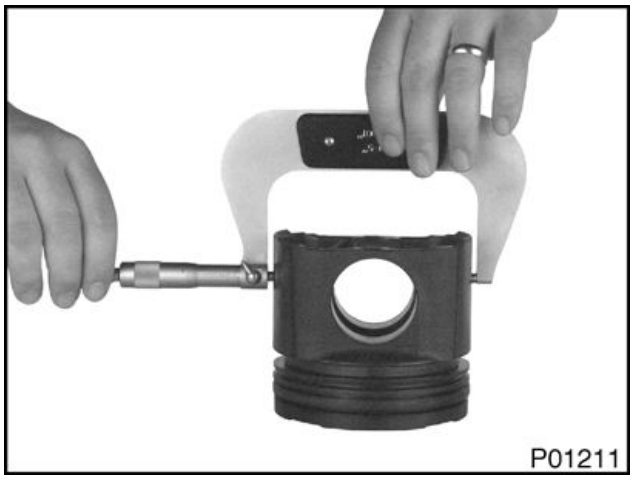


Figure 645 Piston skirt diameter measurement

4. Using a 4 - 5 inch micrometer (page 459), measure diameter of piston at intervals given in specifications (page 458). If measurements do not meet specification, replace piston.

Piston Ring Inspection

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.

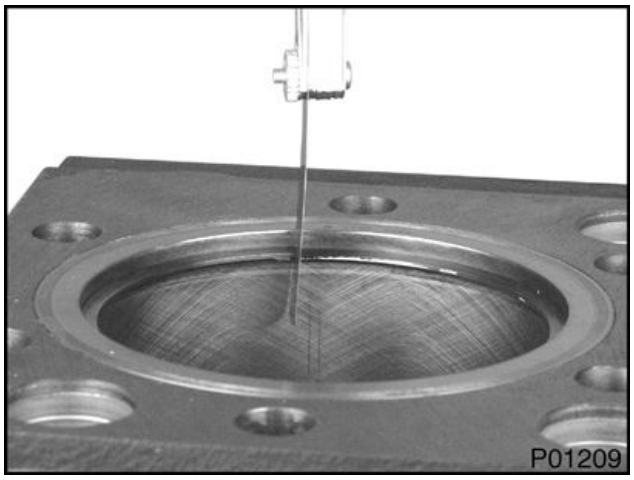


Figure 646 Piston ring end gap clearance in cylinder bore

2. Before installing new piston rings, check ring 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 459) to measure ring gap between ends of each piston ring.
   c. If gap ring does not meet specification (page 458), select another ring or recheck cylinder sleeve wear.

Connecting Rod Inspection

CAUTION: To prevent engine damage, do not allow fractured mating surfaces of the connecting rod or connecting rod cap to contact any surface other than 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 647 Inside diameter of piston pin bore

3. Inspect connecting rod piston pin bore for wear as follows:
   a. Using a telescoping gauge (page 459) and a 2 - 3 inch micrometer (page 459), measure piston pin bore at two locations 90° apart.
   b. If inside diameter of piston pin bore exceeds specification (page 458), replace connecting rod.

Connecting Rod Bore Check

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 USED connecting rod bolts with clean engine oil. Assemble cap to connecting rod without bearings. Tighten bolts to an initial torque of 100 N·m (74 lbf·ft).
2. Rotate each rod bolt 90° clockwise (1/4 turn).

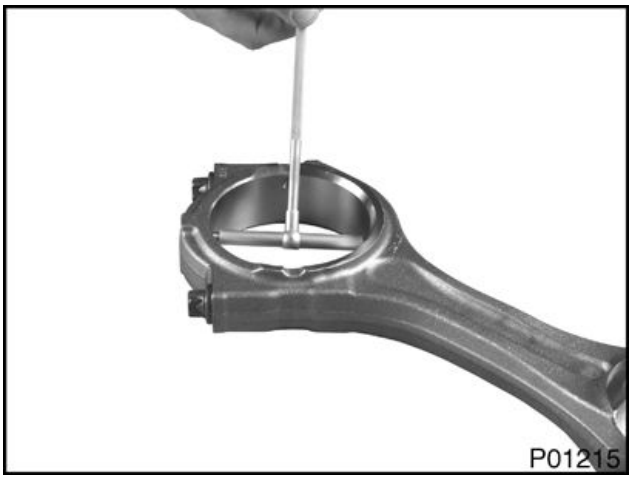


Figure 648 Connecting rod bore measurement

3. Using a telescoping gauge (page 459) and a 3 - 4 inch micrometer (page 459), measure connecting rod bearing bore diameter in three locations. If connecting rod bore diameter does not meet specification (page 458), replace connecting rod.
4. After all connecting rod bores are inspected, disassemble connecting rods and discard used connecting rod bolts.
5. 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 connecting rod assembly as necessary.

Piston Pin Inspection

1. Inspect piston pins for scoring or wear. Replace as necessary.

Figure 649 Piston pin measurement

2. Using a 2 - 3 inch micrometer (page 459), measure piston pin outside diameter at two locations 90° apart. Measure each end of pin. If outside diameter of any piston pin is less than minimum specification (page 458), replace piston pin.

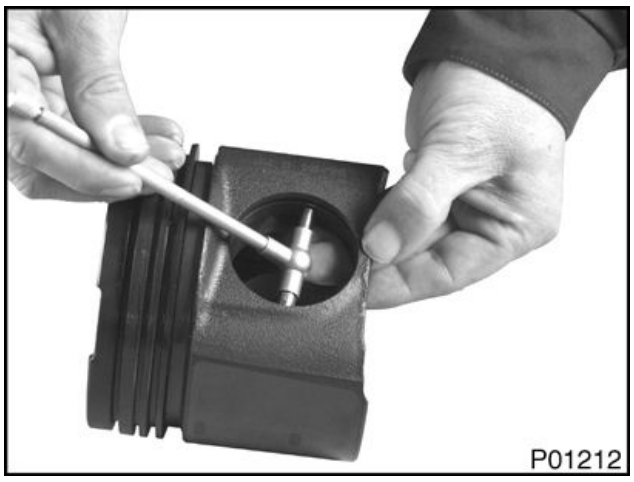


Figure 650 Piston pin bore inside diameter measurement (typical)

NOTE: These pistons have “profiled” pin bores and must be measured carefully to get an accurate result.

NOTE: Measure each piston pin bore inside diameter in front and in rear of piston at one location each, either horizontally (as shown for MaxxForce® 13 piston) or vertically (for MaxxForce® 11 piston) in the pin bore the specified distance from the center line of the piston.

3. Using a telescoping gauge (page 459) and 2 - 3 inch micrometer (page 459), measure each piston pin bore inside diameter at one location either vertically (MaxxForce® 11 piston) or horizontally (MaxxForce® 13 piston) the specified distance from center of piston. If piston pin bore inside diameter is not within specification (page 458), replace piston.
4. To check piston pin running clearance, subtract outside diameter of piston pin from inside diameter of piston pin bore. If clearance exceeds specification (page 458), replace piston pin and check piston pin clearance using new piston pin.

Cylinder Sleeve Inspection

1. Install six cylinder sleeves (without cylinder sleeve O-rings) into crankcase.

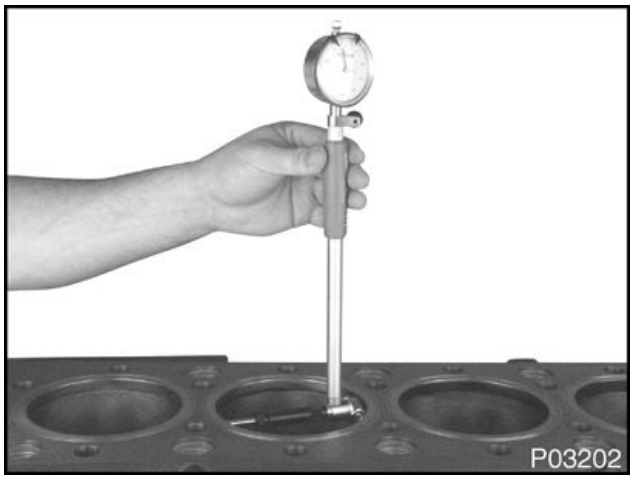


Figure 651 Cylinder sleeve bore measurement

2. Using a dial bore gauge (page 459), measure the cylinder sleeve inside diameter at 120° intervals, at four different depths of cylinder sleeve. If cylinder sleeve inside diameter is not within specification (page 458), replace cylinder sleeve.

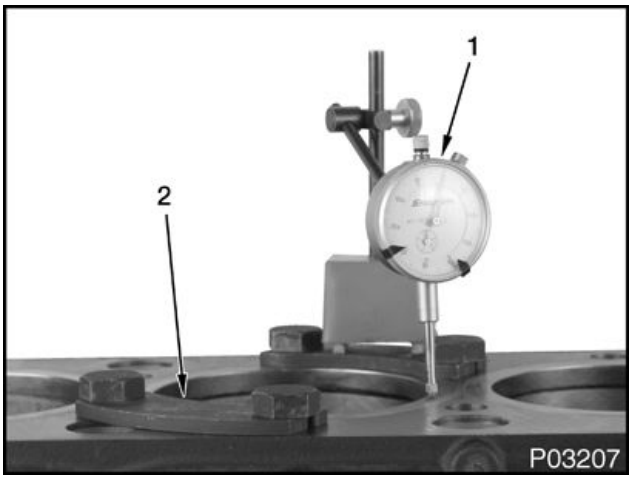


Figure 652 Cylinder sleeve protrusion measurement

1. Dial indicator with magnetic base
2. Sleeve Protrusion Hold Down Clamp

3. Check cylinder sleeve protrusion above crankcase deck as follows:

   a. Install Sleeve Protrusion Hold Down Clamps (page 459) using four included bolts. Torque bolts to special torque (page 459).

   b. Place dial indicator with magnetic base (page 459) on crankcase deck surface.

   c. Position dial indicator tip on crankcase deck adjacent to cylinder sleeve flange. Zero dial indicator.

   d. Carefully pivot dial indicator until tip is resting on cylinder sleeve flange. Record reading.

   e. Measure cylinder sleeve protrusion at three locations evenly spaced around the cylinder sleeve.

   f. If any of the three readings of cylinder sleeve protrusion are not within specification (page 458), fit new cylinder sleeve and repeat steps a through e.

   g. If after trying all available new cylinder sleeves and specification still cannot be met, contact Tech Central at 1-800-336-4500.

   h. Remove six cylinder sleeves and continue with installation.

Installation

Cylinder Sleeves

1. Lubricate two new cylinder sleeve O-rings with clean engine oil and install in crankcase cylinder sleeve bore.
2. Using a soft-faced hammer, install cylinder sleeve by striking evenly until seated.

Piston Assembly

⚠ WARNING: To prevent personal injury or death, wear safety glasses with side shields.

Figure 653 Piston ring installation (typical)

CAUTION: To prevent engine damage, install piston rings correctly. Both top compression and taper face compression rings have the same identification markings. The marking must face up for the ring to be installed correctly. The taper face compression 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.

1. Using piston ring expansion pliers (page 459), install piston rings. Be careful not to “wind” ring into groove.
   a. Install expansion spring component of bevelled oil ring into bottom piston groove.
   b. Install oil scraper component of bevelled oil ring over expansion spring with the gap 180° from the spring wire latch.
   c. Install taper face compression ring into middle piston groove. Make sure ring is installed with identification mark facing up.
   d. Install top compression ring into top piston groove. Make sure ring is installed with identification mark facing up.
2. Space ring gaps approximately 120° apart after ring installation.
3. 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. Set piston crown down so arrow mark stamped on piston crown is at 6 o'clock position.
   c. Using pliers, install one piston pin retainer into groove. Be sure that retainer is fully seated in groove and that tang ends point up.
   d. Hold connecting rod so open end faces 3 o'clock position of piston when installed.
   e. Place connecting rod into piston.

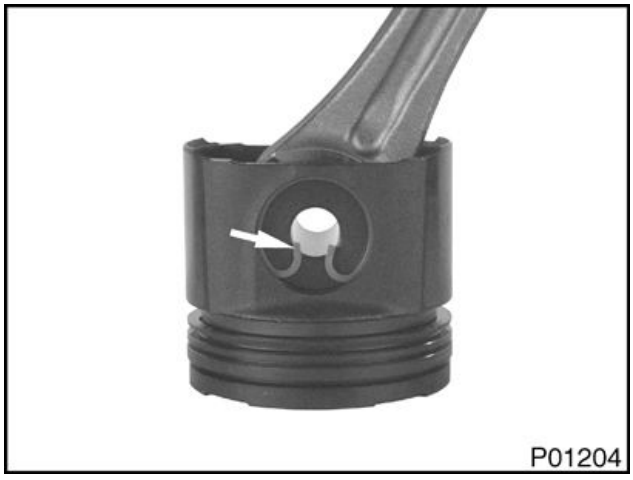


Figure 654 Piston pin retainer

   f. Slide piston pin through piston holes, stopping at installed piston pin retainer.
   g. Using pliers, install second piston pin retainer.

Piston and Connecting Rod

1. Turn crankshaft so crank pin (connecting rod journal) on the cylinder to receive piston installation is at the bottom of its stroke.
2. Lightly coat piston and piston rings with clean engine oil.
3. Coat cylinder sleeve walls, crankshaft journals and Piston Ring Compressor (page 459) with clean engine oil.
4. Place piston in Piston Ring Compressor (page 459).

NOTE: Upper connecting rod bearings have an oil hole and lower connecting rod bearings do not.

5. Install connecting rod bearings in connecting rod and cap. Bearings with oil hole go in the upper position. Coat bearings with clean engine oil.

   Be sure that all bearing locator tabs and oil holes are in alignment with connecting rod and cap and that bearings are flush to fractured mating faces of rod and cap.

Figure 655 Arrow mark on piston (typical)

CAUTION: To prevent engine damage, the arrow stamped on top of piston must face front of engine.

CAUTION: To prevent engine damage, do not damage piston cooling jet when installing connecting rod and piston assembly. If jet is bent during piston assembly installation, replace jet.

CAUTION: To prevent engine damage, do not allow fractured mating surfaces of the connecting rod or connecting rod cap to contact any surface other than its matched fractured surface. Contacting any other surface could cause misalignment of the mating surface, resulting in connecting rod bearing and engine failure.

NOTE: Before installing piston and connecting rod assembly, make sure all piston cooling jets are installed.

6. Carefully put piston and piston ring compressor combination and connecting rod assembly in cylinder sleeve with arrow mark facing towards front of engine.

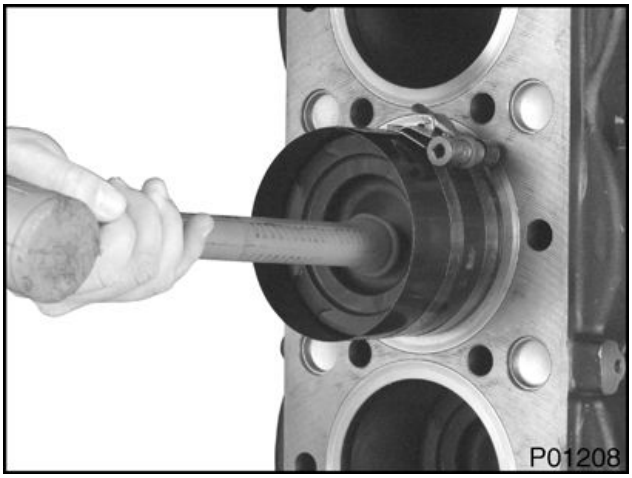


Figure 656 Piston and connecting rod assembly installation (typical)

7. Once piston and connecting rod assembly has been inserted in cylinder sleeve, use a handle (wood or plastic) of a hammer to tap piston into cylinder sleeve. Guide connecting rod in place on crankshaft. Do not let edges of connecting rod or fractured mating face of rod touch the crankshaft journal. Before installing cap with bearing and starting bolts, be sure that bearings are still flush with connecting rod and cap fractured mating faces and have NOT rotated.

CAUTION: To prevent engine damage, lightly lubricate bolt threads and mating surfaces of bolt flanges with clean engine oil. Too much oil causes hydrostatic lock and gives incorrect torque reading.

8. Lightly apply clean engine oil to new bolt threads for connecting rod and upper and lower bearings in cap before installing bolts.

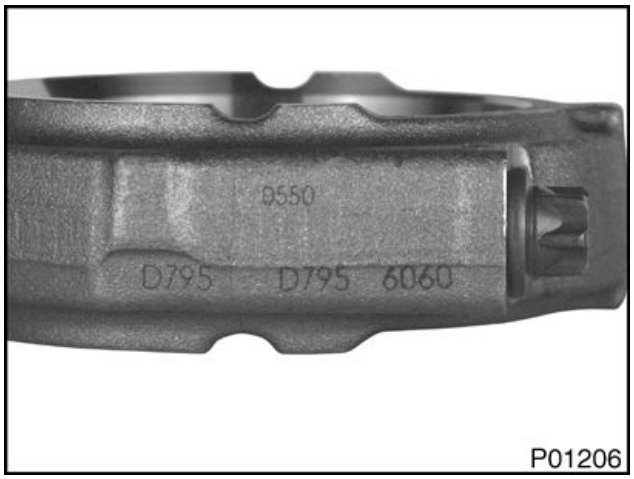


Figure 657 Correct connecting rod and cap joint fit

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 (connecting rod journal) fillets for damage that would require replacement of the crankshaft.

9. Assemble cap to connecting rod with matching identification code on same crankshaft journal from which it was removed. Be certain that longer leg of connecting rod is positioned towards left side of crankcase.

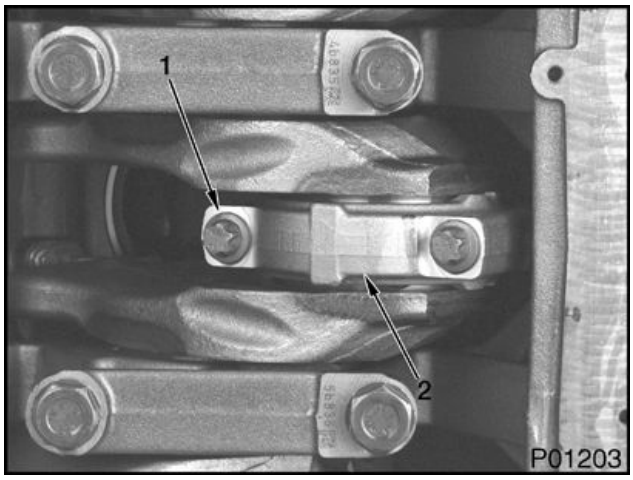


Figure 658 Connecting rod cap

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

CAUTION: To prevent engine damage, install new connecting rod bolts.

CAUTION: To prevent engine damage, do not use powered tools to install connecting rod bolts; rotating bolts too quickly can damage threads.

CAUTION: To prevent engine damage, do not rotate crankshaft until connecting rod bolts are fully tightened, as this may cause bearings to rotate in place.

10. Install two NEW connecting rod bolts.
11. Using Exhaust Manifold Bolt Torx® Socket (page 459), tighten connecting rod bolts evenly to an initial torque of 100 N·m (74 lbf·ft).
12. Rotate (tighten) connecting rod bolts an additional 90 degrees (1/4 turn).
13. Repeat installation procedure for remaining piston and connecting rod assemblies.

Engine Run-in Procedure

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

Use the following engine run-in procedure after installing new pistons, piston rings, piston pins or cylinder sleeves:

1. Start engine and run at low idle with no load. If engine does not exceed 138 kPa (20 psi) oil pressure within 20 to 30 seconds, shutdown engine and correct the problem.
2. Run engine at low idle with no load for 5 minutes and check for any of the following problems:

- Unusual noise
- Coolant leaks
- Oil leaks
- Fuel leaks
- Air leaks
- Excessive exhaust smoke
- Excessive vibration
- Loose turbocharger mounting

3. Turn engine off and correct any of these problems to prevent engine or turbocharger damage.
4. Wait 15 minutes for oil level to stabilize, then check engine oil level. Add oil if needed. See appropriate *Engine Operation and Maintenance Manual* for correct grade and viscosity of engine oil.
5. Start engine and drive vehicle (unloaded) for 30 minutes in city mode, then drive vehicle (unloaded) for an additional 60 minutes in highway mode. Verify no loss in power.
6. Return to idle and check for leaks.
7. Turn off engine and repair any leaks.

Specifications

Table 41 Power Cylinders

Connecting Rods	
Piston pin bore inside diameter	52.06 ± 0.005 mm (2.0496 ± 0.0001 in)
Connecting rod bearing bore diameter (crankshaft end)	95.000 to 95.022 mm (3.7402 to 3.7402 in)
Pistons — MaxxForce® 11	
Skirt diameter measured 16 mm from piston bottom edge, 90° to piston pin axis in “window” on skirt graphite layer, where applicable	119.88 ± 0.009 mm (4.7197 ± 0.0004 in)
Piston protrusion measured from crankcase deck to piston	0.3 ± 0.22 mm (0.0118 ± 0.009 in)
Piston pin bore inside diameter, measured vertically, 38 mm from piston center	52.010 - 52.016 mm (2.0476 - 2.0479 in)
Piston pin running clearance	0.010 - 0.024 mm (0.0004 - 0.0009 in)
Pistons — MaxxForce® 13	
Skirt diameter measured 26.9 mm from piston bottom edge, 90° to piston pin axis in “window” on skirt graphite layer, where applicable	125.950 ± 0.013 mm (4.9587 ± 0.0005 in)
Piston protrusion measured from crankcase deck to piston	0.3 ± 0.22 mm (0.0118 ± 0.009 in)
Piston pin bore inside diameter, measured horizontally 26 mm from piston center	52.04 - 52.05 mm (2.0490 - 2.0492 in)
Piston pin running clearance	0.040 - 0.058 mm (0.0016 - 0.0023 in)
Piston Pins	
Outside diameter	51.992 - 52.000 mm (2.0469 - 2.0472 in)
Piston Rings — MaxxForce® 11	
Top compression ring	
Ring gap	0.4 - 0.55 mm (0.0157 - 0.0217 in)
Taper face compression ring	
Ring gap	1.00 - 1.20 mm (0.0393 - 0.0472 in)
Side clearance	0.09 - 0.13 mm (0.0035 - 0.0051 in)
Bevelled oil ring	
Ring gap	0.25 - 0.50 mm (0.0098 - 0.0197 in)
Side clearance	0.03 - 0.07 mm (0.0012 - 0.0028 in)
Piston Rings — MaxxForce® 13	
Top compression ring	
Ring gap	0.4 - 0.55 mm (0.0157 - 0.0217 in)

Table 41 Power Cylinders (cont.)

Taper face compression ring	
Ring gap	1.00 - 1.20 mm (0.0394 - 0.0472 in)
Side clearance	0.09 - 0.13 mm (0.0035 - 0.0051 in)
Bevelled oil ring	
Ring gap	0.25 - 0.50 mm (0.0098 - 0.0197 in)
Side clearance	0.05 - 0.09 mm (0.0020 - 0.0035 in)
Cylinder sleeve dimensions — MaxxForce® 11	
Sleeve protrusion	0.050 - 0.085 mm (0.0019 - 0.0033 in)
Sleeve inside diameter (bore)	120 ± 0.01 mm (4.7244 ± 0.0004 in)
Cylinder sleeve dimensions — MaxxForce® 13	
Sleeve protrusion	0.050 - 0.085 mm (0.0019 - 0.0033 in)
Sleeve inside diameter (bore)	126 ± 0.01 mm (4.9606 ± 0.0004 in)

Special Torque

Table 42 Power Cylinders

Connecting rod bolts	See tightening steps in procedure
Sleeve Protrusion Hold Down Clamp bolts	80 N·m (59 lbf·ft)

Special Service Tools

Table 43 Power Cylinders

Description	Tool Number
2 - 3 inch micrometer	Obtain locally
3 - 4 inch micrometer	Obtain locally
4 - 5 inch micrometer	Obtain locally
Cylinder Sleeve Puller	ZTSE2536
Dial bore gauge	Obtain locally
Dial indicator with magnetic base	Obtain locally
Exhaust Manifold Bolt Torx® Socket	ZTSE4843
Feeler gauge	Obtain locally
Piston ring compressor	Obtain locally
Piston ring expansion pliers	Obtain locally
Sleeve Protrusion Hold Down Clamps	ZTSE4825
Telescoping gauge	Obtain locally

Table of Contents

Exploded View.....463
- **Crankcase and Crankshaft**.....463

Removal.....464
- **Preliminary Checks**.....465
- **Crankshaft**.....465
- **Piston Cooling Jets**.....466

Cleaning, Inspection and Testing.....467
- **Crankcase**.....467
- **Crankshaft Measurement**.....467
- **Main Bearings Measurement**.....468
- **Piston Cooling Jets**.....469

Installation.....470
- **Piston Cooling Jets**.....470
- **Crankshaft**.....470

Specifications.....473

Special Torque.....473

Special Service Tools.....473

Exploded View

Crankcase and Crankshaft

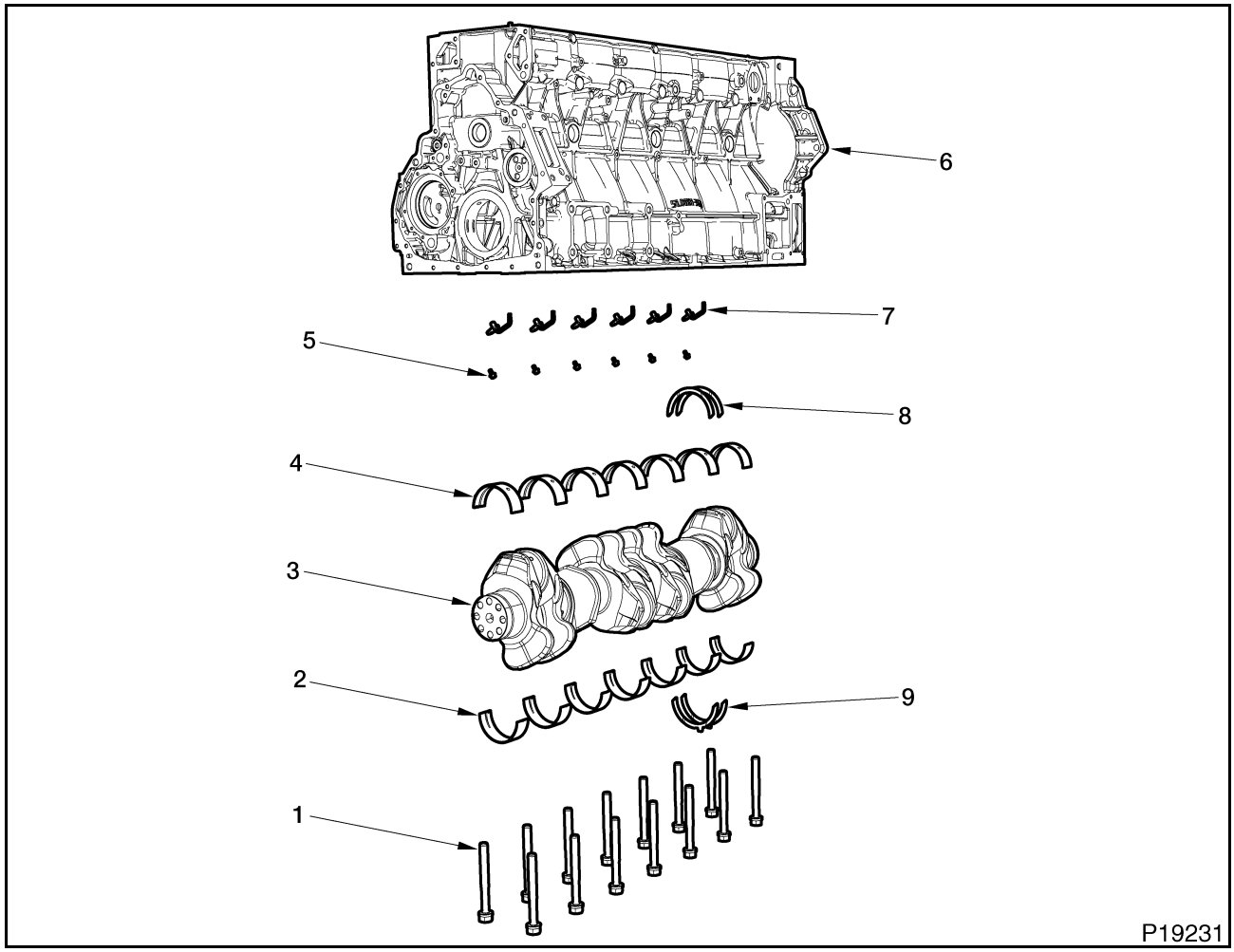


Figure 659 Crankcase and crankshaft

1. M18 x 2 x 160.5 collar bolt (14)
2. Lower main bearing (7)
3. Crankshaft
4. Upper main bearing (with oil hole) (7)
5. M6 x 12 bolt (6)
6. Crankcase
7. Piston cooling jet (6)
8. Upper thrust washer (main bearing) (2)
9. Lower thrust washer (main bearing) (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 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: Refer to the following service sections for information on removal of components prior to this section.

- Engine Electrical
- Mounting Engine on Stand
- Cold Start Assist
- Aftertreatment System
- Exhaust Back Pressure Control
- Turbochargers
- Air Compressor and Power Steering
- Fuel System
- Oil Cooler, Filter Housing and Crankcase Ventilation
- Exhaust Gas Recirculating (EGR) System
- Air Intake Throttle Duct and Exhaust Manifold
- Front Cover, Fan Drive, Cooling System and Related Components
- MaxxForce® Engine Brake by Jacobs (if equipped)
- Cylinder Head, Camshaft and Valve Train
- Flywheel and Flywheel Housing
- Oil Pan and Oil Pickup Tube
- Oil Pump and Timing Gears
- Power Cylinders

Preliminary Checks

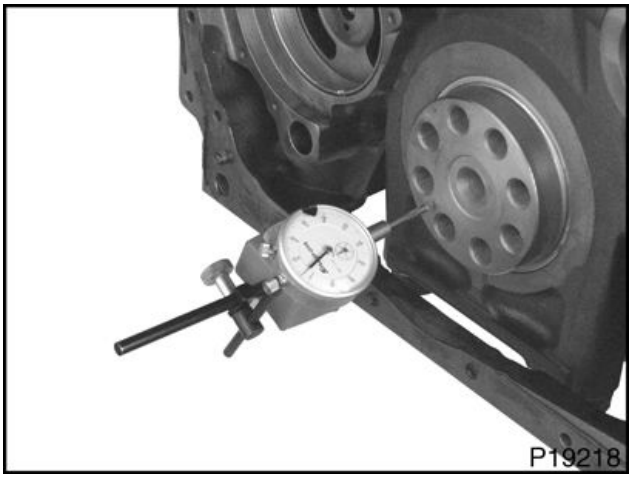


Figure 660 Crankshaft end play

1. Check crankshaft end play as follows:
   a. Mount dial indicator with magnetic base (page 473) on crankcase with indicator tip on end of crankshaft as shown.
   b. Move crankshaft forward with pry bar and zero the dial indicator.
   c. Move crankshaft back and forth while reading dial indicator. Compare dial indicator reading with specification (page 473).
   d. If end play exceeds specified limits, replace main bearing thrust washers.

Crankshaft

1. Position engine so that bottom of main bearing caps are facing upwards.

CAUTION: To prevent engine damage, use permanent markers to identify internal components or their orientation. Do not use paint or temporary markers.

2. Mark main bearing caps for location and orientation.

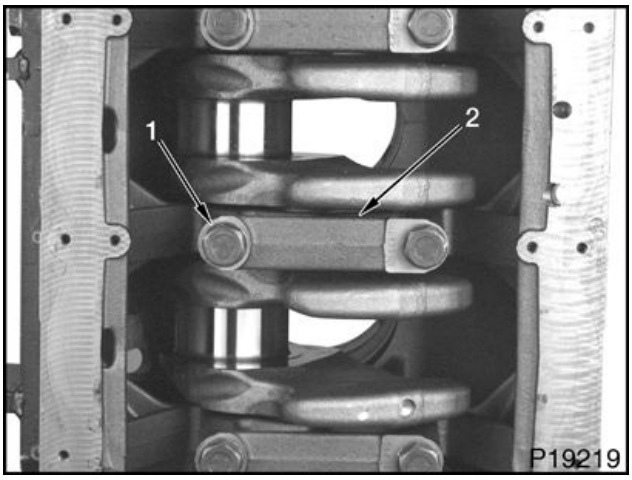


Figure 661 Main bearing caps

1. M18 x 160.5 collar bolt (14)
2. Main bearing cap (7)

CAUTION: To prevent engine damage, do not drop main bearing caps. Damage to the fractured mating surface of a main bearing cap will require replacement of the crankcase and mated main bearing caps.

3. Remove 14 M18 x 160.5 collar bolts and seven main bearing caps. Save bolts for Main Bearings Measurement procedure (page 468).
4. Remove seven lower main bearings and two lower thrust washers from main bearing caps by pushing out.

CAUTION: To prevent engine damage, use permanent markers to identify internal components or their orientation. Do not use paint or temporary markers.

5. Number removed lower main bearings and lower thrust washers on back side (not running surface) and set aside for inspection.

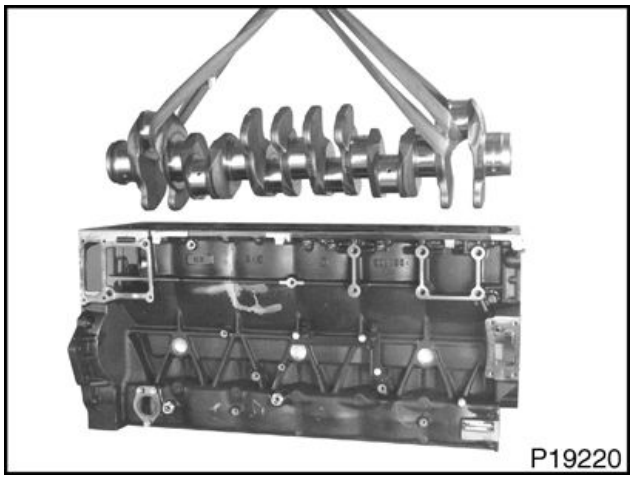


Figure 662 Crankshaft removal

WARNING: To prevent personal injury or death, use a correct size lifting sling and hoist with a safety latch on hook.

CAUTION: To prevent engine damage, do not bend, drop or damage crankshaft.

NOTE: Use only a soft-sided lifting sling. Do not use chains or steel cables.

6. Attach lifting sling (page 473) to crankshaft. Lift crankshaft up and out of crankcase and set aside for inspection.
7. Remove upper main bearings and upper thrust washers from crankcase by pushing out.
8. Number removed upper main bearings and upper thrust washers on back side (not running surface) to match the previously removed lower main bearings and lower thrust washers and set aside for inspection.

Piston Cooling Jets

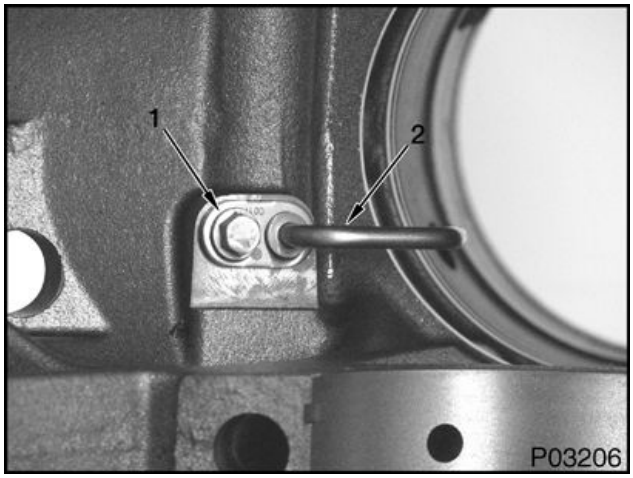


Figure 663 Piston cooling jet

1. M6 x 12 bolt (6)
2. Piston cooling jet (6)

1. Remove six M6 x 12 bolts and six piston cooling jets.

Cleaning, Inspection and Testing

Crankcase

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 use chlorinated solvents on bolts or crankcase tapped holes. Parts should be clean, dry and free of any chemicals other than engine oil.

NOTE: Thoroughly clean and inspect crankcase before and after reconditioning.

1. Clean crankcase in a chemical bath or hot tank. This removes all carbonized material and mineral deposits in coolant passages.

CAUTION: To prevent engine damage, do not use a wire brush to clean the fractured mating surface of crankcase and main bearing caps.

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 crankcase.
   b. Clean crankcase in solvent.
   c. Dry with filtered compressed air.

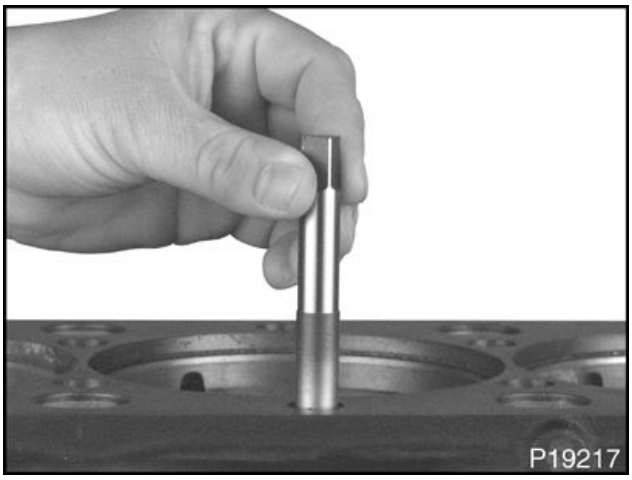


Figure 664 Cylinder head bolt holes

CAUTION: To prevent engine damage, clean and dry threads in the crankcase bolt holes with filtered compressed air. Dirt or oil in holes may cause binding and incorrect torque readings.

3. Clean cylinder head bolt holes with Head Bolt Bottoming Tap (page 473).
4. Clean collar bolt holes with Main Bolt Bottoming Tap (page 473).
5. Clean out debris with filtered compressed air.

Crankshaft Measurement

1. Clean and inspect crankshaft and main bearings.
2. Clean crankshaft with a suitable solvent.
3. Use a stiff nylon brush to clean oil passages in crankshaft. Loosen accumulated dirt, sludge and deposits.
4. Flush oil passages with a suitable solvent.

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

5. Dry with filtered compressed air.
6. Inspect crankshaft journals (main and connecting rod) for scratches, grooves and scoring.

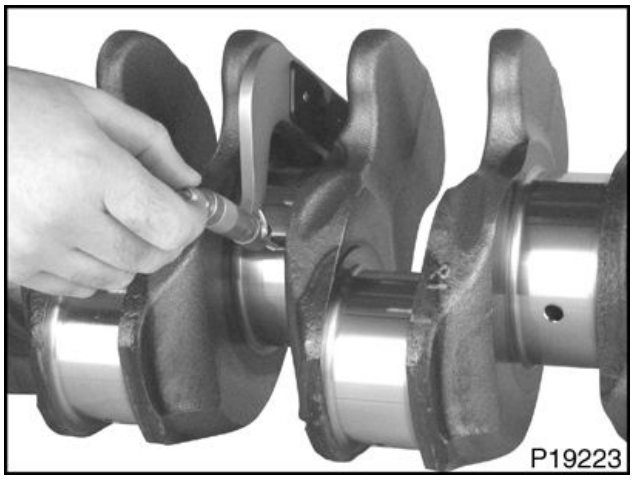


Figure 665 Crankshaft main bearing journal measurement

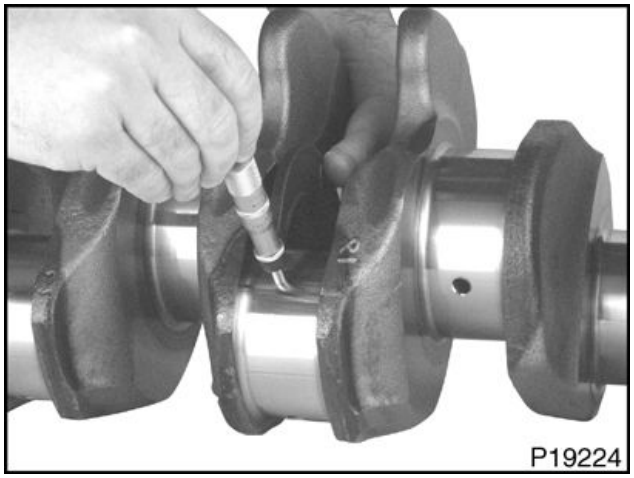


Figure 666 Crankshaft connecting rod bearing journal measurement

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 473) to measure diameter of each connecting rod journal, and a 4 - 5 inch micrometer (page 473) to measure diameter of each main journal. Measure each journal at both sides next to fillet radius at two directions 90° apart. Move micrometer over entire width of journal. If journal wear exceeds specification (page 473), have crankshaft machined, or replace crankshaft.

Main Bearings Measurement

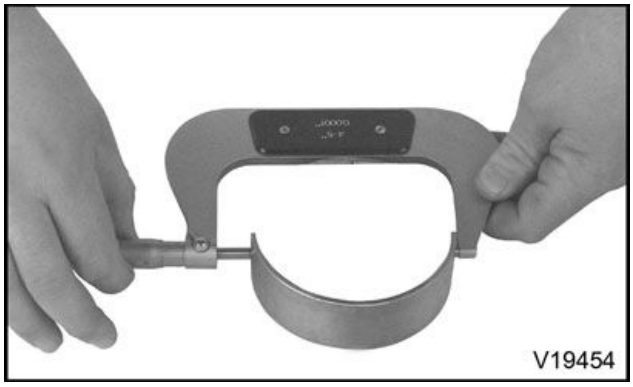


Figure 667 Main bearing uninstalled outside diameter (free spread) measurement

1. Inspect each main bearing for scratches, grooves, scoring, pitting and wear. Replace bearings as required.
2. Using a flat surface, place an individual bearing half on the surface as shown.
3. Using a 4 - 5 inch micrometer (page 473), measure across the ends of the bearing half as shown.
4. If the measurement falls outside of the uninstalled bearing outside diameter (free spread) specification (page 473), replace upper and lower bearing halves as a set. Measure all upper and lower bearing halves and replace bearings as required.
5. Install upper main bearings into crankcase and lower main bearings into main bearing caps in their original positions and orientation.

CAUTION: To prevent engine damage, install main bearing caps with their fractured mating surfaces in the original orientation.

6. Lightly coat used collar bolt threads and under bolt heads with clean engine oil. Do not use new bolts for this inspection procedure.
7. With crankshaft still removed, install seven main bearing caps and 14 previously removed M18 x 160.5 collar bolts.
8. Tighten M18 x 160.5 collar bolts in main bearings caps as follows:

a. Tighten collar bolts at No. 6 main bearing cap to 10 N·m (88 lbf·in).

b. Tighten remaining collar bolts to 10 N·m (88 lbf·in).

c. Tighten collar bolts at No. 6 main bearing cap to 100 N·m (74 lbf·ft).

d. Tighten remaining collar bolts to 100 N·m (74 lbf·ft).

e. Tighten collar bolts at No. 6 main bearing cap to 300 N·m (221 lbf·ft).

f. Tighten remaining collar bolts to 300 N·m (221 lbf·ft).

g. Turn collar No. 6 main bearing cap an additional 90° clockwise.

h. Turn remaining collar bolts an additional 90° clockwise.

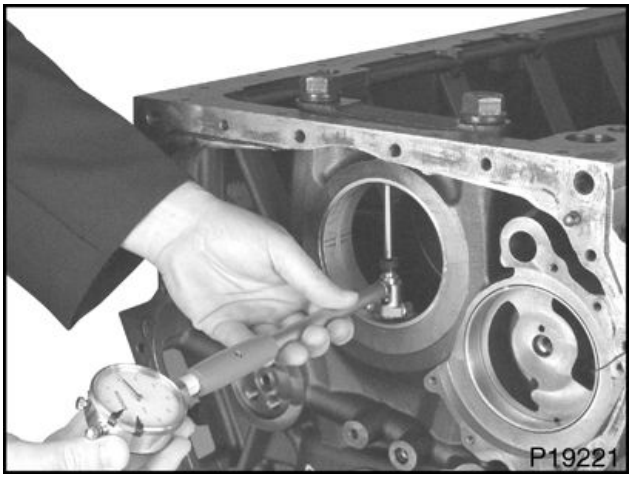


Figure 668 Main bearing installed diameter measurement

9. Using a dial bore gauge (page 473), measure main bearing installed inside diameter. If measurement does not meet specification (page 473), replace main bearings.

10. Remove 14 M18 x 160.5 collar bolts, seven main bearing caps, upper main bearings and lower main bearings. Discard used collar bolts.

Piston Cooling Jets

1. Hold each piston cooling jet under running water. Water should stream from jet end.

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

2. Clear blocked piston cooling jets using filtered compressed air. Replace piston cooling jet if blockage cannot be cleared.

3. Replace any cracked or bent jets.

Installation

Piston Cooling Jets

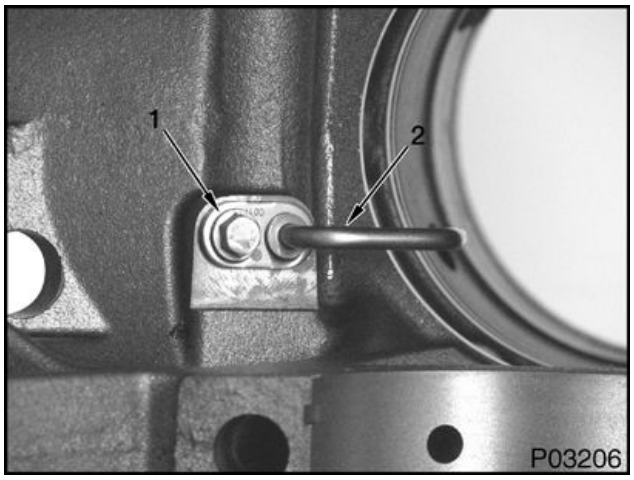


Figure 669 Piston cooling jet

1. M6 x 12 bolt (6)
2. Piston cooling jet (6)

1. Install six piston cooling jets and six M6 x 12 bolts.
2. Tighten bolts to special torque (page 473).

Crankshaft

NOTE: Make sure crankshaft and bearings have been inspected per instructions in this section before proceeding.

1. Use a lint-free cloth to wipe crankcase bearing saddles free of oil.

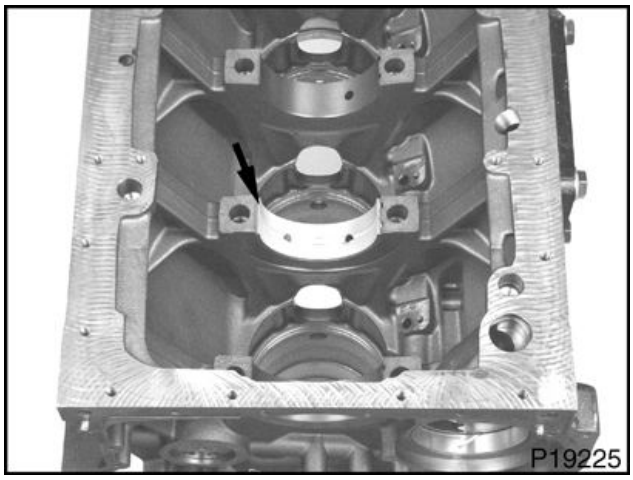


Figure 670 Main bearing

NOTE: When inserting main bearings, make sure oil is not between back side of bearing and crankcase bearing saddles.

2. Place upper main bearings in crankcase. Make sure locking tabs on bearings are snapped into saddle and oil holes in bearings line up with oil holes in crankcase.
3. Lubricate running surface of bearings with clean engine oil.

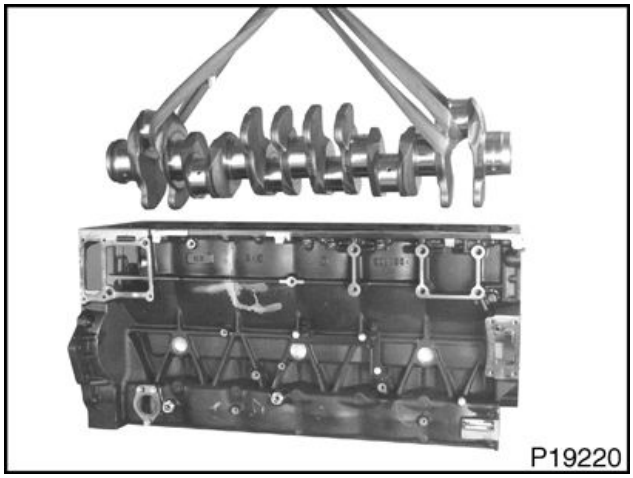


Figure 671 Crankshaft installation

WARNING: To prevent personal injury or death, use a correct size lifting sling and hoist with a safety latch on hook.

CAUTION: To prevent engine damage, do not bend, drop or damage crankshaft.

NOTE: Use only a soft-sided lifting sling. Do not use chains or steel cables.

4. Attach lifting sling (page 473) to crankshaft. Orient crankshaft with front flange (8 bolt holes) and rear flange (10 bolt holes) at crankcase front and rear, respectively. Carefully lower crankshaft down into crankcase.

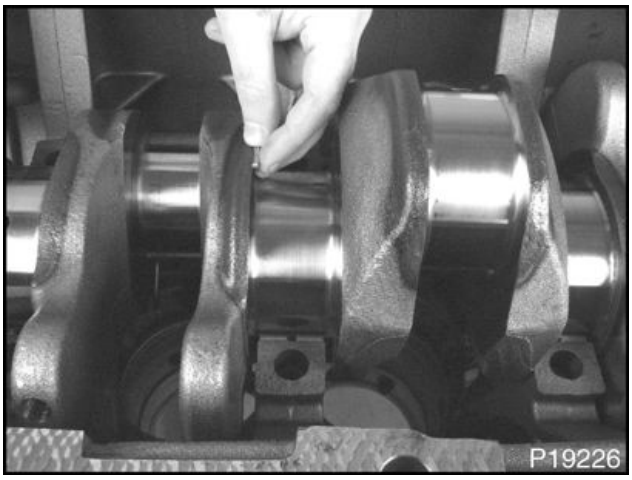


Figure 672 Thrust washer installation

NOTE: Make sure oil grooves on thrust washers face outward towards crankshaft thrust surface.

5. Install two upper thrust washers into crankcase at No. 6 main location as follows:
   a. Set upper thrust washer on top of crankshaft at No. 6 main journal with grooves towards crankshaft thrust surface.
   b. Pivot upper thrust washer around crankshaft and down into position.
6. Install two lower thrust washers onto No. 6 main bearing cap. Make sure lower thrust washer locking tabs align with notches in main bearing cap.
7. Place lower main bearings in main bearing caps. Make sure locking tabs on bearings are snapped into main bearing caps.
8. Lubricate bearings with clean engine oil.

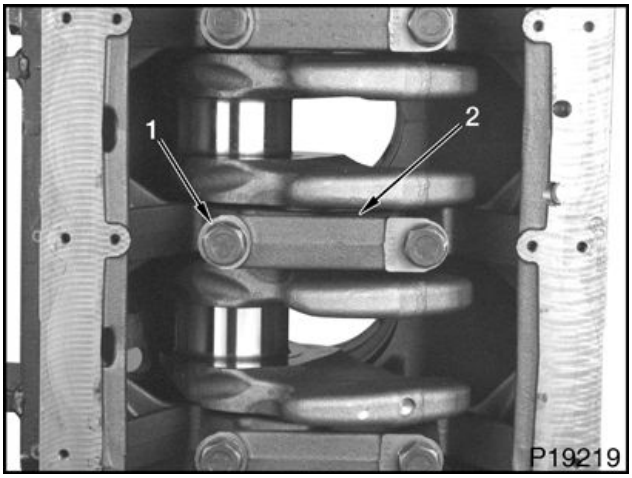


Figure 673 Main bearing caps

1. Collar M18 x 160.5 bolt (14)
2. Main bearing cap (7)

CAUTION: To prevent engine damage, install main bearing caps with their fractured mating surfaces in the original orientation.

CAUTION: To prevent engine damage, do not drop main bearing caps. Damage to the fractured mating surface of a main bearing cap will require replacement of the crankcase and mated main bearing caps.

9. Install seven main bearing caps and 14 new M18 x 160.5 collar bolts.

10. Tighten collar bolts as follows:
    a. Tighten two collar bolts at No. 6 (thrust washer location) main bearing cap to 10 N·m (88 lbf·in).
    b. Tighten remaining collar bolts to 10 N·m (88 lbf·in).
    c. Rotate crankshaft to verify that crankshaft does not bind. Correct as required.
    d. Tighten two collar bolts at No. 6 (thrust washer location) main bearing cap to 100 N·m (74 lbf·ft).
    e. Tighten remaining collar bolts to 100 N·m (74 lbf·ft).
    f. Tighten two collar bolts at No. 6 (thrust washer location) main bearing cap to 300 N·m (221 lbf·ft).
    g. Tighten remaining collar bolts to 300 N·m (221 lbf·ft).
    h. Turn two collar bolts at No. 6 (thrust washer location) main bearing cap bolts an additional 90°.
    i. Turn remaining collar bolts an additional 90°.

Specifications

Table 44 Crankcase and Crankshaft

Crankshaft	
Main Bearing:	
Journal diameter	103.98 - 104.00 mm (4.0937 - 4.0945 in)
Installed bearing inside diameter	104.044 - 104.09 mm (4.0962 - 4.0980 in)
Uninstalled bearing outside diameter (free spread)	111.20 - 112.40 mm (4.3779 - 4.4252 in)
Connecting Rod Bearing:	
Journal diameter	89.98 - 90.00 mm (3.5425 - 3.5433 in)
Crankshaft end play:	
Maximum service	0.200 - 0.401 mm (0.0079 - 0.0158 in)

Special Torque

Table 45 Crankcase and Crankshaft

Collar bolts (main bearing cap), M18 x 160.5	See tightening procedure and sequence (page 471)
Piston cooling jet bolts, M6 x 12	13 N·m (115 lbf·in)

Special Service Tools

Table 46 Crankcase and Crankshaft

Description	Tool Number
3 - 4 inch micrometer	Obtain locally
4 - 5 inch micrometer	Obtain locally
Dial bore gauge	Obtain locally
Dial indicator with magnetic base	Obtain locally
Head Bolt Bottoming Tap	ZTSE4855
Lifting sling	Obtain locally
Main Bolt Bottoming Tap	ZTSE4854

Table of Contents

Abbreviations and Acronyms.....477
Abbreviations and Acronyms.....477

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
B+ or VBAT – Battery Voltage
BARO – Barometric Absolute Pressure
BBDC – Before Bottom Dead Center
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
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 Ignitor
CSFS – Cold Start Fuel Solenoid
CSR – Cold Start Relay
CTC – Coolant Temperature Compensation
Cyl – Cylinder
DB – Decibel
DCA – Diesel Coolant Additive
DDI – Digital Direct Fuel Injection
DDS – Driveline Disengagement Switch
DLC – Data Link Connector
DME – Dimethyl Ether
DMM – Digital Multi-meter
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
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
lbf – Pounds of force
lb/s – Pounds per second
lbf ft – Pounds of force per foot
lbf in – Pounds of force per inch
lbm – Pounds of mass
LSD – Low Sulfur Diesel
m – Meter
m/s – Meters per second
MAF – Mass Air Flow
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
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
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.....**483**
Terms.....**483**

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) – A heat exchanger mounted in the charge air path between the turbocharger and engine intake manifold. The aftercooler reduces the charge air temperature by transferring heat from the charge air to a cooling medium (usually air).

Aftertreatment Fuel Doser (AFTFD) – A part of the Downstream Injection (DSI) unit that sends pressurized fuel to the Hydrocarbon Injector (HCI) assembly to inject fuel into the exhaust pipe.

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.

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 temperature – The environmental air temperature in which a unit is operating. In general, the temperature is measured in the shade (no solar radiation) and represents the air temperature for other engine cooling performance measurement purposes. Air entering the radiator may or may not be the same ambient due to possible heating from other sources or recirculation. (SAE J1004 SEP81)

Ampere (amp) – The standard unit for measuring the strength of an electrical current. The flow rate of a charge in a conductor or conducting medium of one coulomb per second. (SAE J1213 NOV82)

Analog – A continuously variable voltage.

Analog to digital converter (A/D) – A device in the ECM that converts an analog signal to a digital signal.

American Trucking Association (ATA) Datalink – A serial datalink specified by the American Trucking Association and the SAE.

Boost pressure – 1. The pressure of the charge air leaving the turbocharger.

2. Inlet manifold pressure that is greater than atmospheric pressure. Obtained by turbocharging.

Bottom Dead Center (BDC) – The lowest position of the piston during the stroke.

Brake Horsepower (bhp) – The power output from an engine, not the indicated horsepower. The power output of an engine, sometimes-called flywheel horsepower, is less than the indicated horsepower by the amount of friction horsepower consumed in the engine.

Brake Horsepower (bhp) net – Net brake horsepower is measured with all engine components. The power of an engine when configured as a fully equipped engine. (SAE J1349 JUN90)

Calibration – 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) – See **Aftercooler**.

Charge Air 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 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.

Controller Area Network (CAN) – A J1939 high speed communication link.

Coolant – A fluid used to transport heat from one point to another.

Coolant level switch – A switch sensor used to monitor coolant level.

Coolant Flow Valve (CFV) – The CFV is ECM controlled and redirects coolant through the fuel cooler, based on EFT, when directed.

Coolant Mixer Valve (CMV) – Controls coolant flow through the low-temperature radiator.

Continuous Monitor Test – An ECM function that continuously monitors the inputs and outputs to ensure that readings are within set limits.

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.

Current – The flow of electrons passing through a conductor. Measured in amperes.

Damper – A device that reduces the amplitude of torsional vibration. (SAE J1479 JAN85)

Deaeration – The removal or purging of gases (air or combustion gas) entrained in coolant or lubricating oil.

Deaeration tank – A separate tank in the cooling system used for one or more of the following functions:

- Deaeration
- Coolant reservoir (fluid expansion and afterboil)
- Coolant retention
- Filling
- Fluid level indication (visible)

Diagnostic Trouble Code (DTC) – 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.

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 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.

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 Control Module (ECM) – An electronic processor that monitors and controls the engine.

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 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 Temperature (EGT) – The temperature of exhaust gases.

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 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.

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.

Failure Mode Indicator (FMI) – Identifies the fault or condition effecting the individual component.

Filter restriction – A blockage, usually from contaminants, that prevents the flow of fluid through a filter.

Flash code – See **Diagnostic Trouble Code (DTC)**.

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 Combined Weight Rating (GCWR) – Maximum combined weight of towing vehicle (including passengers and cargo) and the trailer. The GCWR indicates the maximum loaded weight that the vehicle is allowed to tow.

Gross brake horsepower – The power of a complete basic engine, with air cleaner, without fan, and alternator, and air compressor not charging.

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 InjectorAssembly – Injects fuel into the exhaust system to increase temperature of the exhaust gases.

Injection Pressure Regulator (IPR) valve – A valve that is used to maintain desired injection control pressure.

Injection Control Pressure (ICP) sensor – Provides a feedback signal to the ECM indicating 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.

International NGV Tool Utilized for Next Generation Electronics (INTUNE) – The diagnostics software for chassis related components and systems.

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.

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 Air Flow – The intake airflow in an engine.

Mass Air Flow (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.

MasterDiagnostics® (MD) – Diagnostics software for engine related components and systems.

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.

Metering unit valve assembly – The Metering unit valve assembly provides a metered amount of fuel to the Hydrocarbon Injector (HCI) assembly.

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.

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.

pH – A measure of the acidity or alkalinity of a solution.

Particulate matter – Particulate matter includes mostly burned particles of fuel and engine oil.

Piezometer – An instrument for measuring fluid pressure.

Power – Power is a measure of the rate at which work (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).

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.

Random Access Memory (RAM) – Computer memory that stores information. Information can be written to and read from RAM. Input information (current engine speed or temperature) can be stored in RAM to be compared to values stored in Read Only Memory (ROM). All memory in RAM is lost when the ignition switch is turned off.

Rated gross horsepower – Engine gross horsepower at rated speed as declared by the manufacturer. (SAE J1995 JUN90)

Rated horsepower – Maximum brake horsepower output of an engine as certified by the engine manufacturer. The power of an engine when configured as a basic engine. (SAE J1995 JUN90)

Rated net horsepower – Engine net horsepower at rated speed as declared by the manufacturer. (SAE J1349 JUN90)

Rated speed – The speed, as determined by the manufacturer, at which the engine is rated. (SAE J1995 JUN90)

Rated torque – Maximum torque produced by an engine as certified by the manufacturer.

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

Reference voltage (V_{REF}) – A 5 volt reference supplied by the ECM to operate the engine sensors.

Reserve capacity – Time in minutes that a fully charged battery can be discharged to 10.5 volts at 25 amperes.

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.

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 (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 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 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 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 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.

Table of Contents

Fuel System.....**495**
Air Inlet Duct and Exhaust Manifolds.....**495**
Engine Brake.....**495**
Cylinder Head, Camshaft and Valve Train.....**495**
Flywheel and Flywheel Housing.....**495**
Oil Pump, Low Mount Fan Drive, and Timing Gears.....**496**
Power Cylinders.....**496**
Crankcase and Crankshaft.....**498**

Fuel System

Table 47 Fuel System

Fuel strainer filtration	300 microns
Fuel filter element filtration	3-5 microns

Air Inlet Duct and Exhaust Manifolds

Table 48 Exhaust Manifolds

Exhaust manifold maximum allowable warpage	0.1 mm (0.003 in)

Engine Brake

Table 49 Engine Brake

Solenoid resistance:

		Cold –	0.1 mm (0.003 in)
Cold — 25° C (77° F)	8.7–10 ohms		
Hot — 121° C (250° F)	12–15.5 ohms		

Cylinder Head, Camshaft and Valve Train

Table 50 Cylinder Head, Camshaft and Valve Train

Camshaft	
Camshaft bearing inside diameter	39.925 – 39.950 mm (1.57185 – 1.57283 in)
Camshaft end play	0.25 – 0.85 mm (0.0098 – 0.0334 in)
Valve Lash Adjustment	
Exhaust valve clearance	0.8 mm (0.0315 in)
Intake valve clearance	0.5 mm (0.0197 in)
Cylinder Head Idler Gear Cup Plug	
Cup plug, DMR 63.10	Recess 2.3 mm (0.9 in)

Flywheel and Flywheel Housing

Table 51 Flywheel and Flywheel Housing

Flywheel minimum thickness (dimension “A”)	46 mm (1.811 in)
Flywheel maximum surface runout	0.20 mm (0.0079 in)

Oil Pump, Low Mount Fan Drive, and Timing Gears

Table 52 Oil Pump, Low Mount Fan Drive, and Timing Gears

Front Timing Gears	
Front intermediate gear backlash	0.057 - 0.183 mm (0.0022 - 0.0072 in)
Oil Pump	
Oil pump pinion and oil pump ring gear end play	0.0030 - 0.120 mm (0.0012 - 0.0047 in)
Rear Timing Gears	
Big intermediate gear backlash	0.052 - 0.176 mm (0.0020 - 0.0069 in)
Crankcase intermediate gear backlash	0.052 - 0.176 mm (0.0020 - 0.0069 in)

Power Cylinders

Table 53 Power Cylinders

Connecting Rods	
Piston pin bore inside diameter	52.06 ± 0.005 mm (2.0496 ± 0.0001 in)
Connecting rod bearing bore diameter (crankshaft end)	95.000 to 95.022 mm (3.7402 to 3.7402 in)
Pistons — MaxxForce® 11	
Skirt diameter measured 16 mm from piston bottom edge, 90° to piston pin axis in “window” on skirt graphite layer, where applicable	119.88 ± 0.009 mm (4.7197 ± 0.0004 in)
Piston protrusion measured from crankcase deck to piston	0.3 ± 0.22 mm (0.0118 ± 0.009 in)
Piston pin bore inside diameter, measured vertically, 38 mm from piston center	52.010 - 52.016 mm (2.0476 - 2.0479 in)
Piston pin running clearance	0.010 - 0.024 mm (0.0004 - 0.0009 in)
Pistons — MaxxForce® 13	
Skirt diameter measured 26.9 mm from piston bottom edge, 90° to piston pin axis in “window” on skirt graphite layer, where applicable	125.950 ± 0.013 mm (4.9587 ± 0.0005 in)
Piston protrusion measured from crankcase deck to piston	0.3 ± 0.22 mm (0.0118 ± 0.009 in)
Piston pin bore inside diameter, measured horizontally 26 mm from piston center	52.04 - 52.05 mm (2.0490 - 2.0492 in)
Piston pin running clearance	0.040 - 0.058 mm (0.0016 - 0.0023 in)

Table 53 Power Cylinders (cont.)

Piston Pins	
Outside diameter	51.992 - 52.000 mm (2.0469 - 2.0472 in)
Piston Rings — MaxxForce® 11	
Top compression ring	
Ring gap	0.4 - 0.55 mm (0.0157 - 0.0217 in)
Taper face compression ring	
Ring gap	1.00 - 1.20 mm (0.0393 - 0.0472 in)
Side clearance	0.09 - 0.13 mm (0.0035 - 0.0051 in)
Bevelled oil ring	
Ring gap	0.25 - 0.50 mm (0.0098 - 0.0197 in)
Side clearance	0.03 - 0.07 mm (0.0012 - 0.0028 in)
Piston Rings — MaxxForce® 13	
Top compression ring	
Ring gap	0.4 - 0.55 mm (0.0157 - 0.0217 in)
Taper face compression ring	
Ring gap	1.00 - 1.20 mm (0.0394 - 0.0472 in)
Side clearance	0.09 - 0.13 mm (0.0035 - 0.0051 in)
Bevelled oil ring	
Ring gap	0.25 - 0.50 mm (0.0098 - 0.0197 in)
Side clearance	0.05 - 0.09 mm (0.0020 - 0.0035 in)
Cylinder sleeve dimensions — MaxxForce® 11	
Sleeve protrusion	0.050 - 0.085 mm (0.0019 - 0.0033 in)
Sleeve inside diameter (bore)	120 ± 0.01 mm (4.7244 ± 0.0004 in)
Cylinder sleeve dimensions — MaxxForce® 13	
Sleeve protrusion	0.050 - 0.085 mm (0.0019 - 0.0033 in)
Sleeve inside diameter (bore)	126 ± 0.01 mm (4.9606 ± 0.0004 in)

Crankcase and Crankshaft

Table 54 Crankcase and Crankshaft

Crankshaft	
Main Bearing:	
Journal diameter	103.98 - 104.00 mm (4.0937 - 4.0945 in)
Installed bearing inside diameter	104.044 - 104.09 mm (4.0962 - 4.0980 in)
Uninstalled bearing outside diameter (free spread)	111.20 - 112.40 mm (4.3779 - 4.4252 in)
Connecting Rod Bearing:	
Journal diameter	89.98 - 90.00 mm (3.5425 - 3.5433 in)
Crankshaft end play:	
Maximum service	0.200 - 0.401 mm (0.0079 - 0.0158 in)

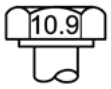
Table of Contents

General Torque....501
Bolt Identification....501
General Torque Guidelines....502
Standard Torque Charts....503
Using a Torque Wrench Extension....504

Special Torques....505
Mounting Engine on Stand....505
Engine Electrical....505
Cold Start Assist....506
Aftertreatment System....506
Exhaust Back Pressure Control....507
Turbochargers....507
Air Compressor and Power Steering/Fuel Pump....508
Fuel System....509
Oil Module Assembly....510
Exhaust Gas Recirculation (EGR) System....510
Air Inlet Duct and Exhaust Manifolds....511
Front Cover, High Mount Fan Drive, Cooling System, Related Components....511
Engine Brake....512
Cylinder Head, Camshaft and Valve Train....513
Flywheel and Flywheel Housing....514
Oil Pan and Oil Suction Tube....515
Oil Pump and Timing Gears....515
Power Cylinders....515
Crankcase and Crankshaft....516

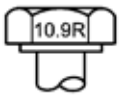
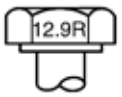
General Torque

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 674 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 675 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 lbf·in)
8	1.25	31 N·m (23 lbf·ft)
10	1.5	62 N·m (45 lbf·ft)
12	1.75	107 N·m (79 lbf·ft)
14	2	172 N·m (127 lbf·ft)
15	2	216 N·m (159 lbf·ft)
16	2	266 N·m (196 lbf·ft)
18	2.5	368 N·m (272 lbf·ft)
20	2.5	520 N·m (384 lbf·ft)

Example: Tighten four M6 x 12 pulley bolts to standard torque. What is the size and standard torque for these four bolts?

M6 x 12 refers to the bolts thread diameter and length. These bolts have a thread diameter of 6 mm and are 12 mm long.

To find the standard torque for a M6 x 12 bolt look at the torque chart above. We see the standard torque for a 6 mm thread diameter class 10.9 bolt should be 13 N·m (115 lbf·in).

Using a Torque Wrench Extension

Occasionally an extension, crowfoot, or other adapter is necessary to use with a torque wrench to torque a bolt or line fitting. Adding adapters or extensions will alter the torque on the fastener from what the torque wrench reads. Use the following formula to calculate the correct torque wrench setting to achieve a specific torque value.

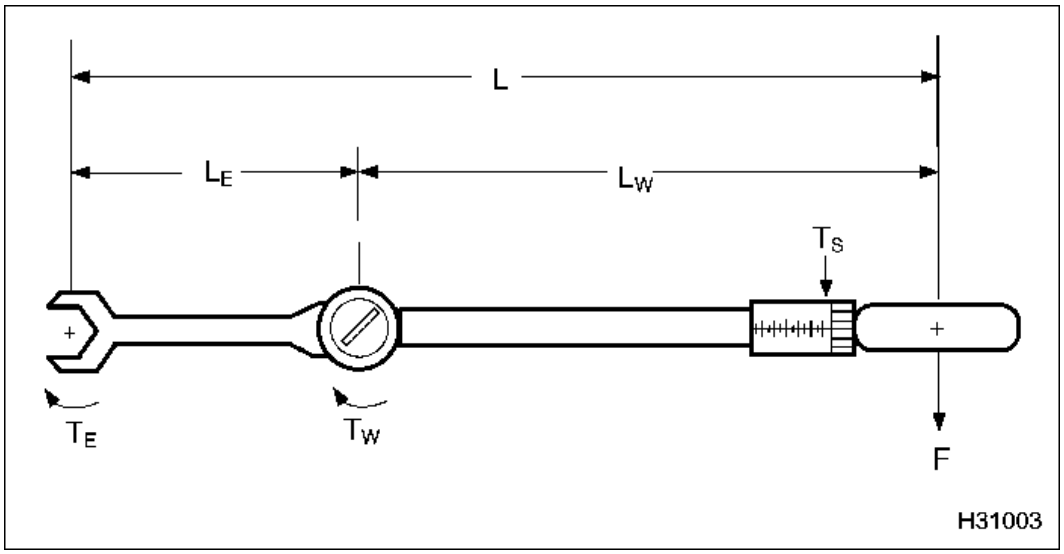


Figure 676 Torque wrench and extension

- F - Force applied by technician
- L - Total length through which force is applied to fastener
- T_W - Torque applied at end of torque wrench

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

- T_S - Torque wrench setting
- T_E - Torque specified at fastener
- L_W - Length of torque wrench
- L_E - Length of extension

Example: A component requires a specified torque value of 65 lbf·ft and a 6 inch extension is required to reach it. What should the torque wrench setting (T_S) be to compensate for the extension?

- Torque specified at fastener (T_E) = 65 lbf·ft
- Length of torque wrench (L_W) = 12 inches
- Length of extension (L_E) = 6 inches

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

T_S = 65 lbf·ft (12 inches / (12 inches + 6 inches)

T_S = 65 lbf·ft (12 inches / (18 inches)

T_S = 65 lbf·ft (0.666)

T_S = 43.33 lbf·ft

Special Torques

Mounting Engine on Stand

Table 55 Mounting Engine on Stand

M14 x 50 engine front mount support bolts	225 N·m (166 lbf·ft)
Oil drain plug	75 N·m (55 lbf·ft)

Engine Electrical

Table 56 Engine Electrical

Camshaft Position (CMP) sensor, M6 x 12 bolt	8 N·m (71 lbf·in)
Charger Air Cooler Outlet Temperature (CACOT) sensor	11 N·m (97 lbf·in)
Crankcase Oil Separator Speed (CCOSS) sensor, M6 x 14 bolt	10 N·m (89 lbf·in)
Crankshaft Position (CKP) sensor, M6 x 16 bolt	8 N·m (71 lbf·in)
Engine Control Module (ECM), M6 x 30 bolt	10 N·m (89 lbf·in) See procedure for tightening sequence
Engine Control Module (ECM) support, M8 x 40 bolt	13 N·m (115 lbf·in)
Engine Coolant Temperature 1 (ECT1) sensor	45 N·m (33 lbf·ft)
Engine Coolant Temperature 2 (ECT2) sensor	45 N·m (33 lbf·ft)
Engine injector harness retainer clip, M6 x 30 bolt	10 N·m (89 lbf·in)
Engine Oil Pressure (EOP) sensor	45 N·m (33 lbf·ft)
Engine Oil Temperature (EOT) sensor	45 N·m (33 lbf·ft)
Engine sensor harness bracket/clip, M8 x 16 bolt	35 N·m (26 lbf·ft)
Exhaust Gas Recirculation Temperature (EGRT) sensor	37 N·m (27 lbf·ft)
Fuel Delivery Pressure (FDP) sensor	45 N·m (33 lbf·ft)
Humidity / Air Inlet Temperature (AIT) sensor, M6 x 16 bolt	9 N·m (80 lbf·in)
Intake Manifold Temperature (IMT) sensor	45 N·m (33 lbf·ft)
Intake Manifold Pressure (IMP) sensor	12 N·m (106 lbf·in)
Mass Air Flow (MAF) sensor, M4 x 0.7 cap screw	0.36 N·m (3 lbf·in)
Oxygen Sensor (O2S)	50 N·m (37 lbf·ft)
Fuel Rail Pressure (FRP) sensor	70 N·m (52 lbf·ft)
Turbocharger 2 Compressor Inlet Sensor (TC2CIS), M6 x 16 bolt	9 N·m (80 lbf·in)

Cold Start Assist

Table 57 Cold Start Assist

Banjo 6 (M10 x 1) and 8 (M12 x 1.5) bolts	15 N·m (11 lbf·ft)
Banjo M8 x 1 bolt	8 N·m (71 lbf·in)
Fuel supply cold start hose fitting nut	10 N·m (11 lbf·ft)
Glow plug locking nut	25 N·m (18 lbf·ft)
Relay assembly M6 x 20 bolts	10 N·m (89 lbf·in)
Solenoid valve M6 x 20 bolts	6 N·m (53 lbf·in)

Aftertreatment System

Table 58 Aftertreatment System

Coolant supply (straight) fitting at coolant manifold	35 N·m (26 lbf·ft)
Fitting (quick-connect adapter) at metering unit valve assembly	35 N·m (26 lbf·ft)
Fitting (straight union orifice) at metering unit valve assembly	35 N·m (26 lbf·ft)
HCI coolant supply and return tube nut at tube M10 elbow fittings	15 N·m (11 lbf·ft)
HCI coolant supply tube nut at coolant manifold	25 N·m (18 lbf·ft)
HCI fuel 1 tube assembly nut at HCI fuel 2 tube fitting (brazed)	25 N·m (18 lbf·ft)
HCI fuel 1 tube assembly nut at metering unit valve assembly	25 N·m (18 lbf·ft)
HCI fuel 2 tube assembly nut at hydrocarbon injector assembly	18 N·m (13 lbf·ft)
Hydrocarbon injector assembly M8 x 45 bolt	See tightening steps in procedure.
Hydrocarbon injector assembly body to assembly (if accidentally loosened during fuel tube nut service)	20 N·m (15 lbf·ft)
Metering unit bracket bolt, M8 x 16	31 N·m (23 lbf·ft)
PDOC clamp	3 N·m (26 lbf·in)
PDOC M10 x 50 bolts	36 N·m (27 lbf·ft)
Tube M10 elbow fittings at hydrocarbon injector assembly	17.5 N·m (13 lbf·ft)

Exhaust Back Pressure Control

Table 59 Exhaust Back Pressure Control

Air supply tube (at bulkhead fitting)	17.5 N·m (13 lbf·ft)
Air supply tube nut (at air control valve)	12 N·m (106 lbf·in)
Exhaust back pressure valve tube nut (at actuator)	15 N·m (11 lbf·ft)
Exhaust back pressure valve tube nut (at air control valve)	15 N·m (11 lbf·ft)
Flare M10 x M12 (24 degree) fitting	17.5 N·m (13 lbf·ft)
TC1TOP sensor tube nut (at air control valve)	15 N·m (11 lbf·ft)
TC1TOP sensor tube nut at flare M10 x M12 (24 degree) fitting	15 N·m (11 lbf·ft)

Turbochargers

Table 60 Turbochargers

3/4 inch and 1 inch worm gear hose clamps	3.5 N·m (31 lbf·in)
High-pressure-to-low-pressure turbine bolts, M10 x 55	47 N·m (35 lbf·ft)
High-pressure wastegate actuator bolts, M8 x 14	16 N·m (12 lbf·ft)
Male stud connector	70 N·m (52 lbf·ft)
M24 threaded fitting	60 N·m (44 lbf·ft)
Oil return low-pressure turbocharger tube (at crankcase)	See tightening steps in procedure.
Oil return low-pressure turbocharger tube fitting nut	See tightening steps in procedure.
Turbocharger oil supply tube assembly fitting nut to male stud connector	27 N·m (20 lbf·ft)

Air Compressor and Power Steering/Fuel Pump

Table 61 Air Compressor and Power Steering/Fuel Pump

1-1/16" 90 degree elbow lock nut	55 N·m (40 lbf·ft)
1/2" 90 degree tube elbow lock nut	45 N·m (33 lbf·ft)
Air compressor M8 x 40, M8 x 110 bolt (one cylinder)	35 N·m (26 lbf·ft)
Air compressor M8 x 40, M8 x 110 bolt (two cylinder)	31 N·m (23 lbf·ft)
(Two cylinder) Air compressor M10 x 110 bolt	67 N·m (49 lbf·ft)
High-pressure tube fitting nut	62 N·m (45 lbf·ft)
M16 straight fitting	35 N·m (26 lbf·ft)
M16 45° fitting	17.5 N·m (13 lbf·ft)
M18 straight fitting	37.5 N·m (28 lbf·ft)
Low-pressure tube fitting nut	164 N·m (120 lbf·ft)
Power steering pump M10 x 40 bolt	67 N·m (49 lbf·ft)

Fuel System

Table 62 Fuel System

Banjo bolt, M14	30 N·m (22 lbf·ft)
Check valve	35 N·m (26 lbf·ft)
Forcing screw adapter plate M10 x 40 bolts	27 N·m (20 lbf·ft)
Fuel drain line fitting nut	26 N·m (19 lbf·ft)
Fuel filter bracket M8 x 30 bolt	35 N·m (26 lbf·ft)
Fuel filter housing assembly M8 x 45 bolt	35 N·m (26 lbf·ft)
Fuel filter cap	25 N·m (18 lbf·ft)
Fuel filter stand pipe	12 N·m (106 lbf·in)
Fuel primer pump assembly M8 x 25 bolt	30 N·m (22 lbf·ft)
Fuel rail M8 x 40 bolt	35 N·m (26 lbf·ft)
Fuel strainer cover	10 N·m (89 lbf·in)
Fuel supply adapter	30 N·m (22 lbf·ft)
Fuel to rail supply clamp assembly screws	5 N·m (44 lbf·in)
High-pressure connector (body) retaining nut	See tightening steps in procedure
High-pressure fuel pump drive housing M12 x 40, M12 x 90, M12 x 130 bolt	105 N·m (77 lbf·ft)
High-pressure fuel pump M10 x 40 bolt	62 N·m (46 lbf·ft)
High-pressure fuel pump M24 jam nut	285 N·m (210 lbf·ft)
High-pressure fuel pump support M14 x 30 bolt	172 N·m (126 lbf·ft)
High-pressure pump to rail tube assembly line fitting nuts	See tightening steps in procedure
High-pressure rail to injector line fitting nut	See tightening steps in procedure
High-pressure pump pulley housing M10 x 40 bolt	62 N·m (46 lbf·ft)
High-pressure pump pulley M16 x 40 LH bolt	280 N·m (207 lbf·ft)
Holding plate M12 bolts	47 N·m (35 lbf·ft)
Injector harness nut	1.5 N·m (13 lbf·in)
Injector hold-down clamp M8 x 50 bolt	See tightening steps in procedure
Pressure limiting valve	110 N·m (81 lbf·ft)
Quick-connect M16 x 1.5 connector	30 N·m (22 lbf·ft)
Threaded unions (M14 x 1.5)	30 N·m (22 lbf·ft)

Oil Module Assembly

Table 63 Oil Module Assembly

Heater return tube assembly bolt, M6 x 16	13 N·m (115 lbf·in)
Heater return tube assembly tube nut	11 N·m (97 lbf·in)
Oil cooler bolts, M8 x 45 and M8 x 90	25 N·m (18 lbf·ft)
Oil filter cover	40 N·m (30 lbf·ft)
Oil module assembly bolts, M10 x 80, M10 x 170 and M10 x 110	65 N·m (48 lbf·ft)
Oil module flange bolts, M8 x 45	24 N·m (18 lbf·ft)
Oil pressure relief valve	40 N·m (30 lbf·ft)
Open breather tube assembly bolt, M6 x 16	13 N·m (115 lbf·in)
Water pump bolt, M8 x 150 (front side of oil module)	35 N·m (26 lbf·ft)

Exhaust Gas Recirculation (EGR) System

Table 64 EGR System

Coolant manifold, M8 x 18 bolt	22 N·m (16 lbf·ft)
Coolant manifold, M8 x 25 heat–resistant bolt	24 N·m (18 lbf·ft)
Coolant manifold, M8 x 45 bolt and M8 x 50 x 16 stud bolt	35 N·m (26 lbf·ft)
EGR dual flap valve, M8 x 30 heat-resistant bolt	See tightening steps in procedure.
EGR inlet (cylinders 1-3) tube, M8 x 25 heat-resistant bolt	See tightening steps in procedure.
EGR inlet (cylinders 4-6) tube, M8 x 25 heat-resistant bolt	See tightening steps in procedure.
EGR module cover, M8 x 85 bolts and M8 x 90 stud bolt	24 N·m (18 lbf·ft)
EGR outlet tube hose clamps	5 N·m (45 lbf·in)
EGR valve coolant supply tube nut	26 N·m (19 lbf·ft)
Front EGR cooler cleaning adapter M8 bolts	24 N·m (18 lbf·ft)
Heat protection (cylinders 4–6) shield, M8 x 25 heat–resistant bolts	24 N·m (18 lbf·ft)
HT EGR cooler mounting studs 7/16 - 14 nuts	41 N·m (30 lbf·ft)
Leak Detection Plate KL20060-4 M8 x 30 bolts	24 N·m (18 lbf·ft)
Low-temperature and high-temperature EGR coolers, M8 x 55 hex socket screws	See tightening steps in procedure.
LT EGR cooler mounting studs 3/8 - 14 nuts	41 N·m (30 lbf·ft)
Rear EGR cooler cleaning adapter M8 bolts	24 N·m (18 lbf·ft)

Air Inlet Duct and Exhaust Manifolds

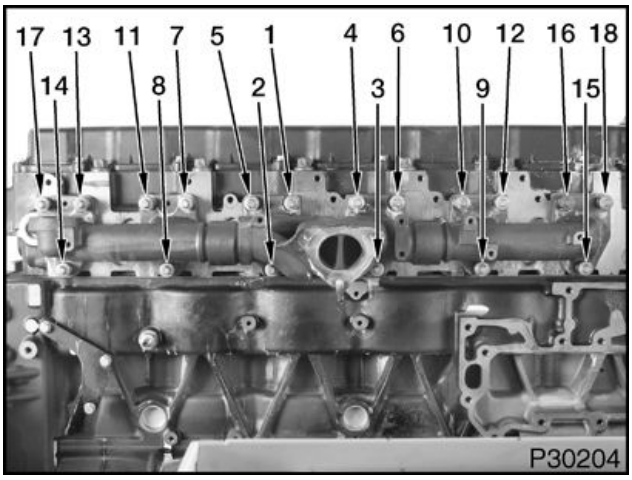


Figure 677 Exhaust manifold tightening sequence

Table 65 Air Intake Throttle Duct and Exhaust Manifolds

Air intake throttle duct bolts, M8	31 N·m (23 lbf·ft)
Exhaust manifold Torx® bolts, M10 x 57	See tightening procedure and sequence in steps

Front Cover, High Mount Fan Drive, Cooling System, Related Components

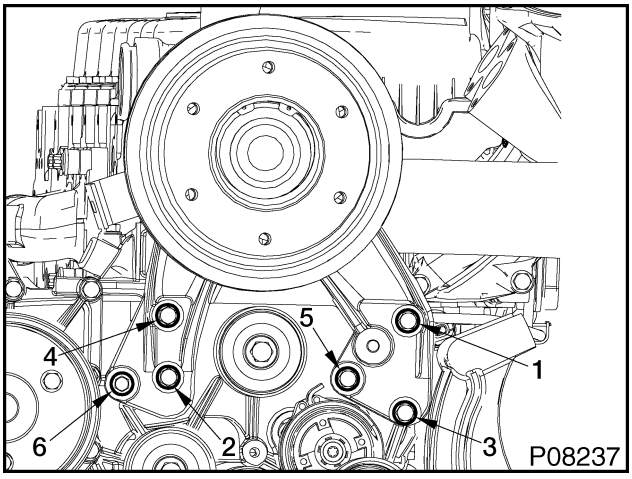


Figure 678 High mount fan drive bolt tightening sequence

Table 66 Front Cover, Fan Drive, Cooling System and Related Components

Automatic belt tensioner countersunk screw, M10 x 70	47 N·m (35 lbf·ft)
CCV assembly stud bolts (with lock washers), M8 x 60	35 N·m (26 lbf·ft)
Coolant heater	41 N·m (30 lbf·ft)
Coolant outlet manifold bolts, M8	35 N·m (26 lbf·ft)
Damper hub and fan drive pulley bolts to vibration damper, M10 x 35	45 N·m (33 lbf·ft)
EGR cooler return manifold bolts, M8	35 N·m (26 lbf·ft)
Engine water inlet bolts, M10 x 30	29 N·m (21 lbf·ft)
Front belt- or gear-driven fan cover bolts,	
• M8	31 N·m (23 lbf·ft)
• M12 x 75	115 N·m (85 lbf·ft)
• M12 x 30	115 N·m (85 lbf·ft)
High mount fan drive clutch assembly bolts, M10	See tightening steps in procedure
High mount fan drive tensioner countersunk screw, M10 x 70	47 N·m (35 lbf·ft)
High mount fan pulley assembly shoulder bolt	62 N·m (46 lbf·ft)
Idler pulley bolt, M12 x 55	60 N·m (44 lbf·ft)
Low mount fan drive bolt, M10 x 110	37 N·m (27 lbf·ft)
Vibration damper socket-head cap screws, M16 x 85	See tightening steps in procedure
Water distribution housing bolts, M8	35 N·m (26 lbf·ft)
Water pump assembly bolts, M8	35 N·m (26 lbf·ft)
Water pump pulley bolts, M8 x 16	17 N·m (13 lbf·ft)

Engine Brake

Table 67 Engine Brake

Brake housing M10 x 90 bolt	75 N·m (55 lbf·ft)
Brake housing M12 x 100 (socket-head) screw	105 N·m (77 lbf-ft)
Brake housing solenoid harness connector nut	3.5 N·m (31 lbf·in)
Slave piston adjusting screw M10 (jam) nut	25 N·m (18 lbf·ft)
Solenoid M6 x 10 socket-head cap screw	12.5 N·m (110 lbf·in)

Cylinder Head, Camshaft and Valve Train

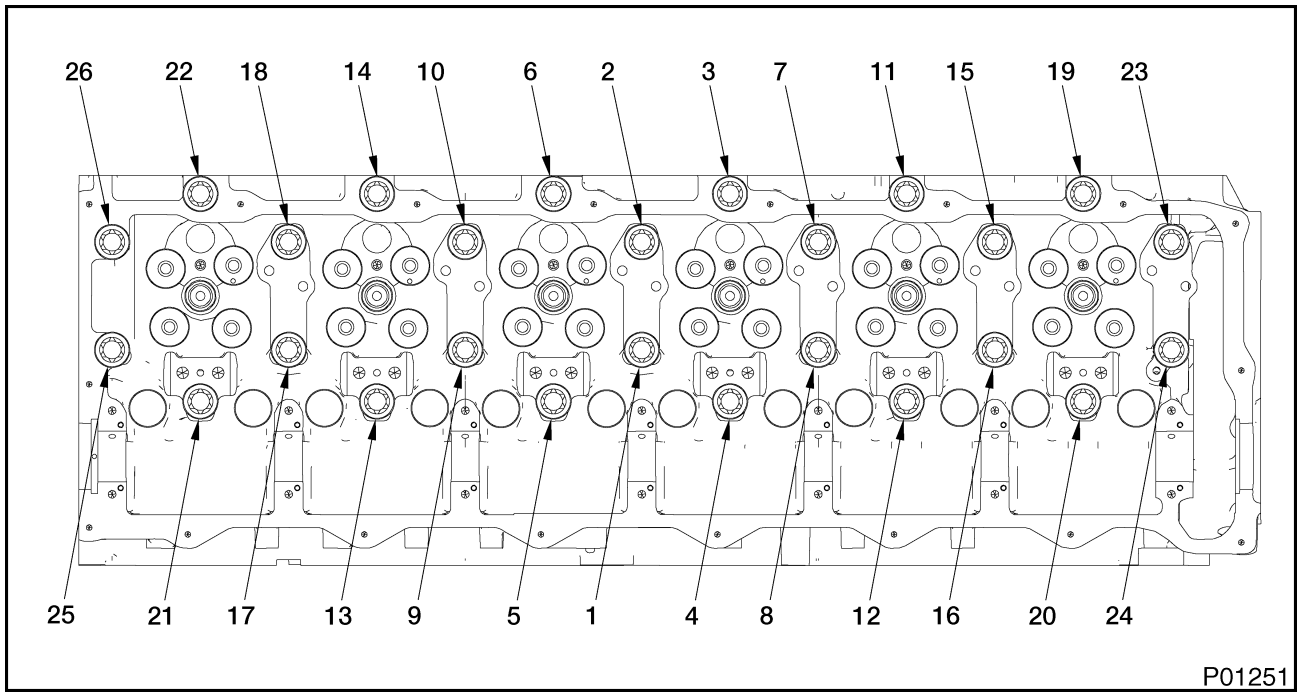


Figure 679 Cylinder head bolts tightening sequence

Table 68 Cylinder Head, Camshaft and Valve Train

Camshaft gear M8 x 30 bolt	See tightening steps in procedure
(Camshaft) bearing cap M8 x 35 bolt	25 N·m (18 lbf·ft)
Cylinder head idler gear M8 x 30 socket-head cap screw	30 N·m (22 lbf·ft)
Cylinder head M18 x 246 Torx® bolt	See tightening steps in procedure
Rocker arm assembly M12 x 60 (socket-head) screw	105 N·m (77 lbf·ft)
Upper valve cover M8 x 30 bolt	10 N·m (89 lbf·in)
Valve cover base screw with damper	11 N·m (97 lbf·in)
Valve lash adjustment M10 nut	45 N·m (33 lbf·ft)

Flywheel and Flywheel Housing

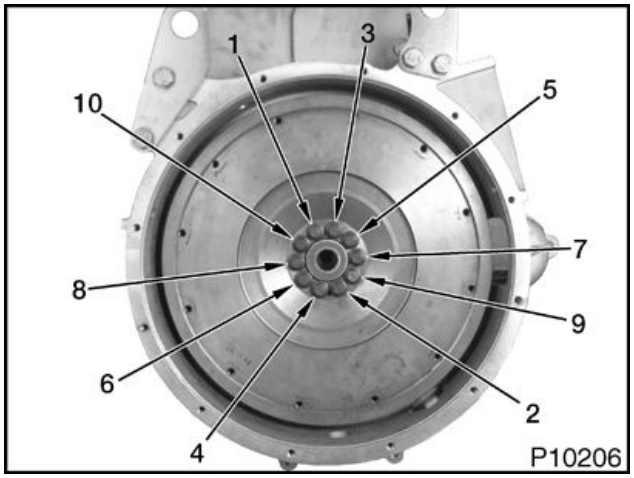


Figure 680 Flywheel bolt tightening sequence

Table 69 Flywheel and Flywheel Housing

12PT flange bolts	See tightening steps in procedure.
Flywheel housing bolts, M10 x 30 and M10 x 40	65 N·m (48 lbf·ft)
Lifting eye bolts, M16 x 150	280 N·m (207 lbf·ft)
Timing hole cover screws	2 N·m (18 lbf·in)

Oil Pan and Oil Suction Tube

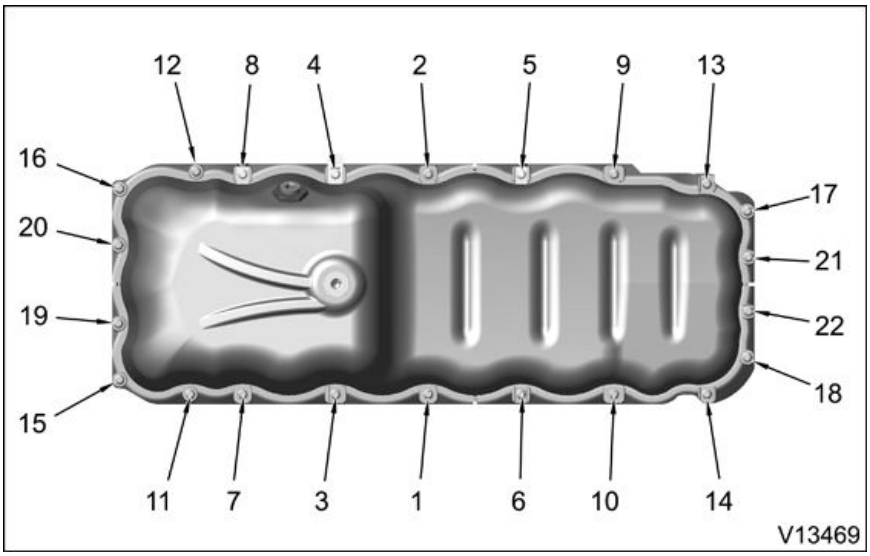


Figure 681 Torque sequence

Table 70 Oil Pan Components

Drain plug, M27 x 2	75 N·m (55 lbf·ft)
Oil pan bolts, M8 x 40	See tightening steps in procedure.
Oil pan heater element or replacement drain plug	75 N·m (55 lbf·ft)

Oil Pump and Timing Gears

Table 71 Oil Pump and Timing Gears

Air compressor coupled idler gear, M12 x 55 bolts	107 N·m (79 lbf·ft)
Axle for pinion (oil pump), M10 x 35 socket-head cap screw	65 N·m (48 lbf·ft)
Crankcase idler gear, M8 x 30 socket-head cap screws	30 N·m (22 lbf·ft)
(Front) idler gear, M12 x 50 socket-head cap screws	105 N·m (77 lbf·ft)
Idler large gear, M14 x 80 bolts	175 N·m (129 lbf·ft)

Power Cylinders

Table 72 Power Cylinders

Connecting rod bolts	See tightening steps in procedure
Sleeve Protrusion Hold Down Clamp bolts	80 N·m (59 lbf·ft)

Crankcase and Crankshaft

Table 73 Crankcase and Crankshaft

Collar bolts (main bearing cap), M18 x 160.5	See tightening procedure and sequence (page 471)
Piston cooling jet bolts, M6 x 12	13 N·m (115 lbf·in)

Table of Contents

Special Tools.....519
- **Contact Information**.....519
- **Mounting Engine on Stand**.....519
- **Engine Electrical**.....519
- **Aftertreatment System**.....519
- **Exhaust Back Pressure Control**.....519
- **Turbochargers**.....520
- **Air Compressor and Power Steering**.....520
- **Fuel System**.....521
- **Oil Cooler, Filter Housing and Crankcase Ventilation**.....521
- **Exhaust Gas Recirculation (EGR) System**.....522
- **Air Inlet Throttle Duct and Exhaust Manifold**.....522
- **Front Cover, Fan Drive, Cooling System and Related Components**.....522
- **MaxxForce Engine Brake by Jacobs**.....522
- **Cylinder Head, Camshaft and Valve Train**.....523
- **Flywheel and Flywheel Housing**.....523
- **Oil Pump, Fan Drive and Timing Gears**.....524
- **Power Cylinders**.....524
- **Crankcase and Crankshaft**.....524

Special Tools.....525
- **Essential Tools**.....525

Special Tools

Contact Information

For concerns or ordering information regarding special tools for the MaxxForce® 11 or MaxxForce® 13 engines, refer to the Service Resource Center on Service Portal, or call 1-800-365-0088.

Mounting Engine on Stand

Table 74 Mounting Engine on Stand

Description	Tool Number
Disposable Air and Fuel Caps	ZTSE4891
Engine Stand Adapter Plate	ZTSE4789

Engine Electrical

Table 75 Engine Electrical

Description	Tool Number
Disposable Air and Fuel Caps	ZTSE4891

Aftertreatment System

Table 76 Aftertreatment System

Description	Tool Number
Fuel Line Disconnect Tool 11.8 mm	ZTSE4773
P-80® rubber lubricant or equivalent	Obtain locally

Exhaust Back Pressure Control

Table 77 Exhaust Back Pressure Control

Description	Tool Number
Crimping pliers	Obtain locally
Superlub™ synthetic high heat lubricant	Obtain locally

Turbochargers

Table 78 Turbochargers

Description	Tool Number
3-inch couplers and clamps	Obtain locally
Charge Air Cooler Test Kit	ZTSE6042
Crimping pliers	Obtain locally
Extension Tube Installer	ZTSE6043
P-80® rubber lubricant or equivalent	Obtain locally
Turbo Alignment Bracket	ZTSE6041

Air Compressor and Power Steering

Table 79 Air Compressor and Power Steering

Description	Tool Number
Coolant Line Release Tool	ZTSE4778
Loctite® 5900 sealant or Wacker® A-442 RTV	Obtain locally
P80® rubber lubricant or equivalent	Obtain locally

Fuel System

Table 80 Fuel System

Description	Tool Number
Crowfoot wrench	Obtain locally
Disposable Air and Fuel Caps	ZTSE4891
Fan Hub/High Pressure Drive Seal Installer	ZTSE6066
Forcing Screw	12-454-01-05
Forcing Screw Adapter	12-454-01-04
Forcing Screw Adapter Holding Plate	12-454-01-01
Fuel Injector Cups	ZTSE4892
Fuel Injector Rack Holder	ZTSE4299B
Fuel Injector Tip Cleaning Brush	ZTSE4301
Fuel Line Disconnect Tool 11.8 mm	ZTSE4773
Fuel System Priming Tool	15-922-01
Guide Stud	12-454-01-02
High-Pressure Pump Removal Tool	12-454-01
Holding Plate	ZTSE6440
Injector Installer	ZTSE4777
Injector Puller	ZTSE4770
Injector Sleeve Brushes	ZTSE4751
P80® Rubber Lubricant or equivalent	Obtain locally
Socket Head Bolt	12-454-01-03
Wacker® A-442 RTV sealant or equivalent	Obtain locally
Slide hammer	Obtain locally

Oil Cooler, Filter Housing and Crankcase Ventilation

Table 81 Oil Cooler, Filter Housing and Crankcase Ventilation

Description	Tool Number
Air pressure regulator	Obtain locally
Extension Tube Installer Large	ZTSE6051-1
Extension Tube Installer Small	ZTSE6051-2
Engine Oil Cooler Pressure Test Plate	ZTSE6063
P-80® rubber lubricant or equivalent	Obtain locally

Exhaust Gas Recirculation (EGR) System

Table 82 EGR System

Description	Tool Number
Cleaning Management System	12-353-01
Coolant Management Tool	KL5007NAV
EGR Cooler Alignment Tool	12-892-01A
Exhaust Gas Recirculation (EGR) Cooler Leak Detection Tool	KL 20060 NAV
Extension Tube Installer Large	ZTSE6046
Extension Tube Installer Small	ZTSE6047
P-80® rubber lubricant or equivalent	Obtain locally

Air Inlet Throttle Duct and Exhaust Manifold

Table 83 Air Inlet Throttle Duct and Exhaust Manifold

Description	Tool Number
Feeler gauge	Obtain locally
FEY Rings Installation Tools	ZTSE6030
Straightedge	Obtain locally
Wacker® A-442 RTV sealant or equivalent	Obtain locally

Front Cover, Fan Drive, Cooling System and Related Components

Table 84 Front Cover, Fan Drive, Cooling System and Related Components

Description	Tool Number
Extension Tube Installer Large	ZTSE6046
Extension Tube Installer Small	ZTSE6047
Fan Seal Installer	ZTSE6066
Front Crankshaft Seal Installer	ZTSE4873
P-80® rubber lubricant or equivalent	Obtain locally
Slide hammer	Obtain locally

MaxxForce Engine Brake by Jacobs

Table 85 MaxxForce Engine Brake by Jacobs

Description	Tool Number
Jacobs® Slave Piston Removal Tool	ZTSE6068

Cylinder Head, Camshaft and Valve Train

Table 86 Cylinder Head, Camshaft and Valve Train

Description	Tool Number
1 - 2 inch micrometer	Obtain locally
Bearing installer	Obtain locally
Connecting Rod Bolt Torx® Socket	ZTSE4835
Cylinder Head Lifting Bracket	ZTSE4869
Dial indicator with magnetic base	Obtain locally
Feeler gauge (standard)	Obtain locally
Feeler gauge (Jacobs® 96-020949)	Obtain from Jacobs
Head Bolt Bottoming Tap	ZTSE4855
Head Bolt Torx® Socket	ZTSE4787
Injector Sleeve Brushes	ZTSE4751
Lash Gauge 0.5 mm (0.020 in)	ZTSE6076-5
Lash Gauge 0.8 mm (0.031 in)	ZTSE6076-7
Loctite® 262™ Threadlocker	Obtain locally
Loctite® 5900 sealant or equivalent	Obtain locally
M8 x 20 class 10.9 bolts	Obtain locally
Telescoping gauge set	Obtain locally

Flywheel and Flywheel Housing

Table 87 Flywheel and Flywheel Housing

Description	Tool Number
1-2 inch micrometer	Obtain locally
Blind hole puller	Obtain locally
Brake cleaner (non-caustic)	Obtain locally
Dial indicator with magnetic base	Obtain locally
Loctite 5900®	Obtain locally
Wacker® A–442 RTV sealant	Obtain locally
Pilot Bearing Installation Tool	ZTSE4898
Rear Oil Seal Installer	ZTSE4875
Slide hammer	Obtain locally

Oil Pump, Fan Drive and Timing Gears

Table 88 Oil Pump, Fan Drive and Timing Gears

Description	Tool Number
Dial indicator with magnetic base	Obtain locally
Feeler gauge	Obtain locally
Gear puller	Obtain locally

Power Cylinders

Table 89 Power Cylinders

Description	Tool Number
2 - 3 inch micrometer	Obtain locally
3 - 4 inch micrometer	Obtain locally
4 - 5 inch micrometer	Obtain locally
Cylinder Sleeve Puller	ZTSE2536
Dial bore gauge	Obtain locally
Dial indicator with magnetic base	Obtain locally
Exhaust Manifold Bolt Torx® Socket	ZTSE4843
Feeler gauge	Obtain locally
Piston ring compressor	Obtain locally
Piston ring expansion pliers	Obtain locally
Sleeve Protrusion Hold Down Clamps	ZTSE4825
Telescoping gauge	Obtain locally

Crankcase and Crankshaft

Table 90 Crankcase and Crankshaft

Description	Tool Number
3 - 4 inch micrometer	Obtain locally
4 - 5 inch micrometer	Obtain locally
Dial bore gauge	Obtain locally
Dial indicator with magnetic base	Obtain locally
Head Bolt Bottoming Tap	ZTSE4855
Lifting sling	Obtain locally
Main Bolt Bottoming Tap	ZTSE4854

Special Tools

Essential Tools

Figure 682 KL 20060 NAV EGR Cooler Pressure Test Kit

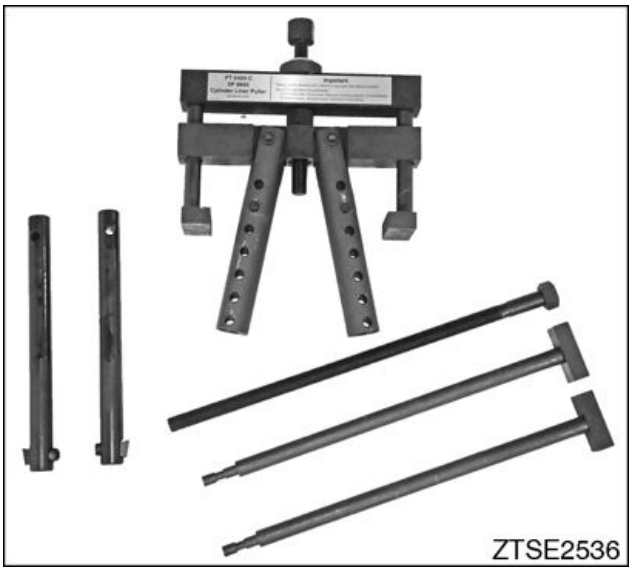


Figure 683 ZTSE2536 Cylinder Sleeve Puller

Figure 684 ZTSE4299B Fuel Injector Rack Holder

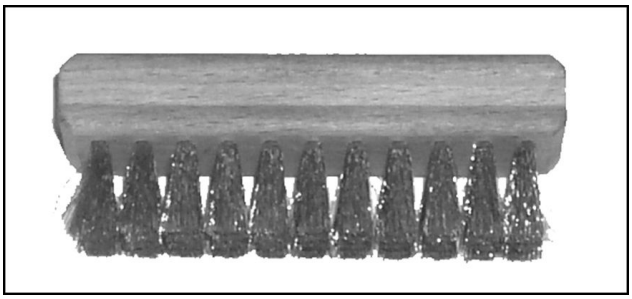


Figure 685 ZTSE4301 Fuel Injector Tip Cleaning Brush

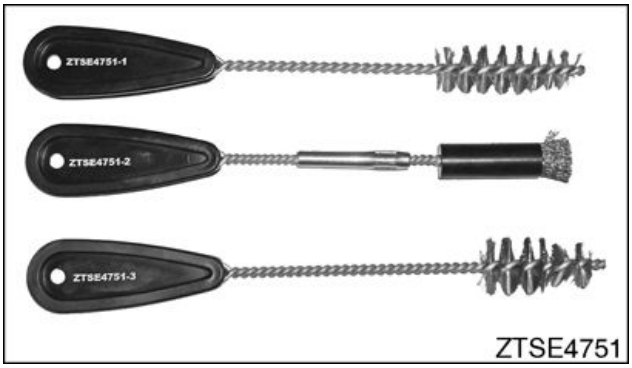


Figure 686 ZTSE4751 Injector Sleeve Brushes

Figure 687 ZTSE4770 injector puller

Figure 689 ZTSE4777 injector installer

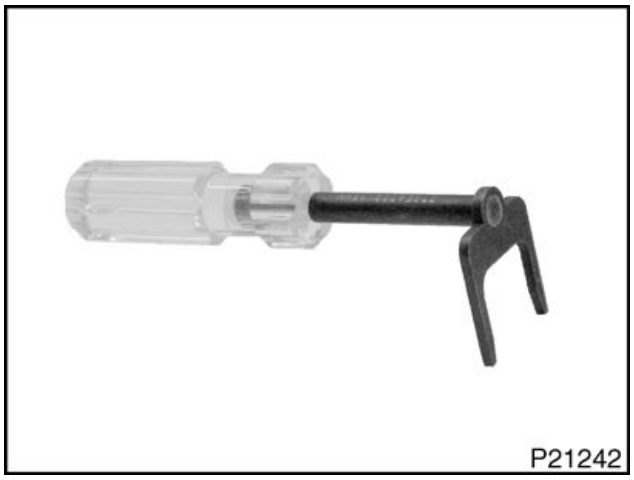


Figure 688 ZTSE4773 fuel line disconnect tool 11.8 mm

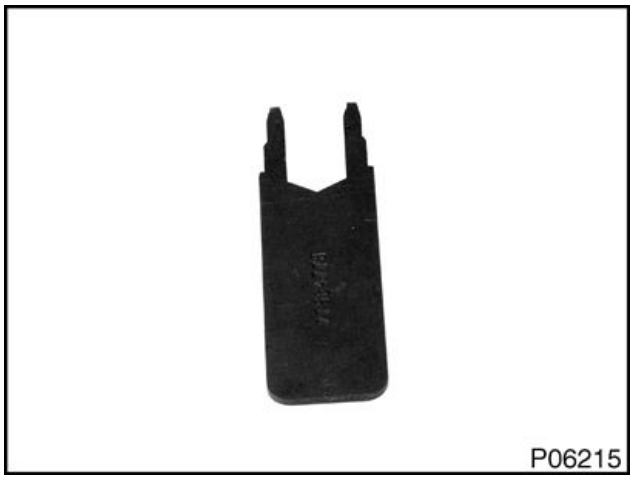


Figure 690 ZTSE4778 coolant line release tool

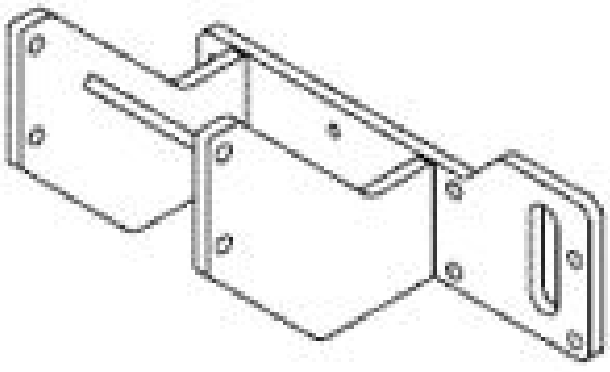


Figure 691 ZTSE4789 Engine Stand Adapter Plate

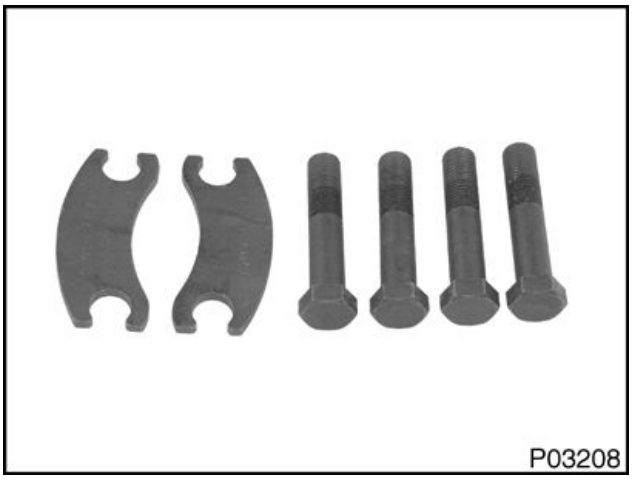


Figure 692 ZTSE4825 Sleeve Protrusion Hold Down Clamps

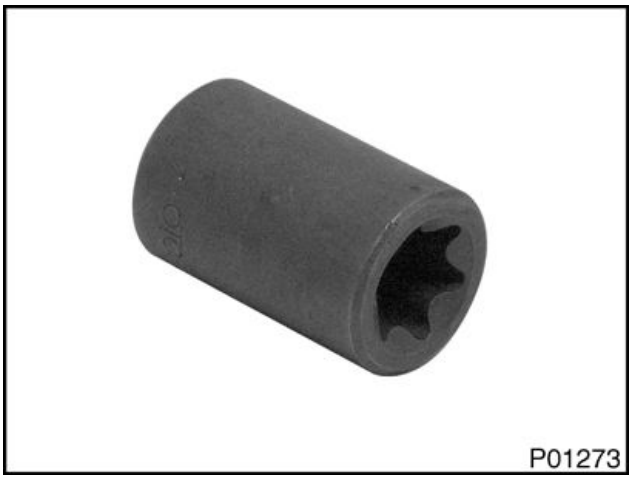


Figure 694 ZTSE4843 Exhaust Manifold Bolt Torx® Socket

Figure 693 ZTSE4787 Head Bolt Torx® Socket (E24)

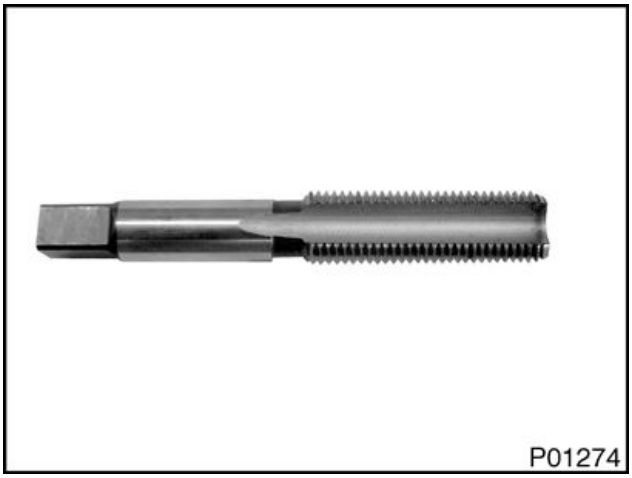


Figure 695 ZTSE4854 Main Bolt Bottoming Tap

Figure 696 ZTSE4855 Head Bolt Bottoming Tap

Figure 698 ZTSE4873 Front Crankshaft Seal Installer

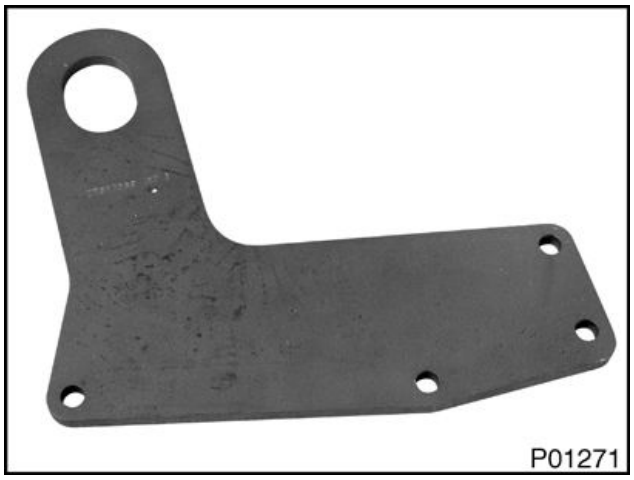


Figure 697 ZTSE4869 Cylinder Head Lifting Bracket

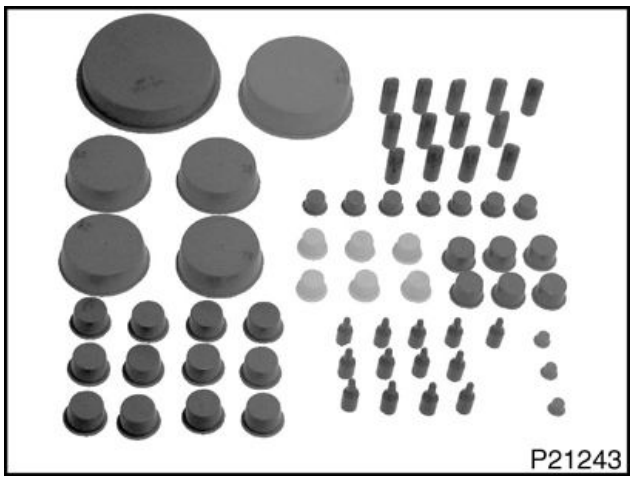


Figure 699 ZTSE4891 Disposable Air and Fuel Caps

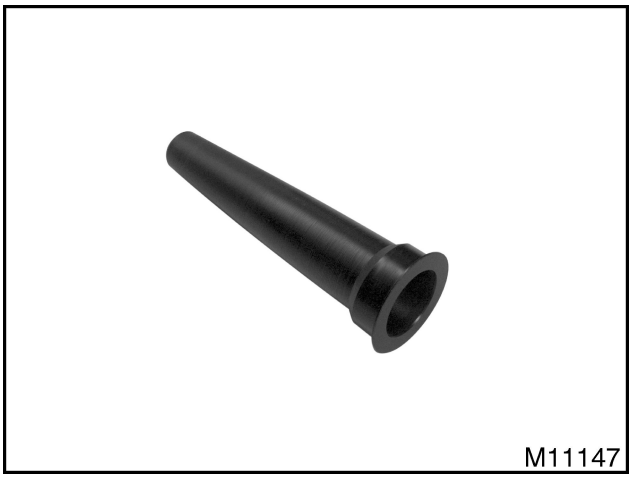


Figure 700 ZTSE4892 Fuel Injector Caps (6)

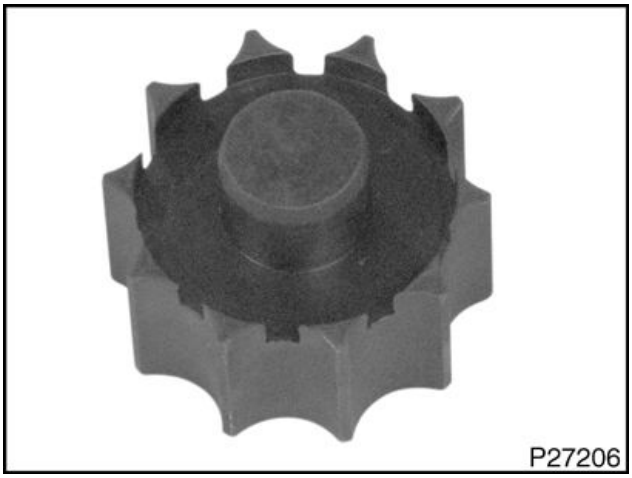


Figure 701 ZTSE4898 Pilot Bearing Installation Tool

Figure 702 ZTSE6030 FEY Rings Installation Tools

Figure 703 ZTSE6042 Charger Air Cooler Test Kit

Figure 704 ZTSE6043 Extension Tube Installer

Figure 705 ZTSE6046 Extension Tube Installer Large

Figure 706 ZTSE6047 Extension Tube Installer Small

Figure 707 ZTSE6051–1 Extension Tube Installer Large

Figure 708 ZTSE6051–2 Extension Tube Installer Small

Figure 709 ZTSE6063 Engine Oil Cooler Pressure Test Plate

Figure 710 ZTSE6066 Fan Hub/High Pressure Drive Seal Installer

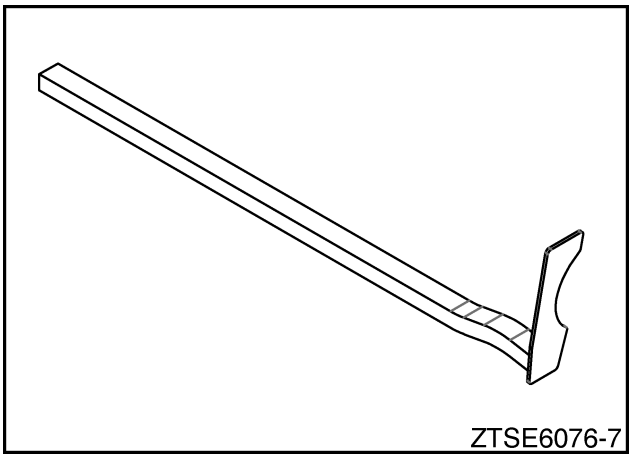


Figure 711 ZTSE6076–5 Lash Gauge

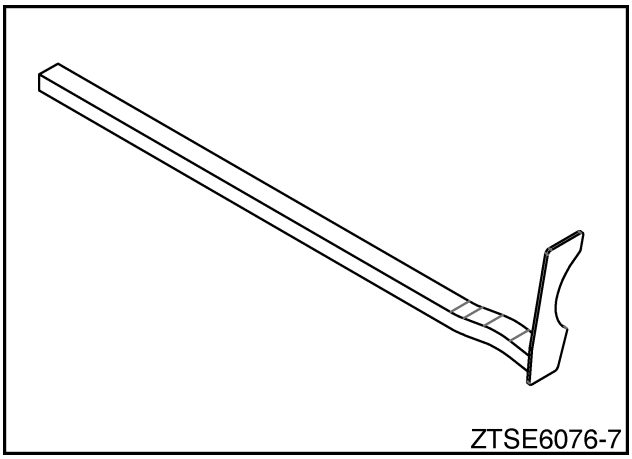


Figure 712 ZTSE6076–7 Lash Gauge

Figure 713 15-922-01 Fuel System Priming Tool