ENGINE SERVICE MANUAL

MaxxForce® DT, 9, and 10

Navistar, Inc.

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Foreword

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

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

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

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

MaxxForce® DT, 9, and 10 *Engine Operations and Maintenance Manual*

MaxxForce® DT, 9, and 10 *Engine Service Manual*

MaxxForce® DT, 9, and 10 *Engine Diagnostic Manual*

MaxxForce®*Diagnostic Form*

MaxxForce® *Electronic Control System Form*

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

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

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Engine Identification

Engine Serial Number

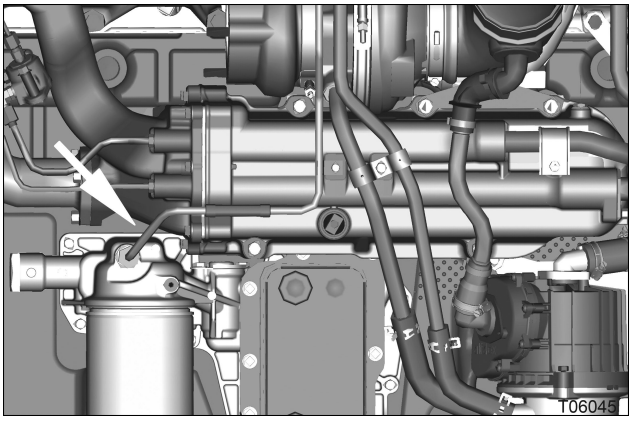


Figure 1 Engine Serial Number

The engine serial number is in two locations:

- Stamped on the right side of the crankcase, just above the oil filter header
- On the engine emission label on the valve cover

Engine Serial Number Examples

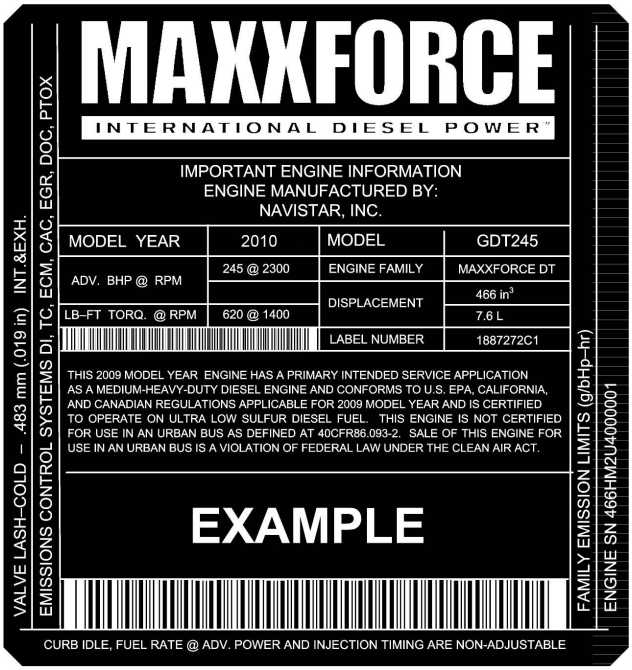
MaxxForce® DT: 466HM2UXXXXXXX

MaxxForce® 9 and 10: 570HM2UXXXXXXX

Engine Serial Number Codes

466 – Engine displacement
570 – Engine displacement
H – Diesel, turbocharged, Charge Air Cooler (CAC) and electronically controlled
M2 – Motor truck
U – United States
7 digit suffix – Engine serial number sequence beginning with 3300001

Engine Emission Label



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

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

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

Engine Accessory Labels

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

- Air compressor
- Air conditioning compressor
- Alternator

- Cooling fan clutch
- Power steering pump
- Starter motor

Engine Description

MaxxForce® DT, 9, and 10 Diesel Engines	
Engine configuration	4 stroke, inline six cylinder diesel
MaxxForce® DT displacement	7.6 L (466 in^3)
MaxxForce® 9 and 10 displacement	9.3 L (570 in^3)
Bore (sleeve diameter)	116.6 mm (4.59 in)
Stroke	
• MaxxForce® DT	119 mm (4.68 in)
• MaxxForce® 9 and 10	146 mm (5.75 in)
Compression ratio	
• MaxxForce® DT	16.9 : 1
• MaxxForce® 9 and 10	16.5 : 1
Aspiration	Dual turbocharged and charge air cooled
Advertised brake horsepower @ rpm	See EPA exhaust emission label.
Peak torque @ rpm	See EPA exhaust emission label.
Engine rotation (facing flywheel)	Counterclockwise
Combustion system	Direct injection turbocharged
Fuel system	Electro-hydraulic injection
Total engine weight (oil and accessories)	
• MaxxForce® DT	824 kg (1816 lbs)
• MaxxForce® 9 and 10	845 kg (1864 lbs)
Cooling system capacity (engine only)	12.8 L (13.5 qts US)
Lube system capacity (including filter)	28 L (30 qts US)
Lube system capacity (overhaul only, with filter)	32 L (34 qts US)
Firing order	1-5-3-6-2-4

Standard Features

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

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

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

MaxxForce® DT engines use one-piece aluminum alloy pistons. MaxxForce® 9 and 10 engines use one-piece steel pistons. All pistons have zero pin offset and centered combustion bowls; therefore, pistons can be installed safely without orientation: there is NO front-of-engine arrow or “CAMSIDE” marking on the piston crown to indicate a necessary piston direction.

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

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

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

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

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

The WIF sensor detects water in the fuel system. When water reaches the level of the sensor located in the fuel filter assembly, the instrument panel's amber FUEL FILTER lamp will illuminate. The collected water must be removed immediately. Water is drained by opening the drain valve on the fuel filter assembly.

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

MaxxForce® DT, 9, and 10 engines use dual turbochargers with an air-to-air High Pressure Charge Air Cooler (HPCAC) after the second stage. An interstage cooler is used after the first stage for applications with 245 hp and above.

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

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

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

The Down Stream Injection (DSI) system aides in controlling emissions by injecting fuel into the exhaust stream. The fuel causes an exothermic reaction which increases the temperature of the exhaust gas. This increase in temperature allows for more efficient conversion of soot into ash within the Diesel Particulate Filter (DPF). Along with DSI, the Diesel Oxidation Catalyst (DOC) aids in creating the required exothermic reaction. DSI consists of the Doser Control Unit (DCU), Downstream Injection

(DSI) assembly, hydrocarbon injector assembly, fuel lines, and coolant lines. The Electronic Control Module (ECM) communicates with the DCU to control the timing and quantity of fuel sprayed from the hydrocarbon injector assembly. The ECM signals the exhaust brake valve assembly to control the position of the exhaust back pressure valve to increase or decrease the exhaust gas back pressure and temperature to allow the DOC and DPF to function efficiently.

The exhaust back pressure valve acts as an aftertreatment device to manage exhaust temperature. The resulting rise in back pressure, increases exhaust temperature.

Optional Features

Optional features include the following:

- Air compressor
- Hydraulic pump
- Engine brake
- Exhaust brake

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

A hydraulic power steering pump can be used with or without the air compressor.

Engine brake and exhaust brake systems are available for applications that could benefit from added speed reduction capability.

Optional Cold Climate Features

Optional cold climate features include the following:

- Oil pan heater
- Coolant heater
- Fuel heater

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

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

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

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

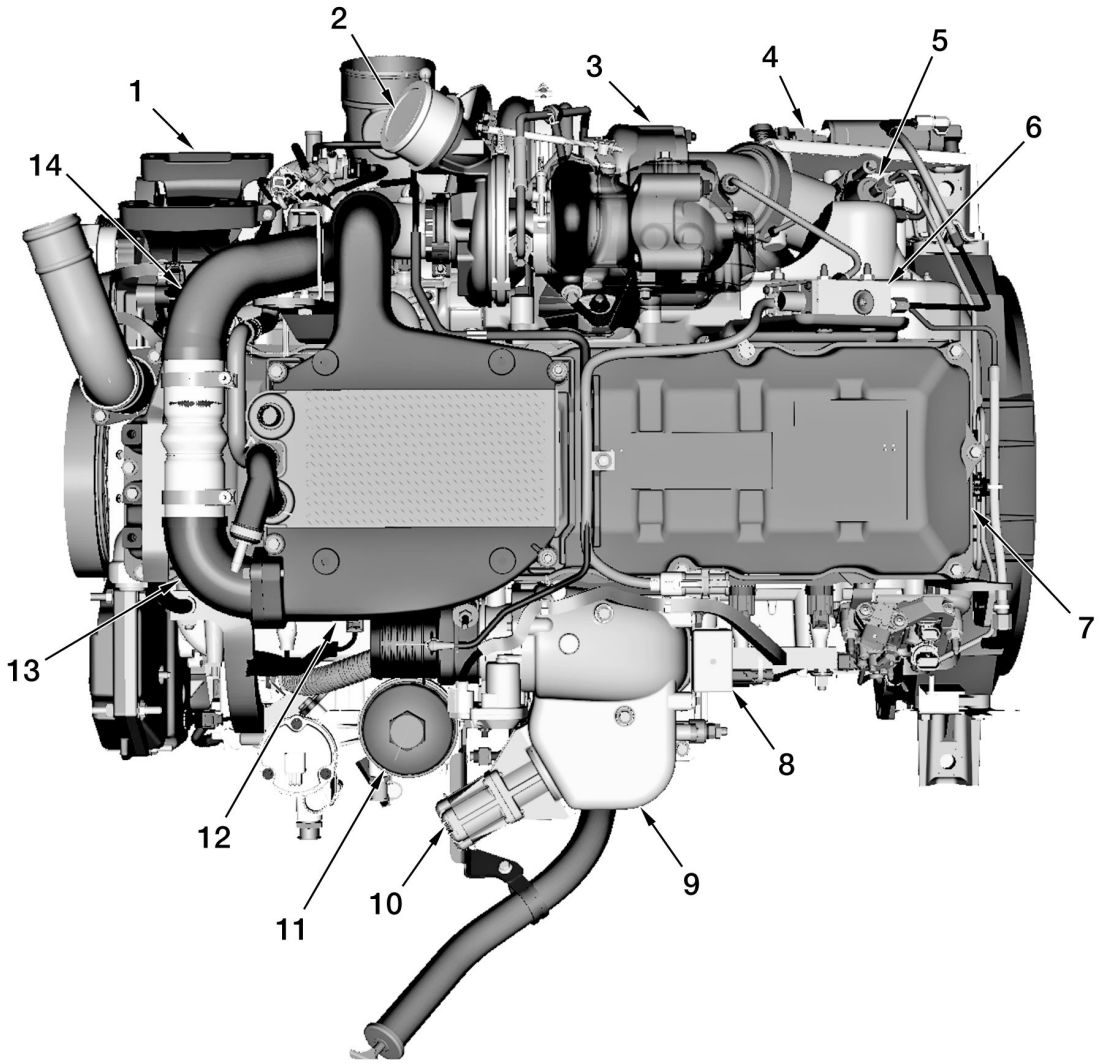
Chassis Mounted Features

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

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

- The Pre-Diesel Oxidation Catalyst (PDOC) aids in creating the required exothermic reaction before the exhaust gas enters the Diesel Oxidation Catalyst (DOC).
- The Diesel Oxidation Catalyst (DOC) oxidizes carbon monoxide, hydrocarbons, and small amounts of nitrogen oxide in the exhaust stream.
- The Diesel Particulate Filter (DPF) captures and oxidizes particulates in the exhaust stream and stores non-combustible ash.

Engine Component Locations (245 hp and above)



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Figure 3 Component Location – Top

1. Alternator bracket
2. High-pressure turbocharger outlet
3. Low-pressure turbocharger
4. Exhaust back pressure valve
5. Hydrocarbon injector assembly
6. Exhaust brake valve assembly
7. Valve cover
8. Intake Air Heater (IAH) relay assembly
9. Air and EGR mixer duct
10. EGR valve
11. Fuel filter cap
12. Interstage cooler (245 hp and above)
13. Interstage cooler inlet elbow (245 hp and above)
14. Interstage cooler inlet duct (245 hp and above)

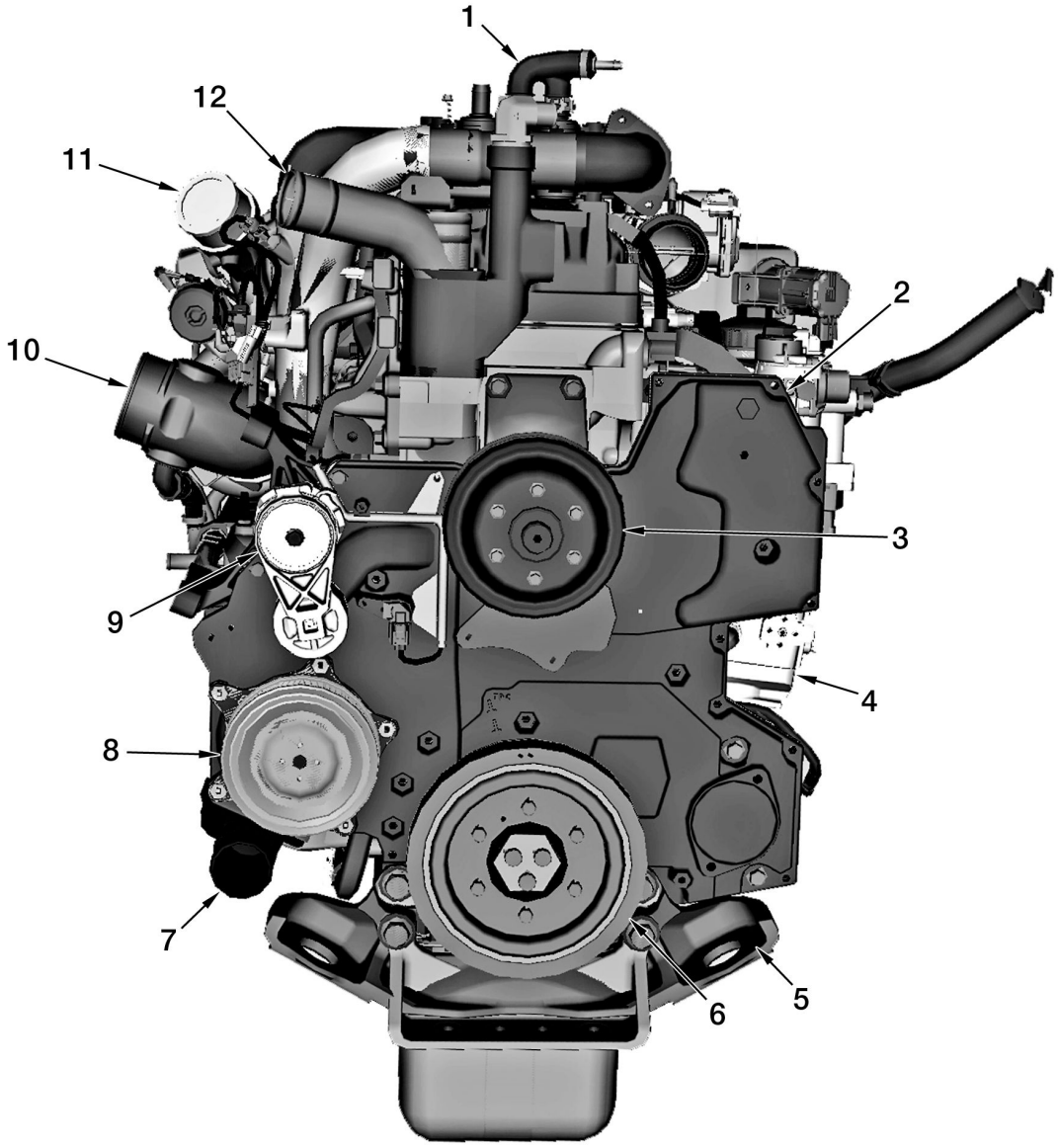


Figure 4 Component Location – Front

1. Deaeration hose elbow
2. Front cover
3. Fan drive pulley
4. Air compressor assembly
5. Front engine mounting bracket
6. Vibration damper assembly
7. Water inlet elbow
8. Water pump pulley
9. Automatic belt tensioner
10. Turbo air inlet duct
11. High-pressure turbocharger outlet
12. Water outlet tube assembly

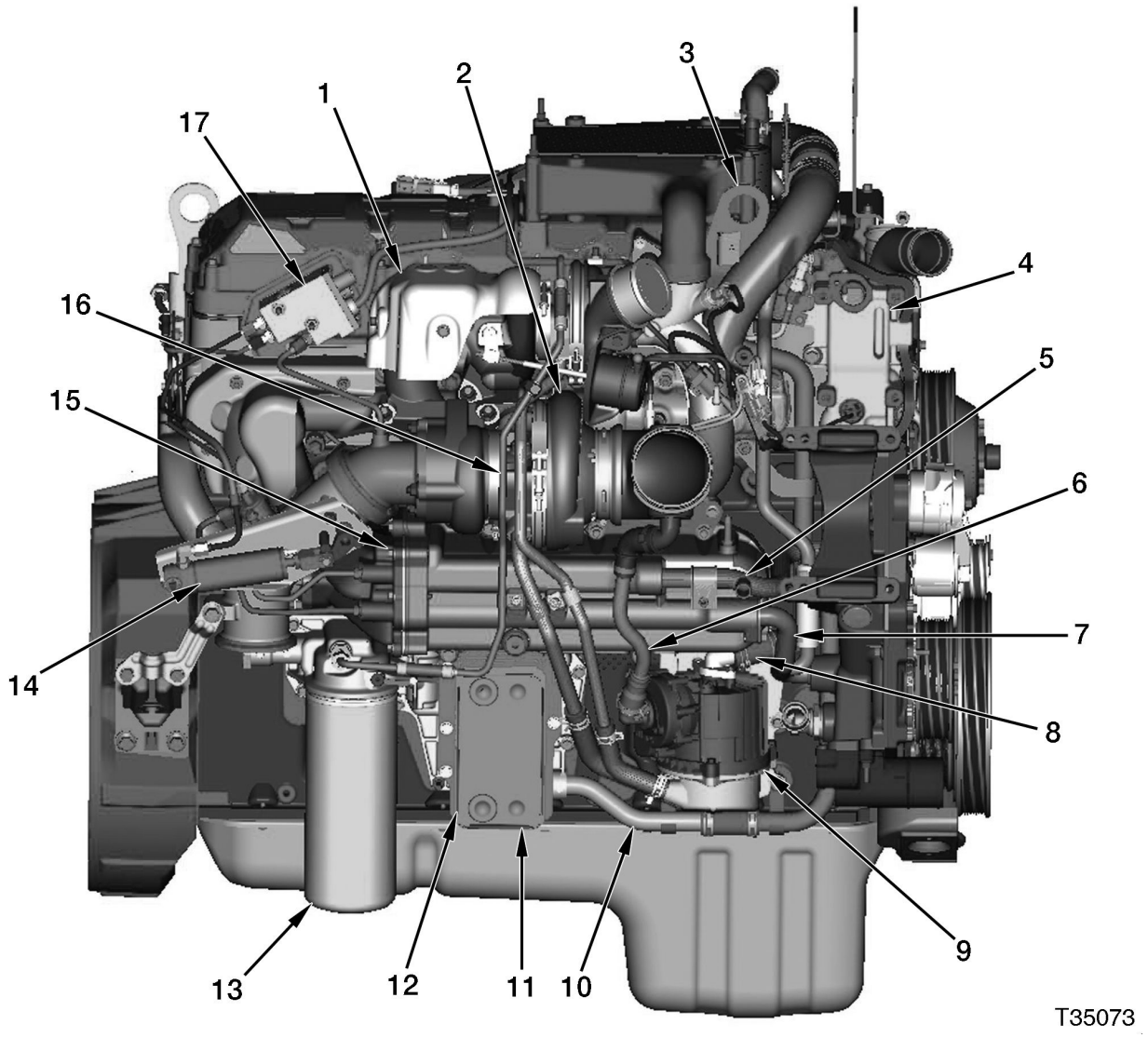


Figure 5 Component Location – Exhaust Side

1. Turbocharger heat shield
2. Dual stage turbocharger assembly
3. Lifting eye
4. Coolant supply housing (refrigerant compressor mount)
5. Coolant supply tube assembly (high fin density EGR cooler)
6. Breather outlet tube
7. Coolant return tube assembly (high fin density EGR cooler)
8. Breather inlet tube
9. Crankcase breather assembly with turbine
10. Coolant return tube
11. M16 plug assembly (coolant drain under oil cooler module)
12. Oil cooler module
13. Oil filter assembly
14. Exhaust back pressure valve
15. EGR cooler assembly
16. Turbo oil supply tube assembly
17. Exhaust brake valve assembly

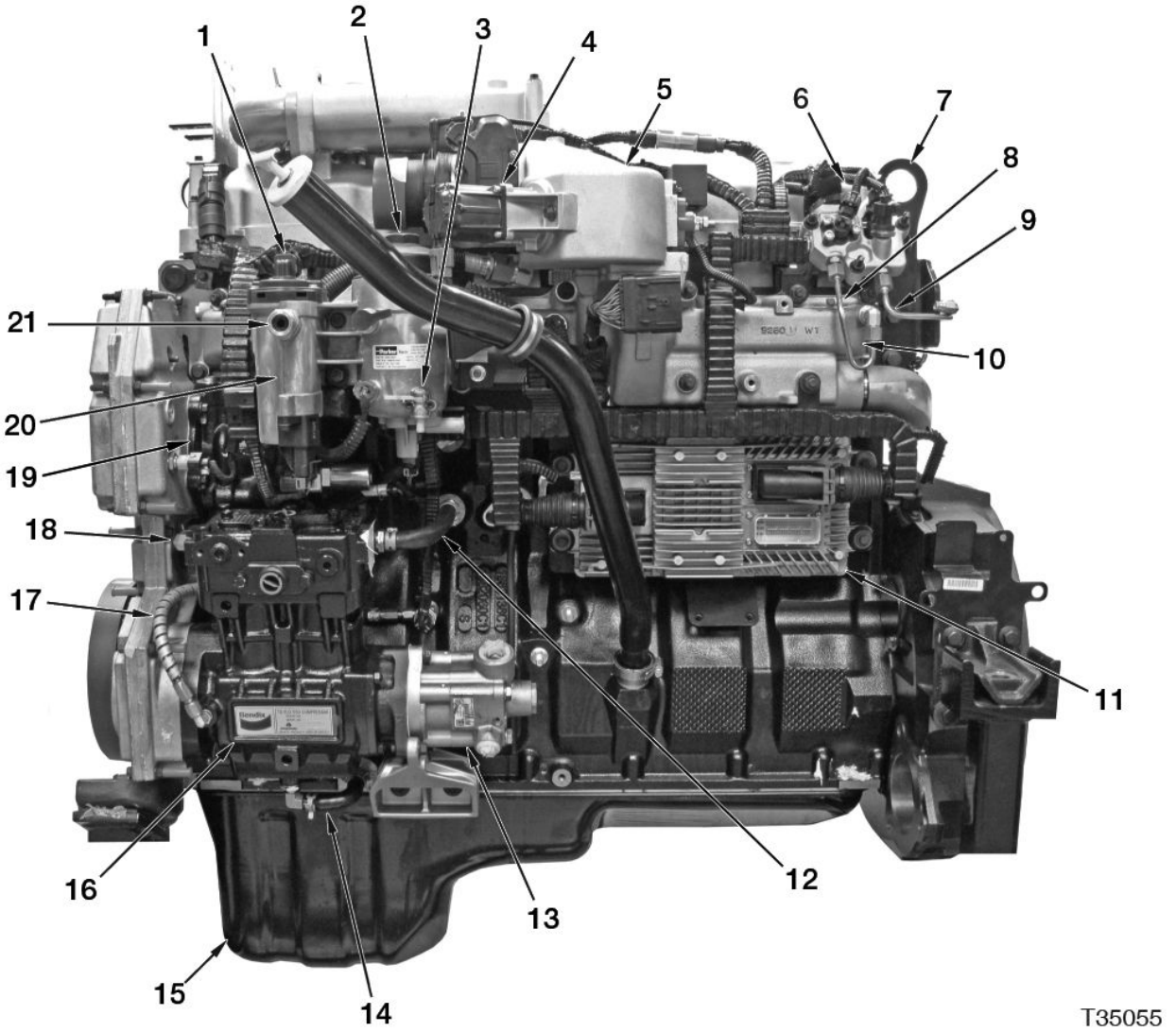
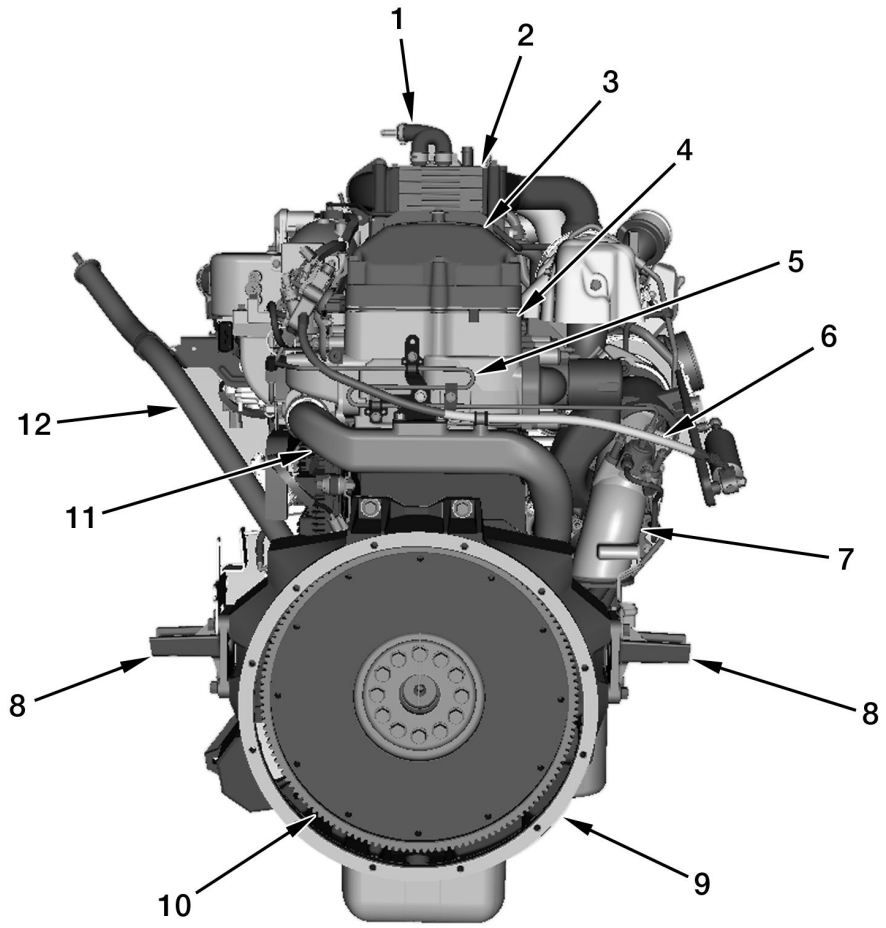


Figure 6 Component Location – Intake Side

1. Electric fuel pump
2. Fuel filter cap
3. Water drain valve assembly
4. Exhaust Gas Recirculation (EGR) valve
5. Air and EGR mixer duct
6. Downstream Injection (DSI) assembly
7. Lifting eye
8. Downstream Injection (DSI) feed tube assembly
9. Injection unit inlet tube assembly
10. Intake manifold
11. Engine Control Module (ECM)
12. Coolant return hose (air compressor)
13. Power steering pump assembly
14. Oil drain hose (air compressor)
15. Oil pan
16. Air compressor assembly
17. Oil supply hose (air compressor)
18. Coolant supply hose (air compressor)
19. High pressure oil pump
20. Fuel filter assembly with heater
21. Electric fuel pump inlet



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Figure 7 Component Location – Rear

1. Deaeration hose elbow
2. Interstage cooler (245 horsepower and above)
3. Valve cover
4. Cylinder head assembly
5. Injection unit inlet tube assembly
6. Exhaust brake valve to actuator hose
7. Exhaust pipe assembly
8. Rear engine mounting bracket (2)
9. Flywheel housing assembly
10. Flywheel
11. EGR crossover duct
12. Oil filler tube

Air Management System (AMS)

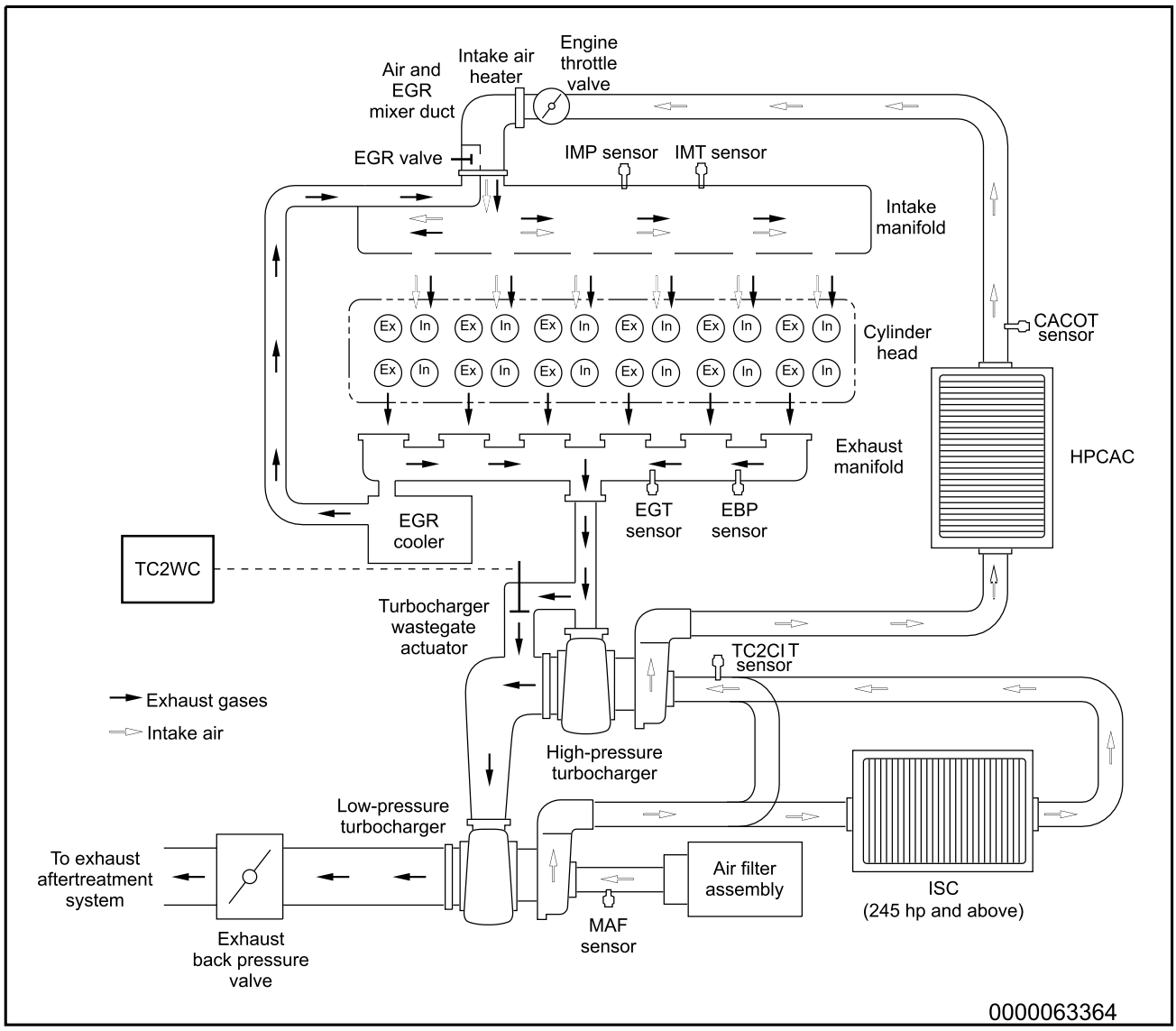


Figure 8 Air Management System (AMS)

The AMS includes the following:

- Air filter assembly
- Charge Air Cooler Outlet Temperature (CACOT)
- Low-pressure turbocharger
- Interstage Cooler (ISC) (245 hp and above)
- High-pressure turbocharger
- High-pressure Charge Air Cooler (HPCAC)
- Engine Throttle Valve (ETV)
- Air and EGR mixer duct
- Exhaust and intake valves
- Exhaust Gas Recirculation (EGR) system
- Exhaust system
- Exhaust back pressure valve
- Exhaust – aftertreatment

- Turbocharger 2 Wastegarte Control (TC2WC)

Air Flow – Pre Combustion

Fresh air from the air filter enters the low-pressure compressor where it is compressed and directed into the ISC (245 hp and above ratings), if equipped. If not equipped with ISC, compressed air from the low-pressure compressor is piped directly to the high-pressure compressor inlet. The high-pressure turbocharger further increases the intake air pressure. The hot, compressed air flows into the HPCAC where it is cooled, then through the Engine Throttle Valve (ETV) on the air and EGR mixer duct.

If the EGR valve is open, exhaust gas enters the high-fin-density EGR cooler from the rear of the exhaust manifold and is transferred to the intake manifold via the EGR crossover duct. The exhaust gas then passes through a port in the intake manifold to the air and EGR mixer duct where it is mixed with filtered intake air. This mixture then flows through the intake manifold and into the cylinder head.

If the EGR valve is closed, only filtered intake air flows through the ETV, air and EGR mixer duct, and into the intake manifold.

Air Flow – Post Combustion

After combustion, gases exit through the cylinder head exhaust valves and ports. Exhaust gas is forced through the exhaust manifold where, depending on the EGR valve position, it is split between the EGR system and the high-pressure turbocharger, low-pressure turbocharger, and the exhaust back pressure valve assembly.

The exhaust back pressure valve acts as an aftertreatment device to regulate exhaust temperatures.

Exhaust gases flow from the engine through the vehicle aftertreatment system to the exhaust tail pipe.

Air Management Components

Turbochargers

MaxxForce® DT, 9, and 10 engines are equipped with an electronically controlled two stage turbocharging system. This system provides high levels of charge air pressure to improve engine performance and to help reduce emissions. Because of its ability to generate very high charge air pressure levels, and to avoid Charge Air Cooler (CAC) overloading conditions, the system is fitted with a spring-loaded turbocharger wastegate.

The turbocharger wastegate is actuated by charge air pressure. The air pressure to the turbocharger wastegate actuator is controlled by the Turbocharger 2 Wastegate Control (TC2WC) valve. The TC2WC valve is controlled by Pulse Width Modulation (PWM) signals from the Electronic Control Module (ECM).

The high and low-pressure turbochargers are installed as an assembly on the exhaust manifold, on right side of the engine.

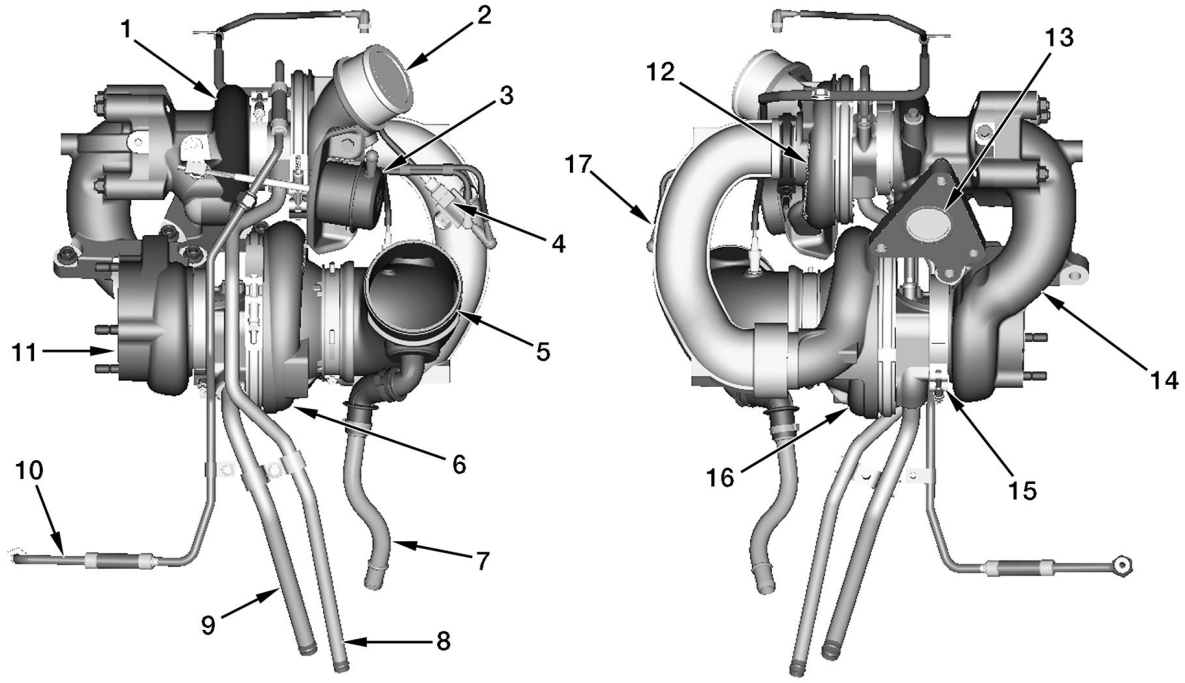


Figure 9 Low and High-Pressure Turbocharger Components (Below 245 hp)

1. High-pressure turbine housing
2. High-pressure turbocharger outlet
3. Turbo wastegate actuator
4. Turbocharger 2 Wastegate Control (TC2WC) valve
5. Turbo air inlet duct
6. Low-pressure compressor housing
7. Breather outlet tube
8. High-pressure turbo oil drain tube
9. Low-pressure turbo oil drain tube
10. Turbo oil supply tube assembly
11. Low-pressure turbine outlet
12. High-pressure compressor housing
13. High-pressure turbine inlet
14. Low-pressure turbine housing
15. Low-pressure bearing housing
16. Low-pressure compressor housing
17. Air crossover duct

The high-pressure turbocharger is connected directly to the exhaust manifold through the high-pressure turbine inlet. The high-pressure turbocharger is equipped with a wastegate that regulates the turbocharger boost by controlling the amount of exhaust gases that pass through the high-pressure turbine. When demand for power is low, such as during cruising speed, the turbocharger wastegate opens allowing part of the exhaust gas flow to bypass the high-pressure turbine.

The low-pressure turbine is attached directly to the output of the high-pressure turbine. The exhaust gas enters the low-pressure turbocharger through the low-pressure turbine housing and exits through the low-pressure turbine outlet.

Interstage Cooler (ISC)

The ISC is installed between the low-pressure and the high-pressure compressor housings for applications with 245 hp and above. The ISC air inlet is connected to the low-pressure compressor outlet and uses engine coolant to regulate the charge air temperature. The ISC air outlet is connected to the compressor inlet on the high-pressure turbocharger.

High-pressure Charge Air Cooler (HPCAC)

The HPCAC is installed between the high-pressure turbocharger and the Engine Throttle Valve (ETV). The HPCAC air inlet is connected to the high-pressure compressor outlet and uses air-to-air to regulate the

charge air temperature. The HPCAC air outlet is connected directly to the ETV body.

Turbocharger 2 Wastegate Control (TC2WC) Valve

The TC2WC valve controls the turbocharger wastegate actuator by regulating the amount of charge air pressure supplied to the wastegate actuator. The Pulse Width Modulated (PWM) signals sent to the TC2WC valve by the Electronic Control Module (ECM) are based on input signals from the Exhaust Back Pressure (EBP) sensor.

When demand for power is high, such as during acceleration, the TC2WC valve opens the wastegate which allows exhaust gas to enter the HP turbocharger in addition to the LP turbocharger. Once the vehicle reaches cruising speed, the TC2WC valve will close the wastegate and direct exhaust gas away from the HP turbocharger and only through the LP turbocharger.

Exhaust Gas Recirculation (EGR) System

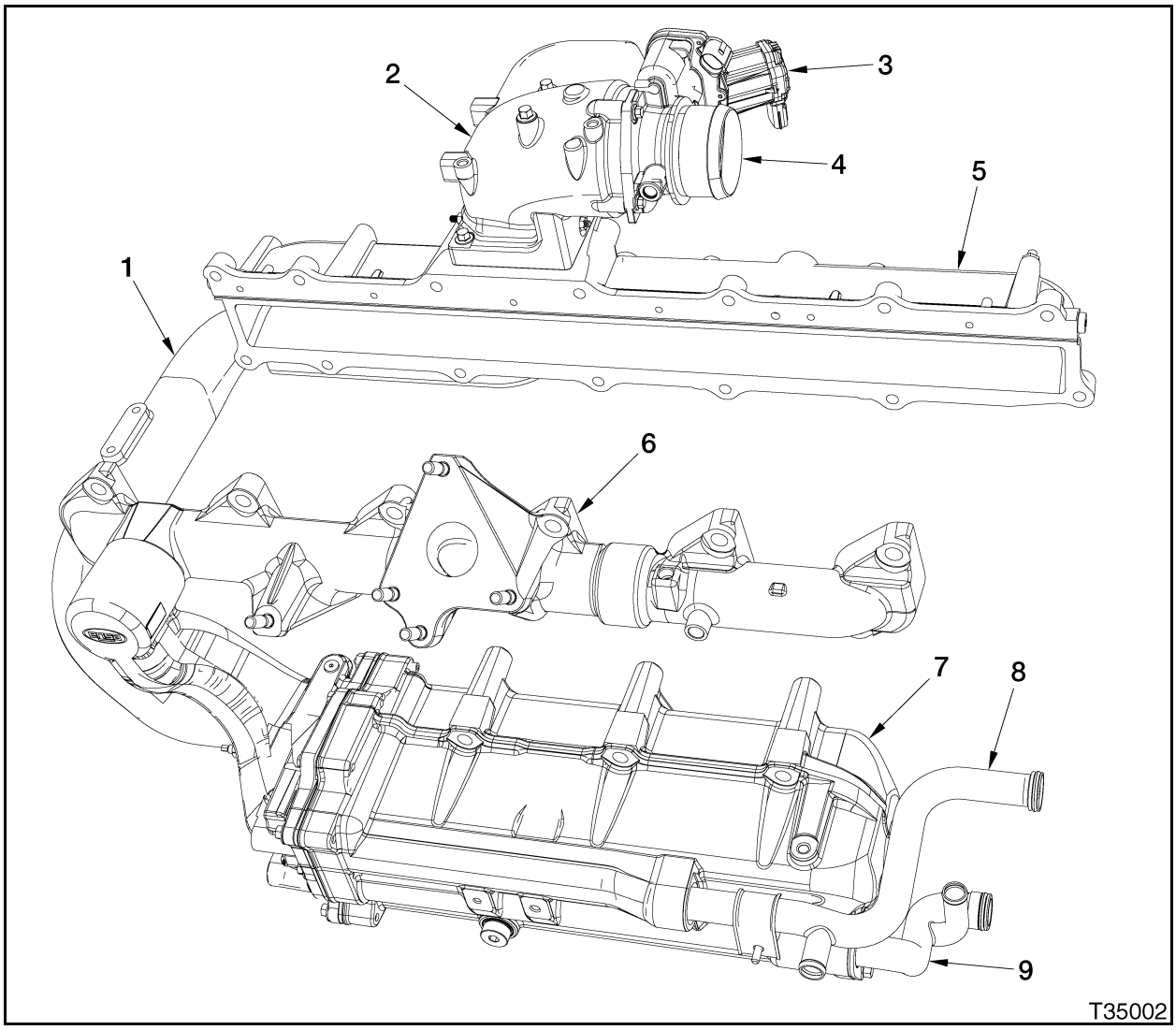


Figure 10 EGR System

1. EGR crossover duct
2. Air and EGR mixer duct assembly
3. EGR valve assembly
4. Engine throttle valve
5. Intake manifold assembly
6. Exhaust manifold assembly
7. High fin density EGR cooler assembly
8. Coolant supply tube
9. Coolant return tube

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

EGR Flow

When EGR is commanded, the EGR valve opens and allows exhaust gas from the exhaust manifold to flow into the EGR cooler for cooling. This cooled exhaust gas is directed through the EGR crossover duct into a port in the intake manifold and directed to the air and EGR mixer duct where it is mixed with filtered intake air.

EGR Valve

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

The EGR valve is installed in the air and EGR mixer duct assembly on the intake side of the engine.

The EGR valve uses a DC motor to control position of the valve assembly. The motor pushes directly on the valve stem to open. The valve assembly has two poppets on a common shaft.

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

EGR Closed Loop System

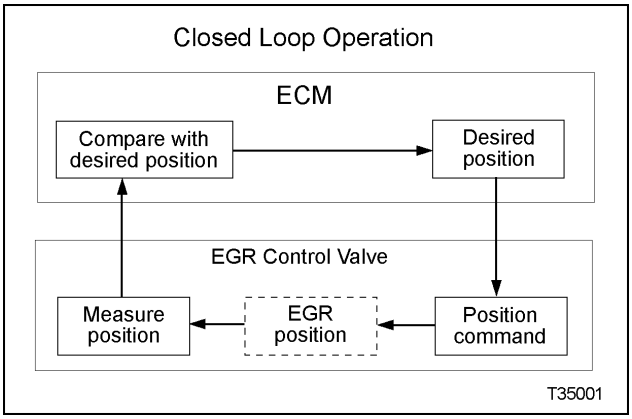


Figure 11 EGR Closed Loop System

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

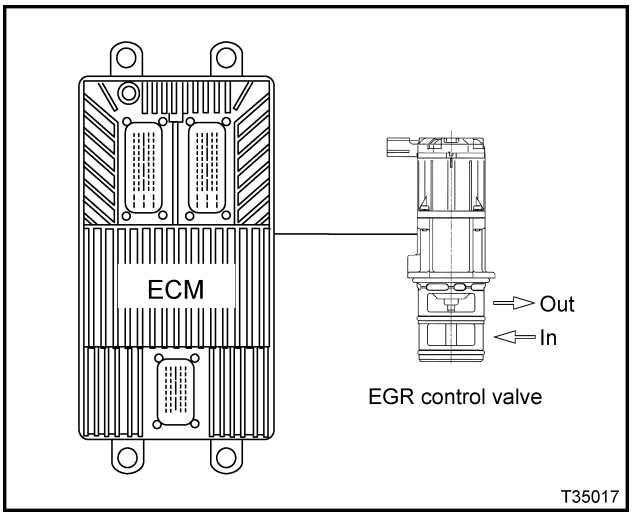


Figure 12 EGR Control

Crankcase Ventilation System

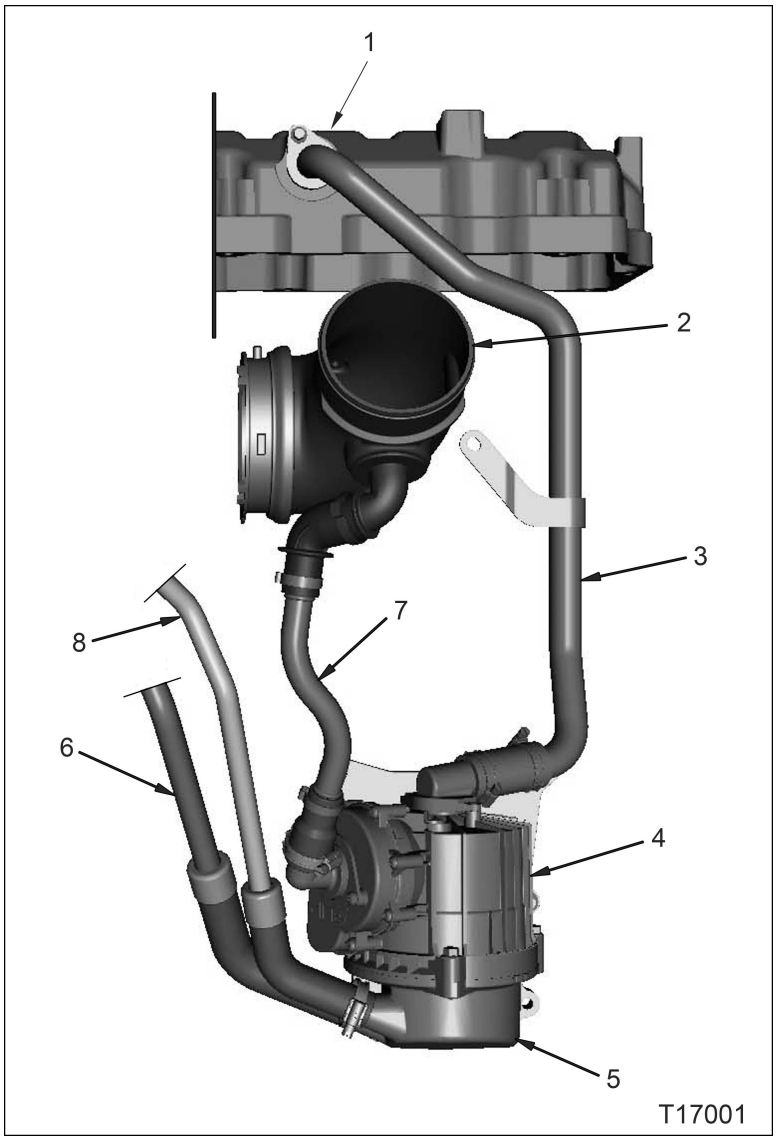


Figure 13 Crankcase Ventilation System

1. Valve cover
2. Turbocharger air inlet duct
3. Crankcase breather inlet tube
4. Housing assembly (breather)
5. Housing assembly (turbine)
6. Low-pressure turbo drain tube
7. Breather outlet tube
8. High-pressure turbo drain tube

The crankcase ventilation system uses an engine mounted oil separator to return oil to the crankcase. The excess crankcase pressure is vented back into the intake system.

Oil extracted blow-by gases flow from the valve cover through the crankcase breather inlet tube into the breather housing assembly.

A high-speed centrifugal oil separator, driven by engine oil pressure, separates and directs oil to the side of housing assembly. The separated oil drains into the oil separator turbine housing, through the crankcase, and into the oil pan. The oil separator is located inside and towards the top of the housing assembly.

The turbine housing also provides oil drainage from the low-pressure and high-pressure turbochargers. The low-pressure and high-pressure turbo oil drain tubes direct turbocharger drain oil into the turbine housing. The oil drains out of the turbine housing, through the crankcase, and into the oil pan.

Blow-by gases are directed through the breather outlet tube and into the turbocharger air inlet duct.

Aftertreatment (AFT) System

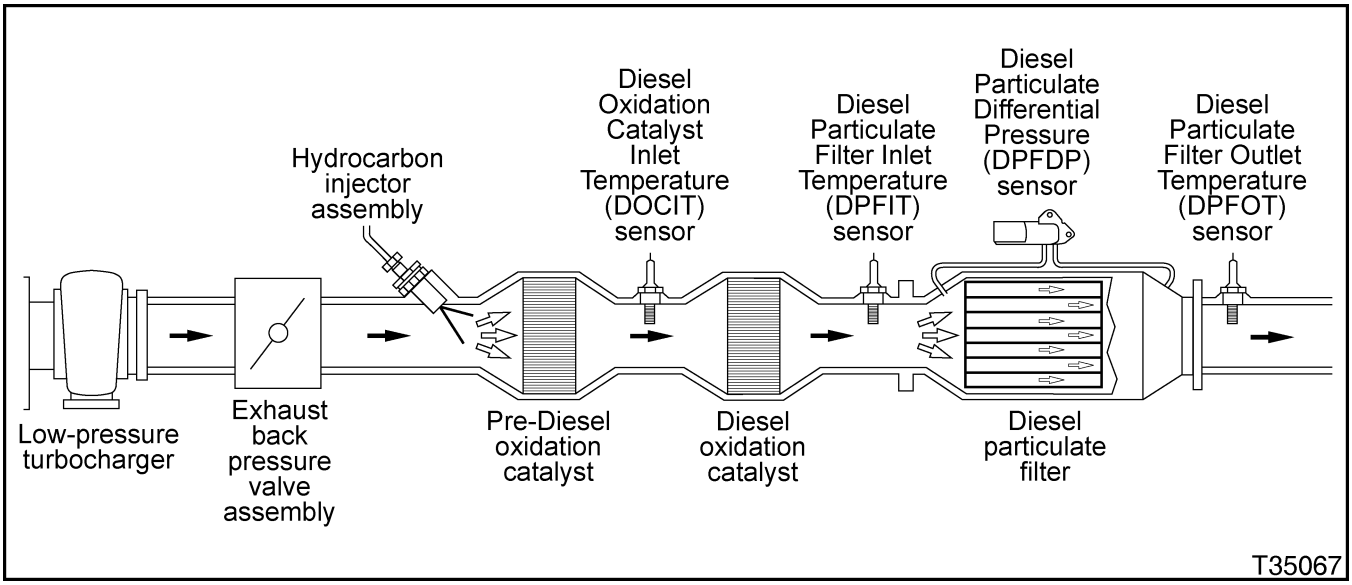


Figure 14 Aftertreatment (AFT) System

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

AFT Control System

The control system performs the following functions:

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

Sensors

Sensors output an electronic signal based on temperature or pressure. The signals are used by the control system to regulate the aftertreatment function.

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

Exhaust Back Pressure Valve

The exhaust back pressure valve also acts as an aftertreatment device to manage exhaust temperatures. The ECM will signal the exhaust back pressure valve to change the amount of air passing through the valve into the exhaust and through the DOC and DPF. The ECM interprets the increased back pressure as an increased load. In response to the increased pressure / load, the engine increases speed to meet the demand, resulting in increased exhaust temperature.

Pre-Diesel Oxidation Catalyst (PDOC)

The PDOC does the following:

- Aids in creating an exothermic reaction to improve exhaust emissions
- Allows for more efficient operation of the aftertreatment system

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

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 back pressure increases to a predetermined level
- Stores noncombustible ash

AFT Conditions and Responses

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

Downstream Injection System

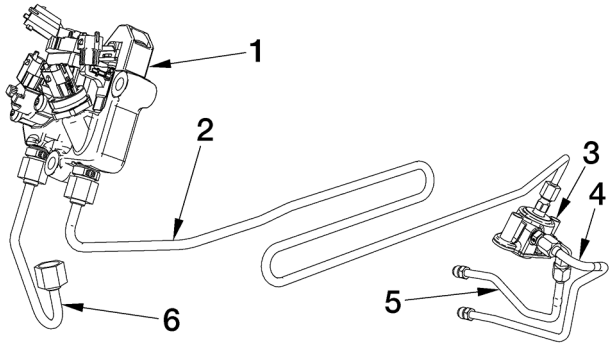


Figure 15 Aftertreatment (AFT) System

1. Downstream Injection (DSI) assembly
2. Injection unit inlet tube assembly
3. Hydrocarbon injector assembly
4. Injector coolant outlet tube
5. Injector coolant inlet tube
6. Downstream Injection (DSI) feed tube assembly

The downstream injection system includes the following:

- Doser Control Unit (DCU)
- Hydrocarbon injector assembly
- Downstream Injection (DSI) assembly
- Coolant lines
- Fuel lines

The Doser Control Unit (DCU) is mounted on the chassis of the vehicle. The DCU receives signals from the ECM and then signals the DSI assembly.

The DSI assembly is installed on the left rear of the engine above the intake manifold.

When the DCU signals the shutoff valve to open, fuel pressure increases in the upstream cavity of the DSI assembly housing. The upstream pressure sensor immediately signals the DCU that pressure is increased by available fuel. The DCU then signals the dosing valve to open, allowing a specific amount of fuel to be injected into the injector unit inlet tube assembly to the hydrocarbon injector assembly.

Fuel is injected into the exhaust stream from the hydrocarbon injector assembly which increases the temperature inside the Diesel Particulate Filter (DPF) in order to convert soot to ash more efficiently.

The hydrocarbon injector assembly is cooled with engine coolant from the EGR cooler assembly.

Fuel Management System

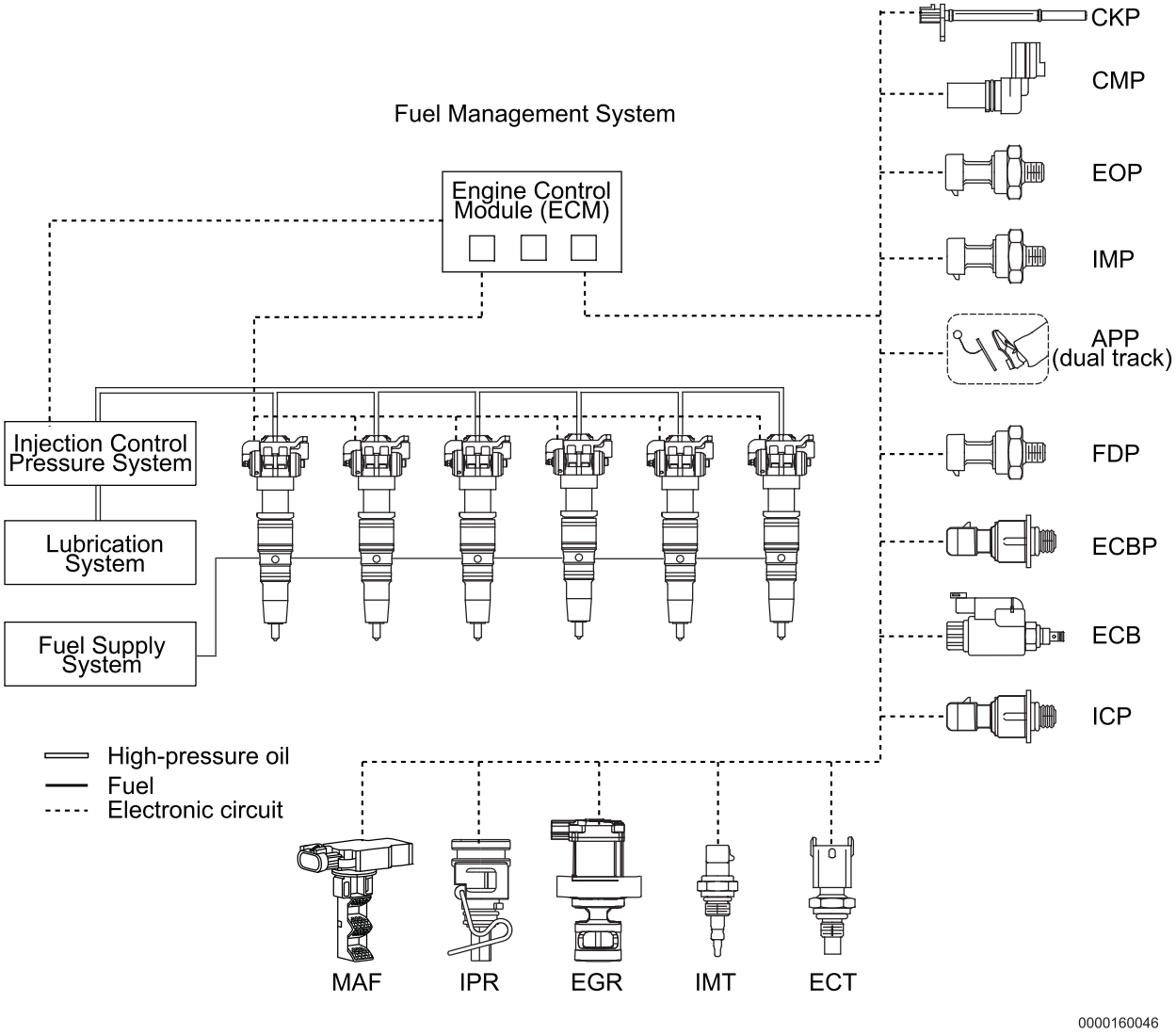


Figure 16 Fuel Management System

The fuel management system includes the following:

- Lubrication system
- Injection Control Pressure (ICP) system
- Engine Compression Brake (ECB)
- Fuel supply system
- Fuel injectors
- Electronic control system

ICP System

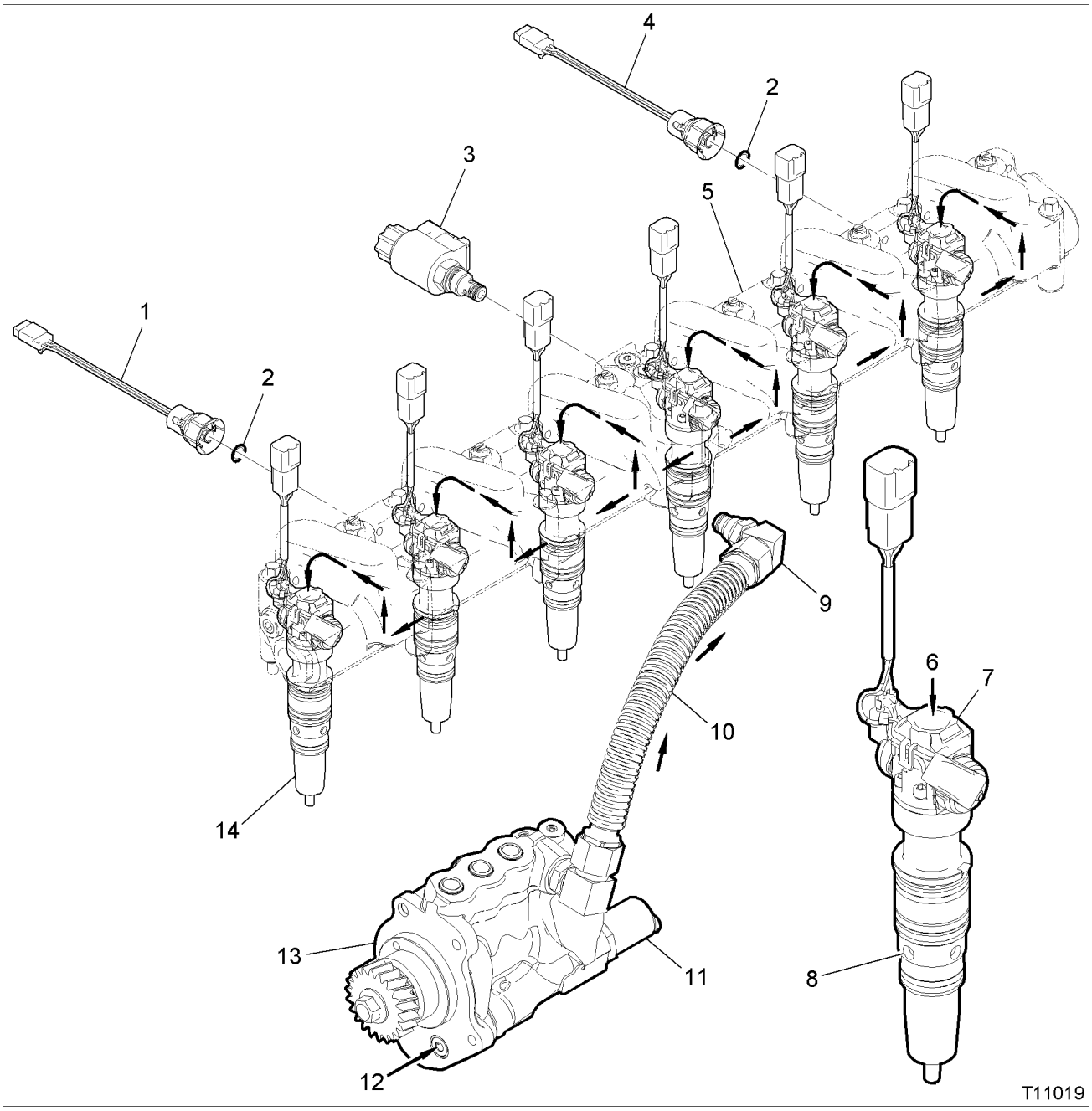


Figure 17 Injection Control Pressure (ICP) System

1. Engine Compression Brake Pressure (ECBP) sensor
2. O-ring (2)
3. Engine Compression Brake (ECB) valve
4. Injection Control Pressure (ICP) sensor
5. High-pressure oil manifold
6. Injector oil inlet from high-pressure oil manifold
7. Oil outlet (2)
8. Fuel inlet port (4)
9. 70 degree elbow
10. High-pressure oil hose
11. Injection Pressure Regulator (IPR) valve
12. Oil inlet from front cover reservoir
13. High-pressure oil pump assembly
14. Fuel injector assembly (6)

High-Pressure Oil Flow

The lubrication system supplies the oil reservoir located in the front cover. The reservoir provides oil for the high-pressure oil pump. The pump is mounted on the backside of the front cover and is gear driven by the upper idler gear.

High-pressure oil is directed to the high-pressure oil hose, cylinder head passage, and high-pressure oil manifold.

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

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

If equipped with the optional engine brake, some high-pressure oil is directed internally to the engine brake pistons when the engine compression brake is activated. Since these two systems share a common gallery, a problem with the engine compression brake system can adversely affect injection control pressure and vise versa.

ICP Closed Loop System

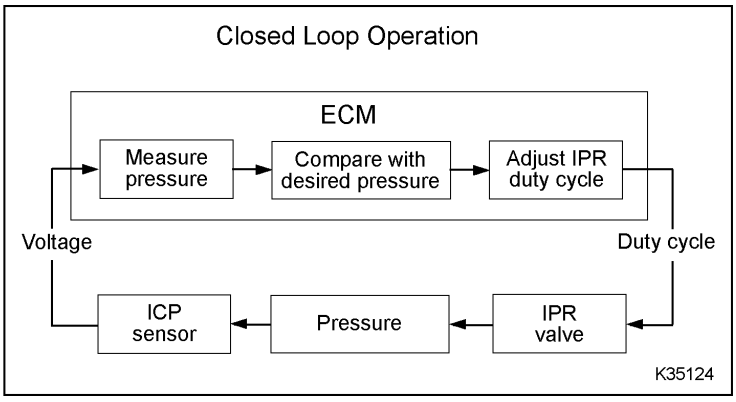


Figure 18 ICP Closed Loop System

The ICP (Injection Control Pressure) system is a closed loop system that uses the ICP sensor to continuously provide feedback to the ECM. The ECM commands the IPR duty cycle to adjust pressure to match engine requirements.

ICP Control System

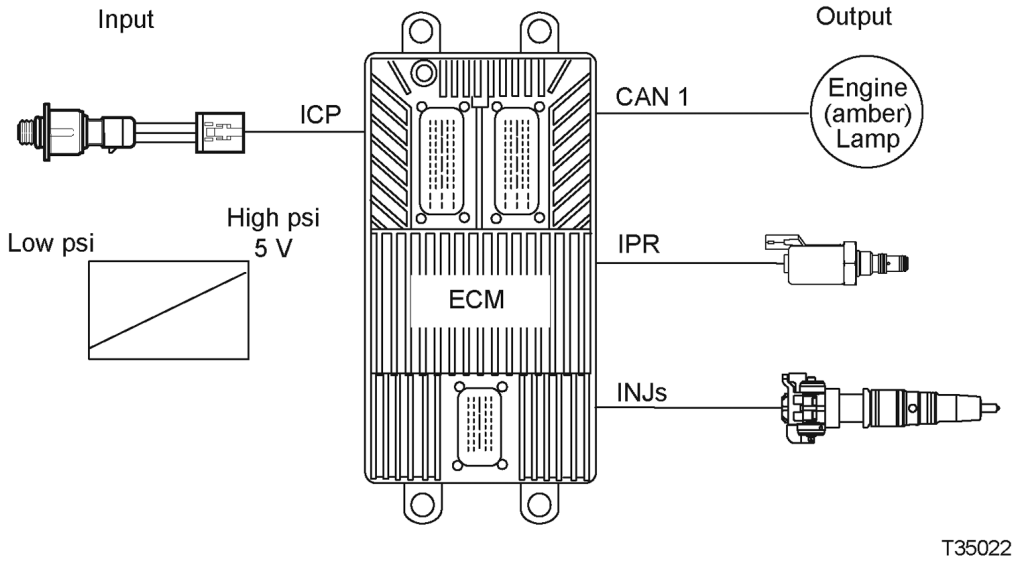


Figure 19 ICP Control System

The IPR valve receives a Pulse Width Modulated (PWM) signal from the ECM. This controls the on and off time the IPR valve is energized. The on / off time is controlled by the ECM to meet calibrated desired values.

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

As demand for ICP increases, the ECM increases the current to the IPR valve solenoid. When demand for ICP decreases, the duty cycle to the IPR valve decreases and more oil is allowed to flow back to the crankcase sump.

When the ICP electrical signal is out-of-range, the ECM sets a fault code.

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

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

Fuel Injector

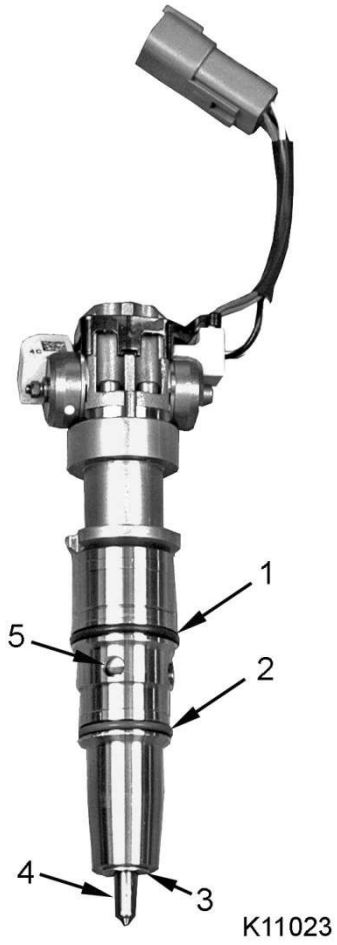


Figure 20 Fuel Injector

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

Fuel Injector Features

Two 50 volt, 25 amp coils control a spool valve that directs oil flow in and out of the injector. Each injector has a single four pin connector that connects to the valve cover gasket assembly.

Injector Coils and Spool Valve

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

- When the spool valve is open, oil flows into the injector from the high-pressure oil manifold.
- When the spool valve is closed, oil exits from the top of the fuel injector and drains back to the crankcase.

Intensifier Piston and Plunger

When the spool valve is open, high-pressure oil enters the injector, pushing down the intensifier piston and plunger. Since the intensifier piston is 10 times greater in surface area than the plunger, the fuel injection pressure is also 10 times greater than injection control pressure on the plunger.

Plunger and Barrel

Fuel pressure builds at the base of the plunger in the barrel. When the intensifier piston pushes the plunger down, the plunger increases fuel pressure in the barrel 10 times greater than injection control pressure. The plunger has a hardened coating to resist scuffing.

Injector Needle

The injector needle opens inward when fuel pressure overcomes the Valve Opening Pressure (VOP). Fuel is atomized at high-pressure through the nozzle tip.

Fuel Injector Operation

The injector operation has three stages:

- Fill stage
- Injection
- End of injection

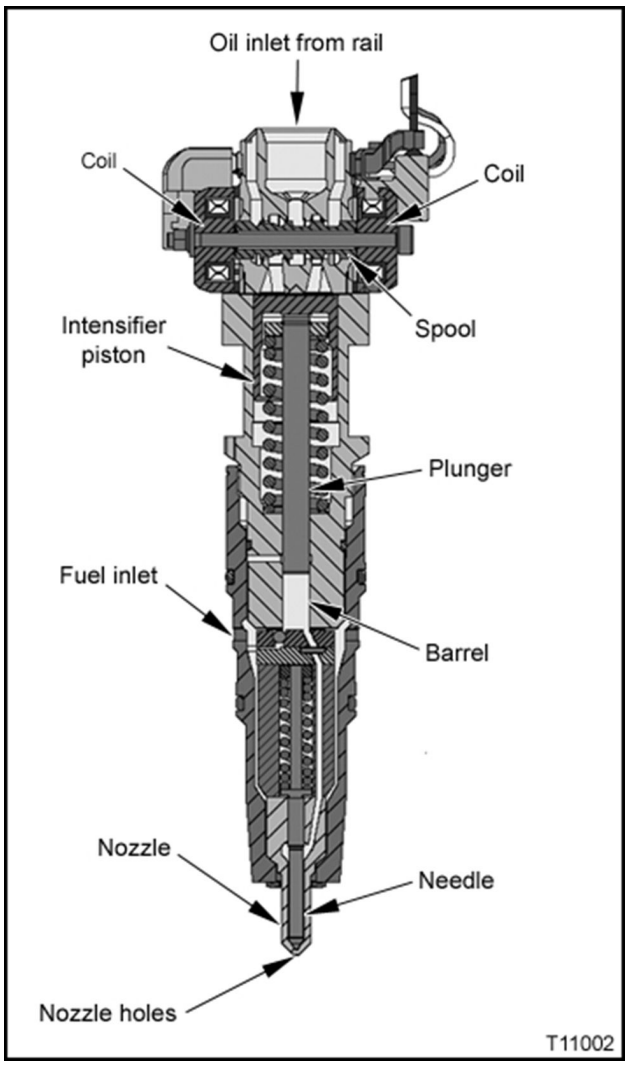


Figure 21 Fuel Injector Cross Section

Fill Stage

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

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

Injection

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

End of Injection

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

Fuel Supply System

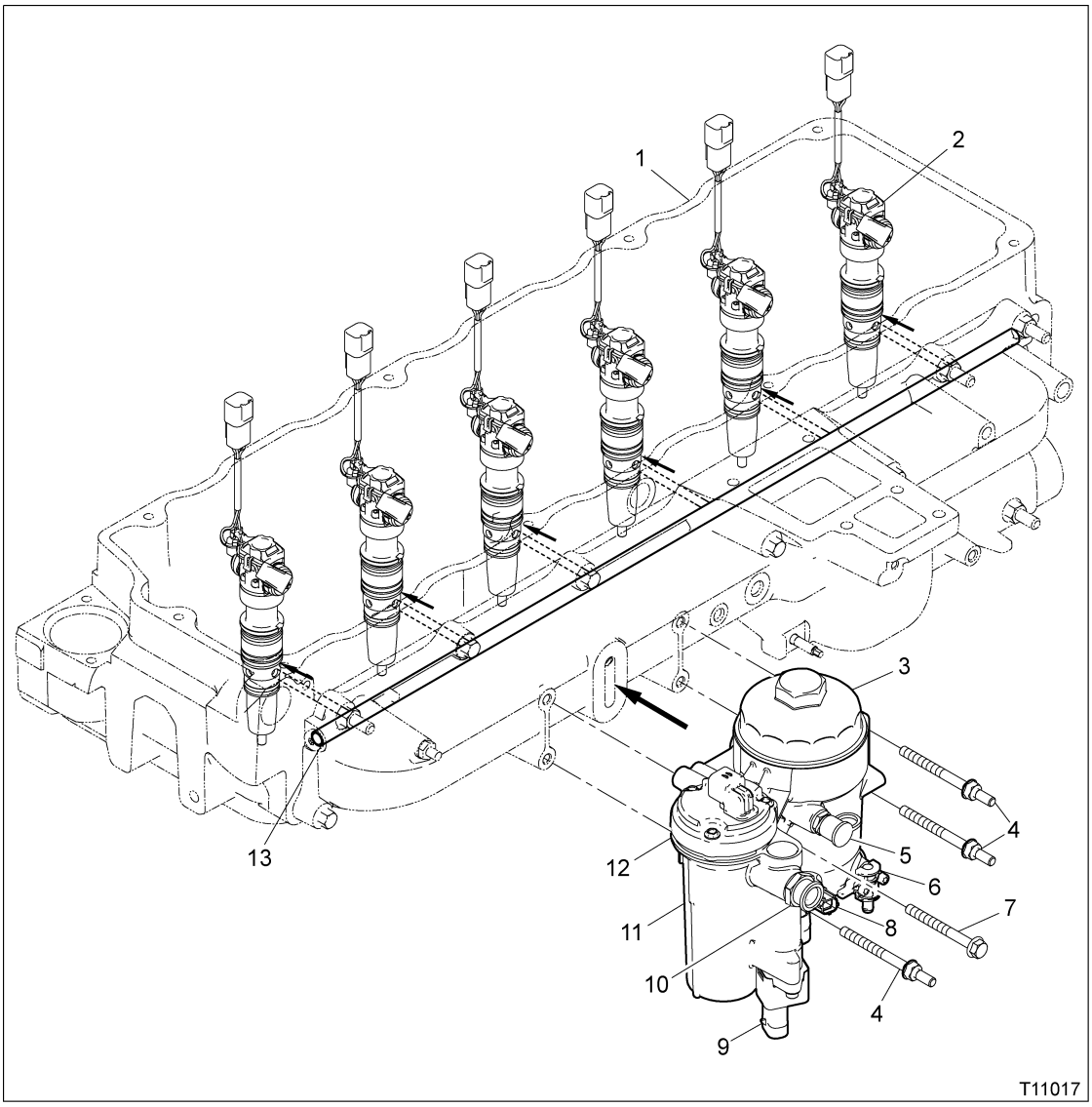


Figure 22 Low-Pressure Fuel System

1. Cylinder Head
2. Fuel injector assembly (6)
3. Fuel filter cap
4. M8 x 75 stud bolt (3)
5. Diagnostic coupling assembly and dust cap
6. Water drain valve assembly
7. M8 x 75 bolt
8. Water In Fuel (WIF) sensor
9. 250 watt heater assembly (optional)
10. Voss® Stop Flow adapter assembly (fuel inlet)
11. Fuel filter assembly (with optional heater)
12. Electric fuel pump assembly
13. Low pressure fuel rail (cast in intake manifold)

Fuel Supply System Flow

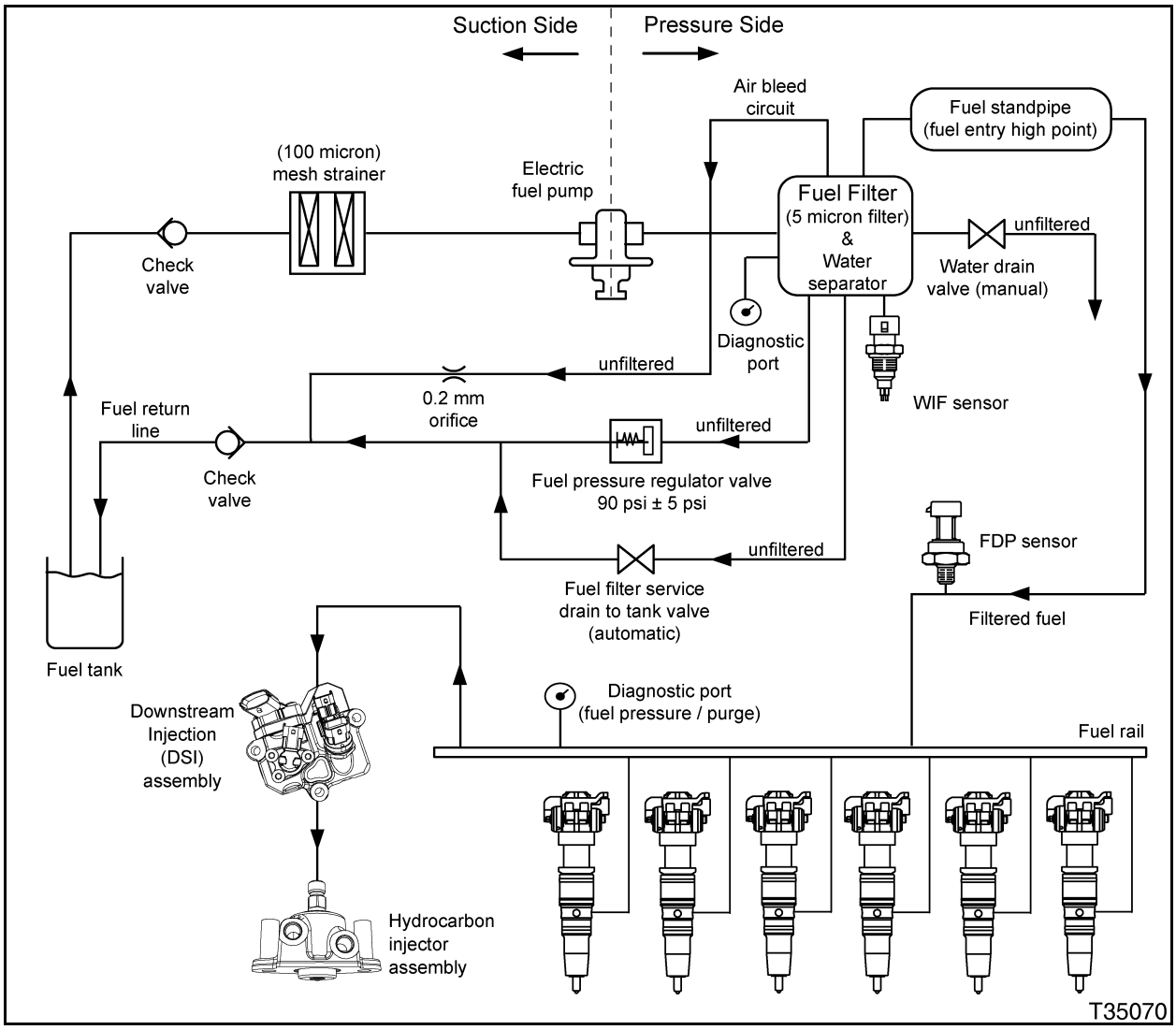


Figure 23 Fuel Flow

The electric fuel pump draws fuel through the fuel lines from the fuel tank. Fuel enters the fuel filter assembly and passes through the 100 micron strainer.

An optional 250 watt electric heating element is available to warm incoming fuel to prevent waxing and optimize cold weather performance. The heater is installed in the fuel filter assembly, below the electric fuel pump.

Fuel flows from the strainer through the electric fuel pump to the fuel filter for further conditioning.

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

Fuel flows through the 5 micron filter element and the standpipe. The filter element removes debris from the fuel. The standpipe prevents fuel from draining from the fuel rail during service.

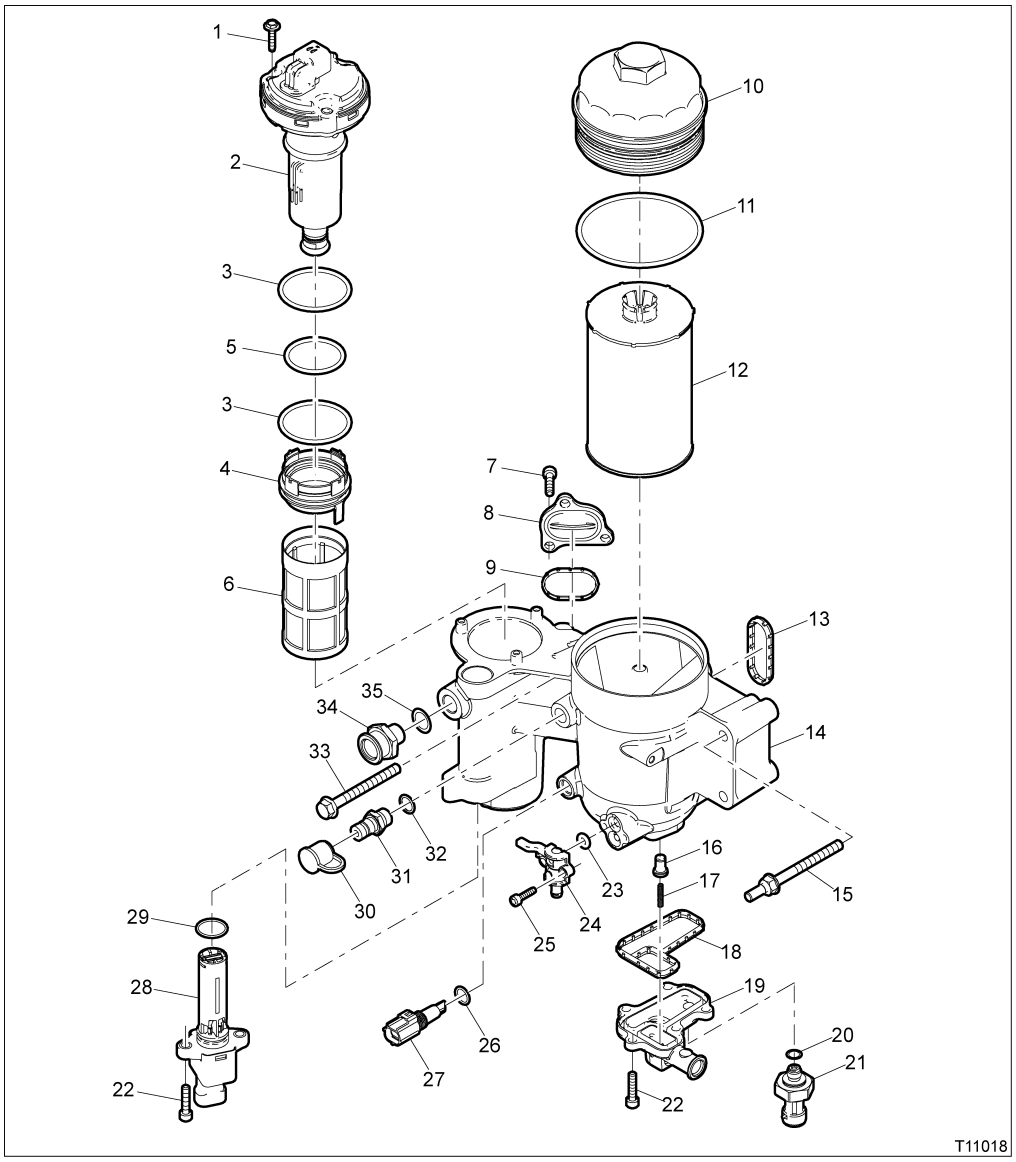


Figure 24 Fuel Filter Assembly Components

1. M5 x 25 screw (3)
2. Electric fuel pump
3. Pump cover and housing O-ring (2)
4. Pump adapter
5. 3.53 x 40.87 ID O-ring
6. Pump strainer
7. M6 screw (3)
8. Port cover
9. Port cover seal
10. Fuel filter cap
11. O-ring gasket
12. Fuel filter element
13. Irregular molded gasket
14. Fuel filter assembly with heater
15. M8 x 75 stud bolt (3)
16. Fuel pressure regulator valve assembly
17. Fuel pressure regulator spring
18. Cover plate seal
19. Bottom cover plate
20. Sensor O-ring
21. Fuel Delivery Pressure (FDP) sensor
22. M6 screw (7)
23. O-ring
24. Water drain valve assembly
25. M5 x 18 Torx® screw (2)
26. O-ring seal
27. Water In Fuel (WIF) sensor
28. 250 watt heater assembly (optional)
29. Heater plug O-ring gasket
30. Dust cap
31. Diagnostic coupling
32. #906 O-ring
33. M8 x 75 bolt
34. Voss® Stop Flow adapter assembly (fuel inlet)
35. Gasket

When the maximum amount of water is collected in the element cavity, the WIF sensor sends a signal to the Electronic Control Module (ECM). The ECM turns on the amber Water In Fuel lamp located on the instrument panel.

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

A fuel pressure regulator valve is built into the fuel filter assembly. The regulator valve is calibrated to relieve excessive fuel pressure. Excess fuel is sent through a fuel return line back to the fuel tank. Return fuel is not filtered.

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

When the fuel filter is removed, a drain-to-tank port valve is opened. Fuel present in the filter assembly then drains out and back to the tank to provide improved cleanliness during servicing. When fuel lines are removed, a check valve eliminates spillage and ensures fuel line cleanliness.

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

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

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

Engine Lubrication System

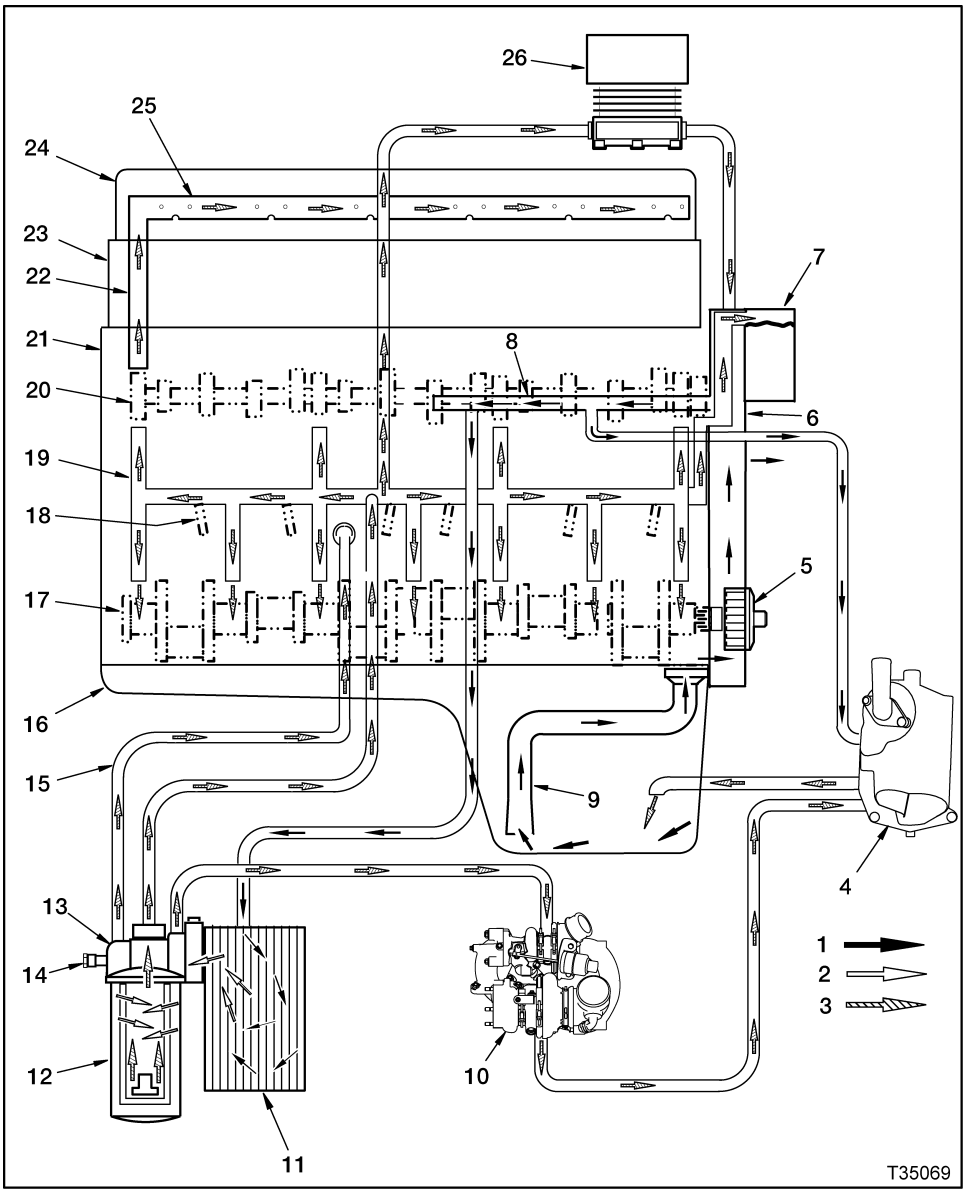


Figure 25 Lubrication System

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

Oil Flow

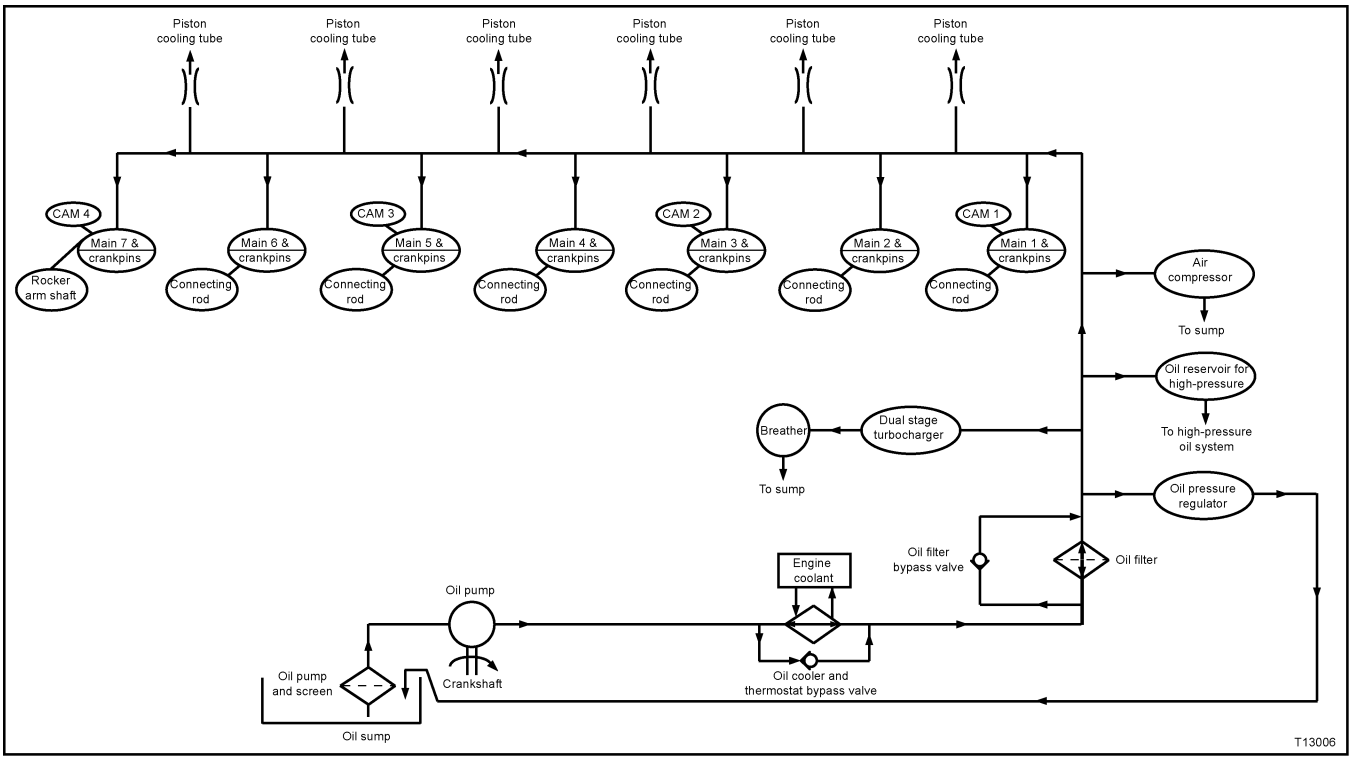


Figure 26 Lubrication System

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

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

When the oil temperature is hot, the thermal bypass valve is fully open. This allows all unfiltered oil to flow through the oil cooler before entering the oil filter.

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

Oil that exits or bypasses the oil cooler mixes and enters the spin-on oil filter. Oil flows from outside the filter element towards the inside to remove debris. When the filter is restricted, the oil filter bypass (located in the oil filter can) opens and allows oil to bypass the filter to maintain engine lubrication. The filter bypass valve opens when pressure reaches 414 kPa (60 psi).

After passing through the filter, the oil travels past the oil pressure regulator. The regulator directs excess oil back to the oil pan to maintain oil pressure at a maximum of 393 kPa (57 psi).

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

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

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

Oil is provided to the cylinder head from the rear cam bearing through a passage at the rear of the crankcase. Oil flows through a passage in the cylinder

head and rear rocker shaft support, then enters the hollow rocker shaft, which lubricates the rocker arms.

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

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

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

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

Engine Cooling System

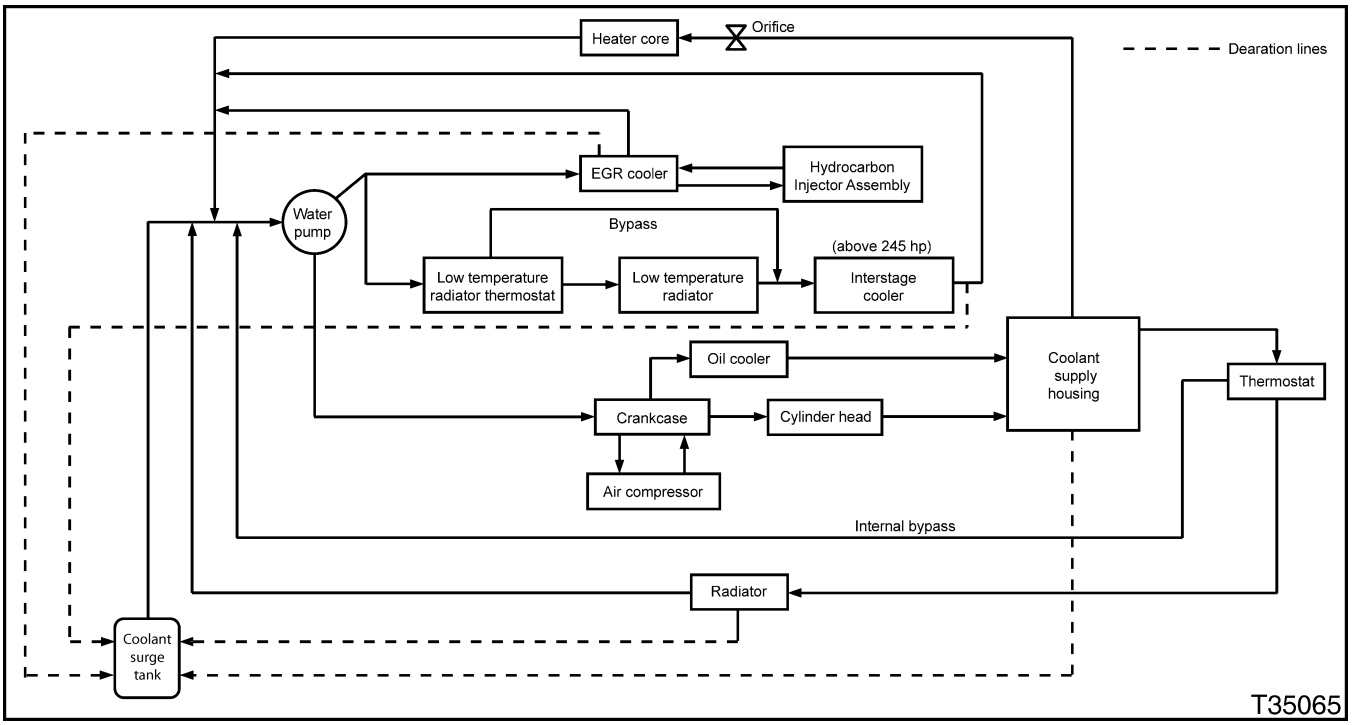


Figure 27 Cooling System Components and Flow

Cooling System Description

The engine cooling system includes the following:

- Chassis mounted radiator
- Low temperature radiator (if equipped)
- Low temperature radiator thermostat (if equipped)
- Interstage cooler (if equipped)
- Coolant fan
- Water inlet elbow
- Front engine cover
- Water pump
- Crankcase
- Cylinder sleeves
- Cylinder head
- Oil cooler module assembly
- Air compressor
- Thermostat
- Coolant supply housing/coolant port
- EGR cooler
- Coolant surge tank
- Coolant heater (if equipped)

The water pump pushes coolant into the crankcase, low temperature radiator, and EGR cooler.

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

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

Coolant flows through the cylinder head water jackets towards the thermostat cavity at the front of the cylinder head. When the thermostat is closed, coolant is directed through the bypass port, crankcase, front cover, and into the water pump. When the thermostat

is open, the bypass port is blocked, and coolant is directed through the radiator.

Coolant passes through the radiator and is cooled by moving air from the coolant fan. Coolant returns to the engine through the inlet elbow and front cover.

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

The oil cooler module assembly receives coolant from a passage in the crankcase. Coolant passes between the oil cooler plates and returns through a tube connected to the coolant supply housing.

The EGR cooler receives coolant from the water pump through a supply tube at the rear of the front cover. Coolant passing through the EGR cooler, flows through the cooler plates, cools the exhaust gas, and exits through a tube to the rear of the front cover that returns coolant to the pump inlet. The hydrocarbon injector assembly receives and returns coolant to the EGR cooler.

The EGR coolant supply tube also branches off to the low temperature radiator and to the interstage cooler (above 245 hp), if equipped. For engines with ratings above 245 hp, the coolant is routed through the low temperature thermostat, then through the low temperature radiator to the interstage cooler. Coolant is regulated by the low temperature radiator thermostat. Warm coolant is directed to the low temperature radiator and into the interstage cooler. Cold coolant bypasses the low temperature radiator and moves directly into the interstage cooler.

The interstage cooler uses coolant to lower the charged air temperature that exits from the turbocharger low-pressure compressor and enters the turbocharger high-pressure compressor.

The surge tank provides expansion space for coolant and deaerates the cooling system. The following four vents provide coolant to the tank:

- Engine vent (top of coolant supply housing)
- EGR vent (top of EGR cooler)
- Main radiator vent (top of radiator)
- Interstage cooler vent (top of interstage cooler)

The surge tank returns coolant through the surge line, back to the water pump inlet.

Cab heat is provided by the heater core, which receives warmed coolant from the coolant supply housing.

Cooling System Components

Coolant Heater (optional)

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

Thermostat Operation

Coolant travels through two ports after it passes through the thermostat. One port directs coolant to the radiator when the engine is at operating temperature. The other port directs coolant to the water pump until the engine reaches operating temperature. The thermostat begins to open at 88 °C (190 °F) and is fully open at 96 °C (205 °F).

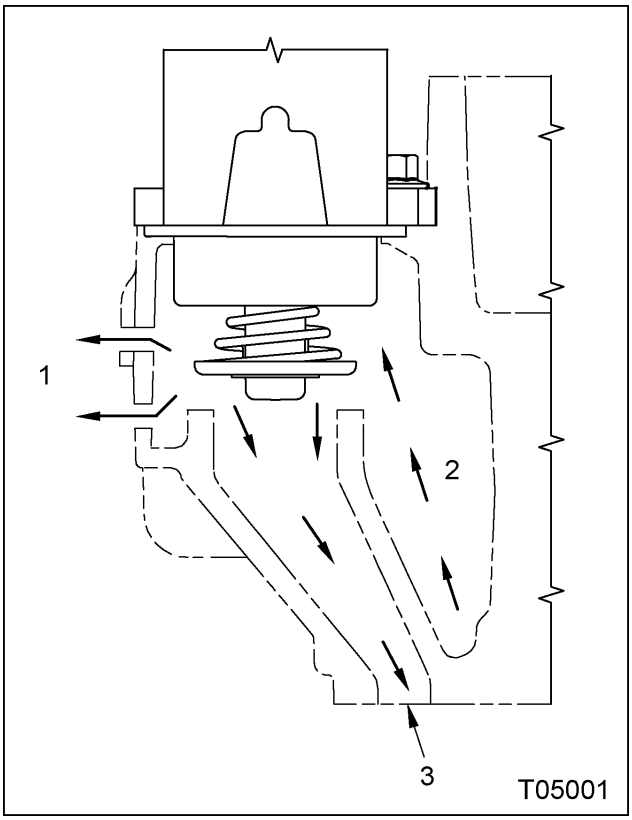


Figure 28 Thermostat Closed

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

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

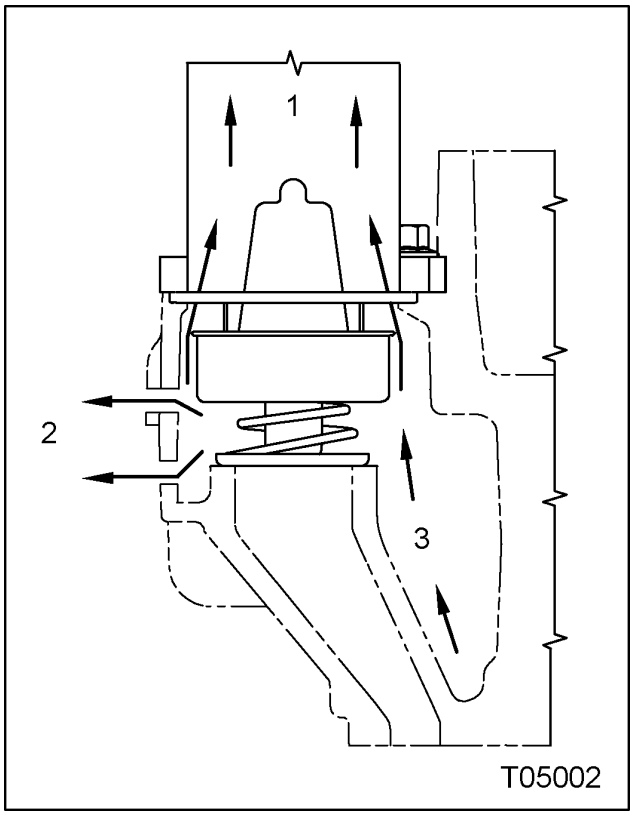


Figure 29 Thermostat Open

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

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

Low Temperature Radiator (LTR) Thermostat Operation

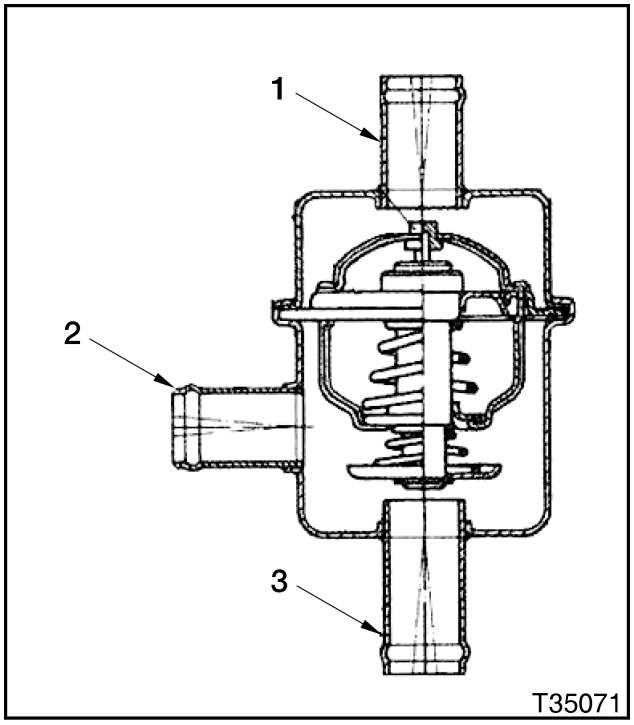


Figure 30 LTR Thermostat

1. Thermostat outlet to low temperature radiator
2. Thermostat inlet
3. Thermostat bypass to ISC

Engines equipped with Interstage Cooler (ISC) will also have a Low Temperature Radiator (LTR) and LTR thermostat. The LTR thermostat is a wax element thermostat in a housing with one inlet port and two outlet ports. During cold engine operation (thermostat closed), coolant is directed to the ISC directly, through the bypass port. At normal operating temperature (thermostat open), coolant is directed to the LTR first and then to the ISC. The thermostat begins to open at 90 °C (194 °F) and is fully open at 98 °C (209 °F). The LTR thermostat is installed on the chassis near the LTR.

Electronic Control System

Electronic Control System Components

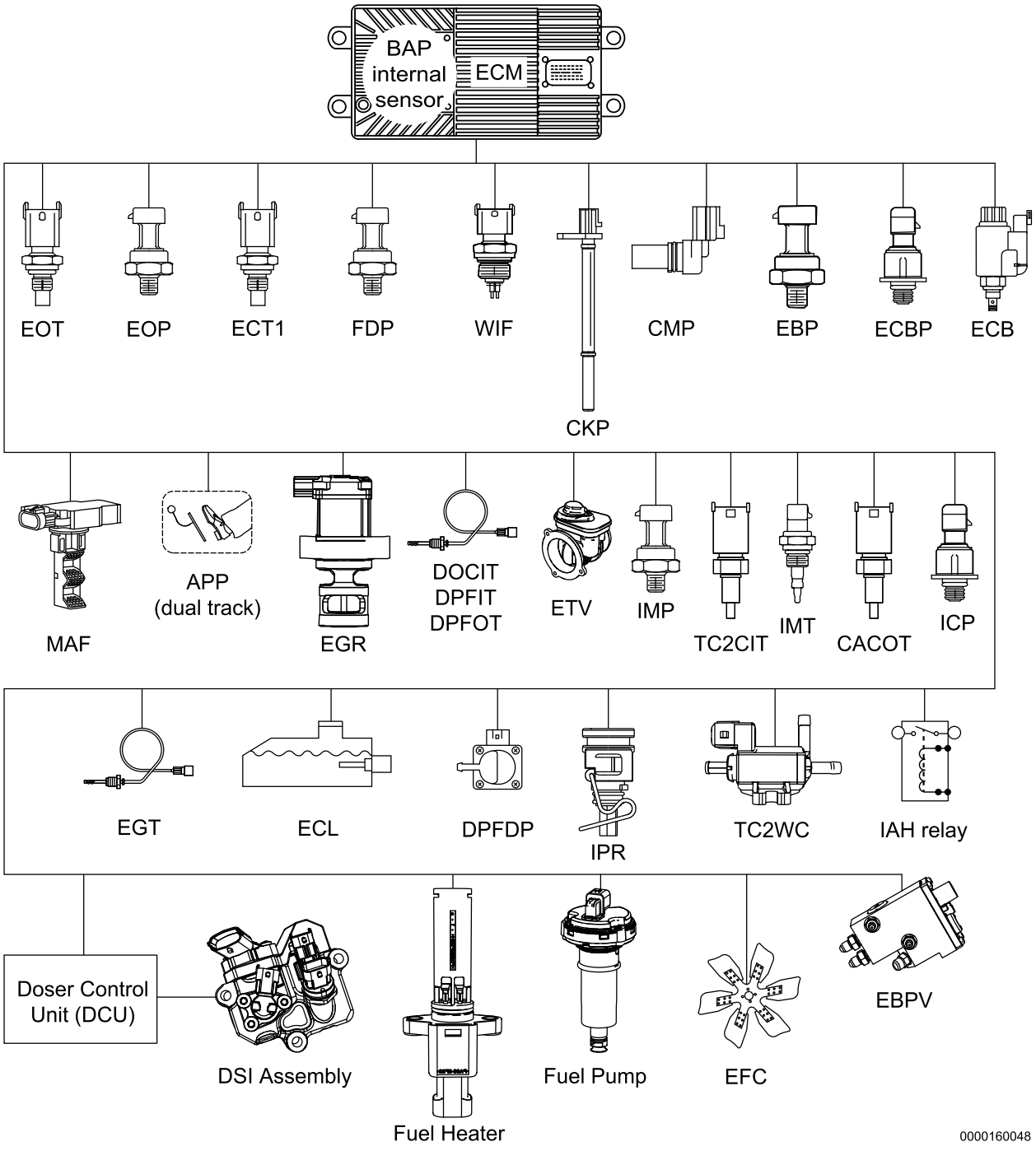


Figure 31 Electronic Control System

Operation and Function

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

- Provides Reference Voltage (VREF)
- Conditions input signals
- Processes and stores control strategies
- Controls actuators

Reference Voltage (VREF)

The ECM internal Power supply generates 5.0V (Vcc) for the internal components, a reference voltage of 5.0V for the A/D converters and also three independent short circuit protected 5.0V tracking voltages (V_REF_1, V_REF_2, V_REF_3) for external devices.

- VREF 1 supplies 5 volts to engine sensors
- VREF 2 supplies 5 volts to vehicle aftertreatment and pedal
- VREF 3 supplies 5 volts to body builder and pedal

Microprocessor

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

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, the 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)
- Controlled pulse width
- Switched on or off

Actuators

The ECM controls engine operation with the following:

- Exhaust Gas Recirculation (EGR) valve
- Intake Air Heater (IAH) relay
- Engine Throttle Valve (ETV) and position sensor
- Turbocharger 2 Wastegate Control (TC2WC) valve (turbocharger wastegate actuator)
- Exhaust Back Pressure Valve (EBPV)
- Engine Compression Brake (ECB) valve
- Injection Pressure Regulator (IPR) valve

Exhaust Gas Recirculation (EGR) Valve

The EGR valve controls the flow of exhaust gases to the air and EGR mixer duct.

The EGR valve receives the desired valve position from the ECM for exhaust gas recirculation.

Sensors within the EGR valve provide feedback to the ECM on valve position and temperature. A fault code will be set if the ECM detects an error.

Intake Air Heater (IAH) Relay

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

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

The ECM activates the IAH relay. The relay supplies battery voltage to the heater elements for a set time, depending on engine coolant temperature and altitude.

Engine Throttle Valve (ETV) and Position Sensor

The engine throttle valve controls the flow of inlet air to regulate operating temperature for exhaust aftertreatment and base engine operation.

The integral throttle actuator controls the engine throttle valve.

The throttle actuator receives the desired engine throttle valve position from the ECM to activate the

throttle valve. The throttle position sensor provides feedback to the ECM on the throttle valve position.

Turbocharger 2 Wastegate Control (TC2WC) valve (turbocharger wastegate actuator)

The turbocharger wastegate actuator regulates the charge air pressure by controlling the amount of exhaust gases that pass through the high-pressure turbine.

The TC2WC valve receives the command signal from the ECM. When the charge air pressure demand is low, the TC2WC valve opens, allowing control air to the turbocharger wastegate actuator. The actuator opens allowing part of the exhaust gas flow to bypass the high-pressure turbine.

Exhaust Back Pressure Valve (EBPV)

The Exhaust Back Pressure Valve (EBPV) controls the position of the exhaust valve increasing or decreasing exhaust gas back pressure and temperature to allow the DOC and DPF to function efficiently.

Engine Compression Brake (ECB) valve

The Engine Compression Brake (ECB) valve controls pressure entering the brake oil gallery from the injector oil gallery. This activates the brake actuator pistons and opens the exhaust valves. The ECB valve is installed in the center of the high-pressure oil manifold.

Injection Pressure Regulator (IPR) valve

The Injection Pressure Regulator (IPR) valve is used to maintain desired injection control pressure. Excess high-pressure oil is directed to the crankcase sump by the IPR valve.

Engine and Vehicle Sensors

Temperature Sensors

Thermistor Sensors

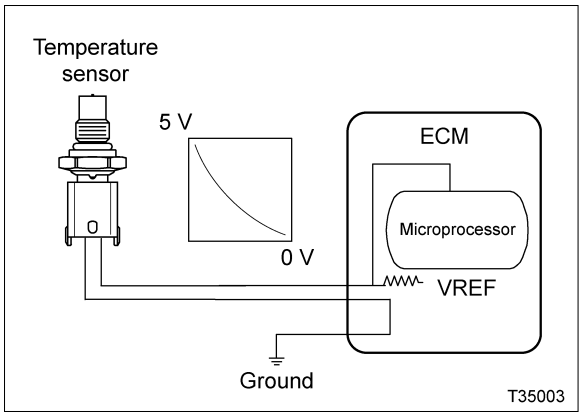


Figure 32 Thermistor Sensor

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

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

Thermistor type sensors include the following:

- Engine Coolant Temperature (ECT) sensor
- Engine Oil Temperature (EOT) sensor
- Air Inlet Temperature (AIT) sensor
- Intake Manifold Temperature (IMT) sensor

ECT Sensor

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

EOT Sensor

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

AIT Sensor

The AIT sensor is integral to the Mass Air Flow (MAF) sensor. The ECM monitors the AIT signal to control injector timing and fuel rate during cold starts. The ECM also uses the AIT signal to control EGR position and engine throttle control.

IMT Sensor

The IMT sensor monitors the air temperature in the intake manifold. The ECM monitors the IMT signal for EGR operation. The IMT sensor is installed in the intake manifold, to the right of the IMP sensor.

Exhaust Gas Temperature (EGT) sensors

The Aftertreatment System and exhaust manifold use the following sensors:

- Exhaust Gas Temperature (EGT) sensor
- Diesel Oxidation Catalyst Intake Temperature (DOCIT) sensor
- Diesel Particulate Filter Intake Temperature (DPFIT) sensor
- Diesel Particulate Filter Outlet Temperature (DPFOT) sensor

The Exhaust Gas Temperature (EGT) sensor used in the exhaust manifold provides a feedback signal to the ECM indicating exhaust gas temperature.

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

The DPFIT sensor provides a feedback signal to the ECM indicating Diesel Particulate Filter Intake (DPF) intake temperature. The DPFIT sensor is the second temperature sensor installed past the turbocharger and just after the 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 sensors along with the Exhaust Gas Recirculation (EGR) System and Engine Throttle Valve (ETV).

Variable Capacitance Sensors

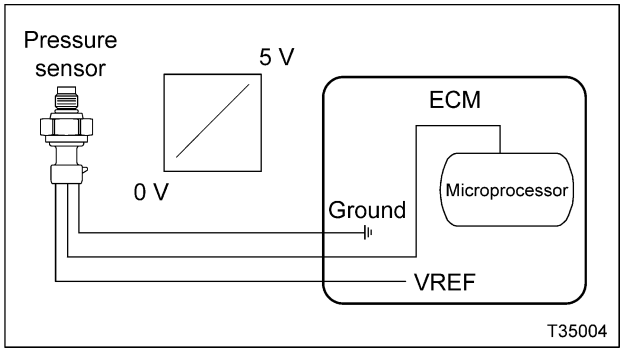


Figure 33 Variable Capacitance Sensor

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

This type of sensor has three wires, VREF, ground and a signal wire.

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

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

Variable capacitance sensors include the following:

- Fuel Delivery Pressure (FDP) sensor
- Engine Oil Pressure (EOP) sensor
- Exhaust Back Pressure (EBP) sensor
- Mass Air Flow (MAF) sensor
- Intake Manifold Pressure (IMP) sensor

FDP Sensor

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

EOP Sensor

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

EBP Sensor

The ECM monitors the exhaust pressure to control the EGR and intake throttle systems. The EBP sensor is installed in a tube mounted on the coolant supply housing (refrigerant compressor bracket).

MAF Sensor

The MAF sensor is used for closed loop control of the EGR valve and ETV. The ECM monitors the MAF signal to control the EGR and intake throttle systems. The MAF sensor also sends air temperature information to the ECM. The MAF sensor is installed in the intake air duct or air cleaner housing.

IMP Sensor

The ECM monitors the IMP signal to control the EGR and intake throttle systems. The IMP sensor is installed in the intake manifold, left of the IMT sensor.

Magnetic Pickup Sensors

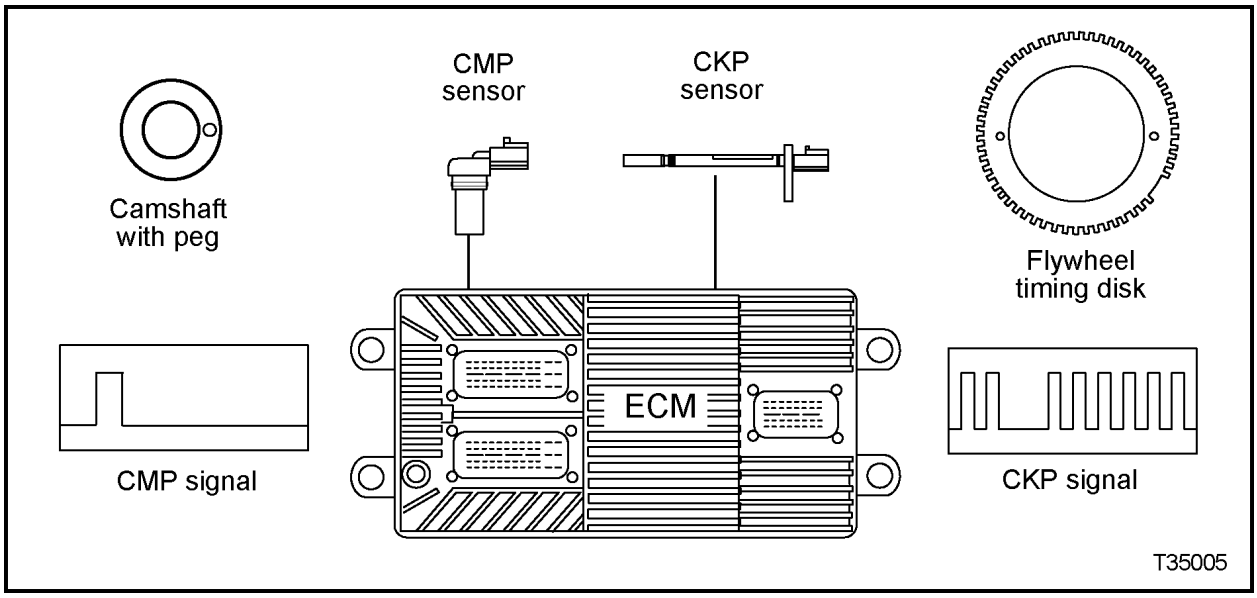


Figure 34 Magnetic Pickup Sensors

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

Magnetic pickup sensors used include the following:

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

CKP Sensor

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

CMP Sensor

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

VSS

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

High-Pressure Sensors

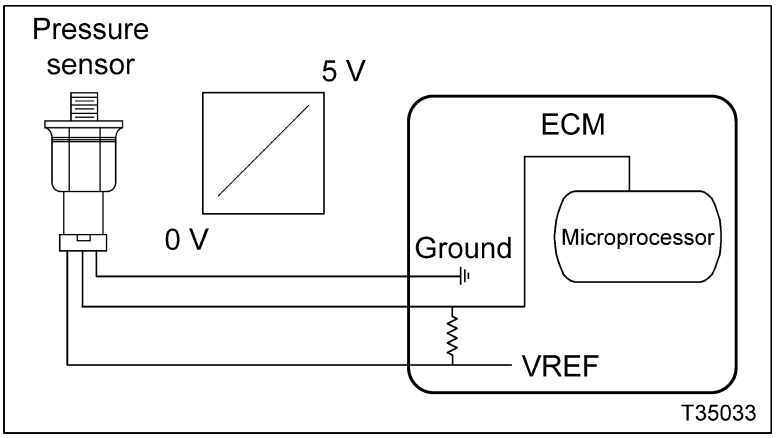


Figure 35 High-Pressure Sensor

High-pressure sensors convert pressure to a linear analog voltage output of 0–5 volts. Pressure to be measured exerts force on a diaphragm with a strain gauge bonded to it. This diaphragm stretches and compresses to change mechanical motion into an electrical signal.

This type of sensor has three wires, VREF, ground and a signal wire.

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

High-pressure sensors include the following:

- Diesel Particulate Filter Differential Pressure (DPFDP) sensor
- Engine Compression Brake Pressure (ECBP) sensor
- Injection Control Pressure (ICP) sensor

DPFDP Sensor

The DPFDP sensor provides a feedback signal to the ECM indicating the pressure difference between the inlet and outlet of the Diesel Particulate Filter (DPF). During a catalyst regeneration, the ECM monitors this sensor along with three Aftertreatment System thermistor sensors, the EGR System, and the Engine Throttle Valve (ETV).

ECBP

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

ICP

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

Potentiometer

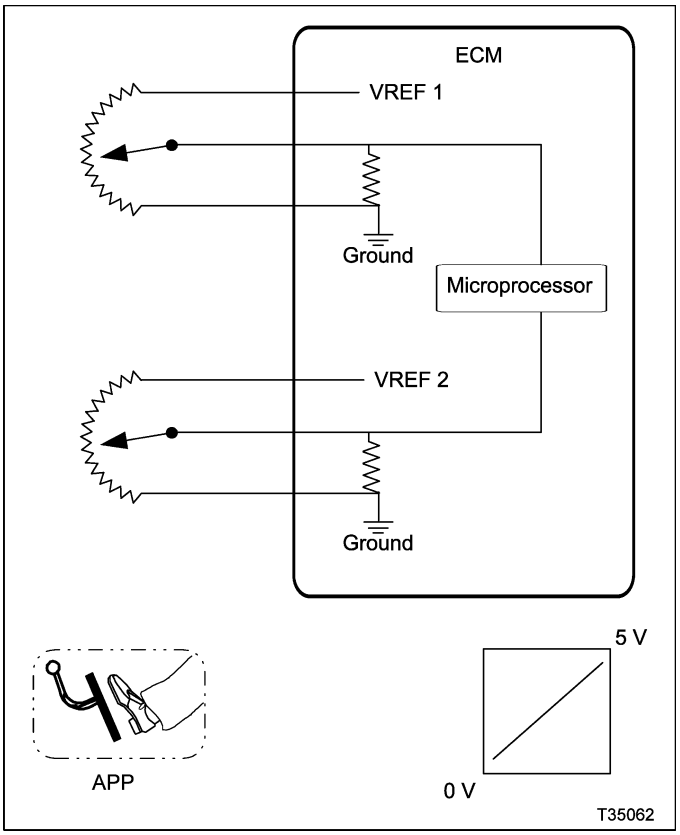


Figure 36 Potentiometer

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

APP

The APP provides the ECM with a feedback signal (linear analog voltage) that indicates the operator's demand for power. There are two potentiometers within the APP sensor. The APP is installed in the cab on the accelerator pedal.

Switches

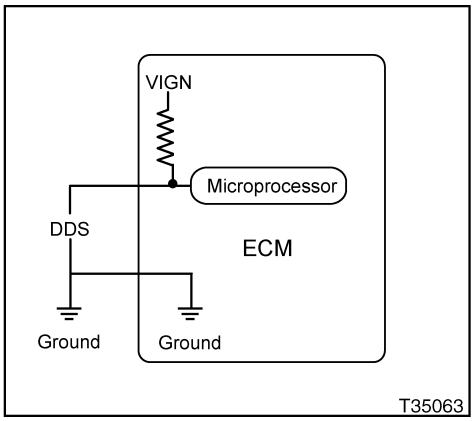


Figure 37 Switch

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

Switches include the following:

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

DDS

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

ECL

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

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

WIF

A Water In Fuel (WIF) sensor in the fuel filter assembly is used to detect water in the fuel. The resistance of the WIF sensor circuit changes when the water level in the fuel filter assembly reaches the sensor. The ECM then sends a message to illuminate the amber water in fuel lamp, alerting the operator. The WIF is installed in the side of the fuel filter assembly.

Engine Throttle Valve Control System

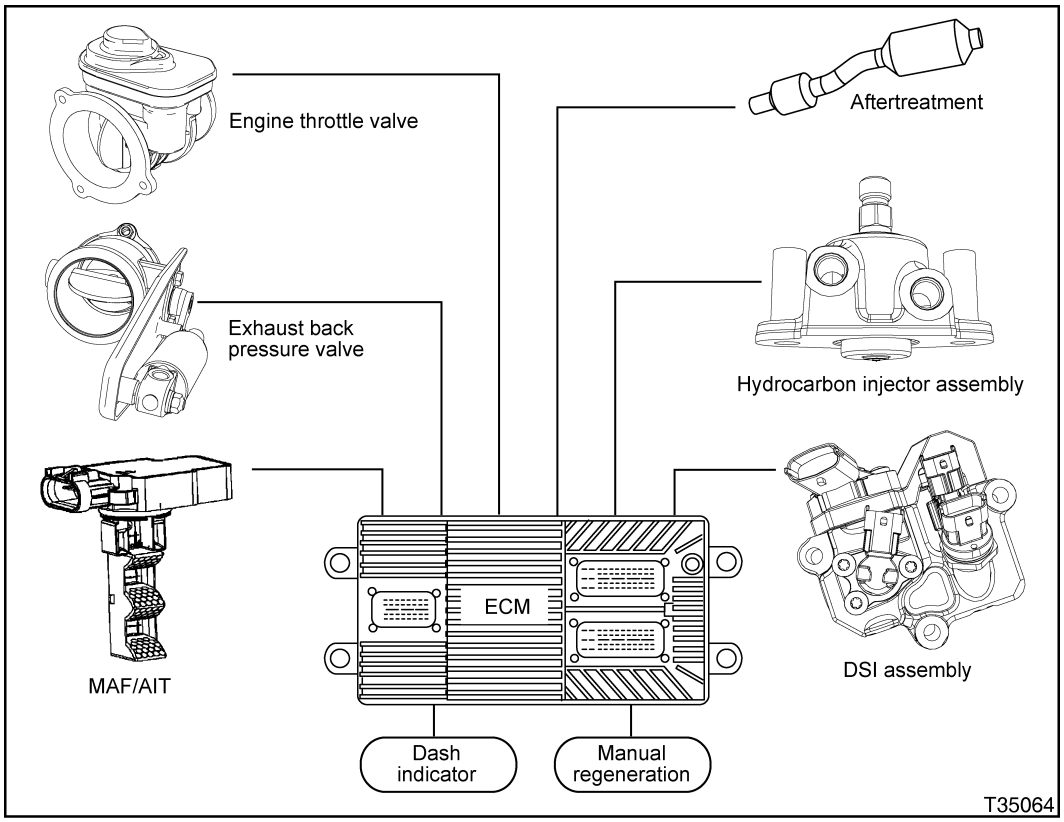


Figure 38 Engine Throttle Valve Control System

The Engine Throttle Valve (ETV) is controlled to limit inlet air. As part of the air management system, the ETV is controlled by the ECM (closed loop) based on input from the Mass Air Flow (MAF) sensor for proper emissions control.

The ETV is also used to help control inlet air during a Diesel Particulate Filter (DPF) regeneration process of the aftertreatment system. It maintains vehicle and engine performance during regenerations.

Exhaust and Engine Brake System

Exhaust Brake

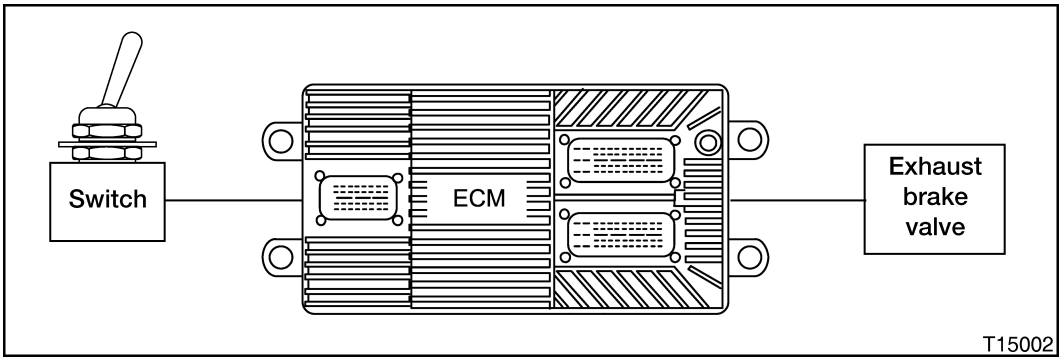


Figure 39 Exhaust Brake System

The exhaust brake is available for all ratings and aids in the deceleration rate of vehicles.

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

The operator can enable the brake function by toggling an instrument panel mounted switch ON or OFF.

Engine Brake

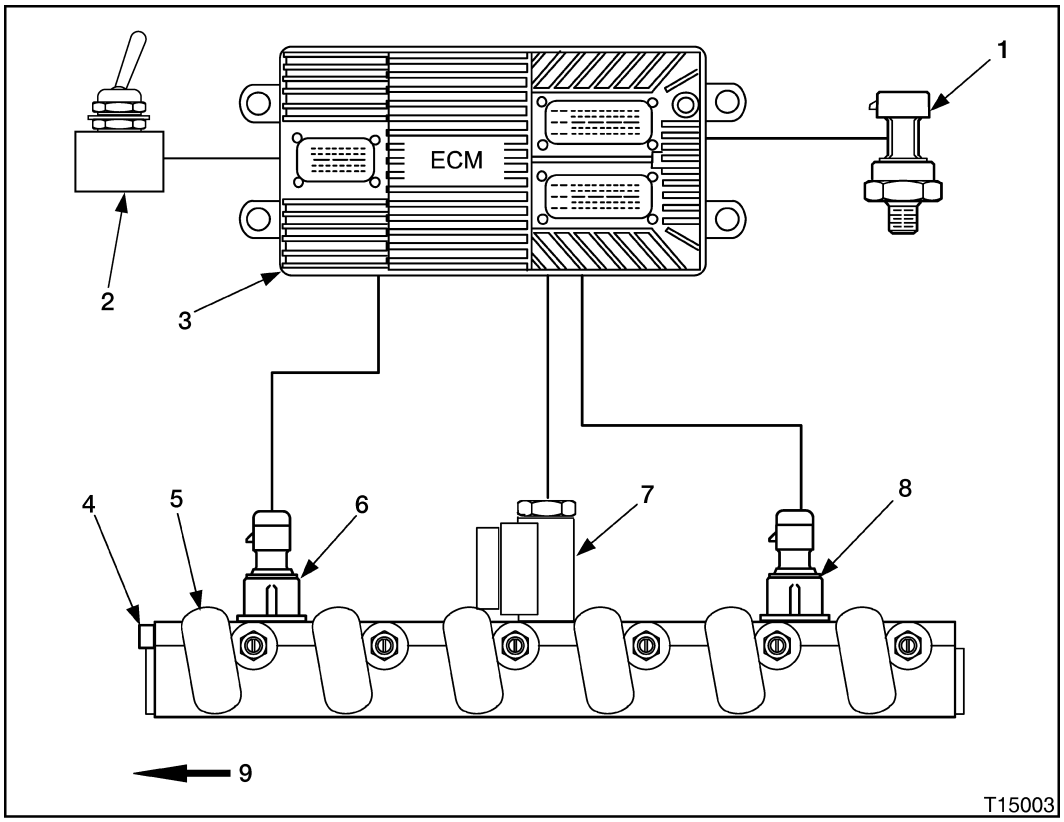


Figure 40 Engine Brake System

1. Exhaust Back Pressure (EBP) sensor
2. Switch
3. Electronic Control Module (ECM)
4. Brake pressure relief valve
5. High-pressure oil manifold
6. Engine Compression Brake Pressure (ECBP) sensor
7. Engine Compression Brake (ECB) valve
8. Injection Control Pressure (ICP) sensor
9. Front of engine

ECBP

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

ECB

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

Brake Pressure Relief Valve

The brake pressure relief valve vents excess pressure under the valve cover. Residual brake gallery pressure initially bleeds from the actuator bore. When brake gallery pressure reaches a set point, the brake pressure relief valve opens and oil drains back to the sump.

EBP

The EBP sensor is an input to the ECM for control of the Turbocharger 2 Wastegate Control (TC2WC)

valve. The TC2WC valve controls the turbocharger wastegate actuator. The EBP sensor is mounted on a tube plumbed to the exhaust manifold on the exhaust side of the engine.

High-pressure Oil Manifold

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

Operation

During engine brake operation, The ECB valve opens to supply high-pressure oil to each brake actuator piston. These brake actuator pistons hold the exhaust valves partially open.

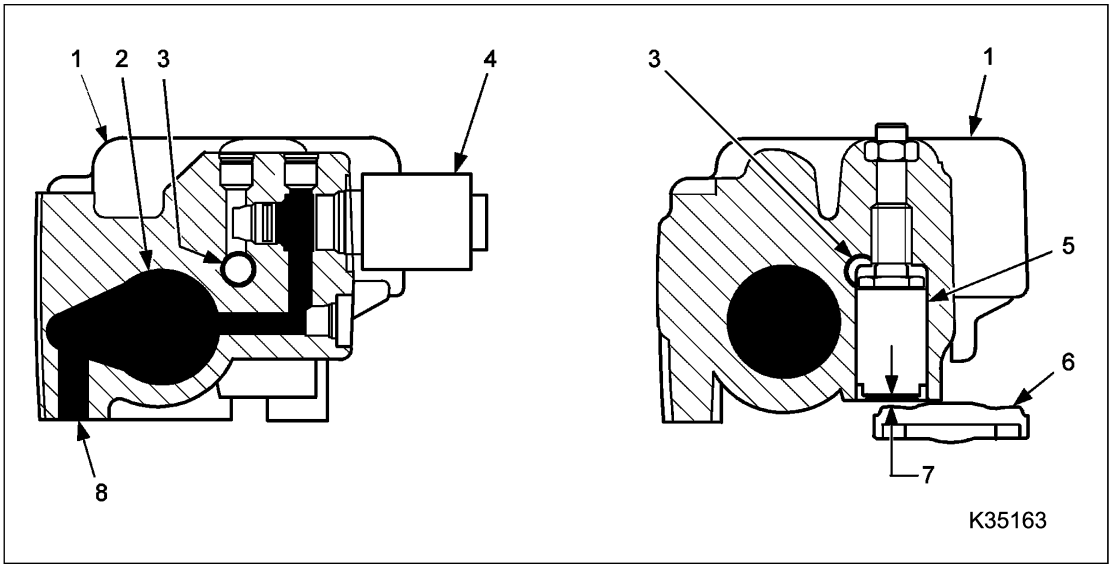


Figure 41 Engine Compression Brake Valve and Brake Actuator – OFF

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

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

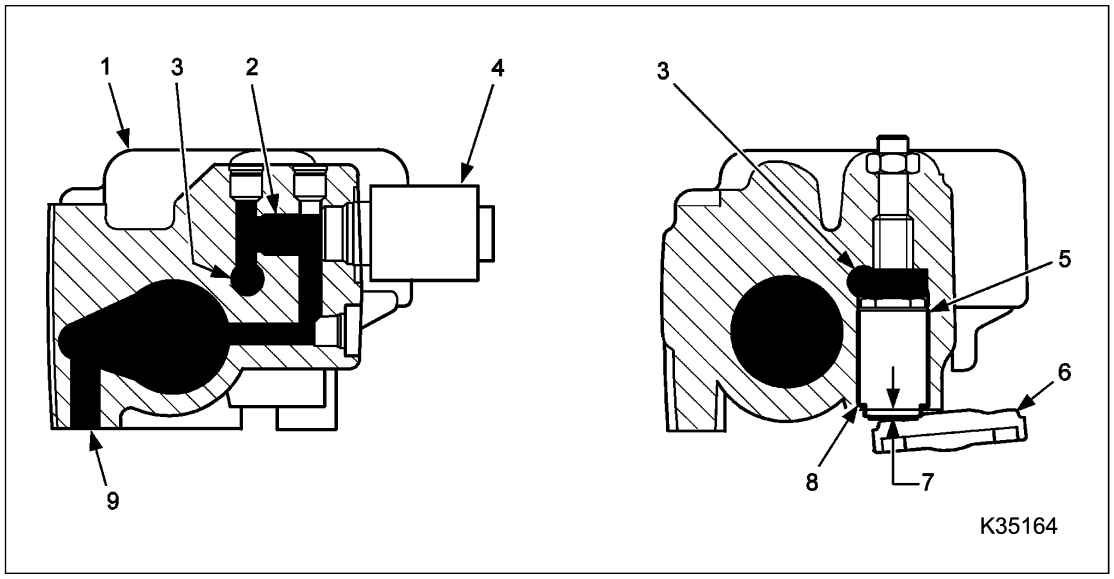


Figure 42 Engine Compression Brake Valve and Brake Actuator – ON

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

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

- Anti-lock Brake System (ABS) (inactive)
- RPM (greater than 1200)
- APP (less than 5%)
- EOT (greater than or equal to 60 °C [140 °F])
- Operator input switches (On/Off)

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

When the engine brake is activated, the ECM provides the power to activate the Engine Compression Brake (ECB) valve to allow oil from the injector oil gallery to flow to the brake oil gallery. High oil pressure activates the brake actuator pistons to open the exhaust valves.

Vehicle momentum is absorbed by the resulting compression release of the engine power cylinders when pistons are near the top of their stroke.

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

The ECM removes the power source from the ECB valve to deactivate the engine brake. Residual brake gallery pressure initially bleeds from the actuator bore. When brake gallery pressure bleeds down the brake pressure relief valve opens, and oil drains back to sump.

Operation Modes

The engine brake system provides three programmable modes of operation based on terrain, driving conditions, or driver preference.

Coast Mode

When the coast mode is programmed, the brake system will activate only when the driver applies the vehicle service brake. The coast mode allows

the vehicle to coast without automatic brake system activation.

Latched Mode

When the latch mode is programmed, the brake system will activate when the driver releases the accelerator pedal. The brake system will deactivate when the driver depresses the accelerator or clutch pedals. The brake system will also deactivate when the engine speed is below a pre-programmed rpm.

Cruise Mode

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

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Engine Preparation

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

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

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

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

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

Clean Engine

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

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

Drain Coolant

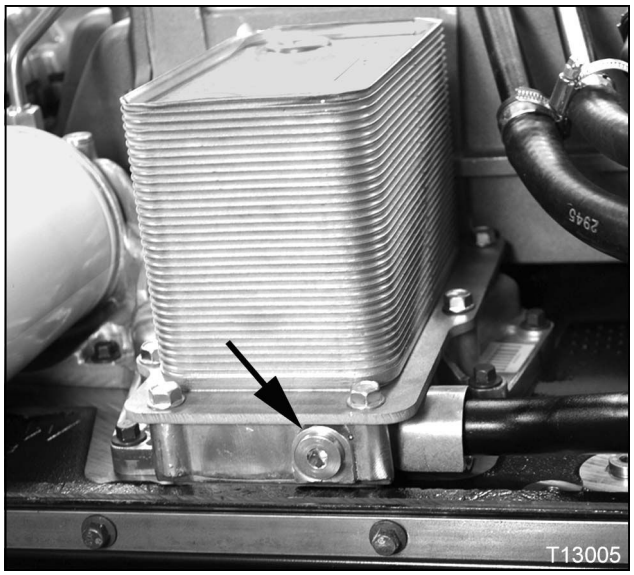


Figure 43 Coolant Drain Plug

⚠ WARNING: To prevent personal injury or death, allow engine to cool before draining coolant.

1. Place a coolant drain pan under the oil system module.
2. Remove M16 coolant drain plug from the bottom of the oil system module. Open radiator cap to allow system to drain quicker.
3. Remove and discard coolant drain plug O-ring.
4. Install a new O-ring on the coolant drain plug.
5. After coolant has drained, install coolant drain plug in the oil system module.
6. Tighten coolant drain plug to special torque (page 70).
7. Recycle or dispose of coolant according to applicable regulations.

Drain Oil

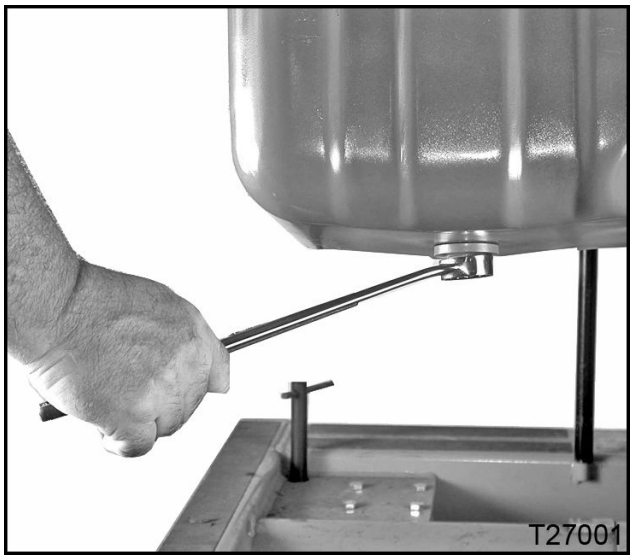


Figure 44 Oil Drain Plug Removal

1. Place an oil drain pan beneath the oil drain plug.
2. Remove the oil pan drain plug and discard O-ring.
3. Inspect drain plug and replace if necessary.
4. Install a new O-ring on the oil drain plug.
5. After oil has drained, lubricate oil drain plug O-ring with clean engine oil and install oil drain plug in the oil pan.
6. Tighten oil drain plug to special torque (page 70).
7. Recycle or dispose of oil according to applicable regulations.

Removing Engine from Vehicle

Remove engine from vehicle. Lift engine using factory installed lifting eyes and an appropriately rated chain hoist equipped with safety hooks.

Removal

Electrical Connections

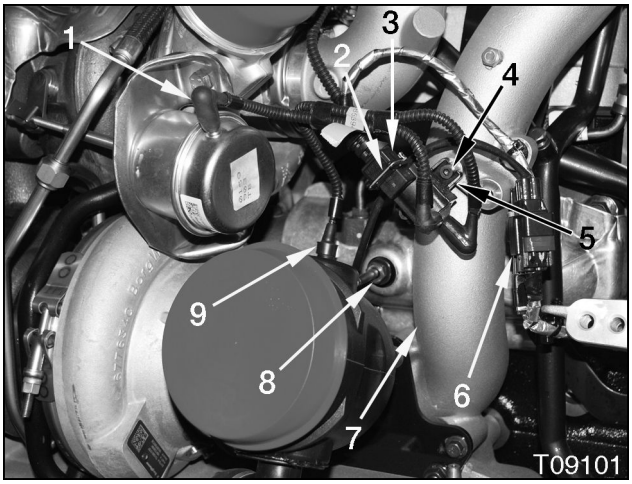


Figure 45 Boost Control Harness and Electrical Connections

1. Turbocharger wastegate actuator connector—vacuum line
2. Connector wire clip lock
3. Turbocharger 2 Wastegate Control (TC2WC) valve 2-pin connector
4. M5 x 16 socket head bolt (2)
5. Insulator—high temperature plastic (2)
6. Exhaust Gas Temperature (EGT) connector
7. Interstage Cooler (ISC) inlet duct
8. Exhaust Gas Temperature (EGT) sensor
9. Turbocharger air inlet duct connector—vacuum line

1. Remove boost control harness assembly and Turbocharger 2 Wastegate Control (TC2WC) Valve. See Boost Control Harness Assembly and Turbocharger 2 Wastegate Control (TC2WC) Valve (page 85).
2. Disconnect connector from Exhaust Gas Temperature (EGT) sensor. See Exhaust Gas Temperature (EGT) Sensor (page 89).
3. Move engine wiring harness to the side so components can be removed to mount the Engine Stand Bracket (page 70) to the crankcase.

Aftertreatment / Turbocharger Disconnection Points

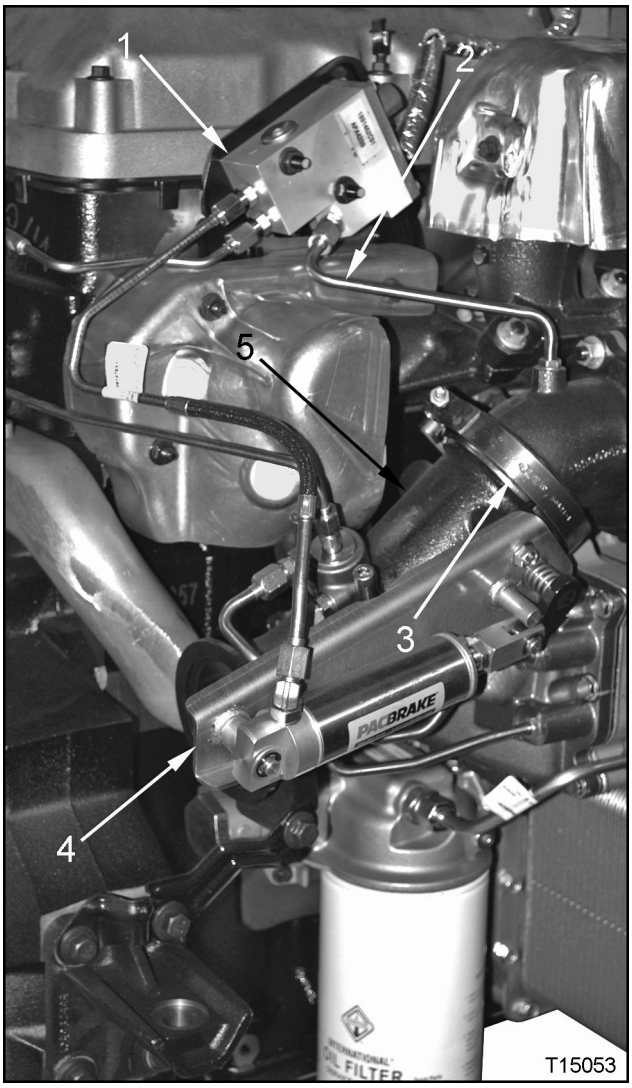


Figure 46 Aftertreatment / Turbocharger Disconnection Points (typical)

1. Exhaust brake valve
2. Exhaust brake tube
3. Exhaust clamp
4. Actuator brake assembly
5. Exhaust brake under rail housing

NOTE: The following procedure is correct for vehicles equipped with either the exhaust under rail brake assembly or the exhaust over rail brake assembly.

1. Loosen the exhaust clamp so it will slide off onto the exhaust brake under rail housing.
2. Loosen the 5/16 nut and the 37 degree nut on the exhaust brake tube. Remove tube; do not discard.

Turbocharger Oil Supply Tube Assembly and Heat Shield

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

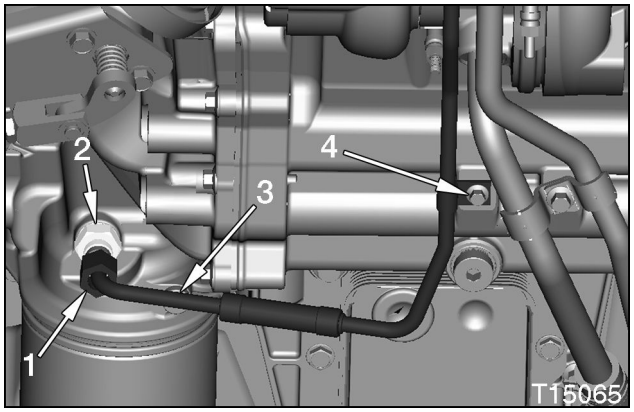


Figure 47 Turbocharger Oil Supply Tube Assembly

1. Turbocharger oil supply tube nut
2. Fitting and O-ring (with screen)
3. Oil supply tube assembly
4. M6 x 12 bolt

1. Remove turbocharger oil supply tube nut from fitting and O-ring (with screen) on the oil cooler housing.
2. Remove M6 x 12 bolt securing turbocharger oil supply tube assembly retainer to EGR cooler.

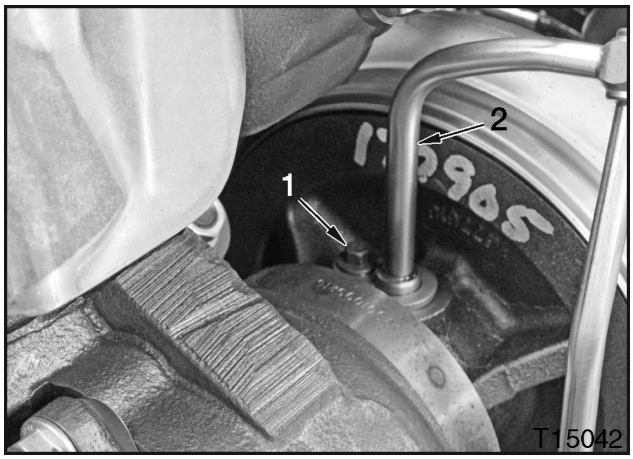


Figure 48 Oil Supply Tube at Low-Pressure Turbocharger Assembly

1. M6 x 16 bolt
2. Oil supply tube assembly

3. Remove M6 x 16 bolt securing oil supply tube assembly to low-pressure turbocharger.

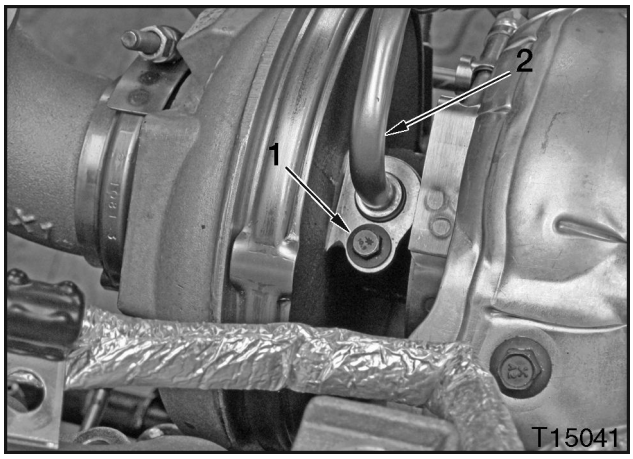


Figure 49 Oil Supply Tube at High-Pressure Turbocharger Assembly

1. M6 x 16 bolt
2. Oil supply tube assembly

4. Remove M6 x 16 bolt securing oil supply tube assembly to high-pressure turbocharger.
5. Remove oil supply tube assembly.
6. Remove and discard two oil supply tube O-rings.

7. Install Disposable Air and Fuel Caps (page 70) on the ends of the turbocharger oil supply tube and on the oil supply ports of the turbocharger and oil system module turbo oil supply adapter.

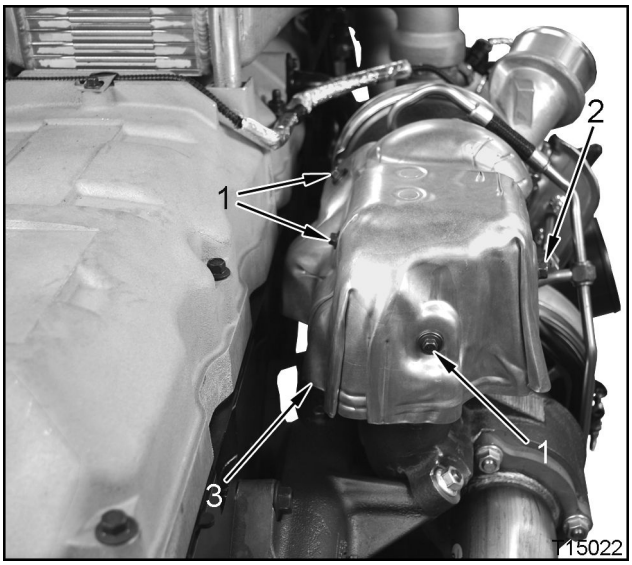


Figure 50 Turbocharger Heat Shield

1. M8 x 12 bolt (3)
2. M8 x 27 bolt (hi temp)
3. Turbocharger heat shield

8. Remove one M8 x 27 bolt.
9. Remove three M8 x 12 bolts. Remove turbocharger heat shield from turbocharger.

ISC Inlet Elbow and Intercooler

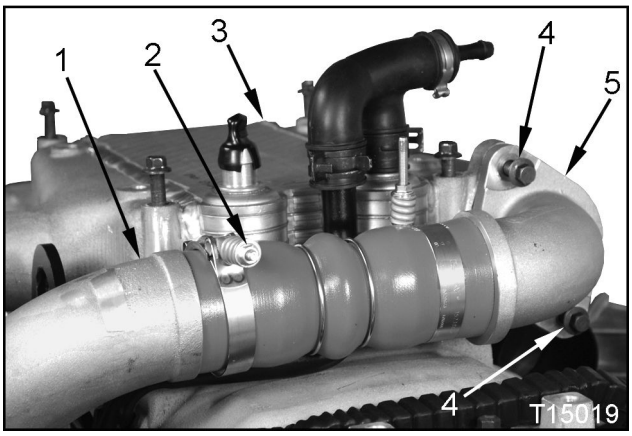


Figure 51 ISC Inlet Elbow

1. Interstage cooler inlet duct
2. Hose T-bolt / coil spring clamp
3. M6 x 30 bolt (2)
4. ISC inlet elbow

1. Remove two M6 x 30 bolts securing the Interstage Cooler (ISC) inlet elbow to the interstage cooler assembly.
2. Loosen nut on hose spring clamp and turn the ISC inlet elbow away from the interstage cooler assembly.

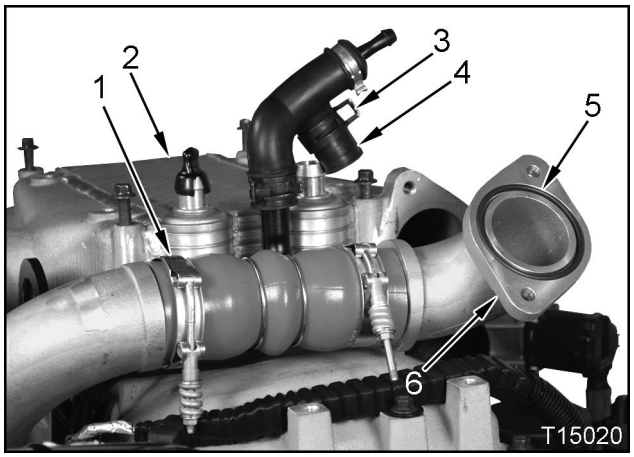


Figure 52 Turned ISC Inlet Elbow and Disengaged Elbow Deaeration Hose

1. Hose T-bolt / coil spring clamp (2)
2. Interstage cooler
3. Heat exchanger clamp
4. Deaeration hose elbow
5. O-ring
6. ISC inlet elbow

3. Loosen heat exchanger clamp on deaeration hose elbow and pull up elbow to disengage from intercooler assembly.
4. Remove and discard ISC inlet elbow O-ring.

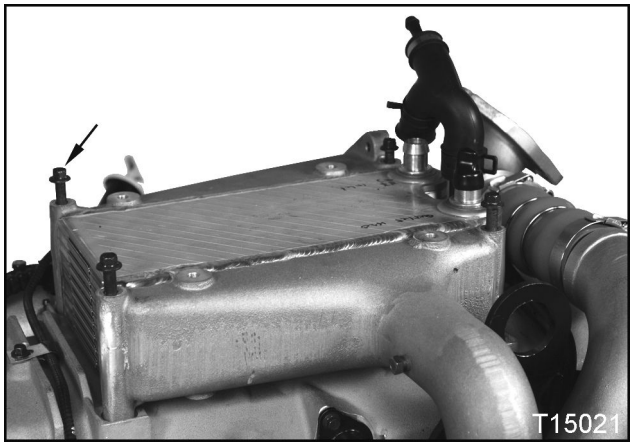


Figure 53 Interstage Cooler Mounting Bolts

5. Loosen and remove four M8 x 110 bolts securing the interstage cooler to the valve cover. Remove interstage cooler from engine.

Turbocharger Oil Drain Tubes and Turbocharger

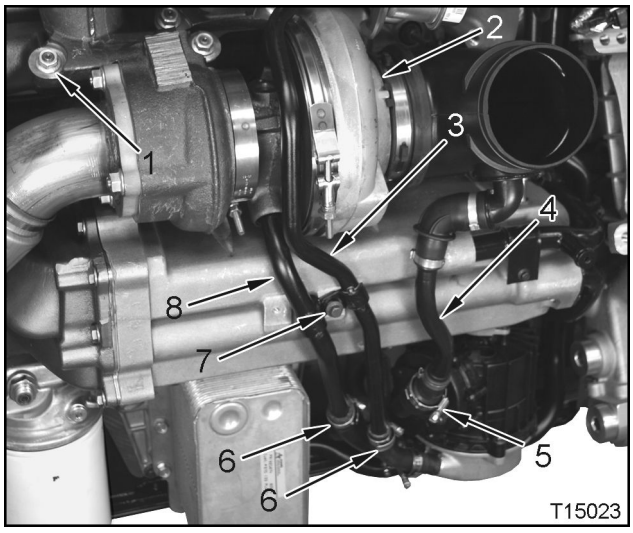


Figure 54 Turbocharger Oil Drain Tubes

1. M10 nut special thread (5)
2. Low-pressure turbocharger
3. High-pressure turbocharger oil drain tube
4. Breather tube assembly
5. Breather tube assembly worm gear clamp
6. Turbocharger oil drain tube worm gear clamp (2)
7. M8 x 25 bolt
8. Low-pressure turbocharger oil drain tube

1. Remove M8 x 25 bolt securing turbocharger oil drain tubes.
2. Loosen turbocharger oil drain tube worm gear clamps and disconnect drain tubes (high and low-pressure) from the turbocharger and crankcase breather.
3. Loosen breather tube assembly worm gear clamp. Disconnect breather tube assembly from crankcase breather.

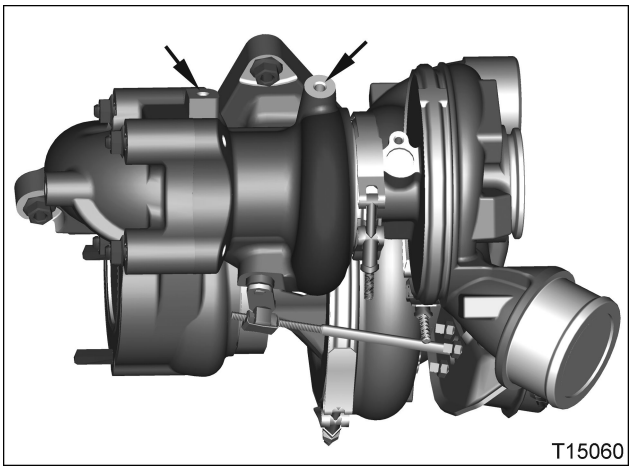


Figure 55 Turbo Lifting Bracket Mounting Location

4. Install Turbo Lifting Bracket (page 70) onto the turbocharger. Install the lifting bracket and secure using the two front bolt holes used to secure the turbocharger heat shield.
5. Attach a hoist to the Turbo Lifting Bracket, then loosen and remove five M10 nuts securing turbocharger to the exhaust manifold.
6. Remove turbocharger assembly and discard gasket.
7. Remove the High Fin Density EGR Cooler and Components (page 173) and the Interstage Inlet Duct Assembly (page 132).

Oil Filter

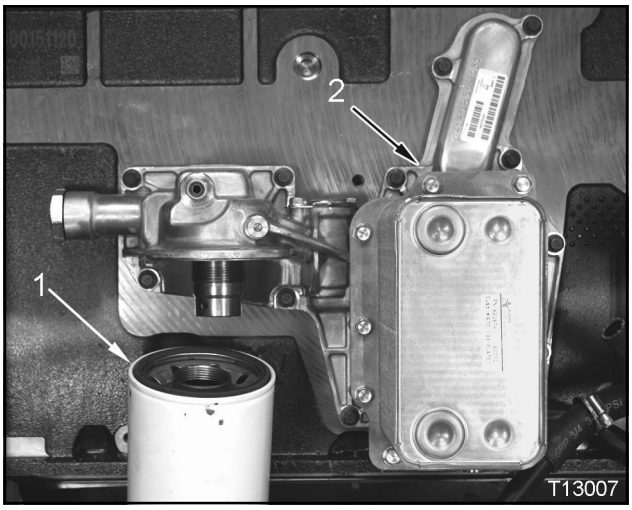


Figure 56 Oil Filter

1. Oil filter (spin-on)
2. Oil cooler module assembly

1. Place an oil drain pan under the oil filter.
2. Rotate oil filter counterclockwise with an oil filter wrench (page 70) and remove oil filter.
3. Remove oil filter gasket and discard, if stuck to the oil cooler module assembly.
4. Recycle or dispose of oil and filter with gasket, according to applicable regulations.

Oil System Module Assembly

NOTE: Components in the following figure have been removed for clarity of tube support location.

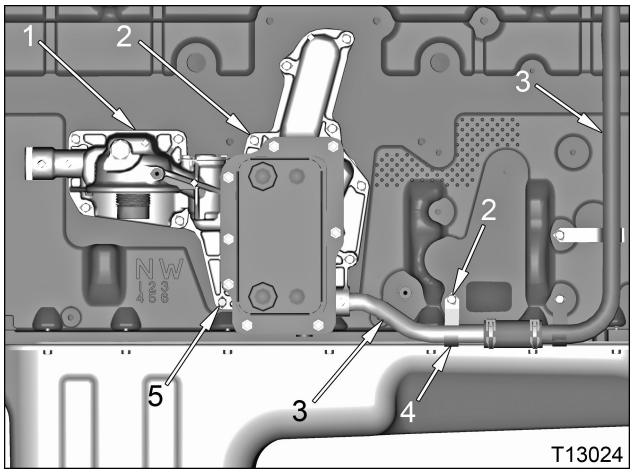


Figure 57 Oil Cooler Module and Coolant Return Tube

1. Oil cooler module assembly
2. M8 x 30 bolt (11)
3. Coolant return tube assembly
4. Tube support
5. M8 x 30 stud bolt

1. Place a drain pan under the oil cooler module assembly.
2. Loosen, do not remove, one M8 x 30 bolt securing the closest tube support to the oil cooler module.
3. Remove, do not discard, one M8 x 30 stud bolt from the oil cooler module.
4. Remove ten M8 x 30 bolts securing the oil cooler module to the crankcase. Pull the oil cooler module slightly away from the crankcase, then pull back to remove the oil cooler module from the coolant return tube.
5. Discard O-ring from the coolant return tube.
6. Recycle or dispose of oil and coolant according to applicable regulations.

Mounting Engine Stand Bracket and Engine

Mounting Engine Stand Bracket

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

⚠ 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.

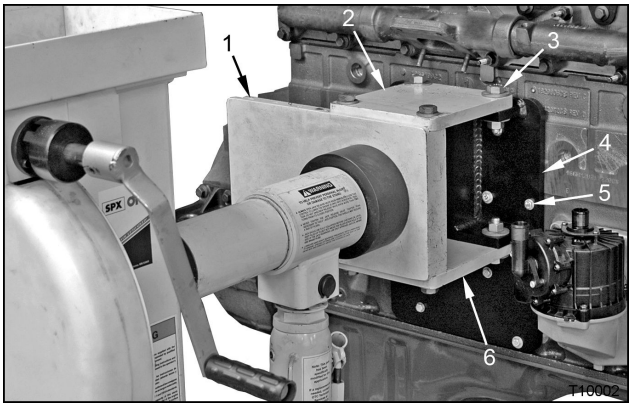


Figure 58 Engine Stand Bracket and Engine Stand

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

1. Install bottom square plate on the Engine Stand (page 70) using two Class 10.9 M16 bolts and tighten to standard torque (page 553).
2. Match Engine Stand Bracket (page 70) holes with bolt holes in the exhaust side of the crankcase and install 11 appropriately sized Class 10.9 M8 bolts.
3. Tighten all 11 bolts to standard torque (page 553).
4. Raise or lower the engine to the approximate height of the Engine Stand.
5. Install two Class 10.9 M16 bolts through the bottom square plate and Engine Stand Bracket. Install two Class 10.9 M16 nuts and washers on bolts and finger tighten.
6. Install the top square plate on the Engine Stand using two Class 10.9 M16 bolts and tighten to standard torque (page 553).
7. Raise or lower the engine as needed to match the engine plate to the Engine Stand.
8. Install two Class 10.9 M16 bolts and washers securing the top plate to the engine stand. Tighten eight M16 bolts to standard torque (page 553).
9. Slowly release tension from engine hoist.
10. Remove hoist safety chain hooks from engine lifting eyes.

NOTE: When installing components back onto engine, be sure to use new gaskets, seals, and O-rings.

Special Torque

Coolant drain plug, M16	21 N·m (15 lb·ft)
Oil pan drain plug	68 N·m (50 lb·ft)

Special Service Tools

Disposable Air and Fuel Caps	ZTSE4891
Engine Stand Bracket	ZTSE4940
Engine Stand	OTC1750A
Oil filter wrench	Obtain locally
Turbo Lifting Bracket	ZTSE 4942

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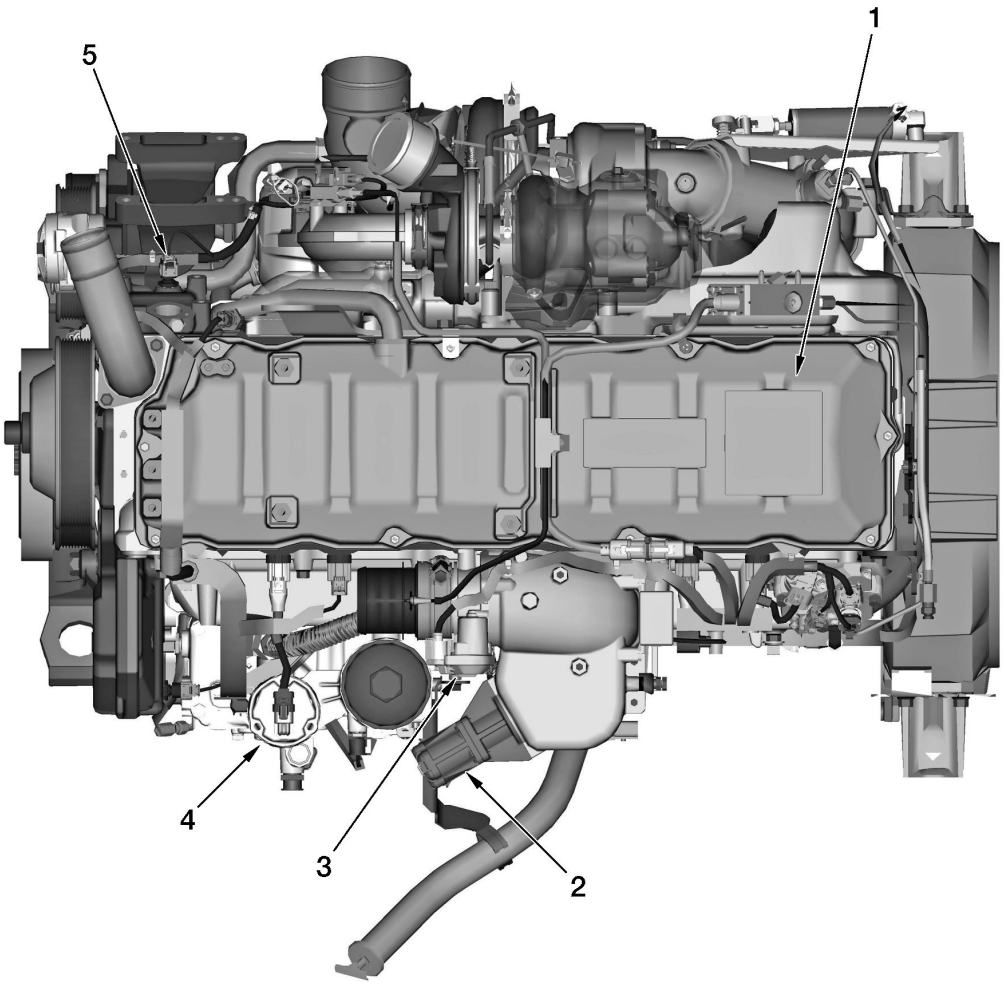


Figure 59 Electronic Components – Top

1. Injection Control Pressure (ICP) sensor (under valve cover)
2. Exhaust Gas Recirculation (EGR) valve assembly
3. Engine Throttle Valve (ETV) assembly
4. Electric fuel pump
5. Engine Coolant Temperature 1 (ECT1) sensor

Electronic Components – Front

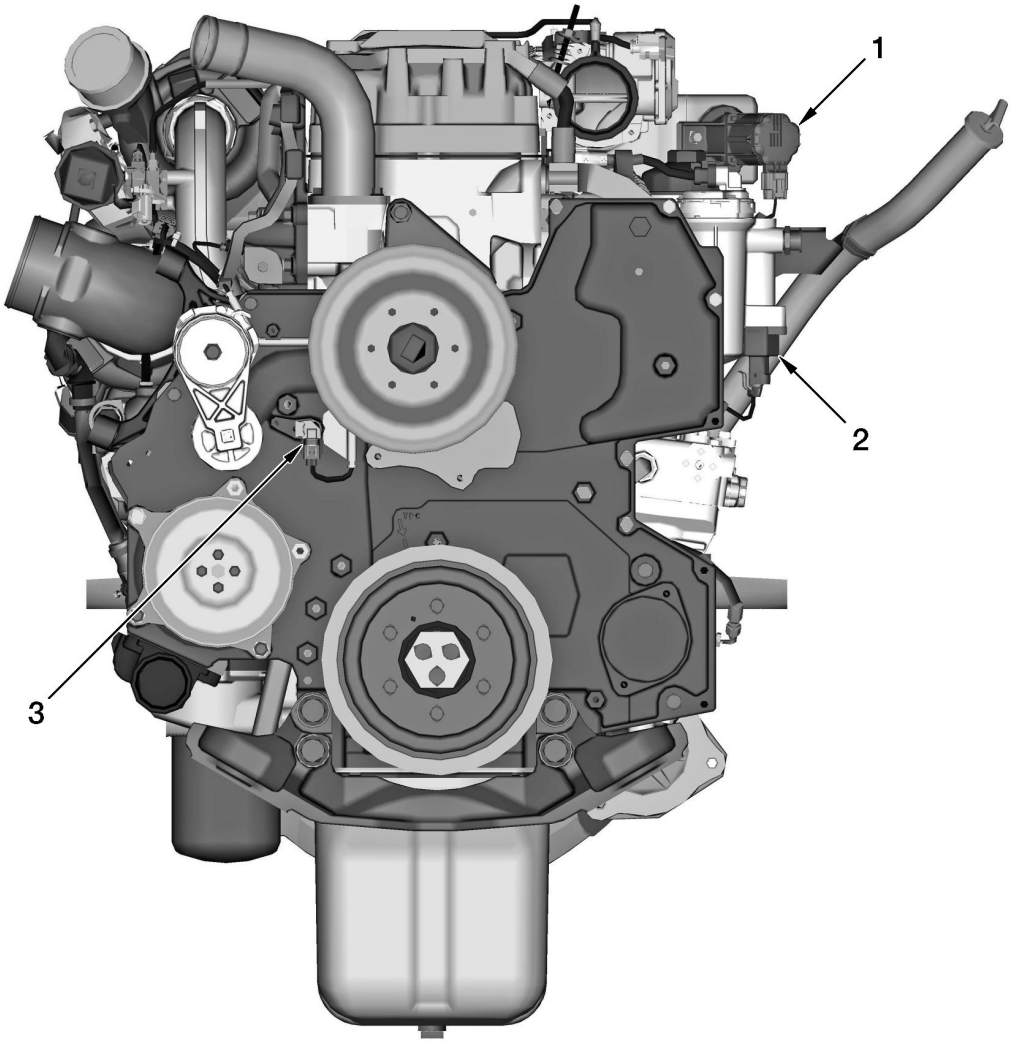


Figure 60 Electronic Components – Front

1. Exhaust Gas Recirculation (EGR) valve assembly
2. Fuel heater
3. Camshaft Position (CMP) sensor

Electronic Components – Exhaust Side

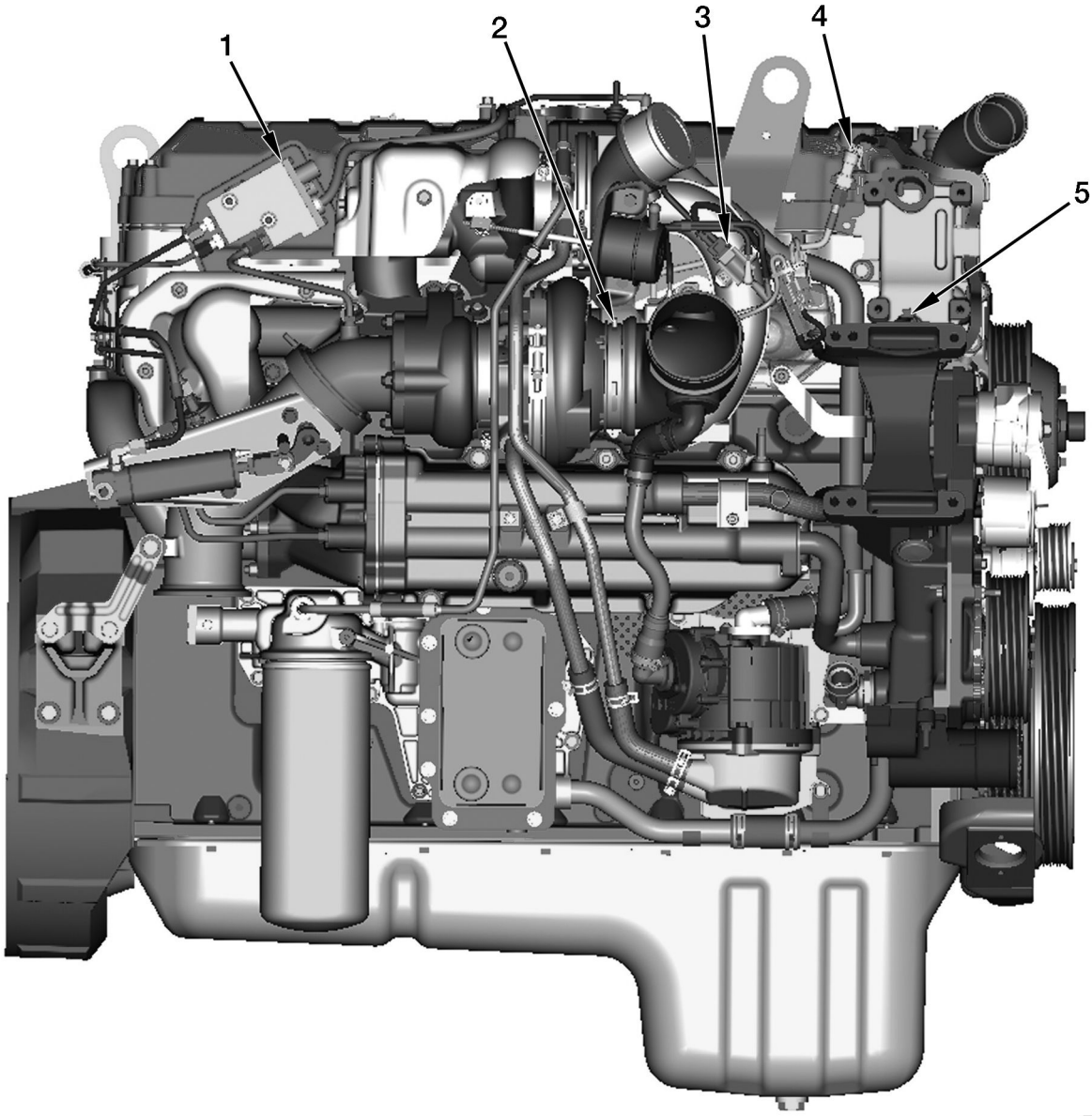
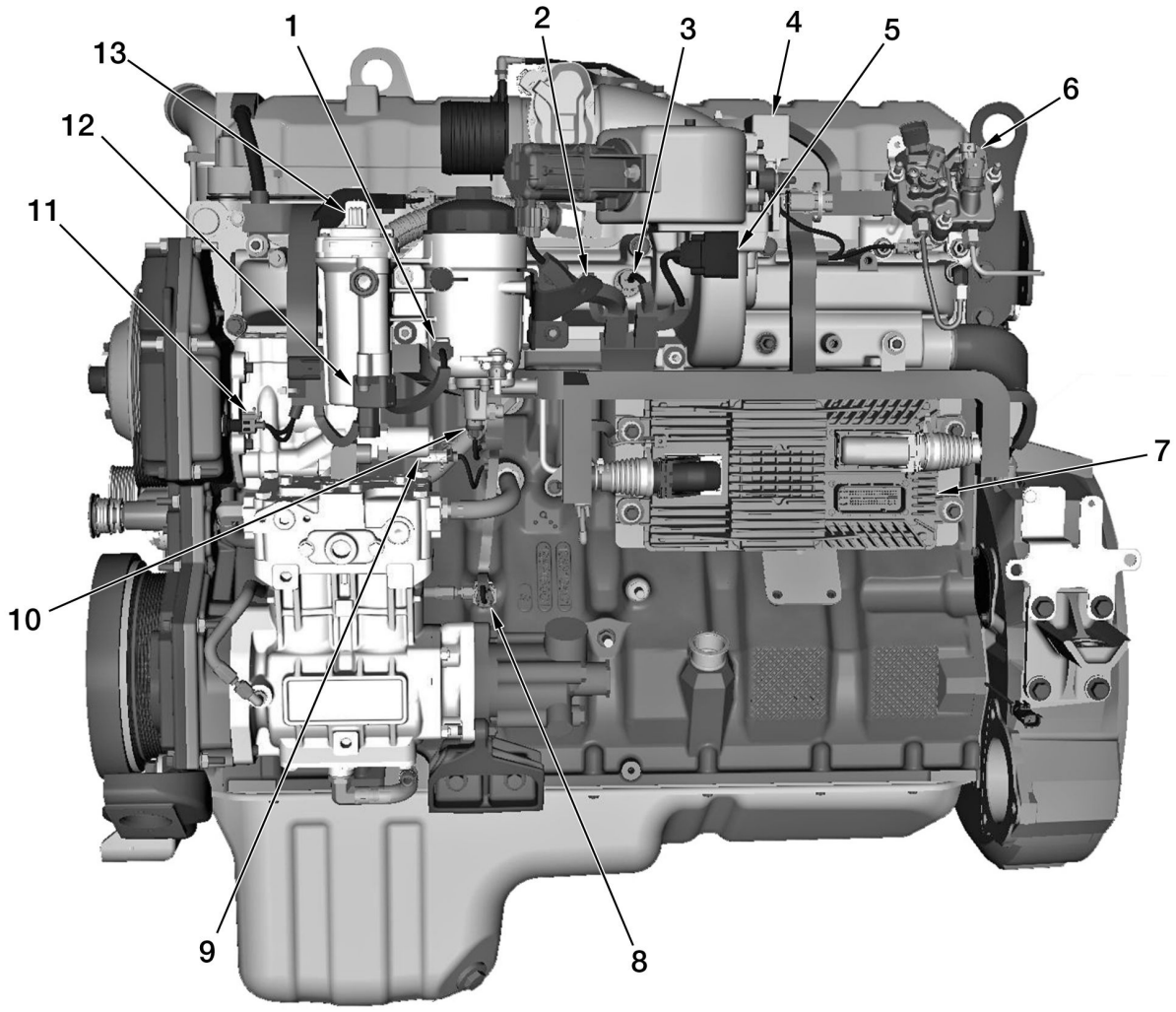


Figure 61 Electronic Components – Exhaust Side

1. Exhaust brake valve
2. Exhaust Gas Temperature (EGT) sensor (behind turbo air inlet duct)
3. Turbocharger 2 Wastegate Control (TC2WC) valve
4. Exhaust Back Pressure (EBP) sensor
5. Engine Coolant Temperature 1 (ECT1) sensor

Electronic Components – Intake Side



T09053

Figure 62 Electronic Components – Intake Side

1. Water In Fuel (WIF) sensor
2. Intake Manifold Pressure (IMP) sensor
3. Intake Manifold Temperature (IMT) sensor
4. Intake Air Heater (IAH) relay assembly
5. 16-pin truck interconnect
6. Downstream Injection (DSI) assembly
7. Engine Control Module (ECM)
8. Engine Oil Pressure (EOP) sensor
9. Injection Pressure Regulator (IPR) valve
10. Fuel Delivery Pressure (FDP) Sensor
11. Engine Oil Temperature (EOT) sensor
12. 250 Watt fuel heater (optional)
13. Electric fuel pump

Electronic Components – Rear

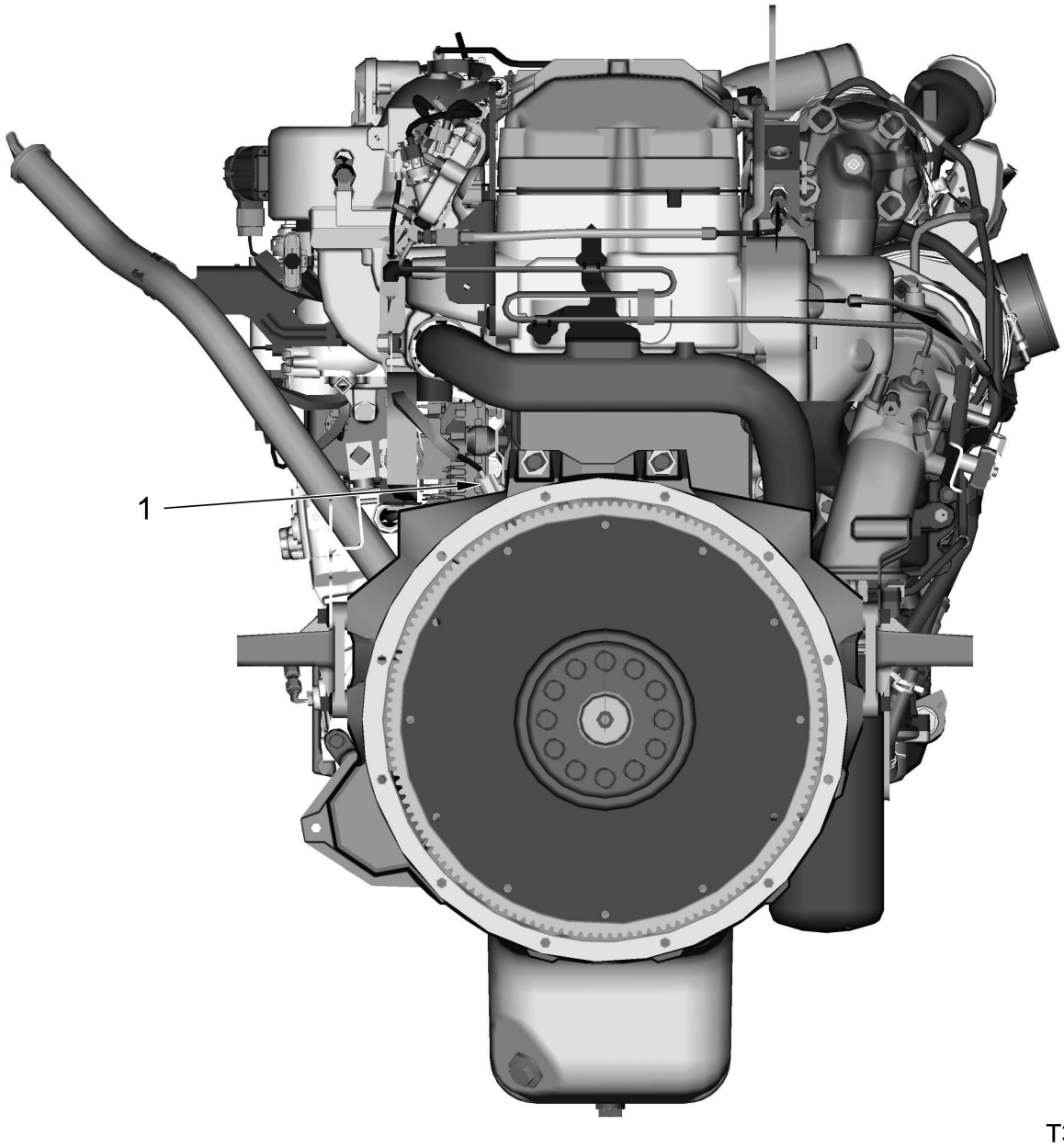


Figure 63 Electronic Components – Rear

1. Crankshaft Position (CKP) sensor

Description of Engine Sensors, Valves, and Actuators

See Electronic Control System (page 44) for additional details.

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

- **MaxxForce® DT, 9, and 10 *Engine Diagnostic Manual***
- **MaxxForce® DT, 9, and 10 Diagnostic Form**
- **MaxxForce® DT, 9, and 10 Electronic Control System Diagnostics Form**

Turbocharger 2 Wastegate Control (TC2WC) Valve

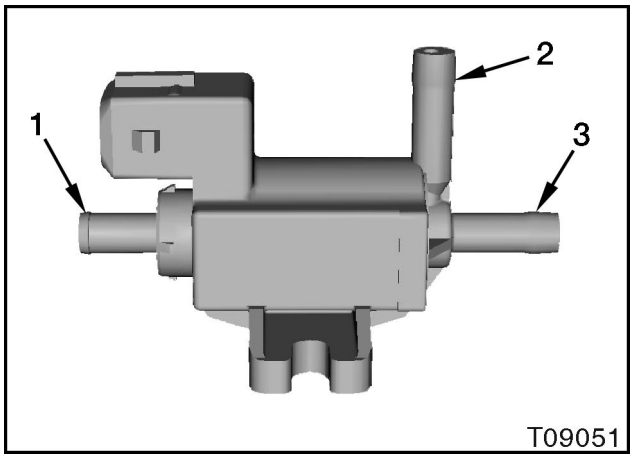


Figure 64 TC2WC Valve

1. Pressurized air from throttle inlet
2. To wastegate actuator
3. To turbocharger air inlet duct

The TC2WC valve controls flow of pressurized air from the Charge Air Cooler (CAC) to control the wastegate actuator of the turbocharger.

The TC2WC is normally open. The Engine Control Module (ECM) applies maximum voltage to the TC2WC during initial engine operation to prevent air pressure from reaching the wastegate actuator. The ECM sends a PWM signal to the TC2WC valve based on input from the Exhaust Back Pressure (EBP) sensor. When EBP exceeds a specified limit, the ECM lowers the PWM signal to the TC2WC valve which allows pressurized air to enter the wastegate actuator.

The wastegate actuator then opens a bypass valve in the high-pressure turbine exhaust stream to lower the amount of exhaust gas pressure directed to the turbocharger. When the exhaust pressure drops below a specified level, the ECM increases the PWM signal to the TC2WC which prevents air pressure from reaching the wastegate actuator. The air pressure in the actuator is then vented through the TC2WC valve and into the intake air duct.

The TC2WC valve is installed on the exhaust side of the engine in front of the turbochargers on the interstage cooler inlet duct near the wastegate actuator.

Camshaft Position (CMP) Sensor

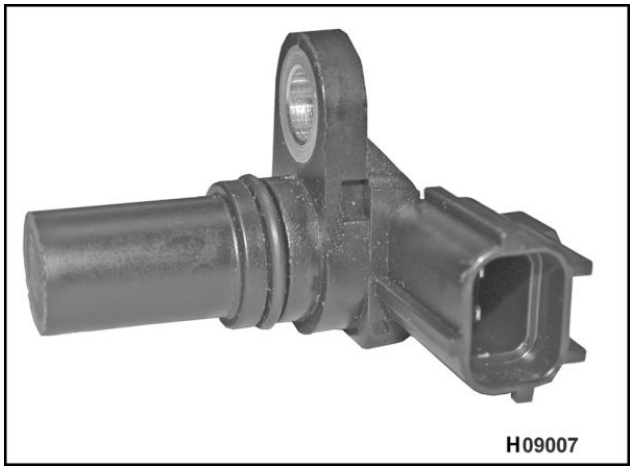


Figure 65 CMP Sensor

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

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

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

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

Crankshaft Position (CKP) Sensor



Figure 66 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 ECM as the crankshaft turns. The CKP sensor reacts to a 60-tooth timing disk rotating on the crankshaft. For crankshaft position reference, teeth 59 and 60 are missing. By comparing the CKP signal with the CMP signal, the ECM calculates engine rpm and timing requirements.

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

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

Engine Compression Brake (ECB) Valve

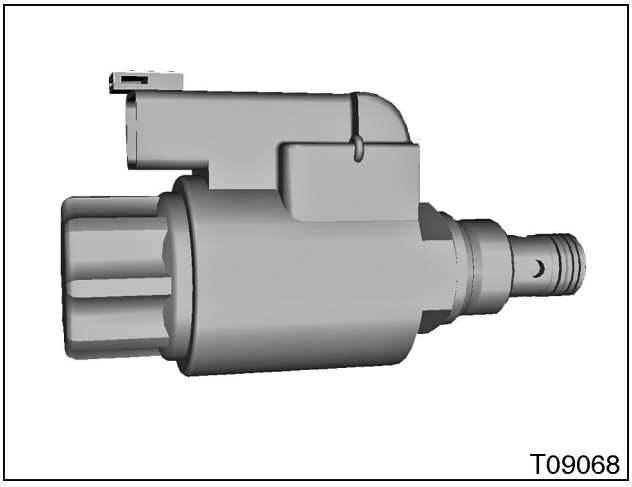


Figure 67 ECB Valve

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

The ECB valve is only used on engines with engine brake.

Engine Compression Brake Pressure (ECBP) Sensor

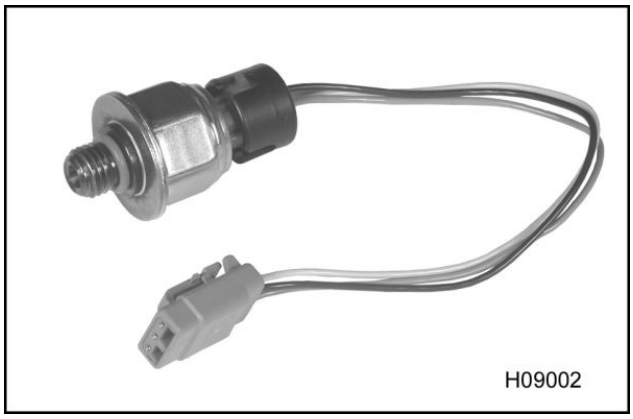


Figure 68 ECBP Sensor

The ECBP sensor is a micro-strain gauge sensor that measures brake gallery pressure.

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

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

The ECBP sensor is only used on engines with engine brake.

Exhaust Back Pressure (EBP) Sensor

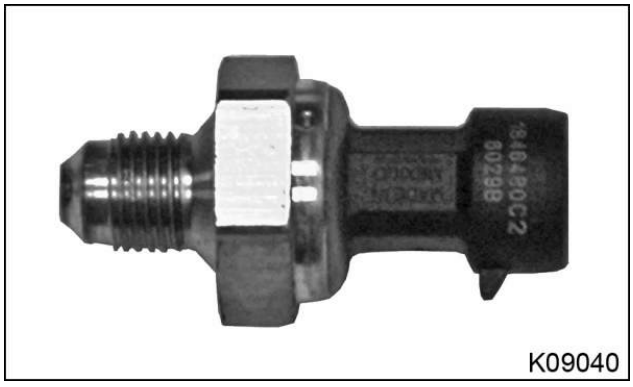


Figure 69 EBP Sensor

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

The EBP sensor provides feedback to the ECM for control of the TC2WC valve, Engine Throttle Valve (ETV), and EGR rate.

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

Engine Coolant Temperature 1 (ECT1) Sensor

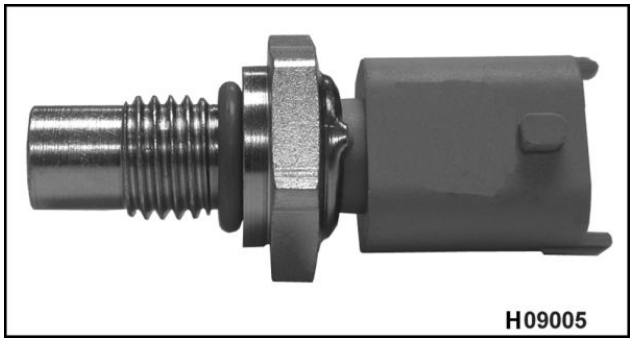


Figure 70 ECT1 Sensor

The ECT1 sensor is a thermistor sensor that detects engine coolant temperature 1.

The ECT1 signal is monitored by the ECM for operation of the instrument panel temperature gauge, coolant temperature compensation, optional Engine Warning Protection System (EWPS), and IAH operation. The ECM uses the ECT1 sensor input as a backup when EOT sensor values are out-of-range.

The ECT1 sensor is installed in the coolant supply housing (refrigerant compressor bracket) on the exhaust side of the engine towards the front.

Fuel Delivery Pressure (FDP) Sensor

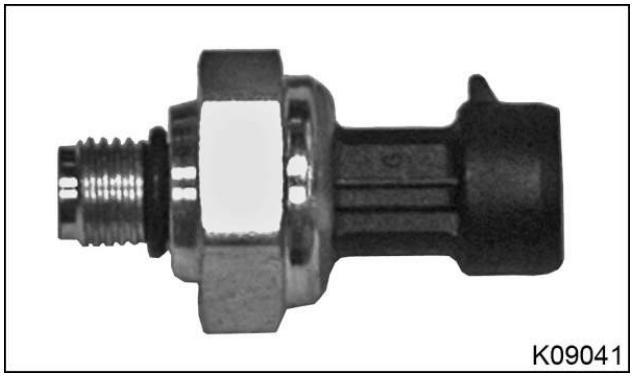


Figure 71 FDP Sensor

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

The FDP sensor detects low fuel pressure caused by a fuel restriction or dirty fuel filter. The FDP sensor sends a signal to the ECM when pressure is below programmed values for various engine conditions. The ECM will send the FUEL FILTER lamp message for display to the operator.

The FDP sensor is installed in the fuel filter assembly on the intake side of the engine.

Exhaust Gas Recirculation (EGR) Valve

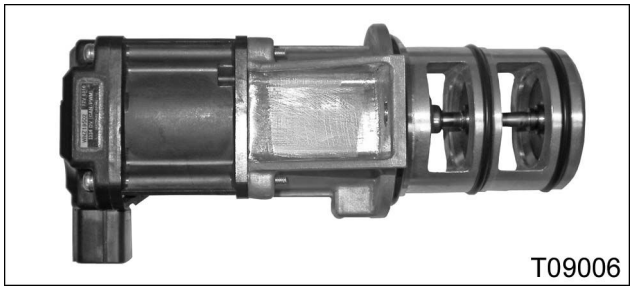


Figure 72 EGR Valve

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

The EGR valve receives the desired valve position from the ECM. When EGR is commanded, the EGR control valve opens and allows cooled exhaust to

enter the air and EGR mixer duct. The cooled exhaust gas flows through the EGR crossover duct, intake manifold, and into the air and EGR mixer duct where it is mixed with filtered intake air.

The EGR valve is installed in the air and EGR mixer duct on the intake side of the engine.

Exhaust Gas Temperature (EGT) Sensor

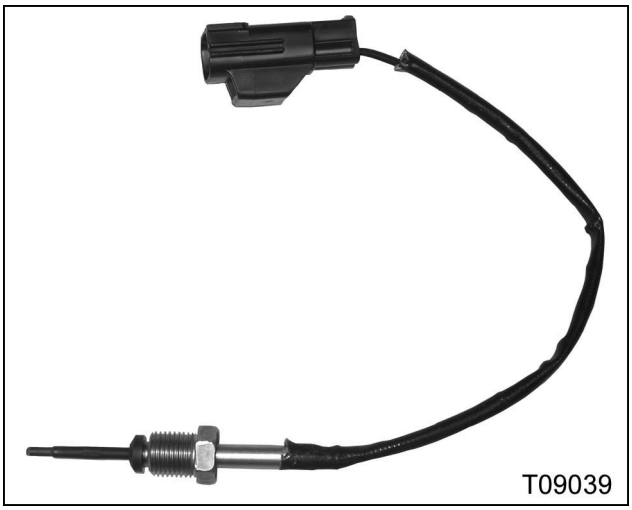


Figure 73 EGT Sensor

The EGT sensor is a Resistance Temperature Detector (RTD) that provides a feedback signal to the ECM indicating the exhaust gas temperature.

The EGT sensor is installed in the front exhaust manifold section.

Engine Oil Pressure (EOP) Sensor

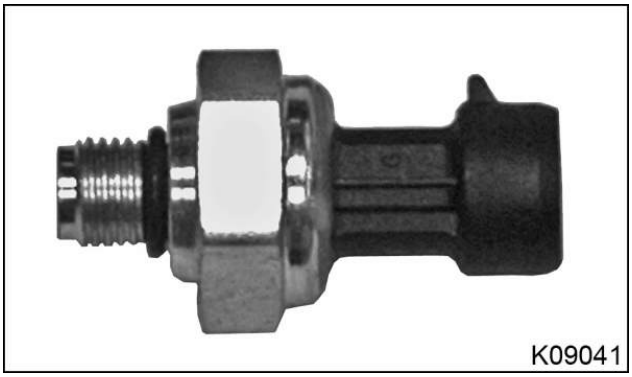


Figure 74 EOP Sensor

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 Engine Warning Protection System (EWPS).

The EOP sensor is installed in the intake side of the crankcase, below the left side of the fuel filter assembly.

Engine Oil Temperature (EOT) Sensor

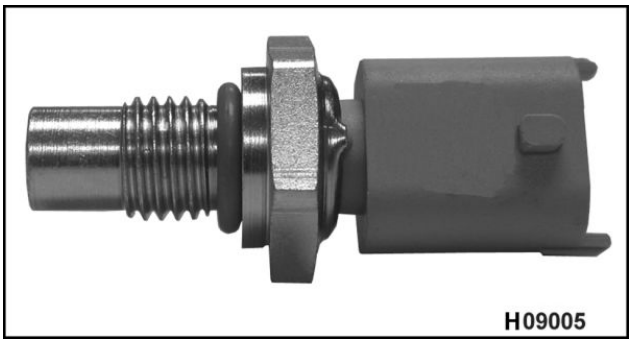


Figure 75 EOT Sensor

The EOT sensor is a thermistor sensor that detects engine oil temperature.

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

The EOT sensor is installed in the rear of the front cover, to the left of the high-pressure pump assembly, on the intake side of the engine.

Fuel Heater (250 watt)

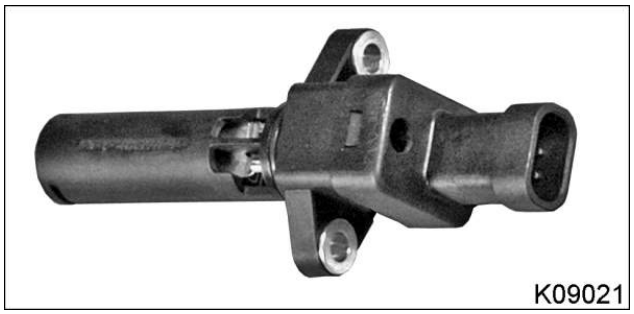


Figure 76 Fuel Heater (Optional)

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

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

The fuel heater is installed in the fuel filter header assembly, on the intake side of the engine.

Intake Air Heater (IAH) Relay Assembly

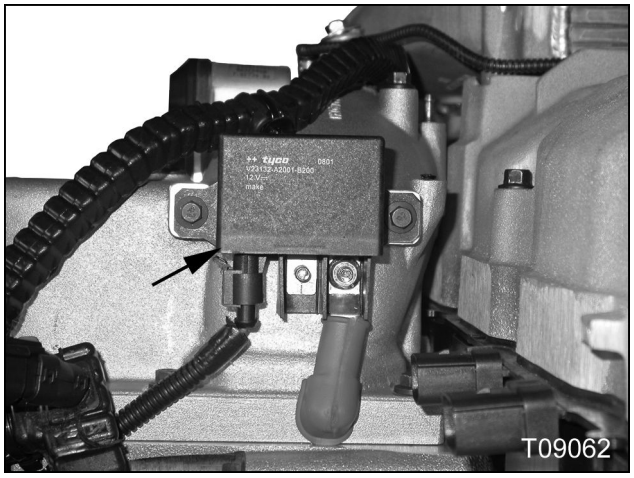


Figure 77 IAH Relay Assembly

The IAH system warms incoming air supply prior to cranking to aid cold engine starting. The IAH continues to operate for several minutes during cold engine operation.

The ECM is programmed to energize the IAH element through the IAH relay while monitoring engine coolant temperature 1, engine oil temperature, and atmospheric pressure.

The IAH relay delivers VBAT to the heater element for a set time, depending on engine coolant temperature 1 and altitude.

The IAH relay is on the air and EGR mixer duct on the intake side of the engine.

Injection Control Pressure (ICP) Sensor

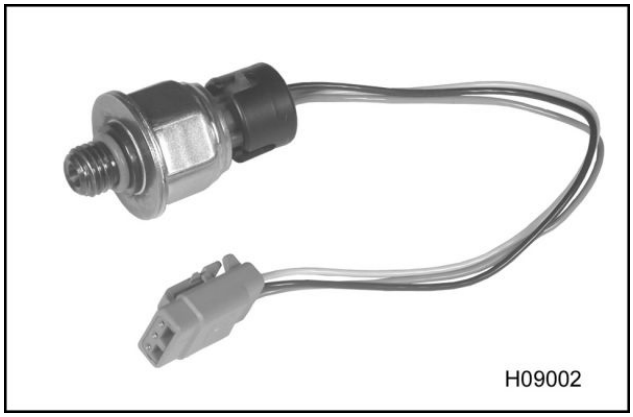


Figure 78 ICP Sensor

The ICP sensor is a high-pressure sensor that measures injection control pressure.

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

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

Intake Manifold Temperature (IMT) Sensor

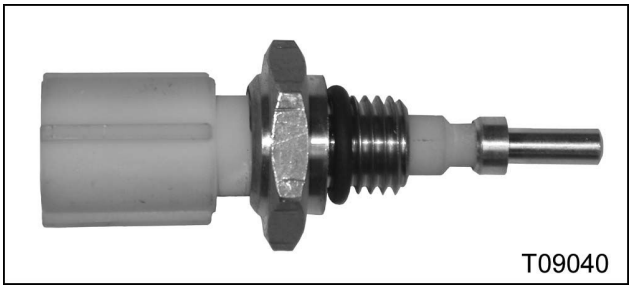


Figure 79 IMT Sensor

The IMT sensor is a thermistor sensor that detects intake manifold temperature.

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

The IMT sensor is installed in the intake manifold, to the right of the IMP sensor.

Intake Manifold Pressure (IMP) Sensor

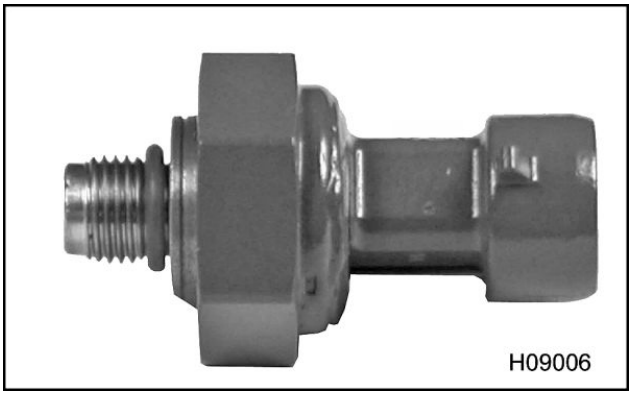


Figure 80 IMP Sensor

The IMP sensor is a variable capacitance sensor that measures intake manifold boost pressure.

The IMP signal is monitored by the ECM, which aids the ECM in controlling mass air flow with the EGR and ETV systems.

The IMP sensor is installed in the intake manifold, left of the IMT sensor.

Engine Throttle Valve (ETV) Assembly

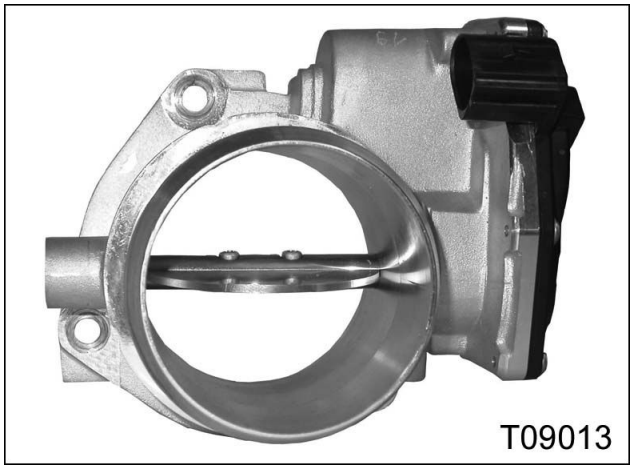


Figure 81 ETV Assembly

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

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

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

Injection Pressure Regulator (IPR) Valve

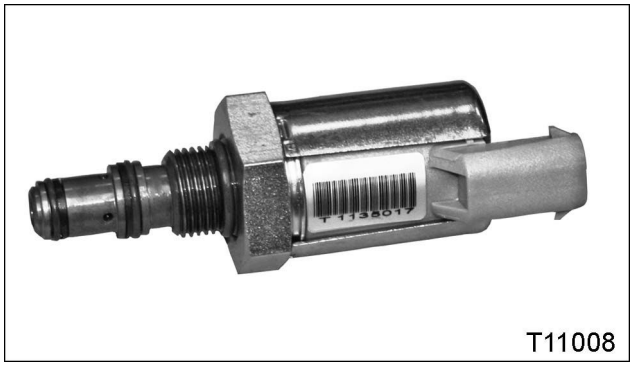


Figure 82 IPR Valve

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

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

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

Downstream Injection (DSI) Assembly

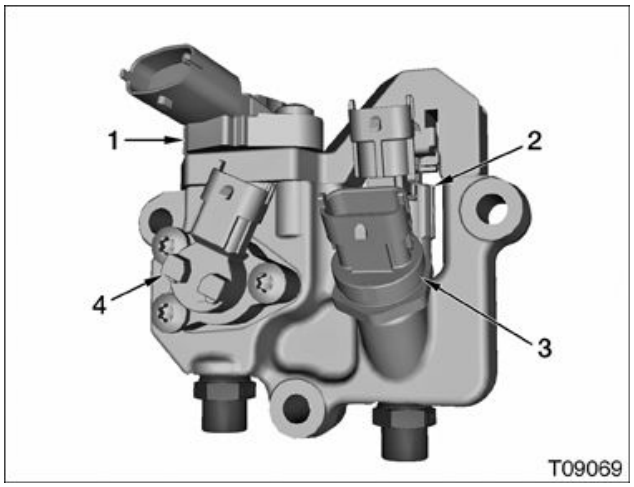


Figure 83 DSI Assembly

1. Upstream pressure / temperature sensor
2. Dosing valve (DV)
3. Downstream pressure sensor
4. Shut-off valve (SV)

NOTE: The DSI assembly is serviced as an assembly. Do not remove valves or sensors separately.

The Doser Control Unit (DCU) is mounted on the chassis side of the vehicle. The DCU receives signals from the ECM and then signals the DSI assembly.

When the DCU signals the shutoff valve to open, fuel pressure increases in the upstream cavity of the DSI housing. The upstream pressure sensor immediately signals the DCU that pressure is increased by available fuel. The DCU then signals the dosing valve to open, allowing a specific amount of fuel to be injected into the injector supply line.

The DSI assembly is installed on the left rear of the engine above the intake manifold.

Water In Fuel (WIF) Sensor

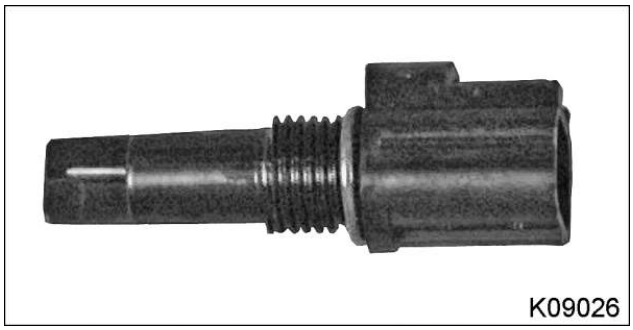


Figure 84 WIF Sensor

The WIF sensor is a switch that detects water in the fuel filter assembly.

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

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

Removal

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

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

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.

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

Boost Control Harness Assembly and Turbocharger 2 Wastegate Control (TC2WC) Valve

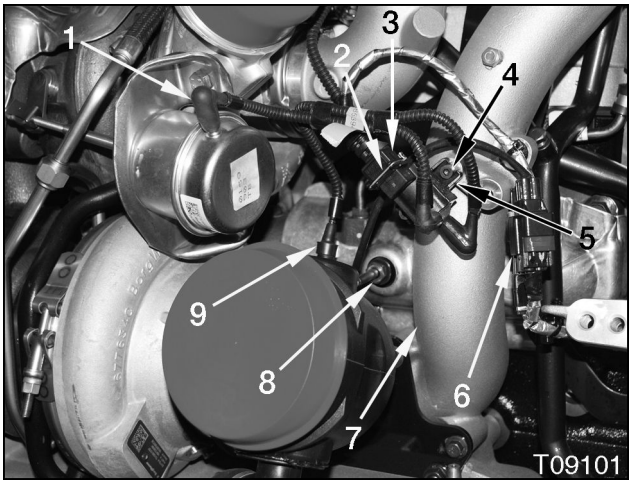


Figure 85 Boost Control Harness Assembly and TC2WC Valve

1. Turbocharger wastegate actuator connector—vacuum line
2. Connector wire clip lock
3. Turbocharger 2 Wastegate Control (TC2WC) valve 2-pin connector
4. M5 x 16 socket head bolt (2)
5. Insulator—high temperature plastic (2)
6. Exhaust Gas Temperature (EGT) connector
7. Interstage Cooler (ISC) inlet duct
8. Exhaust Gas Temperature (EGT) sensor
9. Turbocharger air inlet duct connector—vacuum line

1. Push connector wire clip lock on Turbocharger 2 Wastegate Control (TC2WC) valve 2-pin connector and disconnect connector from TC2WC valve.
2. Disconnect boost control harness assembly (vacuum lines) from TC2WC valve, turbocharger air inlet duct, and turbocharger wastegate actuator connector. Discard boost control harness assembly.
3. Disconnect boost to solenoid tube assembly (vacuum lines) from TC2WC valve and throttle coupling. Discard boost control harness assembly.
4. Remove two M5 x 16 socket head bolts and the TC2WC valve from ISC inlet duct. Remove and discard two insulators (high temperature plastic).

Crankshaft Position (CKP) Sensor

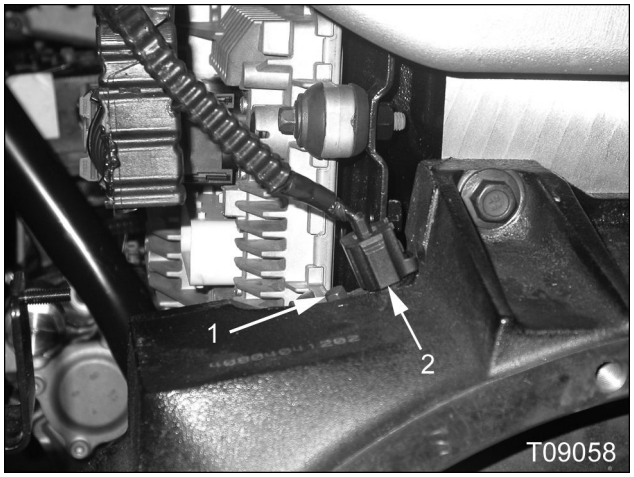


Figure 86 CKP Sensor

1. M6 x 16 sensor retaining bolt
2. CKP 2-pin connector

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

Camshaft Position (CMP) Sensor

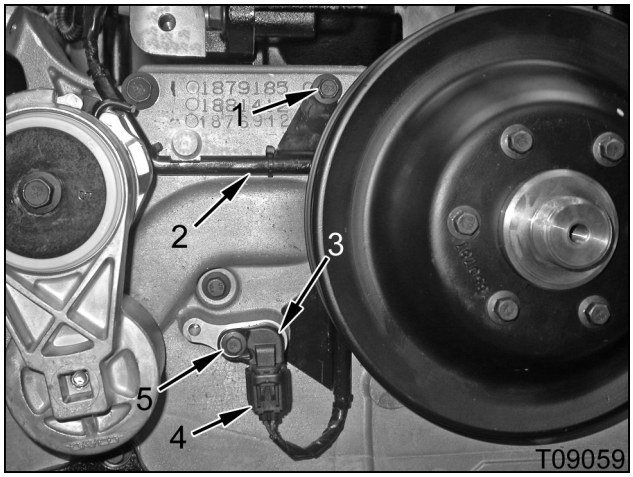


Figure 87 CMP Sensor

1. M8 x 20 bolt
2. Engine harness bracket
3. CMP sensor
4. CMP sensor 2-pin connector
5. M6 x 16 sensor retaining bolt

1. Disconnect CMP sensor 2-pin connector from CMP sensor installed in the front cover.
2. Remove M6 x 16 sensor retaining bolt.
3. Pull out and remove CMP sensor.
4. Discard sensor O-ring.
5. If required, remove M8 x 20 bolt securing sensor bracket to front cover.

Exhaust Back Pressure (EBP) Sensor

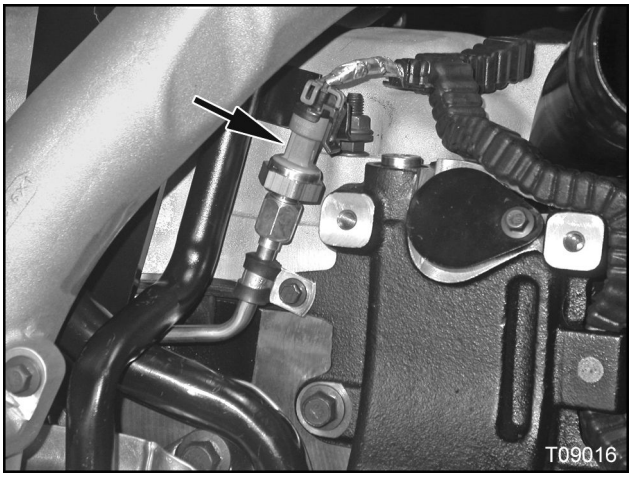


Figure 88 EBP Sensor

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

Engine Control Module (ECM) and Mounting Bracket

1. Disconnect ground (-) cable from battery.

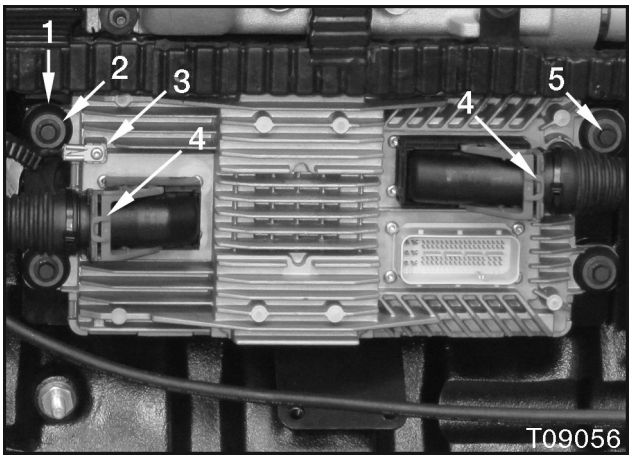


Figure 89 ECM Assembly

1. Isolator grommet (4)
2. Vibration isolator bushing (4)
3. Ground connection
4. Connector lock lever
5. M8 x 45 bolts (4)

2. Pull ground connection from terminal on ECM.
3. Squeeze orange latch on ECM harness connector and swing connector lock lever toward center of ECM.
4. Disconnect engine harness assembly and chassis harness connectors from ECM.
5. Remove four M8 x 45 bolts holding ECM to mounting bracket.
6. Remove ECM assembly with vibration isolator bushings and isolator grommets.

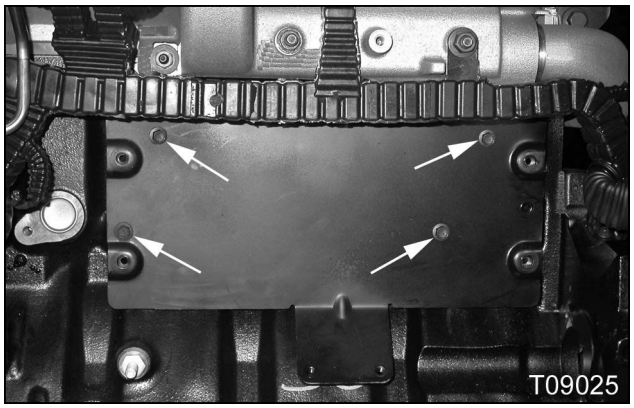


Figure 90 ECM Bracket Mounting Bolts (M8 x 20)

7. Remove four M8 x 20 bolts holding ECM bracket to crankcase and remove bracket assembly.

Engine Coolant Temperature 1 (ECT1) Sensor

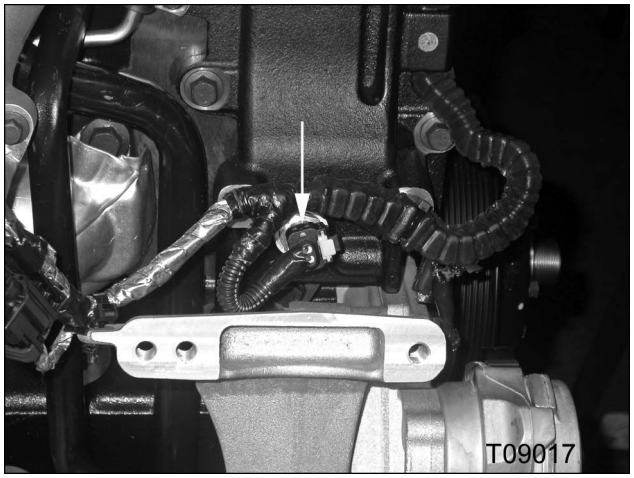


Figure 91 ECT1 Sensor

1. Place a coolant drain pan under the engine.
2. Pull lock tab up to unlock connector.
3. Press the release tab and disconnect 2-pin engine harness connector from the ECT1 sensor, installed in the coolant supply housing (refrigerant compressor bracket).
4. Remove ECT1 sensor.
5. Discard sensor O-ring.
6. Recycle or dispose of coolant according to applicable regulations.

Electric Fuel Pump Connector

See Brushless Electric Fuel Pump Assembly (page 212) for removal procedure.

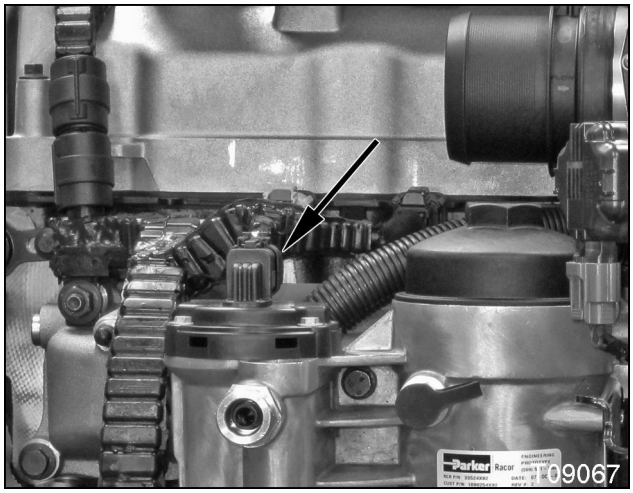


Figure 92 Electric Fuel Pump Connector

1. Pull lock tab out to unlock connector.
2. Press the release tab and disconnect 2-pin engine harness connector from the electric fuel pump.

Fuel Delivery Pressure (FDP) Sensor

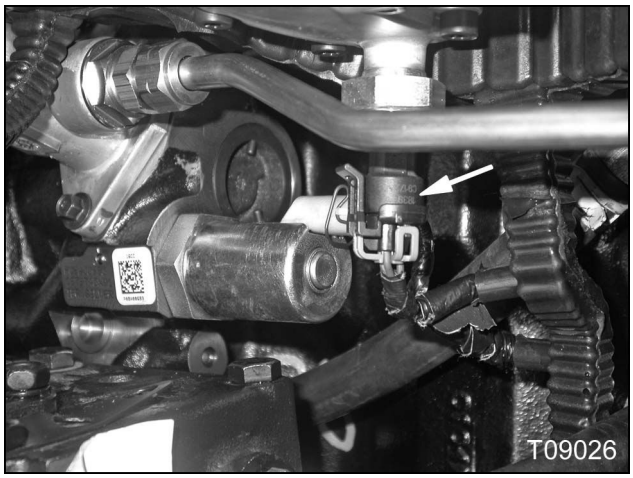


Figure 93 FDP Sensor (Typical)

1. Disconnect 3-pin engine harness connector from the FDP sensor.
2. Remove FDP sensor from fuel filter assembly.

3. Discard sensor O-ring.

Exhaust Gas Recirculation (EGR) Valve Connector

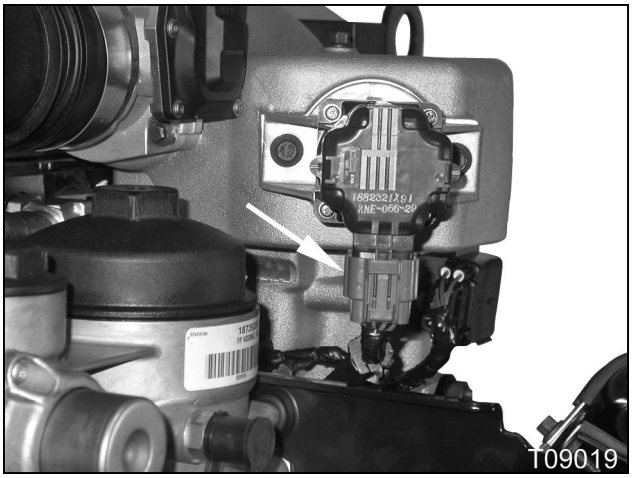


Figure 94 EGR Valve Connector

1. Disconnect engine harness connector from EGR valve, installed in the air and EGR mixer duct.
2. See EGR Valve Assembly (page 176).

Exhaust Gas Temperature (EGT) Sensor

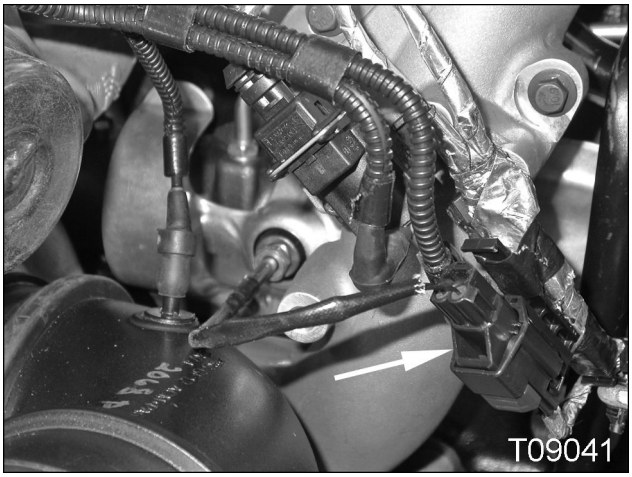


Figure 95 EGT Sensor Connector

1. Press the release tab to disconnect EGT sensor from wiring connector.
2. Remove EGT sensor from front section of exhaust manifold.

Engine Oil Pressure (EOP) Sensor

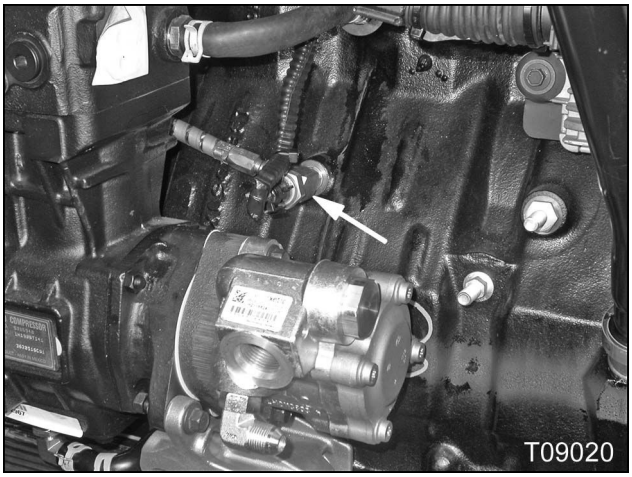


Figure 96 EOP Sensor

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

Engine Oil Temperature (EOT) Sensor

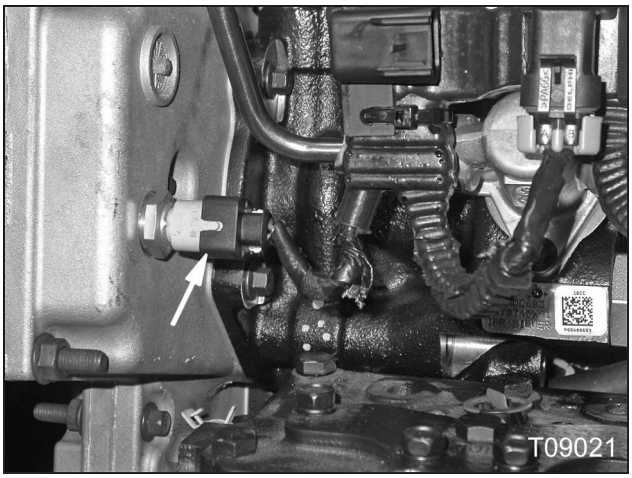


Figure 97 EOT Sensor (Typical)

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

Fuel Heater (250 watt)

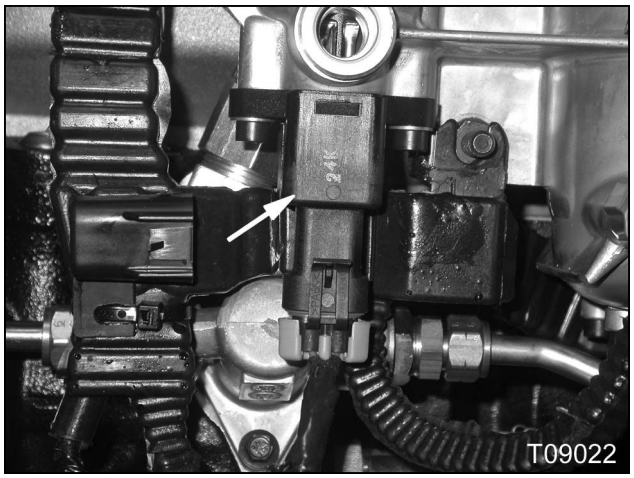


Figure 98 Fuel Heater (250 Watt) (Typical)

1. Disconnect engine harness connector from fuel heater.
2. See WIF sensor, FDP Sensor, and Fuel Heater (page 211).

Intake Air Heater (IAH) Relay Assembly

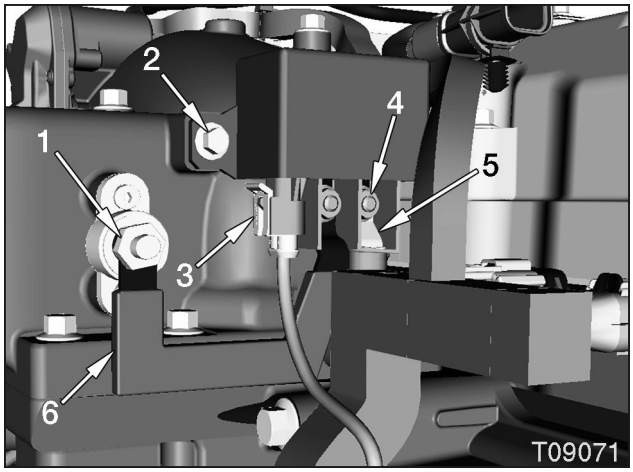


Figure 99 IAH Relay Assembly

1. 5/16 – 18 nut
2. M6 x 25 bolt (2)
3. IAH harness connector
4. M6 serrated nut (2)
5. IAH relay buss bar
6. Battery power supply buss bar

1. Disconnect IAH harness connector.
2. Remove 5/16 – 18 nut that secures the battery power supply buss bar to the battery power junction block.
3. Remove M6 serrated nut that secures the battery power supply buss bar to the IAH relay, then remove the battery power supply buss bar.
4. Remove two M6 serrated nuts securing IAH relay buss bar to the single grid heater assembly and IAH relay.
5. Remove two M6 x 25 bolts that secure the IAH relay.
6. Remove IAH relay assembly.

Injection Control Pressure (ICP) Sensor

1. Remove interstage cooler (if equipped) and valve cover. See Interstage Inlet Duct Assembly (page 132) and Valve Cover (page 357).

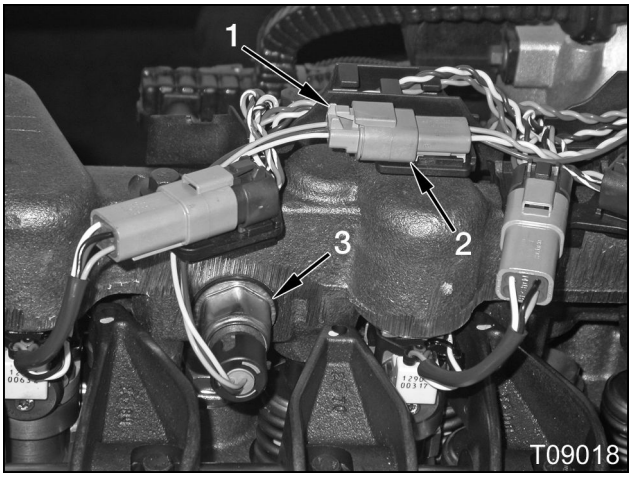


Figure 100 ICP Sensor

1. ICP sensor connector
2. Valve cover gasket harness connector
3. ICP sensor

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

Engine Throttle Valve (ETV) Assembly Connector

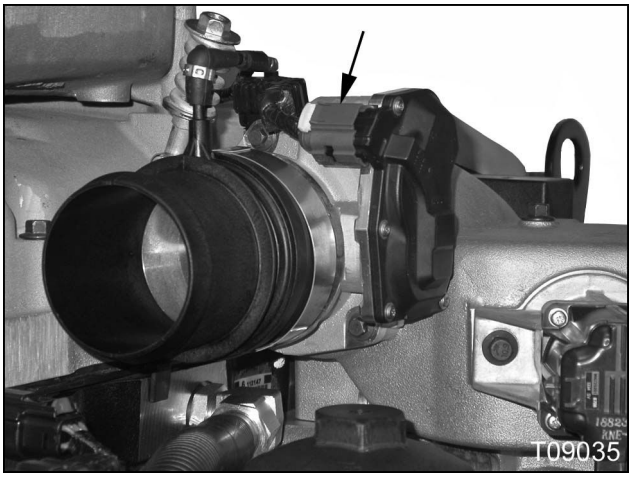


Figure 101 ETV Assembly Connector

1. Pull out locking tab.
2. Push release tab and disconnect engine harness connector from ETV assembly, installed on the intake side of the engine.
3. See Engine Throttle Valve (ETV) Assembly (page 176).

Injection Pressure Regulator (IPR) Valve Connector

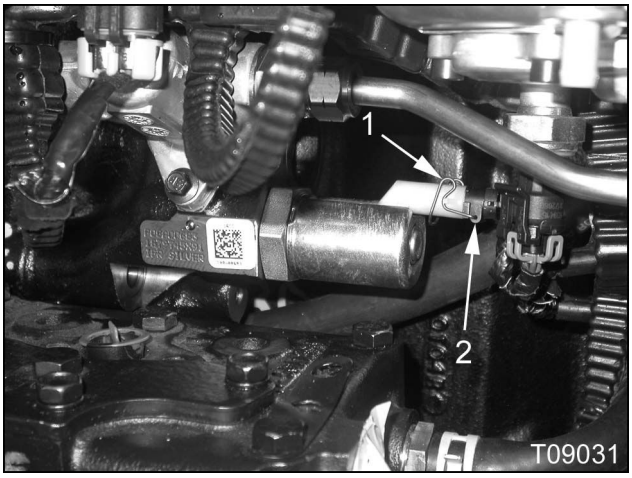


Figure 102 IPR Valve

1. Wire lock clip
2. IPR valve connector

1. Swing wire lock clip downwards to unlock.
2. Pull connector to disconnect from IPR valve, installed in the rear of the high-pressure oil pump on the intake side of the engine.
3. For IPR valve removal, see High-pressure Oil Pump Assembly and Injection Pressure Regulator (IPR) Valve Assembly (page 228).

Intake Manifold Pressure (IMP) Sensor



Figure 103 IMP Sensor

1. Push release tab and disconnect 3-pin engine harness connector from IMP sensor.
2. Remove IMP sensor.
3. Discard IMP sensor O-rings.

Intake Manifold Temperature (IMT) Sensor

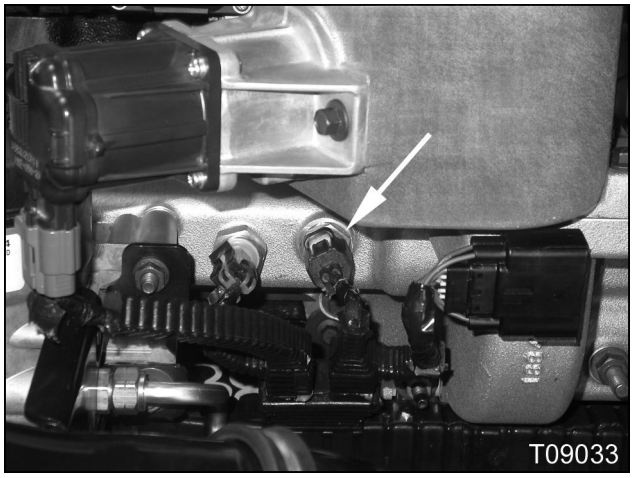


Figure 104 IMT Sensor

1. Pull up IMT sensor locking tab.
2. Push release tab and disconnect 2-pin engine harness connector from IMT sensor.
3. Remove IMT sensor.
4. Discard IMT sensor O-rings.

Downstream Injection (DSI) Assembly Connectors

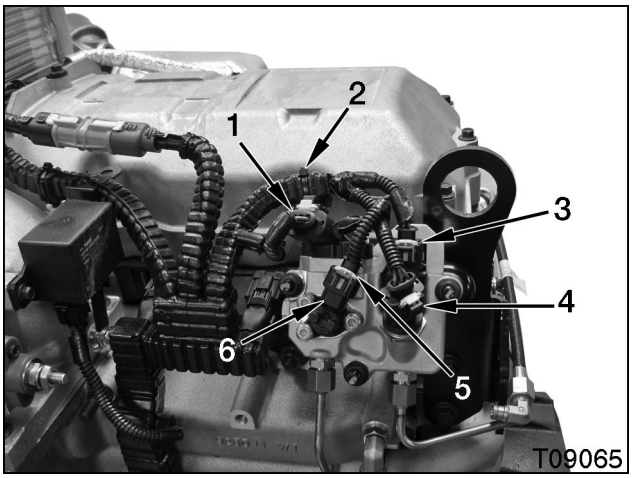


Figure 105 DSI Assembly

1. Upstream pressure/temperature sensor connector
2. Tie strap
3. Dosing Valve (DV) connector
4. Downstream pressure sensor
5. Yellow connector lock
6. Shutoff Valve (SV)

1. Pull out the yellow connector lock and then disconnect engine harness connectors for the Upstream pressure / temperature sensor, DV, downstream pressure sensor and SV.
2. Remove engine harness from DSI assembly.
3. For DSI assembly removal, see Down Stream Injection (DSI) Assembly (page 115).

Water In Fuel (WIF) Sensor

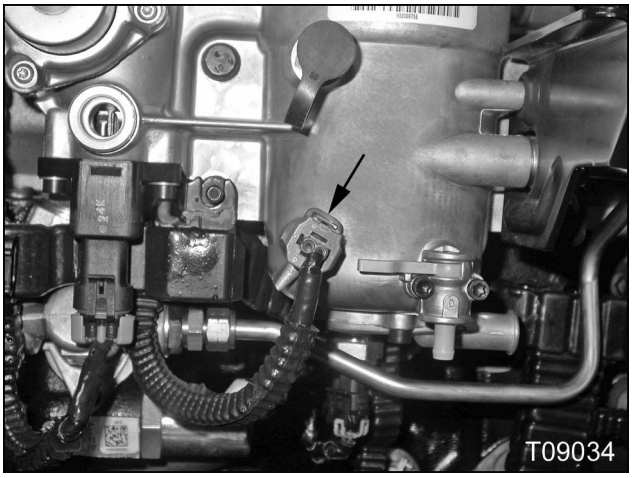


Figure 106 WIF Sensor

1. Disconnect engine harness connector from the WIF sensor.
2. Remove WIF sensor.
3. Discard sensor O-ring.

Engine Harness Assembly

1. Disconnect the battery ground (-) cable.

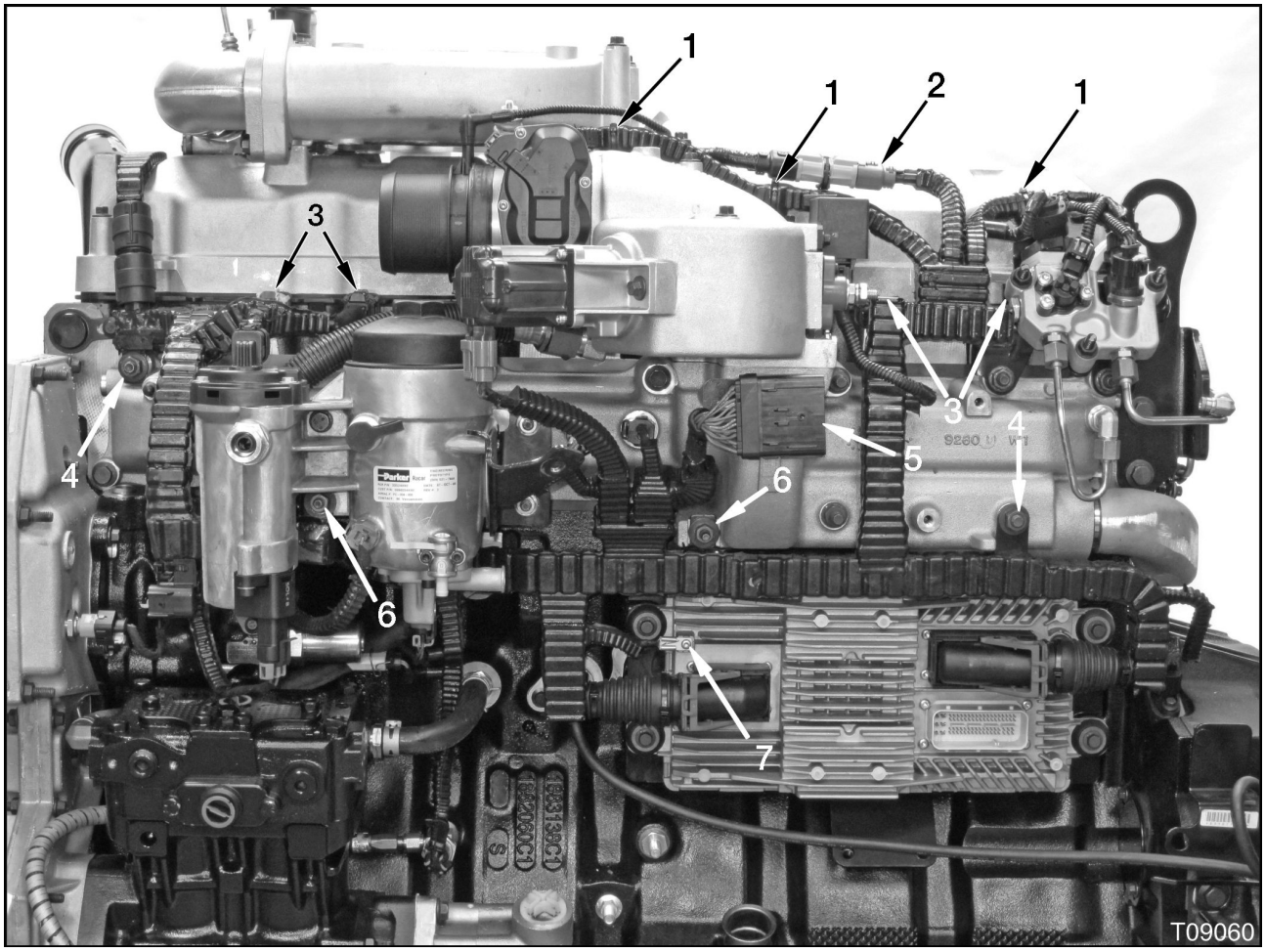


Figure 107 Engine Wiring Harness Connection Points – Intake Side

1. Tie strap (3)
2. Exhaust brake valve assembly connector
3. Valve cover gasket connector (4)
4. M10 nut (2)
5. 16-pin interconnect
6. M8 nut (2)
7. Electro Magnetic Interference (EMI) ground connection

2. Squeeze orange latch on ECM harness connector and lift lever to unlock connectors.
3. Disconnect engine harness assembly and chassis harness connectors from ECM and disconnect EMI ground connection.
4. Disconnect engine harness assembly connectors from sensors and actuators on intake side of engine.
5. Remove two M10 nuts.
6. Cut three tie straps.
7. Remove Engine Harness Assembly from four valve cover gasket connectors.
8. Remove M6 x 16 bolt securing the 16-pin interconnect.
9. Remove two M8 nuts.

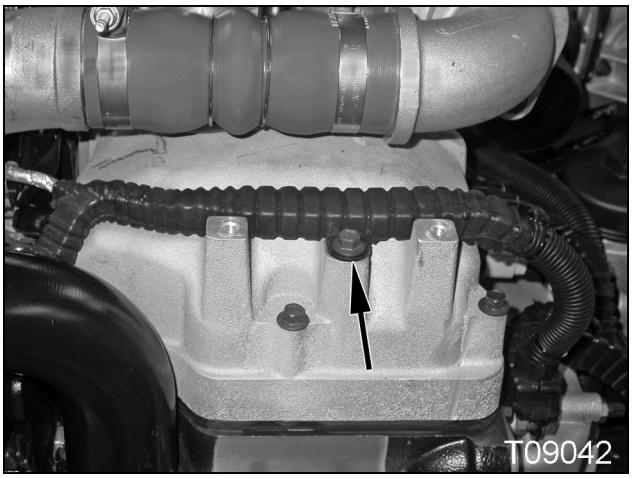


Figure 108 Engine Wiring Harness Connection Points – Front Top View (M8 x 12 Bolt)

10. Remove M8 x 12 bolt.

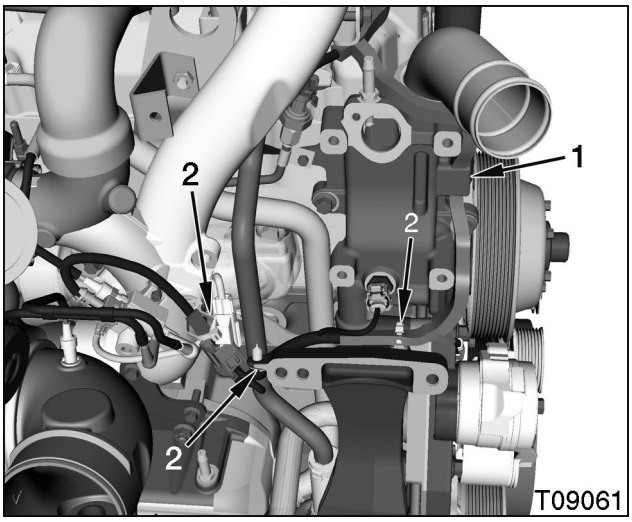


Figure 109 Engine Wiring Harness Connection Points – Exhaust Side

1. Coolant supply housing
2. Tie strap with fir zip harness retainer (3)

11. Cut tie straps on fir zip harness retainers.
12. Disconnect connectors from ECT1 sensor, EGT sensor, and TC2WC valve.
13. Remove engine wiring harness from coolant supply housing.
14. Remove Engine Harness assembly from the engine.

Valve Cover Gasket Assembly

1. Remove interstage cooler and valve cover. See Interstage Cooler (ISC) (page 133) and Valve Cover (page 357).

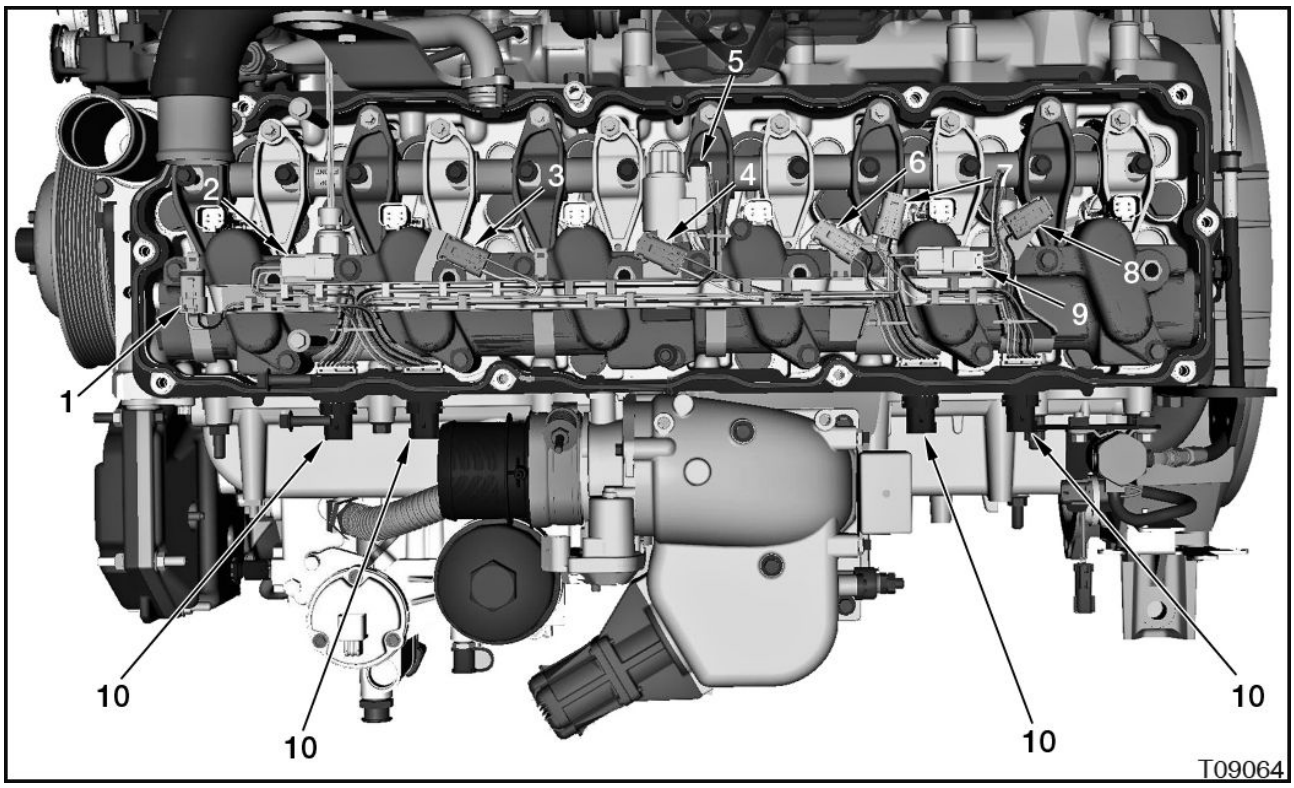


Figure 110 Valve Cover Gasket Assembly Connectors

1. Injector 1 harness connector
2. ECBP sensor connector
3. Injector 2 harness connector
4. Injector 3 harness connector
5. ECB valve connector
6. Injector 4 harness connector
7. Injector 5 harness connector
8. Injector 6 harness connector
9. ICP sensor connector
10. Valve cover gasket connector (4)

2. Disconnect four valve cover gasket connectors, ICP sensor connector, and six injector harness connectors.
3. Disconnect ECBP sensor connector and ECB valve connector.
4. Starting at one side, lightly pry up and open each of the six wire channel retainers while gently pulling up to remove valve cover gasket harness from engine.

Inspect

Inspect Wiring Harness, Connectors, and Electrical Components

1. Inspect each wiring harness for corrosion (green, gray, or white deposits), female connector sleeves that are spread open, and terminal pins that are pushed back relative to the other terminals in the same connector. Clean, repair, or replace connectors and terminals if necessary.
2. Inspect wire harness near sensors and actuators for damage due to sharp bends; see diagnostic manual for continuous monitor testing.
3. Inspect each wiring harness for wear and heat damage to wiring and connectors. Repair or replace if necessary.
4. Replace any broken harness connection points and zip ties.
5. Check for damage caused by zip ties that are too tight.
6. Inspect connector pins on all electrical components. If any pins are bent or pushed in, repair or replace component.
7. Inspect female connector terminals for spreading.
8. Inspect electrical sensors, actuators, and valves for cracks and damage. Replace damaged components if necessary.
9. Inspect pressure sensors for soot, sludge, debris, or other contamination. Clean or replace as needed.

NOTE: See EGES-455 *Engine Diagnostic Manual* for further inspection and repair of engine electrical components and systems.

Installation

Engine Harness Assembly and Camshaft Position (CMP) Sensor

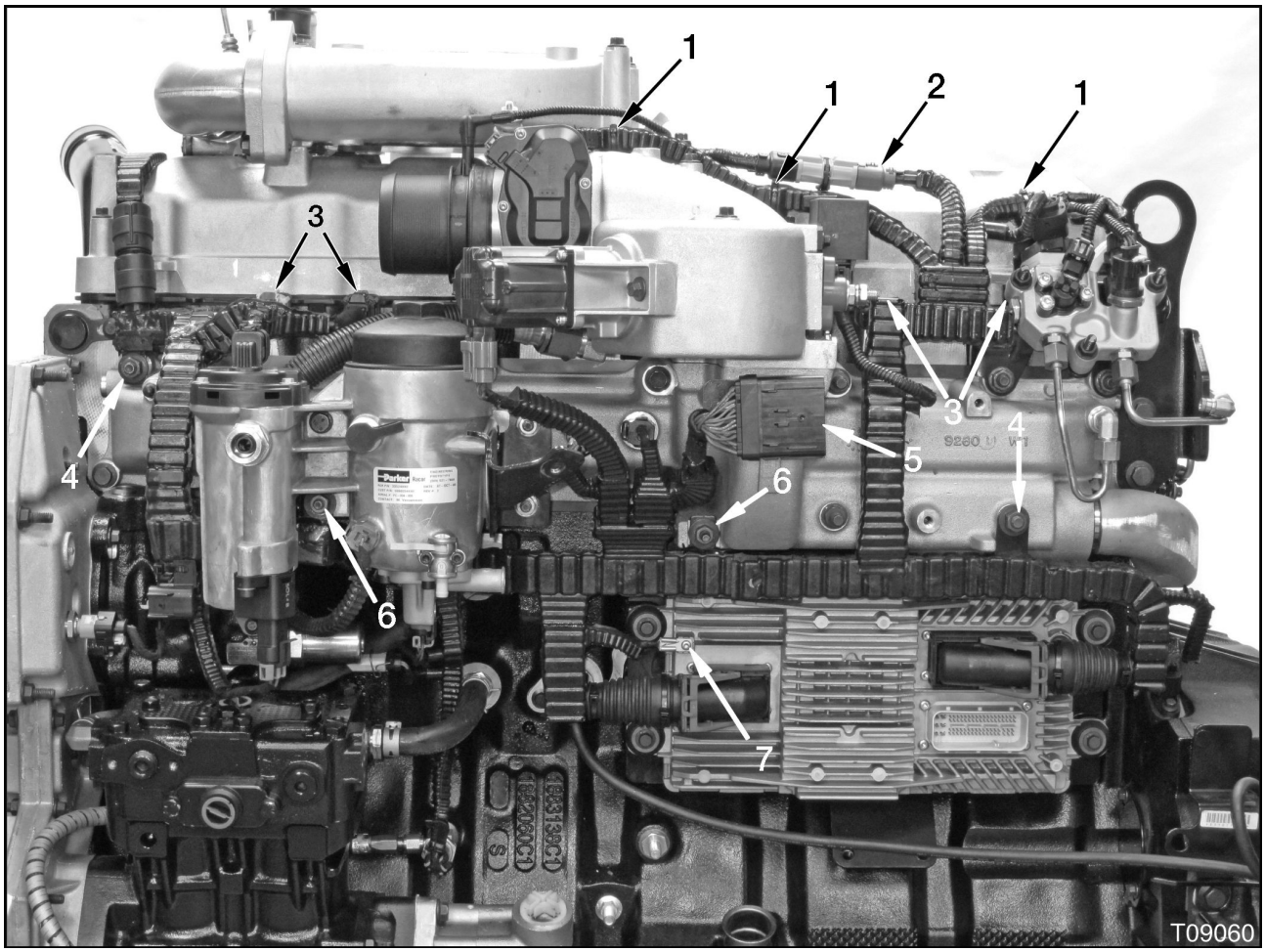


Figure 111 Sensor Wiring Harness Connection Points – Intake Side

1. Tie strap (3)
2. Exhaust brake valve assembly connector
3. Valve cover gasket connector (4)
4. M10 nut (2)
5. 16-pin interconnect
6. M8 nut (2)
7. Electro Magnetic Interference (EMI) ground connection

1. Position engine harness on intake side of engine and under fuel filter assembly.
2. Install M8 and M10 nuts. Tighten to special torque (page 109).
3. Install three new tie straps on fir zip harness retainers.
4. Connect exhaust brake valve assembly connector near top of valve cover.
5. Connect EMI ground connection.
6. Connect four valve cover gasket connectors.
7. Install 16-pin interconnect and tighten M6 x 16 bolt to standard torque (page 553).
8. Position engine harness over top of valve cover.

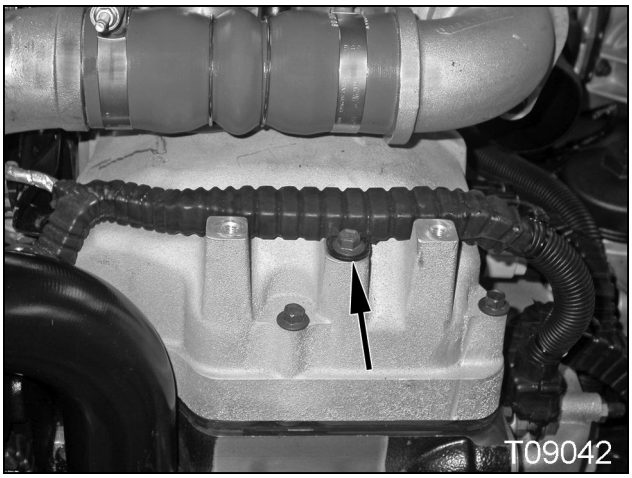


Figure 112 Sensor Wiring Harness Connection Points – Front Top View (M8 x 12 Bolt)

9. Install M8 x 12 bolt to secure wiring harness to valve cover. Tighten to special torque (page 109).

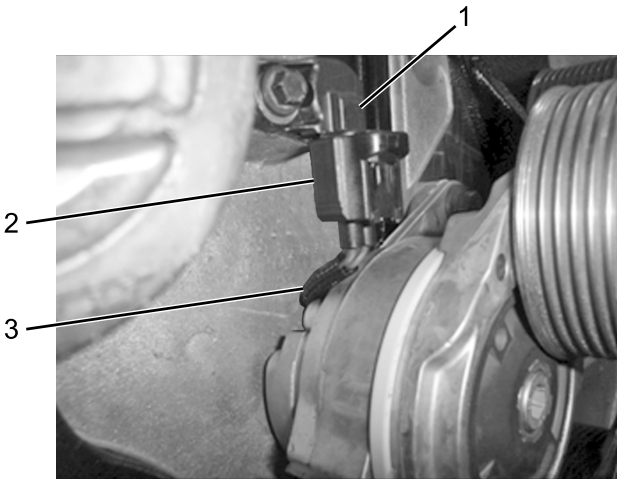


Figure 113 CMP Sensor Connection with Dual Belt Pulley Bracket Installed

1. Camshaft Position (CMP) sensor
2. CMP sensor harness connector
3. Flexible conduit

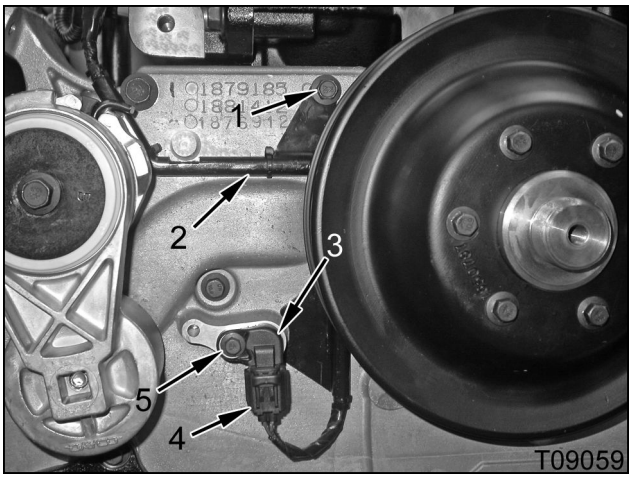


Figure 114 CMP Sensor Connection without Dual Belt Pulley Bracket

1. M8 x 20 bolt
2. Engine harness bracket
3. CMP sensor
4. CMP sensor connector
5. M6 x 16 sensor retaining bolt

NOTE: Perform step 10 only if flexible conduit has not been installed.

10. Install flexible conduit, under CMP sensor connector, on new engine harness.
11. Slide engine harness bracket behind fan pulley. Install M8 x 20 engine harness bracket bolt and tighten to standard torque (page 553).
12. Connect CMP sensor connector to CMP sensor.
    - If engine has dual belt pulley kit installed, refer to (Figure 113).
    - If engine has single pulley installed, refer to (Figure 114).

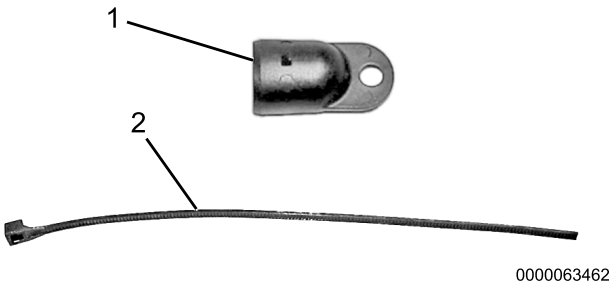


Figure 115 EGR Sensor Connector Cap and Cable Lock Strap

1. Connector cap
2. Cable lock strap

13. For engine harnesses with an Exhaust Gas Recirculation (EGR) pressure sensor connector do the following:
    - Press connector cap (Figure 115) onto the EGR pressure sensor harness connector. A click should be heard when connector cap is installed correctly.
    - Insert cable lock strap (Figure 115) through hole in connector cap and around engine harness under Exhaust Gas Temperature (EGT) sensor connector to secure the cap.

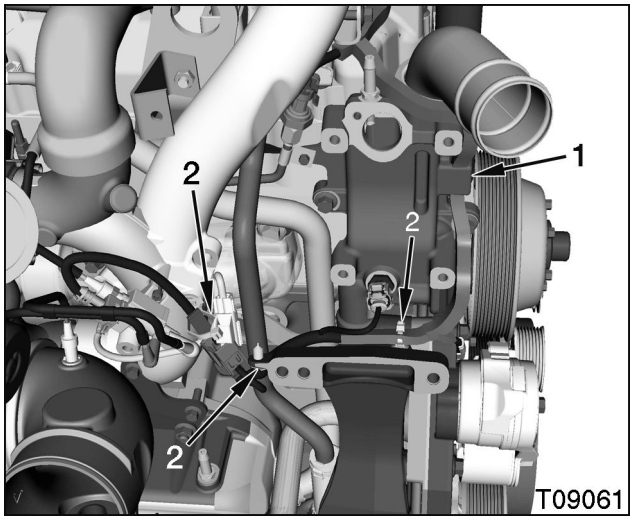


Figure 116 Engine Harness Connection Points – Exhaust Side

1. Coolant supply housing
2. Tie strap with fir zip harness retainer (3)

14. Weave engine harness around casting features on coolant supply housing.
15. Secure engine harness to fir zip harness retainers with new tie straps.
16. Insert fir zip connector into interstage cooler inlet pipe.

Boost Control Harness Assembly and Turbocharger 2 Wastegate Control (TC2WC) Valve

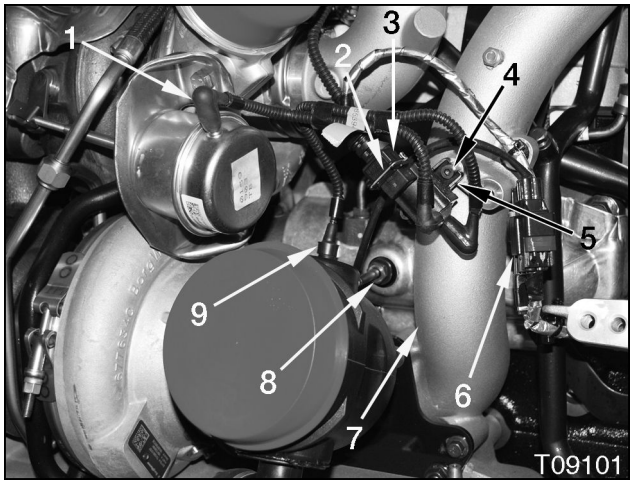


Figure 117 Boost Control Harness Assembly and TC2WC Valve

1. Turbocharger wastegate actuator connector—vacuum line
2. Connector wire clip lock
3. Turbocharger 2 Wastegate Control (TC2WC) valve 2-pin connector
4. M5 x 16 socket head bolt (2)
5. Insulator—high temperature plastic (2)
6. Exhaust Gas Temperature (EGT) connector
7. Interstage Cooler (ISC) inlet duct
8. Exhaust Gas Temperature (EGT) sensor
9. Turbocharger air inlet duct connector—vacuum line

1. Install TC2WC valve on ISC inlet duct with two M5 x 16 socket head bolts and two new insulators. Make sure insulators are placed on bolts between TC2WC valve and ISC inlet duct. Tighten bolts to standard torque (page 553).
2. Install a new boost control harness assembly (vacuum lines) to turbocharger wastegate actuator connector, turbocharger air inlet duct connector, TC2WC valve, and throttle coupling.

Crimp clamps at throttle coupling and TC2WC valve.

3. Connect TC2WC 2-pin connector to TC2WC valve and push in connector wire clip lock.

Crankshaft Position (CKP) Sensor

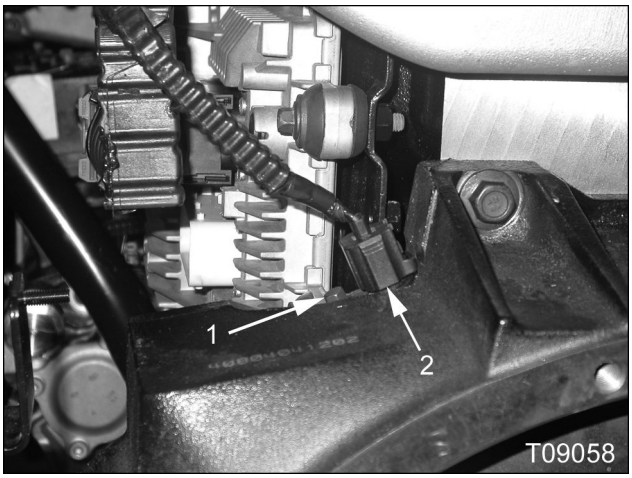


Figure 118 CKP Sensor

1. M6 x 16 sensor retaining bolt
2. CKP 2-pin connector

1. Lubricate new O-rings with clean engine oil and install on CKP sensor.
2. Install CKP sensor into the flywheel housing.
3. Install M6 x 16 retaining bolt and tighten to standard torque (page 553).
4. Connect engine harness connector to CKP sensor.

Exhaust Back Pressure (EBP) Sensor

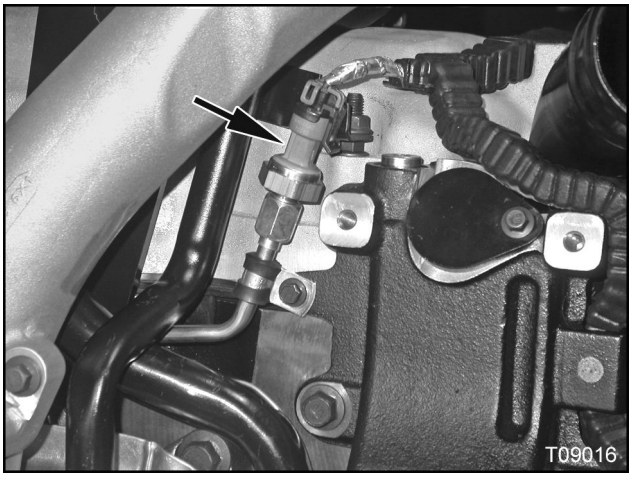


Figure 119 EBP Sensor

1. Install EBP sensor into tube mounted on the coolant supply housing (refrigerant compressor bracket).
2. Tighten EBP sensor to special torque (page 109).
3. Connect engine harness connector to EBP sensor.

Electronic Control Module (ECM) and Mounting Bracket

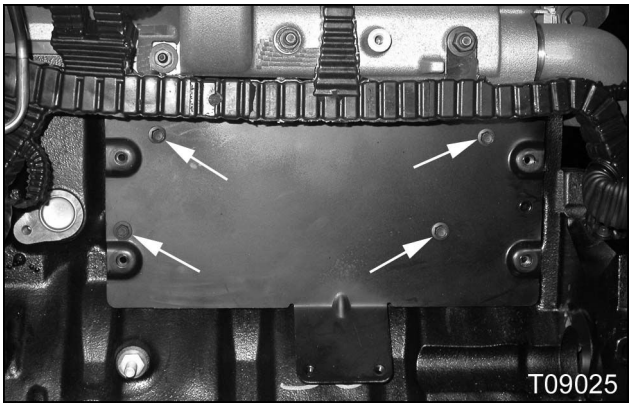


Figure 120 ECM Bracket Bolts

1. Install four M8 x 20 bolts securing the ECM bracket to the crankcase and tighten bolts to standard torque (page 553).

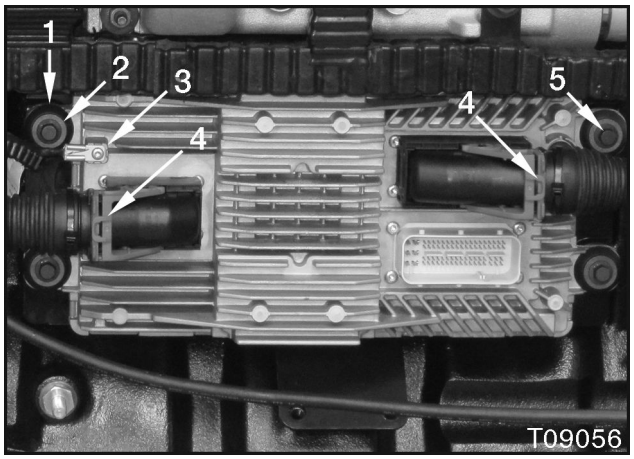


Figure 121 ECM Assembly

1. Isolator grommet (4)
2. Vibration isolator bushing (4)
3. Electro Magnetic Interference (EMI) ground connection
4. Connector lock lever
5. M8 x 45 bolts (4)

2. Install ECM assembly with vibration isolator bushings and isolator grommets.
3. Install four M8 x 45 bolts securing the ECM to the mounting bracket and tighten to special torque (page 109).
4. Push ECM harness and chassis connectors firmly into ECM and rotate connector lock lever until it locks in place.
5. Connect EMI ground connection to terminal on ECM.

Engine Coolant Temperature 1 (ECT1) Sensor

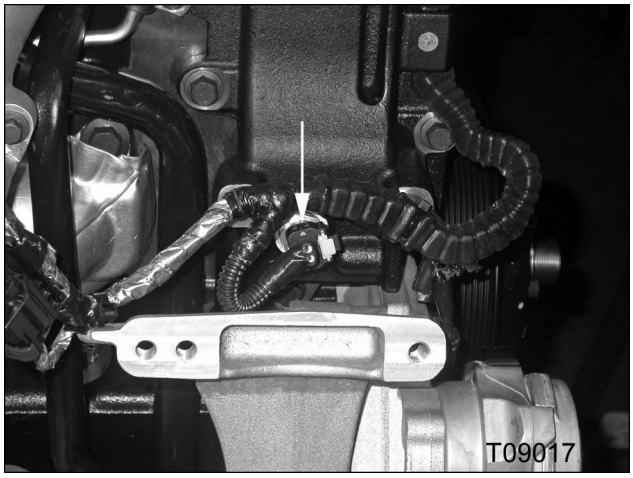


Figure 122 ECT1 Sensor

1. Install a new O-ring on ECT1 sensor.
2. Install ECT1 sensor into the coolant supply housing (refrigerant compressor bracket) and tighten to special torque (page 109).
3. Connect engine harness connector to ECT1 sensor.
4. Push lock tab down to lock connector.

Fuel Delivery Pressure (FDP) Sensor

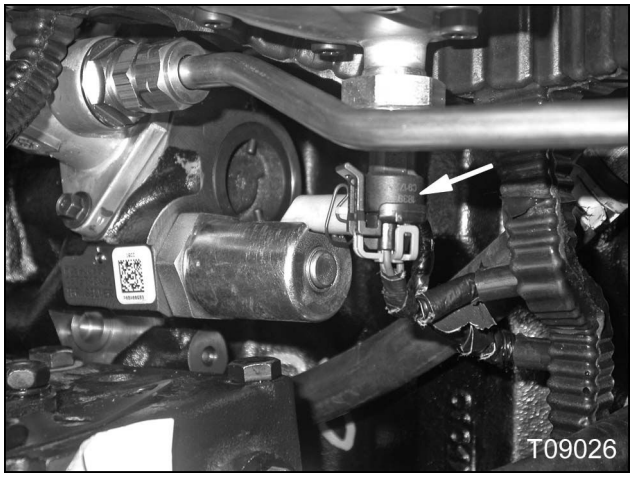


Figure 123 FDP Sensor (Typical)

1. Install new O-ring on FDP sensor

2. Install FDP sensor and tighten to special torque (page 109).
3. Connect 3-pin engine harness connector to the FDP sensor.

Exhaust Gas Recirculation (EGR) Control Valve Connector

1. See EGR Valve Assembly (page 182) for EGR control valve installation.

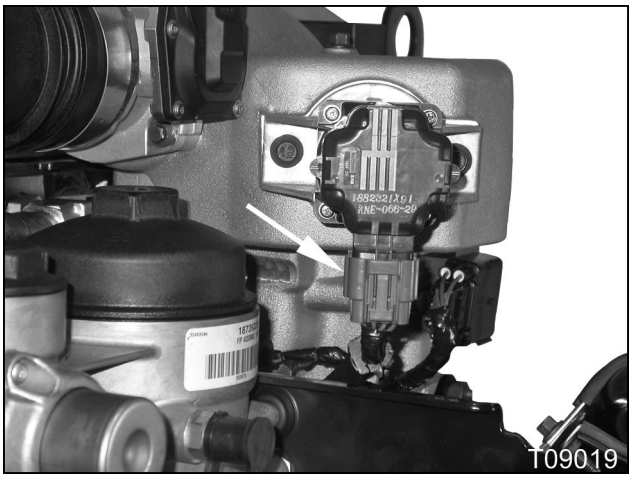


Figure 124 EGR Valve Connector

2. Connect engine harness connector to the EGR valve.

NOTE: Perform steps 3 and 4 if an EGR pressure sensor is not installed in the EGR coolant supply tube.

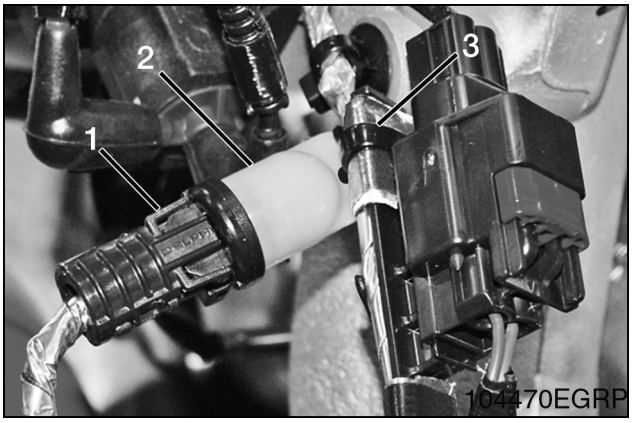


Figure 125 EGR Pressure Sensor Harness Connector

1. EGR pressure sensor harness connector
2. Connector cap
3. Cable lock strap

3. Press connector cap onto EGR pressure sensor harness connector. A click should be heard when connector cap is installed correctly.
4. Insert cable lock strap through hole in connector cap, around engine harness, and under Exhaust Gas Temperature (EGT) sensor connector to secure cap.

Electric Fuel Pump Connector

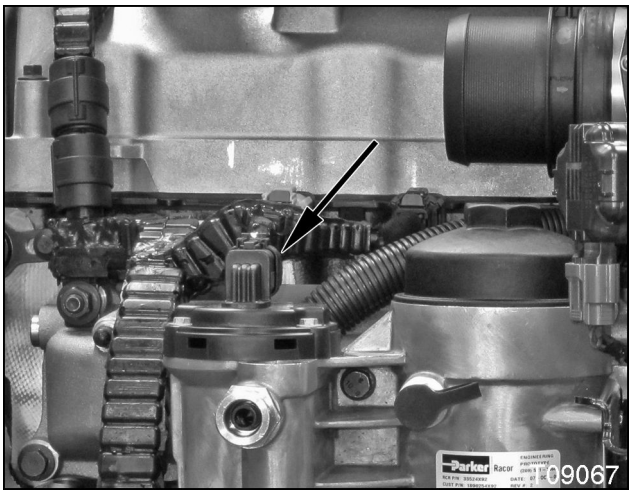


Figure 126 Electric Fuel Pump Connector

1. Connect engine harness connector to electric fuel pump.
2. Push lock tab into lock connector.

Exhaust Gas Temperature (EGT) Sensor

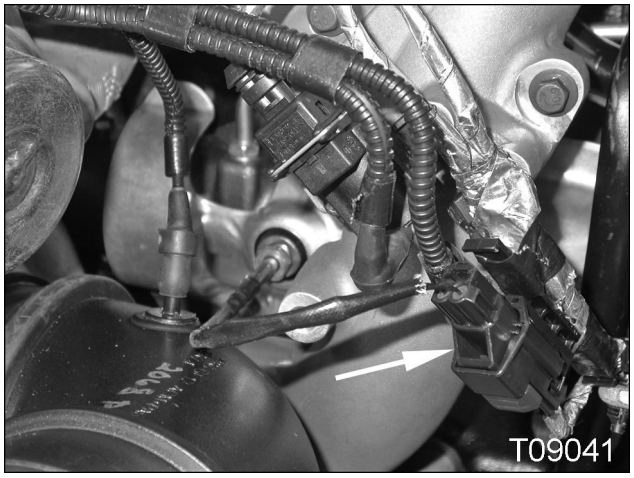


Figure 127 EGT Sensor Connector

1. Install EGT sensor and tighten to special torque (page 109).
2. Connect engine harness connector to the EGT sensor.

Engine Oil Pressure (EOP) Sensor

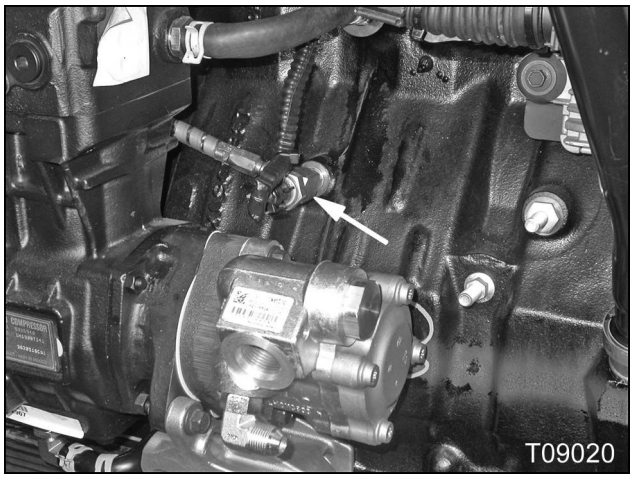


Figure 128 EOP Sensor

1. Lubricate a new O-ring with clean engine oil and install on EOP sensor.
2. Install EOP sensor into the intake side of the crankcase and tighten to special torque (page 109).
3. Connect engine harness connector to EOP sensor.
4. Connect engine sensor harness retaining clip to EOP sensor.

Engine Oil Temperature (EOT) Sensor

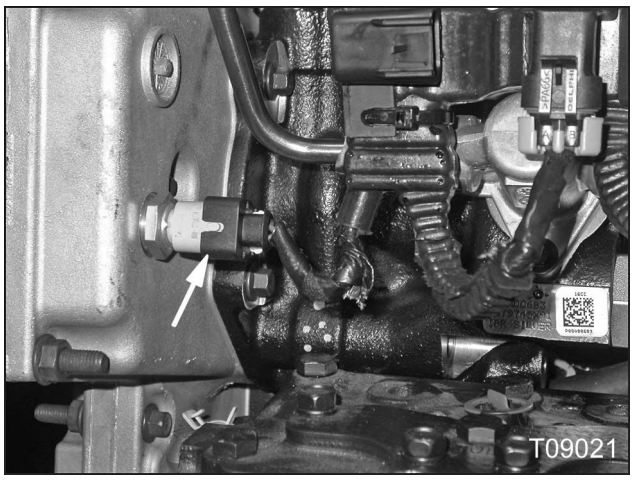


Figure 129 EOT Sensor

1. Lubricate a new O-ring with clean engine oil and install on EOT sensor.
2. Install EOT sensor into the back of the front cover and tighten to special torque (page 109).
3. Connect engine harness connector to the EOT sensor.
4. Push lock tab down to lock connector.

Fuel Heater (250 watt) Connector

1. See Water In Fuel (WIF) Sensor, Fuel Delivery Pressure (FDP) Sensor, and 250 Watt Fuel Heater (page 211) for 250 Watt Fuel Heater installation.

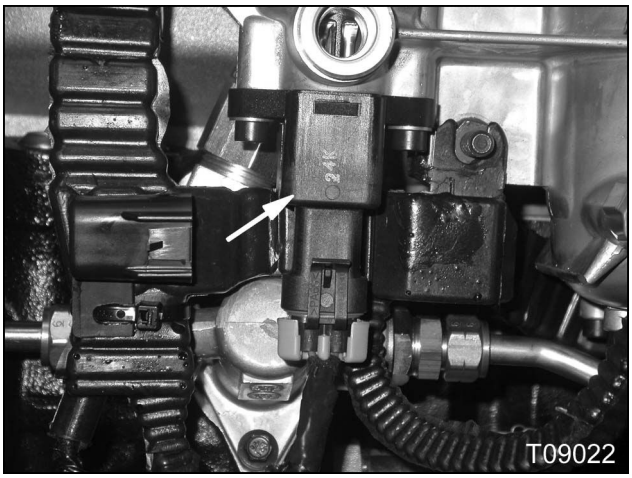


Figure 130 Fuel Heater (250 Watt) (Typical)

2. Connect engine harness connector to 250 watt fuel heater.

Intake Air Heater (IAH) Relay Assembly

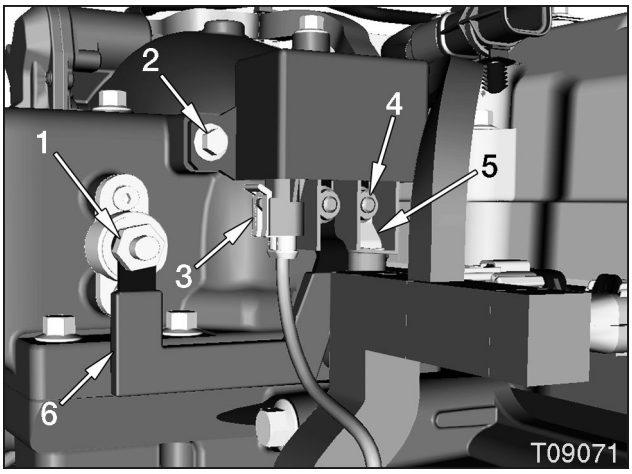


Figure 131 IAH Relay Assembly

1. 5/16 – 18 nut
2. M6 x 25 bolt (2)
3. IAH harness connector
4. M6 serrated nut (2)
5. IAH relay buss bar
6. Battery power supply buss bar

1. Install two M6 x 25 bolts. Tighten bolts to standard torque (page 553).
2. Install IAH relay buss bar on single grid heater stud and secure with two M6 serrated nuts. Tighten nut to special torque (page 109).
3. Install the battery power supply buss bar on 5/16 and M6 studs. Tighten 5/16 – 18 nut and M6 serrated nut to special torque (page 109).
4. Connect IAH harness connector to IAH relay assembly.

Injector Control Pressure (ICP) Sensor

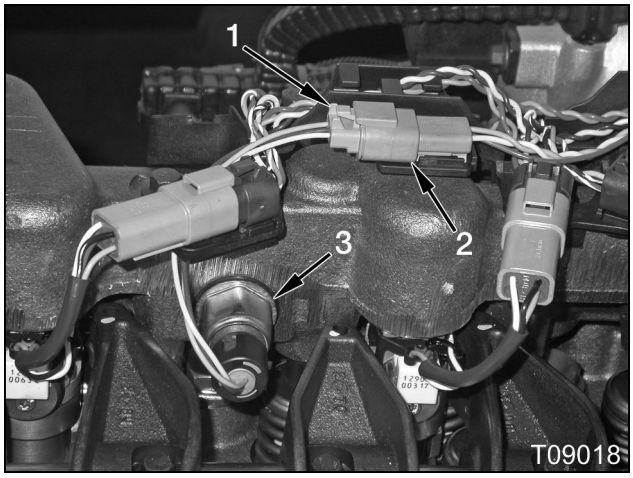


Figure 132 ICP Sensor

1. ICP sensor connector
2. Valve cover gasket harness connector
3. ICP sensor

1. Lubricate a new O-ring with clean engine oil and install on the ICP sensor.
2. Install ICP sensor into high-pressure oil manifold, to the rear of cylinder 5 fuel injector, and tighten to special torque (page 109).
3. Connect valve cover gasket harness connector to the ICP sensor connector.

Engine Throttle Valve (ETV) Assembly Connector

1. See Engine Throttle Valve (ETV) Assembly (page 182) for ETV installation.

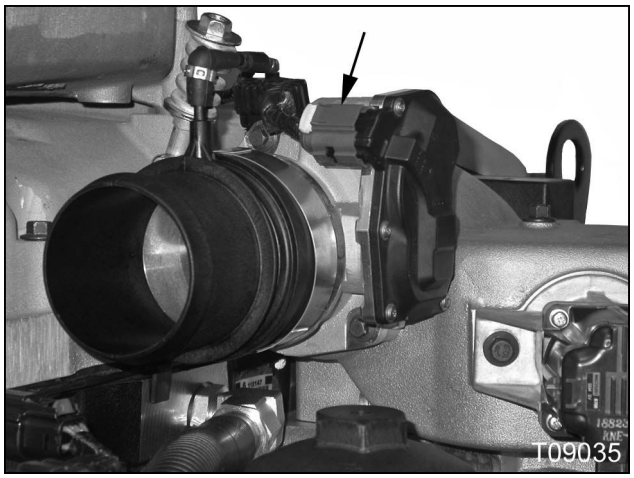


Figure 133 ETV Assembly Engine Harness Connector

2. Connect engine harness connector to ETV assembly.
3. Push down locking tab to lock engine harness connector.

Injection Pressure Regulator (IPR) Valve Connector

1. See High-pressure Oil Pump Assembly and Injection Pressure Regulator (IPR) Valve Assembly (page 226) for IPR valve installation.

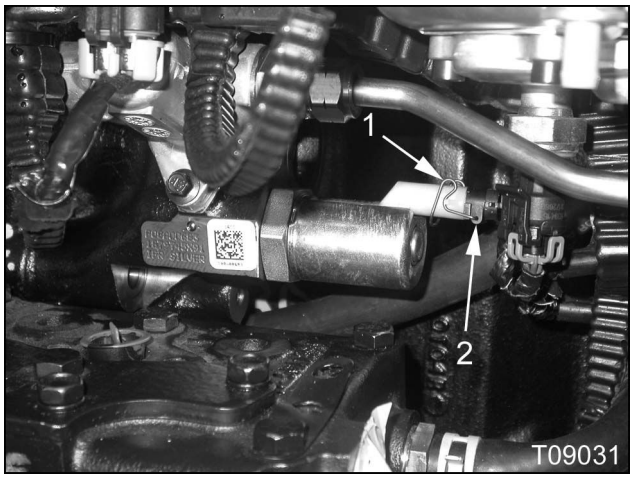


Figure 134 IPR Valve on High-Pressure Oil Pump (Typical)

1. Wire clip lock
2. IPR valve connector

2. Connect IPR valve connector to IPR valve.
3. Connect engine harness wire clip lock.
4. Secure wire clip with a Zip tie.

Intake Manifold Temperature (IMT) Sensor



Figure 135 IMT Sensor

1. Install a new O-ring on the IMT sensor.
2. Install IMT sensor into the intake manifold and tighten to special torque (page 109).

3. Connect engine harness connectors to the IMT sensor.
4. Push down IMT sensor locking tab to lock engine harness connector.

Intake Manifold Pressure (IMP) Sensor

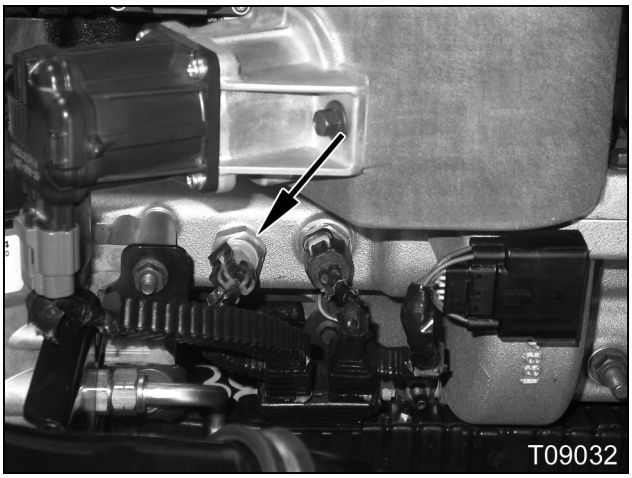


Figure 136 IMP Sensor

1. Install a new O-ring on the IMP sensor.
2. Install IMP sensor into the intake manifold and tighten to special torque (page 109).
3. Connect engine harness connectors to the IMP sensor.

Downstream Injection (DSI) Assembly Connectors

1. Install DSI assembly. See Down Stream Injection (DSI) Assembly (page 122).

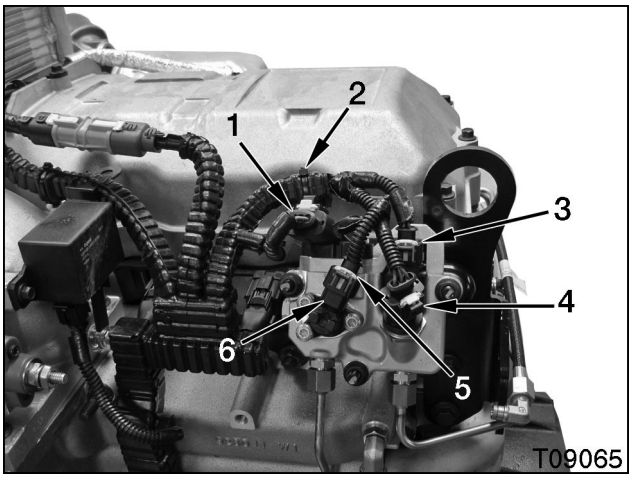


Figure 137 DSI Assembly

1. Upstream pressure/temperature sensor connector
2. Tie strap
3. Dosing Valve (DV) connector
4. Downstream pressure sensor connector
5. Shutoff Valve (SV) connector
6. Shutoff Valve (SV)

2. Connect engine harness connectors to Upstream pressure / temperature sensor, DV, downstream pressure sensor, and SV.
3. Push in the yellow connector lock to secure connector.

Water In Fuel (WIF) Sensor

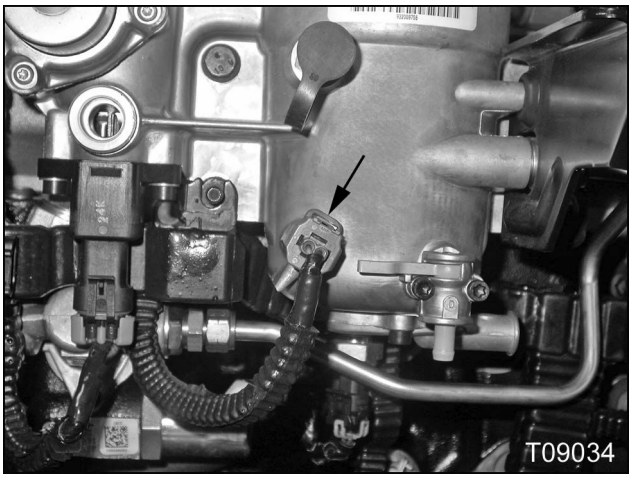


Figure 138 WIF Sensor

1. Install new O-ring on WIF sensor.
2. Install WIF sensor and tighten to special torque (page 109).
3. Connect engine harness connector to WIF sensor.

Valve Cover Gasket Assembly

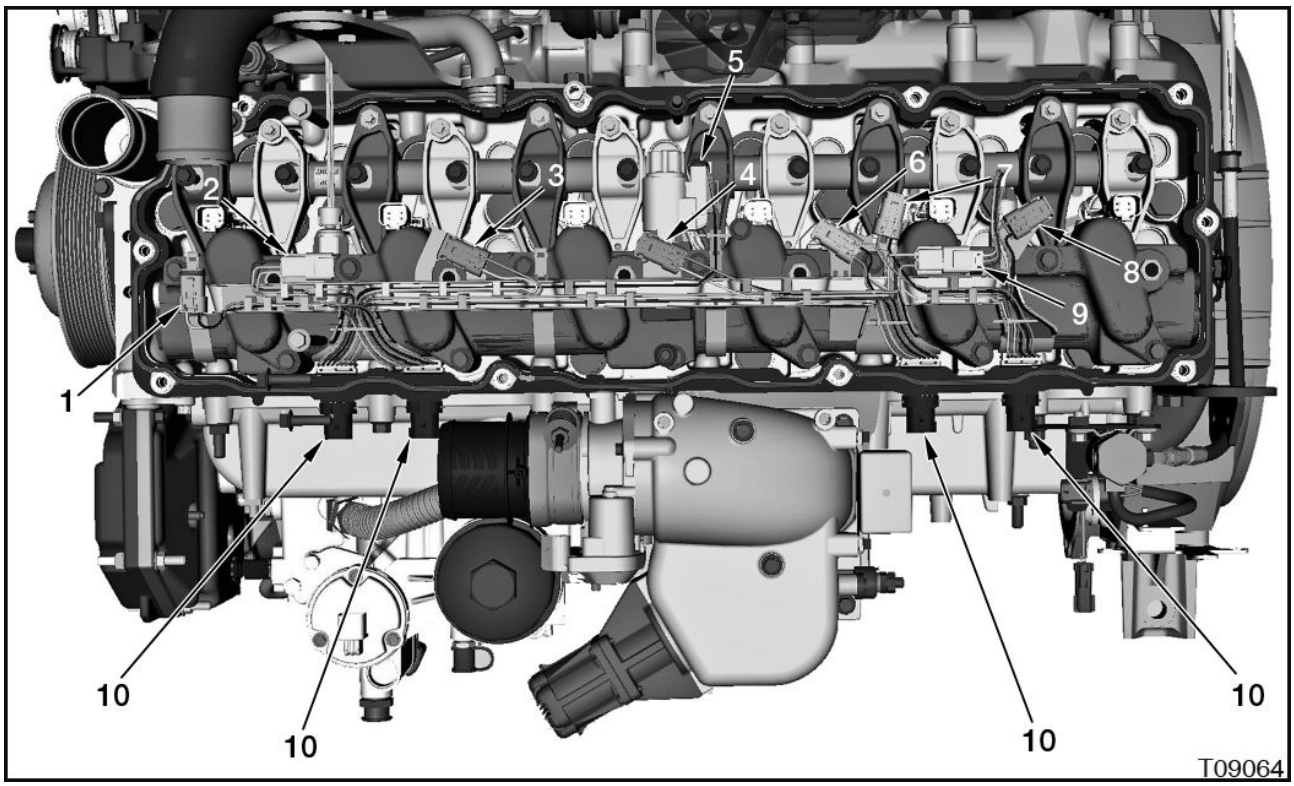


Figure 139 Valve Cover Gasket Assembly Connectors

1. Injector 1 harness connector
2. ECBP sensor connector
3. Injector 2 harness connector
4. Injector 3 harness connector
5. ECB valve connector
6. Injector 4 harness connector
7. Injector 5 harness connector
8. Injector 6 harness connector
9. ICP sensor connector
10. Valve cover gasket connector (4)

1. Position valve cover gasket harness on cylinder head and carefully push down each of the six wire channel retainers to snap harness onto high-pressure oil manifold.
2. Connect four valve cover gasket connectors, ICP sensor connector, and six injector harness connectors.
3. If equipped, connect ECB valve and ECBP sensor connectors.

Special Torque

Battery power junction block, 5/16 – 18 nut	17 N·m (12 lb·ft)
Exhaust Back Pressure (EBP) sensor	20 N·m (15 lb·ft)
Engine Control Module (ECM) mounting bolts, M8 x 45	31 N·m (23 lb·ft)
Engine Coolant Temperature 1 (ECT1) sensor	17.5 N·m (154 lb·in)
Fuel Delivery Pressure (FDP) sensor	12 N·m (102 lb·in)
Exhaust Gas Temperature (EGT) sensor	44 N·m (32 lb·ft)
Engine harness M8 x 12 bolt	34 N·m (25 lb·ft)
Engine harness M8 and M10 nuts	34 N·m (25 lb·ft)
Engine Oil Pressure (EOP) sensor	12 to 18 N·m (106 to 159 lb·in)
Engine Oil Temperature (EOT) sensor	17.5 N·m (154 lb·in)
Intake Air Heater (IAH) relay M6 serrated nuts	4 N·m (35 lb·in)
Injection Control Pressure (ICP) sensor	18 N·m (162 lb·in)
Intake Manifold Pressure (IMP) sensor	11.5 N·m (101 lb·in)
Intake Manifold Temperature (IMT) sensor	10.5 N·m (93 lb·in)
Water In Fuel (WIF) sensor	2 N·m (15 lb·in)

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Exploded Views

Down Stream Injection (DSI) Assembly

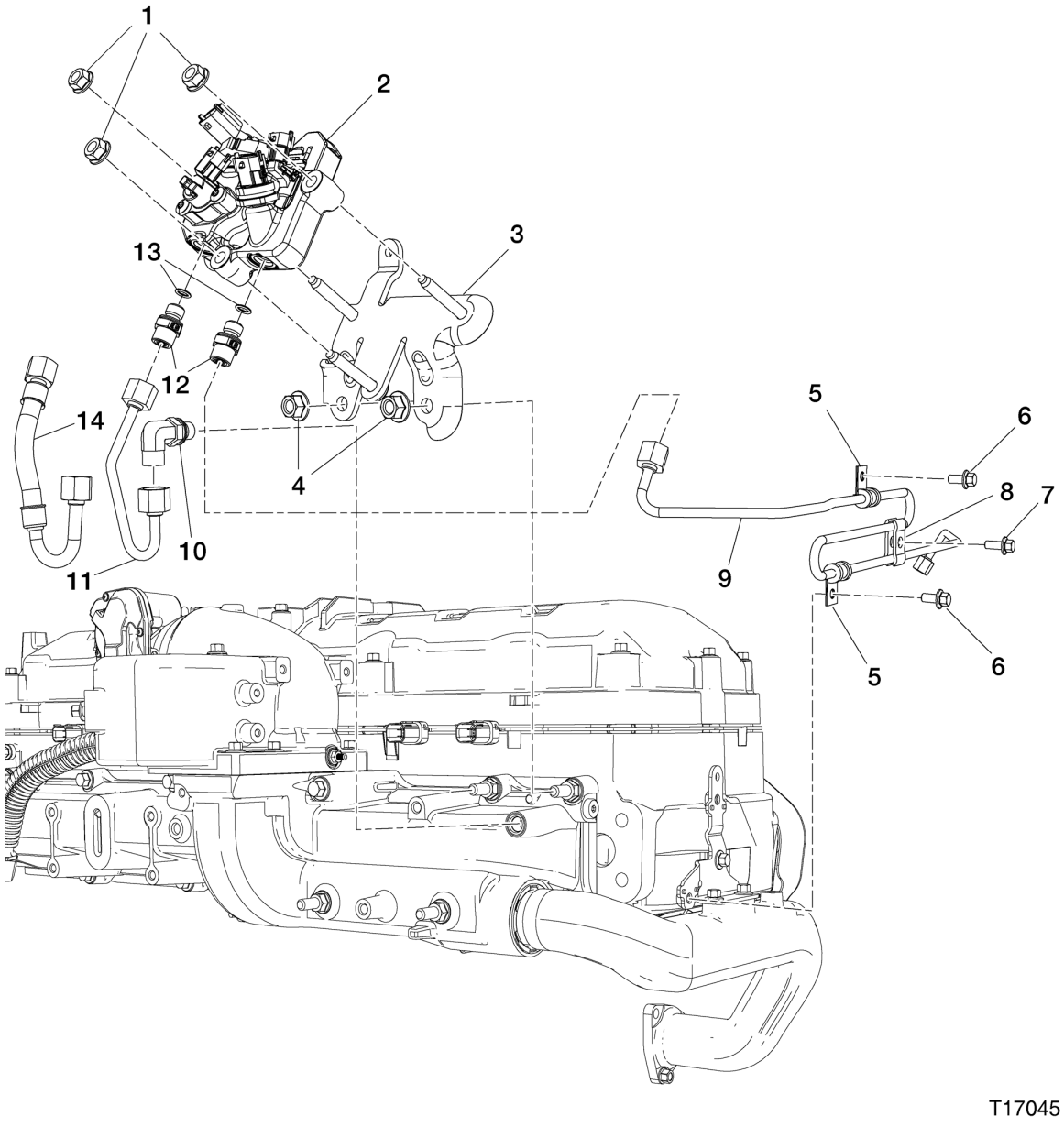


Figure 140 Down Stream Injection (DSI) Assembly

1. M8 nut (3)
2. Down Stream Injection (DSI) assembly
3. Down Stream Injection (DSI) support
4. M10 nut (2)
5. Rubber cushioned clamp (2)
6. M6 x 12 bolt (2)
7. M6 x 14 bolt
8. Tube clamp (2 pcs)
9. Injection unit inlet tube assembly
10. 90 degree M12 tube fitting elbow
11. Down Stream Injection (DSI) inlet tube assembly (hard tube)
12. Fitting assembly (2)
13. O-ring seal (2)
14. Down Stream Injection (DSI) inlet tube assembly (flexible tube)

Hydrocarbon Injector Assembly

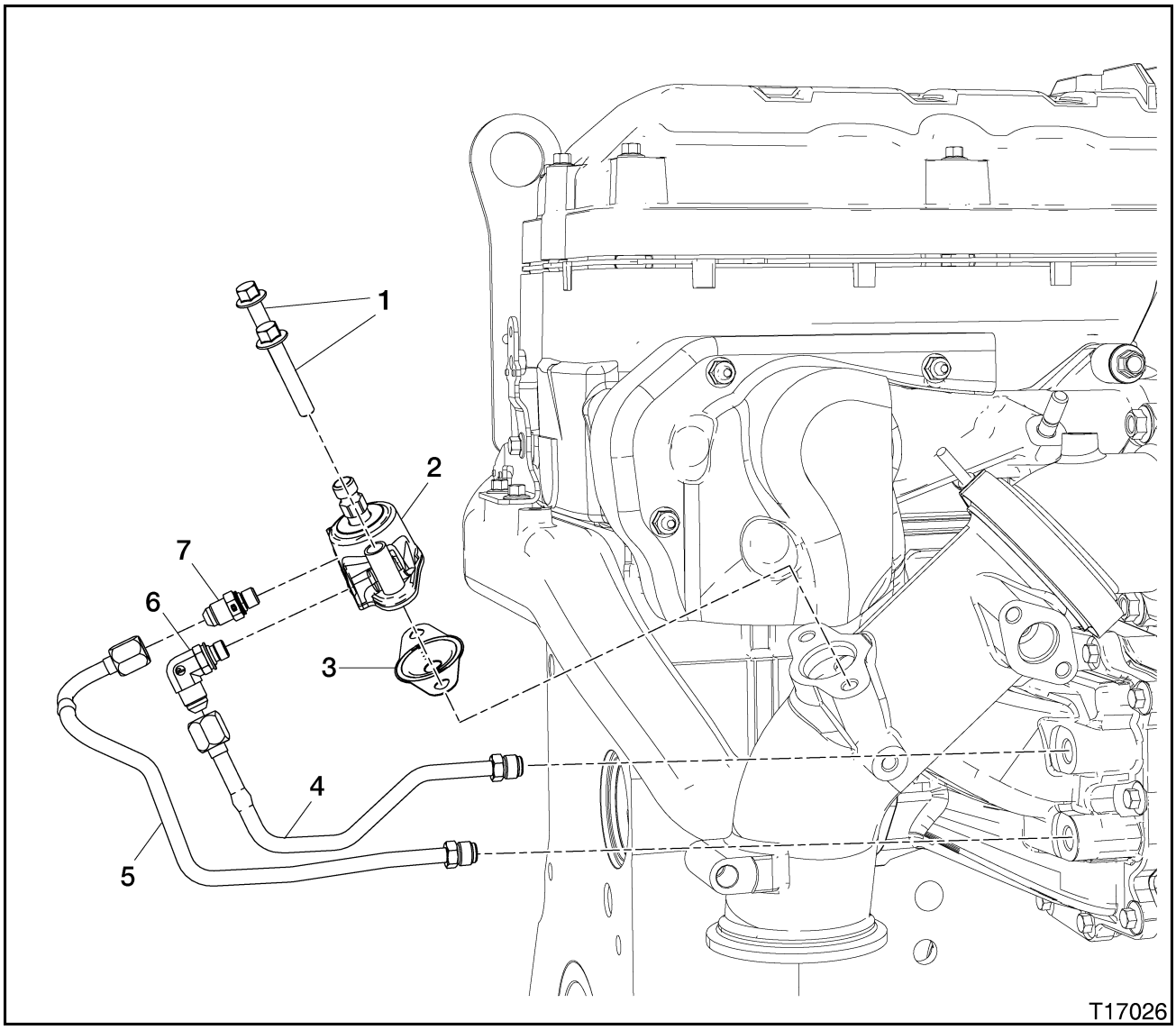


Figure 141 Hydrocarbon Injector Assembly

1. M8 x 45 bolt (2)
2. Hydrocarbon injector assembly
3. Hydrocarbon injector gasket
4. Injector coolant inlet tube assembly
5. Injector coolant outlet tube assembly
6. Tube fitting (90 degree elbow)
7. M10 37 degree flare fitting

Removal

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

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

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

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

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

Down Stream Injection (DSI) Assembly

1. Disconnect engine harness connectors from Down Stream Injection (DSI) assembly electrical connectors.

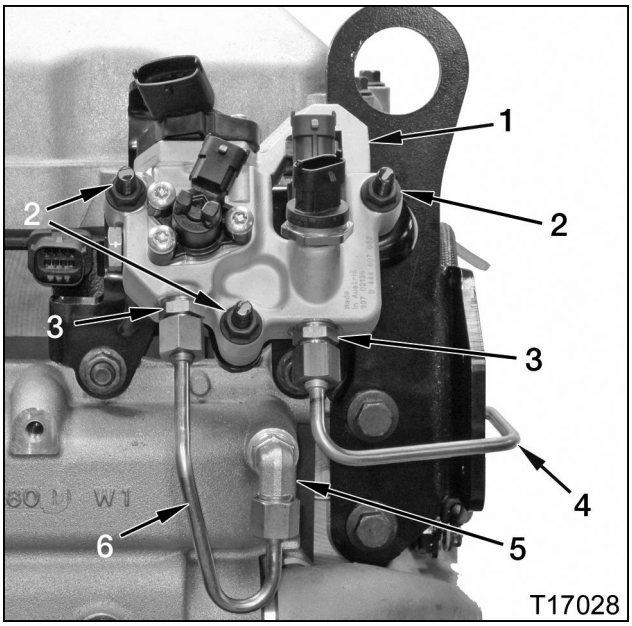


Figure 142 Down Stream Injection (DSI) Assembly (hard tube)

1. Down Stream Injection (DSI) assembly
2. M8 nut (3)
3. Fitting assembly (2)
4. Injection unit inlet tube assembly
5. 90 degree M12 tube fitting elbow
6. Down Stream Injection (DSI) inlet tube assembly

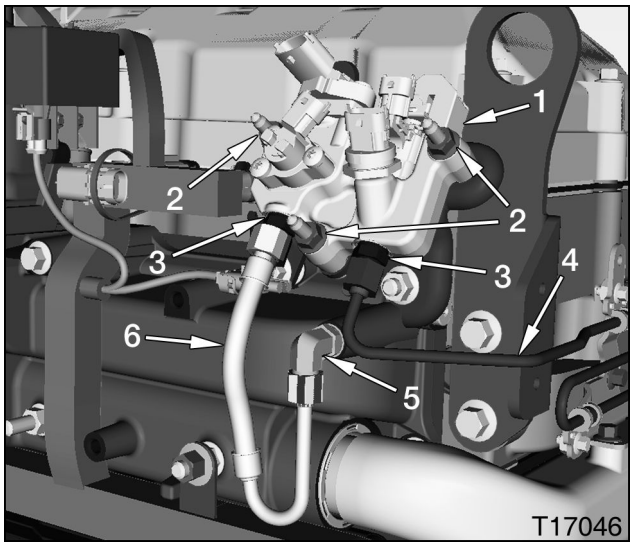


Figure 143 Down Stream Injection (DSI) Assembly (flexible tube)

1. Down Stream Injection (DSI) assembly
2. M8 nut (3)
3. Fitting assembly (2)
4. Injection unit inlet tube assembly
5. 90 degree M12 tube fitting elbow
6. Down Stream Injection (DSI) inlet tube assembly

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

2. Using line wrenches, disconnect Down Stream Injection (DSI) inlet tube assembly and injection unit inlet tube assembly from fitting assemblies on Down Stream Injection (DSI) assembly.
3. Remove DSI inlet tube assembly from 90 degree M12 tube fitting elbow.
4. Remove and save three M8 nuts from DSI assembly.
5. Remove DSI assembly from DSI assembly support.
6. If required, remove fitting assemblies from DSI assembly and discard O-rings.
7. If required, remove 90 degree M12 tube fitting elbow from intake manifold.

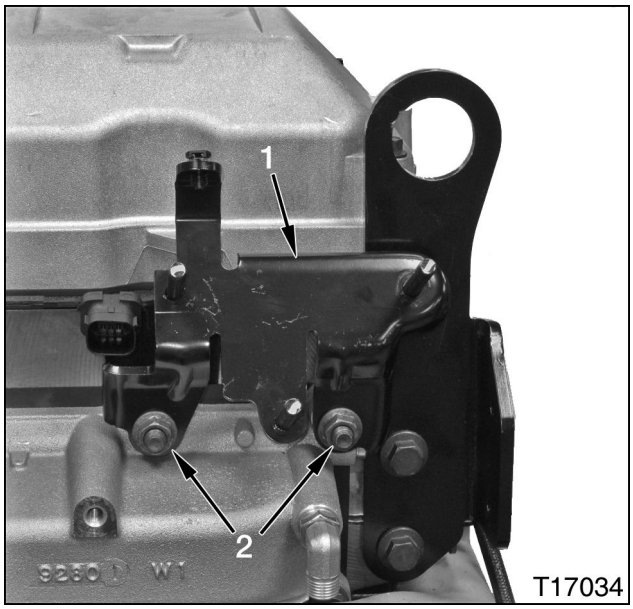


Figure 144 Down Stream Injection (DSI) Support

1. Down Stream Injection (DSI) support
2. M10 nut (2)

8. Remove two M10 nuts from studs in cylinder head.
9. Remove Down Stream Injection (DSI) support from cylinder head.

Injection Unit Inlet Tube Assembly

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

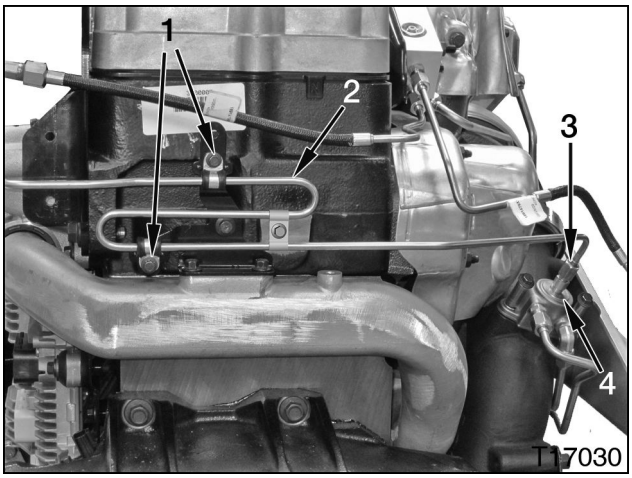


Figure 145 Injection Unit Inlet Tube Assembly at Hydrocarbon Injector

1. M6 x 12 bolts (2)
2. Injection unit inlet tube assembly
3. Injection unit inlet tube flare nut
4. Hydrocarbon injector

1. Use a backup wrench to prevent movement of hydrocarbon injector and disconnect injection unit inlet tube flare nut.
2. Remove two M6 x 12 bolts securing injection unit inlet tube assembly to crossover tube support on cylinder head.
3. Remove injection unit inlet tube assembly.

NOTE: The injection unit inlet tube assembly has precise specifications; only use proper replacement parts. Do not fabricate any fuel lines for Down Stream Injection (DSI) system.

Hydrocarbon Injector Assembly

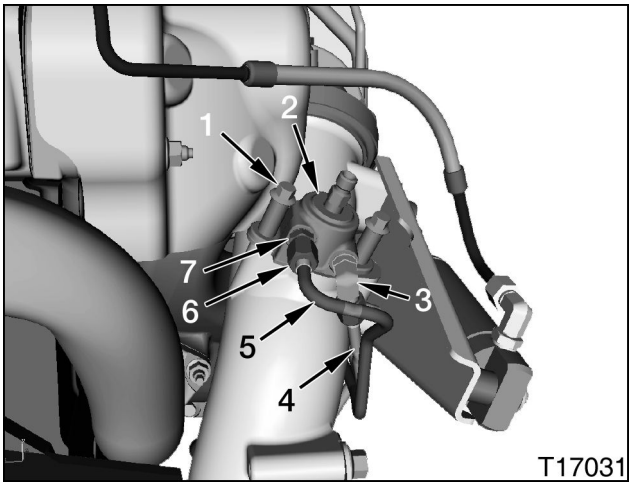


Figure 146 Hydrocarbon Injector Assembly

1. M8 x 45 bolt (2)
2. Hydrocarbon injector assembly
3. Tube fitting (90 degree elbow)
4. Injector coolant inlet tube assembly
5. Injector coolant outlet tube assembly
6. 37 degree flare nut (2)
7. M10 37 degree flare fitting

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

1. Use a backup wrench to prevent movement of M10 37 degree flare fitting while removing 37 degree flare nut. Remove injector coolant outlet tube 37 degree flare nut from fitting.
2. Loosen and remove injector coolant inlet tube 37 degree flare nut from 90 degree elbow tube fitting.

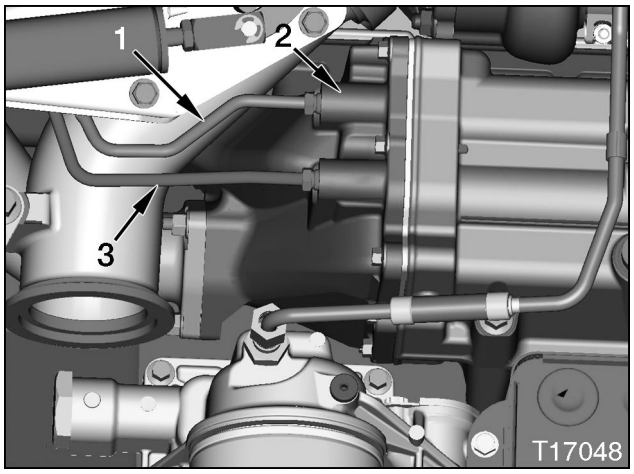


Figure 147 Hydrocarbon Injector Coolant Tubes

1. Injector coolant inlet tube assembly
2. High fin density EGR cooler
3. Injector coolant outlet tube assembly

3. Remove Injector coolant inlet tube assembly and Injector coolant outlet tube assembly from high fin density EGR cooler.
4. Remove M10 37 degree flare fitting and 90 degree elbow tube fitting from hydrocarbon injector, if required.
5. Remove and discard two M8 x 45 bolts that secure hydrocarbon injector assembly.

NOTE: Do not reuse M8 x 45 bolts. These bolts are special high temperature fasteners. Install new bolts.

6. Remove hydrocarbon injector assembly.

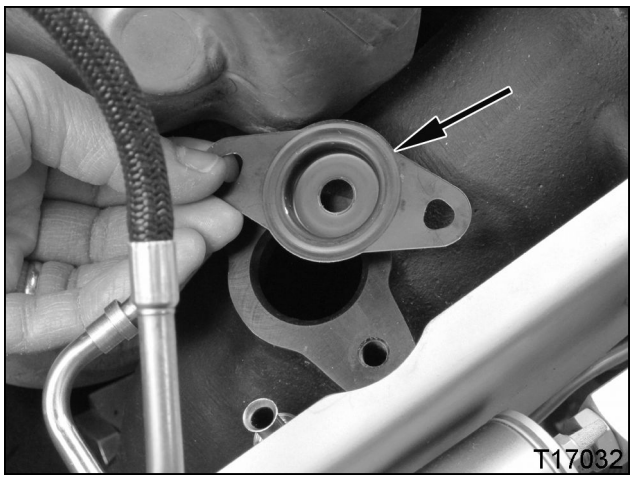


Figure 148 Hydrocarbon Injector Gasket

7. Remove and discard hydrocarbon injector gasket.

Cleaning and Inspection

Hydrocarbon Injector (HCI) / Aftertreatment Fuel Injector (AFI) Cleaning

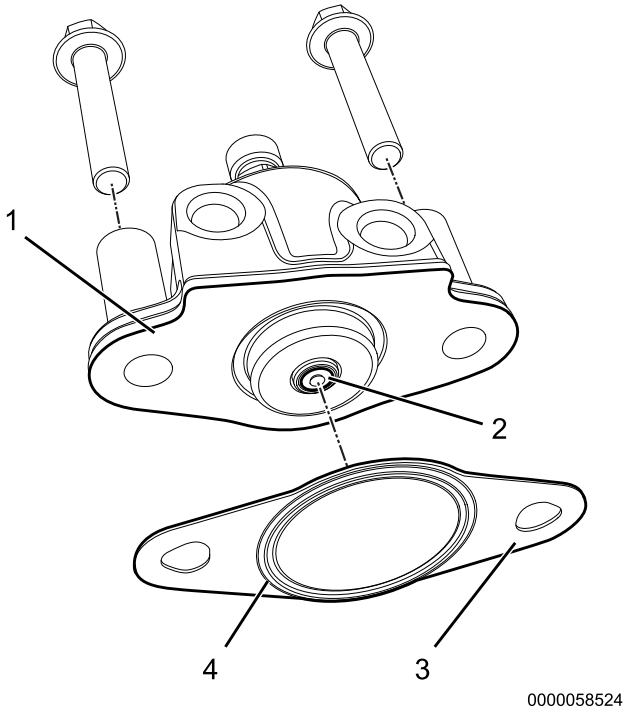


Figure 149 Hydrocarbon / Aftertreatment Fuel Injector Assembly

1. HCI / AFI assembly
2. Injector nozzle tip
3. Hydrocarbon injector gasket
4. Raised sealing lip

CAUTION: To prevent component damage, cleaning of the HCI / AFI assembly using cleaner or solvents is NOT recommended. Do not blast the injector with compressed air. Do not pull or otherwise manipulate the injector nozzle tip.

1. Inspect HCI / AFI assembly (Figure 149) (Item 1) and injector nozzle tip (Figure 149) (Item 2) for cracks and other damage. If damage is present, replace HCI / AFI assembly.
2. Use Fuel Injector Tip Cleaning Brush ZTSE4301 to clean any carbon buildup that may be present on the injector nozzle tip.

Exhaust Back Pressure Valve Housing Cleaning

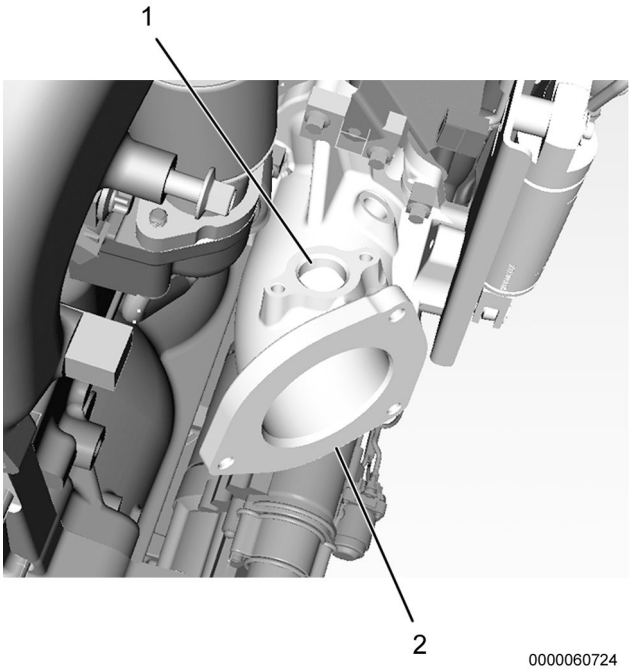


Figure 150 Exhaust Back Pressure Valve Housing

1. HCI / AFI port
2. Exhaust back pressure valve housing

CAUTION: To prevent damage to the aftertreatment system or plugging of the PDOC / DOC / DPF, ensure no carbon debris remains in HCI / AFI port upon completion of steps 1 and 2.

1. Carefully remove carbon from the HCI / AFI port (Figure 150) (Item 1) on the exhaust back pressure valve housing (Figure 150) (Item 2) with a chisel or other appropriate tool. Remove debris with a shop vac.

Installation

Hydrocarbon Injector Assembly

NOTE: New hydrocarbon injector gasket may look different from gasket pictured below.

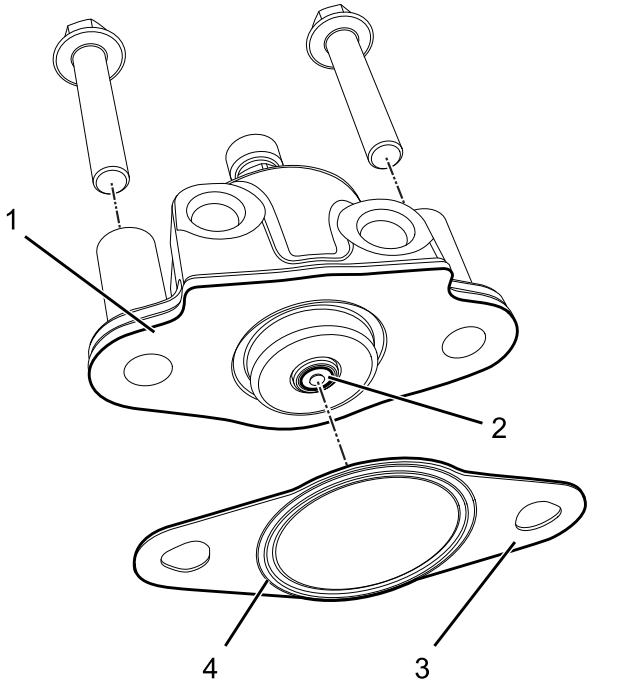


Figure 151 Hydrocarbon (HCI) / Aftertreatment Fuel Injector (AFI) Assembly

1. HCI / AFI assembly
2. Injector nozzle tip
3. Hydrocarbon injector gasket
4. Raised sealing lip

1. Install a new hydrocarbon injector gasket.

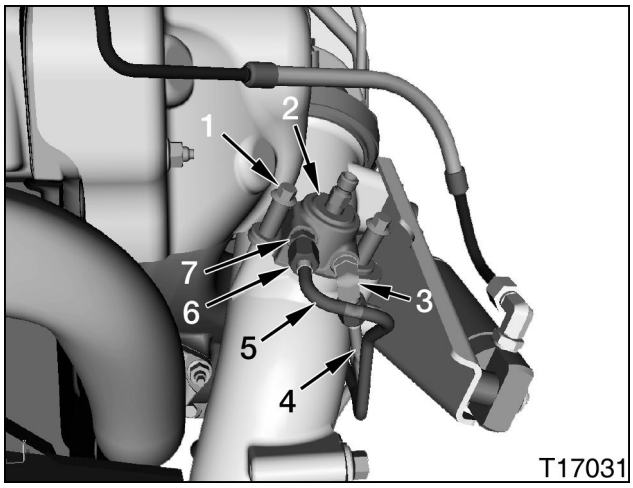


Figure 152 Hydrocarbon Injector Unit

1. M8 x 45 bolt (2)
2. Hydrocarbon injector assembly
3. Tube fitting (90 degree elbow)
4. Injector coolant inlet tube assembly
5. Injector coolant outlet tube assembly
6. 37 degree flare nut (2)
7. M10 37 degree flare fitting

2. Position hydrocarbon injector assembly so mounting holes align with holes in gasket.

NOTE: Do not reuse M8 x 45 bolts. These bolts are special high temperature fasteners. Install new bolts.

3. Install two new M8 x 45 bolts. Tighten bolts to two-step special torque (page 124).

4. If previously removed, install M10 37 degree flare fitting and 90 degree elbow tube fitting into hydrocarbon injector assembly. Tighten M10 37 degree flare fitting to special torque (page 124). Tighten 90 degree elbow tube fitting finger tight. Back out 90 degree elbow tube fitting to allow for installation of Injector coolant inlet tube assembly.

NOTE: Install injector coolant inlet tube assembly first, then the injector coolant outlet tube assembly. The injector coolant inlet tube assembly attaches at the lower port (90 degree elbow tube fitting) on the hydrocarbon injector assembly. Ports are labeled “in” and “out”.

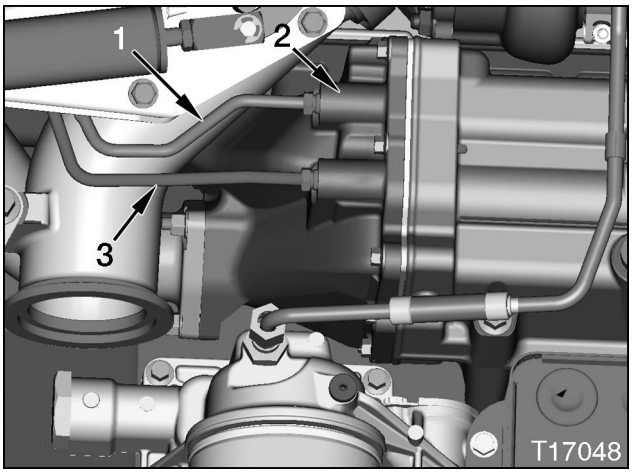


Figure 153 Hydrocarbon Injector Coolant Tubes

1. Injector coolant inlet tube assembly
2. High fin density EGR cooler
3. Injector coolant outlet tube assembly

5. Connect injector coolant inlet tube assembly to high fin density EGR cooler and 90 degree elbow tube fitting. Tighten tube fittings finger tight.
6. Tighten 90 degree elbow tube fitting to special torque (page 124).
7. While maintaining injector coolant inlet tube assembly clearance from exhaust brake housing, tighten fittings to special torque (page 124).
8. Make sure injector coolant inlet tube assembly is not touching casting of exhaust brake housing.
9. Install injector coolant outlet tube assembly to high fin density EGR cooler and M10 37 degree flare fitting. Tighten fittings finger tight.
10. Using backup wrench to hold M10 37 degree flare fitting, tighten tube flare nut to special torque (page 124).
11. Tighten tube fitting at high fin EGR cooler to special torque (page 124).

Injection Unit Inlet Tube Assembly

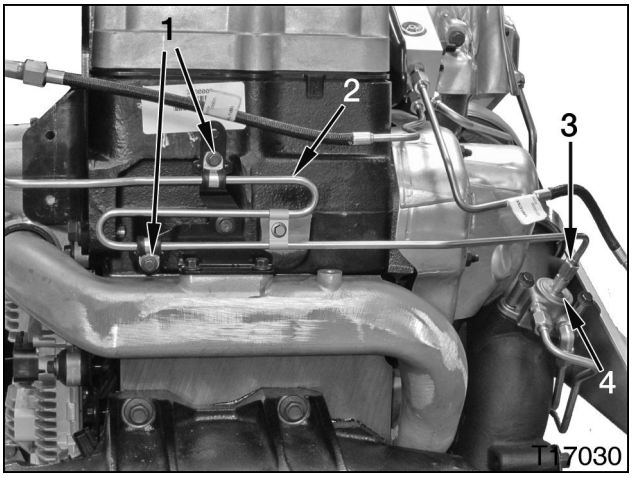


Figure 154 Injection Unit Inlet Tube Assembly at Hydrocarbon Injector

1. M6 x 12 bolts (2)
2. Injection unit inlet tube assembly
3. Injection unit inlet tube flare nut
4. Hydrocarbon injector

CAUTION: The injection unit inlet tube assembly has precise specifications of length, inside diameter, and tubing thickness; only use proper replacement parts. Do not fabricate any fuel lines of the Down Stream Injection (DSI) system.

1. Position injection unit inlet tube assembly in place on rear of cylinder head.
2. Install two M6 x 12 bolts securing injection unit inlet tube assembly to crossover tube support on cylinder head.
3. Connect injection unit inlet tube assembly to hydrocarbon injector. Use a backup wrench to prevent movement of hydrocarbon injector while tightening injection unit inlet tube flare nut. Tighten tube flare nut to special torque (page 124).

Down Stream Injection (DSI) Assembly

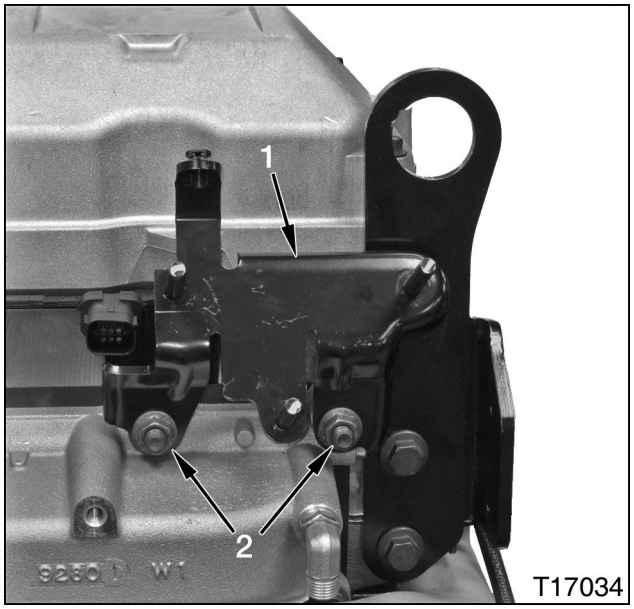


Figure 155 Down Stream Injection (DSI) Support

1. Down Stream Injection (DSI) support
2. M10 nut (2)

1. Install DSI support on cylinder head.
2. Install two M10 nuts on studs to secure DSI support. Tighten nuts to standard torque (page 553).

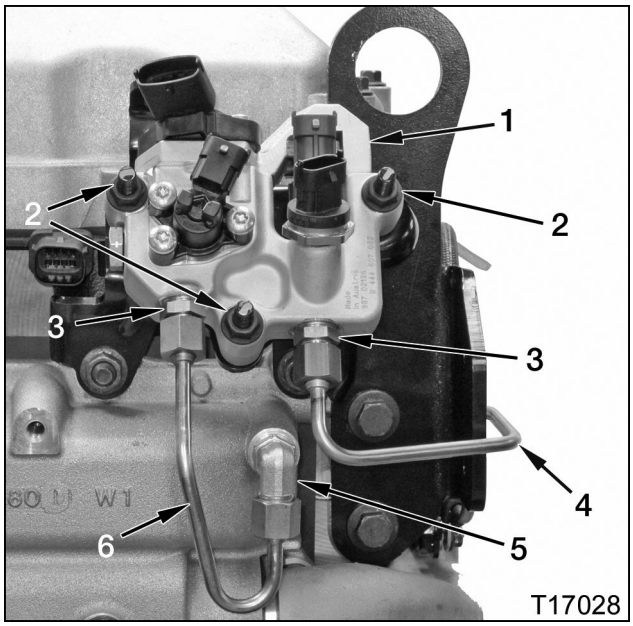


Figure 156 Down Stream Injection (DSI) Assembly (hard tube)

1. Down Stream Injection (DSI) assembly
2. M8 nut (3)
3. Fitting assembly (2)
4. Injection unit inlet tube assembly
5. 90 degree M12 tube fitting elbow
6. Down Stream Injection (DSI) inlet tube assembly

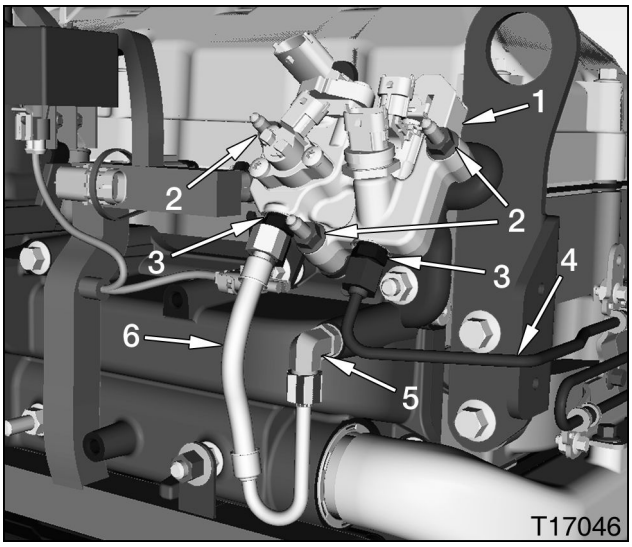


Figure 157 Down Stream Injection (DSI) Assembly (flexible tube)

1. Down Stream Injection (DSI) assembly
2. M8 nut (3)
3. Fitting assembly (2)
4. Injection unit inlet tube assembly
5. 90 degree M12 tube fitting elbow
6. Down Stream Injection (DSI) inlet tube assembly

3. Seat Down Stream Injection (DSI) assembly onto Down Stream Injection (DSI) support.
4. Install three saved M8 nuts. Tighten M8 nuts to standard torque (page 553).
5. If previously removed, install fitting assemblies in DSI assembly with new O-rings. Tighten to special torque (page 124).
6. Install 90 degree M12 tube fitting elbow into intake manifold. Tighten to special torque (page 124).
7. Connect DSI inlet tube assembly to 90 degree M12 tube fitting elbow in intake manifold and fitting in DSI assembly. Tighten tube nuts as follows:
   - For hard DSI inlet tube assembly, use a backup wrench to hold fitting assembly and tighten tube nut to special torque (page 124).
   - For flexible DSI inlet tube assembly, use a backup wrench to hold fitting assembly and tighten the tube nut at the 90 degree M12 tube fitting elbow, then at DSI assembly to special torque (page 124).
8. Connect injection unit inlet tube assembly to DSI assembly and hydrocarbon injector. Use a backup wrench to hold fitting assembly and tighten to special torque (page 124).

Special Torque

90 degree elbow tube fitting	20 N·m (15 lb·ft)
90 degree M12 tube fitting elbow	35 N·m (26 lb·ft)
Coolant line tube flare nuts at HC injector	20 N·m (15 lb·ft)
Coolant line tube nuts at high fin density EGR cooler	20 N·m (15 lb·ft)
Down Stream Injection (DSI) inlet tube assembly nuts	24 N·m (18 lb·ft)
Fitting assembly (on DSI assembly)	35 N·m (26 lb·ft)
Injection unit inlet tube nuts	24 N·m (18 lb·ft)
M8 x 45 bolts (hydrocarbon injector assembly)	Step 1: 11 N·m (8 lb·ft)
	Step 2: 24 N·m (18 lb·ft)
M10 37 degree flare fitting	20 N·m (15 lb·ft)

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Exploded View

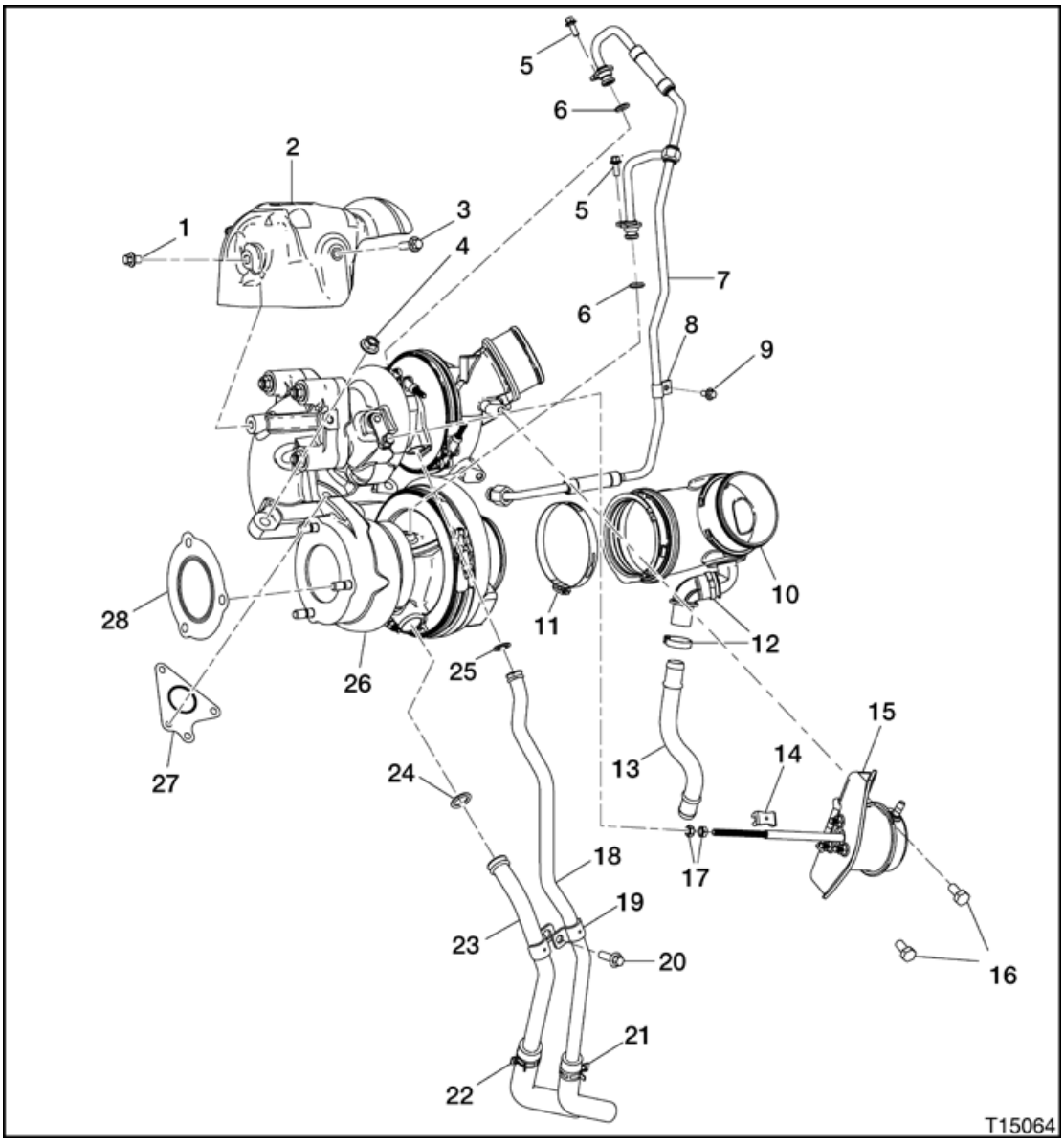


Figure 158 Dual Stage Turbocharger Assembly Components

1. M8 x 12 high temperature bolt (3)
2. Turbo heat shield
3. M8 x 27 high temperature bolt
4. M10 special thread nut (5)
5. M6 x 16 bolt (2)
6. O-ring #305 (2)
7. Turbo oil supply tube assembly
8. Single cushioned clamp
9. M6 x 12 bolt
10. Turbocharger air inlet duct
11. Turbo inlet clamp
12. Oetiker clamp
13. Breather tube
14. Retainer clip
15. Turbocharger wastegate actuator assembly
16. M8 x 16 bolt (2)
17. M6 nut (2)
18. HP turbocharger oil drain tube
19. Tube support
20. M8 x 25 bolt
21. 24 mm spring clamp
22. 26 mm spring clamp
23. LP turbocharger oil drain tube
24. O-ring, (.734 x .139 in)
25. O-ring (green)
26. Dual stage turbocharger assembly
27. Turbocharger mounting gasket
28. Turbocharger outlet gasket

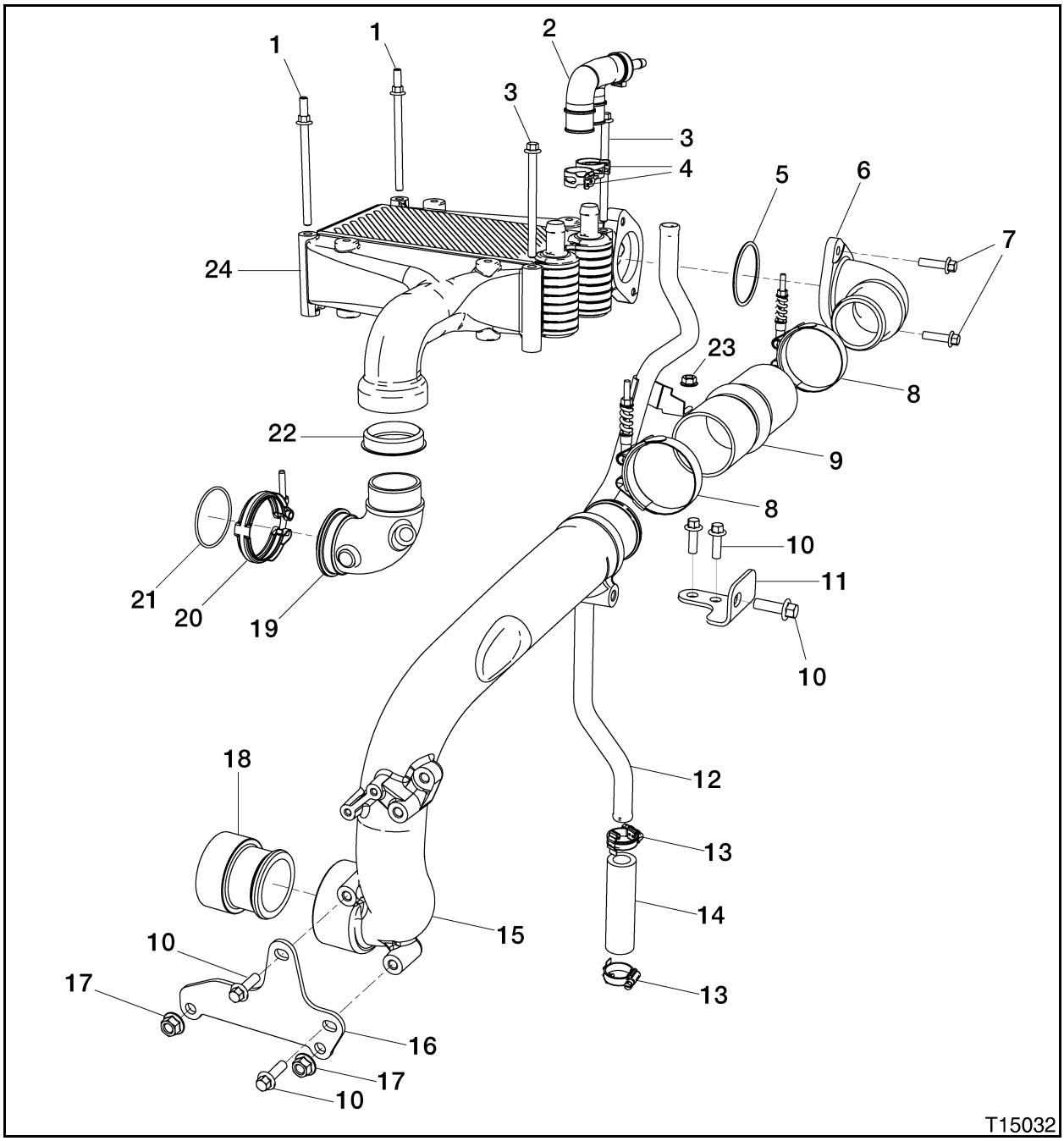


Figure 159 Interstage Cooler (ISC) Components (245 HP and Above)

1. M8 x 110 stud bolt (2)
2. Elbow deaeration hose
3. M8 x 110 bolt (2)
4. 29 mm clipless clamp (2)
5. 3.53 x 63.09 ID O-ring
6. ISC inlet elbow
7. M8 x 30 bolt (2)
8. T-bolt (hose) clamp (2)
9. Flexible air hose
10. M8 x 25 bolt (5)
11. Top ISC duct support
12. ISC coolant return tube
13. 3/4 in. worm gear clamp (2)
14. ISC coolant return hose
15. Interstage inlet duct
16. Intermediate stage support
17. M10 nut (2)
18. Crossover tube seal
19. Turbo inlet elbow
20. V-band clamp
21. 2.62 x 61.6 ID O-ring
22. Crossover tube lip seal
23. M8 nut
24. Interstage Cooler (ISC)

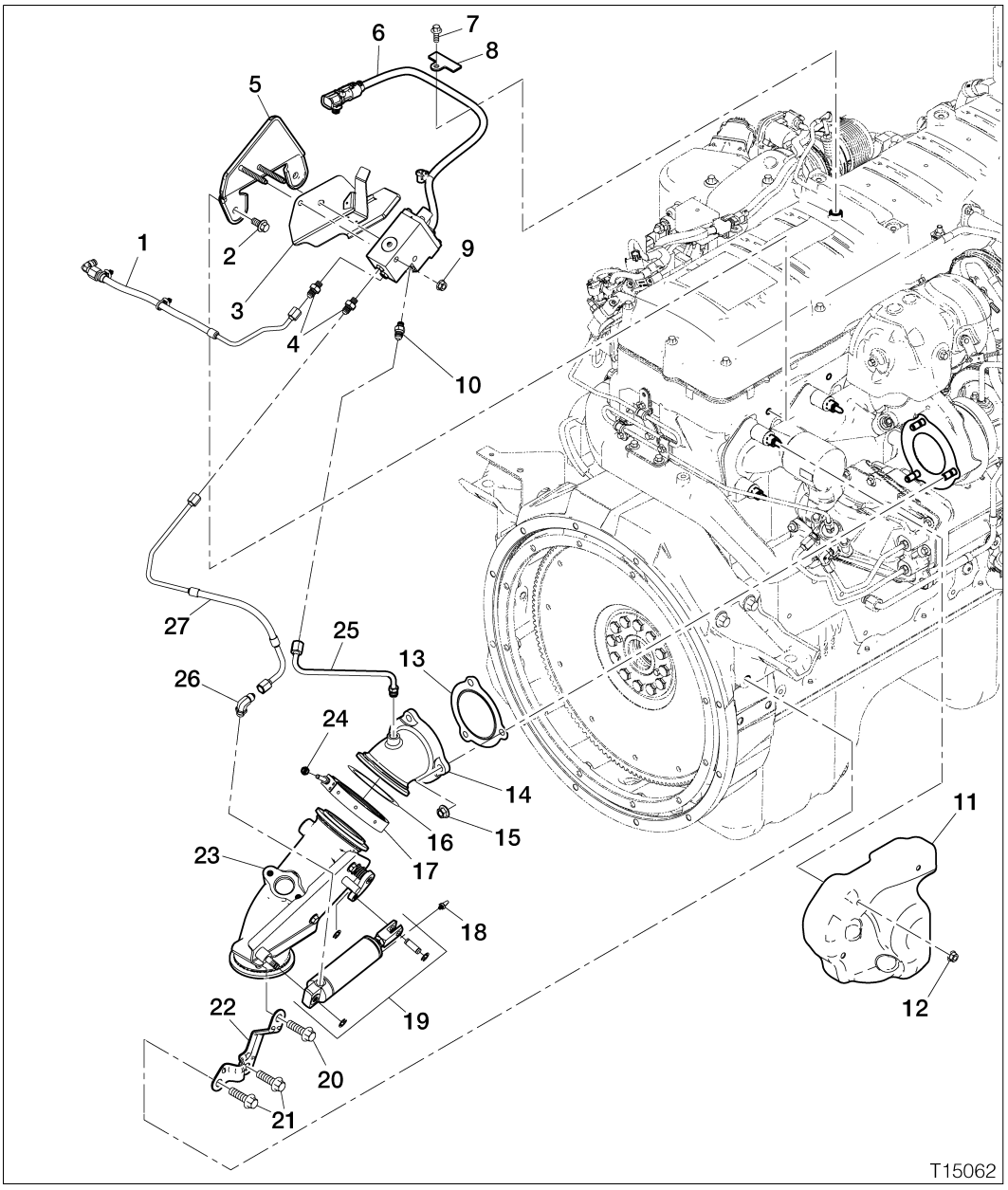


Figure 160 Exhaust Brake Valve Components

1. Exhaust brake valve supply hose
2. M10 x 20 bolt (2)
3. Exhaust brake valve heat shield
4. M10 37 degree flare fitting (2)
5. Exhaust brake support assembly
6. Exhaust brake valve assembly
7. M8 x 20 bolt
8. Harness clamp
9. M8 nut (2)
10. Exhaust tube fitting
11. Exhaust manifold heat shield
12. M8 lock nut (3)
13. Turbocharger outlet gasket
14. Turbocharger outlet elbow
15. M10 Special thread nut (3)
16. Exhaust brake gasket
17. Exhaust clamp
18. Cylinder muffler
19. Actuator assembly, w/ E clips
20. M12 x 25 bolt
21. M12 x 40 bolt (2)
22. Turbocharger pipe under rail support
23. Under rail exhaust brake housing
24. 1/4 lock nut
25. Exhaust brake tube assembly
26. 90 degree tube fitting elbow
27. Exhaust brake valve to actuator hose

Removal

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

WARNING: Read all safety instructions in the "Safety Information" section of this manual before doing any procedures. Follow all warnings, cautions, and notes.

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

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

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

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

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

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

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: When performing specific component removal, only remove components necessary for access.

Interstage Inlet Duct Assembly

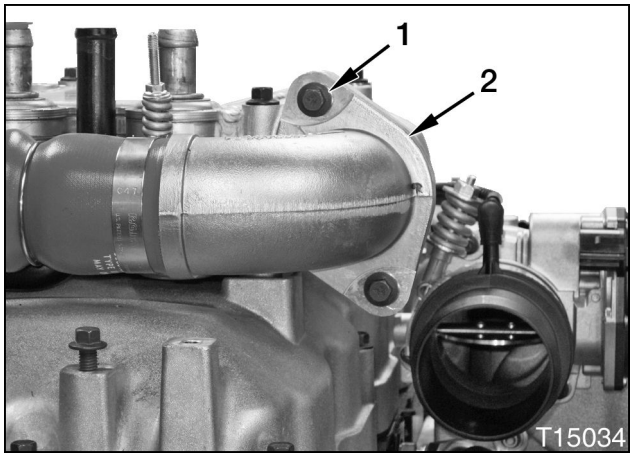


Figure 161 Interstage Cooler (ISC) Inlet Elbow

1. M8 x 30 bolt (2)
2. ISC inlet elbow

1. Remove two M8 x 30 bolts.
2. Remove ISC inlet elbow from ISC.

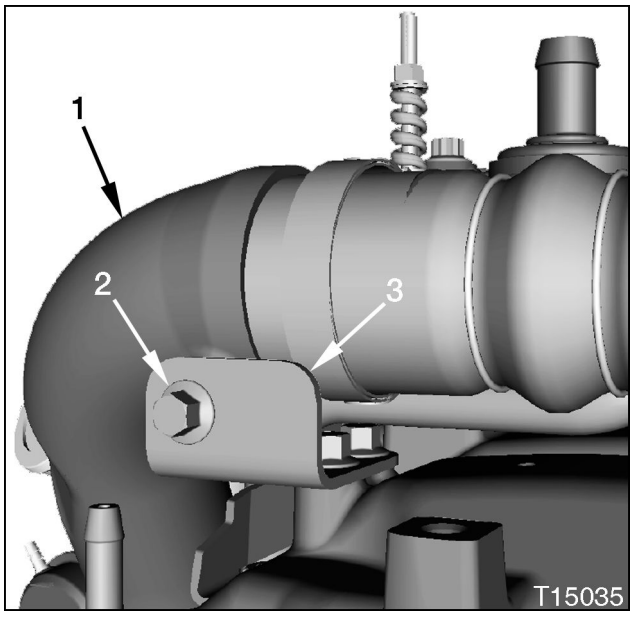


Figure 162 Interstage Inlet Duct and Top ISC Duct Support

1. Interstage inlet duct
2. M8 x 25 bolt (3)
3. Top ISC duct support

3. Remove M8 x 25 bolt from front of top ISC duct support.

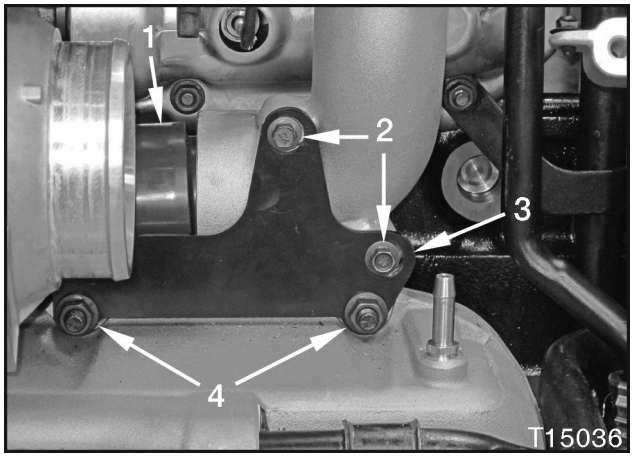


Figure 163 Intermediate Stage Support

1. Crossover tube seal
2. M8 x 25 bolt (2)
3. Intermediate stage support
4. M10 nut (2)

4. Remove two M8 x 25 bolts from intermediate stage support.
5. Remove two M10 nuts from EGR cooler stud bolts.
6. Remove intermediate stage support.
7. Remove interstage inlet duct assembly.
8. If necessary, remove crossover tube seal by hand. Inspect crossover tube seal for wear or damage. See Crossover Tube Seal (page 148).

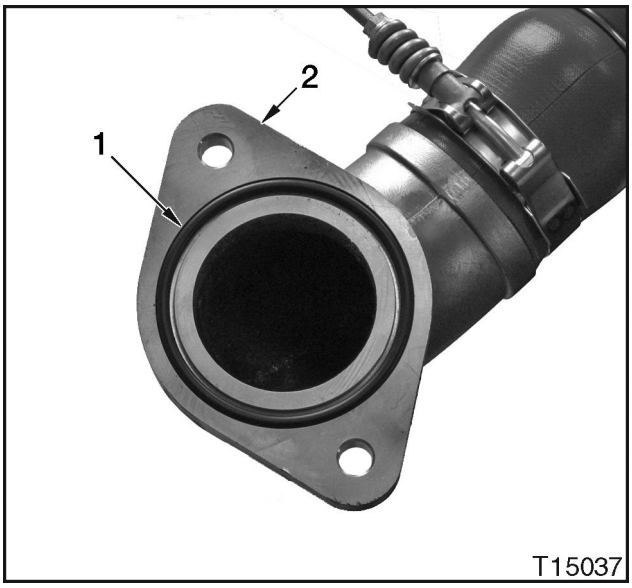


Figure 164 ISC Inlet Elbow O-ring

1. 3.53 x 63.09 O-ring
2. ISC inlet elbow

9. Remove and discard O-ring from ISC inlet elbow.

Interstage Cooler (ISC)

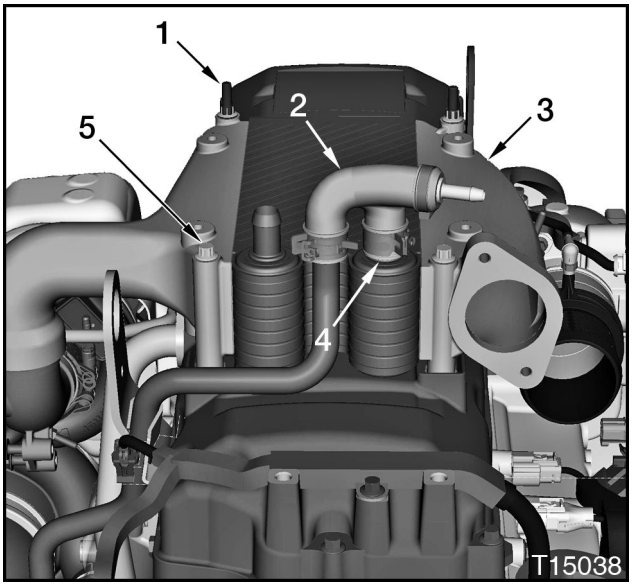


Figure 165 ISC

1. M8 x 110 stud bolt (2)
2. Elbow deaeration hose
3. Interstage cooler (ISC)
4. 29 mm clipless clamp (2)
5. M8 x 110 bolt (2)

1. Loosen both 29 mm clipless clamps and remove elbow deaeration hose.
2. Remove two M8 x 110 bolts and two M8 x 110 stud bolts.
3. Lift ISC from valve cover and pull off of turbocharger inlet elbow.

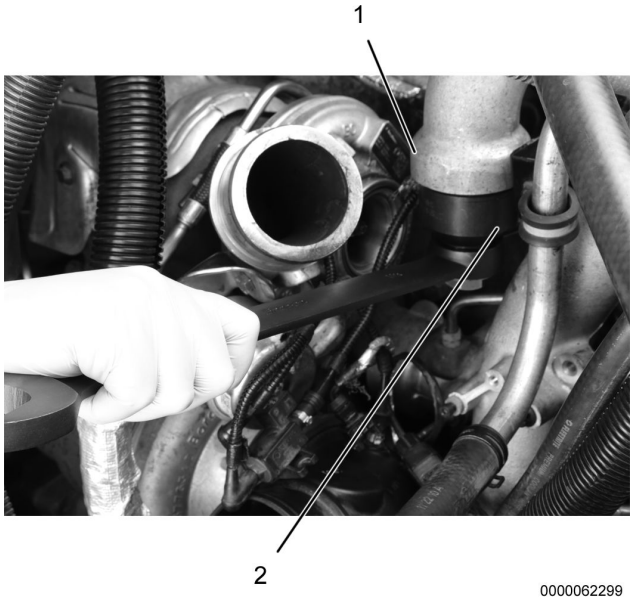


Figure 166 Crossover Tube Outlet Lip Seal Removal

1. ISC outlet
2. ZTSE4937–2 seal remover

4. Install ZTSE4937–2 seal remover into ISC outlet.
5. Using a 1-1/4 in combination wrench, thread ISC seal remover into outlet until it tightly grips crossover tube lip seal.
6. Using provided bolt and washer, secure box end of 1–1/4 in box end wrench to seal remover.
7. Using up-and-down prying motion, remove seal from ISC outlet.

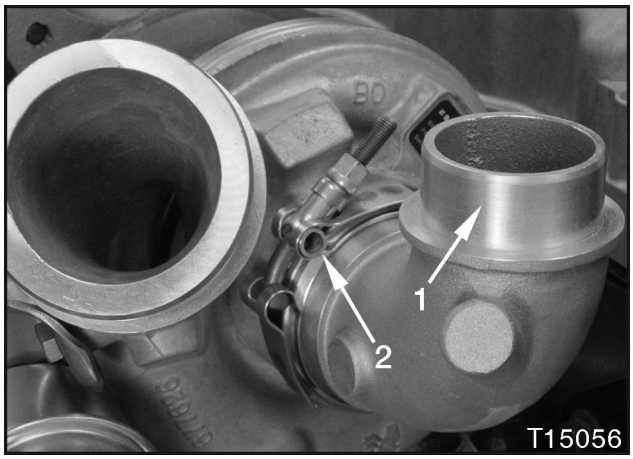


Figure 167 Turbocharger Inlet Elbow

1. Turbocharger inlet elbow
2. V-band clamp

8. Loosen V-band clamp and remove turbocharger inlet elbow.

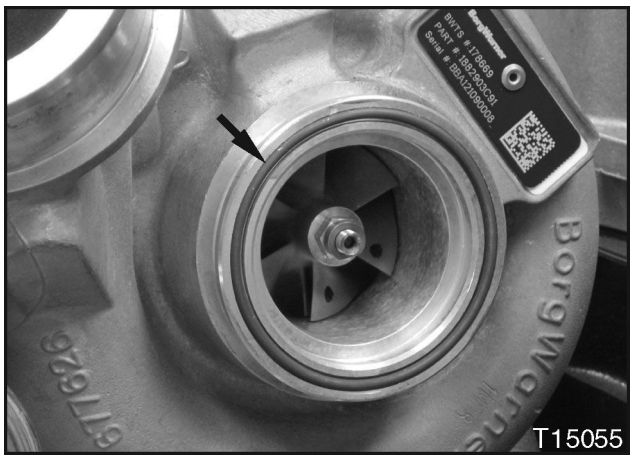


Figure 168 2.62 x 61.6 ID O-ring

9. Remove 2.62 x 61.6 ID O-ring from high-pressure turbocharger assembly and discard.

Throttle Coupling

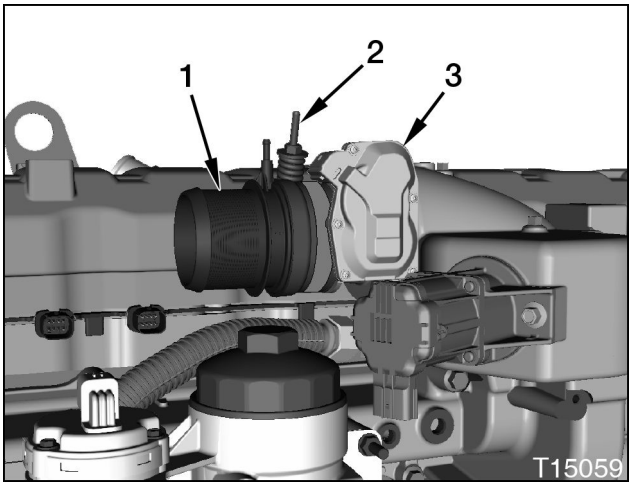


Figure 169 Throttle Coupling

1. Throttle coupling
2. Heat exchanger clamp
3. Engine throttle valve assembly

1. Loosen nut on heat exchanger clamp.
2. Remove throttle coupling from engine throttle valve assembly.

Turbocharger Oil Supply Tube Assembly

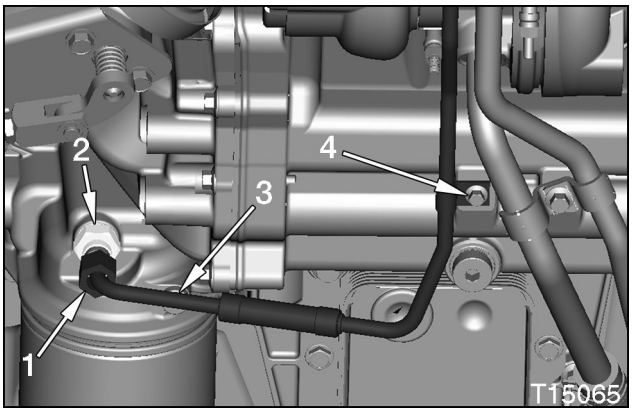


Figure 170 Turbocharger Oil Supply Tube Assembly

1. Turbocharger oil supply tube nut
2. Fitting and O-ring (with screen)
3. Oil supply tube assembly
4. M6 x 12 bolt

1. Remove turbocharger oil supply tube nut from fitting and O-ring (with screen) on the oil cooler housing.
2. Remove M6 x 12 bolt securing turbocharger oil supply tube assembly retainer to EGR cooler.

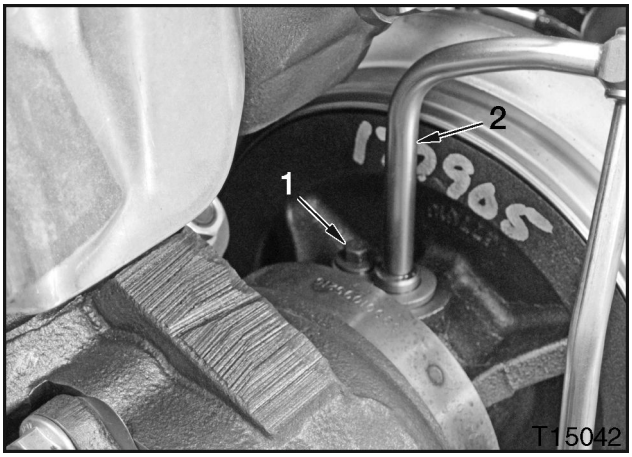


Figure 171 Oil Supply Tube at Low-Pressure Turbocharger Assembly

1. M6 x 16 bolt
2. Oil supply tube assembly

3. Remove M6 x 16 bolt securing oil supply tube assembly to low-pressure turbocharger.

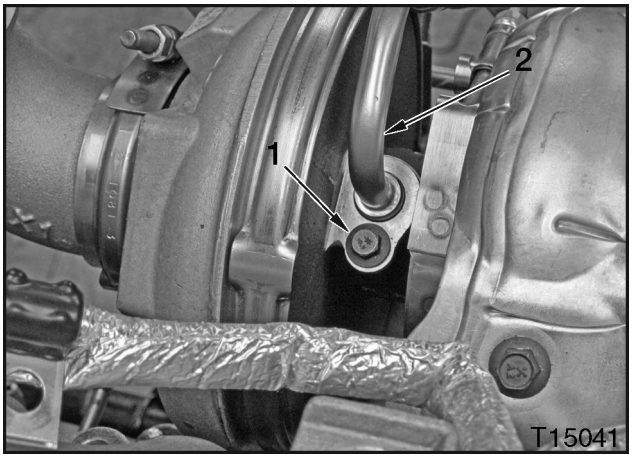


Figure 172 Oil Supply Tube at High-Pressure Turbocharger Assembly

1. M6 x 16 bolt
2. Oil supply tube assembly

4. Remove M6 x 16 bolt securing oil supply tube assembly to high-pressure turbocharger.
5. Remove oil supply tube assembly.
6. Remove and discard two oil supply tube O-rings.

Exhaust Brake Valve and Turbocharger Outlet Elbow

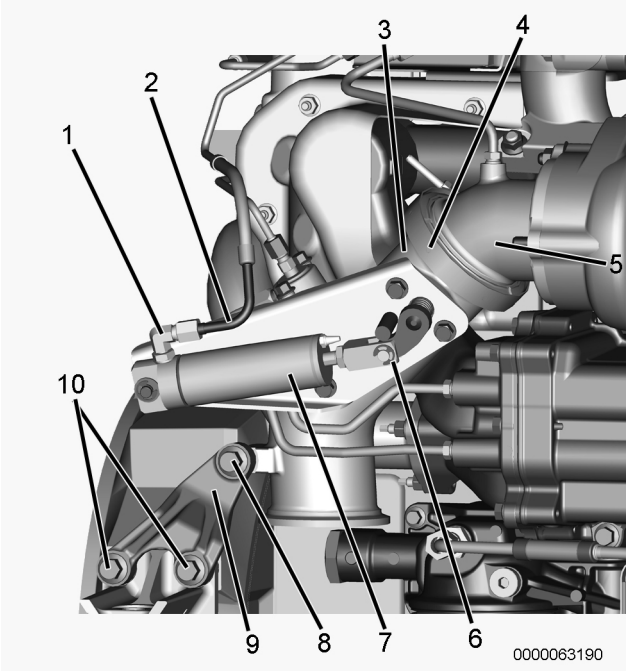


Figure 173 Exhaust Brake Valve and Support Bracket

1. 90 degree tube fitting elbow
2. Exhaust brake valve to actuator hose
3. Under rail exhaust brake housing
4. Exhaust clamp
5. Turbocharger outlet elbow
6. E clip (2)
7. Actuator
8. M12 x 25 bolt
9. Turbocharger pipe under rail support
10. M12 x 40 bolt (2)

1. Remove two M12 x 40 bolts from turbocharger pipe under rail support at engine mount and one M12 x 25 bolt at exhaust brake under rail housing. Remove turbocharger pipe under rail support.
2. Disconnect exhaust brake valve to actuator hose from 90 degree tube fitting elbow on actuator assembly.
3. If required, remove two E clips and remove actuator.
4. Loosen exhaust clamp and remove exhaust brake under rail housing from turbocharger outlet elbow. Discard exhaust brake gasket.

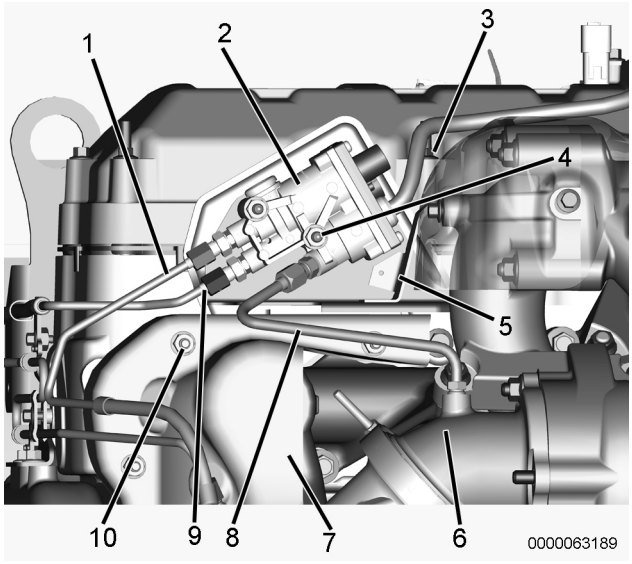


Figure 174 Exhaust Brake Valve Assembly

1. Exhaust brake valve to actuator hose
2. Exhaust brake valve assembly
3. Harness retainer
4. M8 nut (2)
5. Exhaust brake valve heat shield
6. Turbocharger outlet elbow
7. Exhaust manifold heat shield
8. Exhaust brake tube assembly
9. Exhaust brake valve supply hose
10. M8 lock nut (3)

5. Disconnect exhaust brake tube assembly from turbocharger outlet elbow and exhaust brake valve assembly.
6. Remove three M8 lock nuts and exhaust manifold heat shield.
7. Disconnect exhaust brake valve to actuator hose and exhaust brake valve supply hose from exhaust brake valve assembly.

8. Remove M8 x 20 bolt and harness clamp from valve cover (Figure 160) (items 7 and 8).
9. Remove harness retainer from valve cover stud bolt.
10. Remove and save two M8 nuts.
11. Remove exhaust brake valve assembly and exhaust brake valve heat shield from exhaust brake support assembly.

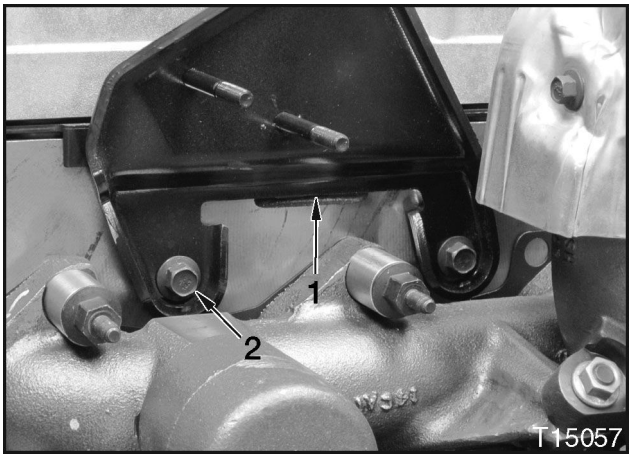


Figure 175 Exhaust Brake Support Assembly

1. Exhaust brake support assembly
2. M10 x 20 bolt (2)

12. Remove two M10 x 20 bolts and exhaust brake support assembly.

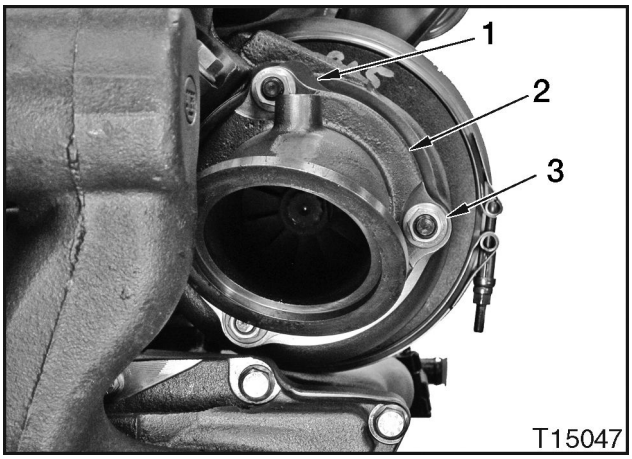


Figure 176 Turbocharger Outlet Elbow

1. Turbocharger outlet gasket
2. Turbocharger outlet elbow
3. M10 special thread nut (3)

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

13. If necessary, remove three M10 special thread nuts securing turbocharger outlet elbow to turbocharger. Discard used M10 special thread nuts.
14. Remove turbocharger outlet elbow from turbocharger. Discard gasket.

Turbocharger Air Inlet Duct

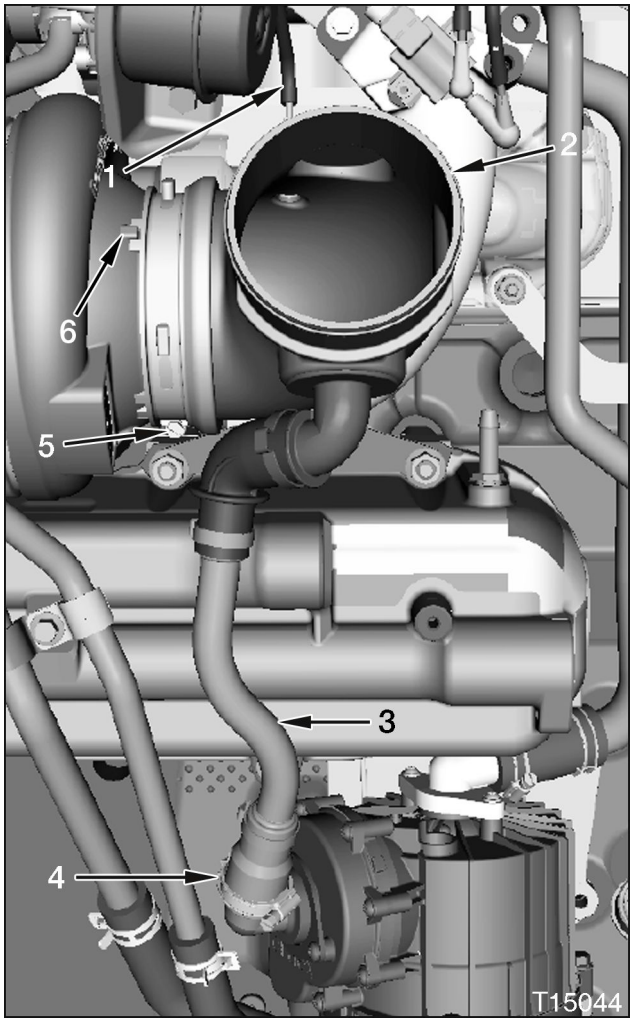


Figure 177 Turbocharger Air Inlet Duct

1. Boost control harness assembly
2. Turbocharger air inlet duct
3. Breather tube
4. 1-inch Oetiker clamp
5. Turbo inlet clamp
6. Tab

1. Disconnect boost control harness assembly from top of turbocharger air inlet duct.
2. Loosen oetiker clamp at bottom of breather tube.
3. Loosen turbo inlet clamp and remove turbocharger air inlet duct with breather tube assembly from low–pressure turbocharger.

Turbocharger Wastegate Actuator Assembly

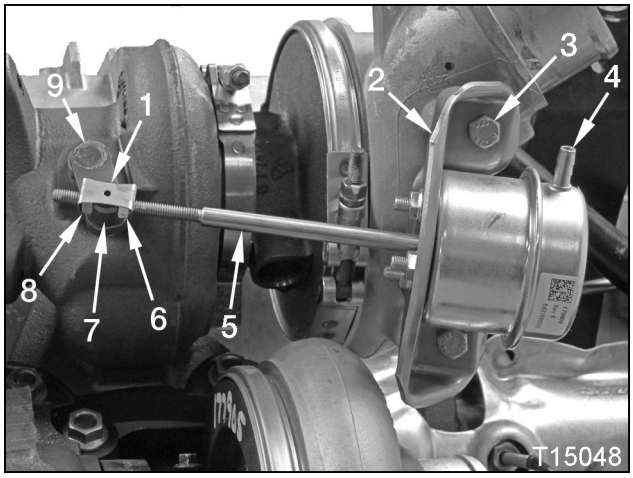


Figure 178 Wastegate Actuator

1. Retainer clip
2. Wastegate actuator assembly
3. M8 x 16 bolt (2)
4. Air tube fitting
5. Wastegate actuator rod
6. M6 nut (inner)
7. Pivot block
8. M6 nut (outer)
9. Wastegate lever

1. Pry retainer clip from actuator rod with a screwdriver.
2. Remove outer M6 nut from actuator rod.
3. Paint a mark on one of the flats of the inner M6 nut to aid in counting turns. Remove the inner M6 nut from the actuator rod while counting the turns used to remove the nut. Make a note of the number for use during installation.
4. Disconnect air tube from air tube fitting.
5. Rotate wastegate lever to slide pivot block off of wastegate actuator rod.
6. Remove two M8 x 16 bolts attaching wastegate actuator assembly to turbocharger assembly.
7. Remove wastegate actuator assembly from dual stage turbocharger assembly.

Dual Stage Turbocharger Assembly

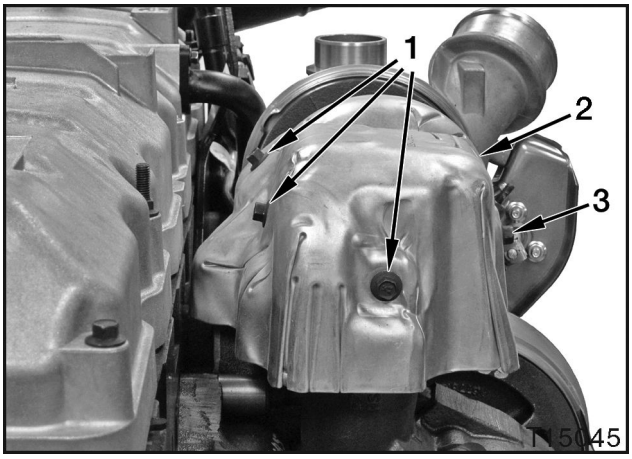


Figure 179 Turbocharger Heat Shield

1. M8 x 12 high temperature bolt (3)
2. Turbocharger heat shield
3. M8 x 27 high temperature bolt

1. Remove three M8 x 12 bolts and one M8 x 27 high temperature bolt from turbocharger heat shield.
2. Remove turbocharger heat shield.

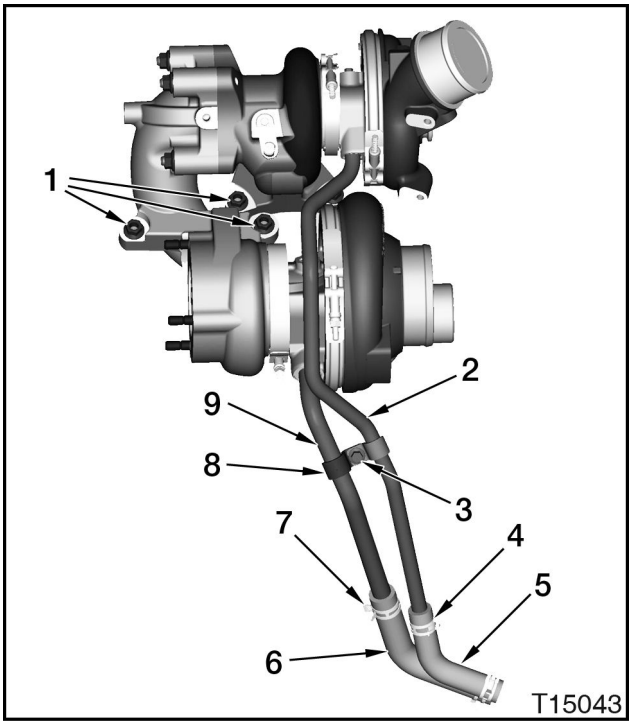


Figure 180 Dual Stage Turbocharger Assembly and Oil Drain Tubes

1. M10 special thread nut (5)
2. HP turbocharger oil drain tube
3. M8 x 25 bolt
4. 24 mm spring clamp
5. 5/8 hose
6. 3/4 hose
7. 26 mm spring clamp
8. Tube support
9. LP turbocharger oil drain tube

3. Remove M8 x 25 bolt from tube support and remove tube support from EGR cooler.
4. Loosen 24 mm spring clamp and disconnect HP oil drain tube from 5/8 hose.
5. Pull HP turbocharger oil drain tube from bottom of high-pressure turbocharger. Remove and discard O-ring (green) from HP turbocharger oil drain tube.
6. Loosen 26 mm spring clamp and disconnect LP oil drain tube from 3/4 hose.
7. Pull LP turbocharger oil drain tube from bottom of low-pressure turbocharger. Remove and discard O-ring from LP turbocharger oil drain tube.

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

⚠ WARNING: To prevent personal injury or death, support turbocharger assembly during removal and installation.

8. Remove five M10 special thread nuts securing the dual stage turbocharger assembly to exhaust manifold. Discard used M10 special thread nuts.
9. Remove dual stage turbocharger assembly from exhaust manifold.
10. Remove and discard turbocharger mounting gasket.

High-Pressure Turbocharger Center Section

1. Bring truck into shop and park on flat surface with wheels turned fully the right.
2. Shift transmission to Park or Neutral, set parking brake, and install wheel chocks.
3. Unlatch and open hood.
4. Open battery box and disconnect negative battery cable.

NOTE: Draining of cooling system and removal of the oil soot centrifuge is not required to perform this procedure.

5. Remove four bolts, washers, and right side inner fender.

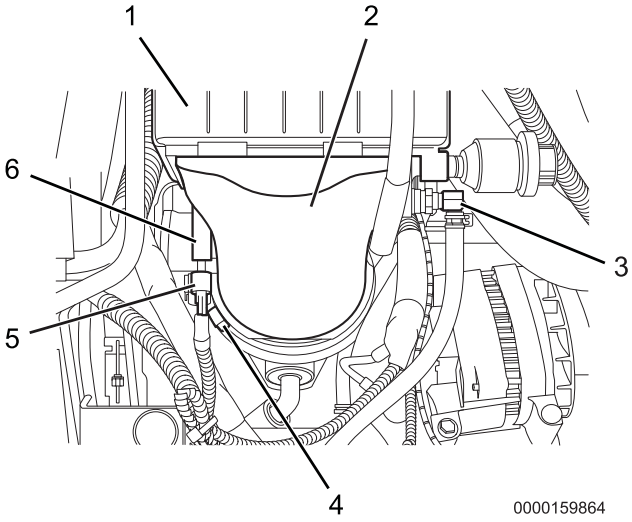


Figure 181 MAF Sensor and Air Compressor Inlet Hose

1. Air box
2. Low Pressure (LP) turbocharger inlet elbow duct
3. Air compressor inlet hose
4. LP turbocharger inlet elbow duct clamp
5. Mass Air Flow (MAF) sensor connector
6. MAF sensor

6. Disconnect MAF sensor connector from MAF sensor.
7. Disconnect air compressor inlet hose from air box.
8. Loosen air box to LP turbocharger inlet elbow duct clamp and remove LP turbocharger inlet elbow duct.
9. Remove bolt, two nuts, and air box with bracket from vehicle.

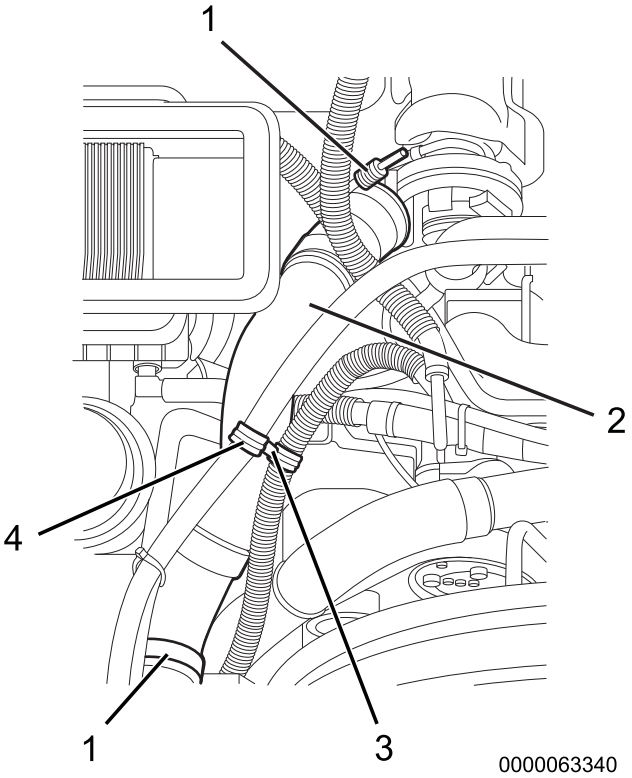


Figure 182 High Pressure Charge Air Cooler (HPCAC) Duct

1. Clamp (2)
2. HPCAC duct
3. Bolt
4. P-clamp

10. Remove bolt from P-clamp on HPCAC duct.
11. Loosen two clamps and remove HPCAC duct.

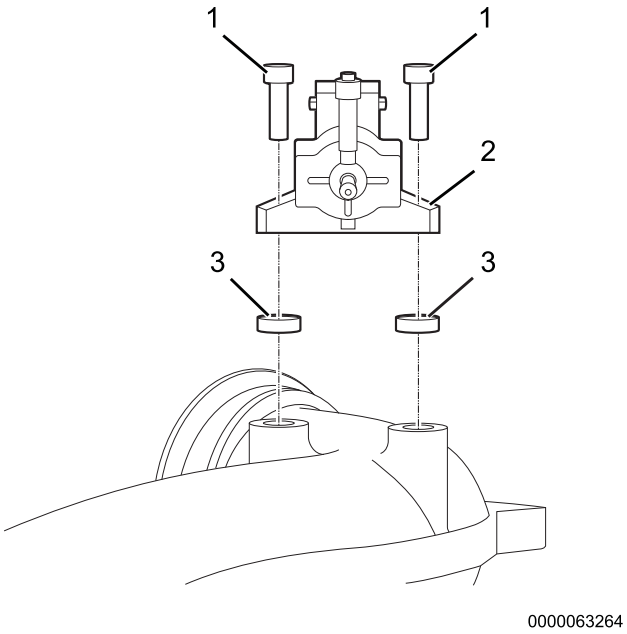


Figure 183 Turbocharger 2 Wastegate Control (TC2WC) Valve

1. M5 x 16 socket head bolt (2)
2. TC2WC
3. Insulator (2)

NOTE: Perform steps 12 and 13 of removal procedure if the engine is not equipped with Interstage Cooler (ISC).

12. Remove two M5 socket head bolts and insulators from TC2WC valve and position for access to High-Pressure (HP) turbocharger.

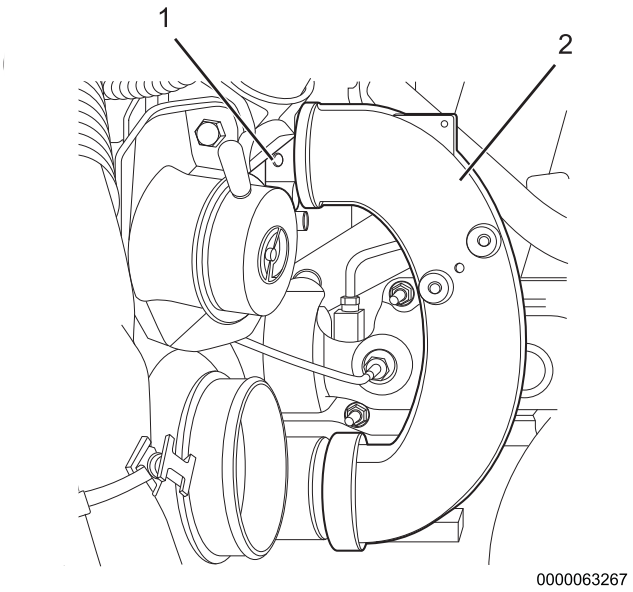


Figure 184 Crossover Tube

1. V-band clamp
2. Crossover tube

13. Remove V-band clamp and crossover tube.

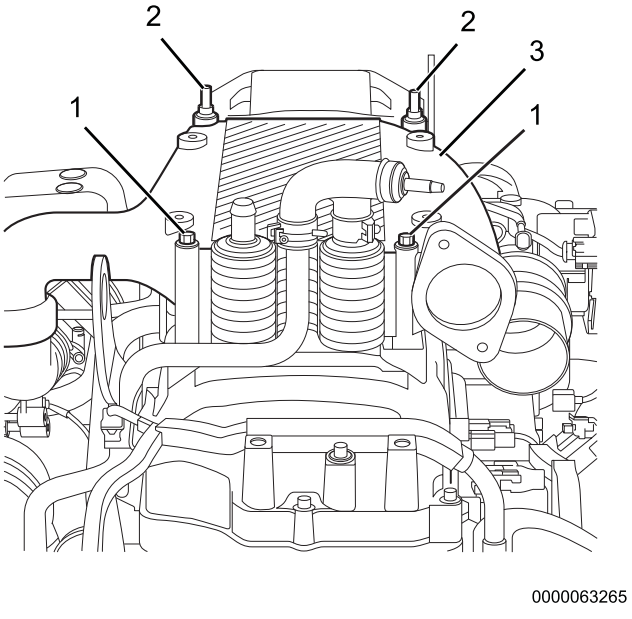


Figure 185 Interstage Cooler (ISC)

1. M8 x 110 bolt (2)
2. M8 x 110 stud bolt (2)
3. ISC

NOTE: Perform steps 14 through 17 of removal procedure if equipped with ISC.

14. Remove two bolts and stud bolts from ISC.

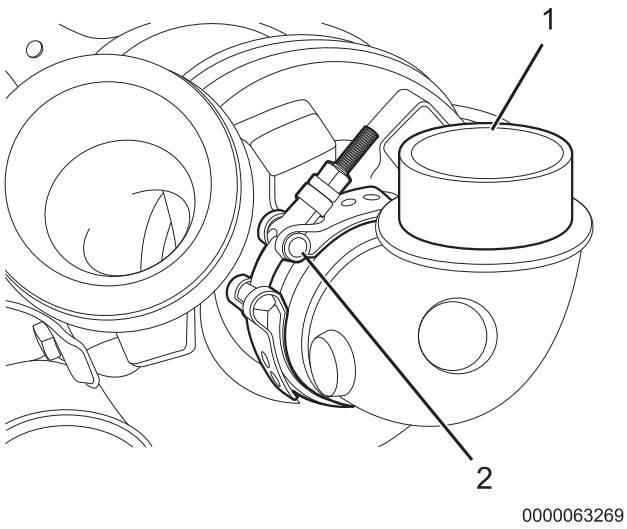


Figure 186 Turbocharger Inlet Elbow

1. Turbocharger inlet elbow
2. V-band clamp

15. Remove V-band clamp from turbocharger inlet elbow.
16. Raise ISC from valve cover and remove turbocharger inlet elbow.
17. Remove crossover tube lip seal using ISC seal remover tool and follow removal procedure (Figure 166) .

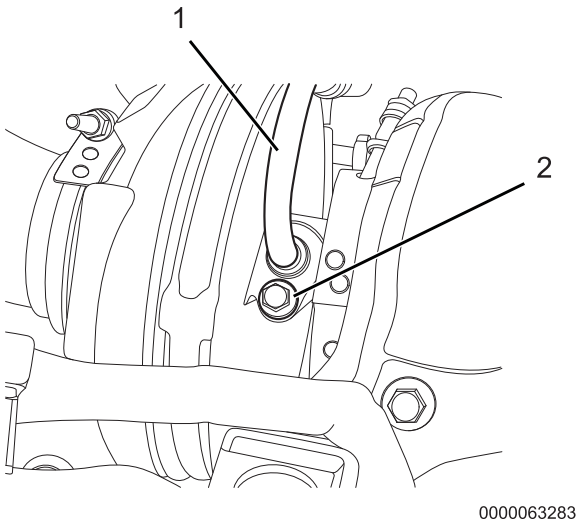


Figure 187 HP Turbocharger Oil Supply Tube

1. M6 x 16 bolt
2. Oil supply tube assembly

18. Remove bolt from oil supply tube. Discard bolt.
19. Apply rust penetrating oil to oil supply tube and disconnect from HP turbocharger.
20. Remove and discard oil supply tube O-ring.

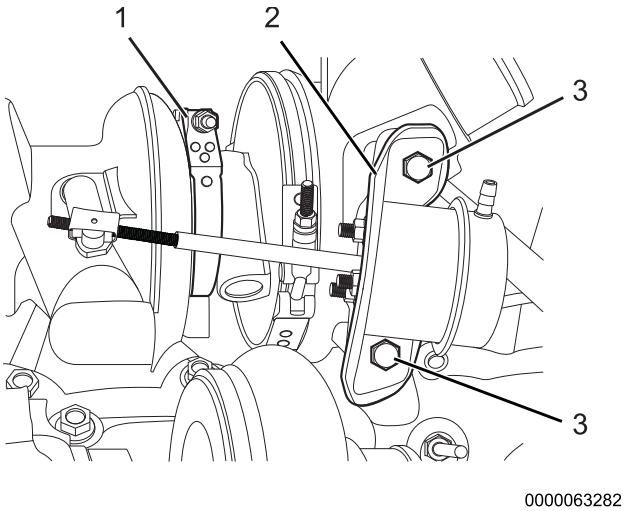


Figure 188 Wastegate Actuator

1. Turbine V-band clamp
2. Wastegate actuator
3. M8 x 16 bolt (2)

CAUTION: When positioning the wastegate actuator for access to HP turbocharger, prevent bending or damaging the wastegate actuator rod. Do not position actuator rod in a way that adjustment can be compromised. Failure to comply may result in damage to equipment.

21. Remove two bolts and position wastegate actuator for access to HP turbocharger.
22. Remove turbine V-band clamp from HP turbocharger.

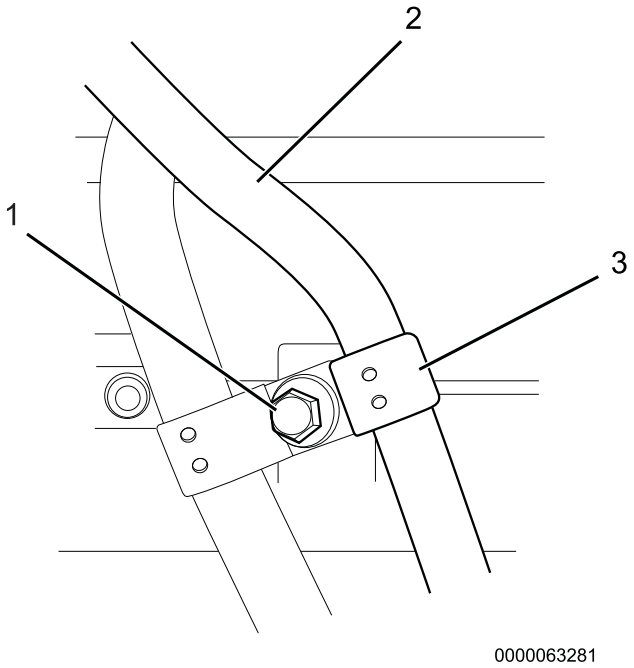
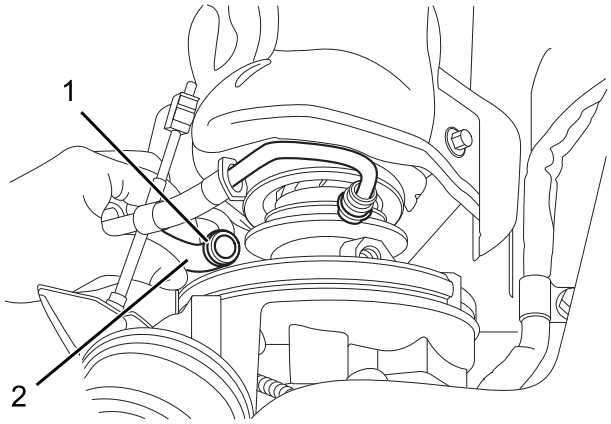


Figure 189 Oil Drain Tube

1. M8 x 25 Bolt
2. Oil drain tube
3. P-clamp

23. Remove M8 bolt from P-clamp on oil drain tube.
24. Using a soft-blow mallet, tap HP turbocharger center section until loose and remove from turbine housing and oil drain tube.
25. Inspect inside of HP turbocharger turbine housing (Inspect High-Pressure Turbine Housing, page 148).
26. Using a clean emery cloth, clean turbine housing and mating surfaces.



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Figure 190 O-rings

1. O-ring (2)
2. Oil supply tube
3. Oil drain tube

27. Remove HP turbocharger oil drain O-ring. Discard O-ring.

NOTE: If HP turbocharger center section is to be replaced, use the HP Supercartridge.

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).

Inspect and Clean Dual Stage Turbocharger Assembly and Related Parts

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

CAUTION: To prevent turbocharger damage, turbocharger oil supply fitting filter screen must be clean.

4. Remove fitting & O-ring (with screen) (Figure 170) (item 2) to clean filter screen. Refer to Cleaning, Inspection, and Testing (page 275).

Dual Turbocharger Compressor Cleaning and Inspection

Inspection

1. Rotate HP and LP turbo charger shafts by hand and check for impeller and compressor wheel contact in housings. Shaft, impeller, and compressor wheel must rotate freely.
   - If metal-to-metal contact or interference is detected, replace the dual stage turbocharger assembly according to procedures in the “Duel Stage Turbocharger and Exhaust Brake” section of the EGES-450 Engine Service Manual.
   - If metal-to-metal contact or interference is not detected, do the following removal and cleaning procedures.

Removal of Turbocharger Compressor Covers

NOTE: Turbochargers are shown for illustration purposes only



Figure 191 Markings for Compressor Cover, Center Section Alignment, and V-band Clamp Orientation (typical)

2. Make alignment marks across HP compressor cover, V-band clamp, and center section of turbocharger to use as reference during assembly.
3. Loosen V-band clamp securing HP compressor cover to center section. Do not remove V-band clamp. This will help keep compressor cover from hitting compressor wheel when cover is unseated.

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

4. Tap on compressor cover with rubber mallet to unseat compressor cover from center section. Finish loosening V-band clamp and remove compressor cover along axis of turbocharger shaft.
5. Match new V-band clamp to old V-band clamp and paint a mark on new V-band clamp opposite the mark on old V-band clamp. Discard old V-band clamp and nut.

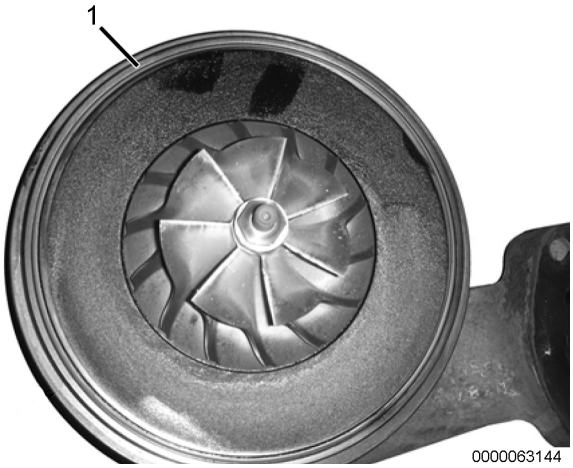


Figure 192 Compressor Cover O-ring (typical)

1. Compressor cover O-ring

6. Remove and discard compressor cover O-ring.
7. Repeat steps 1 through 5 and remove compressor cover from LP turbocharger.

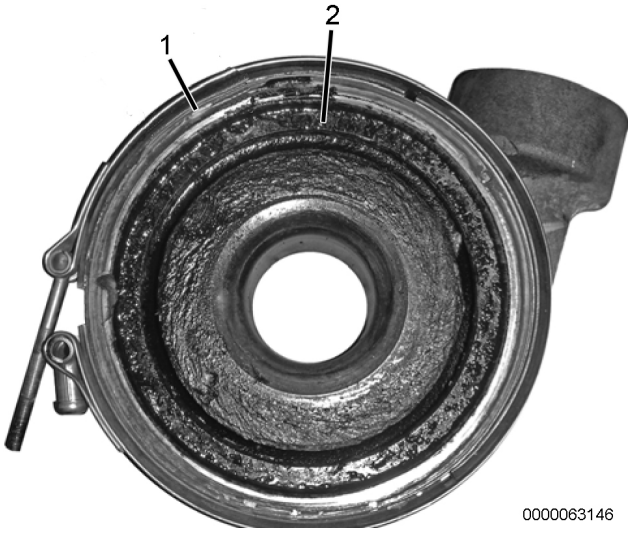


Figure 193 Oil Coking on Inside of Compressor Cover (typical)

1. Compressor cover
2. Coked oil

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

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

8. Clean coked oil

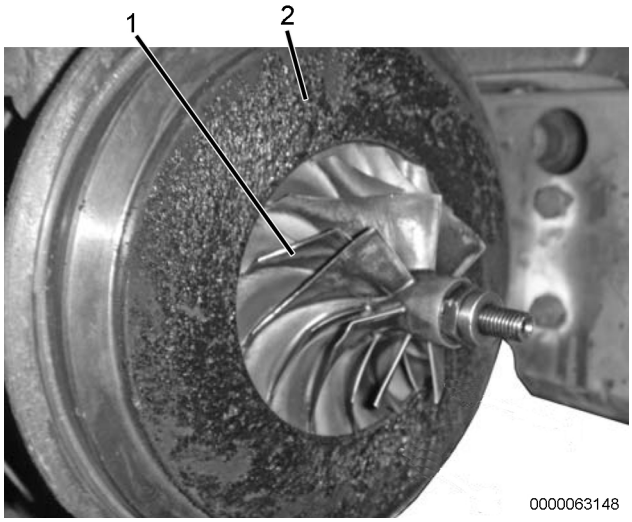


Figure 194 Compressor Wheel and Center Section Face (typical)

1. Compressor wheel
2. Center section face

WARNING: To prevent personal inury or death, discard turbocharger if compressor blades are damaged.

CAUTION: To prevent damage to compressor center section, do not use metal tool to remove coked oil deposits from center section. Use wooden or plastic tools to remove deposits.

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

9. Clean center section faces of both LP and HP turbochargers with non-metallic scraper, suitable solvent, and rags.

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

10. After removing all coked oil deposits from both the LP and HP turbocharger compressor covers and center section faces, wipe remaining residue with damp cloth and dry thoroughly before beginning assembly procedure. Do not use compressed air to dry components.

Assembly

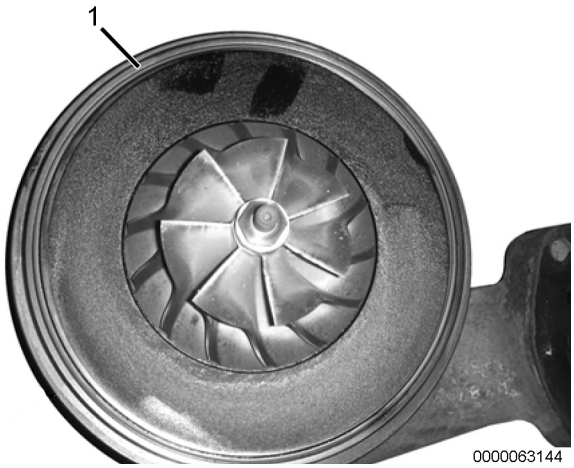


Figure 195 Compressor Cover O-Ring on Center Section (typical)

11. Lubricate new O-ring (LP compressor cover) with P-80® lubricant. Install O-ring on turbocharger center section.

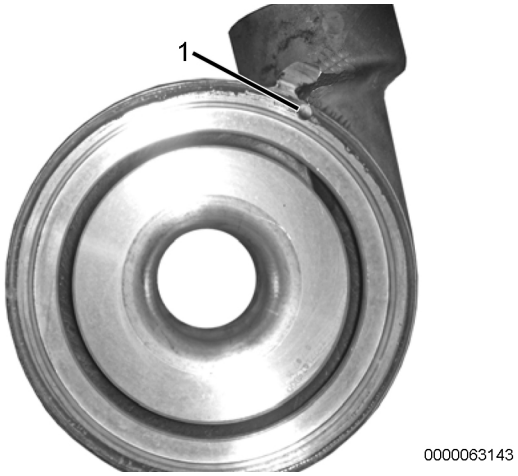


Figure 196 Compressor Cover O-ring on Center Section (typical)

NOTE: Turbochargers are equipped with dowel pins to align compressor cover.



Figure 197 Markings for Compressor Cover, Center Section Alignment, and V-band Clamp Orientation (typical)

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

12. Align marks and position LP turbocharager compressor cover squarely on center section. Fully seat compressor cover on center section.
13. Install new V-band clamp nut on new LP turbocharger V-band clamp. Install new LP turbocharger V-band clamp on turbocharger center section and align to marks on compressor cover and center section. Finger tighten V-band clamp.
14. Rotate turbocharger shaft by hand and check for impeller and wheel contact in housings. Shaft, impeller, and turbine must rotate freely.
15. Tighten V-band clamp nut to 145 lb·in (16 N·m).
16. Rotate turbocharger shaft by hand and check for impeller and compressor wheel contact in housings. Shaft, impeller, and compressor wheel must rotate freely.

Inspect Turbine and Compressor

NOTE: This inspection can be done with the dual stage turbocharger assembly mounted on or off the engine.

1. Inspect dual stage turbocharger assembly for cracks that may cause air leaks. Replace dual stage turbocharger if necessary.
2. Turn turbine shaft by hand and check for wheel rub in each housing. Shaft wheels must rotate freely. If there is any rubbing or interference, replace dual stage turbocharger assembly.

NOTE: Do not attempt to straighten bent blades.

3. Inspect compressor impeller and turbine wheels. If any blades are bent, broken, or eroded, replace dual stage turbocharger assembly.

Inspect High-Pressure Turbine Housing

NOTE: This inspection must be done when the HP Turbocharger center section has been removed

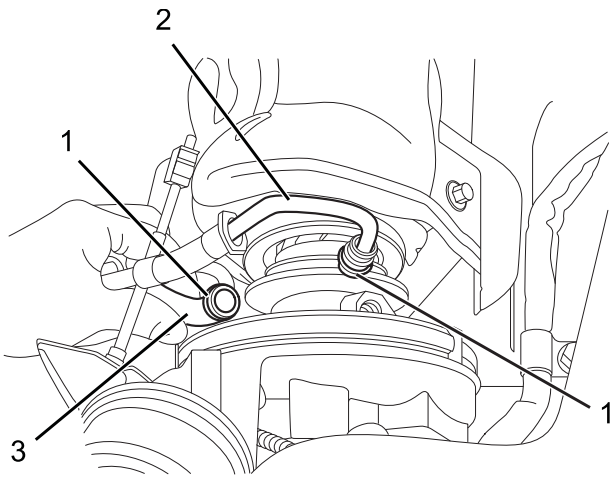
1. Inspect inside of HP turbine housing for evidence of contact with HP turbine wheel. Indications of contact can include bright spots of bare metal, nicks, or gouges on HP turbine housing inner surface.
2. If evidence of turbine wheel contact with inside of HP turbine housing is found, replace the HP turbocharger assembly.

Crossover Tube Seal

1. Inspect crossover tube seal for wear or damage on and around each sealing bead.
2. Inspect for any damage that exposes the steel core of the seal.
3. The crossover tube seal may be reused if no damage is found.

Installation

High Pressure Turbocharger Center Section Assembly



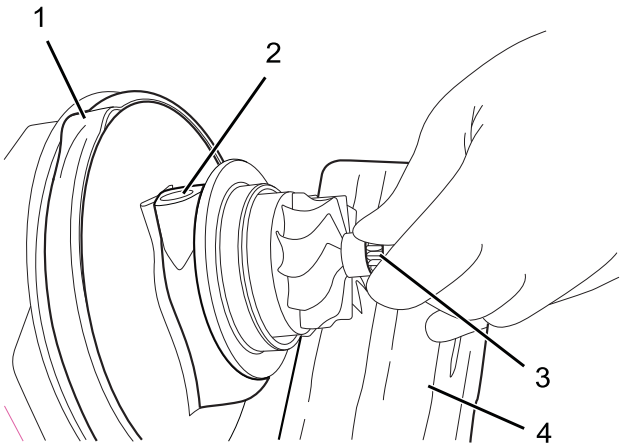
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Figure 198 O-rings

1. O-ring (2)
2. Oil supply tube
3. Oil drain tube

NOTE: Ensure O-rings are lubricated with P-80® or equivalent prior to installation.

1. Install new O-ring onto oil drain tube.
2. Install new O-ring onto oil supply tube.



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Figure 199 Priming HP Turbocharger Center Section

1. HP turbocharger center section
2. Oil supply port
3. Turbine wheel nut
4. Oil drain port

3. Using 15W40 engine oil, prime new HP turbocharger center section oil supply port while spinning turbine wheel via wheel nut. Perform this process until oil is seen seeping from oil drain port.

⚠ WARNING: Ensure drain tube is fully seated in HP turbocharger center section while installing HP turbocharger into turbine housing. Failure to comply may result in injury to personnel and / or equipment.

4. Install new HP turbocharger center section onto the HP oil drain tube while installing into the turbine housing.

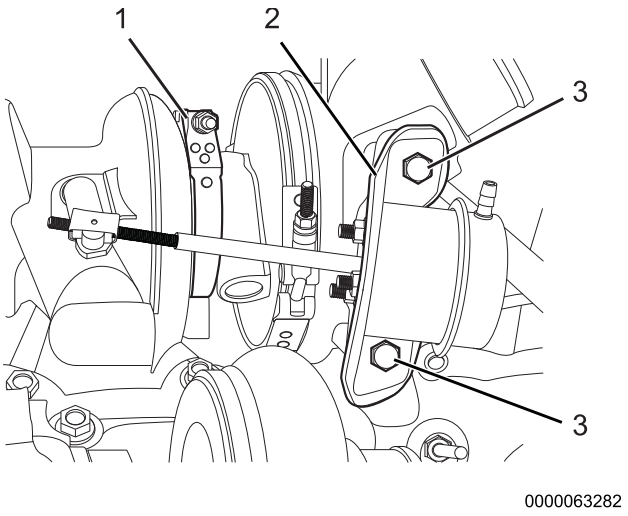


Figure 200 Wastegate Actuator

1. Turbine V-band clamp
2. Wastegate actuator
3. M8 x 16 bolt (2)

5. Install turbine V-band clamp on HP turbocharger.
6. Using torque wrench, tighten turbine V-band clamp to special torque (page 166).

CAUTION: When installing HP turbocharger, prevent bending or damaging the wastegate actuator rod. Do not position actuator rod in a position that may compromise adjustment. Failure to comply may result in damage to equipment.

7. Install wastegate actuator with two M8 bolts. Tighten bolts to special torque (page 166).

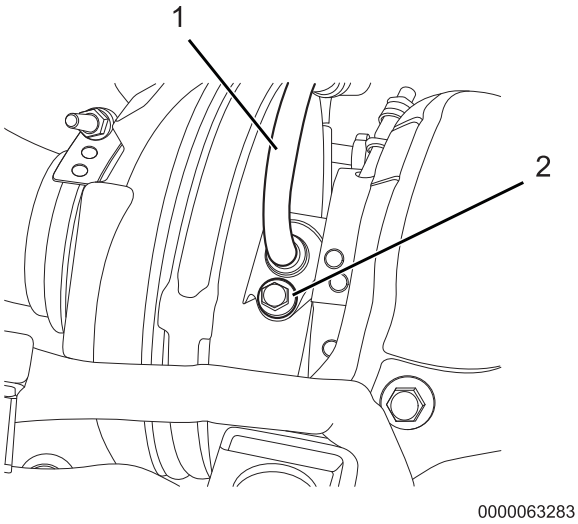


Figure 201 Oil Supply Tube

1. M6 x 16 bolt
2. Oil supply tube assembly

8. Connect oil supply tube to HP turbocharger.
9. Install oil supply tube with M6 x 16 bolt. Tighten bolt to standard torque.

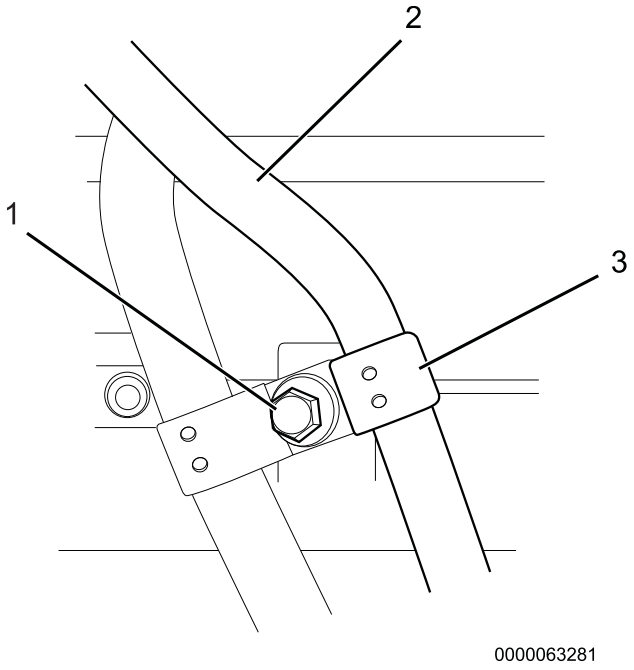


Figure 202 Oil Drain Tube

1. M8 x 25 Bolt
2. Oil drain tube
3. P-clamp

10. Install M8 bolt in P-clamp on oil drain tube. Tighten bolt to standard torque.

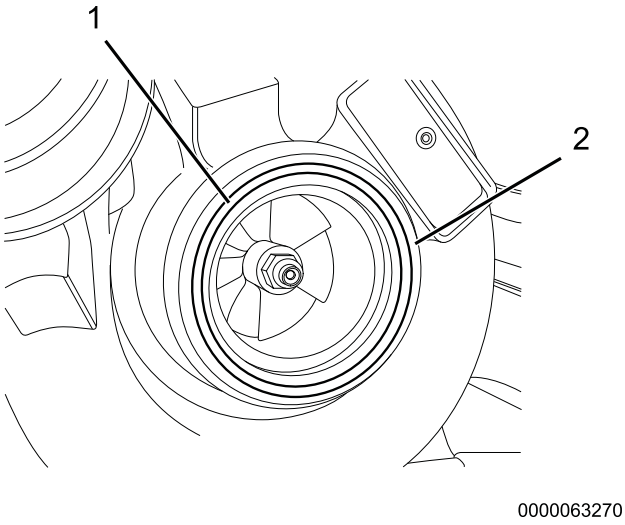


Figure 203 HP Turbocharger O-Ring

1. 2.62 x 61.6 ID O-ring
2. HP turbocharger

11. Install new O-ring into groove on HP turbocharger.

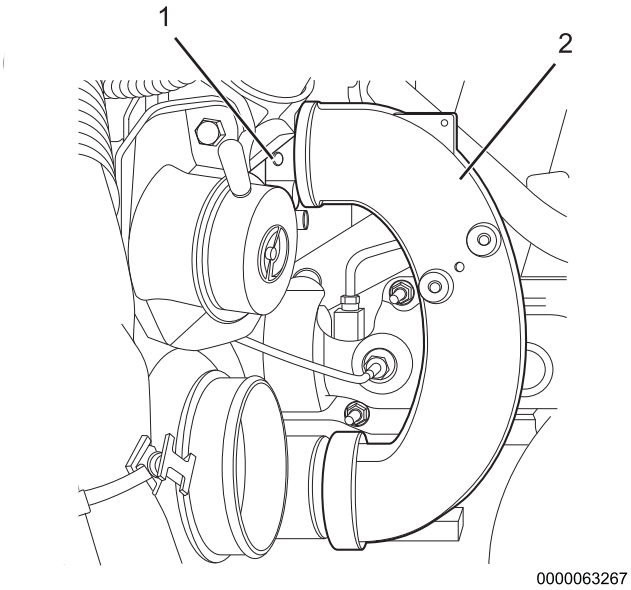
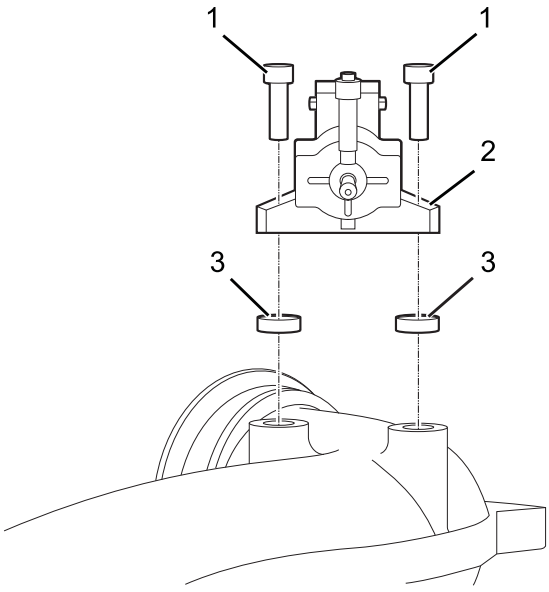


Figure 204 Crossover Tube

1. V-band clamp
2. Crossover tube

NOTE: Perform steps 12 through 15 of installation procedure if not equipped with Interstage Cooler (ISC).

12. Inspect crossover tube seal for damage. If damaged, discard seal.
13. Apply P-80® or equivalent to outside of crossover tube seal and inside interstage inlet duct. Push crossover tube onto crossover tube seal until it pops into place.
14. Install crossover tube on to HP turbocharger with V-band clamp. Tighten clamp to special torque (page 166).

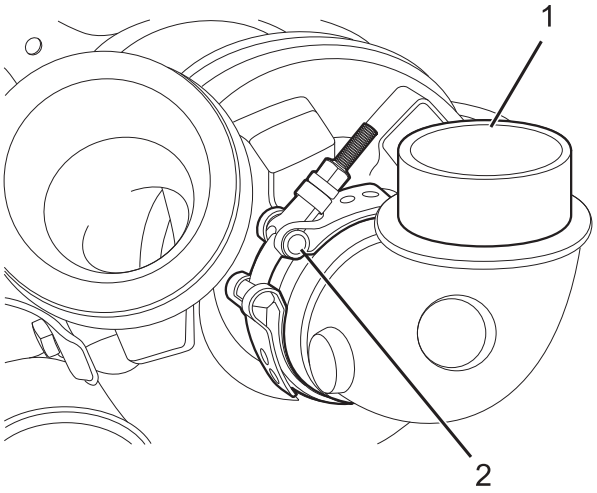


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Figure 205 Turbocharger 2 Wastegate Control (TC2WC) Valve

1. M5 x 16 socket head bolt (2)
2. TC2WC valve
3. Insulator (2)

15. Install TC2WC valve onto crossover tube with two insulators and M5 socket head bolts. Tighten bolts to standard torque.



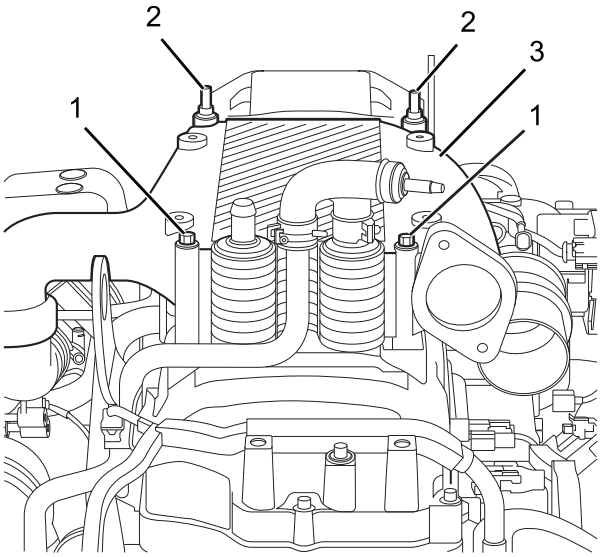
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Figure 206 Turbocharger Inlet Elbow

1. Turbocharger inlet elbow
2. V-band clamp

NOTE: Perform steps 16 through 20 of installation procedure if the engine is equipped with an ISC.

16. Position turbocharger inlet elbow onto HP turbocharger with V-band clamp hand tight.



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Figure 207 ISC

1. M8 x 110 bolt (2)
2. M8 x 110 stub bolt (2)
3. ISC

17. Install new ISC crossover tube outlet lip seal using ISC seal installer and press. Follow installation procedure included in ISC installation (page 161).
18. Install ISC onto turbocharger inlet elbow and valve cover with M8 two bolts and two M8 stud bolts.
19. Using torque wrench, tighten bolts and stud bolts to standard torque.
20. Using torque wrench, tighten V-band clamp to special torque (page 166).

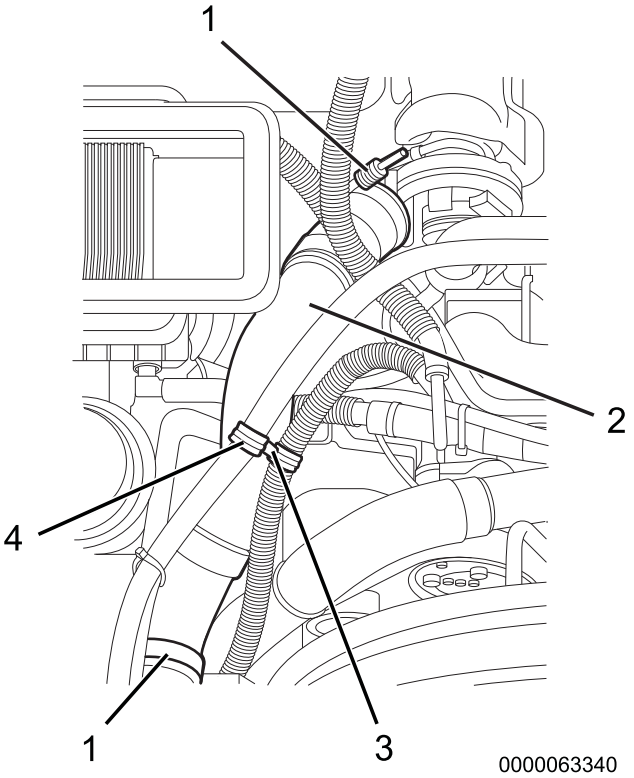


Figure 208 HPCAC Duct

1. Clamp (2)
2. HPCAC duct
3. Bolt
4. P-clamp

21. Install HPCAC duct with two clamps.
22. Install bolt in P-clamp on HPCAC duct.
23. Install air box and bracket with nut and two bolts.

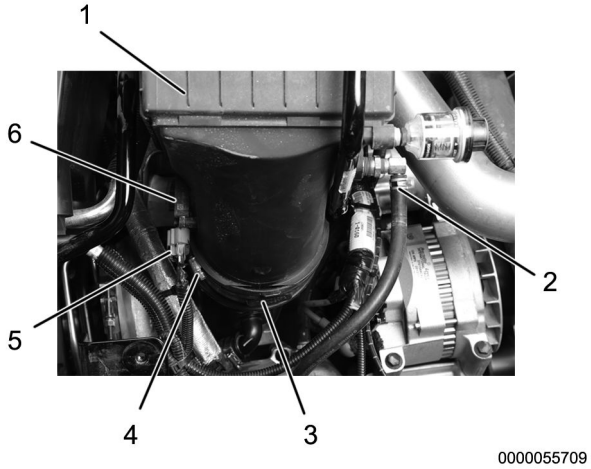


Figure 209 Mass Air Flow (MAF) Sensor and Air Compressor Inlet Hose

1. Air box
2. Air compressor inlet hose
3. LP turbocharger inlet elbow duct
4. LP turbocharger inlet elbow duct clamp
5. MAF sensor connector
6. MAF sensor

24. Install air box outlet into LP turbocharger inlet elbow duct and torque clamp.
25. Connect air compressor inlet hose to air box.
26. Connect MAF sensor connector to MAF sensor.
27. Install right side inner fender with four washers and bolts.
28. Connect negative battery cable and close battery box.
29. Run engine to verify proper operation, no leaks, and no fault codes.
30. Close and latch hood.
31. Remove wheel chocks.
32. Connect to truck with EZ-Tech and use ServiceMaxx™ to calibrate the MAF sensor.

Dual Stage Turbocharger Assembly

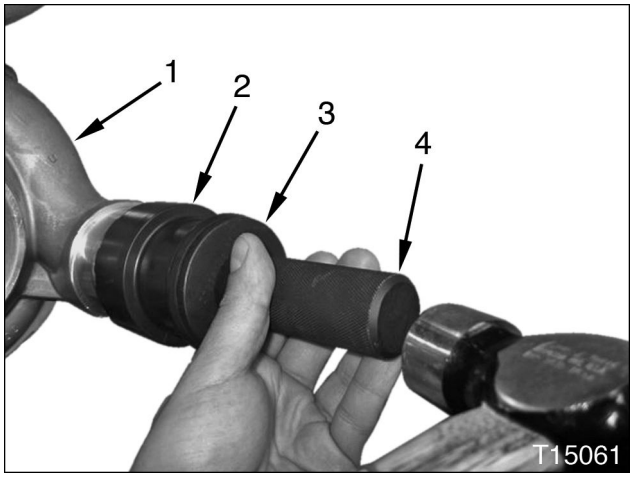


Figure 210 Crossover Tube Seal Installation

1. Low-pressure turbocharger
2. Crossover tube seal
3. Seal Installer
4. Seal Installer Handle

1. Apply P-80® Lube (page 166) to outlet of low-pressure turbocharger and inside of crossover tube seal, then install seal on low-pressure turbocharger using a Seal Installer (page 166).

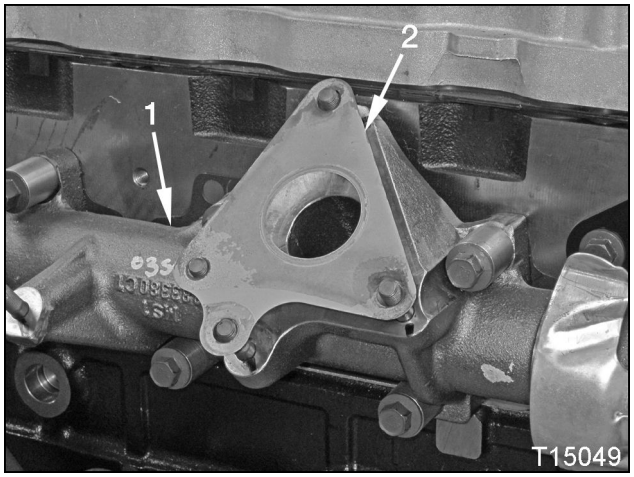


Figure 211 Turbocharger Mounting Gasket

1. Exhaust manifold
2. Turbocharger mounting gasket

2. Place a new turbocharger mounting gasket on exhaust manifold.

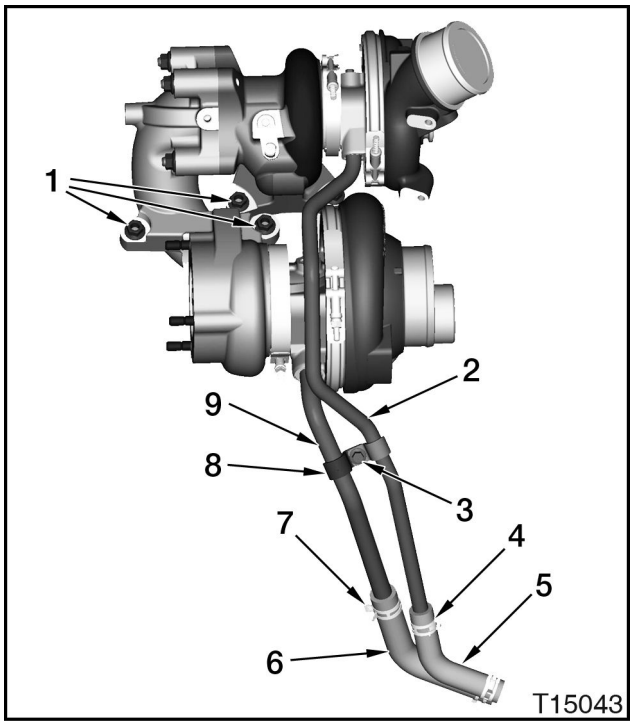


Figure 212 Dual Stage Turbocharger Assembly and Oil Drain Tubes

1. M10 special thread nut (5)
2. HP turbocharger oil drain tube
3. M8 x 25 bolt
4. 24 mm spring clamp
5. 5/8 hose
6. 3/4 hose
7. 26 mm spring clamp
8. Tube support
9. LP turbocharger oil drain tube

⚠ WARNING: To prevent personal injury or death, support turbocharger assembly during removal and installation.

NOTE: If removed, install the turbocharger outlet elbow on the turbocharger assembly. Installing the turbocharger outlet elbow is easier while the turbocharger assembly is off the engine. See Exhaust Brake Valve and Turbocharger Outlet Elbow (page 157).

3. Lift dual stage turbocharger assembly onto engine and install five new M10 special thread nuts on

mounting studs. Tighten M10 special thread nuts to special torque (page 166).

4. Pre-lube turbochargers by adding oil to oil supply port of each turbocharger while rotating turbine shaft. Continue to add oil until oil comes out of drain port of each turbocharger.
5. Lubricate oil drain tube O-rings with clean engine oil. Install new 0.734 x 0.139 in. O-ring on LP turbocharger oil drain tube and a new O-ring (green) on the HP turbocharger oil drain tube.
6. Install LP oil drain tube into low-pressure turbocharger. Connect LP oil drain tube to 3/4 hose and secure with 26 mm spring clamp.
7. Install HP oil drain tube into high-pressure turbocharger. Connect HP oil drain tube to 5/8 hose and secure with 24 mm spring clamp.
8. Install M8 x 25 bolt to secure tube support to EGR cooler. Tighten M8 x 25 bolt to standard torque (page 553).

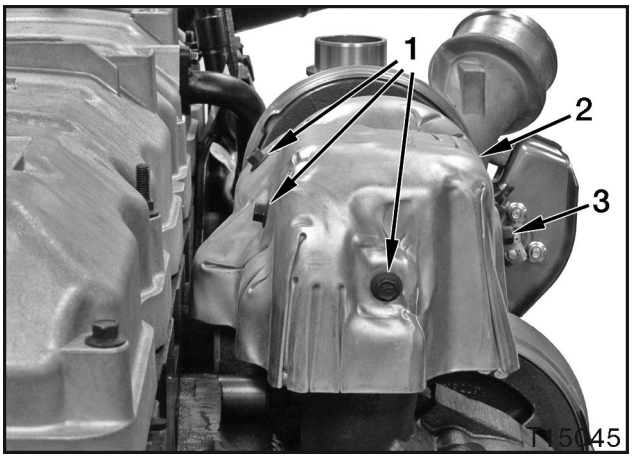


Figure 213 Turbocharger Heat Shield

1. M8 x 12 high temperature bolt (3)
2. Turbocharger heat shield
3. M8 x 27 high temperature bolt

9. Place turbocharger heat shield on HP turbocharger.
10. Install four M8 bolts to secure turbocharger heat shield. Tighten to standard torque (page 553).

Turbocharger Wastegate Actuator Assembly (without precise regulated shop air pressure)

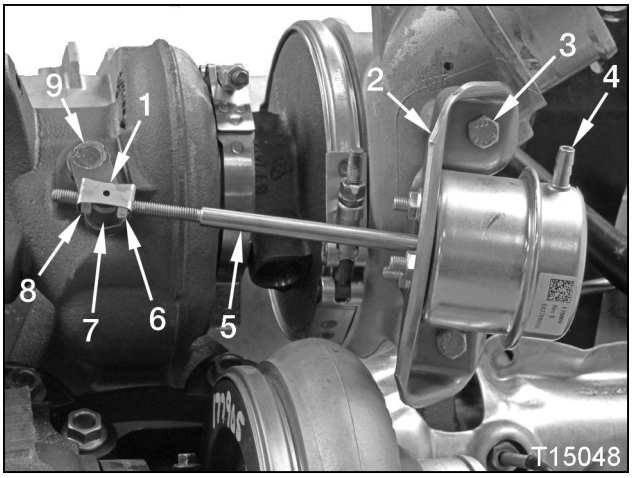


Figure 214 Turbocharger Wastegate Actuator Assembly

1. Retainer clip
2. Wastegate actuator assembly
3. M8 x 16 bolt (2)
4. Air tube fitting
5. Wastegate actuator rod
6. M6 nut (inner)
7. Pivot block
8. M6 nut (outer)
9. Wastegate lever

1. Install wastegate actuator assembly on dual stage turbocharger assembly with two M8 x 16 bolts. Tighten bolts to special torque (page 166).
2. Install inner M6 nut onto wastegate actuator rod the same number of turns noted during removal. (This provides an approximate position for the inner nut).
3. Rotate wastegate lever to slide pivot block onto wastegate actuator rod. Make sure inner M6 nut is at least 10 mm away from pivot block when wastegate is fully closed (counterclockwise). Turn nut as needed to obtain 10 mm distance from pivot block. (This ensures the inner nut does not interfere with remaining installation.)
4. Install outer M6 nut on wastegate actuator rod.
5. Hold wastegate lever fully closed (counterclockwise) and hand tighten outer M6

nut until it touches pivot block. Mark outer M6 nut and tighten additional 3.5 turns.

6. Tighten inner M6 nut to special torque (page 166).
7. Connect air tube to air tube fitting on actuator.
8. Install retainer clip over nuts on wastegate actuator rod.

Turbocharger Wastegate Actuator Assembly (with precise regulated shop air pressure)

NOTE: This method is more precise in establishing wastegate actuator set-point, however, it should only be used with properly regulated air pressure.

1. Install wastegate actuator assembly on dual stage turbocharger assembly with two M8 x 16 bolts. Tighten bolts to special torque (page 166).
2. Install inner M6 nut onto wastegate actuator rod the same number of turns noted during removal. (This provides an approximate position for the inner nut).
3. Rotate wastegate lever to slide pivot block onto wastegate actuator rod. Make sure inner M6 nut is at least 10 mm away from pivot block when wastegate is fully closed (counterclockwise). (This ensures the inner nut does not interfere with remaining installation.)
4. Install outer M6 nut on wastegate actuator rod.
5. Hold wastegate fully closed (counterclockwise) and hand tighten outer M6 nut until it touches pivot block.

CAUTION: To prevent engine damage, do not apply more than 152 kPa (22 psi) of air pressure to the turbocharger wastegate actuator assembly.

6. Apply air pressure regulated to 55 ± 3.4 kPa (8 ± 0.5 psi) to air tube fitting using Pressure Test Kit (page 166). The wastegate actuator rod should extend slightly.
7. Hold wastegate lever arm fully closed (counterclockwise) and hand tighten outer M6 nut until it touches pivot block again.
8. Tighten inner M6 nut to special torque (page 166).
9. Remove regulated air pressure and connect air tube to air tube fitting on actuator.
10. Install retainer clip over nuts on wastegate actuator rod.

Turbocharger Air Inlet Duct

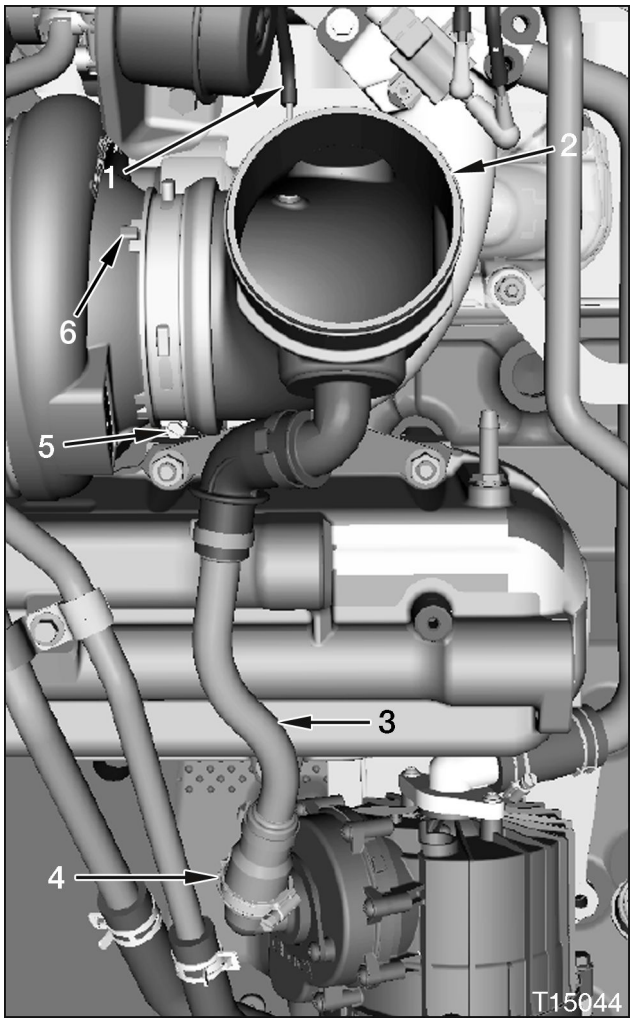


Figure 215 Turbocharger Air Inlet Duct

1. Boost control harness assembly (air hose)
2. Turbocharger air inlet duct
3. Breather tube
4. 1-inch Oetiker clamp
5. Turbo inlet clamp
6. Tab

1. If removed, slide breather tube hose onto crankcase breather assembly. Tighten 1-inch Oetiker clamp to standard torque (page 553).

2. Install turbo air inlet duct on low-pressure turbocharger. Make sure tab on low-pressure turbocharger aligns with notch on air inlet duct. Tighten clamp to standard torque (page 553).
3. Connect boost control harness assembly (air hose) to fitting on top of turbocharger air inlet duct.

Exhaust Brake Valve and Turbocharger Outlet Elbow

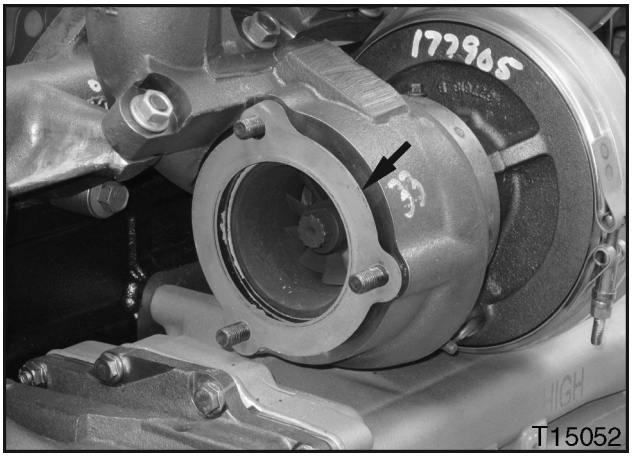


Figure 216 Turbocharger Outlet Gasket

1. Install a new turbocharger outlet gasket on dual stage turbocharger assembly.

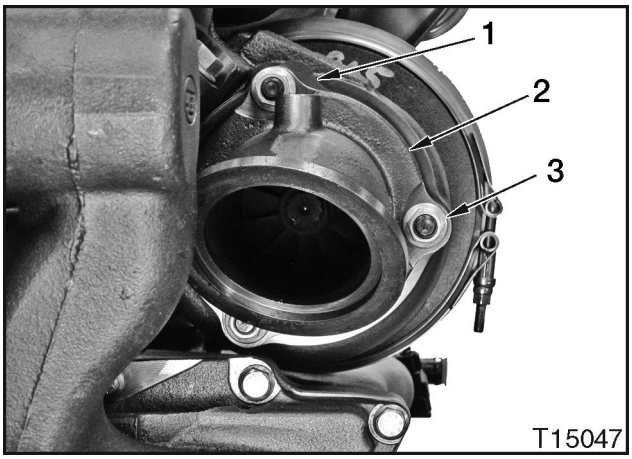


Figure 217 Turbocharger Outlet Elbow

1. Turbocharger outlet gasket
2. Turbocharger outlet elbow
3. M10 special thread nut (3)

2. Install turbocharger outlet elbow with three M10 special thread nuts. Tighten M10 special thread nuts to special torque (page 166).

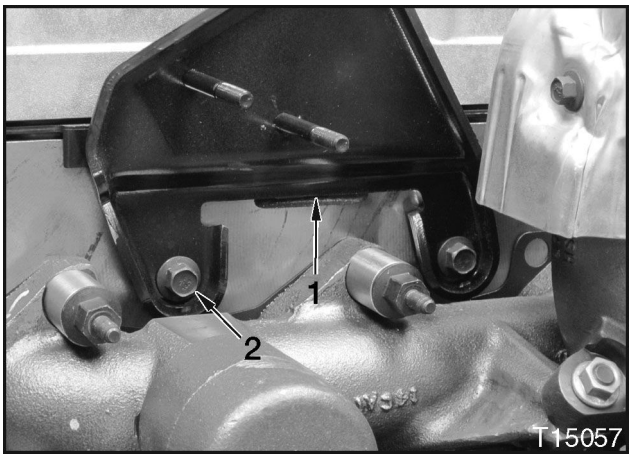


Figure 218 Exhaust Brake Support Assembly

1. Exhaust brake support assembly
2. M10 x 20 bolt (2)

3. Install exhaust brake support assembly on engine with two M10 x 20 bolts. Tighten bolts to standard torque (page 553).

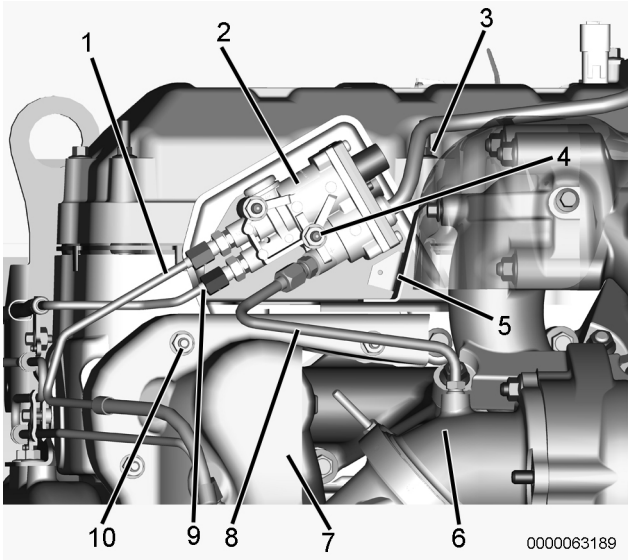


Figure 219 Exhaust Brake Valve Assembly

1. Exhaust brake valve to actuator hose
2. Exhaust brake valve assembly
3. Harness retainer
4. M8 nut (2)
5. Exhaust brake valve heat shield
6. Turbocharger outlet elbow
7. Exhaust manifold heat shield
8. Exhaust brake tube assembly
9. Exhaust brake valve supply hose
10. M8 lock nut (3)

4. Install exhaust manifold heat shield and three M8 lock nuts. Tighten nuts to standard torque (page 553).
5. If removed, install M10 37 degree flare fittings (Figure 160) (item 4) and exhaust tube fitting into exhaust brake valve assembly. Tighten fittings to special torque (page 166).
6. Install exhaust brake valve heat shield on exhaust brake support assembly.
7. Install exhaust brake valve on exhaust brake support assembly with two M8 nuts finger tight. Install exhaust brake tube assembly. Tighten M8 nuts to standard torque (page 553) and exhaust brake tube assembly nuts to special torque (page 166).
8. Secure wiring to valve cover with harness clamp and M8 x 20 bolt (Figure 160) (items 7 and 8). Tighten bolt to standard torque (page 553).
9. Push harness retainer onto valve cover stud.
10. Connect exhaust brake valve supply hose to exhaust brake valve. Tighten exhaust brake valve supply hose fitting to special torque (page 166).
11. Connect exhaust brake valve to actuator hose to exhaust brake valve. Tighten exhaust brake valve to actuator hose fitting to special torque (page 166).

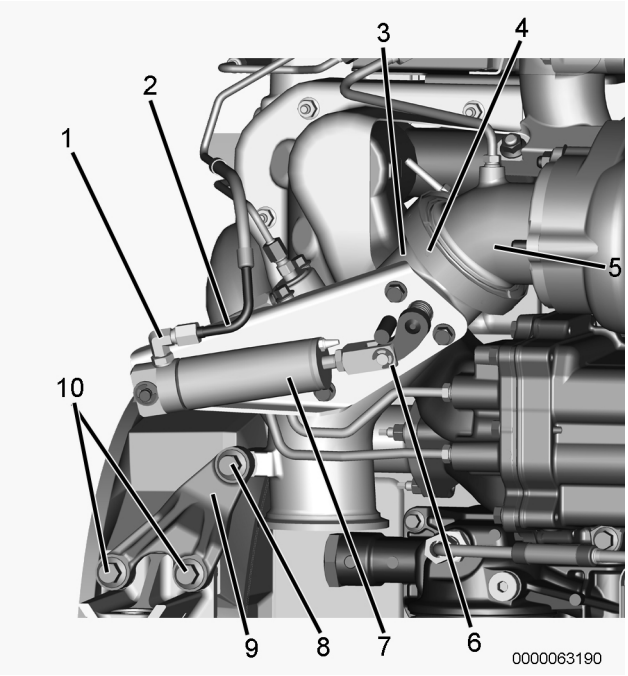


Figure 220 Exhaust Brake Valve and Support Bracket

1. 90 degree tube fitting elbow
2. Exhaust brake valve to actuator hose
3. Exhaust brake under rail housing
4. Exhaust clamp
5. Turbocharger outlet elbow
6. E clip (2)
7. Actuator
8. M12 x 25 bolt
9. Turbocharger pipe under rail support
10. M12 x 40 bolt (2)

12. Connect exhaust brake under rail housing to turbocharger outlet elbow using a new exhaust brake gasket. Do not fully tighten the clamp at this time. Allow exhaust brake under rail housing to rotate slightly.

13. Install turbocharger pipe under rail support with one M12 x 25 and two M12 x 40 bolts. Tighten M12 x 25 bolt to special torque (page 166). Tighten two M12 x 40 bolts to standard torque (page 553).
14. Tighten exhaust clamp to special torque (page 166).
15. Install actuator on exhaust brake under rail housing and secure with E clips.
16. Connect exhaust brake valve to actuator hose to 90 degree tube fitting elbow. Tighten exhaust brake valve to actuator hose fitting to special torque (page 166).

Turbocharger Oil Supply Tube Assembly

1. Lubricate the turbocharger special seals with clean engine oil. Install new turbocharger special seals in grooves on oil supply tube assembly.
2. Install turbocharger oil supply tube assembly into dual stage turbocharger assembly.



Figure 221 Oil Supply Tube Assembly at Low-Pressure Turbocharger Assembly

1. M6 x 16 bolt
2. Oil supply tube assembly

3. Install M6 x 16 bolt securing oil supply tube assembly to low-pressure turbocharger. Tighten M6 x 16 bolt to standard torque (page 553).

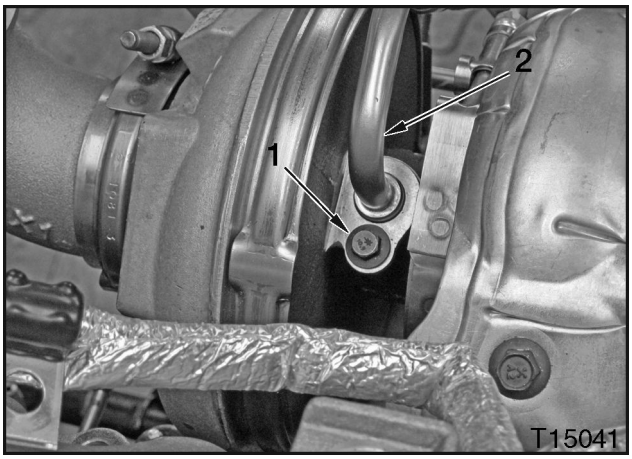


Figure 222 Oil Supply Tube Assembly at High-Pressure Turbocharger Assembly

1. M6 x 16 bolt
2. Oil supply tube assembly

4. Install M6 x 16 bolt securing oil supply tube assembly to high-pressure turbocharger. Tighten M6 x 16 bolt to standard torque (page 553).

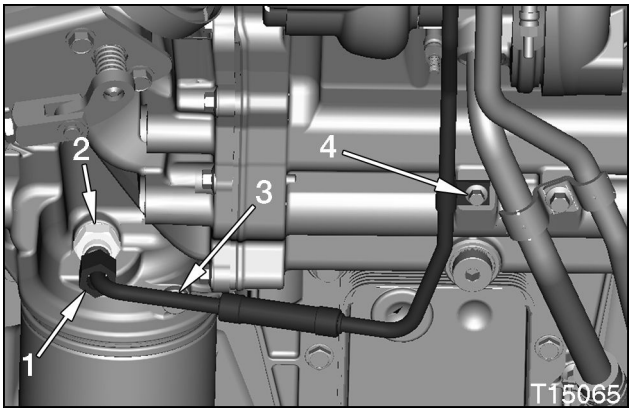


Figure 223 Turbocharger Oil Supply Tube Assembly

1. Turbocharger oil supply tube nut
2. Fitting and O-ring (with screen)
3. Oil supply tube assembly
4. M6 x 12 bolt

CAUTION: To prevent turbocharger damage, turbocharger oil supply fitting filter screen must be clean.

5. Connect turbocharger oil supply tube assembly to fitting and O-ring (with screen) on the oil cooler

housing. Tighten turbocharger oil supply tube nut to special torque (page 166).

6. Install M6 x 12 bolt securing turbocharger oil supply tube assembly retainer to EGR cooler. Tighten bolt to standard torque (page 553).

Throttle Coupling

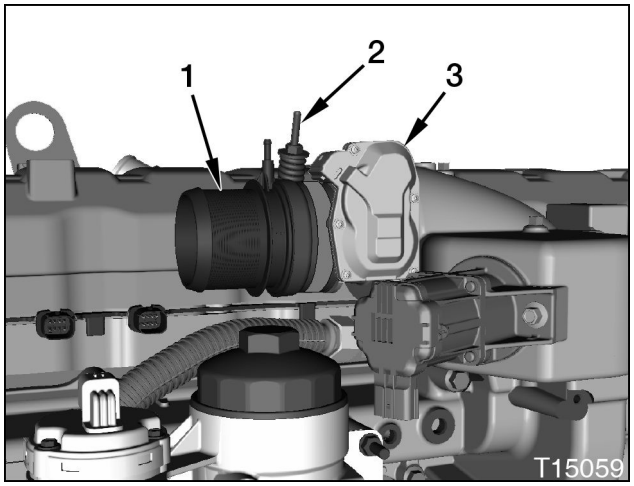


Figure 224 Throttle Coupling

1. Throttle coupling
2. Heat exchanger clamp
3. Engine throttle valve assembly

1. Install throttle coupling on engine throttle valve assembly.
2. Position heat exchanger clamp onto throttle coupling as illustrated in the following image.

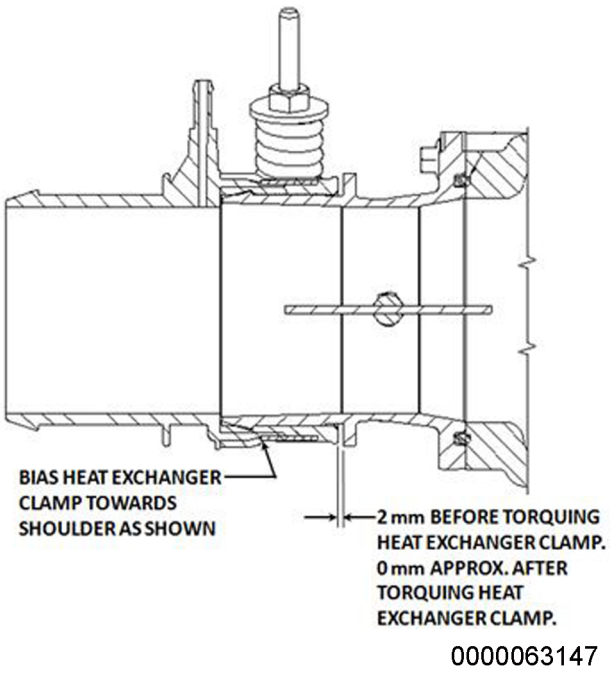


Figure 225 Heat Exchanger Clamp Installation

3. Secure throttle coupling with heat exchanger clamp. Tighten heat exchanger clamp to special torque (page 166).

Interstage Cooler (ISC)

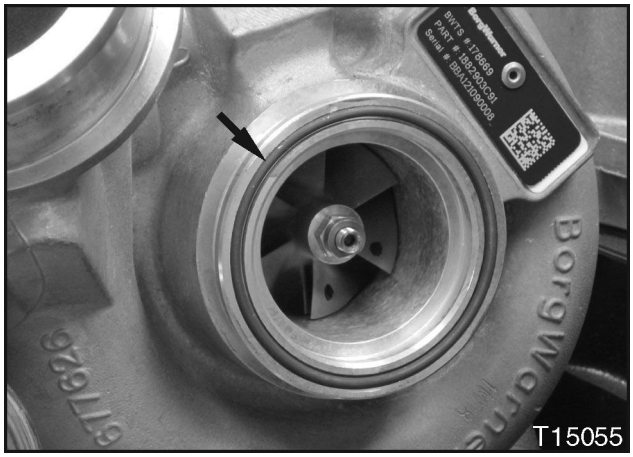


Figure 226 2.62 x 61.6 ID O-ring

1. Install a new 2.62 x 61.6 ID O-ring in groove on HP turbocharger.

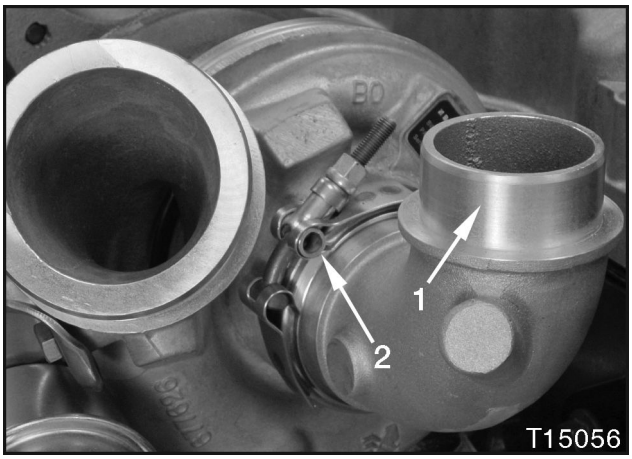


Figure 227 Turbocharger Inlet Elbow

1. Turbocharger inlet elbow
2. V-band clamp

2. Attach turbocharger inlet elbow to HP turbocharger with V-band clamp. Do not fully tighten V-band clamp at this time. Allow turbocharger inlet elbow to rotate as necessary to allow for ISC to be installed.

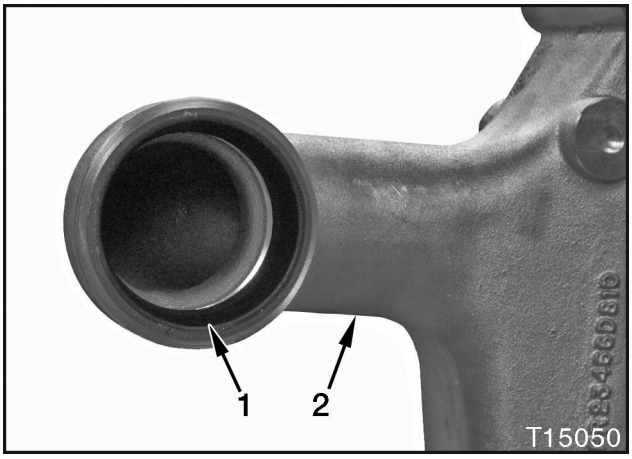


Figure 228 Crossover Tube Lip Seal

1. Crossover tube lip seal
2. ISC

3. Install a new crossover tube lip seal in ISC using ISC Seal Installer and press (page 166).

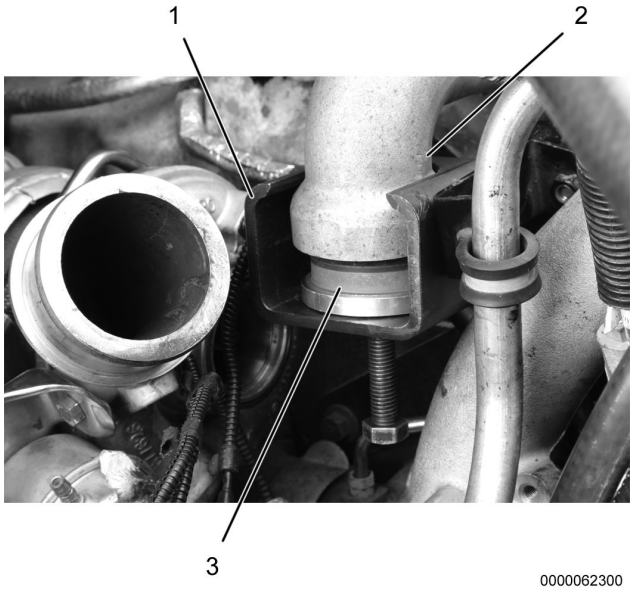


Figure 229 ISC Outlet Lip Seal Installation

1. ZTSE4937–4 Press (3/4-in wrench is required to operate press)
2. ISC outlet
3. ISC oulet lip seal

NOTE: Ensure lip seal is properly aligned with ISC outlet opening.

4. Apply P-80® or equivalent lubricant to new ISC outlet lip seal.
5. Position ZTSE4937–1A seal installer into ZTSE4937–4 press with new seal.

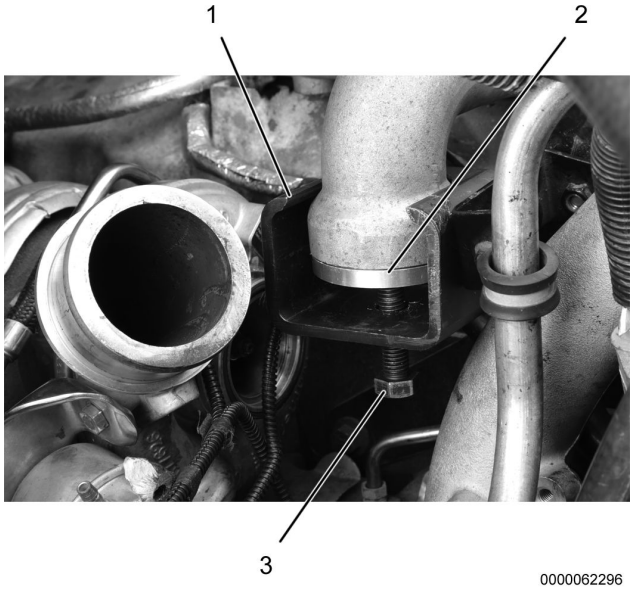


Figure 230 ISC Oulet Lip Seal Plate Installed

1. ZTSE4937–4 press
2. Seal installer
3. Press forcing screw

6. Tighten forcing screw until seal installer is flush with the bottom of outlet.

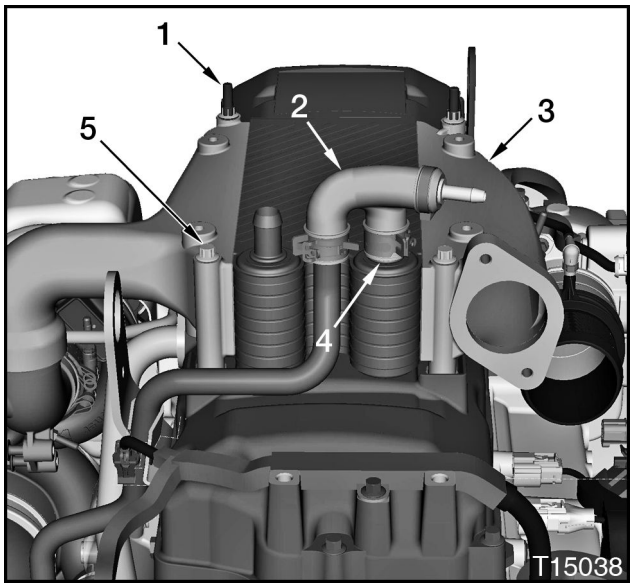


Figure 231 Interstage Cooler (ISC)

1. M8 x 110 stud bolt (2)
2. Elbow deaeration hose
3. ISC
4. 29 mm clipless clamp (2)
5. M8 x 110 bolt (2)

7. Place ISC on turbocharger inlet elbow and valve cover. Install two M8 x 110 bolts and two M8 x 110 stud bolts. Tighten bolts to standard torque (page 553).
8. Tighten turbocharger inlet elbow V-band clamp to special torque (page 166).
9. Install deaeration hose and secure with two 29 mm clipless clamps.

Interstage Inlet Duct Assembly

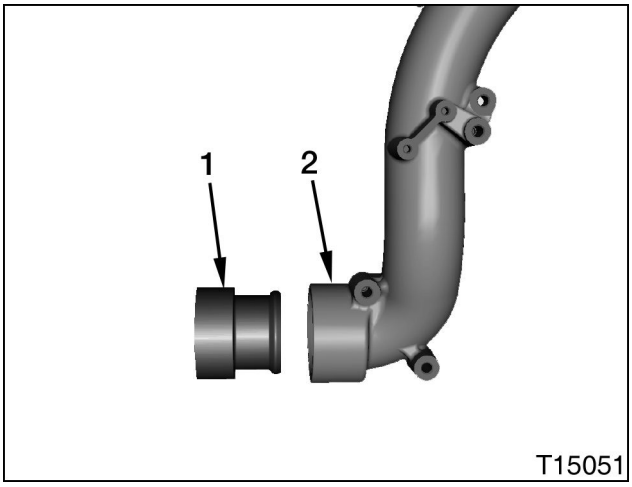


Figure 232 Crossover Tube Seal and Interstage Inlet Duct

1. Crossover tube seal
2. Interstage inlet duct

1. Apply P-80® Lube (page 166) to outside of crossover tube seal and inside of interstage inlet duct. Push interstage inlet duct onto crossover tube seal.

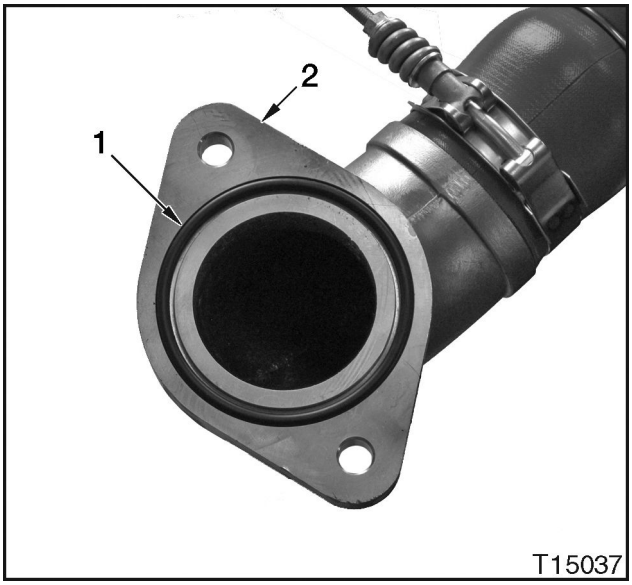


Figure 233 ISC Inlet Elbow O-ring

1. 3.53 x 63.09 ID O-ring
2. ISC inlet elbow

2. Install a new 3.53 x 63.09 ID O-ring into ISC inlet elbow.

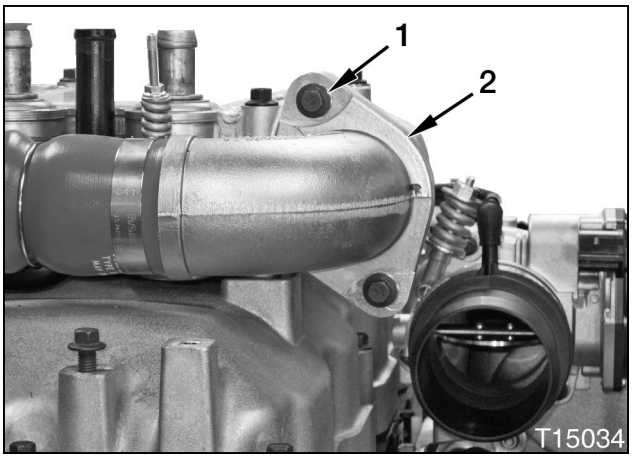


Figure 234 ISC Inlet Elbow

1. M8 x 30 bolt (2)
2. ISC inlet elbow

3. Install two M8 x 30 bolts to secure ISC inlet elbow to ISC. Tighten bolts to standard torque (page 553).

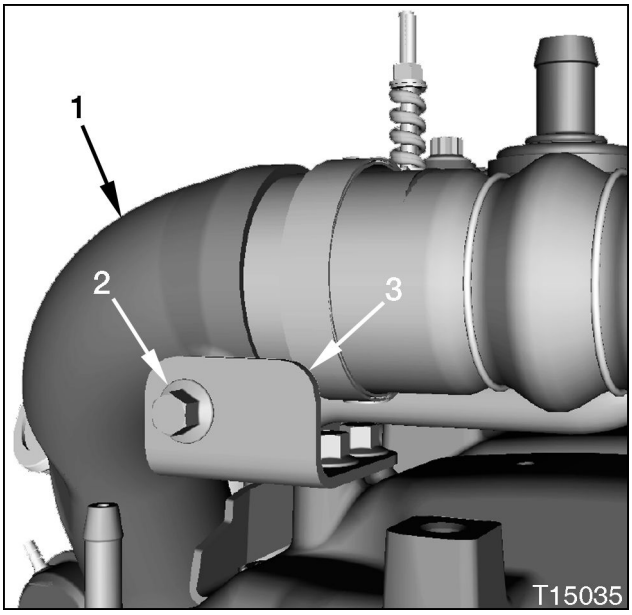


Figure 235 Interstage Inlet Duct and Top Front Bracket

1. Interstage inlet duct
2. M8 x 25 bolt (3)
3. Top ISC duct support

4. Install M8 x 25 bolt through top of ISC duct support into interstage inlet duct. Tighten bolt to standard torque (page 553).

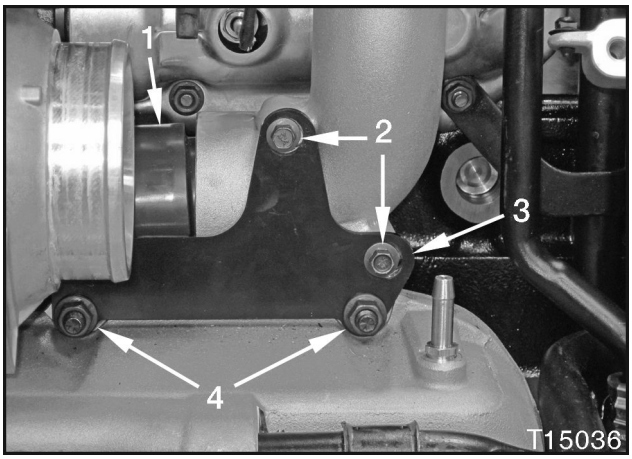


Figure 236 Intermediate Stage Support

1. Crossover tube seal
2. M8 x 25 bolt (2)
3. Intermediate stage support
4. M10 nut (2)

5. Place intermediate stage support on EGR cooler stud bolts. Install two M10 nuts finger tight.
6. Install two M8 x 25 bolts finger tight.
7. Tighten M8 x 25 bolts and M10 nuts to standard torque (page 553).

Special Torque

Exhaust brake tube assembly nuts	24 N·m (18 lb·ft)
Exhaust brake valve to actuator hose fitting	15 N·m (11 lb·ft)
Exhaust brake valve supply hose fitting	15 N·m (11 lb·ft)
Exhaust clamp	8 N·m (75 lb·in)
Exhaust tube fitting	24 N·m (18 lb·ft)
Heat exchanger clamp	7.5 N·m (66 lb·in)
Turbocharger oil supply tube nut	25 N·m (18 lb·ft)
Turbocharger mounting nuts, M10 special thread nuts	71 N·m (52 lb·ft)
Turbocharger outlet elbow, M10 special thread nuts	61 N·m (45 lb·ft)
Turbocharger pipe under rail support, M12 x 25 bolt	65 N·m (48 lb·ft)
90 degree tube fitting elbow	35 N·m (26 lb·ft)
M10 37 degree flare fitting	24 N·m (18 lb·ft)
Wastegate actuator rod inner M6 nut	8 N·m (75 lb·in)
M8 x 16 wastegate actuator bolts	15 N·m (11 lb·ft)
V-band clamp (turbine inlet housing)	17 N·m (12.5 lb·ft)
V-band clamp (turbocharger inlet elbow)	17 N·m (12.5 lb·ft)

Special Service Tools

ISC Seal Installer	ZTSE4937–1
ISC Seal Remover	ZTSE4937–2
ISC Press	ZTSE4937–4
P-80® Lube	Obtain locally
Pressure Test Kit	ZTSE4409
Seal installer (crossover tube seal)	ZTSE6046
Seal installer handle	ZTSE6055-1
Slide Hammer Puller Set	ZTSE1879

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Exploded View

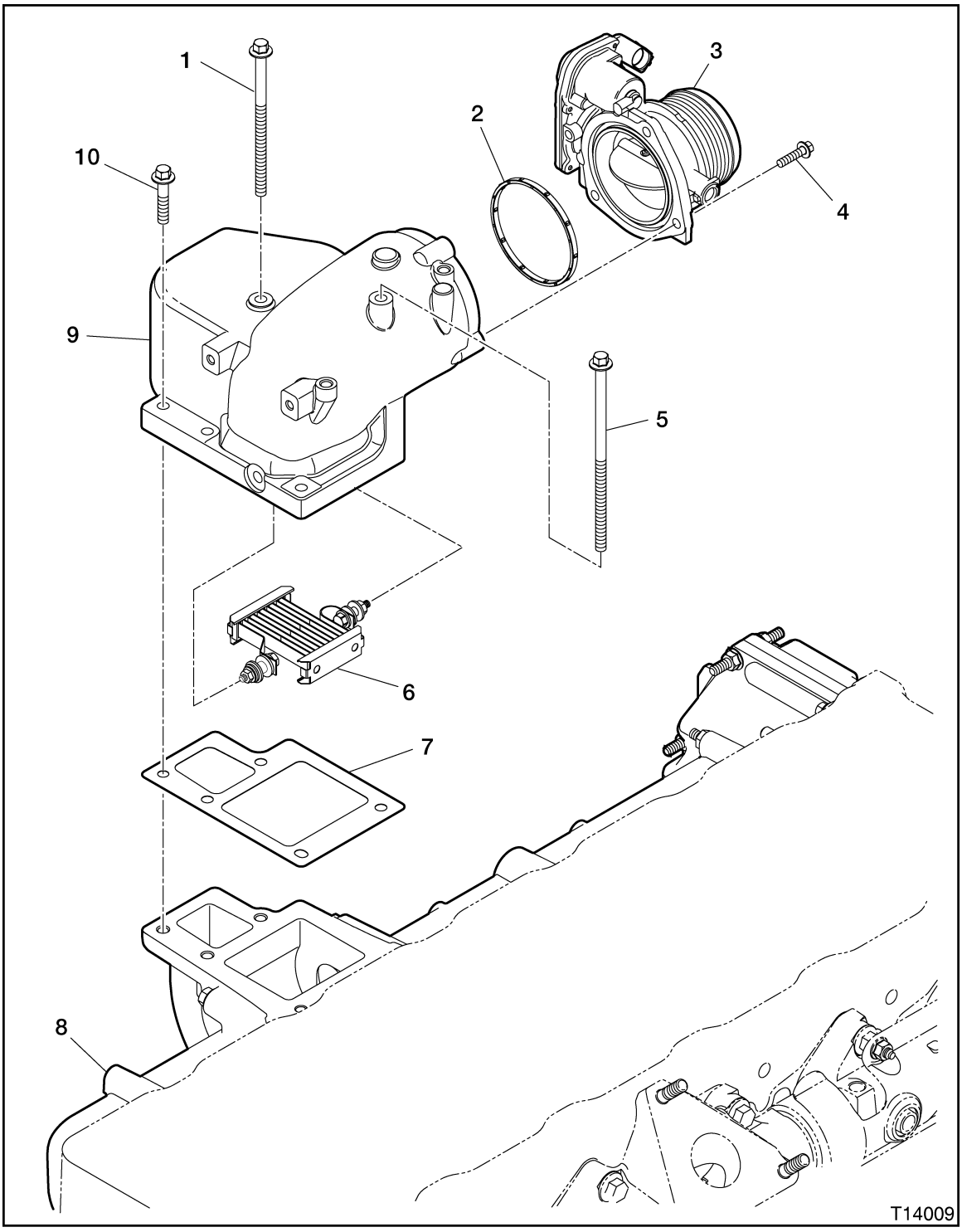


Figure 237 Air and EGR Mixer Duct Assembly

1. M8 x 130 bolt
2. Intake throttle gasket
3. Engine throttle valve assembly
4. M6 x 25 bolt (3)
5. M8 x 170 bolt
6. Single grid heater assembly
7. Inlet duct to intake manifold gasket
8. Intake manifold
9. Air and EGR mixer duct assembly
10. M8 x 40 bolt (3)

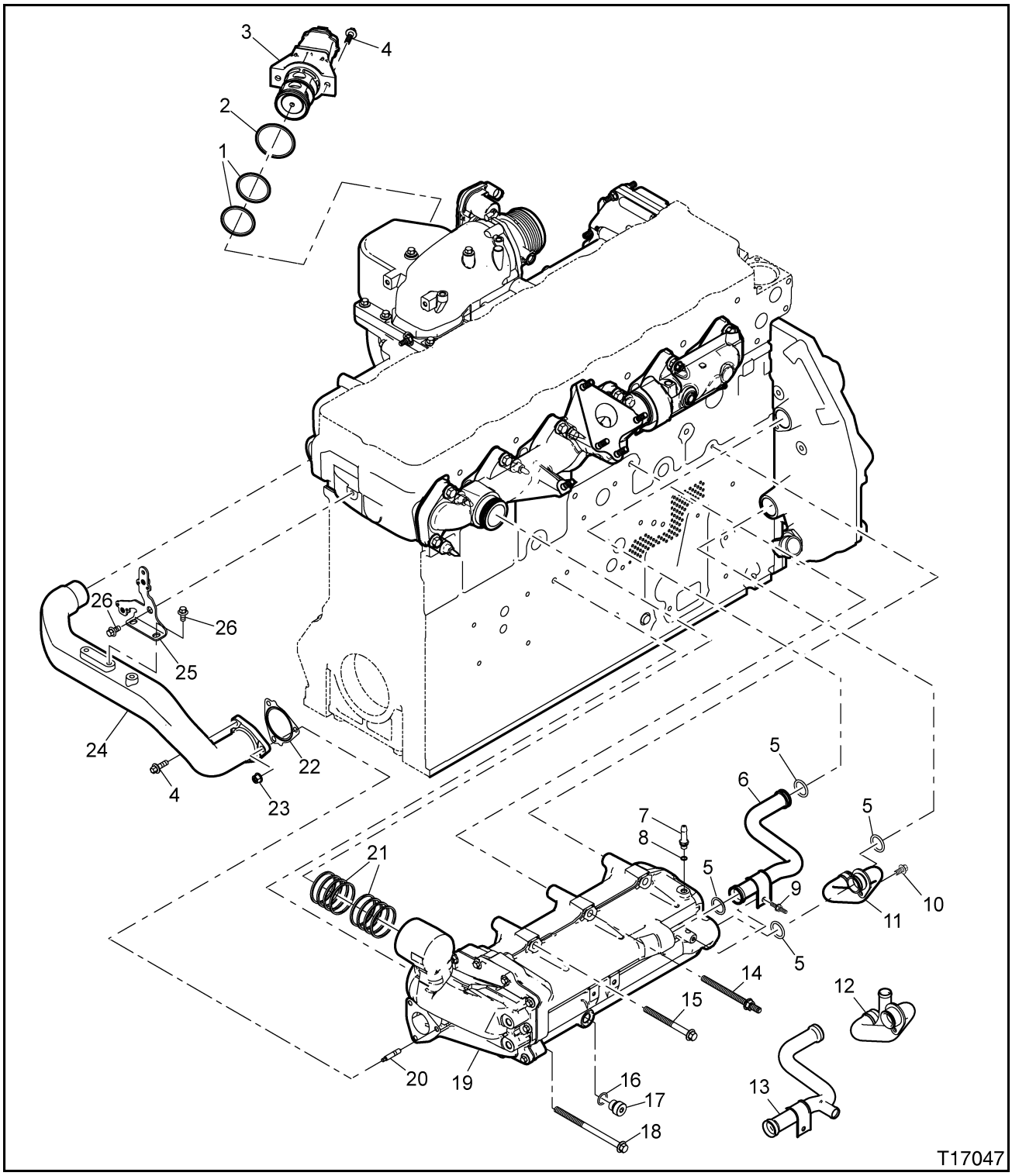


Figure 238 EGR System Components

1. 3.5 x 46.8 ID O-ring (2)
2. EGR valve seal
3. EGR valve assembly
4. M8 x 10 prevailing torque bolt (3)
5. O-ring seal (4)
6. Coolant supply tube assembly (w/o interstage cooler)
7. Deaeration fitting
8. O-ring seal
9. M6 x 16 stud bolt
10. M6 x 12 bolt
11. Coolant return tube assembly (w/o interstage cooler)
12. Coolant return tube assembly (with interstage cooler)
13. Coolant supply tube assembly (with interstage cooler)
14. M10 x 110 stud bolt (2)
15. M10 x 110 bolt
16. Seal
17. M18 O-ring boss plug
18. M10 x 160 bolt (2)
19. High fin density EGR cooler
20. M8 x 1.25 stud with LKG thread (2)
21. Exhaust ring seal (8)
22. Exhaust gasket
23. M8 nut (2)
24. EGR crossover duct
25. Crossover tube support
26. M8 x 16 bolt (with interstage cooler) (3)

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, 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: When performing specific component removal, only remove components necessary for access.

Draining High Fin Density EGR Cooler

WARNING: To prevent personal injury or death, allow engine to cool before draining coolant.

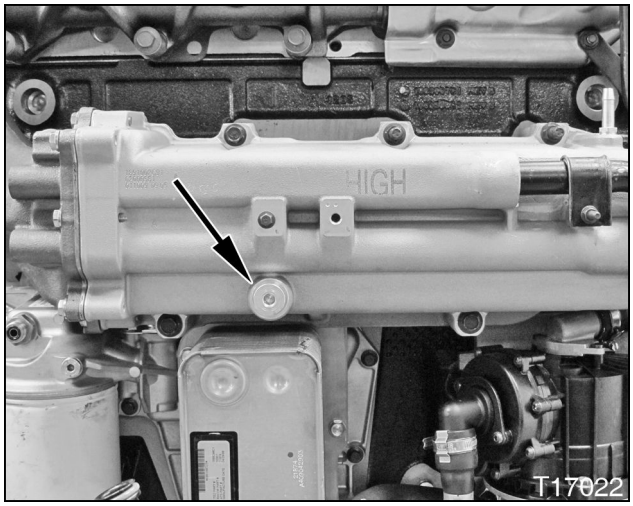


Figure 239 M18 O-ring Boss Plug (Drain Plug)

1. Place a coolant drain pan under M18 O-ring boss plug.
2. Remove M18 O-ring boss plug to allow coolant to drain from EGR cooler.
3. Remove and discard O-ring from M18 O-ring boss plug.
4. Install a new O-ring on M18 O-ring boss plug.
5. After coolant has drained, install M18 O-ring boss plug into high fin density EGR cooler.
6. Tighten M18 O-ring boss plug to standard torque (page 553).
7. Recycle or dispose of coolant according to applicable regulations.

High Fin Density EGR Cooler and Components

1. Remove injection unit inlet tube assembly, hydrocarbon injector assembly and injector coolant inlet and outlet tubes. See Injection Unit Inlet Tube Assembly (page 117) and Hydrocarbon Injector Assembly (page 117).
2. Remove exhaust brake valve assembly and turbocharger oil supply tube. See Exhaust Brake Valve and Turbocharger Outlet Elbow (page 136) and Turbocharger Oil Supply Tube Assembly (page 135).

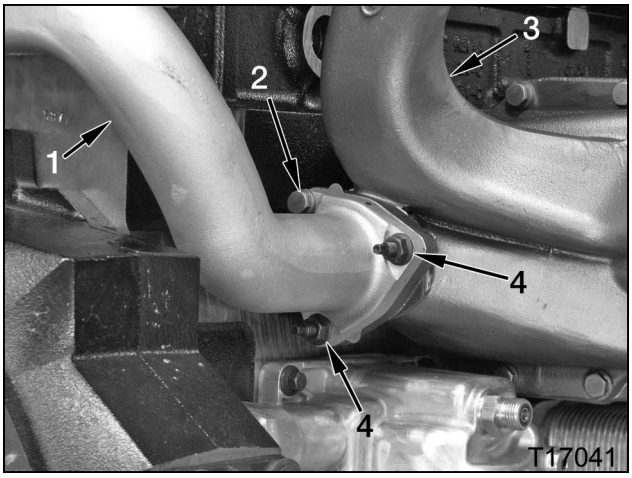


Figure 240 High Fin Density EGR Cooler to Crossover Duct Connection

1. EGR crossover duct
2. M8 x 10 prevailing torque bolt
3. High fin density EGR cooler
4. M8 nut (2)

3. Remove two M8 nuts and one M8 x 10 prevailing torque bolt connecting EGR crossover duct to high fin density EGR cooler.

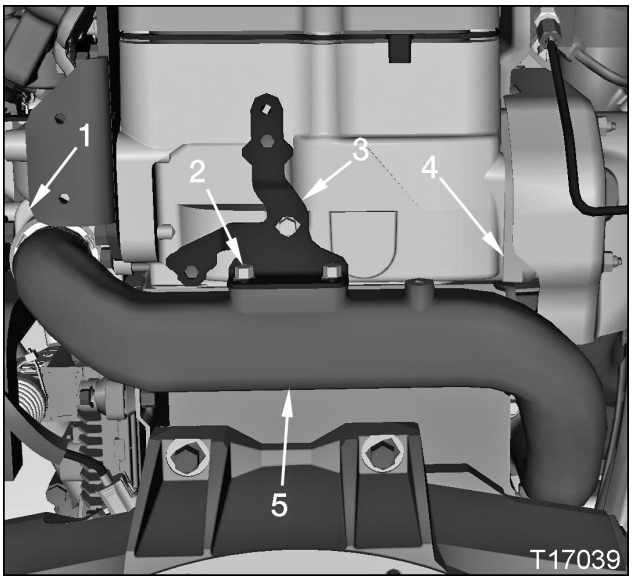


Figure 241 EGR Crossover Duct and Crossover Tube Support

1. Intake manifold
2. M8 x 16 bolt (3)
3. Crossover tube support
4. Exhaust manifold
5. EGR crossover duct

4. Loosen and remove M8 x 16 bolt securing crossover tube support to rear of cylinder head.
5. Pull back and disconnect EGR crossover duct (with crossover tube support still attached) from high fin density EGR cooler and intake manifold.
6. Remove and discard seal from intake manifold. See Intake Manifold, Fuel Valve, and Fuel Rail Plugs (page 193).

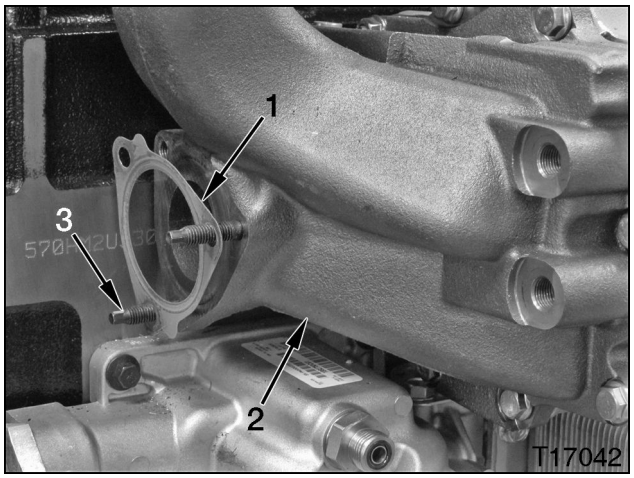


Figure 242 High Fin Density EGR Cooler Exhaust Gasket

1. Exhaust gasket
2. High fin density EGR cooler
3. M8 stud (2)

7. Remove exhaust gasket from high fin density EGR cooler. Discard gasket.
8. Remove alternator support. See Alternator Support (page 304).

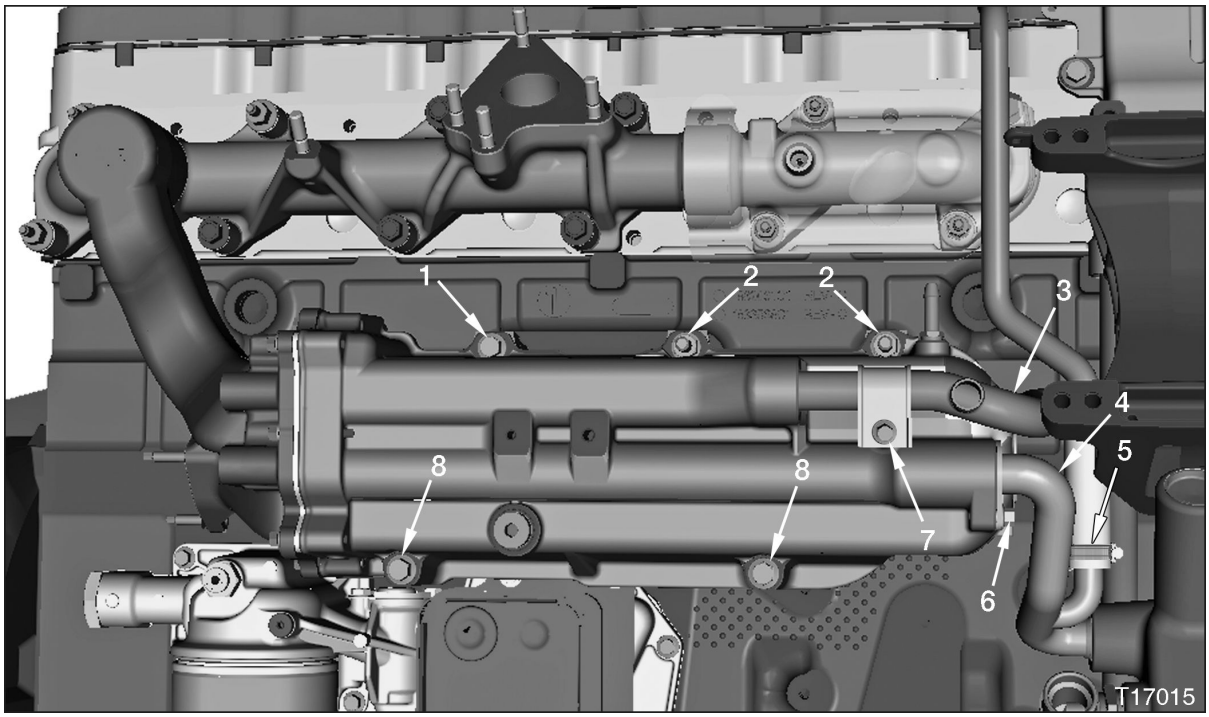


Figure 243 High Fin Density EGR Cooler

1. M10 x 110 bolt
2. M10 x 110 stud bolt (2)
3. EGR coolant supply tube
4. EGR coolant return tube
5. 3/4 inch worm gear clamp
6. M6 x 12 bolt
7. M6 x 16 bolt
8. M10 x 160 bolt (2)

9. Remove M6 x 16 bolt securing EGR coolant supply tube to EGR cooler. Push EGR coolant supply tube forward (deeper into rear half of front cover) to expose free end of tube at EGR cooler. Swing free end of tube up to clear EGR cooler. Pull tube rearward out of rear half of front cover. Remove and discard tube seals.

NOTE: Do next step if equipped with interstage cooler; if not, go to step 12.

10. If engine is equipped with an interstage cooler, loosen 3/4 inch worm gear hose clamp and remove hose from EGR coolant return tube.
11. Remove M6 x 12 bolt securing EGR coolant return tube to EGR cooler. Push EGR coolant return tube forward (deeper into rear half of front cover) to expose free end of tube at EGR cooler. Swing free end of tube downward to clear EGR cooler. Pull tube rearward out of rear half of front cover. Remove and discard tube seals.
12. Remove two M10 x 160 bolts.
13. Remove two M10 x 110 stud bolts. Install both EGR Cooler Guide Pins (page 185) into the empty bolt holes.
14. Remove M10 x 110 bolt.
15. Remove high fin density EGR cooler from crankcase and exhaust manifold by pulling straight out from exhaust manifold.
16. Remove eight exhaust seal rings from grooves on exhaust manifold and discard.

EGR Valve Assembly

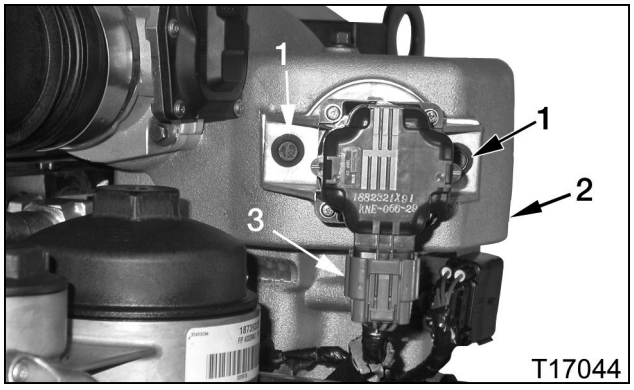


Figure 244 EGR Valve Assembly Bolts

1. M8 x 25.5 bolt (2)
2. Air and EGR mixer duct assembly
3. Engine harness connector

1. Disconnect engine harness connector from EGR valve.
2. Remove two M8 x 25.5 bolts.
3. Remove EGR valve assembly from air and EGR mixer duct assembly by pulling and turning. If valve is stuck, proceed to next step.

CAUTION: To prevent EGR valve assembly damage, use care when installing puller.

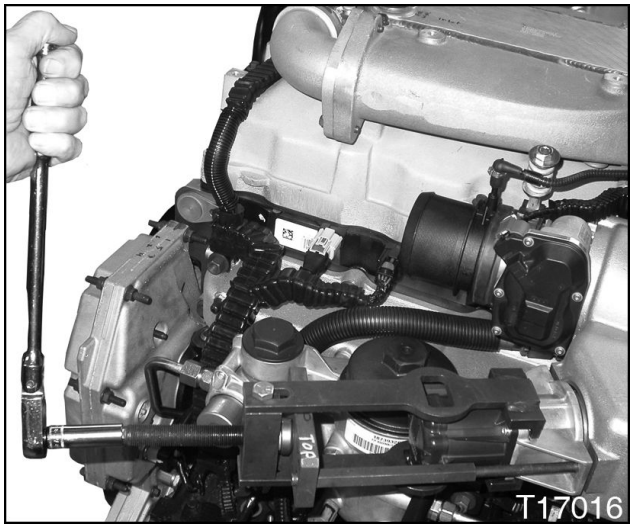


Figure 245 EGR Valve Puller

4. Install EGR Valve Puller (page 185). Ensure puller studs are completely seated in threaded holes.
5. Hook claws of puller on aluminum part of EGR valve assembly as shown.
6. Turn threaded shaft clockwise to remove EGR valve assembly. Remove and discard EGR valve O-rings (2) and seal.

Engine Throttle Valve (ETV) Assembly

1. Disconnect engine harness connector from engine throttle valve assembly.

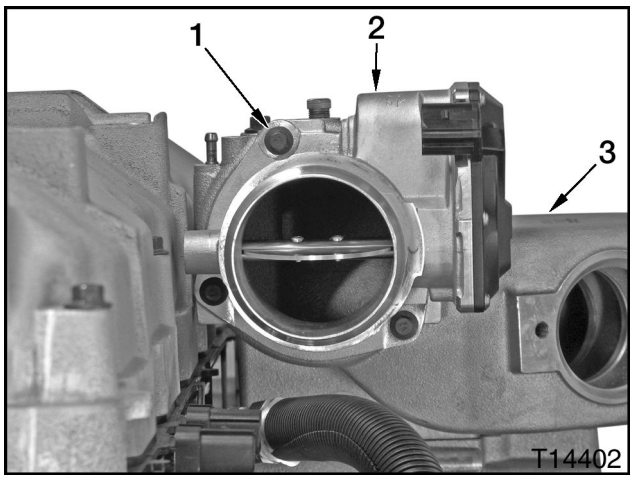


Figure 246 Engine Throttle Valve Assembly

1. M6 x 25 bolt (3)
2. Engine throttle valve assembly
3. Air and EGR mixer duct assembly

2. Remove three M6 x 25 bolts securing engine throttle valve assembly to air and EGR mixer duct assembly and remove engine throttle valve assembly.

Air and EGR Mixer Duct Assembly

1. Disconnect engine harness connector and bus bar from Intake Air Heater (IAH) relay assembly.
2. Remove intake air heater relay assembly if necessary. See Intake Air Heater (IAH) Relay Assembly (page 90).

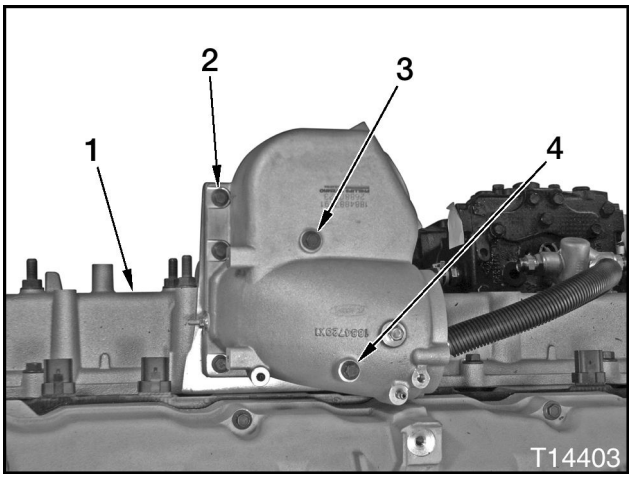


Figure 247 Air and EGR Mixer Duct Assembly (Top View)

1. Intake manifold
2. M8 x 40 bolt (3)
3. M8 x 130 bolt
4. M8 x 170 bolt

3. Remove M8 x 170 bolt.
4. Remove M8 x 130 bolt.
5. Remove three M8 x 40 bolts securing air and EGR mixer duct assembly to intake manifold.
6. Remove air and EGR mixer duct assembly and discard inlet duct to intake manifold gasket.

Cleaning, Inspecting, and Testing

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

Cleaning and Inspecting EGR System Components

NOTE: To maintain and ensure peak engine performance, it is critical to do the following cleaning and inspecting procedures.

1. Clean all mating surfaces to ensure proper gasket sealing.
2. Inspect all EGR system components (Figure 238) for cracks, leaks, and damage. Replace damaged parts as required.

Air and EGR Mixer Duct Assembly

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

EGR Valve Assembly

1. Inspect EGR valve to make sure it is fully closed. Replace the valve if necessary.
2. Inspect electrical connections on EGR valve assembly and engine harness connector for corrosion or damage. Replace if necessary.

NOTE: Refer to MaxxForce® DT, 9, and 10 *Engine Diagnostic Manual* for functional check of EGR valve assembly.

Engine Throttle Valve Assembly

1. Inspect engine throttle valve assembly sealing surfaces and body for cracks or damage. Replace engine throttle valve if sealing surfaces are cracked or damaged.
2. Inspect the butterfly screws. Replace engine throttle valve if screws are loose or missing.
3. Inspect electrical connections on engine throttle valve assembly and engine harness connector for corrosion or damage. Replace if necessary.

High Fin Density EGR Cooler

NOTE: The high fin density EGR cooler should be leak tested both before and after cleaning. If repeated clogging occurs in the EGR cooler on the same engine, replace the EGR cooler, verify there are no trouble codes and inspect ECM for latest software version to ensure engine is running properly.

1. Clean all mating surfaces to ensure proper gasket sealing.
2. Loose carbon can be removed by flowing water through the EGR cooler in both directions or by submerging the EGR cooler in water a few times and allowing it to drain out.

Pressure Testing High Fin Density EGR Cooler

NOTE: Clean all sealing surfaces on EGR cooler to ensure proper sealing of all leak test tools and to eliminate misdiagnosis.

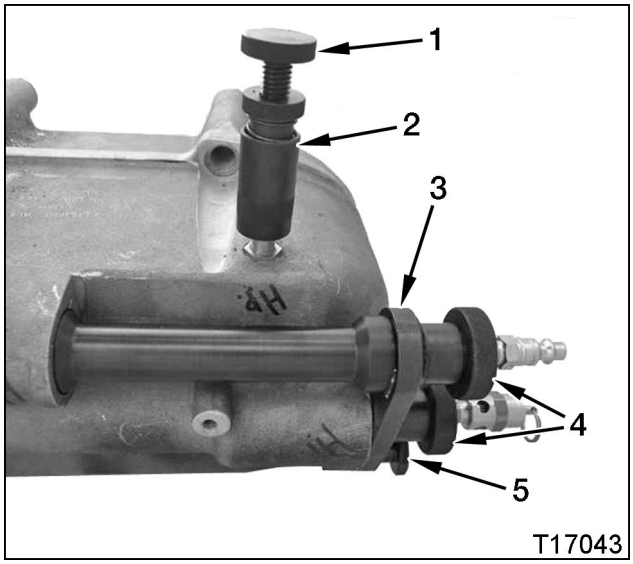


Figure 248 High Fin Density EGR Cooler Pressure Test Set-Up (Front)

1. Knurled knob
2. EGR cooler vent tool
3. EGR cooler coolant port tool
4. Knurled knobs
5. Knurled screw

CAUTION: To prevent EGR tool or component damage, only tighten knurled knobs with enough force to seal EGR cooler.

Obtain EGR Cooler Leak Detection Kit (page 185).

NOTE: Inspect O-rings and seals on EGR Cooler Leak Detection Kit components for damage. Replace O-rings and seals as needed. Air leakage from high fin density EGR cooler may cause inaccurate test results.

EGR Cooler Vent Tool

1. Select EGR cooler vent tool and back out knurled knob to allow enough clearance to install tool on deaeration fitting (on high fin density EGR cooler).
2. Install tool on deaeration fitting. When tool is fully seated, tighten knurled knob to seal end of pipe.

EGR Cooler Coolant Port Tool

1. Select EGR cooler coolant port tool and back out knurled knobs to allow tool to be installed on cooler as shown.
2. Tighten knurled screw to secure EGR cooler coolant port tool to high fin density EGR cooler.
3. Turn knurled knobs under poppet valve and quick connect to compress O-rings and seal ports in the high fin density EGR cooler.

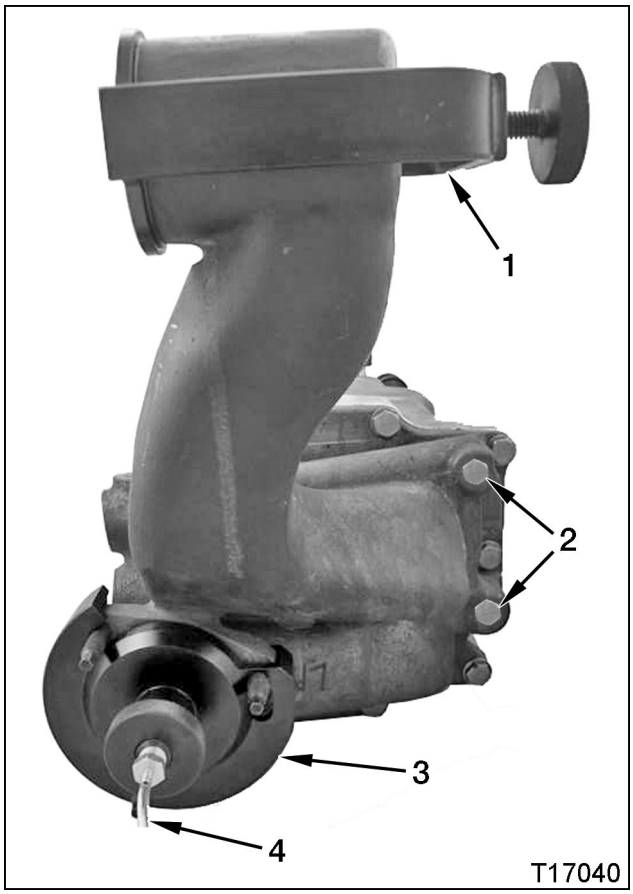


Figure 249 High Fin Density EGR Cooler Pressure Test Setup (Rear)

1. EGR cooler exhaust inlet tool
2. SAE J512 plugs (2)
3. EGR cooler exhaust outlet tool
4. Clear hose

EGR Cooler Exhaust Inlet Tool

1. Select EGR cooler exhaust inlet tool and back out knurled knob to allow clearance for tool to fit on end of EGR cooler. Install tool on EGR cooler as shown.
2. Tighten knurled knob until opening is sealed.

EGR Cooler Exhaust Outlet Tool

1. Select EGR cooler exhaust outlet tool and back out knurled knob to allow enough clearance to properly install tool on flange.

2. Place tool over flange so flange fits in tool opening. The cutout portion of tool provides clearance around EGR cooler. Turn tool clockwise until flange contacts stops on tool.
3. Tighten knurled knob on EGR cooler exhaust outlet tool until rubber seal contacts flange.

SAE J512 Plugs

1. Seal the two hydrocarbon injector coolant line ports with SAE J512 plugs (page 185).
2. Tighten SAE J512 plugs only enough to seal ports.

NOTE: The poppet valve is set to open at 80 psi for safety and to prevent damage to the EGR cooler.

EGR Cooler Leak Test

1. Connect an air hose, regulated to 50 psi, to quick connect on EGR cooler coolant port tool.
2. Place red end of clear hose from EGR cooler exhaust outlet tool into a container of water and watch for air bubbles. Submerge only the red portion of the hose in water. Air bubbles indicate a leak in the EGR cooler. It is not necessary to pressurize the EGR cooler for more than 5 minutes. Replace EGR cooler if air comes out of clear hose.
3. Disconnect air hose from EGR cooler coolant port tool.
4. Remove tools and SAE J512 plugs from EGR cooler. Clean tools as needed and place them in their storage case for future use.

Installation

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

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

Air and EGR Mixer Duct Assembly

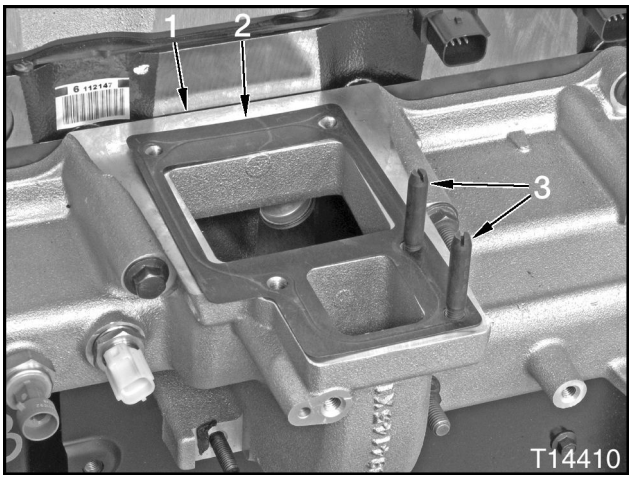


Figure 250 Mixing Bowl Gasket Alignment Pins

1. Intake manifold
2. Inlet duct to intake manifold gasket
3. Mixing bowl gasket alignment pin (2)

1. Install two Mixing Bowl Gasket Alignment Pins (page 185) to intake manifold.
2. Install a new inlet duct to intake manifold gasket on intake manifold and install air and EGR mixer duct assembly on intake manifold.

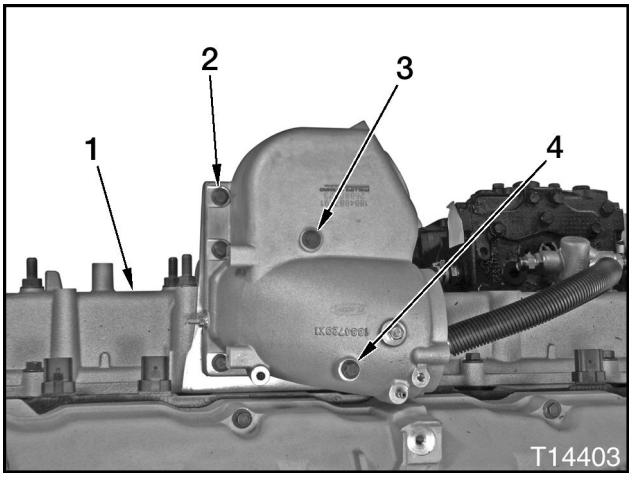


Figure 251 Air and EGR Mixer Duct Assembly

1. Intake manifold
2. M8 x 40 bolt (3)
3. M8 x 130 bolt
4. M8 x 170 bolt

3. Install M8 x 170 bolt finger tight.
4. Install M8 x 130 bolt finger tight.
5. Remove two Mixing Bowl Gasket Alignment Pins (page 185).
6. Install three M8 x 40 bolts finger tight.
7. Tighten three M8 x 40 bolts, M8 x 130 bolt, and M8 x 170 bolt to standard torque (page 553).

Engine Throttle Valve (ETV) Assembly

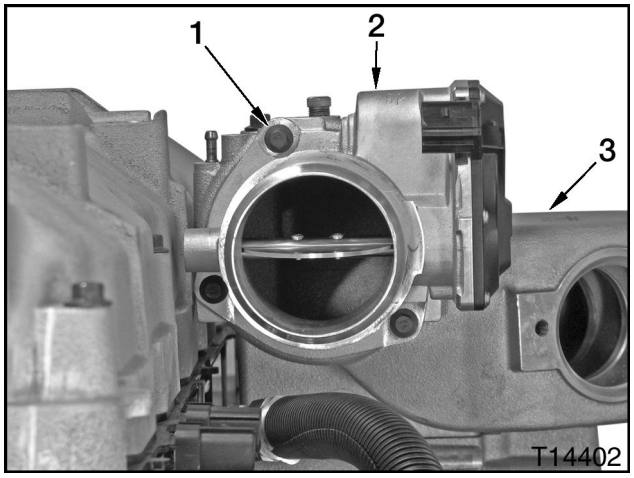


Figure 252 ETV Assembly

1. M6 x 25 bolt (3)
2. Engine throttle valve assembly
3. Air and EGR mixer duct assembly

1. Install engine throttle valve assembly on air and EGR mixer duct assembly with new inlet throttle gasket and finger tighten three M6 x 25 bolts.
2. Tighten three M6 x 25 bolts to special torque (page 185).

EGR Valve Assembly

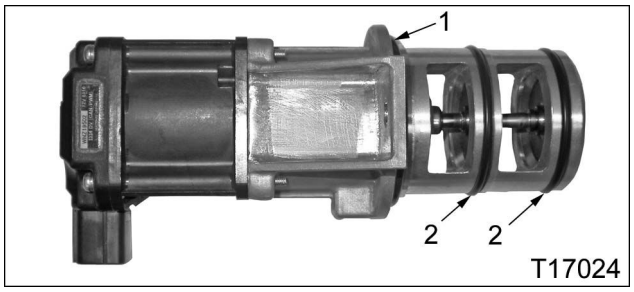


Figure 253 EGR Valve Assembly

1. EGR valve seal
2. O-ring (2)

1. Install new EGR valve seal and O-rings. Do not apply engine oil to O-rings or seal.
2. Install EGR valve assembly into air and EGR mixer duct assembly. Push and turn as needed until valve is completely seated and bolt holes line up.

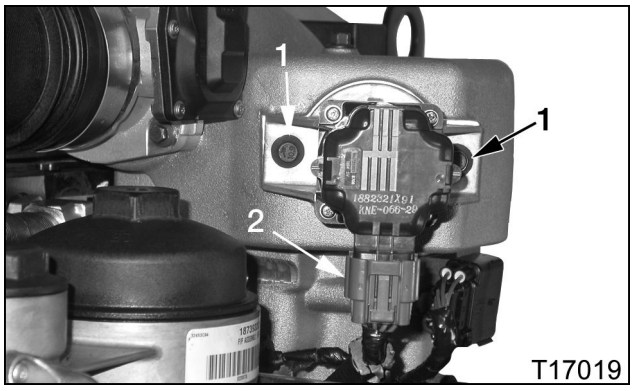


Figure 254 EGR Valve Assembly Bolts

1. M8 x 25.5 bolt (2)
2. Air and EGR mixer duct assembly
3. EGR harness connector

3. Install two M8 x 25.5 bolts and tighten to standard torque (page 553).

High Fin Density EGR Cooler and Components

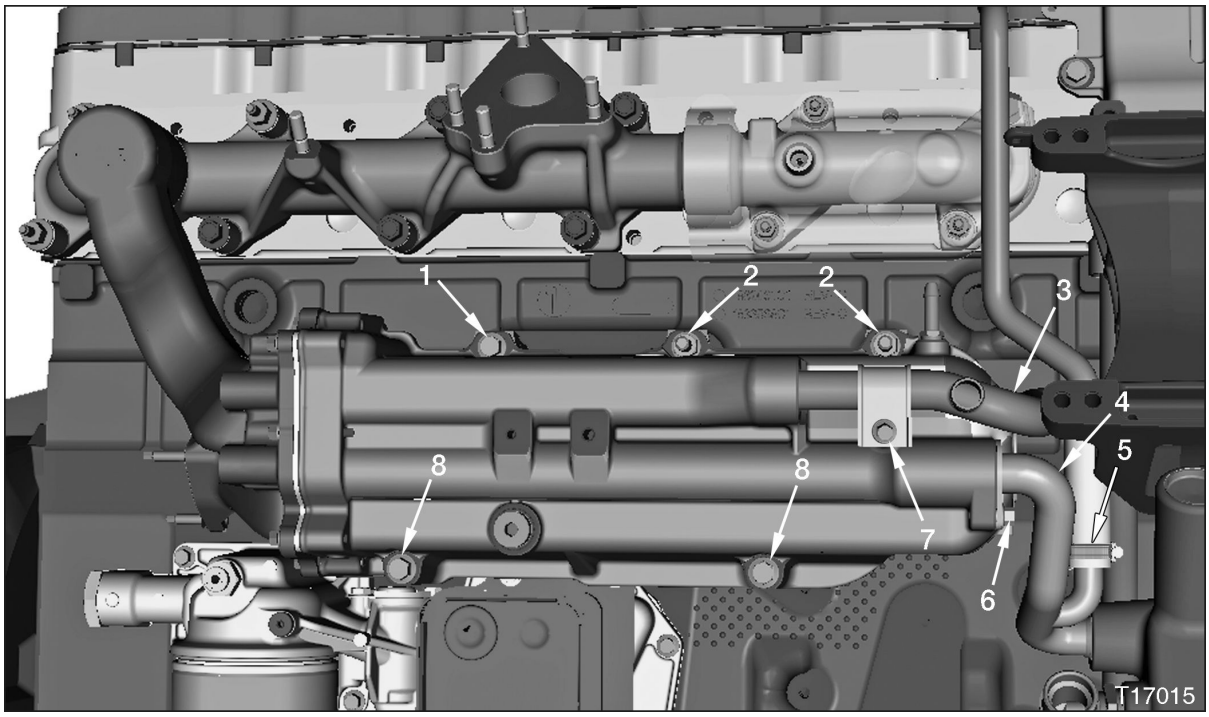


Figure 255 High Fin Density EGR Cooler

1. M10 x 110 bolt
2. M10 x 110 stud bolt (2)
3. EGR coolant supply tube
4. EGR coolant return tube
5. 3/4 inch worm gear clamp (with ISC)
6. M6 x 12 bolt
7. M6 x 16 bolt
8. M10 x 160 bolt (2)

1. Install eight new exhaust sealing rings on exhaust manifold. See Exhaust Manifold (page 197).
2. Install EGR Cooler Guide Pins (page 185) into two upper bolt holes.
3. Place EGR cooler onto EGR Cooler Guide Pins (page 185) and slide toward crankcase and exhaust manifold.
4. Install two M10 x 160 bolts, remove EGR Cooler Guide Pins (page 185) and then install one M10 x 110 bolt, and two M10 x 110 stud bolts to EGR cooler to crankcase. Tighten bolts to standard torque (page 553).
5. Install new O-ring seals (one on each end) on coolant return tube. Lightly lubricate seals with engine coolant. Insert coolant return tube into rear half of front cover first until opposite end can clear EGR cooler. Insert opposite end of coolant return tube into port of EGR cooler.
6. Connect coolant hose to coolant return tube and secure with 3/4 inch worm gear clamp. Tighten clamp to standard torque (page 553).
7. Install M6 x 12 bolt to secure EGR coolant return tube to high fin density EGR cooler. Tighten bolt to standard torque (page 553).
8. Install new O-ring seals (one on each end) on coolant supply tube. Lightly lubricate seals with engine coolant. Insert coolant supply tube into rear half of front cover until opposite end can clear EGR cooler. Insert opposite end of coolant supply tube into port of EGR cooler.
9. Install M6 x 16 bolt to secure EGR coolant supply tube to EGR cooler. Tighten bolt to standard torque (page 553).
10. Using EGR Tube Seal Installer (page 185), install new EGR pipe seal into the intake manifold. See Intake Manifold, Fuel Valve, and Fuel Rail Plugs (page 199).

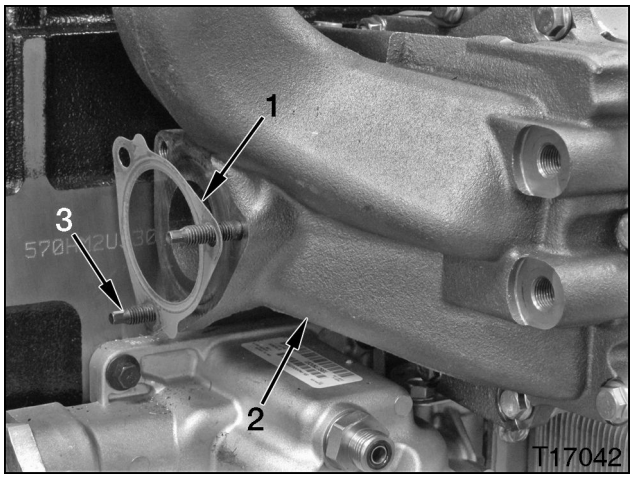


Figure 256 High Fin Density EGR Cooler Exhaust Gasket

1. Exhaust gasket
2. High fin density EGR cooler
3. M8 stud (2)

11. Install a new exhaust gasket on high fin density EGR cooler.

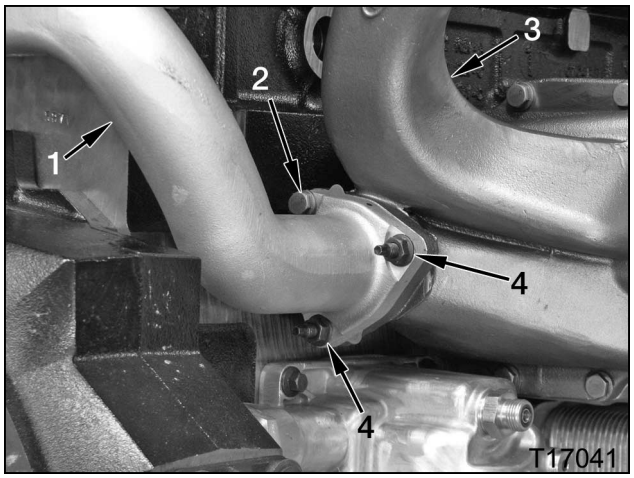


Figure 257 High Fin Density EGR Cooler to Crossover Duct Connection

1. EGR crossover duct
2. M8 x 10 prevailing torque bolt
3. High fin density EGR cooler
4. M8 nut (2)

12. Push EGR crossover duct over high fin density EGR cooler studs and straight into intake manifold.

13. Install two M8 nuts and one M8 x 10 prevailing torque bolt to secure high fin density EGR cooler to EGR crossover duct. Tighten to standard torque (page 553).

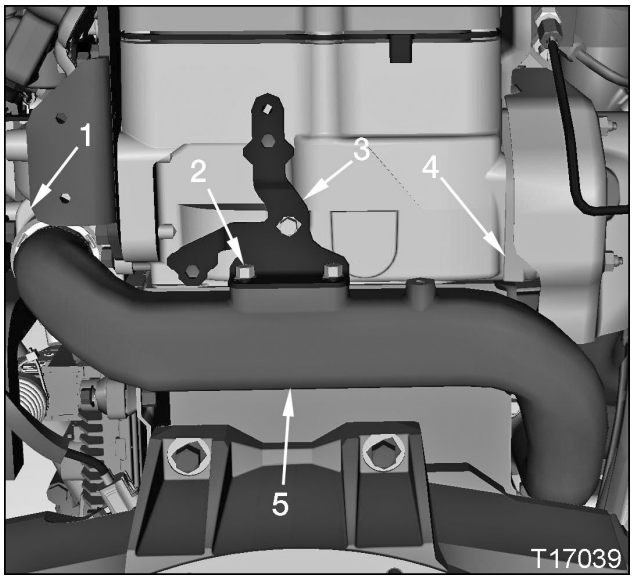


Figure 258 EGR Crossover Duct and Crossover Tube Support

1. Intake manifold
2. M8 x 16 bolt (3)
3. Crossover tube support
4. Exhaust manifold
5. EGR crossover duct

14. Loosen two M8 x 16 bolts holding crossover tube support to EGR crossover duct. The crossover tube support must be able to move freely on EGR crossover duct.

15. Install M8 x 16 bolt to secure crossover tube support to rear of cylinder head. Tighten bolt to cylinder head first, then the other two bolts to standard torque (page 553).

Special Torque

Engine throttle valve M6 x 25 bolts	13 N·m (120 lb·in)

Special Service Tools

EGR Cooler Guide Pins	ZTSE4945
EGR Cooler Leak Detection Kit	KL 20030 NAV
EGR Valve Puller	ZTSE4941
EGR Tube Seal Installer	ZTSE4997
SAE J512 plugs	Obtain locally
Mixing Bowl Gasket Alignment Pins	ZTSE4955

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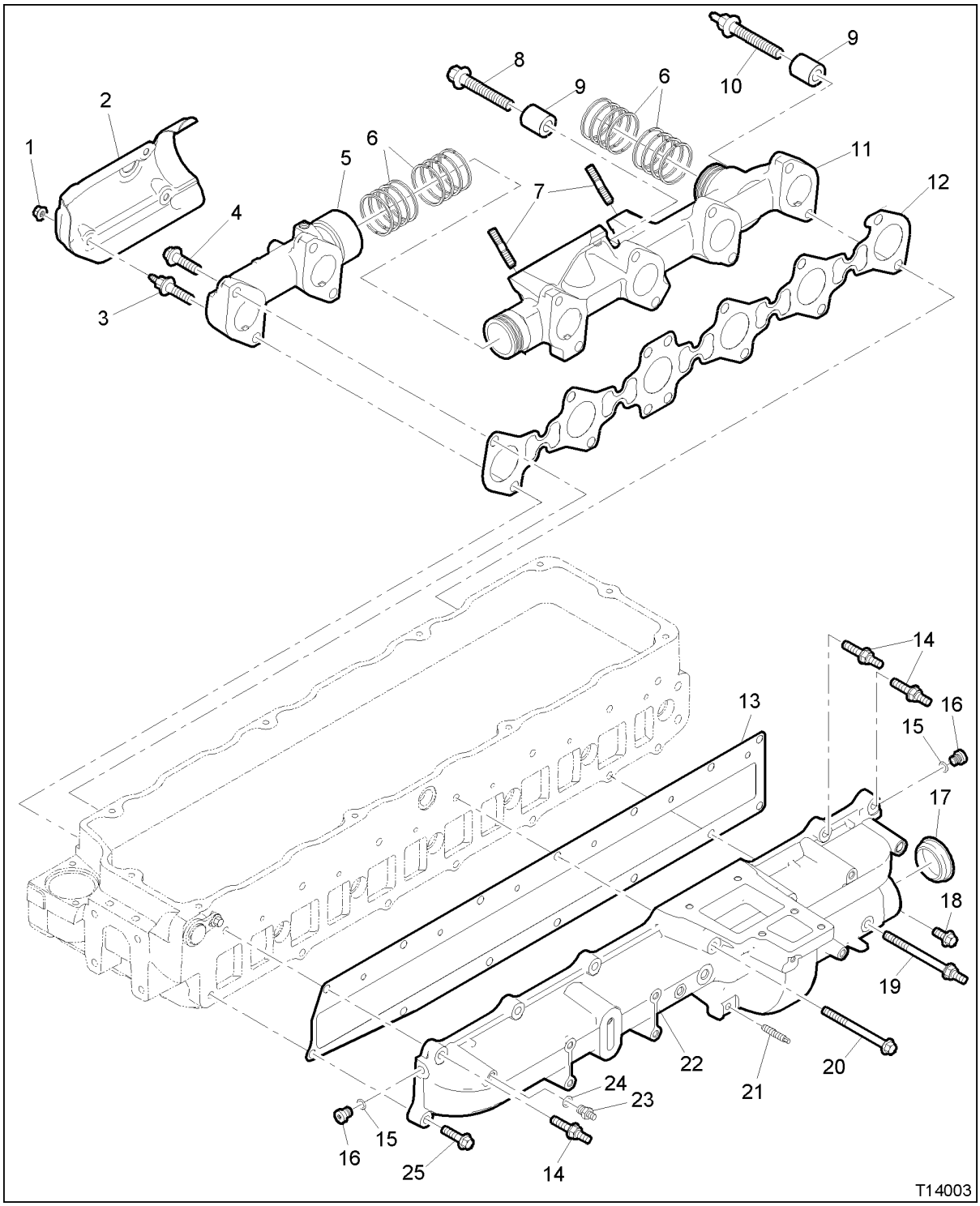


Figure 259 Intake Manifold and Exhaust Manifold Assemblies

1. M8 lock nut (3)
2. Exhaust front manifold shield
3. Prevailing torque stud bolt (3)
4. M12 x 40 prevailing torque bolt
5. Exhaust manifold (front)
6. Exhaust ring seal (16)
7. Turbo adapter stud (5)
8. M12 x 70 bolt (5)
9. Exhaust manifold bolt spacer (8)
10. M12 x 70 stud bolt (3)
11. Exhaust manifold (rear)
12. Exhaust manifold gasket assembly
13. Intake manifold gasket
14. M10 x 35 stud bolt (3)
15. M12 x 1.5 O-ring seal (2)
16. M12 plug assembly (fuel rail) (2)
17. EGR pipe seal
18. M10 x 25 bolt
19. M10 x 110 stud bolt (2)
20. M10 x 110 bolt (2)
21. M8 x 1.25 stud w/locking thread
22. Intake manifold
23. Fuel valve assembly
24. O-ring seal
25. M10 x 35 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, do not smoke and keep fuel away from flames and sparks.

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

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

NOTE: When performing specific component removal, only remove components necessary for access.

Exhaust Manifold

NOTE: If rear exhaust manifold has a square ear, discard and replace with new rear exhaust manifold.

1. Remove dual stage turbocharger assembly. See Dual Stage Turbocharger Assembly (page 139).
2. Remove crankcase breather tube inlet and outlet assemblies. See Crankcase Ventilation System (page 473).
3. Remove high fin density EGR cooler. See High Fin Density EGR Cooler and Components (page 173).
4. If equipped with an interstage cooler, remove interstage inlet duct and interstage coolant return tube. See Interstage Inlet Duct Assembly (page 132).
5. Disconnect engine harness from Exhaust Back Pressure (EBP) sensor. See Exhaust Back Pressure (EBP) Sensor (page 87).
6. Disconnect engine harness from Exhaust Gas Temperature (EGT) sensor. See Exhaust Gas Temperature (EGT) Sensor (page 89).

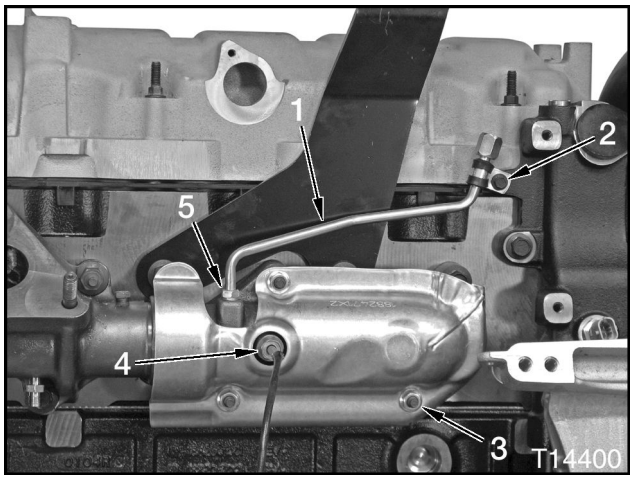


Figure 260 EBP Sensor Tube Assembly and Exhaust Manifold Front Shield

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

7. Remove M6 x 12 bolt (Figure 260) (Item 2) from EBP sensor tube assembly clamp.
8. Loosen EBP sensor tube nut (Figure 260) (Item 5) from exhaust manifold and remove EBP sensor tube assembly (Figure 260) (Item 1).
9. Remove EGT sensor (Figure 260) (Item 4) from exhaust manifold.
10. Remove three M8 lock nuts (Figure 260) (Item 3) and remove exhaust front manifold shield.

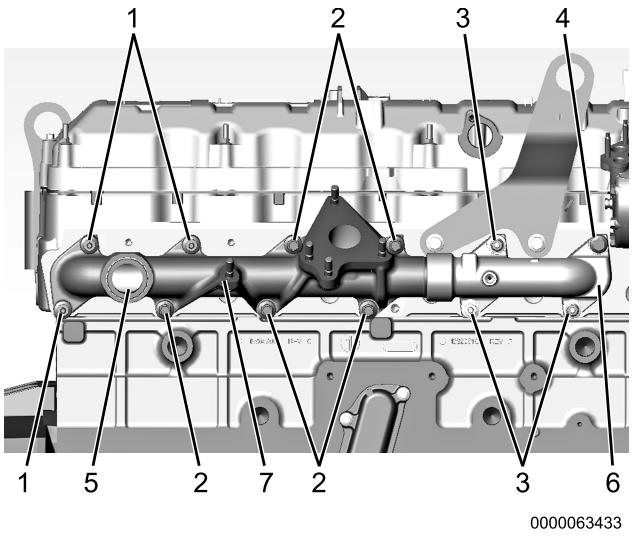


Figure 261 Exhaust Manifold Assembly

1. M12 x 70 prevailing torque stud bolt with spacer (3)
2. M12 x 70 bolt with spacer (5)
3. Prevailing torque stud bolt (3)
4. M12 x 40 prevailing torque bolt
5. Exhaust ring seal (16) (hidden)
6. Exhaust manifold (front)
7. Exhaust manifold (rear)

11. Remove three M12 x 70 prevailing torque stud bolts with spacers (Figure 266) (Item 1) and five M12 x 70 bolts with spacers (Figure 266) (Item 2) from exhaust manifold (rear) (Figure 266) (Item 7). Discard bolts.
12. Support exhaust manifold and remove M12 x 40 prevailing torque bolt (Figure 266) (Item 4) and three prevailing torque stud bolts (Figure 266) (Item 3) from exhaust manifold (front) (Figure 266) (Item 6). Discard bolts.
13. Remove exhaust manifold assembly from engine and discard exhaust manifold gasket assembly.

14. Separate exhaust manifold front and rear sections, and remove eight exhaust ring seals (Figure 266) (Item 5).
15. Remove and discard eight exhaust ring seals from exhaust manifold (rear) at EGR cooler connection.
16. If required, remove five turbocharger adapter studs from exhaust manifold using a stud remover (page 202).

Intake Manifold, Fuel Valve, and Fuel Rail Plugs

1. Remove fuel filter assembly. See Fuel Filter Assembly (page 214).
2. Remove EGR crossover duct. See High Fin Density EGR Cooler and Components (page 173).
3. Remove high-pressure oil hose. See High-pressure Oil Hose and Elbows (page 215).
4. Remove oil level gauge assembly. See Oil Level Gauge Assembly (page 476).

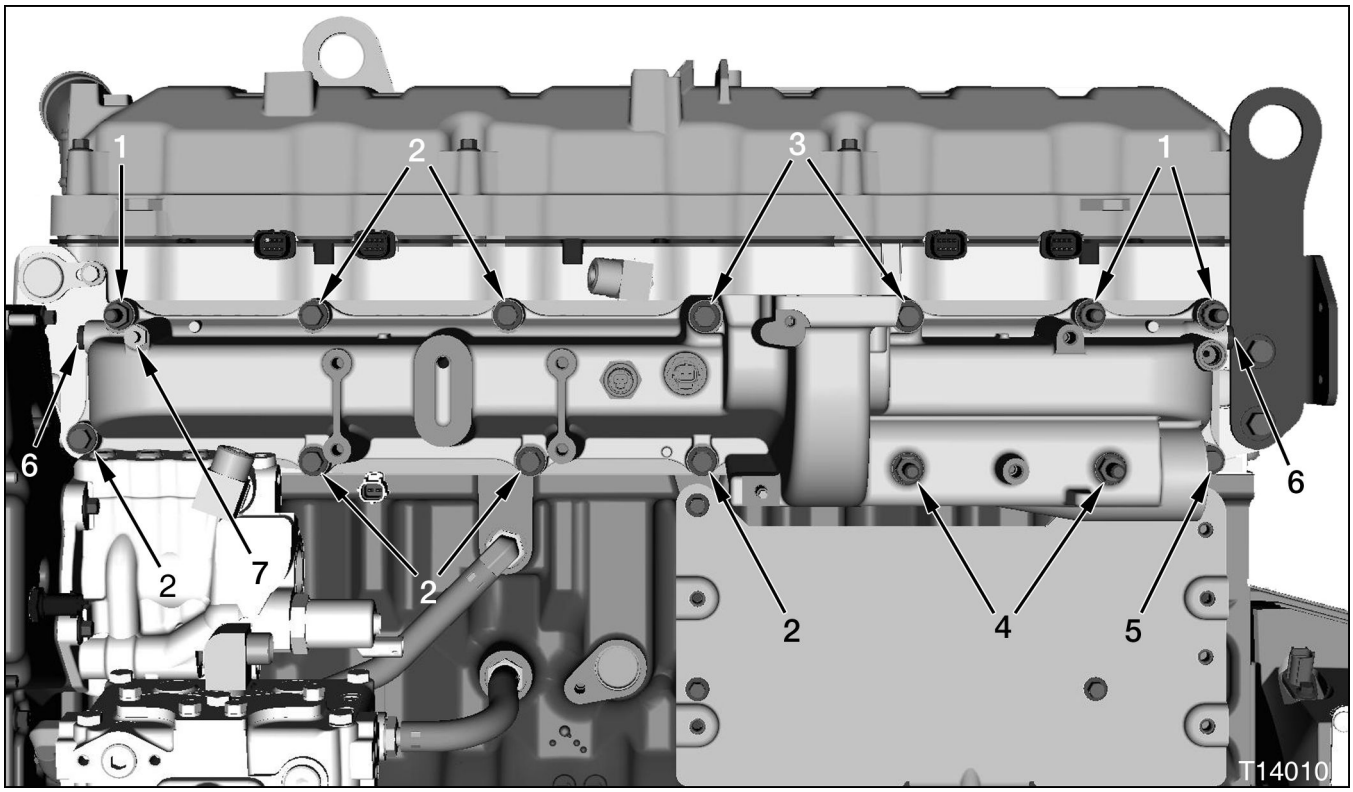


Figure 262 Intake Manifold and Bolts

1. M10 x 35 stud bolt (3)
2. M10 x 35 bolt (6)
3. M10 x 110 bolt (2)
4. M10 x 110 stud bolt (2)
5. M10 x 25 bolt
6. M12 plug assembly (2)
7. Fuel valve assembly

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

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

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

5. Remove two M12 plug assemblies (Figure 262) (Item 6) and discard O-rings. Drain fuel into a correct container marked Diesel Fuel.
6. Remove three M10 x 35 stud bolts (Figure 262) Item 1).
7. Remove M10 x 25 bolt (Figure 262) (Item 5).
8. Remove six M10 x 35 bolts (Figure 262) (Item 2).
9. Remove two M10 x 110 bolts (Figure 262) (Item 3).
10. Remove two M10 x 110 stud bolts (Figure 262) (Item 4) securing intake manifold to cylinder head.
11. Remove intake manifold and gasket from engine. Drain remaining fuel from intake manifold and discard intake manifold gasket.
12. If required, remove fuel valve assembly (Figure 262) (Item 7) (air bleed and pressure test port) and discard O-ring.

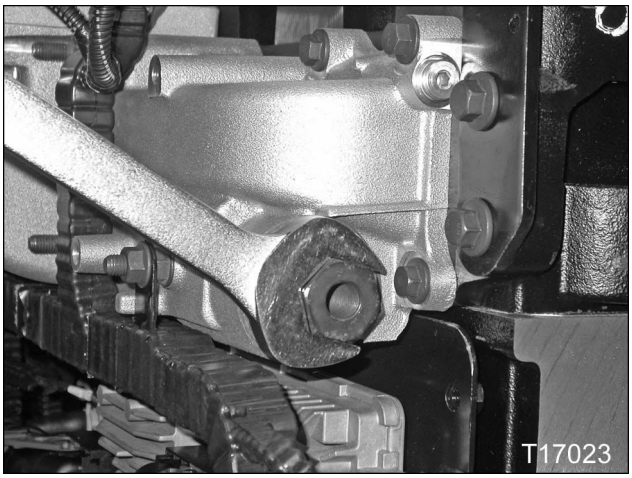


Figure 263 Rear Of Intake Manifold

13. Screw EGR Tube Seal Installer (page 202) into EGR pipe seal and pull seal from intake manifold using a Slide Hammer Puller Set (page 202).

Cleaning, Inspection, and Measurements

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

Exhaust Manifold

CAUTION: To prevent engine damage, do not grind or machine exhaust manifold.

NOTE: All old studs, bolts, and exhaust manifold mounting hardware should be discarded and replaced with new.

1. Using Scotch-Brite™ scouring pads or comparable, scrape excess scale and rust from exhaust manifold surfaces.
2. Inspect exhaust manifold for cracks and damage. Replace exhaust manifold if necessary.

Exhaust Back Pressure (EBP) Sensor Tube Assembly

1. Clean EBP sensor tube assembly thoroughly with a suitable non-caustic solvent.
2. Dry EBP sensor tube assembly using filtered compressed air.
3. Inspect tube for cracks, dents, and internal obstructions. Replace if necessary.
4. Inspect tube fitting for stripped threads and rounded corners. Replace if necessary.

Intake Manifold

CAUTION: To prevent engine damage, do not grind or machine intake manifold.

1. Clean intake manifold thoroughly with a suitable non-caustic solvent.
2. Dry intake manifold using filtered compressed air.
3. Inspect sealing surfaces for corrosion and pitting. Replace if necessary.
4. Inspect intake manifold for cracks and damage. Replace if necessary.

Installation

NOTE: Do not re-use bolts when replacing or servicing exhaust manifold. Always replace exhaust manifold retaining bolts and studs. Proper bolt torque and sequence must be followed. Apply a light coat of clean engine oil on bolt threads and under bolt head when installing.

NOTE: If rear exhaust manifold has a square ear, discard and replace with new rear exhaust manifold.

Exhaust Manifold

1. If removed, install five turbocharger adapter studs in exhaust manifold and tighten to special torque (page 202).

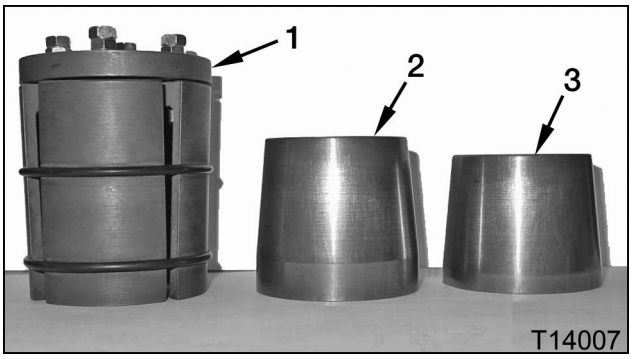


Figure 264 Exhaust Ring Seal Installation Tool Kit

1. Pusher tool
2. Installation cone (taller)
3. Installation cone (shorter)

NOTE: The sixteen exhaust ring seals are installed in sets of four per each seal groove with gaps positioned 180 degrees from gap of the ring next to it.

2. Place four exhaust ring seals with gaps positioned 180 degrees apart on narrow end of taller installation cone (Figure 264) (Item 2) of Exhaust Ring Seal Installation Tool Kit ZTSE6030 (page 202).

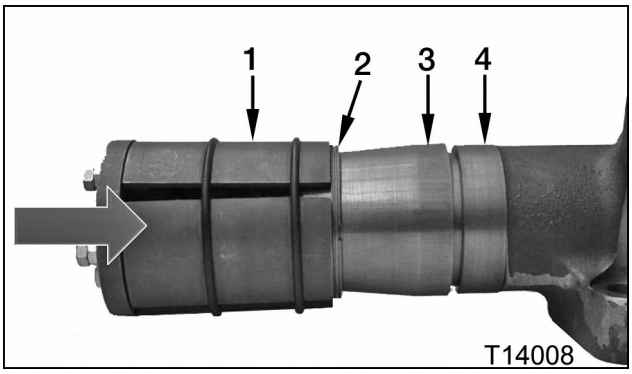


Figure 265 Exhaust Ring Seal Installation

1. Pusher tool
2. Exhaust ring seals
3. Installation cone (taller)
4. Exhaust manifold

3. Place installation cone (Figure 265) (Item 3) and exhaust ring seals (Figure 265) (Item 2) on exhaust manifold joint. The large end of cone should cover outer groove and leave inner groove exposed. Push exhaust ring seals over cone into inner groove using pusher tool (Figure 265) (Item 1).
4. Place four more exhaust ring seals with gaps positioned 180 degrees apart on narrow end of shorter installation cone (Figure 264) (Item 3).
5. Place shorter cone with exhaust rings seals on exhaust manifold joint. The large end of cone should just reach outer groove. Push exhaust ring seals over cone into outer groove using pusher tool.
6. Remove tools from exhaust manifold.
7. Slide rear section of exhaust manifold with exhaust ring seals into front section of exhaust manifold.
8. Insert new exhaust manifold bolt in upper hole at each end of assembly and place new exhaust manifold gasket assembly on assembled exhaust manifold. This will help align exhaust manifold and gasket during installation.

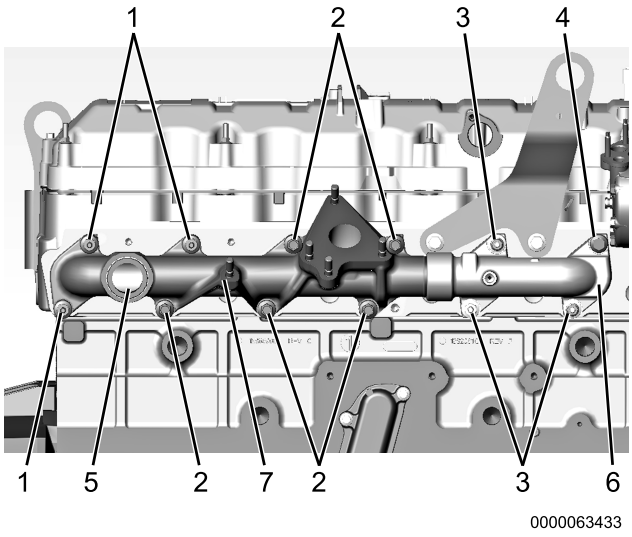


Figure 266 Exhaust Manifold Assembly

1. M12 x 70 prevailing torque stud bolt with spacer (3)
2. M12 x 70 bolt with spacer (5)
3. Prevailing torque stud bolt (3)
4. M12 x 40 prevailing torque bolt
5. Exhaust ring seal (16) (hidden)
6. Exhaust manifold (front)
7. Exhaust manifold (rear)

9. Install exhaust manifold assembly and new exhaust manifold gasket assembly onto cylinder head.

CAUTION: Do not cut exhaust manifold gaskets into pieces during installation. Cut exhaust manifold gaskets will cause improper sealing.

10. Install three new M12 x 70 prevailing torque stud bolts with spacers (Item 1), and five new M12 x 70 bolts with spacers (Item 2) finger tight.
11. Install three new prevailing torque stud bolts (Item 3) and a new M12 x 40 prevailing torque bolt (Item 4) finger tight.

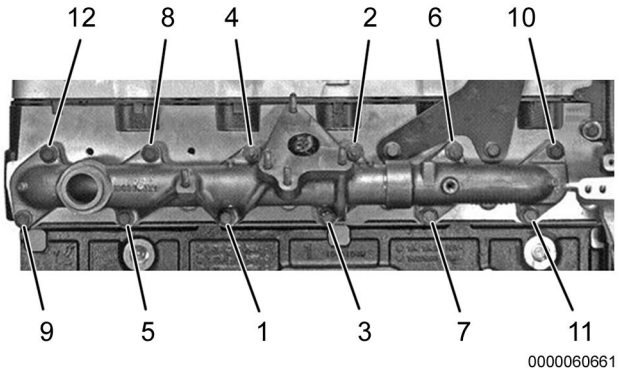


Figure 267 Exhaust Manifold Torque Sequence

12. Torque 12 exhaust manifold bolts using the following four step sequence:
    a. Tighten bolts in sequence 1 12 to 27.1 N·m (20 lb·ft).
    b. Tighten bolts in sequence 1 through 12 to 54 N·m (40 lb·ft).
    c. Tighten bolts in sequence 1 through 12 to 102 N·m (75 lb·ft).

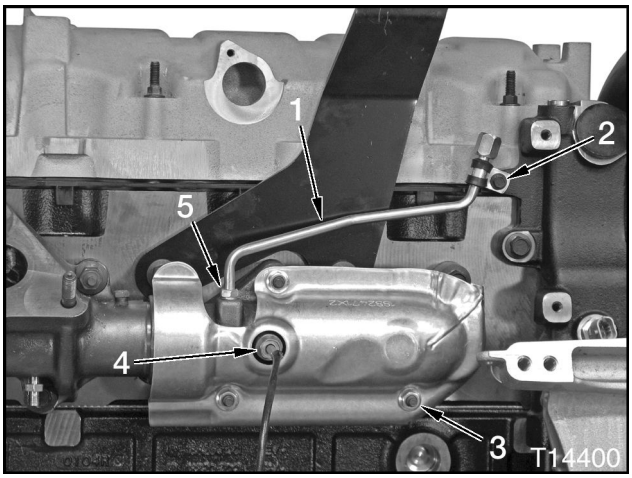


Figure 268 Exhaust Gas Temperature (EGT) Sensor Tube Assembly and Exhaust Manifold Front Shield

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

13. Install exhaust manifold front shield on exhaust manifold studs and install three M8 lock nuts (Figure 268) (Item 3).
14. Tighten three M8 lock nuts to standard torque (page 553).
15. Install EBP sensor tube nut (Figure 268) (Item 5) into exhaust manifold and finger tighten.
16. Install M6 x 12 bolt (Figure 268) (Item 2) through the EBP sensor tube assembly clamp and finger tighten.
17. Tighten EBP sensor tube nut to special torque (page 202).
18. Tighten M6 x 12 bolt to standard torque (page 553).

NOTE: Before installation, clean and inspect EGT threads and exhaust manifold threads for damage. Replace as necessary.

19. Install EGT sensor. Tighten EGT sensor (Figure 268) (Item 4) to special torque (page 202).

Intake Manifold, Fuel Valve, and Fuel Rail Plugs

1. Install new O-rings on M12 plug assemblies and install plugs into ends of intake manifold.
2. Tighten fuel rail plugs to special torque (page 202).
3. If removed, install new O-ring on fuel valve assembly (air bleed and pressure test port) and install valve assembly into intake manifold.
4. Tighten fuel valve assembly to special torque (page 202).
5. Insert one intake manifold bolt in each end of assembly and place new intake manifold gasket on intake manifold. This will help align intake manifold and gasket during installation.
6. Install intake manifold and gasket onto cylinder head and finger tighten two bolts.

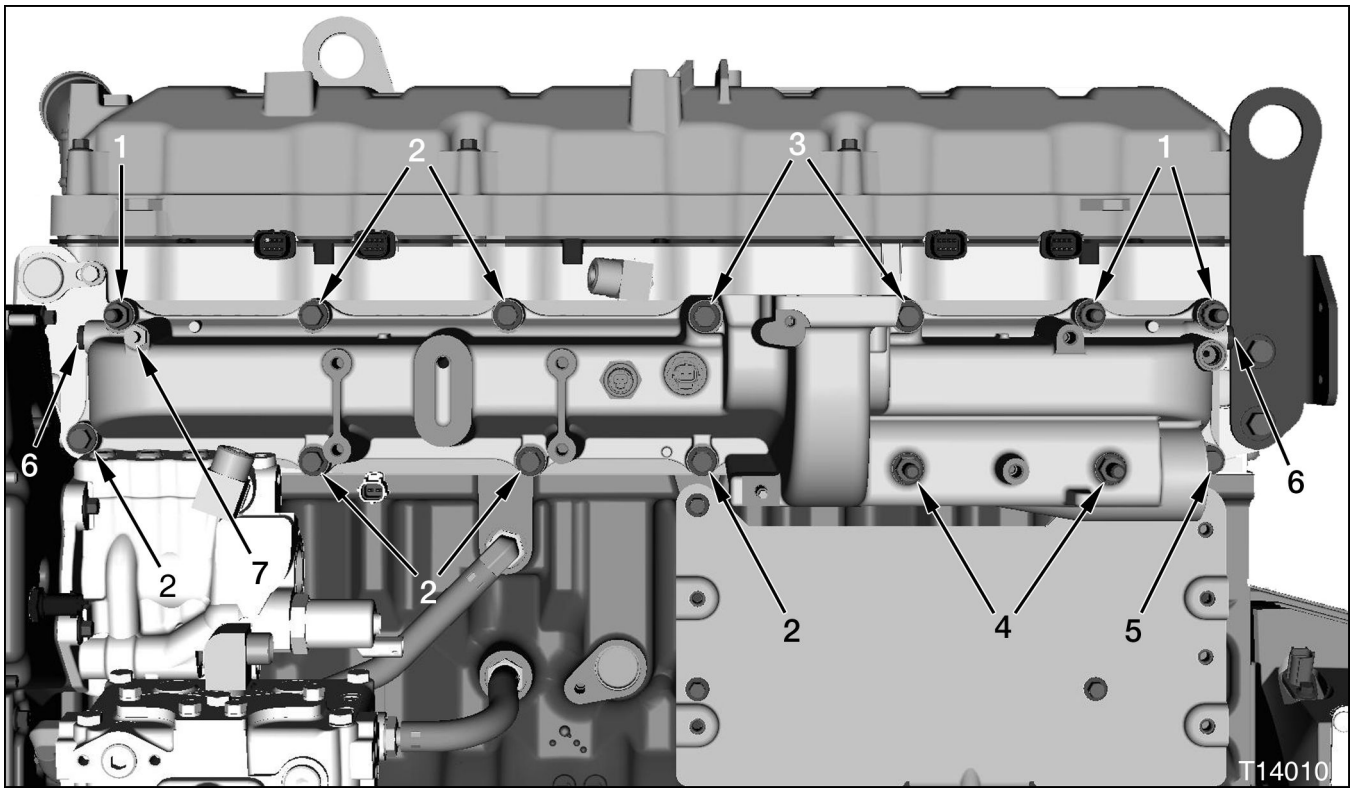


Figure 269 Intake Manifold and Bolts

1. M10 x 35 stud bolt (3)
2. M10 x 35 bolt (6)
3. M10 x 110 bolt (2)
4. M10 x 110 stud bolt (2)
5. M10 x 25 bolt
6. M12 plug assembly (2)
7. Fuel valve assembly

7. Install three M10 x 35 stud bolts finger tight.
8. Install six M10 x 35 bolts finger tight.
9. Install two M10 x 110 bolts finger tight.
10. Install two M10 x 110 stud bolts finger tight.
11. Install M10 x 25 bolt finger tight.

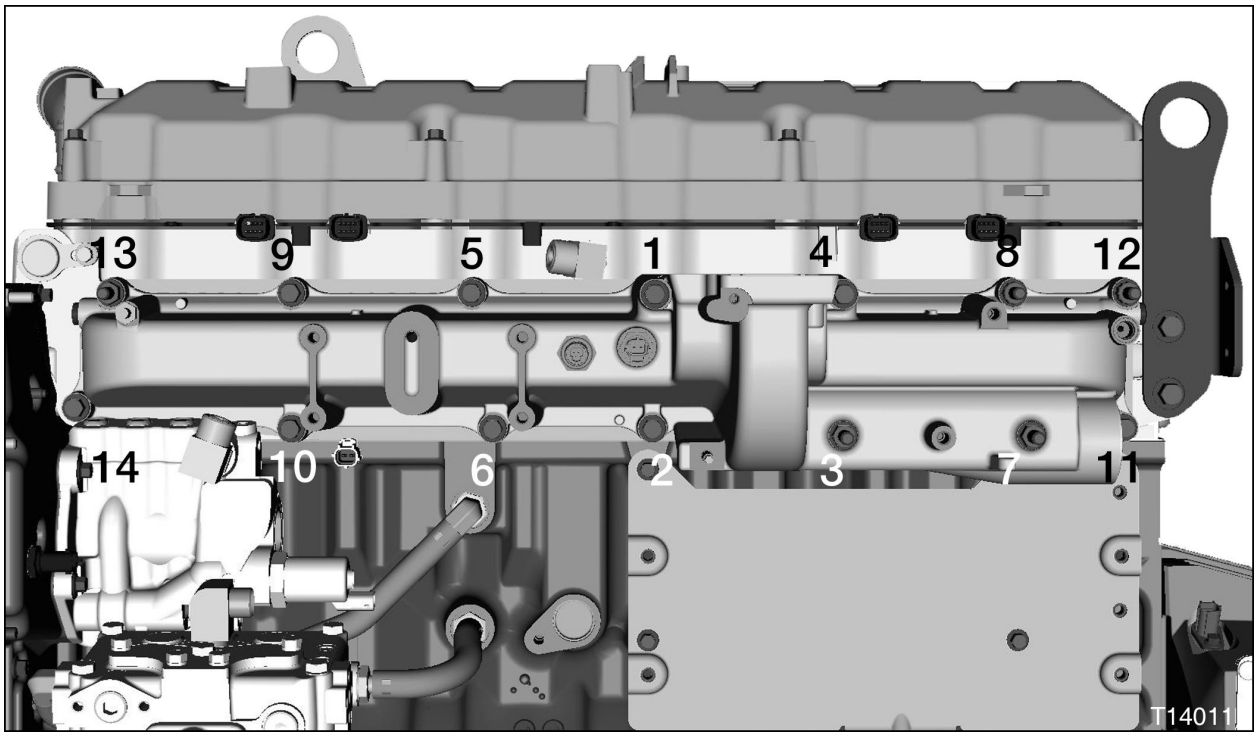


Figure 270 Intake Manifold Torque Sequence

12. Tighten intake manifold bolts to standard torque (page 553) in sequence 1 to 14.
13. Apply P-80® Lube (page 166) to outer surface of EGR pipe seal.
14. Using EGR Tube Seal Installer (page 202), and a hammer, install EGR pipe seal into intake manifold until seal is completely seated.

Special Torque

Exhaust Back Pressure (EBP) sensor tube nut	25 N·m (18 lb·ft)
Exhaust Gas Temperature (EGT) sensor	44 N·m (32 lb·ft)
Exhaust manifold bolts	See Exhaust Manifold (page 197)
Fuel valve assembly	15 N·m (133 lb·in)
M12 plug assembly	25 N·m (18 lb·ft)
Turbocharger adapter stud	12.3 N·m (109 lb·in) to seat stud

Special Service Tools

Feeler gauge	Obtain locally
Exhaust Ring Seal Installation Tool Kit	ZTSE6030
EGR Tube Seal Installer	ZTSE4997
P-80® Lube	Obtain locally
Slide Hammer Puller Set	ZTSE1879
Stud remover	Obtain locally

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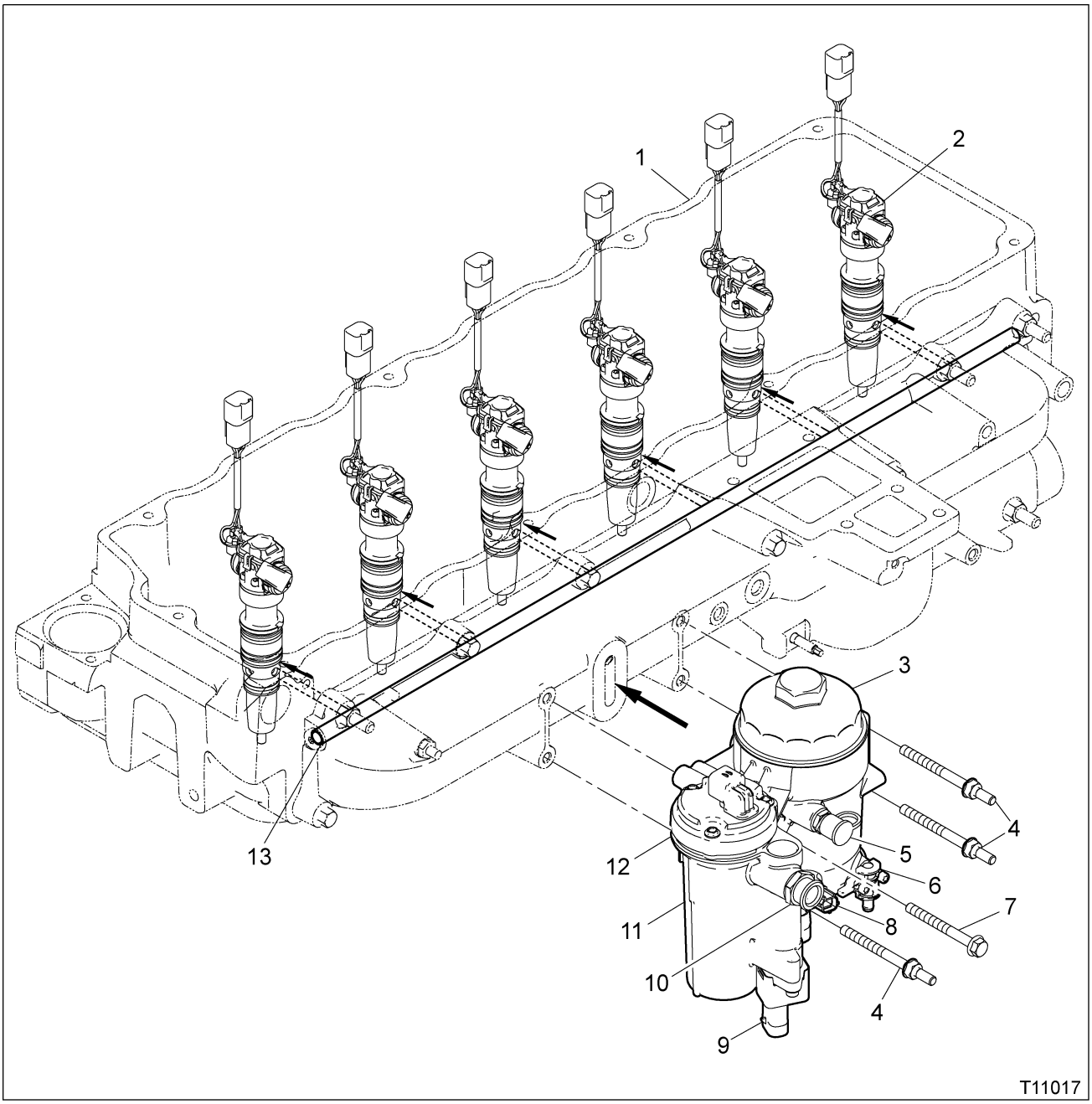


Figure 271 Low-Pressure Fuel System

1. Cylinder head
2. Fuel injector assembly (6)
3. Oil filter cap
4. M8 x 75 stud bolt (3)
5. Diagnostic coupling assembly and dust cap
6. Water drain valve assembly
7. M8 x 75 bolt
8. Water In Fuel (WIF) sensor
9. 250 Watt heater assembly
10. Voss® Stop Flow adapter assembly
11. Fuel filter assembly with heater
12. Brushless electric fuel pump assembly
13. Low-pressure fuel rail (cast in intake manifold)

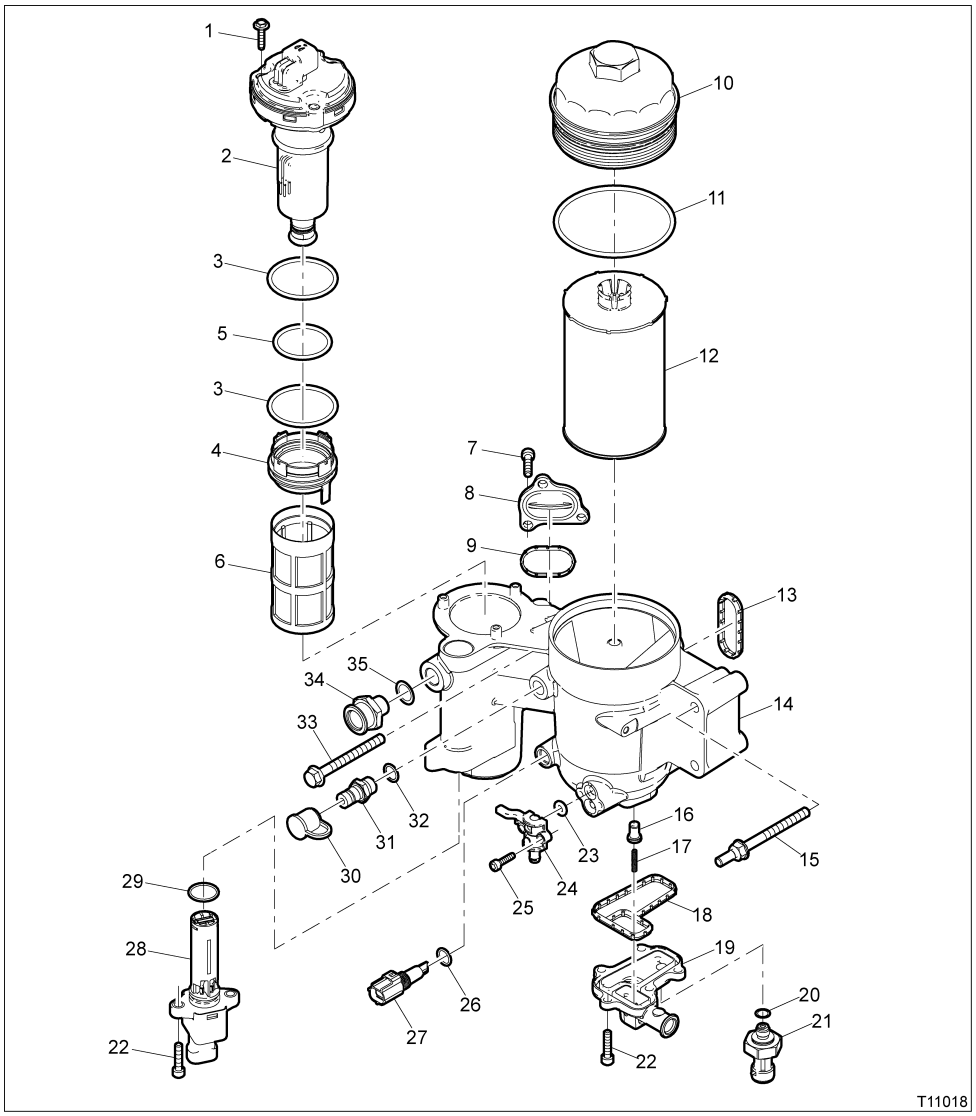


Figure 272 Fuel Filter Assembly with Heater

1. M5 x 25, pump cover screw (3)
2. Brushless electric fuel pump assembly
3. Pump cover and housing O-ring (2)
4. Fuel pump adapter
5. Fuel pump O-ring
6. Pump strainer
7. M6 screw (3)
8. Port cover
9. Port cover seal
10. Oil (fuel) filter cap
11. O-ring gasket
12. Fuel element
13. Irregular molded gasket
14. Fuel filter with heater housing assembly
15. M8 x 75 stud bolt (3)
16. Fuel pressure regulator valve assembly
17. Fuel pressure regulator valve spring
18. Cover plate seal
19. Bottom cover plate
20. Sensor O-ring
21. Fuel Delivery Pressure (FDP) sensor
22. M6 screw (7)
23. O-ring
24. Water drain valve assembly
25. M5 x 27 Torx® screw (2)
26. O-ring seal
27. Water In Fuel (WIF) sensor
28. 250 watt fuel heater assembly (optional)
29. Heater O-ring gasket
30. Dust cap
31. Diagnostic coupling
32. O-ring
33. M8 x 75 bolt
34. Voss® stop flow adapter (fuel inlet)
35. Hand primer gasket

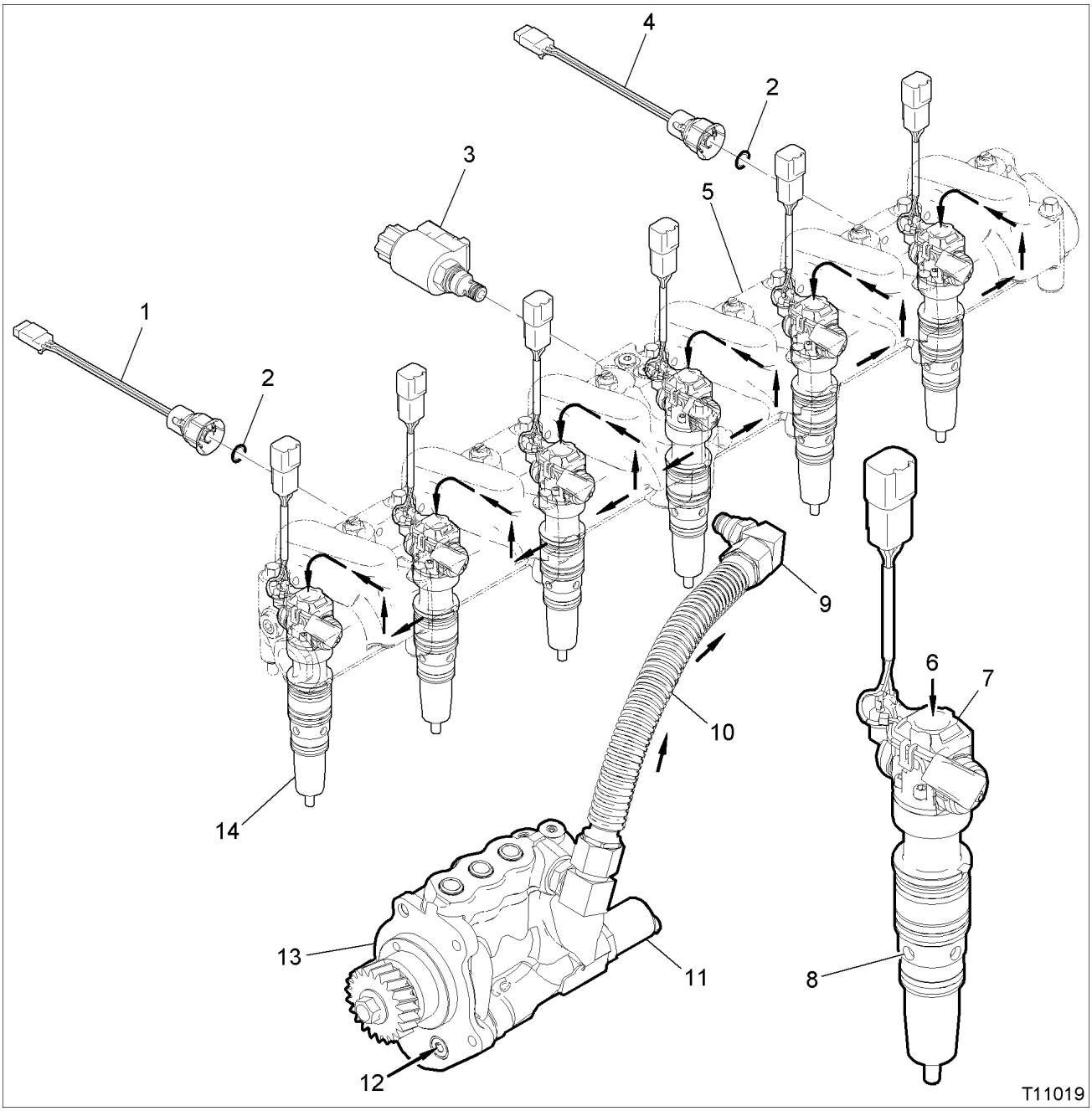


Figure 273 High-Pressure Oil System

1. Engine Compression Brake Pressure (ECBP) sensor
2. Sensor O-ring (2)
3. Engine Compression Brake (ECB) valve
4. Injection Control Pressure (ICP) sensor
5. High-pressure oil manifold
6. Injector oil inlet from high-pressure oil manifold
7. Oil outlet (2)
8. Fuel inlet port (4)
9. 70 degree adapter elbow assembly
10. High-pressure oil hose
11. Injection Pressure Regulator (IPR) valve assembly
12. Oil inlet from front oil cover reservoir
13. High-pressure pump assembly
14. Fuel injector assembly (6)

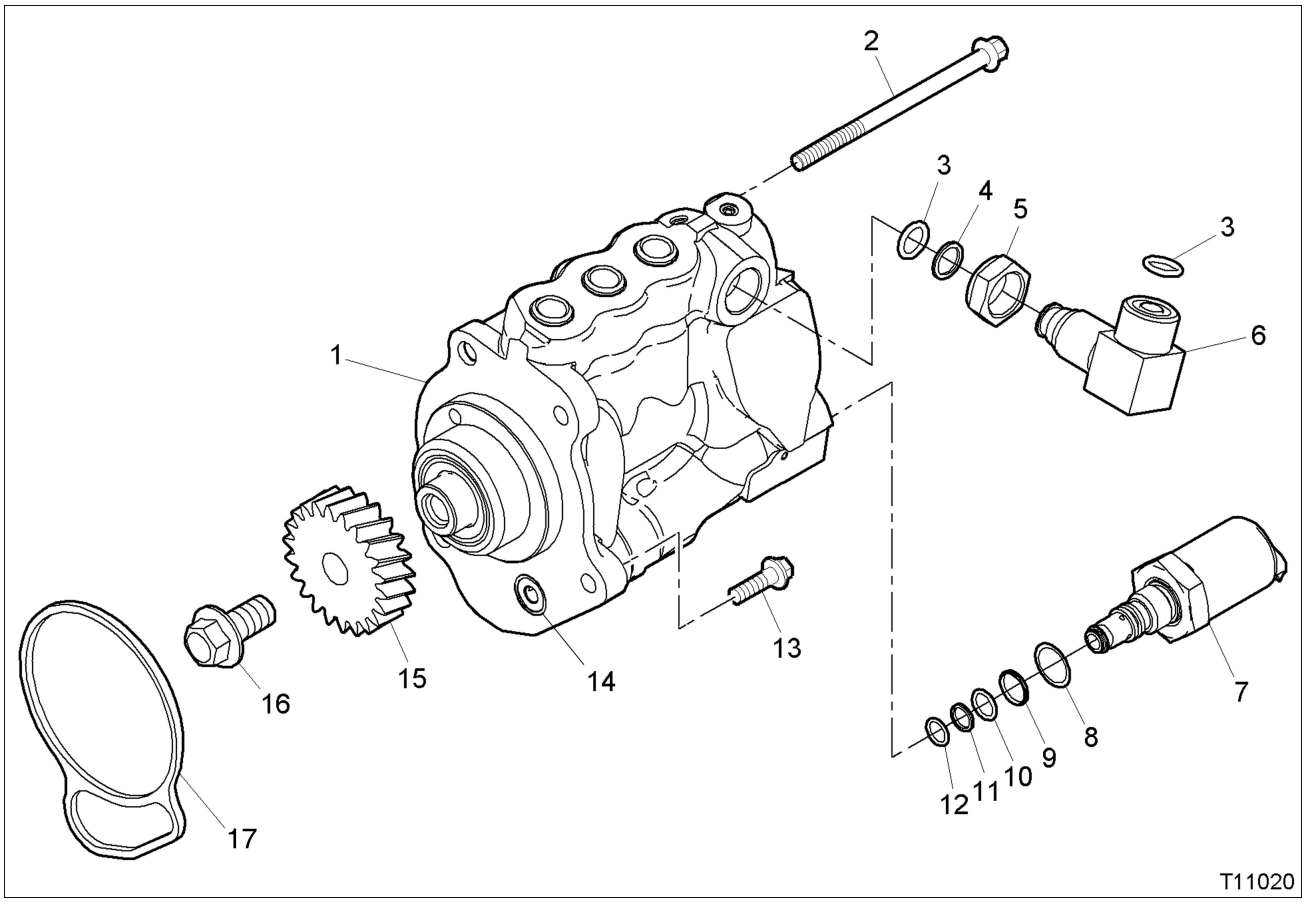


Figure 274 High-Pressure Pump

1. High-pressure 12cc pump
2. M8 x 100 bolt (2)
3. O-ring seal (#112) (2)
4. Back-up ring
5. Elbow jam nut
6. 90 degree adapter elbow
7. Injection Pressure Regulator (IPR) valve assembly
8. O-ring seal
9. PTFE OE profile seal
10. O-ring seal (#13)
11. Back-up ring seal
12. O-ring seal
13. M8 x 30 bolt (2)
14. Inlet filter
15. Pump gear
16. M14 x 1.5 left bolt
17. High-pressure pump gasket

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 transmission to park or neutral, set parking brake, and block wheels before doing diagnostic or service procedures.

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

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

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

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

Fuel Strainer

1. Disconnect fuel pump assembly electrical connector.
2. Remove three M5 x 25 pump cover screws.

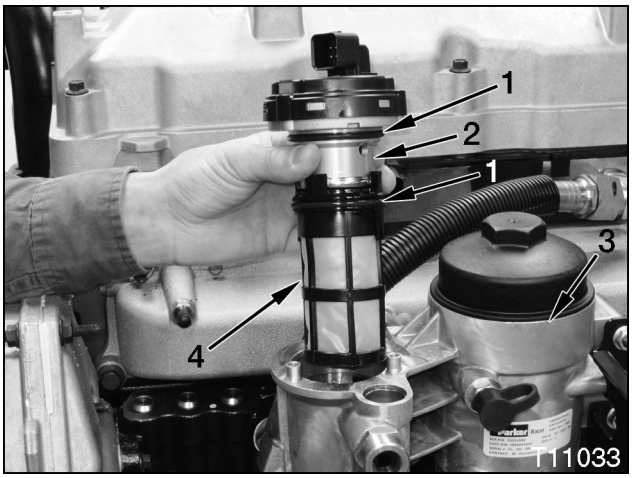


Figure 275 Brushless Electric Fuel Pump Assembly with Pump Strainer

1. Pump cover and housing O-ring (2)
2. Brushless electric fuel pump assembly
3. Fuel filter assembly with heater
4. Pump strainer and pump adapter

3. Remove brushless electric fuel pump assembly with pump strainer and pump adapter.
4. Remove pump strainer and pump adapter from brushless electric fuel pump assembly.
5. Remove and discard two pump cover and housing O-rings.
6. Remove and discard fuel pump O-ring (Figure 272) (item 5) located between pump adapter and brushless electric fuel pump assembly.
7. Clean or replace pump strainer element.

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

8. Using a lint free rag and compressed air, clean out debris from inside fuel filter assembly.
9. Lubricate two new pump cover and housing O-rings and one fuel pump O-ring with clean diesel fuel.
10. Install new fuel pump O-ring (Figure 272) (item 5) located between pump adapter and brushless electric fuel pump assembly.
11. Install new pump cover and housing O-rings.

12. Install new or cleaned pump strainer and pump adapter onto brushless electric fuel pump assembly.
13. Install brushless electric fuel pump assembly into fuel filter assembly with heater.
14. Install three M5 x 25 pump cover screws and tighten to special torque (page 235). Do not over tighten pump cover screws.
15. Turn ignition key ON to pressurize fuel system. Inspect area around top of electric fuel pump for fuel leaks. Turn ignition key OFF and repair leaks as needed.

Fuel Filter



Figure 276 Fuel Filter Assembly (with Optional Heater)

1. Fuel filter cap
2. O-ring gasket
3. Fuel element

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

1. Open water drain valve and drain fuel into a correct container clearly marked DIESEL FUEL. Dispose of diesel fuel according to applicable regulations.
2. Remove fuel filter cap from fuel filter assembly.
3. Remove and discard O-ring gasket.
4. Pull fuel element up and out of fuel filter assembly and dispose of fuel element according to applicable regulations.
5. Clean seal areas. Lubricate new O-ring gasket with clean diesel fuel and install on oil filter cap.
6. Clean out debris from inside fuel filter assembly.
7. Install a new fuel element into fuel filter assembly.
8. Lubricate oil filter cap threads with clean diesel fuel.
9. Tighten fuel filter cap to special torque (page 235).
10. Turn ignition key ON to pressurize fuel system. Inspect area around fuel filter cap for fuel leaks. Turn ignition key OFF and repair leaks as needed.

Draining Water From Fuel Filter Assembly

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

1. Open water drain valve (Figure 281) (item 8) and drain water from fuel filter assembly into container clearly marked DIESEL FUEL. Close water drain valve when all water is drained and a solid stream of fuel runs out of drain valve. Dispose of water and diesel fuel mixture according to applicable regulations.
2. Turn ignition key ON to pressurize fuel system. Inspect drain valve area for fuel leaks. Turn ignition key OFF and repair leaks as needed.

Removal

NOTE: When performing specific component removal, only remove components necessary for access.

Water In Fuel (WIF) Sensor, Fuel Delivery Pressure (FDP) Sensor, and 250 Watt Fuel Heater

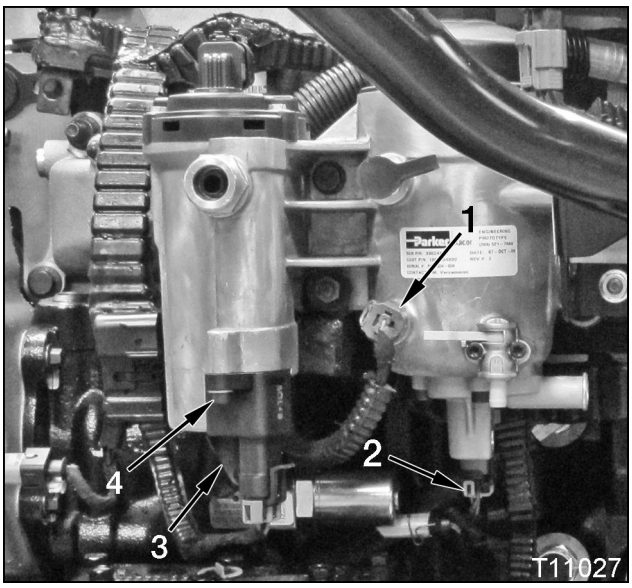


Figure 277 Fuel Filter Assembly With Heater (if Equipped)

1. Water in fuel (WIF) sensor
2. Fuel delivery pressure (FDP) sensor
3. 250 Watt fuel heater (optional)
4. M6 screw (2)

1. If equipped, disconnect engine harness connector from 250 watt fuel heater.
2. Disconnect engine harness connector from WIF sensor.
3. Disconnect 3-pin engine harness connector from FDP sensor.

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

4. Open water drain valve and drain fuel into a correct container clearly marked DIESEL FUEL. Dispose of diesel fuel according to applicable regulations.
5. Remove WIF sensor.
6. Remove and discard WIF sensor O-ring.
7. Remove FDP sensor.
8. Remove and discard FDP sensor O-ring.
9. Disconnect fuel inlet line and drain fuel into a correct container clearly marked DIESEL FUEL. Dispose of diesel fuel according to applicable regulations.

NOTE: Skip steps 10 and 11 if not equipped with 250 watt fuel heater.

10. Remove two M6 screws with a T30 Torx® bit (page 236).
11. Pull 250 watt fuel heater down to remove, and discard O-ring.

Water Drain Valve Assembly

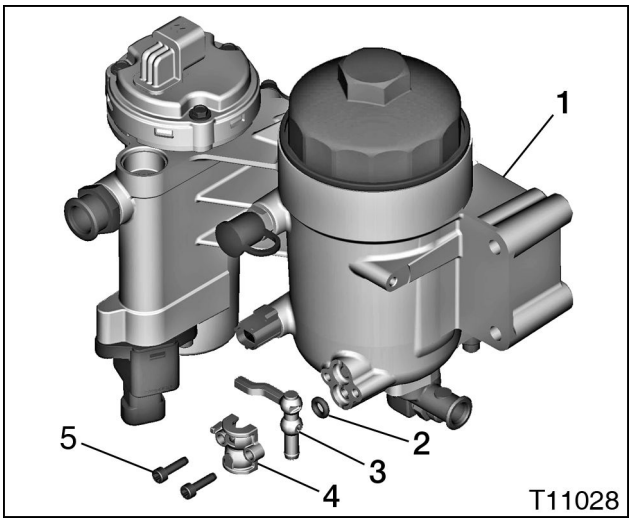


Figure 278 Water Drain Valve Assembly and Fuel Filter Assembly (with Heater Shown)

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

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

1. Open water drain valve and drain fuel into a correct container clearly marked DIESEL FUEL.

Dispose of diesel fuel according to applicable regulations.

2. Remove two M5 screws using a T27 Torx® bit (page 236).
3. Remove drain retainer, drain stem, and O-ring from fuel filter assembly.
4. Discard O-ring.

Brushless Electric Fuel Pump Assembly

1. Remove three M5 x 25 pump cover screws securing brushless electric fuel pump assembly to fuel filter assembly.

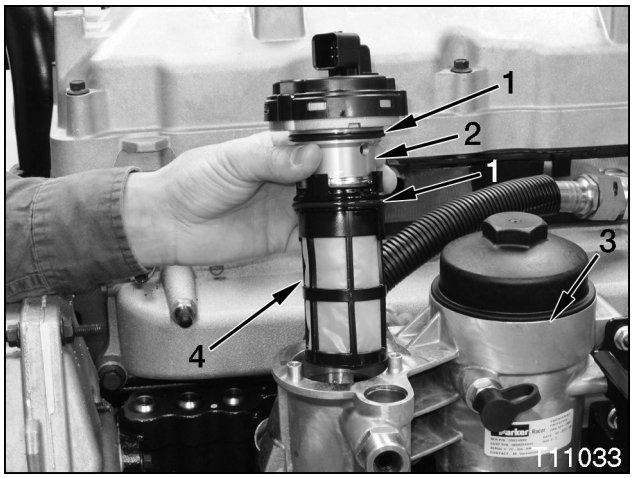


Figure 279 Brushless Electric Fuel Pump Assembly and Fuel Strainer

1. Pump cover and housing O-ring (2)
2. Brushless electric fuel pump assembly
3. Fuel filter assembly with heater
4. Pump strainer and pump adapter

2. Remove fuel pump and fuel strainer assembly.
3. Pull pump strainer and pump adapter from brushless electric fuel pump assembly.
4. Remove and discard two pump cover and housing O-rings.
5. Remove and discard fuel pump O-ring (Figure 272) (item 5) located between pump adapter and brushless electric fuel pump assembly.

Fuel Pressure Regulator Valve Assembly

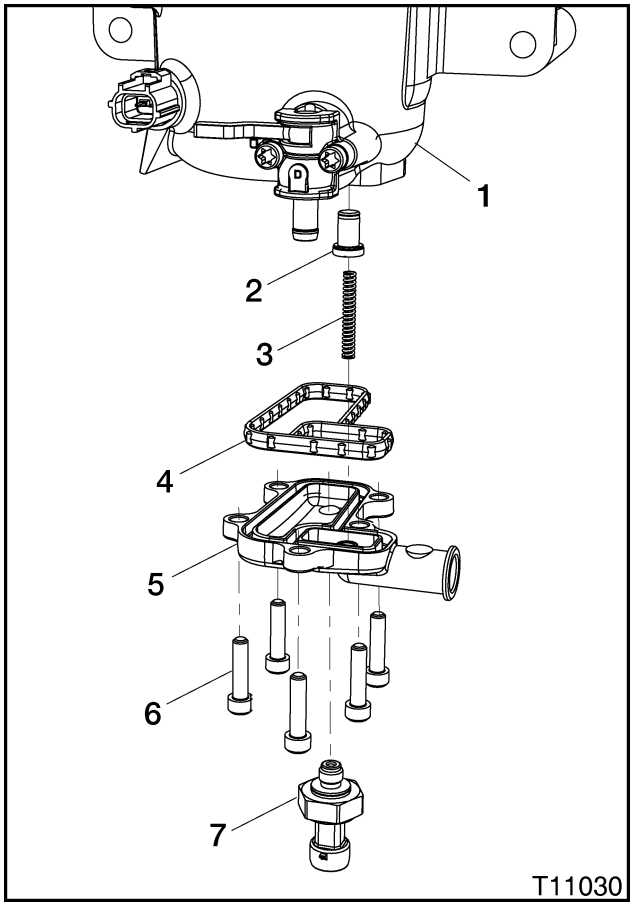


Figure 280 Fuel Pressure Regulator Valve Assembly and Cover Plate

1. Fuel filter assembly
2. Fuel pressure regulator valve assembly
3. Fuel pressure regulator valve spring
4. Cover plate seal
5. Bottom cover plate
6. M6 screw (5)
7. Fuel Delivery Pressure (FDP) sensor

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

1. Place a suitable container below fuel filter assembly. Open water drain valve and drain fuel into container. Close drain valve when fuel is drained.

2. Using a T30 Torx® bit (page 236), remove five M6 screws while holding cover plate in place.
3. Remove bottom cover plate downward so fuel pressure regulator valve assembly and fuel pressure regulator valve spring remain in bottom cover plate. Ensure excess fuel drains into container.
4. Remove and discard fuel pressure regulator valve cover plate seal.
5. Remove all dirt and debris from fuel pressure regulator valve seating area.
6. Clean sealing areas on fuel filter assembly and bottom cover plate.
7. Check for damage in regulator seating area of fuel filter assembly and bottom cover plate.
8. Dispose of diesel fuel according to applicable regulations.

Fuel Filter Assembly

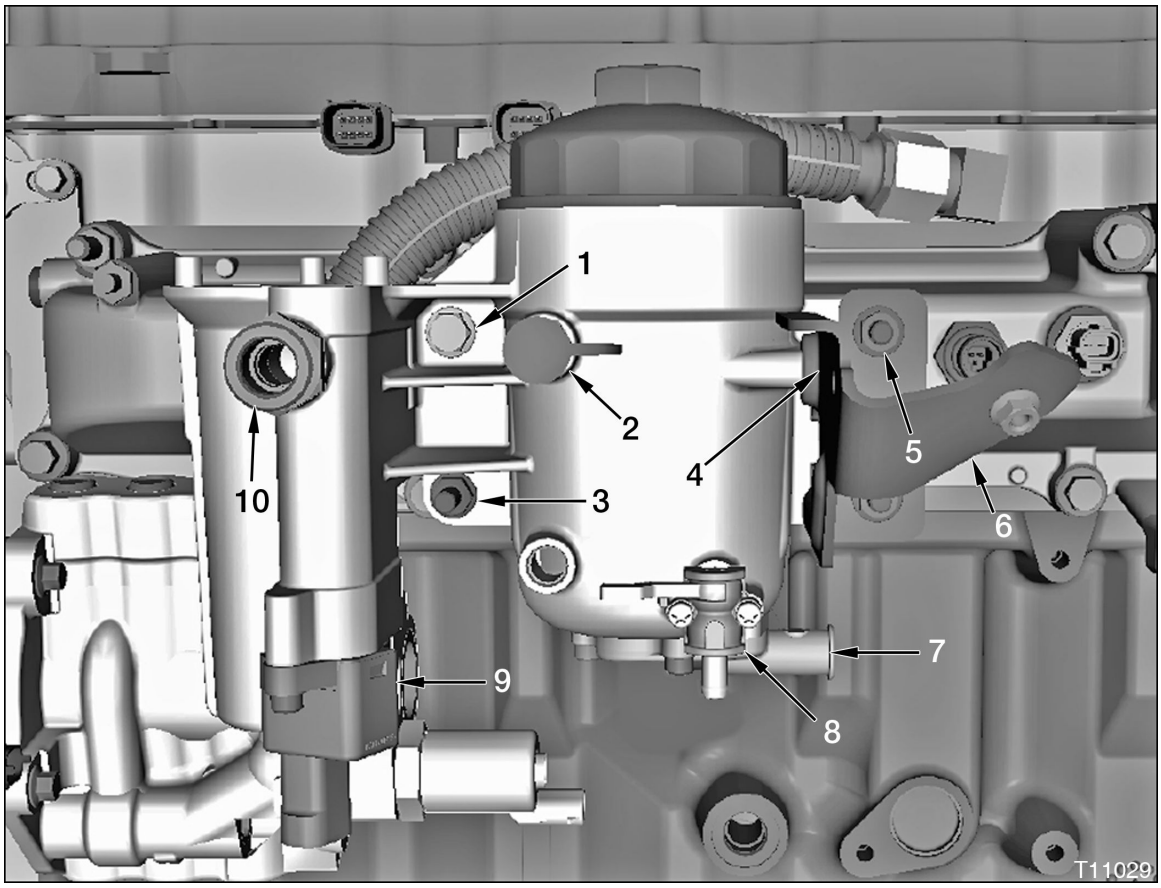


Figure 281 Fuel Filter Assembly (with Heater Shown)

1. M8 x 75 bolt
2. Dust cap and diagnostic coupling
3. M8 x 75 stud bolt (3)
4. M6 x 16 bolt (hidden from view)
5. M8 oil filler tube support nut (2)
6. Oil filler tube support
7. Fuel outlet fitting (return to tank)
8. Water drain valve assembly
9. 250 Watt fuel heater (optional)
10. Voss® Stop Flow adapter assembly (from tank)

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

1. Open water drain valve and drain fuel into a correct container clearly marked DIESEL FUEL. Dispose of diesel fuel according to applicable regulations.
2. Disconnect fuel inlet and return lines from fuel filter assembly.
3. Remove oil level gauge assembly. Refer to Oil Level Gauge Assembly (page 476).
4. Disconnect WIF sensor, if equipped, 250 watt fuel heater, and FDP engine harness connectors.
5. Remove two M8 nuts and one M6 x 16 bolt securing engine oil filler tube support to fuel filter assembly.
6. Remove three M8 x 75 stud bolts and one M8 x 75 bolt securing the fuel filter assembly to intake manifold and remove fuel filter assembly.
7. If damaged or leaking, remove Voss® Stop Flow adapter assembly from fuel filter assembly.
8. If damaged or leaking, remove diagnostic coupling assembly from fuel filter assembly.

9. Remove and discard irregular molded gasket from between fuel filter assembly and intake manifold.
10. If necessary, remove three M6 screws, port cover and port cover seal (Figure 272) (items 7, 8, and 9).

High-pressure Oil Hose and Elbows

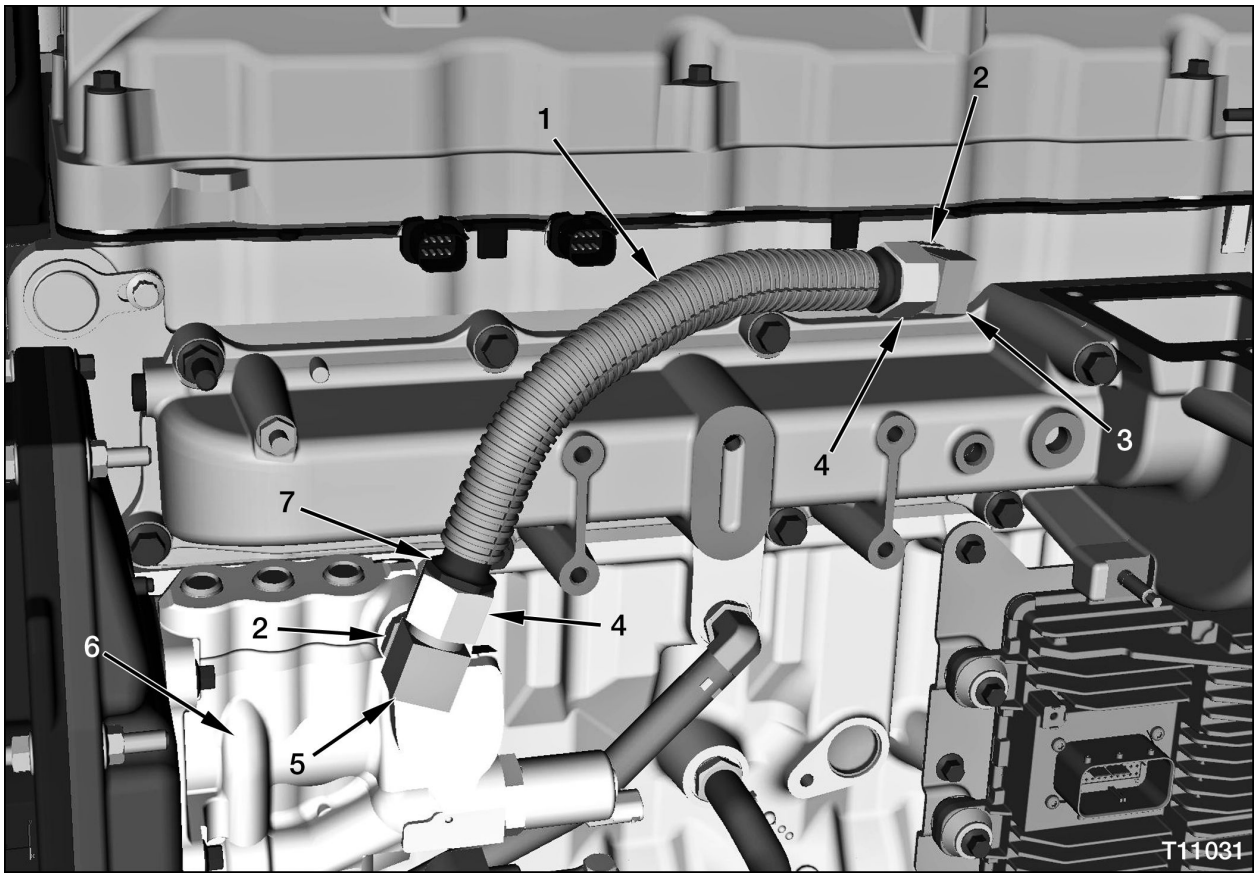


Figure 282 High-Pressure Oil Hose

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

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

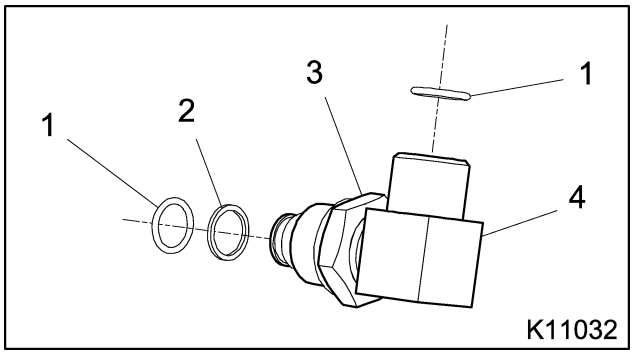


Figure 283 High-Pressure Oil Elbow (typical)

1. O-ring seal (#112) (2)
2. Back-up ring
3. Elbow jam nut
4. Adapter elbow

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

NOTE: See Intake Manifold, Fuel Valve, and Fuel Rail Plugs (page 193) for fuel valve and fuel rail plug removal.

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

NOTE: If an IPR valve assembly without a glued pigtail fails, it must be replaced with a kit containing an IPR valve with a glued pigtail and engine harness modification kit.

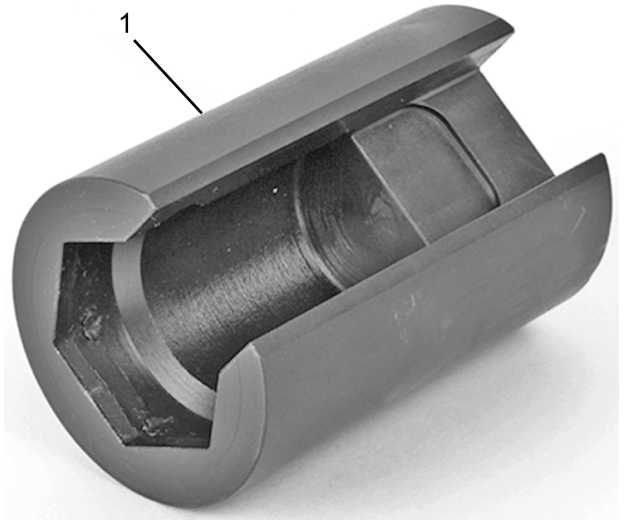


Figure 284 IPR Socket

1. IPR socket 12–800–01

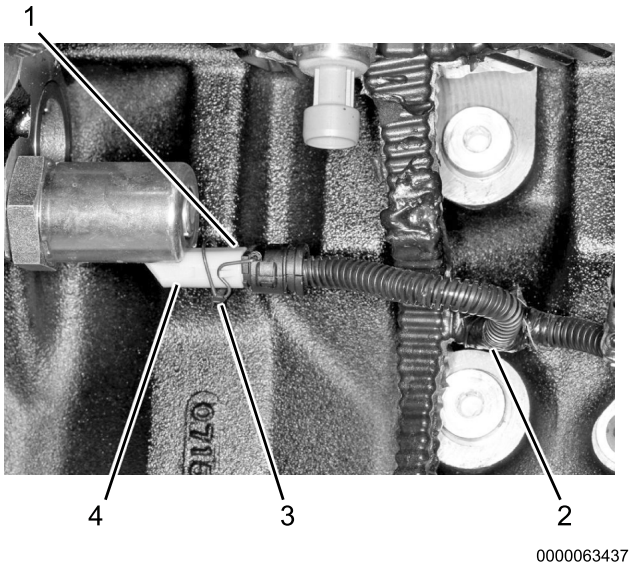
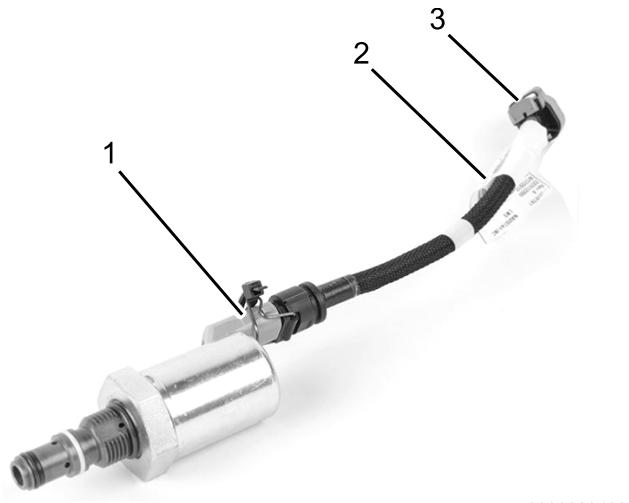


Figure 285 IPR Valve with Straight Connector (Old Engine Harness)

1. 2-way connector
2. Harness breakout
3. Tie-strap
4. IPR connector

1. Disconnect 2-pin connector from IPR valve.
2. Using IPR Socket 12–800–01 (page 236), remove and discard IPR valve.



0000063438

Figure 286 IPR Valve with Glued Pigtail

1. Glued-on pigtail (non-serviceable)
2. Label
3. IPR 2-pin connector

3. Disconnect IPR 2-pin connector and remove from engine harness.
4. Using IPR Socket 12–800–01 (page 236), remove IPR valve.

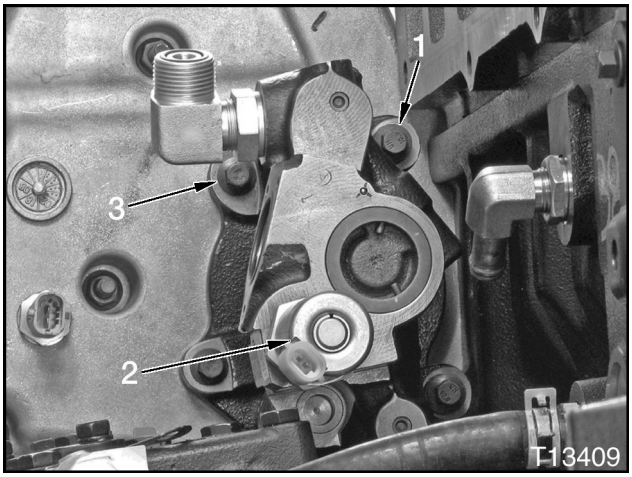


Figure 287 High-Pressure Pump Assembly

1. M8 x 100 bolt (2)
2. IPR valve without glued pigtail
3. M8 x 30 bolt (2)

5. Using IPR Socket (page 236), remove IPR valve.

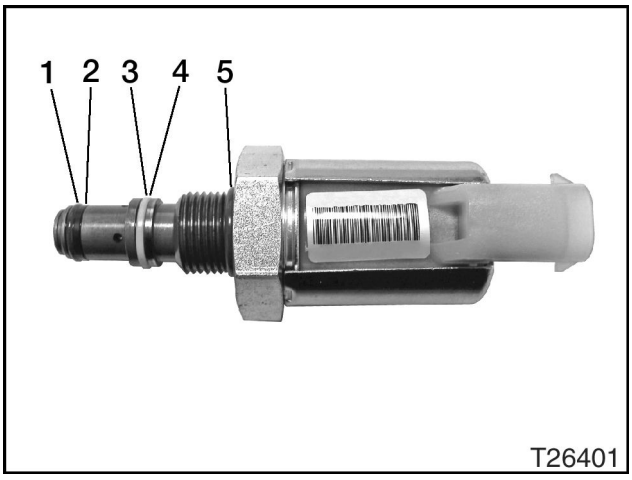


Figure 288 IPR Valve O-rings and Back-Up Rings

1. O-ring seal (valve tip)
2. Back-up ring seal (valve tip)
3. O-ring seal (#13)
4. PTFE OE profile seal
5. O-ring seal (IPR valve sealing)

6. Remove and discard IPR valve O-rings and back-up rings.
7. Remove two M8 x 100 and two M8 x 30 bolts securing high-pressure oil pump assembly to front cover.
8. Remove high-pressure pump assembly and discard high-pressure pump assembly gasket.

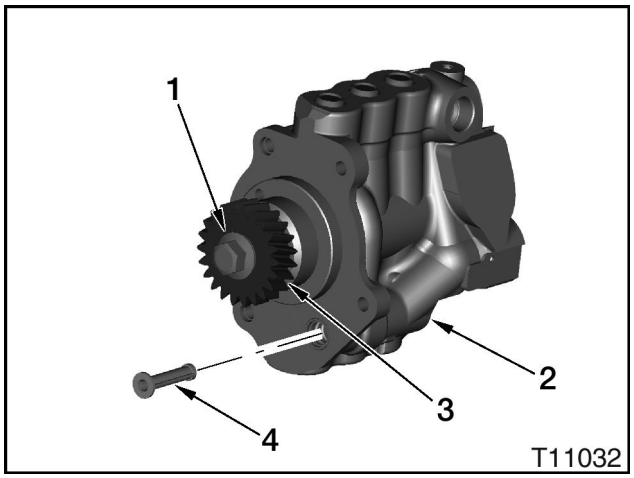


Figure 289 Pump Gear and Inlet Filter

1. M14 x 1.5 left bolt
2. High-pressure oil pump assembly
3. Pump gear
4. Inlet filter

9. Remove and discard inlet filter.
10. If required, remove pump gear by rotating M14 x 1.5 left bolt clockwise (this bolt has left handed threads).

High-pressure Oil Manifold

1. Remove valve cover (page 357).

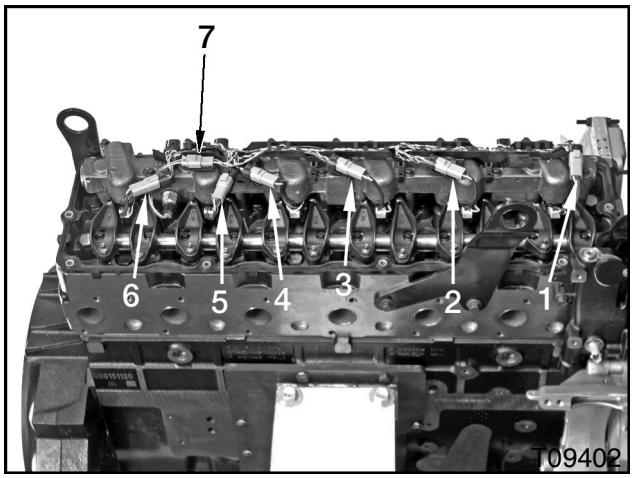


Figure 290 Valve Cover Gasket (Injector Harness)

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

2. Disconnect six injector connectors and ICP sensor connector.
3. Disconnect optional Engine Compression Brake Pressure (ECBP) sensor (page 243) and Engine Compression Brake (ECB) valve connector. (page 243)
4. Remove valve cover gasket (injector harness). Starting at one side, lightly pry up and open each of the six wire channel retainers while gently pulling up to remove harness from cylinder head.

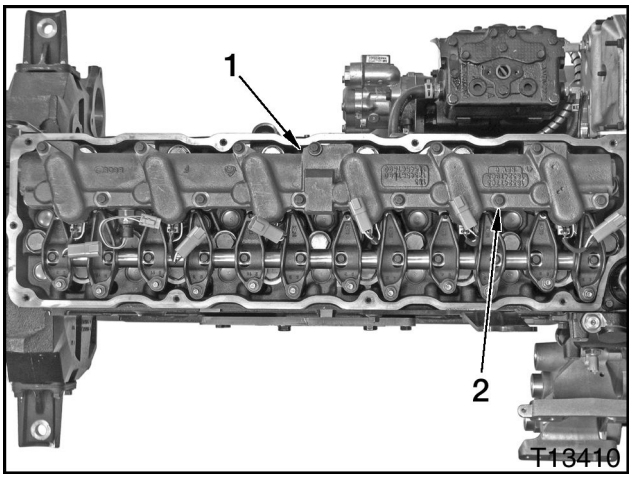


Figure 291 High-Pressure Oil Manifold (Non-Brake)

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

5. Use hand tools to break loose twelve M8 x 90 bolts securing high-pressure oil manifold to cylinder head. Remove twelve bolts.

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

6. Lift high-pressure oil manifold up just enough to drain oil out of manifold before lifting it away from cylinder head.
7. Lift up and remove high-pressure oil manifold from engine.
8. Remove and discard injector oil inlet adapter seals and back-up rings (Figure 292) (items 2 and 3).
9. Remove and discard oil inlet O-ring (page 220) (Figure 293) (item 3).
10. Install Injector Oil Inlet Plugs (page 236) on injectors to keep dirt out.

Injector Oil Inlet Adapter (Puck) Assembly

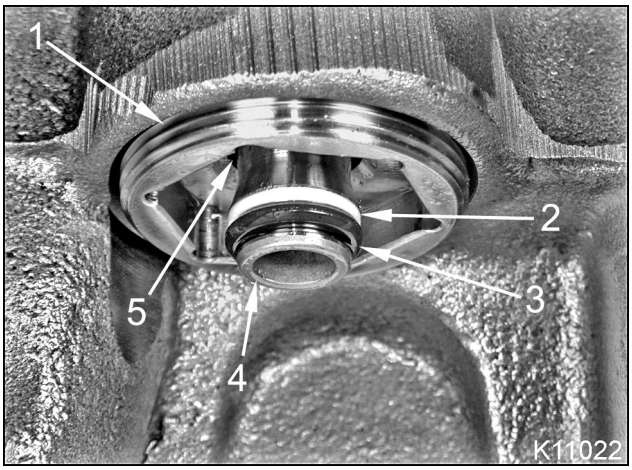


Figure 292 Injector Oil Inlet Adapter Installed In High-pressure Oil Manifold

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

See Cleaning and Inspection (page 221) procedure to inspect the oil inlet adapter for damage. If damaged, remove injector oil inlet adapter assemblies using High Pressure Rail Adapter Socket (page 236).

Fuel Injector Assemblies

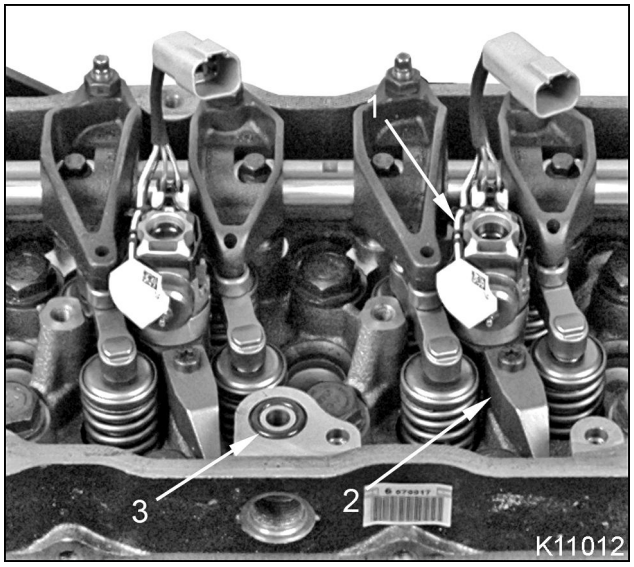


Figure 293 Fuel Injector Assemblies and Oil Inlet O-Ring (typical)

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

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.

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

1. Using Fuel Injector Remover Tool (T40) (page 236), extract six injector hold down clamps and injectors by removing injector clamp bolt.

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

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

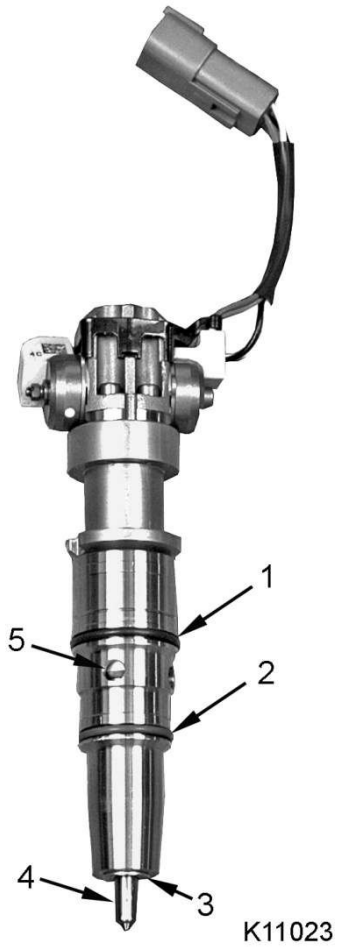


Figure 294 Fuel Injector Assembly

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

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

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

3. Place injectors in a sealable container, cover with clean engine oil, and close container.

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).

Fuel Filter Assembly Service Recommendations

NOTE: Refer to (Figure 271) and (Figure 272).

Disassembly of the fuel filter assembly is not normally recommended beyond service of the following:

- Fuel element replacement
- Pump strainer cleaning or replacement
- Sensor or 250 watt fuel heater assembly replacement
- Diagnostic coupling assembly cleaning or replacement
- Water drain valve assembly cleaning or replacement
- Electric fuel pump replacement
- Fuel pressure regulator cleaning or replacement

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

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

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

High-pressure Oil System Components

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

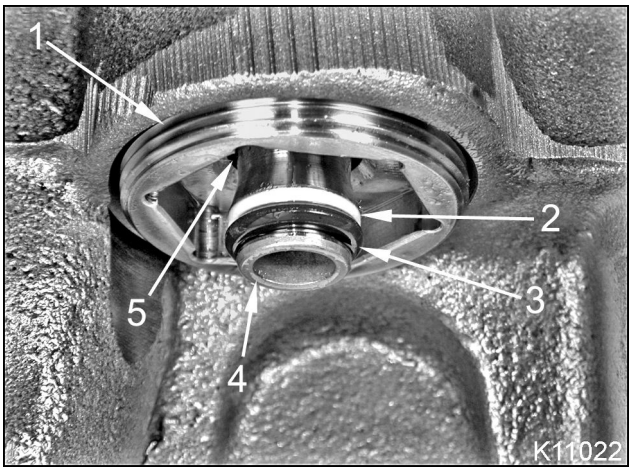


Figure 295 Injector Oil Inlet Adapter Installed in High-pressure Oil Manifold

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

4. Verify six injector oil inlet adapter oil inlet tubes move and are not frozen. Inspect injector oil inlet adapters for internal O-ring extrusion (between adapter and oil outlet tube). Replace any adapter which has an extruded internal O-ring, frozen oil inlet tube, or high-pressure oil leak path.
5. Check IPR valve O-ring seal grooves for erosion or other damage. Replace IPR valve if eroded or damaged.
6. Check IPR valve inlet screen for restrictions. Clean or replace valve as necessary.

NOTE: Fuel injectors should be checked for carbon / soot traces between the lower injector O-ring (Figure 296) (item 2) and the nozzle gasket (Figure 296) (item 3). When removed, the injectors should be clean and shiny, looking like new except for the nozzle. Carbon on these areas may mean that compression leaked through the nozzle gasket due to a loose injector. Mistakenly doubling the nozzle gasket, or poor sealing surfaces may cause loose injectors.

7. Inspect intake manifold and fuel injectors for cracks and leaks. Replace cracked or leaking parts.

8. Inspect all fuel lines for kinks, obstructions, or other damage. Replace fuel lines if necessary.
9. Check high-pressure pump inlet screen for restrictions. Clean or replace high-pressure pump inlet screen as necessary.
10. Clean injector and high-pressure oil manifold threaded holes. Oil in these holes will negatively affect bolt torque and result in engine performance issues.

Installation

Fuel Injector Assemblies

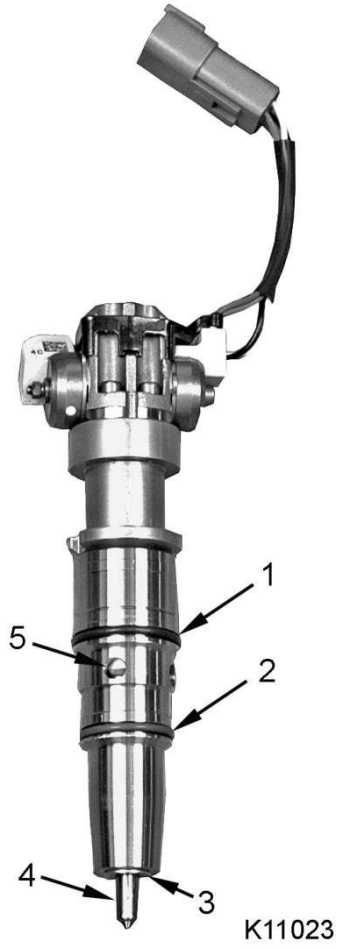


Figure 296 Fuel Injector Assembly

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

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

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

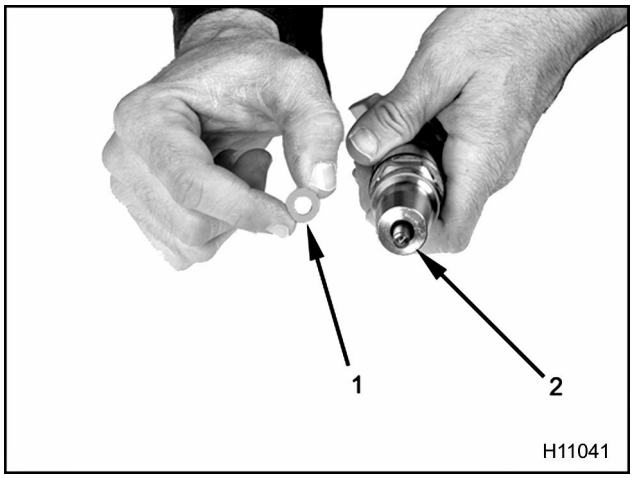


Figure 297 Injector Nozzle Gasket

1. Injector nozzle gasket
2. Injector nozzle

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

3. Push a new injector nozzle gasket on injector nozzle by hand. Nozzle gaskets are non-directional and can be installed with either face out. Verify that old nozzle gaskets are not left at bottom of injector cup.

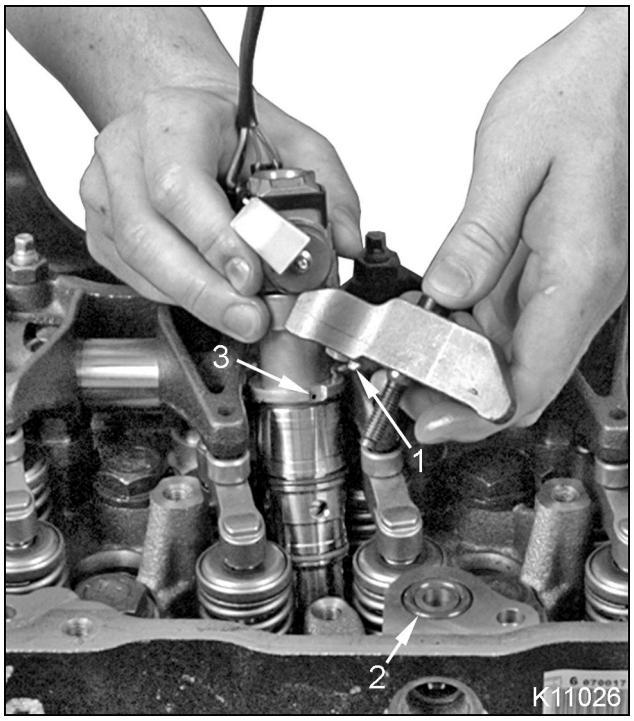


Figure 298 Injector Assembly Installation (typical)

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

4. Using a suction bulb (page 236), purge any oil or fuel that may have dripped in during removal of injectors.
5. Align each injector assembly slot with hold down clamp notch and install assembly in 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.

6. Using Fuel Injector Remover Tool (T40) (page 236), tighten injector hold down clamp bolts. Make sure injector and hold down clamp are installed squarely as bolt is tightened.
7. Tighten six injector hold down clamp bolts to special torque (page 235). Injector will be placed at correct depth.

Injector Oil Inlet Adapter (Puck) Assembly

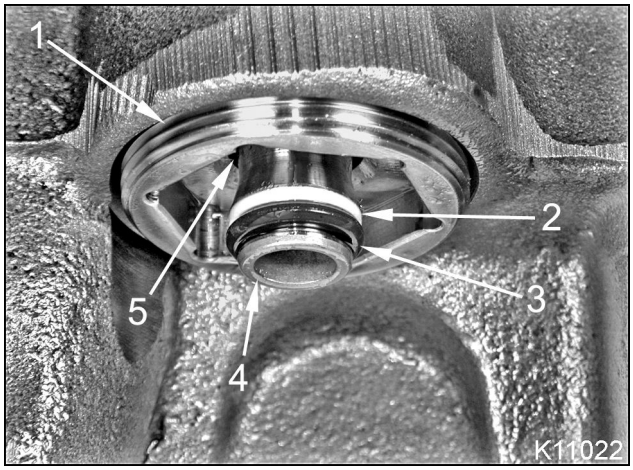


Figure 299 Injector Oil Inlet Adapter Installed in High-Pressure Oil Manifold

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

1. Install injector oil inlet adapters using High Pressure Rail Adapter Socket (page 236).
2. Tighten injector oil inlet adapters to special torque (page 235).

High-pressure Oil Manifold

NOTE: Air trapped in high-pressure oil manifold will be purged automatically during cranking and start up.

1. If not previously done, verify six injector oil inlet adapter oil inlet tubes move and are not frozen. Inspect injector oil inlet adapters for internal O-ring extrusion and high-pressure oil leak paths. Replace any adapter which has an extruded internal O-ring, frozen oil inlet tube, or high-pressure oil leak path (identify during high pressure oil diagnostics).
2. Coat backup rings and injector oil inlet seals with clean engine oil.
3. Install new backup rings and injector oil inlet seals on all oil inlet adapters that were not replaced with new.

4. Coat a new oil inlet O-ring (Figure 298) with clean engine oil and install in cylinder head recess.

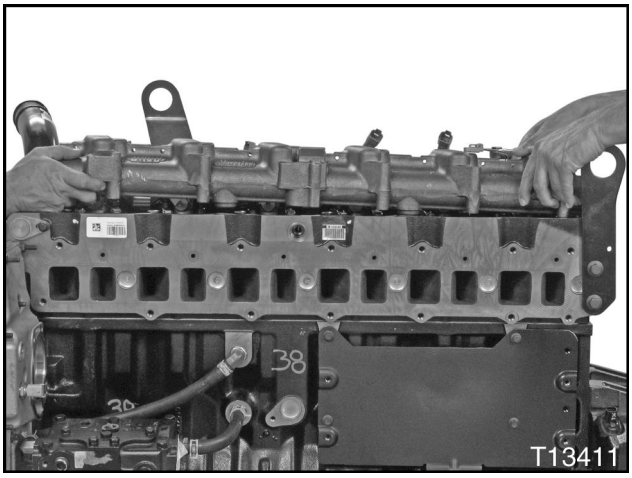


Figure 300 High-Pressure Oil Manifold Installation

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

5. With help from an assistant, lift high-pressure oil manifold up and carefully place on engine.

CAUTION: To prevent engine damage, carefully align six injector oil inlet ports with six injector oil inlet adapters of the high-pressure oil manifold before tightening oil manifold bolts.

6. Carefully align six injector oil inlet ports with six injector oil inlet adapters of the high-pressure oil manifold and firmly push down to “snap” manifold in place. Confirm that manifold is seated against cylinder head at all contact points between the two.

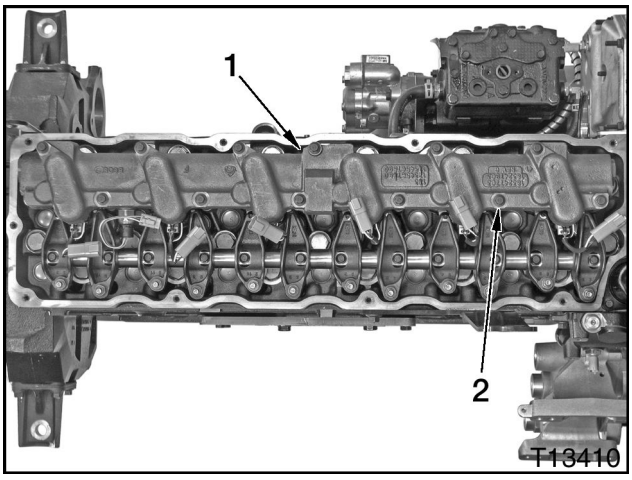


Figure 301 High-Pressure Oil Manifold (typical)

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

7. Install and finger tighten twelve M8 x 90 bolts securing high-pressure oil manifold to cylinder head.

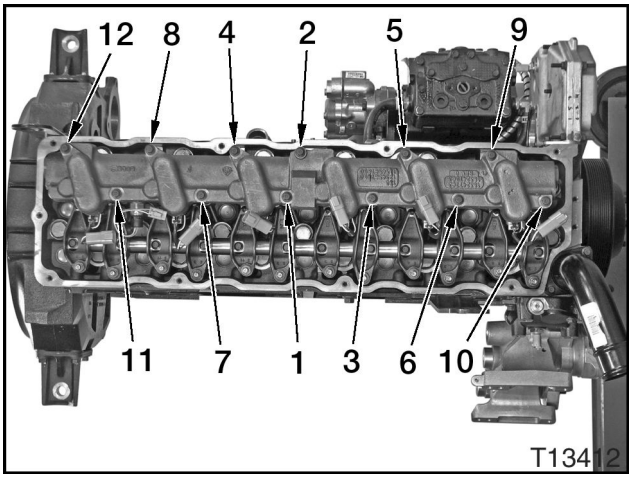


Figure 302 High-Pressure Oil Manifold Bolt Torque Sequence

8. Tighten twelve M8 x 90 bolts to 30 N·m (22 lb·ft) in the torque sequence shown.

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

NOTE: If an IPR valve assembly without a glued pigtail fails, it must be replaced with a kit containing an IPR valve with a glued pigtail and engine harness modification kit.

NOTE: All 2010 model year engines, with engine serial number 3300000 and above, must have a screen on the high–pressure oil pump inlet only and no screen installed at the IPR valve.

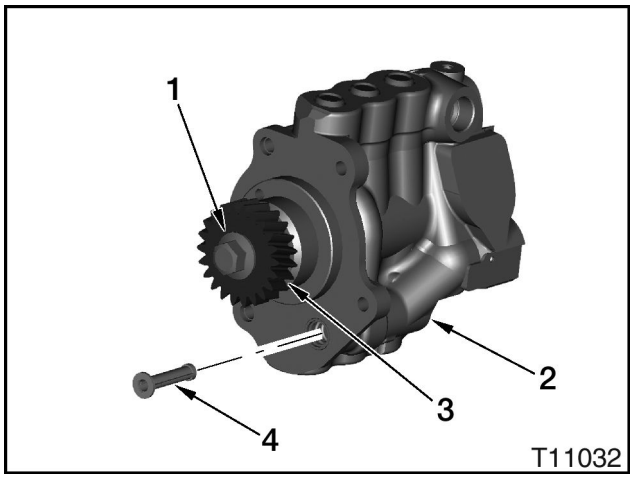


Figure 303 Pump Gear and Inlet Filter

1. M14 x 1.5 left bolt
2. High-pressure pump assembly
3. Pump gear
4. Inlet filter

1. If removed, position pump gear onto high-pressure pump and install M14 x 1.5 left bolt. Tighten to special torque (page 235).
2. Install a new inlet filter.
3. Lubricate a new high-pressure pump gasket with clean engine oil and install on rear of front cover assembly.
4. Install high-pressure pump assembly into front cover, making sure pump gear meshes with upper idler gear.

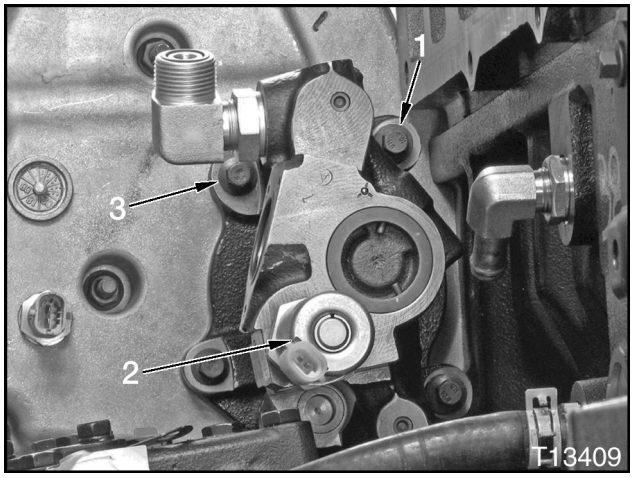


Figure 304 High-Pressure Pump Assembly

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

5. Install two M8 x 100 and two M8 x 30 bolts connecting high-pressure pump to front cover.
6. Tighten two M8 x 100 and two M8 x 30 bolts to special torque (page 235).

NOTE: All 2010 model year engines serial number 3300000 and up must have screen installed on HPOP only. No screen should be installed at Injection Pressure Regulator (IPR) valve.

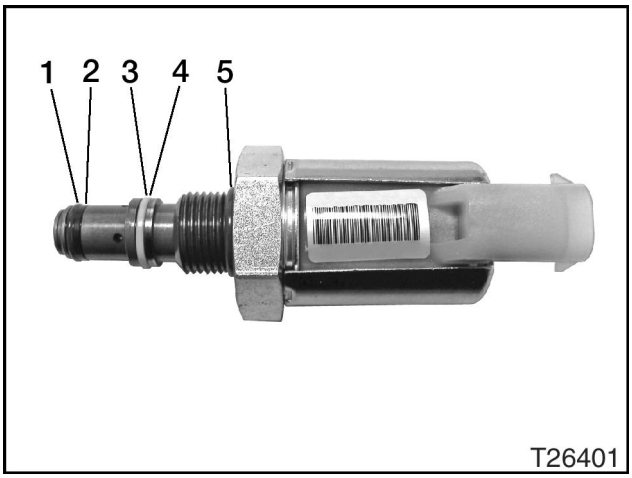


Figure 305 IPR Valve O-rings and Back-Up Rings

1. O-ring seal (valve tip)
2. Back-up ring seal (valve tip)
3. O-ring seal (#13)
4. PTFE OE profile seal
5. O-ring seal (IPR valve sealing)

NOTE: The PTFE OE profile seal (item 4) fits over O-ring seal (#13).

CAUTION: Only stretch IPR valve seals the minimum amount needed for installation.

7. Lubricate new O-ring seals with clean engine oil.
8. Install O-ring seal (IPR valve sealing) on IPR valve.
9. Install O-ring seal (#13).
10. Install back-up ring seal (valve tip).
11. Install O-ring seal (valve tip).
12. Install PTFE OE profile seal over O-ring seal (#13), taking care not to overstretch the seal.
13. Seat the PTFE OE profile seal in the middle O-ring groove with fingertip pressure.
14. Clean IPR valve bore of high pressure pump assembly.

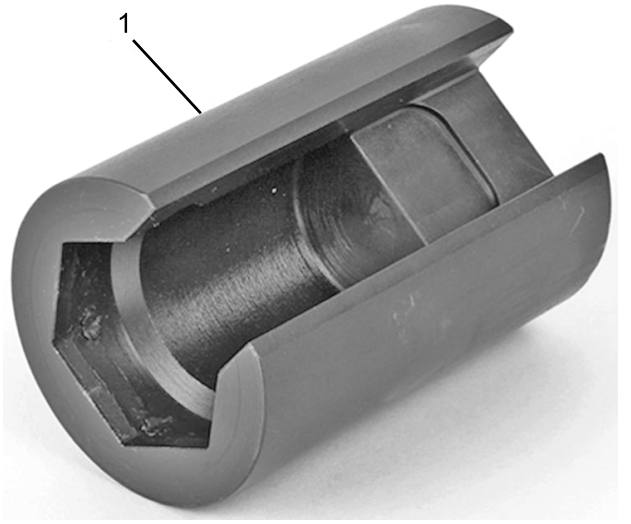


Figure 306 IPR Socket

1. IPR socket 12–800–01

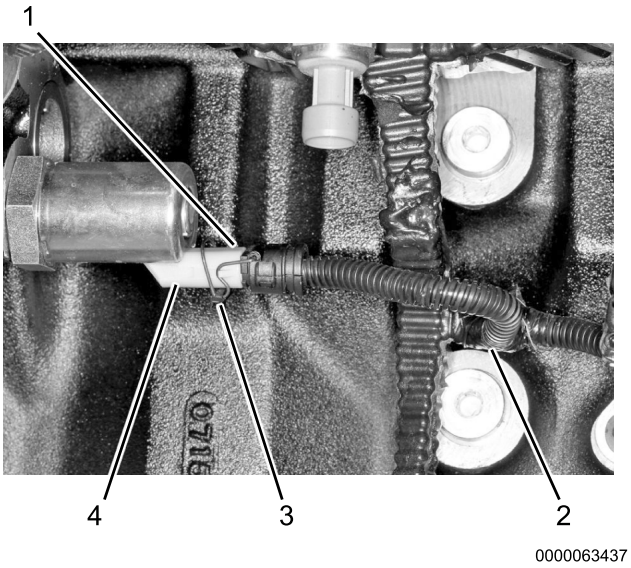


Figure 307 IPR Valve with Straight Connector (Old Engine Harness)

1. 2-way connector
2. Harness breakout
3. Tie-strap
4. IPR connector

15. Coat O-rings on new IPR with clean engine oil.
16. Install IPR valve finger tight.

17. Using IPR Socket 12–800–01 (page 236), torque IPR valve to 37 lb•ft (50 N•m).
18. Turn magnetic coil inward, and position connector at 6 o'clock position.
19. Install new tie-strap to secure wiring.
20. Connect IPR 2-pin connector to engine harness.

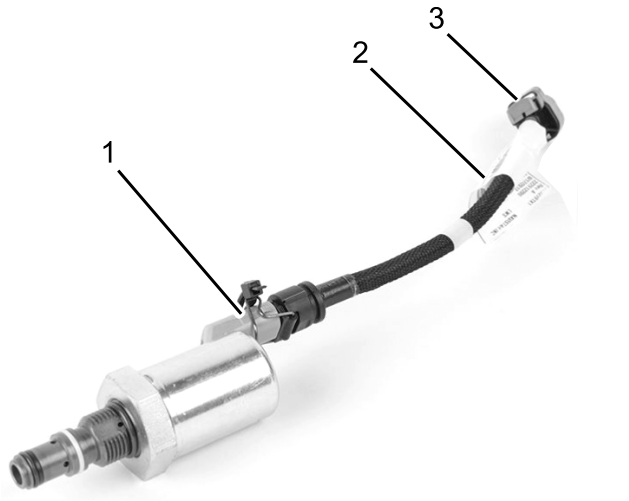


Figure 308 IPR Valve with Glued Pigtail

1. Glued-on pigtail (non-serviceable)
2. Label
3. IPR 2-pin connector

21. Coat O-rings on new IPR with clean engine oil.
22. Install IPR valve finger tight.
23. Using IPR Socket 12–800–01 (page 236), torque IPR valve to 37 lb•ft (50 N•m).
24. Turn magnetic coil inward, and position connector at 6 o'clock position.
25. Connect IPR 2-pin connector to engine harness.

High-pressure Oil Hose and Elbows

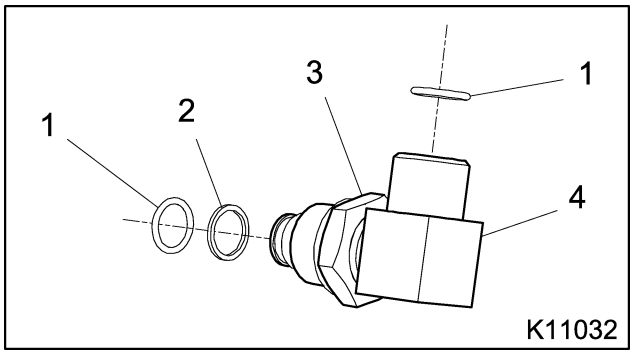


Figure 309 High-Pressure Oil Elbow (typical)

1. O-ring seal (#112) (2)
2. Back-up ring
3. Elbow jam nut
4. Adapter elbow

1. Rotate both elbow jam nuts all the way to base of adapter elbows.
2. Lubricate new O-rings with clean engine oil.
3. Install new O-rings and back-up ring on 70 and 90 degree adapter elbows.

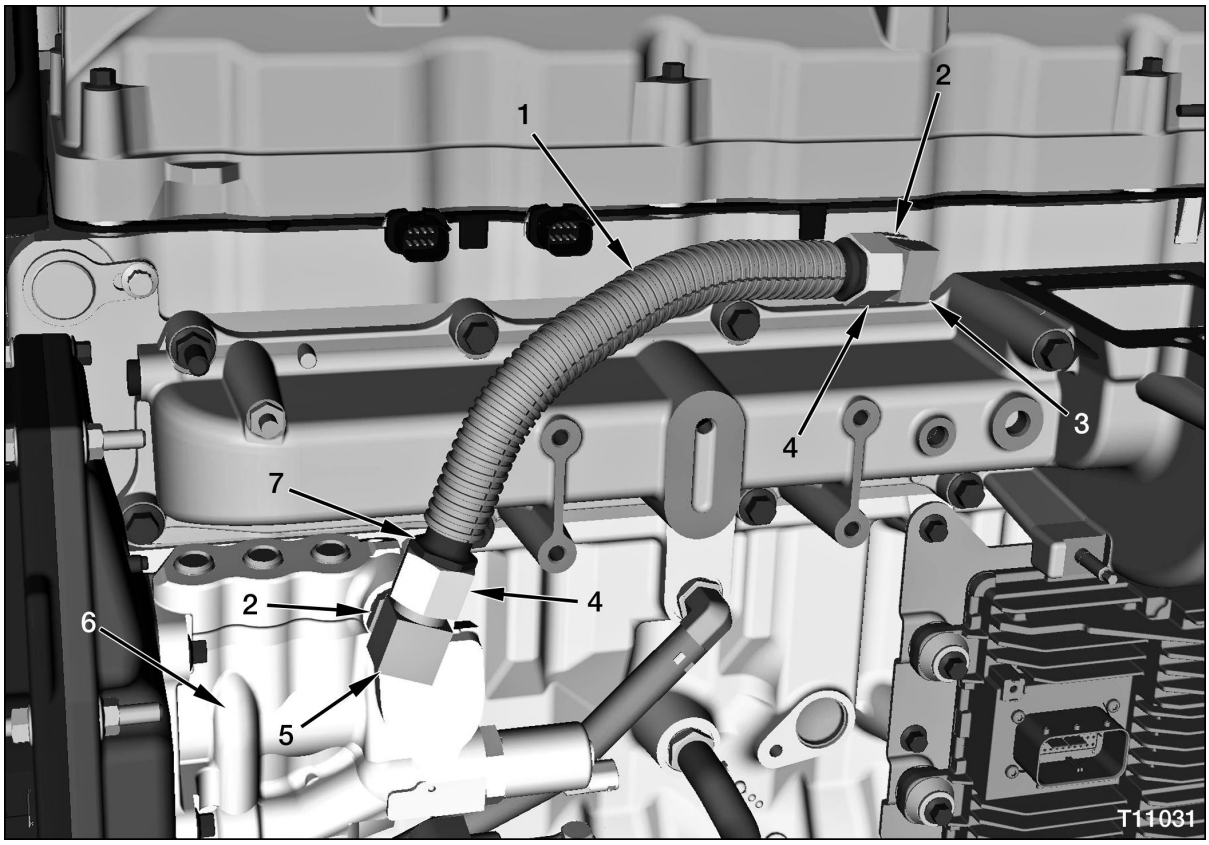


Figure 310 High-Pressure Oil Hose

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

4. Install 70 degree adapter elbow into high-pressure oil port on intake side of cylinder head. Run fitting all the way in finger tight and then back fitting off (less than one full turn) to orient fitting toward front of engine.
5. Install 90 degree adapter elbow into high-pressure oil pump. Run fitting all the way in finger tight and then back fitting off (less than one full turn) to orient fitting.
6. Remove flexible conduit cover from high-pressure oil hose.
7. Install high-pressure oil hose on 70 and 90 degree adapter elbows and finger tighten swivel nuts.

CAUTION: To prevent engine damage, orient the high-pressure oil hose so the hose is not under any excess tension, the hose bends in a smooth arc, is not twisted, and does not touch other engine components.

8. Orient high-pressure oil hose so hose is not under any excess tension and is not twisted. Use one wrench to hold high-pressure oil hose nut in place while tightening its corresponding swivel nut to special torque (page 235) using another wrench.
9. Orient high-pressure oil hose so hose is not under any excess tension and the hose bends in a smooth arc. Use one wrench to hold each adapter elbow in place while tightening its corresponding elbow jam nut to special torque (page 235) using another wrench.

10. Install flexible conduit cover on high-pressure oil hose.

Fuel Filter Assembly

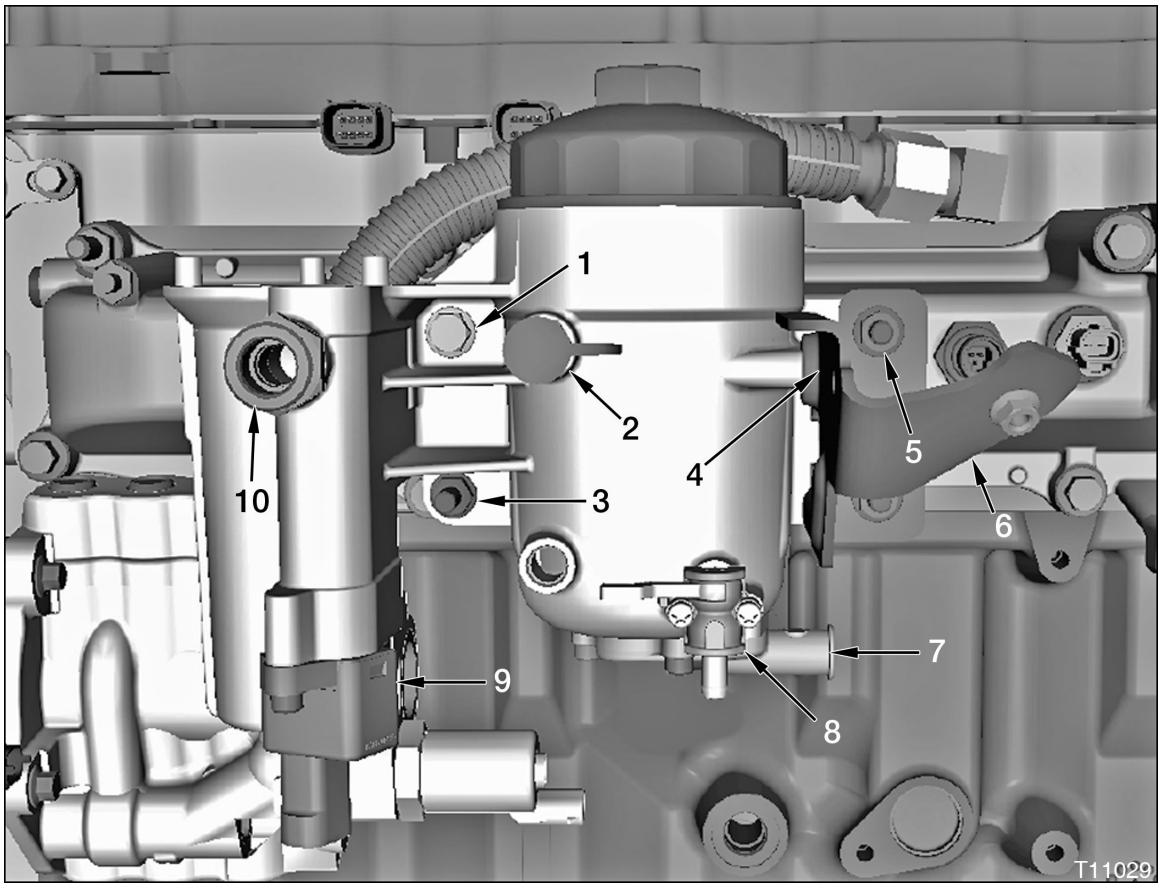


Figure 311 Fuel Filter Assembly (with Heater Shown)

1. M8 x 75 bolt
2. Dust cap and diagnostic coupling
3. M8 x 75 stud bolt (3)
4. M6 x 16 bolt (hidden from view)
5. M8 oil filler tube support nut (2)
6. Oil filler tube support
7. Fuel outlet fitting (return to tank)
8. Water drain valve assembly
9. 250 Watt fuel heater (optional)
10. Voss® Stop Flow adapter assembly (from tank)

1. If removed, install a new port cover seal (Figure 272) (item 9) on fuel filter assembly. Install port cover and tighten three M6 screws to special torque (page 235).
2. Install fuel filter assembly on intake manifold using a new irregular molded gasket. Tighten three M8 x 75 stud bolts and M8 x 75 bolt to special torque (page 235).
3. If removed, install diagnostic coupling and dust cap. Tighten to special torque (page 235).
4. If removed, install Voss® Stop Flow adapter assembly. Tighten to special torque (page 235).
5. Install oil filler tube support, M6 x 16 bolt, and two M8 oil filler tube support nuts. Tighten M6 x 16 bolt and M8 nuts to special torque (page 508).
6. Verify that lever on water drain valve assembly is closed.

Water Drain Valve Assembly

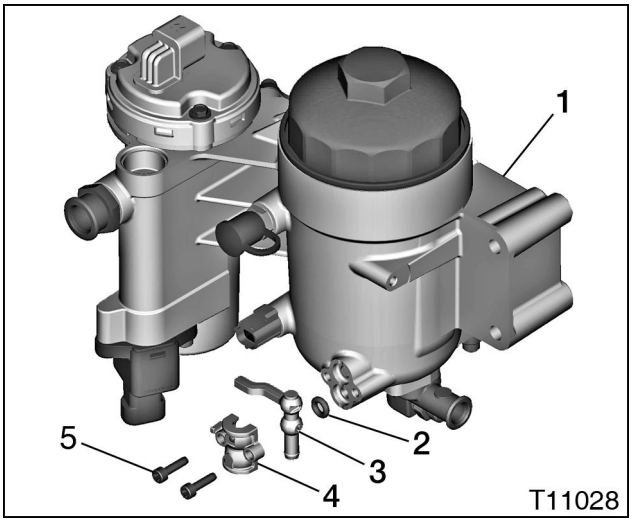


Figure 312 Water Drain Valve Assembly and Fuel Element Assembly (with Heater Shown)

1. Fuel element assembly (with optional) heater
2. O-ring
3. Drain stem
4. Drain retainer
5. M5 screw (2)

1. Install a new water valve O-ring into fuel filter assembly.
2. Install drain stem, drain retainer, and finger tighten two M5 screws.
3. Using a T27 Torx® bit (page 236), tighten two M5 screws to special torque (page 235).

Brushless Electric Fuel Pump Assembly and Fuel Strainer

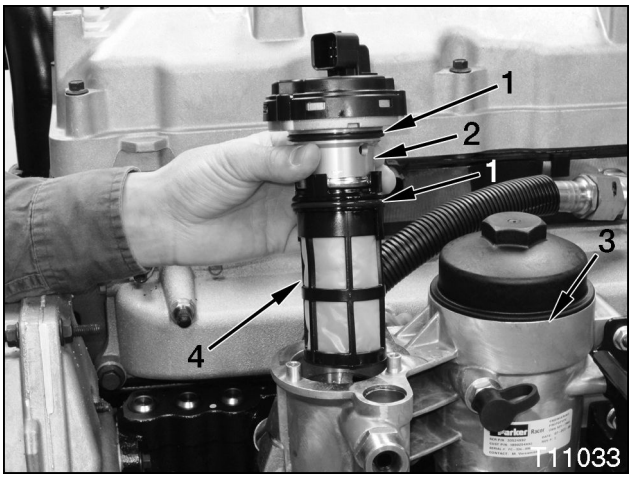


Figure 313 Brushless Electric Fuel Pump Assembly and Fuel Strainer

1. Pump cover and housing O-ring (2)
2. Brushless electric fuel pump assembly
3. Fuel filter assembly with heater
4. Pump strainer and pump adapter

1. Lubricate two new pump cover and housing O-rings with clean diesel fuel and install on fuel pump and outside of pump adapter.
2. Lubricate new fuel pump O-ring (Figure 272) (item 5) with clean diesel fuel and install on inside of pump strainer and pump adapter.
3. Install pump strainer and pump adapter on brushless electric fuel pump assembly.
4. Install brushless electric fuel pump assembly and fuel strainer into fuel filter assembly.
5. Install three M5 x 25 pump cover screws and tighten to special torque (page 235). Do not over tighten pump cover screws.

Fuel Pressure Regulator Valve Assembly

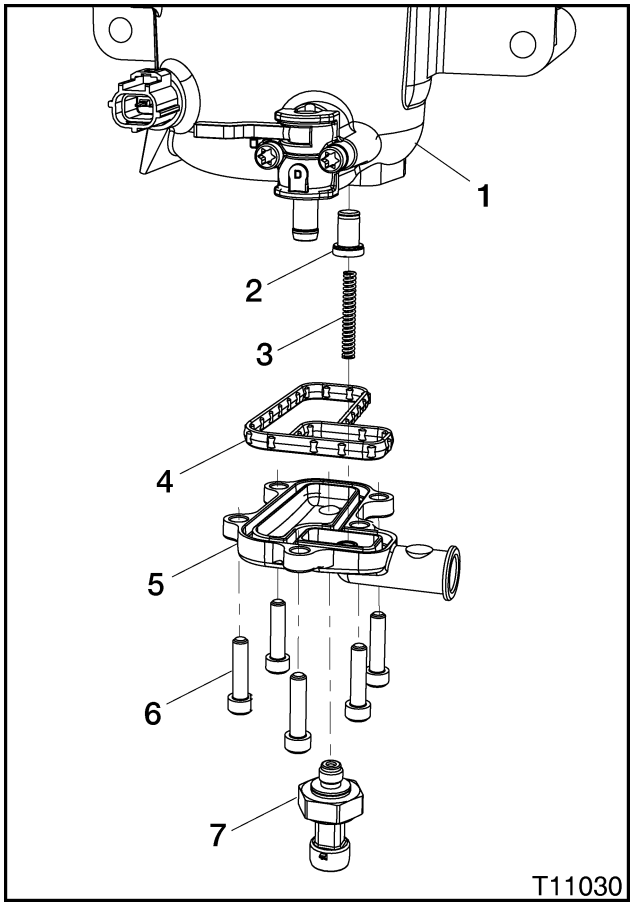


Figure 314 Fuel Pressure Regulator Valve Assembly and Cover Plate

1. Fuel filter assembly (with or without heater)
2. Fuel pressure regulator valve assembly
3. Fuel pressure regulator valve spring
4. Cover plate seal
5. Bottom cover plate
6. M6 screw (5)
7. Fuel delivery pressure (FDP) sensor

1. Install new cover plate seal into groove of bottom cover plate.
2. Lubricate new fuel pressure regulator valve assembly with clean diesel fuel and install on valve spring.
3. Place fuel pressure regulator valve spring and fuel pressure regulator valve assembly onto bottom cover plate.
4. Lift bottom cover plate assembly up to fuel filter assembly. Ensure fuel pressure regulator valve assembly installs smoothly into fuel filter assembly.

NOTE: If fuel pressure regulator valve assembly binds during installation, remove valve spring and regulator valve assembly. Check spring for binding, and check fuel pressure regulator valve assembly for damage. Correct the problem, lubricate fuel pressure regulator valve assembly with clean diesel fuel, and install cover plate assembly.

5. Using a T30 Torx® bit (page 236), install five M6 screws using a star pattern and tighten each screw one full turn at a time until all bolts are snug. Ensure bottom cover plate is flush with bottom surface of fuel filter assembly.
6. Tighten five M6 screws to 9.6 N·m (85 lb·in).

Water In Fuel (WIF) Sensor, Fuel Delivery Pressure (FDP) Sensor, and 250 Watt Fuel Heater

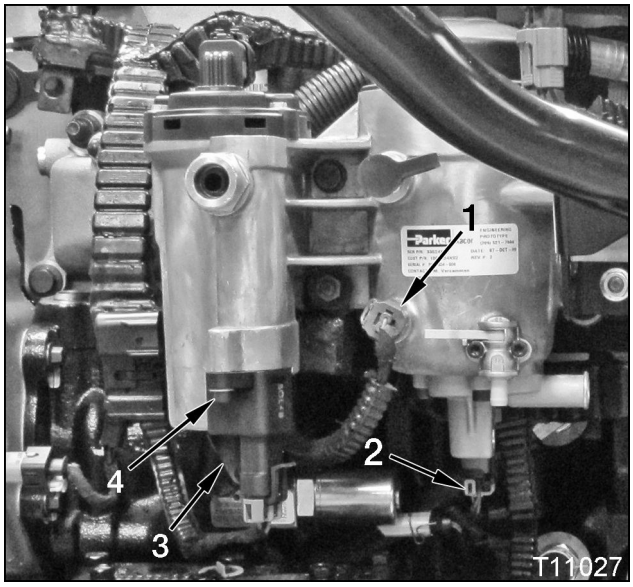


Figure 315 Fuel Filter Assembly With Heater (if Equipped)

1. Water in fuel (WIF) sensor
2. Fuel delivery pressure (FDP) sensor
3. 250 Watt fuel heater (optional)

NOTE: If not equipped with 250 watt fuel heater, skip steps 1 through 3.

1. Lubricate a new O-ring with clean diesel fuel and install O-ring on to 250 watt fuel heater.
2. Install 250 watt fuel heater into fuel filter assembly and finger tighten two M6 x 25 bolts.
3. Tighten two M6 x 25 250 watt fuel heater bolts to special torque (page 235).
4. Lubricate a new O-ring with clean diesel fuel and install on to the WIF sensor.
5. Install WIF sensor into fuel filter assembly with heater and tighten to 2 N·m (15 lb·in) or until O-ring contacts fuel filter assembly with heater and then turn sensor an additional 1/16 of a turn.
6. Lubricate a new O-ring with clean diesel fuel and install O-ring on FDP sensor.
7. Install FDP sensor into bottom of fuel filter assembly and tighten to special torque (page 235).

Specifications

250 Watt fuel heater switching points	On: 7 °C (44.6 °F)
	Off: 21 °C (69.8 °F)
Fuel pressure regulator assembly opening pressure	586 to 655 kPa (85 to 95 psi)
Fuel strainer element	150 micron
High-pressure oil manifold pressure range	5 to 32 MPa (725 to 4,650 psi)
High-pressure pump assembly end play	0.127 to 0.457 mm (0.005 to 0.018 in)

Special Torque

Adapter elbow jam nut, 70 and 90 degree	105 N·m (78 lb·ft)
Brushless electric fuel pump assembly, M5 x 25 screw	5 N·m (44 lb·in)
Diagnostic coupling assembly	17 N·m (145 lb·in)
Fuel Delivery Pressure (FDP) sensor	11 N·m (100 lb·in)
Fuel filter cap	40 N·m (29 lb·ft)
Fuel filter assembly housing bolt and stud bolts, M8 x 75	27 N·m (20 lb·ft)
250 Watt fuel heater bolts, M6 x 25	10 N·m (85 lb·in)
Fuel filter inlet fitting	18 N·m (155 lb·in)
Fuel pressure regulator valve cover plate M6 screw	See Fuel Pressure Regulator Valve Assembly (page 232) for tightening procedure
High-pressure oil hose (swivel nuts)	65 N·m (48 lb·ft)
High-pressure oil manifold bolts, M8 x 90	See High-pressure Oil Manifold (page 225) for correct torque and sequence.
High-pressure oil pump assembly bolts, M8 x 30 and M8 x 100	30 N·m (22 lb·ft)
High-pressure oil pump gear bolt, M14 x 1.5 left	244 N·m (179 lb·ft)
Injector hold down clamp bolt	41 N·m (30 lb·ft)
Injector oil inlet adapter assembly	204 N·m (150 lb·ft)
IPR valve	50 N·m (37 lb·ft)
M12 fuel rail plug	25 N·m (18 lb·ft)
Oil rail plug assembly (bottom)	204 N·m (150 lb·ft)
Plug assembly, M10 and M12	12 N·m (108 lb·in)
Port cover M6 screws	10 N·m (85 lb·in)
Pump cover screws, M5 x 25	5 N·m (45 lb·in)
Rail end plug assembly	204 N·m (150 lb·ft)
Voss® Stop Flow adapter assembly	27 N·m (20 lb·ft)
Water drain valve assembly M5 screws	6 N·m (50 lb·in)
Water In Fuel (WIF) sensor	See Water In Fuel (WIF) Sensor, Fuel Delivery Pressure (FDP) Sensor, and 250 Watt Fuel Heater (page 233) for tightening procedure.

Special Service Tools

Injector Oil Inlet Plugs	ZTSE4660
Fuel Injector Remover Tool (T40)	ZTSE4524
High Pressure Rail Adapter Socket	ZTSE4725
IPR Socket	12–800–01
Suction bulb	Obtain locally
T27 Torx® bit	Obtain locally
T30 Torx® bit	Obtain locally

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Exploded View and Description

High-pressure Oil Manifold (Brake)

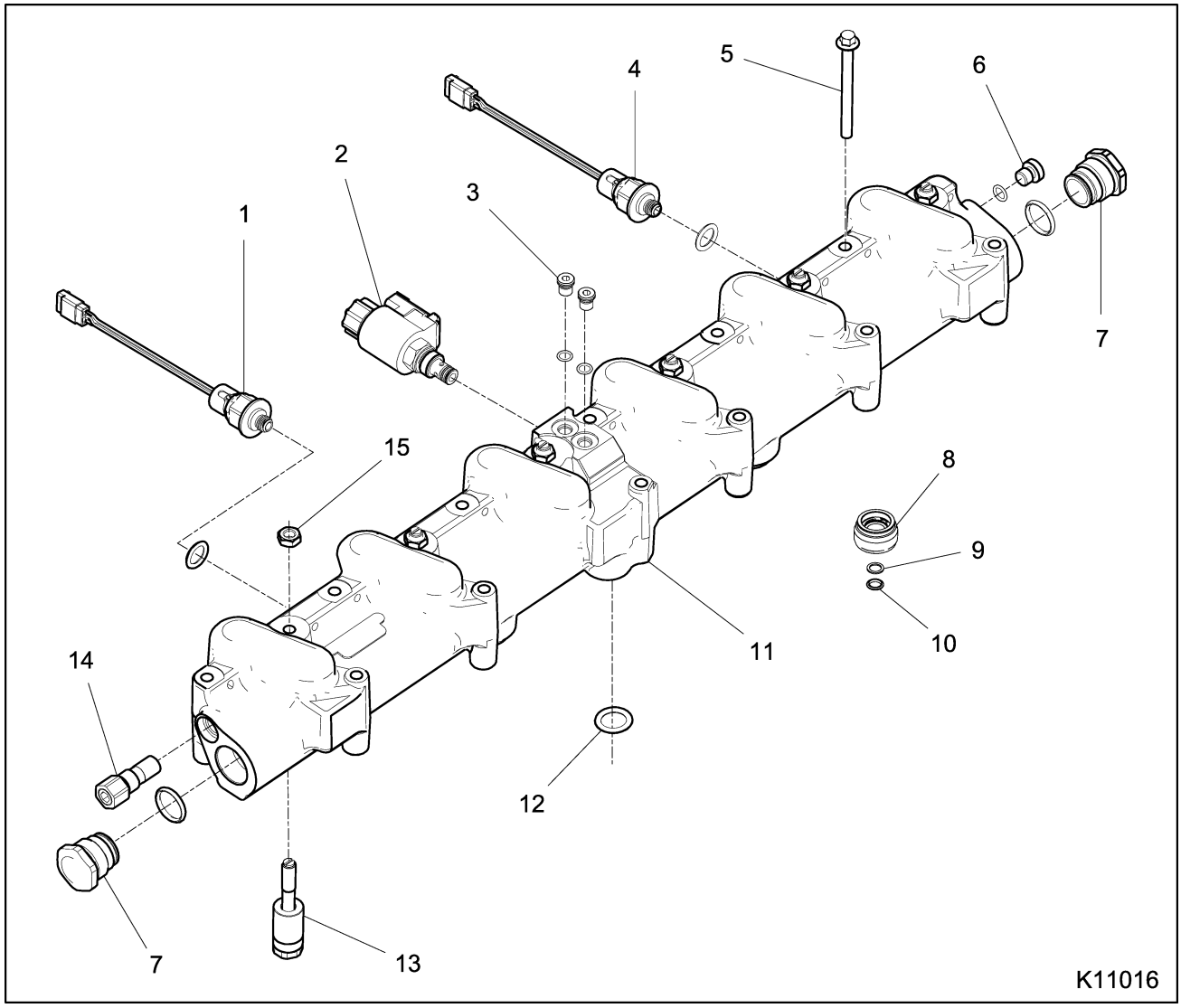


Figure 316 High-Pressure Oil Manifold (Brake)

1. Engine Compression Brake Pressure (ECBP) sensor
2. Engine Compression Brake (ECB) valve assembly
3. M10 plug (2 top, 1 bottom not shown), (3)
4. Injection Control Pressure (ICP) sensor
5. M8 x 90 bolt (12)
6. M12 plug
7. Rail end plug assembly (2)
8. Injector oil inlet adaptor (6)
9. Back-up ring (6)
10. Injector oil inlet seal (6)
11. High-pressure oil manifold (brake)
12. Oil inlet O-ring
13. Brake actuator piston (6)
14. Oil pressure relief valve
15. Brake actuator piston lock nut (6)

The engine brake system uses high-pressure oil in the high-pressure oil manifold, controlled by a Engine Compression Brake (ECB) valve, to force six brake actuator pistons down onto the valve bridges. This

partially opens one exhaust valve for each cylinder resulting in the release of compression pressure on the power stroke, which increases engine braking. See Engine Brake (page 54) for additional details.

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 transmission to park or neutral, set parking brake, and block wheels before doing diagnostic or service procedures.

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

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

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

NOTE: If the valve cover is removed for any reason, verify six brake piston locknuts are tight. If loose, verify and reset brake lash.

Engine Brake Lash Adjustment

NOTE: Engine brake actuator pistons can have either of two styles of lash adjustment drives. The slotted-head style is the original style. New engine brake actuator pistons have an internal hex socket style drive. These parts can be interchanged.

Crankshaft is rotated twice during brake lash adjustment procedure.

- Three brake actuator pistons are adjusted when piston 1 is at Top Dead Center (TDC) compression.
- Three brake actuator pistons are adjusted when piston 6 is at Top Dead Center (TDC) compression.

Corresponding intake and exhaust valve lash can be adjusted (page 353) when piston 1 and 6 are at TDC compression.

NOTE: Valve lash adjustments are not required when adjusting engine brake lash.

1. On engines rated at 245 horsepower and above, remove the interstage cooler and piping. See Interstage Cooler (ISC) (page 133).
2. Remove valve cover. See Valve Cover (page 357).
3. Turn the crankshaft in the direction of engine rotation to remove gear lash. Position piston 1 at TDC compression by observing cylinder 6 rocker arms in overlap as the vibration damper timing mark approaches the TDC mark on the front cover. Cylinder 6 exhaust valve will be closing (coming up) and the intake valve will be starting to open (going down).
4. If piston 1 is at TDC compression, see Chart 1 (page 241) and do steps 4 and 5 for cylinders 1, 3, and 5.

Chart 1

Brake and valve lash adjustments (inches) with piston 1 at TDC compression (Chart 1)											
Cylinder 1		Cylinder 2		Cylinder 3		Cylinder 4		Cylinder 5		Cylinder 6	
intake 1	exhaust 2	intake 3	exhaust 4	intake 5	exhaust 6	intake 7	exhaust 8	intake 9	exhaust 10	intake 11	exhaust 12
0.019	0.019	0.019			0.019	0.019			0.019		
Brake 0.019				Brake 0.019				Brake 0.019			

Brake and Valve Lash Adjustments with Piston 1 at TDC Compression

Chart 2

Brake and valve lash adjustments (inches) with piston 6 at TDC compression (Chart 2)											
Cylinder 1		Cylinder 2		Cylinder 3		Cylinder 4		Cylinder 5		Cylinder 6	
intake 1	exhaust 2	intake 3	exhaust 4	intake 5	exhaust 6	intake 7	exhaust 8	intake 9	exhaust 10	intake 11	exhaust 12
			0.019	0.019			0.019	0.019		0.019	0.019
		Brake 0.019				Brake 0.019				Brake 0.019	

Brake and Valve Lash Adjustments with Piston 6 at TDC Compression

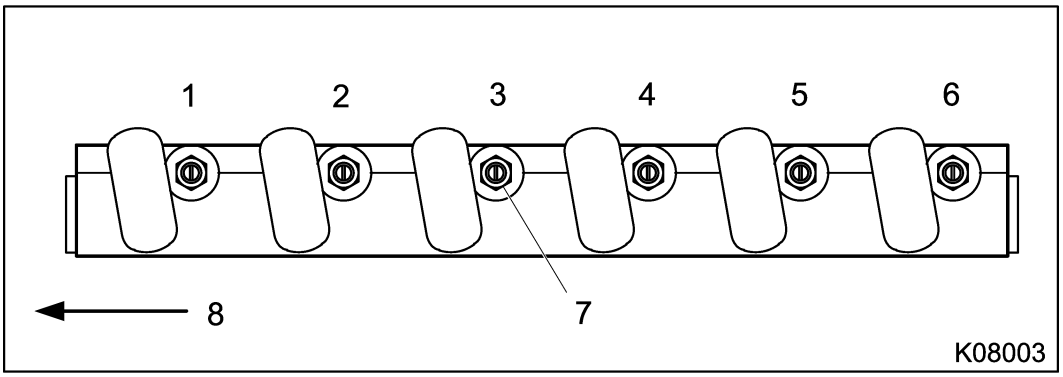


Figure 317 High-Pressure Oil Manifold (Brake)

1. Cylinder 1
2. Cylinder 2
3. Cylinder 3
4. Cylinder 4
5. Cylinder 5
6. Cylinder 6
7. Brake actuator piston locknut (6)
8. Front of engine

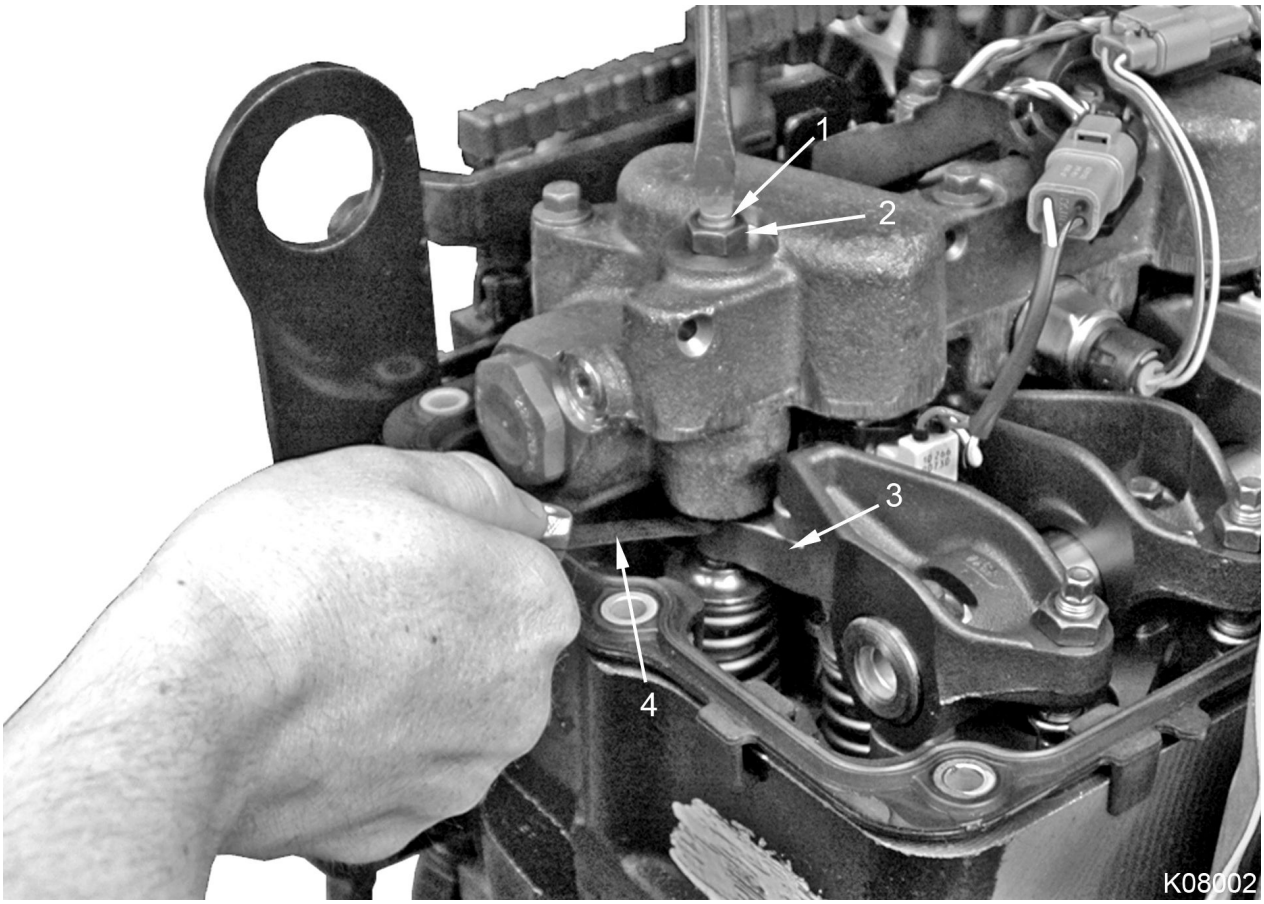


Figure 318 Brake Lash Measurement (typical)

1. Brake actuator piston screw
2. Brake actuator piston locknut
3. Valve bridge
4. Feeler gauge

5. Measure brake lash when engine is cold. Put a 0.48 mm (0.019 in) feeler gauge (page 254) between the brake actuator piston and valve bridge, a light drag on the feeler gauge should be felt. If adjustment is required, loosen actuator piston locknut and turn actuator piston screw.
6. Once brake lash is set, tighten actuator piston locknut to special torque (page 254) and remove feeler gauge. Recheck lash with a light drag on feeler gauge. If drag is too tight or loose, repeat steps 4 and 5.

   Corresponding valve lash can be adjusted before rotating crankshaft for either the intake or exhaust for cylinders 1, 2, and 3, but not both at the same time. See Chart 1 (page 241).
7. Turn the crankshaft 360° in the direction of engine rotation to remove gear lash. Position piston 6 at TDC compression by observing cylinder 1 rocker arms in overlap as the vibration damper timing mark approaches the TDC mark on the front cover.
8. If piston 6 is at TDC compression, see Chart 2 (page 241) and do steps 4 and 5 for cylinders 2, 4, and 6.

   Corresponding valve lash can be adjusted for either the intake or exhaust for cylinders 2, 4, and 6, but not both at the same time. See Chart 2 (page 241).

Removal

Inspect for external damage or oil leaks from sensors or valve. Only remove sensor if damage, diagnostic code, or test indicated a problem.

NOTE: If the valve cover is removed for any reason, verify six brake piston locknuts are tight. If loose, verify and reset engine brake lash (page 240).

Engine Compression Brake (ECB) Valve

1. Remove valve cover. See Valve Cover (page 357).

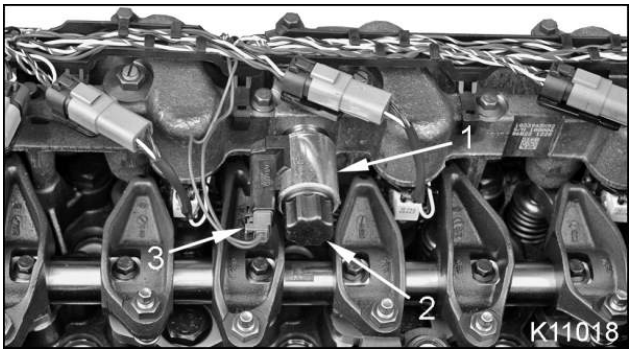


Figure 319 ECB Valve Assembly (typical)

1. Solenoid
2. Nut
3. Harness connector

2. Disconnect harness connector from ECB valve assembly.
3. Use a 12 point (1-1/16 inch) socket to remove nut and solenoid from Engine Compression Brake (ECB) valve.

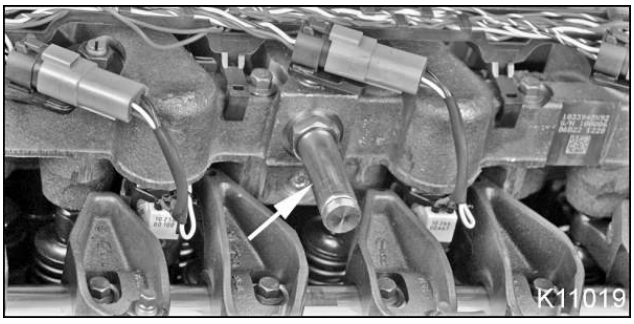


Figure 320 ECB Valve

4. Remove ECB valve from high-pressure oil manifold.
5. Remove and discard ECB valve O-rings and back-up rings.

Engine Compression Brake Pressure (ECBP) Sensor



Figure 321 ECBP Sensor (typical)

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

Valve Cover Gasket (Harness) Assembly (Brake)

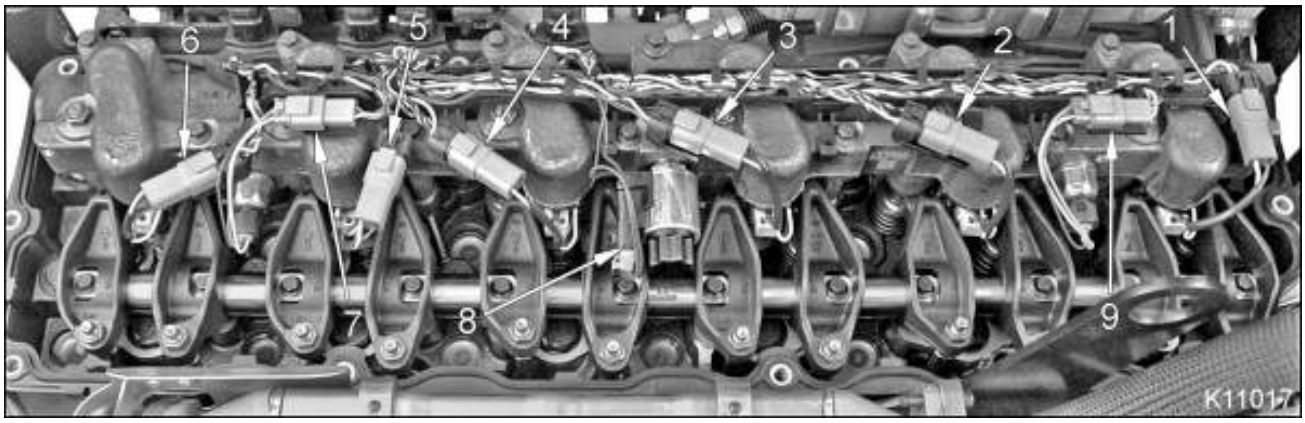


Figure 322 Valve Cover Gasket (harness) Assembly (brake, typical)

1. Injector 1 connector (front of engine)
2. Injector 2 connector
3. Injector 3 connector
4. Injector 4 connector
5. Injector 5 connector
6. Injector 6 connector
7. Injection Control Pressure (ICP) sensor connector
8. Engine Compression Brake (ECB) valve
9. Engine Compression Brake Pressure (ECBP) sensor connector

1. Disconnect four injector wiring harness connectors from the valve cover gasket harness assembly located under the valve cover.

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

2. Disconnect six injector connectors, ICP, and ECBP sensor connectors.
3. Disconnect ECB valve connector.
4. Starting at one side, lightly pry up and open each of the six wire channel retainers while gently pulling up to remove valve cover gasket harness from engine.

High-pressure Oil Manifold (Brake)

1. Remove 12 M8 x 90 bolts holding high-pressure oil manifold to the cylinder head. Do not discard, save for installation.

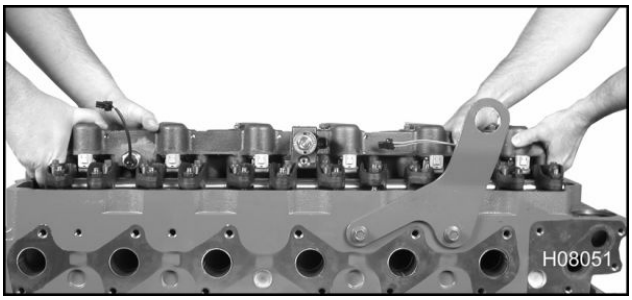


Figure 323 High-Pressure Oil Manifold Removal (typical)

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

2. Lift high-pressure oil manifold straight up just enough to drain oil out of manifold before lifting it away from cylinder head.
3. Lift up and remove high-pressure oil manifold from engine.

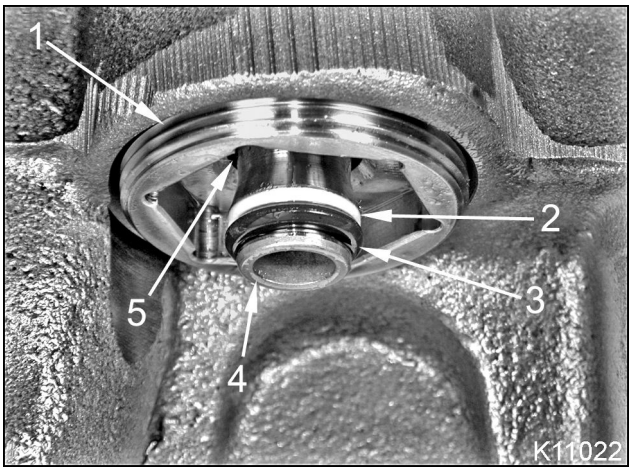


Figure 324 Injector Oil Inlet Adaptor Installed in High-Pressure Oil Manifold

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

4. Remove and discard injector oil inlet adaptor seals and backup rings.
5. Remove any damaged injector oil inlet adaptor assemblies using High Pressure Rail Adapter Socket (page 254).

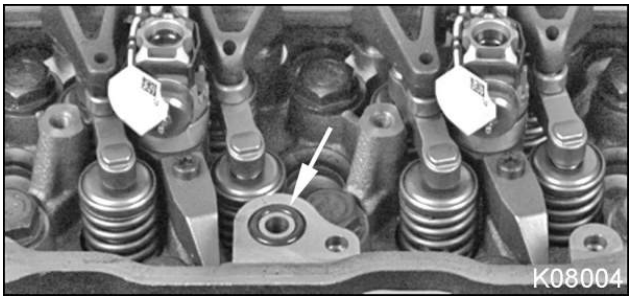


Figure 325 Oil Inlet O-ring (typical)

6. Discard oil inlet O-ring.

Oil Pressure Relief Valve

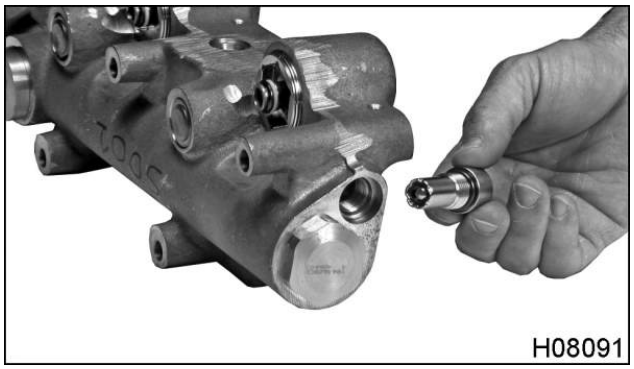


Figure 326 Oil Pressure Relief Valve

1. Remove oil pressure relief valve from high-pressure oil manifold.
2. Discard valve O-ring.

Brake Actuator Piston Assembly

NOTE: Do steps 1 through 3 as required for the six brake actuator piston assemblies.

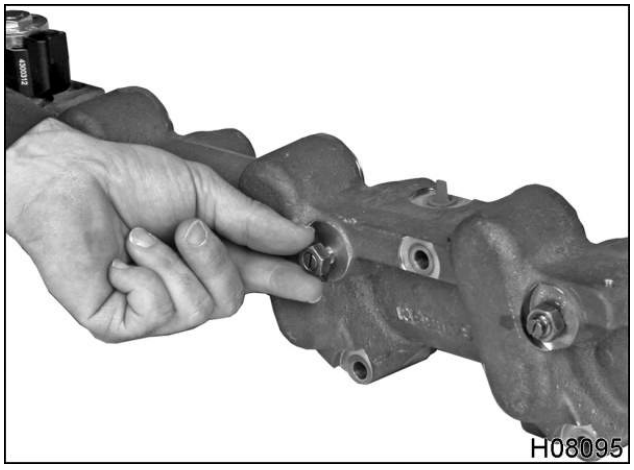


Figure 327 Brake Actuator Piston Locknut

1. Remove brake actuator piston locknut. Do not discard, save for installation.

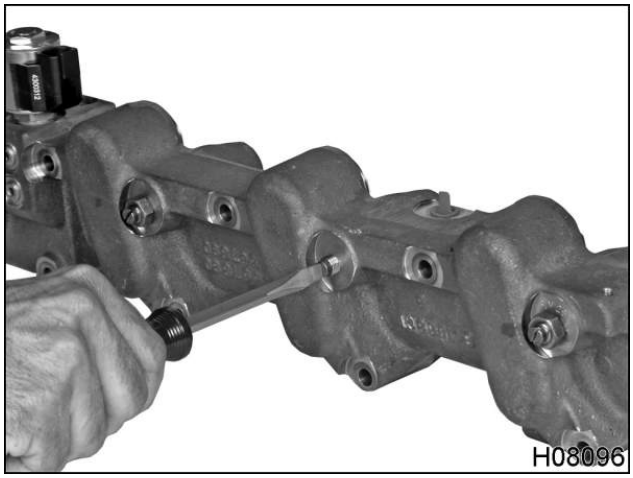


Figure 328 Brake Actuator Piston Removal

NOTE: Brake actuator piston assemblies may have either a slotted head or internal hex socket head. Mixing the two styles is acceptable.

2. Unscrew the brake actuator piston assembly from the high-pressure oil manifold.

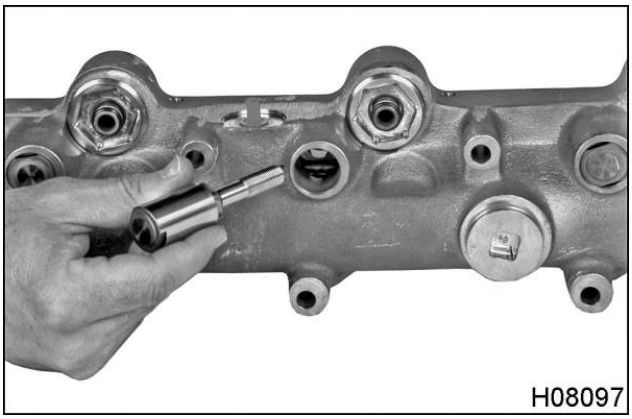


Figure 329 Brake Actuator Piston Assembly

CAUTION: To prevent engine damage, use permanent marker to identify internal engine components and their orientation. Do not use paint or temporary markers.

3. Remove and mark brake actuator piston for installation in original location.

NOTE: There are no seals associated with the brake actuator piston assembly.

Cleaning and Inspection

1. Clean external surface of high-pressure oil manifold, brake actuator pistons, valve bridges, oil pressure relief valve, Engine Compression Brake (ECB) valve, and Engine Compression Brake Pressure (ECBP) sensor with a suitable non-caustic solvent.
2. Clean any oil and debris from the 12 high-pressure oil manifold mounting bolt hole threads. Clean bolt hole threads will ensure the proper torque is reached when tightening the mounting bolts.

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

3. Blow dry parts using filtered compressed air.
4. Inspect high-pressure oil manifold and oil pressure relief valve for cracks and leaks. Replace cracked or leaking parts.

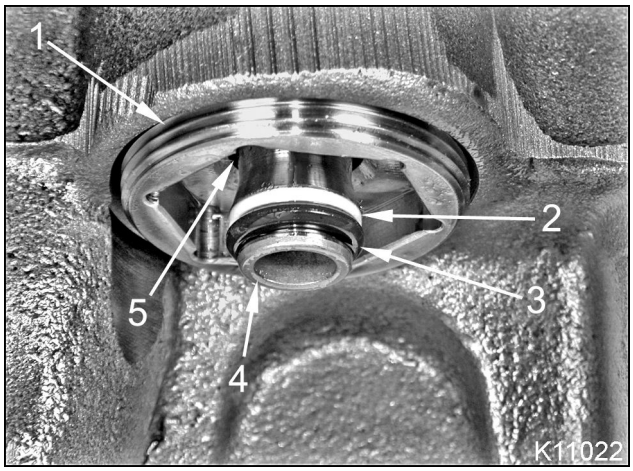


Figure 330 Injector Oil Inlet Adaptor Installed in High-Pressure Oil Manifold

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

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

   Replace old backup ring and injector oil inlet seal with new.
6. Inspect all brake actuator pistons and valve bridge contact surfaces. Look for pitting and material transfer deformation. Replace pitted or deformed parts if necessary. Polished surfaces are acceptable.
7. Inspect the ECB valve and ECBP sensor for cracks. Replace cracked parts.

Installation

Brake Actuator Piston Assembly

NOTE: Be sure the old backup ring and injector oil inlet seal on the high-pressure oil manifold has been replaced with a new seal and ring.

NOTE: Do steps 1 through 4 for each brake actuator piston assembly removed.

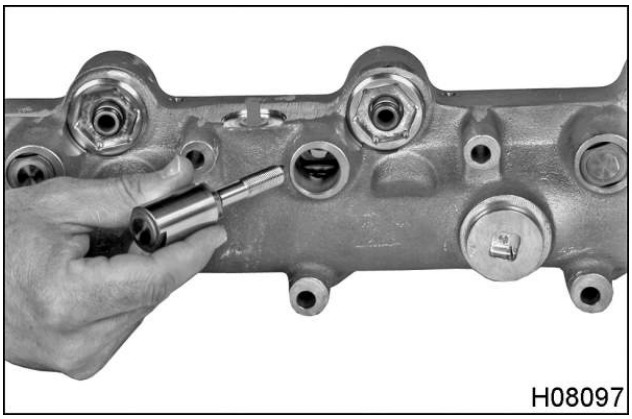


Figure 331 Brake Actuator Piston Assembly

1. Lubricate brake actuator piston and high-pressure oil manifold bore with clean engine oil.
2. Install brake actuator piston into high-pressure oil manifold. Install used brake actuator pistons in the same location as removed.

NOTE: There are no seals associated with the brake actuator piston assembly. It is normal for some oil to exit past the piston assemblies.

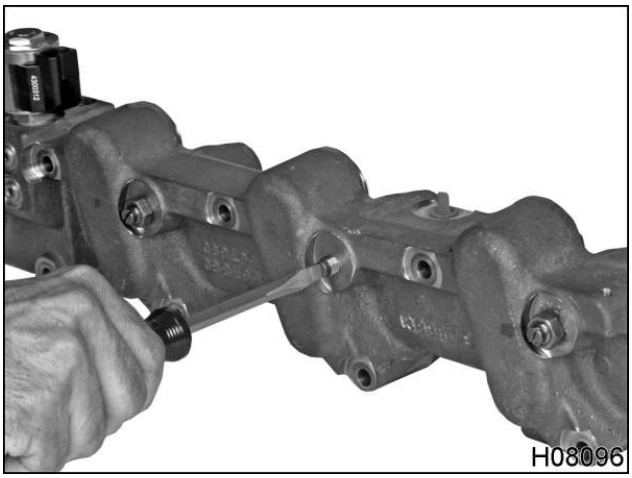


Figure 332 Brake Actuator Piston Installation

NOTE: Brake actuator piston assemblies may have either a slotted head or internal hex socket head. Mixing the two styles is acceptable.

3. Screw brake actuator piston assembly into high-pressure oil manifold until bottomed out.

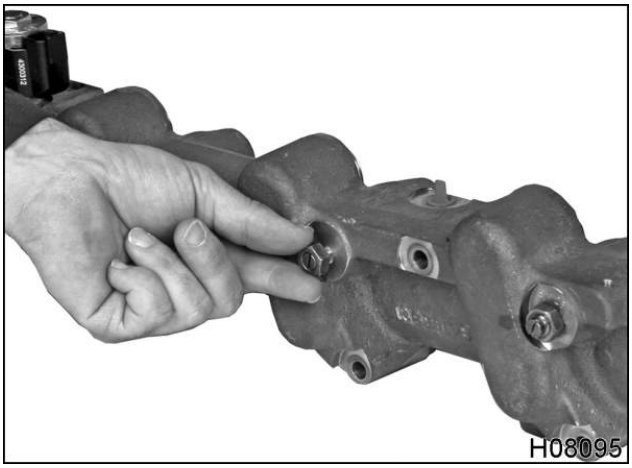


Figure 333 Brake Actuator Piston Locknut

4. Install brake actuator piston locknut. Do not tighten at this time.

NOTE: Final brake lash adjustments will be made after high-pressure oil manifold is installed on the cylinder head.

Oil Pressure Relief Valve

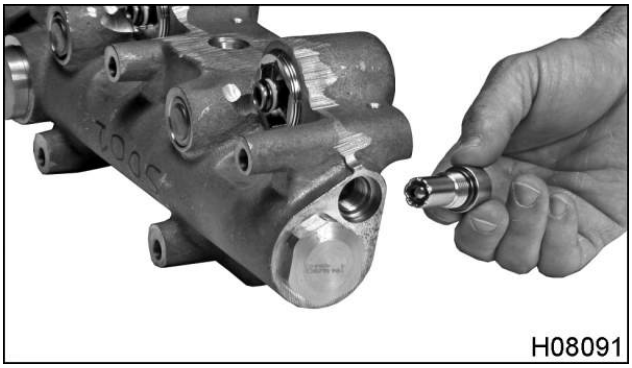


Figure 334 Oil Pressure Relief Valve

1. Install new O-ring on oil pressure relief valve.
2. Install oil pressure relief valve and tighten to special torque (page 254).

High-pressure Oil Manifold (Brake)

1. Back off all brake actuator piston lash adjustments, for correct high-pressure oil manifold bolt torque during high-pressure oil manifold installation.

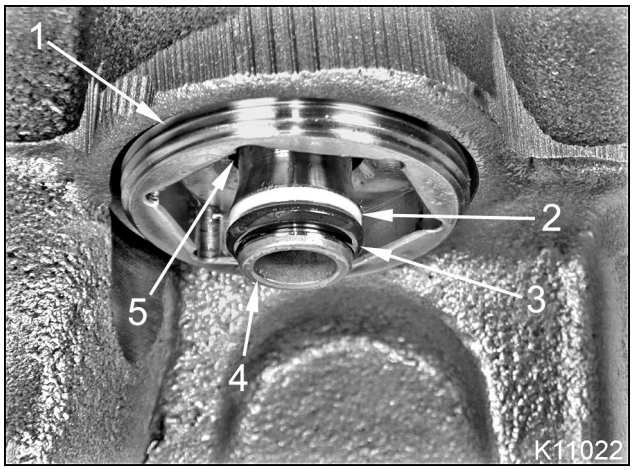


Figure 335 Injector Oil Inlet Adaptor Installed in High-Pressure Oil Manifold

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

2. Install injector oil inlet adaptors with High Pressure Rail Adapter Socket (page 254). Tighten injector oil inlet adaptors to special torque (page 254).
3. Install new backup rings and injector oil inlet seals on all oil inlet adaptors that were not replaced.
4. Coat backup rings and injector oil inlet seals with clean engine oil.

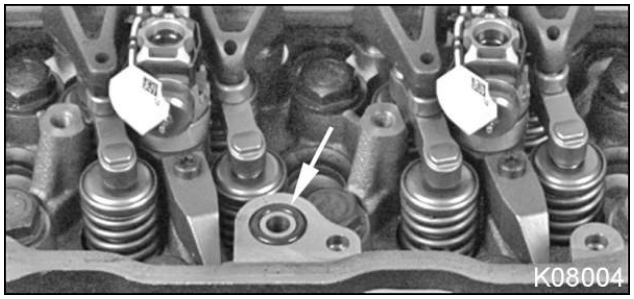


Figure 336 Oil Inlet O-ring (typical)

5. Coat new oil inlet O-ring with clean engine oil and install in cylinder head recess.
6. If valve bridges have been removed install at this time. Also check valve lash adjustment before installing the high-pressure oil manifold. See Valve Lash Adjustment (page 353) for adjustment procedure.

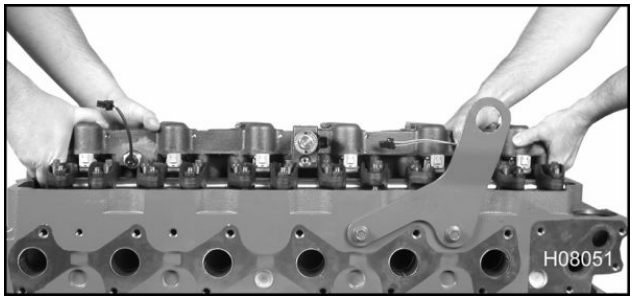


Figure 337 High-Pressure Oil Manifold Installation (typical)

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

7. With help from an assistant, lift the high-pressure oil manifold up and carefully place on engine.

CAUTION: To prevent engine damage, carefully align six injector oil inlet ports with six injector oil inlet adaptors of the high-pressure oil manifold before tightening oil manifold bolts.

8. Carefully align six injector oil inlet ports with six injector oil inlet adapters of the high-pressure oil manifold and firmly push down to “snap” manifold in place.
9. Once the high-pressure oil manifold is set in place onto the cylinder head; shine a flashlight at all the points where the high-pressure oil manifold rests on the cylinder head.
   - If all points of the high-pressure oil manifold are resting on the cylinder head, the high-pressure oil manifold is seated correctly, go to step 10.

- If all the points of the high-pressure oil manifold are not resting on the cylinder head; push down on the high points to “snap” manifold in place. Once again, check all points with the flashlight, if high-pressure oil manifold is seated correctly, go to step 10.

10. Install and finger tighten 12 M8 x 90 bolts securing high-pressure oil manifold to the cylinder head.

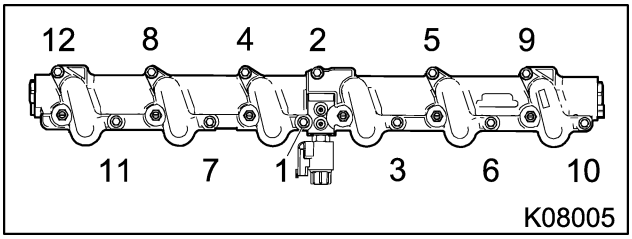


Figure 338 High-Pressure Oil Manifold Bolt Torque Sequence

11. Tighten 12 high-pressure oil manifold M8 x 90 bolts in the proper torque sequence to 30 N·m (22 lb·ft).
12. Adjust engine brake lash (page 240) for all cylinders.

NOTE: Air trapped in the high-pressure oil manifold will be purged automatically during cranking and start up.

Valve Cover Gasket (Harness) Assembly (Brake)

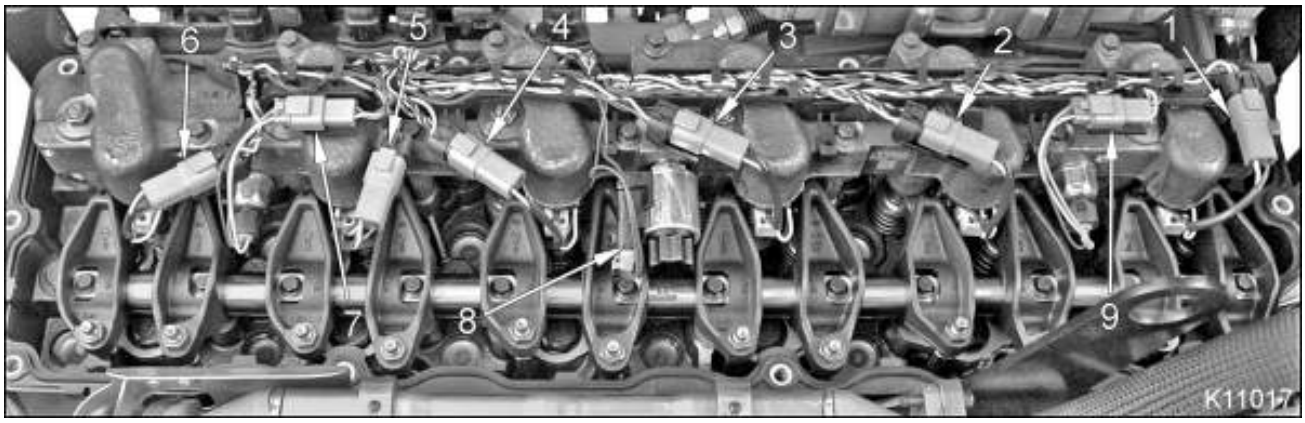


Figure 339 Valve Cover Gasket (Harness) Assembly (Brake, typical)

1. Injector 1 connector (front of engine)
2. Injector 2 connector
3. Injector 3 connector
4. Injector 4 connector
5. Injector 5 connector
6. Injector 6 connector
7. Injection Control Pressure (ICP) sensor connector
8. Engine Compression Brake (ECB) valve connector
9. Engine Compression Brake Pressure (ECBP) sensor connector

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

1. Position valve cover gasket harness on cylinder head and carefully push down each of the six wire channel retainers to snap harness onto high-pressure oil manifold.
2. Connect six injectors, ICP sensor, ECBP sensor, and ECB valve harness connectors.

Engine Compression Brake Pressure (ECBP) Sensor



Figure 340 ECBP Sensor (typical)

1. Install new O-ring on ECBP sensor and lubricate with clean engine oil.
2. Install ECBP sensor into high-pressure oil manifold, forward of cylinder 2 fuel injector, and tighten to special torque (page 254).
3. Connect valve cover gasket harness connector to ECBP sensor.

Engine Compression Brake (ECB) valve assembly

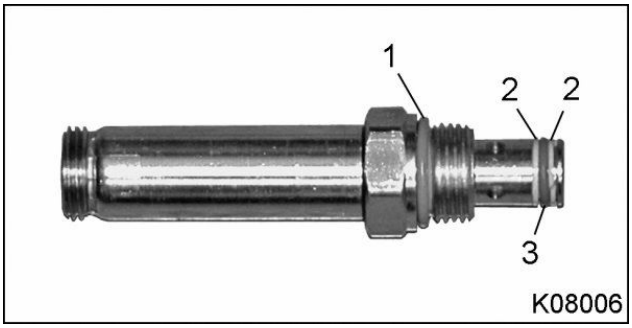


Figure 341 Engine Compression Brake (ECB) Valve Seals

1. O-ring
2. Back-up ring (2)
3. O-ring

1. Install new O-rings and back-up rings on Engine Compression Brake (ECB) valve.
2. Lubricate O-rings with clean engine oil.

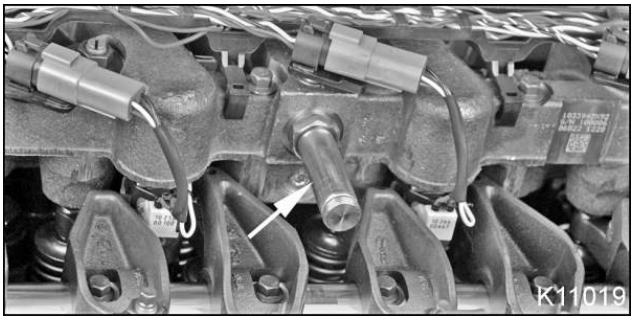


Figure 342 Engine Compression Brake (ECB) Valve (typical)

3. Install Engine Compression Brake (ECB) valve in high-pressure oil manifold.
4. Tighten Engine Compression Brake (ECB) valve to special torque (page 254).

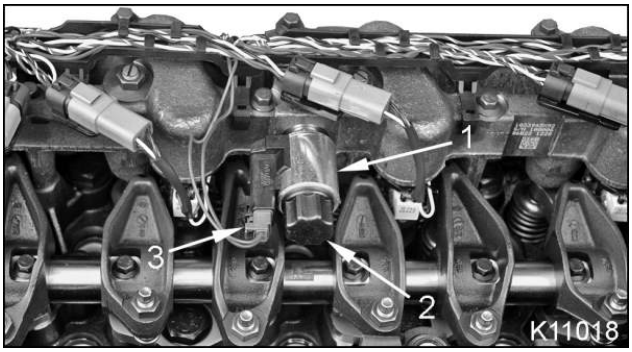


Figure 343 ECB Valve Assembly

1. Solenoid
2. Solenoid nut
3. Harness connector

5. Install solenoid over the Engine Compression Brake (ECB) valve.

CAUTION: To prevent engine damage, ECB valve harness connector must be positioned to give proper clearance for rocker arm movement.

6. Install solenoid nut and position ECB valve harness connector to give proper clearance for rocker arm movement.
7. Using a 12 point (1–1/16 in) socket (page 254), tighten solenoid nut to special torque (page 254).
8. Connect valve cover gasket harness connector to ECB valve assembly.

Specifications

Brake actuator lash (cold)	0.48 mm (0.019 in)

Special Torque

Engine Compression Brake Pressure (ECBP) sensor and Injection Control Pressure (ICP) sensor	18 N·m (162 lb·in)
Brake actuator piston locknut	25 N·m (19 lb·ft)
Engine Compression Brake (ECB) valve nut	5 N·m (45 lb·in)
Engine Compression Brake (ECB) valve	27 N·m (20 lb·ft)
High-pressure oil manifold bolts M8 x 90	See High-pressure Oil Manifold (Brake) (page 251).
Injector oil inlet adaptor assembly	204 N·m (150 lb·ft)
Oil pressure relief valve	45 N·m (33 lb·ft)
Plug assembly, M12	12 N·m (108 lb·in)
Plug assembly, M10	12 N·m (108 lb·in)
Rail end plug assembly	204 N·m (150 lb·ft)

Special Service Tools

Feeler gauge	Obtain locally
5 mm hex key wrench	Obtain locally
12 point (1–1/16 inch) socket	Obtain locally
High Pressure Rail Adapter Socket	ZTSE4725

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Air Compressor

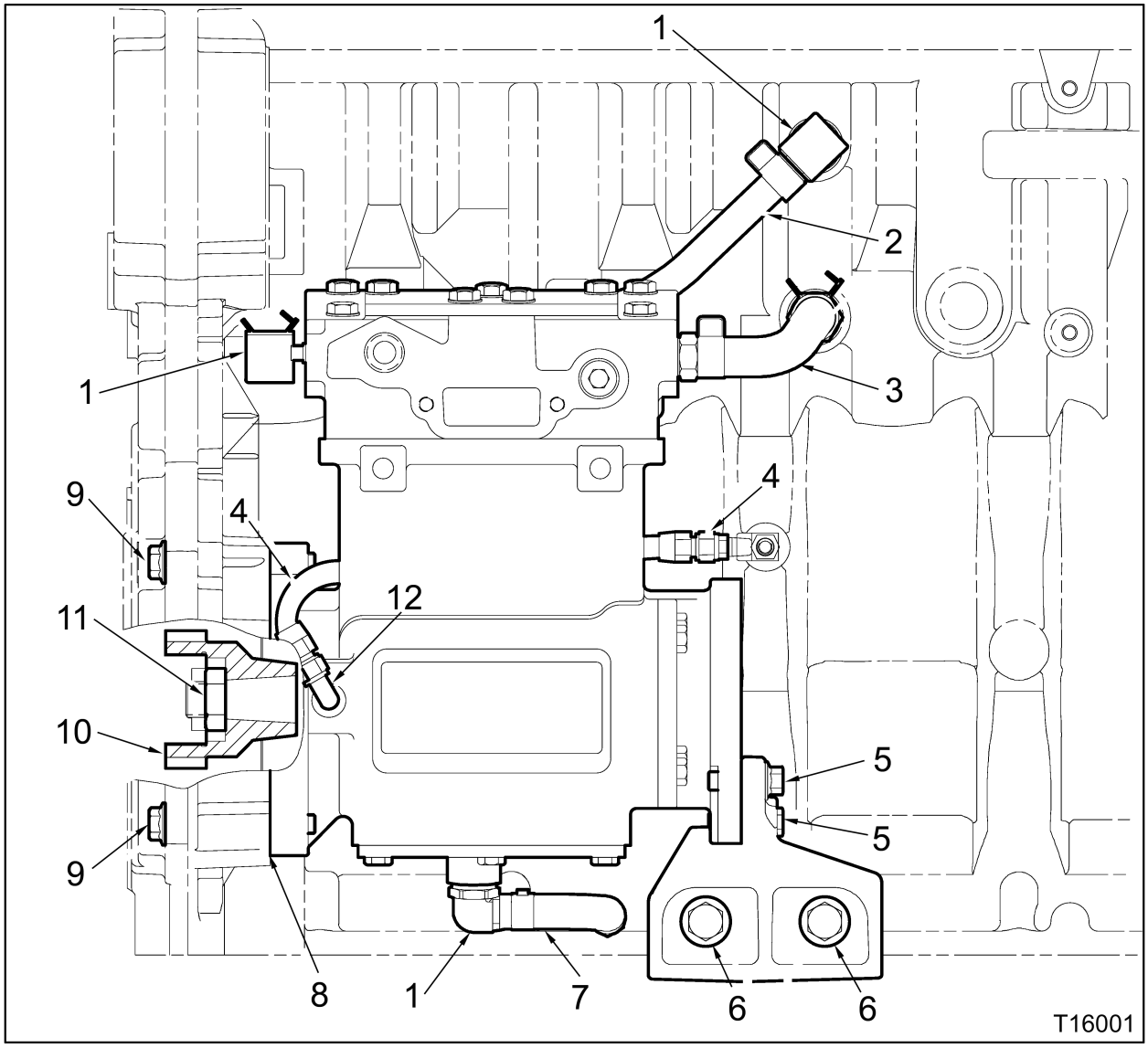


Figure 344 Air Compressor Mounting and Connections (typical)

1. M18 elbow assembly (3)
2. Air compressor hose, 13 mm ID x 375 mm long (0.5 in ID x 14.75 in long)
3. Air compressor hose, 13 mm ID x 152 mm long (0.5 in ID x 6.0 in long)
4. Air compressor (oil supply) hose assembly
5. M10 x 30 bolt (2)
6. M12 x 50 bolt (2)
7. Drain hose (oil)
8. Gasket
9. M12 x 80 bolt (2)
10. Air compressor gear
11. Air compressor gear nut
12. M10 elbow assembly

Power Steering Pump

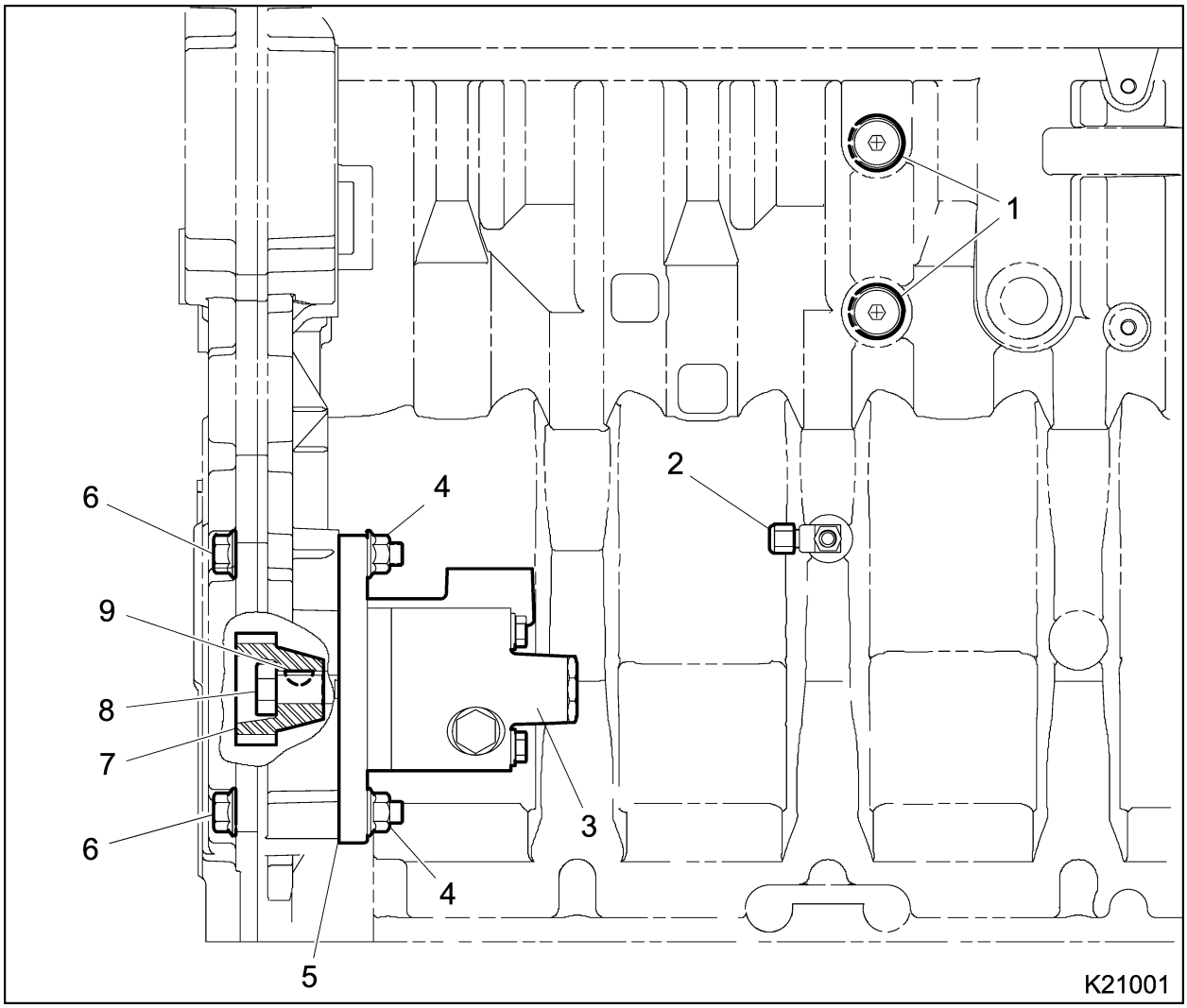


Figure 345 Power Steering Pump without Air Compressor (typical)

1. M18 plug assembly (coolant) (2)
2. Cap (oil)
3. Power steering pump assembly
4. M12 nut (2)
5. Gasket
6. M12 x 90 bolt (2)
7. Drive gear
8. Power steering pump gear nut
9. Shaft key

Description

Air Compressor

The optional air compressor is gear driven from the lower idler gear located in the engine front cover.

Lubrication oil for the air compressor is provided through a hose connected to the engine oil pressure sensor tee. Oil drains back to the crankcase through a hose on the bottom of the compressor.

Filtered air for the air compressor is drawn through an air hose connected to the air cleaner assembly. Air is compressed and delivered to an air tank. When the air tank is full, excess compressed air is vented to the atmosphere.

Coolant for the air compressor is supplied and returned through two hoses connected to the intake side of the crankcase.

Power Steering Pump

The optional power steering pump assembly is mounted in one of two configurations:

- Without an air compressor, the power steering pump is mounted on the front cover and driven by the lower idler gear.
- With an air compressor, the power steering pump is mounted to the air compressor. The compressor is driven by the lower idler gear and torque is transferred to the power steering pump through the compressor crankshaft.

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, allow engine to cool before working with components.

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

NOTE: For air compressor and power steering pump procedures other than removal and installation, refer to the International Service Information Solutions - ISIS® website and then select the “Suppliers” link.

NOTE: Air compressor and power steering pump may be removed together as an assembly or separately depending on service requirements.

Power Steering Pump

1. Place a drain pan under the power steering pump assembly.
2. Disconnect high-pressure power steering hose at power steering pump.
3. Disconnect low-pressure power steering hose at power steering pump.
4. Cap open oil ports and oil lines to keep dirt out and reduce fluid spills.

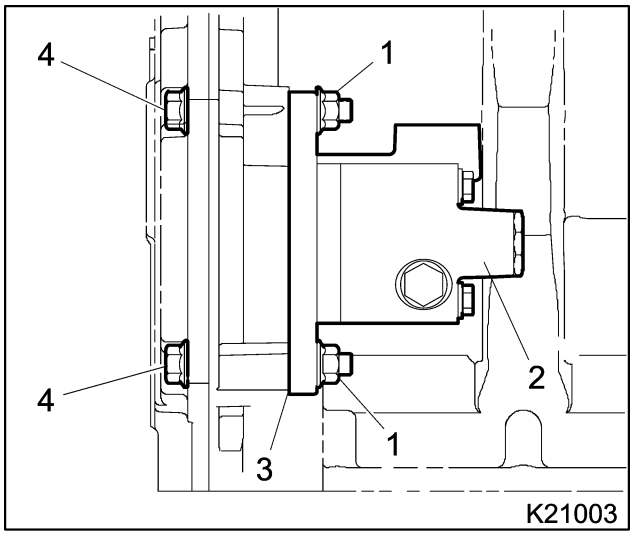


Figure 346 Power Steering Pump without Air Compressor (typical)

1. M12 nut (2)
2. Power steering pump assembly
3. Gasket
4. M12 x 90 bolt (2)

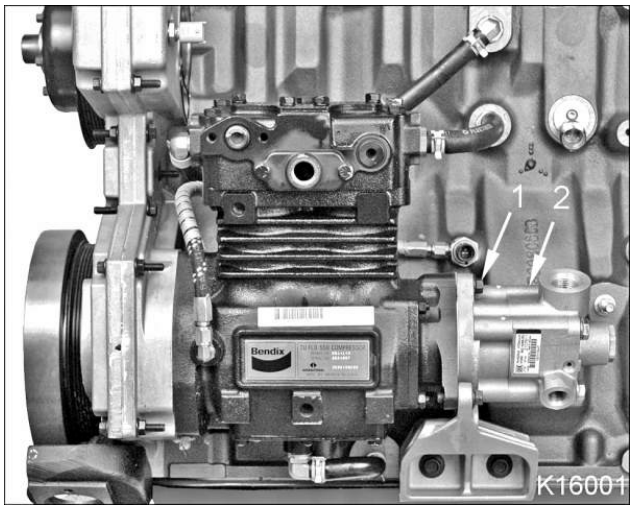


Figure 347 Power Steering Pump with Air Compressor (typical)

1. M10 x 35 bolt (2)
2. Power steering pump assembly

5. Depending on application, do one of the following:
   - For power steering pump without air compressor, remove two M12 x 90 bolts and M12 nuts.
   - For power steering pump with air compressor, remove two M10 x 35 bolts.
6. Remove power steering pump and discard gasket.

Air Compressor

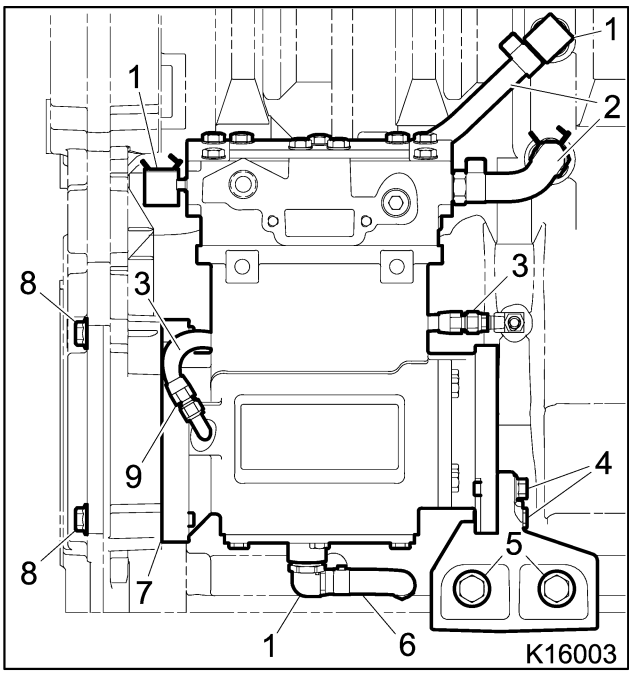


Figure 348 Air Compressor Mounting and Connections (typical)

1. M18 elbow assembly (3)
2. Air compressor hose, 13 mm ID x 375 mm long (0.5 in ID x 14.75 in long)
3. Air compressor hose, 13 mm ID x 152 mm long (0.5 in ID x 6.0 in long)
4. Air compressor (oil supply) hose assembly
5. M10 x 30 bolt (2)
6. M12 x 50 bolt (2)
7. Drain hose (oil)
8. Air compressor gasket
9. M12 x 80 bolt (2)
10. M10 elbow assembly

1. Place a drain pan under the air compressor assembly.
2. Clamp off coolant hoses so engine coolant does not drain out.
3. Loosen coolant hose clamps and remove two coolant hoses from air compressor.
4. Remove air compressor (oil supply) hose assembly.
5. Loosen oil drain hose clamps and remove drain hose.
6. Cap oil and coolant open ports and lines to keep dirt out and reduce fluid spills.
7. Remove two M12 x 80 bolts holding air compressor to the front cover.

⚠ WARNING: To prevent personal injury or death, get assistance to remove and install the air compressor and power steering pump assembly.

8. Support weight of air compressor and remove two M12 x 50 bolts holding the air compressor and support bracket to the crankcase. Remove air compressor and bracket assembly from engine.
9. Remove two M10 x 30 bolts connecting the air compressor bracket to the air compressor.
10. Remove and discard air compressor gasket, mounted between the air compressor and front cover.

Cleaning and Inspection

1. Clean external surfaces of the power steering pump, air compressor, and lines with a rag or brush and a suitable solvent.
2. Check power steering pump and air compressor for cracks and leaks. Replace if required.
3. Check hoses and lines for cracks and leaks. Replace cracked or leaking lines and hoses.

Installation

Air Compressor

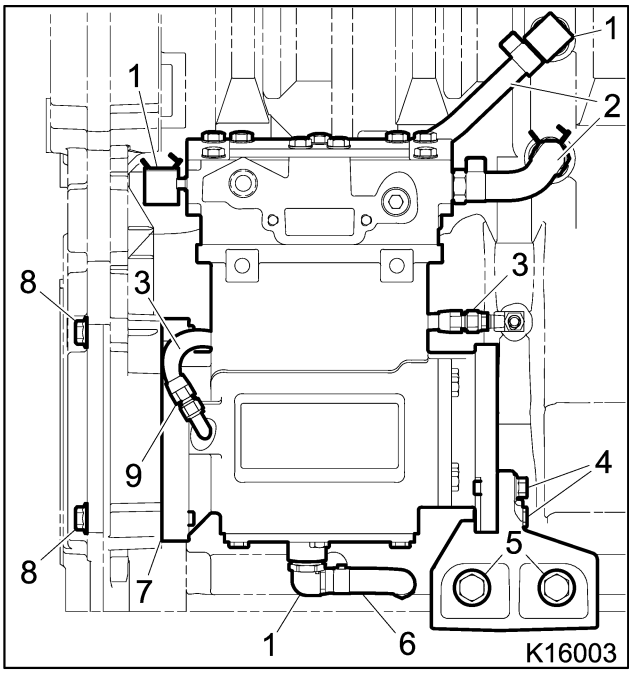


Figure 349 Air Compressor Mounting and Connections (typical)

1. M18 elbow assembly (3)
2. Air compressor hose, 13 mm ID x 375 mm long (0.5 in ID x 14.75 in long)
3. Air compressor hose, 13 mm ID x 152 mm long (0.5 in ID x 6.0 in long)
4. Air compressor (oil supply) hose assembly
5. M10 x 30 bolt (2)
6. M12 x 50 bolt (2)
7. Drain hose (oil)
8. Air compressor gasket
9. M12 x 80 bolt (2)
10. M10 elbow assembly

1. Install two M10 x 30 bolts connecting the air compressor bracket to the air compressor and finger tighten.
2. Install a new air compressor gasket on the front cover.

⚠ WARNING: To prevent personal injury or death, get assistance to remove and install the air compressor and power steering pump assembly.

3. With help from an assistant, install air compressor assembly into front cover while aligning air compressor gear with the lower idler gear. Install two M12 x 50 bolts through air compressor bracket into crankcase and finger tighten.
4. Align air compressor bolt holes with the front cover bolt holes and install two M12 x 80 bolts finger tight.

CAUTION: To prevent engine damage, do not over torque air compressor mounting bolts. Over tightening bolts will result in a fractured front cover.

5. Tighten two M12 x 80 bolts connecting the air compressor to the front cover to special torque (page 265).
6. Tighten two M10 x 30 bolts connecting the air compressor to the air compressor bracket to special torque (page 265).
7. Push up on rear of air compressor and tighten two M12 x 50 bolts connecting the air compressor bracket to the crankcase to special torque (page 265).
8. Install all elbow assemblies and hose connector assemblies removed from the crankcase and air compressor.
9. Orient elbow assemblies to reduce hose stress. Tighten elbow assemblies and hose connector assemblies to special torque (page 265).
10. Install coolant hoses and tighten hose clamps.
11. Install air compressor (oil supply) hose assembly on M10 elbow assembly. Finger tighten hose nut and then turn nut 1/2 to 2 additional turns until tight (page 265).
12. Install oil drain hose and tighten hose clamps.

Power Steering Pump Without Air Compressor

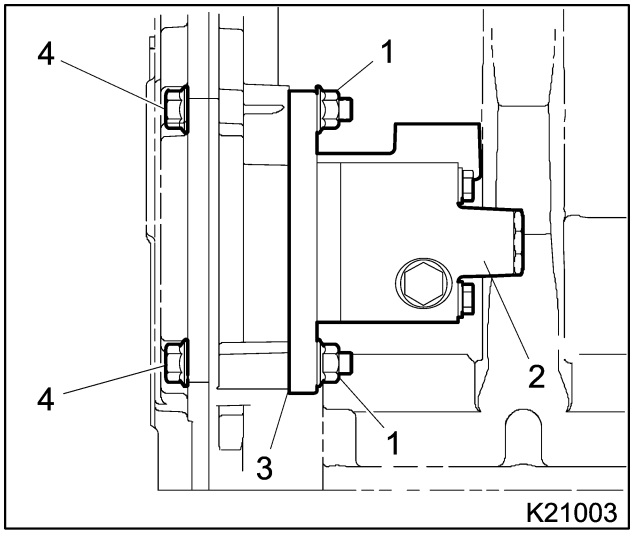


Figure 350 Power Steering Pump without Air Compressor (typical)

1. M12 nut (2)
2. Power steering pump assembly
3. Gasket
4. M12 x 90 bolt (2)

1. Install a new power steering pump gasket on the back of the front cover.
2. Install power steering pump on the front cover and install two M12 x 90 bolts and two M12 nuts.
3. Tighten two M12 x 90 bolts and two M12 nuts to special torque (page 265).
4. Install low-pressure power steering hose.
5. Install high-pressure power steering hose. Tighten hose fitting to special torque (page 265).
6. Fill power steering reservoir to full mark.
7. Start engine and turn steering wheel lock-to-lock several times.
8. Turn ignition switch to OFF.
9. Check for leaks and fill engine power steering reservoir to full mark.

Power Steering Pump With Air Compressor

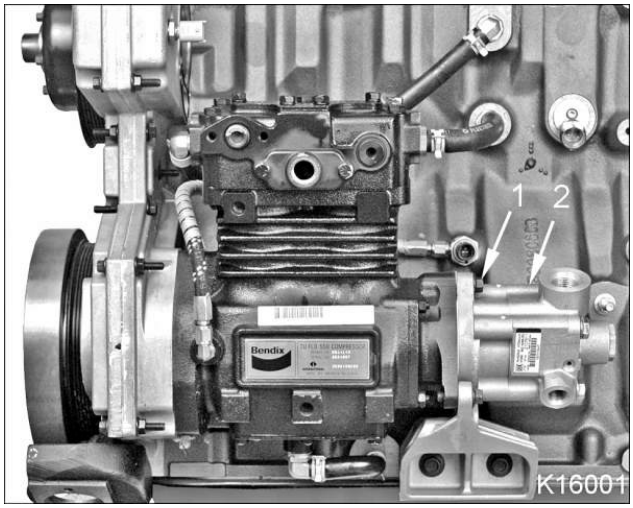


Figure 351 Power Steering Pump with Air Compressor (typical)

1. M10 x 35 bolt (2)
2. Power steering pump assembly

1. Install a new power steering pump gasket on the back of the air compressor.
2. Install power steering pump on the back of the air compressor and secure with two M10 x 35 bolts.
3. Tighten two M10 x 35 bolts to special torque (page 265).
4. Install low-pressure power steering hose.
5. Install high-pressure power steering hose. Tighten hose fitting to special torque (page 265).
6. Fill power steering reservoir to full mark.
7. Start engine and turn steering wheel lock-to-lock several times.
8. Turn ignition switch to OFF.
9. Check for leaks and fill engine power steering reservoir to full mark.

Specifications

Lower idler gear to air compressor gear backlash	0.508 mm (0.020 in)

Special Torque

Air compressor gear nut	150 N·m (110 lb·ft)
Air compressor (oil supply) hose assembly	See Air Compressor (page 263)
Air compressor and power steering pump M12 x 80 mounting bolts	83 N·m (61 lb·ft)
Bracket to air compressor M10 x 30 bolts	67 N·m (49 lb·ft)
Compressor bracket to crankcase M12 x 50 bolts	115 N·m (85 lb·ft)
Elbow assembly, M10	16 N·m (138 lb·in)
Elbow assembly, M18	48 N·m (35 lb·ft)
High-pressure power steering hose fitting	63 N·m (46 lb·ft)
Power steering pump mounting bolts, M10 x 35 (used when mounting pump to back of air compressor)	57 N·m (42 lb·ft)
Power steering pump mounting bolts, M12 x 90 (used when mounting pump to back of front cover)	83 N·m (61 lb·ft)
Power steering pump drive nut	90 N·m (66 lb·ft)

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Exploded View and Description

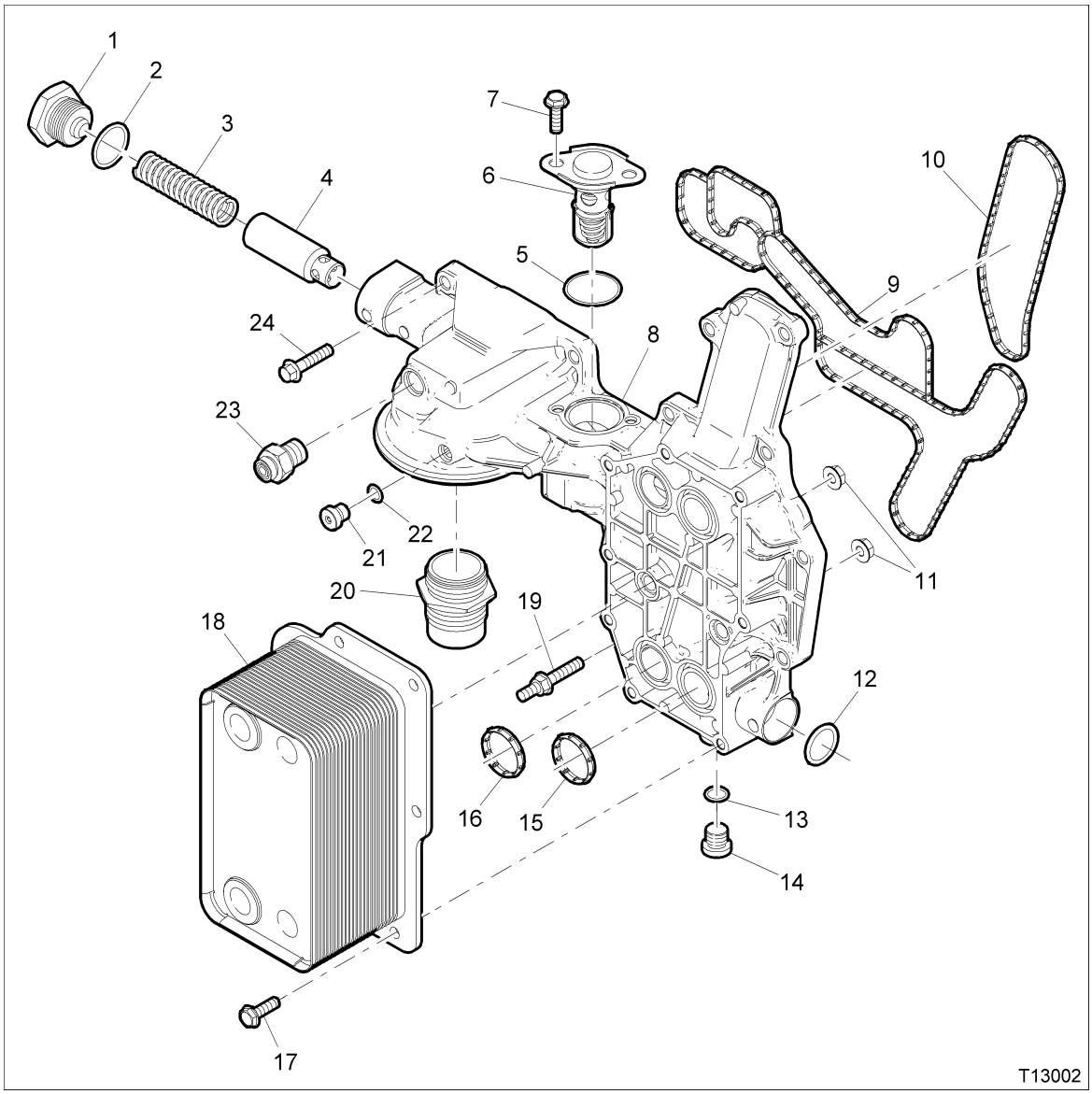


Figure 352 Oil Cooler Module Assembly

1. Pressure regulator valve cap
2. O-ring, 2.9 x 29.6 I.D. (pressure regulator valve)
3. Pressure regulator valve spring
4. Pressure regulator valve piston
5. O-ring gasket (thermal valve assembly)
6. Thermal valve assembly
7. M8 x 25 screw (2)
8. Oil cooler housing
9. Housing to crankcase gasket (oil)
10. Housing to crankcase gasket (coolant)
11. M8 serrated nut (2)
12. Seal (coolant return cooler tube)
13. O-ring, 2.2 x 13.3 I.D.
14. M16 plug (coolant drain)
15. Cooler to housing gasket - coolant (2)
16. Cooler to housing gasket - oil (2)
17. M8 x 25 screw (8)
18. Oil cooler
19. M8 x 15 stud bolt
20. Oil filter adapter
21. M12 plug
22. Seal
23. Fitting & O-ring (with screen) (turbocharger oil supply)
24. M8 x 30 bolt (13)

The oil cooler module assembly uses engine coolant, an oil cooler, and a thermal valve to cool engine oil. An oil pressure regulator valve dumps excess oil to the oil pan to regulate oil pressure and an oil filter filters engine oil. See Engine Lubrication System (page 36) for additional lubrication system information.

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, 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: When performing specific component removal, only remove components necessary for access.

Drain Coolant

WARNING: To prevent personal injury or death, allow engine to cool before draining coolant.

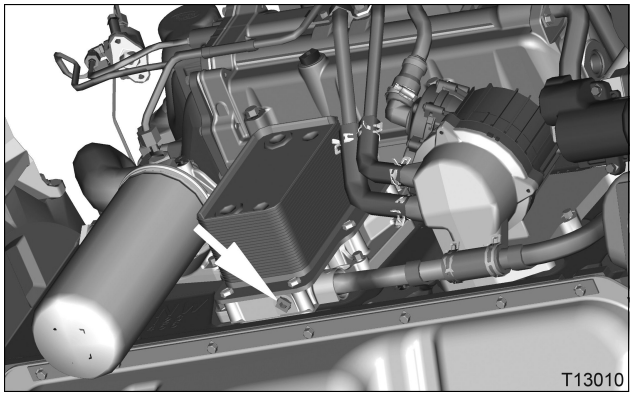


Figure 353 Coolant Drain Plug

1. Place a coolant drain pan under the oil cooler module.
2. Remove M16 coolant drain plug from the bottom of the oil cooler module. Open radiator cap to allow system to drain quicker.
3. Remove and discard coolant drain plug O-ring.
4. Inspect coolant drain plug, replace if necessary.
5. Lubricate a new coolant O-ring with clean coolant. Install O-ring onto the coolant drain plug.
6. After coolant has drained, install coolant drain plug into the oil cooler module.
7. Tighten coolant drain plug to special torque (page 283).
8. Recycle or dispose of coolant according to applicable regulations.

Oil Cooler Module

NOTE: Components in the following figure have been removed for clarity of tube support locations.

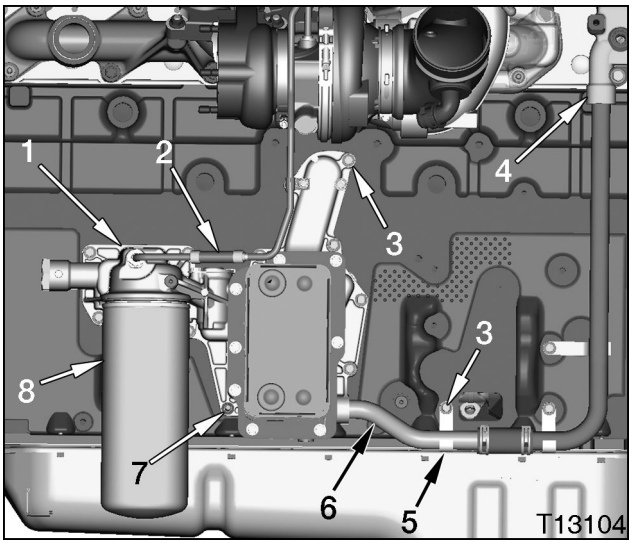


Figure 354 Oil Cooler Module and Coolant Return Tube

1. Oil cooler module
2. Turbocharger oil supply tube
3. M8 x 30 bolt (13)
4. Coolant supply housing
5. Tube support (3)
6. Coolant return tube assembly
7. M8 x 15 stud bolt
8. Oil filter

1. Place a drain pan under the oil cooler module assembly.
2. Rotate oil filter counterclockwise with an oil filter wrench (page 283) and remove oil filter from oil cooler housing.
3. Remove the turbocharger oil supply tube from the oil cooler housing. See Turbocharger Oil Supply Tube Assembly (page 135).
4. Discard turbocharger oil supply tube O-ring.
5. Cap the open ends of the turbocharger oil supply tube and fitting.
6. Loosen and back out, do not remove, one M8 x 30 bolt securing the closest tube support for the coolant return tube assembly to the oil cooler module.
7. Remove, but do not discard, one M8 x 15 stud bolt from the oil cooler module.
8. Remove ten M8 x 30 bolts securing the oil cooler module to the crankcase. Pull oil cooler module slightly away from the crankcase, then remove the coolant return tube.
9. Discard O-ring from the coolant return tube.
10. Remove three M8 x 30 bolts and remove coolant return tube from the coolant supply housing.
11. Recycle or dispose of oil filter, oil, and coolant according to applicable regulations.

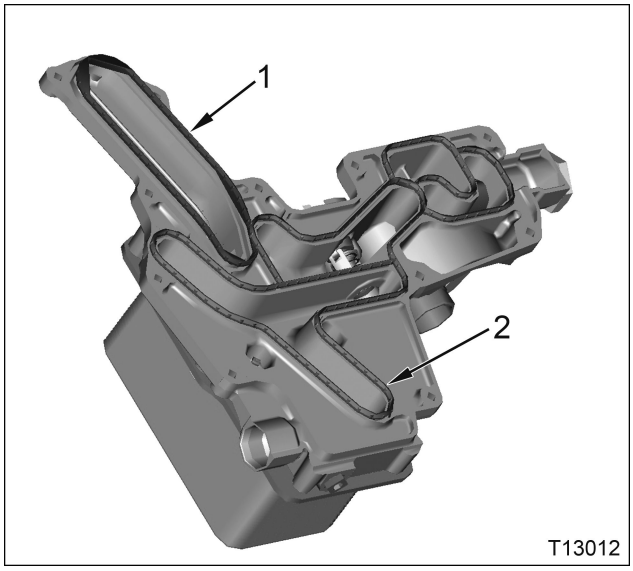


Figure 355 Oil Cooler Housing Gaskets

1. Housing to crankcase gasket (coolant)
2. Housing to crankcase gasket (oil)

12. Remove and discard both the housing to crankcase coolant gaskets.

Disassemble

Pressure Regulator Valve (Oil)

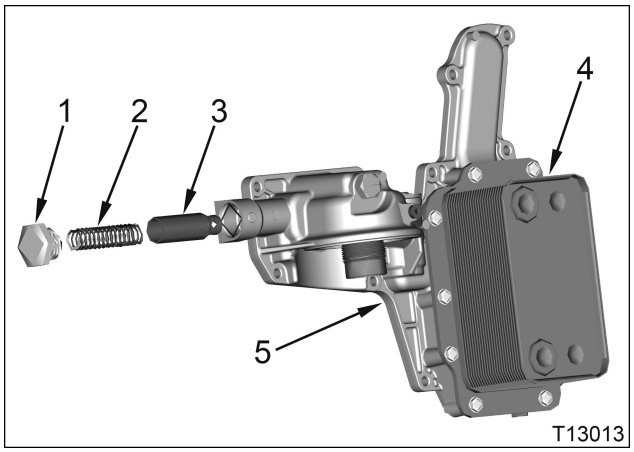


Figure 356 Pressure Regulator Valve Removal

1. Pressure regulator valve cap with O-ring
2. Pressure regulator valve spring
3. Pressure regulator valve piston
4. Oil cooler
5. Oil cooler housing

1. Remove pressure regulator valve cap from the oil cooler housing.
2. Remove and discard pressure regulator valve cap O-ring.
3. Inspect pressure regulator valve cap. If damaged or corroded, replace.
4. Remove pressure regulator spring and piston from oil cooler housing.
5. Inspect spring and piston. If damaged, replace.

Thermal Valve (Oil)

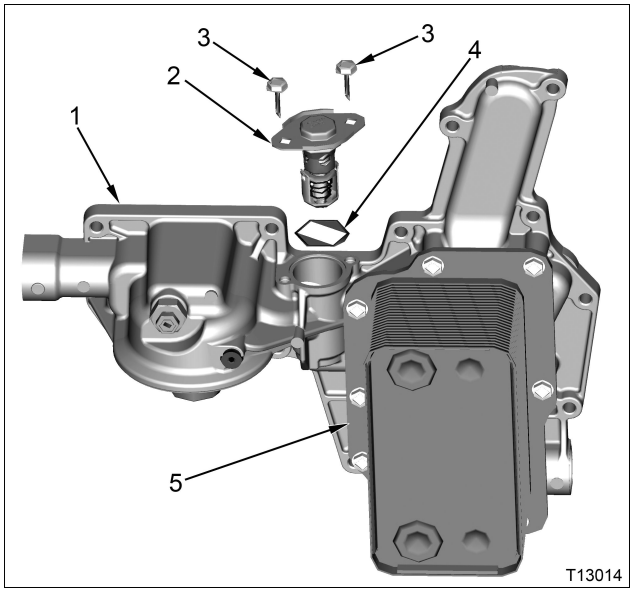


Figure 357 Thermal Valve Removal

1. Oil cooler housing
2. Thermal valve
3. M8 x 25 screw (2)
4. O-ring
5. Oil cooler

1. Loosen and remove, but do not discard two M8 x 25 screws securing thermal valve to oil cooler housing.
2. Remove thermal valve from oil cooler housing.
3. Remove and discard thermal valve O-ring.

Oil Cooler

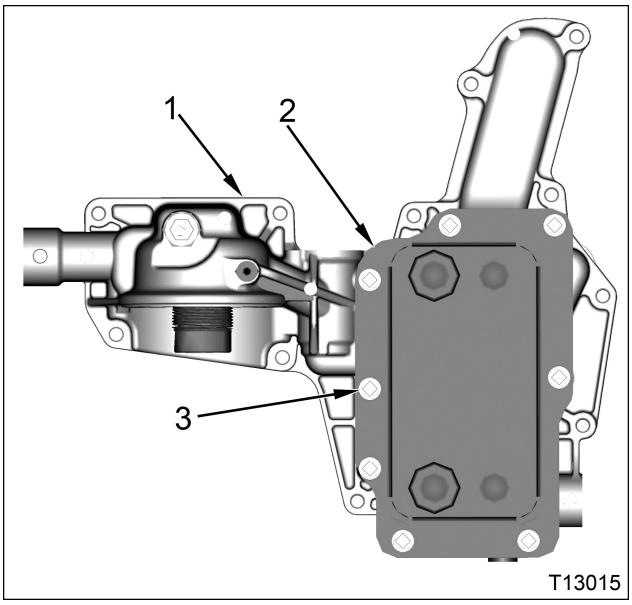


Figure 358 Oil Cooler Removal

1. Oil cooler housing
2. Oil cooler
3. M8 x 25 screw (8)

1. Loosen and remove, but do not discard, eight M8 x 25 screws securing the oil cooler to the oil cooler housing.

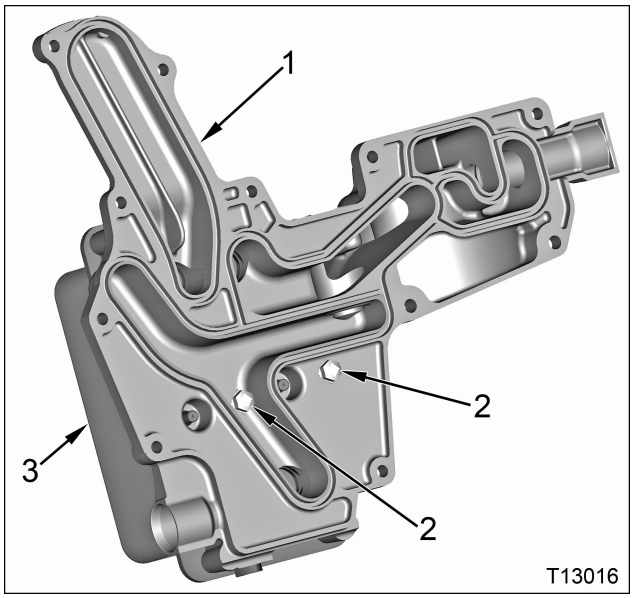


Figure 359 Oil Cooler Mounting Nuts

1. Oil cooler housing
2. M8 serrated nut (2)
3. Oil cooler

2. Flip oil cooler housing over and remove, do not discard, two M8 serrated nuts securing the oil cooler to the oil cooler housing.

CAUTION: To prevent engine damage, do not use excessive force against aluminum cooler plate to separate oil cooler from oil cooler housing. Do not apply any force to oil cooler fins.

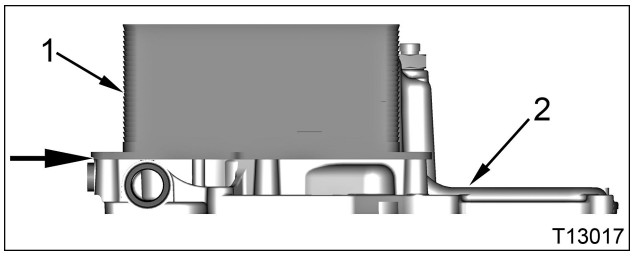


Figure 360 Oil Cooler Separation Point

1. Oil cooler
2. Oil cooler housing

3. Separate oil cooler from the oil cooler housing by applying just enough force at large arrow for separation.
4. Drain oil and coolant out of oil cooler.

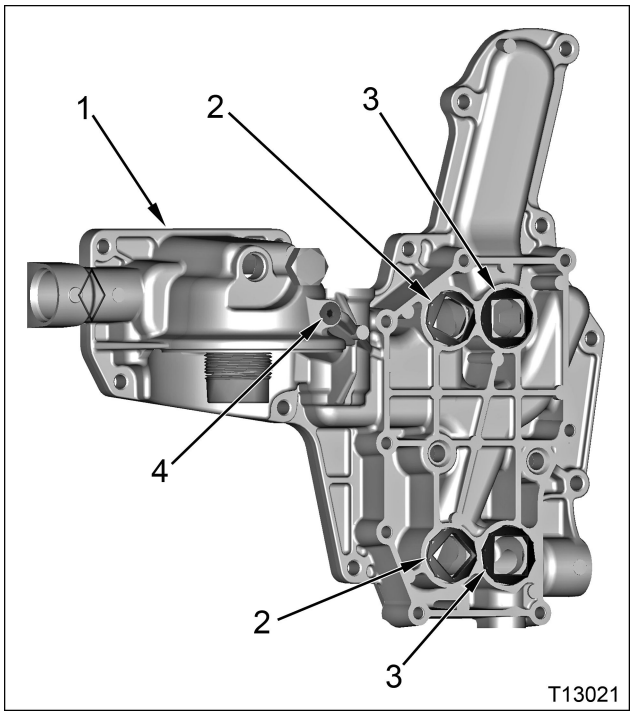


Figure 361 Oil Cooler Seals

1. Oil cooler housing
2. Oil cooler to housing gasket - oil (2)
3. Oil cooler to housing gasket - coolant (2)
4. M12 plug with seal

5. Remove and discard two oil cooler housing gaskets for oil and two oil cooler housing gaskets for coolant from oil cooler housing.
6. Remove M12 plug and seal. Discard seal.

Cleaning, Inspection, and Testing

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

Clean Oil Cooler Housing

CAUTION: To prevent engine damage, replace the oil cooler if an engine bearing fails. Bearing debris can not be removed from the oil cooler.

CAUTION: To prevent engine damage, do not clean the assembled oil cooler housing in solvent. Solvent will be trapped in the oil cooler, regulator valve assembly, and thermal valve assembly.

If not already done, remove the following components from the oil cooler housing before cleaning with solvent:

- Oil cooler
- Regulator valve assembly
- Thermal valve assembly
- Fitting & O-ring (with screen)
- All plugs and O-rings

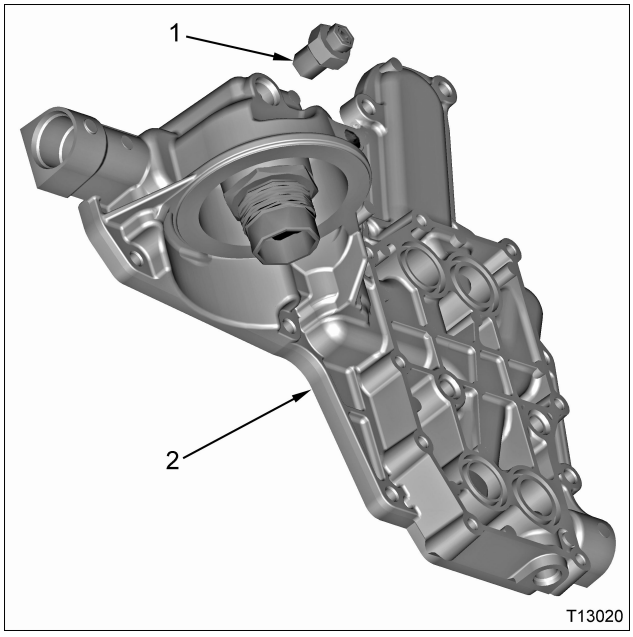


Figure 362 Fitting & O-ring (with screen) (turbocharger oil supply)

1. Fitting & O-ring (with screen)
2. Oil cooler housing

CAUTION: To prevent turbocharger damage, turbocharger oil supply fitting filter screen must be clean.

1. Remove fitting & O-ring (with screen) (turbocharger oil supply) from side of oil cooler housing. Remove and discard O-ring from fitting.

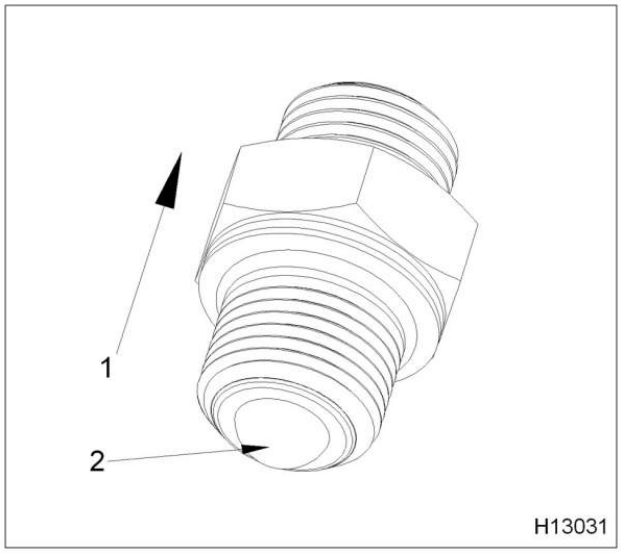


Figure 363 Fitting & O-ring (with screen) (turbocharger oil supply)

1. Direction of oil flow
2. Wire mesh screen

2. Inspect wire mesh screen for damage or particle obstruction. Clean or replace fitting if necessary.
3. The oil cooler housing can be cleaned in solvent and blow dry with filtered compressed air as follows:
   - Clean the disassembled oil cooler housing in a suitable solvent.
   - Flush and drain oil cooler housing to remove any residue. Dry oil cooler housing with filtered compressed air.
   - Check oil cooler housing for blocked orifices and damaged threads. Replace housing if required.
4. Once oil cooler housing has been cleaned and inspected or a new oil cooler housing is to be used, lubricate a new O-ring with clean engine oil and install onto fitting with screen.
5. Install fitting into oil cooler housing and finger tighten.
6. Tighten fitting (turbocharger oil supply tube) to special torque (page 283).

Oil Cooler Pressure Test

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

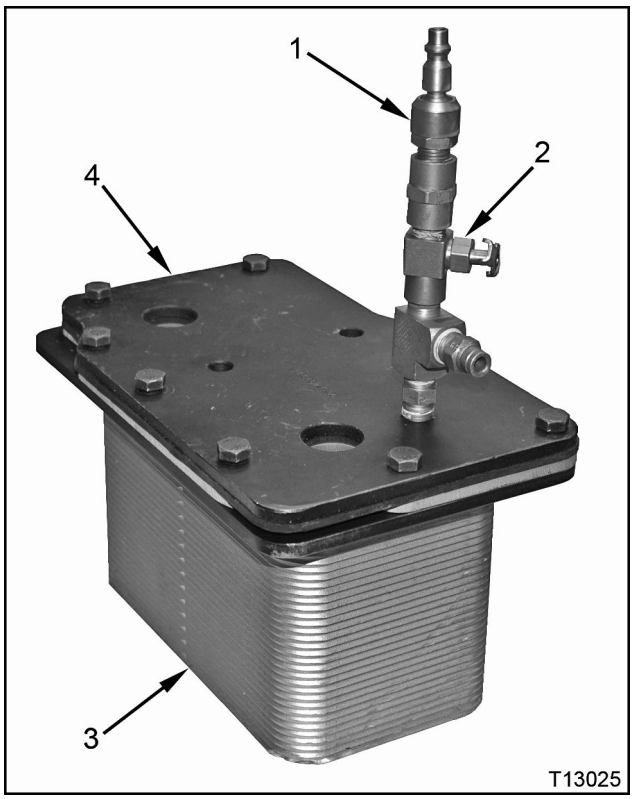


Figure 364 Oil Cooler Leak Test

1. Air pressure regulator connector
2. Port valve
3. Oil cooler housing
4. Oil Pressure Cooler Test Plate

1. Attach Oil Cooler Pressure Test Plate (page 283) to oil cooler housing and torque eight M8 x 25 screws to special torque (page 283).
2. Install a port valve in the coolant side of the oil cooler housing. Close the port valve.
3. Pour water into both oil ports of the oil cooler housing. Fill ports to ¼ inch below the top edge of the oil cooler housing.

CAUTION: To prevent oil cooler damage, do not exceed 207 kPa (30 psi) of regulated air pressure.

4. Connect regulated air pressure and do not to exceed 207 kPa (30 psi) to port valve.
5. Open port valve and allow regulated air to enter oil cooler housing.
6. Observe oil cooler housing ports for bubbles in water.
   - If bubbles appear in the water there is a leak in the housing, replace the oil cooler housing.
   - If no bubbles appear, continue with the next step.
7. Spray soapy water around the outer surfaces of the oil cooler housing.
   - Inspect oil cooler housing and test plate for leaks. If test plate fittings leak, tighten fittings and continue looking for leaks. Air bubbles at any location on the oil cooler housing indicate a leak. Replace oil cooler housing.
   - If no bubbles appear from the soapy water spray the oil cooler housing has passed the pressure test and can be reused.
8. Close port valve and turn off regulated air pressure. Disconnect air supply.
9. Remove port valve from Oil Cooler Pressure Test Plate.
10. Remove Oil Cooler Pressure Test Plate from oil cooler housing.
11. Drain water out of oil cooler housing.
12. Using filtered compressed air, dry the inside and outside of the oil cooler housing.

Assemble

Oil Cooler

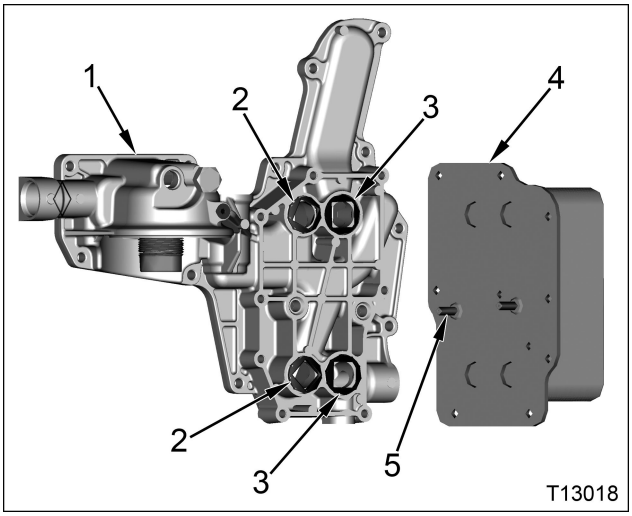


Figure 365 Oil Cooler Seals and Oil Cooler

1. Oil cooler housing
2. Oil cooler to housing gasket - oil (2)
3. Oil cooler to housing gasket - coolant (2)
4. Oil cooler
5. Oil cooler alignment studs (part of cooler)

1. Place oil cooler housing onto a clean work bench, flat side down.
2. Lubricate two new oil cooler housing gaskets for oil with clean engine oil and install into the oil cooler housing recess.
3. Lubricate two new oil cooler housing gaskets for coolant with clean coolant and install into the oil cooler housing recess.
4. Align oil cooler over oil cooler housing. Insert oil cooler studs through oil cooler housing and push down onto the oil cooler.

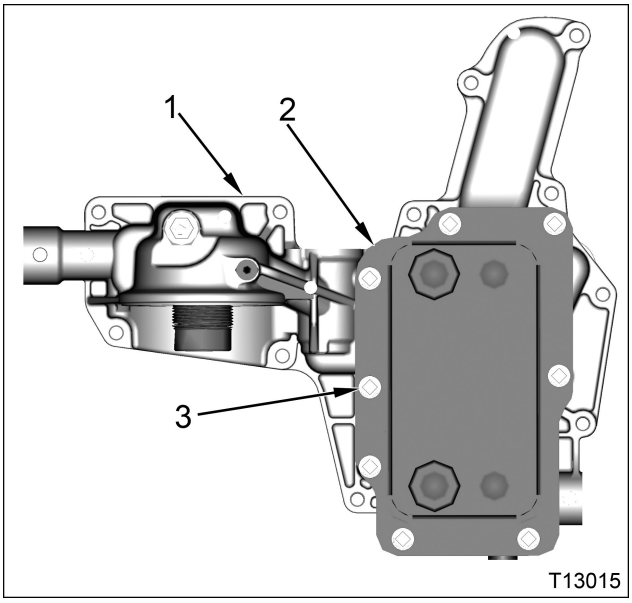


Figure 366 Oil Cooler

1. Oil cooler housing
2. Oil cooler
3. M8 x 25 screw (8)

CAUTION: To prevent engine damage, do not use power tools to install oil cooler screws.

5. Install eight M8 x 25 screws to the oil cooler and oil cooler housing. Finger tighten screws.
6. Tighten oil cooler mounting screws to special torque (page 283).

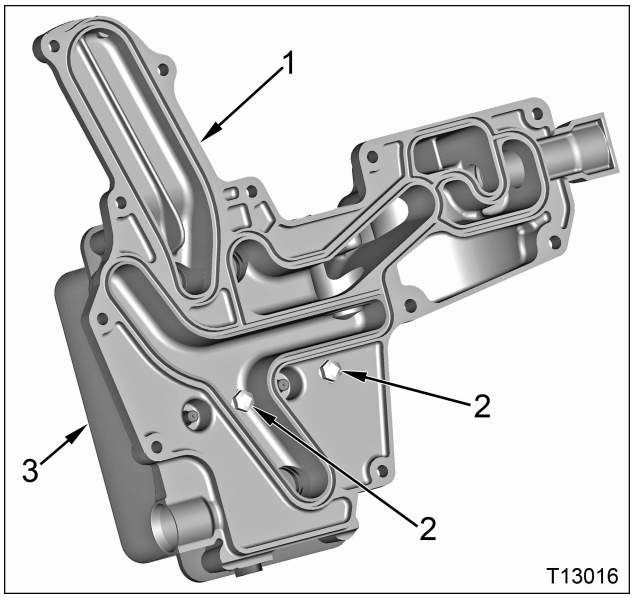


Figure 367 Oil Cooler Mounting Nuts

1. Oil cooler housing
2. M8 serrated nut (2)
3. Oil cooler

7. Flip oil cooler housing and oil cooler over and install two M8 serrated nuts to the oil cooler studs sticking through the oil cooler housing. Finger tighten M8 serrated nuts.
8. Tighten two M8 serrated nuts to special torque (page 283).

Thermal Valve (Oil)

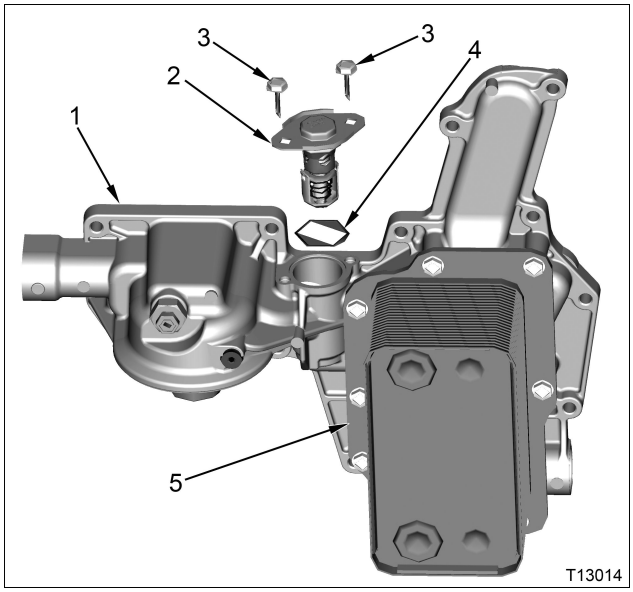


Figure 368 Thermal Valve

1. Oil cooler housing
2. Thermal valve
3. M8 x 25 screw (2)
4. O-ring
5. Oil cooler

1. Lubricate a new O-ring with clean engine oil. Install O-ring onto thermal valve.
2. Install thermal valve into oil cooler housing.
3. Secure with two M8 x 25 screws. Finger tighten screws.
4. Tighten two M8 x 25 screws to special torque (page 283).

Regulator Valve (Oil)

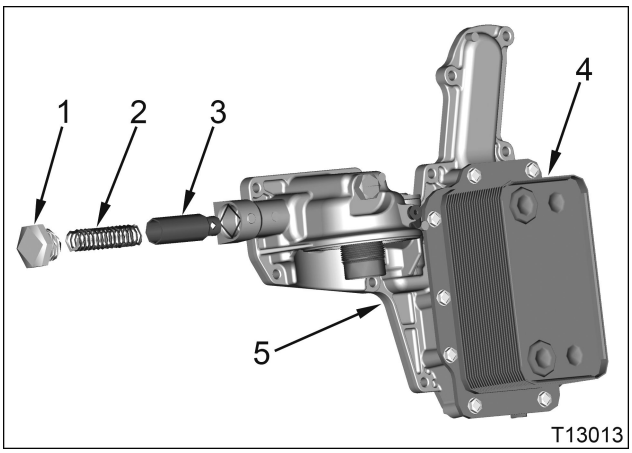


Figure 369 Pressure Regulator Valve (oil)

1. Pressure regulator valve cap with O-ring
2. Pressure regulator valve spring
3. Pressure regulator valve piston
4. Oil cooler
5. Oil cooler housing

1. Install pressure regulator valve piston and spring into oil cooler housing.
2. Lubricate new O-ring with clean engine oil and install onto pressure regulator valve cap.
3. Install pressure regulator valve cap onto oil cooler housing. Finger tighten cap.
4. Tighten pressure regulator valve cap (oil) to special torque (page 283).

Installation

Oil Cooler Module

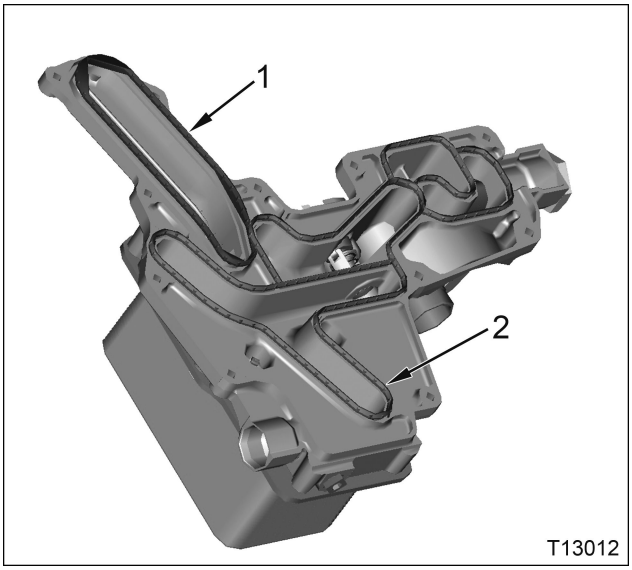


Figure 370 Oil Cooler Module Gaskets

1. Housing to crankcase gasket - coolant
2. Housing to crankcase gasket - oil

1. Lubricate a new housing to crankcase oil gasket with clean engine oil and install into oil cooler housing recess.
2. Lubricate a new housing to crankcase coolant gasket with clean coolant and install into oil cooler housing recess.
3. Clean crankcase oil cooler housing mating surface.

NOTE: Components in the following figure have been removed for clarity of tube support locations.

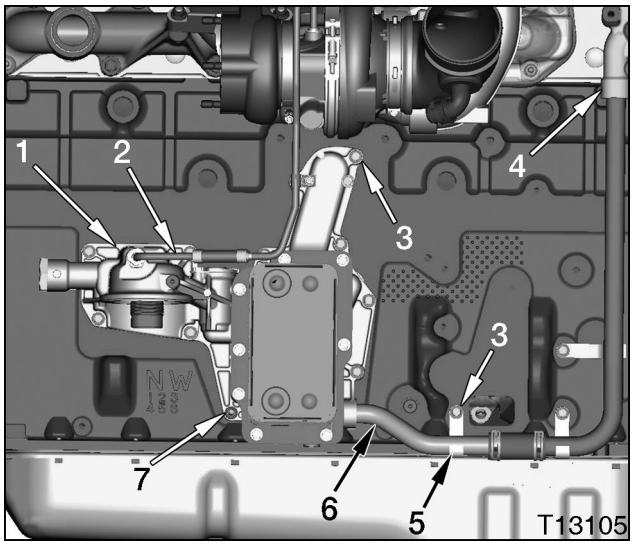


Figure 371 Oil Cooler Module and Coolant Return Tube

1. Oil cooler module
2. Turbocharger oil supply tube
3. M8 x 30 bolt (13)
4. Coolant supply housing
5. Tube support (3)
6. Coolant return tube assembly
7. M8 x 15 stud bolt

4. Lubricate a new O-ring for the coolant return tube with clean coolant and install onto tube.
5. Install crankcase breather assembly, if removed. See Crankcase Ventilation System (page 502) for more information.
6. Install coolant return tube and three M8 x 30 bolts finger tight.
7. Pull coolant return tube assembly outwards enough to engage the oil cooler module. Slide oil cooler module onto coolant return tube, then align bolt holes of oil cooler module with the mounting holes on the crankcase.
8. Place oil cooler module against crankcase and secure with ten M8 x 30 bolts and one M8 x 30 stud bolt. Finger tighten bolts.
9. Tighten M8 x 30 bolts and stud bolt to special torque (page 283).
10. Tighten three M8 x 30 bolts securing the coolant return tube assembly.
11. Uncap the open ends of the turbocharger oil supply tube and fitting.
12. Install the turbocharger oil supply tube to the oil cooler module. See Turbocharger Oil Supply Tube Assembly (page 159).
13. Refill cooling system. See the appropriate *Vehicle Operator Manual* for procedure and quantity of coolant.

Oil Filter

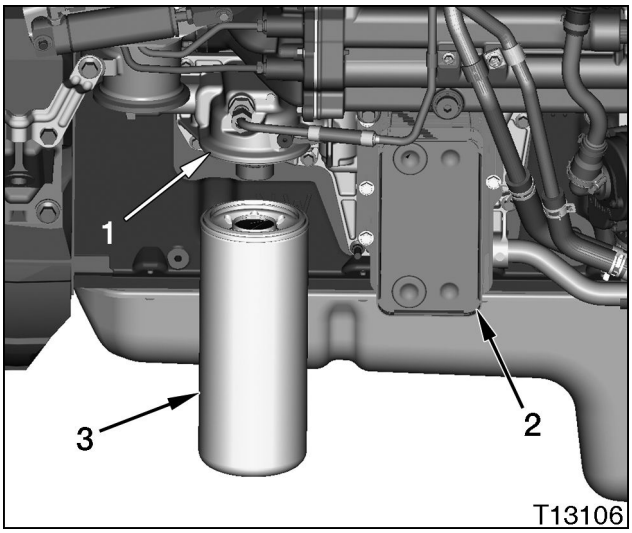


Figure 372 Oil Cooler Module Assembly

1. Oil cooler housing
2. Oil cooler
3. Oil filter

1. Lubricate new oil filter gasket with clean engine oil.

CAUTION: To prevent engine damage, install the correct oil filter for the engine application.

2. Install new oil filter on oil module housing. Verify correct oil filter is used.
   - Standard oil filter (long filter)
   - Front drive / steering axle oil filter (shorter filter)

CAUTION: To prevent engine damage, do not over tighten oil filter.

3. Hand tighten filter 2/3 to 1 full turn after gasket first contacts oil filter header.

CAUTION: To prevent engine damage, do not overfill engine with oil.

NOTE: The amount of oil used to refill the engine is dependent upon the service that was done.

4. Fill engine with the proper grade and viscosity of engine oil. See *Engine Operation and Maintenance Manual* for procedure and oil fill capacities.

Prime Lubrication System

Priming System

CAUTION: To prevent engine damage, after complete engine overhaul, prime engine with oil before starting engine. This will lubricate internal engine components during the critical initial startup phase.

NOTE: If only the oil cooler module was serviced, priming lubrication system is not required.

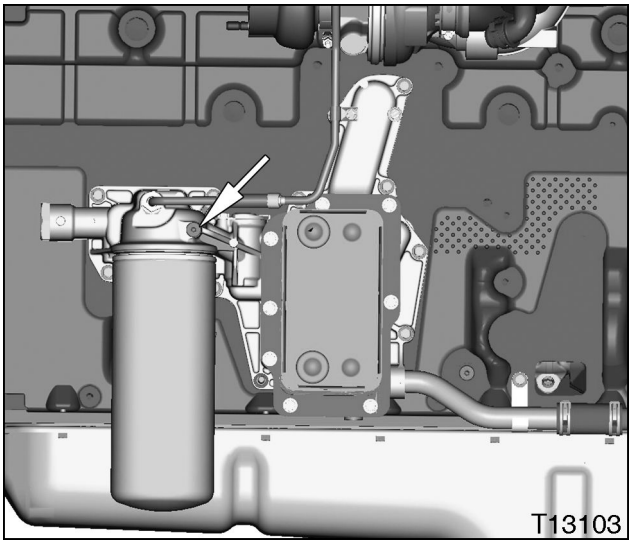


Figure 373 M12 Plug Assembly

1. Remove M12 plug assembly and pressurize lubrication system with sufficient engine oil to fill the oil filter and charge the entire lubrication system. See *Engine Operation and Maintenance Manual* for proper grade and viscosity of engine oil. Do not exceed total oil fill Specifications (page 295)
2. Install M12 plug assembly and tighten to special torque (page 283).
3. Finish filling engine with oil. Remember to subtract oil added during lubrication system pressurization and oil added directly to the oil filter.
4. Start engine and check for leaks. If oil is leaking, turn off engine and repair leaks.
5. Turn off engine. Wait 15 minutes. Check oil level and fill to the full mark.

Cranking Method (Alternate)

CAUTION: To prevent engine damage, use the Pressurization method to prime lubrication system after an engine overhaul.

1. Fill engine with oil. See *Engine Operation and Maintenance Manual* for proper grade and viscosity of engine oil. Do not exceed total oil fill Specifications (page 295).
2. Disconnect Camshaft Position (CMP) sensor connector.
3. Crank engine until the oil pressure gauge shows sufficient oil pressure.
4. After oil pressure is evident in the lubrication system, reconnect CMP sensor connector and start engine.
5. Start engine and check for leaks. Check for oil leaks. If oil is leaking turn off engine and repair leaks.
6. Turn off engine and clear CMP fault code. See *Engine Diagnostic Manual*.
7. Check oil level and fill to the full mark.

Specifications

Oil cooler, all engines with front drive axle	33 plates
Oil cooler, MaxxForce® DT	23 plates
Oil cooler, MaxxForce® 9 and 10	33 plates
Oil pressure regulator valve, opening pressure	393 kPa (57 psi) @ 38 °C (100 °F)
Thermal valve, opening pressure	206 - 241 kPa (30 - 35 psi) @ 111 °C (232 °F)

Special Torque

Coolant drain plug, M16	19 N·m (14 lb·ft)
Coolant tube bracket bolts, M8 x 30	31 N·m (23 lb·ft)
Fitting (turbocharger oil supply tube)	47 N·m (35 lb·ft)
Oil filter adapter	80 N·m (59 lb·ft)
Oil cooler module mounting bolts and stud bolt, M8 x 30	31 N·m (23 lb·ft)
Oil cooler mounting screws, M8 x 25	23 N·m (17 lb·ft)
Oil cooler M8 serrated nuts	22 N·m (16 lb·ft)
Oil cooler pressure test plate mounting screws M8 x 25	23 N·m (17 lb·ft)
Oil pressure regulator valve cap	70 N·m (51 lb·ft)
Plug assembly, M12	5 N·m (46 lb·in)
Thermal valve screws, M8 x 25	23 N·m (17 lb·ft)

Special Service Tools

Air pressure regulator	Obtain locally
Loctite® 272	Obtain locally
Oil Cooler Pressure Test Plate	ZTSE4654
Oil filter wrench	Obtain locally

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Exploded Views

Front Sump

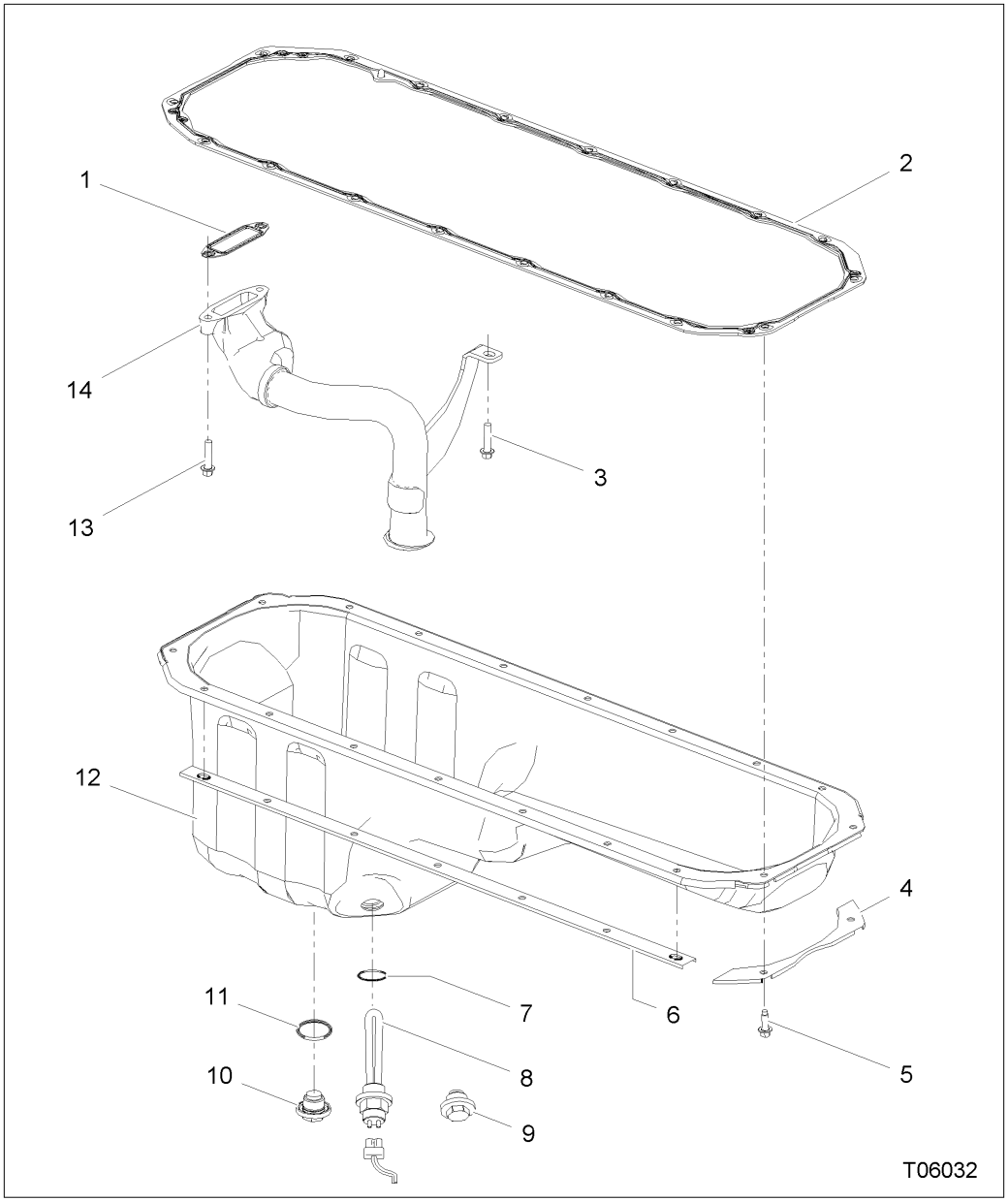


Figure 374 Oil Pan and Oil Suction Tube (front sump)

1. Oil suction tube gasket
2. Oil pan gasket
3. M10 x 25 bolt
4. Oil pan end rail stiffener (2)
5. M8 x 24 bolt (18)
6. Oil pan rail stiffener (2)
7. Drain plug gasket
8. Heater element (optional)
9. Flanged hex head plug (M25 x 1.5, without oil pan heater)
10. Flanged hex head plug (oil drain plug)
11. O-ring seal, #213
12. Oil pan (front sump)
13. M8 x 35 bolt (2)
14. Front sump suction tube assembly

Rear Sump

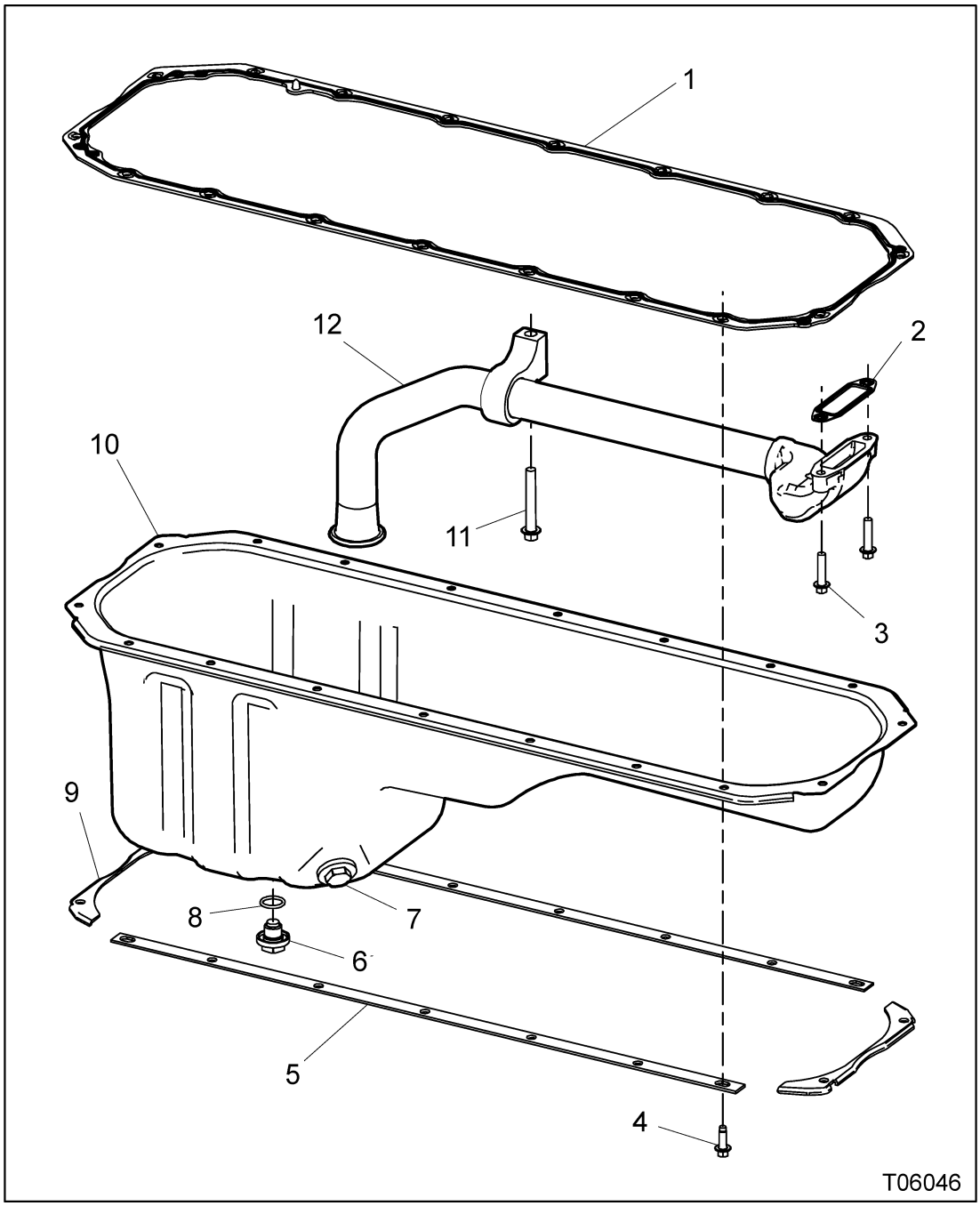


Figure 375 Oil Pan and Oil Suction Tube (rear pump)

1. Oil pan gasket
2. Oil suction tube gasket
3. M8 x 35 bolt (2)
4. M8 x 24 bolt (18)
5. Oil pan rail stiffener (2)
6. Flanged hex head plug (oil drain)
7. Flanged hex head plug (M25 x 1.5, without oil pan heater)
8. O-ring #213 seal
9. Oil pan end rail stiffener (2)
10. Oil pan (rear sump)
11. M10 x 70 bolt
12. Suction rear tube assembly (rear sump)

Removal

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

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

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

WARNING: To prevent personal injury or death, 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: Removal and installation procedures in this section apply to both front and rear sump oil pan and suction tube configurations.

NOTE: When performing specific component removal, only remove components necessary for access.

Drain Engine Oil

1. Place an oil drain pan under the engine oil pan.

WARNING: To prevent personal injury or death, wear protective clothing when draining hot oil.

2. Drain engine oil by removing oil drain plug installed in the bottom of the oil pan.
3. Discard oil drain plug O-ring #213 seal.
4. Inspect drain plug and replace if necessary.
5. Lubricate a new O-ring #213 seal with clean engine oil and install onto oil drain plug.
6. After oil has drained, install oil drain plug in the bottom of the oil pan and tighten to special torque (page 295).
7. Recycle or dispose of oil according to applicable regulations.

Oil Pan and Gasket

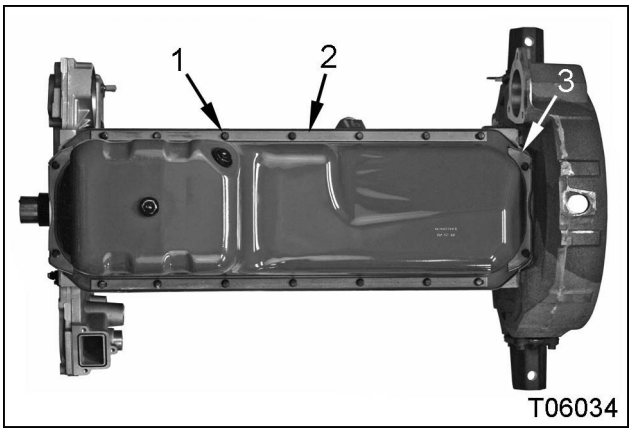


Figure 376 Oil Pan Bolts and Rail Stiffeners (typical)

1. M8 x 24 bolt (18)
2. Oil pan rail stiffener (2)
3. Oil pan end rail stiffener (2)

WARNING: To prevent personal injury or death, allow engine to cool before removing components.

1. Remove 18 M8 x 24 oil pan mounting bolts.
2. Remove two oil pan end rail stiffeners and two oil pan rail stiffeners.
3. Separate oil pan from the oil pan gasket and remove oil pan from engine.

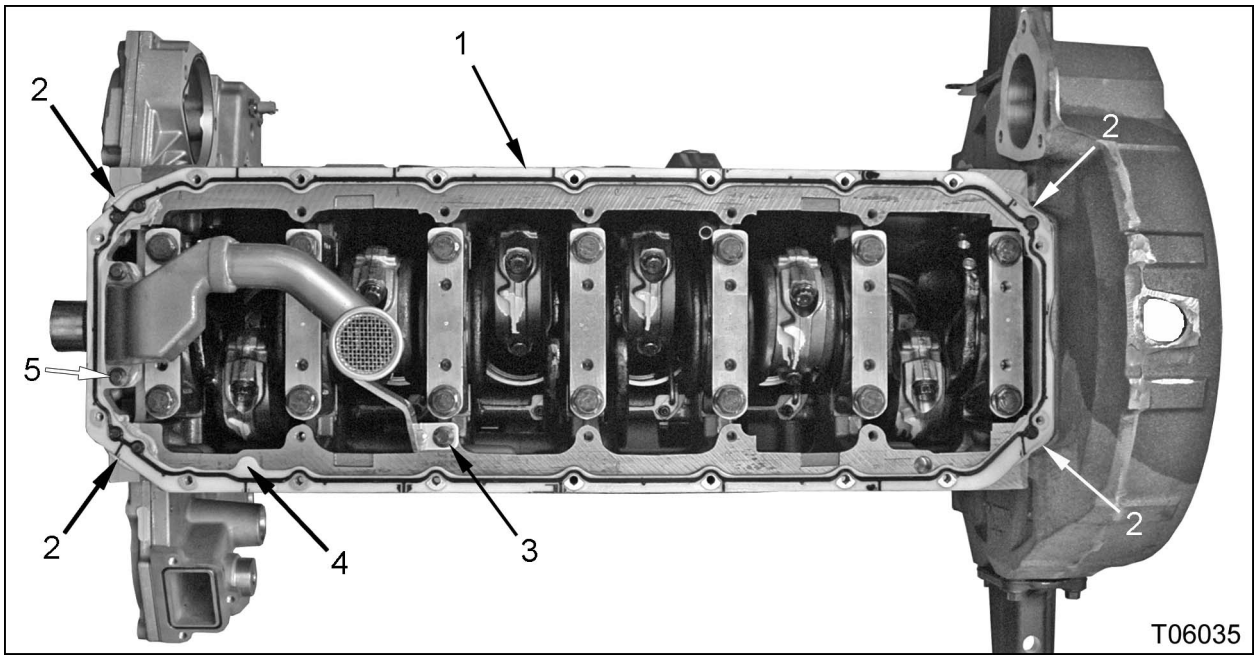


Figure 377 Oil Pan Gasket, RTV Sealant Locations, and Suction Tube Assembly (front sump, typical)

1. Oil pan gasket
2. RTV sealant locations
3. M10 x 25 bolt (front sump)
4. Oil pan gasket dowel (into crankcase)
5. M8 x 35 bolt (2)

4. To preserve the gasket, cut through RTV sealant under the oil pan gasket at indicated locations on the oil pan mounting surface using a flat gasket scraper or similar tool. Cut parallel to the gasket path.

NOTE: The oil pan gasket is reusable if it is not cracked and the sealing surface is in good condition.

5. Remove the oil pan gasket from the front cover, flywheel housing, and crankcase. To ensure gasket reusability, carefully remove any residual RTV from gasket surface.

Suction Tube Assembly

1. Remove M10 bolt holding the suction tube bracket to the crankcase.
2. Remove two M8 x 35 bolts connecting the suction tube assembly to the front cover.
3. Remove the suction tube assembly and discard gasket.

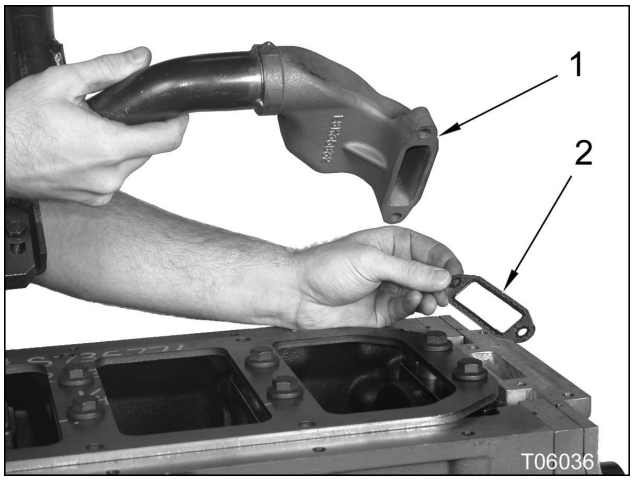


Figure 378 Suction Tube Assembly and Gasket (typical)

1. Suction tube assembly
2. Suction tube gasket

Cleaning and Inspecting

Oil Pan and Suction Tube

1. Remove RTV sealant from the crankcase, oil pan, front cover, and flywheel housing mating surfaces with a flat scraper. Scrape parallel to the gasket path.
2. Clean the oil pan, front cover, flywheel housing, suction tube assembly, and crankcase mating surfaces thoroughly with a suitable solvent.
3. Clean and inspect the oil pan gasket. Inspect gasket for cracks or damaged sealing surface to verify gasket reusability. If gasket is damaged, discard and replace with new gasket.
4. Clean and inspect the oil suction tube assembly. Make sure the suction tube is free of obstructions, cracks, or other damage.
5. Check the oil pan for cracks and damage. Replace components if necessary.

Installation

Suction Tube Assembly

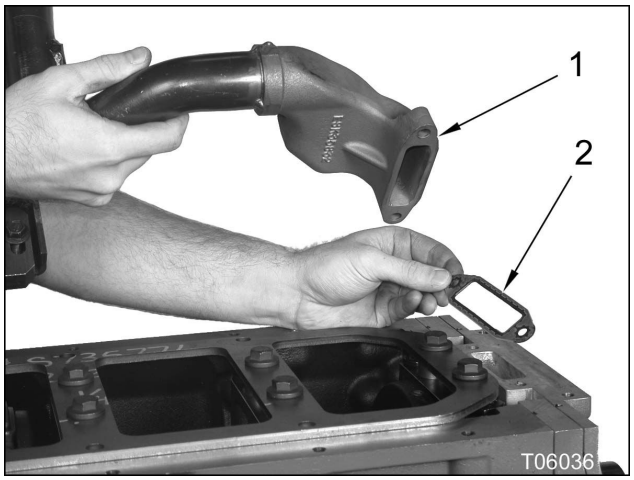


Figure 379 Suction Tube Assembly and Gasket (typical)

1. Suction tube assembly
2. Suction tube gasket

1. Install suction tube assembly and a new gasket on the front cover and finger tighten two M8 x 35 bolts.

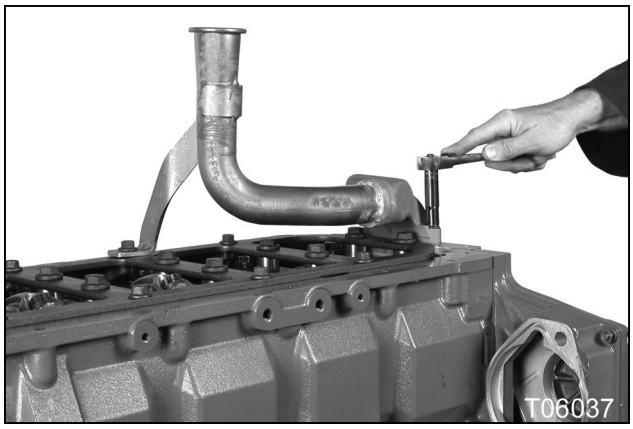


Figure 380 Installing Suction Tube Assembly (typical)

2. Install one M10 bolt connecting the oil suction tube mounting bracket to the crankcase and finger tighten.
3. Tighten two M8 x 35 bolts to special torque (page 295).
4. Tighten M10 bolt to standard torque (page 553).

Oil Pan and Gasket

1. If removed, install flywheel housing (page 419) before oil pan.
2. If removed, install front cover (page 321) before oil pan.

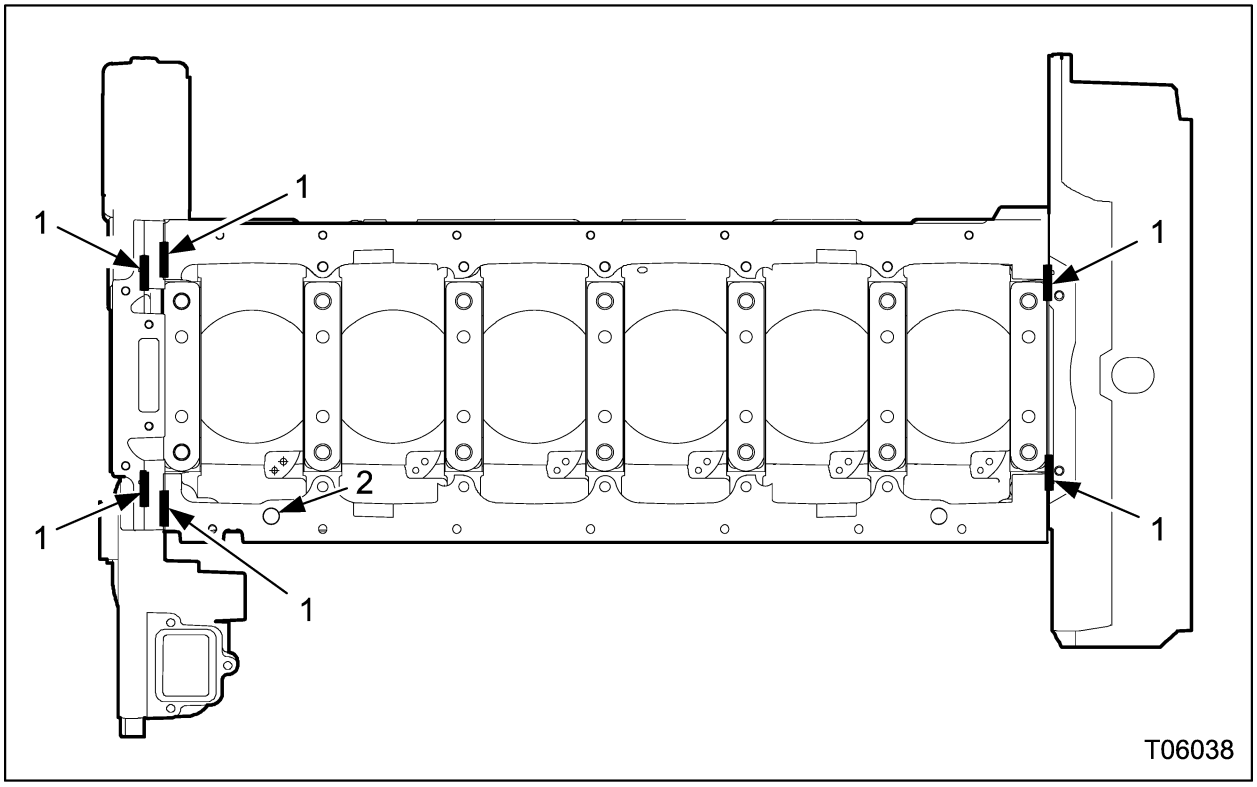


Figure 381 Oil Pan Gasket Mounting Surface (typical)

1. RTV sealant locations
2. Oil pan gasket dowel hole

CAUTION: Install components and tighten bolts within 5 minutes of Liquid Gasket (RTV) application.

3. Apply a 6 mm (0.25 in) bead of Wacker® T – 442 RTV sealant (page 295) to the six locations on the oil pan mounting surface. These locations coincide with gasket joints between the front cover halves, crankcase, and flywheel housing.
4. Before the RTV sealant dries, install a clean oil pan gasket on the crankcase mounting surface. Make sure the oil pan gasket dowel is aligned with the hole in the crankcase mounting surface.
5. Install the oil pan on the crankcase.

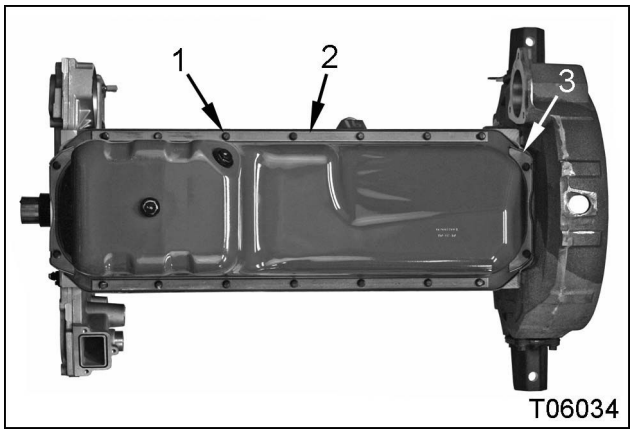


Figure 382 Oil Pan, Bolts, and Rail Stiffeners (typical)

1. M8 x 24 bolt (18)
2. Oil pan rail stiffener (2)
3. Oil pan end rail stiffener (2)

6. Install two oil pan end rail stiffeners and two oil pan rail stiffeners on the oil pan.
7. Install 18 M8 x 24 oil pan mounting bolts finger tight.
8. Tighten M8 x 24 bolts to special torque (page 295).

Fill Engine with Oil

CAUTION: To prevent engine damage, after engine or lubrication system service, prime engine with oil (page 281) before starting engine. This will lubricate internal engine components during the critical initial startup phase.

1. Fill engine with the proper grade, viscosity, and quantity of engine oil. See *Engine Operation and Maintenance Manual*. Do not exceed engine oil Specifications (page 295).
2. Start engine and check for oil leaks. If oil is leaking, turn off engine, repair leaks, and repeat step.
3. Turn off engine.
4. Wait 15 minutes. Check oil level and fill to the full mark.

Specifications

Lube system capacity (after rebuild and new filter)	32 L (34 quarts US)
Lube system capacity (after oil drain and filter change)	28 L (30 quarts US)

Special Torque

Oil pan drain plug	68 N·m (50 lb·ft)
Oil pan heater plug	68 N·m (50 lb·ft)
Oil pan mounting bolts, M8 x 24	32 N·m (24 lb·ft)
Oil suction tube bolts, M8 x 35	27 N·m (20 lb·ft)

Special Service Tools

Wacker® T – 442 RTV sealant	Obtain locally

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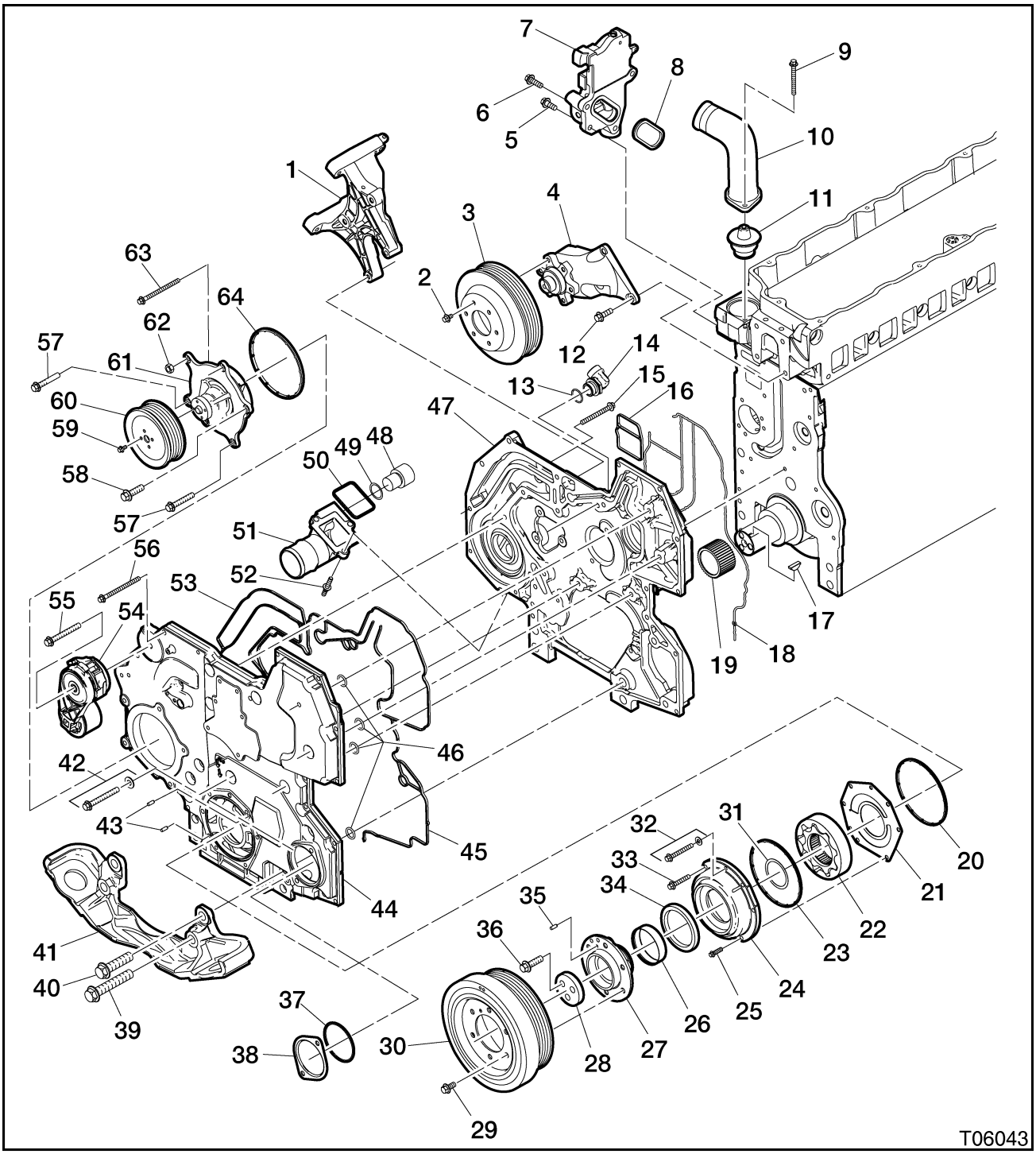


Figure 383 Front Cover and Related Components, Less Gear Train (typical)

1. Alternator support
2. M8 x 20 bolt (6)
3. Fan drive pulley
4. Fan housing assembly
5. M10 x 30 bolt (3)
6. M10 x 45 bolt
7. Coolant supply housing (refrigerant compressor mount)
8. Coolant port seal
9. M8 x 25 bolt (2)
10. Water outlet tube
11. Thermostat assembly
12. M10 x 30 bolt (3)
13. O-ring
14. 90° fitting
15. M8 x 55 bolt
16. Front cover rear half (coolant) gasket
17. Vibration damper key
18. Front cover rear half (oil) gasket
19. Oil pump spline drive
20. Oil pump seal (housing plate)
21. Oil pump housing plate
22. Oil pump rotor assembly
23. Oil pump seal (housing)
24. Oil pump housing
25. M8 x 25 bolt (4) (See Oil Pump Assembly (page 312))
26. Wear sleeve (POSE dust seal for MaxxForce® 9 & 10)
27. Damper hub
28. Damper retainer
29. M10 x 25 bolt (6)
30. Vibration damper assembly
31. Washer, seal
32. M8 x 80 bolt and seal assembly
33. M8 x 60 flange bolt (2)
34. Oil front seal
35. Dowel pin
36. M12 x 40 (12 point) damper bolt, (3)
37. O-ring seal, #235 (PTO equipped only)
38. PTO adapter cover (PTO equipped only)
39. M18 x 100 bolt, lower (2)
40. M18 x 70 bolt, upper (2)
41. Engine front mount bracket
42. M8 x 50 bolt and seal assembly
43. Dowel 5/16 (2)
44. Front cover (front half)
45. Front cover front half (oil) gasket seal assembly
46. O-ring (4)
47. Front cover (rear half)
48. O-ring plug (33 mm)
49. O-ring
50. Water inlet gasket
51. Water inlet elbow
52. M8 x 30 stud bolt (3)
53. Front cover front half (coolant) gasket
54. Tensioner (belt)
55. M10 x 90 bolt
56. M10 x 70 bolt
57. M8 x 40 bolt (2)
58. M8 x 16 bolt
59. M6 x 12 bolt (4)
60. Water pump pulley
61. Water pump assembly
62. M8 nut
63. M8 x 70 bolt (See Water Pump Assembly (page 307))
64. Water pump seal

Removal

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

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

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

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

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

NOTE: Valve train failures from broken or bent push rods, valves, rocker arms, and worn valve retainers and rotators can be caused by improper gear train timing. Depending on valve lash setting, if the camshaft gear is improperly timed by one tooth, the pistons will strike the intake or exhaust valves.

NOTE: When performing specific component removal, only remove components necessary for access.

Dual Drive Belt

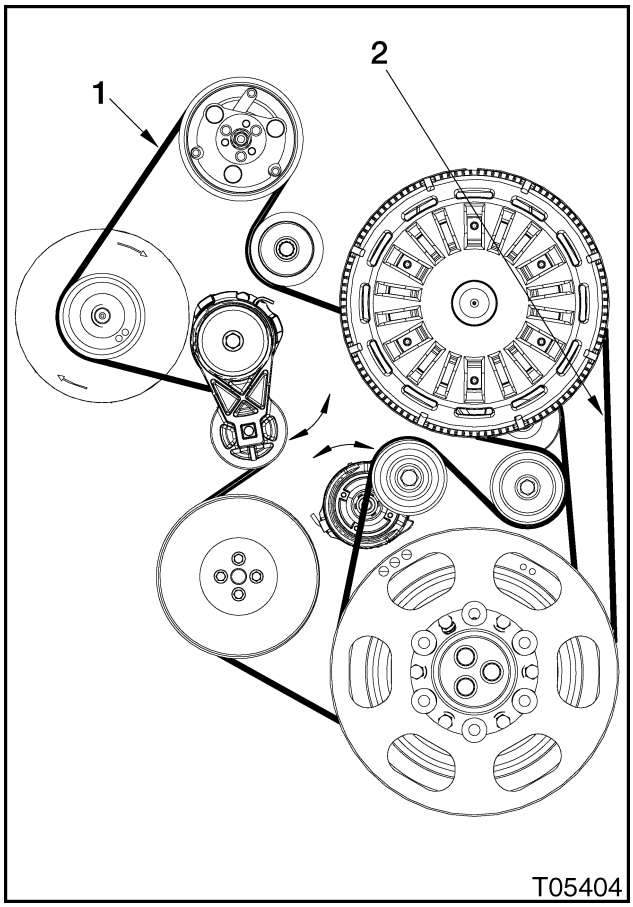


Figure 384 Dual Drive Belt Routing

1. Inner drive belt
2. Outer drive belt

1. Rotate tensioner (outer belt) counter clockwise, using a 16 mm socket and a ratchet or breaker bar.
2. Remove outer drive belt and release tensioner (outer belt).
3. Insert 1/2 inch square drive ratchet or breaker bar into tensioner (inner belt) square hole.
4. Rotate tensioner (inner belt) clockwise to release belt tension.
5. Remove drive belt and release automatic belt tensioner assembly (inner).

Single Drive Belt

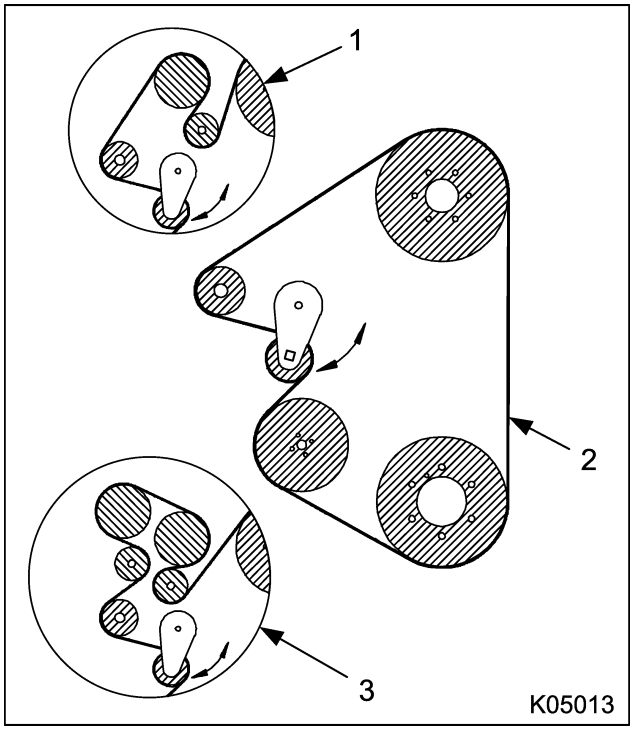


Figure 385 Single Drive Belt Routing

1. Single refrigerant compressor and single idler pulley
2. Without refrigerant compressor
3. Dual refrigerant compressors and dual idler pulleys

1. Insert 1/2 inch square drive ratchet or breaker bar into automatic belt tensioner assembly square hole.
2. Rotate automatic belt tensioner assembly clockwise to release belt tension.
3. Remove drive belt and release automatic belt tensioner assembly.

Dual Idler Pulleys

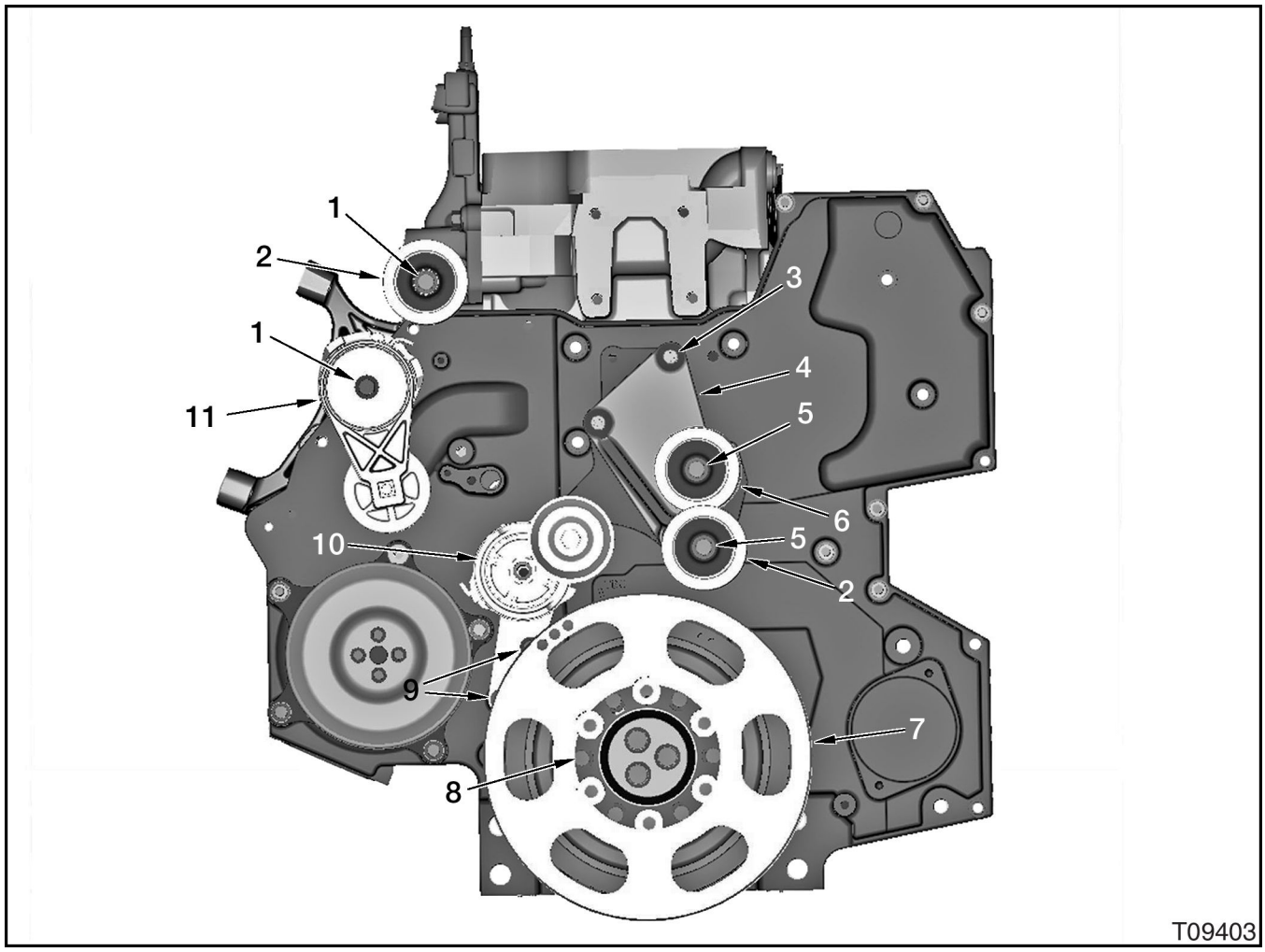


Figure 386 Automatic Belt Tensioner Assembly and Dual Idler Pulley Bolt Locations

1. M10 x 90 bolt (2)
2. Flat idler pulley (2)
3. M8 x 22 Torx® socket head bolt (3)
4. Idler pulley bracket
5. M10 x 30 bolt (2)
6. Pulley (idler)
7. Pulley (crankshaft)
8. M10 x 25 bolt (6)
9. M8 x 75 bolt (2)
10. Tensioner (outer belt)
11. Tensioner (inner belt)

1. Remove six M10 x 25 bolts and remove crankshaft pulley.
2. Remove two M8 x 75 bolts and the tensioner (outer belt).
3. Remove M10 x 90 bolt and the tensioner (inner belt).
4. Remove M10 x 30 bolt and the idler pulley.
5. Remove M10 x 30 bolt and flat idler pulley.
6. Remove M10 x 90 bolt and flat idler pulley from coolant supply housing.
7. Remove three M8 x 22 Torx® socket head bolts and the idler pulley bracket.

Alternator Support

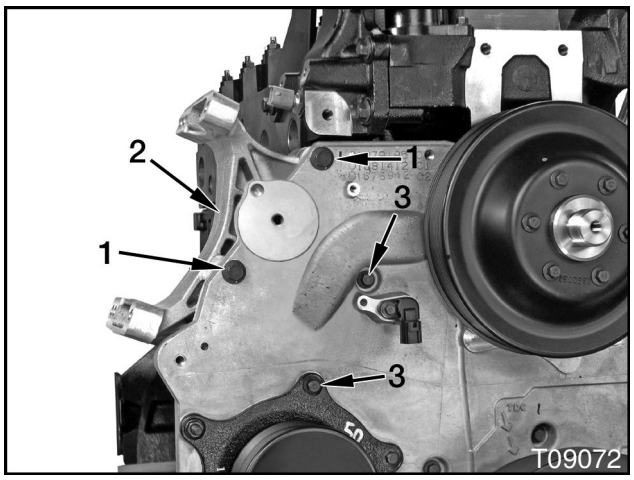


Figure 387 Alternator Support

1. M10 x 70 bolt (2)
2. Alternator support
3. M8 x 70 bolt (2)

1. Remove two M8 x 70 bolts.
2. Remove two M10 x 70 bolts.
3. Remove alternator support.

Secondary Compressor Support, Flat Idler Pulleys, and Idler Support Plate

NOTE: The following procedure only applies to engines equipped with dual refrigerant compressor option.

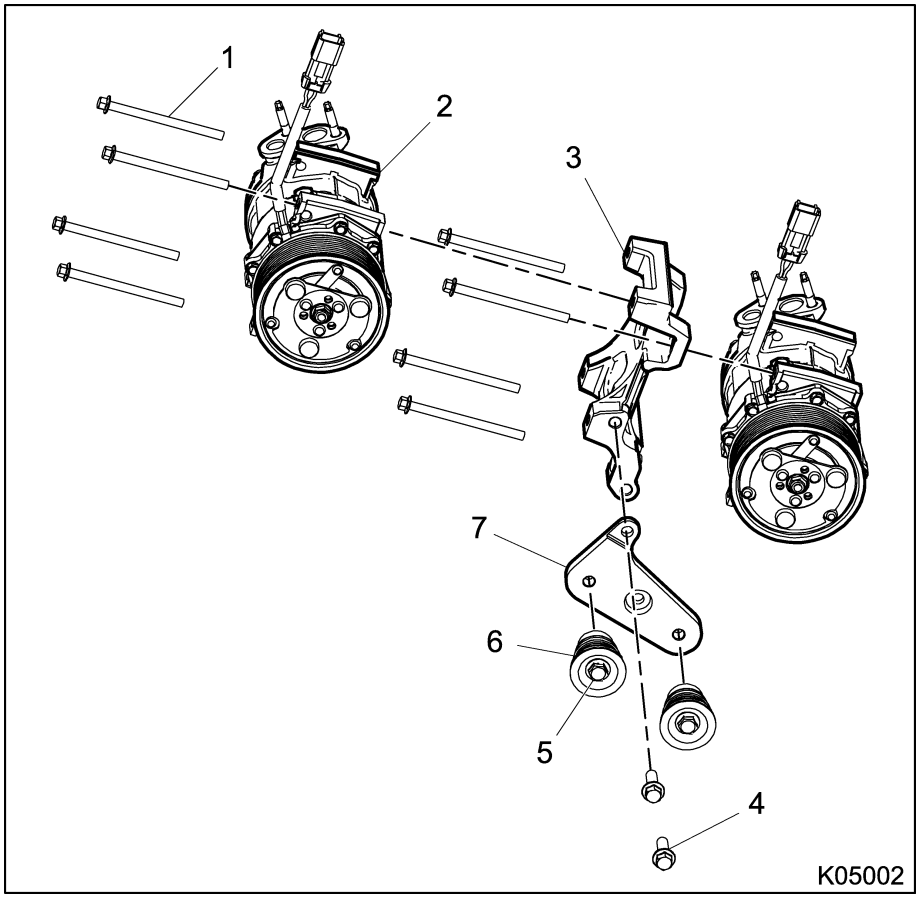


Figure 388 Dual Refrigerant Compressor Support

1. M8 x 110 bolt (8)
2. A/C (refrigerant) compressor (2)
3. Secondary refrigerant compressor support
4. M10 x 30 bolt (2)
5. M10 x 60 bolt (2)
6. Flat idler pulley assembly (2)
7. Idler support plate

WARNING: To prevent personal injury or death, do not open pressurized refrigerant lines.

1. Remove four M8 x 110 bolts holding the outer refrigerant compressor to the secondary refrigerant compressor support.
2. Move outer refrigerant compressor out of the way and secure with a strap or remove from engine.
3. If equipped, remove two M10 x 60 bolts and remove two flat idler pulley assemblies.
4. If equipped, remove two M10 x 30 bolts and remove the idler support plate from the secondary refrigerant compressor support.
5. Remove four M8 x 110 bolts holding the secondary refrigerant compressor support and inner refrigerant compressor to the cylinder head.

Coolant Supply Housing (Refrigerant Compressor Mount)

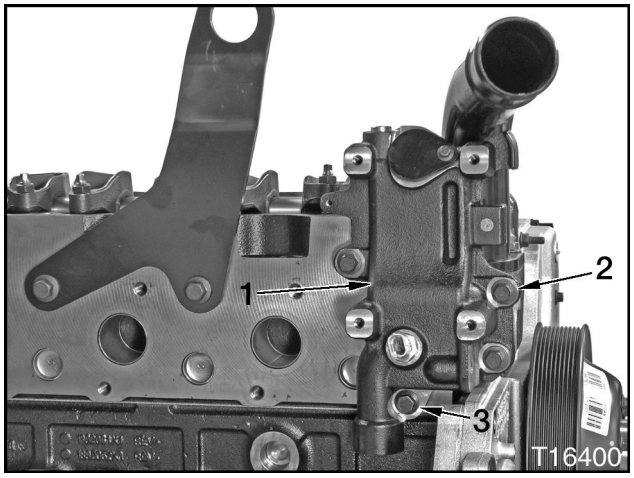


Figure 389 Coolant Supply Housing

1. Coolant supply housing (refrigerant compressor mount)
2. M10 x 30 bolt (3)
3. M10 x 45 bolt

1. Remove three M10 x 30 bolts.
2. Remove M10 x 45 bolt and remove coolant supply housing.

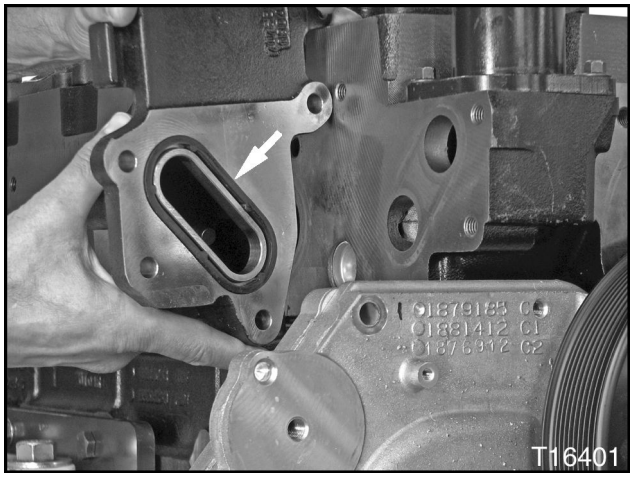


Figure 390 Coolant Housing Seal

3. Remove and discard coolant housing seal.

Water Outlet Tube and Thermostat

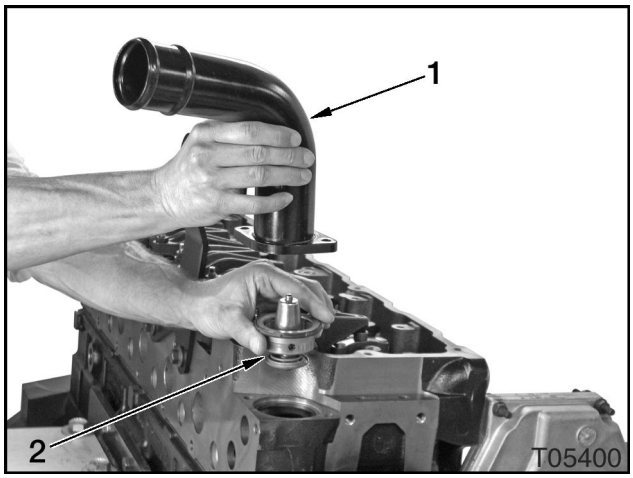


Figure 391 Water Outlet Tube and Thermostat

1. Water outlet tube (typical)
2. Thermostat assembly

NOTE: Water outlet tube configurations use either two M8 x 25 bolts to hold the water outlet tube to the cylinder head or two M8 x 120 bolts to hold the water outlet tube and thermostat bypass housing to the cylinder head.

1. Remove two M8 bolts holding the water outlet tube to the cylinder head or thermostat bypass housing.
2. Remove water outlet tube and thermostat.
3. If equipped, remove the thermostat bypass housing and discard gasket.

Water Pump Assembly

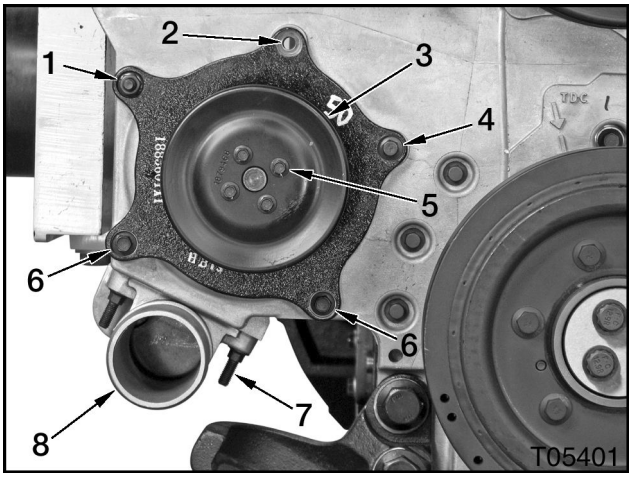


Figure 392 Water Pump and Inlet Elbow (typical)

1. M8 x 55 bolt (nut on front)
2. M8 x 70 bolt
3. Water pump pulley (typical)
4. M8 x 16 bolt
5. M6 bolt (4) (See NOTE)
6. M8 x 50 bolt (2)
7. M8 x 30 stud bolt (3)
8. Water inlet elbow

NOTE: M6 bolts may be M6 x 12 with separate washers or M6 x 14 with captive washers.

1. Remove four M6 x 12 bolts and remove water pump pulley.
2. Remove M8 x 70 bolt.
3. Remove M8 x 55 bolt and nut (nut on front).
4. Remove M8 x 16 bolt.
5. Remove two M8 x 50 bolts.
6. Remove water pump assembly and discard water pump housing seal.

Water Inlet Elbow

NOTE: Water inlet elbow configurations use either three M8 stud bolts or three M8 x 30 bolts to hold the water inlet elbow to the front cover.

1. Remove three M8 x 30 stud bolts holding the water inlet elbow to the front cover.
2. Remove water inlet elbow and discard gasket.

Fan Drive

Spin-on Fan Drive

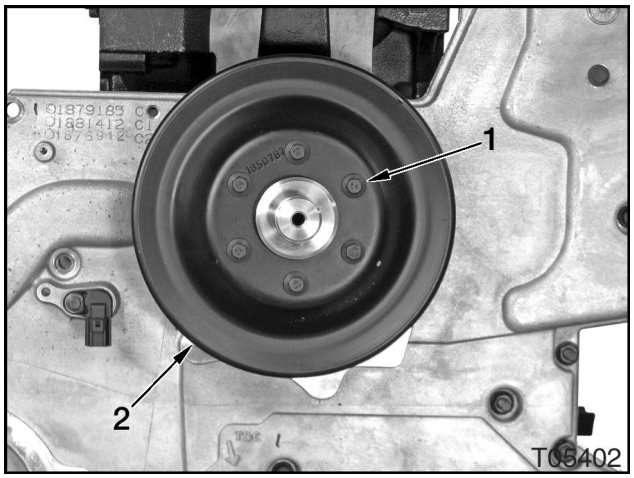


Figure 393 Fan Drive Pulley, Spin-on

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

1. Remove six M8 x 20 bolts and remove the fan drive pulley.

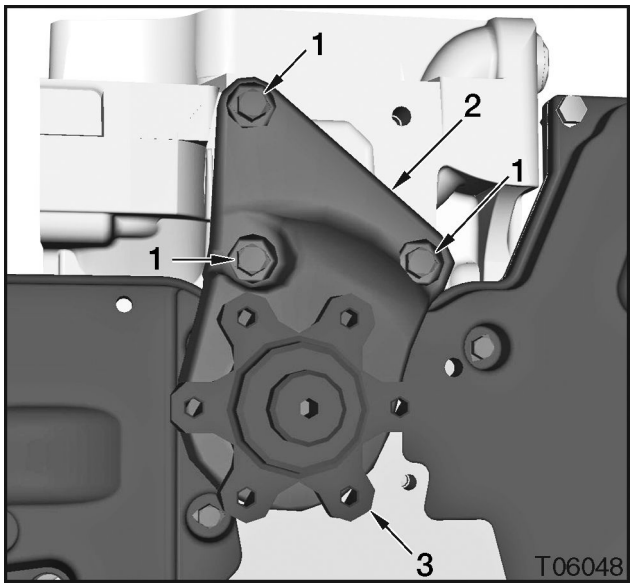


Figure 394 Fan Housing Assembly, Spin-on (typical)

1. M10 x 30 bolt (3)
2. Fan housing assembly (typical)
3. Fan pulley mounting hub

2. Remove three M8 x 30 bolts and remove the fan housing assembly.

Horton DriveMaster® Fan Drive

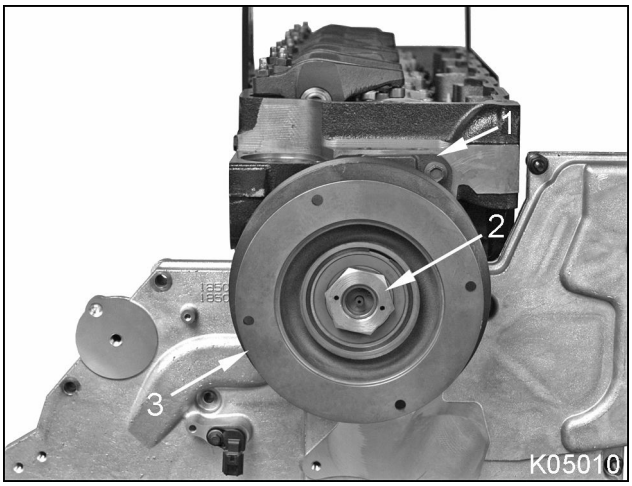


Figure 395 Fan pulley, DriveMaster®

1. Fan mounting bracket (typical)
2. Nut assembly
3. Fan pulley

1. Remove nut assembly from fan mounting bracket, using a Fan Hub Wrench (2 inch) (page 347).

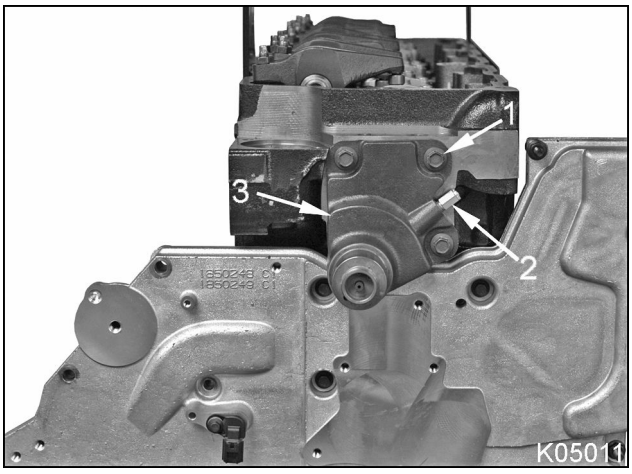


Figure 396 Fan Mounting Bracket, DriveMaster® (typical)

1. M10 x 30 bolt (3)
2. Fan clutch air supply fitting (typical)
3. Fan mounting bracket (typical)

NOTE: Fan drive configurations use either three or four M10 x 30 bolts to hold the fan mounting bracket to the cylinder head.

2. Remove M10 x 30 bolts and remove the fan mounting bracket.

Vibration Damper, Hub, and Wear Sleeve

Vibration Damper—Single Drive Belt Engines

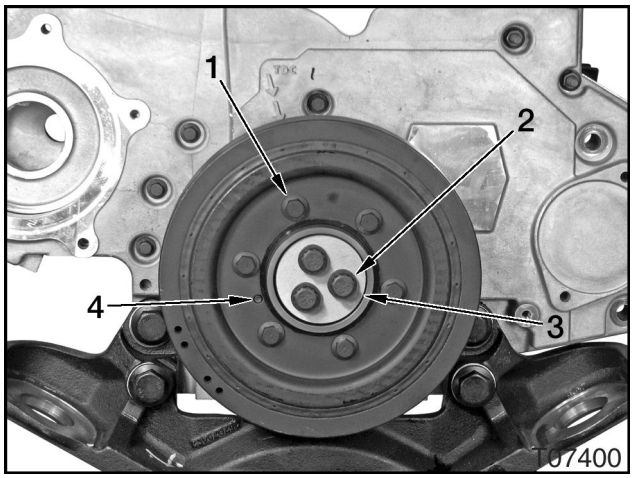


Figure 397 Vibration Damper Assembly

1. M10 x 16 bolt (6)
2. M12 x 40 (12 point) damper bolt (3)
3. Damper retainer
4. Dowel pin

NOTE: The dowel pin for MaxxForce® 9 and 10 vibration dampers is almost flush with the damper front surface. The dowel pin for MaxxForce® DT vibration dampers protrudes out approximately 6 mm (0.24 in).

1. Remove six M10 x 16 bolts holding the vibration damper to the damper hub and remove vibration damper.
2. Remove three M12 x 40 (12 point) damper bolts and remove the damper retainer.

Vibration Damper—Dual Drive Belt Engines

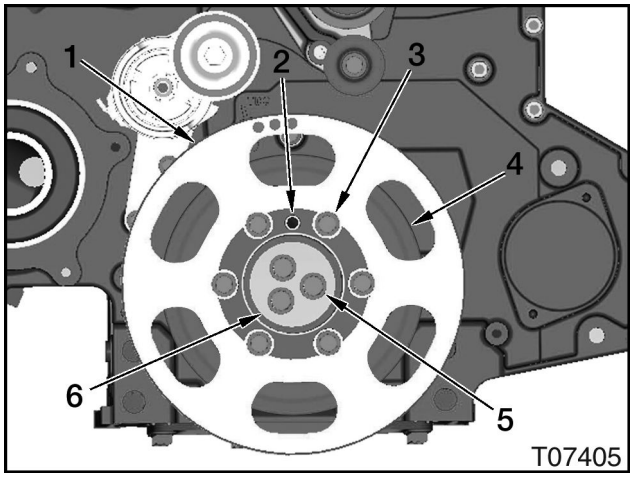


Figure 398 Dual Drive Belt Pulley and Vibration Damper

1. Pulley
2. Dowel pin
3. M10 x 25 bolt (6)
4. Vibration damper
5. M12 x 40 (12 point) damper bolt (3)
6. Damper retainer

NOTE: The dowel pin for MaxxForce® 9 and 10 vibration dampers is almost flush with the damper front surface. The dowel pin for MaxxForce® DT vibration dampers protrudes approximately 6 mm (0.24 in).

1. Remove six M10 x 25 bolts holding the pulley and vibration damper to the damper hub and remove pulley and vibration damper.
2. Remove three M12 x 40 (12 point) damper bolts and remove the damper retainer.

Damper Hub

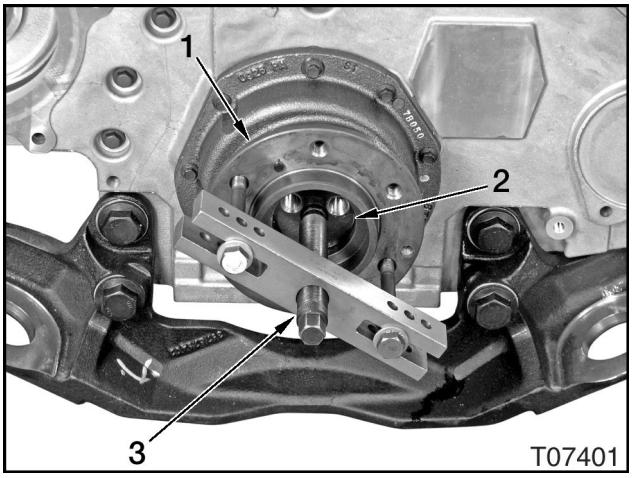


Figure 399 Damper Hub and H-bar Puller

1. Damper hub
2. Crankshaft
3. H-bar puller

1. Install two M10 x 80 bolts and washers through H-bar puller (page 347) and into the damper hub. Adjust M10 x 80 bolts until the bolt heads are at equal lengths from the vibration damper mounting surface.
2. Using hand tools only, tighten H-bar center shaft to pull damper hub off of crankshaft and remove damper hub.

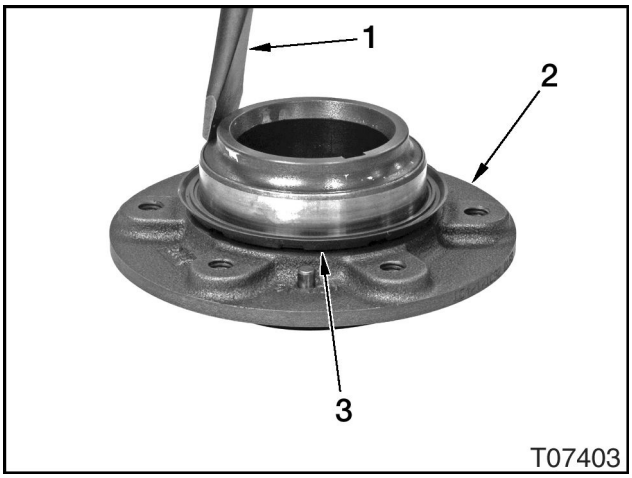


Figure 400 Damper Hub and Wear Sleeve

1. Muffler chisel
2. Damper hub
3. Wear sleeve

CAUTION: To prevent engine damage, do not damage or distort damper hub while removing wear sleeve.

3. Carefully split wear sleeve with a muffler chisel (page 347) and remove sleeve from the damper hub. Be careful not to damage the damper hub.

Oil Pump Assembly

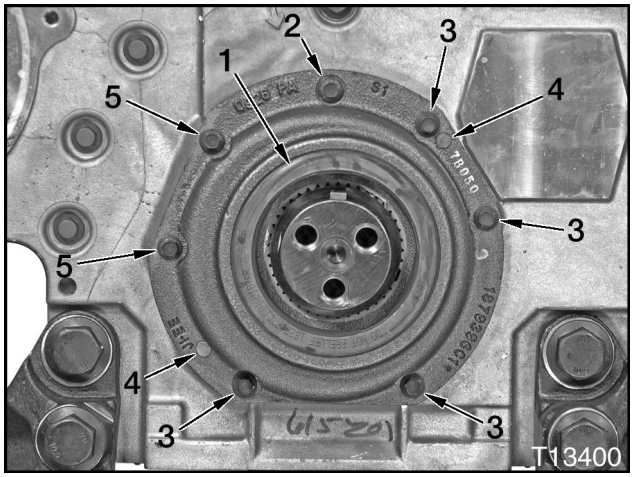


Figure 401 Oil Pump Housing Assembly

1. Oil front seal
2. M8 x 80 bolt and seal assembly
3. M8 x 25 bolt (4)
4. Dowel (2)
5. M8 x 60 bolt (2)

NOTE: Be careful not to damage the crankshaft or oil front seal mounting surface while removing the oil front seal.

1. Remove the oil front seal with a heel bar (page 347) or seal puller, while the oil pump housing assembly is attached to the front cover.
2. Discard oil front seal.
3. Remove and discard M8 x 80 bolt and seal assembly.
4. Remove two M8 x 60 bolts holding the oil pump housing to the front cover.
5. Remove four M8 x 25 bolts.

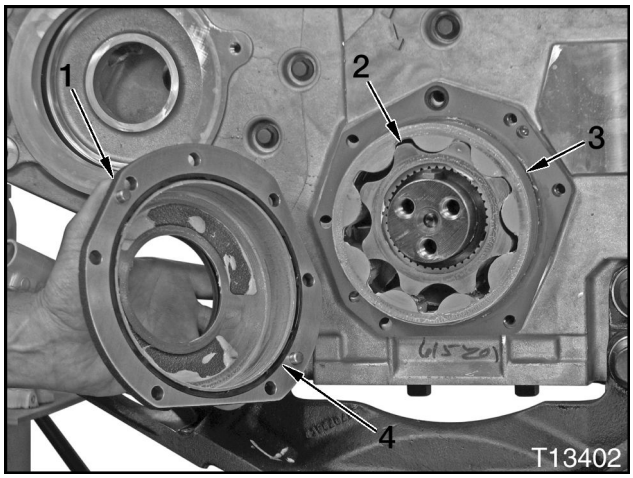


Figure 402 Oil Pump Housing Assembly

1. Oil pump housing
2. Inner rotor
3. Outer rotor
4. Oil pump seal (housing)

6. Remove the oil pump housing and discard oil pump (housing) seal.

CAUTION: To prevent engine damage, use permanent marker to identify internal engine components and their orientation. Do not use paint or temporary markers.

7. Mark inner and outer rotors with a permanent marker, if oil pump is to be reused. Mark will indicate rotor turning direction and orientation to front cover.
8. Remove outer rotor.

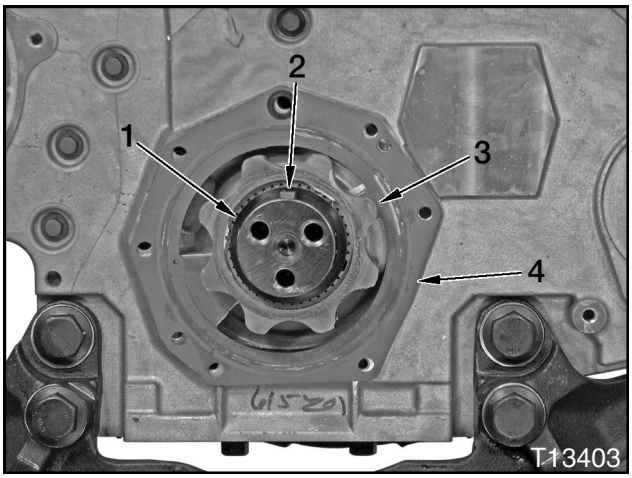


Figure 403 Vibration Damper Key, Inner Rotor, and Oil Pump Housing Plate

1. Washer seal
2. Vibration damper key
3. Inner rotor
4. Oil pump housing plate

CAUTION: To prevent engine damage, do not damage or distort the crankshaft keyway groove during vibration damper key removal or installation.

9. Carefully tap the vibration damper key out of the crankshaft with a hammer and punch.
10. Remove washer seal and inner rotor from crankshaft.
11. Remove oil pump housing plate.
12. Remove oil pump seal (housing) from front cover and discard.

NOTE: To remove the oil pump spline drive, see Oil Pump Spline Drive and Crankshaft Gear (page 482).

Front Engine Mount

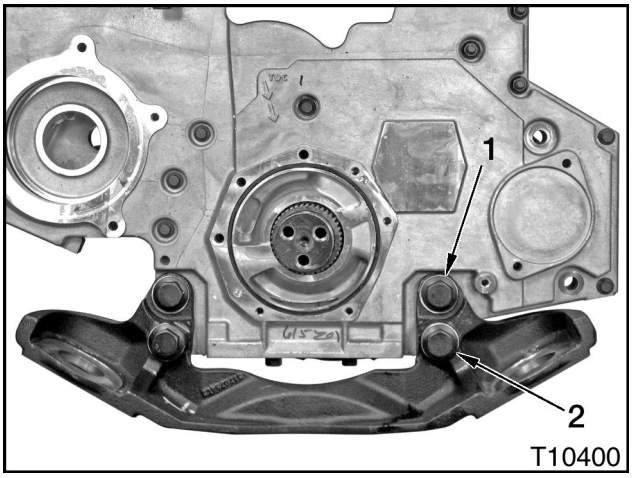


Figure 404 Front Engine Mount

1. M18 x 70 bolt, upper (2)
2. M18 x 100 bolt, lower (2)

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

1. Properly support the engine.
2. Remove two upper M18 x 70 bolts.
3. Support front engine mount and remove two lower M18 x 100 bolts.
4. Remove front engine mounting bracket.

Front Cover (Front Half)

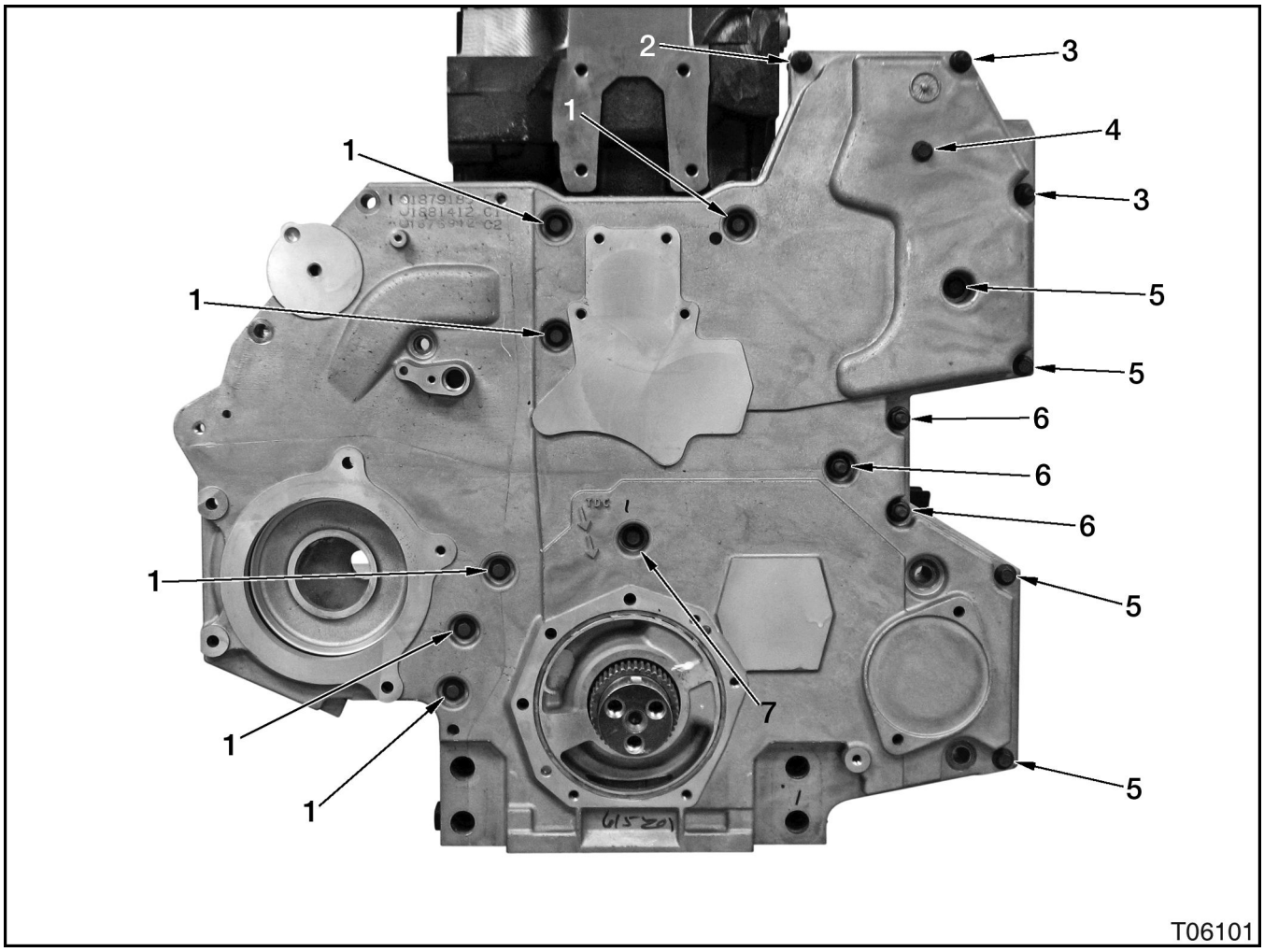


Figure 405 Front Cover (Front Half) – Front Side

1. M8 x 45 bolt (6)
2. M8 x 50 bolt (nut on front)
3. M8 x 73 stud bolt (nut on back) (2)
4. M8 x 75 bolt (dog point)
5. M8 x 50 bolt (nut on back) (4)
6. M8 x 45 bolt (nut on front) (3)
7. Seal assembly, M8 x 50 bolt and seal washer

NOTE: Remove the oil pan and oil suction tube assembly before removing the front cover.

1. Remove the oil pan and oil suction tube assembly.
2. Remove six M8 x 45 bolts holding the front cover to the crankcase.
3. Remove two M8 x 73 stud bolt (nut on back).
4. Remove M8 x 75 bolt (dog point)
5. Remove four M8 x 50 bolts and nuts (nut on back).
6. Remove M8 x 50 bolt and nut (nut on front).

NOTE: On engines up to serial number 3108129, the three bolts above the air compressor mounting pad are M8 x 50 (nut on front).

7. Remove three M8 x 45 bolts and nuts (nut on front).
8. Remove and discard seal assembly M8 x 50 bolt and seal washer.

9. Remove front cover (front half) by sliding cover forward and off two dowel pins.
10. Remove and discard oil and coolant gaskets and O-ring seals from the front cover (front half) – back side.

Idler Gears

NOTE: Measure lower idler, upper idler, and camshaft gear backlash (page 318) before removing any gears from the gear train.

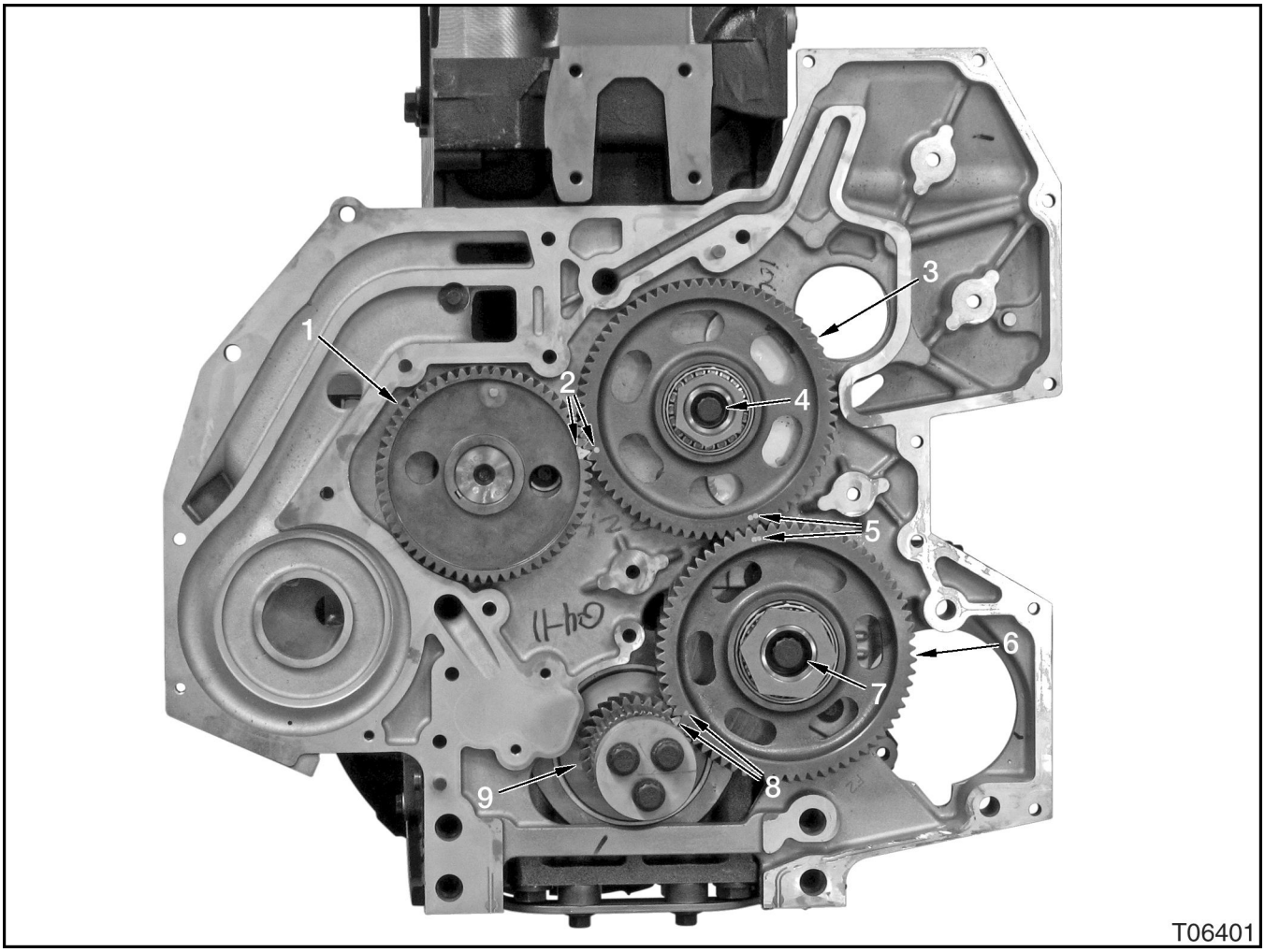


Figure 406 Gear Train

1. Camshaft gear
2. Camshaft to upper idler gear timing marks (single dimple)
3. Upper idler gear
4. M16 x 65 bolt (12 point)
5. Upper idler to lower idler gear timing marks (double dimple)
6. Lower idler gear
7. M20 x 70 bolt
8. Lower idler to crankshaft gear timing marks
9. Crankshaft gear

NOTE: Once timing marks are aligned, the crankshaft will require 34 revolutions to align timing marks again.

1. Rotate crankshaft until camshaft, upper idler, lower idler, and crankshaft gears timing marks are aligned.
2. Remove M20 x 70 bolt using Lower Idler Gear Socket (page 347) and a 3/4 inch drive breaker bar.
3. Remove lower idler gear.
4. Remove M16 x 65 bolt using a 16 mm 12 point impact socket (page 347) and a 1/2 inch drive breaker bar.
5. Remove upper idler gear.

NOTE: If required, measure camshaft end play (page 486) after removing the upper idler gear but before removing camshaft gear.

Front Cover (Rear Half)

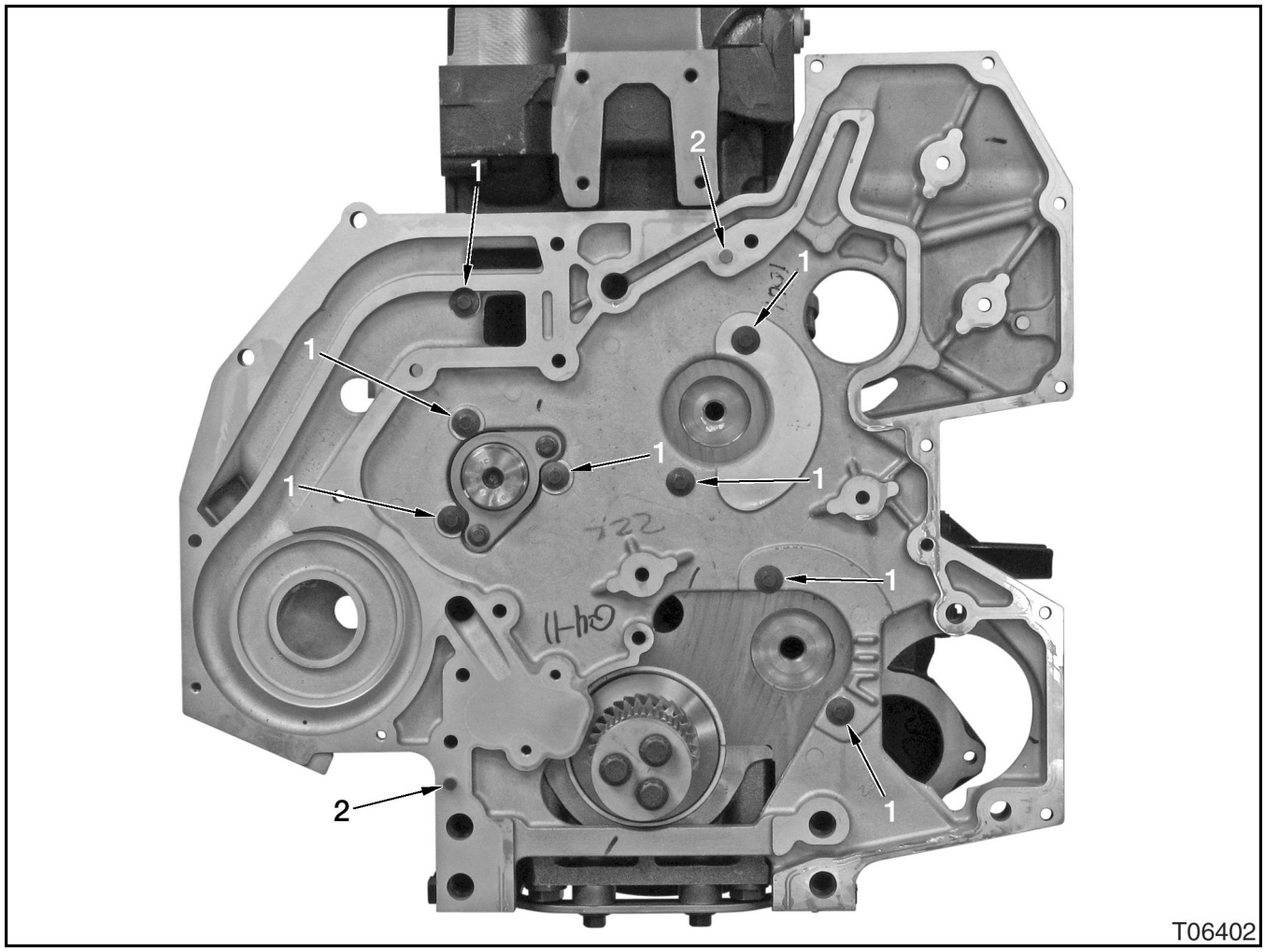


Figure 407 Front Cover (Rear Half) – Front Side

1. Special M8 x 20 hex flange bolt (8)
2. Dowel pins (4)

1. Remove Camshaft Gear (page 477) or remove Camshaft Assembly (page 478).
2. Remove eight special M8 x 20 hex flange bolts holding the front cover (rear half) to the crankcase.
3. Pull cover outward to slide dowel pins out of crankcase and remove cover from engine.
4. Remove and discard oil and coolant gaskets from the front cover (rear half) – crankcase side.

Cleaning, Inspection, and Measurement

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

Cleaning and Inspection

1. Clean coolant supply housing, water pump, water inlet elbow, water outlet tube, oil pump housing, front engine mount, and front cover with a suitable non-caustic solvent.
2. Blow dry parts using filtered compressed air.
3. Clean coolant and oil seal mating surfaces on the cylinder head, coolant supply housing, water pump, water inlet elbow, water outlet tube, oil pump housing, and front cover.
4. Inspect alternator support, secondary refrigerant compressor support, coolant supply housing, water inlet elbow, vibration damper assembly, oil pump housing, oil pump inner and outer rotors, front cover, and idler gears for cracks, damage, or excessive wear. Replace parts if required.
5. Inspect drive belt for excessive cracks and wear. Replace if necessary.
6. Inspect belt tensioner to make sure tensioner arm and pulley are properly in line with the fan drive belt and not coming apart. Make sure tensioner arm is not binding and pulley bearing is not loose. Replace automatic belt tensioner assembly if required.
7. Inspect thermostat and gasket. If thermostat is stuck open, damaged, cracked, or not opening properly replace thermostat and gasket.
8. Inspect fan drive bearing by wiggling fan pulley. If bearing has excess play, replace fan housing or mounting bracket.
9. Inspect water pump. Wiggle water pump pulley. If water pump bearing has excess play, replace water pump. Inspect water pump housing for coolant leaks. Replace water pump if leaking.

Measuring Gear Backlash

NOTE: Remove rocker arm assembly to release pressure exerted by valve train.

Lower Idler Gear Backlash

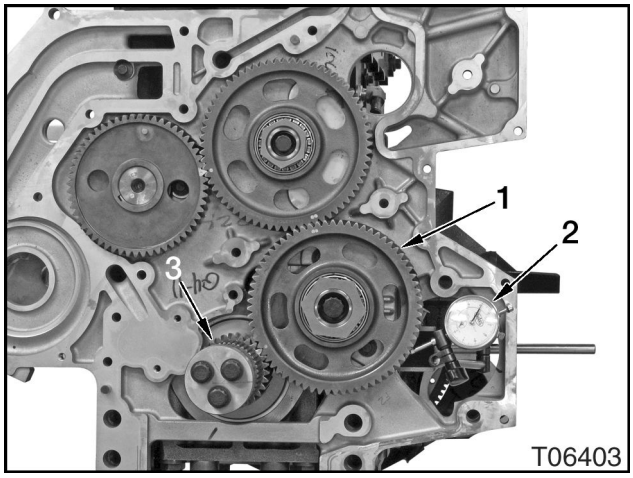


Figure 408 Lower Idler Gear and Dial Indicator

1. Lower idler gear
2. Dial indicator
3. Crankshaft gear

1. Mount a dial indicator set (page 347) on a level engine surface.
2. Place dial indicator tip on one of the lower idler gear teeth. Position dial indicator tangent (90 degrees relative to the plane of the gear tooth).
3. Rotate lower idler gear by hand in one direction, without moving the crankshaft gear, and zero the dial indicator.
4. Rock the lower idler gear back and forth without moving the crankshaft gear. If lower idler gear to crankshaft gear backlash exceeds Specifications (page 345), replace the lower idler gear.

Upper Idler Gear Backlash

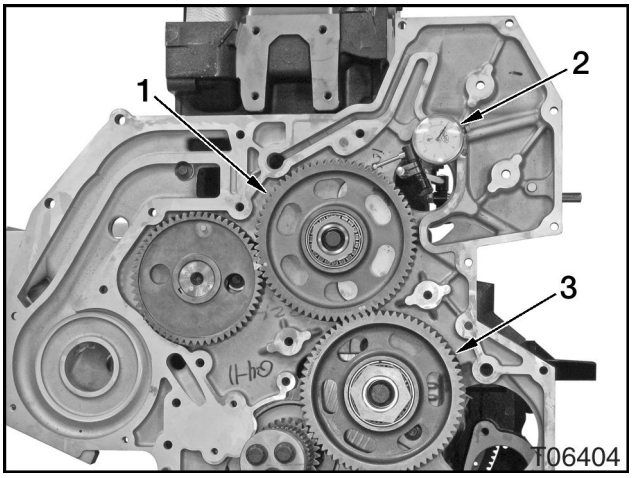


Figure 409 Upper Idler Gear and Dial Indicator

1. Upper idler gear
2. Dial indicator
3. Lower idler gear

1. Mount a dial indicator set (page 347) on a level engine surface.
2. Place dial indicator tip on one of the upper idler gear teeth. Position dial indicator tangent (90 degrees relative to the plane of the gear tooth).
3. Rotate upper idler gear by hand in one direction while holding the lower idler gear stationary with a gear locking tool. Zero the dial indicator.
4. Rock the upper idler gear back and forth without moving the lower idler gear. If upper idler gear to lower idler gear backlash exceeds Specifications (page 345), replace upper idler gear.

Camshaft Gear Backlash

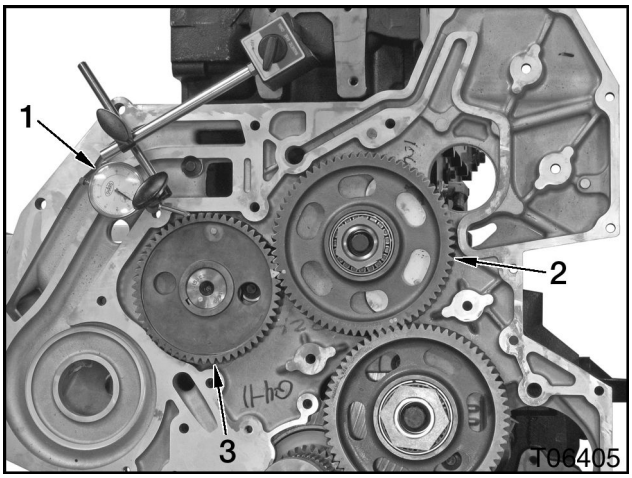


Figure 410 Camshaft Gear and Dial Indicator

1. Dial indicator
2. Upper idler gear
3. Camshaft gear

1. Mount a dial indicator set (page 347) on a level engine surface.
2. Place dial indicator tip on one of the camshaft gear teeth. Position dial indicator tangent (90 degrees relative to the plane of the gear tooth).
3. Rotate camshaft gear by hand in one direction while holding the upper idler gear stationary with a gear locking tool or screwdriver. Zero the dial indicator.
4. Rock the camshaft gear back and forth without moving the upper idler gear. If camshaft gear to upper idler gear backlash exceeds Specifications (page 345), replace camshaft gear.

Measuring Oil Pump Side Clearance

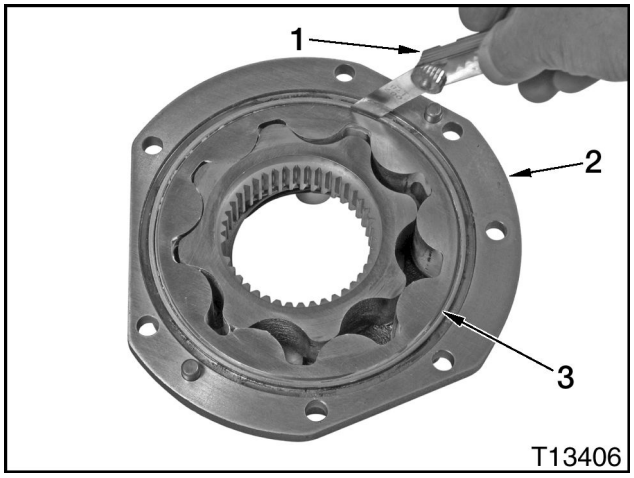


Figure 411 Oil Pump Side Clearance Measurement

1. Feeler gauge
2. Oil pump housing
3. Outer rotor

1. Coat outer rotor with oil and install rotor in oil pump housing.
2. Check oil pump side clearance Specification (page 345) and choose the appropriate thickness feeler gauge (page 347).
3. Insert feeler gauge between the oil pump housing and outer rotor.
4. Replace oil pump assembly if not within specification.

Measuring Oil Pump End Clearance

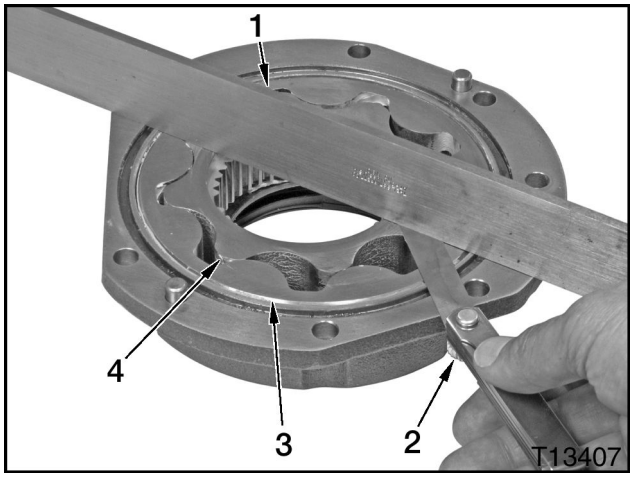


Figure 412 Oil Pump End Clearance Measurement

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

1. Place a straightedge (page 347) across the oil pump mounting surface.
2. Check oil pump end clearance Specification (page 345) and choose the appropriate thickness feeler gauge (page 347).
3. Slide feeler gauge between the straightedge and the oil pump inner and outer rotors.
4. Replace oil pump and rotor assembly if not within specification.

Installation

Front Cover (Rear Half)

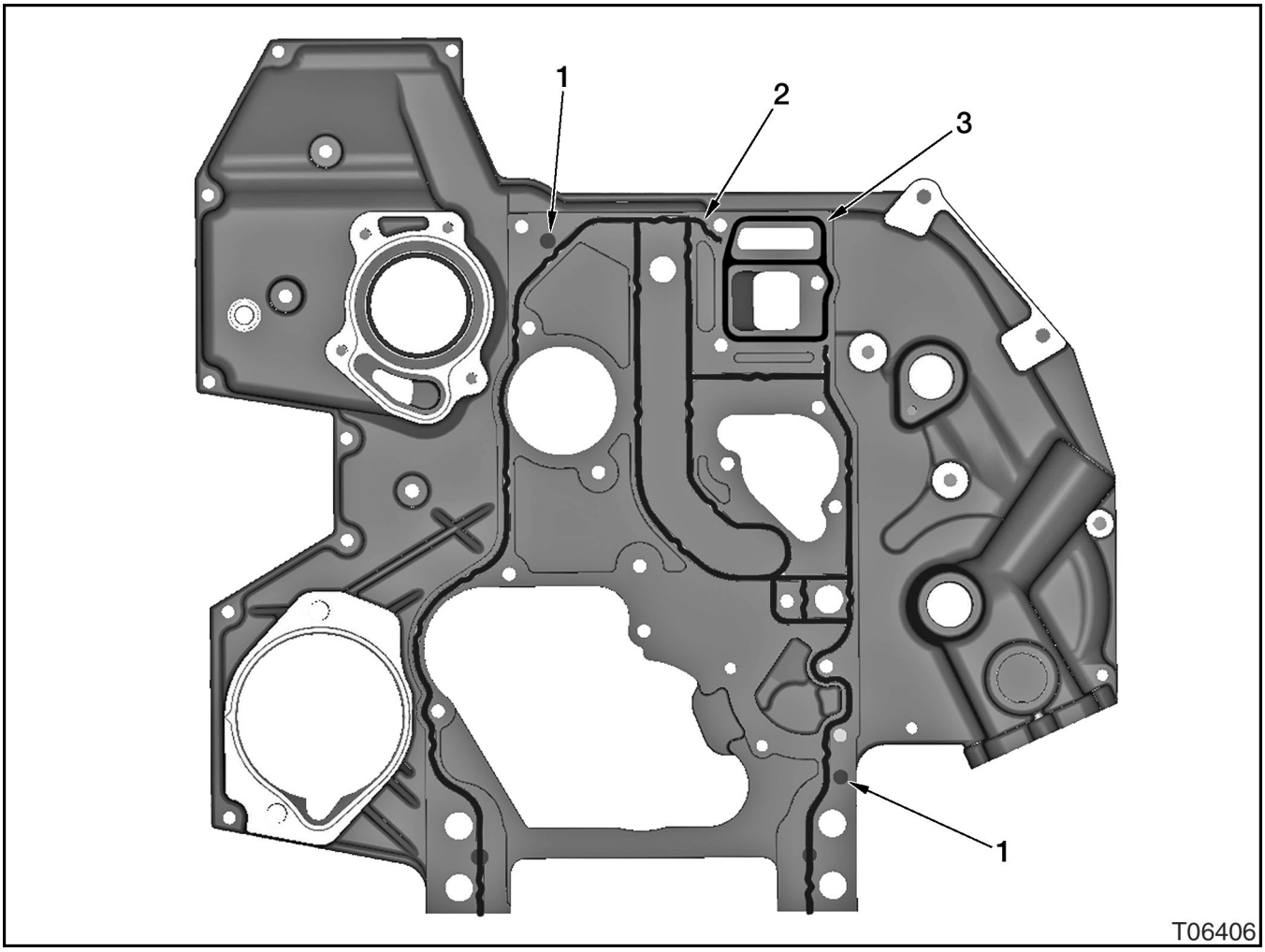


Figure 413 Front Cover (Rear Half) – Crankcase Side

1. Dowel pin (4)
2. Front cover rear half (oil) gasket
3. Front cover rear half (coolant) gasket

1. Install new oil and coolant gaskets on the front cover (rear half) – crankcase side.
2. Align front cover dowel pins with crankcase dowel holes and install front cover (rear half) on the crankcase.

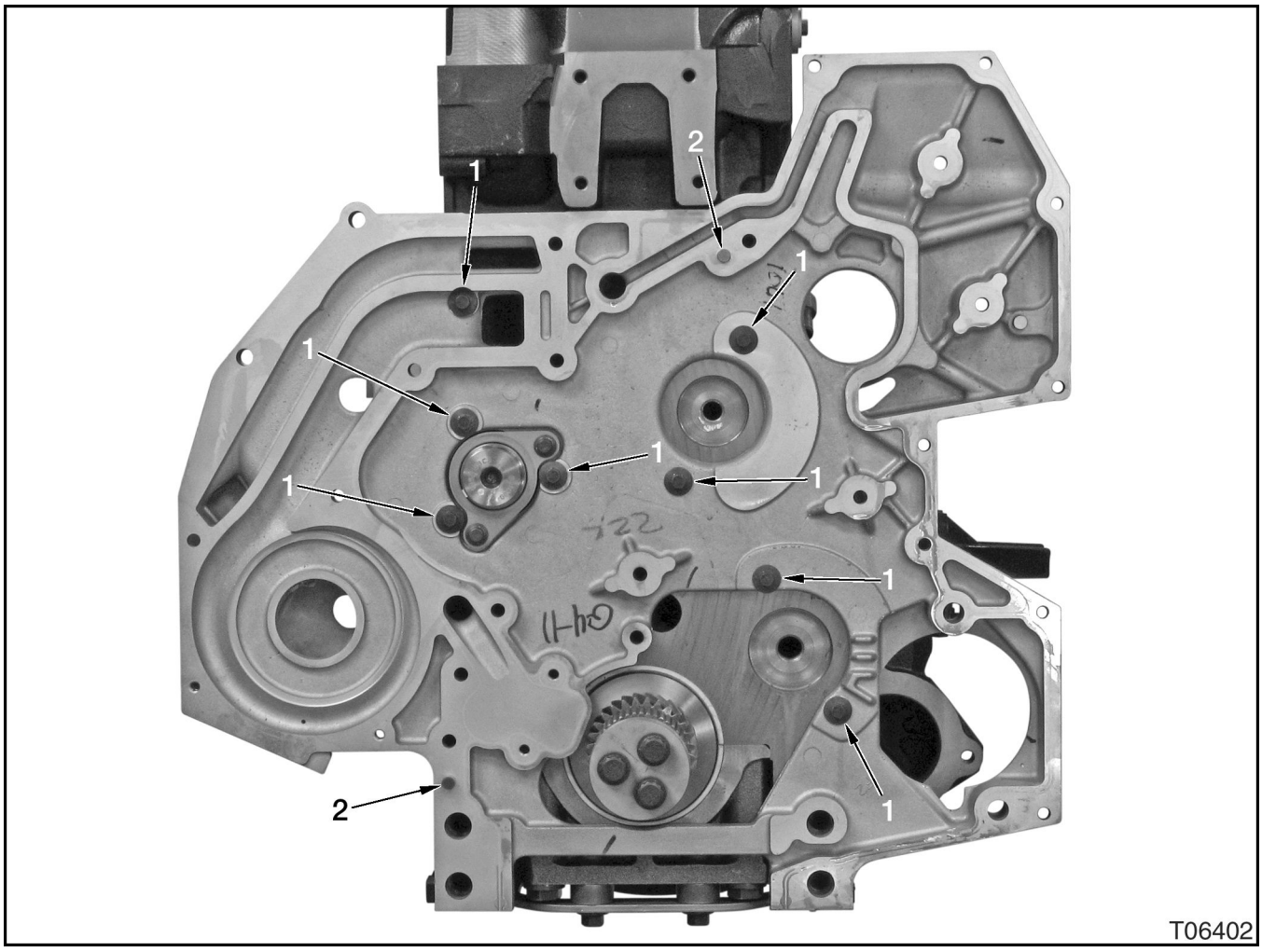


Figure 414 Front Cover (Rear Half) – Front Side

1. Special M8 x 20 hex flange bolt (8)
2. Dowel pins (4)

3. Install eight special M8 x 20 hex flange bolts finger tight.
4. Tighten eight special M8 x 20 hex flange bolts to standard torque (page 553).
5. Install Camshaft Assembly (page 491) or Camshaft Gear (page 491).

Idler Gears

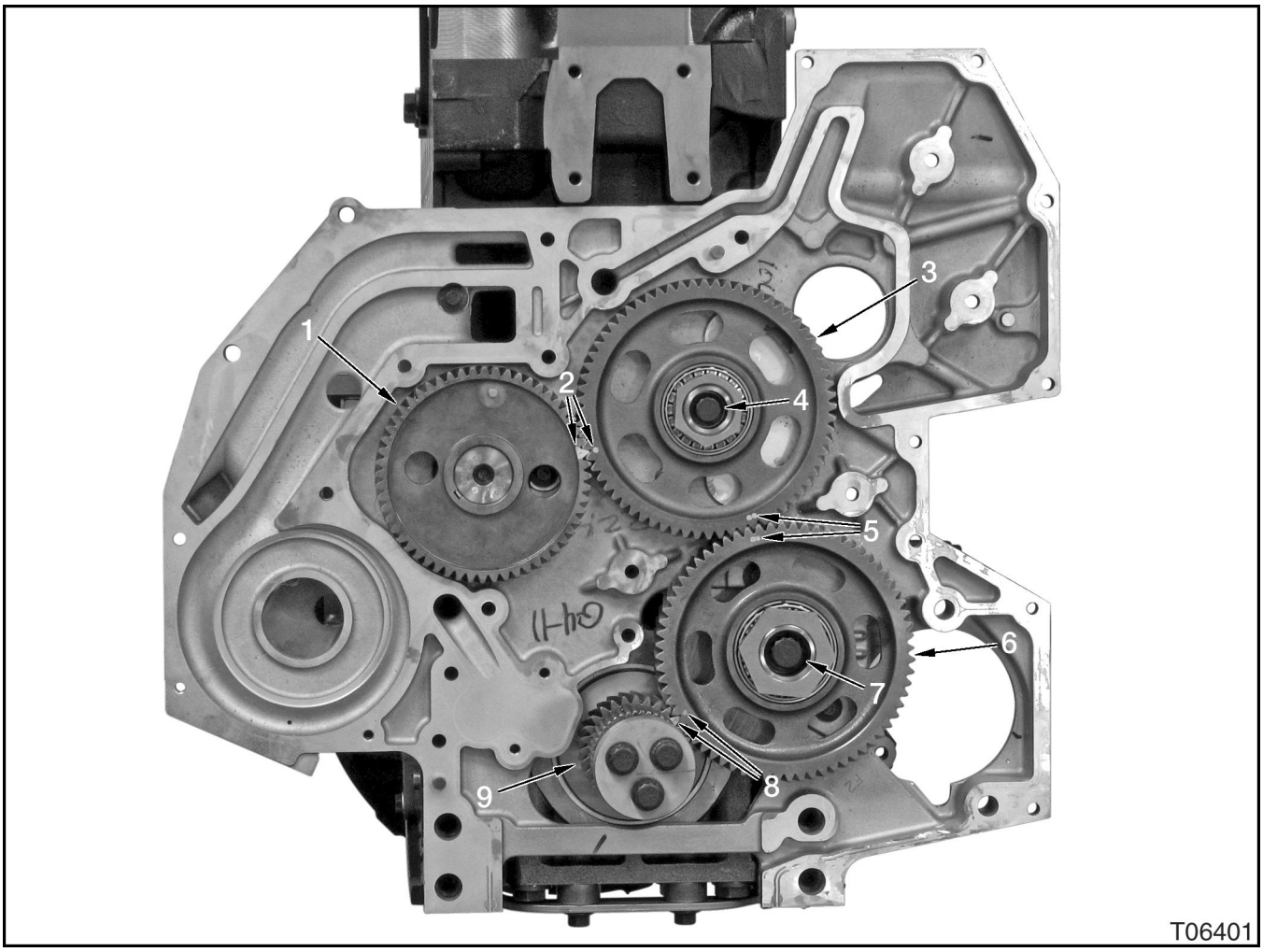


Figure 415 Gear Train

1. Camshaft gear
2. Camshaft to upper idler gear timing marks (single dimple)
3. Upper idler gear
4. M16 x 65 bolt (12 point)
5. Upper idler to lower idler gear timing marks (double dimple)
6. Lower idler gear
7. M20 x 70 bolt
8. Lower idler to crankshaft gear timing marks (single dimple)
9. Crankshaft gear

NOTE: Gear train gears should be assembled and installed with the timing marks facing out as shown.

1. Install upper idler gear on the crankcase and align upper idler gear (single dimple) timing mark with camshaft gear (single dimple) timing mark. Install upper idler gear M16 x 65 bolt finger tight.
2. Install lower idler gear on the crankcase and align lower idler gear (single dimple) timing mark with crankshaft gear timing mark and align lower idler gear (double dimple) timing mark with upper idler gear (double dimple) timing mark. Install lower idler gear M20 x 70 bolt finger tight.
3. Tighten upper idler gear M16 x 65 bolt to special torque (page 346) using a 16 mm 12 point impact socket (page 347).

4. Tighten lower idler gear M20 x 70 bolt to special torque (page 346) using Lower Idler Gear Socket (page 347).

NOTE: Once timing marks are aligned, the crankshaft will require 34 revolutions to align timing marks again.

5. Measure lower idler, upper idler, and camshaft gears backlash (page 318).
6. Install the high-pressure oil pump and measure gear backlash between the upper idler gear and the high-pressure oil pump gear. See Specifications (page 345).
7. Measure high-pressure oil pump end play. See Specifications (page 345).

Front Cover (Front Half)

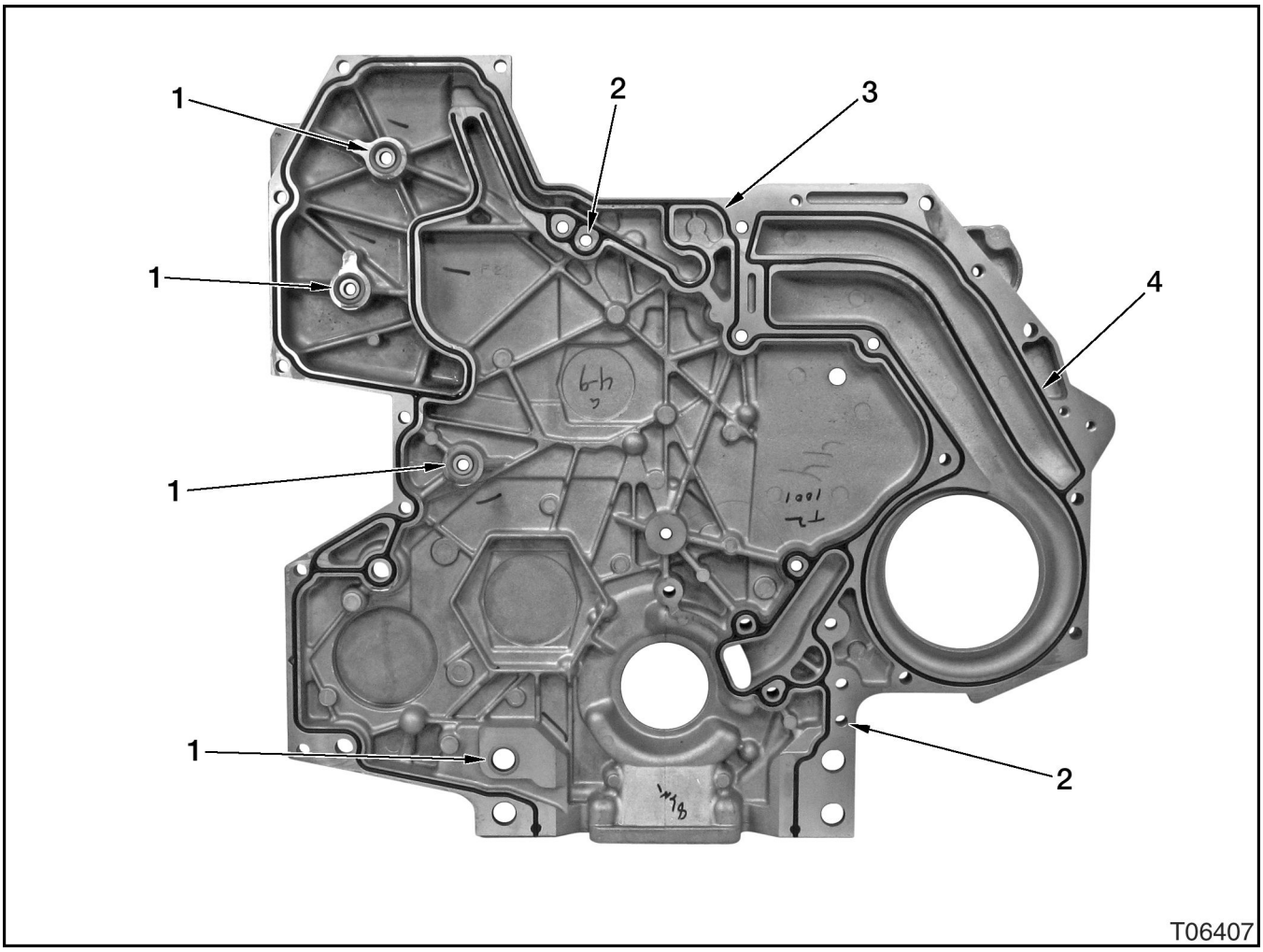


Figure 416 Front Cover (Front Half) – Back Side

1. O-ring (4)
2. Dowel hole (2)
3. Front cover front half (oil) gasket
4. Front cover front half (coolant) gasket

1. Install a new oil gasket, coolant gasket, and four O-rings to the front cover (front half) recesses.
2. Install the front cover (front half) on the front cover (rear half) and align front half dowel holes with rear half dowel pins.

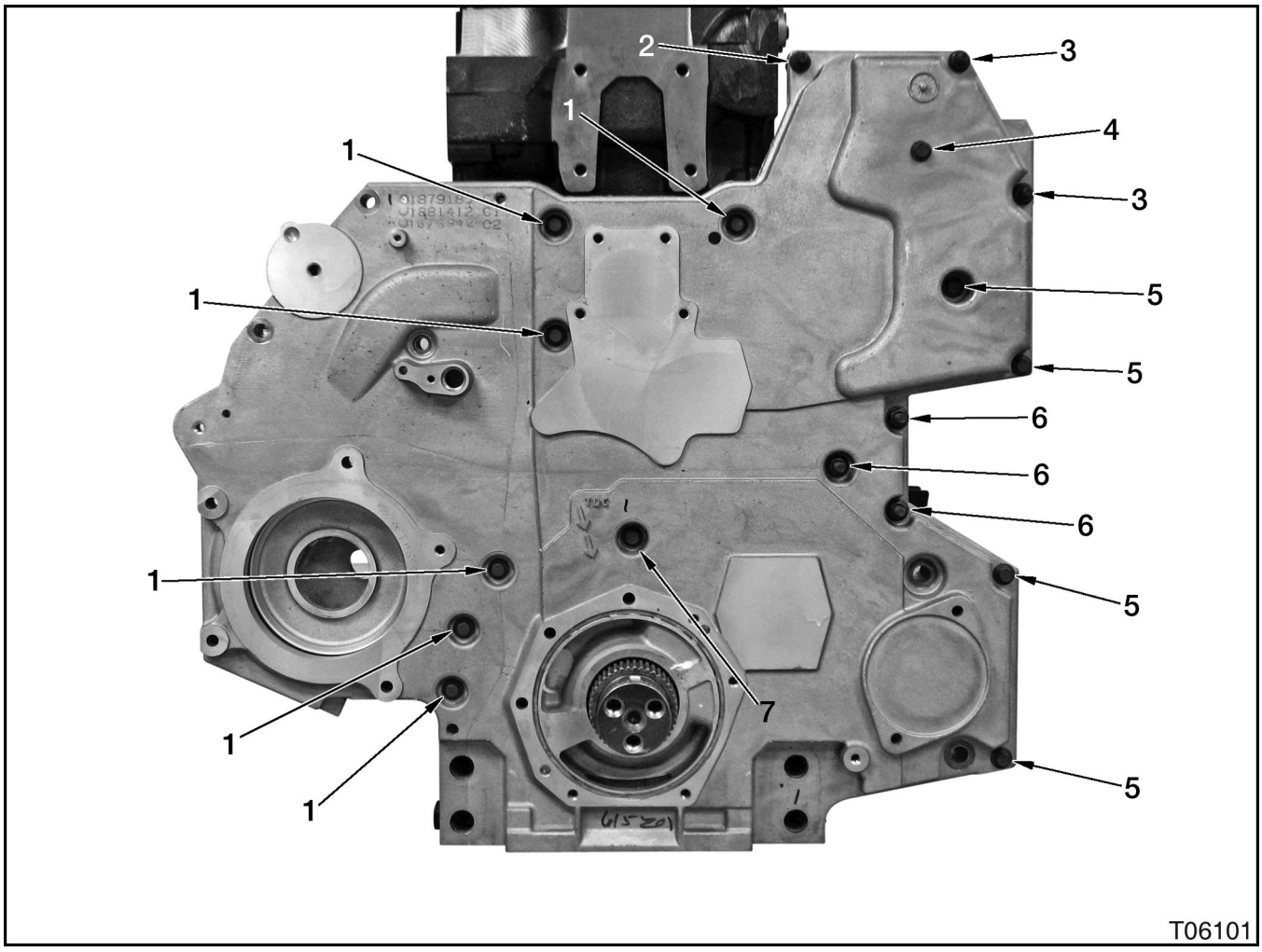


Figure 417 Front Cover (Front Half) – Front Side

1. M8 x 45 bolt (6)
2. M8 x 50 bolt (nut on front)
3. M8 x 73 stud bolt (nut on back) (2)
4. M8 x 75 bolt (dog point)
5. M8 x 50 bolt (nut on back) (4)
6. M8 x 45 bolt (nut on front) (3)
7. Seal assembly, M8 x 50 bolt and seal washer

NOTE: On engines up serial number 3108129, the three bolts above the air compressor mounting pad are M8 x 50 (nut on front).

3. Install three M8 x 45 bolts and nuts (nut on front) finger tight.
4. Install four M8 x 50 bolts and M8 nuts (nut on back) finger tight.

CAUTION: To prevent engine damage, do not substitute seal assembly M8 x 50 bolt and seal washer with any other bolt.

5. Install a new seal assembly M8 x 50 bolt and seal washer finger tight.
6. Install two M8 x 73 stud bolts (nut on back) finger tight.
7. Install M8 x 75 bolt (dog point) finger tight.
8. Install six M8 x 45 bolts finger tight.
9. Install M8 x 50 bolt (nut on front) finger tight.
10. Tighten eighteen M8 front cover (front half) mounting bolts to standard torque (page 553).

Front Engine Mount

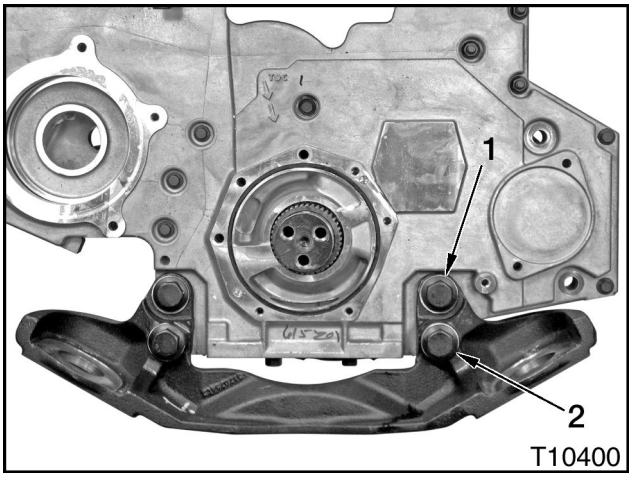


Figure 418 Front Engine Mount

1. M18 x 70 bolt, upper (2)
2. M18 x 100 bolt, lower (2)

1. Position front engine mount on front cover and install two lower M18 x 100 bolts finger tight.
2. Install two upper M18 x 70 bolts finger tight.
3. Tighten two M18 x 100 and two M18 x 70 bolts to special torque (page 346).

Oil Pump Assembly

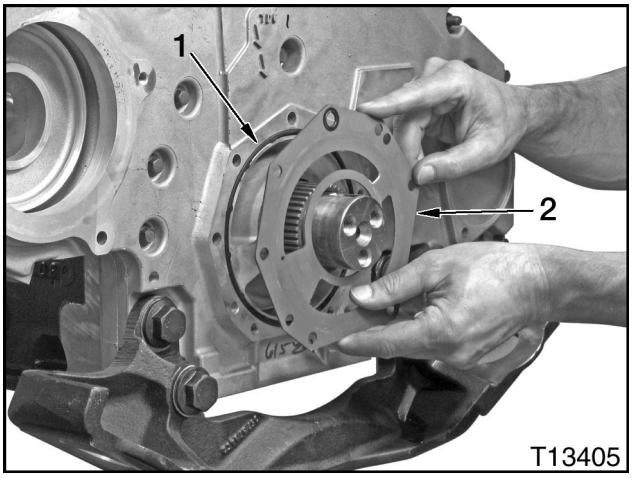


Figure 419 Oil Pump Housing Plate and Seal

1. Oil pump seal (housing plate)
2. Oil pump housing plate

1. Lubricate a new oil pump seal (housing) with clean engine oil and install in the front cover. Install the oil pump housing plate.

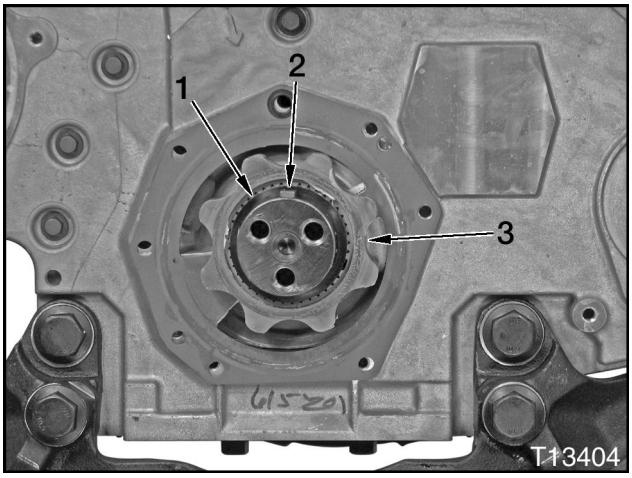


Figure 420 Vibration Damper Key, Inner Rotor, and Washer Seal

1. Washer seal
2. Vibration damper key
3. Inner rotor

CAUTION: To prevent engine damage, make sure used oil pump inner and outer rotors rotate in the same direction as before removal. See marks added during removal for proper rotor orientation.

2. Slide oil pump inner rotor on the crankshaft oil pump spline drive.
3. Install washer seal with angled outer edge pointing out toward the front of the engine.

CAUTION: To prevent engine damage, do not mark or distort the crankshaft keyway groove during vibration damper key installation.

4. Carefully tap the vibration damper key into the crankshaft keyway groove with a hammer.

NOTE: MaxxForce® 9 and 10 engines use a front oil seal with a POSE dust seal mounted on the damper hub wear sleeve. MaxxForce® DT engines use a front oil seal without a dust seal.

CAUTION: To prevent engine damage, for MaxxForce® 9 and 10 engines, replace the POSE dust seal and front oil seal as a set. For MaxxForce® DT engines, only use a front oil seal designed to not use a matching dust seal.



Figure 421 Hydraulic Sealant and Front Oil Seal

5. Apply Loctite® 569 Hydraulic Sealant (page 347) to the outside edge of the front oil seal.

CAUTION: To prevent engine damage, wipe excess hydraulic sealant and other contaminates off the front oil seal inside sealing edge.

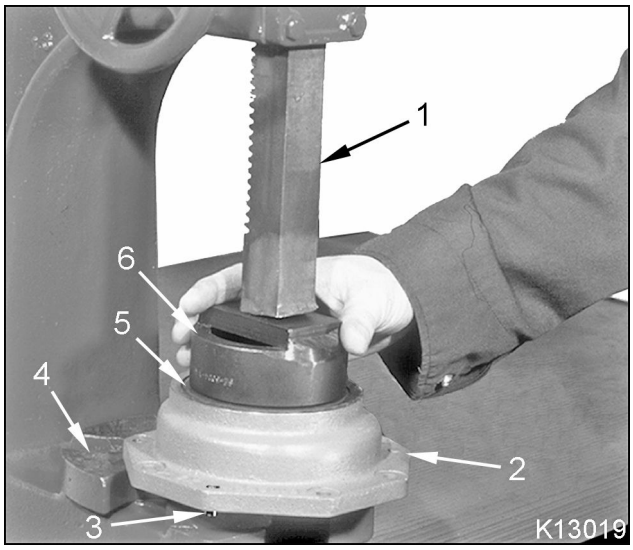


Figure 422 Front Oil Seal Installation

1. Press ram
2. Oil pump housing
3. Dowel pin (2)
4. Press table
5. Front oil seal
6. Front Seal and Wear Sleeve Installer

6. Place oil pump housing, new oil front seal, and Front Seal and Wear Sleeve Installer (page 347) on press table.
7. Position oil pump housing on press table so housing mating surface is level and supported. Dowel pins should be recessed in press table openings.
8. Position press ram on the center of the Front Seal and Wear Sleeve Installer and carefully press the oil front seal into the oil pump housing until seal is fully seated.

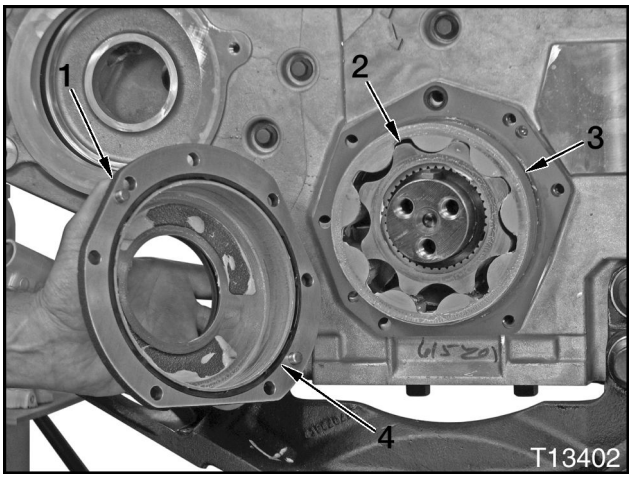


Figure 423 Oil Pump Housing Assembly

1. Oil pump housing
2. Inner rotor
3. Outer rotor
4. Oil pump seal (housing)

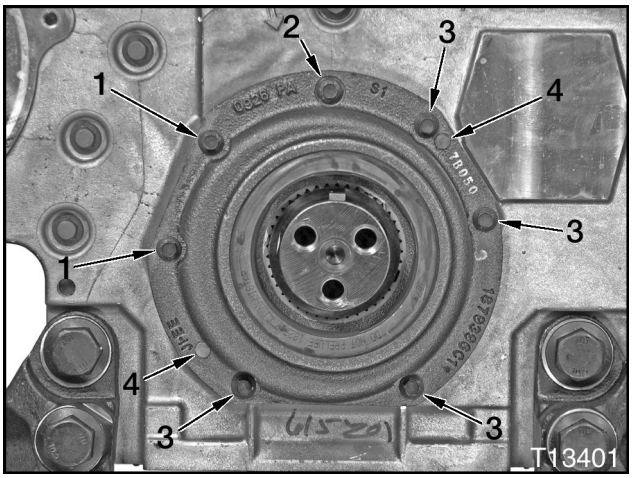


Figure 424 Oil Pump Housing Assembly

1. M8 x 60 bolt (2)
2. Seal assembly (M8 x 80 bolt and seal)
3. M8 x 25 bolt (4)
4. Dowel (2)

9. Lubricate a new oil pump seal with clean engine oil and install in the oil pump housing groove.
10. Coat the outer rotor with clean engine oil.

CAUTION: To prevent engine damage, make sure used oil pump inner and outer rotors rotate in the same direction as before removal. See marks added during removal for proper rotor orientation.

11. Install the outer rotor in the oil pump housing.
12. Lightly coat the front oil seal inside sealing surface with clean engine oil.
13. Align two oil pump housing dowels with two front cover dowel holes and install oil pump housing.

CAUTION: To prevent engine damage, do not substitute seal assembly M8 x 80 bolt and seal washer with any other bolt.

14. Install four M8 x 25 bolts finger tight.
15. Install two M8 x 60 bolts finger tight.
16. Install a new seal assembly, M8 x 80 bolt and seal washer finger tight.
17. Tighten four M8 x 25 bolts and two M8 x 60 bolts to standard torque (page 553).
18. Tighten seal assembly, M8 x 80 bolt and seal washer to standard torque (page 553).

Vibration Damper, Hub, and Wear Sleeve

Damper Hub

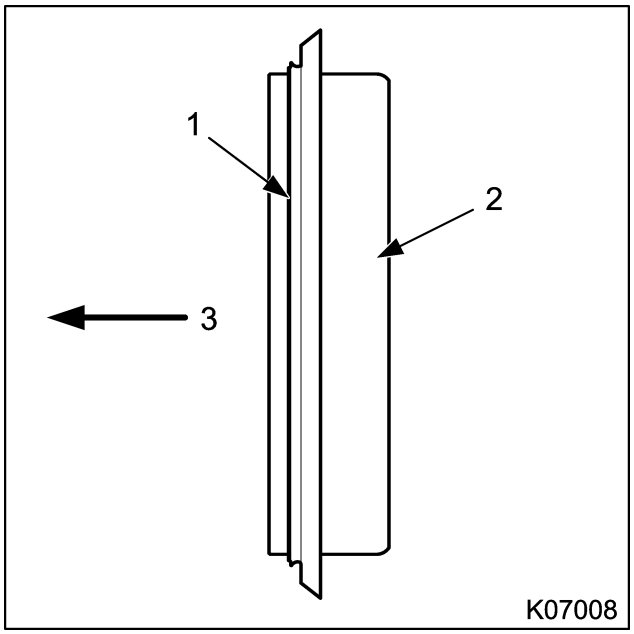


Figure 425 POSE Seal (MaxxForce® 9 and 10 only) and Wear Sleeve Orientation

1. POSE seal (MaxxForce® 9 and 10 only)
2. Wear sleeve
3. Front of engine

NOTE: If service kit contains more than one wear sleeve, use sleeve that has the same width as the current wear sleeve.

NOTE: MaxxForce® 9 and 10 engines have a POSE dust seal attached to the wear sleeve. A dust seal is not used on MaxxForce® DT engines.

CAUTION: To prevent engine damage, for MaxxForce® 9 and 10 engines, replace the POSE dust seal and oil front seal as a set. For MaxxForce® DT engines, only use a oil front seal designed to not use a matching dust seal.

NOTE: The chamfer (rounded edge) of the wear sleeve outside diameter must face in, toward the engine.

1. Apply Loctite® 569 Hydraulic Sealant (page 347) to the inside diameter of a new wear sleeve.

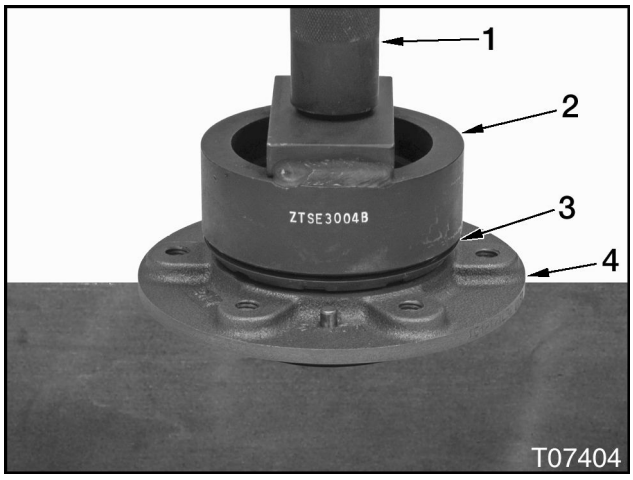


Figure 426 Front Seal and Wear Sleeve Installation

1. Press ram
2. Front Seal and Wear Sleeve Installer
3. POSE dust seal (MaxxForce® 9 and 10 engines only)
4. Damper hub

2. Center the damper hub, new wear sleeve, and Front Seal and Wear Sleeve Installer (page 347) under press ram.
3. Carefully press the new wear sleeve on the damper hub until sleeve is fully seated.
4. Wipe any excess sealant off the outside diameter of the wear sleeve.

5. Mark damper hub with 100 °C (212 °F) Thermo-melt crayon (page 347).



Figure 427 Damper Hub and Hot Plate

CAUTION: To prevent engine damage, do not heat damper hub assembly above 100 °C (212 °F).

6. Heat damper hub on a hot plate (page 347), or other controlled heat source, until Thermo-melt crayon mark melts.



Figure 428 Damper Hub Installation (typical)

⚠ WARNING: To prevent personal injury or death, wear heat insulated gloves when handling heated components.

7. Install damper hub on crankshaft while wearing heat insulated gloves (page 347). Make sure keyway groove on damper hub aligns with keyway in crankshaft.

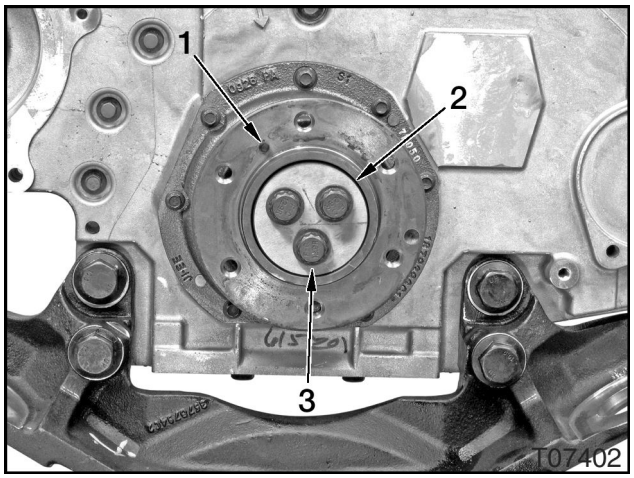


Figure 429 Damper Hub

1. Dowel pin
2. Damper retainer
3. M12 x 40 (12 point) damper bolt (3)

WARNING: To prevent personal injury or death, damper hub must be completely seated on the crankshaft.

CAUTION: To prevent engine damage, only use 15.2 mm (0.60 in) thick damper retainer and Class 12.9 damper bolts.

8. Install damper retainer and three M12 x 40 damper bolts. Verify damper retainer is 15.2 mm (0.60 in) thick and damper bolts are Class 12.9.
9. Tighten three M12 x 40 damper bolts to special torque (page 346).
10. Retighten three M12 x 40 damper bolts to special torque (page 346) several times until each bolt has no movement.

Vibration Damper—Dual Drive Belt Engines

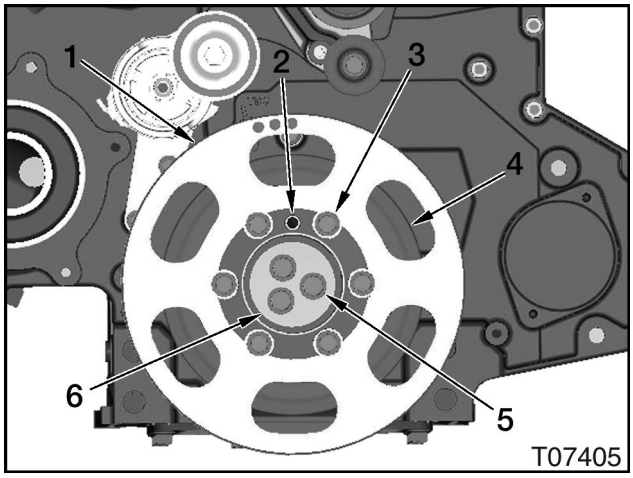


Figure 430 Dual Drive Belt Pulley and Vibration Damper

1. Pulley (crankshaft)
2. Dowel pin
3. M10 x 25 bolt (6)
4. Vibration damper
5. M12 x 40 (12 point) damper bolt (3)
6. Damper retainer

NOTE: The dowel pin for MaxxForce® 9 and 10 vibration dampers is almost flush with the damper front surface. The dowel pin for MaxxForce® DT vibration dampers protrudes approximately 6 mm (0.24 in).

1. Install pulley and vibration damper assembly on damper hub and align dowel holes with dowel pin on damper hub.
2. Install six M10 x 25 bolts finger tight.
3. Tighten six M10 x 25 bolts to 45 lb-ft (61 N•m).

Vibration Damper—Single Drive Belt Engines

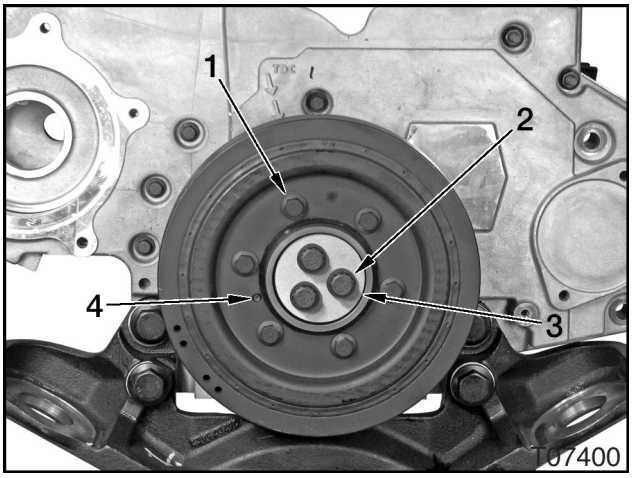


Figure 431 Vibration Damper Assembly

1. M10 x 16 bolt (6)
2. M12 x 40 (12 point) damper bolt (3)
3. Damper retainer
4. Dowel pin

CAUTION: To prevent engine damage, verify damper hub dowel pin is aligned with dowel hole of the vibration damper assembly.

1. Install vibration damper assembly on damper hub and align dowel hole in damper with dowel pin on damper hub.
2. Install six M10 x 16 bolts finger tight.
3. Tighten six M10 x 16 bolts to special torque (page 346).

Fan Drive

Spin-on Fan Drive

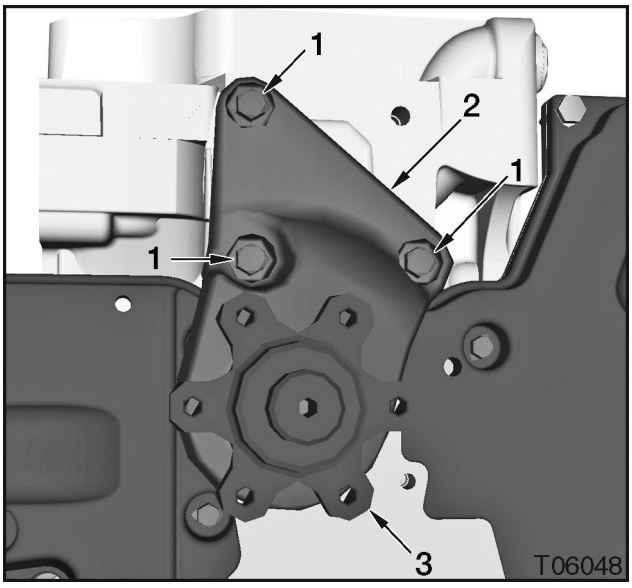


Figure 432 Fan Housing Assembly, Spin-on (typical)

1. M10 x 30 bolt (3)
2. Fan housing assembly (typical)
3. Fan pulley mounting hub

1. Install fan housing assembly on cylinder head and install three M10 x 30 bolts finger tight.
2. Tighten bolts to standard torque (page 553).

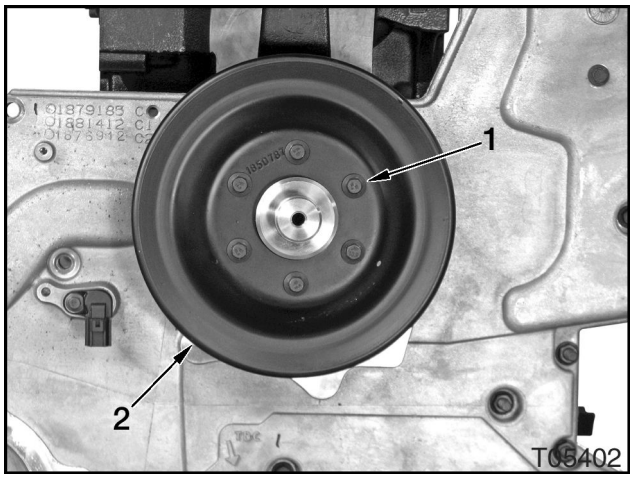


Figure 433 Fan Drive Pulley, Spin-on

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

3. Install fan drive pulley on fan housing assembly and install six M8 x 20 bolts finger tight.

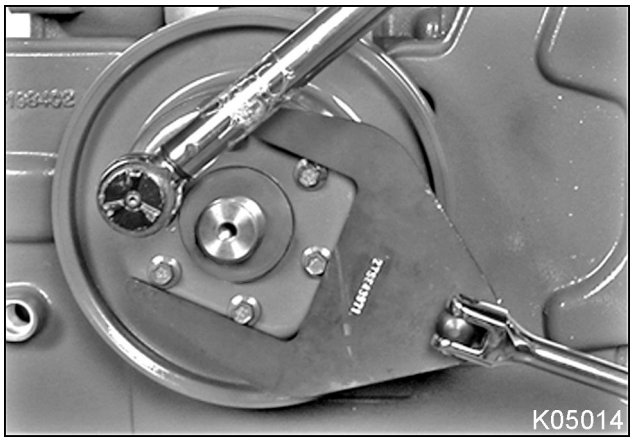


Figure 434 Fan Wrench and Fan Drive Pulley

4. Hold the fan drive pulley stationary with a Fan Wrench (for spin-on fan pulley) (page 347).
5. Tighten six M8 x 20 bolts to standard torque (page 553).

Horton DriveMaster® Fan Drive

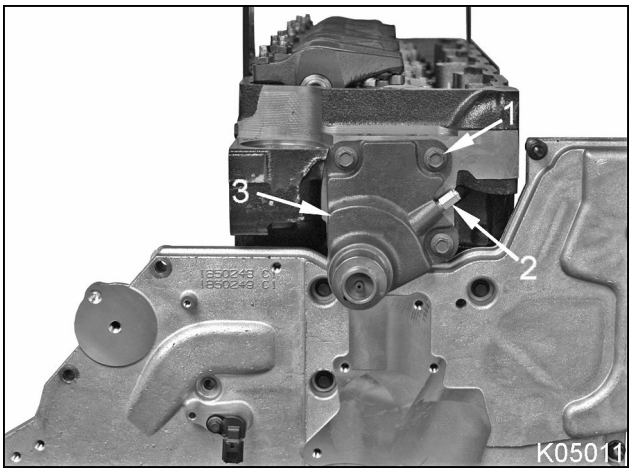


Figure 435 Fan Mounting Bracket, DriveMaster® (typical)

1. M10 x 30 bolt (3)
2. Fan clutch air supply fitting (typical)
3. Fan mounting bracket (typical)

NOTE: Fan drive configurations use either three or four M10 x 30 bolts to hold the fan mounting bracket to the cylinder head.

1. Install fan mounting bracket to the cylinder head and secure with M10 x 30 bolts.
2. Tighten M10 x 30 bolts to standard torque (page 553).

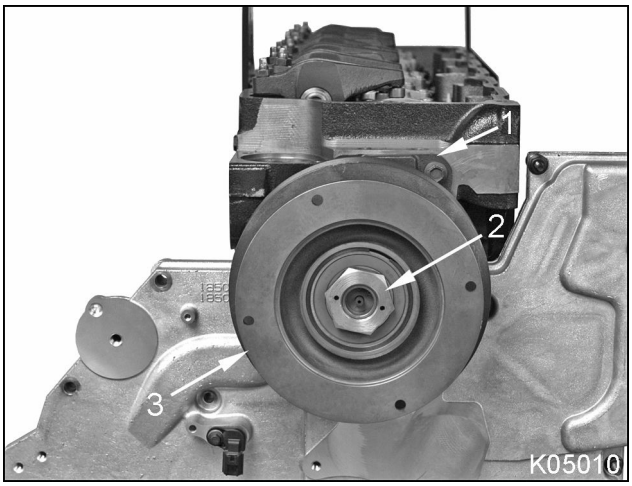


Figure 436 Fan pulley, DriveMaster®

1. Fan mounting bracket (typical)
2. Nut assembly
3. Fan Pulley

3. Slide fan pulley on fan mounting bracket.

CAUTION: To prevent engine damage, install nut assembly with collar toward engine.

4. Install nut assembly (collar toward engine) on the fan mounting bracket and finger tighten.
5. Tighten nut assembly to special torque (page 346) using a Fan Hub Wrench (2 inch) (page 347) and a torque wrench. See Using a Torque Wrench Extension (page 554) to calculate the correct torque wrench setting.

Water Outlet Tube and Thermostat

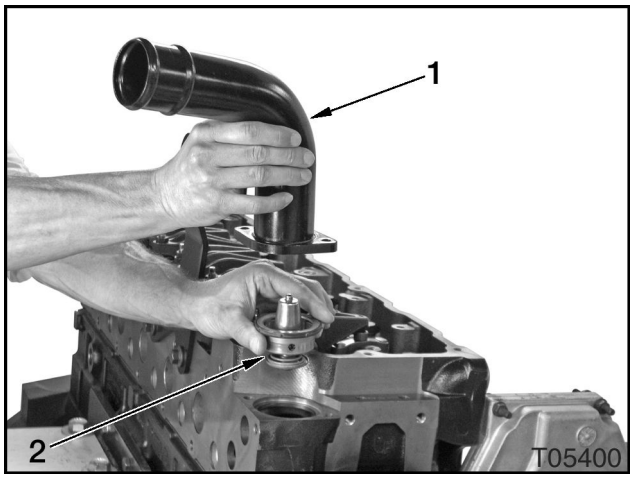


Figure 437 Water Outlet Tube and Thermostat

1. Water outlet tube (typical)
2. Thermostat assembly

1. If equipped with a thermostat bypass, install a new thermostat seal and then install the thermostat bypass housing on the cylinder head.
2. Install thermostat assembly in the cylinder head or thermostat bypass.

NOTE: Water outlet tube configurations use either two M8 x 25 bolts to hold the water outlet tube to the cylinder head or two M8 x 120 bolts to hold the water outlet tube and thermostat bypass housing to the cylinder head.

3. Install water outlet tube and finger tighten two M8 bolts.
4. Tighten two M8 bolts to standard torque (page 553).

Water Pump Assembly

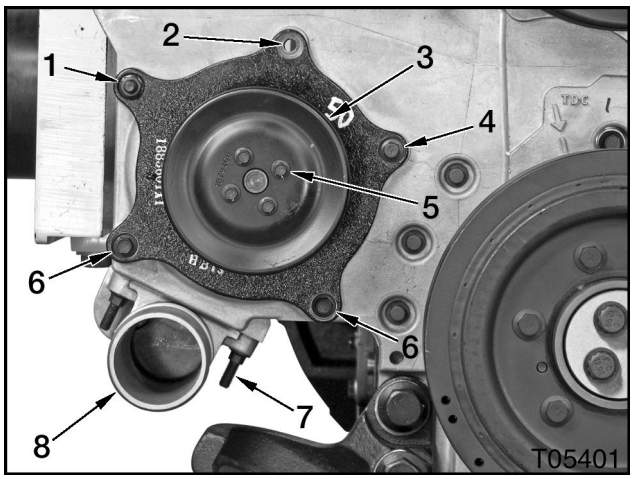


Figure 438 Water Pump and Inlet Elbow

1. M8 x 55 bolt (nut on front)
2. M8 x 70 bolt
3. Water pump pulley (typical)
4. M8 x 16 bolt
5. M6 bolt (4) (See NOTE)
6. M8 x 50 bolt (2)
7. M8 x 30 stud bolt (3)
8. Water inlet elbow

NOTE: M6 bolts may be M6 x 12 with separate washers or M6 x 14 with captive washers.

1. Install a new water pump seal in the water pump assembly.
2. Install water pump assembly on the front cover and install two M8 x 50 bolts.

NOTE: Do not install the M8 x 70 bolt at this time if the alternator bracket was removed.

3. Install M8 x 70 bolt, M8 x 55 bolt (nut on front), and M8 x 16 bolt finger tight.
4. Tighten five M8 water pump bolts to standard torque (page 553).
5. Install the water pump pulley on the water pump and install four M6 pulley bolts finger tight.
6. Tighten four M6 pulley bolts as follows:
   - M6 x 12 with separate washer: standard torque
   - M6 x 14 with captive washer: 15 Nm (11 lb-ft)

(page 553).

Water Inlet Elbow

NOTE: Water inlet elbow configurations use either three M8 stud bolts or three M8 x 30 bolts to hold the water inlet elbow to the front cover.

1. Install a new water inlet elbow gasket into front cover.
2. Install water inlet elbow using three M8 x 30 water inlet elbow stud bolts finger tight.
3. Tighten three M8 x 30 stud bolts to standard torque (page 553).

Coolant Housing (Refrigerant Compressor Mount)

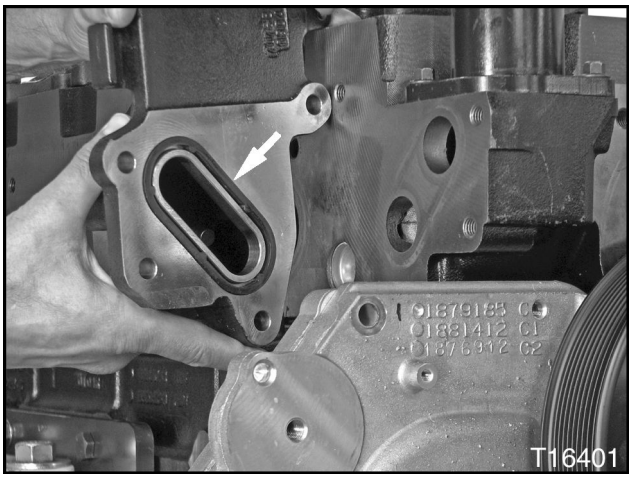


Figure 439 Coolant Housing Seal

1. Install a new coolant housing seal in the coolant housing.

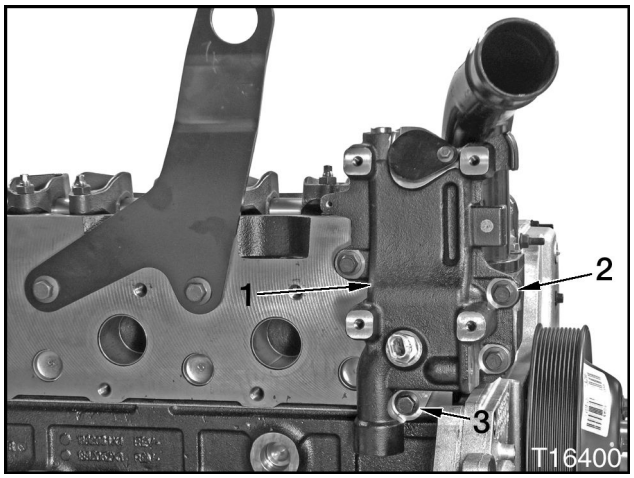


Figure 440 Coolant Supply Housing

1. Coolant housing (refrigerant compressor mount)
2. M10 x 30 bolt (3)
3. M10 x 45 bolt

2. Install coolant supply housing on the cylinder head and install three M10 x 30 bolts finger tight.
3. Install M10 x 45 bolt finger tight.
4. Tighten three M10 x 30 bolts and M10 x 45 bolt to standard torque (page 553).

Alternator Support

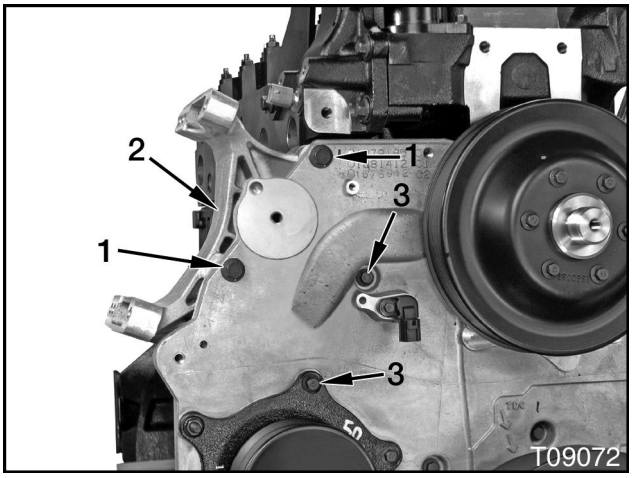


Figure 441 Alternator Support

1. M10 x 70 bolt (2)
2. Alternator support
3. M8 x 70 bolt (2)

1. Position alternator support on the back of the front cover.
2. Install two M10 x 70 bolts through the front cover and alternator support.
3. Install two M8 x 70 bolts through the front cover and alternator support.
4. Tighten two M10 x 70 bolts and two M8 x 70 bolt to standard torque (page 553).

Dual Idler Pulleys

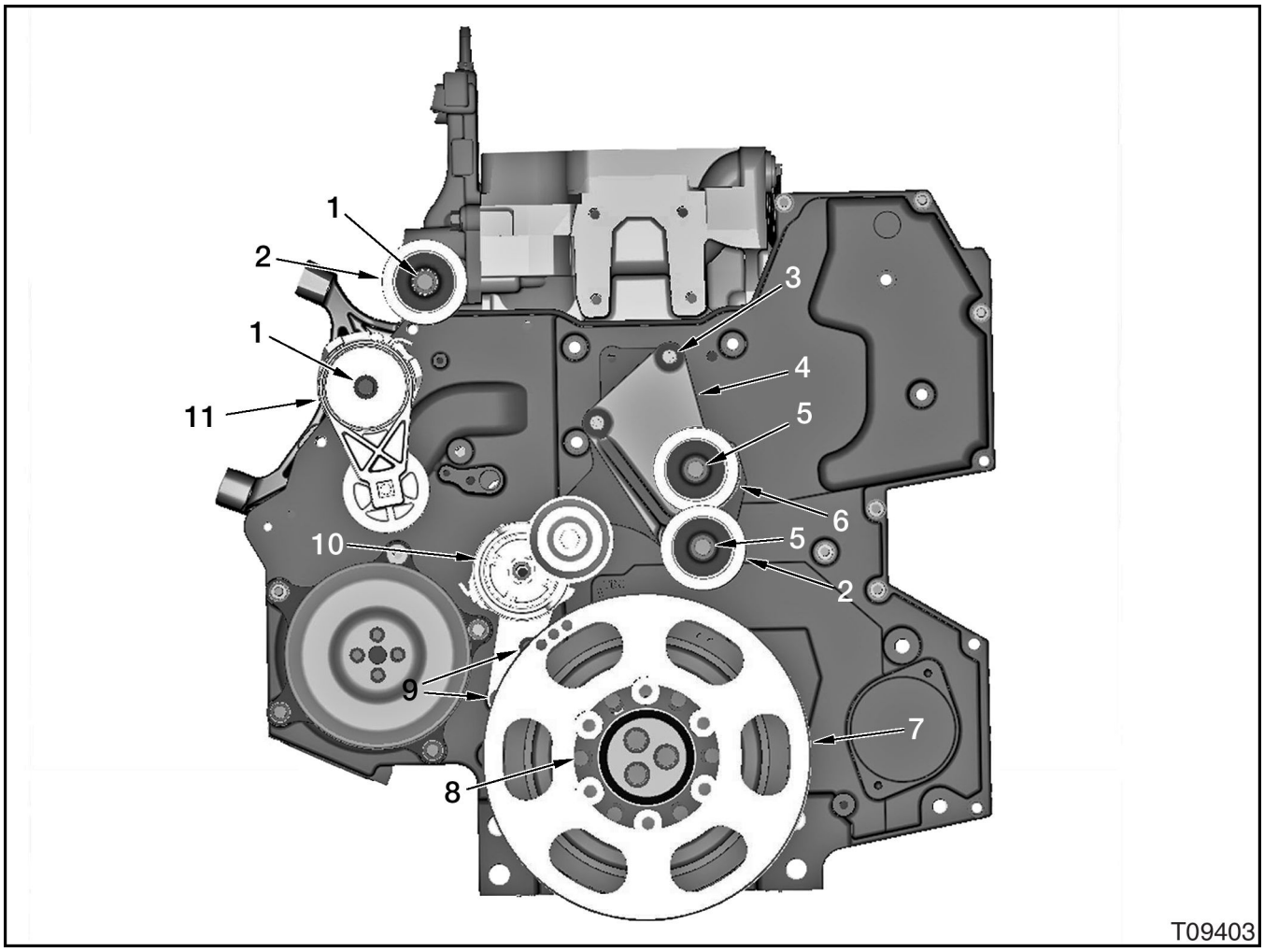


Figure 442 Belt Tensioner and Dual Idler Pulley Bolt Locations

1. M10 x 90 bolt (2)
2. Flat idler pulley (2)
3. M8 x 22 Torx® socket head bolt (3)
4. Idler pulley bracket
5. M10 x 30 bolt (2)
6. Pulley (idler)
7. Pulley (crankshaft)
8. M10 x 25 bolt (6)
9. M8 x 75 bolt (2)
10. Tensioner (outer belt)
11. Tensioner (inner belt)

1. Install the idler pulley bracket and the three M8 x 22 Torx® socket head bolts and tighten bolts to standard torque (page 553).
2. Install the flat idler pulley and the M10 x 90 bolt on the coolant supply housing and tighten bolt to standard torque (page 553).
3. Install the flat idler pulley and the M10 x 30 bolt and tighten bolt to standard torque (page 553).
4. Install the pulley (idler) and the M10 x 30 bolt and tighten bolt to standard torque (page 553).
5. Install the inner belt drive belt tensioner and the M10 x 90 bolt and tighten bolt to standard torque (page 553).
6. Install the outer belt drive belt tensioner and the two M8 x 75 bolts and tighten bolts to standard torque (page 553).

7. Install the pulley and the six M10 x 25 bolts and tighten bolts to special torque (page 346).

Secondary Compressor Support, Flat Idler Pulleys, and Idler Support Plate

NOTE: The following procedure only applies to engines equipped with dual A/C (refrigerant) compressor option.

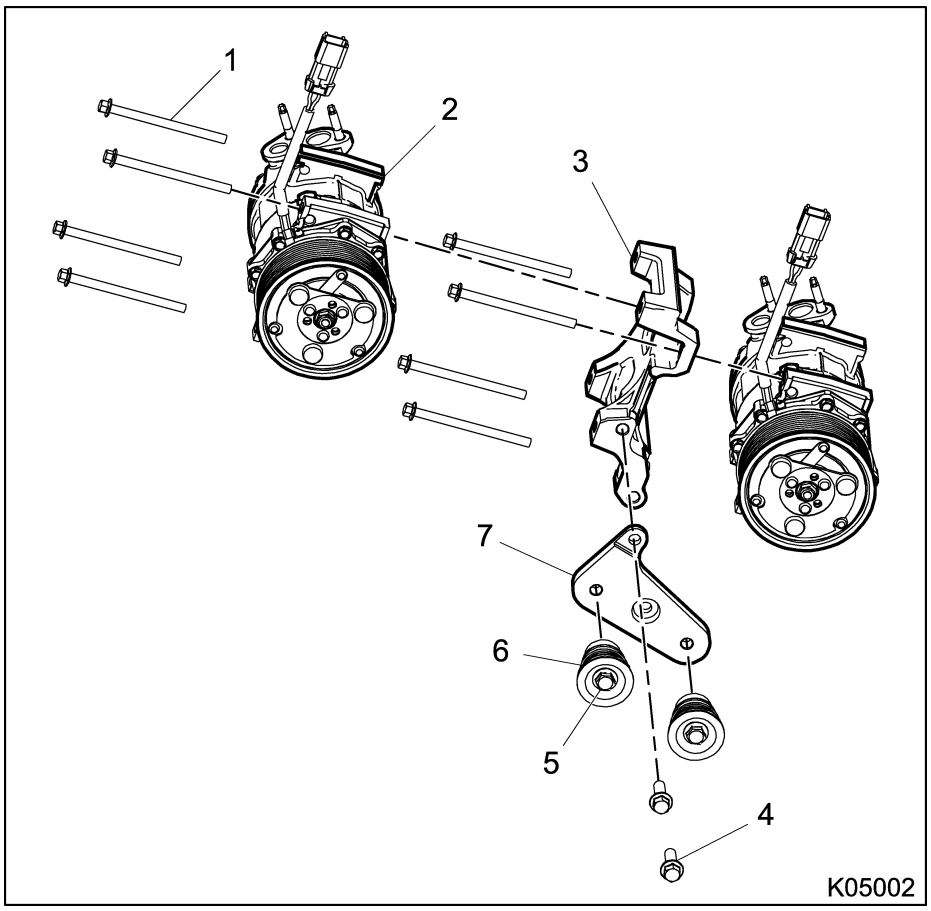


Figure 443 Dual Refrigerant Compressor Support

1. M8 x 110 bolt (8)
2. A/C (refrigerant) compressor (2)
3. Secondary refrigerant compressor support
4. M10 x 30 bolt (2)
5. M10 x 60 bolt (2)
6. Flat idler pulley assembly (2)
7. Idler support plate

⚠ WARNING: To prevent personal injury or death, do not open pressurized refrigerant lines.

1. Position inner refrigerant compressor on the coolant supply housing (refrigerant compressor mount).
2. Install the secondary refrigerant compressor support and four M8 x 110 bolts.
3. Tighten four M8 x 110 bolts to standard torque (page 553).
4. Install the idler support plate and two M10 x 30 bolts on the secondary refrigerant compressor support.
5. Tighten two M10 x 30 bolts to standard torque (page 553).
6. Install two flat idler pulley assemblies on the idler support plate and tighten two M10 x 60 bolts to standard torque (page 553).
7. Install outer refrigerant compressor and four M8 x 110 bolts.
8. Tighten four M8 x 110 bolts to standard torque (page 553).

Single Drive Belt

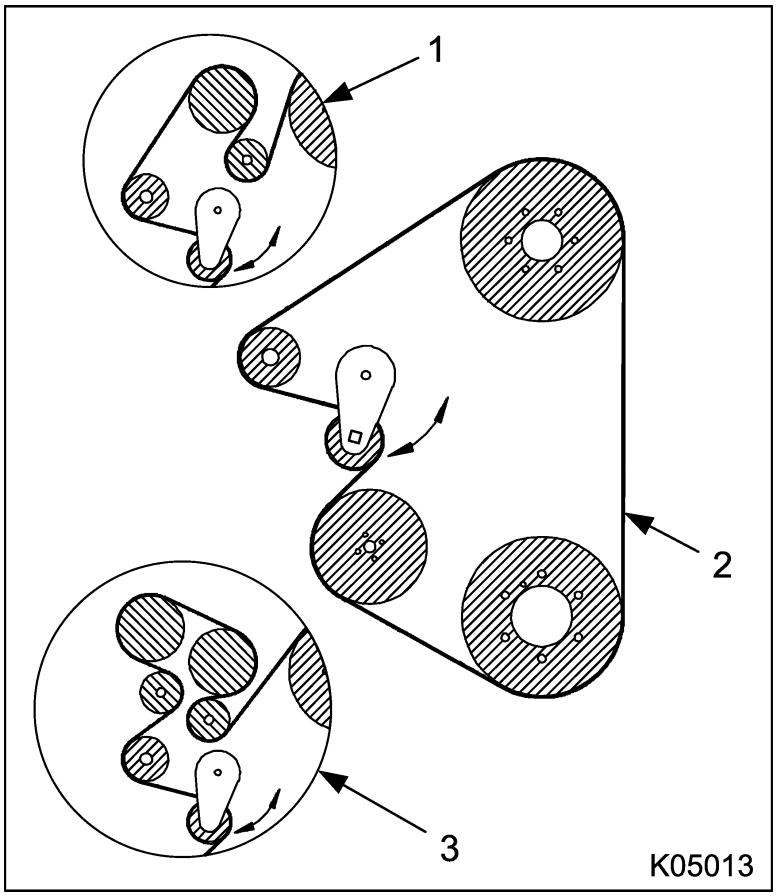


Figure 444 Single Drive Belt Routing

1. Single refrigerant compressor and single idler pulley
2. Without refrigerant compressor
3. Dual refrigerant compressors and dual idler pulleys

1. Install drive belt on all engine pulleys, except one.
2. Insert 1/2 inch square drive ratchet or breaker bar into automatic belt tensioner assembly square hole.
3. Rotate tensioner (belt) clockwise.
4. Fit drive belt on last pulley and slowly release automatic belt tensioner assembly.
5. Inspect each pulley to verify drive belt is properly seated.

Dual Drive Belt

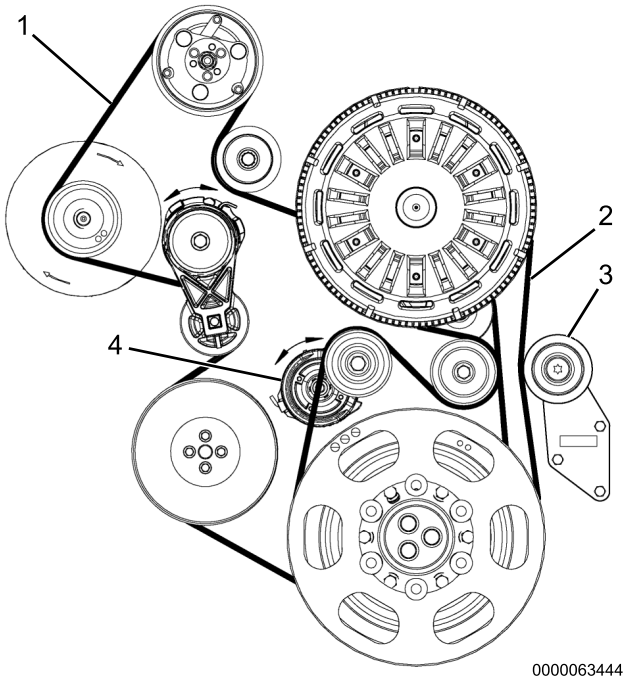


Figure 445 Dual Drive Belt Routing

1. Inner drive belt
2. Outer drive belt
3. Outer drive belt idler pulley assembly
4. Outer drive belt tensioner

1. Install inner drive belt on all engine pulleys, except one.
2. Insert 1/2 inch square drive ratchet or breaker bar into inner belt drive belt tensioner square hole.
3. Rotate inner belt automatic tensioner clockwise.
4. Fit inner drive belt on last pulley and slowly release inner belt drive belt tensioner.
5. Inspect each pulley to verify drive belt is properly seated.
6. Position outer drive belt (flat side facing pulley) on outer belt idler pulley assembly (if installed), and install belt on all pulleys except outer drive belt tensioner flat drive pulley.
7. Rotate outer drive belt tensioner counterclockwise, using a 16 mm socket and a ratchet or breaker bar.
8. Fit outer belt on flat idler pulley and slowly release outer drive belt tensioner.
9. Inspect each pulley to verify drive belt is properly seated.

Specifications

Camshaft gear to upper idler gear maximum backlash	0.312 mm (0.012 in)
High-pressure oil pump end play	0.127 to 0.457 mm (0.005 to 0.018 in)
Lower idler gear to air compressor gear maximum backlash	0.310 mm (0.012 in)
Lower idler gear to crankshaft gear maximum backlash	0.338 mm (0.013 in)
Oil pump end clearance	0.05 to 0.13 mm (0.002 to 0.005 in)
Oil pump side clearance	0.48 to 0.62 mm (0.019 to 0.024 in)
Upper idler gear to high-pressure oil pump gear maximum backlash	0.342 mm (0.013 in)
Upper idler gear to lower idler gear maximum backlash	0.310 mm (0.012 in)
Vibration damper face runout (maximum)	1.52 mm (0.060 in)

Water Pump Pulley Diameters and Spin Ratios

Engine	Pulley Diameter	Spin Ratio
MaxxForce® DT 215 – 230 BHP	15.54 cm (6.12 in)	1.40: 1
MaxxForce® DT 245 – 260 BHP	13.93 cm (5.48 in)	1.55: 1
MaxxForce® DT 270 – 300 BHP	13.93 cm (5.48 in)	1.55: 1
MaxxForce® 9 and 10	12.54 cm (4.94 in)	1.73: 1

Fan Drive Configurations Diameters and Ratios (Spin-on)

		Fan Center Line (CL)			
Fan Drive Configuration	Engine	Vertical above Crank	Lateral Offset (toward turbo)	Pulley Diameter	Fan Drive Ratio
Spin-on 11” fan center	MaxxForce® DT	279.4 mm (11 in)	none	200.66 mm (7.9 in)	1.08 : 1
Spin-on 13” fan center	MaxxForce® DT	330.2 mm (13 in)	25.4 mm (1 in)	201.2 mm (7.92 in)	1.08 : 1
Spin-on 14.3” fan center	MaxxForce® DT	363.22 mm (14.3 in)	none	218.95 mm (8.62 in)	0.99 : 1
Spin-on 14.3” fan center	MaxxForce® DT	363.22 mm (14.3 in)	none	200.66 mm (7.9 in)	1.08 : 1
Spin-on 16.2” fan center	MaxxForce® DT	411.5 mm (16.2 in)	95.3 mm (3.75 in)	219.5 mm (8.64 in)	0.99 : 1
Spin-on 16.2” fan center	MaxxForce® DT	411.5 mm (16.2 in)	95.3 mm (3.75 in)	201.2 mm (7.92 in)	1.08 : 1
Spin-on 20” fan center	MaxxForce® DT	508 mm (20 in)	none	21.95 cm (8.64 in)	0.99 : 1

Fan Drive Configurations Diameters and Ratios (DriveMaster®) — Single Drive Belt

		Fan Center Line (CL)			
Fan Drive Configuration	**Engine**	**Vertical above Crank**	**Lateral Offset (toward turbo)**	**Pulley Diameter**	**Fan Drive Ratio**
Horton DriveMaster® 11” fan center	MaxxForce® DT	279.4 mm (11 in)	none	200.66 mm (7.9 in)	1.08 : 1
Horton DriveMaster® 13” fan center	MaxxForce® DT	330.2 mm (13 in)	25.4 mm (1 in)	20.12 cm (7.92 in)	1.08 : 1
Horton DriveMaster® 14.3” fan center	MaxxForce® DT	363.22 mm (14.3 in)	none	218.95 mm (8.62 in)	0.99 : 1
Horton DriveMaster® 16.2” fan center	MaxxForce® DT	411.5 mm (16.2 in)	95.3 mm (3.75 in)	20.12 cm (7.92 in)	1.08 : 1
Horton DriveMaster® 20” fan center	MaxxForce® DT	508 mm (20 in)	none	21.95 cm (8.64 in)	0.99 : 1

Fan Drive Configurations Diameters and Ratios (DriveMaster®) — Dual Drive Belt

		Fan Center Line (CL)			
Fan Drive Configuration	**Engine**	**Vertical above Crank**	**Lateral Offset (toward turbo)**	**Pulley Diameter**	**Fan Drive Ratio**
Horton DriveMaster® 14.3” fan center	MaxxForce® DT	363.22 mm (14.3 in)	none	200.66 mm (7.9 in)	1.08 : 1
Horton DriveMaster® 14.3” fan center	MaxxForce® DT	508 mm (20 in)	none	18.14 cm (7.14 in)	1.2 : 1
Horton DriveMaster® 20” fan center	MaxxForce® DT	508 mm (20 in)	none	20.12 cm (7.92 in)	1.08 : 1
Horton DriveMaster® 20” fan center	MaxxForce® DT	508 mm (20 in)	none	18.14 cm (7.14 in)	1.2 : 1

Special Torque

Damper (hub) bolts, M12 x 40	135 N·m (99 lb·ft) Re-torque all bolts until no movement
Fan pulley M6 x 14 bolts with captive washers	15 Nm (11 lb-ft)
Front engine mount M18 bolts	368 N·m (271 lb·ft)
Horton DriveMaster® nut assembly (2 inch)	177 N·m (130 lb·ft)
Lower idler gear M20 x 70 bolt	639 N·m (470 lb·ft)
PTO adapter cover, M10 x 25 bolts (PTO equipped engines only)	61 N·m (45 lb·ft)
Upper idler gear M16 x 65 bolt	326 N·m (240 lb·ft)
Vibration damper assembly M10 x 16 bolts	58 N·m (43 lb·ft)
Vibration damper and pulley assembly M10 x 25 bolts	61 N·m (45 lb·ft)

Special Service Tools

Dial indicator set	Obtain locally
Fan Wrench (for spin-on fan pulley)	ZTSE43971
Fan Hub Wrench, 2 inch (for DriveMaster® nut assembly)	ZTSE43972
Feeler gauge	Obtain locally
Front Seal and Wear Sleeve Installer	ZTSE3004B
H-bar puller	Obtain locally
Heat insulated gloves	Obtain locally
Heel bar	Obtain locally
Hot plate	Obtain locally
Loctite® 569 Hydraulic Sealant	Obtain locally
Lower Idler Gear Socket	ZTSE4383
Muffler chisel	Obtain locally
Straightedge	Obtain locally
Thermo-melt crayon, 100 °C (212 °F)	Obtain locally
16 mm 12 point impact socket	Obtain locally

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Illustrations and Description

Exploded View of Cylinder Head and Valve Train Components

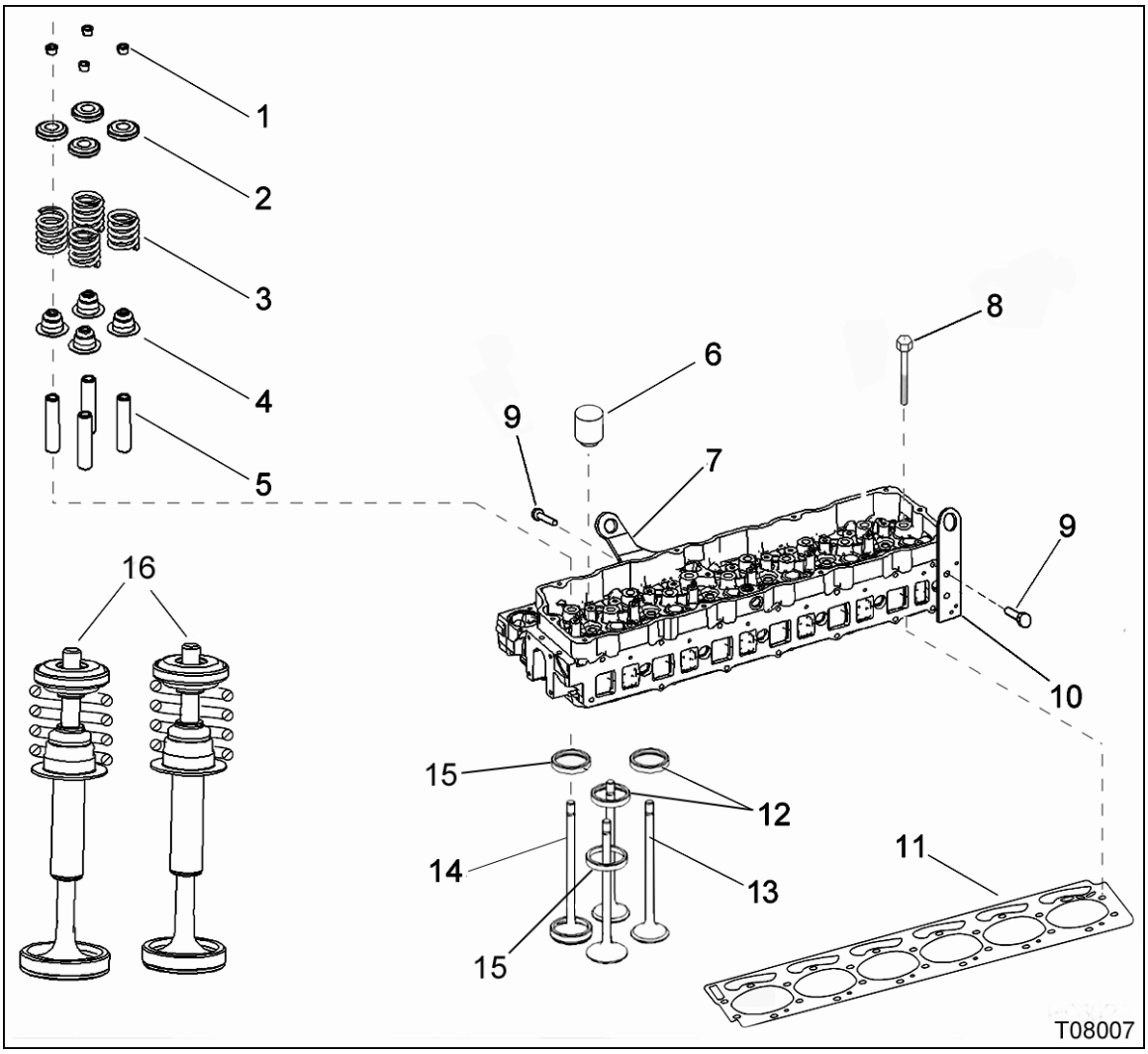


Figure 446 Cylinder Head and Valve Train Components

1. Valve spring retainer keys (48)
2. Valve rotators or retainers (24)
3. Valve springs (24)
4. Valve stem seals (24)
5. Valve guide inserts (24)
6. Fuel injector sleeve (6)
7. Front lifting eye
8. Cylinder head bolt, (26)
9. M12 x 25 bolt (2 each lift eye)
10. Rear lifting eye
11. Cylinder head gasket
12. Valve seat insert intake seats (12)
13. Exhaust valve (12)
14. Intake valve (12)
15. Valve seat insert exhaust seats (12)
16. Valve assemblies (12)

MaxxForce® DT, 9, and 10 cylinder heads are cast grey iron and feature four valves per cylinder. A single camshaft transfers lifting force through a roller tappet, push rod, rocker arm, and onto a valve bridge where both intake or exhaust valves are opened and closed simultaneously. Four valves per cylinder

allows greater air volume to flow into and out of each cylinder than comparably sized engines using only two valves per cylinder.

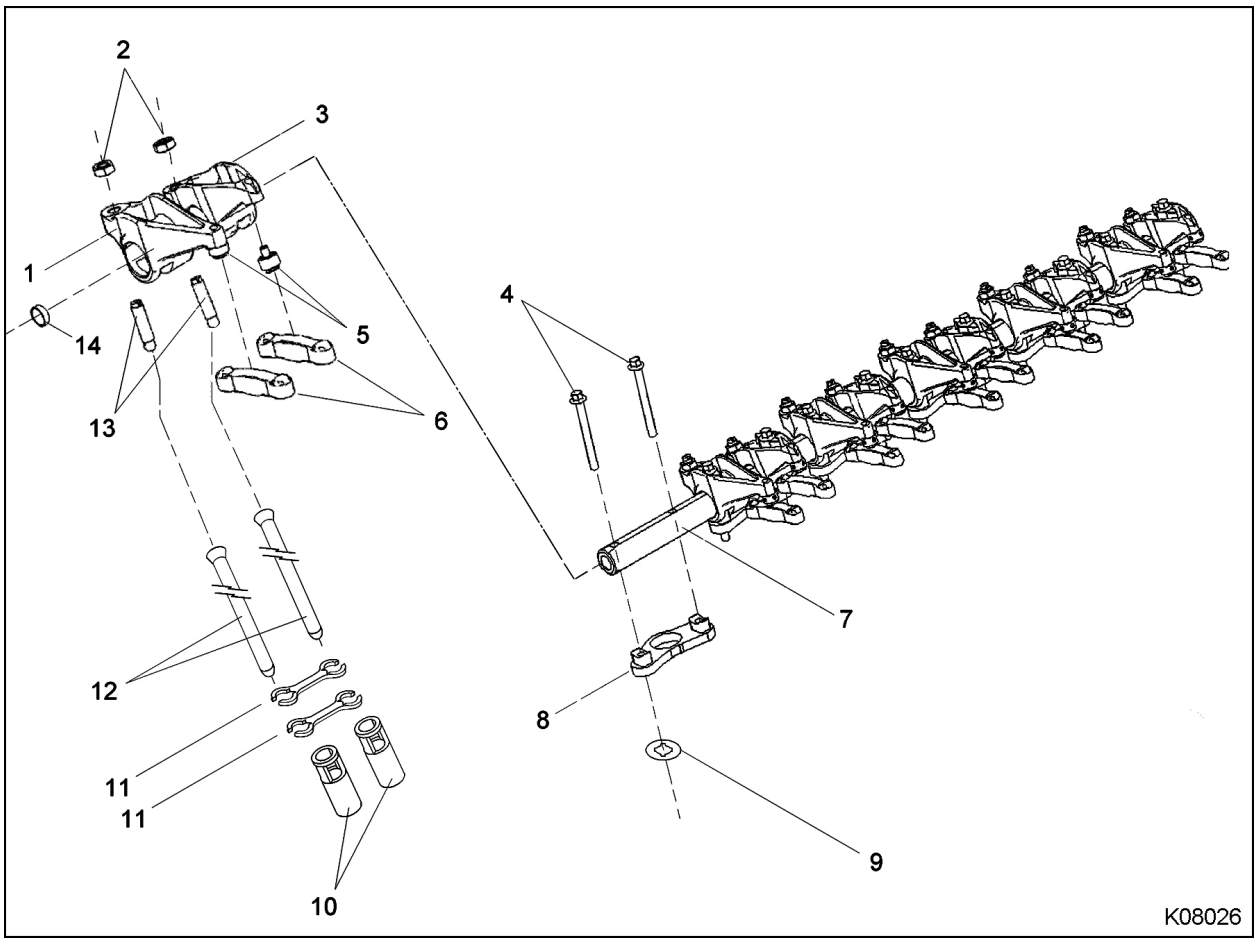


Figure 447 Valve Train Components

1. Intake rocker arm (6)
2. Valve adjusting screw lock nut, M10 (12)
3. Exhaust rocker arm (6)
4. M8 x 60 shaft bolt (12)
5. Pivot foot assembly (12)
6. Valve bridge (12)
7. Rocker arm shaft
8. Rocker shaft support (6)
9. Support washer (assembly aid) (6)
10. Roller tappets (12)
11. Roller tappet guide (12)
12. Push rods (12)
13. Valve lash adjuster screw, M10 (12)
14. Rocker shaft plug (2)

Description

Valve bridges, guides, springs, retainer keys, and valve stem seals are common between the intake and exhaust sides of the cylinder head. Rotators are always used on intake valves and can be used on exhaust valves.

New valve bridges can be installed on the intake or exhaust valves in either direction, and are also part of compression brake operation.

Valve guides and valve seats are replaceable.

Valve rotators allow valves to rotate for increased valve face life.

Valve stem seals are one piece and have an integral hardened valve spring seat.

Phosphate coating is used on rocker arms for initial break-in and to extend life.

Pressurized oil is fed from the crankcase through the cylinder head at the cylinder 6 rocker shaft support. Oil then enters the rocker shaft and is distributed to the rocker arms.

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 transmission to park or neutral, set parking brake, and block wheels before doing diagnostic or service procedures.

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

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

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

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

NOTE: There are two types of valve lash adjuster screw drive features available. The hex-head style screw is the original style. The new style adjuster screw has an internal hex socket. New socket head screws can be used to replace original hex-head screws.

CAUTION: To prevent engine damage, do not replace new drilled forced-lubrication valve lash adjuster screws with solid adjuster screws.

Valve Lash Adjustment

The crankshaft is rotated twice during valve lash adjustment procedure.

- Six valves are adjusted when piston 1 is at Top Dead Center (TDC) compression.
- Six valves are adjusted when piston 6 is at Top Dead Center (TDC) compression.

If engine is equipped with an engine brake, corresponding engine brake actuator lash can be adjusted when piston 1 and 6 are at TDC compression.

NOTE: Engine brake lash adjustments are not required when adjusting valve lash.

1. On engines rated at 245 horsepower and above, remove the interstage cooler and piping. See Interstage Cooler (ISC) (page 133).
2. Remove, do not discard the M6 x 20 bolt securing the crankcase breather inlet tube to the valve cover. See Crankcase Ventilation System (page 473).
3. Remove valve cover from cylinder head. See Valve Cover (page 357).
4. Turn the crankshaft in the direction of engine rotation to remove gear lash. Position piston 1 at TDC compression by observing cylinder 6 rocker arms in overlap as the vibration damper timing mark approaches the TDC mark on the front cover. Cylinder 6 exhaust valve will be closing (coming up) and the intake valve will be starting to open (going down).

5. If piston 1 is at TDC compression, see Chart 3 (page 355) and do steps 6 and 7.

Chart 3

Valve and brake lash adjustments (inches) with piston 1 at TDC compression (Chart 3)											
Cylinder 1		Cylinder 2		Cylinder 3		Cylinder 4		Cylinder 5		Cylinder 6	
intake 1	exhaust 2	intake 3	exhaust 4	intake 5	exhaust 6	intake 7	exhaust 8	intake 9	exhaust 10	intake 11	exhaust 12
0.019	0.019	0.019			0.019	0.019			0.019		
Brake 0.019				Brake 0.019				Brake 0.019			

Valve and Brake Lash Adjustments with Piston 1 at TDC Compression

Chart 4

Valve and brake lash adjustments (inches) with piston 6 at TDC compression (Chart 4)											
Cylinder 1		Cylinder 2		Cylinder 3		Cylinder 4		Cylinder 5		Cylinder 6	
intake 1	exhaust 2	intake 3	exhaust 4	intake 5	exhaust 6	intake 7	exhaust 8	intake 9	exhaust 10	intake 11	exhaust 12
			0.019	0.019			0.019	0.019		0.019	0.019
		Brake 0.019				Brake 0.019				Brake 0.019	

Valve and Brake Lash Adjustments with Piston 6 at TDC Compression

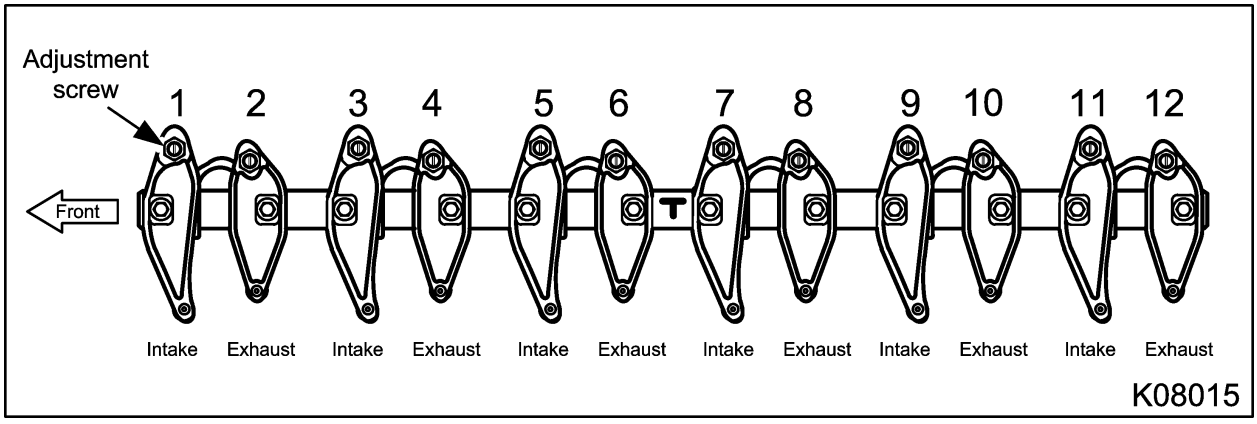


Figure 448 Valve Lash Adjustment

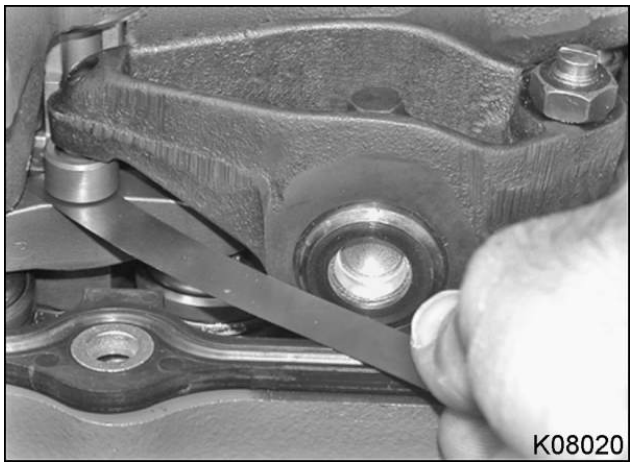


Figure 449 Valve Lash Measurement

6. Measure valve lash when the engine is cold. Put a 0.48 mm (0.019 in) feeler gauge (page 398) between the rocker arm pivot foot and the valve bridge. A light drag should be felt on the feeler gauge. If adjustment is required, loosen lock nut and turn valve adjustment screw until a light drag is felt.
7. Once valve lash is set, tighten valve adjustment screw lock nut to special torque (page 398) and remove feeler gauge. Recheck lash, a light drag should be felt on the feeler gauge. If drag is too tight or loose, repeat steps 6 and 7.

   If engine is equipped with an engine brake, corresponding brake actuator lash can be adjusted before rotating crankshaft.
8. Turn crankshaft 360° in the direction of engine rotation to remove gear lash. Position piston 6 at TDC compression by observing cylinder 1 rocker arms in overlap as the vibration damper timing mark approaches the TDC mark on the front cover.
9. If piston 6 is at TDC compression, see Chart 4 (page 355) and do steps 6 and 7.

Removal

NOTE: When performing specific component removal, only remove components necessary for access.

Valve Cover

NOTE: If the valve cover is removed for any reason and engine is equipped with an engine brake, verify six brake piston locknuts are tight. If loose, check brake lash, see Valve Lash Adjustment (page 353).

1. Disconnect EBP sensor harness. See Exhaust Back Pressure (EBP) Sensor (page 87).
2. On engines rated at 245 horsepower and above, remove the interstage cooler and interstage cooler inlet duct. See Interstage Cooler (ISC) (page 133) and Interstage Inlet Duct Assembly (page 132).
3. Remove, do not discard, the M6 x 20 bolt securing the ISC coolant return tube to the valve cover. See Crankcase Ventilation System (page 473).

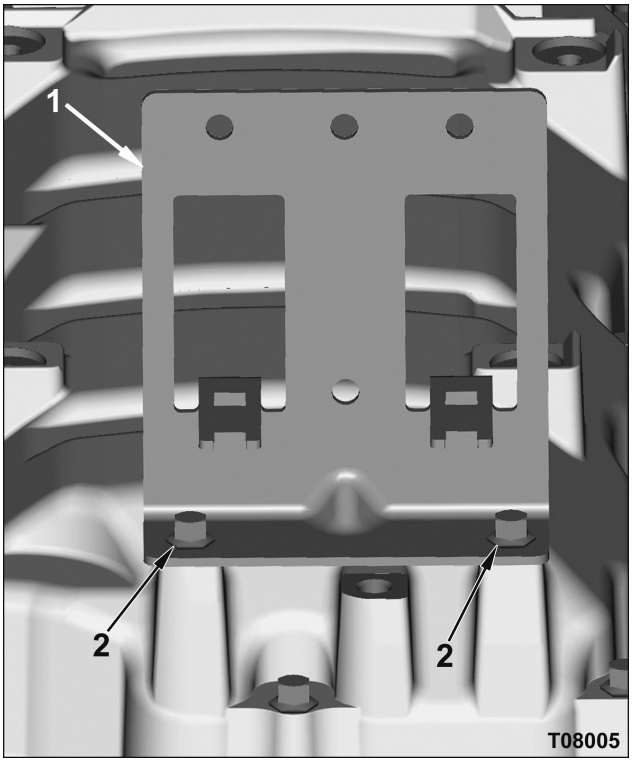


Figure 450 Clipping Plate

1. Clipping plate
2. M8 x 25 bolt (2)

4. Remove, do not discard, two M8 x 25 bolts securing the clipping plate to the valve cover. Remove clipping plate.
5. Disconnect CMP sensor connector and remove sensor harness from front cover. See Camshaft Position (CMP) Sensor (page 86).
6. Disconnect ECT1 sensor connector. See Engine Coolant Temperature 1 (ECT1) Sensor (page 88).

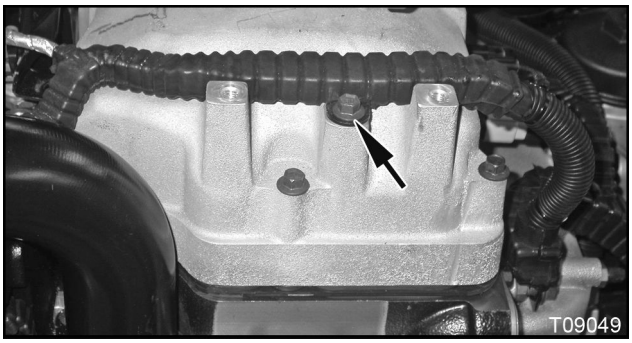


Figure 451 Sensor Wiring Harness Clamp

7. Remove, do not discard, M8 x 12 bolt securing engine wiring harness to the front of the valve cover.
8. Disengage engine wiring harness from the valve cover and water housing. Push or pull engine wiring harness out of the way just enough so valve cover can be removed from engine.
9. Remove M8 x 20 bolt and clip located on the middle of the valve cover securing boost solenoid tube assembly and exhaust brake valve assembly wiring harnesses to the valve cover. Do not discard bolt or nut. See Turbocharger 2 Wastegate Control (TC2WC) Valve (page 85).
10. Disconnect boost to solenoid tube assembly from engine throttle valve and the Turbocharger 2 Wastegate Control (TC2WC) valve. Place tube assembly on side. See Turbocharger 2 Wastegate Control (TC2WC) Valve (page 85).
11. Follow the wiring harness from the exhaust brake valve assembly to the main wiring harness connector. Disconnect main wiring harness connector and place wiring harness on the side.

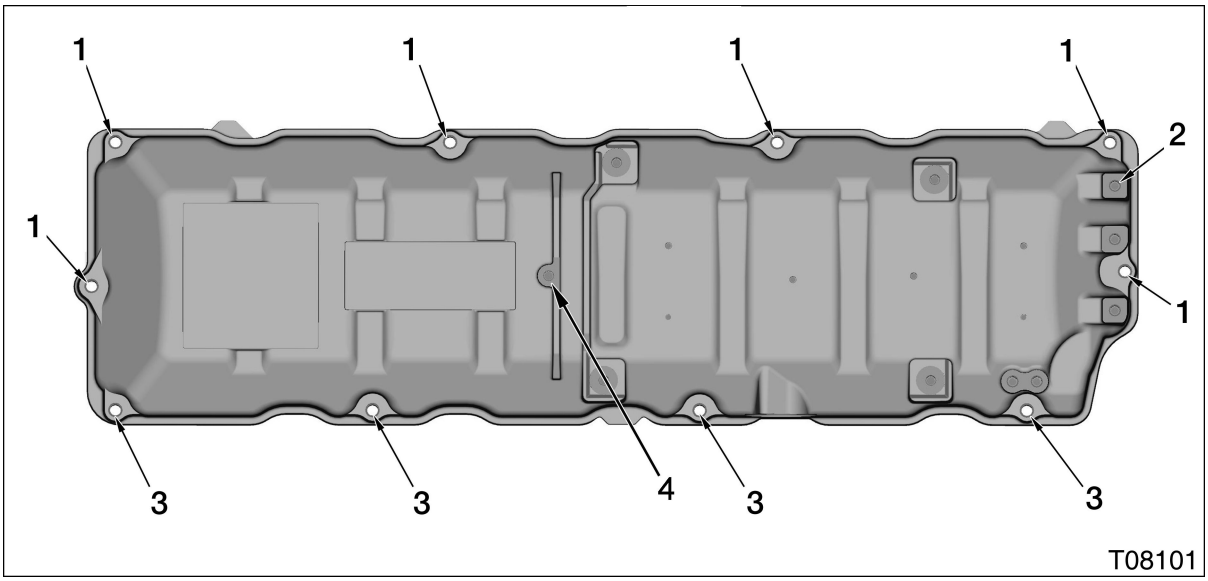


Figure 452 Valve Cover Bolts

1. Bolt, M8 x 80 (6)
2. Bolt, M8 x 25 (secures optional radiator piping support)
3. Stud bolt, M8 x 80 (4)
4. Bolt, M8 x 20

12. Remove and save four M8 x 80 stud bolts and six M8 x 80 bolts.
13. Lift valve cover off of cylinder head.

Rocker Arm Assembly

NOTE: Lash adjuster screws on forced-lubrication engines have an internal hex socket-style bolt head. Lash adjustment procedure remains the same.

1. Remove the valve cover gasket (page 96) .
2. Remove the high-pressure oil manifold (page 218).

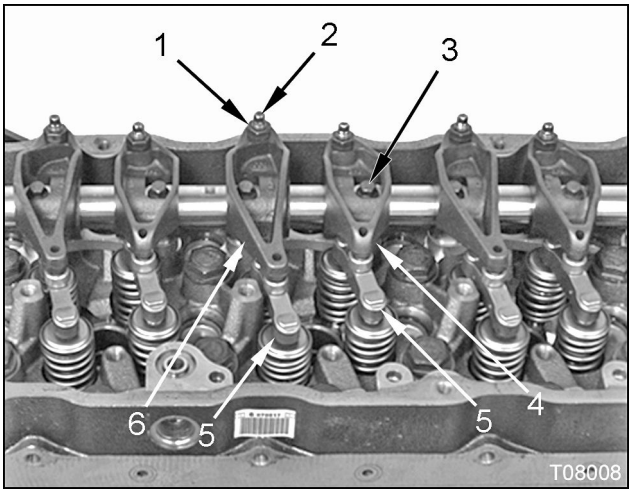


Figure 453 Valve Train Components

1. Valve adjusting screw lock nut (12)
2. Adjuster screw (12)
3. Rocker shaft bolt (12)
4. Exhaust rocker arm (6)
5. Valve bridge (12)
6. Intake rocker arm (6)

3. Loosen 12 adjuster screws and lock nuts. This will help prevent valve train damage and false torque readings during installation.
4. Loosen, but do not remove, 12 rocker shaft bolts.

NOTE: There are six support washers, one for each rocker shaft support for assembly.

5. Push down on rocker shaft bolts. This will latch support washers onto shaft bolts and keep rocker shaft supports from falling off.
6. Lift rocker arm shaft assembly up and off cylinder head.



Figure 454 Valve Bridge Removal

CAUTION: To prevent engine damage, use permanent marker to identify internal engine components and their orientation. Do not use paint or temporary markers.

7. Mark all valve bridges for installation in original location and orientation.
8. Remove valve bridges.

NOTE: If required, measure camshaft lobe lift before removing push rods or cylinder head. See Measure Camshaft Lobe Lift (page 362).

Rocker Arms

CAUTION: To prevent engine damage, use permanent marker to identify internal engine components and their orientation. Do not use paint or temporary markers.

NOTE: Lash adjuster screws on forced-lubrication engines have an internal hex socket-style bolt head.

1. Mark each rocker arm for installation in original location.
2. Remove 12 rocker shaft bolts.

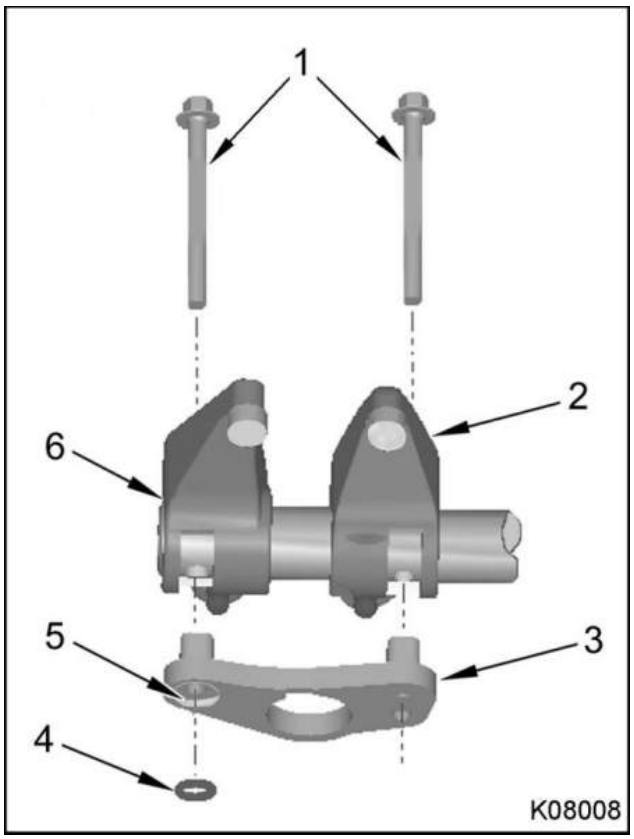


Figure 455 Rocker Arm Components

1. M8 x 60 shaft bolt
2. Exhaust rocker arm
3. Rocker arm shaft support
4. Support washer (assembly aid)
5. Machined recess
6. Intake rocker arm

3. Slide rocker arms off rocker arm shaft.
4. Remove and tag each push rod with cylinder number, orientation, and valve association (intake or exhaust).

Cylinder Head

NOTE: If required, measure camshaft lobe lift before removing push rods or cylinder head. See Measure Camshaft Lobe Lift (page 362).

1. Drain engine coolant. See Drain Coolant (page 62).
2. Remove ISC coolant return tube, interstage cooler inlet duct assembly, interstage cooler, and water outlet tube. See ISC Inlet Elbow and Intercooler (page 65).
3. Remove the oil level gauge. See Oil Level Gauge Assembly (page 476).
4. Remove the fuel filter assembly. See Fuel Filter Assembly (page 214).
5. Remove the air and EGR Mixer duct assembly. See Air and EGR Mixer Duct Assembly (page 176).
6. Remove the exhaust brake assembly and turbocharger outlet elbow. See Exhaust Brake Valve and Turbocharger Outlet Elbow (page 136).
7. Remove the turbocharger oil supply tube assembly (page 135), dual stage turbocharger assembly (page 139), crankcase breather inlet tube (page 473), and EBP sensor and tubing (page 87).
8. Remove the DSI assembly and tubing. See Down Stream Injection (DSI) Assembly (page 115).
9. Remove the exhaust manifold (page 192) and intake manifold (page 193).
10. Remove the coolant supply housing (page 306), thermostat housing (page 336), and fan housing assembly (page 308).

CAUTION: To prevent engine damage, remove fuel injectors before removing the cylinder head.

11. Remove the high-pressure oil hose and swivel nuts (page 215), valve cover gasket assembly (page 96), high-pressure oil manifold (page 218), and fuel injectors (page 220).

12. Remove and discard 26 cylinder head mounting bolts.

⚠ WARNING: To prevent personal injury or death, use a hoist rated for the weight of the cylinder head and follow the manufacturer's operation and safety instructions. Attach safety lifting hooks to the cylinder head lifting eyes.

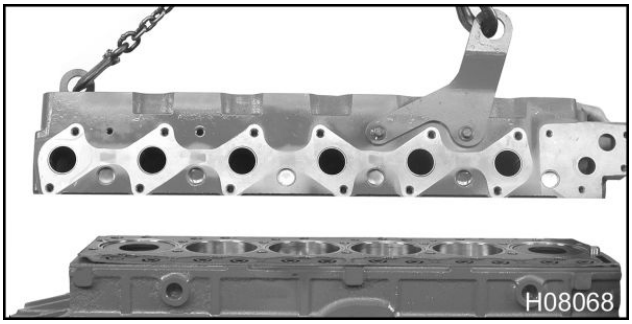


Figure 456 Cylinder Head and Crankcase (typical)

13. Attach appropriate hoist and lifting hooks to cylinder head lifting eyes.
14. Carefully lift cylinder head off crankcase.

NOTE: Place cylinder head on wood blocks to protect valves and bottom deck surface.

15. Place the cylinder head on a workbench. Support cylinder head with wooden blocks.
16. Remove four M12 x 25 bolts and both lifting eyes from cylinder head.



Figure 457 Cylinder Head Gasket (typical)

17. Remove cylinder head gasket from crankcase and discard.

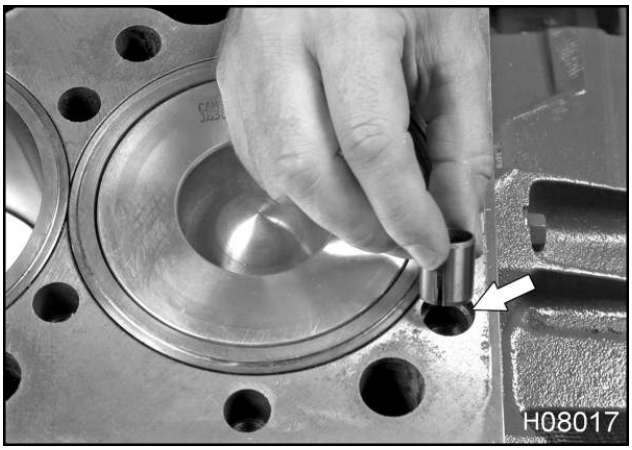


Figure 458 Cylinder Head Alignment Dowels (typical)

18. Remove two cylinder head alignment dowels from the top of crankcase.

Roller Tappets and Guides

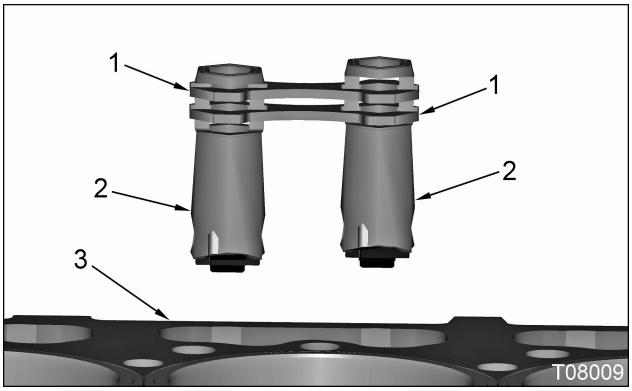


Figure 459 Roller Tappets and Guides

1. Roller tappet guide (2)
2. Roller tappet (2)
3. Crankcase

CAUTION: To prevent engine damage, use permanent marker to identify internal engine components and their orientation. Do not use paint or temporary markers.

Remove each roller tappet and two guides from tappet bores and mark with cylinder number, valve association (intake or exhaust), and roller orientation.

Cleaning, Inspection, Measurement, and Testing

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

Measuring Camshaft Lobe Lift

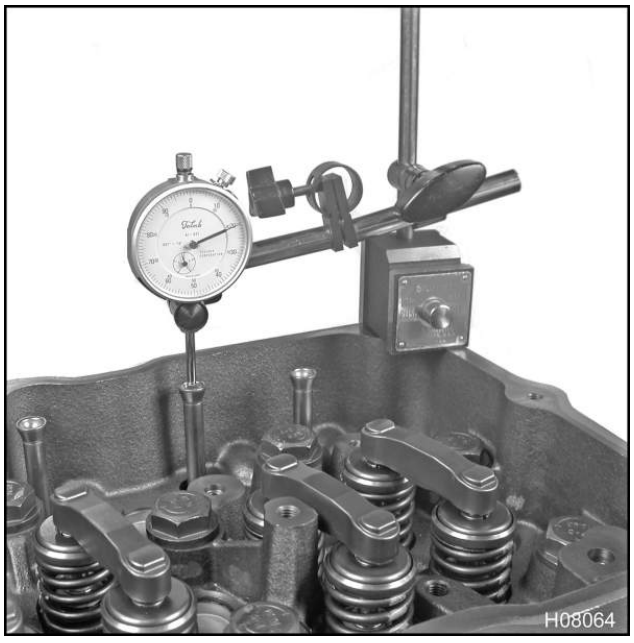


Figure 460 Dial Indicator with Magnetic Base

NOTE: If a complete engine overhaul is scheduled, camshaft wear can be accurately determined by measuring with a micrometer after the camshaft is removed. Measure camshaft lobes and journals (page 486). If this is not a complete engine overhaul, camshaft lobe lift can be measured using the following procedure.

1. Mount a dial indicator set (page 398) on the cylinder head.
2. Place dial indicator tip on top of push rod and rotate engine until push rod is at its lowest point of travel (base circle), then “zero” indicator.
3. Rotate the crankshaft and bring push rod to its highest point of travel. Record readings.
4. Repeat steps 2 and 3 for all twelve camshaft lobes.
5. Compare readings to camshaft lobe lift Specification (page 396).

Cylinder Head Cleaning

CAUTION: To prevent engine damage, leave valves installed in cylinder head to protect valve seats during cleaning.

1. Remove deposits and gasket material from the cylinder head gasket surface using a rotary wire brush or sanding block with mineral spirits.
2. Clean all cylinder head mounting bolt holes using an appropriately sized brush.
3. Wash rocker arm assemblies, roller tappets, and push rods in a suitable solvent and dry thoroughly. Replace any bolts that have damaged threads.

CAUTION: To prevent engine damage, do not use chlorinated solvents on bolts or crankcase tapped holes. Parts should be clean, dry, and free of any chemicals other than engine oil.

Cleaning and Inspection of Roller Tappets and Guides

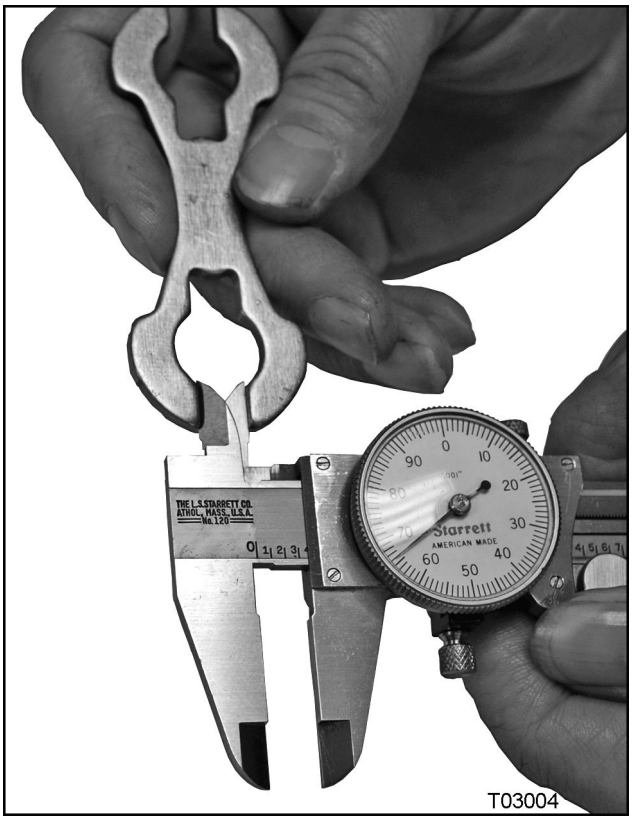


Figure 461 Roller Tappet Guide Slot Measurement

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

1. Clean roller tappets and guides using a suitable solvent and dry using filtered compressed air.
2. Inspect roller tappet guides for wear and damage.
3. Using a vernier caliper (page 398), measure the width of the slots of the roller tappet guides.
4. If Specifications (page 396) are exceeded, replace roller tappet guide.

Cleaning and Inspection of Push Rods

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

1. Clean push rods using a suitable solvent and dry using filtered compressed air.
2. Inspect push rods for wear at both ends. Replace if required.

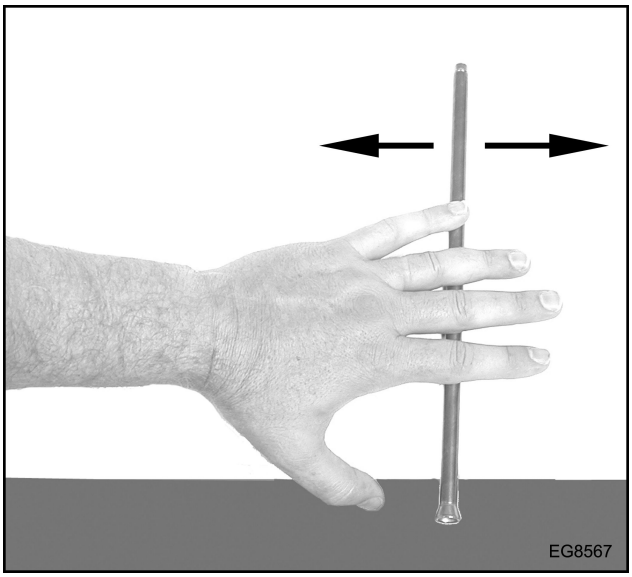


Figure 462 Push Rod Straightness Inspection

3. Inspect push rods for straightness by rolling on a flat surface with the cup end hanging over an edge.
4. Measure push rod runout with a feeler gauge (page 398) between the flat surface and push rod.
5. If Specifications (page 396) are exceeded, replace push rod.

Measuring Rocker Shaft

CAUTION: To prevent engine damage, if replacing the rocker arm shaft, all rocker arms must be replaced. Reusing rocker arms on a new shaft will not allow proper break-in, causing premature failure.

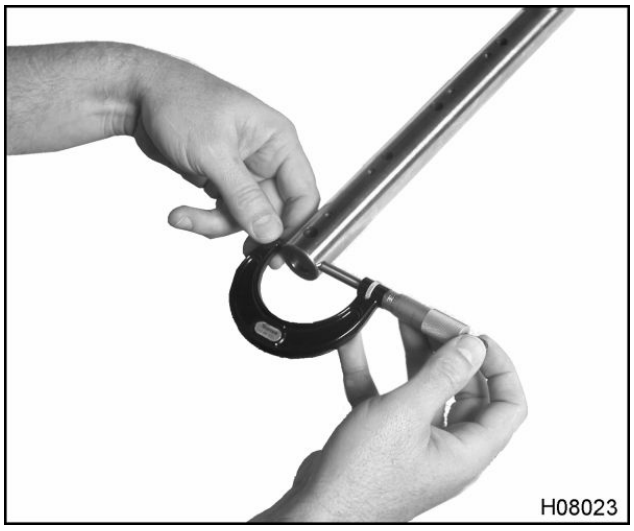


Figure 463 Rocker Arm Shaft Measurement

1. Inspect rocker shaft for scoring, pitting, and wear. Replace rocker arm shaft and all of the rocker arms if required.

NOTE: It is normal to see slight polishing at rocker arm contact areas.

2. Measure a non-contact area of the rocker arm shaft using an outside micrometer (page 398). This dimension will be used as a baseline for shaft diameter.
3. Measure each of the 12 rocker arm contact areas of the rocker arm shaft with a micrometer. If the difference between the baseline measurement and any of the contact area measurements is greater than 0.03 mm (0.001 in), replace the rocker shaft and all rocker arms.
4. Clean oil supply holes with a small wire or another suitable tool.
5. Inspect cup plugs at each end of the rocker arm shaft. Do not disturb the cup plugs unless they are damaged. If replacement is required, pry out plugs and press in new plugs.

Inspection and Measurement of Rocker Arms

1. Inspect rocker arms for scoring, pitting, or signs of excessive wear. If the bore has visible damage, replace the rocker arm. Inspect the lower half of the rocker arm, significant wear can occur at this location. If the phosphate coating is worn off the rocker arms, they may only be reused on the original rocker arm shaft in their original locations.

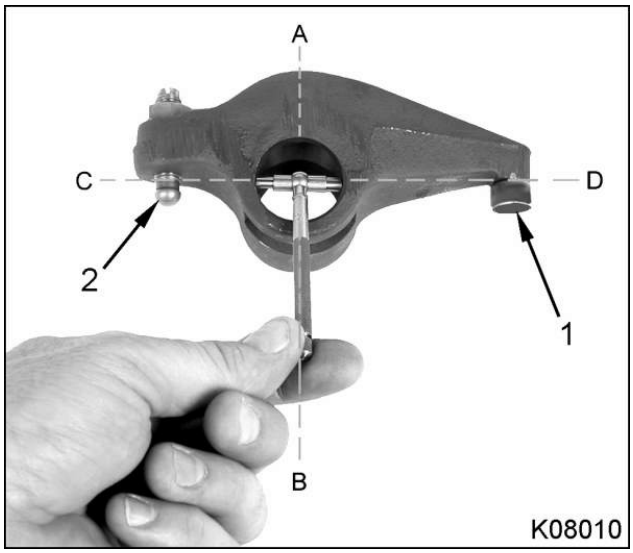


Figure 464 Rocker Arm Bore Measurement

1. Pivot foot assembly
2. Valve lash adjuster screw

NOTE: The black phosphate coating on rocker arms provides break-in lubricant between the rocker shaft and rocker arm bore. It is normal for the black phosphate coatings to wear off the bottom of the lever arm in the shaft and bore contact area. Rocker arms must be labeled and installed in their original locations to maintain proper wear patterns.

2. Use a telescoping gauge and outside micrometer (page 398) to measure rocker arm bore diameter at two locations. Measure diameter at A-B and C-D. If difference between diameters is greater than or equal to 0.03 mm (0.001 in), replace rocker arm.
3. Inspect twelve rocker arm pivot foot assemblies for scoring, pitting, or signs of excessive wear. Replace rocker arms if necessary.
4. Inspect valve lash adjuster screw for wear. Replace adjuster screw if excessively worn.

Measuring Cylinder Head Warpage

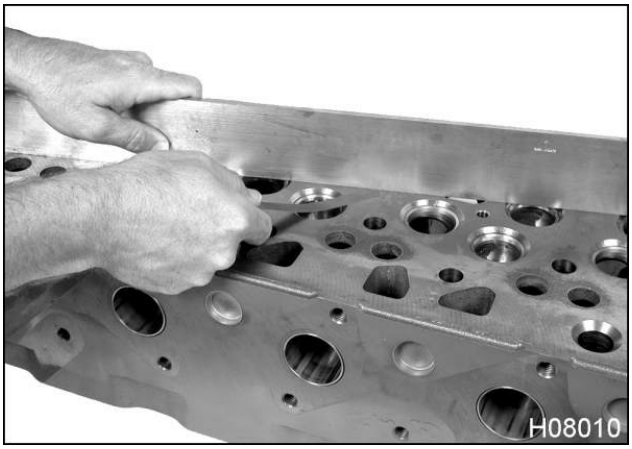


Figure 465 Cylinder Head Warpage Measurement (typical)

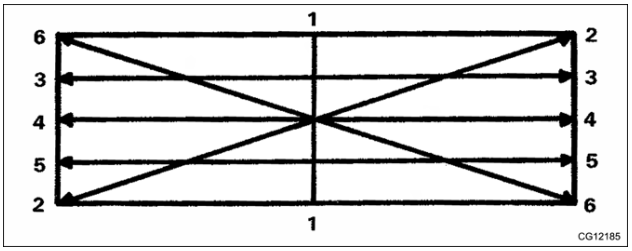


Figure 466 Cylinder Head Warpage Measurement Pattern

Use a straightedge and feeler gauge (page 398) to measure cylinder head gasket surface for warpage. If warpage exceeds cylinder head gasket surface flatness Specifications (page 396), measure cylinder head thickness to determine if cylinder head can be resurfaced. If the cylinder head can not be brought within surface flatness specification, replace cylinder head.

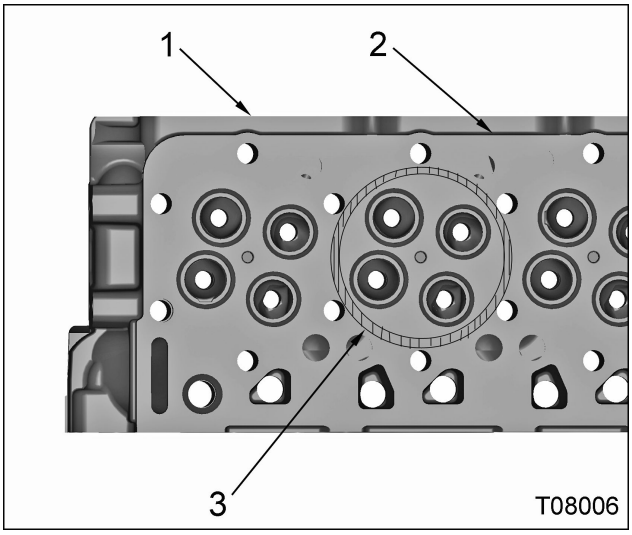


Figure 467 Cylinder Head Deck Brinelling

1. Cylinder head
2. Cylinder head deck
3. Brinelling (indentation area)

Inspect cylinder head deck surface in the area of the cylinder bore O.D. looking for circular brinelling (indentation) into the cylinder head deck. Replace cylinder head if brinelling indentation exceeds Specifications (page 396).

Measuring Cylinder Head Thickness

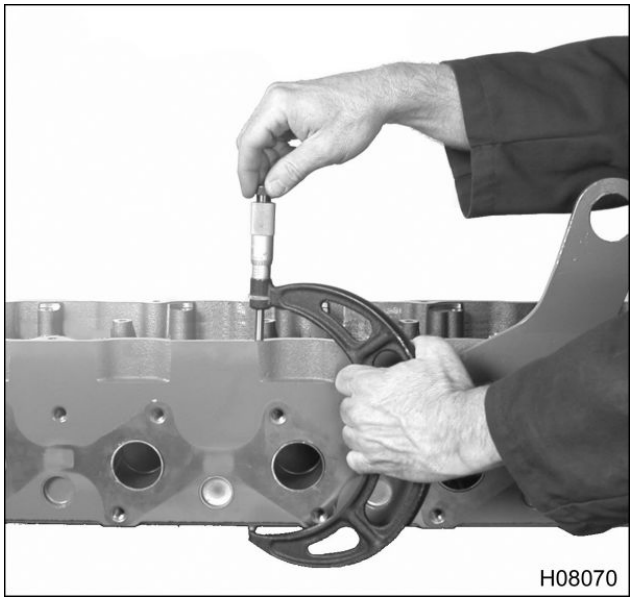


Figure 468 Cylinder Head Thickness Measurement

Use a 6 to 7 inch micrometer to measure cylinder head thickness at six locations (four corners and two center points). All cylinder head thickness measurements must equal or exceed minimum Specification (page 396) after resurfacing. Replace cylinder head if under minimum specification.

Measuring Valve Seat Leakage

NOTE: This test does not check condition of valve guides or valve stem-to-guide clearance.

1. Position cylinder head on wood blocks with gasket surface facing down.
2. Squirt mineral spirits in the intake and exhaust valve ports and wait 5 minutes.
3. Use an inspection mirror to inspect valve seat area for leakage of mineral spirits past valve seats.

   NOTE: If leakage occurs, valves and seats must be reconditioned.

Inspecting Cylinder Head for Cracks

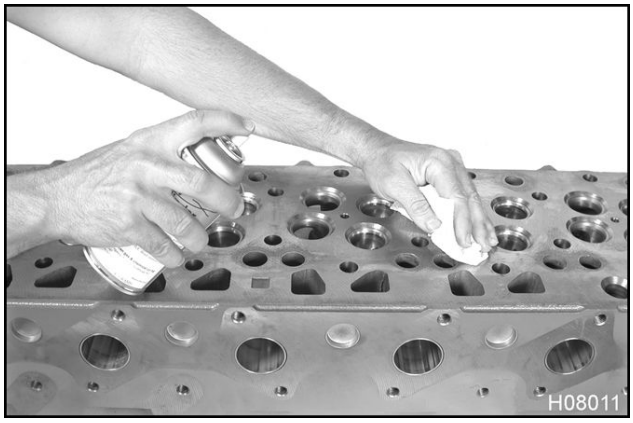


Figure 469 Spraying Cleaner on Cylinder Head

NOTE: Cylinder head crack inspection can be performed with or without valves installed.

1. Spray cleaner, from dye penetrant kit (page 398), on cylinder head gasket surface and wipe dry.

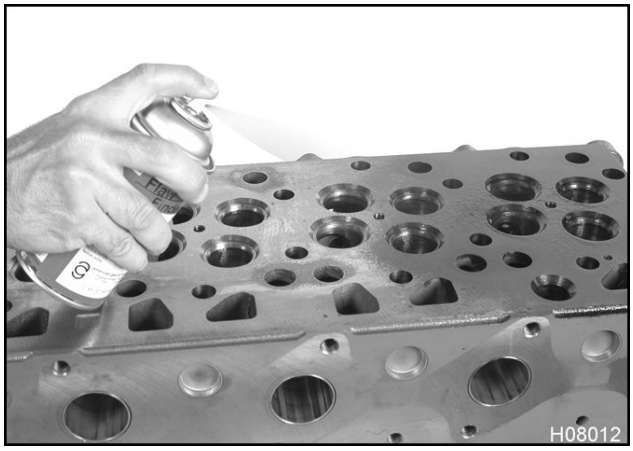


Figure 470 Spraying Dye Penetrant on Cylinder Head

2. Spray dye penetrant, from dye penetrant kit, on cylinder head gasket surface. Leave dye penetrant on for 1 to 10 minutes.

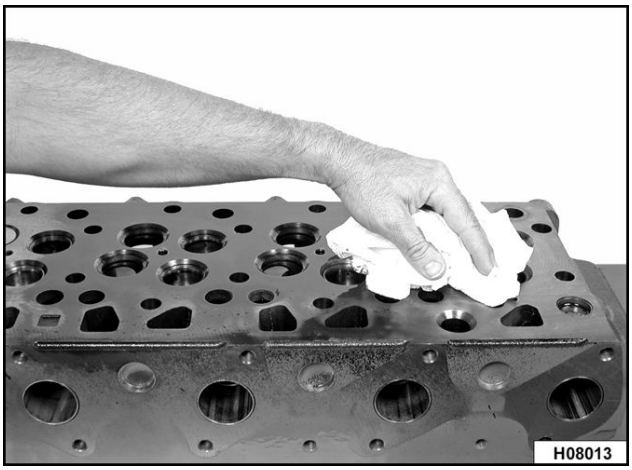


Figure 471 Wiping Dye Penetrant off Cylinder Head

3. Wipe off dye penetrant after 1 to 10 minutes. Dye will remain in any cracks in the cylinder head.

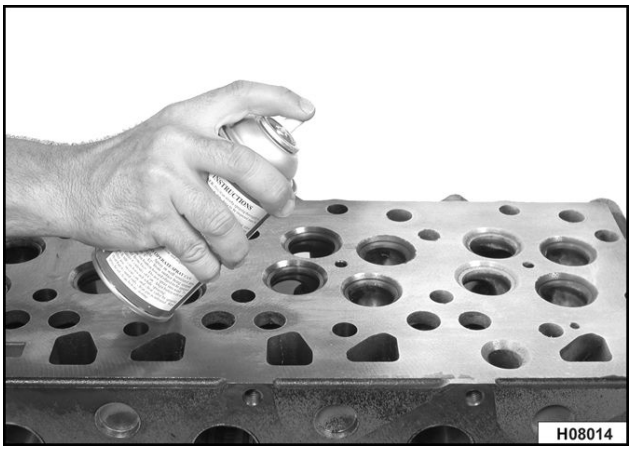


Figure 472 Spraying Developer onto Cylinder Head

4. Spray developer, from dye penetrant kit, on cylinder head gasket surface. Allow developer to dry for 5 to 15 minutes.

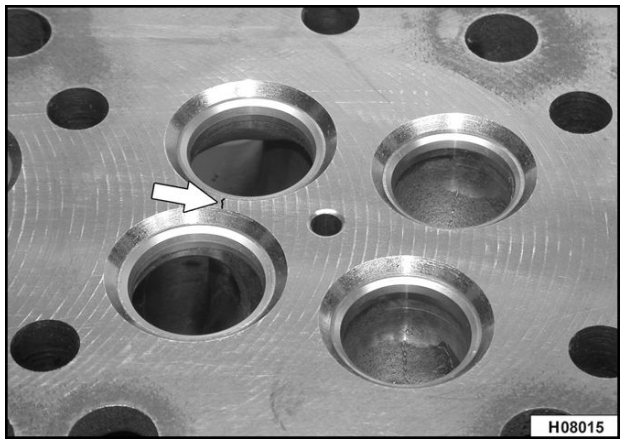


Figure 473 Crack in Cylinder Head

NOTE: Any cracks will show up as purple lines against the white developer. If any cracks are present, replace cylinder head.

Cylinder Head Pressure Test

NOTE: Pressure testing the cylinder head will reveal cracks in ports or sleeve leakage which can not be seen using dye penetrant.

1. Remove valves from the cylinder head. See Remove Valves from Cylinder Head (page 369).
2. Install fuel injectors into cylinder head injector bores. See Fuel Injector Assemblies (page 223).

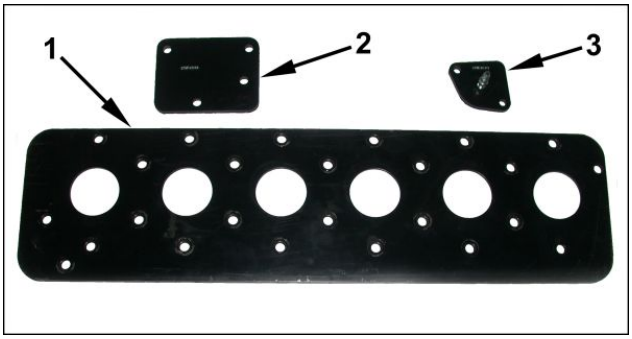


Figure 474 Cylinder Head Pressure Test Tools

1. Cylinder Head Test Plate
2. Water Supply Housing Pressure Adapter
3. Thermostat Opening Pressure Adapter

3. Pressure test cylinder head using Cylinder Head Test Plate, Water Supply Housing Pressure Adapter, Thermostat Opening Pressure Adapter, and a pressure regulator (page 398).

4. Attach Cylinder Head Test Plate to cylinder head gasket surface using mounting bolts and nuts supplied with kit.
5. Attach Water Supply Housing Pressure Adapter to cylinder head and secure with mounting bolts.
6. Remove thermostat and fill cylinder head with hot water.
7. Attach Thermostat Opening Pressure Adapter to cylinder head and secure with mounting bolts.

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

8. Attach compressed air hose and pressure regulator to hose fitting on Thermostat Opening Pressure Adapter.
9. Apply 124 to 138 kPa (18 to 20 psi) air pressure and inspect cylinder head for leaks. Check the following:
   - Fuel injector nozzle sleeve areas
   - Intake and exhaust valve ports
   - Upper deck
   - Lower deck

If leakage is observed from any fuel injector nozzle sleeves, replace injector sleeves and pressure test cylinder head again. If cylinder head leakage is observed, replace the cylinder head.

Reconditioning

Removal of Valves from Cylinder Head

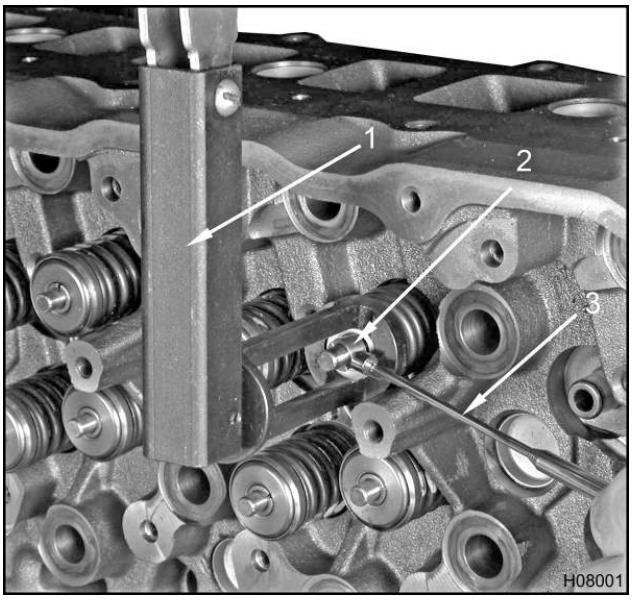


Figure 475 Valve Spring Retainer Key Removal (typical)

1. Valve Spring Compressor
2. Valve spring retainer key
3. Magnet

WARNING: To prevent personal injury or death, wear safety glasses when removing valves or valve spring retainer keys.

1. Install a Valve Spring Compressor (page 398) with appropriate valve spring compressor jaws, over the valve and compress the valve spring.
2. Use a magnet to remove valve spring retainer keys.

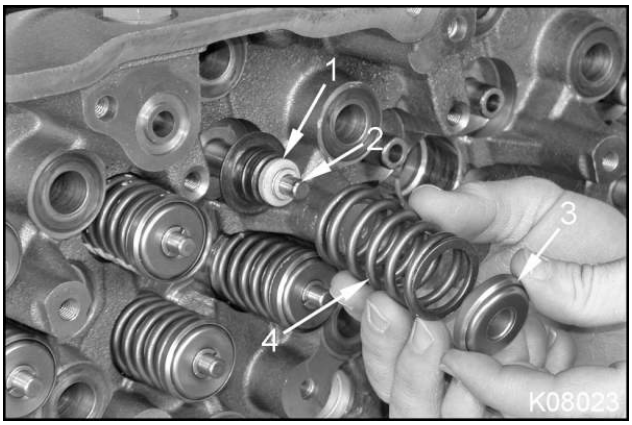


Figure 476 Valve Rotator, Spring, and Valve Stem Seal

1. Valve stem seal
2. Valve stem
3. Valve rotator or retainer (typical)
4. Valve spring

3. Release Valve Spring Compressor and remove valve rotator or retainer and valve spring.
4. Remove and discard valve stem seal.
5. Remove valve from the cylinder head.
6. Repeat steps 1 through 5 for all 24 valves.

Inspection and Measurement of Valve Guides

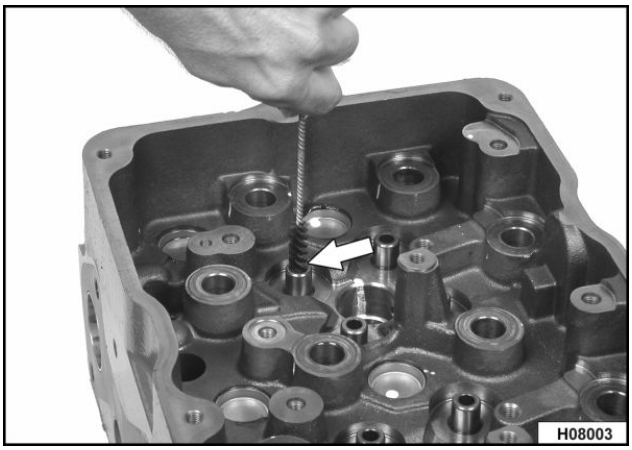


Figure 477 Cleaning Valve Guides

1. Clean valve guides with soap, water, and a nylon brush.

2. Position an inspection light at the bottom of valve guide bores. Inspect bores for burning or cracks. Replace any damaged valve guides.



Figure 478 Valve Guide Measurement with Ball Gauge



Figure 479 Ball Gauge Measurement with Micrometer

3. Measure inside diameter of each valve guide with a ball gauge or small hole gauge set and an outside micrometer (page 398).

   If valve guide bore inside diameter, taper, or out of round exceeds Specifications (page 396), replace the valve guide.

4. Measure valve guides within 0.64 mm (0.025 in) of each end and 90 degrees from crankshaft center line. Record measurements. Determine valve stem-to-guide running clearance after doing Inspecting and Measurement of Valve procedure (page 372).

Replacing Valve Guides

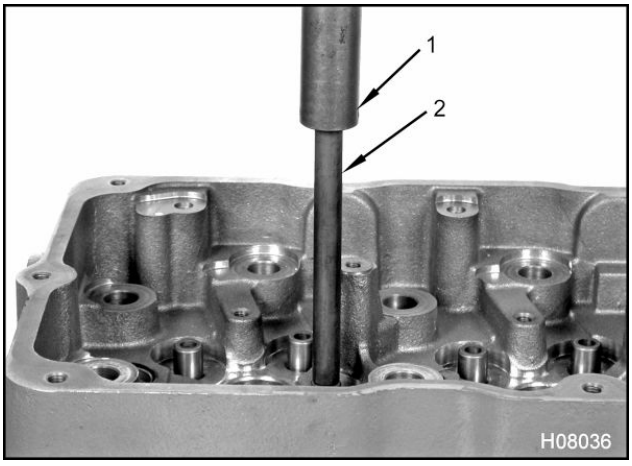


Figure 480 Pressing Out Valve Guide Insert

1. Press ram
2. Valve Guide Remover

NOTE: Replace valve guides if damaged or out of specifications.

CAUTION: To prevent engine damage, do not use a hammer or other improper tool to remove or install valve guides.

1. Secure cylinder head on a press table with the gasket surface down.
2. Insert Valve Guide Remover (page 398) in the valve guide from the top side of the cylinder head.
3. Align Valve Guide Remover and valve guide to be replaced with center of press ram and press out valve guide insert.

NOTE: Chilling valve guide inserts may help installation.

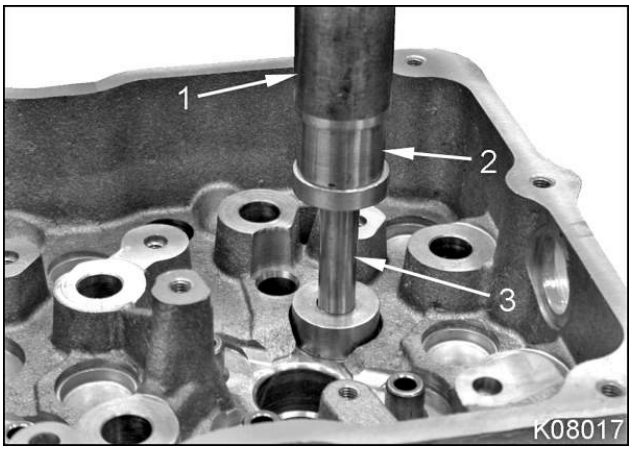


Figure 481 Pressing in Valve Guide Insert

1. Press ram
2. Valve Guide Installer
3. Valve guide insert

4. Lubricate each new valve guide insert with clean engine oil.
5. Center valve guide insert and Valve Guide Installer (page 398) under press ram and install valve guide insert until installer bottoms out against cylinder head.

NOTE: Do not ream inside diameter of valve guide after installation. Service valve guides are finish reamed.

6. After installing valve guide insert, deburr valve guide with Valve Guide Deburring Tool (page 398).

Inspecting and Measurement of Valve

1. Remove carbon deposits from valve stems and valve heads.
2. Inspect each valve for burn marks, warpage, scuffing, and bending. Replace any damaged valves.
3. Inspect valve stem tip for scoring, pitting, or signs of excessive wear. Reface valve stem tip or replace valve, if required.

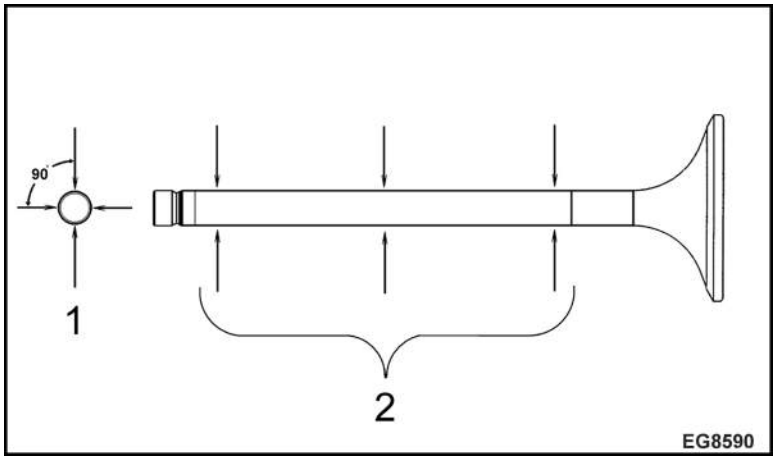


Figure 482 Valve Stem Diameter Measurement Locations

1. Two measurements 90 degrees apart
2. Three valve stem diameter measurement locations

4. Measure valve stem diameter with a micrometer (page 398) at three locations. At each location, take two measurements 90 degrees apart. Average the two measurements from each location.

   If the average of measurements at any of the three locations is not within valve stem diameter Specification (page 396), replace that valve.
5. Determine valve stem-to-guide running clearance using the valve stem diameter measurements above and valve guide inside diameter measurements. Subtract the average valve stem diameter from the average valve guide inside diameter.

   NOTE: Valve Stem-to-guide Running Clearance = Valve Guide Inside Diameter – Valve Stem Diameter.
6. Replace valve or valve guide if not within Specifications (page 396).

Refacing Valves

Valve Face

NOTE: If valves are in good condition and within specifications, they may be refaced to specified angles.

CAUTION: To prevent engine damage, maintain minimum valve face margin across the entire valve face. An insufficient valve face margin will not allow proper heat dissipation, causing that valve to warp or break.



Figure 483 Grind Valve Face

NOTE: Make sure there is sufficient coolant in the valve grinding machine reservoir. Turn coolant pump on before grinding.

1. Dress the grinder cutting stone using the dressing stud attachment.

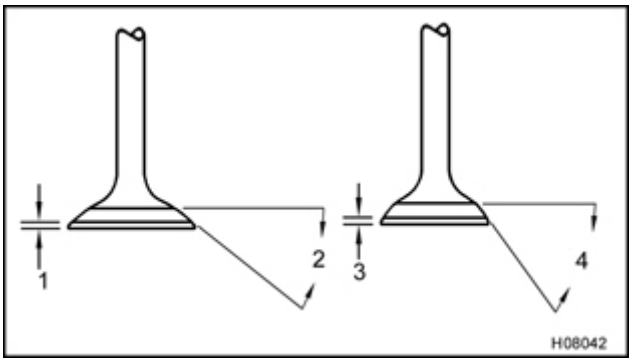


Figure 484 Valve Face Angles

1. Intake margin
2. Intake valve angle
3. Exhaust margin
4. Exhaust valve angle

NOTE: Intake valves and exhaust valves have different valve face margins.

2. Install valve in grinder and set grinder to specified intake or exhaust valve face angle (page 398).
3. Turn on coolant and grinder.

NOTE: Removal of too much material may reduce valve face margin below minimum specifications.

4. Grind valve face. Only remove the minimum amount of material necessary.

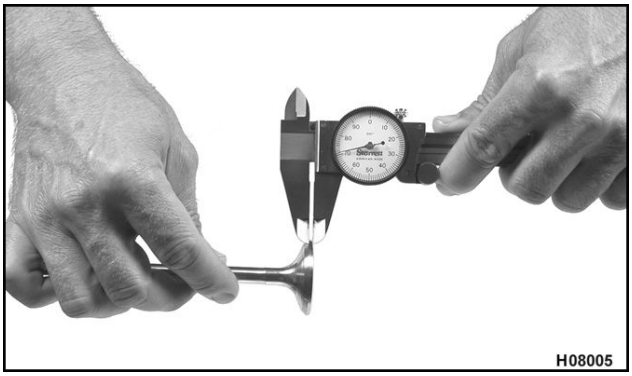


Figure 485 Valve Face Margin Measurement

5. Measure valve face margin at four locations with a vernier caliper (page 398). If any measurements are less than minimum Specification (page 396), replace valve.

Refacing Valve Stem Tip

CAUTION: To prevent engine damage, leave sufficient material on the tip of the valve stem so the valve bridge does not contact the valve retainer keys or valve rotator during operation. Maintain a minimum of 1.524 mm (0.060 in) gap between the valve bridge and valve spring retainer keys.

1. Dress the cutting stone using the dressing stud attachment on the grinder.

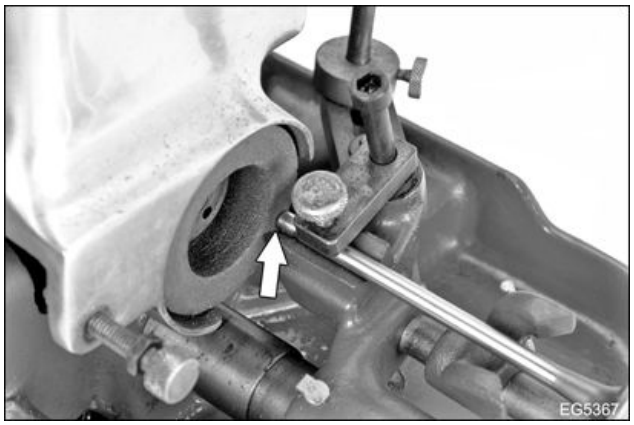


Figure 486 Valve Stem Grinding

2. Install valve in grinder so the tip of the valve stem is close to the grinding stone.
3. Briefly touch the tip of the valve stem to the grinding stone. Only remove the minimum amount of material necessary.

Valve Face-to-Seat Contact Inspection



Figure 487 Marker Paste Application to Valve Face

1. After refacing a valve, spread a thin film of marker paste (Prussian Blue® or equivalent) on the valve face and insert the valve in the valve guide.



Figure 488 Imprinting Marker Paste onto Valve Seat

2. Apply pressure to the center of the valve head while turning valve 90 degrees on the valve seat.
3. Remove valve from cylinder head. Inspect impression on valve seat and valve face. Marker paste should appear around entire contact surface of valve seat and valve face.
4. Perform impression inspection several times to rule out any errors.
   - If marker paste contact impression is good, continue to Valve Spring Inspection (page 379).
   - If marker paste contact impression is not good, verify correct valve face angles and then continue to resurface valve seats. See Resurfacing Valve Seats (page 375).

Resurfacing Valve Seats

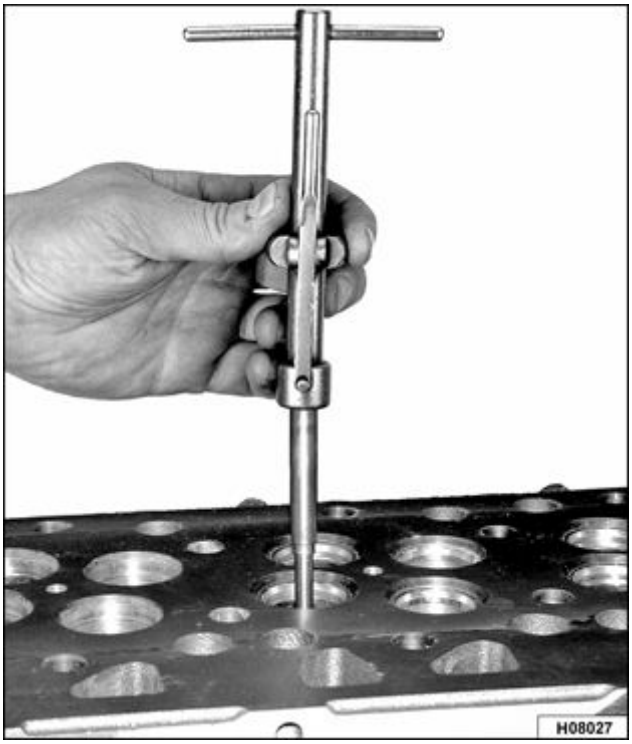


Figure 489 Valve Guide Pilot

1. Lightly lubricate correct size grinding pilot from Valve Seat Grinder (page 398). Install grinding pilot in valve guide.
2. Choose correct angle valve seat grinding stone (page 398) and dress stone. See Specification (page 396) for correct valve seat angle.
3. Install grinding stone over pilot.

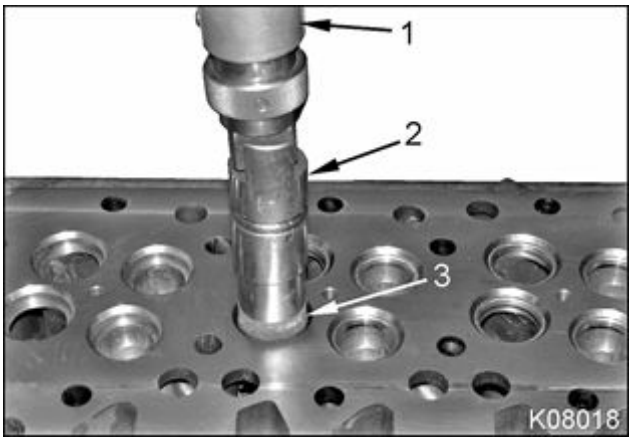


Figure 490 Valve Seat Grinding

1. Motor and drive
2. Holder
3. Grindstone

4. Turn on grinding motor and gently apply pressure to the grindstone. Raise grinding stone frequently to prevent overheating. Grind valve seat to a smooth even finish, paying attention to achieving uniform width.



Figure 491 Valve Seat Width Measurement

5. Measure valve seat width using a vernier caliper (page 398). If valve seat width exceeds Specifications (page 396), the valve seat may be corrected by grinding with a 15 degree or smaller angle stone.

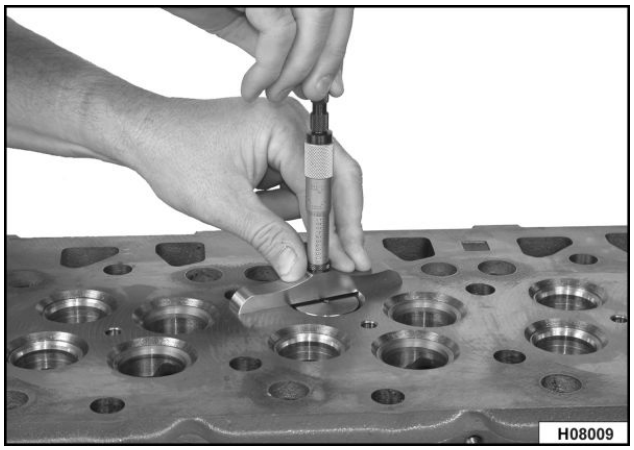


Figure 492 Measuring Valve Recession

6. Install each valve in its valve guide. Use a depth micrometer (page 398) to measure valve recession and check Specification (page 396).
   - If valve recedes too far into head, install a new valve or replace valve seat. Reinspect valve face-to-seat contact (page 374).
   - If valve protrudes above cylinder head surface, regrind valve seat. After regrinding valve seat, check valve seat width again. Reinspect valve face-to-seat contact.

Replacing Valve Seats

Removal

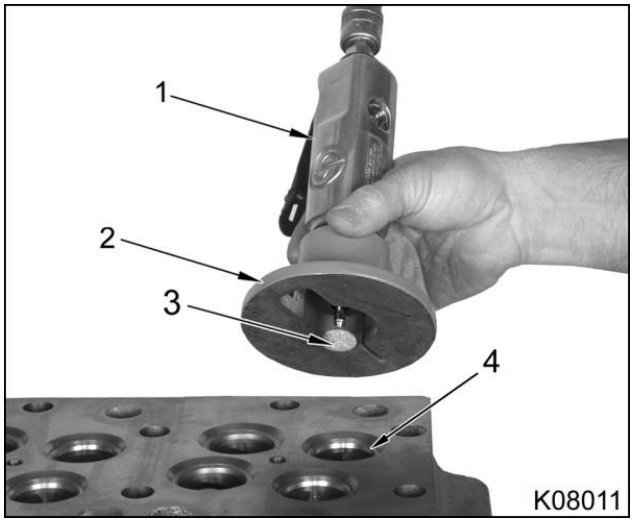


Figure 493 Valve Seat Groove Grinder

1. Air motor
2. Grinding base
3. Grinding wheel
4. Valve seat insert

NOTE: Replace valve seats if damaged or out of specifications.

1. Carefully grind a groove in valve seat insert to be removed using Valve Seat Extractor Kit (Universal) (page 398). Do not grind into cylinder head.

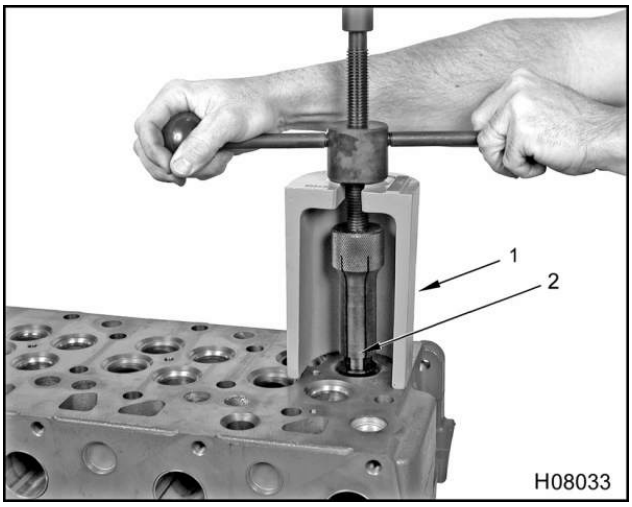


Figure 494 Removing Valve Seat Insert

1. Lifting bridge
2. Valve Seat Remover (collet)

2. Position appropriate size Valve Seat Remover (collet) (page 398) in valve seat.
3. Expand collet by threading shaft into valve seat remover until tight inside valve seat. Turn T-handle on shaft to pull valve seat insert out of cylinder head.

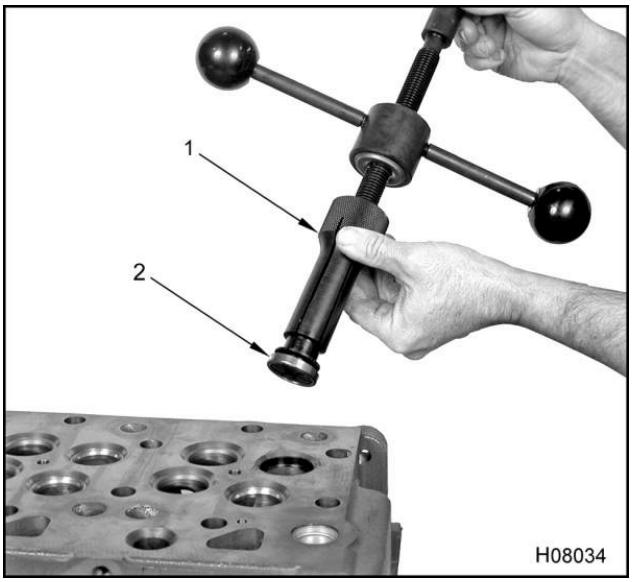


Figure 495 Valve Seat Insert Removal

1. Collet
2. Valve seat insert

4. Unlock collet by loosening threaded shaft and discard valve seat insert.

Installation

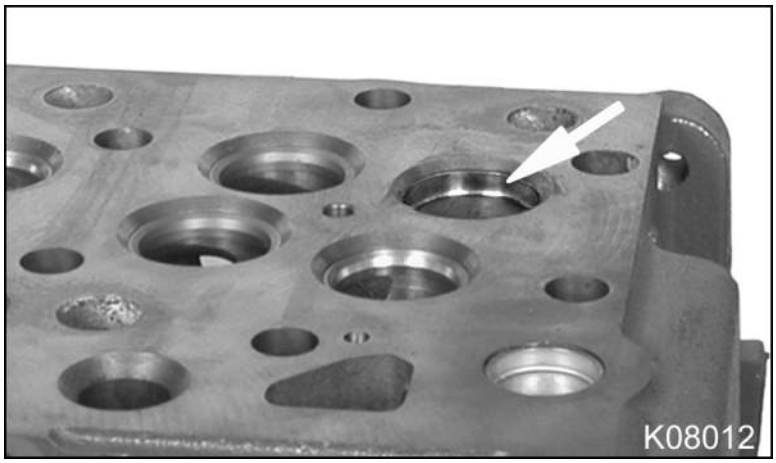


Figure 496 Valve Seat Counterbore

1. Measure valve seat counterbore diameter at two locations 90° apart, using an inside micrometer (page 398). Average the two measurements to determine the appropriate size valve seat insert to install.

CAUTION: To prevent engine damage, maintain proper diametral interference between valve seat insert outside diameter and valve seat counterbore diameter.

Valve Seat Insert Selection Chart

Available inserts (Intake and Exhaust)	Intake counterbore average diameter	Exhaust counterbore average diameter
Standard	40.120 to 40.170 mm (1.5795 to 1.5815 in)	37.478 to 37.528 mm (1.4755 to 1.4775 in)
Oversize - 0.05 mm (0.002 in)	40.170 to 40.220 mm (1.5815 to 1.5835 in)	37.529 to 37.579 mm (1.4775 to 1.4795 in)

2. Chill valve seat insert in a freezer for 30 minutes. This will slightly shrink insert and prevent the outer layer of metal from being shaved off during installation.

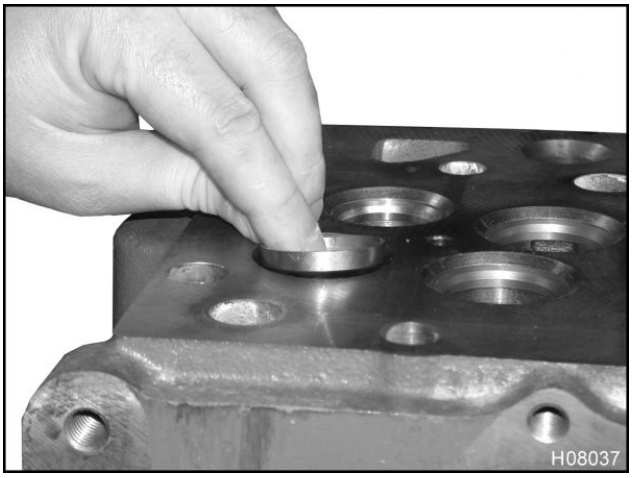


Figure 497 Valve Seat Insert

3. Align chilled valve seat insert over counterbore.

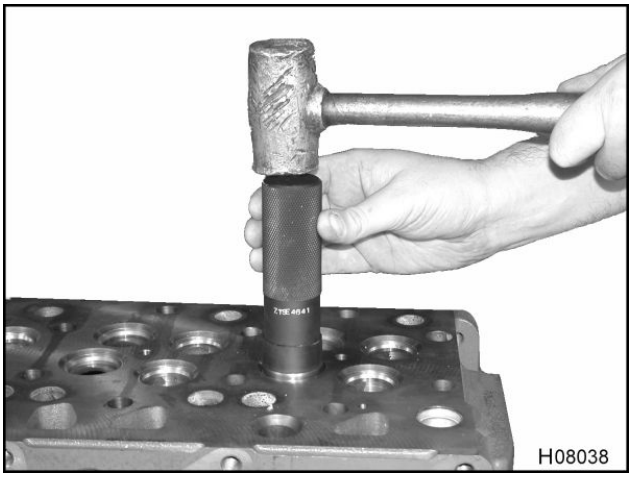


Figure 498 Valve Seat Insert Installation

4. Carefully drive valve seat into place, until fully seated, using a hammer and Valve Seat Installer (page 398).
5. Grind new valve seats to specified angles and widths.

Valve Spring Inspection

CAUTION: To prevent engine damage, do not grind valve springs or use a wire brush for cleaning. Disruption of spring surface may cause fatigue cracks and spring failure.

1. Clean valve springs in a suitable solvent.
2. Inspect valve springs for rust, cracks, and pitting. Replace any damaged valve springs.

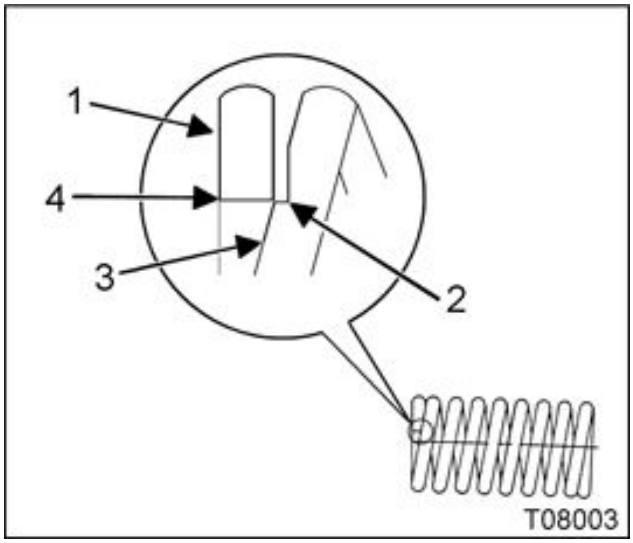


Figure 499 Valve Spring

1. Cutoff end
2. Wear notch
3. Adjacent coil
4. Push here

3. Inspect both ends of each valve spring at contact points between the cutoff end of the last coil and the adjacent coil. If the cutoff end has worn a notch in the adjacent coil, replace the spring.

   NOTE: Valve spring wear notches can also be detected by compressing the spring and listening for a clicking sound.

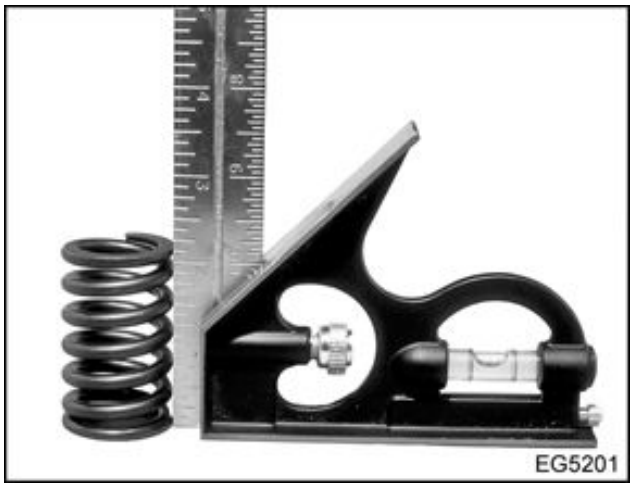


Figure 500 Measuring Perpendicularity and Flatness of Valve Spring

NOTE: Valve springs that are not perpendicular to a flat surface put an unequal load on the valve stem, causing premature valve and valve guide wear.

4. Use a square (page 398) to check flatness and perpendicularity of spring ends. If the end of any valve spring is not flat and square, replace spring.



Figure 501 Measuring Valve Spring Tension

5. Use a Valve and Clutch Spring Tester (page 398) to measure valve spring tension. Measure the maximum and minimum lengths of the spring at appropriate test loads (valve closed and valve open). Replace any valve spring that does not meet Specifications (page 396).

Inspecting Valve Rotators and Retainers

1. Clean all valve rotators and retainers in a suitable solvent.

CAUTION: To prevent engine damage, install rotators on intake valves.

NOTE: Some low horse power engines have retainers on the exhaust valves. Rotators must be used on intake valves and can be used on exhaust valves to extend valve life.

2. Inspect valve retainers and rotators for wear, deformation, cracking, or corrosion. Replace if damaged.

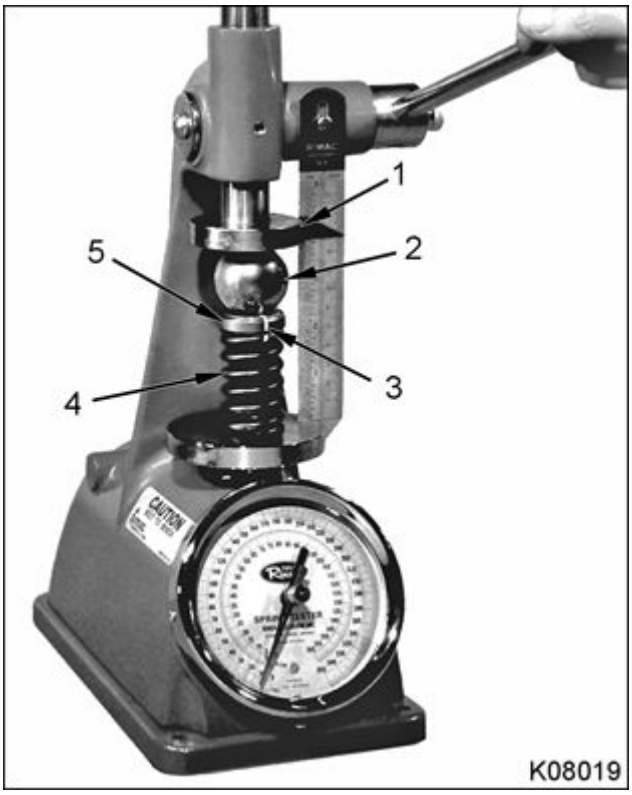


Figure 502 Inspecting Valve Rotator

1. Ram
2. Steel ball bearing
3. Paint reference line
4. Spring
5. Valve rotator

WARNING: To prevent personal injury or death, suitable protection must be placed between tester and rotator and ram of Valve and Clutch Spring Tester.

3. Lubricate valve rotator with clean engine oil. Place valve spring and rotator in Valve and Clutch Spring Tester.
4. Place a ball bearing between the valve rotator and ram of the spring tester. The ball bearing must be large enough to prevent the ram from touching any part of the rotator.
5. Paint a reference line on the valve rotator and spring.
6. Compress valve spring repeatedly and rapidly with even pressure and observe the valve rotator as it turns. Replace any valve rotator that does not turn.

Inspecting Valve Spring Retainer Keys

1. Clean all valve spring retainer keys with a suitable solvent.
2. Check the inside and outside of the valve spring retainer keys for wear. Replace any worn retainer keys.

Replacing Fuel Injector Sleeves

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 the Service and Diagnostic Engine Manuals for the engine model being serviced.

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

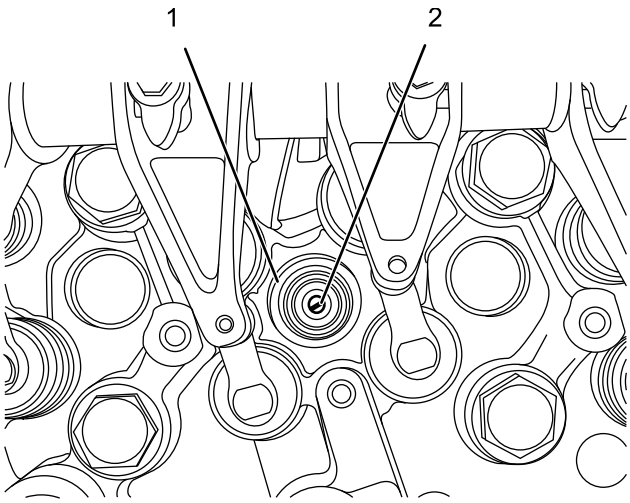
WARNING: To prevent personal injury or death, shift transmission to park or neutral, set parking brake, and block wheels before doing diagnostic or service procedures.

WARNING: To prevent personal injury or death, allow engine to cool before draining coolant.

Removal

CAUTION: If removing fuel injector sleeves with engine in-chassis, protective cup plugs must be installed into injector bore before sleeve removal to prevent chips from falling into cylinder.

NOTE: Replace injector sleeves if damaged or excessively worn.

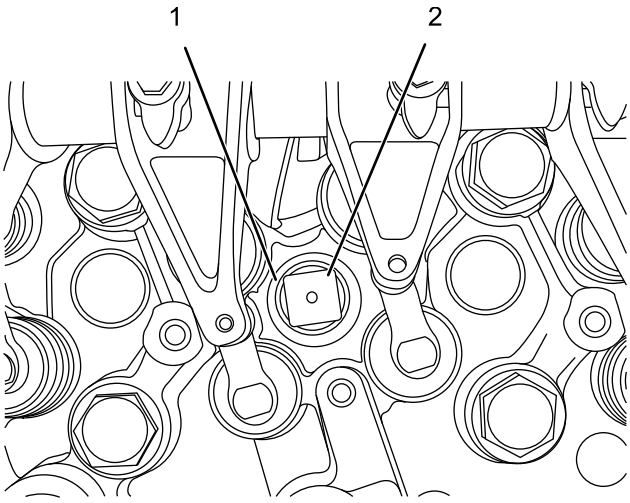


0000106371

Figure 503 Protective Plug

1. Injector sleeve
2. Protective plug

1. Using long needle nose pliers or other suitable tool, install protective plug into injector bore of injector sleeve.



0000106375

Figure 504 Injector Sleeve

1. Injector sleeve
2. Tap and guide assembly

2. Lubricate tap assembly, part of Injector Cup Removal Tool.
3. Insert tap assembly and tap guide into bore or fuel injector sleeve.
4. Screw tap assembly into bore of fuel injector sleeve. Using a suitable tool, fully thread tap assembly into bore or injector sleeve until it bottoms out on tap guide.

   NOTE: Threads must be cut at least ¾ inch deep to accommodate injector cup remover assembly.

   NOTE: Suitable tool might include 20 mm socket 4-, 8-, or 12-point, suitable ratchet handle, and extension.
5. Remove tap assembly and tap guide from bore of injector sleeve.

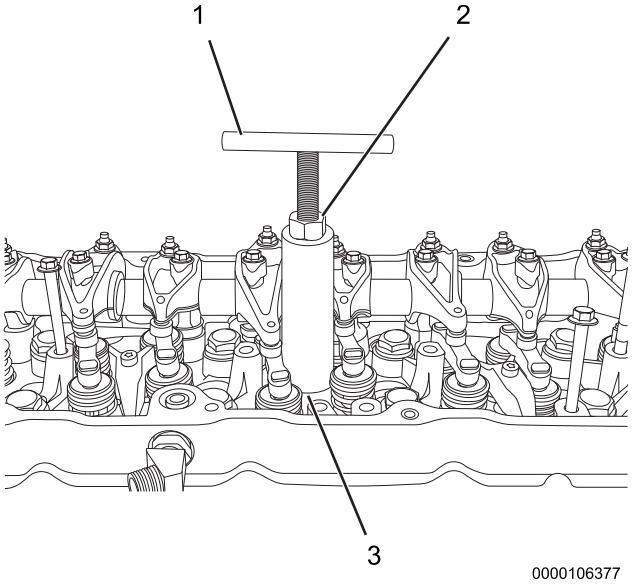


Figure 505 Injector Cup Remover Assembly

1. Tee handle
2. Injector cup remover assembly
3. Injector sleeve

6. Position injector cup remover assembly into threads cut in injector sleeve, using tee handle of injector cup remover assembly, thread injector cup remover assembly into injector sleeve until it bottoms out.

   NOTE: Ensure fuel injector sleeve puller threads sufficiently into fuel injector sleeve.

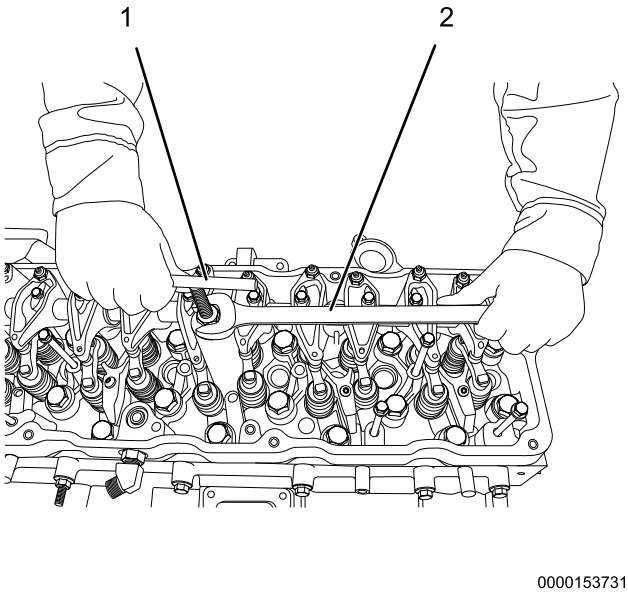


Figure 506 Extract Injector Sleeve

1. Tee handle (injector cup remover assembly)
2. Wrench (or other suitable tool)

7. Using suitable wrench on injector cup remover assembly nut, rotate nut clockwise while holding injector cup remover assembly tee handle, to extract injector sleeve from injector bore.
8. Install appropriate adapter from Slide Hammer Puller Set (page 398) on fuel injector sleeve puller tool, and remove fuel injector sleeve from injector bore.

Tool Removal

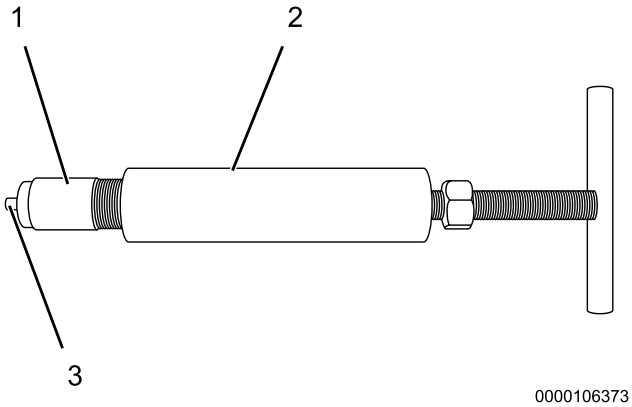


Figure 507 Injector Sleeve Removed

1. Old injector sleeve
2. Injector cup remover assembly
3. Protective plug

1. Remove old injector sleeve from injector cup remover assembly.
2. Remove protective plug from old injector sleeve.
3. Store Injector cup removal tool for reuse.

Cleaning

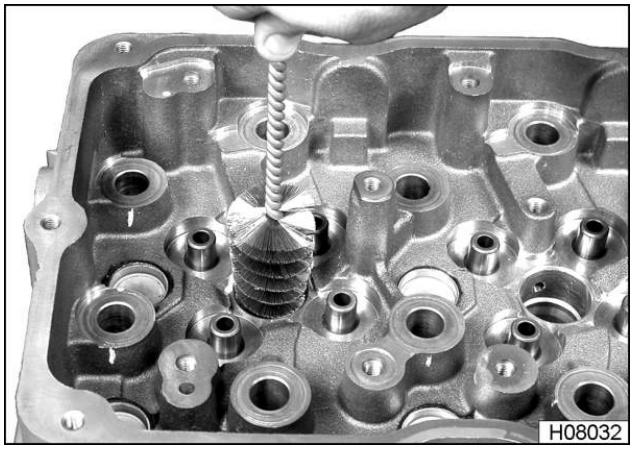


Figure 508 Cleaning Fuel Injector Bore

1. Using a stiff wire brush from the Injector Sleeve Brush Set (set of 2) (page 398), clean deposits and hardened sealant from the fuel injector bore.
2. Insert a small stiff nylon brush tool into oil gallery for cleaning.

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

3. Use compressed air to clean out all fuel and oil galleries.

Installation

1. Use an Injector Sleeve Installer (page 398) that does not have a bent pilot shaft or any nicks where the sleeve will seat.
2. Install a new fuel injector sleeve on the end of the Injector Sleeve Installer.

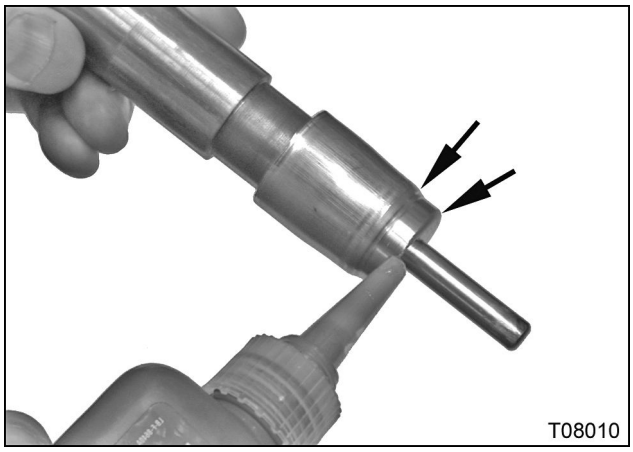


Figure 509 Applying Sealant to Fuel Injector Sleeve

3. Apply Loctite® 620 Retaining Compound (page 398) around outside bottom of injector sleeve and around beginning of taper at middle of sleeve.

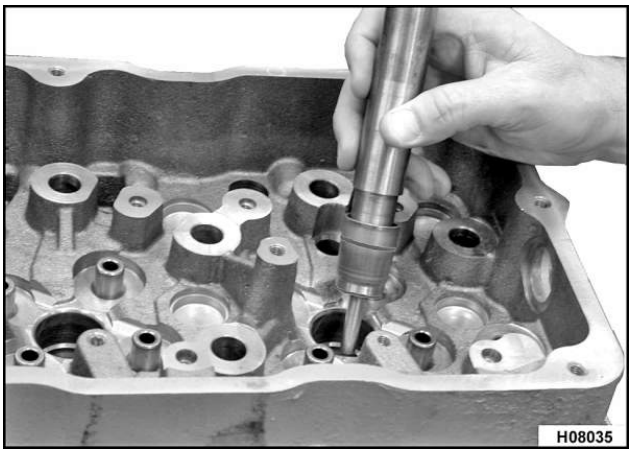


Figure 510 Fuel Injector Sleeve and Injector Bore

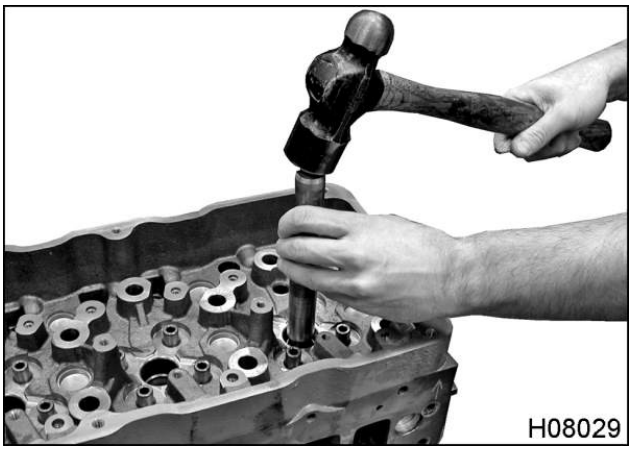


Figure 511 Installing Fuel Injector Sleeve

4. Insert fuel injector sleeve and Injector Sleeve Installer into injector bore.
5. Carefully drive fuel injector sleeve into injector bore with a hammer.
6. Clean fuel injector sleeve with a soft nylon brush.
7. Inspect inside surfaces of installed fuel injector sleeve. If nicked or scratched, replace sleeve again. Make sure Injector Sleeve Installer is not causing damage. Use a different Injector Sleeve Installer, if necessary.

Installing Valves

Cleaning

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

1. Clean valve faces and seats with a suitable solvent. Dry all components using filtered compressed air.
2. To clean valve guides, coat a brush with soap and water. Insert brush into each valve guide bore and rotate in one direction with an up and down motion. Dry valve guide bores using filtered compressed air.

Assembly

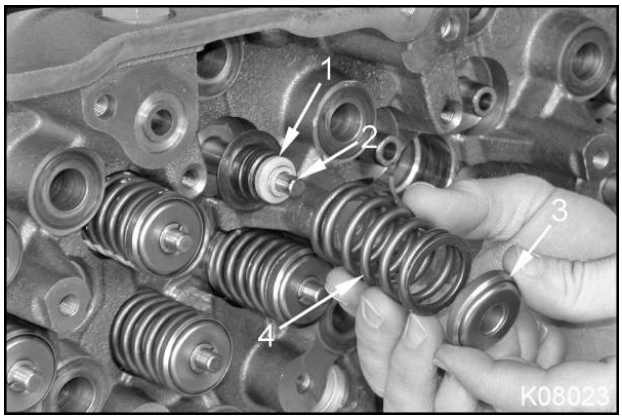


Figure 512 Valve Stem Seal, Spring, and Rotator

1. Valve stem seal
2. Valve stem
3. Valve rotator or retainer (typical)
4. Valve spring

1. Lubricate valve stem with clean engine oil and insert valve in valve guide.
2. Lubricate inside diameter of new valve stem seals with clean engine oil. Install seals over valve stems and valve guides. Make sure seals are completely seated against cylinder head spring pockets.
3. Install valve springs over valve stem seals.

CAUTION: To prevent engine damage, rotators must be installed on intake valves.

4. Install valve rotators on top of intake valve springs. Install valve rotators or retainers on top of exhaust valve springs.

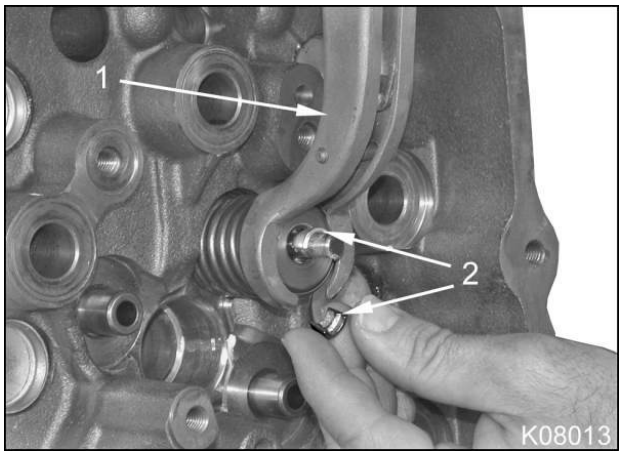


Figure 513 Valve Spring Compressor and Retainer Keys

1. Valve Spring Compressor
2. Valve spring retainer keys

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

5. Install Valve Spring Compressor (page 398) over valve and compress valve spring.
6. Install valve spring retainer keys and release spring compressor.

Installation

NOTE: Differences may be noticed between removed parts and new parts. New forced-lubrication engines incorporate new rocker arms, lash adjusters, and pushrods to allow for better oiling to prevent failure under high demand (stop-and-go) conditions. Forced-lubrication rocker arms now have a casting that allows for better oiling as well as increased structural rigidity. Forced lubrication lash adjusters have new machining features that allow for better oiling. Forced lubrication pushrods contain a lube passage that allows for better oiling.

NOTE: Reference CN-000865 prior to installation of Rocker Support Shaft, rocker arms, and adjuster screws, as the updated part numbers may appear different than the ones removed. It is okay to mix replacement parts with old style parts.

CAUTION: Do not use old design parts on a forced lubrication engine. Failure to comply will result in product damage.

Roller Tappets and Guides

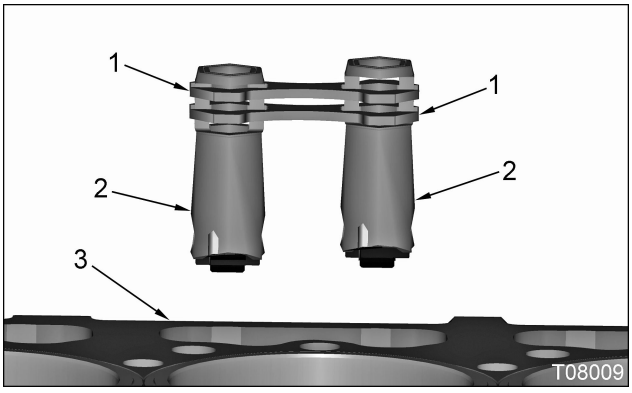


Figure 514 Roller Tappets and Guides

1. Roller tappet guide (2)
2. Roller tappet (2)
3. Crankcase

1. Lubricate roller tappets with clean engine oil.
2. Install each roller tappet and two guides into tappet bore. Install used roller tappets in their original locations, revolving in the same direction as before removal.

Cylinder Head

CAUTION: To prevent engine damage, measure cylinder sleeve protrusion (page 448) and verify within specification before installing cylinder head and adjust as needed.

1. Install two lifting eyes with four M12 x 25 bolts onto cylinder head. Tighten bolts to standard torque (page 553).

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

2. Clean head bolt holes in crankcase of oil and debris with Head Bolt Bottoming Tap (page 398). Dry with filtered compressed air. Clean and dry cylinder head gasket surfaces.

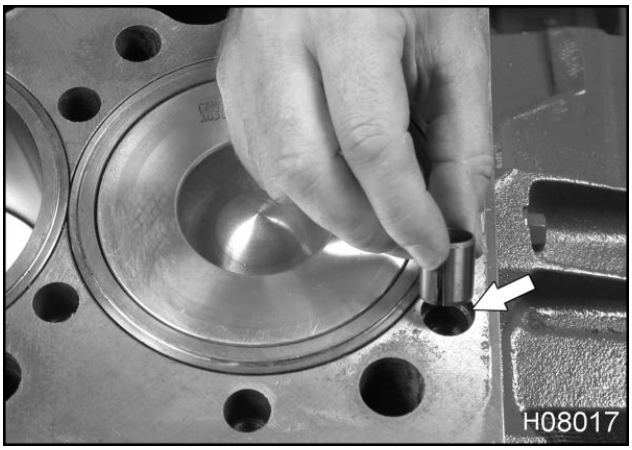


Figure 515 Cylinder Head Alignment Dowel

3. Install or verify two alignment dowels are correctly installed in top of crankcase.

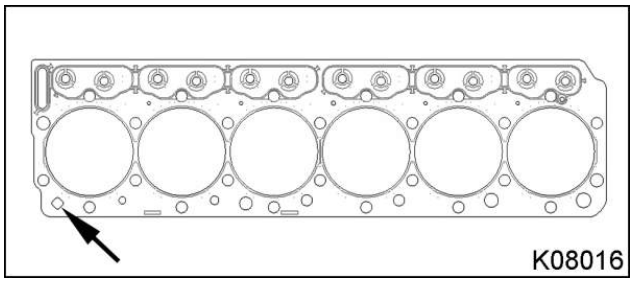


Figure 516 Cylinder Head Gasket Diamond Shape Hole (2007 - 2009 Model Years only)

NOTE: Do not use cylinder head gaskets with diamond-shaped hole. Only install new cylinder head gaskets without diamond-shaped hole.

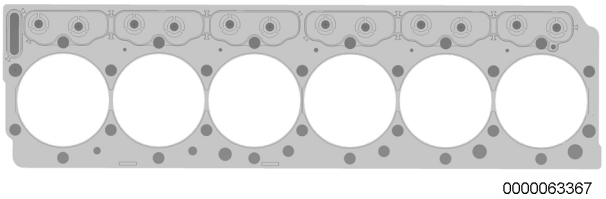


Figure 517 Cylinder Head Gasket Without Diamond Shaped Hole

NOTE: When installing cylinder head gasket without diamond shaped hole, a set of redesigned head bolts will be required.



Figure 518 Cylinder Head Gasket and Alignment Dowels (typical)

4. Install a new cylinder head gasket on crankcase, over alignment dowels.

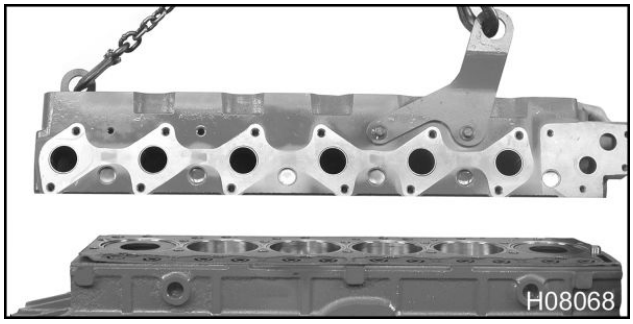


Figure 519 Cylinder Head and Crankcase (typical)

WARNING: To prevent personal injury or death, use a hoist rated for the weight of the cylinder head and follow the manufacturer's operation and safety instructions. Attach safety lifting hooks to the cylinder head lifting eyes.

5. Attach an appropriate hoist and lifting hooks to cylinder head lifting eyes.

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

6. Carefully lower cylinder head onto crankcase and align cylinder head alignment dowels in the crankcase with dowel holes in the cylinder head.

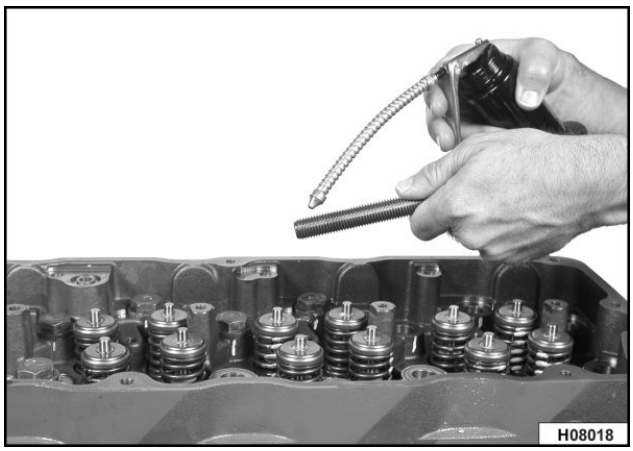


Figure 520 Cylinder Head Bolts Lubrication

CAUTION: Be sure to use new cylinder head mounting bolts. Do not reuse old cylinder head bolts as these will have excessive stretch and may break or give the wrong clamp load.

CAUTION: Do not use chlorinated solvents on cylinder head bolts. Parts should be clean, dry, and free of chemicals other than engine oil.

7. Install new cylinder head mounting bolts. Lightly lubricate the threads and bolt flange of each with clean engine oil.
8. Install all the new cylinder head bolts finger tight.

Torque Procedure for Torque-to-yield Head Bolts

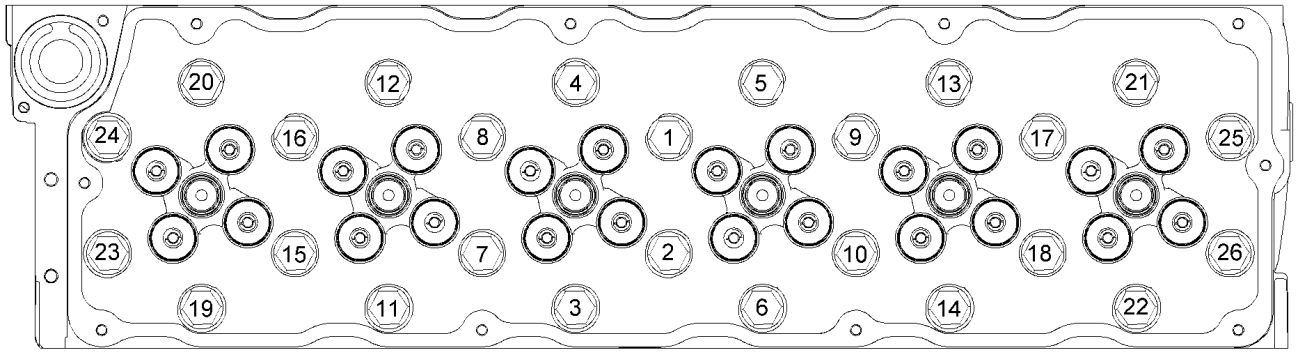


Figure 521 Cylinder Head Torque Sequence A

1. Rotate crankshaft to TDC for Cylinder 1. Then rotate crankshaft 30 degrees past TDC.

NOTE: It is necessary to torque cylinder head bolts three times before doing final torque-to-yield procedure in order to obtain uniform head bolt torque.

2. Torque each cylinder head bolt to 150 N·m (111 lb·ft) in cylinder head torque sequence A.
3. Retorque each cylinder head bolt to 238 N·m (176 lb·ft) in cylinder head torque sequence A.

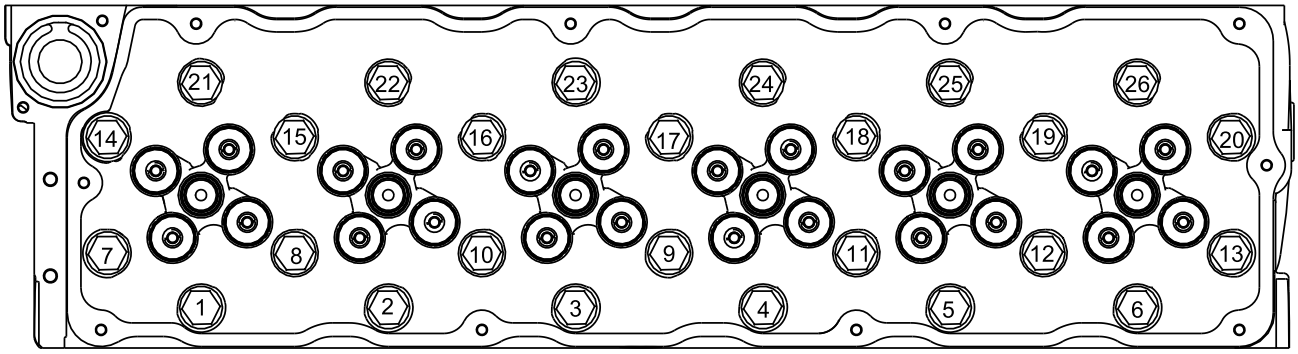


Figure 522 Cylinder Head Torque Sequence B

4. Torque each cylinder head bolt again to 238 N·m (176 lb·ft) in cylinder head torque sequence B.

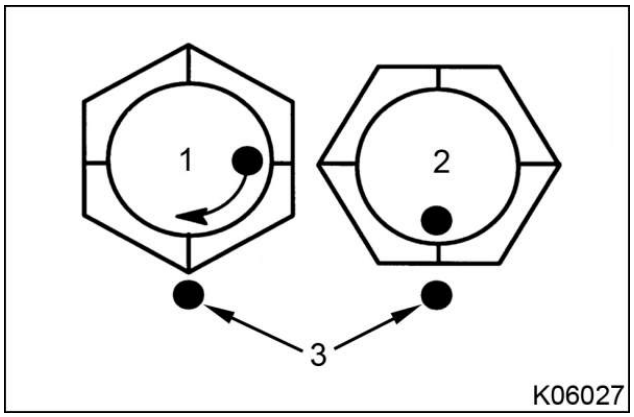


Figure 523 Head Bolt Torque-to-Yield Marking

1. Top of head bolt before Torque-to-Yield
2. Top of head bolt after Torque-to-Yield
3. Mark on cylinder head surface

CAUTION: To prevent engine damage, use permanent marker to identify internal engine components and their orientation. Do not use paint or temporary markers.

5. Using a permanent marker, place a mark on each head bolt and put another mark on the head bolt socket (page 398) directly in line with the mark on each head bolt.
6. Put a mark on the cylinder head surface 90° clockwise from each head bolt mark.
7. Install head bolt socket on head bolt to be torqued and align mark on socket with the mark on the head bolt.
8. Torque-to-yield each cylinder head bolt by rotating bolt 90 degrees clockwise (1/4 turn) in cylinder head torque sequence A (Figure 521). The marks on the head bolt socket, head bolt, and cylinder head surface should be aligned.

Rocker Arms

NOTE: Differences may be noticed between removed parts and new parts. New forced-lubrication engines incorporate new rocker arms, lash adjusters, and pushrods to allow for better oiling to prevent failure under high demand (stop-and-go) conditions. Forced-lubrication rocker arms now have a casting that allows for better oiling as well as increased structural rigidity. Forced lubrication lash adjusters have new machining features that allow for better oiling. Forced lubrication pushrods contain a lube passage that allows for better oiling.

NOTE: Updated part number items such as: Rocker Support Shaft, rocker arms, and adjuster screws, may appear different than those removed. It is acceptable to replace older parts with newer design equivalents.

CAUTION: Do not use old design parts on a forced lubrication engine. Failure to comply will result in product damage.

NOTE: See Fuel Injector Assemblies for fuel injector installation (page 223).

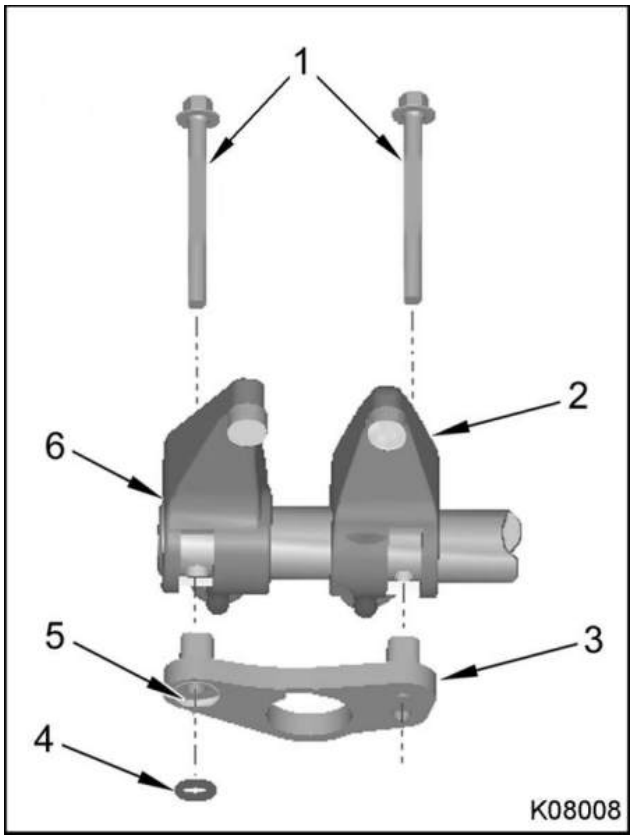


Figure 524 Rocker Arm Configuration

1. M8 x 60 shaft bolt
2. Exhaust rocker arm
3. Rocker arm shaft support
4. Support washer (assembly aid)
5. Machined recess
6. Intake rocker arm

1. Slide 12 rocker arms onto rocker shaft in order removed (rocker arms should have been marked during removal procedure).

NOTE: Ensure rocker arm shaft has big “T” stamp facing up.

2. Install twelve shaft bolts through rocker arm shaft and into rocker arm shaft supports.
3. Install a support washer (assembly aid) onto each intake rocker arm shaft bolt (recessed side of shaft support only).

Rocker Arm Assembly

NOTE: Reference CN-000865 prior to installation of Rocker Support Shaft, rocker arms, and adjuster screws as the updated part numbers may appear different than the ones removed. It is ok to mix replacement parts with old style parts.



Figure 525 Valve Bridge Installation

1. Install valve bridges on each set of intake and exhaust valve stems. Used valve bridges must be reinstalled in their original location and orientation. (See marks from removal.)

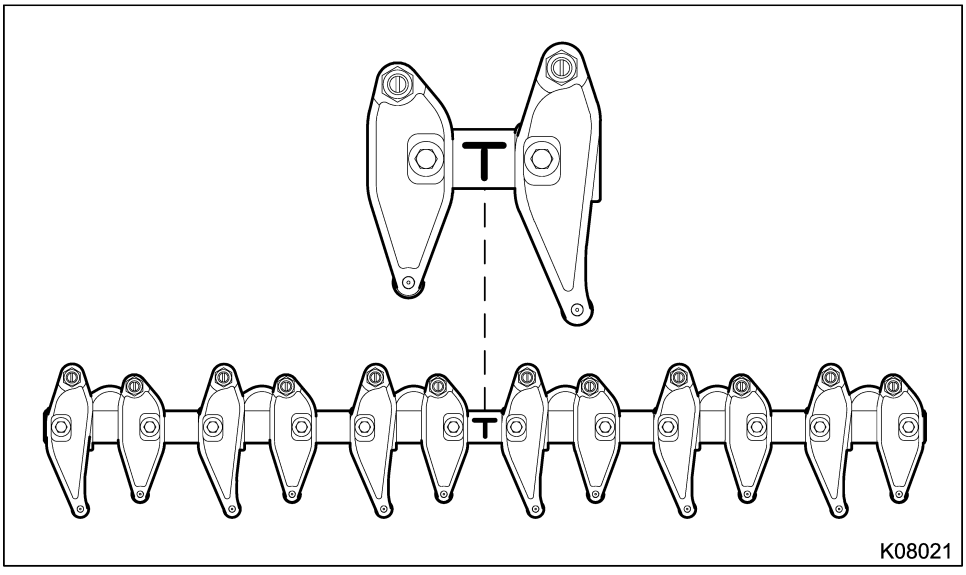


Figure 526 Rocker Arm Orientation and Big "T" Stamp

2. Install rocker arm shaft assembly with 12 shaft bolts and six shaft supports, onto cylinder head.
3. Align shaft bolts with mating bolt holes in cylinder head. Finger tighten bolts.

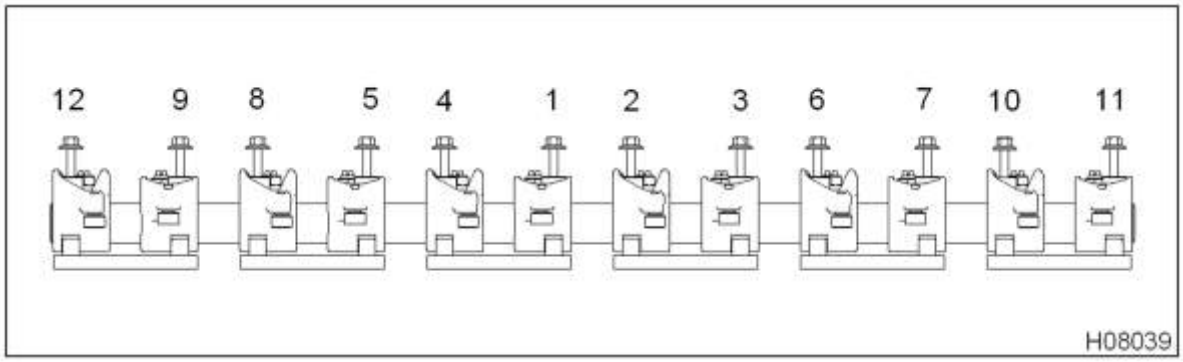


Figure 527 Rocker Arm Torque Sequence

NOTE: Check that all valve adjustment screws should be loose. They should have been loose since removing the rocker arm.

4. Tighten shaft bolts in two steps using rocker arm torque sequence.
   a. Torque rocker arm shaft bolts in sequence to 27 N·m (20 lb·ft).
   b. Torque rocker arm shaft bolts in sequence to 37 N·m (27 lb·ft).
5. Adjust valve lash (page 353) for all 12 rocker arms.

Valve Cover

1. Install the valve cover gasket on top of the cylinder head before installing the valve cover. See Valve Cover Gasket Assembly (page 108).

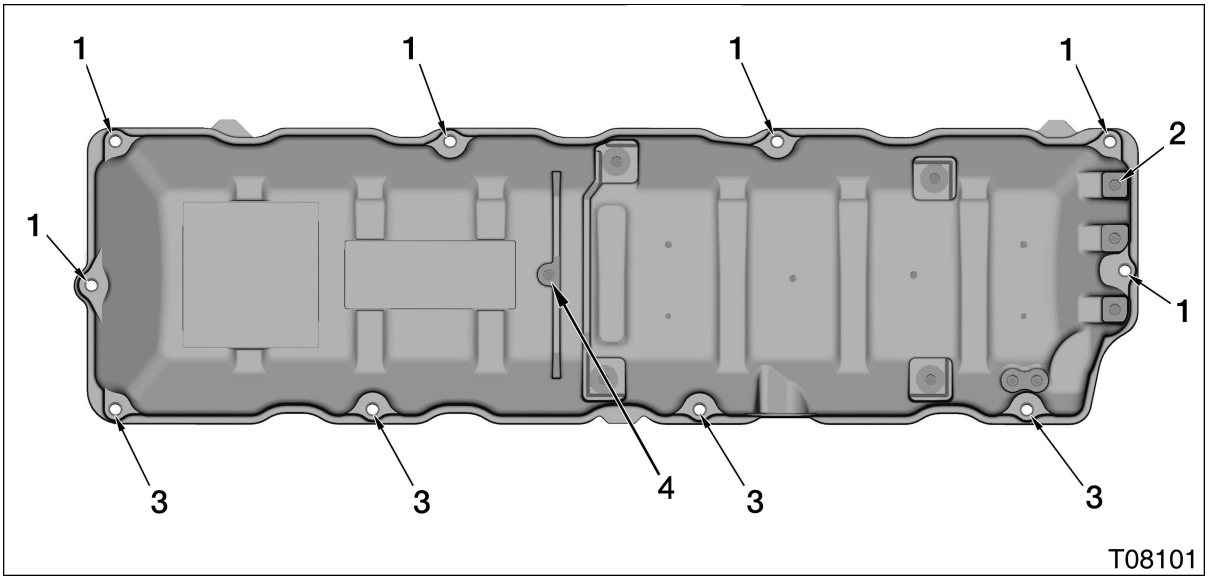


Figure 528 Valve Cover Bolts

1. Bolt, M8 x 80 (6)
2. Bolt, M8 x 25 (secures optional radiator piping support)
3. Stud bolt, M8 x 80 (4)
4. Bolt, M8 x 20

2. Install valve cover and finger tighten saved four M8 x 80 stud bolts and six M8 x 80 bolts. Tighten to standard torque (page 553).

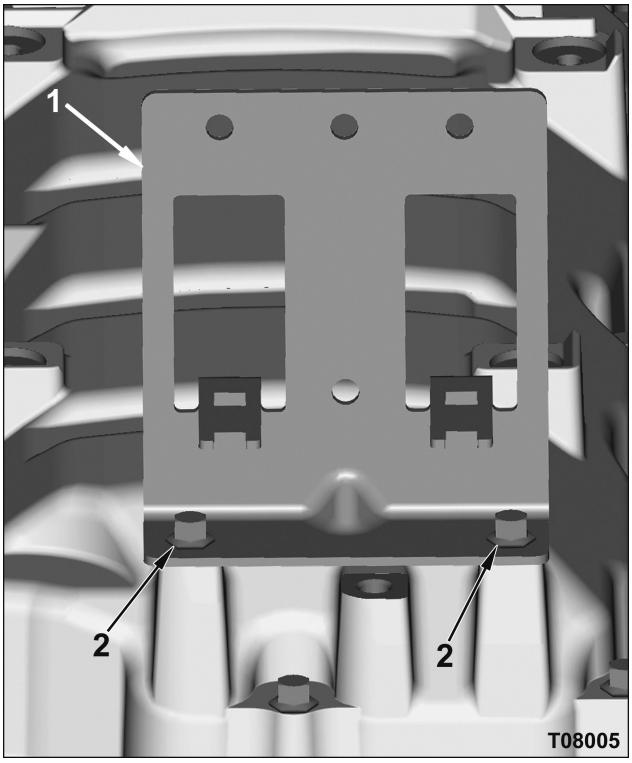


Figure 529 Clipping Plate

1. Clipping plate
2. M8 x 25 bolt (2)

3. Install two M8 x 25 bolts securing the clipping plate to the valve cover. Tighten bolts to standard torque (page 553).

Specifications

Valve Specifications

Camshaft lobe lift	Intake: 6.68 mm (0.263 in) 0.254 mm (0.010 in) maximum wear limit Exhaust: 6.91 mm (0.272 in) 0.254 mm (0.010 in) maximum wear limit
Roller tappet guide slot width	9.271 ± 0.05 mm (0.365 ± 0.002 in)
Valve face angle	Intake: 59.75 to 60.00° Exhaust: 44.75 to 45.00°
Valve face margin (minimum)	Intake: 1.32 mm (0.052 in) Exhaust: 1.16 mm (0.046 in)
Valve face-to-valve stem runout (maximum)	0.038 mm (0.0015 in)
Valve lash (cold), intake and exhaust	0.48 mm (0.019 in)
Valve stem diameter (new condition)	Intake: 7.92861 ± 0.0089 mm (0.31215 ± 0.00035 in) Exhaust: 7.9083 ± 0.0089 mm (0.31135 ± 0.00035 in)
Valve stem straightness (maximum)	0.010 mm (0.0004 in)
Valve stem-to-guide running clearance (maximum)	Intake: 0.10 mm (0.004 in) Exhaust: 0.11 mm (0.004 in)
Intake valve head diameter	39.73 ± 0.13 mm (1.564 ± 0.005 in)
Exhaust valve head diameter	36.55 ± 0.13 mm (1.439 ± 0.005 in)

Valve Spring Specifications

Intake and Exhaust Valve Springs	
Free length	52.35 mm (2.061 in)
Solid height (maximum)	27.46 mm (1.081 in)
Valve closed test length @ 410.1 ± 24.5 N (92.2 ± 5.5 lb) test load	40 mm (1.575 in)
Valve closed test length @ 764.2 ± 48.9 N (171.8 ± 11.0 lb) test load	29.3 mm (1.155 in)

Cylinder Head and Valve Train Specifications

Cylinder head gasket surface flatness	0.10 mm (0.004 in.) per 229 mm (9.0 in)
Cylinder head thickness	New: 160.48 mm (6.318 in)
	Minimum: 159.97 mm (6.298 in)
Cylinder head valve guide bore diameter	14.308 ± 0.017 mm (0.5633 ± 0.0007 in)
Cylinder head deck brinelling indentation	0.05 mm (0.002 in.)
Exhaust valve seat counterbore diameter	Standard: 37.503 ± 0.025 mm (1.4765 ± 0.0010 in)
	Oversize: 0.05 mm (0.002 in): 37.55 ± 0.03 mm (1.4785 ± 0.001 in)
Exhaust valve seat insert outside diameter	Standard: 37.57 ± 0.01 mm (1.479 ± 0.0004 in)
	Oversize: 0.05 mm (0.002 in): 37.62 ± 0.01 mm (1.481 ± 0.0004 in)
Intake valve seat counterbore diameter	Standard: 40.145 ± 0.025 mm (1.5805 ± 0.001 in)
	Oversize 0.05 mm (0.002 in): 40.195 ± 0.025 mm (1.5825 ± 0.0010 in)
Intake valve seat insert outside diameter	Standard: 40.21 ± 0.01 mm (1.583 ± 0.0005 in)
	Oversize 0.05 mm (0.002 in): 40.26 ± 0.01 mm (1.585 ± 0.0004 in)
Valve seat insert OD to valve seat counterbore diametral interference	0.025 to 0.102 mm (0.001 to 0.004 in)
Valve guide bore out-of-round (maximum)	0.005 mm (0.0002 in)
Valve guide bore taper (maximum)	0.013 mm (0.0005 in)
Valve guide height from cylinder head spring pocket	16.54 ± 0.25 mm (0.651 ± 0.010 in)
Valve guide inside diameter (installed)	7.98 to 8.00 mm (0.314 to 0.315 in)
Valve guide inside diameter (installed), maximum wear limit	Intake: 0.102 mm (0.005 in)
	Exhaust: 0.127 mm (0.005 in)
Valve guide interference fit dimension	0.043 mm (0.0017 in)
Valve guide outside diameter	14.351 ± 0.010 mm (0.5650 ± 0.0004 in)
Valve guide length (overall)	65.71 mm (2.587 in)

Cylinder Head and Valve Train Specifications (cont.)

Valve recession	Intake: 1.02 ± 0.13 mm (0.040 ± 0.005 in) Exhaust: 1.40 ± 0.13 mm (0.055 ± 0.005 in)
Valve seat angles	Intake: 60.00 - 60.25° Exhaust: 45.00 - 45.25°
Valve seat to valve guide bore concentricity (maximum)	0.076 mm (0.003 in)
Valve seat width	1.91 to 2.16 mm (0.075 to 0.085 in)
Push rod runout (maximum)	0.508 mm (0.020 in)

Special Torque

Cylinder head mounting bolts torque and sequence	See Torque Procedure for Torque-to-yield Head Bolts (page 389)
Rocker arm bolts torque and sequence	See torque procedure in Rocker Arm Assembly (page 392)
Valve adjustment screw lock nut	27 N·m (20 lb·ft)

Special Service Tools

5 mm hex key wrench	Obtain locally
Ball gauge	Obtain locally
Cylinder Head Test Plate	ZTSE4289A
Depth micrometer	Obtain locally
Dial indicator set	Obtain locally
Dye penetrant kit	Obtain locally
Feeler gauge	Obtain locally
Head bolt socket	Obtain locally
Head Bolt Bottoming Tap	ZTSE4671
Injector Sleeve Brush Set (set of 2)	ZTSE4304
Injector Sleeve Installer	ZTSE4642
Injector Cup Removal Tool.	12-342-01
Inside micrometer	Obtain locally

Loctite® 620 Retaining Compound	Obtain locally
Outside micrometer	Obtain locally
Prussian® Blue	Obtain locally
Pressure regulator	Obtain locally
Slide Hammer Puller Set	ZTSE1879
Small hole gauge set	Obtain locally
Square	Obtain locally
Straightedge	Obtain locally
Telescoping gauge	Obtain locally
Thermostat Opening Pressure Adapter	ZTSE4647
Valve and Clutch Spring Tester	ZTSE2241
Valve Guide Deburring Tool	ZTSE4393
Valve Guide Installer	ZTSE1943
Valve Guide Remover	ZTSE4377
Valve Seat Extractor Kit (Universal)	ZTSE1951C
Valve Seat Grinder	ZTSE1631A
Valve seat grinding stones 45° (exhaust)	Obtain locally
Valve seat grinding stones 60° (intake)	Obtain locally
Valve Seat Installer	ZTSE4641
Valve Seat Remover (collet)	ZTSE4640
Valve Spring Compressor	ZTSE1846
Valve Spring Compressor Jaws	ZTSE4652
Vernier caliper	Obtain locally
Water Supply Housing Pressure Adapter	ZTSE4648

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Exploded View and Description

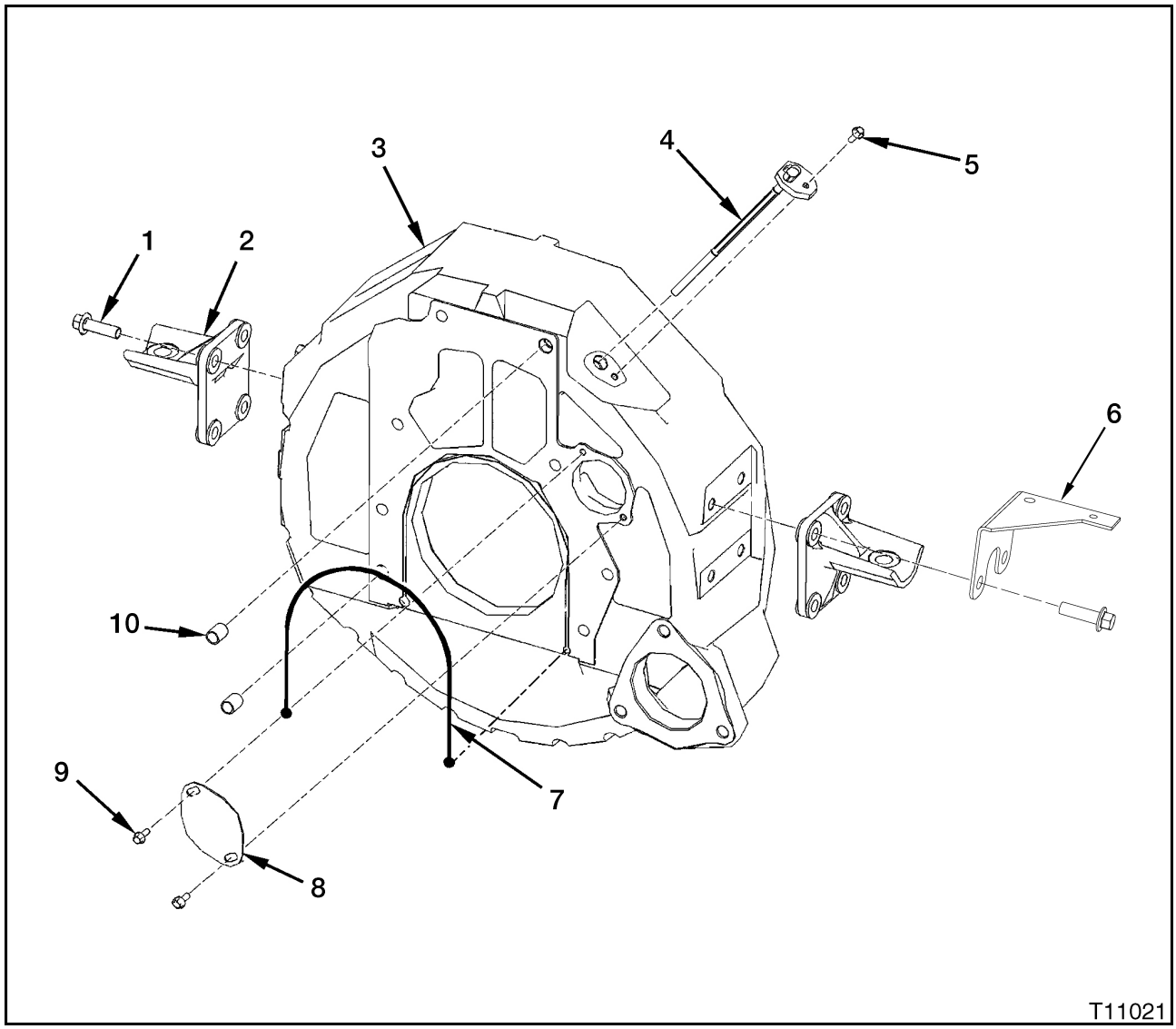


Figure 530 Flywheel Housing and Related Parts (typical)

1. M12 x 40 bolt (8)
2. Rear engine mounting bracket (2)
3. Flywheel housing
4. Crankshaft Position sensor (CKP)
5. M6 x 16 bolt
6. Copper fuel line clip
7. Flywheel housing seal
8. Cover plate
9. M6 x 16 bolt (2)
10. Hollow dowel (2)

The flywheel housing assembly is bolted to the back of the crankcase and supports the transmission, starter motor, rear engine mounting brackets, and crankshaft position sensor. A flywheel and clutch assembly (manual transmission) or a flexplate and torque converter assembly (automatic transmission) are housed inside the flywheel housing to transfer engine power to the transmission. Several flywheel housing, flywheel, and flexplate options are available to fit different applications.

All transmission applications are designed to attach to one of the following four flywheel housing assembly configurations:

Flywheel housing SAE 1

- Houses a flywheel or flexplate with a 148-tooth ring gear
- SAE 1 transmission opening
- SAE 1 starter motor location (will only work with a 148-tooth ring gear)
- Standard SAE 2 side mount locations

Flywheel housing SAE 1A

- Houses a flywheel or flexplate with a 138-tooth ring gear
- SAE 1 transmission opening
- SAE 2 starter motor location (will only work with a 138-tooth ring gear)
- Standard SAE 2 side mount locations

Flywheel housing SAE 2

- Houses a flywheel or flexplate with a 138-tooth ring gear
- SAE 2 transmission opening
- SAE 2 starter motor location (will only work with a 138-tooth ring gear)
- Standard SAE 2 side mount locations

Flywheel housing (Bus) SAE 2

- Houses a flywheel or flexplate with a 138-tooth ring gear
- SAE 2 starter motor location (will only work with a 138-tooth ring gear)
- High side mounts for bus

Flywheel and Flexplate Applications

Manual Transmissions

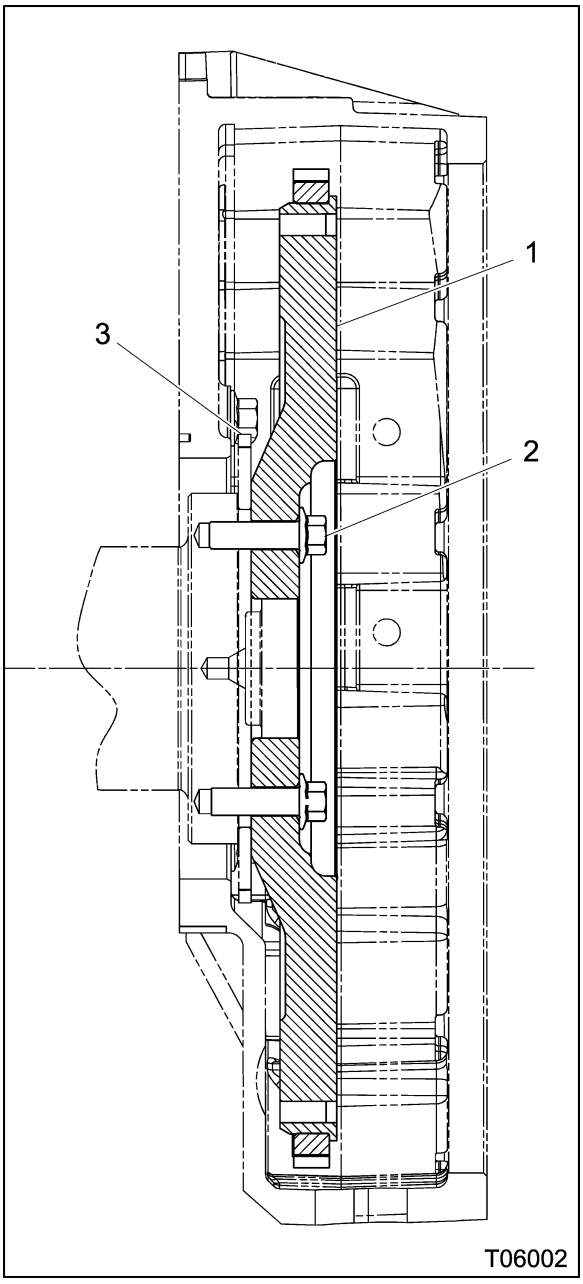


Figure 531 14 inch Flywheel - for Multiple Plate Clutch Applications (800 lb·ft and below)

1. Flywheel assembly
2. M12 x 40 bolt (12)
3. Crankshaft timing disk

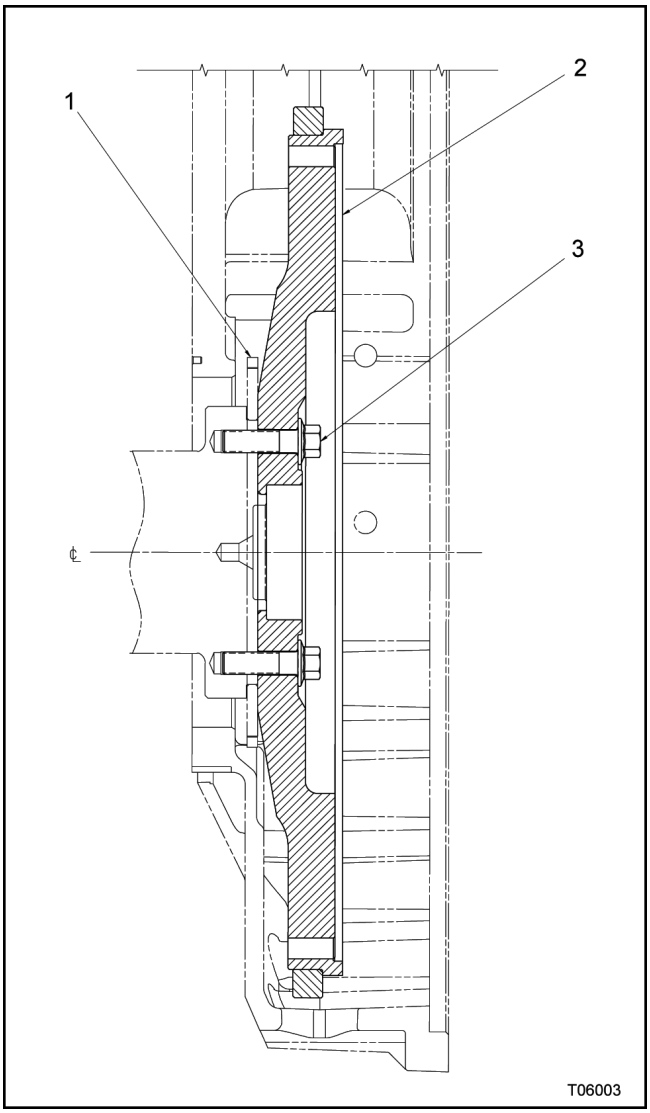


Figure 532 15.5 inch Flywheel - for Multiple Plate Clutch Applications (800 lb·ft and above)

1. Crankshaft timing disk
2. Flywheel assembly
3. M12 x 37 bolt (12)

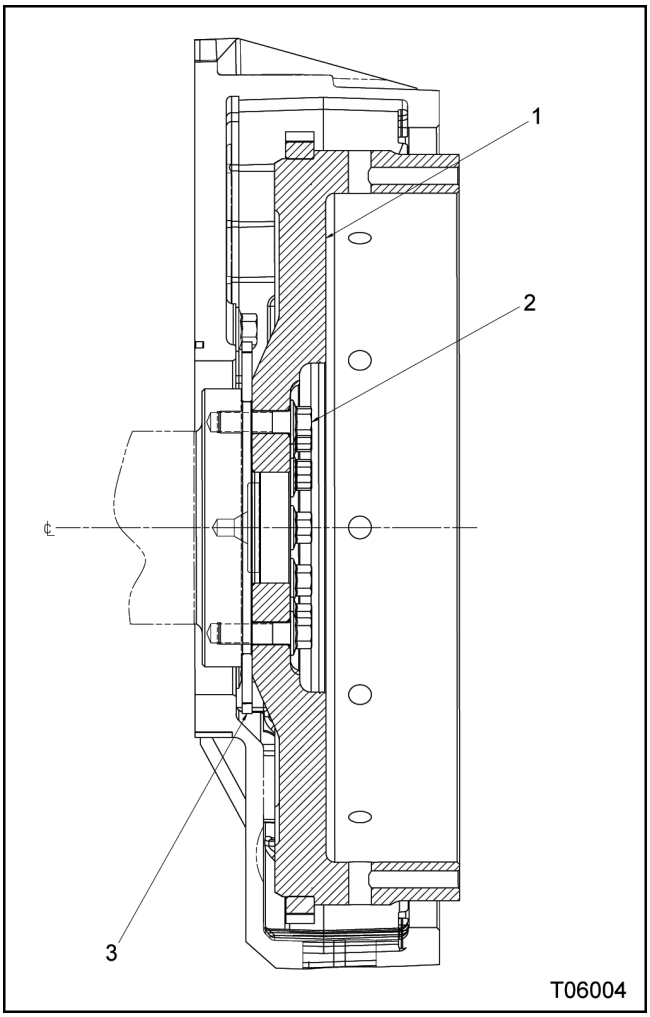


Figure 533 Pot Type Flywheel - for Multiple Plate Clutch Applications (800 lb·ft and above)

1. Flywheel assembly
2. M12 x 40 bolt (12)
3. Crankshaft timing disk

Automatic Transmissions

NOTE: Side of reinforcement ring stamped with the part number or logo must face outward.

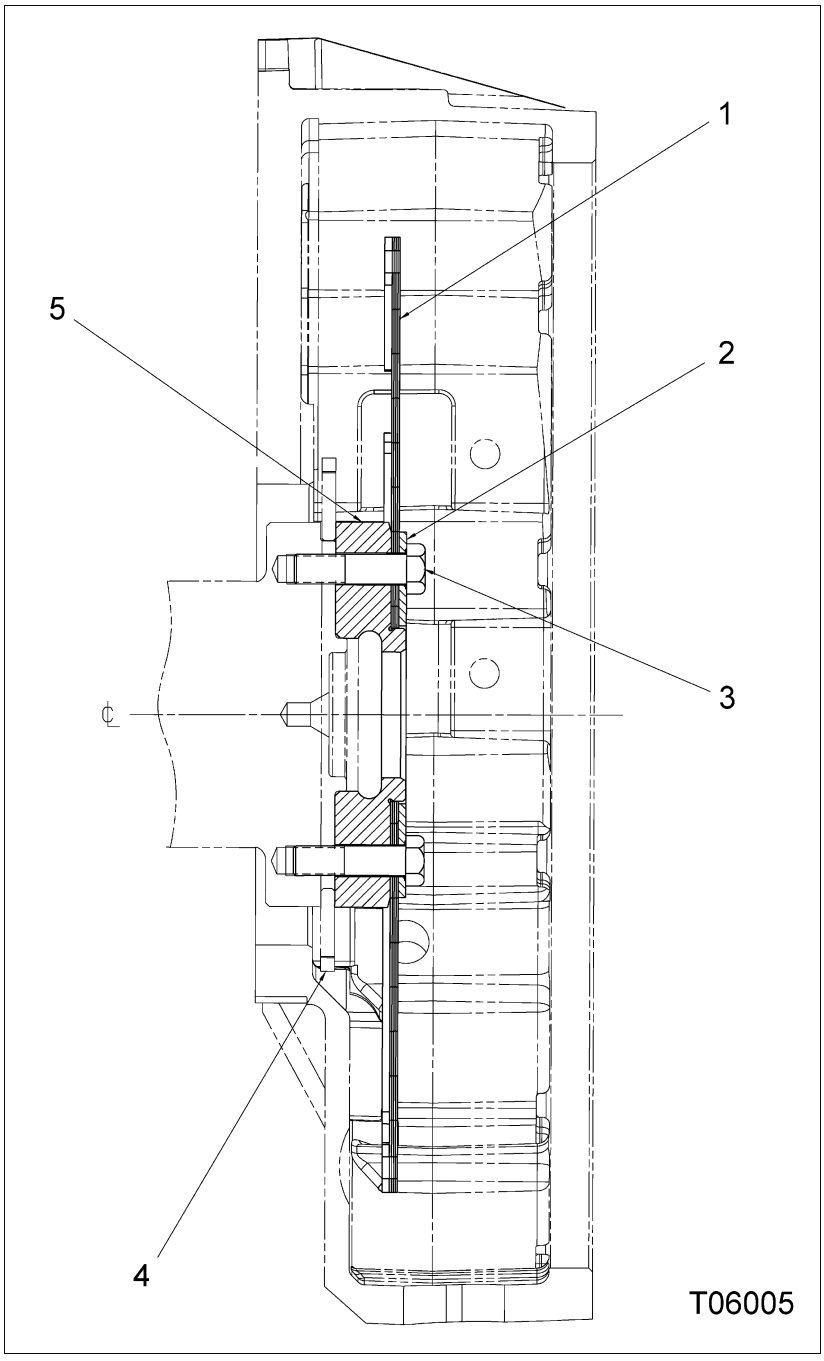


Figure 534 Application for Allison World Transmissions - MD-3060 and MD-3560

1. Flexplate assembly
2. Reinforcement ring (Allison transmissions only)
3. M12 x 45 bolt (12)
4. Crankshaft timing disk
5. Adapter hub crankshaft

NOTE: Side of reinforcement ring stamped with the part number or logo must face outward.

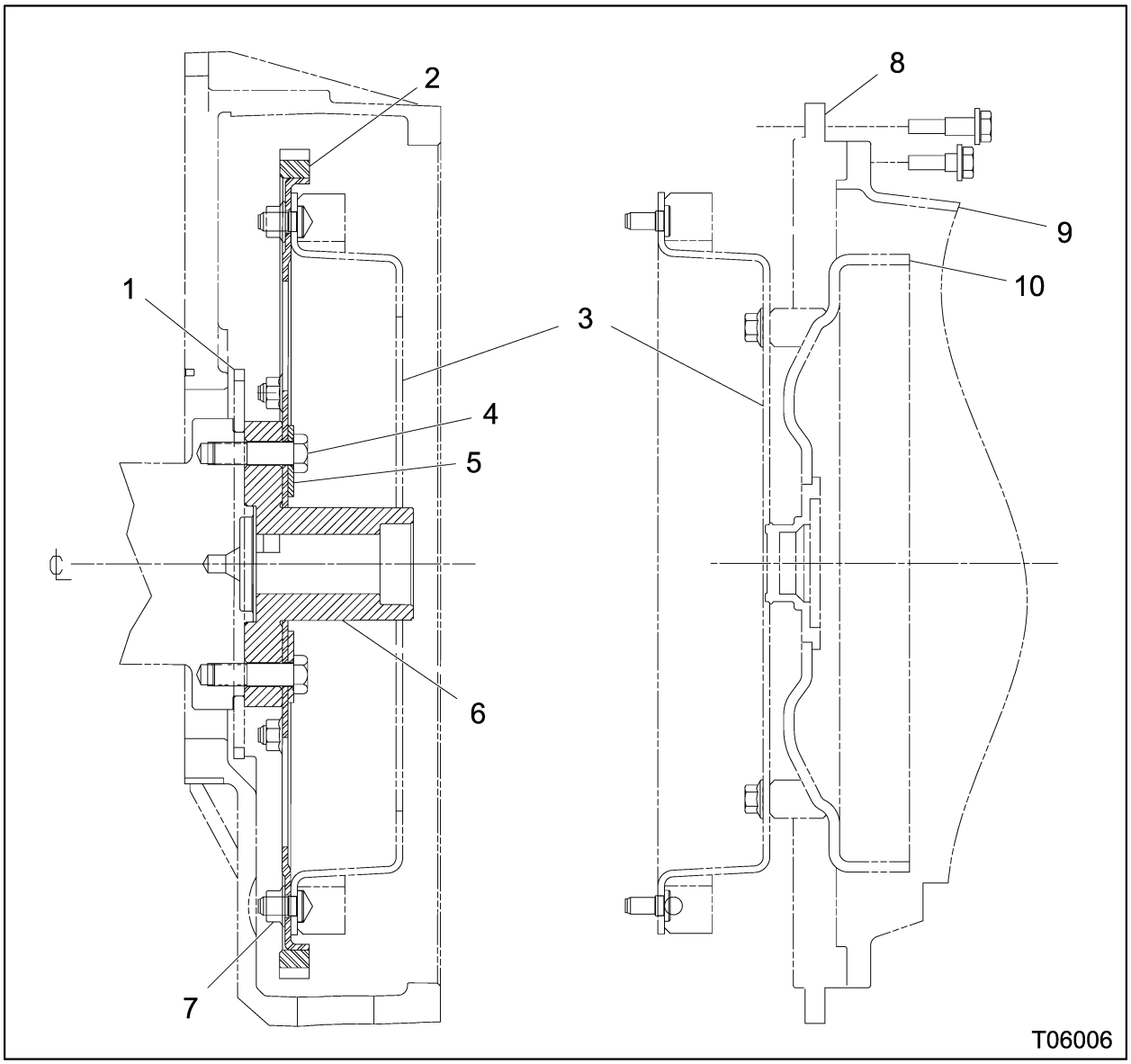


Figure 535 Application for Allison Transmissions

1. Crankshaft timing disk
2. Ring gear & flex plate assembly
3. Plate assembly, Allison AT transmissions
4. M12 x 43 bolt (12)
5. Reinforcement ring
6. Adapter hub, AT
7. M10 x 1.5 nut
8. Converter adapter ring (SAE 2 to SAE 3 ring)
9. Transmission case
10. Torque converter assembly

Removal

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

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

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

NOTE: When performing specific component removal, only remove components necessary for access.

Flywheel Assembly

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

1. Disconnect the negative (ground) cable from the battery.
2. Disconnect the electrical cable and wires from the starter motor.
3. Remove bolts holding the starter motor to the flywheel housing and remove the starter.
4. Remove the transmission and clutch assembly.

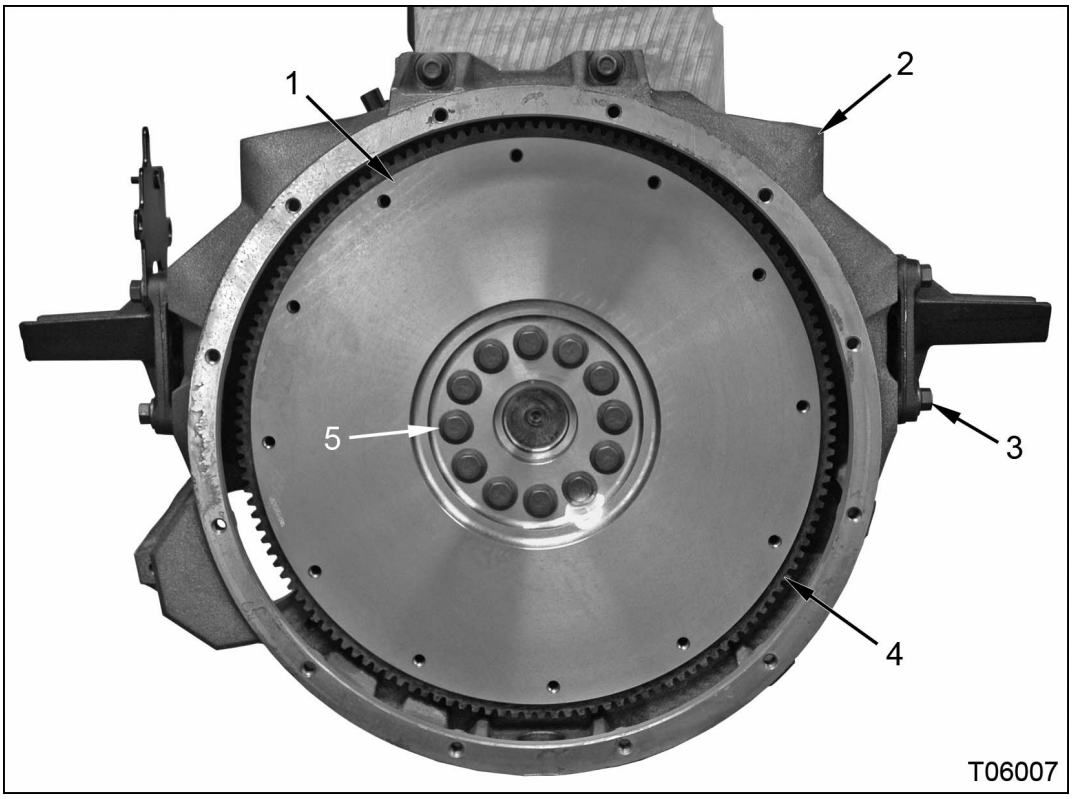


Figure 536 Flywheel and Flywheel Housing (typical)

1. Flywheel assembly (typical)
2. Flywheel housing assembly (typical)
3. M12 x 40 bolt (8)
4. Ring gear
5. M12 x 40 bolt (12)

NOTE: There are two flywheel options for manual transmissions: 138-tooth ring gear and 148-tooth ring gear. For 148-tooth flywheels, loosen the two lowest, rear most M12 x 40 rear engine mount bolts to provide clearance for flywheel removal.

5. Remove two M12 x 40 flywheel bolts, 180° from each other.
6. Install two guide pins (made locally) in place of the two flywheel bolts.
7. Remove remaining ten M12 x 40 flywheel bolts.
8. Carefully slide flywheel out of flywheel housing and off guide pins.
9. Remove guide pins.

Flexplate (Automatic Transmissions)

NOTE: Flexplate assemblies are available as fully assembled service part assemblies. Typically, there is no need to disassemble flexplate assemblies.

Allison 2000 Series Transmissions

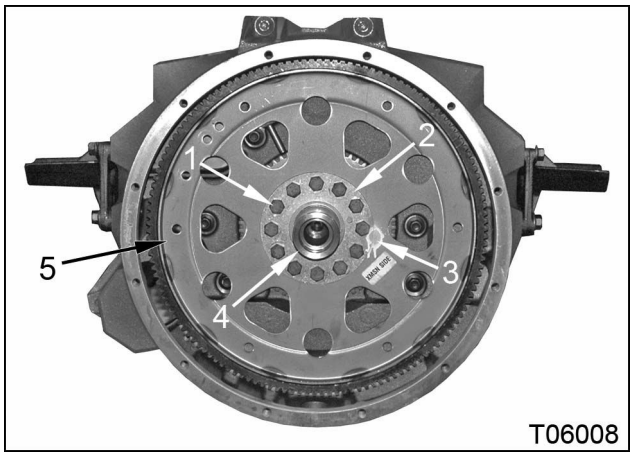


Figure 537 Flexplate, Reinforcement Ring, and Adaptor Hub

1. M12 x 43 bolt (12)
2. Reinforcement ring
3. Paint marking index
4. Adapter hub A/T
5. Flexplate assembly

1. Remove transmission and torque converter assembly.
2. Put a paint mark on the exposed face of the reinforcement ring and flexplate for proper installation orientation.
3. Remove two M12 x 43 flywheel bolts, 180° from each other.
4. Install two guide pins (made locally) in place of two M12 x 43 flywheel bolts.
5. Remove remaining ten M12 x 43 flywheel bolts.
6. Slide reinforcement ring, flexplate, and adapter hub off guide pins.
7. Remove guide pins.

MD-3000 Series Transmissions

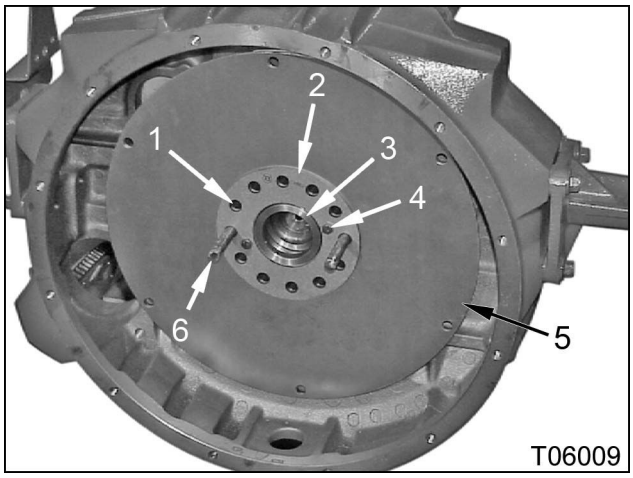


Figure 538 Flexplate, Reinforcement Ring, and Guide Pins

1. M12 x 45 bolt hole (12)
2. Reinforcement ring
3. Adapter crankshaft hub
4. M6 flexplate assembly bolt (2)
5. Flexplate assembly
6. Guide pin (2)

1. Remove transmission and torque converter assembly.

CAUTION: To prevent engine or vehicle damage, do not remove two M6 flexplate assembly bolts.

2. Remove two M12 x 45 flexplate bolts, 180° from each other.
3. Install two guide pins (made locally) in place of two M12 x 45 flexplate bolts.
4. Remove remaining ten M12 x 45 flexplate bolts.
5. Slide flexplate assembly off guide pins.
6. Remove guide pins.

Crankshaft Timing Disk

CAUTION: To prevent engine damage, do not contact the rear oil seal with bolts threaded into the crankshaft timing disk for disk removal. Damage to the rear oil seal could cause oil leaks.

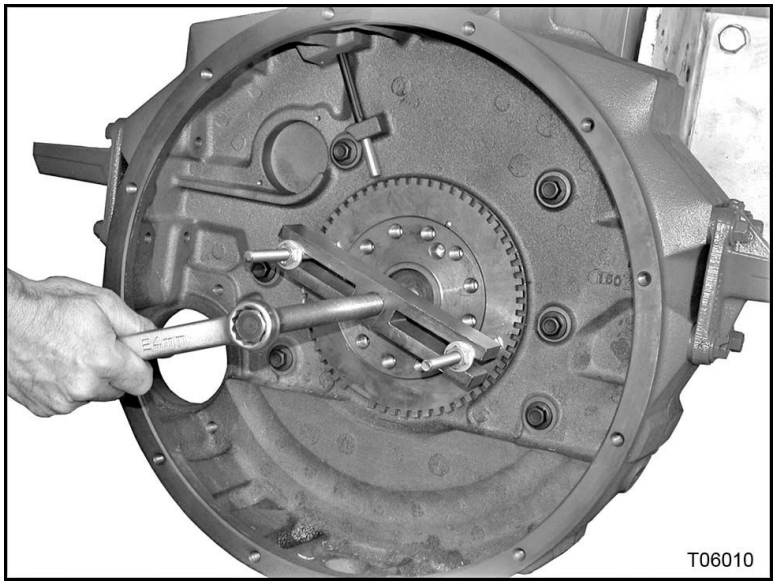


Figure 539 Crankshaft Timing Disk Removal

1. Install two bolts and washers through H-bar puller (page 427) and into the crankshaft timing disk. Install bolt heads at equal lengths from the timing disk.
2. Tighten H-bar puller center shaft to pull timing disk off the crankshaft.

Rear Oil Seal Assembly

NOTE: If the flywheel housing is to be removed, then remove flywheel housing (page 413) first. The rear oil seal will remain in the flywheel housing and can be knocked out with a hammer.

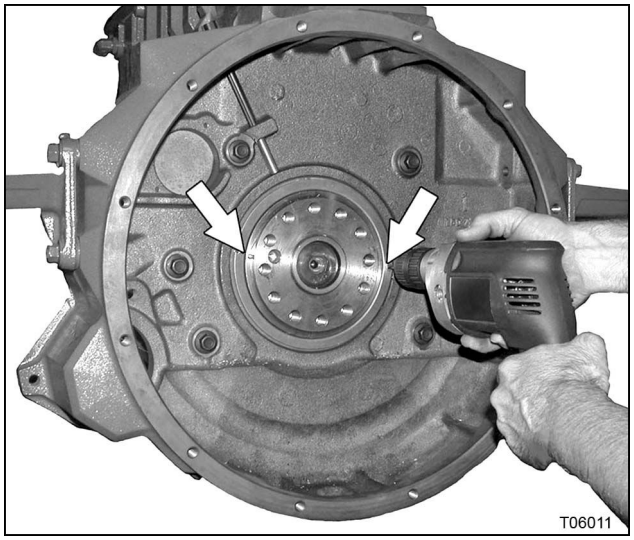


Figure 540 Puller Screw Holes in Rear Oil Seal Assembly

NOTE: Use an appropriate size drill bit to fit Slide Hammer Puller screw.

1. Carefully drill two puller screw holes approximately 180° from each other in the rear oil seal assembly.

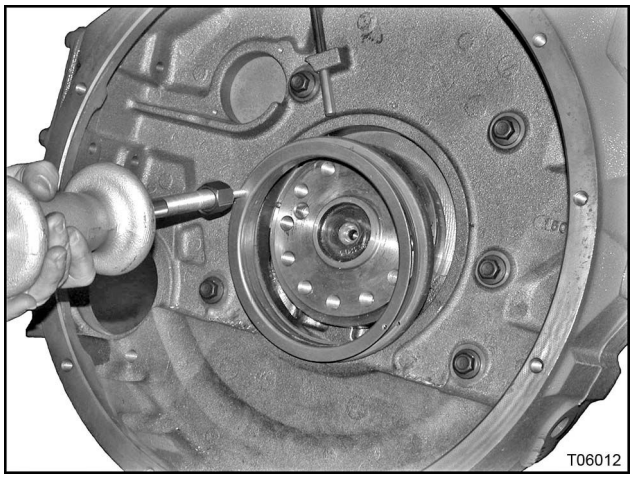


Figure 541 Rear Oil Seal Assembly and Slide Hammer

2. Screw Slide Hammer Puller Set (page 427) screw into holes drilled in the rear oil seal assembly.
3. Alternately pull each side of the rear oil seal out.
4. Remove and discard rear oil seal.

NOTE: When replacing crankshaft rear oil seal, note that production engines will not have a wear sleeve. Wear sleeves are only available as a service item included with replacement crankshaft rear oil seals.

5. If installed, remove and discard wear sleeve using Slide Hammer Puller Set (page 427).

Flywheel Housing

1. Remove the oil pan (page 289).

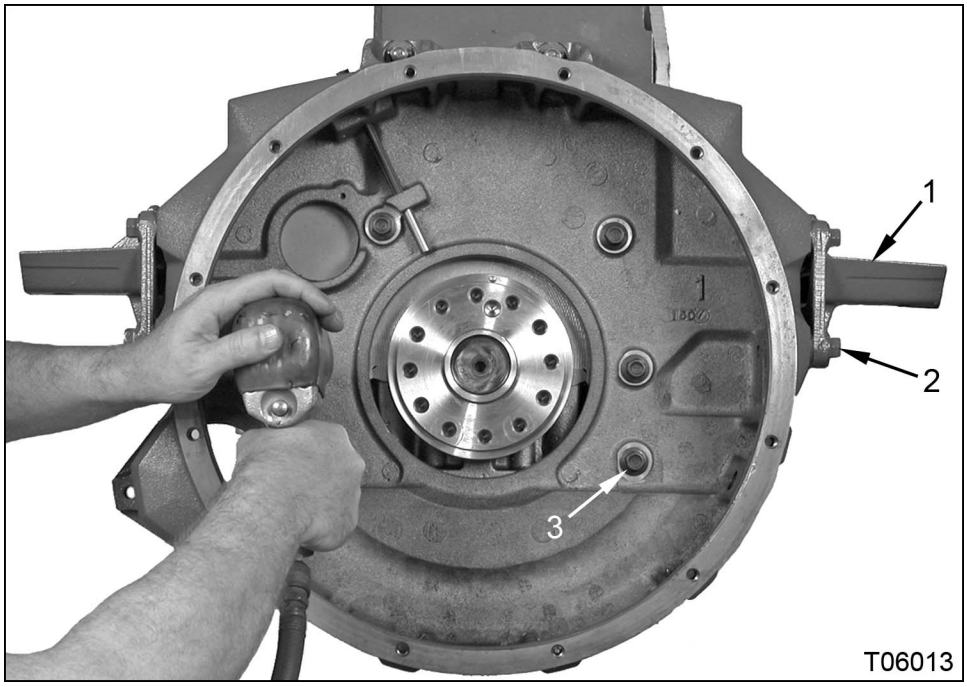


Figure 542 Flywheel Housing Removal (typical)

1. Rear engine mounting bracket (2)
2. M12 x 40 bolt (8)
3. M12 x 50 bolt (8)

WARNING: To prevent personal injury or death, support engine (if in chassis) before removing any engine mounting bracket or flywheel housing bolts.

2. Properly support the engine and remove eight M12 x 40 rear engine mounting bracket bolts and two rear engine mounting brackets.

WARNING: To prevent personal injury or death, get assistance to remove or install the flywheel housing.

3. Remove seven of the eight M12 x 50 flywheel housing mounting bolts.
4. Support the flywheel housing with help from an assistant.
5. Remove the final M12 x 50 flywheel housing mounting bolt and remove flywheel housing from the crankcase.

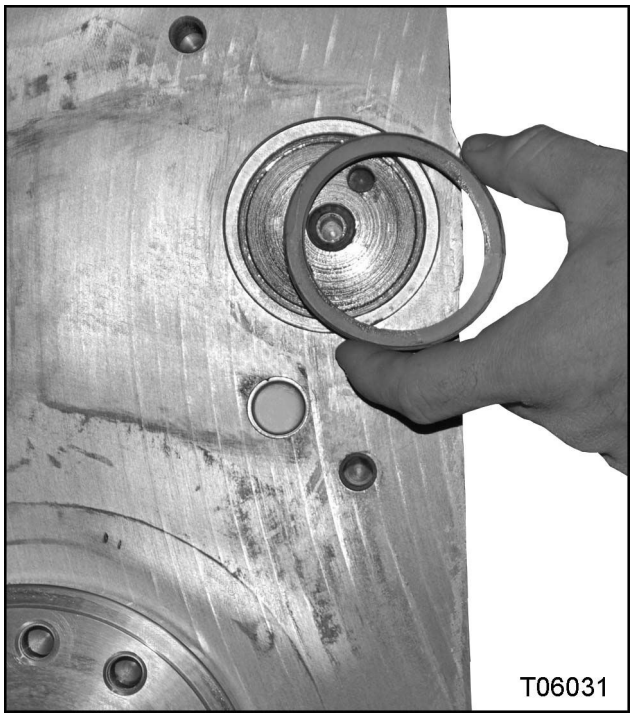


Figure 543 Camshaft Rear Seal Ring

6. Remove camshaft rear seal ring over camshaft end opening at rear of crankcase.

Cleaning, Inspection, and Measurement

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

Clean and Inspect

1. Clean flywheel or flexplate, flywheel housing, and rear engine mounting brackets with a non-caustic solvent and dry with filtered compressed air.
2. Inspect flywheel housing and rear engine mounting brackets for cracks and damage. Replace if required.
3. If equipped, inspect flexplate for cracks, damage, and warpage. Replace if required.
4. If equipped, inspect flywheel for cracks, heat checks, and extensive scoring. Resurface or replace as required.
5. Inspect crankshaft timing disk for missing, bent, chipped, or otherwise damaged gear teeth. Lay timing disk on a flat surface to ensure disk is not bent. If teeth are damaged or disk is bent, replace the timing disk.
6. Inspect ring gear for worn, chipped, or cracked teeth. If teeth are damaged, replace the ring gear.
7. Clean and inspect crankshaft and crankcase where flywheel and flywheel housing mount.

Measurement of Flywheel Housing Face Runout

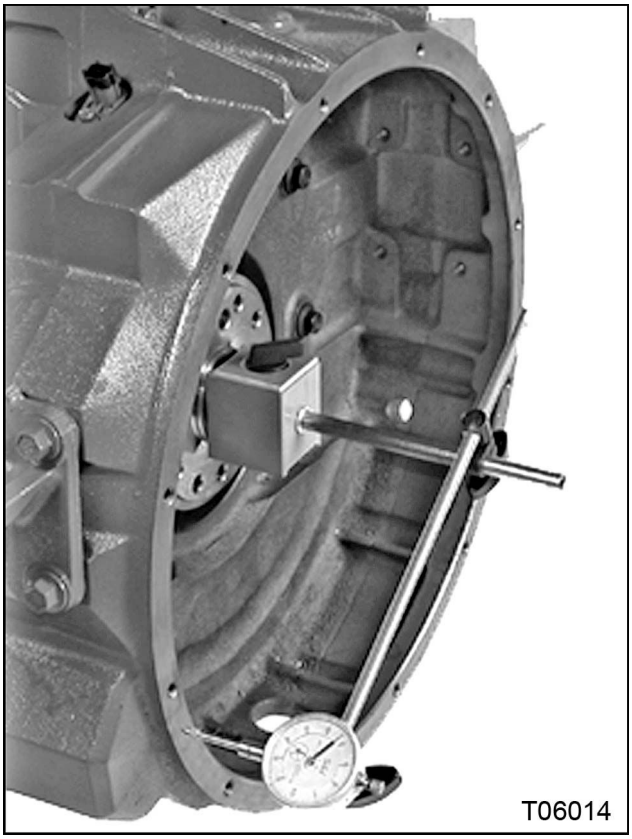


Figure 544 Flywheel Housing Face Runout Measurement

1. Push the crankshaft in by hand to bring crankshaft end play to zero.
2. Center the magnetic base of a dial indicator set (page 427) on the end of the crankshaft.
3. Place the dial indicator tip against the face of the flywheel housing.
4. Zero dial indicator.
5. Slowly rotate crankshaft 360° while keeping crankshaft end play at zero and observe dial indicator measurements.
6. Compare the total dial indicator variation (highest – lowest reading) to flywheel housing face runout Specifications (page 426).

Measurement of Flywheel Housing Bore Concentricity

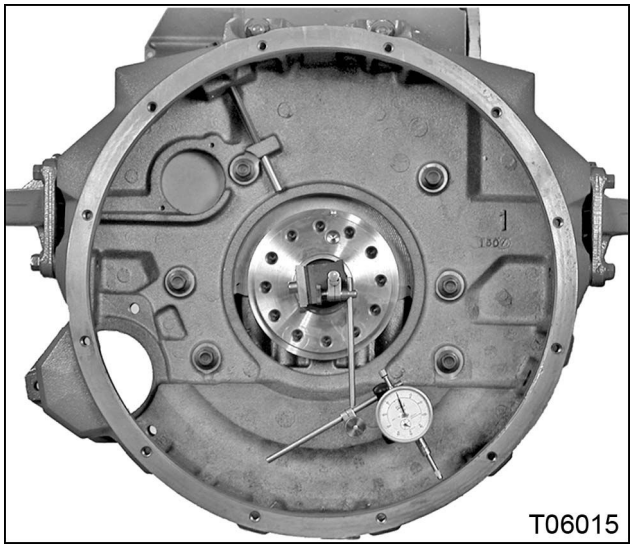


Figure 545 Flywheel Housing Bore Concentricity Measurement

1. Attach the magnetic base of a dial indicator set (page 427) on the end of the crankshaft.
2. Place the tip of the dial indicator against the flywheel housing bore.
3. Zero the dial indicator.
4. Slowly rotate the crankshaft 360° and observe dial indicator measurements.
5. Compare the total dial indicator variation (highest – lowest reading) to flywheel housing bore concentricity Specification (page 426).

Measurement of Crankshaft Pilot Concentricity

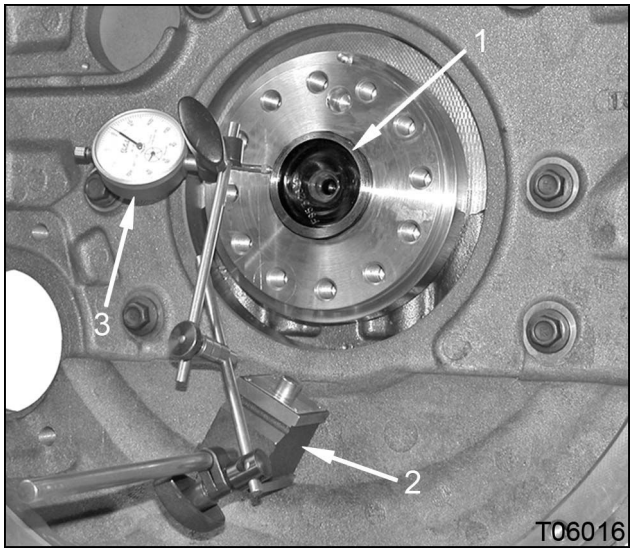


Figure 546 Crankshaft Pilot Concentricity Measurement

1. Crankshaft pilot
2. Magnetic base
3. Dial indicator

1. Attach the magnetic base of a dial indicator set (page 427) to the flywheel housing.
2. Place dial indicator tip against the crankshaft pilot outer edge.
3. Zero the dial indicator.
4. Slowly rotate the crankshaft 360° and observe dial indicator measurements.
5. Compare the total dial indicator variation (highest – lowest reading) to crankshaft pilot concentricity Specification (page 426).

Measurement of Flywheel Surface Runout



Figure 547 Flywheel Surface Runout Measurement

1. Attach the magnetic base of a dial indicator set (page 427) to the face of the flywheel housing.
2. Place dial indicator tip against the face of the flywheel near the pressure plate mounting holes.
3. Zero the dial indicator.
4. Slowly rotate the crankshaft 360° and observe dial indicator measurements.
5. Compare the total dial indicator variation (highest – lowest reading) to flywheel surface runout Specification (page 426).

Recondition

Resurface Flywheel

NOTE: Flywheels used with manual transmissions may be resurfaced to correct minor wear and scoring if flywheel is not cracked or damaged and meets minimum thickness Specification (page 426).

WARNING: To prevent personal injury or death, do not machine flywheel beyond minimum thickness specified for flywheel resurfacing.

NOTE: Flywheel resurfacing information is provided for guidance only. 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.

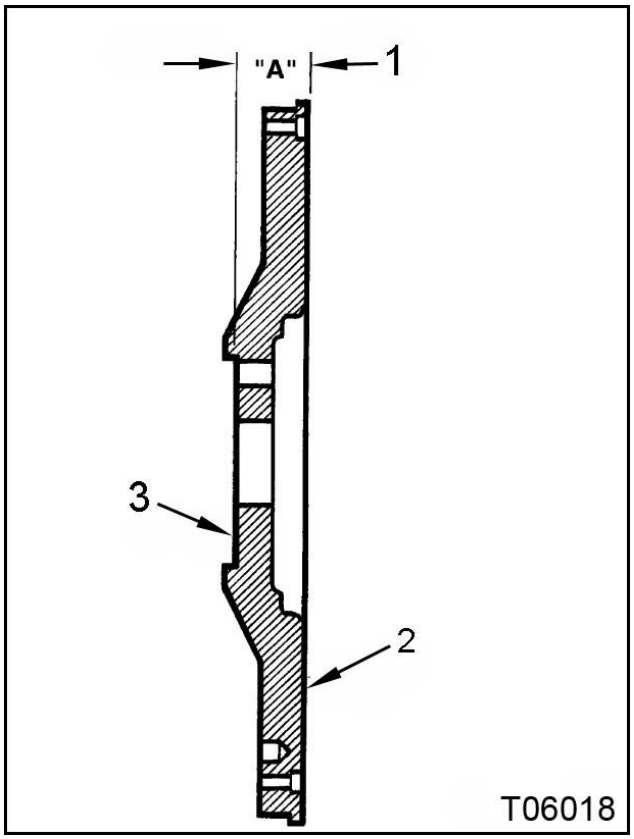


Figure 548 Flywheel Surface Dimension (typical)

1. Flywheel thickness (dimension “A”)
2. Clutch disc mounting face
3. Crankshaft flange mounting face

WARNING: To prevent personal injury or death, carefully examine flywheel for any cracks or heat checks before and after resurfacing. Cracks in the flywheel can cause it to separate. If there are any questions, do not reuse the flywheel.

1. Check flywheel for cracks and damage. Replace flywheel if required.
2. Measure flywheel thickness and compare to minimum required thickness Specification (page 426). 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.

Replacement of Flywheel Ring Gear

WARNING: To prevent personal injury or death, wear heat resistant gloves when handling heated components.

CAUTION: To prevent engine damage, do not heat ring gear higher than 278 °C (500 °F). Heating beyond this temperature will adversely affect the ring gear hardness.

1. Evenly heat ring gear with a torch to expand the gear for removal.

CAUTION: To prevent engine damage, do not hit the flywheel when knocking the ring gear off the flywheel.

2. After the ring gear is heated, carefully knock the ring gear off the flywheel. Do not hit the flywheel when removing the ring gear.
3. Heat the new ring gear evenly until gear expands enough to slip onto the flywheel.
4. Make sure ring gear is properly seated against flywheel shoulder along the entire radius of the flywheel.

Installation

Flywheel Housing and Rear Engine Mounting Brackets

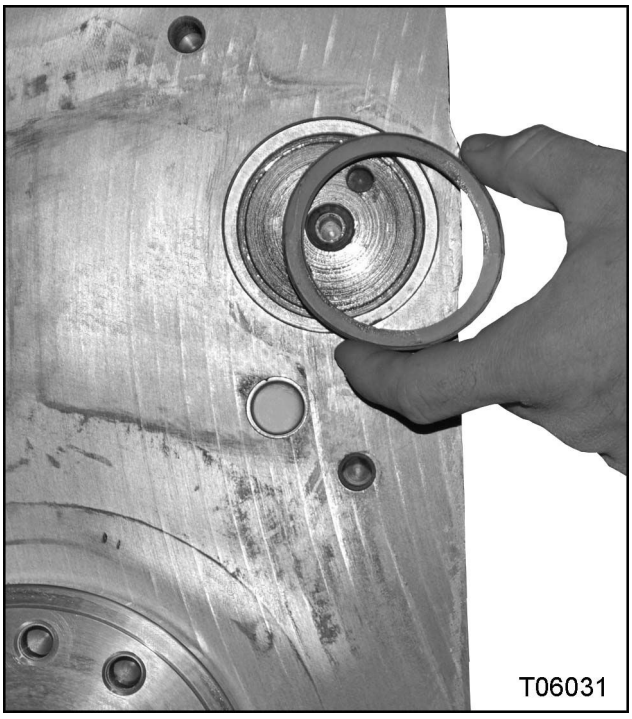


Figure 549 Camshaft Rear Seal Ring

1. Install new camshaft rear seal ring over camshaft end opening at rear of crankcase.

⚠ WARNING: To prevent personal injury or death, support engine (if in chassis) before removing any engine mounting bracket or flywheel housing bolts.

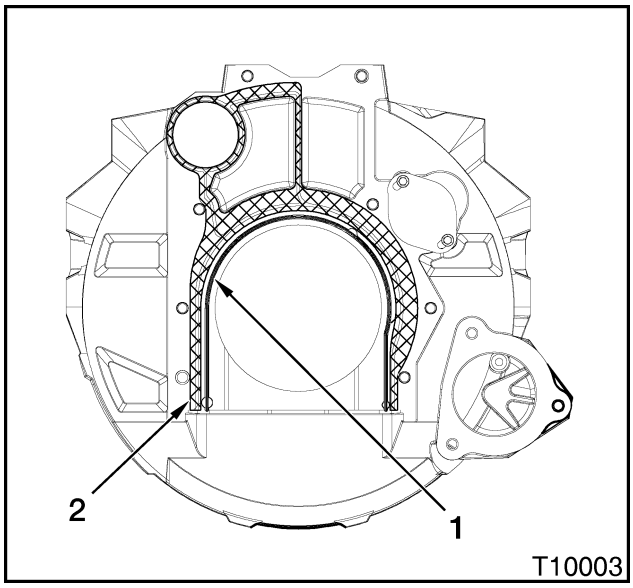


Figure 550 Loctite Application

1. Flywheel housing Seal
2. Apply Loctite® 5127

2. Install a new flywheel housing seal in the crankcase side of the flywheel housing.
3. Apply an approximately 1/8” continuous bead of Loctite® 5127 (page 427) on the flat mounting face (engine side) of the housing. Avoid applying any Loctite® on seals or bolt holes.

⚠ WARNING: To prevent personal injury or death, get assistance to remove or install the flywheel housing.

NOTE: Verify two hollow dowels are installed in the crankcase side of the flywheel housing before installing the housing.

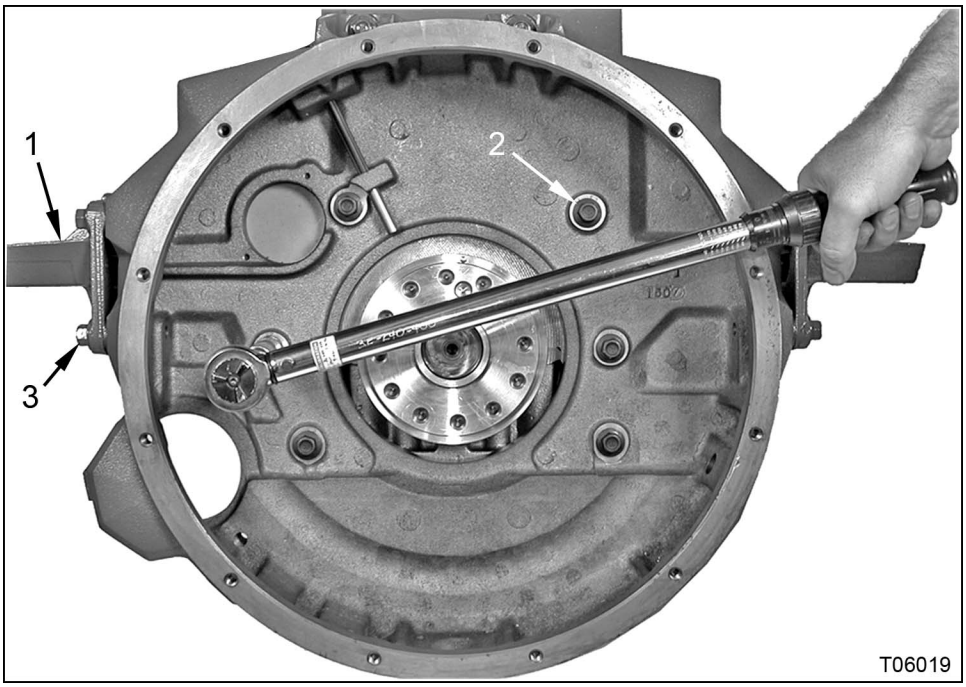


Figure 551 Flywheel Housing Installation

1. Rear engine mounting bracket (2)
2. M12 x 50 bolt (8)
3. M12 x 40 bolt (8)

4. With help from an assistant, lift the flywheel housing into position and align two hollow dowels of the flywheel housing with dowel holes in the crankcase and install one M12 x 50 flywheel housing bolt finger tight.
5. Install seven remaining M12 x 50 flywheel housing bolts finger tight.
6. Tighten eight M12 x 50 bolts to standard torque (page 553).

NOTE: On engines with a 148-tooth ring gear, leave the lowest, rear most M12 x 40 mounting bracket bolt loose (2 or 3 threads) on each side of the flywheel housing (SAE 1A). This will provide clearance for installation of the flywheel and ring gear assembly.

7. Install two rear engine mounting brackets and finger tighten eight M12 x 40 mounting bracket bolts.
8. Tighten eight M12 x 40 bolts to standard torque (page 553).

Rear Oil Seal

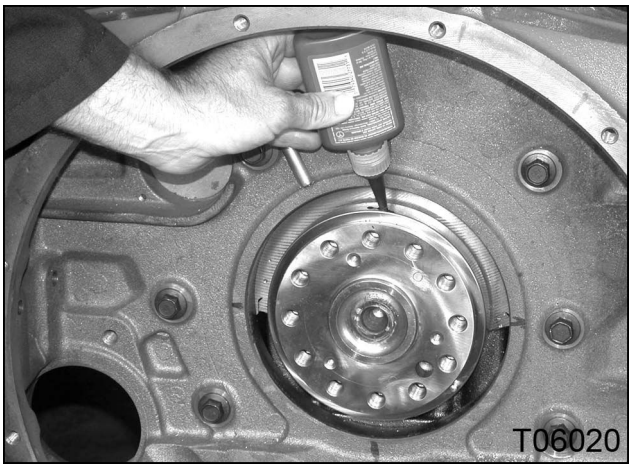


Figure 552 Application of Sealant to Crankshaft Wear Sleeve Area

1. Apply a 360° bead of Loctite® 569 Hydraulic Sealant (page 427) to the crankshaft where the rear oil seal wear sleeve will be positioned.

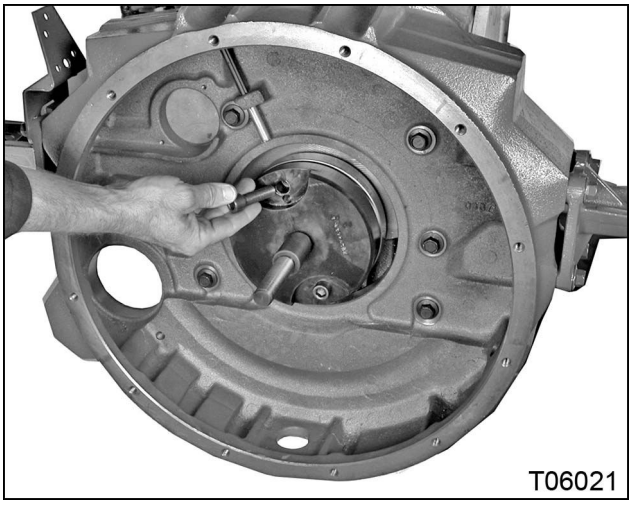


Figure 553 Rear Seal Installer Base

2. Install base of Rear Seal Installer (page 427) on the crankshaft and tighten two bolts.

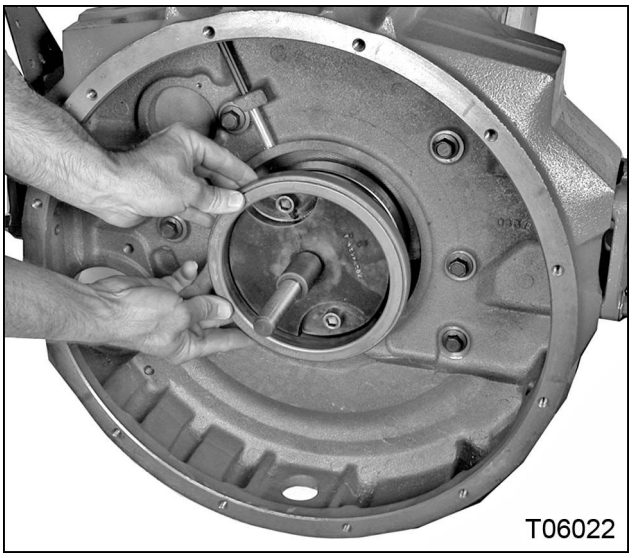


Figure 554 Rear Oil Seal Installation on Base

3. With steel surface of rear oil seal facing outwards (towards transmission), install seal assembly on the Rear Seal Installer base.

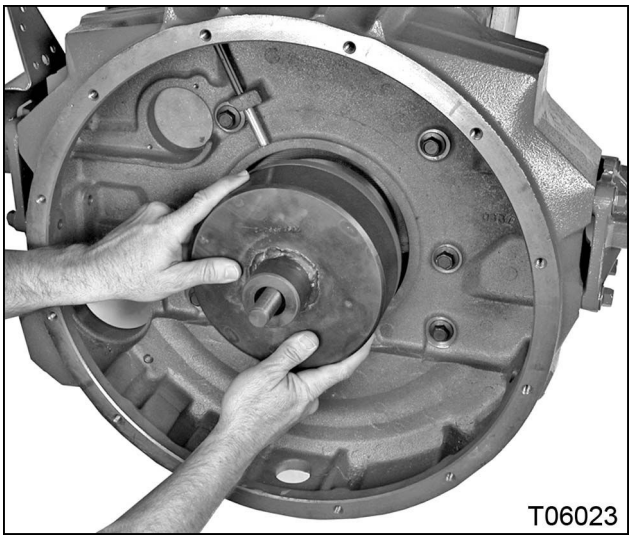


Figure 555 Rear Seal Installer Installation onto Base

4. Install Rear Seal Installer against steel face of rear oil seal and gently push into flywheel housing as far as possible by hand.

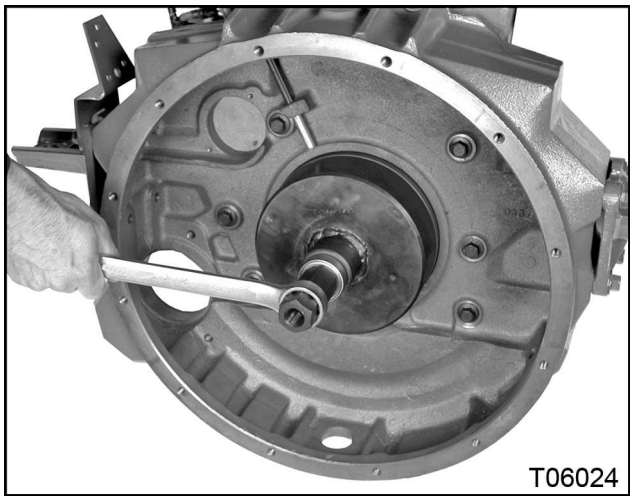


Figure 556 Rear Oil Seal Installation

5. Install bearing, washer, and forcing nut on installer shaft.

CAUTION: To prevent engine damage, do not use air tools to tighten Rear Seal Installer nut.

6. Tighten forcing nut until rear oil seal installer bottoms out. Rear oil seal assembly will be placed at the correct depth.

Crankshaft Timing Disk

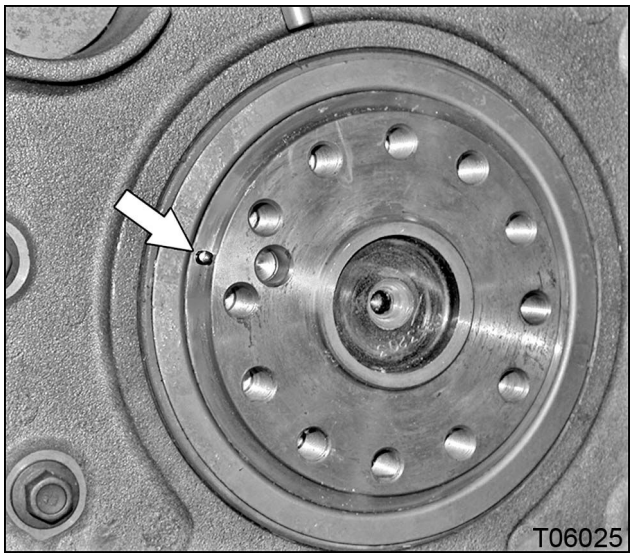


Figure 557 Crankshaft Timing Disk Alignment Spring Pin

CAUTION: To prevent engine damage, timing disk alignment spring pin must protrude out of the crankshaft.

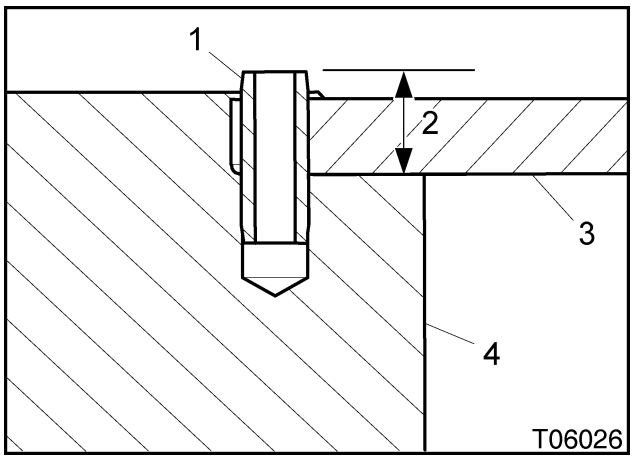


Figure 558 Crankshaft Timing Disk Alignment Spring Pin (cut-away)

1. Slotted spring pin
2. 7.6 mm (0.30 in) max
3. Crankshaft timing disk
4. Crankshaft

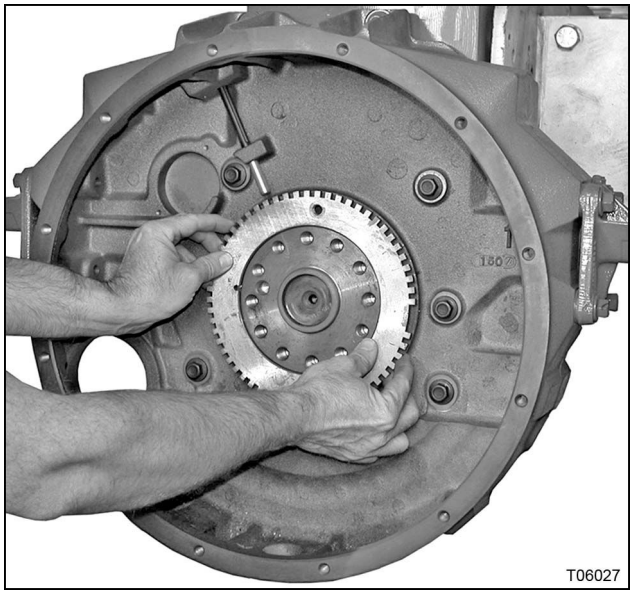


Figure 559 Crankshaft Timing Disk Installation

NOTE: Crankshaft timing disk can be installed with either side out. Best practice is to install with the part number facing outwards.

1. Align index notch of the crankshaft timing disk with crankshaft timing disk alignment pin.
2. Use a rubber mallet to carefully tap the crankshaft timing disk onto the crankshaft. Tap evenly around the crankshaft timing disk to ensure a flush fit against the end of the crankshaft.

NOTE: Rear Seal Installer (page 427) can be used to press the crankshaft timing disk onto the crankshaft.

Flywheel Assembly

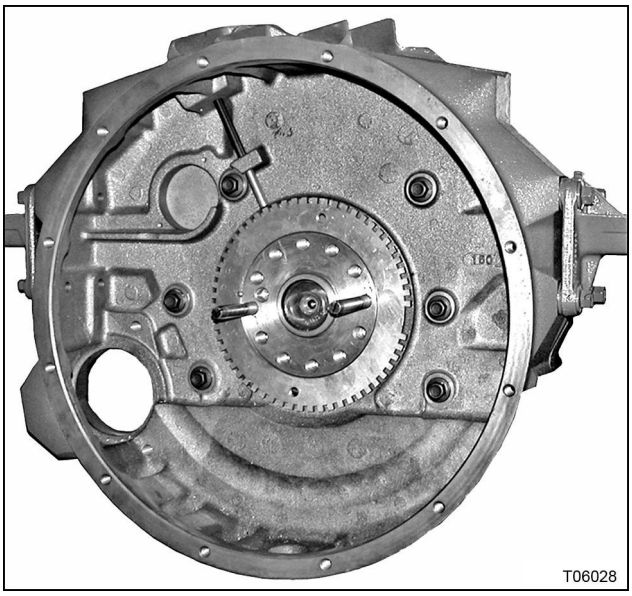


Figure 560 Guide Pins for Flywheel Installation

1. Install two guide pins (made locally) in the flywheel mounting bolt holes, 180° from each other.
2. Install flywheel over the guide pins.
3. Install ten M12 x 40 flywheel mounting bolts finger tight.
4. Remove two guide pins and install remaining two M12 x 40 flywheel mounting bolts finger tight.

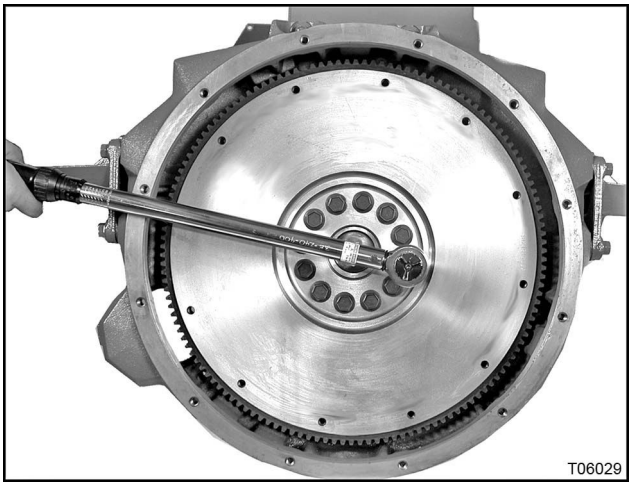


Figure 561 Flywheel Mounting Bolts (typical)

5. Tighten bolts to special torque (page 427).
6. Tighten two remaining rear engine mounting bracket bolts on manual transmission applications with 148-tooth ring gears to standard torque (page 553).
7. Measure flywheel surface runout (page 417).

Flexplate (Automatic Transmissions)

Allison 2000 Series Transmissions

1. Install two guide pins (made locally) in flexplate mounting bolt holes, 180° from each other.

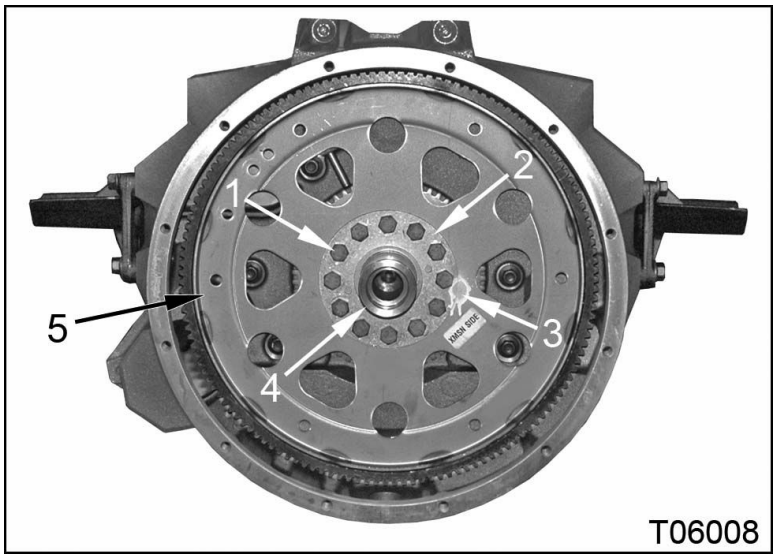


Figure 562 Adaptor Hub, Flexplate, and Reinforcement Ring

1. M12 x 43 bolt (12)
2. Reinforcement ring
3. Paint marking index
4. Adapter hub AT
5. Flexplate assembly

2. Install adapter hub AT on guide pins.

NOTE: When installed correctly, the ring gear of the flexplate is offset (not centered) toward the transmission.

3. Install flexplate assembly on the guide pins.

CAUTION: To prevent engine damage, make sure the reinforcement ring is installed with the paint mark or XMSN SIDE facing outward (towards the transmission), otherwise, premature flexplate failure may occur.

4. Install reinforcement ring on the guide pins with paint mark (or XMSN SIDE) facing outward.
5. Install ten M12 x 43 flexplate mounting bolts finger tight.
6. Remove guide pins and install remaining two M12 x 43 flywheel mounting bolts finger tight.
7. Tighten twelve M12 x 43 flexplate mounting bolts to special torque (page 427).

MD-3000 Series World Transmissions

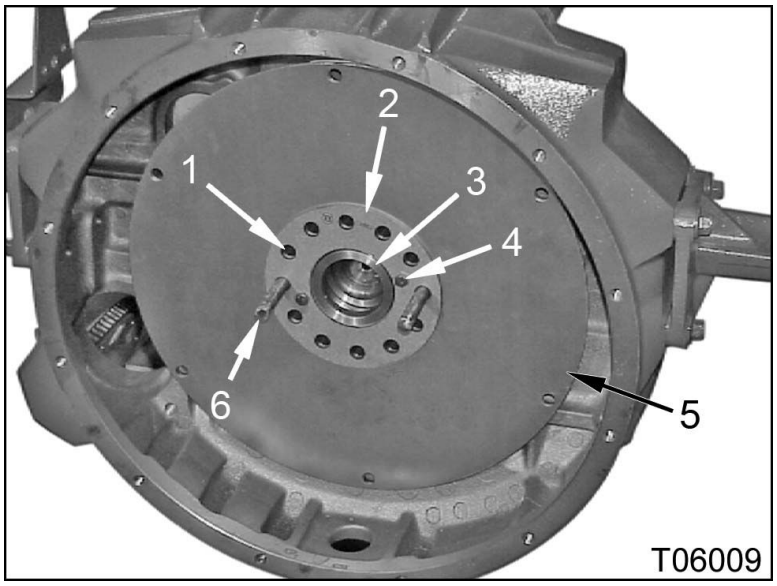


Figure 563 Flexplate Assembly

1. M12 x 45 bolt hole (12)
2. Reinforcement ring
3. Crankshaft hub adapter
4. M6 bolt (2)
5. Flexplate assembly
6. Guide pin (2)

1. Install two guide pins (made locally) in mounting bolt holes, 180° from each other.

CAUTION: To prevent engine damage, make sure the paint mark, part number, or XMSN SIDE on the flexplate is facing outward (towards the transmission).

NOTE: The flexplate assembly is available as a complete assembled service part.

2. Install flexplate assembly over the guide pins.

NOTE: The following step applies to MD transmissions only.

3. Install reinforcement ring with part number or logo facing out (towards the transmission).
4. Install ten M12 x 45 flexplate mounting bolts finger tight.
5. Remove guide pins and install remaining two M12 x 45 bolts finger tight.
6. Tighten M12 x 45 flexplate mounting bolts to special torque (page 427).

NOTE: Flywheel and ring gear are part of the torque converter assembly.

Specifications

WARNING: To prevent personal injury or death, do not machine flywheel beyond minimum thickness specified for flywheel resurfacing.

WARNING: To prevent personal injury or death, carefully examine flywheel for any cracks or heat checks after resurfacing. Any cracks or heat checks in the flywheel could cause it to separate. If there are any questions, do not reuse the flywheel.

NOTE: Flywheel resurfacing information is provided for guidance only. Navistar, Inc. assumes no responsibility either for the results of any work performed in accordance with this information or for the ability of service personnel to detect cracks.

Flywheel Housing

Flywheel housing bore concentricity	SAE 1 = 0.30 mm (0.012 in) SAE 2 = 0.28 mm (0.011 in)
Flywheel housing face runout	SAE 1 = 0.30 mm (0.012 in) SAE 2 = 0.28 mm (0.011 in)

Crankshaft Pilot

Crankshaft pilot concentricity	0.13 mm (0.005 in)

Flywheel

Flat flywheel surface runout maximum (measure at 17.8 cm (7 in) from center)	0.20 mm (0.008 in)
Pot flywheel surface runout maximum (measure at 16.5 cm (6.5 in) from center)	0.20 mm (0.008 in)
Pot flywheel clutch mounting surface runout maximum	0.30 mm (0.012 in)

Flywheel Resurfacing Specifications

Flat flywheel minimum thickness after resurfacing	36.32 mm (1.430 in)
Pot flywheel minimum thickness after resurfacing	39.37 mm (1.550 in)
NOTE: Requires measurement from crankshaft mounting surface of flywheel to clutch surface of flywheel.	

Special Torque

Flexplate mounting bolts, M12	136 N·m (100 lb·ft)
Flywheel mounting bolts, M12 x 40	136 N·m (100 lb·ft)

Special Service Tools

Dial indicator set	Obtain locally
Guide pins	Obtain locally
H-bar puller	Obtain locally
Loctite® 569 Hydraulic Sealant	Obtain locally
Loctite® 5127	Obtain locally
Rear Seal Installer	ZTSE4637
Slide Hammer Puller Set	ZTSE1879

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Exploded View and Description

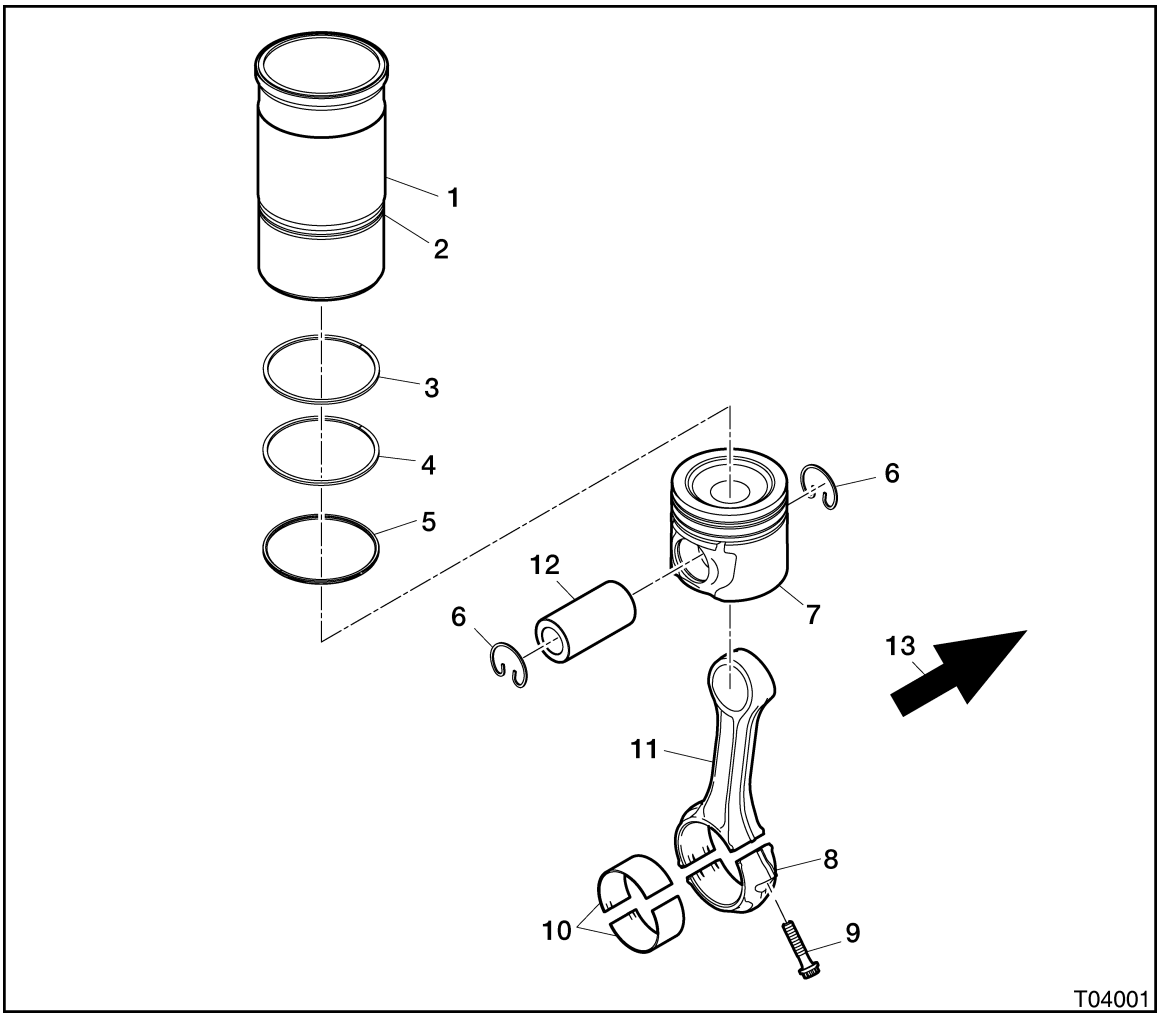


Figure 564 Cylinder, Piston, Rings, and Connecting Rod (typical)

1. Cylinder sleeve
2. Crevice seal ring
3. Top compression piston ring
4. Intermediate compression piston ring
5. Oil control piston ring
6. Piston pin retainer (2)
7. Piston
8. Connecting rod cap
9. Connecting rod bolt (2)
10. Connecting rod bearing (2)
11. Connecting rod
12. Piston pin
13. Front of engine

Six removable cylinder sleeves, each with a single crevice seal ring, are installed in the crankcase.

Pistons are one-piece cast aluminum or one-piece forged steel and use floating piston pins.

Piston cooling tubes spray oil on the bottom of the pistons for cooling and lubrication.

Three rings are installed on each piston to seal the combustion chamber and to control oil on the cylinder walls.

Connecting rods have a fractured surface at the connecting rod cap bolted joint (big end). These are match-mated surfaces and are not interchangeable.

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, allow engine to cool before working with components.

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

CAUTION: To prevent engine damage, do not allow connecting rod or connecting rod cap fractured mating surfaces to contact any surface other then its matched fractured surface. Contacting any other surface could cause misalignment of the mating surface, resulting in connecting rod bearing and engine failure.

NOTE: When performing specific component removal, only remove components necessary for access.

Piston Cooling Tubes

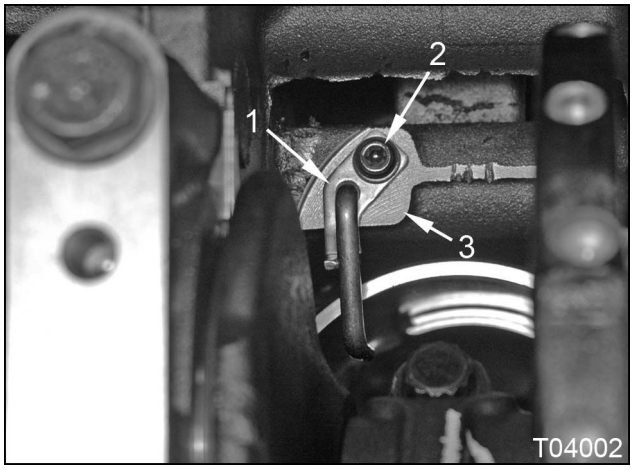


Figure 565 Piston Cooling Tube (typical)

1. Piston cooling tube assembly (6)
2. Piston cooling jet bolt (6)
3. Crankcase piston cooling tube mounting pad (6)

NOTE: The crankshaft may need to be rotated to access some piston cooling tubes.

1. Remove and discard six piston cooling jet bolts, securing the piston cooling tubes to the crankcase.
2. Remove piston cooling tubes and discard sealing rings.

Piston Protrusion Measurement – Preliminary Check

NOTE: Evaluate piston protrusion before removing any piston and connecting rod assemblies. This helps identify bent, twisted, or worn conditions.

1. Install cylinder Sleeve Protrusion Hold Down Clamps (page 466) with 10.9 or higher grade bolts finger tight. See Measuring Cylinder Sleeve Protrusion (page 448) for proper installation procedures.
2. Tighten cylinder sleeve holding adaptor bolts to 55 N·m (40 lb·ft).
3. Tighten cylinder sleeve holding adaptor bolts to 110 N·m (80 lb·ft).

4. Place Cylinder Liner Height Gauge (page 466) on crankcase deck.
5. Place Cylinder Liner Height Gauge indicator tip on crankcase deck and zero dial indicator.
6. Bring piston to be measured to Top Dead Center (TDC).
7. Depress indicator plunger and slide Cylinder Liner Height Gauge to allow indicator tip to rest on piston top flat surface, as close to area above wrist pin as possible.
8. Hold Cylinder Liner Height Gauge and slightly bar engine fore and aft to measure maximum piston protrusion above crankcase deck. Compare to piston protrusion above crankcase top deck Specification (page 463).

Piston and Connecting Rod Assembly

CAUTION: To prevent engine damage, do not allow connecting rod or connecting rod cap fractured mating surfaces to contact any surface other then its matched fractured surface. Contacting any other surface could cause misalignment of the mating surface, resulting in connecting rod bearing and engine failure.

NOTE: If a carbon ridge has developed on the top of the cylinder sleeve, remove the cylinder sleeve and piston as an assembly and then remove the piston from the bottom of the cylinder sleeve.

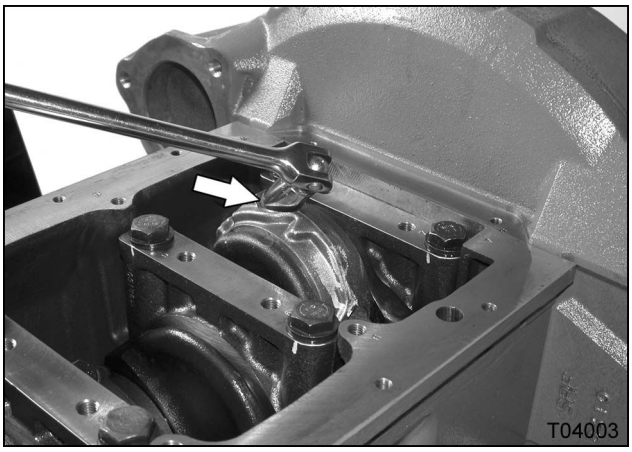


Figure 566 Connecting Rod Bolt Removal

1. Loosen both connecting rod bolts. Leave bolts attached to the connecting rod.
2. Push connecting rod bolts down to separate connecting rod from crankshaft journal.

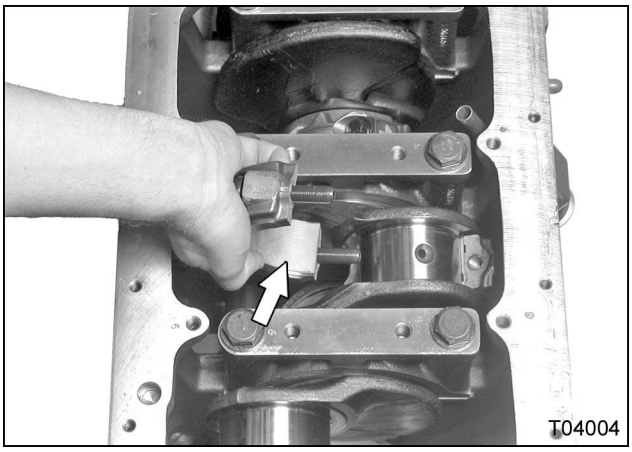


Figure 567 Connecting Rod Cap and Bolts Removal

3. Remove connecting rod cap and bolts.

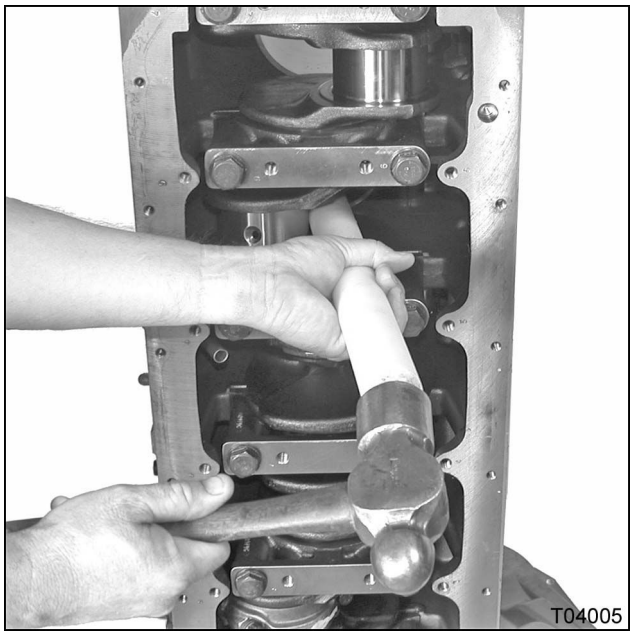


Figure 568 Piston and Connecting Rod Assembly Removal

CAUTION: To prevent engine damage, do not push on the connecting rod fractured surface.

4. Push the piston out of the cylinder sleeve using the butt end of a plastic or wooden hammer handle or a non-marring punch. Do not push on the connecting rod fractured surface.

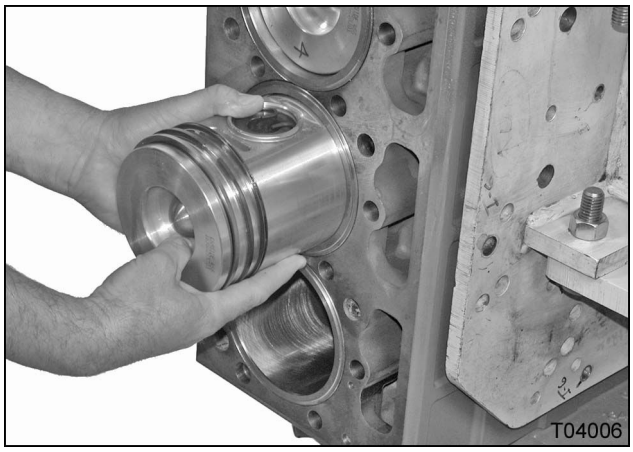


Figure 569 Piston and Connecting Rod Assembly Removal (typical)

5. When the piston rings are free of the cylinder sleeve, remove the assembly from the top of the crankcase.

CAUTION: To prevent engine damage, use permanent marker to identify internal engine components and their orientation. Do not use paint or temporary markers.

6. Mark each piston, connecting rod, and cap with its cylinder number. Also, mark the front of each piston as it was installed in the engine.
7. Install each connecting rod cap on its matched connecting rod and finger tighten connecting rod cap bolts to protect connecting rod fractured surface.

NOTE: Each piston, connecting rod, and cylinder sleeve can be removed together without removing the piston from the cylinder sleeve. Remove the cylinder head and connecting rod cap and then carefully drive the cylinder sleeve straight out using a wood block and a hammer. Be careful not to damage the piston cooling tubes. Maintain the power cylinder package undisturbed while replacing sleeve O-rings.

Piston Pin and Rings

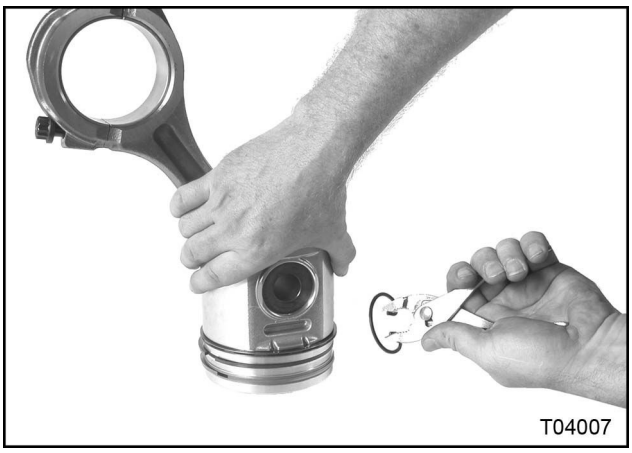


Figure 570 Piston Pin Retaining Ring Removal (typical)

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

1. Use pliers to contract the piston pin retaining rings. Remove two piston pin retaining rings.

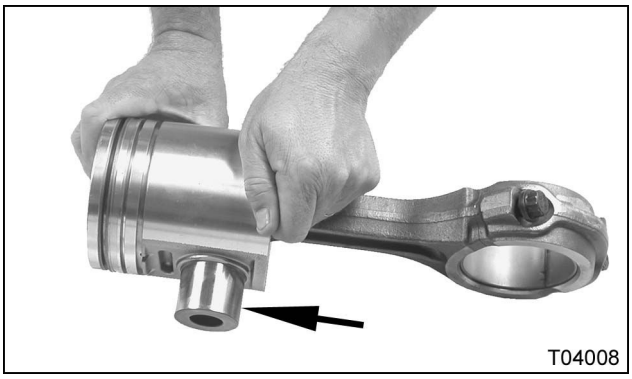


Figure 571 Remove Piston Pin (typical)

2. Push the piston pin out of the piston and connecting rod by hand.

CAUTION: To prevent engine damage, use care to not allow piston pins to contact other pins or other objects. Store individually.

3. Separate the piston from the connecting rod.
4. Mark the front of the piston pin with its cylinder number.



Figure 572 Piston Ring Removal (typical)

5. Use a piston ring expander (page 466) to expand each piston ring and remove rings from the pistons.

Cylinder Sleeve

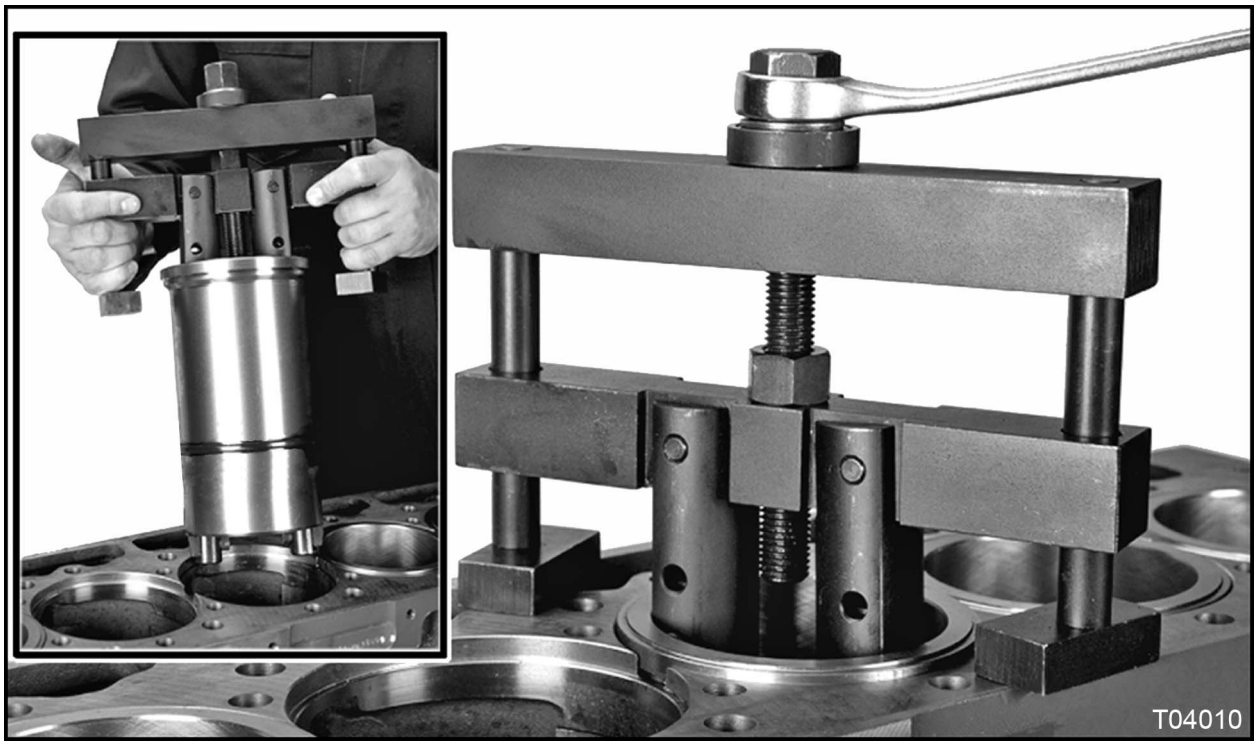


Figure 573 Cylinder Sleeve Removal

CAUTION: To prevent engine damage, before installing the Cylinder Sleeve Puller in each cylinder, rotate the crankshaft so the crankshaft journal is at the bottom (low point) of its travel. This can prevent damage to the journal during puller installation.

CAUTION: To prevent engine damage, be careful not to damage the piston cooling tubes when installing or removing the Cylinder Sleeve Puller.

NOTE: When removing the sleeve from the puller, mark the sleeve with its cylinder number. Also mark the sleeve position in the crankcase for inspection and assembly.

1. If the cylinder sleeve is to be reused, mark the position of the cylinder sleeve on the crankcase deck for reference during installation.
2. Position the Cylinder Sleeve Puller (page 466) in the cylinder sleeve and spread the lifting jaws so the tangs grip the bottom of the sleeve.
3. With the Cylinder Sleeve Puller lifting bridge squarely on the crankcase deck surface, turn the center shaft bolt to pull the cylinder sleeve out of the crankcase.
4. Lift sleeve and puller out of the crankcase.
5. Use a pick to remove the crevice seal ring at the lower counterbore area of each cylinder sleeve. Discard crevice seal ring.

Cleaning, Inspecting, and Measuring

Cleaning and Inspecting

CAUTION: To prevent engine damage, do not use caustic solvent, wire brushes, or media blasting to clean pistons.

1. Soak pistons in a soap and water solution and clean with a non-metallic brush.
2. Scrub piston ring grooves thoroughly. Make sure the oil drain holes in the oil ring grooves are not blocked.
3. Inspect pistons for cracks, excessive wear, and worn ring lands. Replace damaged pistons if required.

CAUTION: To prevent engine damage, do not clean the fractured mating surfaces of connecting rods.

4. Use a suitable solvent and a non-metallic brush to clean the connecting rods and caps, piston rings, pins, and cylinder sleeves.
5. Inspect piston pins for damage, nicks, and excessive wear. Replace piston pins if required.
6. Clean the connecting rod bolt holes and threads. Do not tap the connecting rod bolt holes. Inspect the finished surface of the connecting rod bearing bore for nicks, burrs, and scoring. Replace the connecting rod if required.
7. Inspect cylinder sleeves for excessive wear, scoring, and cracks. Replace damaged cylinder sleeves if required.
8. Clean crankcase crevice seal ring bore area of any scale, deposits, or sealant.

Measuring Pistons

Top Compression Ring Grooves

Piston Ring Gauge Pin Selection

Engine	Ring / Groove Type	Gauge Pin Diameter
MaxxForce® DT	Top / keystone cross section	2.885 mm (0.1136 in)
MaxxForce® 9 and 10	Top / keystone cross section	2.70 mm (0.1063 in)



Figure 574 Measuring Piston Ring Groove (Top / Keystone Cross Section)

1. Install Piston Gauge Pins (page 466) in the top compression ring groove. Make sure the gauge pins are parallel.
2. With pistons at room temperature 20 °C (68 °F), measure the diameter of the piston over the gauge pins using an outside micrometer (page 466).
3. If the top compression ring groove width measurement exceeds Specification (page 463), replace the piston.

Intermediate and Oil Control Ring Groove

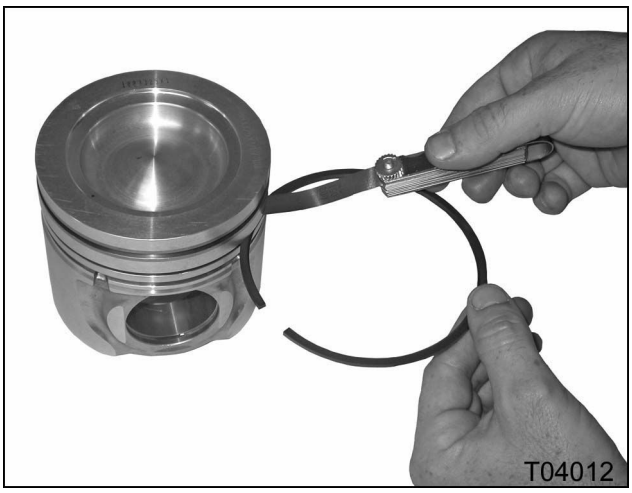


Figure 575 Measuring Ring Groove (typical)

1. Place the edge of a new intermediate compression piston ring in the middle piston ring groove. Roll the intermediate compression piston ring all the way around the piston ring groove to ensure the ring is free in its groove.
2. With the edge of the intermediate compression piston ring in the piston intermediate compression piston ring groove, use a feeler gauge (page 466) to measure clearance between the ring and groove.

   If the intermediate compression ring side clearance exceeds Specification (page 463), replace the piston.
3. Place the edge of a new oil control piston ring in the oil control ring groove. Roll the oil control piston ring all the way around the piston to ensure the ring is free in its groove.
4. With the edge of the oil control piston ring in the piston oil ring groove, use a feeler gauge (page 466) to measure clearance between the ring and groove.

   If the oil control ring side clearance exceeds Specification (page 463), replace the piston.

Piston-to-Cylinder Sleeve Running Clearance



Figure 576 Measuring Piston Skirt Diameter (typical)

1. With pistons at room temperature 20 °C (68 °F), use an outside micrometer (page 466) to measure piston skirt diameter. Place micrometer 90° from the piston pin bore.
   - For MaxxForce® DT aluminum pistons, take skirt diameter measurement 22 mm (0.87 in) from the bottom of the piston skirt.
   - For MaxxForce® 9 and 10 steel pistons, take skirt diameter measurement 12 mm (0.47 in) from the bottom of the piston skirt.
2. Subtract the piston skirt diameter from the inside diameter of the cylinder sleeve. See Measuring Cylinder Sleeves (page 445). The result is the running clearance between the piston and the cylinder sleeve.

   NOTE: Piston to Cylinder Sleeve Running Clearance = Cylinder Sleeve Inside Diameter – Piston Skirt Diameter
3. If piston to cylinder sleeve running clearance is not within Specification (page 463), recheck piston and cylinder sleeve measurements and specifications. Replace the part that is out of specification.

Measuring Piston Rings



Figure 577 Measuring Piston Ring End Gap

NOTE: The top of a piston can be used to push piston ring down in the cylinder sleeve to insure ring is squarely positioned in the sleeve.

1. Install each piston ring into its cylinder bore. Make sure the ring is perpendicular to the cylinder wall. If measuring used rings, install ring just below the top of piston ring travel.
2. Use a feeler gauge (page 466) to measure the end gap between the ends of each piston ring.

   Discard any piston ring that does not meet Specifications (page 464).

NOTE: If replacement of the cylinder sleeve is required, replace the cylinder sleeve and piston rings as a set.

NOTE: If any piston ring is replaced, replace all piston rings and the cylinder sleeve for that cylinder.

Measuring Piston Pins

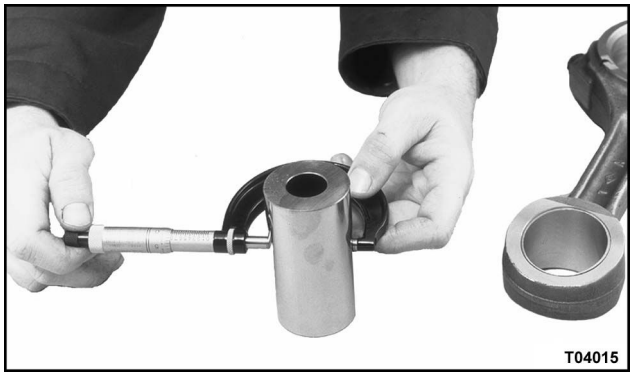


Figure 578 Measuring Piston Pin

1. Use an outside micrometer (page 466) to measure the diameter of the each piston pin at two locations.
2. If the diameter of any piston pin is less than minimum Specification (page 464), replace the piston pin.
3. With pistons at room temperature 20° C (68° F), measure each piston pin bore.
4. Calculate piston pin clearance. Subtract the diameter of the piston pin from the inside diameter of the piston pin bore.

   NOTE: Piston Pin Clearance in Piston = Piston Pin Bore Inside Diameter – Piston Pin Diameter
5. If piston pin clearance in piston exceeds Specification (page 464), replace the piston.

Measuring and Inspecting Connecting Rods

Piston Pin Bushing

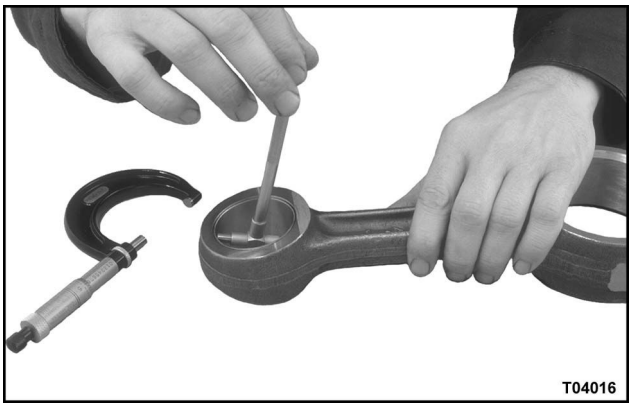


Figure 579 Measuring Piston Pin Bushing

1. Measure the inside diameter of the piston pin bushing at two locations, 90° apart, using a telescoping gauge (page 466).
2. Measure telescoping gauge measurements with an outside micrometer and compare to piston pin bushing inside diameter Specification (page 464).
3. Replace connecting rod if piston pin bushing is out of specification.

Connecting Rod Bolt Holes Inspection

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. Lubricate threads of new connecting rod bolts with clean engine oil. Match serial numbers on the connecting rod and rod cap (on same side of fractured rod).
2. Install the connecting rod cap on the connecting rod, without the connecting rod bearings, and install new connecting rod cap bolts by hand. If you feel resistance, reclean the bolt holes in the connecting rod. If bolts do not turn in freely, replace the connecting rod. The threads in the bolt holes cannot be tapped.

Connecting Rod Bearing Bore (Big End)

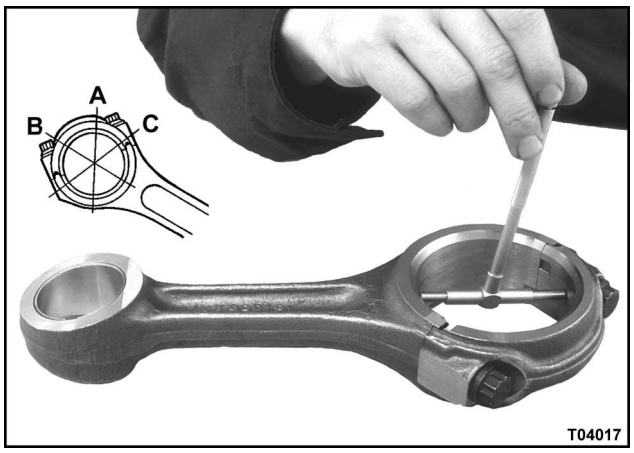


Figure 580 Measuring Connecting Rod Bearing Bore Out-of-Round

NOTE: If performing bearing fit procedure, do not torque-to-yield connecting rod cap bolts. Tighten connecting rod cap bolts to 109 N·m (80 lb·ft).

1. Measure the inside diameter of each connecting rod bearing bore at three locations 60° apart, using an inside micrometer (page 466).

   If the difference between measurement B and the average of measurements A and C exceeds out-of-round Specification (page 463), replace the connecting rod.

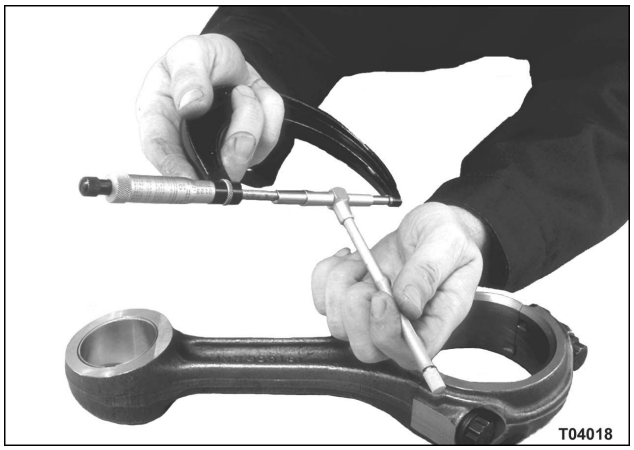


Figure 581 Measuring Connecting Rod Bearing Bore Taper

2. Use a telescoping gauge and an outside micrometer (page 466), measure the inside diameter of the connecting rod bearing bore at the edge of each side of the bore.

   If the difference between the two measurements exceeds bore taper Specification (page 463), replace the connecting rod assembly.

Connecting Rod Bend and Twist

Engine component wear patterns can often be identified and used to diagnose problems. Some common examples of connecting rod wear patterns include:

- A shiny surface on the edge of the piston pin bore usually indicates that a connecting rod is bent or a piston pin hole is not positioned properly in relation to the piston skirt and piston ring grooves.
- Abnormal wear on the connecting rod bearing may indicate that a connecting rod is bent or the bearing bore is excessively tapered.
- A twisted connecting rod will not create an easily identifiable wear pattern, although severely twisted connecting rods will disturb the action of the entire piston and connecting rod assembly and may be the cause of excessive oil consumption.

If any of these conditions exist, use a suitable alignment fixture to check the connecting rod for bends and twists. Follow the instructions of the alignment fixture manufacturer. If bend or twist exceeds Specification (page 463), replace the connecting rod.

Bearing Fitting Procedures

CAUTION: To prevent engine damage, do not attempt to reduce journal-to-bearing running clearance by reworking the connecting rod bearing cap or the bearings. Grind the crankshaft to the next available under size or replace the crankshaft.

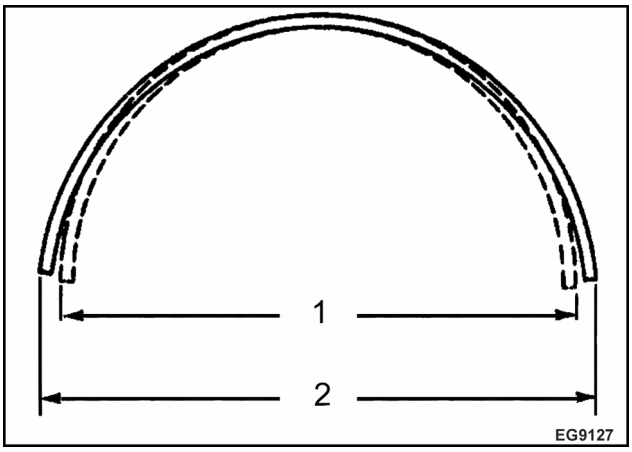


Figure 582 Effects of Bearing Crush

1. Diameter at open ends after bearing crush load
2. Diameter at open ends before bearing crush load

NOTE: Connecting rod bearings must fit tightly in the connecting rod bore. When bearings are inserted in the connecting rod and cap, they protrude slightly above the parting surface. This protrusion is required to achieve bearing crush. Bearing crush forces the ends inward at the parting line when a load is applied by tightening the bolts. Some snap may be lost in normal use, but bearing replacement is not required because of a nominal loss of snap.

When the connecting rod bearing is installed and the connecting rod cap bolts are tightened, the bearing is compressed, ensuring a positive contact between the backside of the bearing and the machined surface of the connecting rod bore.

Measuring Bearing Running Clearance

1. Install new bearings in the connecting rod and cap.

CAUTION: To prevent engine damage, correct mating of connecting rod and cap are required to prevent damage to connecting rod fractured surface.

CAUTION: To prevent engine damage, do not torque-to-yield connecting rod cap bolts while doing this measurement procedure.

CAUTION: To prevent engine damage, when torquing connecting rod bolts use a calibrated torque wrench. Correct torque of connecting rod cap bolts is important.

2. Match serial numbers on the connecting rod and rod cap (on same side of fractured rod) and install the connecting rod and cap on the crankshaft. See Piston and Connecting Rod Assembly (page 458).
3. Remove the connecting rod cap. Wipe the oil from the face of the bearings in the cap and the exposed portion of the crankshaft.
4. Place a piece of undamaged Plastigage across the full width of the connecting rod bearing, about 6 mm (0.25 in) from the center of the connecting rod cap.
5. Install the connecting rod cap and tighten the bolts to 109 N·m (80 lb·ft).

NOTE: Do not turn the crankshaft. This will smear the Plastigage making it unusable.

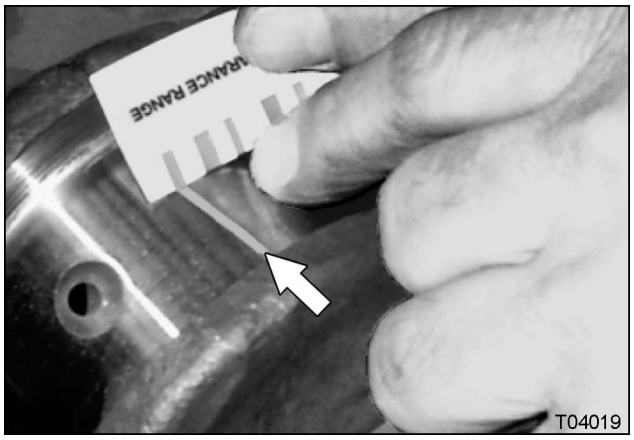


Figure 583 Measuring with Plastigage

6. Remove the connecting rod cap. The Plastigage material will adhere to either the connecting rod bearing or the crankshaft. Do not remove the Plastigage.
7. Use the Plastigage paper scale to measure the widest point of the flattened material. The numbers in the graduated marks on the wrapper scale indicate the running clearance in thousandths of an inch or millimeters.
8. Compare Plastigage measurements with connecting rod bearing running clearance Specification (page 463).

NOTE: If running clearance is not within specifications, grinding the crankshaft and using undersized bearings may be necessary. Re-measure running clearance before condemning the crankshaft.

9. Remove the Plastigage material. Repeat the test for each connecting rod bearing.

Measuring Connecting Rod Side Clearance

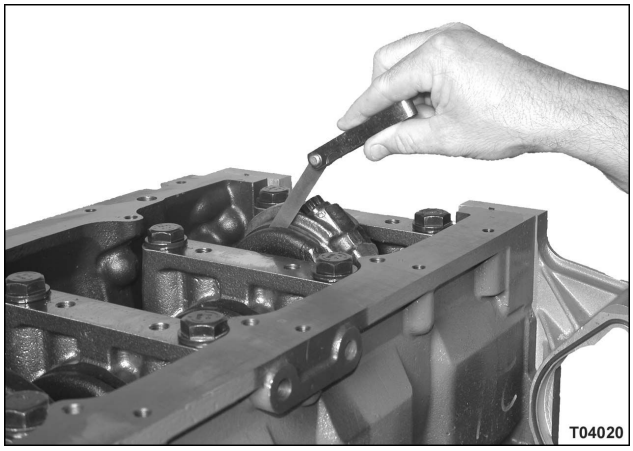


Figure 584 Measuring Connecting Rod Side Clearance

1. Insert a feeler gauge (page 466) between the connecting rod and crankshaft journal.
2. If the connecting rod side clearance is not in Specification (page 463), replace the connecting rod.

NOTE: If there is too little side clearance, the connecting rod may be damaged or the bearing may be out of position. If there is too much clearance, the connecting rod or crankshaft may be damaged.

Measuring Cylinder Sleeves

NOTE: If replacement of the cylinder sleeve is required, replace the cylinder sleeve and piston rings as a set.

Measure cylinder sleeve wear (taper), using one of the following methods:

Telescoping Gauge Method

1. Measure the inside diameter of each cylinder sleeve at two locations 90° apart just below the top of piston ring travel and again just above the bottom area of piston ring travel using a telescoping gauge (page 466) and an outside micrometer (page 466).

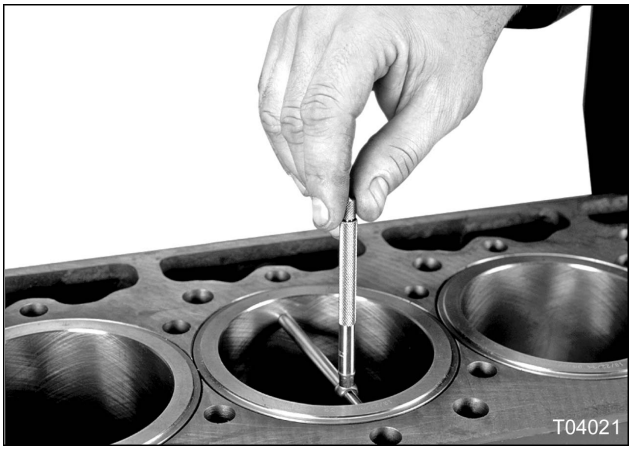


Figure 585 Measuring Cylinder Sleeve Taper

2. Install telescoping gauge plungers perpendicular to the cylinder sleeve center line. Unlock and fit plungers to the cylinder sleeve. Lock and then rotate gauge out of cylinder sleeve.



Figure 586 Measuring Telescoping Gauge

3. Measure the telescoping gauge with an outside micrometer (page 466).
4. Calculate cylinder sleeve taper by subtracting the average of the lower reading from the average of the higher reading.
5. If cylinder sleeve taper exceeds Specification (page 465), replace the cylinder sleeve and piston rings.
6. Repeat steps 1 through 5 for all six cylinder sleeves.

Dial Bore Gauge Method



Figure 587 Measuring Cylinder Sleeve Taper

1. Measure the inside diameter of each cylinder sleeve at two locations 90° apart just below the top of piston ring travel and again just above the bottom area of piston ring travel using a cylinder bore gauge (page 466).
2. Calculate cylinder sleeve taper by subtracting the average of the lower reading from the average of the higher reading.
3. If cylinder sleeve taper exceeds Specification (page 465), replace the cylinder sleeve and piston rings.

Feeler Gauge Method



Figure 588 Measuring Cylinder Sleeve Piston Ring End Gap

1. Install the top compression ring squarely into its cylinder bore just below the top of piston ring travel. Make sure the ring is perpendicular to the cylinder wall.
2. Use a feeler gauge (page 466) to measure the ring end gap.
3. Move the top compression ring squarely on the bottom of the piston ring travel area.
4. Measure piston ring end gap using a feeler gauge.

NOTE: Every increase of 0.07 mm (0.003 in) between the measurements equals a 0.0223 mm (0.0009 in) increase in cylinder sleeve inside diameter.

5. If the cylinder sleeve is worn beyond Specification (page 465), replace the cylinder sleeve and piston rings.

Measuring Counterbore Depth

NOTE: Remove any existing shims and clean counterbore surface before measuring counterbore depth. Inspect each crankcase counterbore for cracks.

Use one of the following methods to measure depth of each crankcase counterbore:

Cylinder Liner Height Gauge Method

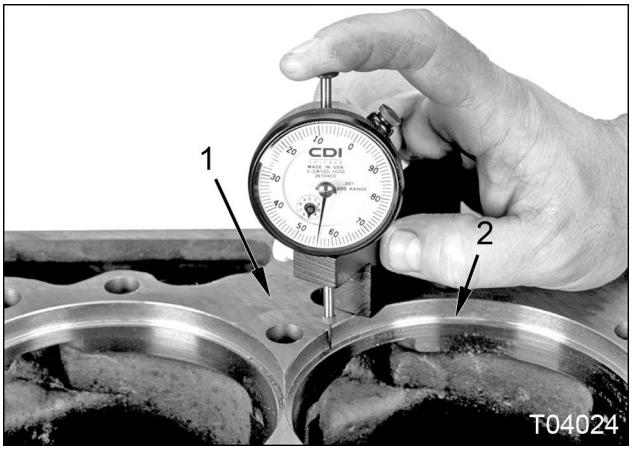


Figure 589 Measuring Counterbore Depth

1. Crankcase deck surface
2. Counterbore ledge

1. Place the indicator tip of a Cylinder Liner Height Gauge (page 466) on the crankcase deck surface and zero the dial indicator.
2. Move the gauge indicator tip to the counterbore ledge and measure the counterbore depth.
3. Measure counterbore depth at four evenly spaced locations around each counterbore ledge.
4. If the maximum variation between the four measurements exceeds Specification (page 465), resurface the counterbore.

Depth Micrometer Method



Figure 590 Measuring Counterbore Depth

1. Place a depth micrometer (page 466) on the crankcase deck surface and measure the distance to the counterbore ledge (counterbore depth).
2. Measure counterbore depth at four evenly spaced locations around the counterbore ledge.
3. If the maximum variation between the four measurements exceeds Specification (page 465), resurface the counterbore.

Measuring Cylinder Sleeve Protrusion

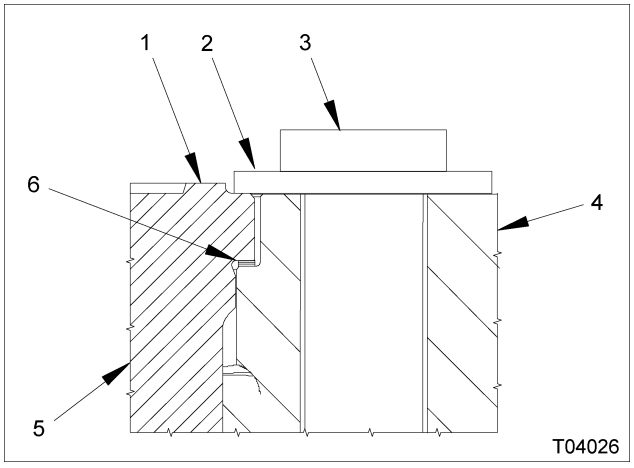


Figure 591 Cylinder Sleeve Clamping (Cut-Away)

1. Cylinder sleeve fire dam (highest point on cylinder sleeve)
2. Cylinder Sleeve Protrusion Hold Down Clamp
3. Cylinder sleeve holding adapter bolt
4. Crankcase
5. Cylinder sleeve
6. Shim pack (if required)

CAUTION: To prevent engine damage, do not apply holding adapters to the "fire dam" ridge of the cylinder sleeve. Clamping forces should not be applied to this ridge as internal cracking could develop adjacent to the shim land.

1. Clean the cylinder sleeve, cylinder sleeve crevice bore, and crankcase counterbore surfaces.
2. Install the cylinder sleeve with proper orientation in the proper cylinder bore without the crevice seal ring.

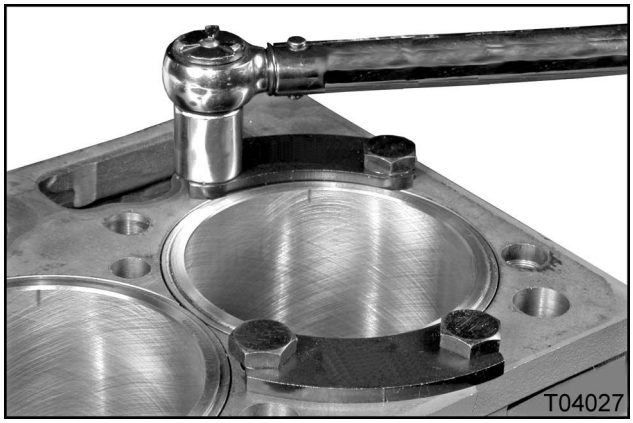


Figure 592 Installing Sleeve Protrusion Hold Down Clamps

3. Install Cylinder Sleeve Protrusion Hold Down Clamps (page 466) with 10.9 or higher grade bolts and finger tighten. Locate clamps on the cylinder sleeve flange as indicated in (Figure 591) and (Figure 592).

CAUTION: To prevent engine damage, do not torque-to-yield hold down clamp bolts.

4. Tighten supplied hold down clamp bolts to 55 N·m (40 lb·ft).
5. Tighten supplied hold down clamp bolts to 110 N·m (80 lb·ft).

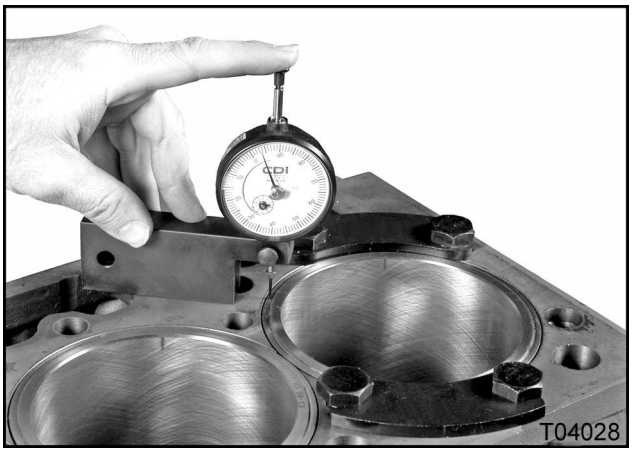


Figure 593 Measuring Cylinder Sleeve Protrusion

6. Place the indicator tip of a Cylinder Liner Height Gauge (page 466) on the cylinder sleeve flange and zero the dial indicator.
7. Move the Cylinder Liner Height Gauge until the indicator tip slides off the flange to the surface of the crankcase.

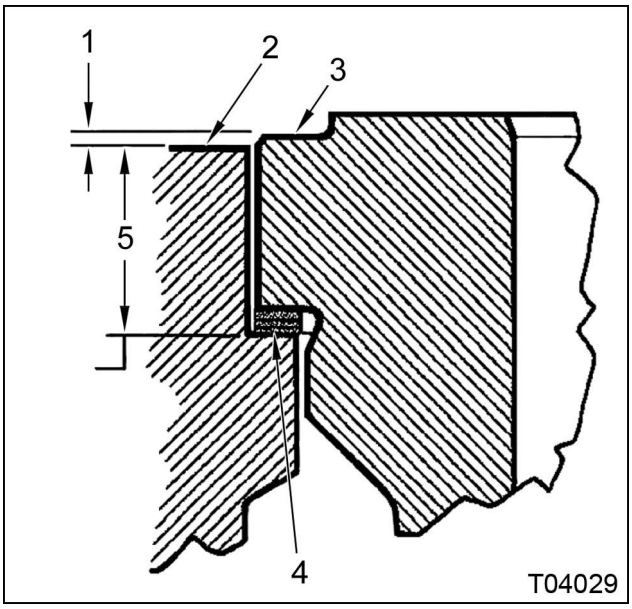


Figure 594 Cylinder Sleeve Protrusion (Cut-Away)

1. Cylinder sleeve protrusion
2. Top surface of crankcase
3. Cylinder sleeve flange
4. Shim
5. Counterbore depth

8. Measure cylinder sleeve protrusion at four locations evenly spaced around the cylinder sleeve. Average the four readings to determine cylinder sleeve protrusion.

   If cylinder sleeve protrusion does not meet Specification (page 465), determine shim thickness necessary to meet the cylinder sleeve protrusion specification.
9. Remove the cylinder sleeve and install the necessary cylinder sleeve shims.
10. Repeat steps 2 through 8 for all six cylinders.
11. If the difference in cylinder sleeve protrusion between all six sleeves is greater than 0.03 mm (0.001 in), remove the highest cylinder sleeve and install the correct shim or resurface counterbore. Measure cylinder sleeve protrusion again.

Reconditioning

Resurfacing Counterbore

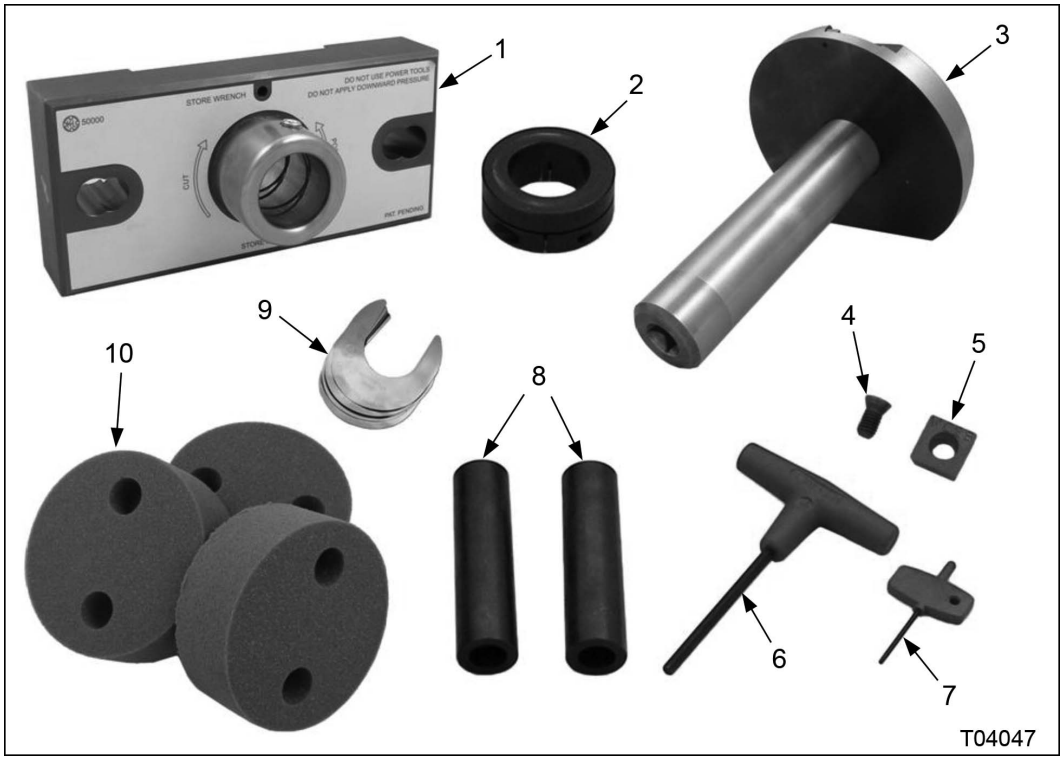


Figure 595 Counterbore Reconditioning Tool Kit

1. Base assembly
2. Stop collar
3. Cutter head assembly
4. Carbide cutting screw (spare)
5. Carbide cutting insert (spare)
6. T-handle allen wrench
7. Torx® wrench
8. Bolt spacers (2)
9. Shims (4)
10. Cutter foam plugs (3)

To ensure optimal counterbore ledge machining results, obtain a Counterbore Reconditioning Tool Kit (page 466) and do the following:

- Inspect all counterbore ledges and always machine worst condition ledge first and follow in succession.
- Inspect cutter head integrity prior to setting tool assembly. Ensure tool is free of sharp edges, grooves, and burrs.
- Ensure final setting remains intact for all remaining counterbore ledges after final cutting depth is established.

Preparation

1. Remove cylinder head, connecting rods, pistons, and all cylinder liners for counterbore ledges requiring machining.
2. Block all exposed oil gallery holes to prevent debris from entering lubrication system.
3. Clean crankcase deck surface and ensure surface is free of gasket material. Inspect surface for nicks or burrs to ensure proper seating of tool assembly. Repair as required.

Mounting the Counterbore Reconditioning Tool

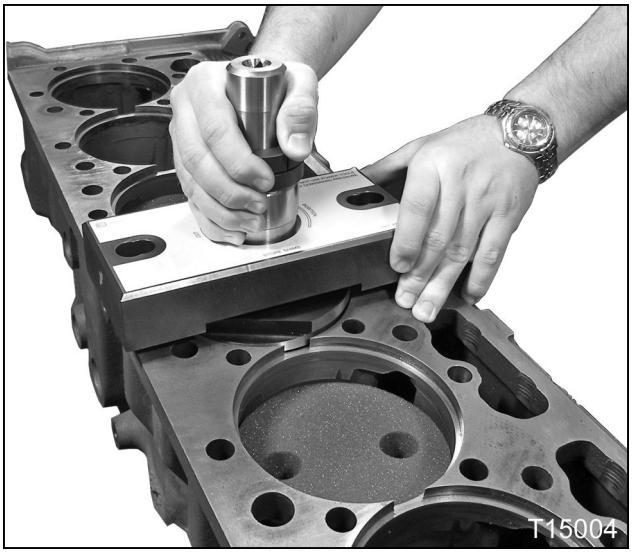


Figure 596 Mounting Counterbore Cutting Tool

1. Insert foam plugs 1/2” deep into cylinder housing to be machined and adjacent cylinder housings. This prevents debris from entering the engine.
2. Mount the counterbore cutting tool to the crankcase for cylinder bore to be machined. The tool must not bind.

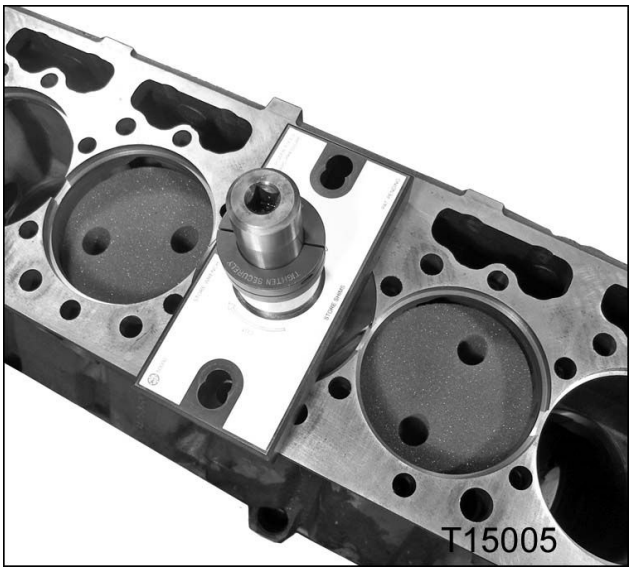


Figure 597 Aligning Counterbore Tool

3. Align the holes of the base assembly to the crankcase mounting hole.

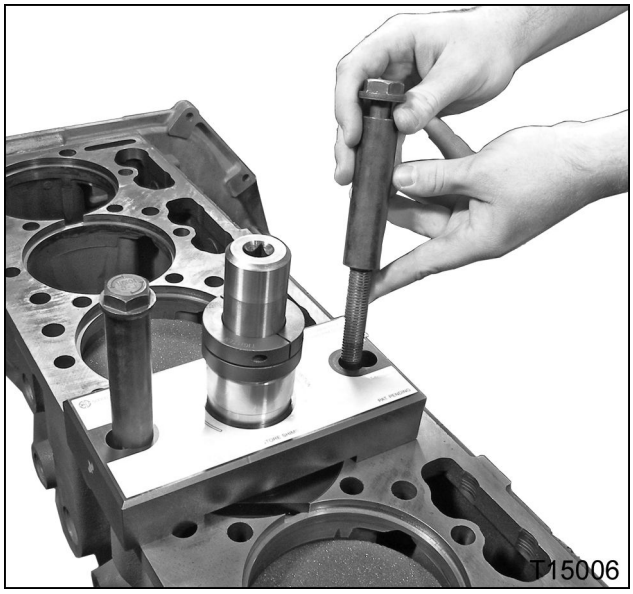


Figure 598 Inserting Bolt Spacers and Head Bolts

4. Place one bolt spacer onto each of the two head bolts. Insert head bolts through the base assembly and into the crankcase. Finger tighten both bolts.

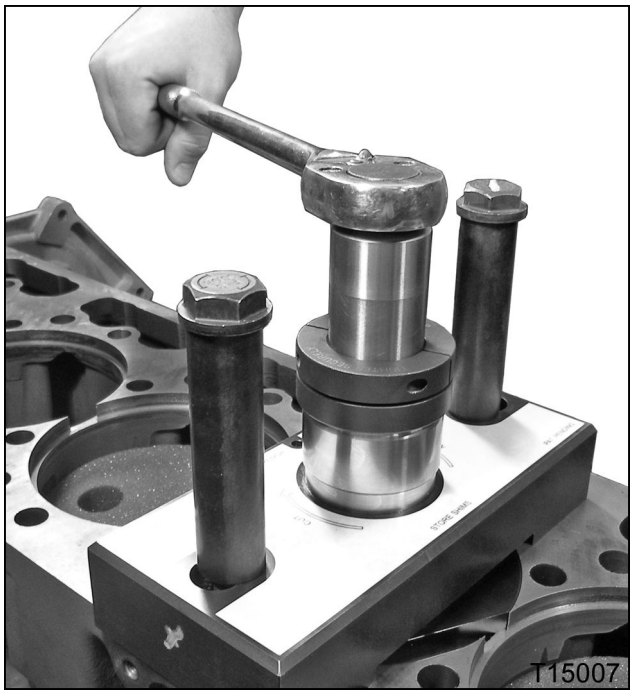


Figure 599 Centering Cutter Head

5. Turn the cutter head assembly 1 to 2 revolutions counter clockwise to center the cutter head. A “position” arrow is located on the base assembly for directional reference.
6. Tighten two cylinder head bolts to 40 N·m (30 lb·ft).

Tool Settings

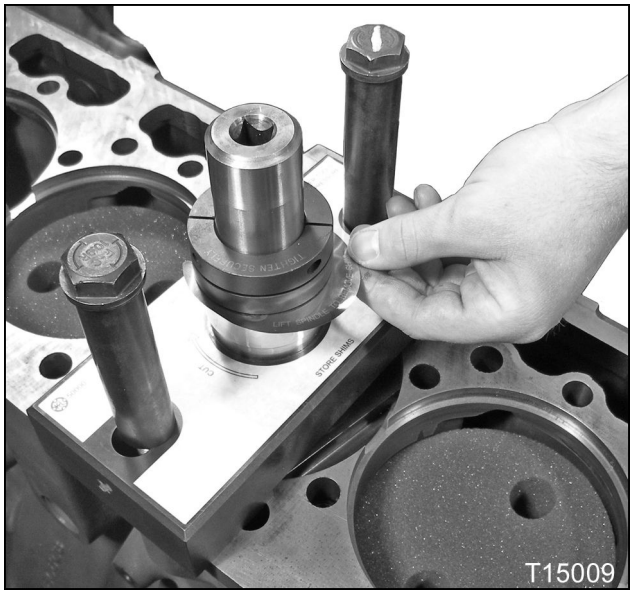


Figure 600 Installing Shims

NOTE: See Cylinder Sleeve Specifications (page 465) for allowable counterbore depths.

1. Determine required depth of cut. Select shims to achieve desired cut depth. Install shims under the stop collar.



Figure 601 Locking the Stop Collar

NOTE: The crankcase counterbore ledge can be inspected past the flat on the edge of the cutter head while cutting. If the desired cut is not obtained after performing cut, the depth of the cut can be reset and adjusted with shims to achieve desired cut. To maintain uniformity, ensure the final setting remains intact for all remaining cylinder bore ledges.

2. Apply hand pressure downward on the stop collar on top of the shim. Lock the collar securely. Remove the shim before proceeding. Lift the spring loaded cutter head assembly to remove the shim.

Cutting Counterbore Ledge

NOTE: Prior to cutting, pay close attention to the following notes:

- **Do not use power tools for cutting procedure. Cutting tool is designed for hand tools only.**
- **Always machine worst condition ledge first and follow in succession.**
- **Do not apply downward pressure while rotating the cutting tool. Spring plungers in the base assembly will apply pressure required by the cutting tool.**
- **Clean the cutting tool thoroughly after every cut. Remove chips and dust from deck surface. Debris can cause binding, inconsistent cuts, and tool damage.**

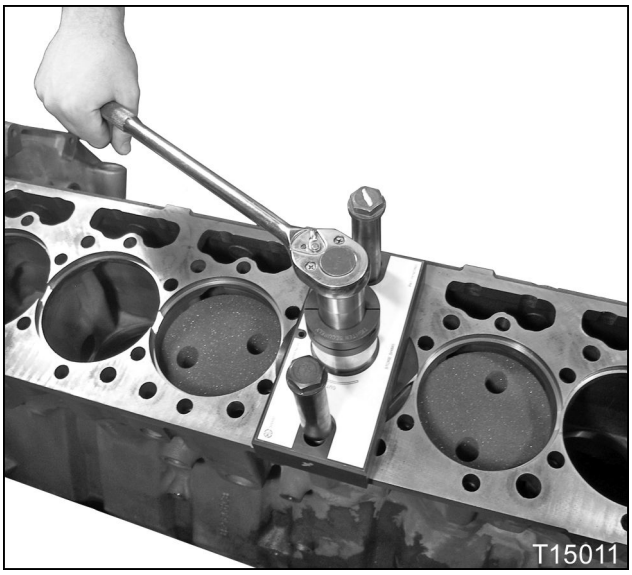


Figure 602 Cutting the Counterbore

1. After the counterbore cutting tool is positioned and secured, rotate the cutter clockwise. A “cut” arrow is located on the base assembly for directional reference. Continue clockwise rotation until the cutter turns freely.
2. Remove the counterbore cutting tool. Repeat tool installation and cutting procedure for remaining crankcase counterbore ledges. Ensure that the depth setting remains intact for all remaining cuts.

Tool Care and Maintenance

After counterbore ledge machining is finished, do the following procedures to maintain tool integrity.

1. Remove all debris and dust from the tool assembly.



Figure 603 Spindle Lubrication Access Screw

2. Lubricate base assembly spindle with light machine oil after each use. To lubricate spindle, remove access screw located on bushing.

Installation

Cylinder Sleeve

CAUTION: To prevent engine damage, if any piston ring or cylinder sleeve is replaced, replace that cylinder sleeve and piston rings as a set.

NOTE: If required, install appropriate shim(s) in each crankcase counterbore based on counterbore depth measurements (page 447).

1. If required, install shim(s) in each crankcase counterbore to bring cylinder sleeve protrusion within Specification (page 465).

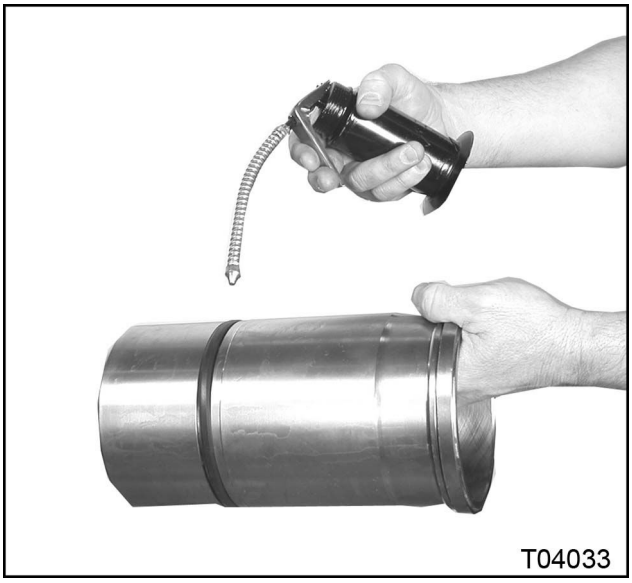


Figure 604 Cylinder Sleeve and Crevice Seal Ring

NOTE: Each cylinder sleeve has one crevice seal ring.

2. A new cylinder sleeve will come kitted with a new crevice seal ring. If reinstalling a used cylinder sleeve, a new crevice seal ring must be used. In this case, lightly lubricate the new crevice seal ring with clean engine oil and install in cylinder sleeve groove.
3. Apply clean engine oil to the lower crankcase counterbore and crevice seal ring bore.

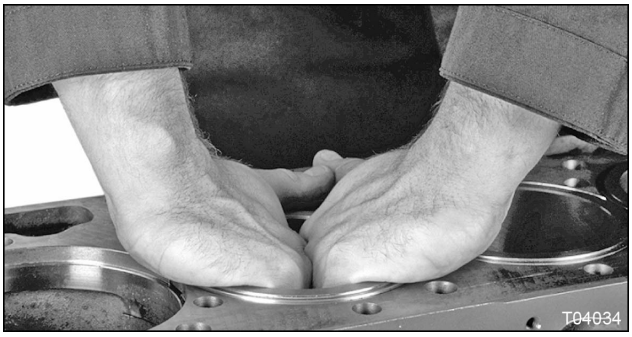


Figure 605 Cylinder Sleeve Installation

4. Carefully install each cylinder sleeve in its crankcase counterbore. If a new cylinder sleeve is installed, it can be installed without regard to orientation. If cylinder sleeves are re-used, however, each sleeve should be installed back into its original counterbore (cylinder number) and clocked so that camside or front-of-engine mark is in the same engine orientation as prior to removal.
5. After installation, measure cylinder sleeve protrusion (page 448).
6. Measure cylinder sleeve protrusion at four locations evenly spaced around each cylinder sleeve. If the difference of the four measurements for any one cylinder is greater than (0.001 in), check for an improperly aligned crevice seal ring and re-measure protrusion.

   Average the four measurements and check cylinder sleeve protrusion Specification (page 465). If required, determine shim thickness necessary to meet the cylinder sleeve protrusion specification.

Piston Rings

CAUTION: To prevent engine damage, if any piston ring or cylinder sleeve is replaced, replace that cylinder sleeve and piston rings as a set.

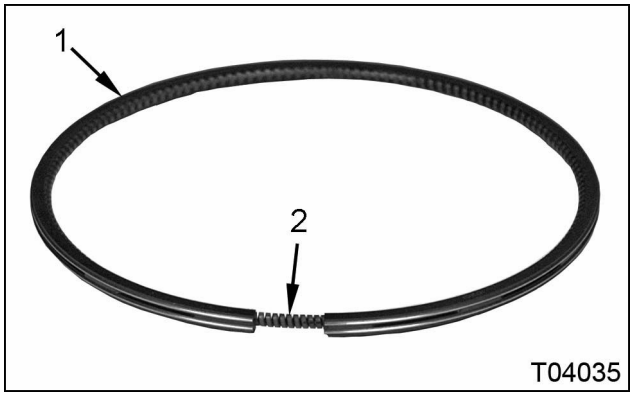


Figure 606 Oil Control Piston Ring

1. Oil control ring
2. Ring expander coil, paint stripe

NOTE: The orange paint stripe on the ring expander coil must align and show through the oil ring gap.



Figure 607 Installing Piston Rings (typical)

NOTE: Make sure the top side of both compression rings (marked with a dot) are facing up. The oil control piston ring may be installed with either side facing up, if new.

1. Install rings on each piston using a piston ring expander (page 466). Expand the oil control piston ring enough to fit it over the piston crown and install in the lower ring groove of the piston.
2. Expand the intermediate compression piston ring and install in the middle piston ring groove.
3. Expand the top compression piston ring and install in the top piston ring groove.

Piston Pin

NOTE: New pistons may not have orientation markings.

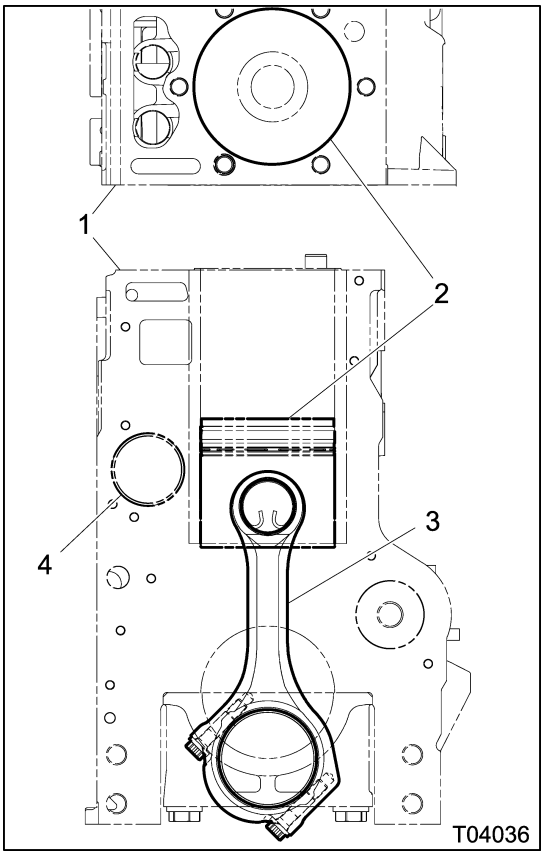


Figure 608 Orienting Piston and Connecting Rod

1. Crankcase
2. Piston
3. Connecting rod
4. Camshaft bore



Figure 609 Installing Piston Pin (typical)

1. Lubricate each piston pin and piston pin bore with clean engine oil.
2. Align the bores in the connecting rod and piston and install the piston pin.



Figure 610 Installing Piston Pin Retaining Ring (typical)

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

3. Contract piston retaining ring using pliers and install one piston pin retaining ring in each end of the piston pin bore.

Piston and Connecting Rod Assembly

CAUTION: To prevent engine damage, do not allow the connecting rod or connecting rod cap fractured mating surfaces to contact any surface other then its matched fractured surface. Contacting any other surface will cause misalignment of the mating surface, resulting in connecting rod bearing and engine failure.

NOTE: Turn crankshaft so connecting rod journals 1 and 6 are at Bottom Dead Center (BDC). Install piston and connecting rod assemblies 1 and 6 first. Then repeat the procedure for piston and connecting rod assemblies 2 and 5. Finish with piston and connecting rod assemblies 3 and 4.

1. Install connecting rod bearings into connecting rods and connecting rod caps dry (without oil), being sure to fit bearing tabs into slots and placing the ends of the bearings flush to rod and cap joint lines.
2. Lubricate bearing surface of bearing in connecting rod with clean engine oil.
3. Lubricate piston rings and inside diameter of the cylinder sleeve with clean engine oil. Stagger piston ring gaps approximately 120° from each other.

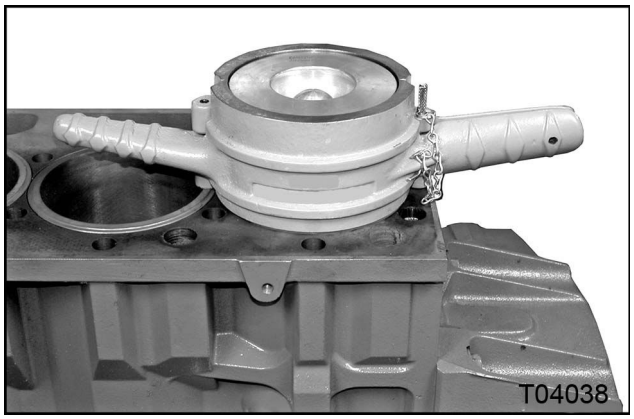


Figure 611 Piston Ring Compressor Tool

4. Install a Piston Ring Compressor Tool (page 466) over the piston rings and compress the rings down into the piston grooves, such that the rings will fit into the cylinder sleeve. Be sure the rings remain in their respective grooves during this procedure.
5. Re-confirm that the rod is properly assembled to the piston: when installed, the piston will have proper orientation and the connecting rod's "open side" will face the CAM SIDE of the engine, when viewed from above. If the piston has a CAM SIDE mark or a front-of-engine arrow, these marks should be properly aligned with engine orientation. Confirm that if a used piston is installed, it is going back into its previous cylinder sleeve with the same orientation it had prior to removal.
6. Carefully install the piston and connecting rod assembly into the cylinder sleeve.

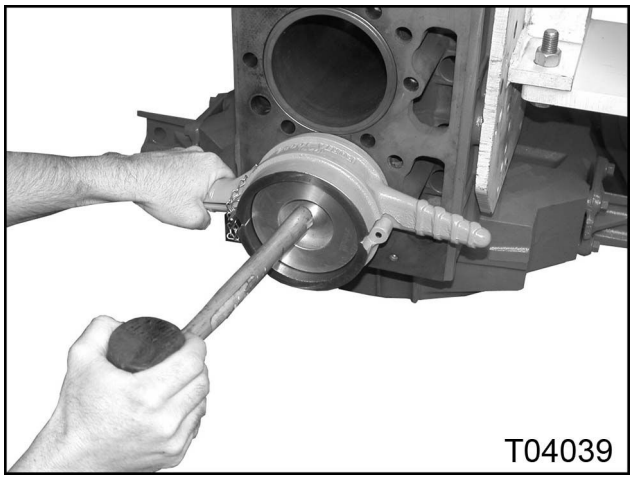


Figure 612 Installing Piston and Connecting Rod Assembly

7. Push the piston and connecting rod assembly into the cylinder sleeve using a wooden or plastic handle. Carefully guide the connecting rod over the crankshaft connecting rod journal. Do not touch the crankshaft journal with the fractured mating surface of the connecting rod.

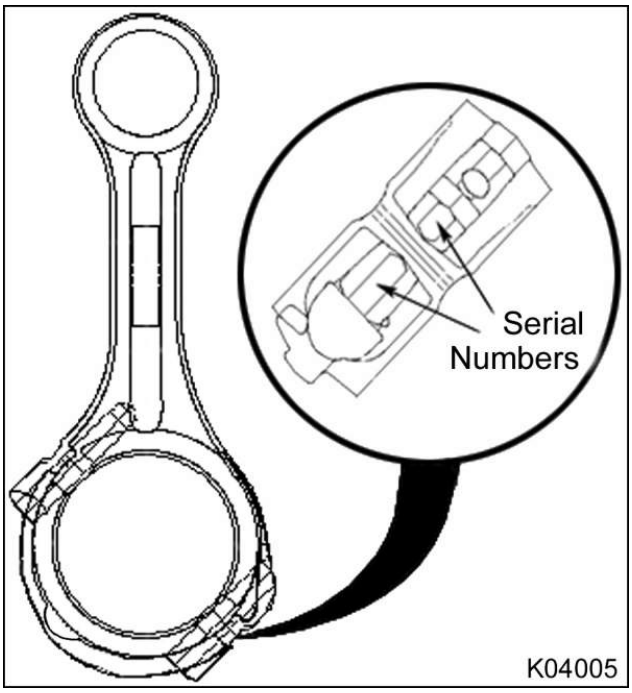


Figure 613 Connecting Rod and Cap Serial Number Locations

CAUTION: To prevent engine damage, each connecting rod cap serial number must be assembled on the same side as its connecting rod serial number (they must match). If the rod cap is reversed when assembled on the connecting rod, or a rod cap is not installed on its original matching connecting rod, the fractured mating surfaces will be ruined. The entire connecting rod assembly must then be replaced.

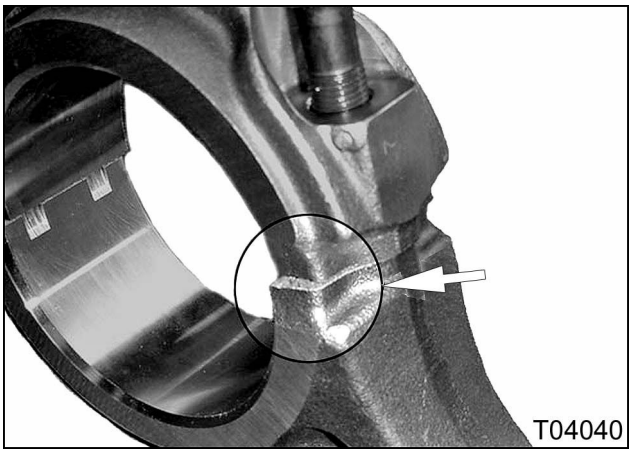


Figure 614 Incorrect Connecting Rod Cap Orientation

NOTE: If the connecting rod cap is reversed during assembly, an obvious offset will be seen at the rod mating surfaces. If the connecting rod cap is installed in the reverse orientation, the connecting rod must be replaced. Also, check the crankshaft journal for damage.

NOTE: Each connecting rod cap mark must point toward the front of the engine.

8. Lubricate the connecting rod bearing inside diameter with clean engine oil.

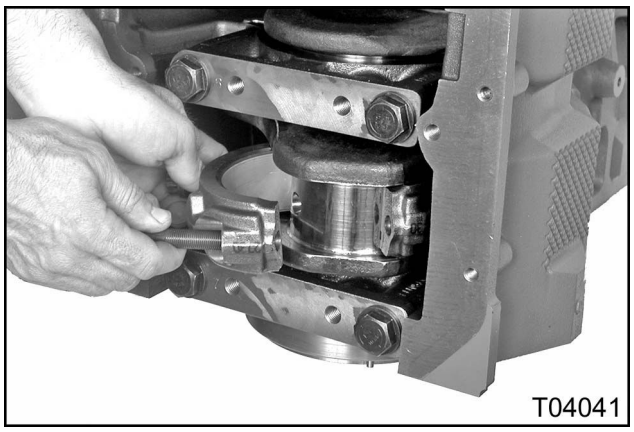


Figure 615 Installing Connecting Rod Cap

9. Carefully install connecting rod cap and two new rod bolts over the crankshaft journal and finger tighten rod bolts into connecting rod.

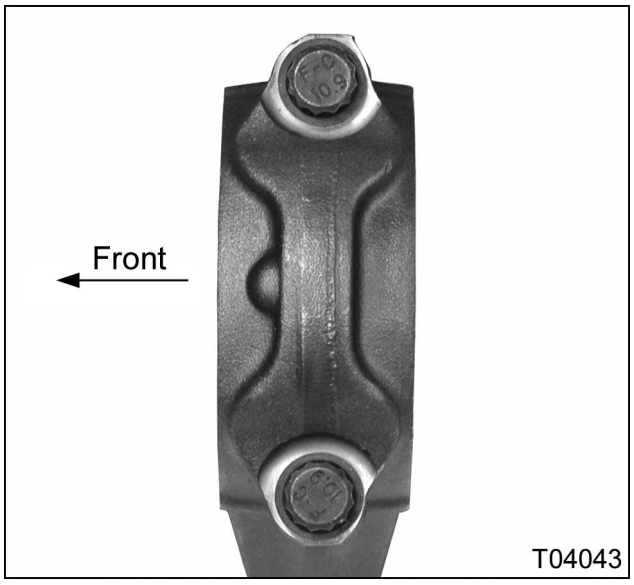


Figure 616 Connecting Rod with M11 Bolts (Mark Pointing to Front of Engine)

10. Verify all connecting rods are properly installed with mark pointing towards front of engine.

Torque-to-yield Procedure for Connecting Rods

NOTE: If performing bearing fit procedure, do not torque-to-yield connecting rod cap bolts. Tighten connecting rod cap bolts to 109 N·m (80 lb·ft).

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. Tighten two new M11 connecting rod bolts to 41 N·m (30 lb·ft).

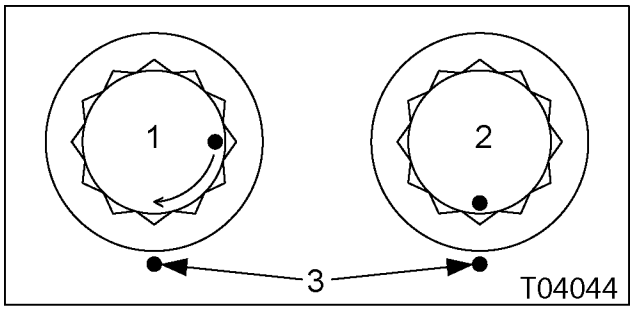


Figure 617 M11 Connecting Rod Bolt Torque-to-Yield Markings

1. Connecting rod bolt with permanent marker spot (before torque-to-yield)
2. Connecting rod bolt with permanent marker spot (after torque-to-yield)
3. Permanent marker spot on connecting rod cap

CAUTION: To prevent engine damage, use permanent marker to identify internal engine components and their orientation. Do not use paint or temporary markers.

2. Using a permanent marker, place a mark on each connecting rod bolt and put another mark on a 15 mm 12 point socket (page 466) directly in line with the mark on each rod bolt.
3. Put a mark on the connecting rod cap surface 90° clockwise from each rod bolt mark.
4. Install the socket on the rod bolt to be torqued and align mark on socket with the mark on the rod bolt.
5. Torque-to-yield each M11 rod bolt by rotating bolt exactly 90° clockwise (1/4 turn). The marks on the socket, rod bolt, and connecting rod cap surface should be aligned when finished.

Piston Cooling Tubes

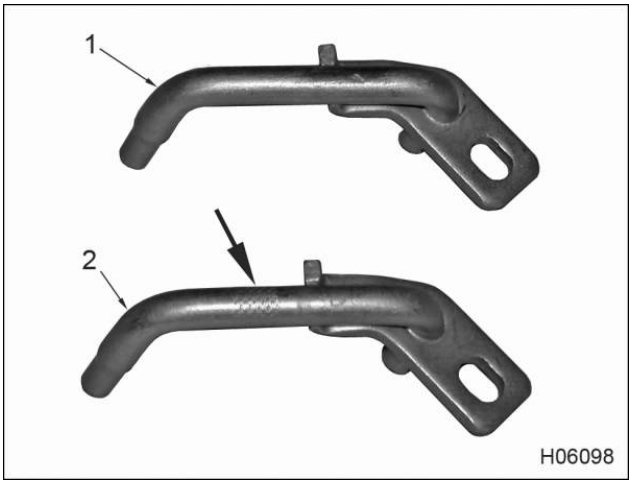


Figure 618 Piston Cooling Tube Assemblies

1. Piston cooling tube (unknurled) – MaxxForce® DT engines
2. Piston cooling tube (knurled) – MaxxForce® 9 and 10 engines

CAUTION: To prevent engine damage, correct piston cooling tube assemblies must be installed. Unknurled piston cooling tube assemblies are required for MaxxForce® DT engines: A painted green stripe designates Model Years 2007-2009. A painted blue stripe designates Model Year 2010 and up. Knurled piston cooling tube assemblies, without a painted stripe, are required for MaxxForce® 9 and 10 engines.

NOTE: The crankshaft may need to be rotated to install some piston cooling tubes.

NOTE: Piston cooling tubes are self aligning. Do not bend.

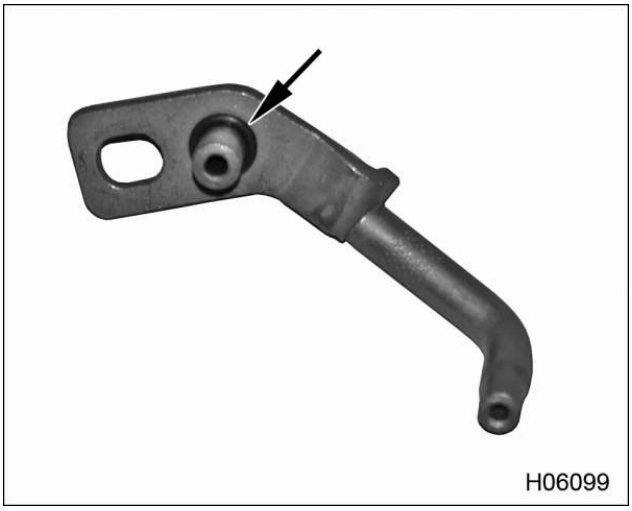


Figure 619 O-ring on Underside of Piston Cooling Tube

1. Install a new O-ring onto piston cooling tubes.

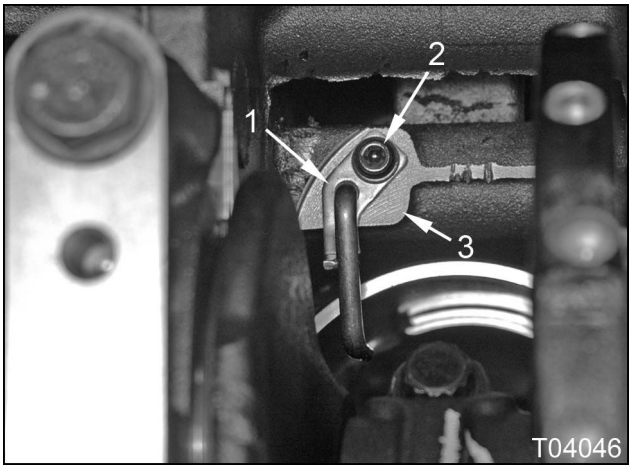


Figure 620 Piston Cooling Tube

1. Piston cooling tube assembly (6)
2. M6 x 12 piston cooling jet bolt (6)
3. Crankcase mounting pad for piston cooling tube (6)

CAUTION: To prevent engine damage, piston cooling tubes use a special mounting bolt. Do not substitute.

2. Install six piston cooling tube assemblies and six new M6 x 12 piston cooling jet bolts into the crankcase mounting pads.
3. Tighten new M6 x 12 piston cooling jet bolts to special torque (page 465).

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.

If new pistons, piston rings, or cylinder sleeves have been installed, use the following engine run-in procedure:

1. Start engine and run at low idle with no load for 5 minutes. Check for leaks in the cooling, oil, fuel, and air induction systems.
2. Check the turbocharger for all of the following conditions:
   - Unusual noise
   - Oil leaks
   - Air leaks
   - Excessive exhaust smoke
   - Excessive vibration
   - Loose mounting
3. Turn engine off and correct any of these problems to prevent engine or turbocharger damage.
4. Start engine and drive vehicle (unloaded) for 25 minutes in city mode, then drive vehicle (unloaded) for an additional 15 minutes in highway mode.
5. Return to idle and check for leaks.

Specifications

Connecting Rod Specifications

Bend (maximum)	0.051 mm (0.002 in)
Center-to-center distance between connecting rod bearing bore and piston pin bushing bore	
MaxxForce® DT	239.600 to 239.702 mm (9.433 to 9.437 in)
MaxxForce® 9 and 10	219.4 to 219.5 mm (8.638 to 8.642 in)
Connecting rod bearing bore inside diameter	85.130 to 85.156 mm (3.3516 to 3.3526 in)
Connecting rod bearing inside diameter (installed)	80.05 to 80.10 mm (3.1518 to 3.1536 in)
Connecting rod bearing bore out-of-round (maximum)	0.02 mm (0.00078 in)
Connecting rod bearing bore taper (maximum)	0.02 mm (0.00078 in)
Connecting rod bearing running clearance	0.030 to 0.107 mm (0.0012 to 0.0042 in)
Connecting rod to crankshaft side clearance	0.190 to 0.419 mm (0.0075 to 0.0165 in)
Twist (maximum)	0.051 mm (0.002 in)
Piston pin bushing inside diameter	
MaxxForce® DT	48.039 to 48.047 mm (1.8913 to 1.892 in)
MaxxForce® 9 and 10	46.393 to 46.401 mm (1.8265 to 1.8268 in)

Piston Specifications – MaxxForce® DT

Piston	One-piece aluminum
Piston rings	Top ring - keystone cross section
	Intermediate - rectangular cross section
Running clearance between piston and cylinder sleeve	0.088 to 0.132 mm (0.00335 to 0.00524 in)
Skirt diameter	116.467 to 116.485 mm (4.5853 to 4.5860 in)
Top compression ring groove width, measure over 2.885 mm (0.1135 in) gauge pins	117.325 to 117.545 mm (4.6191 to 4.6278 in)
Intermediate compression ring side clearance	0.05 to 0.10 mm (0.002 to 0.0039 in)
Oil control ring side clearance	0.03 to 0.08 mm (0.0012 to 0.00315 in)
Piston protrusion above crankcase top deck	0.622 to 0.813 mm (0.025 to 0.032 in)
Piston cooling tube diameter (spray hole)	2.18 mm (0.086 in)

Piston Specifications – MaxxForce® 9 and 10

Piston	One-piece steel
Piston rings	Top ring - keystone cross section
	Intermediate - rectangular cross section
Running clearance between piston and cylinder sleeve	0.085 to 0.133 mm (0.00335 to 0.00524 in)
Skirt diameter	116.498 to 116.528 mm (4.5865 to 4.5877 in)
Top compression ring groove width, measure over 2.70 mm (0.1063 in) gauge pins	116.104 to 116.304 mm (4.5710 to 4.5866 in)
Intermediate compression ring side clearance	0.07 to 0.12 mm (0.0028 to 0.0047 in)
Oil control ring side clearance	0.03 to 0.08 mm (0.0012 to 0.00315 in)
Piston protrusion above crankcase top deck	0.622 to 0.813 mm (0.025 to 0.032 in)

Piston Ring Specifications (in 116.573 mm diameter gage ring)

Top compression ring end gap	0.35 to 0.50 mm (0.014 to 0.0197 in)
Intermediate compression ring end gap	1.20 to 1.45 mm (0.0472 to 0.0571 in)
Oil control ring end gap	0.35 to 0.65 mm (0.014 to 0.0256 in)

Piston Pin Specifications

Clearance in piston	
MaxxForce® DT	0.006 to 0.016 mm (0.00024 to 0.00063 in)
MaxxForce® 9 and 10	0.083 to 0.103 mm (0.00327 to 0.00406 in)
Length	
MaxxForce® DT	94.3 to 94.6 mm (3.7126 to 3.7244 in)
MaxxForce® 9 and 10	77.88 to 78.13 mm (3.066 to 3.076 in)
Diameter	
MaxxForce® DT	46.352 to 46.357 mm (1.8249 to 1.8251 in)
MaxxForce® 9 and 10	47.997 to 48.002 mm (1.8896 to 1.8898 in)

Cylinder Sleeve Specifications

Counterbore depth allowable variation between four points (maximum)	0.03 mm (0.001 in)
Counterbore depth before adding shims (maximum)	10.49 mm (0.413 in)
Counterbore depth (including shims - if any)	8.84 to 8.89 mm (0.348 to 0.350 in)
Cylinder sleeve protrusion	0.05 to 0.13 mm (0.002 to 0.005 in)
Cylinder sleeve protrusion difference between all six sleeves (maximum)	0.03 mm (0.001 in)
Cylinder sleeve taper travel (maximum)	0.10 mm (0.004 in)
Flange thickness	8.94 to 8.96 mm (0.352 to 0.353 in)
Inside diameter	116.57 to 116.60 mm (4.5895 to 4.5905 in)

Special Torque

Connecting rod bolts	See Torque-to-yield Procedure for Connecting Rods with M11 bolts (page 460).
Piston cooling jet bolts, M6 x 12	13 N·m (114 lb·in)

Special Service Tools

Counterbore Cutting Head	ZTSE25144A
Counterbore Reconditioning Tool Kit	KL50000
Cylinder bore gauge	Obtain locally
Cylinder Liner Height Gauge	ZTSE2515A
Cylinder Sleeve Puller	ZTSE2536
Depth micrometer	Obtain locally
Dial indicator set	Obtain locally
Feeler gauge	Obtain locally
Inside micrometer	Obtain locally
Outside micrometer	Obtain locally
Piston Ring Compressor Tool	ZTSE4396
Piston ring expander	Obtain locally
Piston Gauge Pins (set of 3)	ZTSE4653
Plastigage	Obtain locally
Sleeve Protrusion Hold Down Clamps	ZTSE4672
Telescoping gauge set	Obtain locally
15 mm 12 point socket	Obtain locally

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Exploded Views and Description

Centrifuge Oil Filter

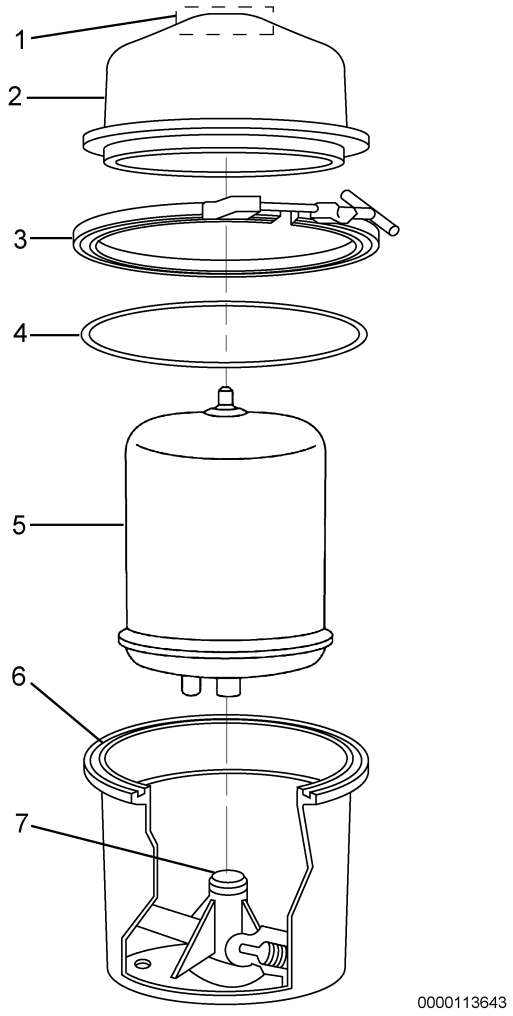


Figure 621 Centrifuge Oil Filter

1. Upper bearing
2. Cover assembly
3. Band clamp
4. Seal
5. Centrifuge oil filter
6. Body assembly
7. Lower bearing

The remote-mounted centrifuge oil filter is used to remove soot particles from the engine oil, thus 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 36 psi (248 kPa), 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.

Crankcase Breather Assembly with Turbine

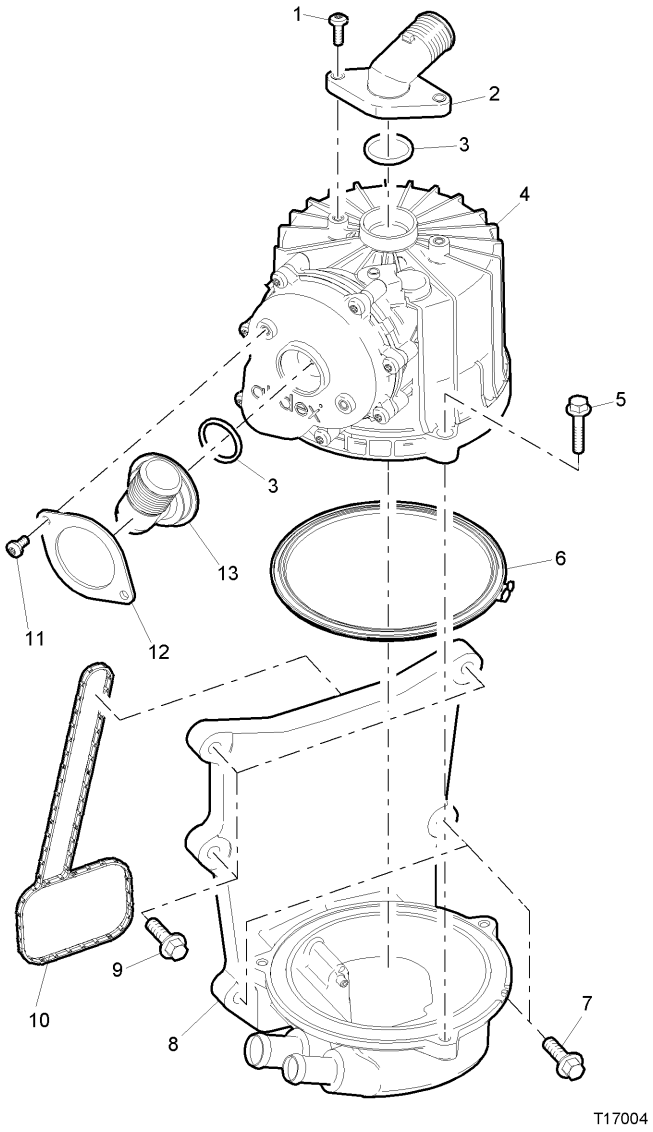


Figure 622 Crankcase Breather Assembly with Turbine

1. M5 x 16 bolt (2)
2. Inlet elbow
3. Breather fitting seal (2)
4. Housing assembly (breather)
5. M6 x 30 bolt (3)
6. Breather turbine seal
7. M8 x 30 bolt (used with coolant return tube supports) (3)
8. Housing assembly (turbine)
9. M8 x 25 bolt (3)
10. Breather to crankcase seal
11. M5 x 10 bolt (2)
12. Breather flange
13. Breather elbow

The crankcase breather assembly separates oil from crankcase gases. A turbine in the breather housing assembly is driven by engine oil pressure that separates the oil mist from crankcase gases. The closed breather system returns crankcase gases to the engine intake air and oil to the oil pan.

Crankcase, Crankshaft, and Camshaft

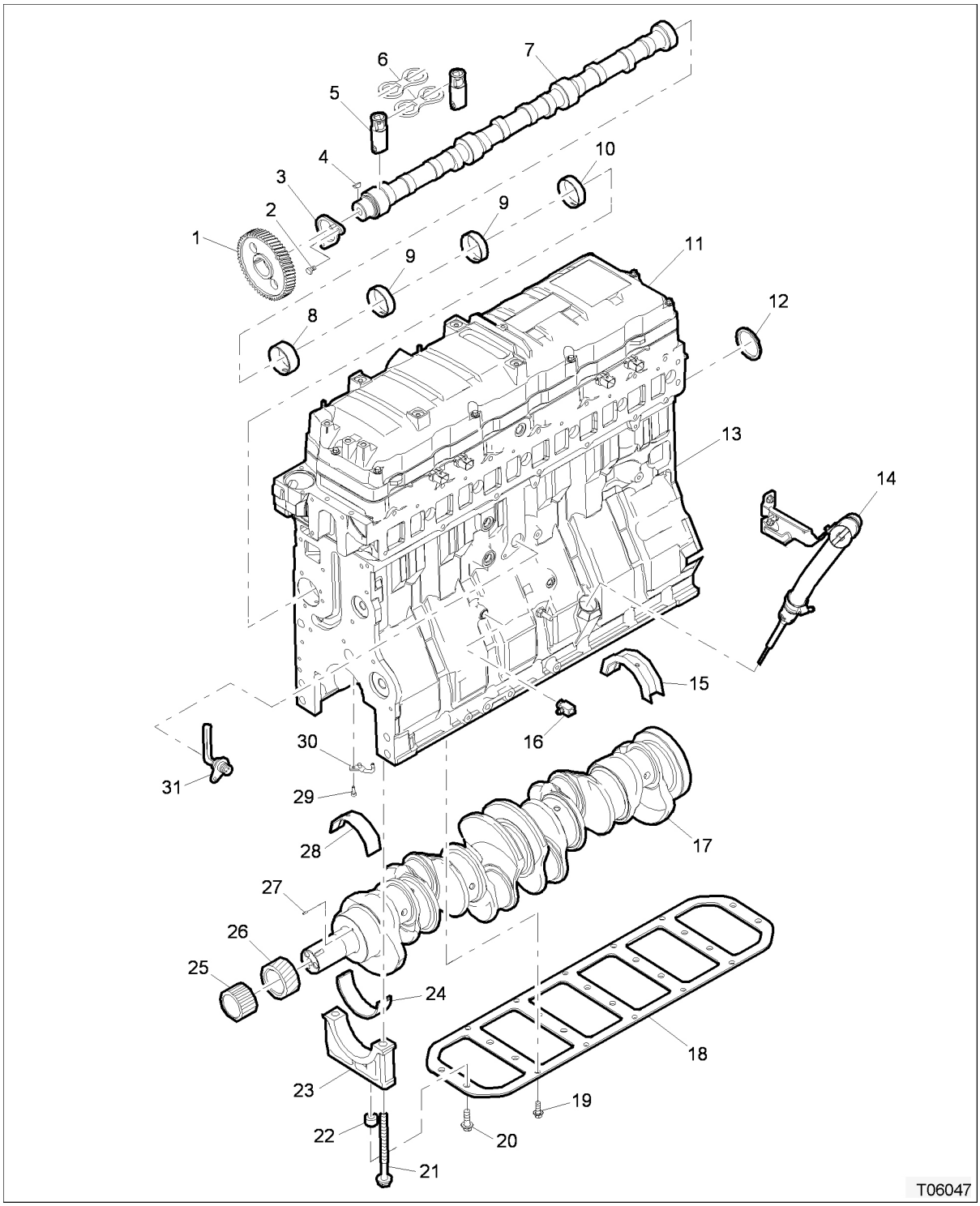


Figure 623 Crankcase, Crankshaft, and Camshaft

1. Camshaft gear assembly
2. M8 x 20 bolt (2)
3. Camshaft thrust plate
4. Woodruff key, ¼ x ¾
5. Roller tappet assembly (12)
6. Roller tappet guide (12)
7. Camshaft
8. Front #1 bearing (camshaft)
9. Intermediate #2 and #3 bearing (camshaft) (2)
10. Rear #4 bearing (camshaft)
11. Valve cover
12. Camshaft seal, ring (rear)
13. Crankcase assembly
14. Oil level gauge assembly
15. Thrust main bearing (#7 upper)
16. M12 Tee assembly
17. Crankshaft
18. Crankcase ladder
19. M10 x 25 bolt (10)
20. M12 x 35 bolt (14)
21. M15 x 162 bearing cap bolt (14)
22. Spacer (14)
23. Main bearing cap (7)
24. Lower main bearing (7)
25. Oil pump spline drive
26. Crankshaft gear
27. Slotted spring pin, 5/32 x 5/16
28. Front & intermediate upper main bearing (6)
29. M6 x 12 piston cooling tube bolt (6)
30. Piston cooling tube with O-ring assembly (6)
31. Coolant heater assembly (optional)

The one piece cast grey iron crankcase has removable cylinder sleeves and seven main bearing caps with 2 bolts per main cap.

The forged steel crankshaft has one journal for each connecting rod and thrust is taken by number 7 upper main bearing.

The single roller tappet camshaft is gear driven by the upper idler gear.

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, allow engine to cool before working with components.

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

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

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

Centrifuge Oil Filter

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

1. Shut engine off and allow centrifuge rotor to stop.
2. Place oil drain pan under centrifuge assembly.

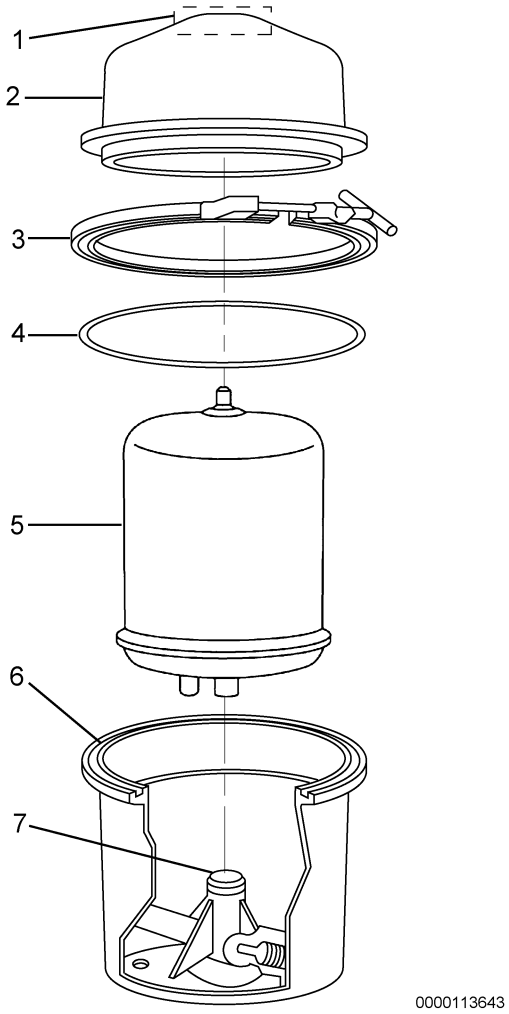


Figure 624 Centrifuge Oil Filter

1. Upper bearing
2. Cover assembly
3. Band clamp
4. Seal
5. Centrifuge oil filter
6. Body assembly
7. Lower bearing

3. Loosen handle on band clamp and disengage tee bolt. Remove band clamp.
4. Put suitable leverage tool into gap between cover assembly and body assembly. Pry open and remove cover assembly.

NOTE: The upper bearing is not serviceable and cannot be removed from the cover assembly.

5. Remove and discard seal.

NOTE: The centrifuge oil filter is not serviceable and cannot be opened.

6. Remove centrifuge oil filter and allow it to drain. Discard centrifuge oil filter according to applicable regulations.

Crankcase Ventilation System

NOTE: If not previously done, drain coolant from the coolant drain plug located in the oil cooler module, before removing the crankcase breather from the engine.

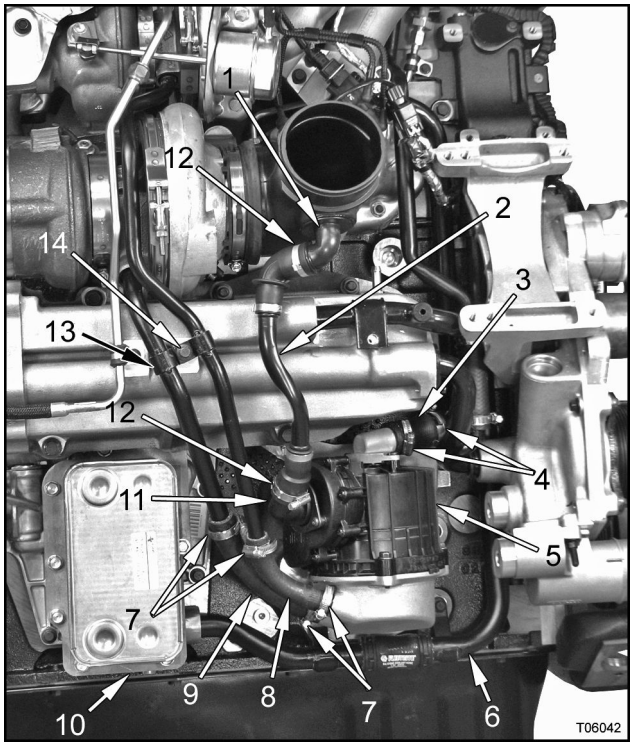


Figure 625 Crankcase Breather Assembly and Tubes

1. Port elbow
2. Crankcase breather outlet tube
3. Crankcase breather inlet tube
4. Crankcase breather inlet tube hose clamp (2)
5. Crankcase breather assembly with turbine
6. Coolant return tube assembly (two tubes and interconnecting hose)
7. High and low-pressure turbo drain tube hose clamp (4)
8. High-pressure turbo drain hose
9. Low-pressure turbo drain hose
10. Oil cooler module
11. Breather elbow
12. Crankcase breather outlet tube hose clamp
13. High and low-pressure turbo drain tube clamp
14. M8 x 25 bolt

NOTE: Two different size bolts secure the crankcase breather assembly to the crankcase. There are three M8 x 30 bolts securing the two bottom and middle right side of the crankcase breather assembly as well as securing the coolant return tube supports. The other three bolts are M8 x 25, secure the crankcase breather assembly to the crankcase. The correct bolts must be placed in the correct locations to correctly secure the crankcase breather assembly to the crankcase.

1. Place a drain pan under the coolant return tube assembly.
2. Loosen and remove, but do not discard, three M8 x 30 bolts which secure the coolant return tube supports to the crankcase breather assembly and coolant supply housing.
3. Pull coolant tube out of the coolant supply housing and the oil cooler module.
4. Discard coolant return tube assembly O-rings (one on each end of assembly). Place coolant return tube assembly on a clean workbench.
5. Dispose of coolant per applicable regulations.
6. Loosen hose clamp securing breather outlet tube to breather elbow. Disconnect breather outlet tube from breather elbow.
7. Loosen hose clamp securing breather outlet tube to port elbow. Disconnect breather outlet tube from port elbow and place breather outlet tube on a clean workbench.
8. Loosen hose clamps connecting high and low-pressure turbo drain tubes to high and low-pressure turbo hoses.
9. Remove M8 x 25 bolt securing the high and low-pressure turbo drain tube clamp to the EGR. Do not discard bolt.
10. Remove, but do not discard, high and low-pressure turbo drain tube clamp.
11. Pull high and low-pressure turbo drain tubes off of turbochargers and crankcase breather assembly.
12. Loosen hose clamps securing breather inlet tube to inlet elbow on crankcase breather assembly.
13. Pull breather inlet tube off of inlet elbow.
14. Loosen and remove three M8 x 25 bolts securing crankcase breather assembly to crankcase.
15. Remove crankcase breather assembly from crankcase.

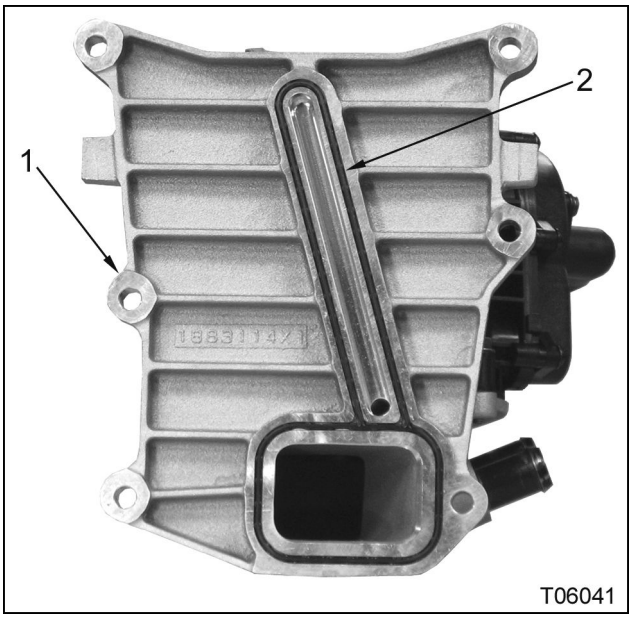


Figure 626 Crankcase Breather Housing Assembly (turbine) and Seal

1. Housing assembly (turbine)
2. Breather to crankcase seal

16. Remove and discard breather to crankcase seal from housing assembly (turbine).

Oil Level Gauge Assembly

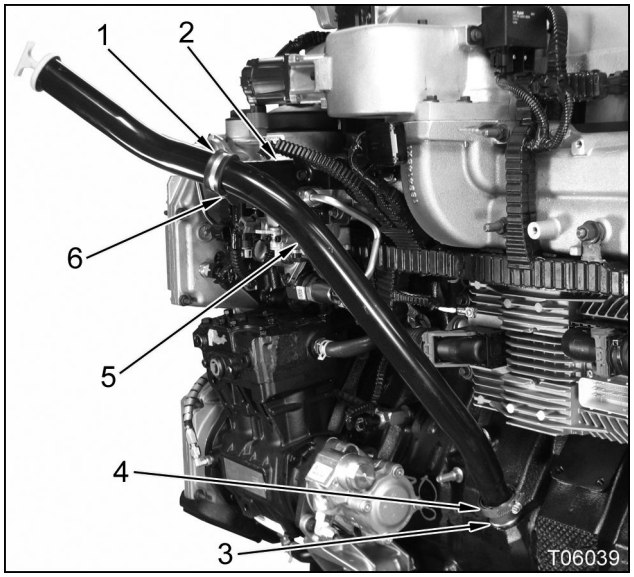


Figure 627 Oil Level Gauge Assembly

1. Cushioned clamp
2. Oil filler tube support
3. Oil level gauge tube
4. Tube clamp
5. Oil filler tube
6. M6 x 25 bolt and M6 nut

1. Remove M6 x 25 bolt and M6 nut securing the oil filler tube to the oil filler tube support.
2. Loosen tube clamp and remove the oil filler tube assembly from the oil level gauge tube.
3. If required, remove the oil filler tube support. Remove two M8 nuts and one M6 x 16 bolt holding the oil filler tube support to the fuel filter header.
4. If required, remove the oil level gauge tube by driving the tube up and out of the crankcase using a brass punch and hammer.

Coolant Heater Assembly (optional)

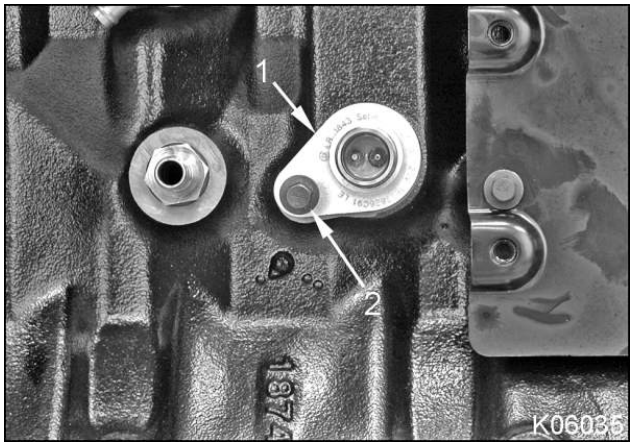


Figure 628 Coolant Heater (intake side of crankcase)

1. Coolant heater mounting flange
2. M8 x 20 bolt

1. If not previously done, drain engine coolant to a level below the coolant heater. Dispose of engine coolant according to applicable regulations.
2. Remove M8 x 20 bolt.
3. Pull out and remove coolant heater assembly from crankcase.
4. Discard O-ring.

Crankcase Ladder Assembly

1. Drain engine oil. See Drain Oil (page 62).
2. Remove oil pan (page 289) and oil suction tube assembly (page 290).
3. Rotate engine on stand to bring the crankcase to the vertical position so components do not fall into the crankcase.

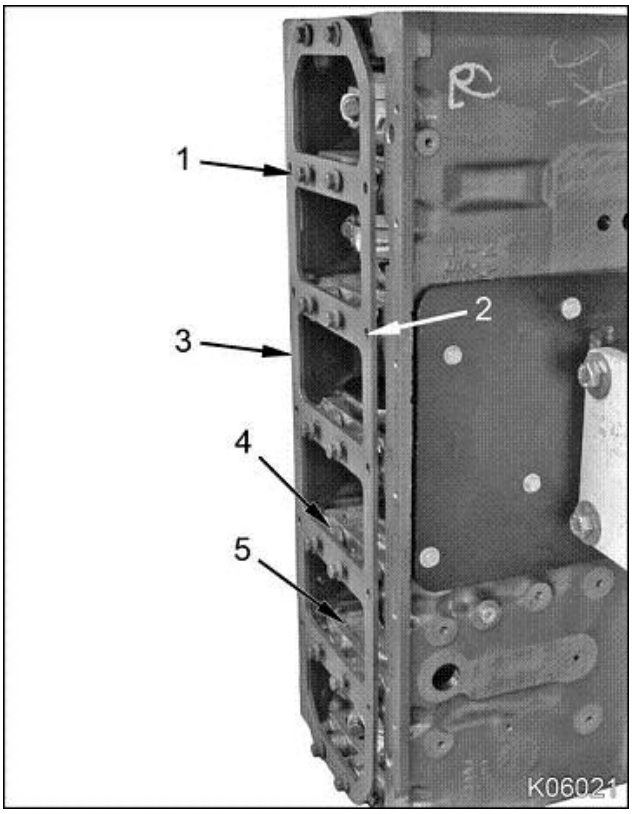


Figure 629 Crankcase Ladder Assembly (typical)

1. M12 x 35 bolt (14)
2. M10 x 25 bolt hole (10)
3. Crankcase ladder
4. Spacer (14)
5. Main bearing cap (7)

NOTE: Plastic washers are used as an assembly aid to hold each bolt and spacer to the crankcase ladder. Plastic washers are not required.

4. Remove ten M10 x 25 bolts securing the crankcase ladder to the crankcase.
5. Loosen fourteen M12 x 35 bolts securing the crankcase ladder to the main bearing caps and remove crankcase ladder assembly from the engine.
6. Remove 14 loose spacers that were under the crankcase ladder at the M12 x 35 bolt locations.
7. Carefully inspect crankcase for broken debris from plastic washers or washers that may have fallen into the crankcase. Remove and discard all plastic washers and any debris from plastic washers found in the crankcase or on the ladder assembly.

Camshaft Gear

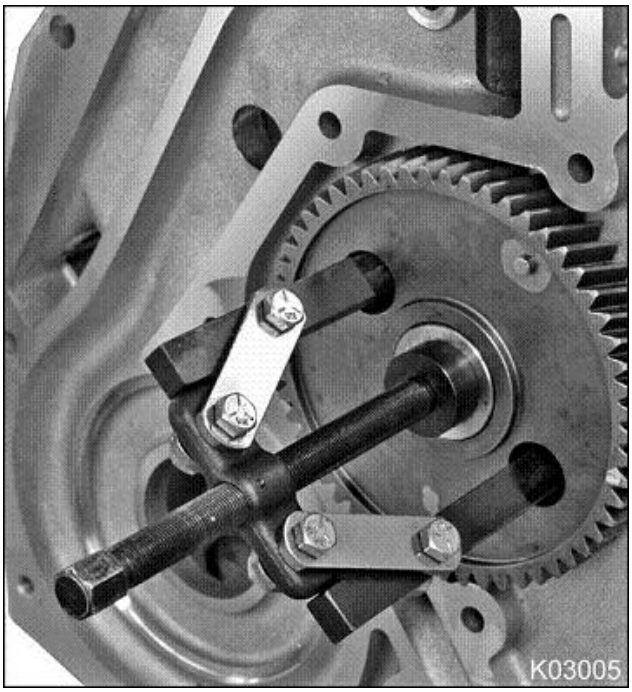


Figure 630 Camshaft Gear and Cam Gear Puller

NOTE: Before removing the camshaft, measure camshaft end play (page 486). For easier camshaft gear removal, remove the camshaft gear before removing camshaft, using the following procedure. To remove the camshaft and gear as an assembly, skip this procedure and go to Camshaft Assembly.

1. Bar engine until the number 1 cylinder is at Top Dead Center (TDC)
2. Install two claws of the Cam Gear Puller (page 509) into two holes of the camshaft gear.
3. Center the gear puller threaded shaft on the center of the camshaft and tighten shaft while firmly attaching puller claws on the camshaft gear.

NOTE: Keep the Cam Gear Puller center shaft in line with the camshaft center line while removing the cam gear.

4. Remove the camshaft gear by rotating the gear puller center shaft in a continuous motion using a

breaker bar, while holding the camshaft gear and Cam Gear Puller from rotating.

Camshaft Assembly

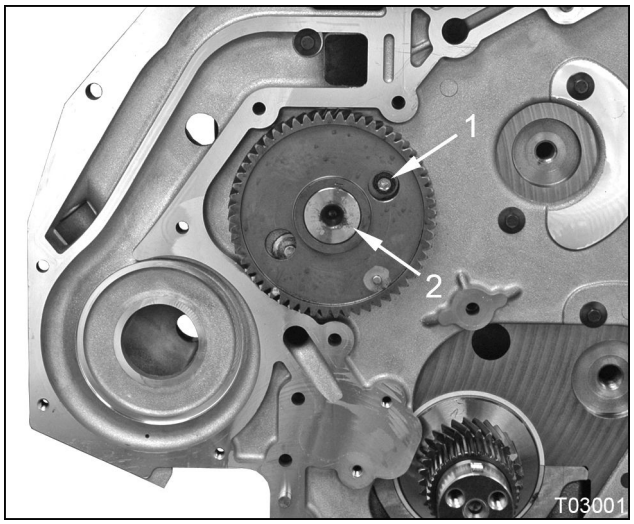


Figure 631 Camshaft Thrust Plate Bolts (typical)

1. M8 x 20 bolt (2)
2. Camshaft

NOTE: Roller tappets must be removed before removing camshaft. See Roller Tappets and Guides (page 361).

1. Remove two M8 x 20 camshaft thrust plate bolts.



Figure 632 Camshaft Assembly Removal (typical)

2. Rotate engine on stand so camshaft can be pulled straight up.
3. Carefully pull camshaft assembly up and out of crankcase.

Camshaft Bearings

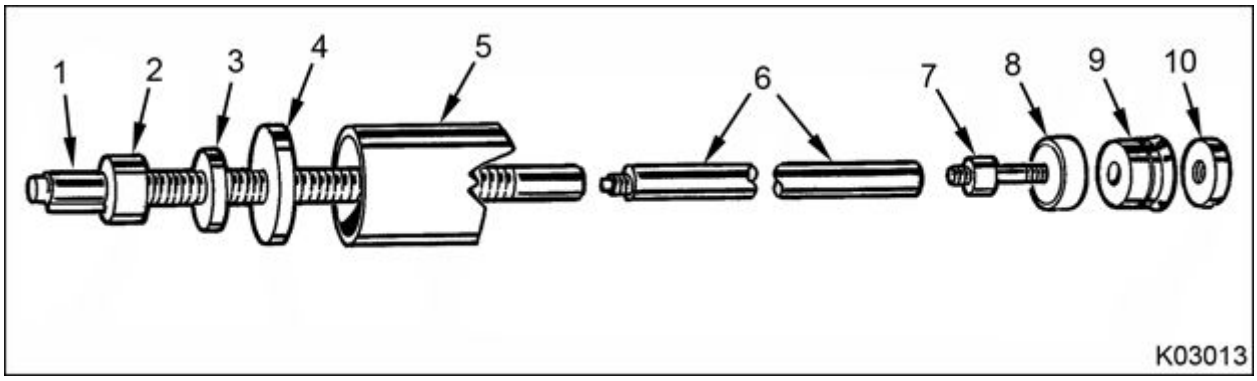


Figure 633 Camshaft Bearing Puller (installer)

1. Puller screw
2. Pulling nut
3. Thrust bearing
4. Pulling plate
5. Pulling spacer
6. Extension tube
7. Puller screw extension
8. Camshaft bearing (not part of tool)
9. Expanding collet
10. Backup nut

NOTE: Although the inside diameter of each camshaft bearing is the same, the outside diameters and widths are different depending on bearing location. See crankcase and camshaft bearing Specifications (page 505).

Use Camshaft Bearing Puller (page 509) to remove camshaft bearings. Remove the front and rear camshaft bearings first. Remove the camshaft seal ring and rear camshaft bearing from the rear of the crankcase.

1. Assemble the correct expanding collet and backup nut on the puller screw extension. See camshaft bearing Specifications (page 505).

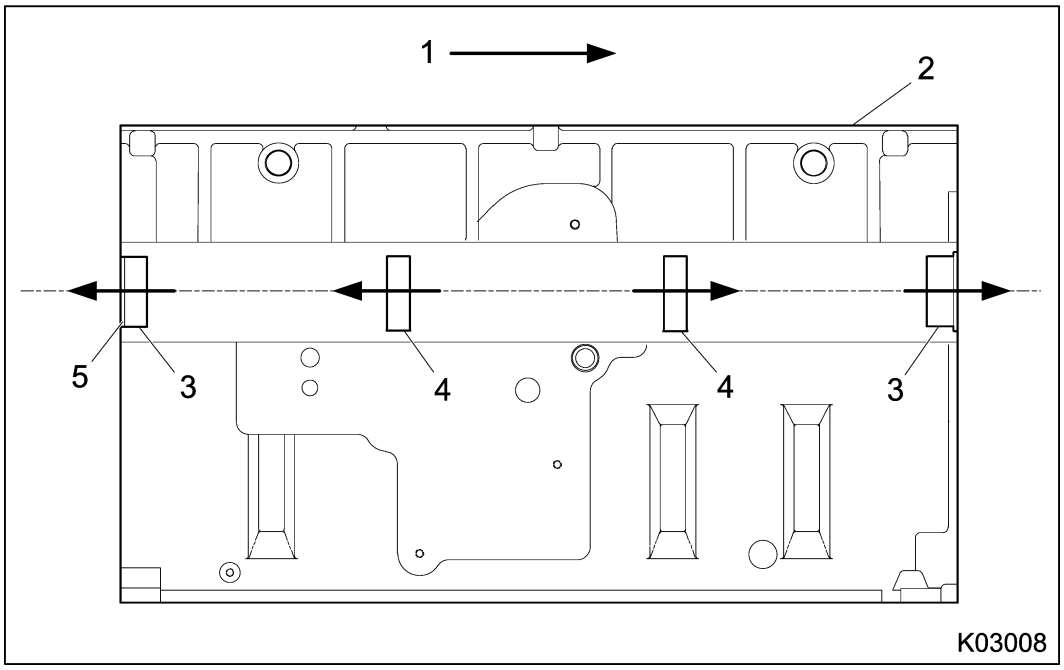


Figure 634 Camshaft Bearing Removal Pull Direction

1. Front of engine
2. Crankcase assembly
3. Front and rear camshaft bearings
4. Intermediate camshaft bearings
5. Camshaft seal ring

2. Remove the camshaft seal ring from the back of the crankcase.
3. With the expanding collet collapsed, install the collet assembly in the camshaft bearing and tighten backup nut until the collet fits the camshaft bearing.
4. Assemble the Camshaft Bearing Puller and install extension tube on the puller screw extension.

NOTE: Make sure pulling spacer is squarely mounted on the crankcase before tightening pulling nut.

5. Hold the end of the puller screw with a wrench and tighten the pulling nut against the thrust bearing and pulling plate until the camshaft bearing is removed.
6. Remove the front and rear camshaft bearings and then remove the two intermediate bearings using the pull direction indicated in (Figure 634).

Main Bearing Caps, Crankshaft, and Main Bearings

1. Disconnect the connecting rod assemblies. See Piston and Connecting Rod Assembly (page 433).

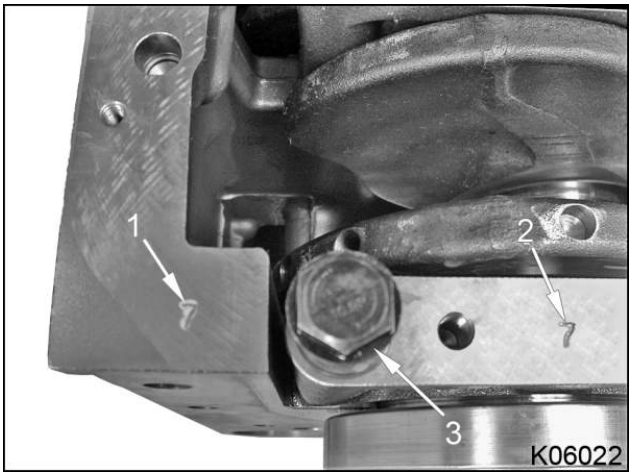


Figure 635 Main Bearing Cap and Crankcase Stamps (typical)

1. Crankcase stamp for #7 main bearing
2. Main bearing cap stamp on #7 main bearing cap
3. M15 x 162 main bearing cap bolt (14)

NOTE: Crankcase and main bearing caps may need to be cleaned to see stamped numbers.

2. Verify main bearing caps and crankcase have corresponding numbers stamped in each.
3. Loosen fourteen M15 x 162 main bearing cap bolts.

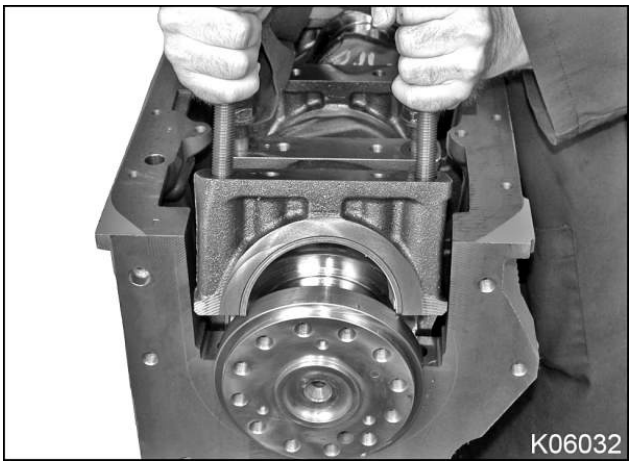


Figure 636 Main Bearing Cap Removal

4. Lift up both bolts of each main bearing cap so about half the threads are exposed.
5. Rock each main bearing cap free from the crankcase using both main bearing cap bolts.
6. Remove each main bearing cap and discard main bearing cap bolts.

NOTE: Main bearing cap bolts are not reusable, due to permanent deformation caused when bolts are tightened to the yield point (torque-to-yield).

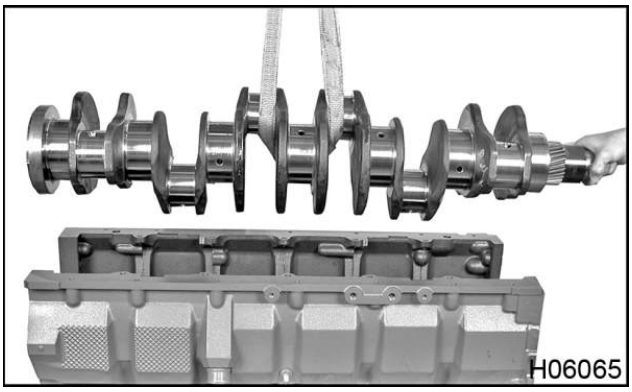


Figure 637 Crankshaft Assembly Removal

CAUTION: To prevent engine damage, do not drop or bend the crankshaft.

⚠ WARNING: To prevent personal injury or death, use a correct size lifting sling and hoist with a safety latch on hook.

7. Place an appropriate sling around the middle of the crankshaft and attach the sling to a hoist or crane.
8. Carefully lift the crankshaft out of the crankcase.

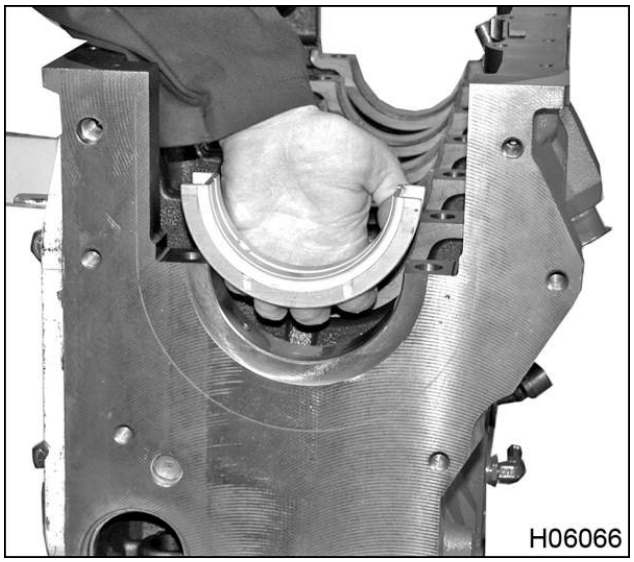


Figure 638 Thrust Main Bearing Removal

9. Push thrust main bearing and six other upper main bearings out of the crankcase main bearing saddles by hand. Mark each upper main bearing with its bearing number and orientation. Set aside each upper main bearing with its corresponding lower main bearing for later inspection and measurements.

Oil Pump Spline Drive and Crankshaft Gear

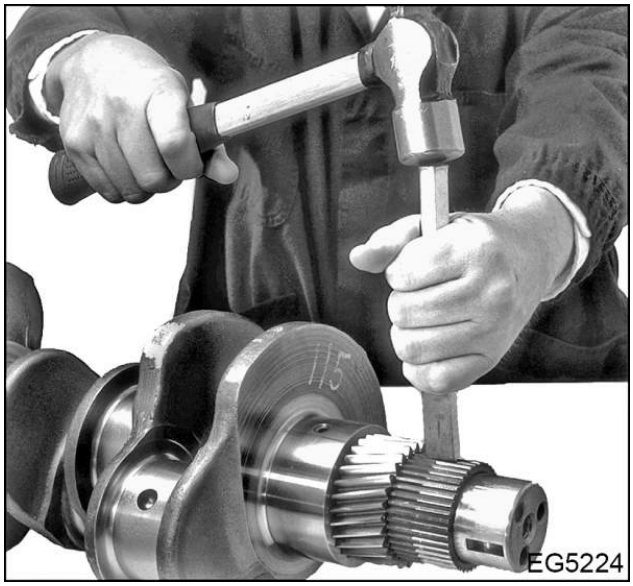


Figure 639 Oil Pump Spline Drive Removal

CAUTION: To prevent engine damage, strike chisel carefully to prevent damage to the crankshaft during oil pump spline drive and crankshaft gear removal.

1. Inspect oil pump drive spline for excessive wear. If worn, remove oil pump drive spline. Place chisel between teeth of oil pump drive spline. Strike chisel with hammer to break spline off crankshaft.
2. Remove oil pump drive spline from the crankshaft.
3. If worn or chipped, remove crankshaft gear. Place chisel between teeth of crankshaft gear. Strike chisel with hammer to break gear off crankshaft.
4. Remove crankshaft gear from the crankshaft.

Cleaning, Inspection, and Measurement

Camshaft Assembly

1. Use a soft bristle brush and a suitable solvent to clean the camshaft assembly and camshaft gear.
2. Inspect the camshaft gear for worn and damaged teeth. Replace gear if necessary.
3. Inspect camshaft for scuffed, scored, and cracked lobes. Replace camshaft if necessary.
4. Inspect the camshaft thrust plate for wear, cracks, and distortion. Replace thrust plate if necessary.
5. Measure camshaft thrust plate thickness using an outside micrometer. Replace thrust plate if not within Specifications (page 505).

Centrifuge Oil Filter Cleaning and Inspection

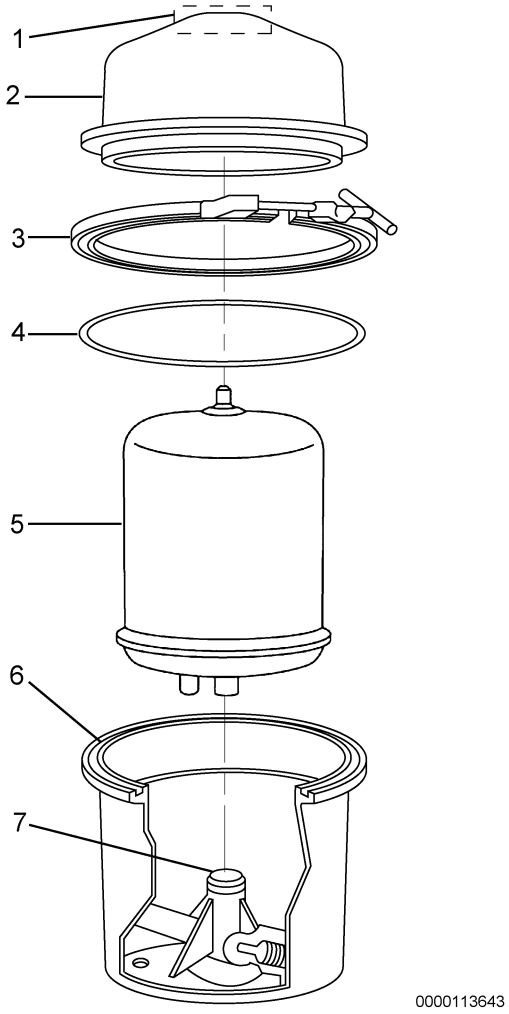


Figure 640 Centrifuge Oil Filter

1. Upper bearing
2. Cover assembly
3. Band clamp
4. Seal
5. Centrifuge oil filter
6. Body assembly
7. Lower bearing

1. Inspect upper bearing in cover assembly. If upper bearing is worn, broken, or contains debris, replace complete centrifuge assembly.
2. Inspect lower bearing in body assembly. If lower bearing is worn, broken, or contains debris, replace complete centrifuge assembly.

3. Clean and inspect cover assembly for cracks. If cracked, replace complete centrifuge assembly.
4. Use a clean, dry cloth to remove debris and residual fluids from the upper O-ring groove in body assembly.

Crankcase Breather Assembly

1. Clean all tubing, hoses, and crankcase breather assembly.

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

2. Dry parts with filtered compressed air.
3. Inspect tubing, hoses, and crankcase breather assembly for leaks or cracks. Replace cracked or leaking parts.

Crankcase, Cup Plugs, and Piston Cooling Tubes

NOTE: The best way to clean the crankcase during an engine overhaul is in a chemical bath or "hot tank". If hot tank cleaning is not available, use the following cleaning procedure.

1. Remove deposits and gasket material from gasket surfaces using a rotary wire brush or sanding block with mineral spirits.

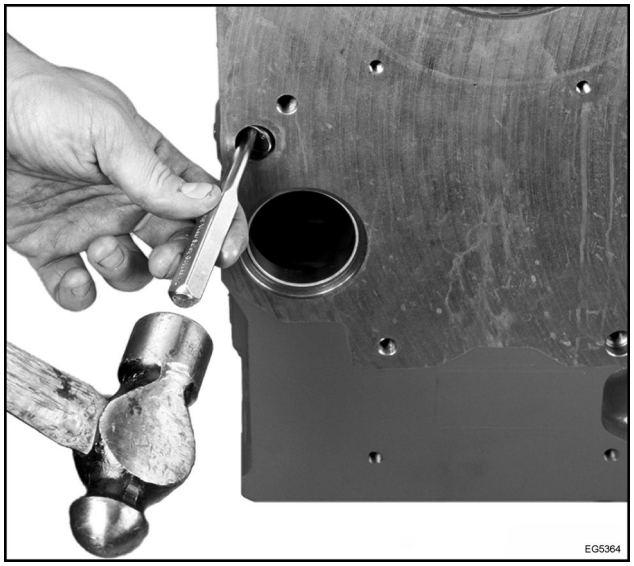


Figure 641 Crankcase Cup (freeze) Plug Removal

2. Remove the main oil gallery cup plug, located in the rear of the crankcase. Carefully knock out cup plugs with a hammer and chisel.
3. Clean oil galleries in the crankcase using a Stiff Nylon Brush (page 509) with soap and water.
4. Clean cross drillings in the crankcase using a Nylon Brush with soap and water.

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

5. Blow out oil galleries and cross drillings with filtered compressed air.
6. Clean all cylinder head bolt holes with the head bolt bottoming tap. This tap is part of the Tap Set (page 509).
7. Clean all crankcase threaded holes using an appropriate sized tap from the Tap Set.
8. Clean crankcase mating surfaces for cup plugs.
9. Apply Loctite® 262 (page 509) to the outside edge of cup plugs.
10. Drive cup plug into the crankcase using a punch approximately 6 mm (0.25 in) smaller in diameter than the plug being installed.
11. Recess cup plugs 2.3 mm (0.09 in) below machined surface.
12. Remove Piston Cooling Tubes (page 432). Hold each piston cooling tube under running water. Water should stream out of tube end. Clear blocked piston cooling tubes using filtered compressed air. Replace piston cooling tube if blockage can not be cleared.
13. Inspect both ends of each piston cooling tube. Verify the flanged end is intact and the orifice end protruding from the crankcase is not broken. Replace any cooling tubes that are damaged.
14. Clean engine block heater port in the intake side of the crankcase.
15. Inspect each crankcase counterbore for cracks.

Crankshaft and Main Bearings

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

1. Inspect crankshaft gear for chips or excessive wear. Replace gear if required.
2. Clean each main bearing and cap in solvent and dry with filtered compressed air. Do not scrape gum or varnish deposits from main bearings.
3. Clean internal oil passages of the crankshaft using a Stiff Nylon Brush (page 509). Flush oil passages with a suitable non-caustic solvent.
4. Blow crankshaft oil passages dry with filtered compressed air.
5. Inspect crankshaft journals (main and rod) for scratches, grooves, and scoring. Use dye penetrant kit (page 509) to check for cracks.
6. Inspect all upper and lower main bearings. Replace bearings that are scored, chipped, or excessively worn.

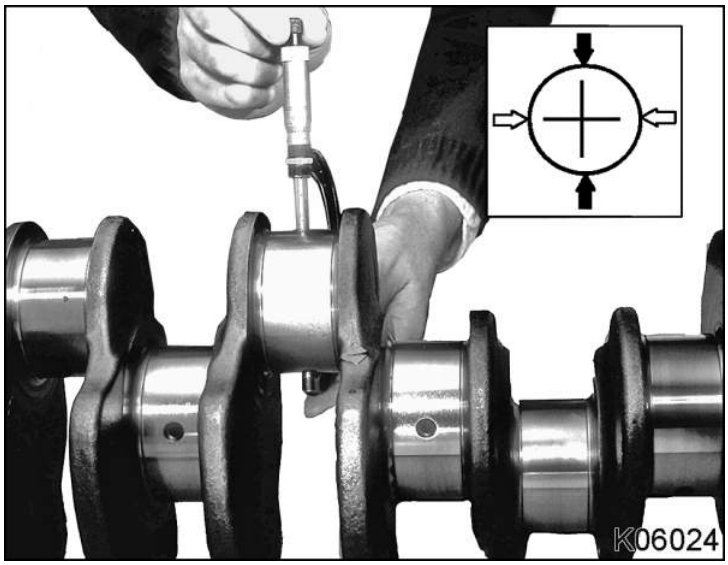


Figure 642 Crankshaft Journal Measurement

7. Measure diameter of each crankshaft journal at two points 90 degrees from each other using an outside micrometer (page 509). Move the micrometer over the entire width of the journal at each measurement point.
8. Compare measurements to crankshaft Specification (page 505).

NOTE: If crankshaft journals exceed maximum out-of-round or other specifications the crankshaft must be reground or replaced.

The crankshaft can be ground to the following undersizes:

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

Camshaft End Play Measurement

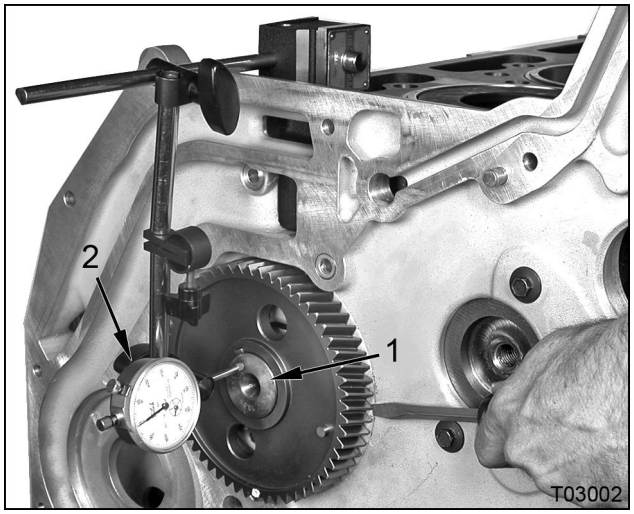


Figure 643 Camshaft End Play Measurement

1. Camshaft
2. Dial indicator set

1. Mount magnetic base of a dial indicator set (page 509) on a flat engine surface.
2. Push camshaft toward the engine and put tip of dial indicator on the camshaft end.
3. Zero dial indicator.
4. Lightly pry camshaft toward the dial indicator and then push away.
5. See camshaft end play Specification (page 505).
   - If camshaft end play exceeds maximum specification, remove the camshaft gear, pull camshaft forward, and reinstall camshaft gear making sure gear is seated all the way on the camshaft. Repeat steps 2 through 4.
   - If camshaft end play is less then minimum specification correct camshaft thrust plate or mating surface problems.

Camshaft Lobes and Journals Measurement

NOTE: See Measure Camshaft Lobe Lift (page 362) to measure camshaft lift without removing the camshaft or cylinder head.

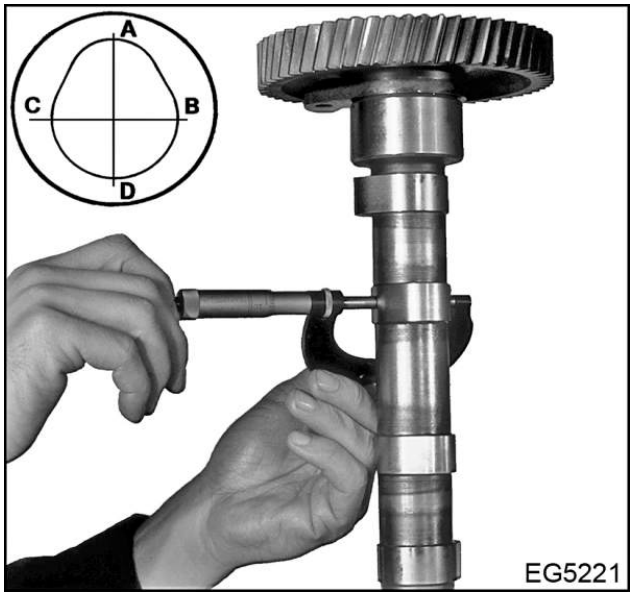


Figure 644 Camshaft Lobe Measurement

1. Measure across each camshaft lobe from points A-D and B-C using an outside micrometer (page 509).
2. Subtract measurement B-C from measurement A-D. This is lobe lift.
3. If any camshaft lobe lift measurement is 0.25 mm (0.010 in) or more below Specification (page 505), replace camshaft.
4. Measure the diameter of each camshaft journal using an outside micrometer.
5. If any journal measurement is below Specification (page 505), replace the camshaft.

Crankshaft End Play Measurement

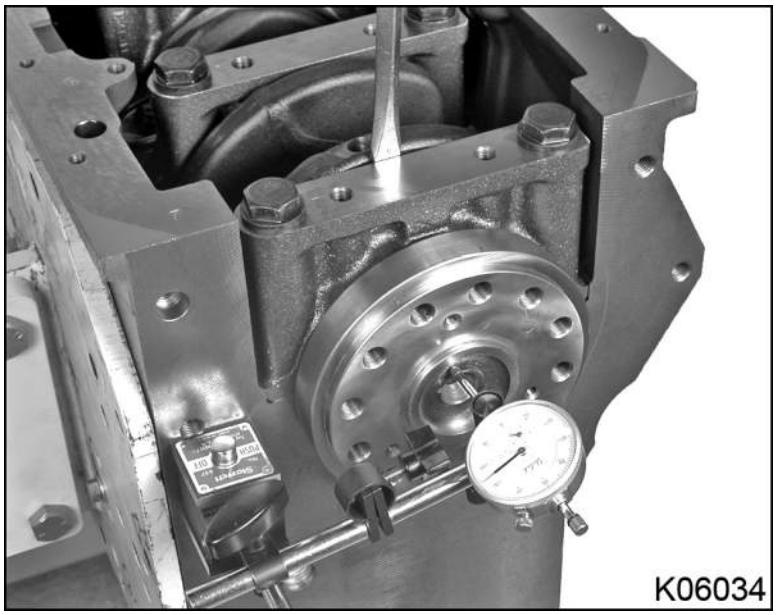


Figure 645 Crankshaft End Play Measurement

1. Mount magnetic base of a dial indicator set (page 509) on a flat engine surface.
2. Push crankshaft toward the rear of the engine and put tip of dial indicator on the crankshaft end.
3. Zero dial indicator.
4. Lightly pry crankshaft toward the front of the engine and then away. Pry between the crankshaft counter weight and crankcase main bearing caps.

CAUTION: To prevent engine damage, install new main bearing cap bolts whenever main bearing bolts are removed.

5. See crankshaft end play Specification (page 505).
   - If crankshaft end play exceeds maximum specification, replace thrust main bearing (number 7 upper). Install and torque new main bearing cap bolts (page 498). Repeat steps 1 through 4.
   - If crankshaft end play is less than minimum specification, loosen main bearing caps and reposition bearings. Install and torque new main bearing cap bolts (page 498). Repeat steps 1 through 4.

Installation

Camshaft Bearings

CAUTION: To prevent engine damage, camshaft bearings must be installed in the proper order due to different outside diameters. Both intermediate camshaft bearings are the same and have an outer diameter slightly smaller than bearings used in the front and rear.

1. Identify each camshaft bearing according to its outside diameter and width. See Camshaft Bearing Specifications (page 505).

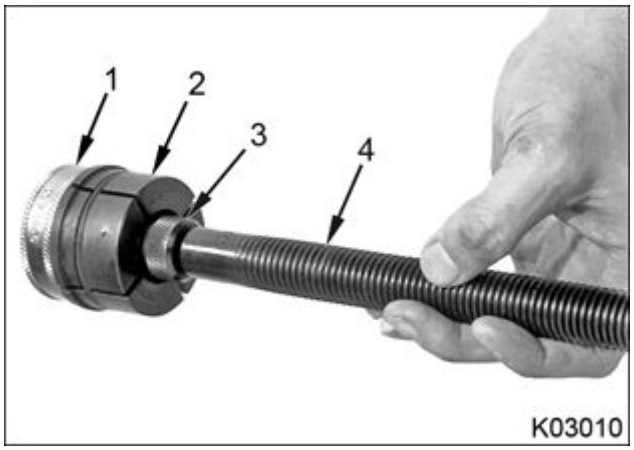


Figure 646 Camshaft Bearing Puller (installer)

1. Backup nut
2. Expanding collet
3. Puller screw extension
4. Puller shaft

2. Install a new camshaft bearing on the Camshaft Bearing Puller (page 509) expanding collet.
3. Tighten expanding collet by turning backup nut until camshaft bearing is held securely.



Figure 647 Camshaft Bearing Oil Slot Location Mark

4. Mark each camshaft bearing oil slot location on the backup nut of the Camshaft Bearing Puller to insure bearing oil slot gets installed in the optimum bearing lubrication position.

CAUTION: To prevent engine damage, the number 2 intermediate camshaft bearing must be installed from the front of the engine. Face the crankcase from the front of the engine and rotate the bearing oil slot to the four o'clock position for installation of the number 2 intermediate camshaft bearing. Aligning the oil slot of the camshaft bearing in this position ensures optimum bearing lubrication. Note that the front camshaft bearing bore does not have the annulus (groove).

CAUTION: To prevent engine damage, the number 3 intermediate camshaft bearing and rear camshaft bearing must be installed from the rear of the engine. Face the crankcase from the rear of the engine and rotate the bearing oil slot to the 8 o'clock position (4 o'clock position if viewed from the front of the engine). Aligning the oil slot of the camshaft bearing in this position ensures optimum bearing lubrication.

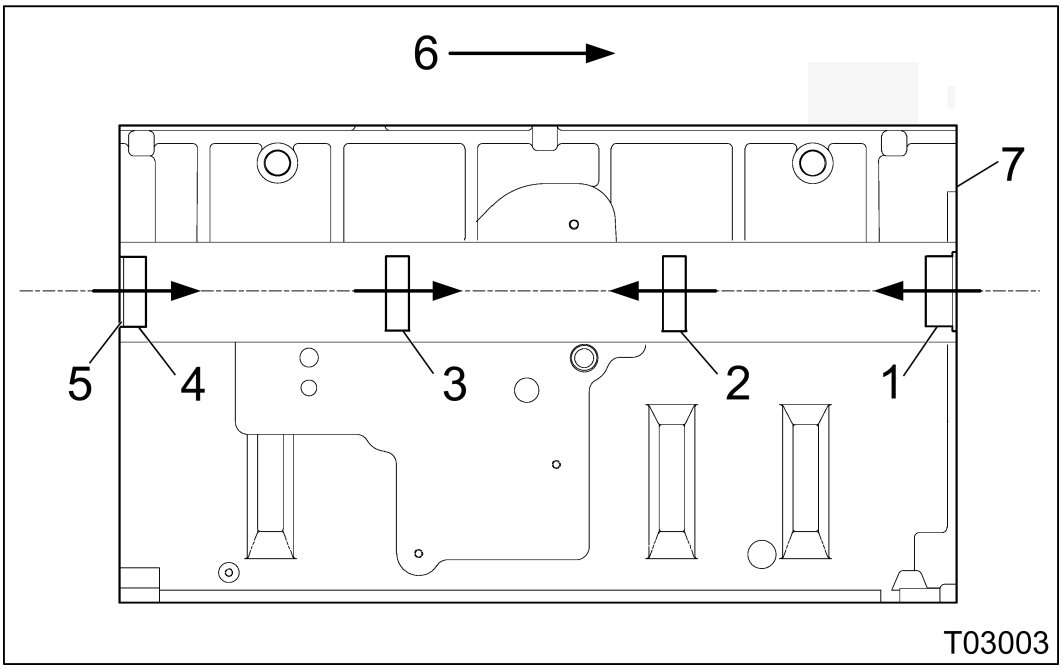


Figure 648 Camshaft Bearing Installation Pull Direction

1. Front camshaft bearing
2. Number 2 intermediate camshaft bearing
3. Number 3 intermediate camshaft bearing
4. Rear camshaft bearing
5. Camshaft seal ring
6. Front of engine
7. Crankcase assembly

5. Install number 3 intermediate camshaft bearing through the rear of the crankcase. Make sure the camshaft bearing is pulled past the chamfer and is fully supported in the block. Align camshaft bearing oil slot in the eight o'clock position, as viewed from the rear of the engine, 4 o'clock position as viewed from the front of the engine.
6. Pull camshaft bearing in place from the front of the crankcase by turning the pulling nut on the puller screw.

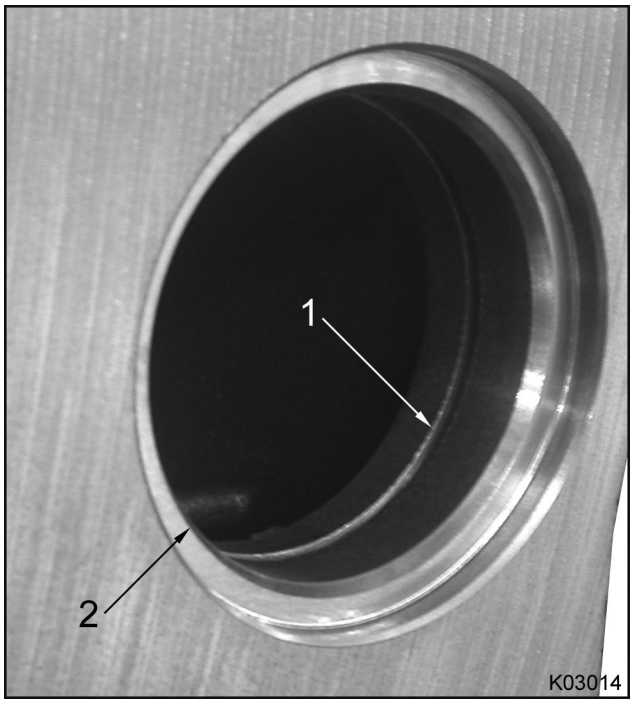


Figure 649 Annulus (groove) in Cam Bore Positions 2, 3, and 4)

1. Annulus
2. Cam bore

7. Remove the Camshaft Bearing Puller and verify camshaft bearing oil slot and annulus alignment.
8. Install the number 2 intermediate camshaft bearing through the front of the crankcase. Make sure the camshaft bearing is pulled past the chamfer and is fully supported in the block. Align camshaft bearing oil slot in the four o'clock position, as viewed from the front of the engine, 8 o'clock position as viewed from the rear of the engine.
9. Pull camshaft bearing in place from the rear of the crankcase by turning the pulling nut on the puller screw.
10. Remove the Camshaft Bearing Puller and verify camshaft bearing oil slot and annulus alignment.

NOTE: The oil slot of the front camshaft bearing, must align with the oil transfer drilling in the crankcase to ensure proper oil will flow around the cam bearing. the front camshaft bearing bore does not have the annulus (groove).

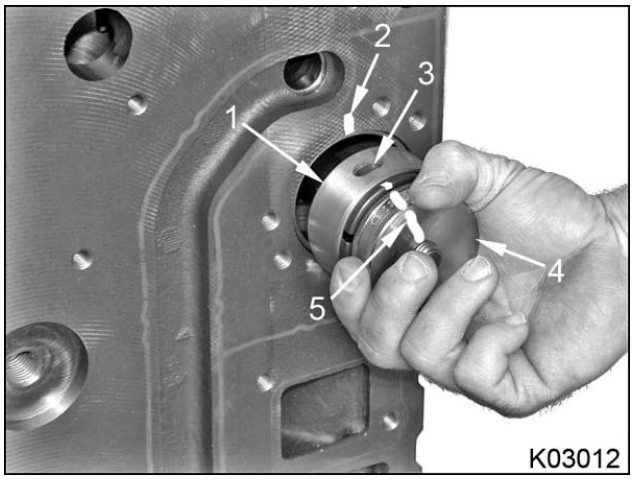


Figure 650 Front Camshaft Bearing Installation

1. Front camshaft bearing
2. Crankcase oil slot alignment mark
3. Camshaft bearing oil slot
4. Camshaft bearing Puller (installer)
5. Camshaft bearing oil slot alignment mark

11. Install front camshaft bearing through the front of the crankcase. Align camshaft bearing oil slot and oil transfer drilling in crankcase.
12. Pull camshaft bearing in place from the rear of the crankcase by turning the pulling nut on the puller screw.
13. Remove the Camshaft Bearing Puller and verify camshaft bearing oil slot and oil transfer drilling alignment.
14. Install rear camshaft bearing through the rear of the crankcase. Align camshaft bearing oil slot and annulus in crankcase; eight o'clock position as viewed from the rear of the engine, 4 o'clock position as viewed from the front of the engine.
15. Pull camshaft bearing in place from the front of the crankcase by turning the pulling nut on the puller screw.
16. Remove the Camshaft Bearing Puller and verify camshaft bearing oil slot and annulus alignment.
17. Install camshaft seal ring in rear of crankcase.

Camshaft Assembly



Figure 651 Camshaft Assembly Installation

1. Rotate crankcase to a vertical position.
2. Lubricate all camshaft journals and bearings with clean engine oil.
3. Carefully install camshaft assembly into crankcase. Do not scratch or damage camshaft journals or bearings during installation.

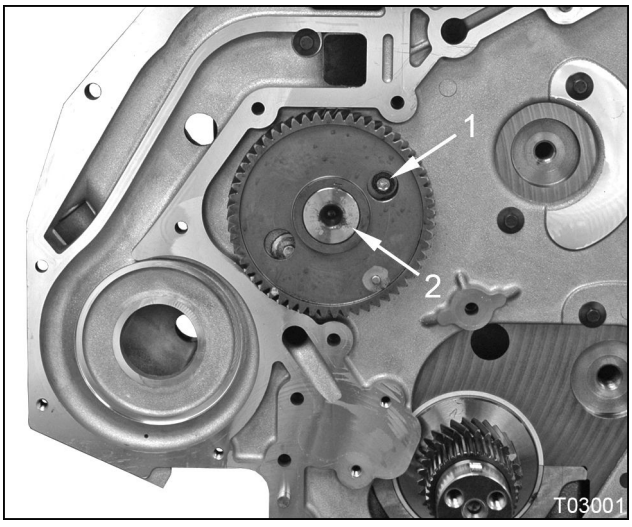


Figure 652 Camshaft Thrust Plate Bolts (typical)

1. M8 x 20 bolt (2)
2. Camshaft

4. Install two M8 x 20 camshaft thrust plate bolts and tighten to standard torque (page 553).
5. Measure camshaft end play (page 486).

Camshaft Gear



Figure 653 Camshaft Gear and Hot Plate

⚠ WARNING: To prevent personal injury or death, wear heat protective gloves when installing hot camshaft gear.

1. Heat camshaft gear on a hot plate (page 509) or other controlled heat source to 191 to 202 °C (375 to 395 °F).

CAUTION: To prevent engine damage, do not heat cam gear above 202 °C (395 °F).

2. Pull camshaft assembly forward prior to sliding heated camshaft gear on the camshaft and ensure woodruff key is in place.

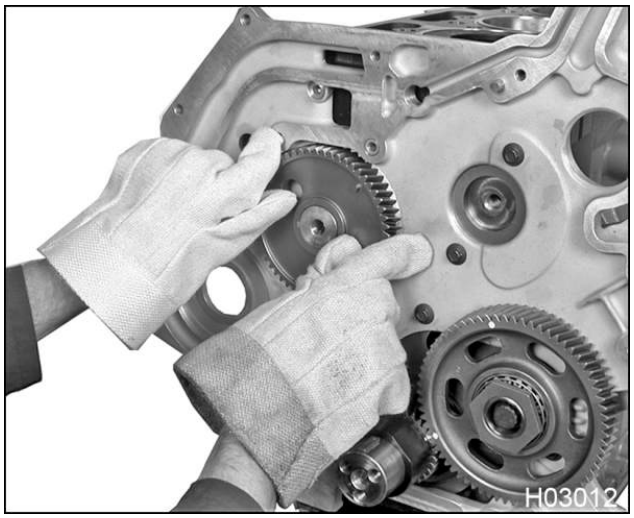


Figure 654 Camshaft Gear Installation (typical)

CAUTION: To prevent engine damage, do not tap or hammer camshaft gear onto camshaft.

NOTE: Heated gear should easily slide on camshaft. If gear does not slide easily, inspect camshaft gear mounting surface and repeat steps 1 and 2.

3. Install heated camshaft gear on the camshaft while wearing heat insulated gloves. Make sure woodruff key groove on gear aligns with key in camshaft. Camshaft gear should slide on the camshaft with only slight hand pressure. Hold the camshaft gear (while thoroughly seated) until it cools on the camshaft (approximately 30 seconds).

NOTE: The camshaft should stick out of the camshaft gear slightly when the camshaft gear is properly installed.

4. Measure camshaft end play (page 486).

Crankshaft Gear and Oil Pump Spline Drive

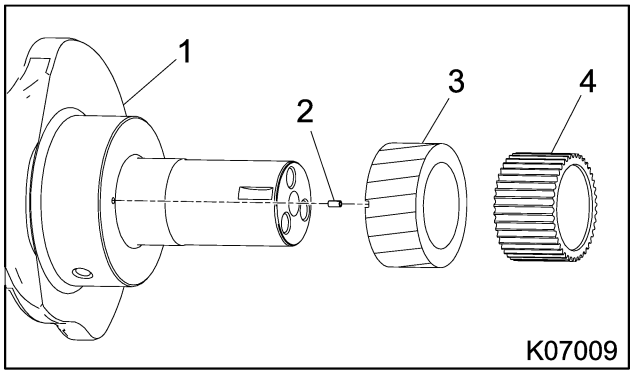


Figure 655 Crankshaft Gear and Oil Pump Spline Drive

1. Crankshaft
2. Slotted spring pin, 3.967 x 7.938 mm (5/32 x 5/16 in)
3. Crankshaft gear
4. Oil pump spline drive

1. Carefully tap slotted spring pin into hole in the crankshaft.

WARNING: To prevent personal injury or death, wear heat protective gloves when handling heated components.

CAUTION: To prevent engine damage, do not heat crankshaft gear and oil pump spline above 202 °C (395 °F).

2. Heat crankshaft gear and oil pump spline drive on a hot plate (page 509) or other controlled heat source to 188 to 202 °C (370 to 395 °F).
3. Install heated crankshaft gear while wearing heat insulated gloves. Align the slotted spring pin in the crankshaft with corresponding slot in the crankshaft gear. Press crankshaft gear against the crankshaft shoulder and hold until gear cools (approximately 30 seconds).
4. Install heated oil pump spline drive on the crankshaft against the crankshaft gear while wearing heat insulated gloves. Hold spline drive against the crank gear until spline cools (no orientation required).

Upper Main Bearings and Crankshaft Assembly

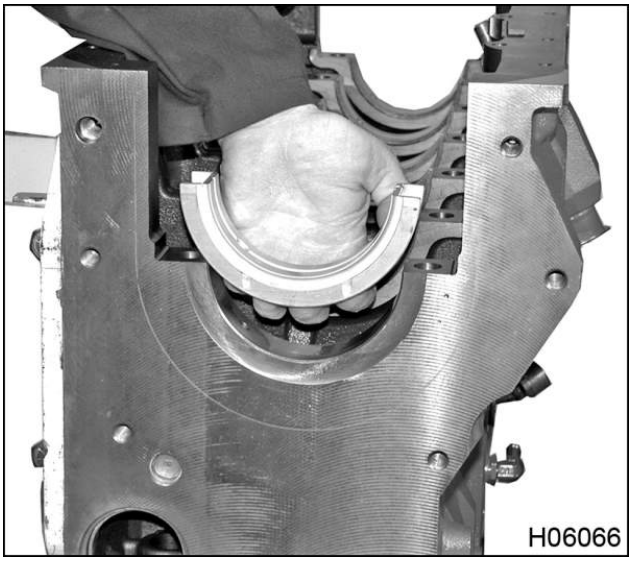


Figure 656 Thrust Bearing Installation

1. Rotate crankcase so main bearing saddles are facing up.
2. Clean oil off crankcase main bearing saddles with a lint-free cloth. Do not lubricate the back side of main bearings.
3. Install thrust main bearing in the rear #7 upper main bearing saddle. Make sure locking tab on bearing aligns with notch in the crankcase.
4. Install the remaining six upper main bearings in their corresponding saddles. Make sure locking tab on each bearing aligns with notch in the crankcase.
5. Apply marker paste Prussian Blue (page 509) or equivalent) on the crankshaft main bearing journals.

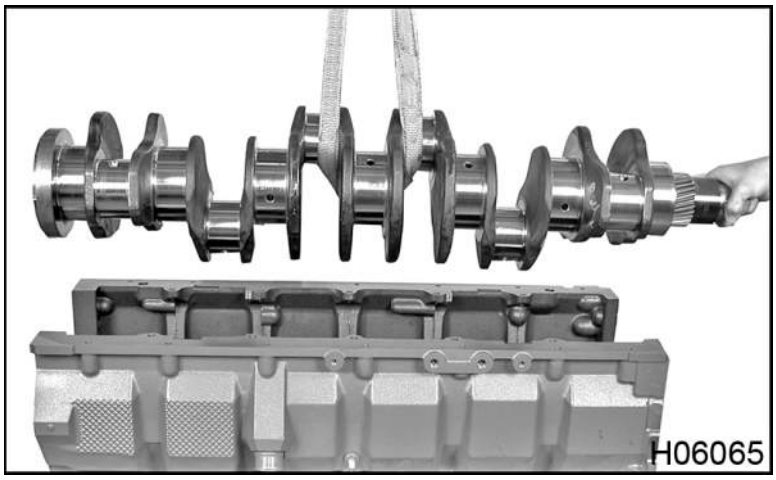


Figure 657 Crankshaft Assembly Installation

⚠ 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 or vehicle damage, do not drop, bend, or gouge crankshaft.

6. Install and center an appropriate lifting sling on the crankshaft, supported by two connecting rod journals.
7. Carefully lift and lower the crankshaft onto the upper main bearings in the crankcase.

NOTE: Do not install the main bearing caps at this time.

8. Rotate the crankshaft 180 degrees (½ turn).
9. Carefully remove the crankshaft and inspect the upper bearings for an even transfer of bluing agent from the journals to the bearings.
    - If voids appear in the bluing agent transfer, inspect and measure the crankcase and crankshaft. Correct any problems and then repeat steps 7 through 13.
    - If the bluing agent transfer is even and normal and the crankcase and crankshaft are not damaged, then proceed to step 10.
10. Clean all marker paste off bearings and crankshaft journals.
11. Lubricate upper main bearings with clean engine oil.
12. Install and center an appropriate lifting sling on the crankshaft, supported by two connecting rod journals.
13. Carefully lift and lower the crankshaft onto the main bearings in the crankcase.

Main Bearing Fit Procedure

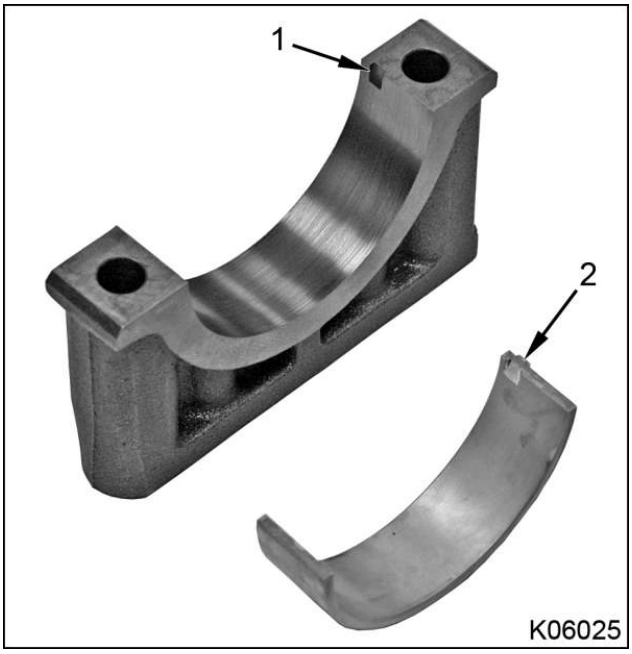


Figure 658 Main Bearing Cap and Lower Main Bearing

1. Main bearing cap notch
2. Bearing alignment tab

NOTE: Main bearing caps and the back of main bearing surfaces must be free of oil and dirt. Do not lubricate the backside of main bearings.

1. Install lower main bearing in each main bearing cap. Make sure bearing alignment tabs snap in each bearing cap notch.

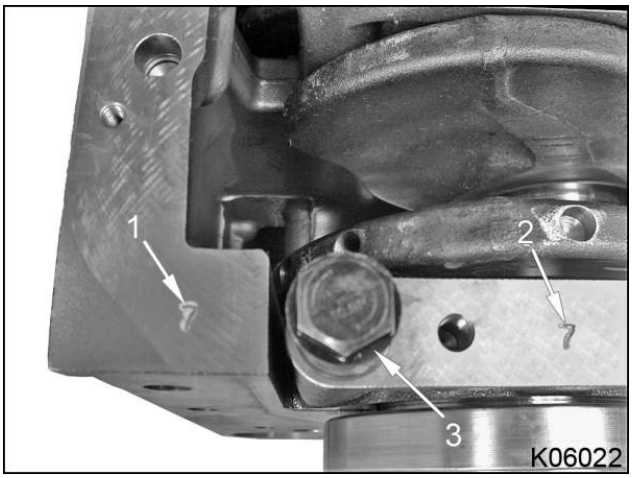


Figure 659 Main Bearing Cap and Crankcase Stamps (typical)

1. Crankcase stamp for #7 main bearing
2. Main bearing cap stamp on #7 main bearing cap
3. M15 x 162 main bearing cap bolt (14)

2. Orient each main bearing cap with its matching crankcase stamp.
3. Clean each lower main bearing surface and the exposed half of the crankshaft journal. These surfaces must be free of oil.
4. Install each main bearing cap assembly. Lightly oil threads of new main bearing bolts with clean engine oil.

NOTE: Bearing clearance measurement checks bearing fit and will not permanently stretch main bearing bolts. Do not torque-to-yield main bearing bolts until final assembly.

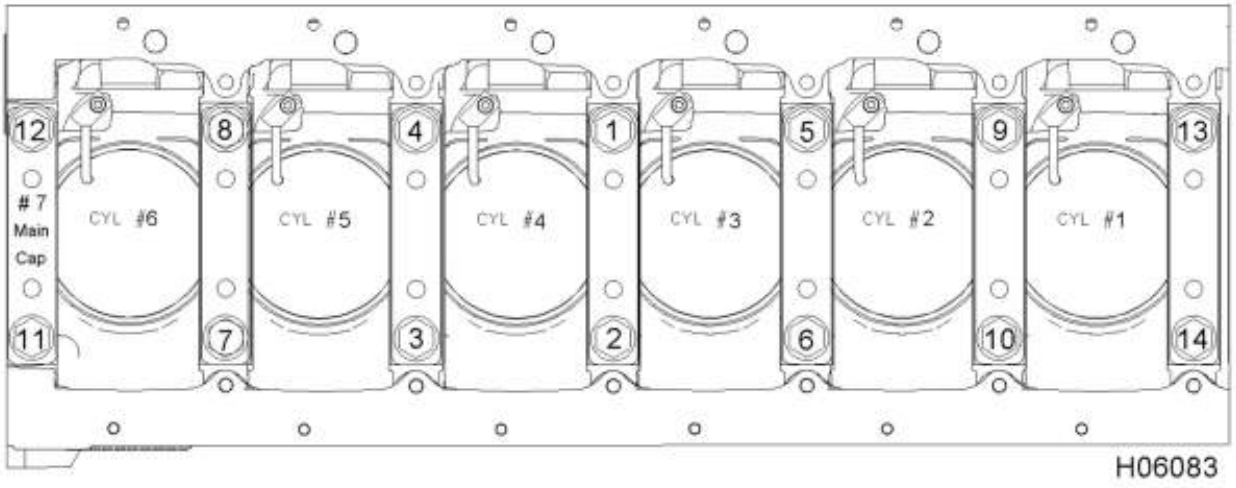


Figure 660 Main Bearing Cap Bolt Torque Sequence

5. Tighten each main bearing cap bolt to 136 N·m (100 lb·ft) using main bearing cap bolt torque sequence.
6. Tighten each main bearing bolt to 177 N·m (130 lb·ft) using main bearing cap bolt torque sequence.
7. Remove one main bearing cap assembly at a time. Leave other caps tight.
8. Wipe oil from all contact surfaces of the exposed crankshaft journal and main bearing.

NOTE: For in chassis service only: the crankshaft must be supported and held against the upper main bearing halves to get a correct Plastigage (page 509) reading. Use a jack to support the crankshaft at the counterweight nearest each main bearing being checked. Failure to support the crankshaft will result in inaccurate readings.

NOTE: Do not rotate the crankshaft.

9. Place a piece of Plastigage across the full width of the bearing surface on the crankshaft journal (or bearing insert) approximately 6 mm (0.25 in) off center. Install the bearing cap and tighten main bearing cap bolts to 177 N·m (130 lb·ft).
10. Remove main bearing cap assembly. Do not disturb the Plastigage.

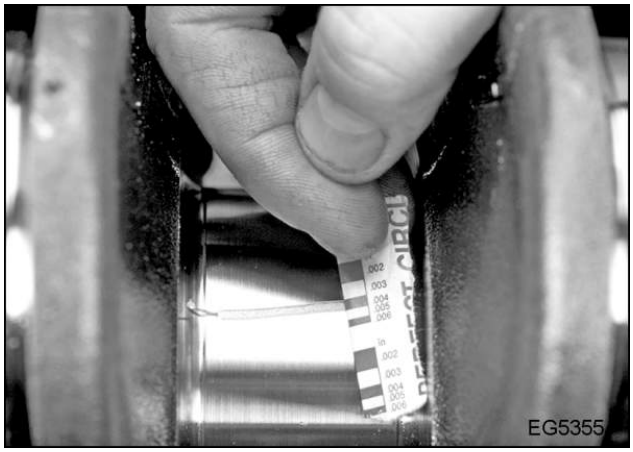


Figure 661 Plastigage Measurement

11. Measure Plastigage using the scale on the Plastigage envelope. Measure and record the widest point of the flattened Plastigage. This reading indicates the bearing clearance in thousandths of an inch or millimeters.
12. Remove Plastigage, install main bearing cap assembly, and tighten main bearing bolts to 177 N·m (130 lb·ft). Repeat steps 7 through 11 for all seven main bearings.
13. If main bearing to crankshaft running clearances are not within Specifications (page 505), replace the crankshaft or resurface the crankshaft and install oversize main bearings.

Main Bearings and Caps

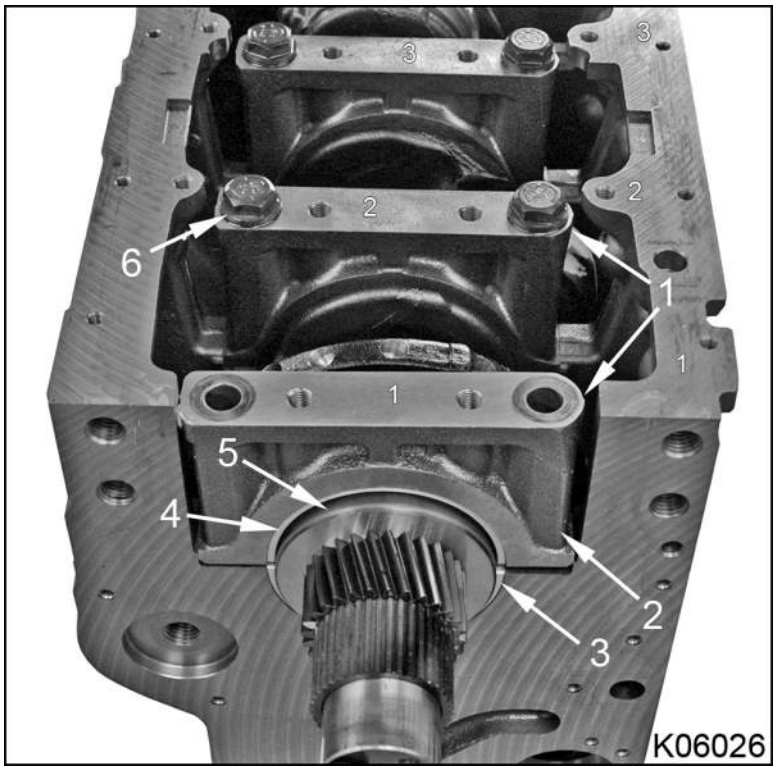


Figure 662 Main Bearings and Caps

1. Rounded end of main bearing caps
2. Main bearing cap #1 (front of engine)
3. Upper main bearing
4. Lower main bearing
5. Crankshaft #1 main bearing journal
6. M15 x 162 main bearing cap bolt (14)

CAUTION: To prevent engine damage, use new main bearing cap bolts whenever main bearing cap bolts that have been torqued to yield are removed.

NOTE: Thrust main bearing is only located on the crankcase number 7 upper main bearing saddle. All seven lower bearings are the same part number.

1. Clean all Plastigage and marker paste from main bearing and crankshaft journal surfaces.
2. Coat all main bearing journal surfaces with clean engine oil.
3. Lightly coat new main bearing cap bolts with clean engine oil (coat threads and under bolt head).

NOTE: Main bearing cap rounded ends go toward the cam or exhaust side of the crankcase. Match the upper and lower main bearing tabs on the cam side of the engine.

CAUTION: To prevent engine damage, match and orient each main bearing cap with its corresponding number stamped in the crankcase. Install #1 main bearing cap on the front main bearing journal and install remaining main bearing caps numbered from the front of the engine to the rear (number 7).

4. Install seven main bearing cap assemblies in their corresponding crankcase saddles. Make sure number on each bearing cap is correctly oriented and matches its corresponding number stamped in the crankcase.
5. Install fourteen new M15 x 162 main bearing cap bolts and finger tighten. See Torque Procedure

for Torque-to-yield Main Bearing Cap Bolts (page 498).

Torque Procedure for Torque-to-yield Main Bearing Cap Bolts

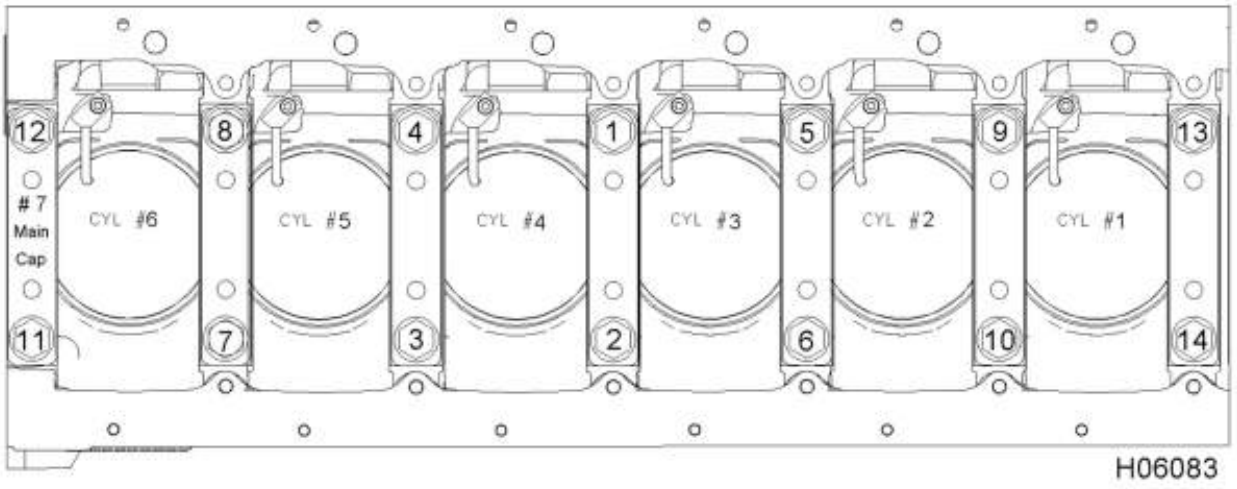


Figure 663 Main Bearing Cap Bolt Torque Sequence

1. Tighten each main bearing cap bolt to 136 N·m (100 lb·ft) using main bearing cap bolt torque sequence.
2. Measure crankshaft end play (page 487). Do not proceed to the next step in this procedure until end play is within Specification (page 505).
3. Tighten each main bearing cap bolt to 177 N·m (130 lb·ft) using main bearing cap bolt torque sequence.

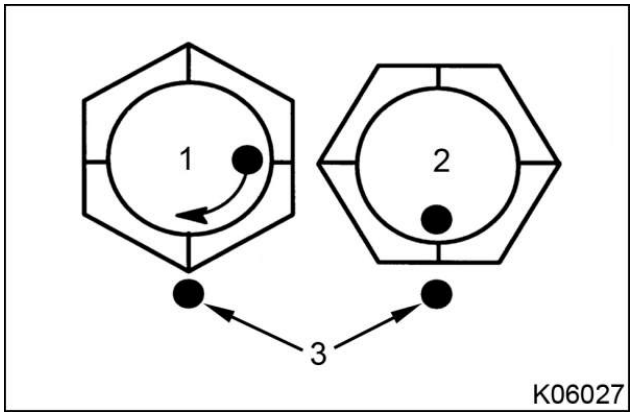


Figure 664 Main Bearing Cap Bolt Torque-to-Yield Marking

1. Head of main bearing cap bolt before Torque-to-yield
2. Head of main bearing cap bolt after Torque-to-yield
3. Mark on main bearing cap surface

CAUTION: To prevent engine damage, use new main bearing cap bolts whenever main bearing cap bolts that have been torqued to yield are removed.

CAUTION: To prevent engine damage, use permanent marker to identify internal engine components and their orientation. Do not use paint or temporary markers.

4. Using a permanent marker, place a mark on each new main bearing cap bolt and put another mark on the socket directly in line with the mark on each new main bearing cap bolt.
5. Put a mark on the main bearing cap surface 90° clockwise from each main bearing cap bolt mark.
6. Install socket on main bearing cap bolt to be torqued and align mark on socket with the mark on the main bearing cap bolt.
7. Torque-to-yield each main bearing cap bolt by rotating each bolt 90 degrees clockwise (1/4 turn). The marks on the socket, main bearing cap bolt, and main bearing cap surface should be aligned.

Crankcase Ladder Assembly

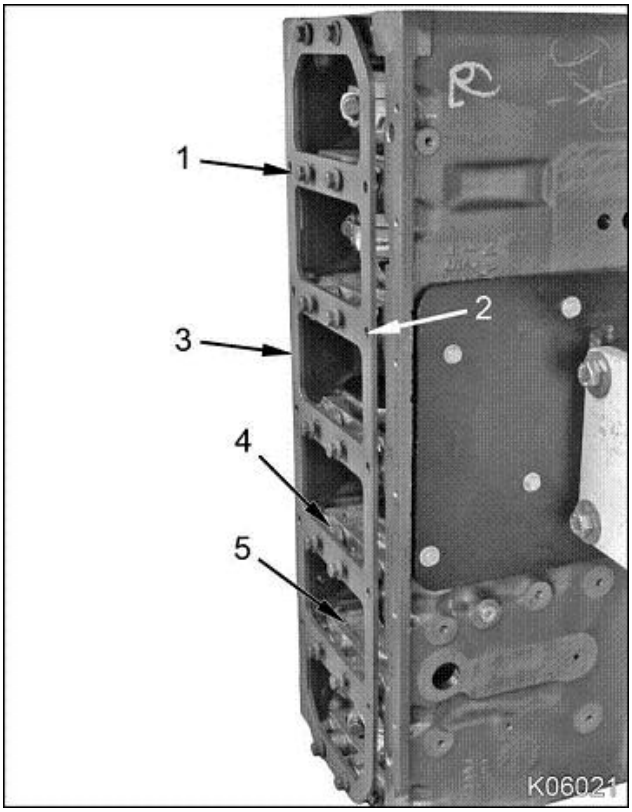


Figure 665 Crankcase Ladder Assembly

1. M12 x 35 bolt (14)
2. M10 x 25 bolt hole (10)
3. Crankcase ladder
4. Spacer (14)
5. Main bearing cap (7)

CAUTION: To prevent engine damage, the crankcase ladder side marked TOP must face away from the crankshaft.

1. Position 14 spacers over 14 main bearing cap bolt holes.
2. Position crankcase ladder assembly on the crankcase and over the spacers. Be sure to install crankcase ladder with the TOP embossing facing away from the crankshaft.
3. Install 14 M12 x 35 bolts through the ladder and spacers and into the main bearing cap bolt holes. Tighten bearing cap bolts finger tight.
4. Install ten M10 x 25 bolts through the ladder and into the crankcase and finger tighten.

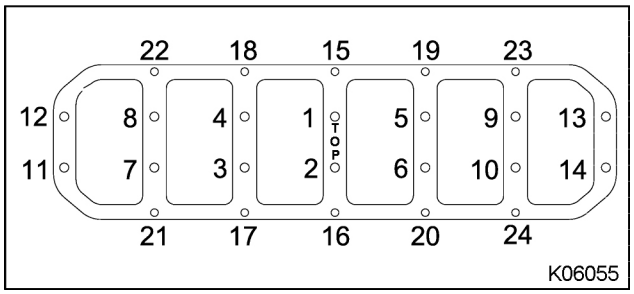


Figure 666 Crankcase Ladder Torque Sequence

5. Tighten 14 M12 x 35 bolts through crankcase ladder, numbers 1 through 14, in sequence to special torque (page 508).
6. Tighten ten M10 x 25 bolts through crankcase ladder, numbers 15 through 24, in sequence to special torque (page 508).

Coolant Heater Assembly (optional)

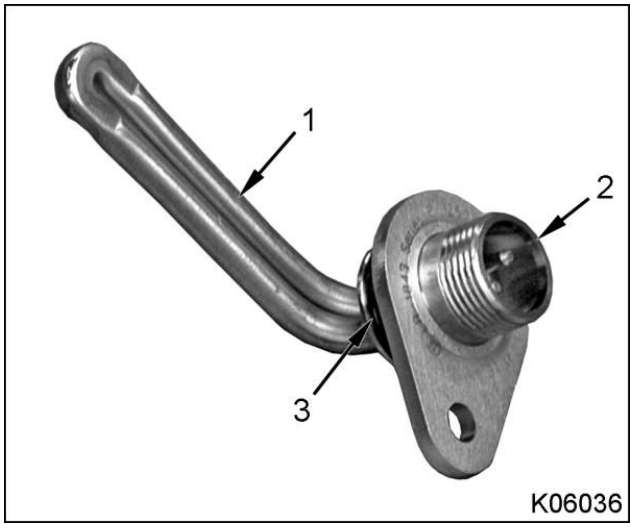


Figure 667 Coolant Heater Assembly

1. Heater element
2. Cord adaptor
3. O-ring

1. Lubricate a new O-ring with clean coolant and install on the coolant heater assembly.

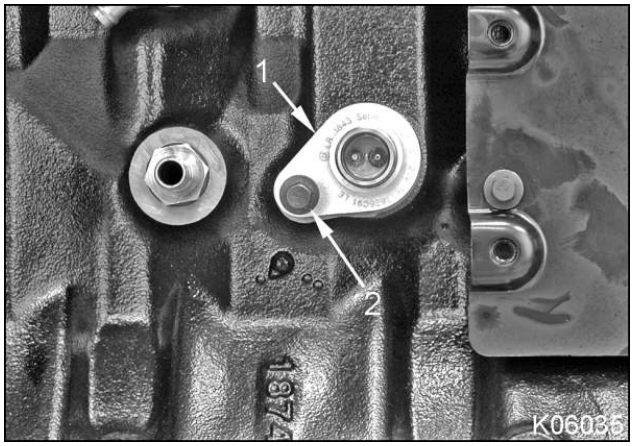


Figure 668 Coolant Heater (intake side of crankcase)

1. Coolant heater mounting flange
2. M8 x 20 bolt

2. Install coolant heater element into the crankcase. Press coolant heater mounting flange flush with crankcase mounting surface.
3. Tighten M8 x 20 bolt to standard torque (page 553).
4. Refill cooling system and check for leaks.

Oil Level Gauge Assembly



Figure 669 Oil Level Gauge Tube

1. If removed, install oil level gauge tube in crankcase. Apply Loctite® 277™ (page 509) around entire outside circumference of tube. Drive oil level gauge tube into crankcase until bead of tube is seated in chamfer of crankcase boss (tube orientation is not required).



Figure 670 Oil Filler Tube Support

1. M6 x 16 bolt
2. M8 nut (2)

NOTE: If oil filler tube support was removed, do steps 2 through 8. If oil filler tube support was not removed, go to step 5.

2. Install oil filler tube support and two M8 nuts on the fuel filter header assembly mounting studs.
3. Install M6 x 16 bolt and tighten to special torque (page 508).
4. Tighten two M8 nuts to special torque.

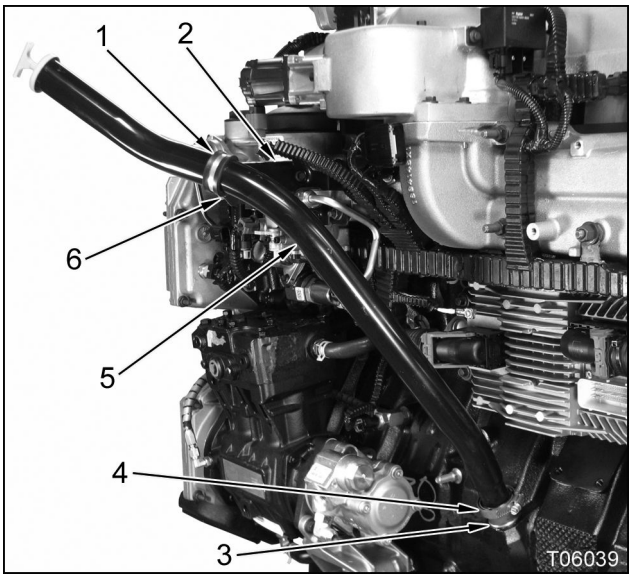


Figure 671 Oil Level Gauge Assembly

1. Cushioned clamp
2. Oil filler tube support
3. Oil level gauge tube
4. Tube clamp
5. Oil filler tube
6. M6 x 25 bolt and M6 nut

5. Install oil filler tube and tube clamp on the oil level gauge tube.
6. Install cushioned clamp on the oil filler tube and install the M6 x 25 bolt through the cushioned clamp and oil filler tube support. Install M6 nut on M6 x 25 bolt
7. Tighten tube clamp.
8. Tighten M6 x 25 bolt and nut to special torque (page 508).

Crankcase Ventilation System

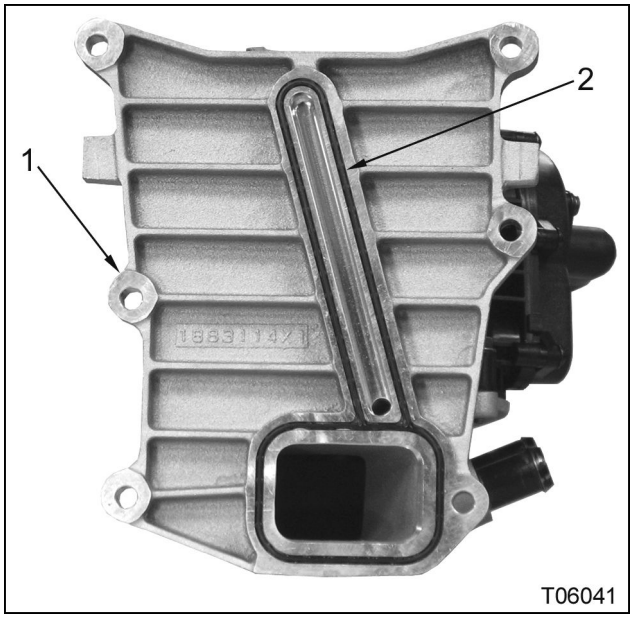


Figure 672 Crankcase Breather Assembly Back Plate and Seal

1. Housing assembly (turbine)
2. Breather to crankcase seal

1. Lubricate a new breather to crankcase seal with clean engine oil and install into the back plate of the crankcase breather assembly.

NOTE: Two different size bolts secure the crankcase breather assembly to the crankcase. There are three M8 x 30 bolts securing the two bottom and middle right side of the crankcase breather assembly as well as securing the coolant return tube supports. The other three bolts are M8 x 25, secure the crankcase breather assembly to the crankcase. The correct bolts must be placed in the correct locations to correctly secure the crankcase breather assembly to the crankcase.

2. Install crankcase breather assembly to the crankcase and secure with three M8 x 25 bolts. Finger tighten bolts.
3. Lubricate two new coolant return tube O-rings with clean coolant and install onto coolant return tube assembly ends.
4. Install the coolant return tube assembly into the oil cooler module and coolant supply housing.
5. Use the three M8 x 30 bolts and secure the coolant return tube supports and the crankcase breather assembly to the crankcase. Finger tighten bolts.
6. Tighten six M8 bolts, securing the crankcase breather to the crankcase, see special torque (page 508).

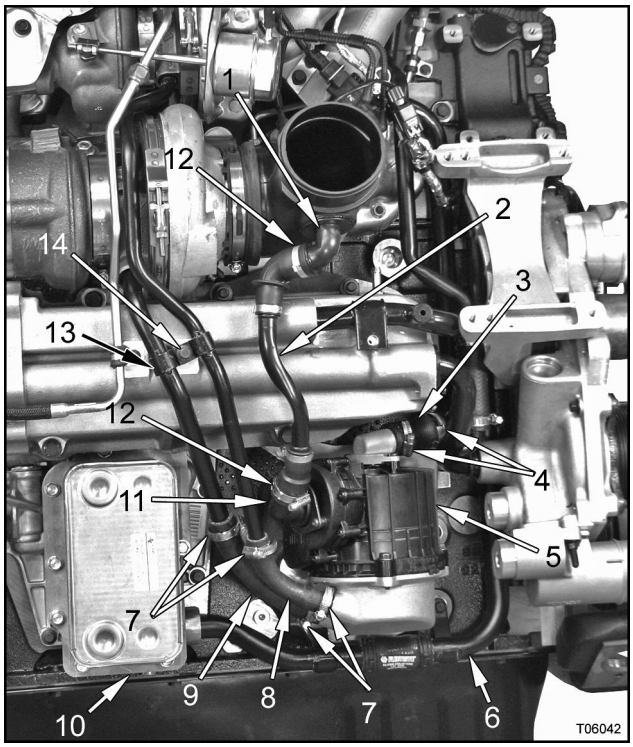


Figure 673 Crankcase Breather Assembly and Inlet Tube

1. Port elbow
2. Crankcase breather outlet tube
3. Crankcase breather inlet tube
4. Crankcase breather inlet tube hose clamp (2)
5. Crankcase breather assembly with turbine
6. Coolant return tube assembly (two tubes and interconnecting hose)
7. High and low-pressure turbo drain tube hose clamp (4)
8. High-pressure turbo drain hose
9. Low-pressure turbo drain hose
10. Oil cooler module
11. Breather elbow
12. Crankcase breather outlet tube hose clamp (2)
13. High and low-pressure turbo drain tube clamp
14. M8 x 25 bolt

7. Install new O-rings onto the high and low-pressure turbo drain tubes.
8. Install high and low-pressure turbo drain tubes into the high and low-pressure turbochargers.
9. Loosely place hose clamps over drain tubes and install both high and low-pressure turbo drain tubes onto hoses.
10. Tighten hose clamps securing high and low-pressure turbocharger drain tubes to hoses.
11. Install high and low-pressure turbo drain tube clamp over tube and secure to the EGR cooler with an M8 x 25 bolt. Finger tighten bolt.
12. Tighten M8 x 25 bolt to standard torque (page 553).
13. Loosely place hose clamp over the breather outlet tube. Install breather outlet tube onto port elbow.
14. Loosely place hose clamp over the breather outlet tube. Install breather outlet tube onto breather elbow.
15. Tighten both the port elbow and breather elbow hose clamps.
16. Loosely place hose clamp over breather inlet tube. Install breather inlet tube onto inlet elbow.
17. Tighten the inlet elbow hose clamp securing the inlet tube to the inlet elbow.

Centrifuge Oil Filter

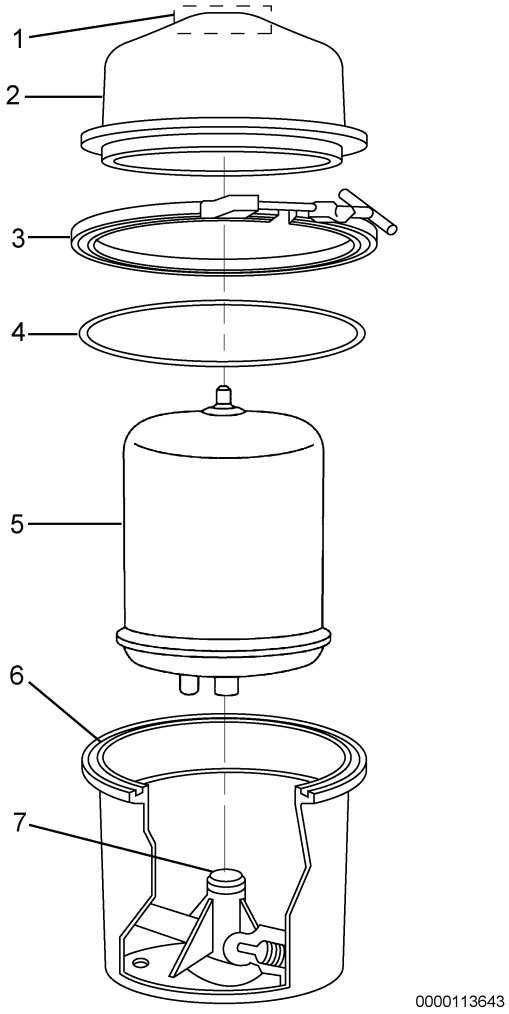


Figure 674 Centrifuge Oil Filter

1. Upper bearing
2. Cover assembly
3. Band clamp
4. Seal
5. Centrifuge oil filter
6. Body assembly
7. Lower bearing

NOTE: Ensure centrifuge oil filter assembly cleaning procedure has been performed before installation of new centrifuge oil filter.

1. Lubricate new seal with P-80® rubber lubricant or equivalent and install into upper O-ring groove.

2. Install new centrifuge oil filter into cover assembly by pressing rotor firmly to seat correctly.
3. Align centrifuge oil filter inlet with lower bearing in body assembly. Firmly press cover assembly with attached centrifuge oil filter into body assembly.
4. Position band clamp uniformly over cover assembly and body assembly flanges. Hand tighten band clamp handle.
5. Start engine and check centrifuge oil filter assembly for leaks.

Specifications

Crankcase Specifications

Main cap attachment	2 bolts per main cap
Main bearing type	Precision replaceable
Main bearing material	Steel-backed copper, lead, tin
Thrust taken by	Rear upper main bearing #7
Engine block heater rating	1250 W, 120 V
Center line of main bearing bore to head deck	368.3 ± 0.05 mm (14.50 ± 0.002 in)
Counterbore depth allowable variation between four points (maximum)	0.025 mm (0.001 in)
Counterbore depth in crankcase	8.865 ± 0.025 mm (0.349 ± 0.001 in)
Counterbore diameter in crankcase	136.14 + 0.381 – 0.127 mm (5.360 + 0.015 – 0.005 in)
Counterbore maximum allowable depth	9.25 mm (0.364 in)
Crankcase deck flatness	0.076 mm (0.003 in)
Crankcase main bearing bore diameter	116.421 ± 0.127 mm (4.5835 ± 0.005 in)
Piston cooling tube diameter (spray hole) MaxxForce® DT	2.18 mm (0.086 in)
Piston cooling tube diameter (spray hole) MaxxForce® 9 and 10	2.59 mm (0.102 in)
Roller tappet outside diameter	28.435 to 28.448 mm (1.1195 to 1.1200 in)
Sleeve protrusion above crankcase	0.051 to 0.127 mm (0.002 to 0.005 in)
Tappet bore diameter	28.5306 ± 0.01905 mm (1.12325 ± 0.00075 in)
Camshaft Bearing Bore Diameter in Crankcase:	
Front	63.5521 ± 0.01905 mm (2.50205 ± 0.00075 in)
Intermediate (2)	63.0238 ± 0.01905 mm (2.48125 ± 0.00075 in)
Rear	63.5521 ± 0.01905 mm (2.50205 ± 0.00075 in)

Camshaft Specifications

Camshaft bearing inner diameter (ID) (installed)	58.04 to 58.12 mm (2.285 to 2.288 in)
Cam lobe lift, exhaust	6.91 mm (0.272 in)
Cam lobe lift, intake	6.68 mm (0.263 in)
Camshaft end play	0.18 to 0.33 mm (0.007 to 0.013 in)
Camshaft journal diameter	57.96 to 57.99 mm (2.282 to 2.283 in)
Camshaft journal to bearing radial clearance	0.025 to 0.076 mm (0.001 to 0.003 in)
Maximum permissible cam lobe wear	0.25 mm (0.010 in)
Service bearings furnished to size	Yes
Thrust plate thickness (new)	6.96 to 7.01 mm (0.274 to 0.276 in)

Camshaft Bearing Specifications

Bearing Location	Outside Diameter (nominal)	Width (nominal)
Front	63.5 mm (2.50 in)	25.4 mm (1.00 in)
Rear	63.5 mm (2.50 in)	17.8 mm (0.70 in)
Intermediate	63.0 mm (2.48 in)	26.7 mm (1.05 in)

Crankshaft Specifications

Crankshaft	Forged steel, induction hardened, grindable
Number of main bearings	7
Thrust taken by	Number 7 rear upper main bearing
Main bearing journal diameter:	
Standard size	107.95 ± 0.015 mm (4.250 ± 0.0006 in)
0.254 mm (0.010 in) undersized	107.70 ± 0.015 mm (4.240 ± 0.0006 in)
0.508 mm (0.020 in) undersized	107.44 ± 0.015 mm (4.230 ± 0.0006 in)
0.762 mm (0.030 in) undersized	107.19 ± 0.015 mm (4.220 ± 0.0006 in)
Crankshaft journal waviness (maximum)	0.00381 mm (0.00015 in)
Crankshaft journal surface finish	0.00015 mm (0.000006 in)
NOTE: Grind all crankshaft journals against operating rotation (when looking at front end of crankshaft, operating rotation is clockwise). Lap all Journals with operating rotation, not more than 0.0127 mm (0.0005 in) stock to be removed by lapping.	
Thrust Bearing Journal Length:	
Standard size to 0.76 mm (0.030 in) undersized	34.404 ± 0.546 mm (1.3545 ± 0.0015 in)
Connecting rod journal diameter:	
Standard size	80.010 ± 0.015 mm (3.1500 ± 0.0006 in)
0.0254 mm (0.010 in) undersized	79.756 ± 0.015 mm (3.1400 ± 0.0006 in)
0.508 mm (0.020 in) undersized	79.502 ± 0.015 mm (3.1300 ± 0.0006 in)
0.762 mm (0.030 in) undersized	79.248 ± 0.015 mm (3.1200 ± 0.0006 in)

Crankshaft Specifications (continued)

Connecting rod bearing to crankshaft running clearance	0.030 to 0.107 mm (0.0012 to 0.0042 in)
Connecting rod bearing width	39.99 mm (1.5745 in)
Connecting rod journal maximum out-of-round	0.0064 mm (0.00025 in)
Connecting rod journal taper (maximum per inch)	0.0051 mm (0.0002 in)
Connecting rod to crankshaft side clearance	0.190 to 0.419 mm (0.0075 to 0.0165 in)
Crankshaft end play	0.152 to 0.305 mm (0.006 to 0.012 in)
Crankshaft end play maximum wear limit	0.51 mm (0.020 in)
Crankshaft flange outside diameter	155.58 mm (6.125 in)
Damper mounting surface runout (maximum)	0.0127 mm (0.0005 in)
Flywheel mounting surface runout (maximum)	0.05 mm (0.002 in)
Main bearing journal maximum out-of-round	0.00635 mm (0.00025 in)
Main bearing journal taper (maximum per inch)	0.0051 mm (0.0002 in)
Main bearing thrust face runout (TIR maximum)	0.026 mm (0.001 in)
Main bearing to crankshaft running clearance	0.046 to 0.127 mm (0.0018 to 0.0050 in)
Main bearing width (except rear thrust)	34.19 ± 0.13 mm (1.346 ± 0.005 in)
Rear oil seal journal runout (maximum)	0.08 mm (0.003 in)

Special Torque

Crankcase breather assembly to crankcase M8 x 25 and M8 x 30 bolts	27 N·m (20 lb·ft)
Crankcase ladder, M12 x 35	122 N·m (90 lb·ft)
Crankcase ladder, M10 x 25	63 N·m (46 lb·ft)
Main bearing cap bolt torque and sequence	See Torque Procedure for Torque-to-yield Main Bearing Cap Bolts (page 498)
M12 tee assembly	24 N·m (18 lb·ft)
Oil filler tube support bolt, M6 x 16	13.6 N·m (120 lb·in)
Oil filler tube support, M8 nuts	34 N·m (25 lb·ft)
Oil filler tube support, M6 x 25 bolt and M6 nut	13.6 N·m (120 lb·in)

Special Service Tools

Cam Gear Puller	ZTSE4411
Camshaft Bearing Puller	ZTSE2893B
Dial indicator set	Obtain locally
Dye penetrant kit	Obtain locally
Hot plate	Obtain locally
Loctite® 262	Obtain locally
Loctite® 277	Obtain locally
Outside micrometer	Obtain locally
Plastigage	Obtain locally
Prussian Blue	Obtain locally
Stiff Nylon Brush	ZTSE4392
Tap Set	ZTSE4386

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Abbreviations and Acronyms

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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 – Accelerator
ACD – Air Conditioner Demand
ACM – Aftertreatment Control Module
ACT PWR GND – Actuator Power Ground
ACV – Air Control Valve
A/F – Air to Fuel ratio
AFD – Aftertreatment Fuel Drain
AFI – Aftertreatment Fuel Injector
AFP – Aftertreatment Fuel Pressure
AFS – Aftertreatment Fuel Supply
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
APS – Accelerator Position Sensor
APS/IVS – Accelerator Position Sensor / Idle Validation Switch
ASTM – American Society for Testing and Materials
ATA – American Trucking Association
ATAH – American Trucking Association Link High
ATAL – American Trucking Association Link Low
ATDC – After Top Dead Center
AWG – American Wire Gauge
AWL – Amber Warning Lamp
B+ or VBAT – Battery Voltage
BAP or BARO – Barometric Absolute Pressure
BARO or BAP – Barometric Absolute Pressure
BBDC – Before Bottom Dead Center
BC – Body Controller
BCP – Brake Control Pressure
BCS – Boost Control Solenoid
BDC – Bottom Dead Center
bhp – Brake Horsepower
BNO – Brake Normally Open
BOO – Brake On / Off
BPP – Brake Pedal Position
BPS – Brake Pressure Switch
BSV – Brake Shut-off Valve
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
CCV – Coolant Control Valve
CCOSS – Crankcase Oil Separator Speed
CCPS – Crankcase Pressure Sensor
CCS – Cruise Control Switches
CDR – Crankcase Depression Regulator
cfm – Cubic feet per minute
cfs – Cubic feet per second
CFV – Coolant Flow Valve
CID – Cubic Inch Displacement
CKP – Crankshaft Position
CKPH – Crankshaft Position High
CKPL – Crankshaft Position Low
CKPO – Crankshaft Position Out
cm – Centimeter
CMP – Camshaft Position
CMPH – Camshaft Position High
CMPL – Camshaft Position Low
CMPO – Camshaft Position Out
CMV – Coolant Mixer Valve
CO – Carbon Monoxide
COO – Cruise On / Off switch
CPU – Central Processing Unit
CSFI – Cold Start Fuel Igniter
CSFS – Cold Start Fuel Solenoid
CSR – Cold Start Relay
CSS – Cold Start Solenoid

CTC – Coolant Temperature Compensation
Cyl – Cylinder

DB – Decibel
DC – Direct Current
DCA – Diesel Coolant Additive
DDI – Digital Direct Fuel Injection
DDS – Driveline Disengagement Switch
DLC – Data Link Connector
DME – Dimethyl Ether
DMM – Digital Multimeter
DOC – Diesel Oxidation Catalyst
DOCIT – Diesel Oxidation Catalyst Inlet Temperature
DOCOT – Diesel Oxidation Catalyst Outlet Temperature
DPF – Diesel Particulate Filter
DPFDP – Diesel Particulate Filter Differential Pressure
DPFIT – Diesel Particulate Filter Inlet Temperature
DPFOT – Diesel Particulate Filter Outlet Temperature
DSI – Down Stream Injection
DT – Diesel Turbocharged
DTC – Diagnostic Trouble Code
DTCs – Diagnostic Trouble Codes
DTRM – Diesel Thermo Recirculation Module

EBC – Exhaust Brake Controller
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
ECB3 – Engine Compression Brake 3
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
EFANS – Engine Fan Speed
EFC – Engine Fan Control
EFP – Engine Fuel Pressure
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
EIM – Engine Interface Module
ELS – Exhaust Lambda Sensor
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
EVB – Exhaust Valve Brake
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
HCI – Hydrocarbon Injection
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 – Intake Air Heater
IAHC – Intake Air Heater Control
IAHD – Intake Air Heater Diagnostic
IAHR – Intake Air Heater Relay
IAT – Intake Air Temperature
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
IDM – Injector Driver Module
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 Solutions
IST – Idle Shutdown Timer
ITP – Internal Transfer Pump
ITV – Intake Throttle Valve
ITVH – Intake Throttle Valve High control
ITVL – Intake Throttle Valve Low control
ITVP – Intake Throttle Valve Position
IVS – Idle Validation Swtich

J1939H – J1939 Data Link High
J1939L – J1939 Data Link Low
JCT – Junction (electrical)

kg – Kilogram
km – Kilometer
km/h – Kilometers per hour
km/l – Kilometers per liter
KOEO – Key-On Engine-Off
KOER – Key-On Engine-Running
kPa – Kilopascal

L – Liter
L/h – Liters per hour
L/m – Liters per minute
L/s – Liters per second
lb – Pound
lb – Pounds of force
lb/s – Pounds per second
lb ft – Pounds of force per foot
lb in – Pounds of force per inch
lbm – Pounds of mass
LPCAC – Low-pressure Charge Air Cooler
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
MAP/IAT – Manifold Absolute Pressure / Intake Air Temperature
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
RSE – Radiator Shutter Enable
RVAR – Remote Variable

SAE – Society of Automotive Engineers
SCA – Supplemental Cooling Additive
SCCS – Speed Control Command Switches
SCS – Speed Control Switch
SHD – Shield (electrical)
SID – Subsystem Identifier
SIG GND – Signal Ground
SIG GNDB – Signal Ground Body
SIG GNDC – Signal Ground Chassis
SIG GNDE – Signal Ground Engine
S/N – Serial Number
SPEEDO – Speedometer
SPN – Suspect Parameter Number
SW – Switch (electrical)
SWBAT – Switch Battery
SYNC – Synchronization

TACH – Tachometer output signal
TBD – To Be Determined
TC2CIS – Turbocharger 2 Compressor Inlet Sensor
TC2CIT – Turbocharger 2 Compressor Inlet Temperature
TC1TOP – Turbocharger 1 Turbine Outlet Pressure
TC2TOP – Turbocharger 2 Turbine Outlet Pressure
TC1WC – Turbocharger 1 Wastegate Control
TC2WC – Turbocharger 2 Wastegate Control
TCAPE – Truck Computer Analysis of Performance and Economy
TCM – Transmission Control Module
TCWC – Turbocharger Wastegate Control
TDC – Top Dead Center
TDE – Transmission Driving Engaged
TOP – Transmission Oil Pressure
TOSS – Transmission Output Shaft Speed
TOT – Transmission Oil Temperature
TTS – Transmission Tailshaft Speed

ULSD – Ultra-Low Sulfur Diesel
UVC – Under Valve Cover

V – Volt
VBAT or B+ – Battery Voltage
VC – Volume Control
VEPS – Vehicle Electronics Programming System
VGT – Variable Geometry Turbo
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

VSO or VSS_CAL – Vehicle Speed Output
VSS – Vehicle Speed Sensor
VSS_CAL or VSO – Vehicle Speed Output
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

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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 – See Charge Air Cooler.

Aftertreatment (AFT) system – A part of the exhaust system that processes engine exhaust to meet emission requirements and traps particulate matter (soot) to prevent it from leaving the tailpipe.

Aftertreatment Fuel Doser (AFTFD) – A part of the Downstream Injection (DSI) unit that sends pressurized fuel to the Aftertreatment Fuel Injector (AFI) to inject fuel into the exhaust pipe.

Aftertreatment Fuel Inlet Sensor (AFTFIS) – A sensor that monitors fuel temperature in the DSI system and provides constant feedback to the ECM.

Aftertreatment Fuel Pressure 2 Sensor (AFTP2) – A sensor that monitors fuel pressure in the DSI system and provides constant feedback to the ECM.

Aftertreatment Fuel Shutoff Valve (AFTFSV) – A valve used to prevent fuel flow to the Aftertreatment Fuel Injector (AFI), and prevents all uncontrolled fuel delivery for the Aftertreatment system during an AFTFD valve malfunction.

Air Control Valve (ACV) – Contains the LP turbocharger wastegate control port, HP turbocharger wastegate control port, the EBPV control port, and the TC1TOP port. Although these components are integral to the ACV, each circuit is controlled by the ECM. The ACV controls compressed air for each control valve.

Air Inlet Temperature (AIT) sensor – A thermistor sensor that monitors intake air temperature.

Ambient Air Temperature (AAT) sensor – A sensor that sends an ambient air temperature signal to the ECM.

Ambient temperature – The environmental air temperature in which a unit is operating. In general, the temperature is measured in the shade (no solar radiation) and represents the air temperature for other engine cooling performance measurement purposes. Air entering the radiator may or may not be the same ambient due to possible heating from other sources or recirculation. (SAE J1004 SEP81)

American Trucking Association (ATA) Datalink – A serial datalink specified by the American Trucking Association and the SAE.

Ampere (amp) – The standard unit for measuring the strength of an electrical current. The flow rate of a charge in a conductor or conducting medium of one coulomb per second. (SAE J1213 NOV82)

Analog – A continuously variable voltage.

Analog to digital converter (A/D) – A device in the ECM that converts an analog signal to a digital signal.

Barometric Absolute Pressure (BAP) sensor – A sensor built into the ECM that provides barometric pressure information to the ECM.

Boost pressure – 1. The pressure of the charge air leaving the turbocharger.

2. Inlet manifold pressure that is greater than atmospheric pressure. Obtained by turbocharging.

Bottom Dead Center (BDC) – The lowest position of the piston during the stroke.

Brake Horsepower (bhp) – The power output from an engine, not the indicated horsepower. The power output of an engine, sometimes-called flywheel horsepower, is less than the indicated horsepower by the amount of friction horsepower consumed in the engine.

Brake Horsepower (bhp) net – Net brake horsepower is measured with all engine components. The power of an engine when configured as a fully equipped engine. (SAE J1349 JUN90)

Brake On/Off (BOO) switch – A switch located on the brake pedal lever, that provides a brake pedal position signal to the ECM.

Brake Pressure Switch (BPS) – A switch located in the brake pressure line that provides a brake pedal position signal to the ECM.

Calibration – ECM programming strategy to solve engine performance equations and make decisions. Calibration values are stored in ROM and put into the processor during programming to allow the engine to operate within certain parameters.

Camshaft Position (CMP) sensor – A magnetic pickup sensor that provides the ECM with a camshaft speed and position signal.

Carbon Monoxide (CO) – A colorless, odorless, highly poisonous gas that is formed by the incomplete combustion of carbon burning diesel engine. It is present in the exhaust gases of diesel engines.

Catalyst – A substance that produces a chemical reaction without undergoing a chemical change itself.

Catalytic converter – An antipollution device in the exhaust system that contains a catalyst for chemically converting some pollutants in the exhaust gases (carbon monoxide, unburned hydrocarbons, and oxides of nitrogen) into harmless compounds.

Cavitation – A dynamic condition in a fluid system that forms gas-filled bubbles (cavities) in the fluid.

Cetane number – 1. The auto-ignition quality of diesel fuel.

2. A rating applied to diesel fuel similar to octane rating for gasoline.

3. A measure of how readily diesel fuel starts to burn (self-ignites) at high compression temperature.

Diesel fuel with a high cetane number self-ignites shortly after injection into the combustion chamber. Therefore, it has a short ignition delay time. Diesel fuel with a low cetane number resists self-ignition. Therefore, it has a longer ignition delay time.

Charge air – Dense, pressurized, heated air discharged from the turbocharger.

Charge Air Cooler (CAC) – A heat exchanger mounted in the charge air path between the turbocharger and engine intake manifold. The charge air cooler reduces the charge air temperature by transferring heat from the charge air to a cooling medium (usually air).

Charge Air Cooler Outlet Temperature (CACOT) sensor – A thermistor sensor that monitors the temperature of charge air entering the intake air duct.

Closed crankcase – A crankcase ventilation that recycles crankcase gases through a breather, then back to the clean air intake.

Closed loop operation – A system that uses sensors to provide feedback to the ECM. The ECM uses the sensor input to continuously monitor variables and adjust actuators to match engine requirements.

Cloud point – The point when wax crystals occur in fuel, making fuel cloudy or hazy. Usually below -12°C (10°F).

Cold cranking ampere rating (battery rating) – The sustained constant current (in amperes) needed to produce a minimum terminal voltage under a load of 7.2 volts per battery after 30 seconds.

Cold Start Fuel Igniter (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 Flow Valve (CFV) – The CFV is ECM controlled and redirects coolant through the fuel cooler, based on EFT, when directed.

Coolant level switch – A switch sensor used to monitor coolant level.

Coolant Mixer Valve (CMV) – Controls coolant flow through the low-temperature radiator.

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.

Cruise Control Switches (CCS) – A set of switches used for cruise control, Power TakeOff (PTO), and remote hand throttle system.

Current – The flow of electrons passing through a conductor. Measured in amperes.

Cylinder Balance – An ECM control strategy to even-out the power contributions of each power cylinder.

Damper – A device that reduces the amplitude of torsional vibration. (SAE J1479 JAN85)

Deaeration – The removal or purging of gases (air or combustion gas) entrained in coolant or lubricating oil.

Deaeration tank – A separate tank in the coolant system used for one or more of the following functions:

- Deaeration
- Coolant reservoir (fluid expansion and afterboil)
- Coolant retention
- Filling
- Fluid level indication (visible)

Diagnostic Trouble Code (DTC) – 2010 model year vehicles no longer utilize DTC identification by number. DTCs are now identified using the Suspect Parameter Number (SPN) and Failure Mode Indicator (FMI) identifiers only.

Diamond Logic Builder (DLB) – The diagnostics software for chassis related components and systems.

Diesel Oxidation Catalyst (DOC) – A DOC is part of the diesel exhaust Aftertreatment system. DOCs are devices that use a chemical process to break down pollutants in the exhaust stream into less harmful components. More specifically, DOCs utilize rare metals such as palladium and platinum to reduce hydrocarbon based Soluble Organic Fraction (SOF) and carbon monoxide content of diesel exhaust by simple oxidation. The DOC can be used during an active regeneration to create higher exhaust temperatures, thereby reducing soot in the DPF.

Diesel Oxidation Catalyst Inlet Temperature sensor (DOCIT) – A sensor that provides DOC inlet temperature signal to the ECM.

Diesel Particulate Filter (DPF) – A diesel particulate filter, sometimes called a DPF, is a device designed to remove diesel particulate matter or soot from the exhaust gas of a diesel engine.

Diesel Particulate Filter Differential Pressure (DPFDP) sensor – A sensor that measures pressure difference between the inlet and outlet of the DPF and provides feedback to the ECM.

Diesel Particulate Filter Inlet Temperature sensor (DPFIT) – A sensor that provides DOC inlet temperature signal to the ECM.

Diesel Particulate Filter Outlet Temperature sensor (DPFOT) – A sensor that provides DOC outlet temperature signal to the ECM.

Digital Multimeter (DMM) – An electronic meter that uses a digital display to indicate a measured value. Preferred for use on microprocessor systems because it has a very high internal impedance and will not load down the circuit being measured.

Disable – A computer decision that deactivates a system and prevents operation of the system.

Displacement – The stroke of the piston multiplied by the area of the cylinder bore multiplied by the number of cylinders in the engine.

Down Stream Injection (DSI) – The DSI system injects fuel into the exhaust system to increase temperature of the exhaust gases, and is necessary for DPF regeneration.

Driver (high side) – A transistor within an electronic module that controls the power to an actuator circuit.

Driver (low side) – A transistor within an electronic module that controls the ground to an actuator circuit.

Dual Stage Turbocharger – An assembly of two turbochargers (low-pressure and high-pressure) in series to provide a wide range of charge air pressures efficiently.

Duty cycle – A control signal that has a controlled on/off time measurement from 0 to 100%. Normally used to control solenoids.

EGR Cooler – A cooler that allows heat to dissipate from the exhaust gasses before they enter the intake manifold.

Engine Back Pressure Valve (EBPV) – The ECM commands the EBPV to control the Exhaust Brake.

Engine Compression Brake (ECB) valve – The ECB valve controls pressure entering the brake oil gallery from the high-pressure oil rail gallery. This activates the brake actuator pistons and opens the exhaust valves.

Engine Compression Brake 1 (ECB1) solenoid – The ECB1 solenoid controls pressure entering the brake oil gallery from the high-pressure oil rail gallery.

Engine Compression Brake 2 (ECB2) solenoid – The ECB2 solenoid controls pressure entering the brake oil gallery from the high-pressure oil rail gallery.

Engine Compression Brake Pressure (ECBP) sensor – A high-pressure sensor that provides a feedback signal to the ECM indicating brake control pressure.

Engine Control Module (ECM) – An electronic processor that monitors and controls the engine.

Engine Coolant Level (ECL) sensor – A switch sensor that monitors coolant level.

Engine Coolant Temperature 1 (ECT1) sensor – A thermistor sensor that detects engine coolant temperature.

Engine Coolant Temperature 2 (ECT2) sensor – A thermistor sensor that detects engine coolant temperature.

Engine Fuel Temperature (EFT) sensor – A thermistor sensor that measures fuel temperature.

Engine lamp – An instrument panel lamp that comes on when DTCs are set. DTCs can be read as flash codes (red and amber instrument panel lamps).

Engine OFF tests – Tests that are done with the ignition switch ON and the engine OFF.

Engine Oil Pressure (EOP) sensor – A variable capacitance sensor that measures oil pressure.

Engine Oil Temperature (EOT) sensor – A thermistor sensor that measures oil temperature.

Engine rating – Engine rating includes **Rated hp** and **Rated rpm**.

Engine RUNNING tests – Tests done with the engine running.

Engine Throttle Valve (ETV) and Engine Throttle Position Sensor – The ETV valve is used to control airflow during a regeneration process of the aftertreatment system. The ETV valve is also used to ensure a smooth engine shut down by restricting airflow to the engine at shut down.

Engine Warning Protection System (EWPS) – Safeguards the engine from undesirable operating conditions to prevent engine damage and to prolong engine life.

Exhaust Back Pressure (EBP) – The pressure present in the exhaust system during the exhaust period.

Exhaust Back Pressure Valve (EBPV) – A valve that regulates the amount of air pressure applied to the EBPV pneumatic actuator.

Exhaust brake – A brake device using engine exhaust back pressure as a retarding medium.

Exhaust Gas Recirculation (EGR) – A system used to recirculate a portion of the exhaust gases into the power cylinder in order to reduce oxides of nitrogen.

Exhaust Gas Recirculation Temperature (EGRT) sensor – A thermistor sensor that detects the exhaust gas temperature entering the EGR cooler.

Exhaust Gas Recirculation (EGR) valve – The EGRV controls the flow of exhaust gases to the intake manifold. The EGRV is integrated with an EGR Position (EGRP) sensor.

Exhaust Gas Temperature (EGT) – The temperature of exhaust gases.

Exhaust manifold – Exhaust gases flow through the exhaust manifold to the turbocharger exhaust inlet and are directed to the EGR cooler.

Exhaust Manifold Pressure (EMP) sensor – A variable capacitance sensor used to indicate air pressure in the exhaust manifold.

Exhaust Manifold Temperature (EMT) sensor – A thermistor style sensor used to indicate air temperature in the exhaust manifold.

Failure Mode Indicator (FMI) – Identifies the fault or condition effecting the individual component.

Fault detection/management – An alternate control strategy that reduces adverse effects that can be caused by a system failure. If a sensor fails, the ECM substitutes a good sensor signal or assumed sensor value in its place. A lit amber instrument panel lamp signals that the vehicle needs service.

Filter restriction – A blockage, usually from contaminants, that prevents the flow of fluid through a filter.

Flash code – See **Diagnostic Trouble Code (DTC)**.

Fuel Cooler Control Valve – A valve used to redirect coolant through the fuel cooler.

Fuel Delivery Pressure (FDP) sensor – A variable capacitance sensor that monitors fuel pressure coming from the fuel tank and sends a signal to the ECM.

Fuel inlet restriction – A blockage, usually from contaminants, that prevents the flow of fluid through the fuel inlet line.

Fuel pressure – The force fuel exerts on the fuel system as it is pumped through the fuel system.

Fuel Pressure Control Valve (FPCV) – The FPCV controls the fuel pressure to the fuel rails and is controlled by the ECM. FPCV control depends on fuel pressure and fuel temperature.

Fuel Rail Pressure (FRP) – The amount of pressure in the fuel rail.

Fuel Rail Pressure (FRP) sensor – A variable capacitance sensor that monitors fuel pressure in the fuel rail and sends a signal to the ECM.

Fuel strainer – A pre-filter in the fuel system that keeps larger contaminants from entering the fuel system.

Fuel Volume Control Valve (FVCV) – The FVCV regulates the volume of flow sent to the HPFP. The FVCV allows a sufficient quantity of fuel to be delivered to the HPFP depending on engine load, speed, injector quantity, fuel temperature, and number of injections per cycle.

Fully equipped engine – A fully equipped engine is an engine equipped with only those accessories necessary to perform its intended service. A fully equipped engine does not include components that are used to power auxiliary systems. If these components are integral with the engine or, for any reason are included on the test engine, the power absorbed may be determined and added to the net brake power. (SAE J1995 JUN90)

Fusible link (fuse link) – A fusible link is a special section of low tension cable designed to open the circuit when subjected to an extreme current overload. (SAE J1156 APR86)

Gradeability – The maximum percent grade, which the vehicle can transverse for a specified time at a specified speed. The gradeability limit is the grade upon which the vehicle can just move forward. (SAE J227a)

Gross 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 Injector – Injects fuel into the exhaust system to increase temperature of the exhaust gases.

Idle Shutdown Timer (IST) – An engine calibration that allows the ECM to shut down the engine during extended engine idle times.

Injection Control Pressure (ICP) sensor – Provides a feedback signal to the ECM indicating injection control pressure.

Injection Pressure Regulator (IPR) valve – A valve that is used to maintain desired injection control pressure.

Intake Air Heater (IAH) – The IAH is primarily used to assist in starting the engine during cold weather. In addition, it helps to reduce white smoke emissions by heating the incoming air.

Intake manifold – Engine component that evenly supplies air to each intake port in the cylinder head(s).

Intake Manifold Pressure (IMP) sensor – A variable capacitance sensor used to indicate air pressure in the intake manifold.

Intake Manifold Temperature (IMT) sensor – A thermistor sensor used to indicate air temperature in the intake manifold.

Internal Transfer Pump (ITP) – The ITP is part of the HPFP assembly and driven off the same shaft as the HPFP assembly. The ITP supplies fuel at a slightly higher pressure and flow to the HPFP though the Fuel Volume Control Valve (FVCV). The ITP also provides fuel for cooling and lubrication of the HPFP. Fuel is rerouted as pump return flow through the HPFP cooling and lubrication valve. Pressure is maintained at the inlet of the HPFP piston pump by an ITP regulator.

Interstage Cooler (ISC) – Uses cooled coolant to lower the charged air temperature that exits from the turbocharger low-pressure compressor and enters the turbocharger high-pressure compressor.

Low speed digital inputs – Switched sensor inputs that generate an on/off (high/low) signal to the ECM. The input to the ECM from the sensor could be from a high input source switch (usually 5 or 12 volts) or from a grounding switch that grounds the signal from a current limiting resistor in the ECM that creates a low signal (0 volts).

Low temperature radiator thermostat – Coolant flow to the low temperature radiator is regulated by the low temperature radiator thermostat.

Lubricity – Lubricity is the ability of a substance to reduce friction between solid surfaces in relative motion under loaded conditions.

Lug (engine) – A condition when the engine is run at an overly low RPM for the load being applied.

Malfunction Indicator Lamp (MIL) – An indicator lamp in the Electronic Instrument Cluster that will illuminate when a detected emissions fault occurs.

Manifold Absolute Pressure (MAP) – Boost pressure in the manifold that is a result of the turbocharger.

Manifold Absolute Pressure (MAP) sensor – A variable capacitance sensor that measures boost pressure.

Manometer – A double-leg liquid-column gauge, or a single inclined gauge, used to measure the difference between two fluid pressures. Typically, a manometer records in inches of water.

Mass 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.

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 Aftertreatment Fuel Injector (AFI).

Microprocessor – An integrated circuit in a microcomputer that controls information flow.

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

Nitrogen Oxides (NO_x) – Nitrogen oxides form by a reaction between nitrogen and oxygen at high temperatures and pressures in the combustion chamber.

Normally closed – Refers to a switch that remains closed when no control force is acting on it.

Normally open – Refers to a switch that remains open when no control force is acting on it.

Ohm (Ω) – The unit of electrical resistance. One ohm is the value of resistance through which a potential of one volt will maintain a current of one ampere. (SAE J1213 NOV82)

On demand test – A self-test the technician initiates using the EST that is run from a program in the software.

Output Circuit Check (OCC) – An on-demand test done during an Engine OFF self-test to check the continuity of selected actuators.

Output Shaft Speed (OSS) sensor – A sensor mounted to the rear of the transmission that supplies a vehicle speed signal to the ECM. The ECM uses this signal to control PTO, road speed limiting, and cruise control. Automatic transmissions use this signal for shift scheduling.

Oxides of Nitrogen (NOx) – Nitrogen oxides formed by a reaction between nitrogen and oxygen at high temperatures.

Oxygen Sensor (O2S) – A sensor that monitors oxygen levels in the exhaust.

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.

Radiator Shutter Enable (RSE) – A feature that uses various input signals to open or close radiator shutters by energizing or de-energizing a solenoid that controls an air or hydraulic cylinder.

Random Access Memory (RAM) – Computer memory that stores information. Information can be written to and read from RAM. Input information (current engine speed or temperature) can be stored in RAM to be compared to values stored in Read Only Memory (ROM). All memory in RAM is lost when the ignition switch is turned off.

Rated gross horsepower – Engine gross horsepower at rated speed as declared by the manufacturer. (SAE J1995 JUN90)

Rated horsepower – Maximum brake horsepower output of an engine as certified by the engine manufacturer. The power of an engine when configured as a basic engine. (SAE J1995 JUN90)

Rated net horsepower – Engine net horsepower at rated speed as declared by the manufacturer. (SAE J1349 JUN90)

Rated speed – The speed, as determined by the manufacturer, at which the engine is rated. (SAE J1995 JUN90)

Rated torque – Maximum torque produced by an engine as certified by the manufacturer.

Ratiometric Voltage – In a Micro Strain Gauge (MSG) sensor, pressure to be measured exerts force on a pressure vessel that stretches and compresses to change resistance of strain gauges bonded to

the surface of the pressure vessel. Internal sensor electronics convert the changes in resistance to a ratiometric voltage output.

Reference voltage (V_{REF}) – A 5 volt reference supplied by the ECM to operate the engine sensors.

Regeneration – Oxidation of accumulated soot (carbon-based particulates) in the Diesel Particulate Filter (DPF). The soot is reduced to ash and stored in the PDF.

Remote Accelerator Pedal Position (RAPP) – A feature that allows the operator to set and maintain a constant engine speed from outside the vehicle cab. This feature may also be known as Remote Engine Speed Control (RESC). Control over engine speed is accomplished by using remote mounted switches to turn on the RESC and select the desired engine speed.

Remote Engine Speed Control (RESC) – See Remote Accelerator Pedal Position.

Reserve capacity – Time in minutes that a fully charged battery can be discharged to 10.5 volts at 25 amperes.

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

ServiceMaxx™ software – Diagnostics software for engine related components and systems.

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

Signal ground – The common ground wire to the ECM for the sensors.

Speed Control Command Switches (SCCS) – A set of switches used for cruise control, Power TakeOff (PTO), and remote hand throttle system.

Starter Motor Control (SMC) – An ECM function that prevents starter engagement while the engine is running (above a set calibrated rpm), when the automatic transmission is in gear, or when the manual transmission clutch pedal is not depressed.

Steady state condition – An engine operating at a constant speed and load and at stabilized temperatures and pressures. (SAE J215 JAN80)

Strategy – A plan or set of operating instructions that the microprocessor follows for a desired goal. Strategy is the computer program itself, including all equations and decision making logic. Strategy is always stored in ROM and cannot be changed during calibration.

Stroke – The movement of the piston from Top Dead Center (TDC) to Bottom Dead Center (BDC).

Substrate – Material that supports the wash coating or catalytic materials.

Suspect Parameter Number (SPN) – A 19-bit number used to identify the item for which diagnostics are being reported. The SPN is used for multiple purposes, some that are specific to diagnostics are as follows;

- Identify the least repairable subsystem that has failed.
- Identify subsystems or assemblies that may not have hard failures but may be exhibiting abnormal operating performance.
- Identify a particular event or condition that will be reported.
- Report a component and non-standard failure mode.

System restriction (air) – The static pressure differential that occurs at a given airflow from air entrance through air exit in a system. Usually measured in inches (millimeters) of water. (SAE J1004 SEP81)

Tachometer output signal – Engine speed signal for remote tachometers.

Thermistor – A semiconductor device. A sensing element that changes resistance as the temperature changes.

Thermistor Sensor – Changes electrical resistance with changes in temperature. Resistance in the thermistor decreases as temperature increases, and increases as temperature decreases. Thermistors work with a resistor that limits current to form a voltage signal matched with a temperature value.

Thrust load – A thrust load pushes or reacts through a bearing in a direction parallel to the shaft.

Top Dead Center (TDC) – The uppermost position of the piston during the stroke.

Torque – A force having a twisting or turning effect. For a single force, the cross product of a vector from some reference point to the point of application of the force within the force itself. Also known as moment of force or rotation moment. Torque is a measure of the ability of an engine to do work.

Truck Computer Analysis of Performance and Economy (TCAPE) – A computer program that simulates the performance and fuel economy of trucks.

Turbocharger – A turbine driven compressor mounted on the exhaust manifold. The turbocharger increases the pressure, temperature and density of intake air to charge air.

Turbocharger 1 Turbine Outlet Pressure (TC1TOP) sensor – A variable capacitance sensor that monitors exhaust back-pressure.

Turbocharger 2 Compressor Inlet (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 2 Compressor Inlet Temperature (TC2CIT) sensor – The TC2CIT sensor is a thermistor-based sensor that monitors the temperature of charge air entering the HP turbocharger.

Turbocharger Outlet Temperature (TCOT) sensor – A sensor that provides a turbocharger outlet temperature signal to the ECM.

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 Output (VSO) – A vehicle speed signal sent to the EGC through the J1939 network.

Vehicle Speed Sensor (VSS) – Normally a magnetic pickup sensor mounted in the tailshaft housing of the transmission, used to indicate ground speed.

Viscosity – The internal resistance to the flow of any fluid.

Viscous fan – A fan drive that is activated when a thermostat, sensing high air temperature, forces fluid through a special coupling. The fluid activates the fan.

Volt (v) – A unit of electromotive force that will move a current of one ampere through a resistance of one Ohm.

Voltage – Electrical potential expressed in volts.

Voltage drop – Reduction in applied voltage from the current flowing through a circuit or portion of the circuit current multiplied by resistance.

Voltage ignition – Voltage supplied by the ignition switch when the key is ON.

Washcoat – A layer of alumina applied to the substrate in a monolith-type converter.

Water In Fuel (WIF) sensor – A switch sensor that measures the amount of water in the fuel.

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Specifications

Fuel and High-Pressure Oil Systems

250 Watt fuel heater switching points	On: 7 °C (44.6 °F)
	Off: 21 °C (69.8 °F)
Fuel pressure regulator assembly opening pressure	586 to 655 kPa (85 to 95 psi)
Fuel strainer element	150 micron
High-pressure oil manifold pressure range	5 to 32 MPa (725 to 4,650 psi)
High-pressure pump assembly end play	0.127 to 0.457 mm (0.005 to 0.018 in)

Engine Brake

Brake actuator lash (cold)	0.48 mm (0.019 in)

Air Compressor and Power Steering Pump

Lower idler gear to air compressor gear backlash	0.508 mm (0.020 in)

Oil System Module Assembly

Oil cooler, all engines with front drive axle	33 plates
Oil cooler, MaxxForce® DT	23 plates
Oil cooler, MaxxForce® 9 and 10	33 plates
Oil pressure regulator valve, opening pressure	393 kPa (57 psi) @ 38 °C (100 °F)
Thermal valve, opening pressure	206 - 241 kPa (30 - 35 psi) @ 111 °C (232 °F)

Oil Pan and Oil Suction Tube

Lube system capacity (after rebuild and new filter)	32 L (34 quarts US)
Lube system capacity (after oil drain and filter change)	28 L (30 quarts US)

Front Cover, Cooling System, and Related Components

Camshaft gear to upper idler gear maximum backlash	0.312 mm (0.012 in)
High-pressure oil pump end play	0.127 to 0.457 mm (0.005 to 0.018 in)
Lower idler gear to air compressor gear maximum backlash	0.310 mm (0.012 in)
Lower idler gear to crankshaft gear maximum backlash	0.338 mm (0.013 in)
Oil pump end clearance	0.05 to 0.13 mm (0.002 to 0.005 in)
Oil pump side clearance	0.48 to 0.62 mm (0.019 to 0.024 in)
Upper idler gear to high-pressure oil pump gear maximum backlash	0.342 mm (0.013 in)
Upper idler gear to lower idler gear maximum backlash	0.310 mm (0.012 in)
Vibration damper face runout (maximum)	1.52 mm (0.060 in)

Water Pump Pulley Diameters and Spin Ratios

Engine	Pulley Diameter	Spin Ratio
MaxxForce® DT 215 – 230 BHP	15.54 cm (6.12 in)	1.40: 1
MaxxForce® DT 245 – 260 BHP	13.93 cm (5.48 in)	1.55: 1
MaxxForce® DT 270 – 300 BHP	13.93 cm (5.48 in)	1.55: 1
MaxxForce® 9 and 10	12.54 cm (4.94 in)	1.73: 1

Fan Drive Configurations Diameters and Ratios (Spin-on)

		Fan Center Line (CL)			
Fan Drive Configuration	**Engine**	**Vertical above Crank**	**Lateral Offset (toward turbo)**	**Pulley Diameter**	**Fan Drive Ratio**
Spin-on 11” fan center	MaxxForce® DT	279.4 mm (11 in)	none	200.66 mm (7.9 in)	1.08 : 1
Spin-on 13” fan center	MaxxForce® DT	330.2 mm (13 in)	25.4 mm (1 in)	201.2 mm (7.92 in)	1.08 : 1
Spin-on 14.3” fan center	MaxxForce® DT	363.22 mm (14.3 in)	none	218.95 mm (8.62 in)	0.99 : 1
Spin-on 14.3” fan center	MaxxForce® DT	363.22 mm (14.3 in)	none	200.66 mm (7.9 in)	1.08 : 1
Spin-on 16.2” fan center	MaxxForce® DT	411.5 mm (16.2 in)	95.3 mm (3.75 in)	219.5 mm (8.64 in)	0.99 : 1
Spin-on 16.2” fan center	MaxxForce® DT	411.5 mm (16.2 in)	95.3 mm (3.75 in)	201.2 mm (7.92 in)	1.08 : 1
Spin-on 20” fan center	MaxxForce® DT	508 mm (20 in)	none	21.95 cm (8.64 in)	0.99 : 1

Fan Drive Configurations Diameters and Ratios (DriveMaster®) — Single Drive Belt

		Fan Center Line (CL)			
Fan Drive Configuration	**Engine**	**Vertical above Crank**	**Lateral Offset (toward turbo)**	**Pulley Diameter**	**Fan Drive Ratio**
Horton DriveMaster® 11” fan center	MaxxForce® DT	279.4 mm (11 in)	none	200.66 mm (7.9 in)	1.08 : 1
Horton DriveMaster® 13” fan center	MaxxForce® DT	330.2 mm (13 in)	25.4 mm (1 in)	20.12 cm (7.92 in)	1.08 : 1
Horton DriveMaster® 14.3” fan center	MaxxForce® DT	363.22 mm (14.3 in)	none	218.95 mm (8.62 in)	0.99 : 1
Horton DriveMaster® 16.2” fan center	MaxxForce® DT	411.5 mm (16.2 in)	95.3 mm (3.75 in)	20.12 cm (7.92 in)	1.08 : 1
Horton DriveMaster® 20” fan center	MaxxForce® DT	508 mm (20 in)	none	21.95 cm (8.64 in)	0.99 : 1

Fan Drive Configurations Diameters and Ratios (DriveMaster®) — Dual Drive Belt

		Fan Center Line (CL)			
Fan Drive Configuration	**Engine**	**Vertical above Crank**	**Lateral Offset (toward turbo)**	**Pulley Diameter**	**Fan Drive Ratio**
Horton DriveMaster® 14.3” fan center	MaxxForce® DT	363.22 mm (14.3 in)	none	200.66 mm (7.9 in)	1.08 : 1
Horton DriveMaster® 14.3” fan center	MaxxForce® 9 and 10	508 mm (20 in)	none	18.14 cm (7.14 in)	1.2 : 1
Horton DriveMaster® 20” fan center	MaxxForce® DT	508 mm (20 in)	none	20.12 cm (7.92 in)	1.08 : 1
Horton DriveMaster® 20” fan center	MaxxForce® 9 and 10	508 mm (20 in)	none	18.14 cm (7.14 in)	1.2 : 1

Cylinder Head and Valve Train

Valve Specifications

Camshaft lobe lift	Intake: 6.68 mm (0.263 in) 0.254 mm (0.010 in) maximum wear limit Exhaust: 6.91 mm (0.272 in) 0.254 mm (0.010 in) maximum wear limit
Roller tappet guide slot width	9.271 ± 0.05 mm (0.365 ± 0.002 in)
Valve face angle	Intake: 59.75 to 60.00° Exhaust: 44.75 to 45.00°
Valve face margin (minimum)	Intake: 1.32 mm (0.052 in) Exhaust: 1.16 mm (0.046 in)
Valve face-to-valve stem runout (maximum)	0.038 mm (0.0015 in)
Valve lash (cold), intake and exhaust	0.48 mm (0.019 in)
Valve stem diameter (new condition)	Intake: 7.92861 ± 0.0089 mm (0.31215 ± 0.00035 in) Exhaust: 7.9083 ± 0.0089 mm (0.31135 ± 0.00035 in)
Valve stem straightness (maximum)	0.010 mm (0.0004 in)
Valve stem-to-guide running clearance (maximum)	Intake: 0.10 mm (0.004 in) Exhaust: 0.11 mm (0.005 in)
Intake valve head diameter	39.73 ± 0.13 mm (1.564 ± 0.005 in)
Exhaust valve head diameter	36.55 ± 0.13 mm (1.439 ± 0.005 in)

Valve Spring Specifications

Intake and Exhaust Valve Springs	
Free length	52.35 mm (2.061 in)
Solid height (maximum)	27.46 mm (1.081 in)
Valve closed test length @ 410.1 ± 24.5 N (92.2 ± 5.5 lb) test load	40 mm (1.575 in)
Valve closed test length @ 764.2 ± 48.9 N (171.8 ± 11.0 lb) test load	29.3 mm (1.155 in)

Cylinder Head and Valve Train Specifications

Cylinder head gasket surface flatness	0.10 mm (0.004 in.) per 229 mm (9.0 in)
Cylinder head thickness	New: 160.48 mm (6.318 in)
	Minimum: 159.97 mm (6.298 in)
Cylinder head valve guide bore diameter	14.308 ± 0.017 mm (0.5633 ± 0.0007 in)
Cylinder head deck brinelling indentation	0.05 mm (0.002 in.)
Exhaust valve seat counterbore diameter	Standard: 37.503 ± 0.025 mm (1.4765 ± 0.0010 in)
	Oversize: 0.05 mm (0.002 in): 37.55 ± 0.03 mm (1.4785 ± 0.001 in)
Exhaust valve seat insert outside diameter	Standard: 37.57 ± 0.01 mm (1.479 ± 0.0005 in)
	Oversize: 0.05 mm (0.002 in): 37.62 ± 0.01 mm (1.481 ± 0.0005 in)
Intake valve seat counterbore diameter	Standard: 40.145 ± 0.025 mm (1.5805 ± 0.001 in)
	Oversize 0.05 mm (0.002 in): 40.195 ± 0.025 mm (1.5825 ± 0.0010 in)
Intake valve seat insert outside diameter	Standard: 40.21 ± 0.01 mm (1.583 ± 0.0005 in)
	Oversize 0.05 mm (0.002 in): 40.26 ± 0.01 mm (1.585 ± 0.0005 in)
Valve seat insert OD to valve seat counterbore diametral interference	0.025 to 0.102 mm (0.001 to 0.004 in)
Valve guide bore out-of-round (maximum)	0.005 mm (0.0002 in)
Valve guide bore taper (maximum)	0.013 mm (0.0005 in)
Valve guide height from cylinder head spring pocket	16.54 ± 0.25 mm (0.651 ± 0.010 in)
Valve guide inside diameter (installed)	7.98 to 8.00 mm (0.314 to 0.315 in)
Valve guide inside diameter (installed), maximum wear limit	Intake: 0.102 mm (0.004 in)
	Exhaust: 0.127 mm (0.005 in)
Valve guide interference fit dimension	0.043 mm (0.0017 in)
Valve guide outside diameter	14.351 ± 0.010 mm (0.5650 ± 0.0004 in)
Valve guide length (overall)	65.71 mm (2.587 in)

Cylinder Head and Valve Train Specifications (cont.)

Valve recession	Intake: 1.02 ± 0.13 mm (0.040 ± 0.005 in) Exhaust: 1.40 ± 0.13 mm (0.055 ± 0.005 in)
Valve seat angles	Intake: 59.75 - 60° Exhaust: 44.75 - 45°
Valve seat to valve guide bore concentricity (maximum)	0.076 mm (0.003 in)
Valve seat width	1.91 to 2.16 mm (0.075 to 0.085 in)
Push rod runout (maximum)	0.508 mm (0.020 in)

Flywheel and Flywheel Housing

WARNING: To prevent personal injury or death, do not machine flywheel beyond minimum thickness specified for flywheel resurfacing.

WARNING: To prevent personal injury or death, carefully examine flywheel for any cracks or heat checks after resurfacing. Any cracks or heat checks in the flywheel could cause it to separate. If there are any questions, do not reuse the flywheel.

NOTE: Flywheel resurfacing information is provided for guidance only. Navistar, Inc. assumes no responsibility either for the results of any work performed in accordance with this information or for the ability of service personnel to detect cracks.

Flywheel Housing

Flywheel housing bore concentricity	SAE 1 = 0.30 mm (0.012 in) SAE 2 = 0.28 mm (0.011 in)
Flywheel housing face runout	SAE 1 = 0.30 mm (0.012 in) SAE 2 = 0.28 mm (0.011 in)

Crankshaft Pilot

Crankshaft pilot concentricity	0.13 mm (0.005 in)

Flywheel

Flat flywheel surface runout maximum (measure at 17.8 cm (7 in) from center)	0.20 mm (0.008 in)
Pot flywheel surface runout maximum (measure at 16.5 cm (6.5 in) from center)	0.20 mm (0.008 in)
Pot flywheel clutch mounting surface runout maximum	0.30 mm (0.012 in)

Flywheel Resurfacing Specifications

Flat flywheel minimum thickness after resurfacing	36.32 mm (1.430 in)
Pot flywheel minimum thickness after resurfacing	39.37 mm (1.550 in)
NOTE: Requires measurement from crankshaft mounting surface of flywheel to clutch surface of flywheel.	

Power Cylinders

Connecting Rod Specifications

Bend (maximum)	0.051 mm (0.002 in)
Center-to-center distance between connecting rod bearing bore and piston pin bushing bore	
MaxxForce® DT	239.600 to 239.702 mm (9.433 to 9.437 in)
MaxxForce® 9 and 10	219.4 to 219.5 mm (8.638 to 8.642 in)
Connecting rod bearing bore inside diameter	85.130 to 85.156 mm (3.3516 to 3.3526 in)
Connecting rod bearing inside diameter (installed)	80.05 to 80.10 mm (3.1518 to 3.1536 in)
Connecting rod bearing bore out-of-round (maximum)	0.02 mm (0.00078 in)
Connecting rod bearing bore taper (maximum)	0.02 mm (0.00078 in)
Connecting rod bearing running clearance	0.030 to 0.107 mm (0.0012 to 0.0042 in)
Connecting rod to crankshaft side clearance	0.190 to 0.419 mm (0.0075 to 0.0165 in)
Twist (maximum)	0.051 mm (0.002 in)
Piston pin bushing inside diameter	
MaxxForce® DT	48.039 to 48.047 mm (1.8913 to 1.892 in)
MaxxForce® 9 and 10	46.393 to 46.401 mm (1.8265 to 1.8268 in)

Piston Specifications – MaxxForce® DT

Piston	One-piece aluminum
Piston rings	Top ring - keystone cross section Intermediate - rectangular cross section
Running clearance between piston and cylinder sleeve	0.088 to 0.132 mm (0.00335 to 0.00524 in)
Skirt diameter	116.467 to 116.485 mm (4.5853 to 4.5860 in)
Top compression ring groove width, measure over 2.885 mm (0.1135 in) gauge pins	117.325 to 117.545 mm (4.6191 to 4.6278 in)
Intermediate compression ring side clearance	0.05 to 0.10 mm (0.002 to 0.0039 in)
Oil control ring side clearance	0.03 to 0.08 mm (0.0012 to 0.00315 in)
Piston protrusion above crankcase top deck	0.622 to 0.813 mm (0.025 to 0.032 in)
Piston cooling tube diameter (spray hole)	2.18 mm (0.086 in)

Piston Specifications – MaxxForce® 9 and 10

Piston	One-piece steel
Piston rings	Top ring - keystone cross section
	Intermediate - rectangular cross section
Running clearance between piston and cylinder sleeve	0.085 to 0.133 mm (0.00335 to 0.00524 in)
Skirt diameter	116.498 to 116.528 mm (4.5865 to 4.5877 in)
Top compression ring groove width, measure over 2.70 mm (0.1063 in) gauge pins	116.104 to 116.304 mm (4.5710 to 4.5866 in)
Intermediate compression ring side clearance	0.07 to 0.12 mm (0.0028 to 0.0047 in)
Oil control ring side clearance	0.03 to 0.08 mm (0.0012 to 0.00315 in)
Piston protrusion above crankcase top deck	0.622 to 0.813 mm (0.025 to 0.032 in)

Piston Ring Specifications (in 116.573 mm diameter gage ring)

Top compression ring end gap	0.35 to 0.50 mm (0.014 to 0.0197 in)
Intermediate compression ring end gap	1.20 to 1.45 mm (0.0472 to 0.0571 in)
Oil control ring end gap	0.35 to 0.65 mm (0.014 to 0.0256 in)

Piston Pin Specifications

Clearance in piston	
MaxxForce® DT	0.006 to 0.016 mm (0.00024 to 0.00063 in)
MaxxForce® 9 and 10	0.083 to 0.103 mm (0.00327 to 0.00406 in)
Length	
MaxxForce® DT	94.3 to 94.6 mm (3.7126 to 3.7244 in)
MaxxForce® 9 and 10	77.88 to 78.13 mm (3.066 to 3.076 in)
Diameter	
MaxxForce® DT	46.352 to 46.357 mm (1.8249 to 1.8251 in)
MaxxForce® 9 and 10	47.997 to 48.002 mm (1.8896 to 1.8898 in)

Cylinder Sleeve Specifications

Counterbore depth allowable variation between four points (maximum)	0.03 mm (0.001 in)
Counterbore depth before adding shims (maximum)	10.49 mm (0.413 in)
Counterbore depth (including shims - if any)	8.84 to 8.89 mm (0.348 to 0.350 in)
Cylinder sleeve protrusion	0.05 to 0.13 mm (0.002 to 0.005 in)
Cylinder sleeve protrusion difference between all six sleeves (maximum)	0.03 mm (0.001 in)
Cylinder sleeve taper travel (maximum)	0.10 mm (0.004 in)
Flange thickness	8.94 to 8.96 mm (0.352 to 0.353 in)
Inside diameter	116.57 to 116.60 mm (4.5895 to 4.5905 in)

Crankcase, Crankshaft, and Camshaft

Crankcase Specifications

Main cap attachment	2 bolts per main cap
Main bearing type	Precision replaceable
Main bearing material	Steel-backed copper, lead, tin
Thrust taken by	Rear upper main bearing #7
Engine block heater rating	1250 W, 120 V
Center line of main bearing bore to head deck	368.3 ± 0.05 mm (14.50 ± 0.002 in)
Counterbore depth allowable variation between four points (maximum)	0.025 mm (0.001 in)
Counterbore depth in crankcase	8.865 ± 0.025 mm (0.349 ± 0.001 in)
Counterbore diameter in crankcase	136.14 + 0.381 – 0.127 mm (5.360 + 0.015 – 0.005 in)
Counterbore maximum allowable depth	9.25 mm (0.364 in)
Crankcase deck flatness	0.076 mm (0.003 in)
Crankcase main bearing bore diameter	116.421 ± 0.127 mm (4.5835 ± 0.005 in)
Piston cooling tube diameter (spray hole) MaxxForce® DT	2.18 mm (0.086 in)
Piston cooling tube diameter (spray hole) MaxxForce® 9 and 10	2.59 mm (0.102 in)
Roller tappet outside diameter	28.435 to 28.448 mm (1.1195 to 1.1200 in)
Sleeve protrusion above crankcase	0.051 to 0.127 mm (0.002 to 0.005 in)
Tappet bore diameter	28.5306 ± 0.01905 mm (1.12325 ± 0.00075 in)
Camshaft Bearing Bore Diameter in Crankcase:	
Front	63.5521 ± 0.01905 mm (2.50205 ± 0.00075 in)
Intermediate (2)	63.0238 ± 0.01905 mm (2.48125 ± 0.00075 in)
Rear	63.5521 ± 0.01905 mm (2.50205 ± 0.00075 in)

Camshaft Specifications

Camshaft bearing inner diameter (ID) (installed)	58.04 to 58.12 mm (2.285 to 2.288 in)
Cam lobe lift, exhaust	6.91 mm (0.272 in)
Cam lobe lift, intake	6.68 mm (0.263 in)
Camshaft end play	0.18 to 0.33 mm (0.007 to 0.013 in)
Camshaft journal diameter	57.96 to 57.99 mm (2.282 to 2.283 in)
Camshaft journal to bearing radial clearance	0.025 to 0.076 mm (0.001 to 0.003 in)
Maximum permissible cam lobe wear	0.25 mm (0.010 in)
Service bearings furnished to size	Yes
Thrust plate thickness (new)	6.96 to 7.01 mm (0.274 to 0.276 in)

Camshaft Bearing Specifications

Bearing Location	Outside Diameter (nominal)	Width (nominal)
Front	63.5 mm (2.50 in)	25.4 mm (1.00 in)
Rear	63.5 mm (2.50 in)	17.8 mm (0.70 in)
Intermediate	63.0 mm (2.48 in)	26.7 mm (1.05 in)

Crankshaft Specifications

Crankshaft	Forged steel, induction hardened, grindable
Number of main bearings	7
Thrust taken by	Number 7 rear upper main bearing
Main bearing journal diameter:	
Standard size	107.95 ± 0.015 mm (4.250 ± 0.0006 in)
0.254 mm (0.010 in) undersized	107.70 ± 0.015 mm (4.240 ± 0.0006 in)
0.508 mm (0.020 in) undersized	107.44 ± 0.015 mm (4.230 ± 0.0006 in)
0.762 mm (0.030 in) undersized	107.19 ± 0.015 mm (4.220 ± 0.0006 in)
Crankshaft journal waviness (maximum)	0.00381 mm (0.00015 in)
Crankshaft journal surface finish	0.00015 mm (0.000006 in)
NOTE: Grind all crankshaft journals against operating rotation (when looking at front end of crankshaft, operating rotation is clockwise). Lap all Journals with operating rotation, not more than 0.0127 mm (0.0005 in) stock to be removed by lapping.	
Thrust Bearing Journal Length:	
Standard size to 0.76 mm (0.030 in) undersized	34.404 ± 0.546 mm (1.3545 ± 0.0015 in)
Connecting rod journal diameter:	
Standard size	80.010 ± 0.015 mm (3.1500 ± 0.0006 in)
0.0254 mm (0.010 in) undersized	79.756 ± 0.015 mm (3.1400 ± 0.0006 in)
0.508 mm (0.020 in) undersized	79.502 ± 0.015 mm (3.1300 ± 0.0006 in)
0.762 mm (0.030 in) undersized	79.248 ± 0.015 mm (3.1200 ± 0.0006 in)

Crankshaft Specifications (continued)

Connecting rod bearing to crankshaft running clearance	0.030 to 0.107 mm (0.0012 to 0.0042 in)
Connecting rod bearing width	39.99 mm (1.5745 in)
Connecting rod journal maximum out-of-round	0.0064 mm (0.00025 in)
Connecting rod journal taper (maximum per inch)	0.0051 mm (0.0002 in)
Connecting rod to crankshaft side clearance	0.190 to 0.419 mm (0.0075 to 0.0165 in)
Crankshaft end play	0.152 to 0.305 mm (0.006 to 0.012 in)
Crankshaft end play maximum wear limit	0.51 mm (0.020 in)
Crankshaft flange outside diameter	155.58 mm (6.125 in)
Damper mounting surface runout (maximum)	0.0127 mm (0.0005 in)
Flywheel mounting surface runout (maximum)	0.05 mm (0.002 in)
Main bearing journal maximum out-of-round	0.00635 mm (0.00025 in)
Main bearing journal taper (maximum per inch)	0.0051 mm (0.0002 in)
Main bearing thrust face runout (TIR maximum)	0.026 mm (0.001 in)
Main bearing to crankshaft running clearance	0.046 to 0.127 mm (0.0018 to 0.0050 in)
Main bearing width (except rear thrust)	34.19 ± 0.13 mm (1.346 ± 0.005 in)
Rear oil seal journal runout (maximum)	0.08 mm (0.003 in)

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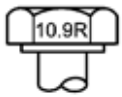
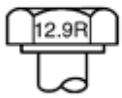
General Torque

Bolt Identification

INTERNATIONAL Class	ISO R 898 I	MATERIAL	THERMAL TREATMENT	HEAD MARKING Preferred	HEAD MARKING Optional
5.8	5.8	Low or medium Carbon steel	Non required		
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 675 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 676 Special fasteners – Classification and identification

General Torque Guidelines

CAUTION: To prevent engine damage, do not substitute fasteners. All original equipment fasteners are hardened and phosphate coated.

NOTE: Inspect parts for cleanliness and defects before assembly.

Many conditions affect torque and the results of torque applications. The major purpose in tightening a fastener to a specified torque is to obtain a clamping load which exceeds any possible loading imposed on parts.

New phosphate coated fasteners do not require oil lubrication during assembly and torque application. Reused fasteners (even if originally phosphate coated) do require oil lubrication to threads and under head area for correct torque application.

Threads that are dry, excessively rough, battered, or filled with dirt require considerable effort just to rotate. Then when the clamping load is developed or the bolt tension is applied, the torque reading mounts rapidly (due to thread friction) to the specified torque value. However, the desired bolt tension and correct clamping load is not achieved. This condition can lead to failure of the fastener to maintain component integrity. The correct bolt tension and clamping effect can never be attained if the fastener is dry. Fastener threads must be new condition phosphate coated or have a film of clean lubricant (engine oil) to be considered lubricated.

Standard Torque Charts

CAUTION: To prevent engine damage, do not use this standard torque chart with other International brand engines or engines made by other manufacturers.

Standard torque chart provides tightening values for all hardware that do not require special torque.

Standard Torque Values - Class 10.9 Metric Flange Head Bolts and Studs

Thread Diameter (mm)	Thread Pitch (mm)	Torque
6	1	13 N·m (115 lb·in)
8	1.25	31 N·m (23 lb·ft)
10	1.5	62 N·m (45 lb·ft)
12	1.75	107 N·m (79 lb·ft)
14	2	172 N·m (127 lb·ft)
15	2	216 N·m (159 lb·ft)
16	2	266 N·m (196 lb·ft)
18	2.5	368 N·m (272 lb·ft)
20	2.5	520 N·m (384 lb·ft)

Example: Tighten four M6 x 12 pulley bolts to standard torque. What is the size and standard torque for these four bolts?

M6 x 12 refers to the bolts thread diameter and length. These bolts have a thread diameter of 6 mm and are 12 mm long.

To find the standard torque for a M6 x 12 bolt look at the torque chart above. We see the standard torque for a 6 mm thread diameter class 10.9 bolt should be 13 N·m (115 lb·in).

Using a Torque Wrench Extension

Occasionally an extension, crowfoot, or other adapter is necessary to use with a torque wrench to torque a bolt or line fitting. Adding adapters or extensions will alter the torque on the fastener from what the torque wrench reads. Use the following formula to calculate the correct torque wrench setting to achieve a specific torque value.

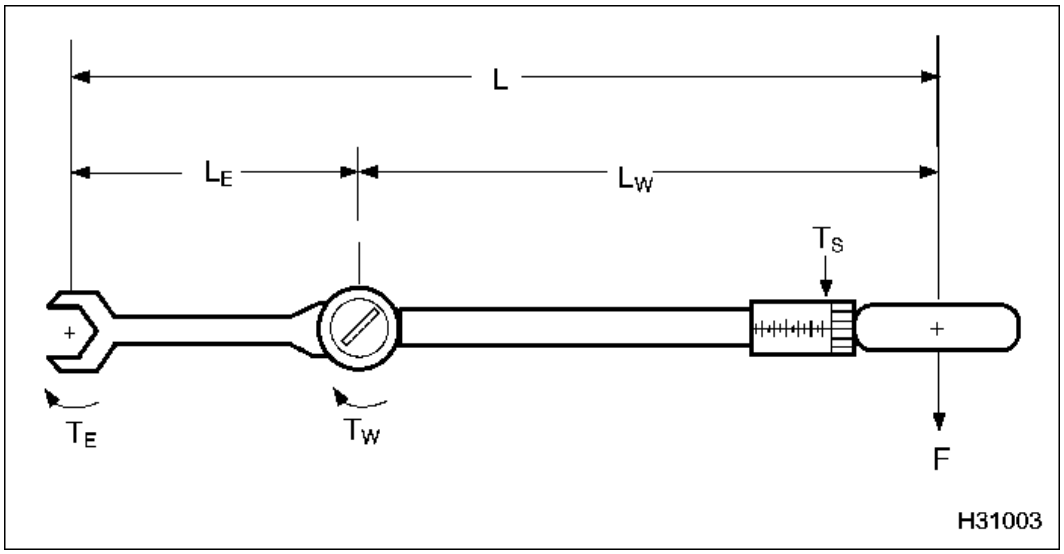


Figure 677 Torque wrench and extension

- F - Force applied by technician
- L - Total length through which force is applied to fastener
- T_W - Torque applied at end of torque wrench

$T_S = T_E (L_W / (L_W + L_E))$

- T_S - Torque wrench setting
- T_E - Torque specified at fastener
- L_W - Length of torque wrench
- L_E - Length of extension

Example: A component requires a specified torque value of 65 lb·ft and a 6 inch extension is required to reach it. What should the torque wrench setting (T_S) be to compensate for the extension?

- Torque specified at fastener (T_E) = 65 lb·ft
- Length of torque wrench (L_W) = 12 inches
- Length of extension (L_E) = 6 inches

$T_S = T_E (L_W / (L_W + L_E))$

T_S = 65 lb·ft (12 inches / (12 inches + 6 inches)

T_S = 65 lb·ft (12 inches / (18 inches)

T_S = 65 lb·ft (0.666)

T_S = 43.33 lb·ft

Special Torque

Mounting Engine on Engine Stand

Coolant drain plug, M16	21 N·m (15 lb·ft)
Oil pan drain plug	68 N·m (50 lb·ft)

Engine Electrical

Battery power junction block, 5/16 – 18 nut	17 N·m (12 lb·ft)
Exhaust Back Pressure (EBP) sensor	20 N·m (15 lb·ft)
Engine Control Module (ECM) mounting bolts, M8 x 45	31 N·m (23 lb·ft)
Engine Coolant Temperature 1 (ECT1) sensor	17.5 N·m (154 lb·in)
Fuel Delivery Pressure (FDP) sensor	12 N·m (102 lb·in)
Exhaust Gas Temperature (EGT) sensor	44 N·m (32 lb·ft)
Engine harness M8 x 12 bolt	34 N·m (25 lb·ft)
Engine harness M8 and M10 nuts	34 N·m (25 lb·ft)
Engine Oil Pressure (EOP) sensor	12 to 18 N·m (106 to 162 lb·in)
Engine Oil Temperature (EOT) sensor	17.5 N·m (154 lb·in)
Intake Air Heater (IAH) relay M6 serrated nuts	4 N·m (35 lb·in)
Injection Control Pressure (ICP) sensor	18 N·m (162 lb·in)
Intake Manifold Pressure (IMP) sensor	11.5 N·m (101 lb·in)
Intake Manifold Temperature (IMT) sensor	10.5 N·m (93 lb·in)
Water In Fuel (WIF) sensor	2 N·m (15 lb·in)

Down Stream Injection (DSI) & Related Components

90 degree elbow tube fitting	20 N·m (15 lb·ft)
90 degree M12 tube fitting elbow	35 N·m (26 lb·ft)
Coolant line tube flare nuts at HC injector	20 N·m (15 lb·ft)
Coolant line tube nuts at high fin density EGR cooler	20 N·m (15 lb·ft)
Down Stream Injection (DSI) inlet tube assembly nuts	24 N·m (18 lb·ft)
Fitting assembly (on DSI assembly)	35 N·m (26 lb·ft)
Injection unit inlet tube nuts	24 N·m (18 lb·ft)
M8 x 45 bolts (hydrocarbon injector assembly)	Step 1: 11 N·m (8 lb·ft) Step 2: 24 N·m (18 lb·ft)
M10 37 degree flare fitting	20 N·m (15 lb·ft)

Dual Stage Turbocharger and Exhaust Brake

Exhaust brake tube assembly nuts	24 N·m (18 lb·ft)
Exhaust brake valve to actuator hose fitting	20 N·m (15 lb·ft)
Exhaust brake valve supply hose fitting	20 N·m (15 lb·ft)
Exhaust clamp	8 N·m (75 lb·in)
Exhaust tube fitting	24 N·m (18 lb·ft)
Heat exchanger clamp	8 N·m (66 lb·in)
Turbocharger oil supply tube nut	25 N·m (18 lb·ft)
Turbocharger mounting nuts, M10 special thread nuts	71 N·m (52 lb·ft)
Turbocharger outlet elbow, M10 special thread nuts	61 N·m (45 lb·ft)
Turbocharger pipe under rail support, M12 x 25 bolt	65 N·m (48 lb·ft)
90 degree tube fitting elbow	35 N·m (26 lb·ft)
M10 37 degree flare fitting	24 N·m (18 lb·ft)
Wastegate actuator rod inner M6 nut	8 N·m (75 lb·in)
M8 x 16 wastegate actuator bolts	15 N·m (11 lb·ft)
V-band clamp (turbine inlet housing)	17 N·m (12.5 lb·ft)
V-band clamp (turbocharger inlet elbow)	17 N·m (12.5 lb·ft)

Exhaust Gas Recirculation (EGR) System

Engine throttle valve M6 x 25 bolts	13 N·m (120 lb·in)

Intake, Inlet and Exhaust Manifolds

Exhaust Back Pressure (EBP) sensor tube nut	25 N·m (18 lb·ft)
Exhaust Gas Temperature (EGT) sensor	44 N·m (32 lb·ft)
Fuel valve assembly	15 N·m (132 lb·in)
M12 plug assembly	25 N·m (18 lb·ft)
Turbocharger adapter stud	12.3 N·m (108 lb·in) to seat stud

Fuel and High-pressure Oil Systems

Adapter elbow jam nut, 70 and 90 degree	105 N·m (78 lb·ft)
Brushless electric fuel pump assembly, M5 x 25 screw	5 N·m (44 lb·in)
Diagnostic coupling assembly	17 N·m (145 lb·in)
Fuel Delivery Pressure (FDP) sensor	11 N·m (100 lb·in)
Fuel filter cap	40 N·m (29 lb·ft)
Fuel filter assembly housing bolt and stud bolts, M8 x 75	27 N·m (20 lb·ft)
250 Watt fuel heater bolts, M6 x 25	10 N·m (85 lb·in)
Fuel filter inlet fitting	18 N·m (155 lb·in)
Fuel pressure regulator valve cover plate M6 screw	See Fuel Pressure Regulator Valve Assembly (page 232) for tightening procedure
High-pressure oil hose (swivel nuts)	65 N·m (48 lb·ft)
High-pressure oil manifold bolts, M8 x 90	See High-pressure Oil Manifold (page 225) for correct torque and sequence.
High-pressure oil pump assembly bolts, M8 x 30 and M8 x 100	30 N·m (22 lb·ft)
High-pressure oil pump gear bolt, M14 x 1.5 left	244 N·m (179 lb·ft)
Injector hold down clamp bolt	41 N·m (30 lb·ft)
Injector oil inlet adapter assembly	204 N·m (150 lb·ft)
IPR valve	50 N·m (37 lb·ft)
M12 fuel rail plug	25 N·m (18 lb·ft)
Oil rail plug assembly (bottom)	204 N·m (150 lb·ft)
Plug assembly, M10 and M12	12 N·m (108 lb·in)
Port cover M6 screws	10 N·m (85 lb·in)
Pump cover screws, M5 x 25	5 N·m (45 lb·in)
Rail end plug assembly	204 N·m (150 lb·ft)
Voss® Stop Flow adapter assembly	27 N·m (20 lb·ft)
Water drain valve assembly M5 screws	6 N·m (50 lb·in)
Water In Fuel (WIF) sensor	See Water In Fuel (WIF) Sensor, Fuel Delivery Pressure (FDP) Sensor, and 250 Watt Fuel Heater (page 233) for tightening procedure.

Engine Brake

Engine Compression Brake Pressure (ECBP) sensor and Injection Control Pressure (ICP) sensor	18 N·m (162 lb·in)
Brake actuator piston locknut	25 N·m (19 lb·ft)
Engine Compression Brake (ECB) valve nut	5 N·m (45 lb·in)
Engine Compression Brake (ECB) valve	27 N·m (20 lb·ft)
High-pressure oil manifold bolts M8 x 90	See High-pressure Oil Manifold (Brake) (page 251).
Injector oil inlet adaptor assembly	204 N·m (150 lb·ft)
Oil pressure relief valve	45 N·m (33 lb·ft)
Plug assembly, M12	12 N·m (108 lb·in)
Plug assembly, M10	12 N·m (108 lb·in)
Rail end plug assembly	204 N·m (150 lb·ft)

Air Compressor and Power Steering Pump

Air compressor gear nut	150 N·m (110 lb·ft)
Air compressor (oil supply) hose assembly	See Air Compressor (page 263)
Air compressor and power steering pump M12 x 80 mounting bolts	83 N·m (61 lb·ft)
Bracket to air compressor M10 x 30 bolts	67 N·m (49 lb·ft)
Compressor bracket to crankcase M12 x 50 bolts	115 N·m (85 lb·ft)
Elbow assembly, M10	16 N·m (138 lb·in)
Elbow assembly, M18	48 N·m (35 lb·ft)
Power steering pump mounting bolts, M10 x 35 (used when mounting pump to back of air compressor)	57 N·m (42 lb·ft)
Power steering pump mounting bolts, M12 x 90 (used when mounting pump to back of front cover)	83 N·m (61 lb·ft)
Power steering pump drive nut	90 N·m (66 lb·ft)

Oil System Module Assembly

Coolant drain plug, M16	19 N·m (14 lb·ft)
Coolant tube bracket bolts, M8 x 30	31 N·m (23 lb·ft)
Fitting (turbocharger oil supply tube)	47 N·m (35 lb·ft)
Oil filter adapter	80 N·m (59 lb·ft)
Oil cooler module mounting bolts and stud bolt, M8 x 30	31 N·m (23 lb·ft)
Oil cooler mounting screws, M8 x 25	23 N·m (17 lb·ft)
Oil cooler M8 serrated nuts	22 N·m (16 lb·ft)
Oil cooler pressure test plate mounting screws M8 x 25	23 N·m (17 lb·ft)
Oil pressure regulator valve cap	70 N·m (51 lb·ft)
Plug assembly, M12	5 N·m (46 lb·in)
Thermal valve screws, M8 x 25	23 N·m (17 lb·ft)

Oil Pan and Oil Suction Tube

Oil pan drain plug	68 N·m (50 lb·ft)
Oil pan heater plug	68 N·m (50 lb·ft)
Oil pan mounting bolts, M8 x 24	32 N·m (24 lb·ft)
Oil suction tube bolts, M8 x 35	27 N·m (20 lb·ft)

Front Cover, Cooling System, and Related Components

Damper (hub) bolts, M12 x 40	135 N·m (99 lb·ft) Retorque all bolts until no movement
Front engine mount M18 bolts	368 N·m (271 lb·ft)
Horton DriveMaster® nut assembly (2 inch)	177 N·m (130 lb·ft)
Lower idler gear M20 x 70 bolt	639 N·m (470 lb·ft)
PTO adapter cover, M10 x 25 bolts (PTO equipped engines only)	61 N·m (45 lb·ft)
Upper idler gear M16 x 65 bolt	326 N·m (240 lb·ft)
Vibration damper assembly M10 x 16 bolts	58 N·m (43 lb·ft)
Vibration damper and pulley assembly M10 x 25 bolts	61 N·m (45 lb·ft)

Cylinder Head and Valve Train

Cylinder head mounting bolts torque and sequence	See Torque Procedure for Torque-to-yield Head Bolts (page 389)
Rocker arm bolts torque and sequence	See torque procedure in Rocker Arm Assembly (page 392)
Valve adjustment screw lock nut	27 N·m (20 lb·ft)

Flywheel and Flywheel Housing

Flexplate mounting bolts, M12x40	136 N·m (100 lb·ft)
Flywheel mounting bolts	136 N·m (100 lb·ft)

Power Cylinders

Connecting rod bolts	See Torque-to-yield Procedure for Connecting Rods with M11 bolts (page 460).
Piston cooling jet bolts, M6 x 12	13 N·m (114 lb·in)

Crankcase, Crankshaft, and Camshaft

Crankcase breather assembly to crankcase M8 x 25 and M8 x 30 bolts	27 N·m (20 lb·ft)
Crankcase ladder, M12 x 35	122 N·m (90 lb·ft)
Crankcase ladder, M10 x 25	63 N·m (46 lb·ft)
Main bearing cap bolt torque and sequence	See Torque Procedure for Torque-to-yield Main Bearing Cap Bolts (page 498)
M12 tee assembly	24 N·m (18 lb·ft)
Oil filler tube support bolt, M6 x 16	13.6 N·m (120 lb·in)
Oil filler tube support, M8 nuts	34 N·m (25 lb·ft)
Oil filler tube support, M6 x 25 bolt and M6 nut	13.6 N·m (120 lb·in)

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Tool Ordering Information

If you would like to order tools or need replacement parts, please refer to the Navistar Service Tool Catalog.

If you have questions, concerns or feedback, please contact Navistar Service Tool Support Center: Phone Number 1–800-365-0088 (toll free).

Special Tools

Mounting Engine on Engine Stand

Disposable Air and Fuel Caps	ZTSE4891
Engine Stand Bracket	ZTSE4940
Engine Stand	OTC1750A
Oil filter wrench	Obtain locally
Turbo Lifting Bracket	ZTSE 4942

Dual Stage Turbocharger and Exhaust Brake

ISC Seal Installer	ZTSE4937–1
ISC Seal Remover	ZTSE4937–2
P-80® Lube	Obtain locally
Pressure Test Kit	ZTSE4409
Seal installer (crossover tube seal)	ZTSE6046
Seal installer handle	ZTSE6055-1
Slide Hammer Puller Set	ZTSE1879

Exhaust Gas Recirculation (EGR) System

EGR Cooler Guide Pins	ZTSE4945
EGR Cooler Leak Detection Kit	KL 20030 NAV
EGR Valve Puller	ZTSE4941
EGR Tube Seal Installer	ZTSE4997
SAE J512 plugs	Obtain locally
Mixing Bowl Gasket Alignment Pins	ZTSE4955

Intake, Inlet and Exhaust Manifolds

Feeler gauge	Obtain locally
Exhaust seal ring installation tool kit	ZTSE6030
EGR Tube Seal Installer	ZTSE4997
P-80® Lube	Obtain locally
Stud remover	Obtain locally

Fuel and High-pressure Oil Systems

Injector Oil Inlet Plugs	ZTSE4660
Fuel Injector Remover Tool (T40)	ZTSE4524
High Pressure Rail Adapter Socket	ZTSE4725
IPR Socket	12–800–01
Suction Bulb	Obtain locally
T27 Torx® bit	Obtain locally
T30 Torx® bit	Obtain locally

Engine Brake

Feeler gauge	Obtain locally
12 point (1–1/16 inch socket)	Obtain locally
High Pressure Rail Adapter Socket	ZTSE4725

Oil System Module Assembly

Air pressure regulator	Obtain locally
Loctite® 272	Obtain locally
Oil Cooler Pressure Test Plate	ZTSE4654
Oil filter wrench	Obtain locally

Oil Pan and Oil Suction Tube

Wacker® T – 442 RTV sealant	Obtain locally

Front Cover, Cooling System, and Related Components

Dial indicator set	Obtain locally
Fan Wrench (for spin-on fan pulley)	ZTSE43971
Fan Hub Wrench, 2 inch (for DriveMaster® nut assembly)	ZTSE43972
Feeler gauge	Obtain locally
Front Seal and Wear Sleeve Installer	ZTSE3004B
H-bar puller	Obtain locally
Heat insulated gloves	Obtain locally
Heel bar	Obtain locally
Hot plate	Obtain locally
Loctite® 569 Hydraulic Sealant	Obtain locally
Lower Idler Gear Socket	ZTSE4383
Muffler chisel	Obtain locally
Straightedge	Obtain locally
Thermo-melt crayon, 100 °C (212 °F)	Obtain locally
16 mm 12 point impact socket	Obtain locally

Cylinder Head and Valve Train

Ball gauge	Obtain locally
Cylinder Head Test Plate	ZTSE4289A
Depth micrometer	Obtain locally
Dial indicator set	Obtain locally
Dye penetrant kit	Obtain locally
Feeler gauge	Obtain locally
Head bolt socket	Obtain locally
Head Bolt Bottoming Tap	ZTSE4671
Injector Sleeve Brush Set (set of 2)	ZTSE4304
Injector Sleeve Installer	ZTSE4642
Injector Cup Removal Tool	12-342-01
Inside micrometer	Obtain locally
Loctite® 620 Retaining Compound	Obtain locally
Outside micrometer	Obtain locally
Prussian® Blue	Obtain locally
Pressure regulator	Obtain locally

Slide Hammer Puller Set	ZTSE1879
Small hole gauge set	Obtain locally
Square	Obtain locally
Straightedge	Obtain locally
Telescoping gauge	Obtain locally
Thermostat Opening Pressure Adapter	ZTSE4647
Valve and Clutch Spring Tester	ZTSE2241
Valve Guide Deburring Tool	ZTSE4393
Valve Guide Installer	ZTSE1943
Valve Guide Remover	ZTSE4377
Valve Seat Extractor Kit (Universal)	ZTSE1951C
Valve Seat Grinder	ZTSE1631A
Valve seat grinding stones 45° (exhaust)	Obtain locally
Valve seat grinding stones 60° (intake)	Obtain locally
Valve Seat Installer	ZTSE4641
Valve Seat Remover (collet)	ZTSE4640
Valve Spring Compressor	ZTSE1846
Valve Spring Compressor Jaws	ZTSE4652
Vernier caliper	Obtain locally
Water Supply Housing Pressure Adapter	ZTSE4648

Flywheel and Flywheel Housing

Dial indicator set	Obtain locally
Guide pins	Obtain locally
H-bar puller	Obtain locally
Loctite® 569 Hydraulic Sealant	Obtain locally
Loctite® 5127	Obtain locally
Rear Seal Installer	ZTSE4637
Slide Hammer Puller Set	ZTSE1879

Power Cylinders

Counterbore Cutting Head	ZTSE25144A
Counterbore Reconditioning Tool Kit	KL50000
Cylinder bore gauge	Obtain locally
Cylinder Liner Height Gauge	ZTSE2515A
Cylinder Sleeve Puller	ZTSE2536
Depth micrometer	Obtain locally
Dial indicator set	Obtain locally
Feeler gauge	Obtain locally
Inside micrometer	Obtain locally
Outside micrometer	Obtain locally
Piston Ring Compressor Tool	ZTSE4396
Piston ring expander	Obtain locally
Piston Gauge Pins (set of 3)	ZTSE4653
Plastigage	Obtain locally
Sleeve Protrusion Hold Down Clamps	ZTSE4672
Telescoping gauge set	Obtain locally
15 mm 12 point socket	Obtain locally

Crankcase, Crankshaft, and Camshaft

Cam Gear Puller	ZTSE4411
Camshaft bearing Puller	ZTSE2893B
Dial indicator set	Obtain locally
Dye penetrant kit	Obtain locally
Hot plate	Obtain locally
Loctite® 262	Obtain locally
Loctite® 277	Obtain locally
Outside micrometer	Obtain locally
Plastigage	Obtain locally
Prussian Blue	Obtain locally
Stiff Nylon Brush	ZTSE4392
Tap Set	ZTSE4386

Photos of Essential Tools

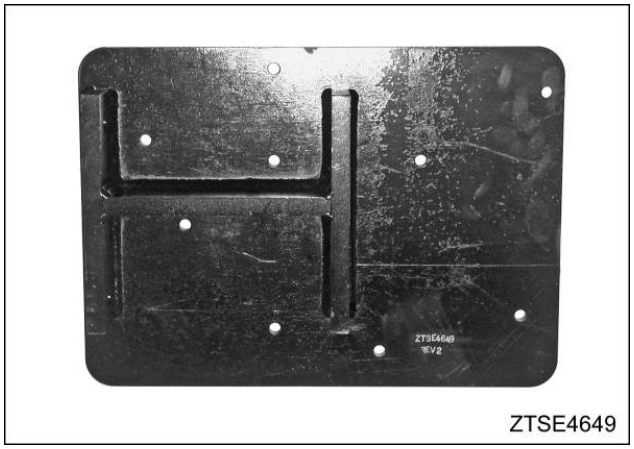


Figure 678 Engine Stand Bracket, ZTSE4649



Figure 679 EGR Cooler Pressure Test Kit, KL20030NAV

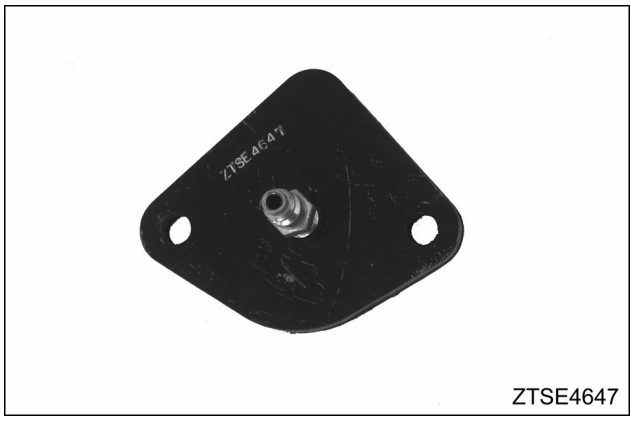


Figure 680 Thermostat Opening Pressure Adapter - cylinder head, ZTSE4647

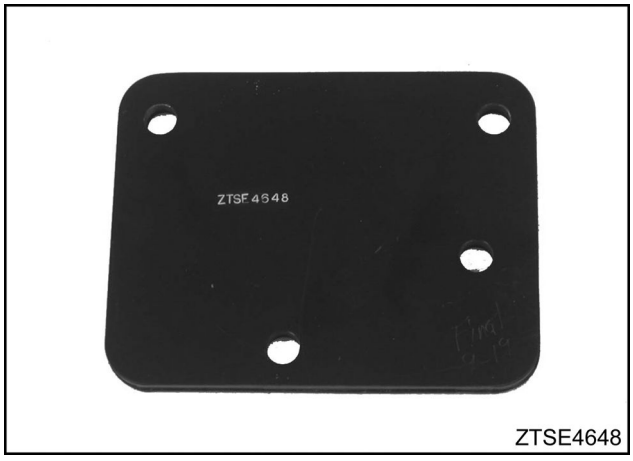


Figure 681 Water Supply Housing Pressure Adapter - cylinder head, ZTSE4648

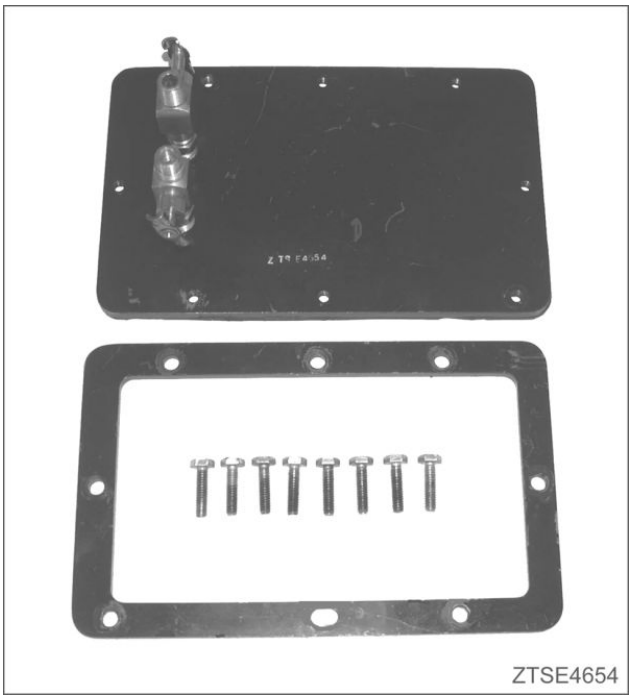


Figure 682 Oil Cooler Pressure Test Plate, ZTSE4654

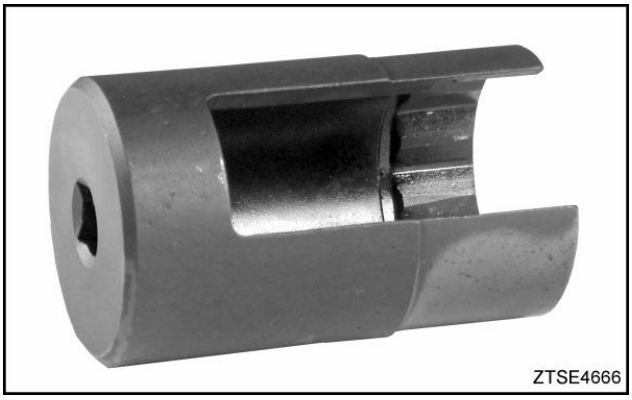


Figure 683 IPR valve removal and installation tool, 12–800–01

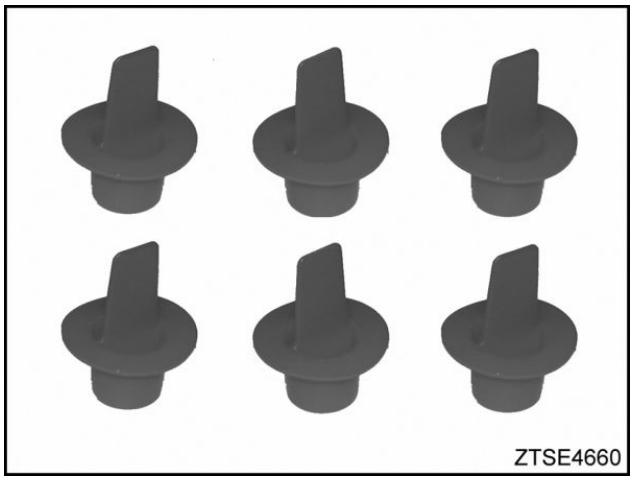


Figure 684 Injector Oil Inlet Plugs, ZTSE4660



Figure 685 Injector Sleeve Installer, ZTSE4642



Figure 686 Valve Spring Compressor Jaws, ZTSE4652



Figure 687 Valve Seat Remover (collet), ZTSE4640

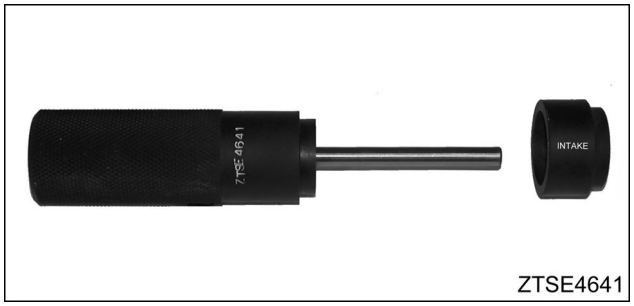


Figure 688 Valve Seat Installer, ZTSE4641



Figure 689 Head Bolt Bottoming Tap, ZTSE4671

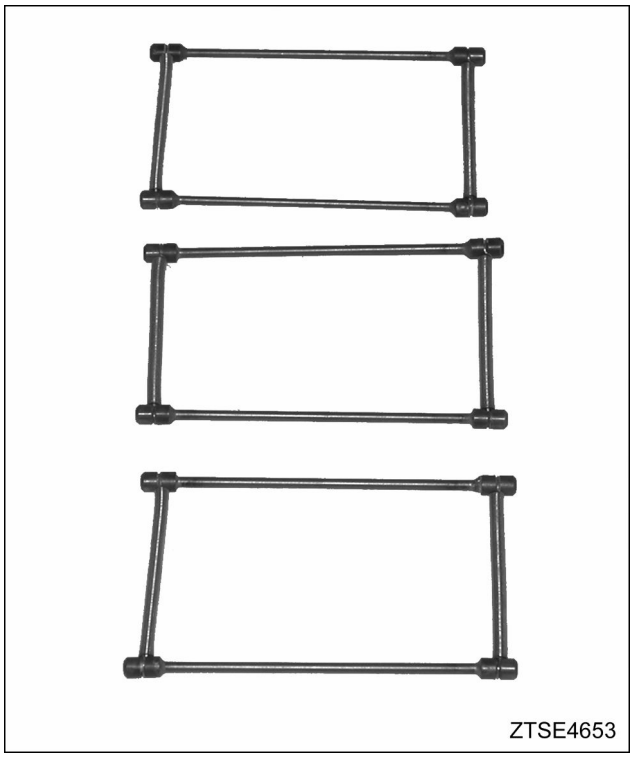


Figure 690 Piston Gauge Pins (set of three), ZTSE4653



Figure 691 Sleeve Protrusion Hold Down Clamps, ZTSE4672

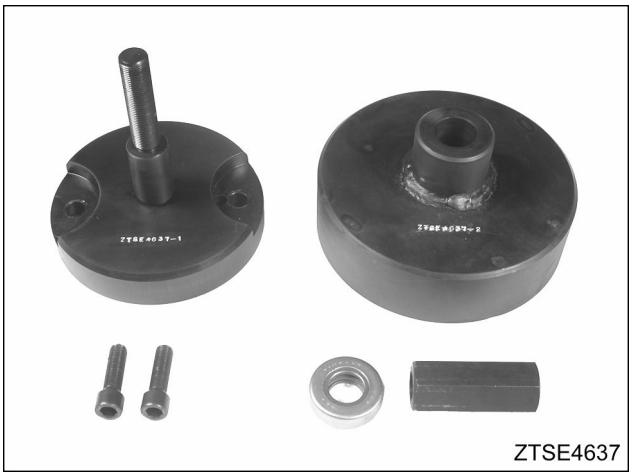


Figure 692 Rear Seal Installer, ZTSE4637



Figure 693 EGR Cooler Guide Pins ZTSE4945