
ENGINE SERVICE MANUAL

MaxxForce® 15L Diesel Engine

Navistar, Inc.

2701 Navistar Drive, Lisle, IL 60532 USA

TABLE OF CONTENTS

Foreword.....	1
Service Diagnosis.....	2
Safety Information.....	3
Engine Systems.....	5
Mounting Engine on Engine Stand.....	53
Engine Electrical.....	63
Cold Start Assist.....	111
Aftertreatment System.....	123
Turbochargers.....	139
Air Compressor and Power Steering.....	171
Fuel System.....	183
Exhaust Gas Recirculation (EGR) System.....	205
Oil Cooler, Filter Housing and Crankcase Ventilation.....	257
Air Inlet and Exhaust Manifold.....	281
Front Cover, High Mount Fan Drive, Cooling System, and Related Components.....	295
Engine Brake.....	351
Cylinder Head, Camshaft and Valve Train.....	369
Oil Pan, Oil Pickup Tube and Oil Pump.....	429
Flywheel and Flywheel Housing.....	453
Power Cylinders.....	477
Crankcase and Crankshaft.....	499
Abbreviations and Acronyms.....	529
Terminology.....	537
Appendix A – Specifications.....	549
Appendix B – Torques.....	557

Appendix C – Special Service Tools.....573

Foreword

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

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

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

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

Technical Service Literature

1172042	MaxxForce® 15 <i>Engine Operation and Maintenance Manual</i>
0000001746	MaxxForce® 15 <i>Engine Service Manual</i>
EGES-515	MaxxForce® 15 <i>Engine Diagnostic Manual</i>
EGED-520	MaxxForce® 15 Hard Start and No Start Form
EGED-525	MaxxForce® 15 Engine Wiring Schematic Form
EGED-535	MaxxForce® 15 Performance Diagnostic Form

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

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

All marks are trademarks of their respective owners.

Service Diagnosis

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

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

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

Prerequisites for Effective Diagnosis

- Availability of gauges, diagnostic test equipment, and diagnostic software.
- Availability of current information for engine application and engine systems.

- Knowledge of the principles of operation for engine application and engine systems.
- Knowledge to understand and do procedures in diagnostic and service publications.

Technical Service Literature required for Effective Diagnosis

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

Safety Information

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

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

Obey Safety Instructions, Warnings, Cautions, and Notes in this manual. Not following warnings, cautions, and notes can lead to injury, death or damage to the engine or vehicle.

Safety Terminology

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

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

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

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

Safety Instructions

Work Area

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

Safety Equipment

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

Protective Measures

- Wear protective safety glasses and shoes.
- Wear correct hearing protection.
- Wear cotton work clothing.
- Wear sleeved heat protective gloves.

- Do not wear rings, watches or other jewelry.
- Restrain long hair.

Vehicle

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

Engine

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

Fire Prevention

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

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

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

Batteries

- Always disconnect the main negative battery cable first.
- Always connect the main negative battery cable last.
- Avoid leaning over batteries.

- Protect your eyes.
- Do not expose batteries to flames or sparks.
- Do not smoke in workplace.

Compressed Air

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

Tools

- Make sure all tools are in good condition.
- Make sure all standard electrical tools are grounded.

- Check for frayed or damaged power cords before using power tools.

Fluids Under Pressure

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

Fuel

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

Removal of Tools, Parts, and Equipment

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

Table of Contents

Engine Identification.....	7
Engine Serial Number.....	7
Engine Emission Label.....	7
Engine Accessory Labels and Identification Plates.....	8
Engine Specifications.....	9
Engine Description.....	9
Optional Features.....	10
Chassis Mounted Features.....	10
Engine Component Locations.....	11
Air Management System (AMS).....	16
Air Flow.....	16
Air Management Components.....	17
Turbochargers.....	17
Interstage Cooler (ISC).....	18
High-Pressure Charge Air Cooler (HPCAC).....	19
Air Control Valve.....	19
Exhaust Gas Recirculation (EGR) System.....	20
Aftertreatment (AFT) System.....	22
Aftertreatment Fuel Injection Components.....	24
Fuel Management System.....	26
Chassis Mounted Components.....	27
Engine Mounted Components.....	29
Engine Lubrication System.....	31
Oil Flow and Components.....	32
Engine Cooling System.....	35
Cooling System Components.....	35
Cooling System Flow.....	36
Thermostat Operation.....	38
Coolant Control Valve (CCV) Assembly Operation.....	38
MaxxForce® Engine Brake System.....	40
Engine Brake System Components.....	40
Engine Brake Operation.....	41
Open Crankcase Breather System.....	42
Open Crankcase Breather System Components.....	42
Open Crankcase Breather System Operation.....	43
Cold Start Assist System.....	44
Cold Start Assist System Operation.....	45

Electronic Control System.....	46
Electronic Control System Components.....	46
Operation and Function.....	46
Reference Voltage (VREF).....	46
Signal Conditioner.....	46
Microprocessor.....	46
Diagnostic Trouble Codes.....	46
Microprocessor Memory.....	46
Actuator Control.....	47
Actuators.....	47
Coolant Flow Valve and Coolant Mixer Valve.....	47
Exhaust Gas Recirculation (EGR) Valve Assembly.....	47
Air Control Valve.....	47
Cold Start Relay (CSR).....	47
Cold Start Fuel Solenoid (CSFS).....	47
Engine Throttle Valve (ETV).....	48
Fuel Pressure Control Valve (FPCV).....	48
Engine and Vehicle Sensors.....	48
Thermistor Sensor.....	48
Variable Resistance Sensor.....	49
Magnetic Pickup Sensor.....	50
Potentiometer.....	51
Switches.....	51
Oxygen Sensor (O2S)	52
Turbocharger 2 Compressor Inlet Sensor (TC2CIS).....	52

Engine Identification

Engine Serial Number

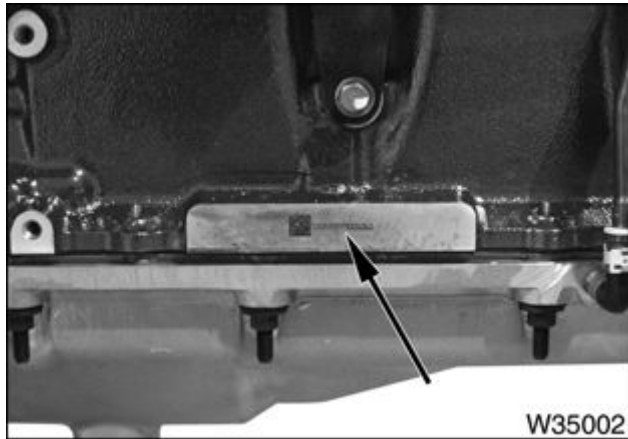


Figure 1 Engine serial number location

The engine serial number is located on the lower left side of the crankcase above the oil pan flange.

Engine Serial Number Example

152HM2YXXXXXXX

Engine Serial Number Codes

15.2 – Engine displacement

H – Diesel, turbocharged, Charge Air Cooler (CAC) and electronically controlled

M2 – Motor truck

Y – United States, Huntsville

7 digit suffix – Engine serial number sequence

Engine Emission Label

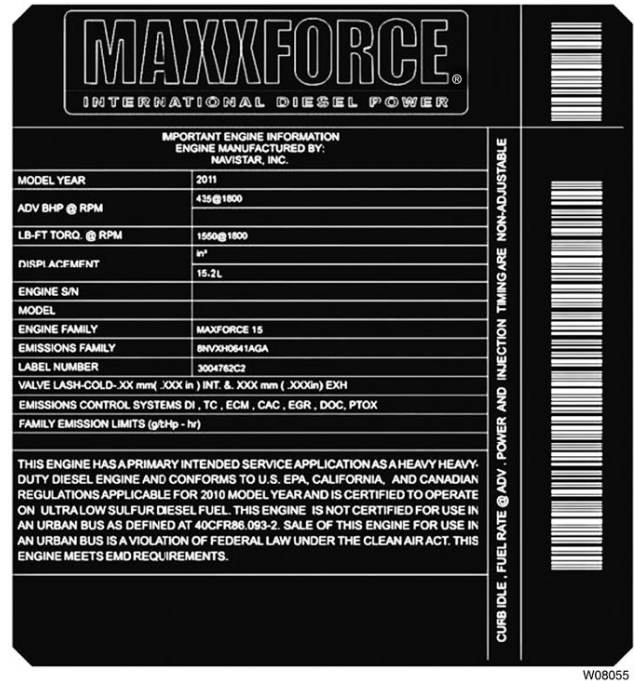


Figure 2 U.S. Environmental Protection Agency (EPA) exhaust emission label (example)

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

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

Engine Accessory Labels and Identification Plates

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

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

Engine Specifications

MaxxForce® 15 Diesel Engine

Engine Configuration	4 stroke, inline six cylinder diesel
Advertised brake horsepower @ rpm	See EPA exhaust emission label
Peak torque @ rpm	See EPA exhaust emission label
Displacement	15.2 L (928 in ³)
Compression ratio	16.0:1
Stroke	171.5 mm (6.75 in)
Bore (sleeve diameter)	137.2 mm (5.40 in)
Engine weight (dry, without trim or accessories)	1 429 kg (3,150 lbs)
Firing order	1-5-3-6-2-4
Engine rotation (facing flywheel)	Counterclockwise
Aspiration	Dual turbocharged and Charge Air Cooled (CAC)
Combustion system	Direct injection turbocharged
Fuel system	High-pressure common rail
Lube system refill capacity (including filter)	
• Gravity drain from right rear and bottom front sump plugs	38 L (40 qts)
• Suction oil recovery option	34.5 L (36.5 qts)
Engine lubrication oil pressure at 99°C (210°F)	
• 600 rpm	Minimum 83 kPa (12 psi)
• 1,600 rpm	275 - 550 kPa (40 - 80 psi)
Idle speed (no load)	600 rpm, nominal
Thermostat transition range (start open — full open)	88°C - 103°C (190°F - 217°F)

Engine Description

The MaxxForce® 15 diesel engine has been designed for increased durability and reliability.

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 overhead camshaft is supported by seven bearings in the cylinder head. The camshaft gear is driven from the front of the engine. The overhead valve train includes roller rocker arms and dual valves that open using a valve bridge.

The MaxxForce® 15 engine uses one piece forged steel pistons. Cooling jet cutouts and feed holes are placed on both sides of the pistons. Pistons may be installed in either direction however pistons are originally installed with casting bump on bottom of pin boss toward rear of engine.

The one piece crankcase can withstand high-pressure loads during operation. The crankcase uses replaceable wet cylinder sleeves that are sealed by a system of three O-rings.

Sound shields are strategically placed on the engine to reduce noise.

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

An oil pump is mounted within the oil pan to the bottom of the crankcase behind the front cover and is driven by the crankshaft. Pressurized oil is supplied to internal engine components, air compressor, power steering pump and turbochargers. All MaxxForce® 15 engines use an engine oil cooler and a spin-on can style engine oil filter element.

Fuel is drawn from the fuel tank through the frame-mounted fuel/water filter separator. A hand operated primer pump is located either on top of or next to the frame-mounted fuel/water separator. The fuel is then routed into the fuel pump and to the engine-mounted fuel filter. Conditioned fuel is then pumped to the fuel injectors.

The fuel injection system is direct common rail. The system includes a high-pressure fuel pump, fuel rail and fuel injectors. The injectors are installed in the cylinder head under the valve cover.

The MaxxForce® 15 engine uses dual turbochargers with an air-to-liquid Interstage Cooler (ISC) between turbochargers, and a chassis-mounted air-to-air Charge Air Cooler (CAC) to reduce air temperature before entering the intake.

The cold start assist system warms the incoming air supply before, during, and a short period after cranking to aid cold engine starting and reduce white smoke during warm-up.

The Exhaust Gas Recirculation (EGR) system circulates cooled exhaust into the intake air stream in the mixing duct. This cools the combustion process and reduces the formation of Nitrogen Oxides (NO_x) engine emissions. The EGR cooler assembly cools the exhaust gas in two stages.

An open crankcase breather system uses an oil separator to return oil to the crankcase and vent

the crankcase gasses to the atmosphere. The oil separator is mounted on the cylinder head.

The engine brake is standard on the MaxxForce® 15. The engine brake is a compression release system that provides additional vehicle braking performance. The operator can control the engine brake for different operating conditions.

Optional Features

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

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

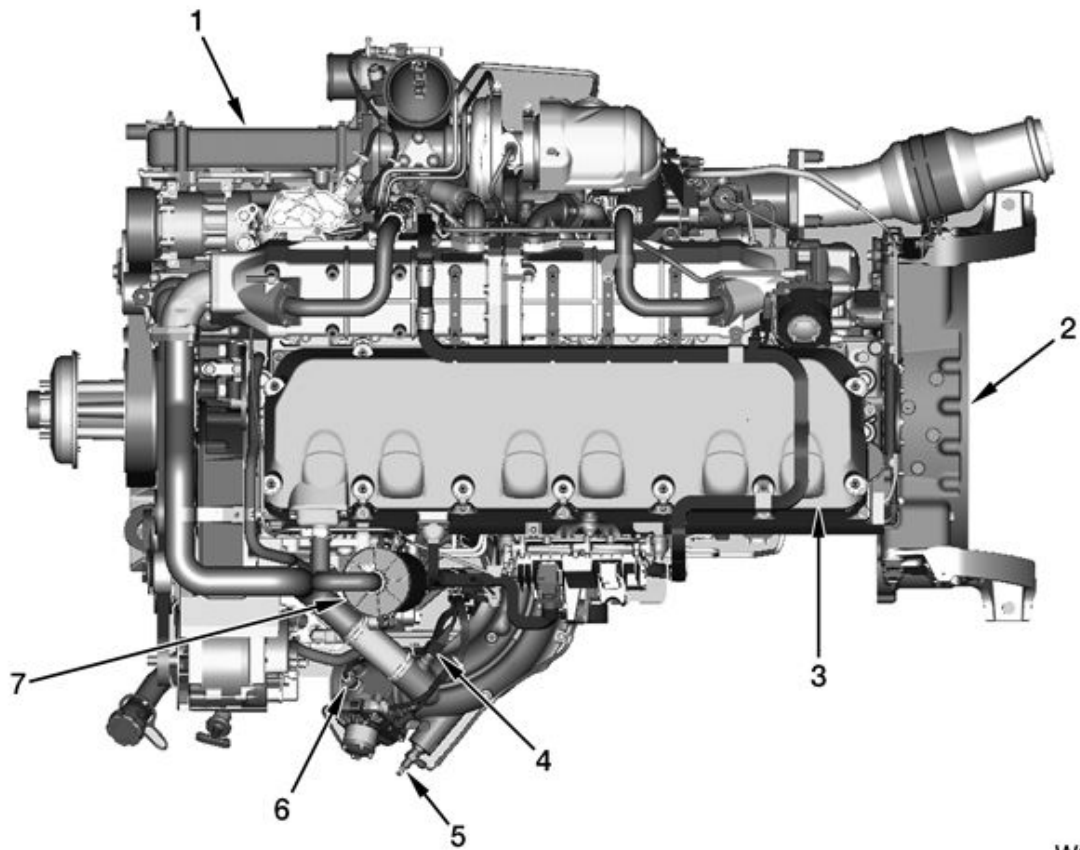
The coolant heater warms the engine coolant surrounding the cylinders. Warmed engine coolant increases fuel economy and aids start-up in cold weather conditions.

Chassis Mounted Features

The aftertreatment system, part of the larger exhaust system, processes engine exhaust so that it meets tailpipe emission requirements. Most of the aftertreatment system is mounted on the chassis.

- The Pre-Diesel Oxidation Catalyst (PDOD) and Diesel Oxidation Catalyst (DOC) which is mounted on the chassis, oxidizes hydrocarbons and carbon monoxide, provides heat for exhaust system warm-up, and aids in temperature management for the Diesel Particulate Filter (DPF) for passive DPF regeneration.
- The DPF temporarily stores carbon-based particulates then oxidizes the particulates and stores the noncombustible ash.

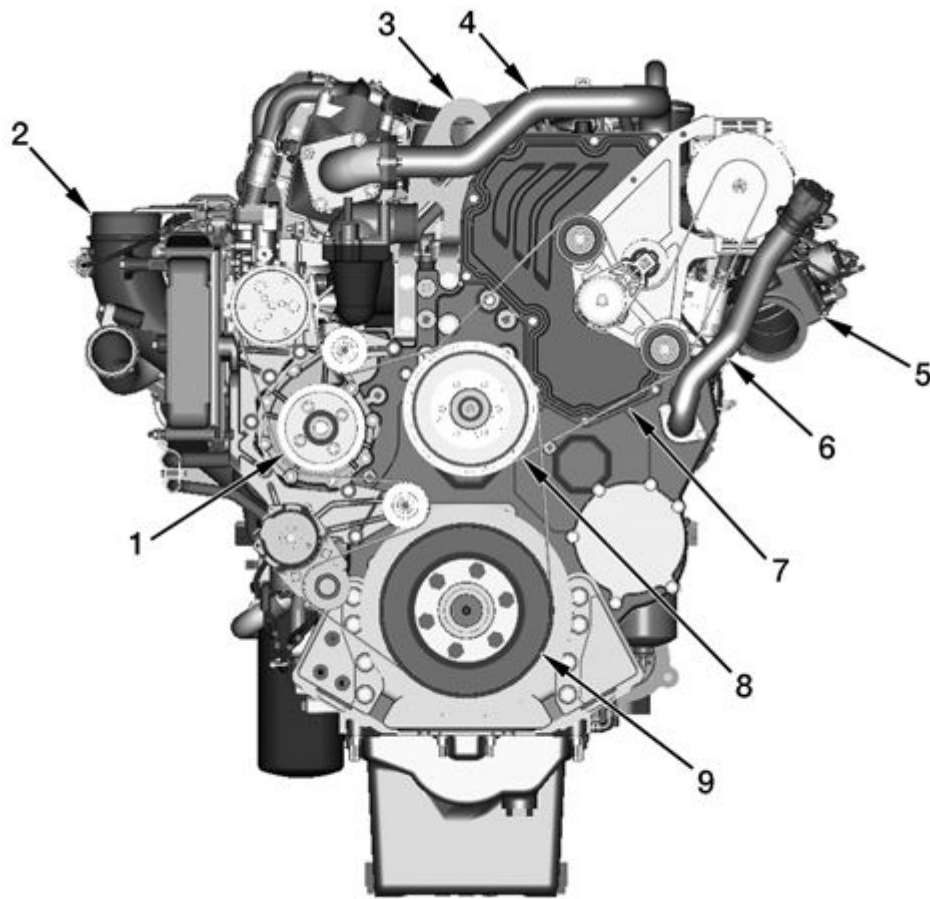
The High-Pressure Charge Air Cooler (HPCAC) mounted on the vehicle cooling module, is connected between the outlet of the high-pressure turbocharger and the inlet to the engine throttle valve assembly. The HPCAC is an air-to-air cooler that uses ambient air to cool pressurized air before it enters the engine.

Engine Component Locations

W35014

Figure 3 Component location – top

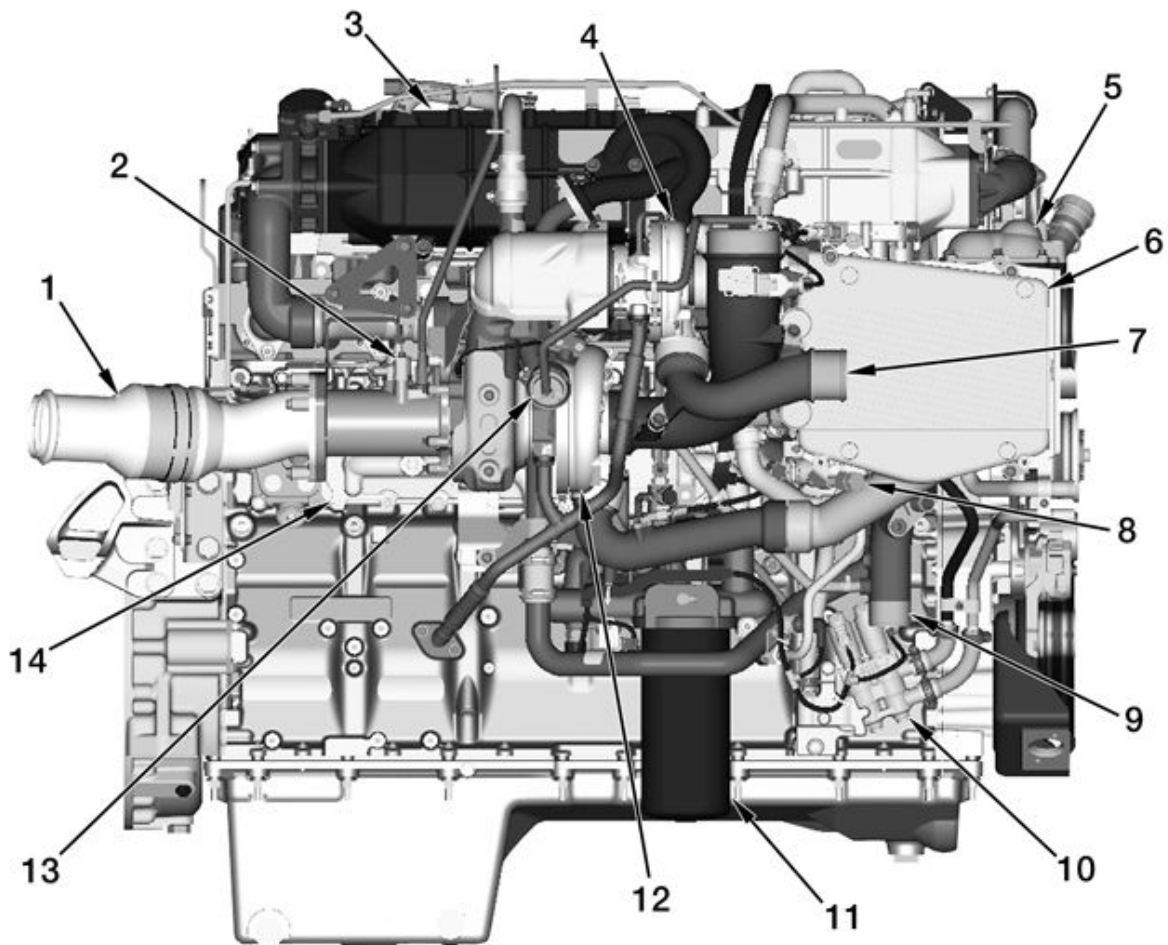
1. Turbocharger interstage cooler assembly	3. Valve cover assembly	6. Charge Air Cooler Outlet Temperature (CACOT) sensor
2. Flywheel housing assembly	4. Exhaust gas temperature sensor	7. Breather filter assembly
	5. Cold Start Fuel Igniter (CSFI)	



W35015

Figure 4 Component location – front

1. Water pump pulley	4. EGR crossover tube assembly	7. Camshaft gear cover
2. Air inlet duct (turbocharger)	5. Engine throttle valve assembly	8. Low mount fan drive
3. Front lifting eye	6. Oil filler pipe assembly	9. Damper (crankshaft)



W35021

Figure 5 Component location – right

1. Pre-Diesel Oxidation Catalyst (PDOC) assembly	6. Interstage cooler assembly	11. Oil filter
2. Fuel doser	7. High-pressure turbocharger compressor outlet	12. Low-Pressure (LP) turbocharger assembly
3. Exhaust Gas Recirculation (EGR) cooler assembly	8. Oil supply tube for secondary filtration (to soot filter)	13. High-pressure turbocharger wastegate actuator
4. High-Pressure (HP) turbocharger assembly	9. Coolant inlet (from radiator)	14. Engine oil cooler assembly
5. Thermostat housing	10. Coolant Control Valve (CCV) assembly	

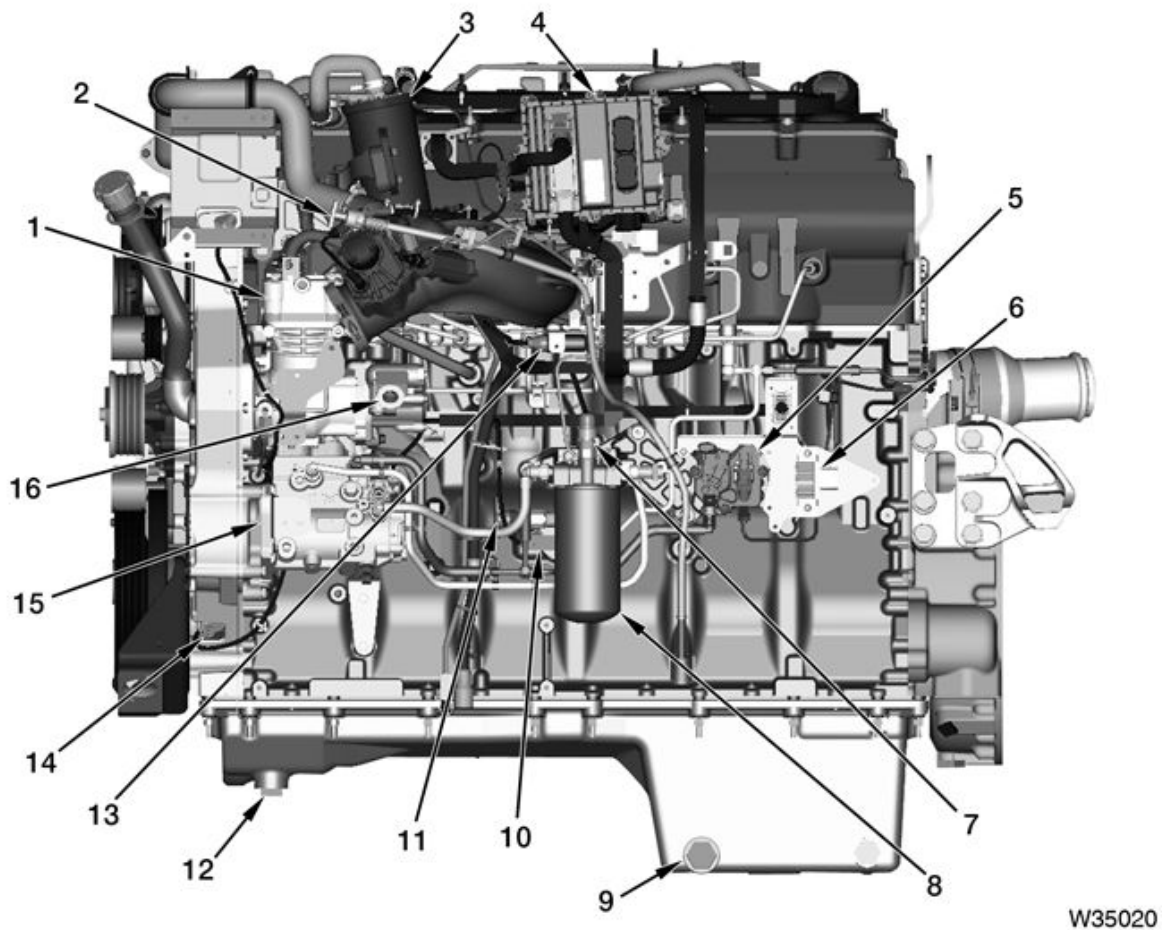
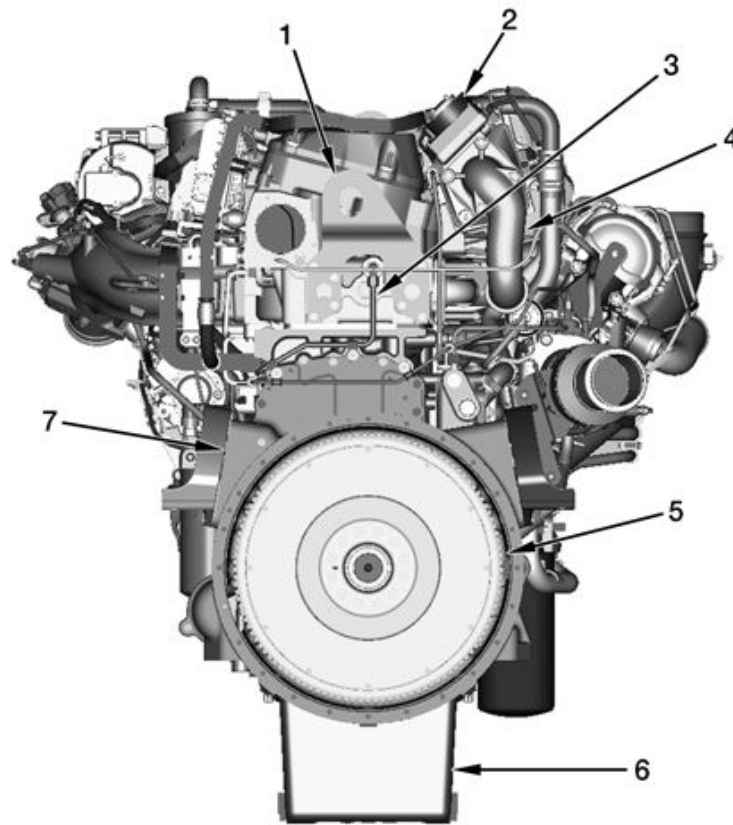


Figure 6 Component location – left

1. Air compressor	7. Fuel Delivery Pressure (FDP) sensor	12. Oil pan drain plug (front sump)
2. Oil level gauge assembly	8. Fuel filter	13. Cold Start Fuel Solenoid (CSFS)
3. Crankcase breather	9. Oil pan drain plug (rear sump)	14. 5 mm 60 degree speed sensor (crankshaft position sensor)
4. Engine Control Module (ECM)	10. Crankcase Pressure (CPS) sensor	15. High-pressure fuel pump
5. Down Stream Injection (DSI) assembly	11. Engine Oil Pressure (EOP) sensor	16. Power steering pump
6. 12V relay (for cold start assist solenoid)		



W35017

Figure 7 Component location – rear

1. Rear lifting eye	3. Fuel return tube assembly	6. Oil pan
2. Exhaust Gas Recirculation (EGR) valve assembly	4. EGR cooler supply tube	7. Flywheel housing
	5. Flywheel	

Air Management System (AMS)

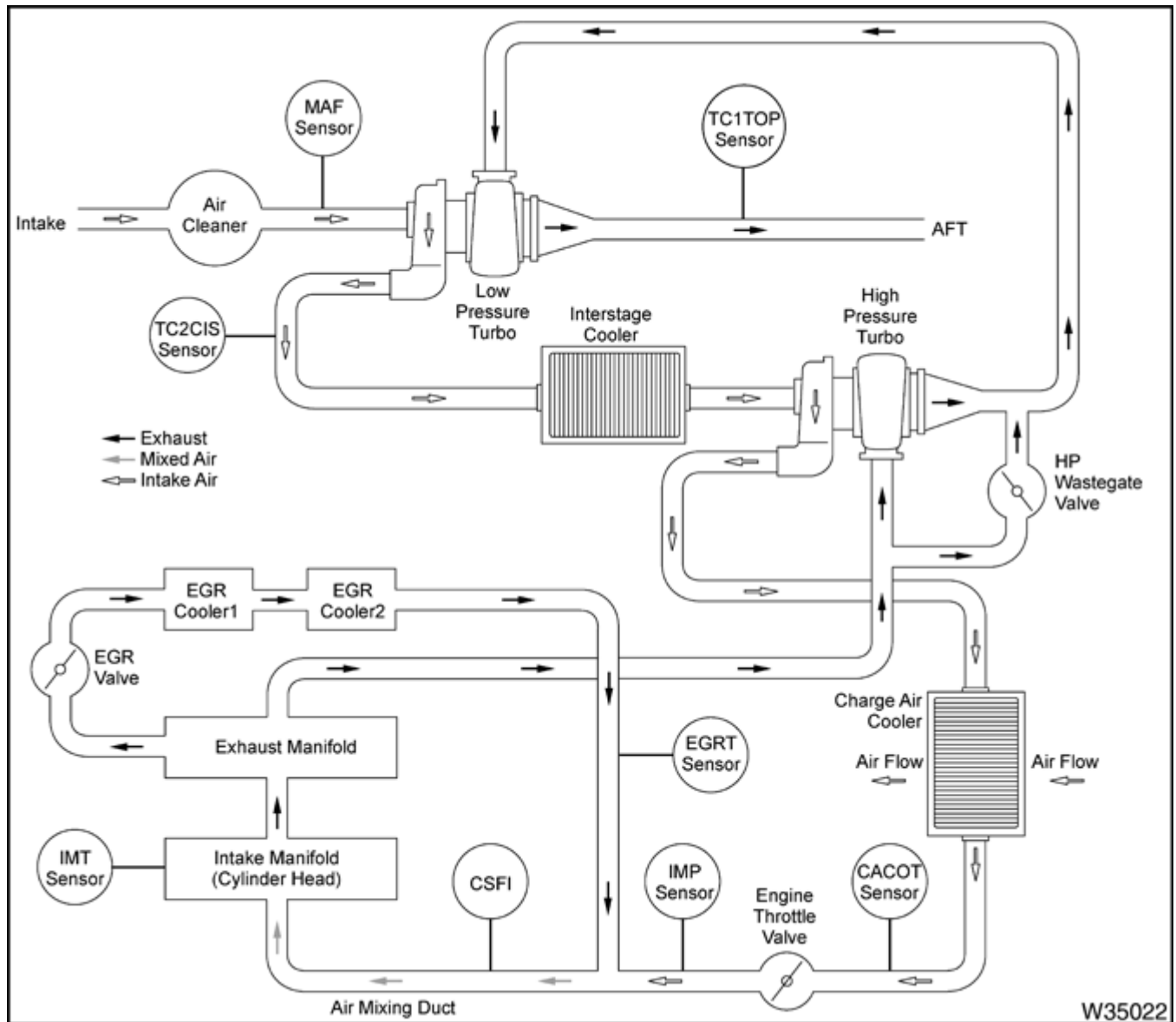


Figure 8 Air Management System (AMS)

Air Flow

Air flows through the air cleaner assembly and enters the low-pressure turbocharger. The low-pressure turbocharger increases the pressure, temperature, and density of the intake air before it enters the Interstage Cooler (ISC). Cooled compressed air flows from the ISC into the high-pressure turbocharger. The high-pressure turbocharger increases the intake air pressure up to 345 kPa (50 psi). The hot compressed

air flows into the Charge Air Cooler (CAC) where it is cooled, and then directed to the Engine Throttle Valve (ETV) and mixing duct area of the throttle valve assembly.

If the EGR control valve is open, exhaust gas passes through the EGR system into the mixing duct where it is mixed with the filtered intake air. This mixture flows through the mixing duct into the intake manifold and

cylinder head. The intake manifold is an integral part of the cylinder head casting.

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

During cold weather, the Cold Start Fuel Igniter (CSFI) rapidly heats the intake air by injecting and igniting small quantities of fuel into the mixing duct.

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

The exhaust gases flow from the low-pressure turbocharger through the vehicle aftertreatment system to the exhaust tail pipe.

Air Management Components

Turbochargers

The MaxxForce® 15 engine is equipped with an electronically controlled, pneumatically actuated two stage turbocharging system. This system provides high levels of charge air pressure to improve engine performance and help reduce emissions. Because of its ability to generate very high charge air pressure levels, the system is fitted with an air control valve to control over-boost and surging conditions. The air control valve is supplied compressed air from the vehicle air supply tank. The compressed air flow to the wastegate actuator is electronically controlled by the air control valve based on the Pulse Width Modulated (PWM) signal supplied by the Engine Control Module (ECM). The high and low-pressure turbochargers are installed as an assembly on the exhaust manifold, on the right side of the engine.

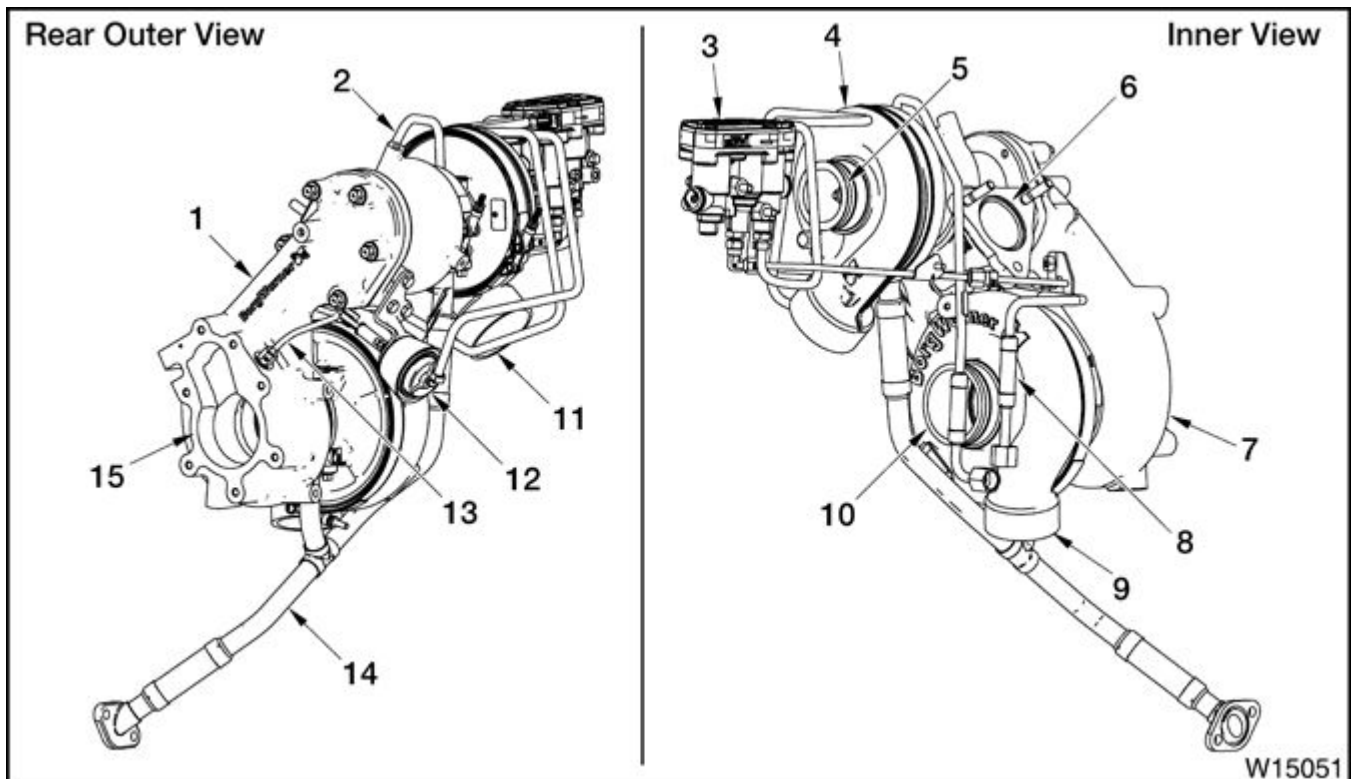


Figure 9 Low and high-pressure turbocharger components

1. Low-pressure turbocharger assembly	6. High-pressure turbocharger turbine inlet	11. High-pressure turbocharger compressor outlet
2. High-pressure turbocharger oil supply hose	7. Low-pressure turbocharger assembly	12. High-pressure turbocharger wastegate actuator
3. Air control valve	8. Low-pressure turbocharger oil supply hose	13. Turbine output pressure tube
4. High-pressure turbocharger assembly	9. Low-pressure turbocharger compressor outlet	14. Turbocharger oil drain tube assembly
5. High-pressure turbocharger compressor inlet	10. Low-pressure turbocharger compressor inlet	15. Low-pressure turbocharger turbine outlet

The low and high-pressure turbochargers are installed in series on the right side of the engine. The high-pressure turbocharger is connected directly to the exhaust manifold through the high-pressure turbine inlet. The turbine input of the low-pressure turbocharger is connected to the turbine outlet of the high-pressure turbocharger. The high-pressure turbocharger is equipped with a wastegate actuator which regulates turbocharger boost by controlling the amount of exhaust gases that pass through the turbine. When boost demand is low, the wastegate opens, allowing part of the exhaust gas flow to bypass the turbine.

Fresh air from the air filter enters the low-pressure compressor where it is compressed and directed into the Interstage Cooler (ISC). Cooled condensed air from the ISC enters the high-pressure compressor, where it is further compressed and directed to the High-Pressure Charge Air Cooler (HPCAC) mounted near the cooling module. Cooled and condensed air then flows directly into the engine throttle valve.

Interstage Cooler (ISC)

The ISC is installed between the low-pressure and the high-pressure turbochargers. 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 compressor outlet and the Engine Throttle Valve (ETV). The HPCAC uses ambient air flow to regulate the charge air temperature. The HPCAC air outlet is connected to the ETV body.

Air Control Valve

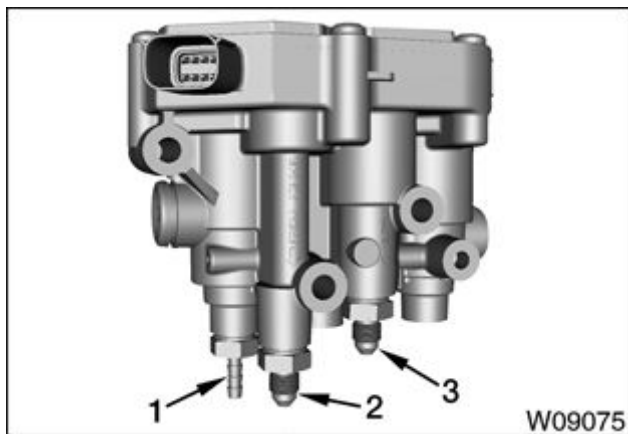


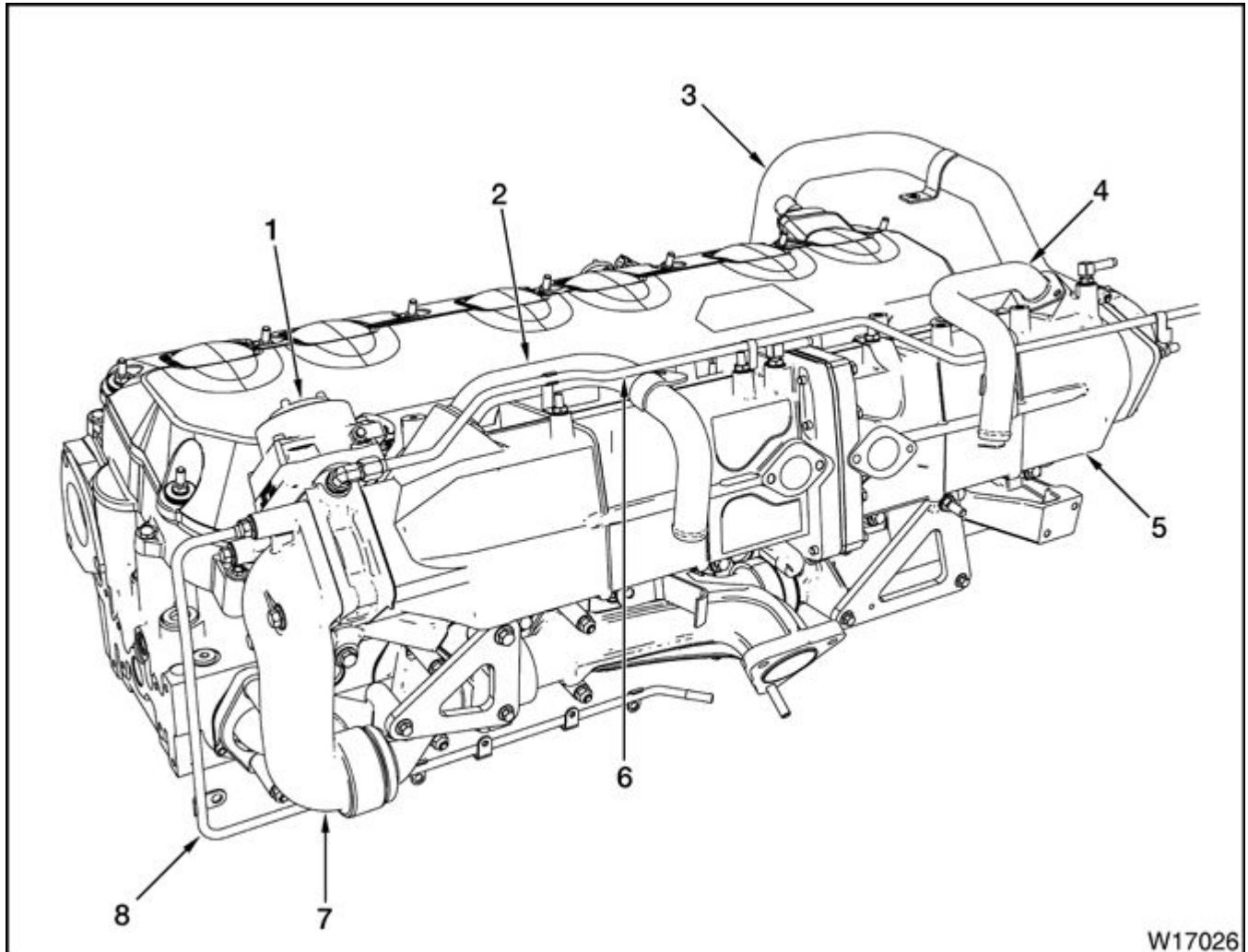
Figure 10 Air control valve

1. To high-pressure turbocharger wastegate actuator
2. Turbocharger 1 Turbine Output Pressure (TC1TOP) input to sensor
3. Compressed regulated air supply from chassis air tank

The air control valve controls air pressure to the high-pressure wastegate actuator based on turbine output pressure from a port on the output of the low-pressure turbocharger. The turbine output pressure sensor is integral to the air control valve. Air pressure to the air control valve is supplied from an air tank mounted on the chassis. The air control valve is controlled by the Engine Control Module (ECM).

The air control valve is normally closed. Thus, with no Pulse Width Modulated (PWM) signal, the air control valve remains closed and no air pressure is supplied to the wastegate actuator on the high-pressure turbocharger. When a decrease in charge air pressure is required, the ECM supplies a PWM ground voltage to the negative side of the wastegate control solenoid. The other side of the wastegate control solenoid is connected to 12V supply voltage. This causes the air control valve to open which supplies air pressure to the wastegate actuator.

The limit values of the PWM signal are between approximately 95%, corresponding to an open air control valve, and 5%, corresponding to a closed air control valve. When the air control valve closes, it interrupts the air supply to the wastegate actuator and at the same time relieves air pressure from the wastegate by allowing it to vent to atmosphere. The wastegate actuator then closes, resulting in increased charge air pressure.

Exhaust Gas Recirculation (EGR) System

W17026

Figure 11 EGR system

1. EGR valve assembly	5. EGR cooler assembly	8. EGRV coolant supply tube assembly
2. EGR coolant tube assembly	6. EGRV coolant return tube assembly	
3. EGR crossover tube assembly	7. EGR cooler supply tube	
4. EGR coolant tube assembly		

EGR System Overview

The EGR system reduces Nitrogen Oxides (NO_x) engine emissions by introducing cooled exhaust gas into the mixing duct. NO_x forms during a reaction between nitrogen and oxygen at high temperatures during combustion. An Oxygen Sensor (O2S) located in the turbo exhaust duct, monitors the oxygen content in the exhaust gas and provides input to the Engine

Control Module (ECM) to control the EGR valve assembly.

The EGR system consists of an EGR valve, EGR cooler assembly and an O2S. The EGR valve assembly is mounted on the rear of the EGR cooler assembly.

The EGR cooler assembly is located on the right side of the valve cover above the exhaust manifold.

EGR Flow

Exhaust gas from the exhaust manifold flows through the EGR cooler supply tube to the EGR valve assembly. When the EGR is activated, the EGR valve assembly opens and allows exhaust gas to enter the EGR cooler assembly for cooling. Cooled exhaust gas flows from the EGR cooler assembly into the mixing duct where it is mixed with filtered intake air.

EGR Control

The ECM monitors signals from the Intake Manifold Temperature (IMT) sensor and Engine Coolant Temperature (ECT) sensor to control the EGR system. The EGR is switched off (EGR valve assembly closed) if any of the following conditions are present:

- Charge air temperature is low
- Intake manifold temperature is low
- Engine coolant temperature is low
- During engine brake operation
- When Cold Ambient Protection (CAP) mode is active

The Oxygen Sensor (O2S) is installed in the turbocharger exhaust duct, in front of the

aftertreatment fuel injector. The O2S has a heater element that heats the sensor to its normal operating temperature of 780°C (1,436°F). During initial engine warm-up, the O2S heater element is activated only after the engine coolant reaches 40°C (104°F) and the exhaust gas temperature exceeds 100°C (212°F) for more than 30 seconds.

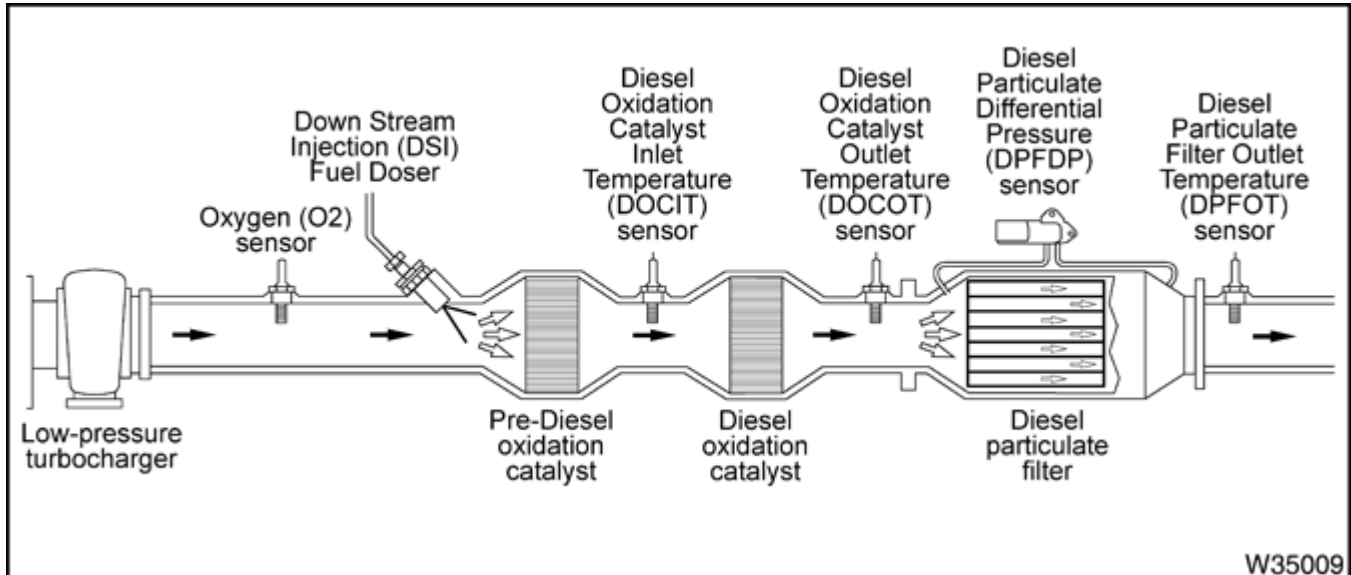
EGR Open Loop System

During the engine warm-up period and before the Oxygen Sensor (O2S) reaches its normal operating temperature, the EGR system operates in open loop. In open loop, the EGR system is controlled by the ECM based on the charge air temperature, engine coolant temperature, engine speed, and load conditions. The EGR actuator provides feedback to the ECM on current valve position through the EGRP sensor.

EGR Closed Loop System

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

Aftertreatment (AFT) System



W35009

Figure 12 AFT system overview

The Aftertreatment (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.

The AFT system performs the following functions:

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

Sensors

Sensors output an electronic signal based on oxygen (O₂), temperature and pressure. The signals are used by the control system to regulate the aftertreatment function.

The sensors measure O₂, temperature and pressure at the center of the exhaust flow.

Down Stream Injection (DSI)

The aftertreatment system injects fuel through the fuel doser into the exhaust gas to increase the temperature necessary for DPF regeneration. The fuel doser is located in the turbo exhaust duct, directly after the low-pressure turbocharger, on the engine. Control of the down stream injection is done by the Engine Control Module (ECM). The ECM receives data from the aftertreatment sensors directly and determines when regeneration is required.

Pre-Diesel Oxidation Catalyst (PDOC)

The PDOC is located on the engine after the DSI.

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 is located in the vehicle exhaust system.

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 is located in the vehicle exhaust system.

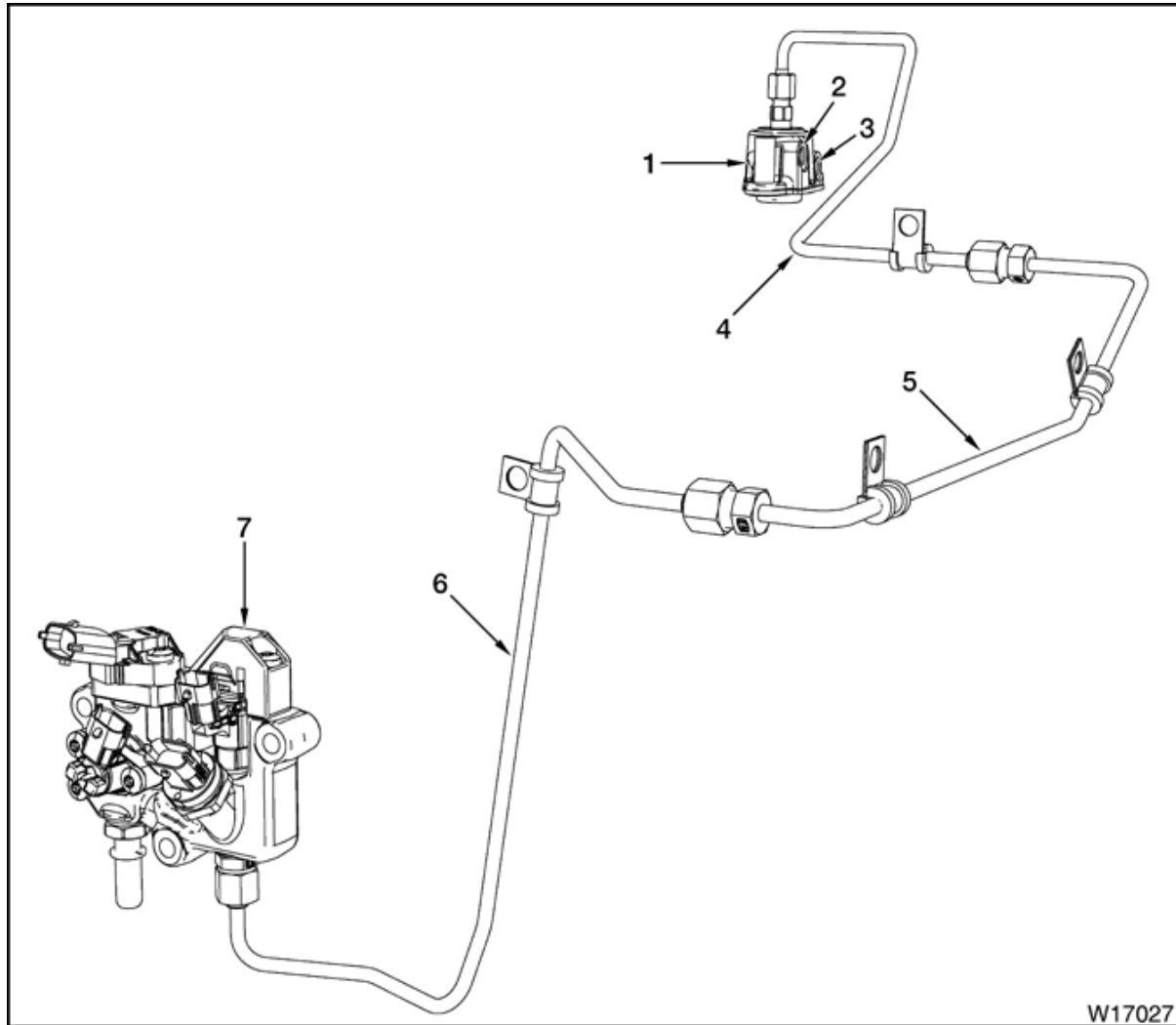
The DPF does the following:

- 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.

Aftertreatment Fuel Injection Components**Figure 13 Aftertreatment fuel injection components**

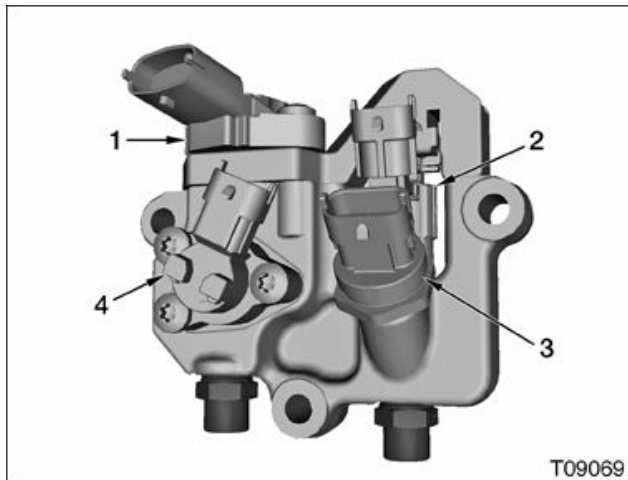
1. Fuel doser	4. Doser fuel from valve tube assembly	6. Doser fuel to injector tube assembly
2. Coolant supply port	5. Feed Injector unit tube assembly	7. Down Stream Injection (DSI) assembly
3. Coolant return port		

The down stream injection system includes the following:

- Engine Control Module (ECM)
- Fuel doser
- Down Stream Injection (DSI) assembly

- Fuel lines

The Engine Control Module (ECM) is mounted on the left side of the engine. The Down Stream Injection (DSI) assembly is installed on the left rear of the engine below the cylinder head.



When the ECM signals the AFTFSV to open, fuel pressure increases in the upstream cavity of the DSI assembly housing. The upstream AFTFIS immediately signals the ECM that pressure is increased by available fuel. The ECM then signals the AFTFD valve to open, allowing a specific amount of fuel to be pumped through the three fuel tubes to the fuel doser.

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

The fuel doser is cooled with engine coolant.

Figure 14 Down Stream Injection (DSI) assembly

1. AFT fuel inlet sensor (AFTFIS) (press and temp)
2. AFT fuel doser (AFTFD) (valve)
3. AFT fuel pressure 2 (AFTFP2)
4. AFT fuel shut-off valve (AFTFSV)

Fuel Management System

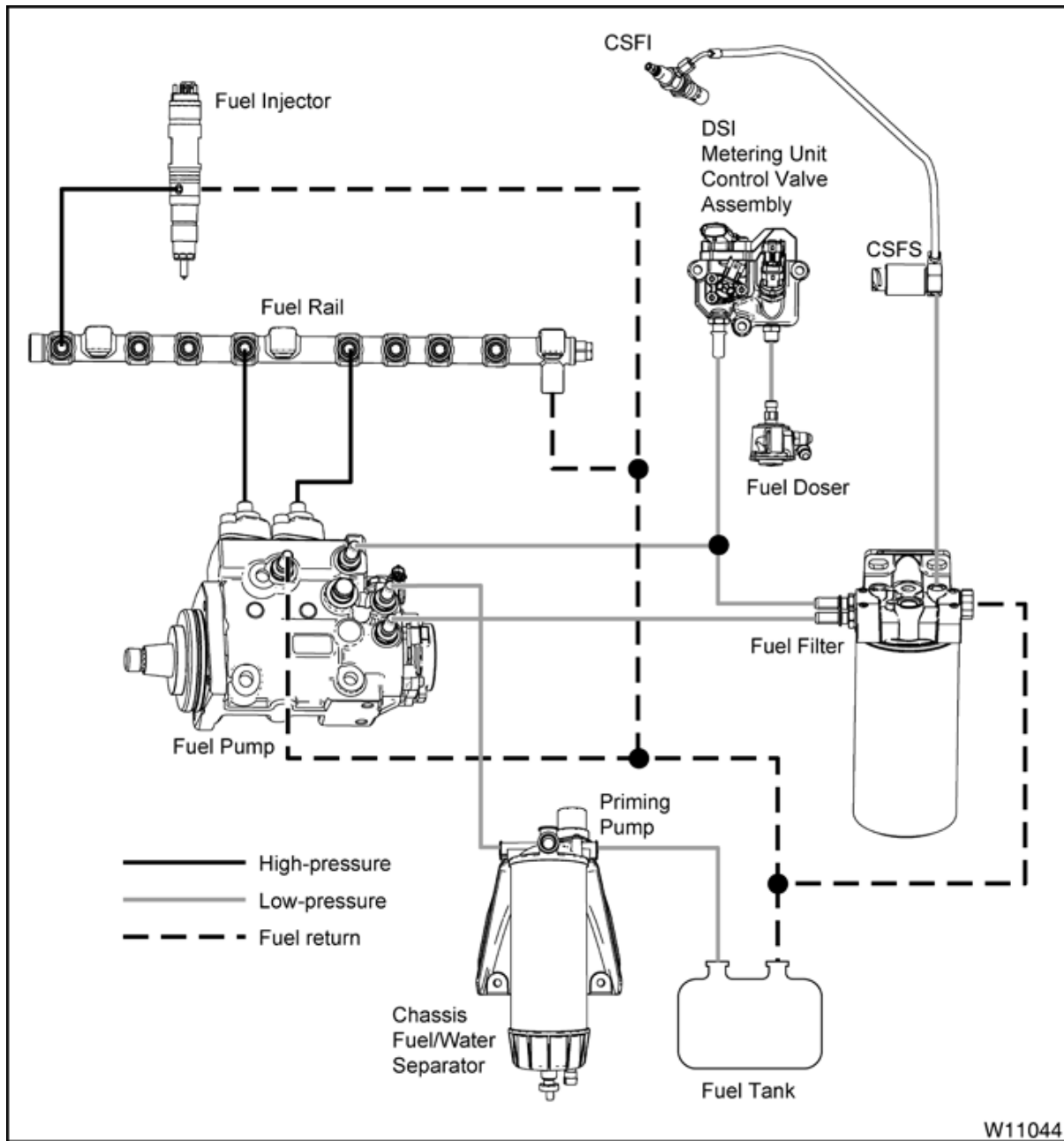


Figure 15 Fuel supply system flow

The MaxxForce® 15 engine is equipped with a high-pressure common rail injection system. The common rail fuel injection system provides fuel under constant high-pressure to the fuel injectors for optimal fuel atomization in the combustion chamber.

Fuel is drawn from the tank and through the frame mounted fuel filter/water separator by a low-pressure fuel pump mounted on the engine. Fuel flows from the low-pressure fuel pump through an engine mounted fuel filter before being supplied to a high-pressure pump. The high-pressure pump

supplies high-pressure fuel to a pressure pipe rail, which feeds the injectors through individual tubes. Unused fuel from injectors is returned to the tank through a passage around the quill tubes in the cylinder head. The low-pressure fuel pump and high-pressure pump are assembled as one gear driven unit on the engine.

The fuel system is controlled by the ECM, various sensors, and the Fuel Pressure Control Valve (FPCV) located in the high-pressure pump.

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

DSI and Fuel Doser

In the aftertreatment system, filtered fuel from the fuel filter at supply pressure is delivered to the DSI assembly. The DSI assembly supplies precise amounts of fuel to the fuel doser.

Cold Start System

During cold weather, fuel is delivered to the Cold Start Fuel Igniter (CSFI) through the Cold Start Fuel Solenoid (CSFS). The CSFI then heats the intake air by injecting and igniting small quantities of fuel into the mixing duct.

Fuel Filter and Housing

An orifice and an additional regulator located within the fuel filter housing work together to reduce fuel pressure to 10 psi for the cold start system solenoid. Supply system pressure is regulated by a pressure regulator valve located in the supply pump. Excess fuel relieved to achieve the pressure reduction is returned back to the fuel pump. The maximum system pressure is regulated to 1 300 kPa (189 psi).

Chassis Mounted Components

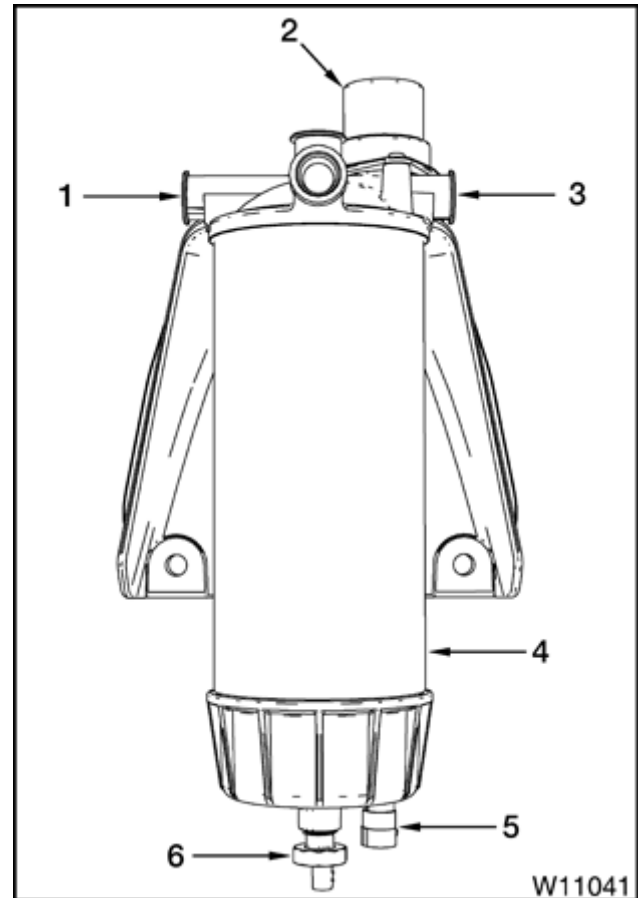


Figure 16 Racor® fuel filter assembly

1. Fuel outlet
2. Fuel primer pump assembly
3. Fuel inlet from tank
4. Fuel filter water separator assembly
5. Water In Fuel (WIF) sensor
6. Drain valve

Fuel Filter and Water Separator Assembly

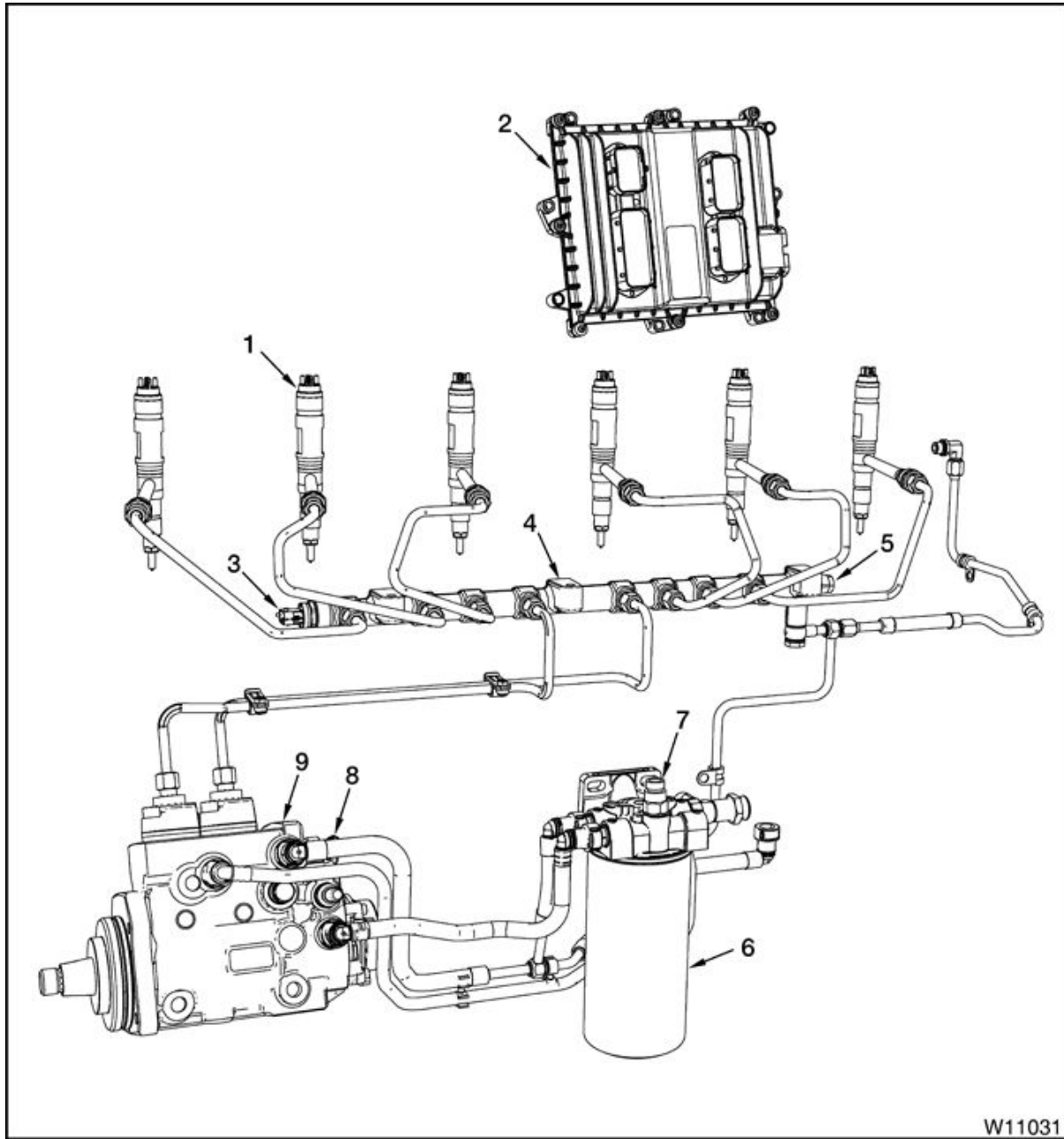
The Racor® fuel filter/water separator assembly is standard equipment. There is also an optional Davco® fuel filter water separator available depending on customer needs.

Fuel Primer Pump Assembly

The fuel is drawn from the tank through the chassis fuel filter and water separator assembly, through the chassis mounted fuel primer pump assembly and into

the low-pressure fuel pump. The fuel primer pump assembly is manually operated and is used to prime the low-pressure fuel system when the system is emptied.

Engine Mounted Components

**Figure 17 Engine mounted fuel system components**

1. Injector (6)	5. Pressure relief valve	8. Fuel Pressure Control Valve (FPCV)
2. Engine Control Module (ECM)	6. Fuel filter (low pressure)	9. Fuel pump (low and high-pressure)
3. Fuel Rail Pressure (FRP) Sensor	7. Fuel Delivery Pressure (FDP) sensor	
4. Rail assembly		

ECM

The ECM controls the fuel pressure with a PWM signal to the Fuel Pressure Control Valve (FPCV). Low pulse width PWM signals equal high-pressure and high pulse width signals equal low pressure. To protect the system, a PLV (Pressure Limiting Valve) is installed in the end of the fuel rail. When pressure exceeds 2,650 +/- 100 bar (38,435 +/-1,450 psi), the PLV opens and reduces pressure to 1,000-1,200 bar (14,503-17,404 psi) to facilitate limp-home operation.

The fuel system is controlled by the ECM. Various engine sensors are input into fueling calculations. The ECM then controls the FPCV and the injectors for proper engine operation. The injection timing and quantity are calculated in the Engine Control Module (ECM) and implemented by solenoid valve controlled injectors.

Fuel Filter

The fuel filter housing assembly is located on the left side of the engine and has a disposable spin-on type filter element. An Engine Fuel Delivery Pressure (FDP) sensor is installed on the front side of the fuel filter housing assembly and it measures fuel pressure between the low-pressure fuel pump and the filter element. An additional function of the fuel filter housing assembly is fuel system self-deaeration. The air separated from fuel is pushed back into the fuel tanks through the return line.

The fuel filter housing assembly is equipped with two additional ports to provide filtered fuel to the aftertreatment system and to the cold start assist system. An orifice regulator is integrated into the fuel filter housing assembly and regulates the fuel pressure for the cold start assist system to 70 kPa (10 psi).

Fuel Pump

Fuel injection pressure is generated by the high-pressure side of the fuel pump. High-pressure fuel quantity from the fuel pump is controlled by a FPCV. The fuel pump supplies both low and high-pressure fuel from one unit. The fuel pump is gear driven and is fuel lubricated. Fuel from the low-pressure side is forced through the fuel filter housing assembly and into the high-pressure side of the fuel pump. The flow of fuel to the suction chamber of the high-pressure pump is controlled by the FPCV in order to control the high-pressure fuel output.

Rail Assembly (Fuel Common Rail)

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

Fuel Rail Pressure (FRP) Sensor

The FRP sensor is a variable resistance sensor that monitors the fuel pressure in the high-pressure fuel rail.

The FRP sensor is mounted in the front of the high-pressure pipe rail on the left side of the engine.

Pressure Relief Valve

The pressure relief valve maintains fuel pressure in the rail assembly below 265 000 kPa (38,500 psi). If the rail assembly pressure exceeds this value, the relief valve opens and allows fuel to flow to the return line, and back to the tank. When the relief valve opens, the system goes into a limp-home mode and a steady rail pressure of 120 000 kPa (17,400 psi) is maintained until the engine is switched off. This will reset to normal operation upon the next key-in event.

Injector

The MaxxForce® 15 engine is equipped with electronically controlled solenoid valve injectors. During engine operation, injectors are supplied at all times with high-pressure fuel, and the injector solenoid valves open up to three times per cycle. The injectors are positioned vertically in the center of the cylinder head and are held in place by injector clamps. The seal between the injectors and the combustion chamber consists of a copper washer on the tip of each injector.

The use of solenoid valve controlled injectors allows three injections per cycle. The first injection is used to reduce combustion noise and emissions by introducing a small amount of fuel into the cylinder, preventing a rapid rise in cylinder pressure when combustion begins. This first injection occurs only during idling and in partial load mode. The second injection is the main injection. This injection allows high temperatures to be maintained during

combustion, but not long enough to allow generation of large soot amounts. The third injection is done during the power stroke to maximize cylinder temperature and reduce engine soot generation.

Engine Lubrication System

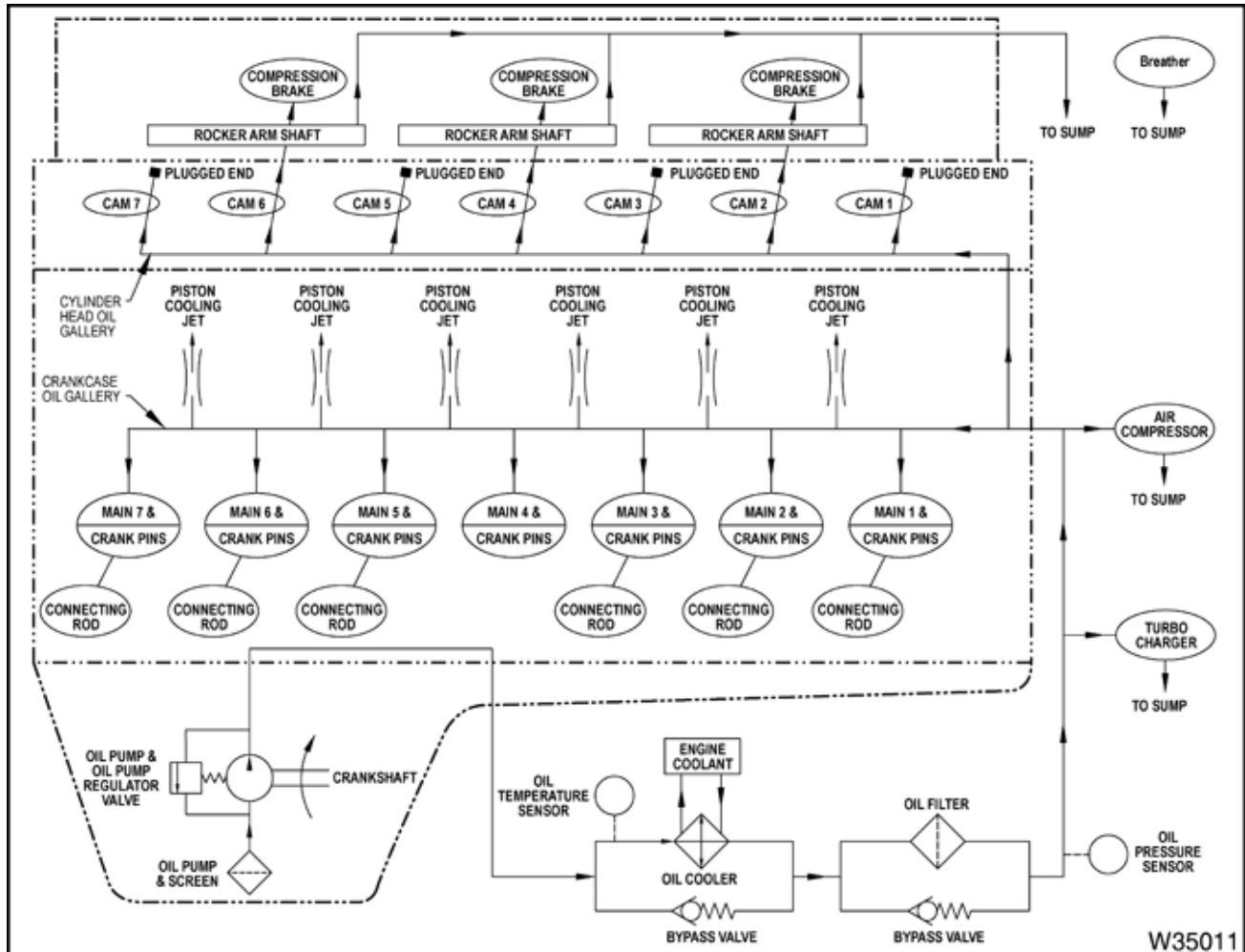


Figure 18 Oil system overview (typical)

Engine oil pressure is generated by an oil pump located under the oil pan which is driven off the crankshaft gear. The oil cooler and filter housing are located on the right side of the engine. The oil pump contains the oil pressure regulator. Oil flows to the cylinder head by means of an internal passage.

The front of the crankcase contains oil passages that supply oil to the gear train and air compressor. These passages ultimately supply oil to the cylinder head through the front hollow dowel that locates the cylinder head to the engine block. Oil drains back to the crankcase through passages in the cylinder head.

Oil Flow and Components

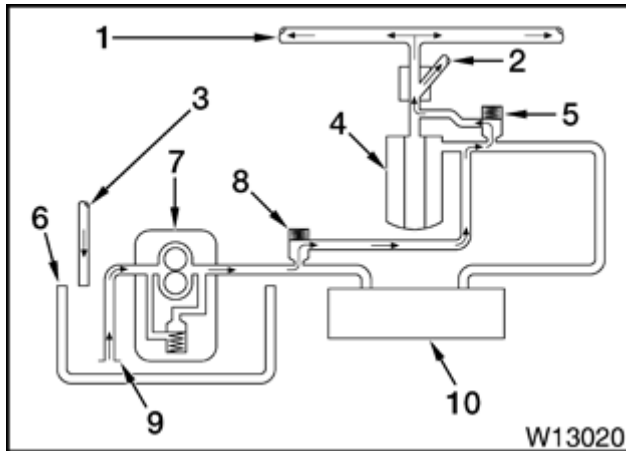


Figure 19 Oil flow through filter when oil is cold

1. Main oil gallery
2. Turbocharger oil supply line
3. Turbocharger oil drain tube
4. Oil filter element
5. Bypass valve (oil filter)
6. Oil pan
7. Oil pump
8. Bypass valve (oil cooler)
9. Oil pick-up tube
10. Engine oil cooler

When the engine oil is cold, oil is drawn from the oil pan through the pick-up tube to the oil pump. Due to the high viscosity of the cold oil, both bypass valves open. These bypass valves provide immediate lubrication to engine components when cold oil with high viscosity may not pass through the oil filter easily. The bypass valves allow oil to bypass the engine oil cooler and oil filter.

The bypass valve will also allow oil to bypass the oil filter in case the oil filter becomes restricted. This prevents a restricted oil filter from blocking oil flow to engine components.

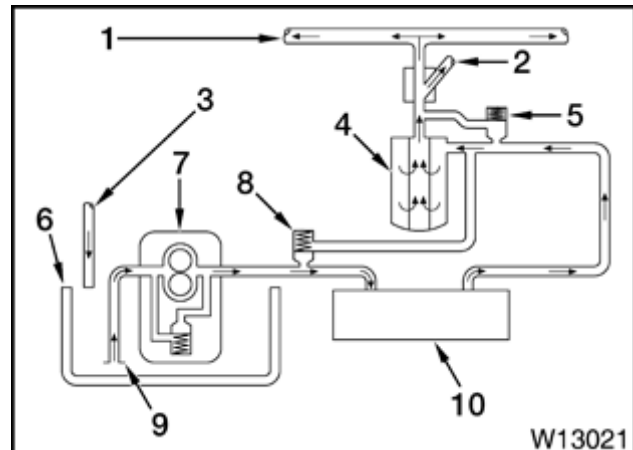


Figure 20 Oil flow through filter when oil is warm

1. Main oil gallery
2. Turbocharger oil supply line
3. Turbocharger oil drain tube
4. Oil filter element
5. Bypass valve (oil filter)
6. Oil pan
7. Oil pump
8. Bypass valve (oil cooler)
9. Oil pick-up tube
10. Engine oil cooler

When the oil is warm, unfiltered oil is drawn from the oil pan through the pick-up tube to the oil pump. The oil pump pushes the warm oil through the oil cooler towards the oil filter. The bypass valves will be closed due to the lower viscosity of the oil and its ability to flow through the oil cooler and oil filter. Filtered oil is directed to the turbocharger oil supply line and main oil gallery where it is distributed to engine components.

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

Clean oil enters the crankcase directly from the oil filter housing to lubricate the crankshaft, air compressor, intermediate gears, and turbochargers.

The crankshaft has cross-drillings that direct oil to the connecting rods.

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

The turbochargers are lubricated with filtered oil from an external supply tube that connects the oil filter

housing to the center housing of each turbocharger. Oil drains back to the oil pan through the low and high-pressure turbocharger oil return tubes connected to the crankcase.

Remote Mounted Centrifugal Oil Filter (Optional)

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

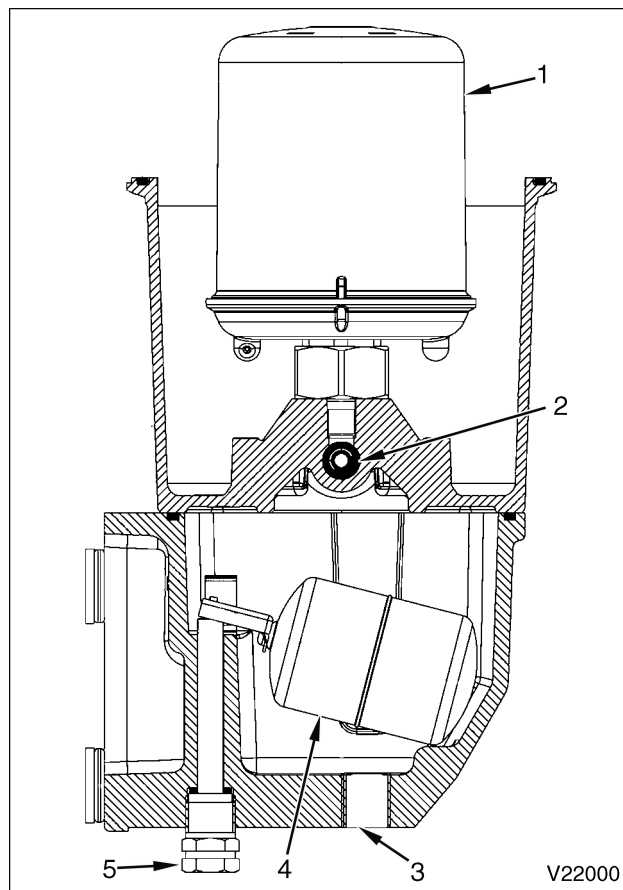


Figure 21 Remote mounted centrifugal oil filter

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

Engine Cooling System

Cooling System Components

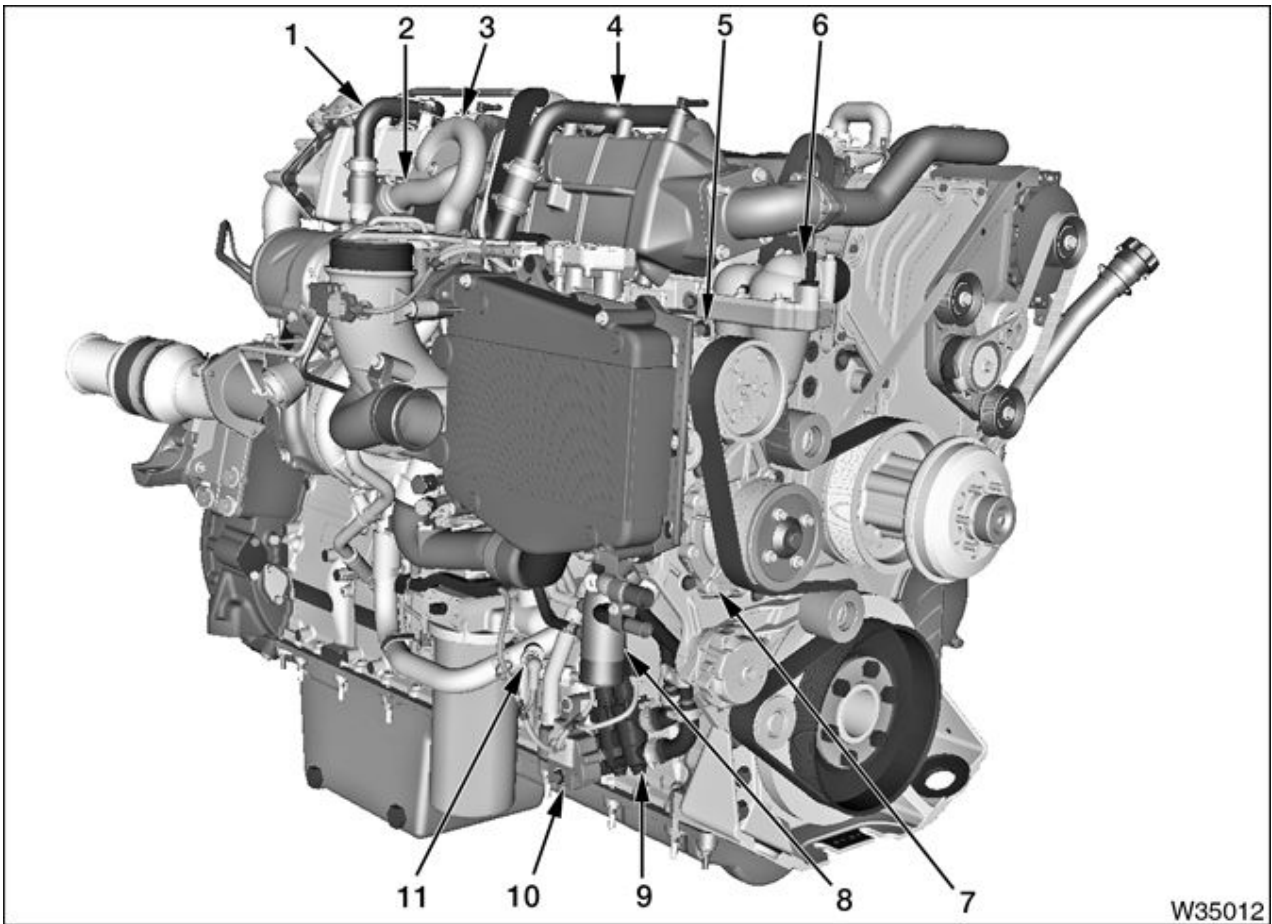


Figure 22 Cooling system components

1. EGR coolant tube assembly (primary EGR cooler)	4. EGR coolant tube assembly (secondary EGR cooler)	8. Water pump inlet
2. EGR coolant return (secondary EGR cooler)	5. Engine Coolant Temperature 1 (ECT1) sensor (behind ISC)	9. Coolant Control Valve (CCV) assembly
3. EGR coolant return (primary EGR cooler)	6. Thermostat housing cover	10. Coolant adapter
	7. Water pump	11. Engine Coolant Pressure 1 (ECP1) sensor

Cooling System Flow

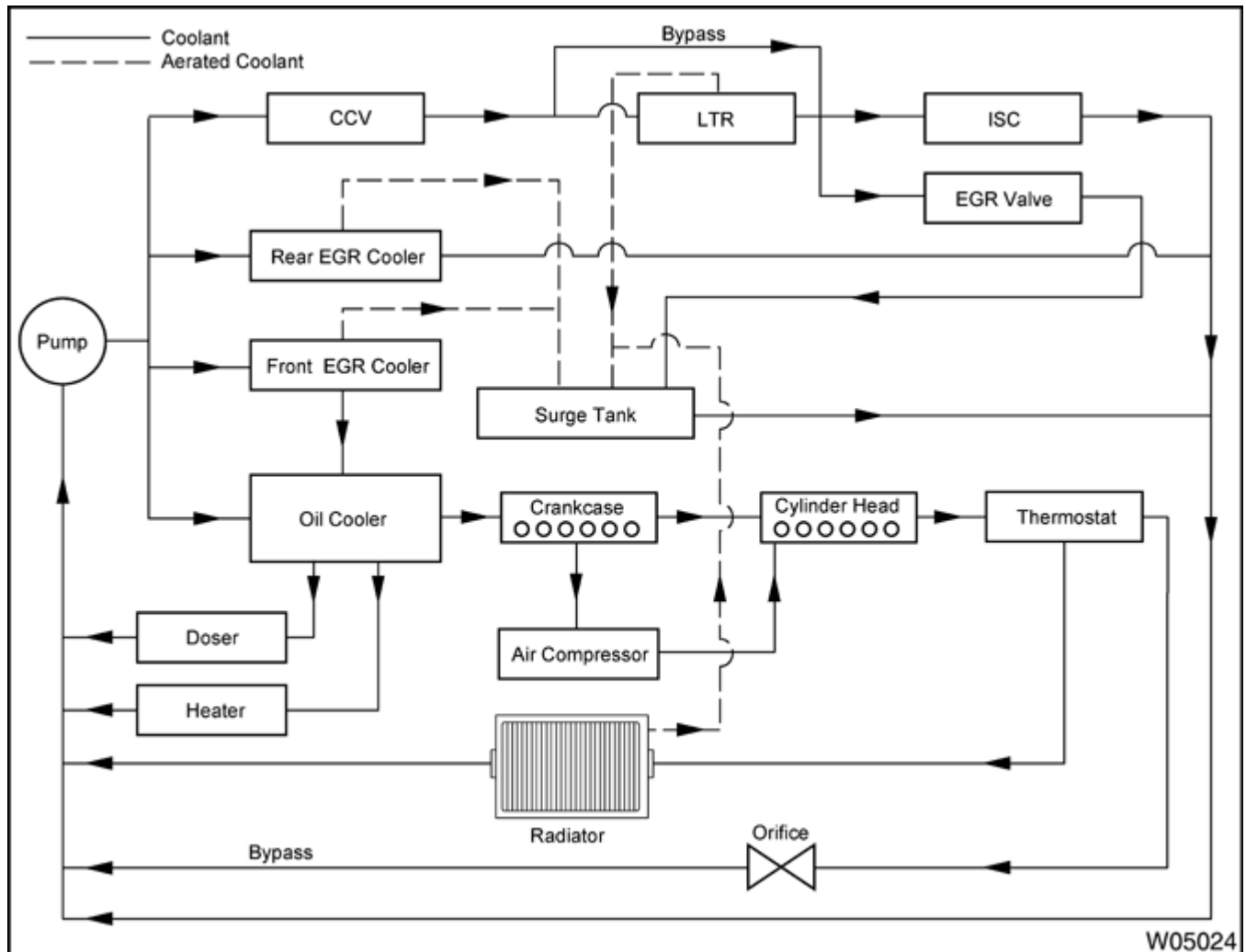


Figure 23 Cooling system flow (manual transmission)

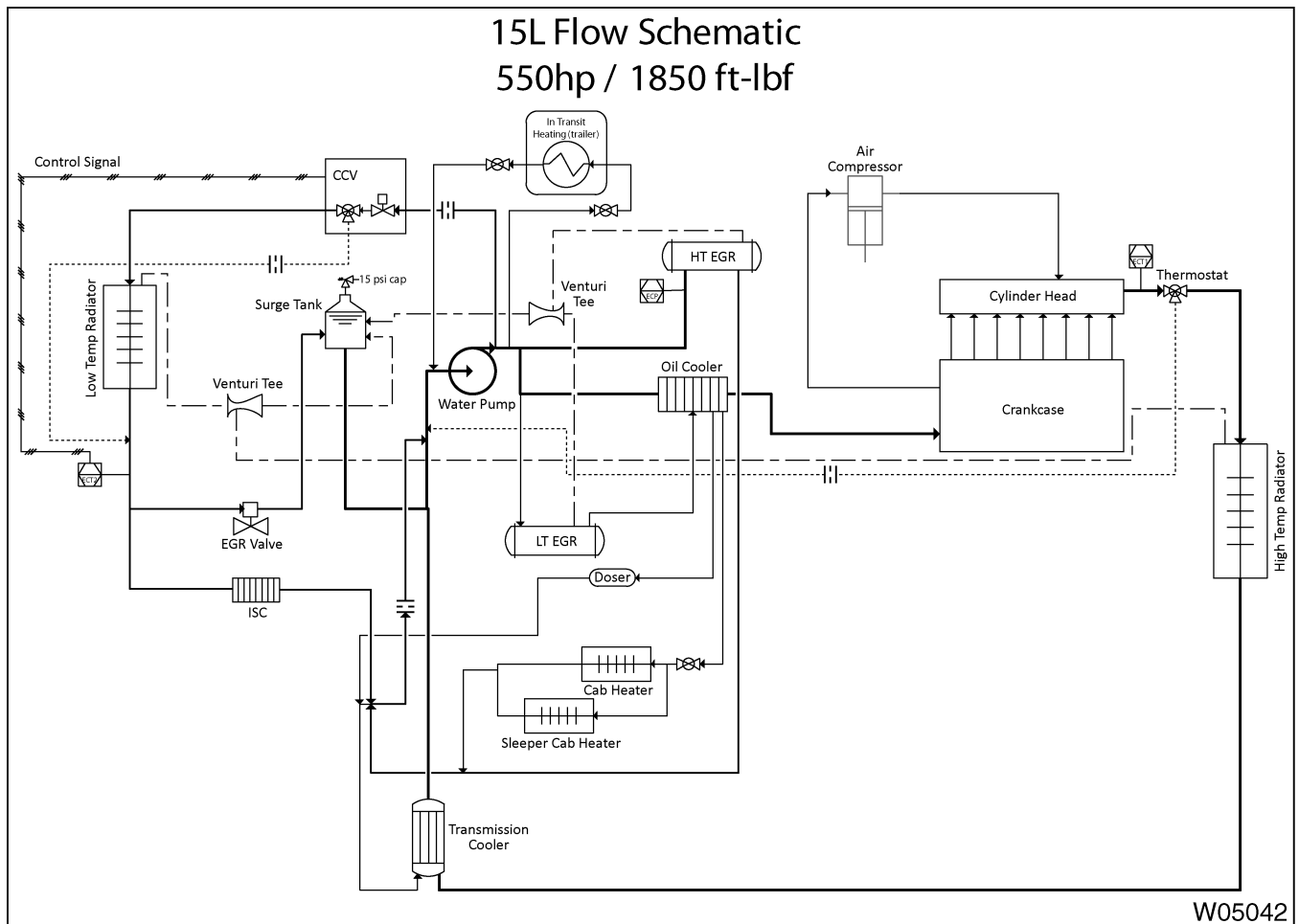


Figure 24 Cooling system flow (automatic transmission)

The water pump is located on the front cover and draws coolant from the radiator through the coolant inlet at the lower right side of the engine. The water pump pushes coolant to the oil cooler through a passage in the front cover.

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

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

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

When the thermostat is open, the bypass port is blocked, and coolant is directed from the engine into the radiator. Coolant passes through the radiator and is cooled by moving air from the radiator fan. The coolant returns to the engine first through the transmission cooler, then through the engine water inlet pipe.

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

The fuel doser is also cooled with engine coolant supplied by the oil cooler module. Coolant passes

through the fuel doser and is returned to the engine water inlet pipe.

For vehicles equipped with an automatic transmission, an additional coolant junction is added to supply coolant to the transmission cooler box.

The oil cooler assembly receives coolant from the front cover water outlet pipe. Coolant passes between the oil cooler plates and returns to the crankcase.

Coolant from the water pump also flows through an external pipe to the rear EGR cooler and to the front EGR cooler. Coolant passes between the EGR cooler plates. Rear EGR cooler section coolant travels parallel to the exhaust flow. The front EGR cooler section coolant flows opposite to the exhaust flow. The coolant from the rear EGR cooler is then returned to the water inlet pipe. The coolant from the front EGR cooler is returned to an external pipe to the back of the oil cooler module. Deaeration ports are located on the top of both the rear and front EGR coolers which directs coolant and trapped air to the coolant surge tank.

Coolant from the water pump also flows through the Interstage cooler to regulate the charge air temperature. Flow through the Interstage cooler is controlled by the Coolant Controlled Valve (CCV). Depending on the coolant flow, CCV sends coolant through the Low Temperature Radiator (LTR) or bypass directly to the Interstage Cooler (ISC). When the charge air temperature is too low, CCV bypasses the LTR and directs all the coolant through the ISC. When the charge air temperature increases, CCV directs a percentage of coolant to the LTR before it enters the ISC to cool the charge air. If the engine coolant temperature is too high, CCV sends all of the coolant flow through the LTR and through the ISC to help cool the engine faster.

Coolant from the CCV also flows to the EGR valve. Flow through the EGR valve is supplied by an external pipe that also supplies to the Interstage cooler. The EGR valve coolant flow is then returned to the top port of the surge tank.

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

- Rear and Front EGR Cooler
- Main radiator vent
- Low temperature radiator vent

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.

Thermostat Operation

The MaxxForce® 15 engine is fitted with two thermostats in a common housing to ensure sufficient coolant flow in all operating conditions. The thermostats are located at the front of the engine on the right side of the cylinder head.

The thermostat housing assembly has two outlets. One directs coolant to the radiator when the engine is at operating temperature. The second outlet directs coolant to the water pump until the engine reaches operating temperature. The thermostats begin to open at 88°C (190°F) and are fully open at 103°C (217°F).

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

When coolant temperature reaches the opening temperature of 88°C (190°F), the thermostats open and allow some coolant to flow to the radiator. When coolant temperature exceeds 103°C (217°F), the lower seat blocks the bypass port and directs full coolant flow to the radiator.

Coolant Control Valve (CCV) Assembly Operation

The CCV assembly is installed on the lower right side of the engine and controls coolant flow to the ISC, EGR valve, and LTR.

The CCV assembly has two separate solenoid actuated valves: Coolant Mixer Valve (CMV) and Coolant Flow Valve (CFV). The CMV and the CFV are part of the CCV assembly and cannot be serviced separately. The CMV and CFV solenoids are controlled by two separate Pulse Width Modulated (PWM) signals from the ECM. The PWM signal duty cycles vary between 0% and 100% depending on the coolant and charge air temperature.

CFV

The flow valve varies the rate of coolant flow to the mixing valve. At 0% duty cycle the flow valve is fully open and coolant to the mixing valve is not restricted.

When the flow valve receives 100% duty cycle, it partially closes restricting coolant to the mixing valve.

CMV

The mixing valve varies the amount of coolant that passes through the low temperature radiator, or LTR.

With a 0% signal to the mixing valve, all coolant flows to the LTR before entering the ISC and the EGR valve. When 100% duty cycle is applied to the mixing valve, full coolant flow bypasses the LTR and is directed to the ISC and EGR valve.

MaxxForce® Engine Brake System

The MaxxForce® engine brake is standard equipment on the MaxxForce® 15L engine. The engine brake uses engine oil pressure to improve the engine braking power by holding the exhaust valves slightly open during the cylinder compression and power strokes.

During engine brake operation, both the compression and expansion strokes of the power cylinders are used to absorb road speed energy through the powertrain.

The operator can enable or disable the engine brake by pressing a dash mounted ON/OFF switch.

brake housing assemblies. This provides progressive braking capabilities with the retarding effect of two cylinders, four cylinders, or all six cylinders.

Engine Brake System Components

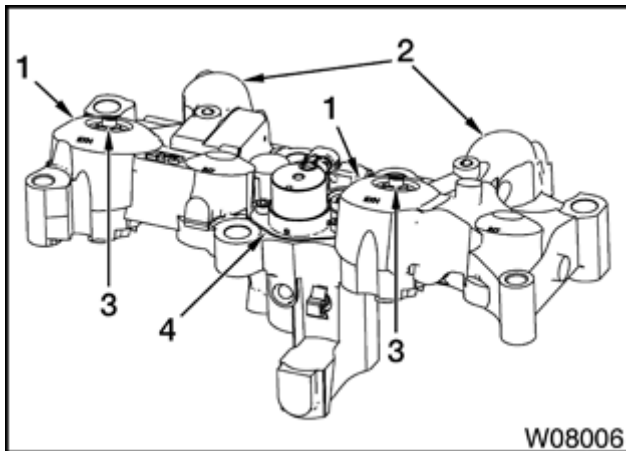


Figure 25 Engine brake housing

1. Slave piston
2. Master piston
3. Slave piston adjustment screw
4. Engine brake solenoid and spool valve

The engine brake consists of three identical housing assemblies; each housing is positioned over two cylinders. The housing assembly is mounted to the supports for the rocker shaft assembly with studs and nuts. The rocker arm and exhaust bridge assembly is used to transfer force from the slave piston to the exhaust valves.

The engine brake is controlled by the ECM. The control circuit for the engine brake permits the operation of either one, two, or all three engine

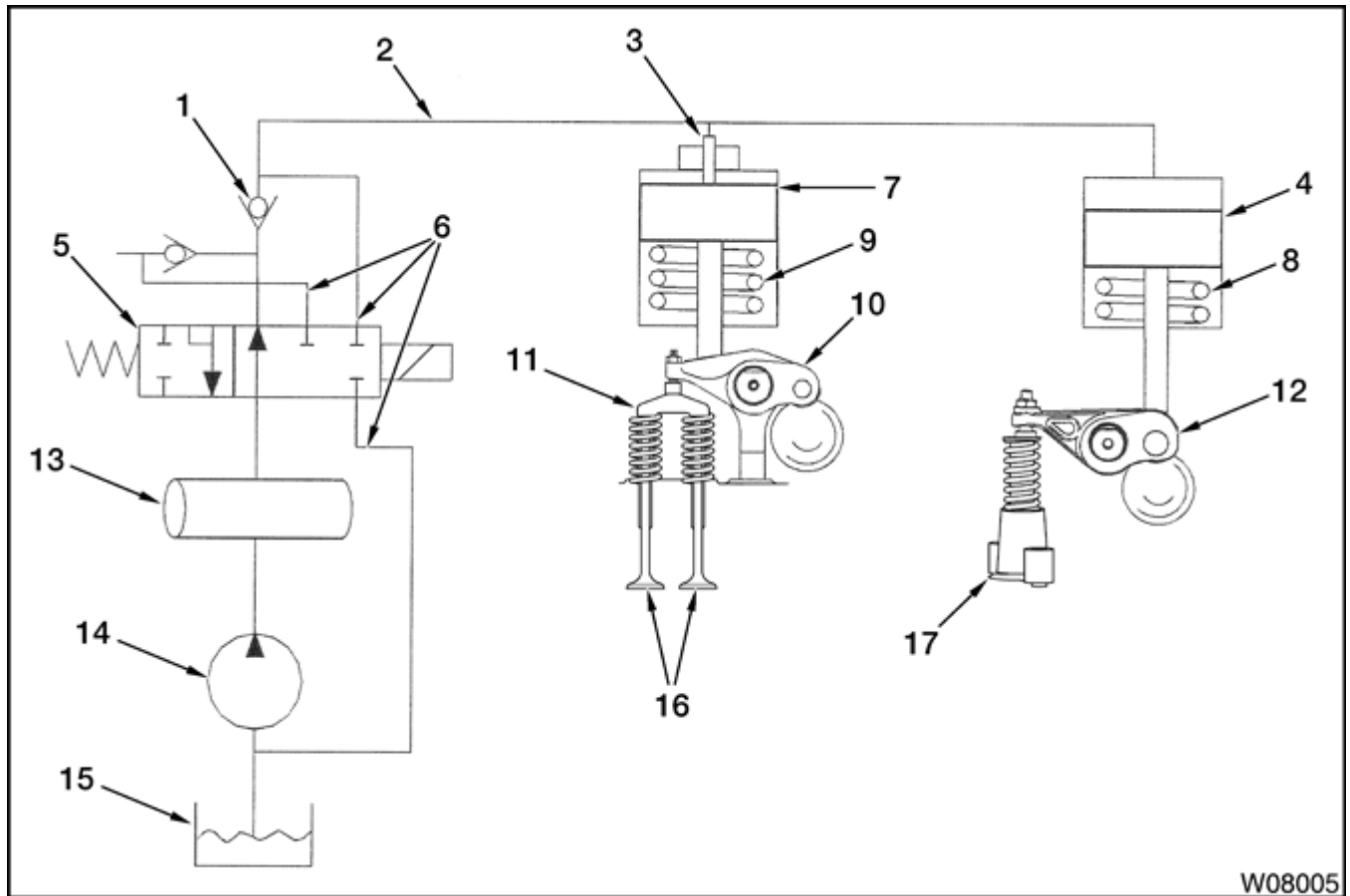


Figure 26 Engine brake system

1. Check valve	7. Slave piston	13. Rocker arm shaft oil passage
2. High-pressure oil passage	8. Master piston spring	14. Engine oil pump
3. Slave piston adjustment screw	9. Slave piston spring	15. Engine oil pan
4. Master piston	10. Exhaust rocker arm	16. Exhaust valve
5. Spool valve	11. Exhaust bridge	17. Lost motion assembly
6. Oil drain passage	12. Lost motion rocker arm	

Engine Brake Operation

The engine brake is operated by pressurized engine oil. Engine oil is supplied to the engine brake through a passage in the rocker shaft assembly. The spool valve controls the flow of oil to the engine brake components.

When the spool valve is moved by the engine brake solenoid, low pressure oil passes through the spool valve. The oil flow opens a check valve and flows into the high-pressure oil passage to supply oil to the master and slave cylinders. The oil pressure overcomes the spring in the master cylinder and forces the master piston toward the lost motion rocker

arm. Oil fills the master cylinder and high-pressure oil passage between the master cylinder and slave cylinder. The master piston will follow the movement of the lost motion rocker arm. The check valve will close when the master piston moves upward causing the pressure in the high-pressure oil passage to rise. This increase in pressure causes the slave cylinder to move downward contacting the exhaust valve bridge and open the exhaust valves.

The ECM will disable the fuel injectors during engine brake operation. Without fuel injection or combustion, the power stroke is transformed into an energy absorption stroke. This will create an engine braking

force at the flywheel. As the lost motion rocker arm moves down, the master piston will also move down and reduce the oil pressure on the slave piston. As a result, the slave piston will move upward and return exhaust valve operation to the engine valve train.

De-energizing the solenoid allows oil to drain back into the engine oil pan through the drain passages in the spool valve.

Open Crankcase Breather System

Open Crankcase Breather System Components

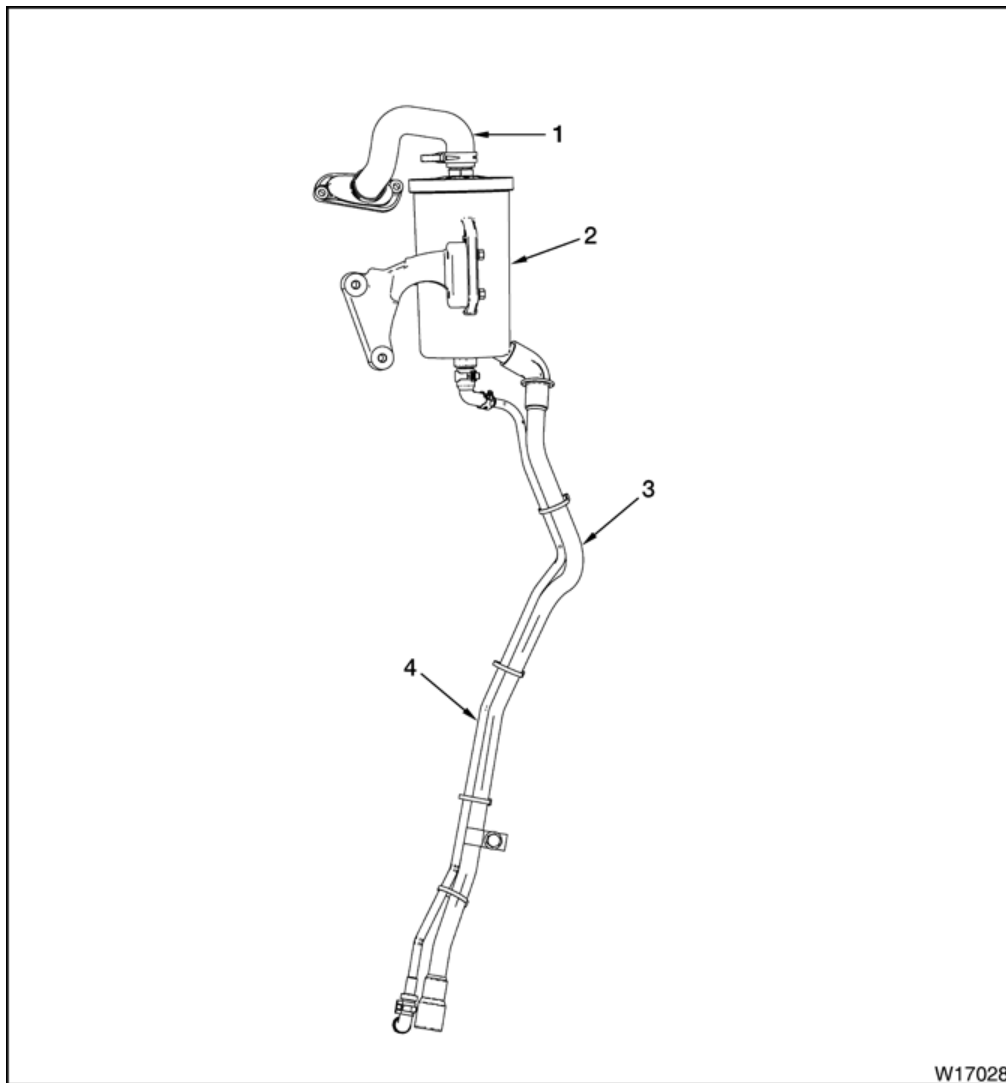


Figure 27 Open crankcase breather system

1. Breather inlet tube	3. Breather outlet tube
2. Breather filter assembly	4. Breather drain tube

Open Crankcase Breather System Operation

The open crankcase breather system uses an engine mounted oil separator to return oil to the crankcase and vent blow-by gases to the atmosphere. The primary component of the system is the breather filter in the breather filter assembly. The breather filter separates oil mist from blow-by gases.

The blow-by gases exit the crankcase from the valve cover and enter the breather system through the

breather inlet tube. From the breather inlet tube, blow-by gases enter the breather filter assembly where heavy oil particles are separated and drain into the oil pan through check valves in oil drain tube.

The cleaned blow-by gases exit to the atmosphere through the breather outlet tube.

Cold Start Assist System

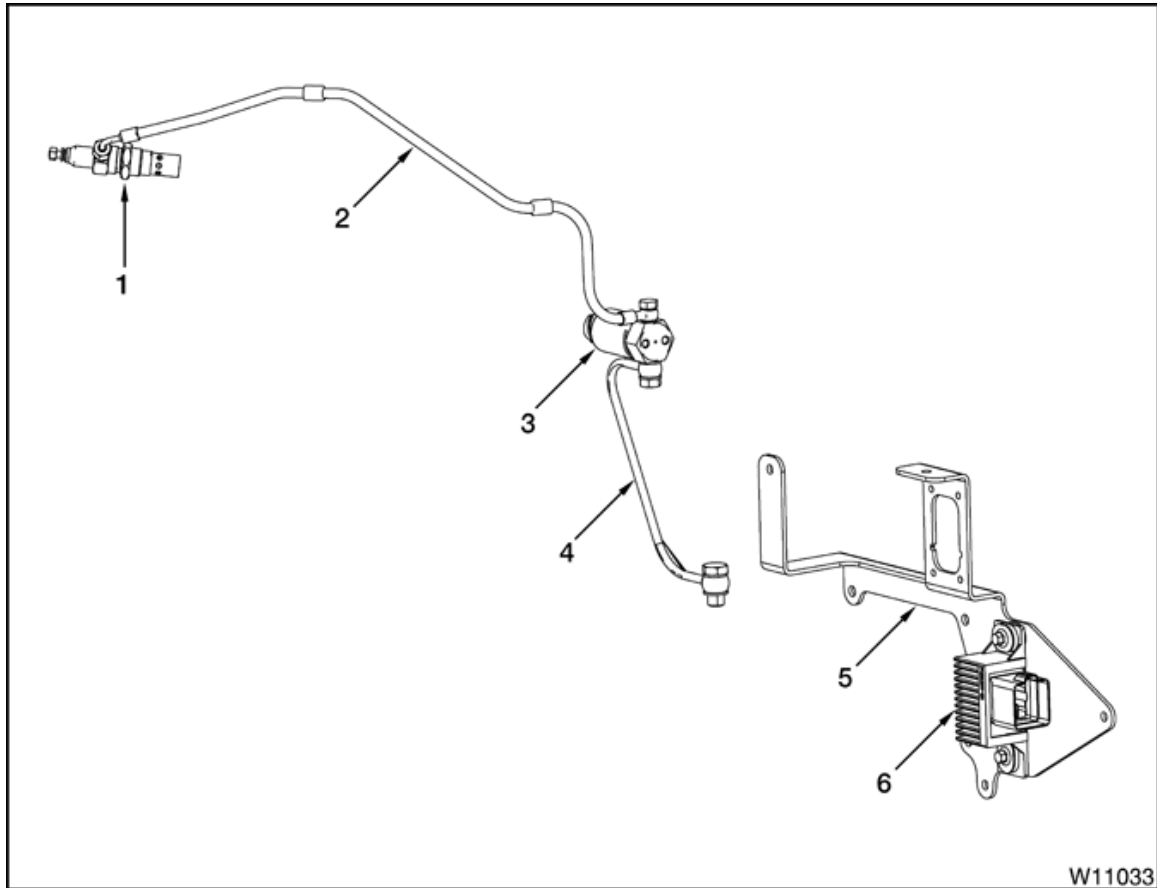


Figure 28 Cold start assist system components

1. Cold Start Fuel Igniter (CSFI)	3. Cold Star Fuel Solenoid (CSFS)	6. Cold Start Relay (CSR)
2. Solenoid to injector tube assembly	4. Filter to solenoid tube assembly	
	5. Relay support assembly	

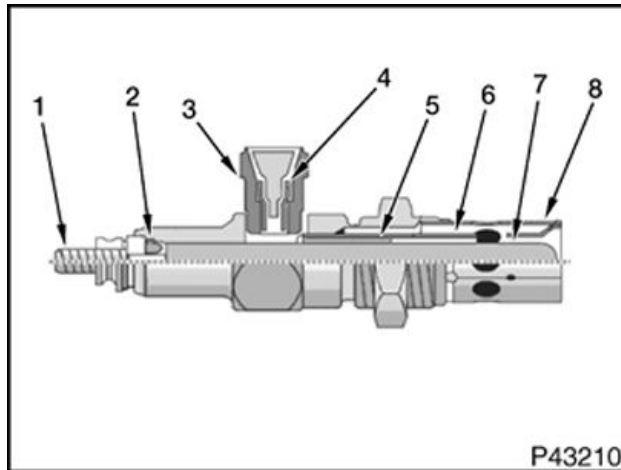
Cold Start Fuel Igniter (CSFI)

Figure 29 Cold Start Fuel Igniter (CSFI)

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

The function of the CSFI is to spray ignited fuel into the mixing duct. The ignited fuel warms incoming air to assist starting a cold engine. The CSFI is essentially a fuel injector and glow plug in one unit.

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

The CSFI is installed on the left front side of the engine in the mixing duct.

Cold Start Relay (CSR)

The CSR is located on the rear left side of the engine. The CSR provides voltage to the CSFI and is controlled by the Engine Control Module (ECM).

Cold Start Fuel Solenoid (CSFS)

The CSFS valve is located on the left side of the engine and is controlled by the ECM. The CSFS valve is supplied regulated low pressure fuel from the fuel filter housing assembly through the solenoid to injector tube.

When the ECM provides 12 volts to the solenoid valve, the CSFS valve opens and allows fuel to flow to the CSFI through the solenoid to injector tube. Ground control is provided by the ECM.

Cold Start Assist System Operation

The cold start assist system operates only in temperatures lower than 11°C (52°F).

When the vehicle operator turns the ignition switch to ON, the wait-to-start lamp in the instrument cluster illuminates. The ECM activates the Cold Start Relay (CSR) based on the temperature readings from the Engine Coolant Temperature (ECT), Engine Oil Temperature (EOT), and the Intake Air Temperature (IAT) sensors. The CSR then energizes the CSFI for approximately 45 seconds.

Once the CSFI is heated to approximately 1 000°C (1,832°F), the wait-to-start lamp starts to flash and the operator needs to crank the engine. When the engine starts rotating, the solenoid valve opens and allows fuel to enter the CSFI through the solenoid to injector tube. The fuel passes through the vaporizer tube inside the CSFI. The vaporized fuel then mixes with the intake air and ignites in contact with the heater element.

Once the engine starts, the CSFI remains energized and fuel continues to be injected to the CSFI, and the wait-to-start lamp continues to flash for a maximum of 4 minutes. When the wait-to-start lamp stops flashing, the CSFI and the solenoid valve are deactivated. If the operator accelerates while the wait-to-start lamp flashes, the cold start assist system will shut down.

Electronic Control System

Electronic Control System Components

The MaxxForce® 15 engine is equipped with an Engine Control Module (ECM) that monitors and controls all functions of the engine and aftertreatment system.

Operation and Function

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

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

Reference Voltage (VREF)

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

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 control module's microprocessors can process.

Microprocessor

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

Continuous calculations in the ECM occur in the foreground and background.

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

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

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

Diagnostic Trouble Codes

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

Microprocessor Memory

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

ROM

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

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

RAM

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

- Engine temperature
- Engine rpm
- Accelerator pedal position

Actuator Control

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

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

- Pulse Width Modulated (PWM)
- Switched on or off
- CAN messages

Actuators

The ECM controls engine operation with the following:

- Coolant Flow Valve (CFV)
- Coolant Mixer Valve (CMV)
- Exhaust Gas Recirculation (EGR) valve
- Air control valves (TC1WC and TC2WC)
- Cold Start Fuel Solenoid (CSFS)
- Cold Start Relay (CSR)
- Engine Throttle Valve (ETV)
- Fuel Pressure Control Valve (FPCV)

Coolant Flow Valve and Coolant Mixer Valve

The Coolant Flow Valve (CFV) controls the maximum pressure in the LTR and the Coolant Mixer Valve (CMV) regulates the temperature of the coolant by directing the coolant either through the Low Temperature Radiator (LTR) or through an internal bypass. Both valves are controlled by the ECM.

The CFV and CMV are part of the Coolant Control Valve (CCV) assembly which is mounted on the lower right side of the engine.

Exhaust Gas Recirculation (EGR) Valve Assembly

The EGR valve assembly controls the flow of exhaust gases entering the EGR cooler assembly.

The EGR valve operates on a Pulse Width Modulated (PWM) voltage signal from the ECM. The ECM will then regulate the duty cycle of the PWM voltage signal to the EGR valve assembly actuator to open or close the valve as required.

A sensor within the EGR valve provides feedback to the ECM on the valve position. A fault code will be set if the ECM detects an error.

The EGR valve assembly is mounted on the rear of the EGR cooler assembly, on the right side of the engine.

Air Control Valve

The air control valve controls the wastegate actuator on the high-pressure turbocharger.

The air control valve either applies air pressure to the wastegate actuator, or vents system pressure to the atmosphere in response to commands from the ECM.

The air control valve is mounted on a bracket on the right side of the engine, below the secondary EGR cooler.

Cold Start Relay (CSR)

The cold start assist system aids cold engine starting by warming the incoming air supply during cranking and initial idling.

The CSR is a solid state relay that is pulse width modulated by the ECM to energize the CSFI. The CSFI is case grounded to the ETV assembly. The total time that the CSR energizes the CSFI is dependent on engine coolant temperature.

Cold Start Fuel Solenoid (CSFS)

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

When the cold start assist is required, the ECM provides voltage to open the CSFS valve during cranking and initial idling.

The CSFS valve is mounted on the left side of the engine, above the fuel filter.

Engine Throttle Valve (ETV)

The ETV is a variable position actuator that restricts intake air flow by way of an internal butterfly valve to help heat the exhaust aftertreatment during regeneration, and to assist when heavy EGR is requested.

The ETV changes butterfly valve position in response to ECM signals. The ETV contains an internal position sensor that monitors butterfly valve position and transmits a position signal to the ECM.

The ETV is mounted on the left side of the engine.

Fuel Pressure Control Valve (FPCV)

The FPCV is a variable position actuator that regulates fuel pressure in the pressure pipe rail.

The FPCV changes valve position through pulse width modulated signals from the ECM. It controls the flow of fuel to the suction side of the high-pressure pump.

The FPCV is mounted on the high-pressure pump. They are serviced as an assembly.

Engine and Vehicle Sensors

Thermistor Sensor

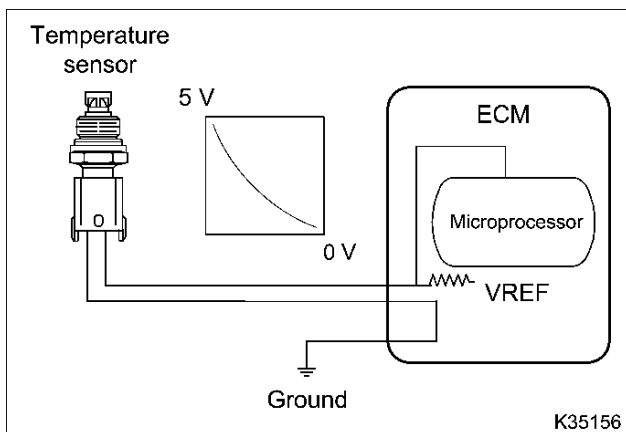


Figure 30 Thermistor sensor

A thermistor sensor changes electrical resistance with changes in temperature. Resistance in the thermistor

decreases as temperature increases, and increases as temperature decreases. Thermistors work with a resistor that limits current in the control module to a voltage signal matched with a temperature value.

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

Thermistor type sensors include the following:

- Aftertreatment temperature sensors
- Charge Air Cooler Outlet Temperature (CACOT)
- Engine Coolant Temperature (ECT) sensors
- Engine Oil Temperature (EOT) sensor
- Intake Manifold Temperature (IMT) sensor

Aftertreatment Temperature Sensors

Three sensors used in the Aftertreatment System include the following:

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

The DOCIT sensor provides a feedback signal to the Engine Control Module (ECM) indicating Diesel Oxidation Catalyst (DOC) inlet temperature. The DOCIT sensor is the first temperature sensor installed past the pre-diesel oxidation catalyst and just before the DOC.

The DOCOT sensor provides a feedback signal to the Engine Control Module (ECM) indicating Diesel Oxidation Catalyst (DOC) outlet temperature. The DOCOT sensor is installed just after the DOC.

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

During a DPF regeneration, the ECM monitors these sensors along with the EGR system and ETV.

Charge Air Cooler Outlet Temperature (CACOT) Sensor

Early production engines come equipped with a CACOT sensor; however, even though it is electronically connected to the system, it is disabled in the ECM software and not currently utilized. The CACOT sensor is installed in the engine throttle valve assembly.

Engine Coolant Temperature 1 (ECT1) Sensor

The ECT sensor is a thermistor sensor that detects engine coolant temperature.

This engine has two ECT sensors. The ECT1 sensor is installed on the right side of the engine behind the thermostat assembly. The ECT2 sensor is installed in the coolant manifold behind the interstage cooler.

The ECT1 and ECT2 signals are monitored by the ECM for operation of the instrument panel temperature gauge, coolant temperature compensation, charge air temperature control, optional Engine Warning Protection System (EWPS), and the wait-to-start lamp.

Engine Oil Temperature (EOT) Sensor

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

The EOT signal is monitored by the ECM for the Engine Warning Protection System (EWPS). The EOT sensor is also used by the oil temperature gauge in the instrument cluster.

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

Intake Manifold Temperature (IMT) Sensor

The IMT sensor is a thermistor sensor that monitors the temperature of the intake air.

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

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

Variable Resistance Sensor

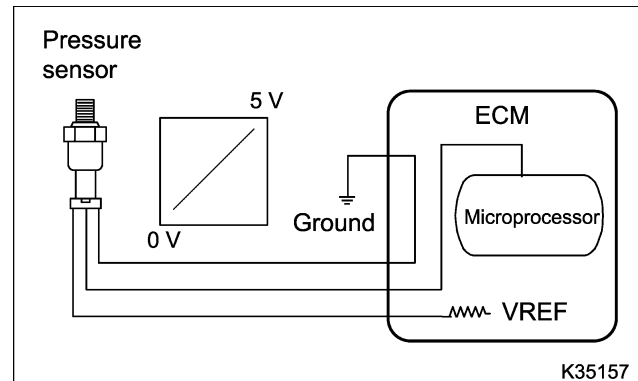


Figure 31 Variable resistance sensor

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

The sensor is connected to the control module through the VREF, signal, and signal ground wires.

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

Variable resistance sensors include the following:

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

Exhaust Gas Differential Pressure (EGDP) Sensor

The EGDP sensor provides a feedback signal to the Engine Control Module (ECM) indicating the pressure difference between the inlet and outlet of the particulate filter. The ECM monitors this sensor to determine DPF soot levels.

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

Engine Fuel Delivery Pressure (FDP) Sensor

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

The FDP sensor provides feedback to the ECM for the low-pressure fuel system.

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

Engine Oil Pressure (EOP) Sensor

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

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

The EOP sensor is installed in the oil pressure sensor support, on the left side of the engine.

Fuel Rail Pressure (FRP) Sensor

The FRP sensor is a variable resistance sensor that monitors the fuel pressure in the pressure pipe rail.

The FRP sensor measures the fuel pressure just prior to injection.

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

Intake Manifold Pressure (IMP) Sensor

The IMP sensor is used to measure the absolute charge-air pressure.

The IMP sensor is installed in the ETV on top of the engine.

Magnetic Pickup Sensor

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)

Crankshaft Position (CKP) Sensor

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

The CKP sensor sends a pulsed signal to the Engine Control Module (ECM) as the crankshaft turns. The CKP sensor reacts to a 58 tooth timing disk on the front of the crankshaft. By comparing the CKP signal with the CMP signal, the ECM calculates engine rpm and timing requirements.

The CKP sensor is installed at the bottom left of the engine, in the front cover.

Camshaft Position (CMP) Sensor

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

The CMP sensor sends a pulsed signal to the ECM as the camshaft timing ring mounted on the rear of the camshaft gear rotates past the CMP sensor. The ECM calculates camshaft speed and position from CMP signal frequency.

The CMP sensor is installed at the top left of the engine, in the front cover.

Vehicle Speed Sensor (VSS)

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

Potentiometer

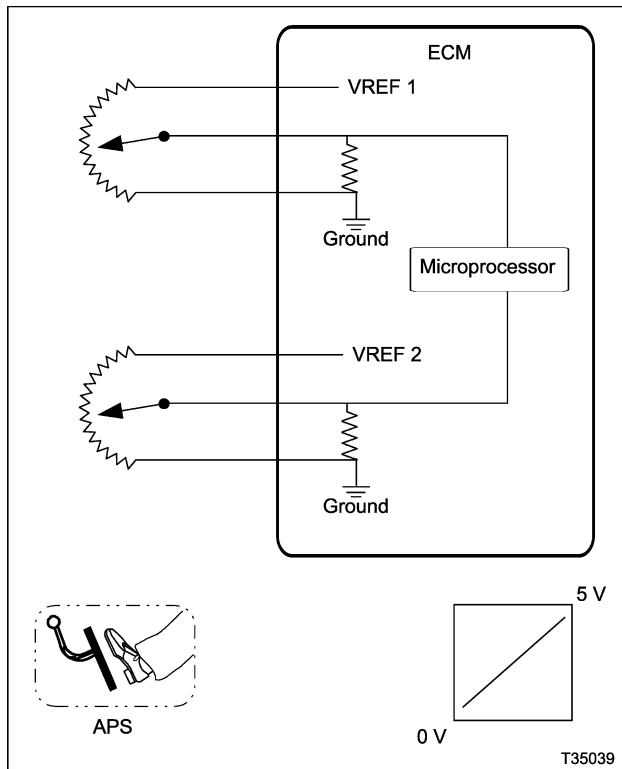


Figure 32 Potentiometer

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

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

Accelerator Pedal Position (APP) Sensors

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

Switches

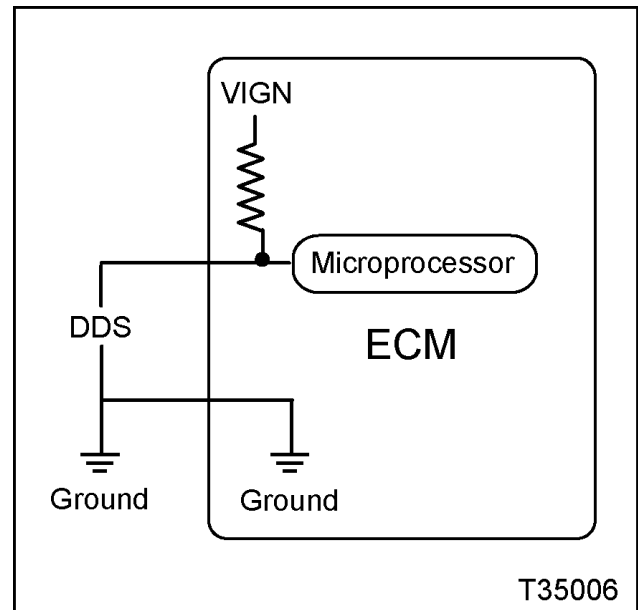


Figure 33 Switch

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 control module with a voltage when it is closed. A grounding switch grounds the circuit when closed, causing a zero voltage signal. Grounding switches are usually installed in series with a current limiting resistor.

Switches include the following:

- Driveline Disengagement Switch (DDS)
- Engine Coolant Level (ECL)

Driveline Disengagement Switch (DDS)

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

Engine Coolant Level (ECL) Switch

The ECL switch is part of the Engine Warning Protection System (EWPS). The ECL switch is located on the deaeration tank. When the magnetic switch is open, the tank is considered full of coolant.

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

Oxygen Sensor (O2S)

The O2S monitors oxygen levels in exhaust gases.

The O2S is used to tune the engine operation to a specified air-to-fuel ratio.

The O2S compares oxygen levels in the exhaust stream with oxygen levels in the outside air. It then generates a voltage that is transmitted to the ECM. The level of voltage generated by the O2S

corresponds to the oxygen levels in the exhaust stream.

The O2S is installed in the turbocharger exhaust duct.

Turbocharger 2 Compressor Inlet Sensor (TC2CIS)

Early production engines will be equipped with a TC2CIS, however this sensor is not used by the engine control system at this time.

The TC2CIS is installed in the low-pressure turbocharger compressor outlet duct.

Table of Contents

Engine Preparation.....	55
Clean Engine.....	55
Drain Engine Coolant.....	56
Drain Oil.....	58
Removing Engine from Vehicle.....	58
Removal.....	59
Electrical Connections.....	59
Aftertreatment System Components.....	59
Turbocharger System Components.....	59
EGR Coolant Tubes.....	59
Oil Cooler and Filter Housing.....	59
Mounting Engine On Stand.....	59
Special Torque.....	61
Special Service Tools.....	61

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, make sure the engine has cooled before removing components.

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

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

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 with Disposable Air and Fuel Caps (page 61).
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 Engine Coolant

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

1. Place coolant drain pan under the lower radiator drain fitting.
2. Open the radiator lower drain fitting and allow the engine coolant to drain. Open radiator cap to allow system to drain quicker.
3. Close the radiator lower drain fitting.

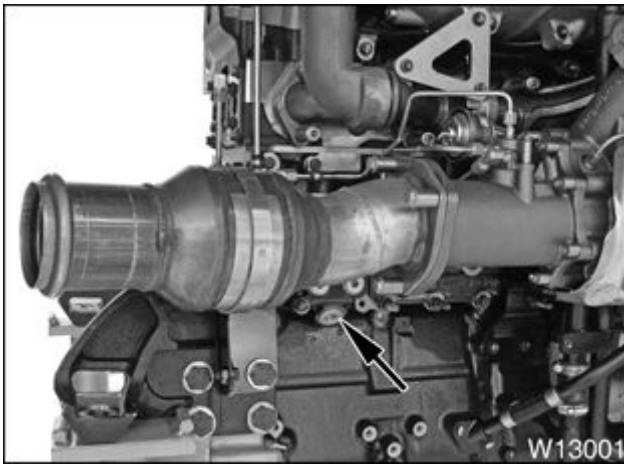


Figure 34 Engine coolant 1 3/16-12 O-ring boss plug

4. Place coolant drain pan under the engine oil cooler assembly.
5. Remove 1 3/16-12 O-ring boss plug from the bottom of the engine oil cooler assembly. Open radiator cap to allow system to drain quicker.
6. Remove and discard 1 3/16-12 O-ring boss plug O-ring.
7. Install new O-ring on the 1 3/16-12 O-ring boss plug.
8. After coolant has drained, install 1 3/16-12 O-ring boss plug in the engine oil cooler assembly.

9. Tighten 1 3/16-12 O-ring boss plug to special torque (page 61).
10. Recycle or dispose of engine coolant according to applicable regulations.

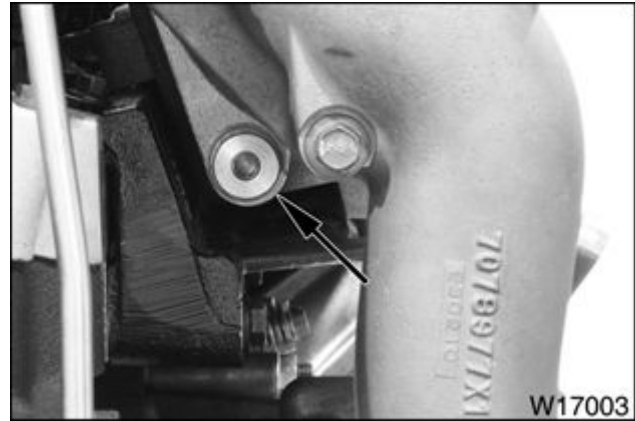


Figure 35 High Temperature EGR cooler assembly M18 O-ring boss plug

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

11. Place coolant drain pan under the high temperature EGR cooler assembly.
12. Remove M18 O-ring boss plug from the bottom of the EGR cooler assembly.
13. Remove and discard M18 O-ring boss plug O-ring.
14. Install new O-ring on the M18 O-ring boss plug.
15. After coolant has drained, install M18 O-ring boss plug in the EGR cooler assembly.
16. Tighten M18 O-ring boss plug to special torque (page 61).
17. Recycle or dispose of engine coolant according to applicable regulations.

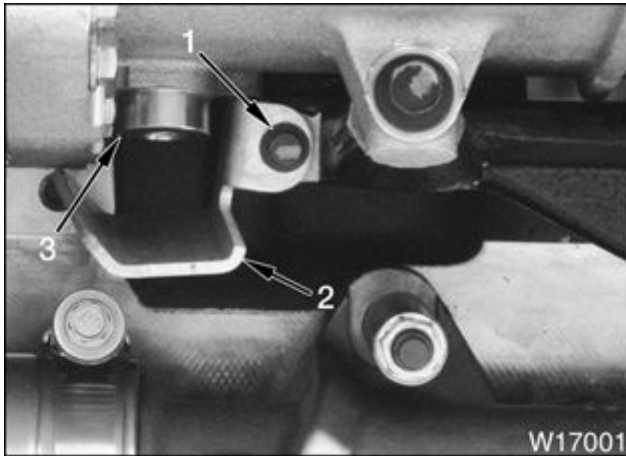


Figure 36 Low Temperature EGR cooler assembly M18 O-ring boss plug

1. M6 x 12 hex flange bolt
2. EGRC coolant drain guide
3. M18 O-ring boss plug

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

18. Place coolant drain pan under the low temperature EGR cooler assembly.

CAUTION: To prevent engine damage, the EGRC coolant drain guide must be installed during reassembly before running the engine. The EGRC coolant drain guide also acts as a heat shield and provides protection from heat damage to the M18 O-ring boss plug O-ring.

19. Remove M6 x 12 hex flange bolt and the EGRC coolant drain guide.
20. Remove M18 O-ring boss plug from the bottom of the EGR cooler assembly.
21. Remove and discard M18 O-ring boss plug O-ring.
22. Install new O-ring on the M18 O-ring boss plug.
23. After coolant has drained, install M18 O-ring boss plug in the EGR cooler assembly.

24. Tighten M18 O-ring boss plug to special torque (page 61).
25. Recycle or dispose of engine coolant according to applicable regulations.
26. During reassembly, install the EGRC coolant drain guide and M6 x 12 hex flange bolt. Tighten M6 x 12 hex flange bolt to standard torque (page 561).

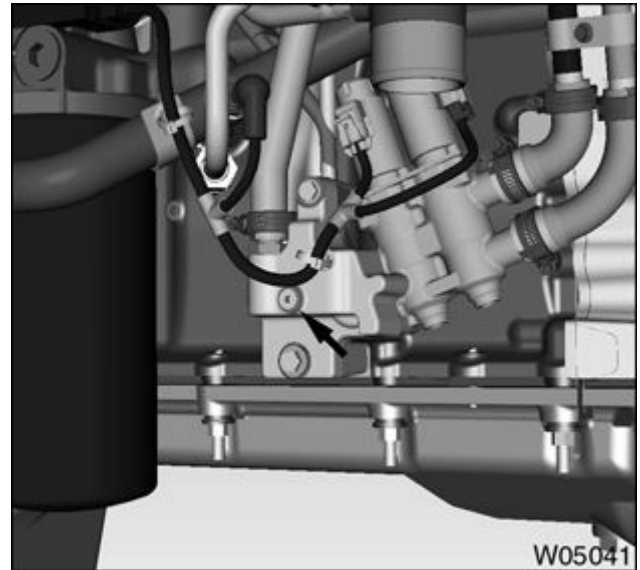


Figure 37 Coolant adapter plug assembly

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

27. Place coolant drain pan under the coolant adapter.
28. Remove plug assembly and allow coolant to drain.
29. Install new O-ring on plug assembly.
30. Install plug assembly and tighten to special torque (page 61).
31. Recycle or dispose of engine coolant according to applicable regulations.

Drain Oil

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

! WARNING: To prevent personal injury or death, wear protective clothing when draining hot oil.

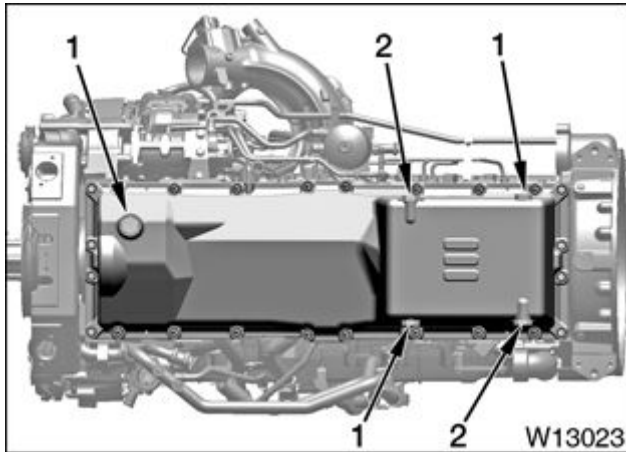


Figure 38 Oil drain plugs

1. 1-1/8 - 12 oil drain plug
 2. 1-5/16-12 oil drain plug
1. Place oil drain pan under the right rear oil drain plug of the engine oil pan lower sump.
 2. Remove the right rear 1-5/16-12 oil drain plug and drain oil into a suitable container.
 3. Inspect oil drain plug and replace if necessary.
 4. Install new O-ring on the 1-5/16-12 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 1-5/16-12 oil drain plug to special torque (page 61).
 7. Recycle or dispose of oil according to applicable regulations.
 8. Place oil drain pan under the engine oil pan upper sump.
 9. Remove 1-1/8 - 12 oil drain plug and O-ring and drain oil into a suitable container.
 10. Inspect oil drain plug and replace if necessary.
 11. Install new O-ring on the 1-1/8 - 12 oil drain plug.
 12. After oil has drained, lubricate oil drain plug O-ring with clean engine oil and install oil drain plug in the oil pan.
 13. Tighten 1-1/8 - 12 oil drain plug to special torque (page 61).
 14. 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

1. Disconnect the engine oil pressure (EOP) sensor, mass air flow (MAF) sensor, wastegate control valve, charge air pressure sensor, charge air cooler temperature sensor, engine coolant temperature (ECT) sensor and coolant control valve (CCV) electrical connectors. See Engine Electrical (page 76).
2. Cut and remove the tie straps from RH side of the engine sensor harness assembly. See Engine Sensor Harness Assembly (page 88).

NOTE: Note the routing of the engine sensor harness assembly for reinstallation.

3. Route the engine sensor harness assembly to the top of the engine and position the harness assembly over the valve cover.

Aftertreatment System Components

1. Remove the Pre-Diesel Oxidation Catalyst (PDOC) and support. See Pre-Diesel Oxidation Catalyst (PDOC) (page 127).
2. Remove the injector unit feed tube assembly and doser fuel from valve tube assembly. See Injector Unit Feed Tube Assembly and Doser Fuel from Valve Tube Assembly (page 129), and Down Stream Injection (DSI) Assembly and Doser Fuel to Injector Tube Assembly (page 128).
3. Remove the turbocharger exhaust duct. See Turbocharger Exhaust Duct (page 131).

Turbocharger System Components

1. Remove the turbocharger oil supply and return tubes. See Turbocharger Oil Drain Tube Assembly (page 145) and Turbocharger Oil Supply Tube Assemblies (page 153).
2. Remove the Interstage Cooler (ISC) and brackets. See Turbocharger Interstage Cooler (ISC) Assembly (page 148).

3. Remove the turbochargers and supports. See Turbochargers (page 154).

EGR Coolant Tubes

1. Remove all Exhaust Gas Recirculation (EGR) coolant tubes below the EGR cooler assembly. See EGR System (page 214).

Oil Cooler and Filter Housing

1. Remove the oil cooler assembly and oil filter base assembly. See Engine Oil Cooler Assembly and Oil Filter Base Assembly (page 263).

Mounting Engine On Stand

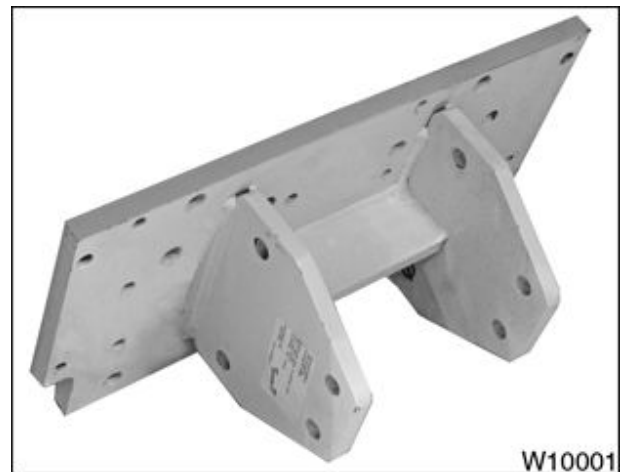


Figure 39 Engine Adapter Mounting Plate

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

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

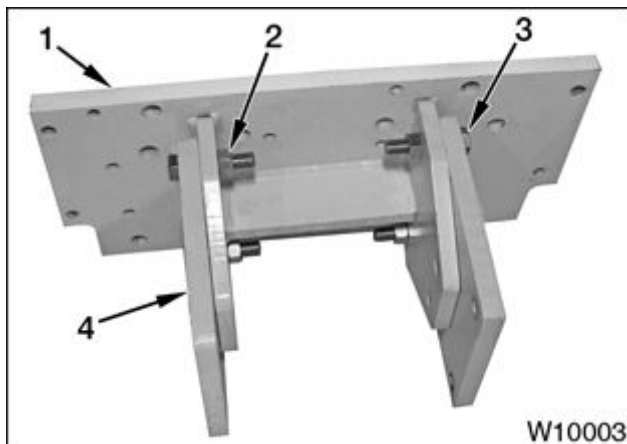


Figure 40 Engine Adapter Mounting Plate and Universal Adapter Plates

1. Engine Adapter Mounting Plate
 2. 5/8-11 nut (4)
 3. 5/8-11 x 2.75 hex bolt (4)
 4. Universal Adapter Plate (2)
1. Position two Universal Adapter Plates (page 61) to the Engine Adapter Mounting Plate (page 61). Loosely install four 5/8-11 x 2.75 hex bolts and four 5/8-11 nuts.

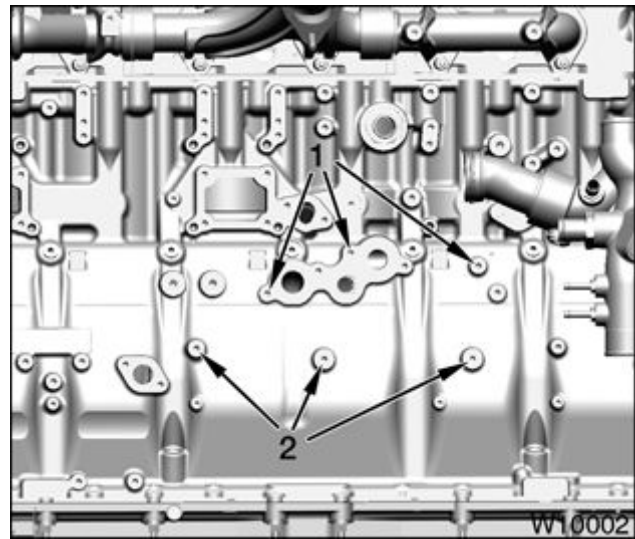


Figure 41 Engine Adapter Mounting Plate attachment points

1. 3/8-16 x 3.25 large cap screw, 3/8 washer and 3/4 O.D. x 1 13/16 spacer
 2. 3/8-16 x 1.5 large cap screw and 3/8 washer
2. Position Engine Adapter Mounting Plate (page 61) on right side of engine. Secure bracket with three 3/8-16 x 3.25 large cap screw, 3/8 washer and 3/4 O.D. x 1 13/16 spacer, and 3/8-16 x 1.5 large cap screw and 3/8 washer. Tighten bolts to standard torque (page 562).

NOTE: The balance point for the engine is two inches above the crankshaft center line. Mount the Universal Adapter Plates to the engine lift stand arm and align the center line of the engine lift stand arm to the balance point of the engine.

3. Mount engine on engine lift stand using four 5/8 x 1.5 inch grade 8 mounting bolts. Tighten Universal Adapter Plate bolts to standard torque (page 562).

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

Special Torque

1-1/8 – 12 oil drain plugs	70 N·m (50 lbf·ft)
1 3/16–12 O-ring boss plug	135 N·m (100 lbf·ft)
1-5/16–12 oil drain plugs	90 N·m (65 lbf·ft)
M18 O-ring boss plugs	24 N·m (18 lbf·ft)
Plug assembly (coolant adapter)	23 N·m (17 lbf·ft)

Special Service Tools

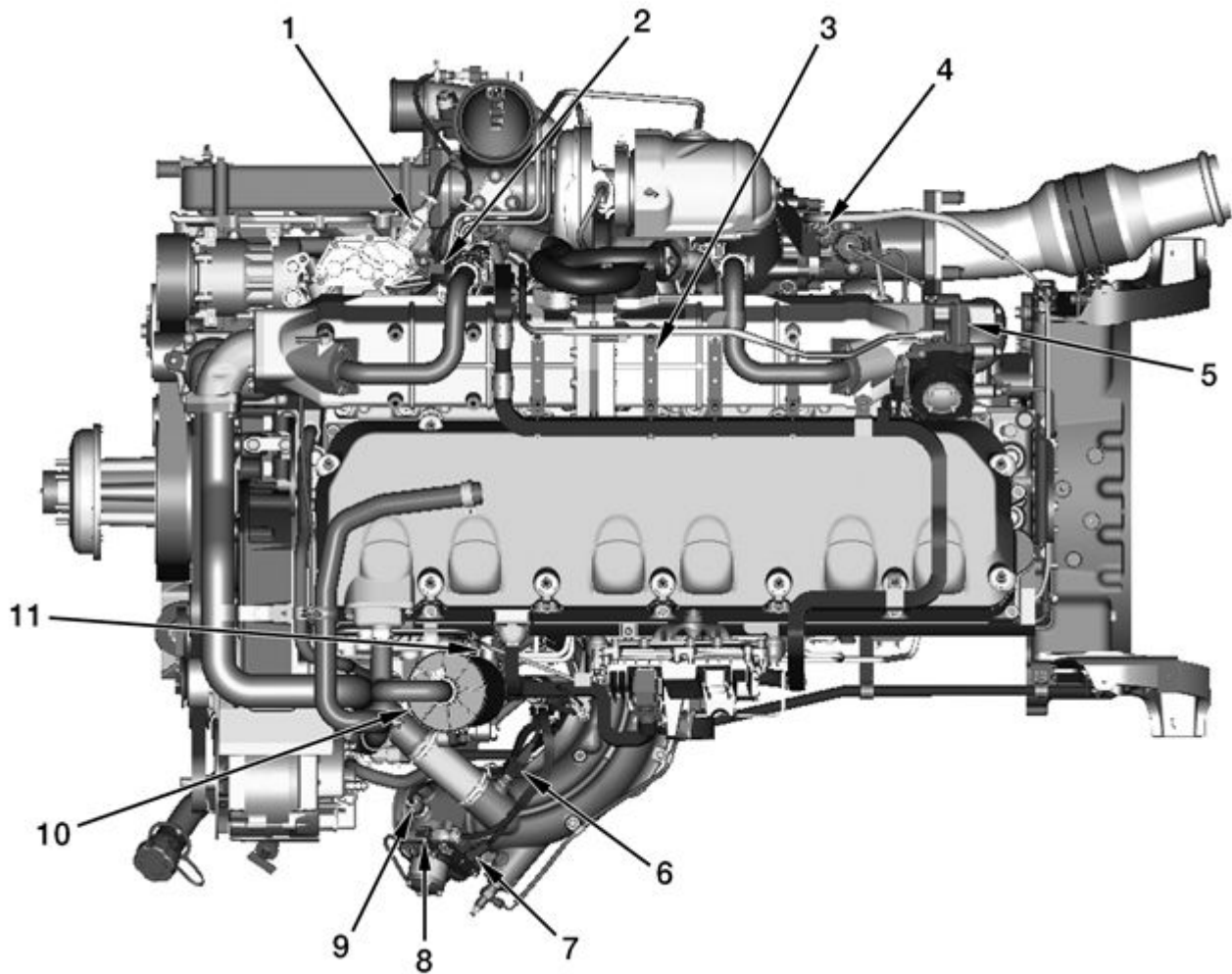
Description	Tool Number
Disposable Air and Fuel Caps	ZTSE4891
Engine Adapter Mounting Plate	OTC205060
Universal Adapter Plates	OTC205061

Table of Contents

Engine Electronic Components.....	65
Engine Sensor Harness Assembly.....	68
Description of Engine Sensors, Valves, and Actuators.....	69
5 mm 60 Degree Speed Sensor used to sense Crankshaft Position (CKP).....	69
5 mm 60 Degree Speed Sensor used to sense Camshaft Position (CMP).....	69
6 Bar Pressure sensor used to sense Engine Oil Pressure (EOP).....	69
15 Bar Pressure Sensor used to sense Fuel Delivery Pressure (FDP).....	70
Charge Pressure Sensor used as Turbocharger 2 Compressor Inlet Sensor (TC2CIS).....	70
Coolant Control Valve (CCV) Assembly.....	70
Coolant Pressure Sensor used to sense Engine Coolant Pressure (ECP1).....	71
Crankcase Pressure (CCP) Sensor	71
EGR Temperature (EGRT) Sensor.....	71
Engine Throttle Valve (ETV) Assembly.....	72
Exhaust Gas Recirculation (EGR) Valve Assembly.....	72
Fuel Rail Pressure (FRP) Sensor.....	73
Intake Manifold Pressure (IMP) Sensor.....	73
Mass Air Flow (MAF) Sensor.....	73
Oxygen Sensor (O2S).....	73
Temperature Sensor used to sense Engine Coolant Temperature 1 (ECT1) and 2 (ECT2).....	74
Temperature Sensor used to sense Engine Oil Temperature (EOT).....	74
Temperature Sensor used to sense Charge Air Cooler Outlet Temperature (CACOT).....	74
Temperature Sensor used to sense Intake Manifold Temperature (IMT).....	75
Wastegate Control Valve (Air Control Valve).....	75
Removal.....	76
Crankshaft Position (CKP) Sensor.....	76
Camshaft Position (CMP) Sensor.....	76
Engine Oil Pressure (EOP) Sensor.....	77
Fuel Delivery Pressure (FDP) Sensor.....	77
Body Harness Interconnect.....	78
Coolant Control Valve (CCV) Assembly Connectors.....	78
Turbocharger 2 Compressor Inlet Sensor (TC2CIS).....	79
Engine Coolant Pressure 1 (ECP1) Sensor.....	79
Crankcase Pressure (CCP) Sensor.....	80
Engine Control Module (ECM) Connections.....	80
EGR Temperature (EGRT) Sensor.....	81
Exhaust Gas Recirculation (EGR) Valve Assembly Connector.....	81
Engine Throttle Valve (ETV) Assembly Connector.....	82
Fuel Rail Pressure (FRP) Sensor.....	82
High-Pressure Fuel Pump Connector.....	83
Intake Manifold Pressure (IMP) Sensor.....	83
Mass Air Flow (MAF) Sensor.....	84
Cold Start Fuel Solenoid (CSFS) Valve Connector.....	84
Charge Air Cooler Output Temperature (CACOT) Sensor.....	85

Engine Coolant Temperature 1 (ECT1) Sensor.....	85
Engine Coolant Temperature 2 (ECT2) Sensor.....	86
Engine Oil Temperature (EOT) Sensor.....	86
Intake Manifold Temperature (IMT) Sensor.....	87
Air Control Valve Connector.....	87
Engine Sensor Harness Assembly.....	88
Engine Control Module (ECM) and ECM Support.....	90
Harness Support (EGR Cooler).....	90
Harness Support (Fuel Pump).....	91
Oxygen Sensor (O2S).....	91
Oil Pressure Sensor Support.....	92
 Cleaning and Inspection.....	 93
Main Engine Wiring Harness.....	93
Sensors and Valves.....	93
 Installation.....	 94
Engine Control Module (ECM) and ECM Support.....	94
Harness Support (EGR Cooler).....	95
Harness Support (Fuel Pump).....	95
Oxygen Sensor (O2S).....	95
Oil Pressure Sensor Support.....	96
Engine Sensor Harness Assembly.....	96
Crankshaft Position (CKP) Sensor.....	98
Camshaft Position (CMP) Sensor.....	99
Engine Oil Pressure (EOP) Sensor.....	99
Fuel Delivery Pressure (FDP) Sensor.....	99
Body Harness Interconnect.....	100
Coolant Control Valve (CCV) Assembly Connectors.....	100
Turbocharger 2 Compressor Inlet Sensor (TC2CIS).....	101
Engine Coolant Pressure 1 (ECP1) Sensor.....	101
Crankcase Pressure (CCP) Sensor.....	101
Engine Control Module (ECM) Connections.....	102
EGR Temperature (EGRT) Sensor.....	103
Exhaust Gas Recirculation (EGR) Valve Assembly Connector.....	103
Engine Throttle Valve (ETV) Assembly Connector.....	104
Fuel Rail Pressure (FRP) Sensor.....	104
High-Pressure Fuel Pump Connector.....	105
Intake Manifold Pressure (IMP) Sensor.....	105
Mass Air Flow (MAF) Sensor.....	106
Cold Start Fuel Solenoid (CSFS) Valve Connector.....	106
Charge Air Cooler Outlet Temperature (CACOT) Sensor.....	107
Engine Coolant Temperature 1 (ECT1) Sensor.....	107
Engine Coolant Temperature 2 (ECT2) Sensor.....	108
Engine Oil Temperature (EOT) Sensor.....	108
Intake Manifold Temperature (IMT) Sensor.....	109
Air Control Valve Connector.....	109
 Special Torque.....	 110
 Special Service Tools.....	 110

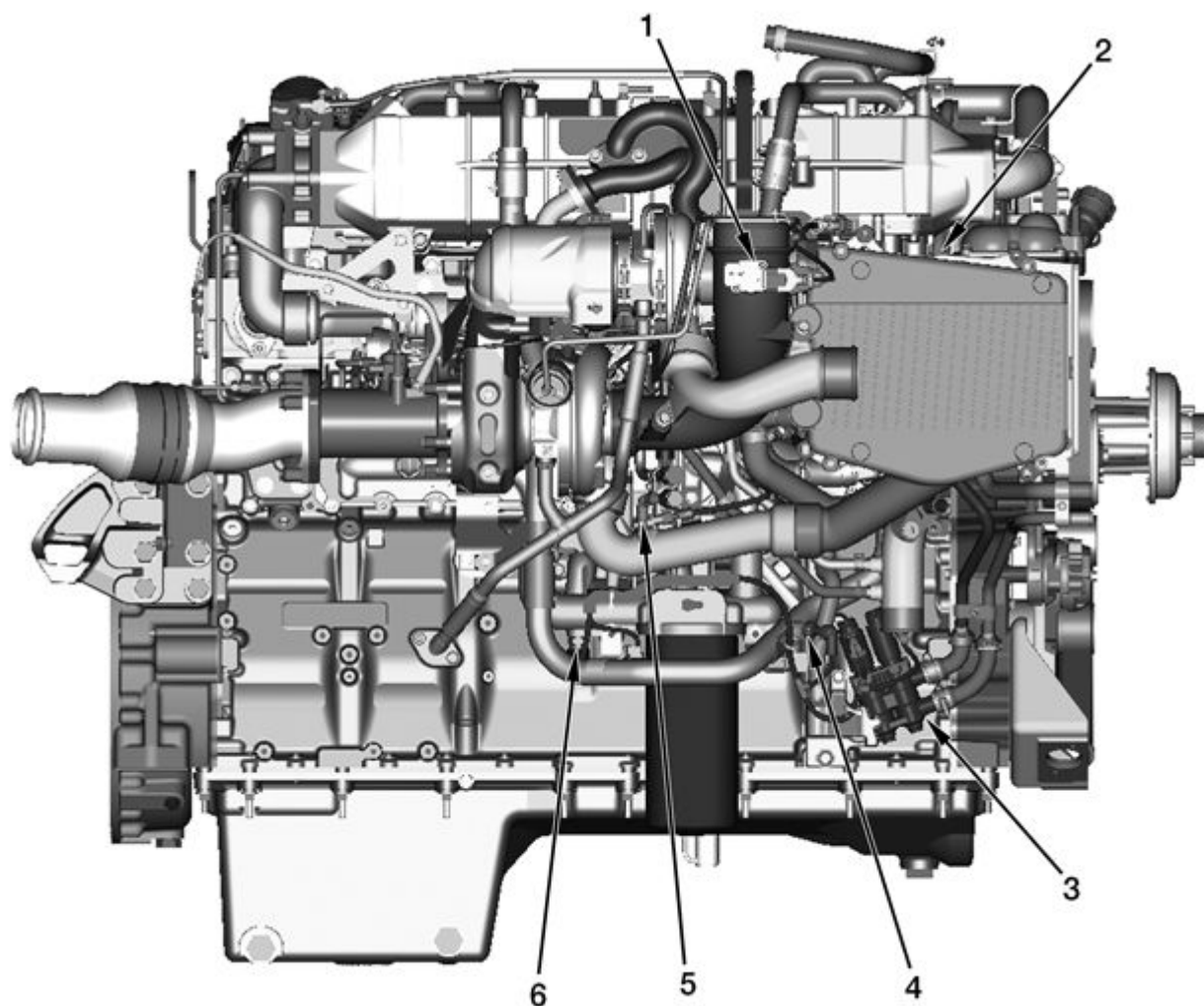
Engine Electronic Components



W09004

Figure 42 Electronic components – top

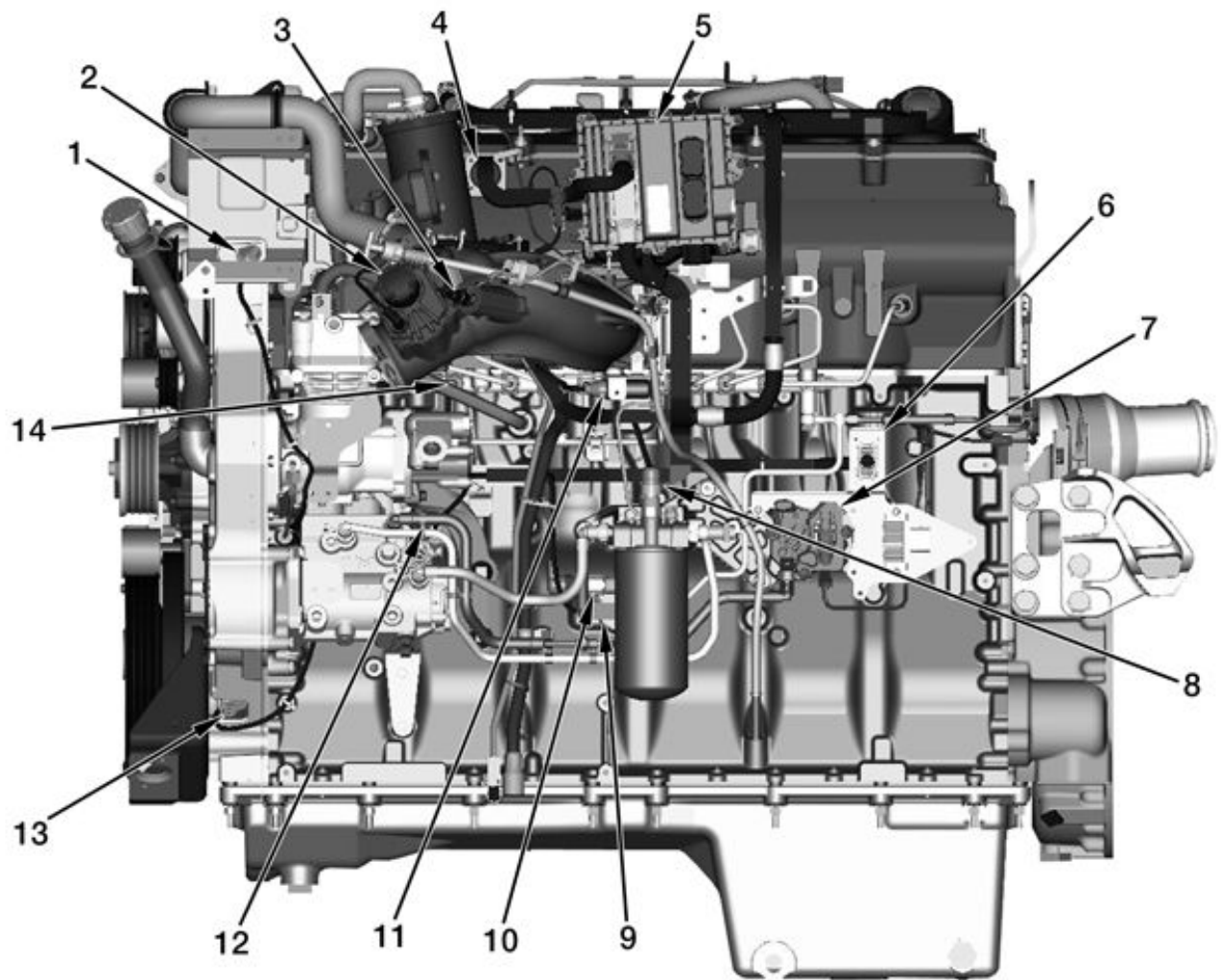
1. Air control valve	6. EGR Temperature (EGRT) sensor	9. Charge Air Cooler Outlet Temperature (CACOT) sensor
2. Engine Coolant Temperature 2 (ECT2) sensor	7. Intake Manifold Pressure (IMP) sensor	10. Breather filter assembly
3. Harness support (4)	8. Engine Throttle Valve (ETV) assembly	11. Intake Manifold Temperature (IMT) sensor
4. Oxygen Sensor (O2S)		
5. Exhaust Gas Recirculation (EGR) valve assembly		



W09005

Figure 43 Electronic components – right

1. Mass Air Flow (MAF) sensor	3. Coolant Control Valve (CCV) assembly	5. Turbocharger 2 Compressor Inlet Sensor (TC2CIS)
2. Engine Coolant Temperature 1 (ECT1) sensor	4. Engine Coolant Pressure 1 (ECP1) sensor	6. Engine Oil Temperature (EOT) sensor



W09070

Figure 44 Electronic components – left

1. Camshaft Position (CMP) sensor (behind alternator)	7. Down Stream Injection (DSI) assembly	11. Cold Start Fuel Solenoid (CSFS)
2. Engine throttle valve assembly	8. Fuel Delivery Pressure (FDP) sensor	12. Injection Pressure Regulator (IPR) valve
3. Cold Start Fuel Igniter (CSFI)	9. Crankcase Pressure (CCP) sensor	13. Crankshaft Position (CKP) sensor
4. Engine injector harness assembly	10. Engine Oil Pressure (EOP) sensor	14. Fuel Rail Pressure (FRP) sensor
5. Engine Control Module (ECM)		
6. Body harness interconnect		

Engine Sensor Harness Assembly

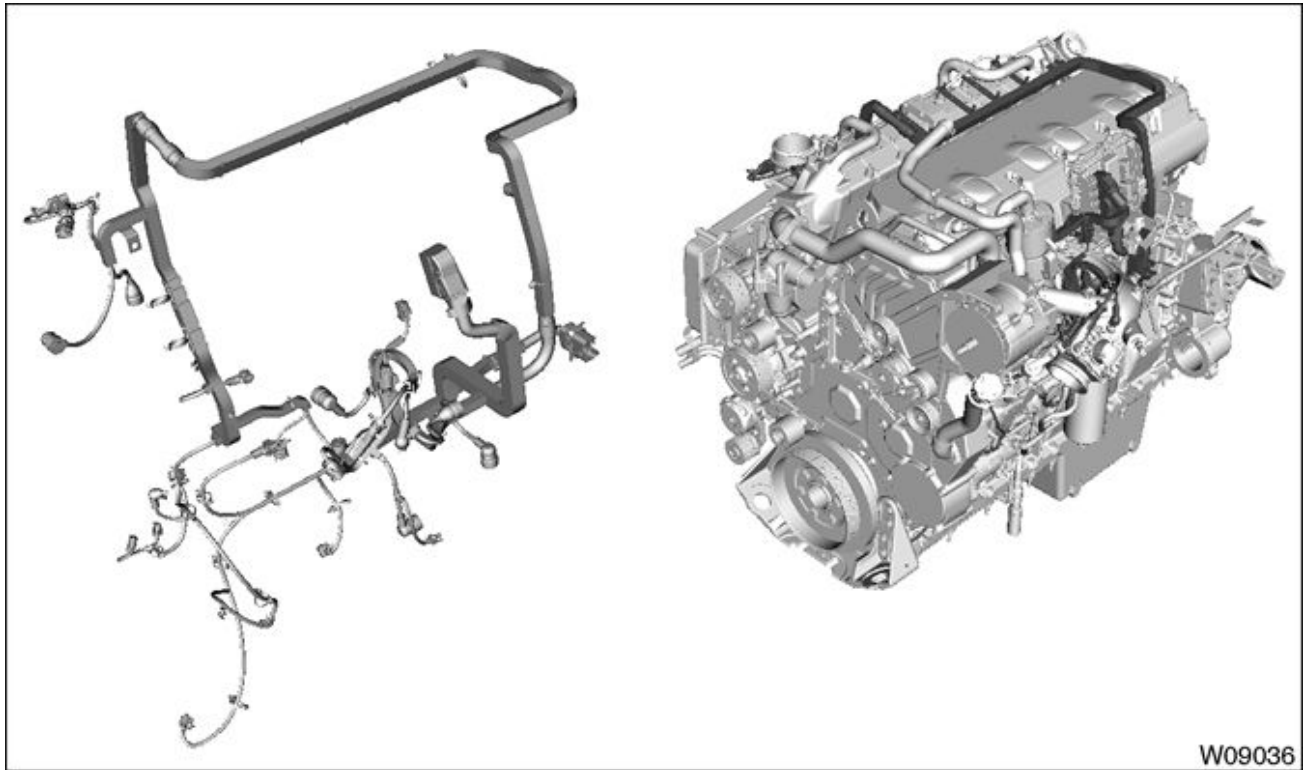


Figure 45 Engine sensor harness assembly

Description of Engine Sensors, Valves, and Actuators

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

- EGES-515 MaxxForce® 15 *Engine Diagnostic Manual*
- EGED-520 MaxxForce® 15 *Engine Hard Start and No Start Diagnostic Form*
- EGED-535 MaxxForce® 15 *Engine Performance Diagnostic Form*
- EGED-525 MaxxForce® 15 *Engine Wiring Schematic Form*

5 mm 60 Degree Speed Sensor used to sense Crankshaft Position (CKP)



Figure 46 CKP sensor

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

The CKP sensor sends a pulsed signal to the Engine Control Module (ECM) as the crankshaft turns. The CKP sensor reacts to a 58-tooth timing disk on the front of the crankshaft. By comparing the CKP signal with the CMP signal, the ECM calculates engine rpm and timing requirements.

The CKP sensor is installed at bottom left side of front cover.

5 mm 60 Degree Speed Sensor used to sense Camshaft Position (CMP)



Figure 47 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 Engine Control Module (ECM) as a toothed wheel on the camshaft rotates past the CMP sensor. The ECM calculates camshaft speed and position from CMP signal frequency.

The CMP sensor is installed at top left side of front cover below alternator.

6 Bar Pressure sensor used to sense Engine Oil Pressure (EOP)

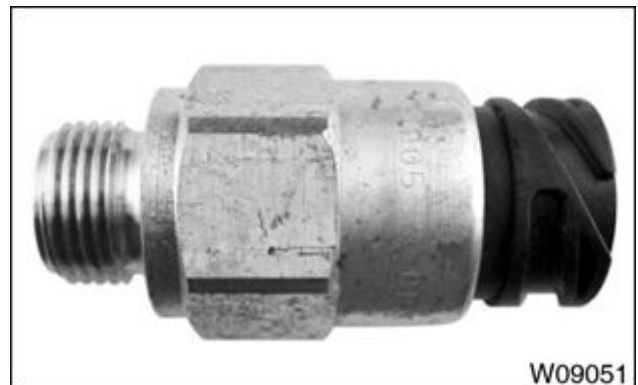


Figure 48 EOP sensor

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

The EOP signal is monitored by the ECM for operation of the instrument panel pressure gauge and optional Engine Warning Protection System (EWPS).

The EOP sensor is installed in oil pressure sensor support behind fuel filter assembly.

15 Bar Pressure Sensor used to sense Fuel Delivery Pressure (FDP)

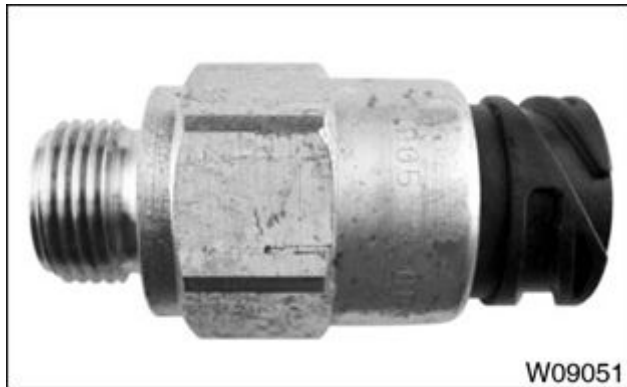


Figure 49 FDP sensor

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

The FDP sensor provides feedback to the ECM for the low pressure fuel system. 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 set a lamp message for the operator.

The FDP sensor is installed on top of the fuel filter housing assembly.

Charge Pressure Sensor used as Turbocharger 2 Compressor Inlet Sensor (TC2CIS)



Figure 50 TC2CIS

The TC2CIS is used to measure absolute charge air pressure and air temperature.

The TC2CIS is installed on the turbo to intercooler tube above the oil filter base assembly.

Coolant Control Valve (CCV) Assembly

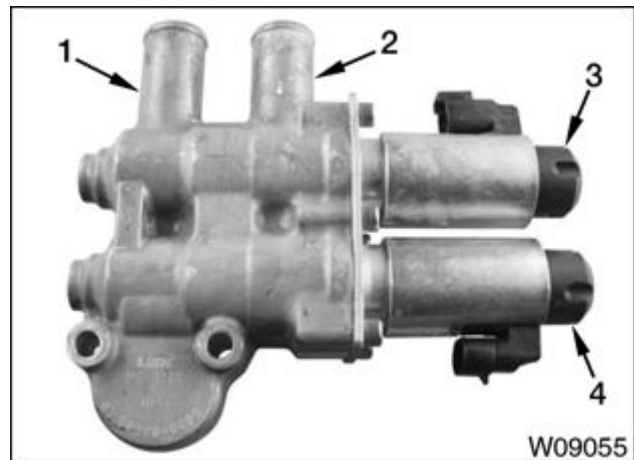


Figure 51 CCV assembly

1. Low temperature radiator supply port
2. Low temperature radiator bypass port
3. Coolant Flow Valve (CFV)
4. Coolant Mixer Valve (CMV)

The CCV is a combined solenoid assembly that regulates coolant flow and temperature. The CCV has two separate solenoid actuated valves: Coolant Flow Valve (CFV) and Coolant Mixer Valve (CMV). The CMV and CFV solenoids are controlled by two separate Pulse Width Modulated (PWM) signals from the ECM. The PWM signal duty cycles vary between 0% and 100% depending on the coolant and charge air temperature.

The CFV controls the amount of coolant flow through the Interstage Cooler (ISC). If the engine coolant temperature is too low, the CFV closes to reduce the coolant flow.

The CMV regulates the temperature of the coolant by directing the coolant either through the Low Temperature Radiator (LTR) or through an internal bypass. When the temperature of the charge air and coolant coming out of the ISC is low, the CMV directs the coolant through a LTR bypass directly into the ISC. This helps the engine reach its normal operating temperature faster. If the temperature of the charge air and coolant coming out of the ISC is high, the CMV directs the coolant flow through the LTR.

The CCV is installed at lower right side of engine between the front cover and oil filter base assembly.

Coolant Pressure Sensor used to sense Engine Coolant Pressure (ECP1)

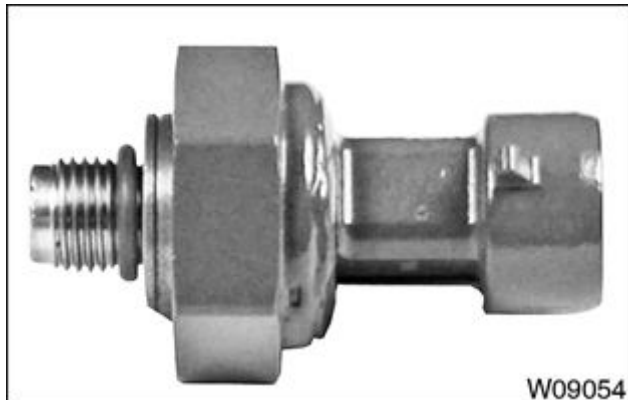


Figure 52 ECP1 sensor

The ECP1 sensor is a variable resistance sensor that detects coolant pressure.

The ECP1 sensor is installed on the EGR coolant tube assembly near the oil filter base assembly.

Crankcase Pressure (CCP) Sensor



Figure 53 CCP sensor

The CCP sensor is a variable resistance sensor that detects crankcase oil pressure.

The CCP sensor is installed in the oil pressure sensor support behind the fuel filter assembly.

EGR Temperature (EGRT) Sensor

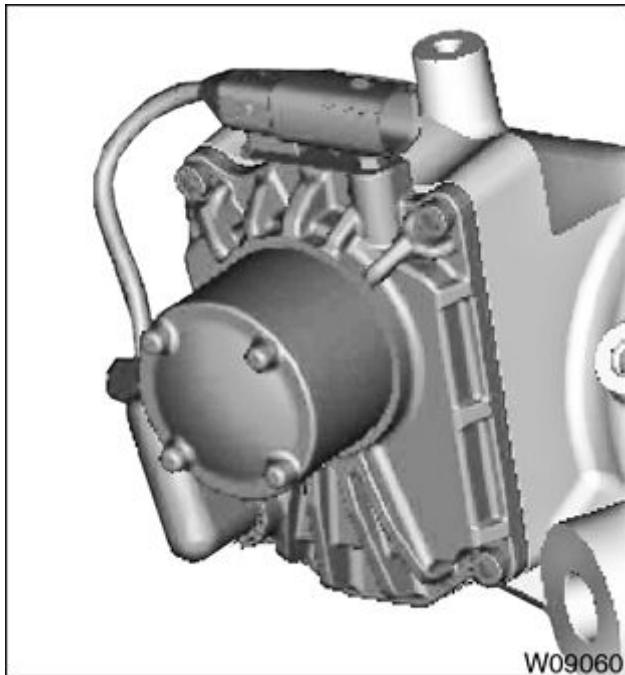


Figure 54 EGRT sensor

The EGRT sensor is a thermistor sensor that detects exhaust gas temperature.

The EGRT sensor is monitored by the ECM for EGR operation.

The EGRT sensor is installed on the EGR branch of the engine throttle valve assembly.

Engine Throttle Valve (ETV) Assembly**Figure 55 ETV assembly**

The ETV assembly has a variable position actuator that restricts intake air flow by way of an internal butterfly valve to help during aftertreatment regeneration and to assist with EGR.

The ETV assembly changes butterfly valve position in response to ECM pulse width modulated signals. The ETV assembly contains an internal position sensor that monitors butterfly valve position and transmits a position signal to the ECM. This sensor, butterfly valve, and actuator are part of the ETV assembly and cannot be serviced separately.

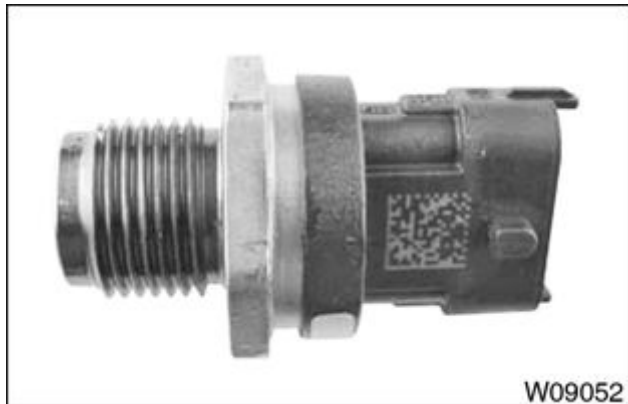
The ETV assembly is installed on the left side of the engine.

Exhaust Gas Recirculation (EGR) Valve Assembly**Figure 56 EGR valve assembly**

The EGR valve assembly has a variable position actuator that controls the flow of exhaust gases through the EGR system by way of an internal butterfly valve.

The EGR valve assembly changes butterfly valve position in response to ECM pulse width modulated signals. The EGR valve assembly contains an internal position sensor that monitors butterfly valve position and transmits a position signal to the ECM. This sensor is part of the EGR valve assembly and cannot be serviced separately.

The EGR valve assembly is installed at the rear of the EGR cooler assembly.

Fuel Rail Pressure (FRP) Sensor**Figure 57 FRP sensor**

The FRP sensor is a variable resistance sensor that monitors the fuel pressure delivered to the fuel rail assembly. The FRP sensor measures the fuel pressure just prior to injection.

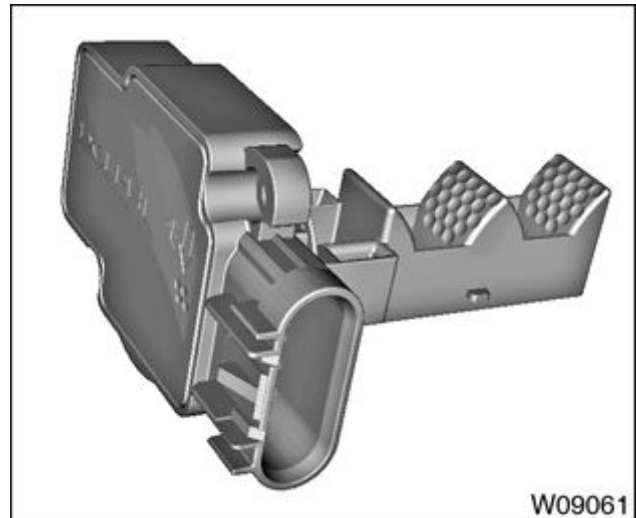
The FRP sensor is installed at the front end of the fuel rail assembly.

Intake Manifold Pressure (IMP) Sensor**Figure 58 IMP sensor**

The IMP sensor is a variable resistance sensor that measures the absolute charge air pressure.

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

The IMP sensor is installed on the engine throttle valve assembly.

Mass Air Flow (MAF) Sensor**Figure 59 MAF sensor**

A MAF sensor is used to measure density of intake air.

Early production engines come equipped with a MAF sensor; however, even though it is electronically connected to the system, it is disabled in the ECM software and not currently utilized.

The MAF sensor is installed on the turbocharger air inlet duct.

Oxygen Sensor (O2S)**Figure 60 Oxygen Sensor (O2S)**

The O2S monitors oxygen levels in exhaust gases.

The O2S is used to tune the engine operation to a specified air-to-fuel ratio in the exhaust.

The O2S compares oxygen levels in the exhaust stream with oxygen levels in the outside air. It then generates a voltage that is transmitted to the ECM. The level of voltage generated by the O2S corresponds to the oxygen levels in the exhaust stream.

The O2S is installed on the turbo exhaust duct ahead of the fuel doser.

Temperature Sensor used to sense Engine Coolant Temperature 1 (ECT1) and 2 (ECT2)



Figure 61 ECT sensor

The ECT sensors are thermistor sensors that detect engine coolant temperature.

This engine has two ECT sensors: ECT1 and ECT2. The ECT signals are monitored by the ECM for operation of the instrument panel temperature gauge, coolant temperature compensation, charge air temperature control, optional Engine Warning Protection System (EWPS), and the wait-to-start lamp. The ECM uses ECT sensor input as a backup if EOT sensor values are out of range.

The ECT1 sensor is installed in the thermostat housing at top front right side of engine.

The ECT2 sensor is installed on the coolant manifold at top right side of engine.

NOTE: This engine is equipped with several temperature sensors of similar physical construction. If removing or replacing a temperature sensor, observe and record the part number identification embossed on the hex face of the sensor body. Replace only with a temperature sensor of the same part number.

Temperature Sensor used to sense Engine Oil Temperature (EOT)



Figure 62 EOT sensor

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

The EOT signal is monitored by the ECM for cold start assist, EGR valve control, and 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 bottom of the oil filter base assembly.

NOTE: This engine is equipped with several temperature sensors of similar physical construction. If removing or replacing a temperature sensor, observe and record the part number identification embossed on the hex face of the sensor body. Replace only with a temperature sensor of the same part number.

Temperature Sensor used to sense Charge Air Cooler Outlet Temperature (CACOT)



Figure 63 CACOT sensor

The CACOT sensor is a thermistor sensor that detects intake air temperature.

The CACOT sensor is monitored by the ECM and aids the ECM in controlling air flow with the EGR and ETV systems.

The CACOT sensor is installed on the engine throttle valve assembly.

Temperature Sensor used to sense Intake Manifold Temperature (IMT)



Figure 64 IMT sensor

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

The IMT signal is monitored by the ECM for EGR operation. EGR system operation is shut down under certain temperature conditions to prevent sulphurous acids from condensing under cold charge air temperatures and to protect the engine from excessively hot intake air in the event of an EGR fault.

The IMT sensor is installed on the cylinder head below the breather filter assembly.

NOTE: This engine is equipped with several temperature sensors of similar physical construction. If removing or replacing a temperature sensor, observe and record the part number identification embossed on the hex face of the sensor body. Replace only with a temperature sensor of the same part number.

Wastegate Control Valve (Air Control Valve)



Figure 65 Wastegate control valve (air control valve)

The air control valve controls air pressure to the high-pressure wastegate actuator based on exhaust back pressure from a port on the output of the low-pressure turbocharger.

The exhaust back pressure sensor is integral to the air control valve. Air pressure to the air control valve is supplied from an air tank mounted on the chassis. The air control valve is controlled by the Engine Control Module (ECM).

The air control valve is installed below the front of the EGR cooler assembly at right front of engine.

Removal

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

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

⚠ 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, straps, or retainers.

Crankshaft Position (CKP) Sensor

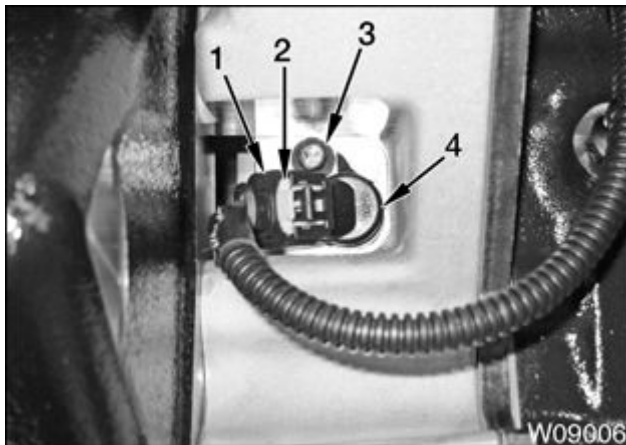


Figure 66 CKP sensor

1. Electrical connector
2. Yellow locking tab
3. M6 x 16 hex flange bolt
4. Crankshaft Position (CKP) sensor

1. Pull out yellow locking tab on electrical connector.
2. Press release lever and disconnect electrical connector from CKP sensor installed at bottom left side of front cover.
3. Remove M6 x 16 hex flange bolt.
4. Remove CKP sensor and discard O-ring.

Camshaft Position (CMP) Sensor

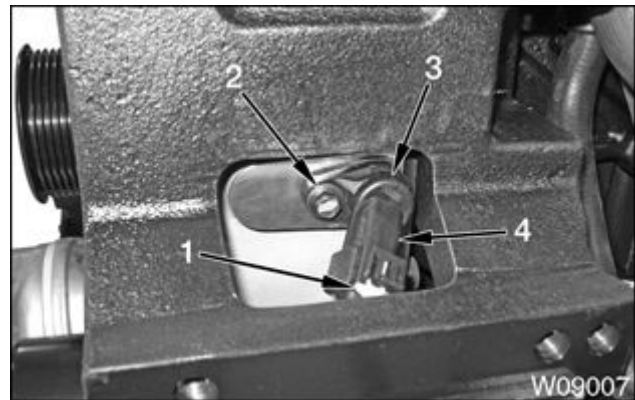
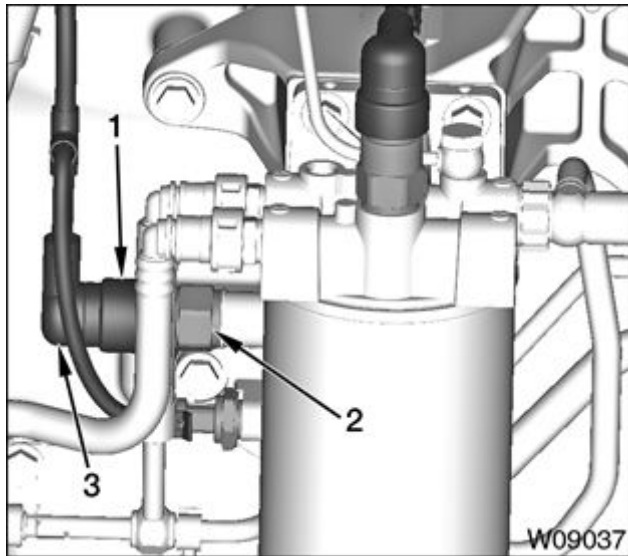


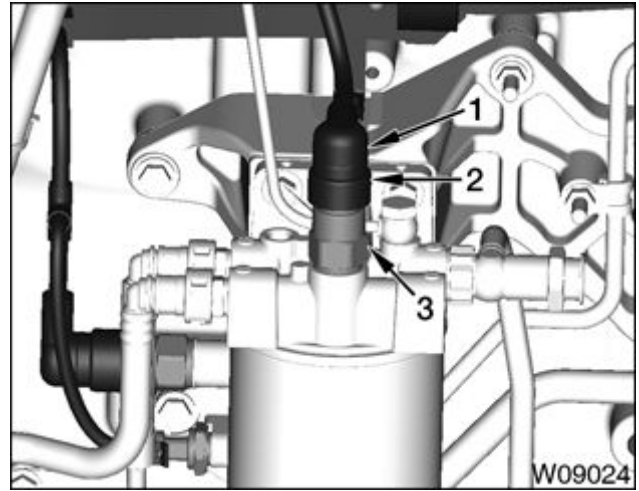
Figure 67 CMP sensor

1. Yellow locking tab
2. M6 x 16 hex flange bolt
3. Camshaft Position (CMP) sensor
4. Electrical connector

1. Pull out yellow locking tab on electrical connector.
2. Press release lever and disconnect electrical connector from CMP sensor installed at top left side of front cover below the alternator.
3. Remove M6 x 16 hex flange bolt.
4. Remove CMP sensor and discard O-ring.

Engine Oil Pressure (EOP) Sensor**Figure 68 EOP sensor**

1. Locking collar
 2. Engine Oil Pressure (EOP) sensor
 3. Electrical connector
1. Turn EOP sensor electrical connector locking collar 90° counterclockwise.
 2. Disconnect electrical connector from EOP sensor installed in oil pressure sensor support behind fuel filter assembly.
 3. Remove EOP sensor and discard 18.7 x 26.0 x 1.5 seal ring.
 4. Cover exposed oil pressure sensor support opening using Disposable Air and Fuel Caps (page 110).

Fuel Delivery Pressure (FDP) Sensor**Figure 69 FDP sensor**

1. Electrical connector
 2. Locking collar
 3. Fuel Delivery Pressure (FDP) sensor
1. Turn FDP sensor electrical connector locking collar 90° counterclockwise.
 2. Disconnect electrical connector from FDP sensor installed on top of fuel filter assembly.
 3. Remove FDP sensor and discard 16.7 x 24 seal ring.
 4. Cover exposed fuel filter assembly opening using Disposable Air and Fuel Caps (page 110).

Body Harness Interconnect

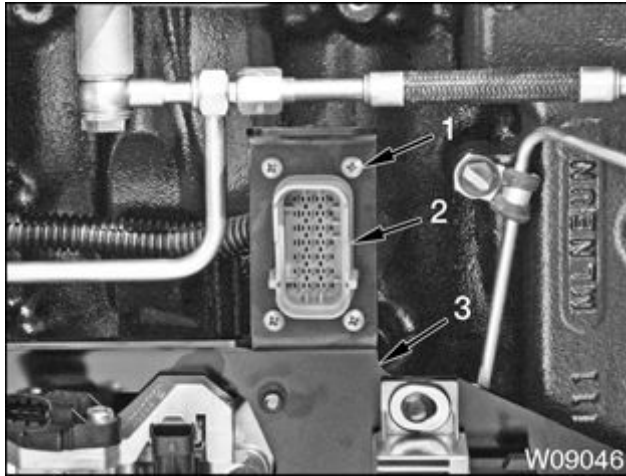


Figure 70 Body harness interconnect

1. 4.8 x 13 self tapping screw (4)
 2. Body harness interconnect
 3. Relay support assembly
1. If not previously done, disconnect ground (-) cable from battery.
 2. Remove four 4.8 x 13 self tapping screws.
 3. Remove body harness interconnect of engine sensor harness assembly by sliding out of opening in relay support assembly.

Coolant Control Valve (CCV) Assembly Connectors

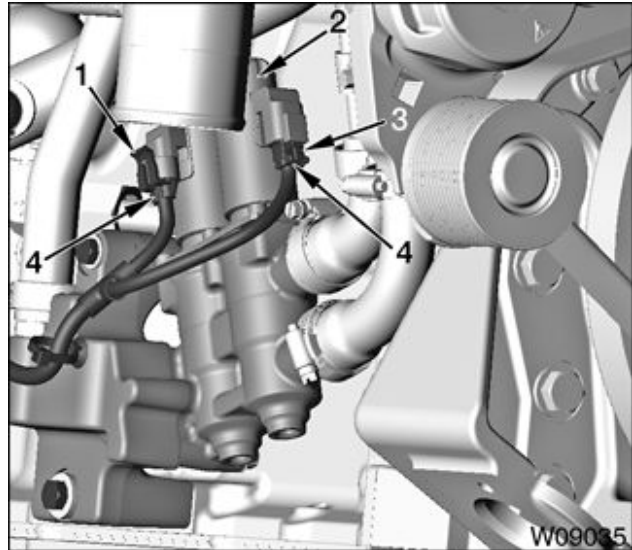


Figure 71 CCV assembly

1. Coolant Mixer Valve (CMV) release lever (pull)
 2. CCV assembly
 3. Coolant Flow Valve (CFV) release lever (press)
 4. Electrical connector (2)
1. Pull release lever and disconnect CMV electrical connector from CCV assembly installed at lower right side of engine between front cover and oil filter base assembly.
 2. Press release lever and disconnect CFV electrical connector from CCV assembly.

NOTE: For removal of CCV assembly, see Coolant Control Valve (CCV) Assembly and Coolant Adapter (page 217).

Turbocharger 2 Compressor Inlet Sensor (TC2CIS)

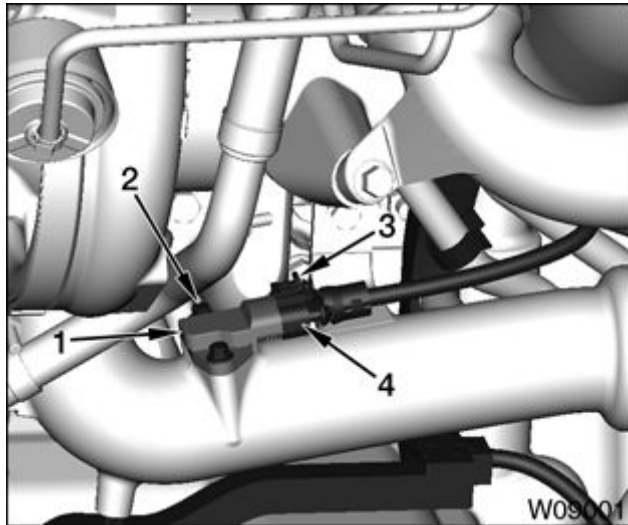


Figure 72 TC2CIS

1. Turbocharger 2 Compressor Inlet Sensor (TC2CIS)
 2. M6 x 16 hex flange bolt (2)
 3. Yellow locking tab
 4. Electrical connector
1. Pull out yellow locking tab on electrical connector.
 2. Press release lever and disconnect electrical connector from TC2CIS installed on turbo to intercooler tube above oil filter base assembly.
 3. Remove two M6 x 16 hex flange bolts
 4. Remove TC2CIS and discard O-ring.

Engine Coolant Pressure 1 (ECP1) Sensor

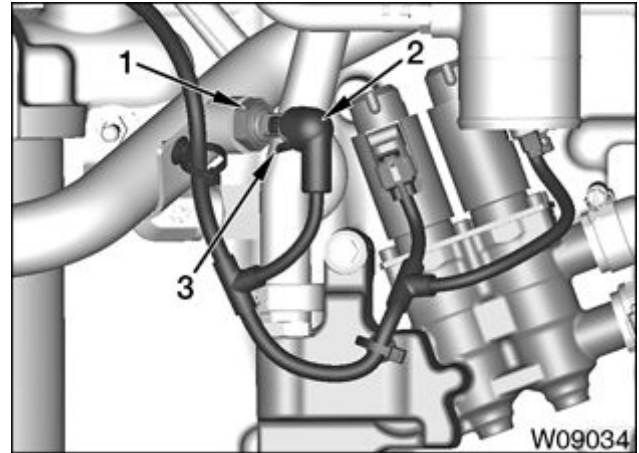


Figure 73 ECP1 sensor

1. Engine Coolant Pressure 1 (ECP1) sensor
 2. Electrical connector
 3. Release lever
1. Pull release lever and disconnect electrical connector from ECP1 sensor installed on EGR coolant tube assembly near oil filter base assembly.
 2. Remove ECP1 sensor and discard O-ring.

Crankcase Pressure (CCP) Sensor

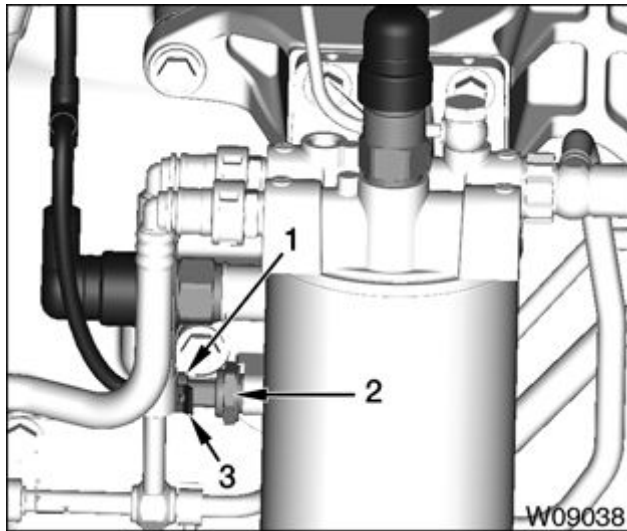


Figure 74 CCP sensor

1. Electrical connector
2. Crankcase Pressure (CCP) sensor
3. Release lever

1. Pull release lever and disconnect electrical connector from CCP sensor installed in the oil pressure sensor support behind the fuel filter assembly.
2. Remove CCP sensor and discard O-ring.
3. Cover exposed oil pressure sensor support opening using Disposable Air and Fuel Caps (page 110).

Engine Control Module (ECM) Connections

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

1. Disconnect ground (-) cable from battery.

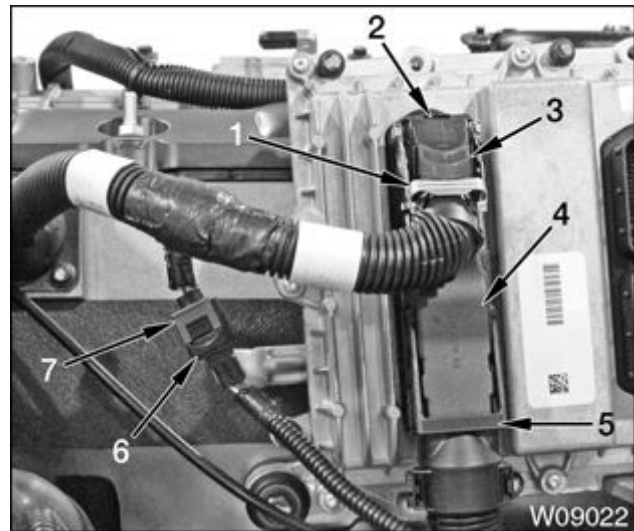
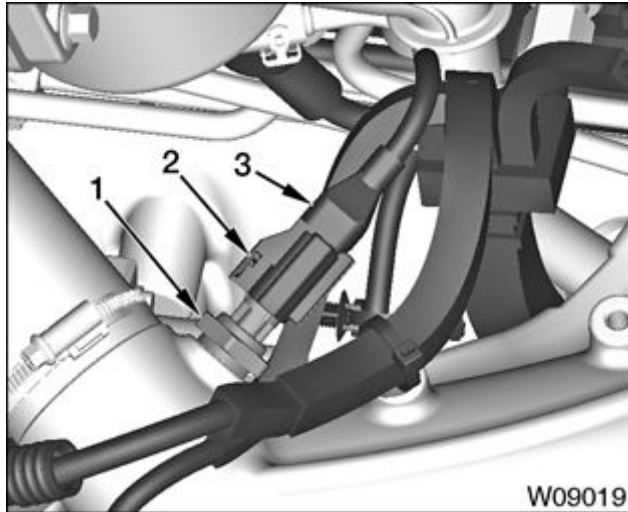


Figure 75 ECM electrical connections

1. Release lever (injector harness)
2. Engine injector harness assembly ECM connector
3. Red locking tab (injector harness)
4. Engine sensor harness assembly ECM connector
5. Release lever (engine harness)
6. Engine injector harness assembly to engine sensor harness assembly interconnect
7. Red locking tab (harness interconnect)

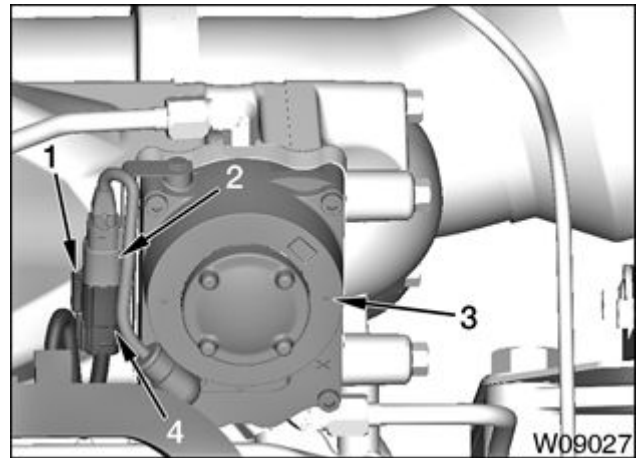
2. Push in on red locking tab while pulling up on release lever and disconnect engine injector harness assembly ECM connector from ECM.
3. Push in on red locking tab while pulling up on release lever and disconnect engine sensor harness assembly connector from ECM.
4. Pull out red locking tab on engine injector harness assembly to engine sensor harness assembly interconnect (brake interconnect).
5. Press release lever and disconnect engine injector harness assembly to engine sensor harness assembly interconnect.

NOTE: For removal of engine injector harness assembly, see Valve Cover Base (page 387).

EGR Temperature (EGRT) Sensor**Figure 76 EGRT sensor**

1. EGR Temperature (EGRT) sensor
2. Red locking tab
3. Electrical connector

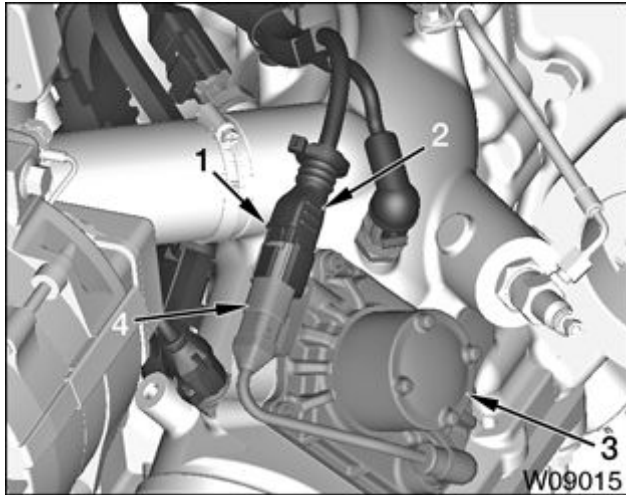
1. Pull out red locking tab on electrical connector.
2. Press release lever and disconnect electrical connector from EGRT sensor installed on engine throttle valve assembly.
3. Remove EGRT sensor.

Exhaust Gas Recirculation (EGR) Valve Assembly Connector**Figure 77 EGR valve assembly**

1. Release lever
2. Electrical connector (EGR valve)
3. EGR valve assembly
4. Electrical connector (harness)

1. Press release lever and disconnect electrical connectors from one another at EGR valve assembly installed at rear of EGR cooler assembly.

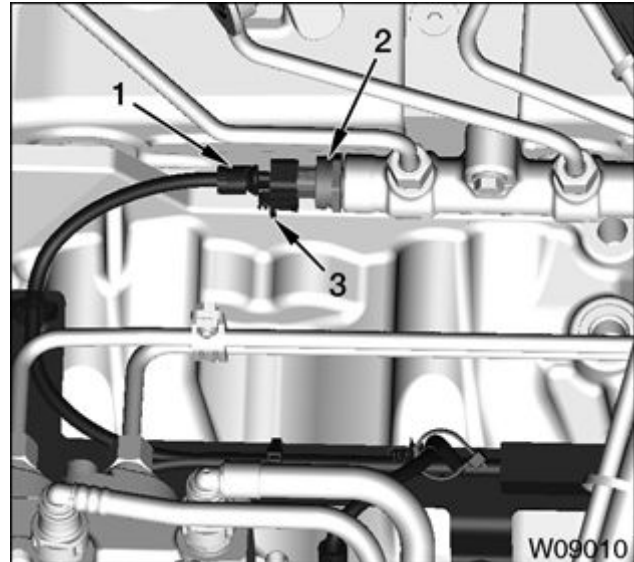
NOTE: For removal of EGR valve assembly, see EGR Cooler Supply Tube and EGR Valve Assembly (page 225).

Engine Throttle Valve (ETV) Assembly Connector**Figure 78 ETV assembly**

1. Release lever
2. Electrical connector (harness)
3. Engine Throttle Valve (ETV)
4. Electrical connector

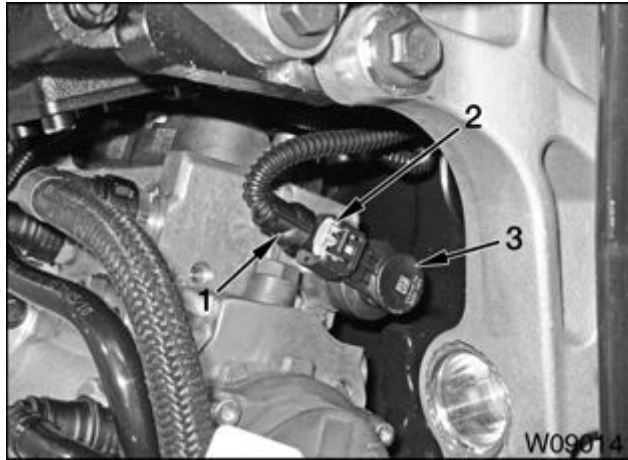
1. Press release lever and disconnect electrical connectors from one another at engine throttle valve assembly on air inlet at top left side of engine.

NOTE: For removal of ETV assembly, see Air Inlet (page 287).

Fuel Rail Pressure (FRP) Sensor**Figure 79 FRP sensor**

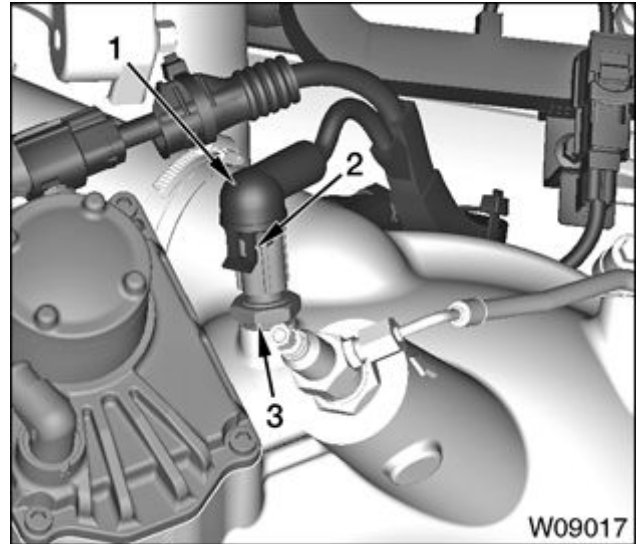
1. Electrical connector
2. Fuel Rail Pressure (FRP) sensor
3. Yellow locking tab

1. Pull out yellow locking tab on electrical connector.
2. Press release lever and disconnect electrical connector from FRP sensor installed at end of fuel rail assembly towards front of engine.
3. Remove FRP sensor.
4. Cover exposed rail assembly opening using Disposable Air and Fuel Caps (page 110).

High-Pressure Fuel Pump Connector**Figure 80 High-pressure fuel pump connector**

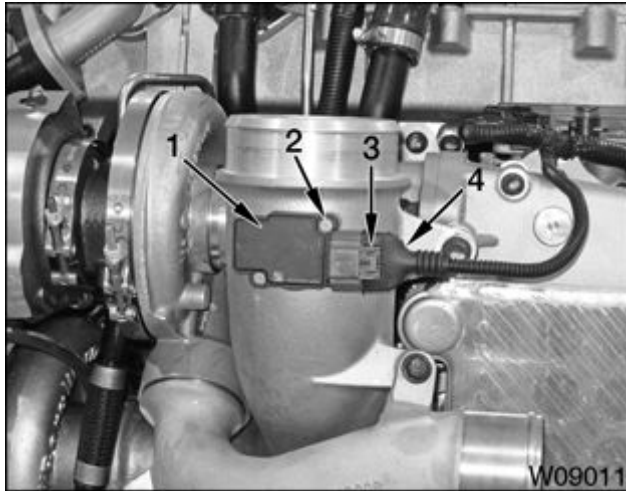
1. Electrical connector
2. Yellow locking tab
3. High-pressure fuel pump

1. Pull out yellow locking tab on electrical connector.
2. Press release lever and disconnect electrical connector from high-pressure fuel pump installed at left forward side of engine.

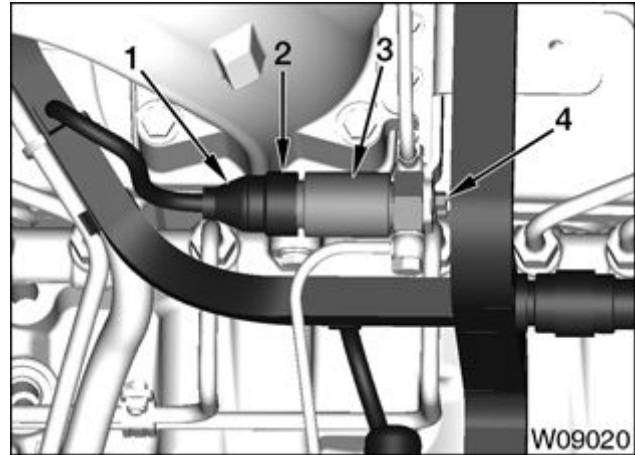
Intake Manifold Pressure (IMP) Sensor**Figure 81 IMP sensor**

1. Electrical connector
2. Release lever
3. Intake Manifold Pressure (IMP) sensor

1. Pull release lever and disconnect electrical connector from IMP sensor installed on engine throttle valve assembly.
2. Remove IMP sensor and discard O-ring.

Mass Air Flow (MAF) Sensor**Figure 82 MAF sensor**

1. Mass Air Flow (MAF) sensor
 2. M4 x 0.7 hex head cap screw (2)
 3. Release lever
 4. Electrical connector
-
1. Press release lever and disconnect electrical connector from MAF sensor installed on turbocharger air inlet duct.
 2. Remove two M4 x 0.7 hex head cap screws.
 3. Remove MAF sensor and discard O-ring.

Cold Start Fuel Solenoid (CSFS) Valve Connector**Figure 83 CSFS valve**

1. Electrical connector
 2. Locking collar
 3. Cold Start Fuel Solenoid (CSFS) valve
 4. M6 x 12 hex flange bolt (2)
-
1. Turn CSFS valve electrical connector locking collar 90° counterclockwise.
 2. Disconnect electrical connector from CSFS valve installed at end of solenoid to injector tube near middle of fuel rail assembly.

NOTE: For removal of CSFS valve, see Cold Start Fuel Solenoid (CSFS) (page 116).

Charge Air Cooler Output Temperature (CACOT) Sensor

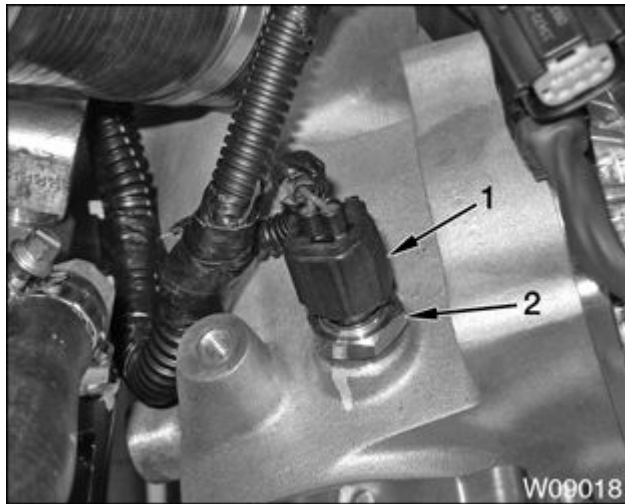


Figure 84 CACOT sensor

1. Electrical connector
 2. Charge Air Cooler Output Temperature (CACOT) sensor
1. Press release lever and disconnect electrical connector from CACOT sensor installed on engine throttle valve assembly.
 2. Remove CACOT sensor and discard O-ring.

Engine Coolant Temperature 1 (ECT1) Sensor

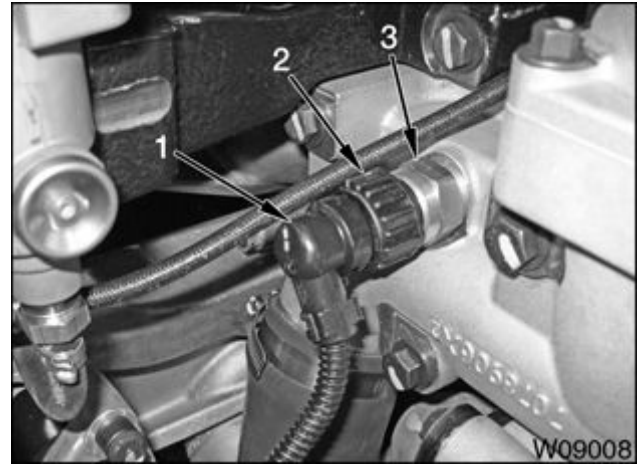


Figure 85 ECT1 sensor

1. Electrical connector
2. Locking collar
3. Engine Coolant Temperature 1 (ECT1) sensor

NOTE: This engine is equipped with several temperature sensors of similar physical construction. If removing or replacing a temperature sensor, observe and record the part number identification embossed on the hex face of the sensor body. Replace only with a temperature sensor of the same part number.

1. Turn ECT1 sensor electrical connector locking collar 90° counterclockwise.
2. Disconnect electrical connector from ECT1 sensor installed in thermostat housing.
3. Remove ECT1 sensor and discard 16.7 x 24 seal ring.

Engine Coolant Temperature 2 (ECT2) Sensor

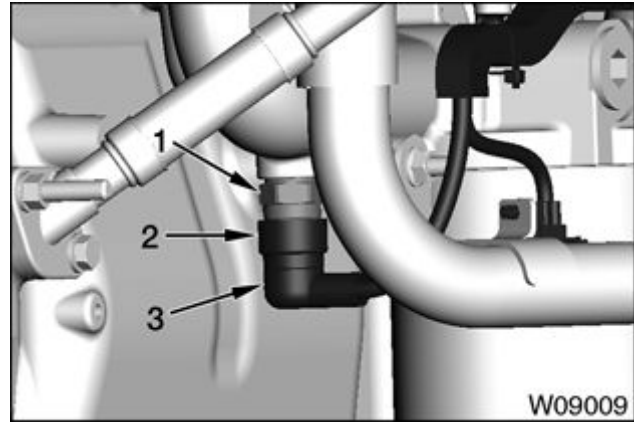
**Figure 86 ECT2 sensor**

1. Electrical connector
2. Locking collar
3. Engine Coolant Temperature 2 (ECT2) sensor

NOTE: This engine is equipped with several temperature sensors of similar physical construction. If removing or replacing a temperature sensor, observe and record the part number identification embossed on the hex face of the sensor body. Replace only with a temperature sensor of the same part number.

1. Turn ECT2 sensor electrical connector locking collar 90° counterclockwise.
2. Disconnect electrical connector from ECT2 sensor installed on coolant manifold.
3. Remove ECT2 sensor and discard 16.7 x 24 seal ring.

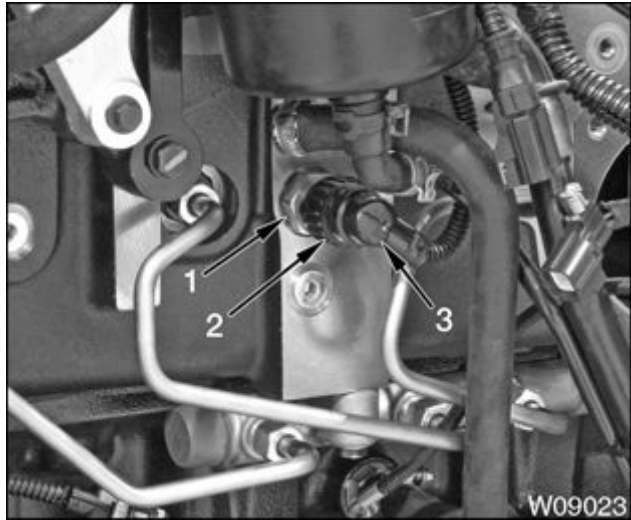
Engine Oil Temperature (EOT) Sensor

**Figure 87 EOT sensor**

1. Engine Oil Temperature (EOT) sensor
2. Locking collar
3. Electrical connector

NOTE: This engine is equipped with several temperature sensors of similar physical construction. If removing or replacing a temperature sensor, observe and record the part number identification embossed on the hex face of the sensor body. Replace only with a temperature sensor of the same part number.

1. Turn EOT sensor electrical connector locking collar 90° counterclockwise.
2. Disconnect electrical connector from EOT sensor installed in bottom of oil filter base assembly.
3. Remove EOT sensor and discard 16.7 x 24 seal ring.

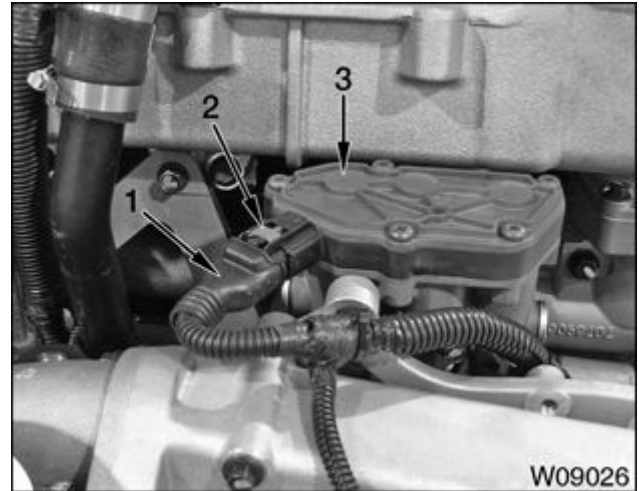
Intake Manifold Temperature (IMT) Sensor**Figure 88** IMT sensor

1. Intake Manifold Temperature (IMT) sensor
2. Locking collar
3. Electrical connector

NOTE: This engine is equipped with several temperature sensors of similar physical construction. If removing or replacing a temperature sensor, observe and record the part number identification embossed on the hex face of the sensor body. Replace only with a temperature sensor of the same part number.

1. Turn IMT sensor electrical connector locking collar 90° counterclockwise.
2. Disconnect electrical connector from IMT sensor installed on cylinder head below breather filter assembly.

3. Remove IMT sensor and discard 16.7 x 24 seal ring.

Air Control Valve Connector**Figure 89** Air control valve

1. Electrical connector
2. Red locking tab
3. Air control valve

1. Pull out red locking tab on electrical connector.
2. Press release lever and disconnect electrical connector from air control valve installed at right front of engine below front of EGR cooler assembly.

NOTE: For removal of air control valve, see Air Control Valve (page 150).

Engine Sensor Harness Assembly

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

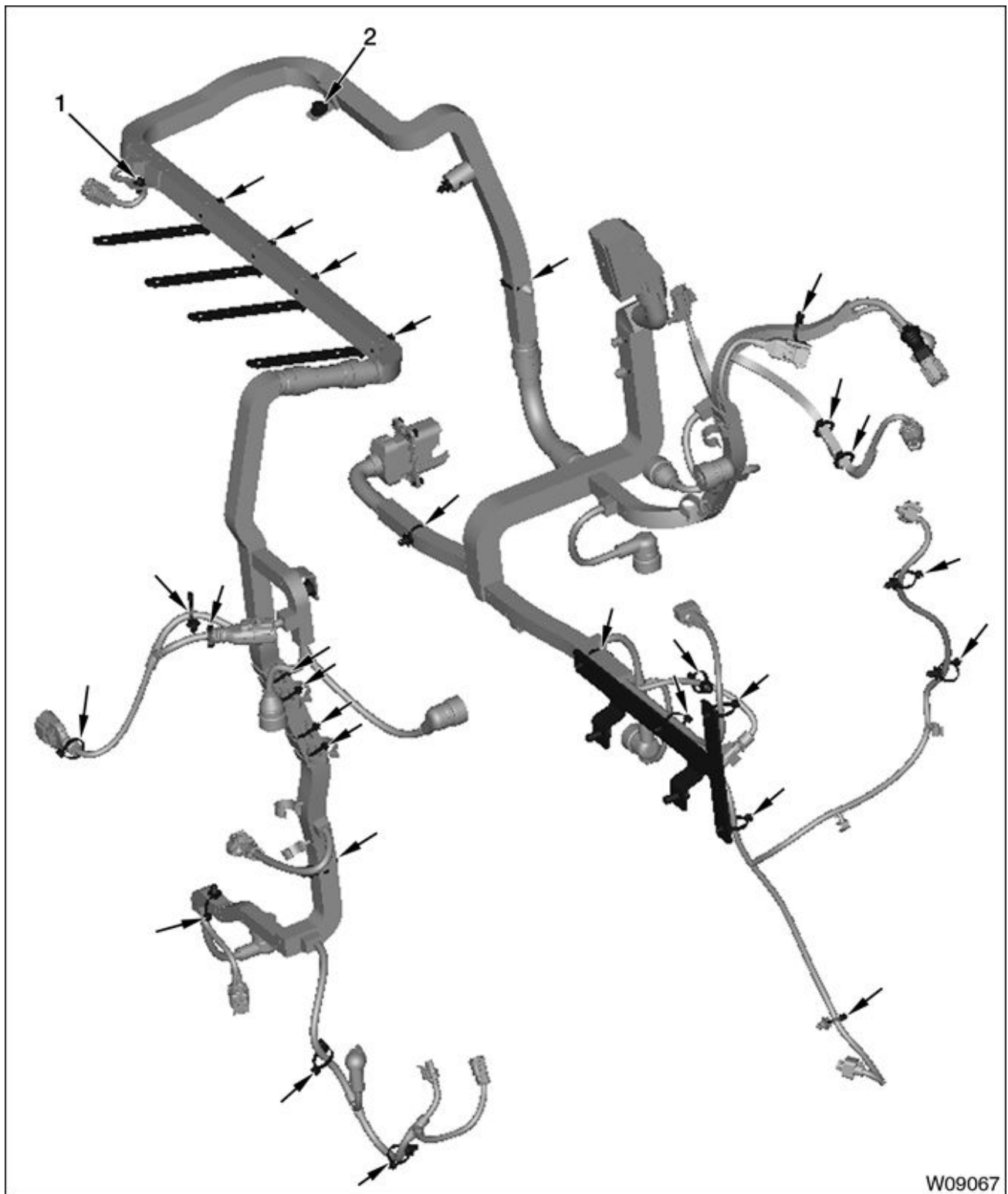
CAUTION: To prevent engine damage, do not tug on wiring harnesses; if resistance is felt, find the problem and free connectors or clips.

1. Disconnect ground (-) cable from battery.

NOTE: Mark or label routing and attachment points of engine sensor harness assembly for later installation.

2. Disconnect engine sensor harness assembly electrical connections at the following:
 - Crankshaft Position (CKP) Sensor (page 76)
 - Camshaft Position (CMP) Sensor (page 76)
 - Engine Oil Pressure (EOP) Sensor (page 77)
 - Fuel Delivery Pressure (FDP) Sensor (page 77)
 - Coolant Control Valve (CCV) Assembly Connectors (page 78)
 - Turbocharger 2 Compressor Inlet Sensor (TC2CIS) (page 79)
 - Engine Coolant Pressure 1 (ECP1) Sensor (page 79)
 - Crankcase Pressure (CCP) Sensor (page 80)
 - Engine Control Module (ECM) Connections (page 80)

- Exhaust Gas Recirculation (EGR) Valve Assembly Connector (page 81)
 - EGR Temperature (EGRT) Sensor (page 81)
 - High-Pressure Fuel Pump Connector (page 83)
 - Intake Manifold Pressure (IMP) Sensor (page 83)
 - Engine Throttle Valve (ETV) Assembly Connector (page 82)
 - Mass Air Flow (MAF) Sensor (page 84)
 - Fuel Rail Pressure (FRP) Sensor (page 82)
 - Cold Start Fuel Solenoid (CSFS) Valve Connector (page 84)
 - Engine Coolant Temperature 2 (ECT2) Sensor (page 86)
 - Charge Air Cooler Output Temperature (CACOT) Sensor (page 85)
 - Engine Coolant Temperature 1 (ECT1) Sensor (page 85)
 - Engine Oil Temperature (EOT) Sensor (page 86)
 - Intake Manifold Temperature (IMT) Sensor (page 87)
 - Air Control Valve Connector (page 87)
 - Body Harness Interconnect (page 78)
-



W09067

Figure 90 Engine sensor harness assembly fasteners and tie strap locations

1. M6 x 12 hex flange bolt
2. 5/16–18 hex nut

3. Remove 28 tie straps. Some tie straps mount to harness fir zip retainers. Inspect retainers during tie strap removal and replace broken or worn harness fir zip retainers as necessary.
4. Remove M6 x 12 hex flange bolt fastening engine sensor harness assembly to rear of EGR cooler assembly.
5. Remove 5/16–18 hex nut fastening engine sensor harness assembly to rear of valve cover.
6. Carefully separate engine sensor harness assembly from engine.

Engine Control Module (ECM) and ECM Support

1. If not previously done, disconnect ground (-) cable from battery.
2. If not previously done, disconnect electrical connectors from ECM. See ECM Connections (page 80).

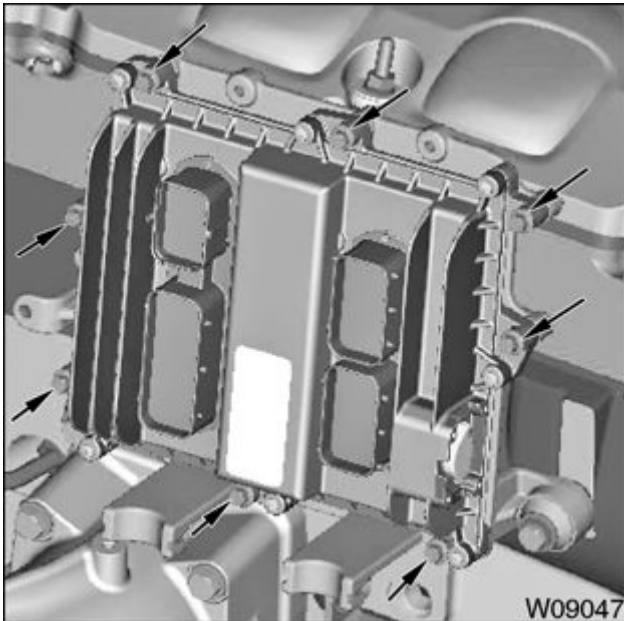


Figure 91 ECM mounting bolts

3. Remove eight M6 x 30 hex flange ECM mounting bolts.
4. Remove ECM.

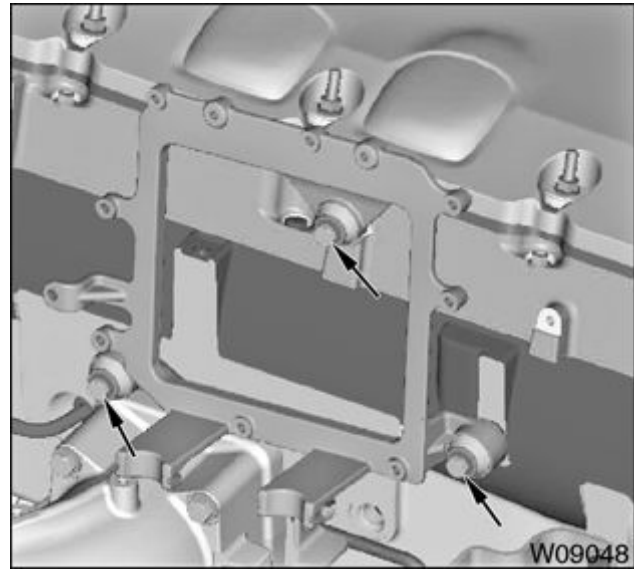


Figure 92 ECM support fastener locations

5. At each of three ECM support fastener locations, remove the 5/16–18 x 2 hex head bolt, 8.8 x 17 x 1.6 mm washer, and ECM support.
6. At each of three fastener locations on the ECM support, remove the vibration isolator bushing, and two vibration isolator grommets (one from each side of ECM support).

Harness Support (EGR Cooler)

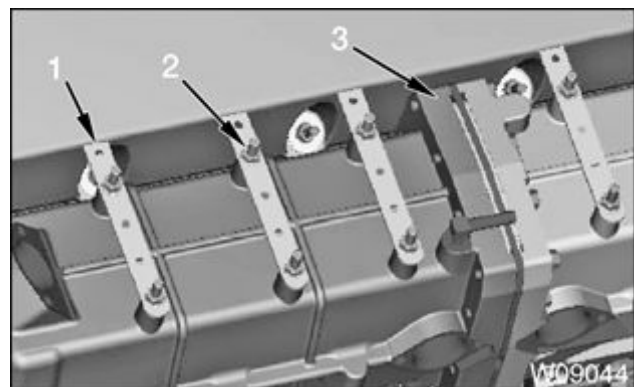


Figure 93 Harness supports at EGR cooler assembly

1. Harness support (4)
2. M8 x 35 x 15 stud bolt (8)
3. EGR cooler assembly

1. If engine sensor harness assembly has not been removed, cut and remove four tie straps attaching engine sensor harness assembly to harness supports.
2. Remove eight M8 x 35 x 15 stud bolts.
3. Remove four harness supports.
2. Remove two 3/8–16 x 7/8 bolts and two 3/8 flat washers.
3. Remove harness support.

Harness Support (Fuel Pump)

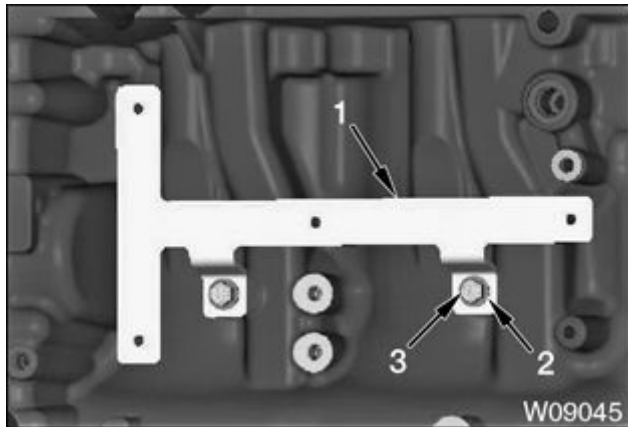


Figure 94 Harness support

1. Harness support
 2. 3/8 flat washer (2)
 3. 3/8–16 x 7/8 bolt (2)
1. If engine sensor harness assembly has not been removed, cut and remove four tie straps attaching engine sensor harness assembly to harness support installed near high-pressure fuel pump.

Oxygen Sensor (O2S)

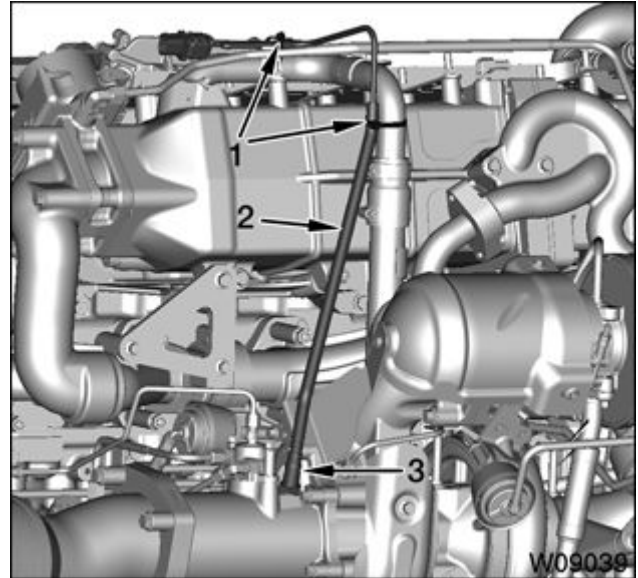
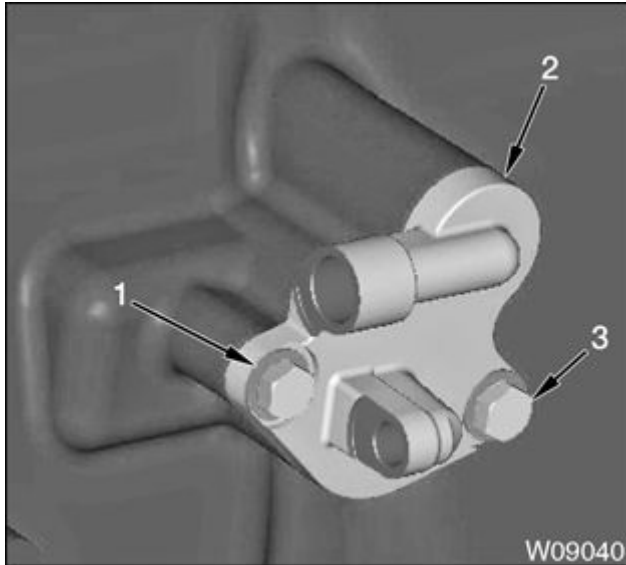


Figure 95 O2S

1. Tie strap (2)
 2. Pigtail wiring
 3. Oxygen sensor (O2S)
1. Cut two tie straps securing pigtail wiring to engine.
 2. Remove O2S from turbocharger exhaust duct.

Oil Pressure Sensor Support**Figure 96 Oil pressure sensor support**

1. 3/8 hardened washer (2)
2. Oil pressure sensor support
3. 3/8-16 x 1 hex bolt (2)

1. Remove two 3/8-16 x 1 hex bolts and two 3/8 hardened washers.
2. Remove oil pressure sensor support installed on engine block behind fuel filter assembly.
3. Remove and discard two O-rings from mounting side of oil pressure sensor support.

Cleaning and Inspection

Main Engine Wiring Harness

1. Carefully inspect main engine sensor harness assembly for worn conduit, frayed insulation, or heat damage to wires. Repair or replace as necessary.
2. Inspect sensor, actuator and valve connectors for cracked connector bodies, bent or loose pins, circuit chafing, and damaged or missing seals. Repair or replace as necessary.
3. Inspect each electrical connector for the following conditions and repair or replace as necessary:
 - Corroded connectors and green, gray, or white deposits on metal terminals.
 - Terminals incorrectly latched in connector body or pushed back relative to other terminals in same connector.
4. Replace any broken or worn harness fasteners and tie straps.

- Make sure that each connector has its seals in place. During disassembly, a seal may pull off its connector and remain in mating socket of a sensor or actuator. A connector assembled without correct seals can be contaminated with moisture and corrode terminals, causing a poor electrical connection.

Sensors and Valves

1. Check all connector pins on sensors or valves. If bent or corroded, replace damaged sensor.
 2. Remove scale or carbon build up.
 3. Check for body cracks and leakage.
 4. If orifices or valves are plugged, replace sensors or valves.
 5. Inspect pressure sensors for soot, sludge, debris, or other contamination. Repair or replace as necessary.
-

Installation

Engine Control Module (ECM) and ECM Support

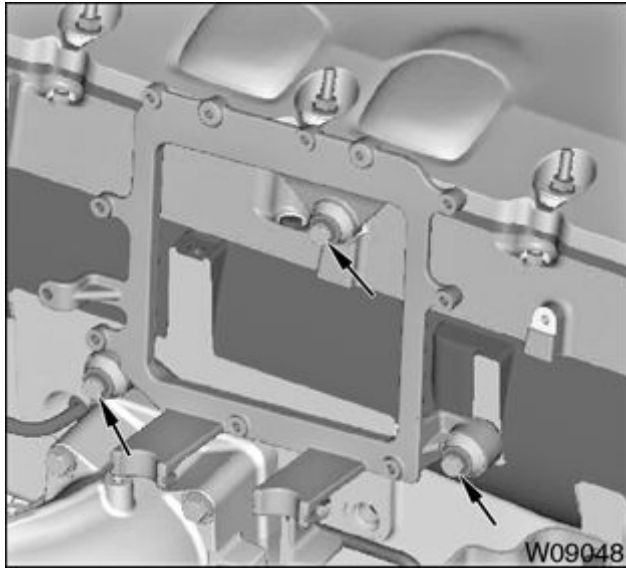


Figure 97 ECM support fastener locations

1. There are three fastener locations that secure the ECM support.

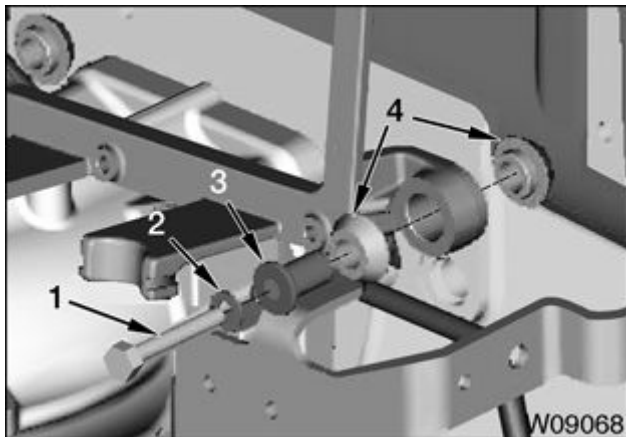


Figure 98 ECM support fastener installation

1. 5/16-18 x 2 hex head bolt
2. 8.8 x 17 x 1.6 mm washer
3. Vibration isolator bushing
4. Vibration isolator grommet (2)

2. At each of the three ECM support fastener locations, install the two vibration isolator grommets (one on each side of ECM support) and vibration isolator bushing through the support and grommets.
3. Install the three 5/16-18 x 2 hex head bolts with 8.8 x 17 x 1.6 mm washers. Tighten bolts to standard torque (page 562).

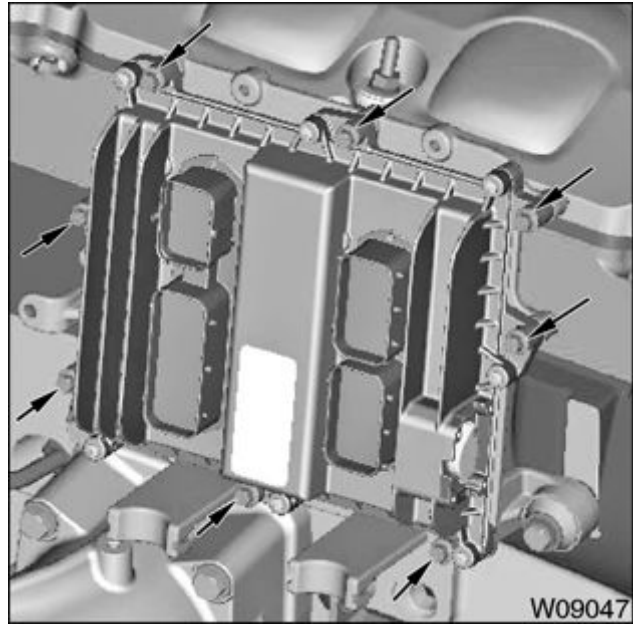
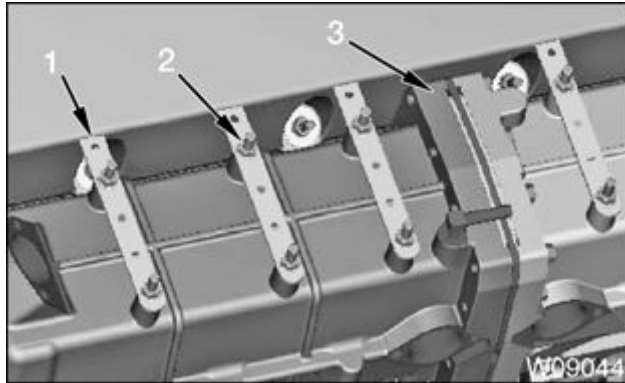
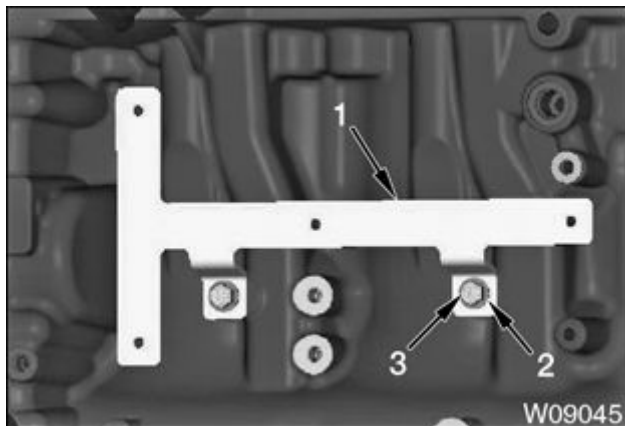


Figure 99 ECM mounting bolts

4. Position ECM on ECM support.
5. Install eight M6 x 30 hex flange bolts. Tighten bolts to standard torque (page 561).

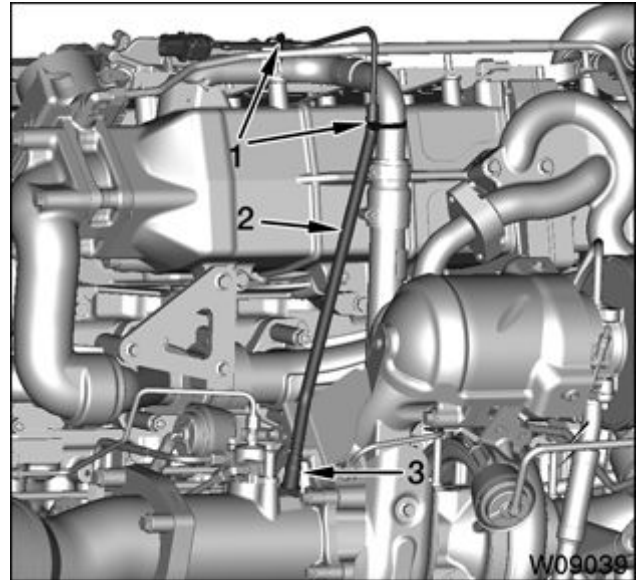
Harness Support (EGR Cooler)**Figure 100** Harness supports at EGR cooler assembly

1. Harness support (4)
 2. M8 x 35 x 15 stud bolt (8)
 3. EGR cooler assembly
1. Position four harness supports on top of EGR cooler assembly.
 2. Install eight M8 x 35 x 15 stud bolts. Tighten bolts to standard torque (page 561).

Harness Support (Fuel Pump)**Figure 101** Harness support

1. Harness support
2. 3/8 flat washer (2)
3. 3/8-16 x 7/8 bolt (2)

1. Position harness support on engine block near high-pressure fuel pump.
2. Install two 3/8-16 x 7/8 bolts with two 3/8 flat washers under bolt heads. Tighten bolts to standard torque (page 562).

Oxygen Sensor (O2S)**Figure 102** O2S

1. Tie strap (2)
 2. Pigtail wiring
 3. Oxygen sensor (O2S)
1. Install O2S in turbo exhaust duct. Tighten to special torque (page 110).
 2. Secure pigtail wiring to engine with two tie straps.

Oil Pressure Sensor Support

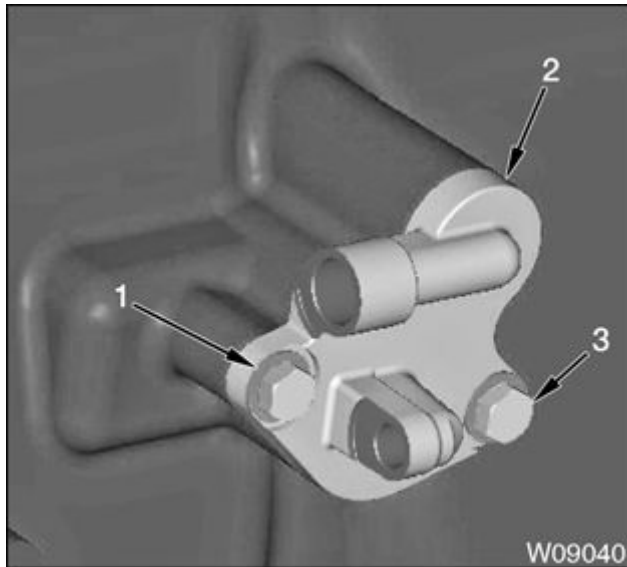


Figure 103 Oil pressure sensor support

1. 3/8 hardened washer (2)
 2. Oil pressure sensor support
 3. 3/8-16 x 1 hex bolt (2)
1. Lubricate two new O-rings with P-80® rubber lubricant or equivalent (page 110) and install to mounting side of oil pressure sensor support.
 2. Position oil pressure sensor support on engine block behind fuel filter assembly.
- CAUTION:** To prevent engine damage, O-rings must remain seated within their respective grooves prior to tightening 3/8-16 x 1 hex bolts.
3. Install two 3/8-16 x 1 hex bolts with two 3/8 hardened washers under bolt heads. Tighten bolts to standard torque (page 562).

Engine Sensor Harness Assembly

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

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

NOTE: Be sure to properly route and secure engine sensor harness assembly in its correct position. Use markings and labeling made during disassembly as a guide.

1. Carefully position engine sensor harness assembly onto engine.

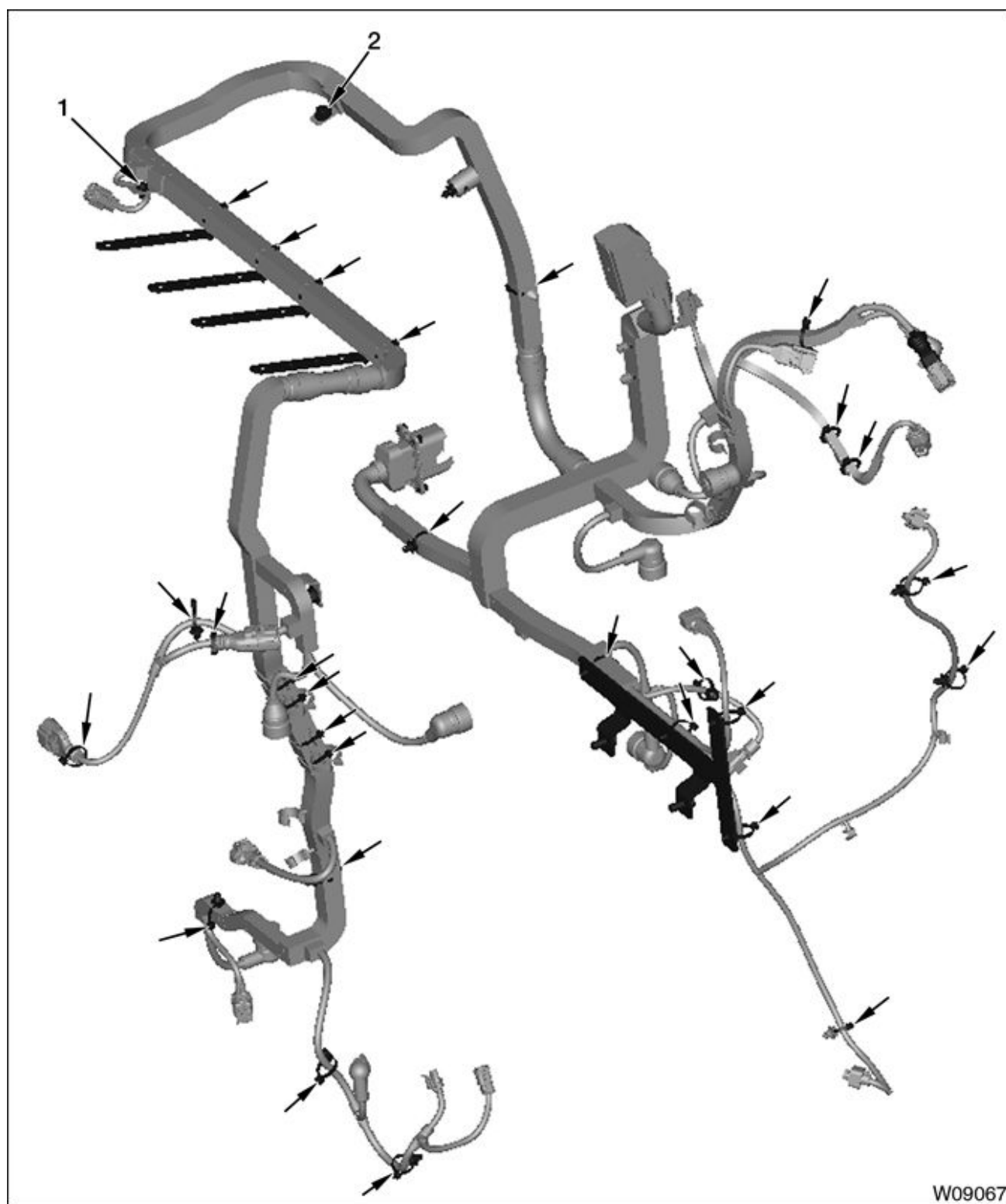


Figure 104 Engine sensor harness assembly fasteners and tie strap locations

1. M6 x 12 hex flange bolt	2. 5/16-18 hex nut

2. Install 5/16–18 hex nut fastening engine sensor harness assembly to rear of valve cover. Tighten to standard torque (page 562).
3. Install M6 x 12 hex flange bolt fastening engine sensor harness assembly to rear of EGR cooler assembly. Tighten to standard torque (page 561).
4. Connect engine sensor harness assembly electrical connections to the following:
 - Crankshaft Position (CKP) Sensor (page 98)
 - Camshaft Position (CMP) Sensor (page 99)
 - Engine Oil Pressure (EOP) Sensor (page 99)
 - Fuel Delivery Pressure (FDP) Sensor (page 99)
 - Coolant Control Valve (CCV) Assembly Connectors (page 100)
 - Turbocharger 2 Compressor Inlet Sensor (TC2CIS) (page 101)
 - Engine Coolant Pressure 1 (ECP1) Sensor (page 101)
 - Crankcase Pressure (CCP) Sensor (page 101)
 - Engine Control Module (ECM) Connections (page 102)
 - Exhaust Gas Recirculation (EGR) Valve Assembly Connector (page 103)
 - EGR Temperature (EGRT) Sensor (page 103)
 - High-Pressure Fuel Pump Connector (page 105)
 - Intake Manifold Pressure (IMP) Sensor (page 105)
 - Engine Throttle Valve (ETV) Assembly Connector (page 104)
 - Mass Air Flow (MAF) Sensor (page 106)
 - Fuel Rail Pressure (FRP) Sensor (page 104)
 - Cold Start Fuel Solenoid (CSFS) Valve Connector (page 106)
 - Engine Coolant Temperature 2 (ECT2) Sensor (page 108)
 - Charge Air Cooler Outlet Temperature (CACOT) Sensor (page 107)

- Engine Coolant Temperature 1 (ECT1) Sensor (page 107)
 - Engine Oil Temperature (EOT) Sensor (page 108)
 - Intake Manifold Temperature (IMT) Sensor (page 109)
 - Air Control Valve Connector (page 109)
 - Body Harness Interconnect (page 100)
5. Install 28 tie straps. Some tie straps mount to harness fir zip retainers. Inspect retainers and replace broken or worn harness fir zip retainers as necessary.
 6. Connect ground (-) cable to battery only when completely done with vehicle service.

Crankshaft Position (CKP) Sensor

1. Lubricate new O-ring with P-80® rubber lubricant or equivalent (page 110) and install on CKP sensor.

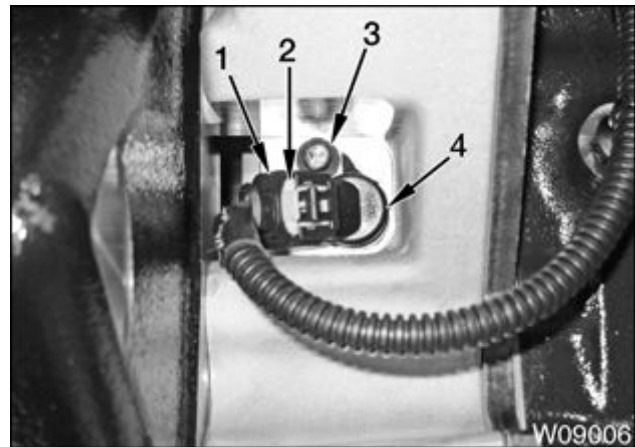


Figure 105 CKP sensor

1. Electrical connector
 2. Yellow locking tab
 3. M6 x 16 hex flange bolt
 4. Crankshaft Position (CKP) sensor
2. Install CKP sensor at bottom left side of front cover.
 3. Install M6 x 16 hex flange bolt and tighten to special torque (page 110).

4. Connect electrical connector by pushing in until the release lever clicks into place (click may be heard or felt).
5. Push in yellow locking tab on CKP sensor electrical connector.

Camshaft Position (CMP) Sensor

1. Lubricate new O-ring with P-80® rubber lubricant or equivalent (page 110) and install on CMP sensor.

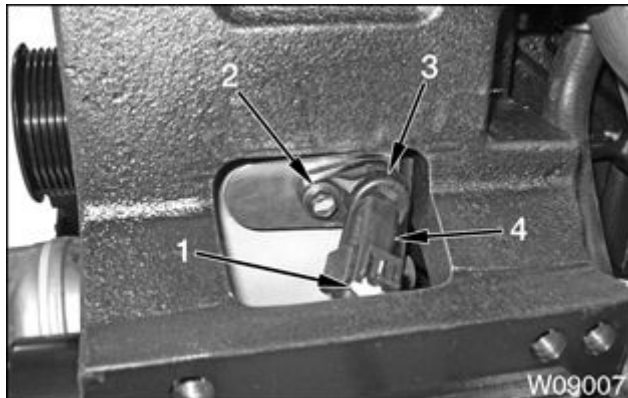


Figure 106 CMP sensor

1. Yellow locking tab
 2. M6 x 16 hex flange bolt
 3. Camshaft Position (CMP) sensor
 4. Electrical connector
2. Install CMP sensor at top left side of front cover below alternator.
 3. Install M6 x 16 hex flange bolt and tighten to special torque (page 110).
 4. Connect electrical connector by pushing in until the release lever clicks into place (click may be heard or felt).
 5. Push in yellow locking tab on CMP sensor electrical connector.

Engine Oil Pressure (EOP) Sensor

1. If installed during removal, remove Disposable Air and Fuel Caps covering exposed oil pressure sensor support opening.
2. Install new 8.7 x 26.0 x 1.5 seal ring on EOP sensor.

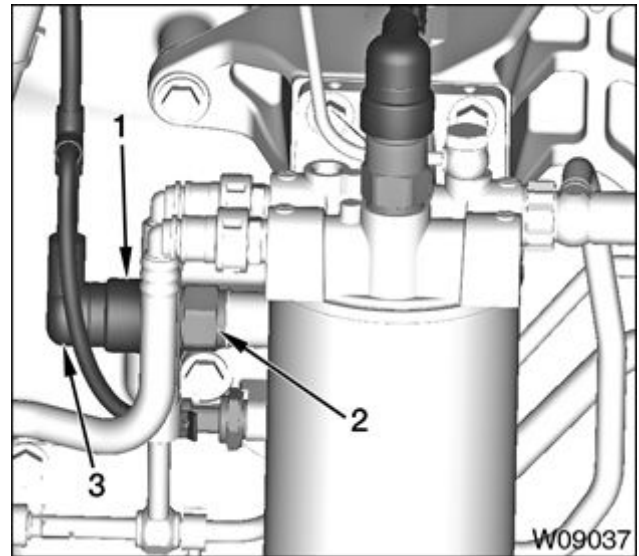


Figure 107 EOP sensor

1. Locking collar
 2. Engine Oil Pressure (EOP) sensor
 3. Electrical connector
3. Install EOP sensor in oil pressure sensor support behind fuel filter assembly and tighten to special torque (page 110).
 4. Connect electrical connector and turn locking collar 90° clockwise.

Fuel Delivery Pressure (FDP) Sensor

1. If installed during removal, remove Disposable Air and Fuel Caps covering exposed fuel filter assembly opening.
2. Install new 16.7 x 24 seal ring on FDP sensor.

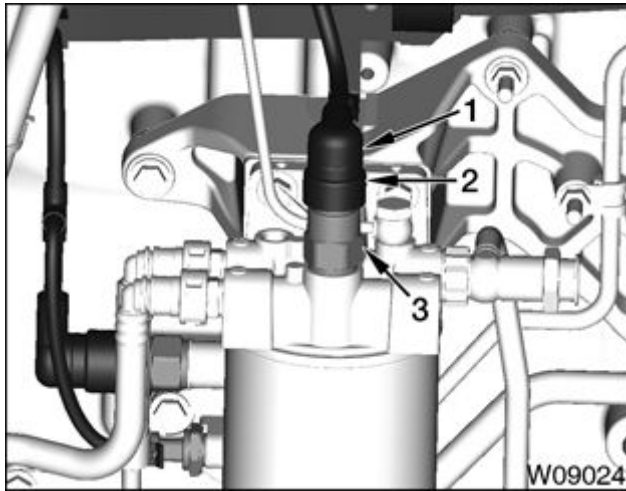


Figure 108 FDP sensor

1. Electrical connector
 2. Locking collar
 3. Fuel Delivery Pressure (FDP) sensor
3. Install FDP sensor on top of fuel filter assembly and tighten to special torque (page 110).
 4. Connect electrical connector and turn locking collar 90° clockwise.

Body Harness Interconnect

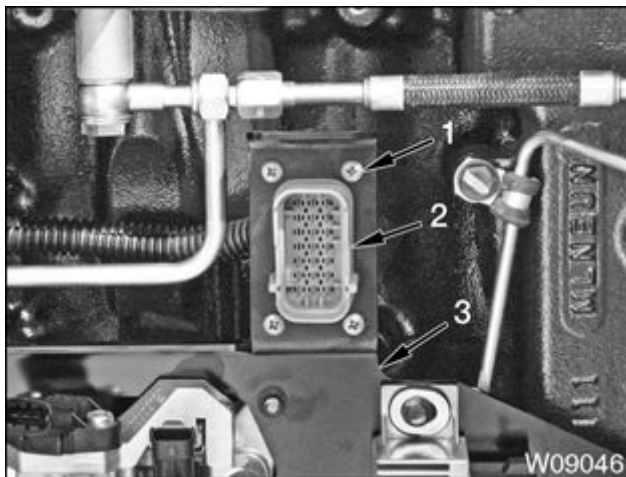


Figure 109 Body harness interconnect

1. 4.8 x 13 self tapping screw (4)
2. Body harness interconnect
3. Relay support assembly

1. Position body harness interconnect of engine sensor harness assembly by sliding into opening in back of relay support assembly.

NOTE: Do not overtighten screws; screws can snap or strip if overtightened.

2. Install four 4.8 x 13 self tapping screws and tighten to special torque (page 110).

Coolant Control Valve (CCV) Assembly Connectors

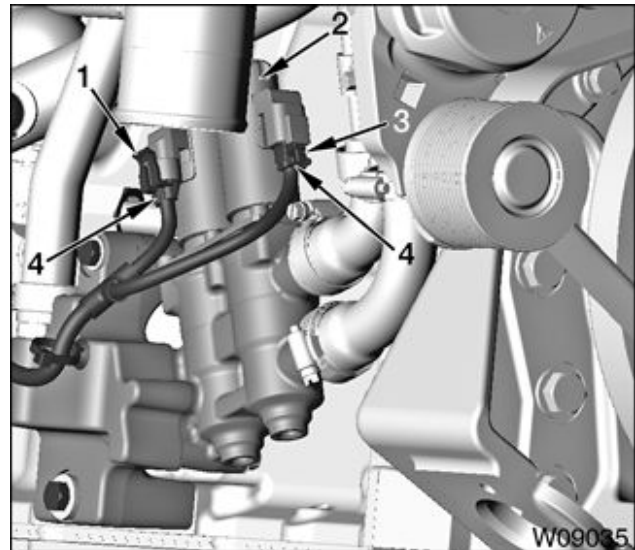


Figure 110 CCV assembly

1. Coolant Mixer Valve (CMV) release lever (pull)
2. CCV assembly
3. Coolant Flow Valve (CFV) release lever (press)
4. Electrical connector (2)

NOTE: Electrical connections at CCV assembly are two different configurations. Match engine sensor harness assembly connectors to appropriate connection.

1. Connect two electrical connectors at CCV assembly installed at lower right side of engine between front cover and oil filter base assembly. Push in each electrical connector until the release lever clicks into place (click may be heard or felt).

Turbocharger 2 Compressor Inlet Sensor (TC2CIS)

1. Lubricate new O-ring with P-80® rubber lubricant or equivalent (page 110) and install on TC2CIS.

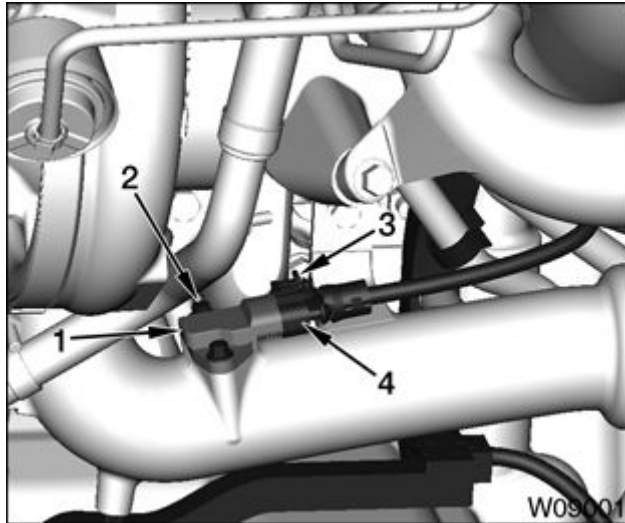


Figure 111 TC2CIS

1. Turbocharger 2 Compressor Inlet Sensor (TC2CIS)
 2. M6 x 16 hex flange bolt (2)
 3. Yellow locking tab
 4. Electrical connector
2. Install TC2CIS on turbo to intercooler tube above oil filter base assembly.
 3. Install two M6 x 16 hex flange bolts and tighten to special torque (page 110).
 4. Connect electrical connector by pushing in until the release lever clicks into place (click may be heard or felt).
 5. Push in yellow locking tab on TC2CIS electrical connector.

Engine Coolant Pressure 1 (ECP1) Sensor

1. Lubricate new O-ring with P-80® rubber lubricant or equivalent (page 110) and install on ECP1 sensor.

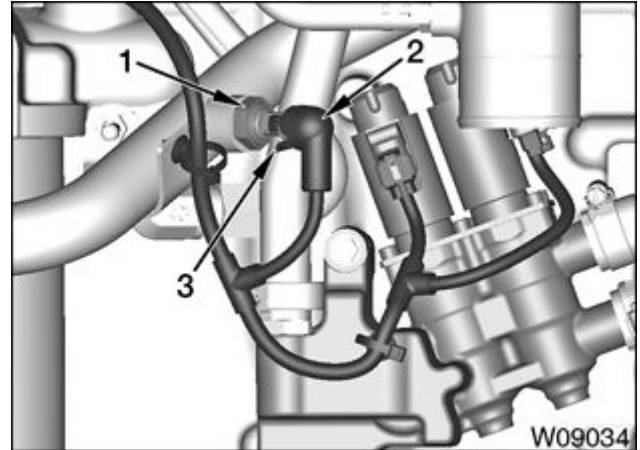


Figure 112 ECP1 sensor

1. Engine Coolant Pressure 1 (ECP1) sensor
 2. Electrical connector
 3. Release lever
2. Install ECP1 sensor on EGR coolant tube assembly near oil filter base assembly and tighten to special torque (page 110).
 3. Connect electrical connector by pushing in until the release lever clicks into place (click may be heard or felt).

Crankcase Pressure (CCP) Sensor

1. If installed during removal, remove Disposable Air and Fuel Caps covering exposed oil pressure sensor support opening.
2. Lubricate new O-ring with P-80® rubber lubricant or equivalent (page 110) and install on CCP sensor.

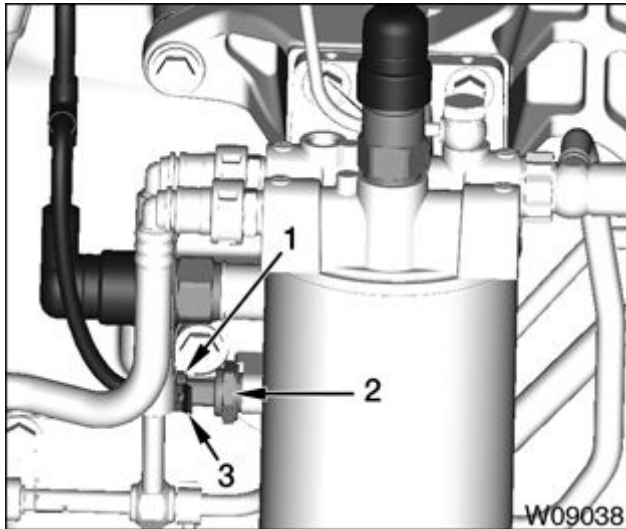


Figure 113 CCP sensor

1. Electrical connector
 2. Crankcase Pressure (CCP) sensor
 3. Release lever
3. Install CCP sensor in oil pressure sensor support behind fuel filter assembly. Tighten to special torque (page 110).
 4. Connect electrical connector by pushing in until the release lever clicks into place (click may be heard or felt).

Engine Control Module (ECM) Connections

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

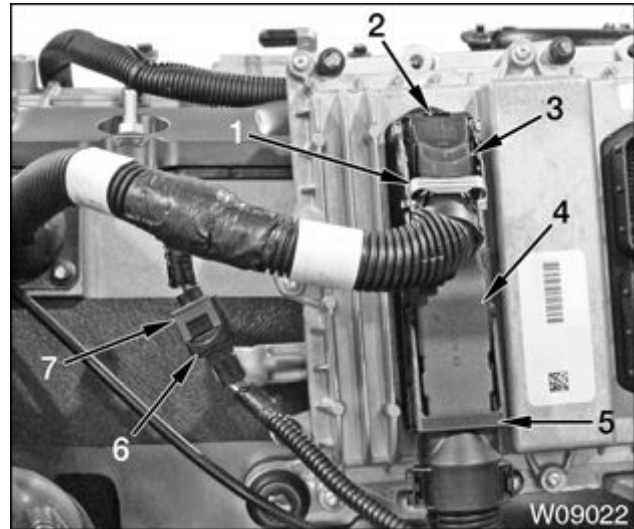
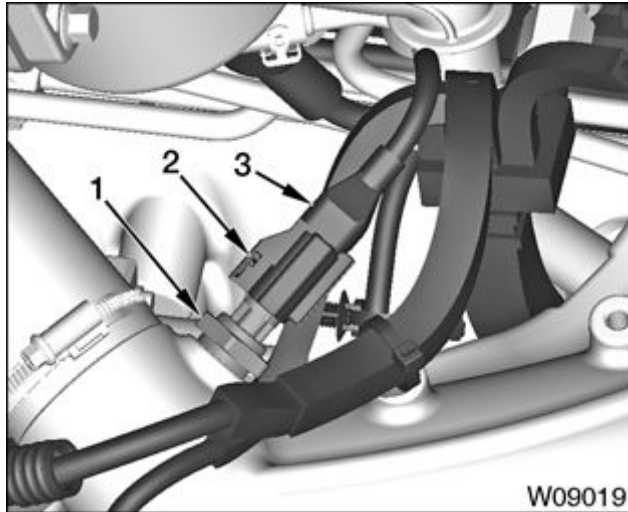


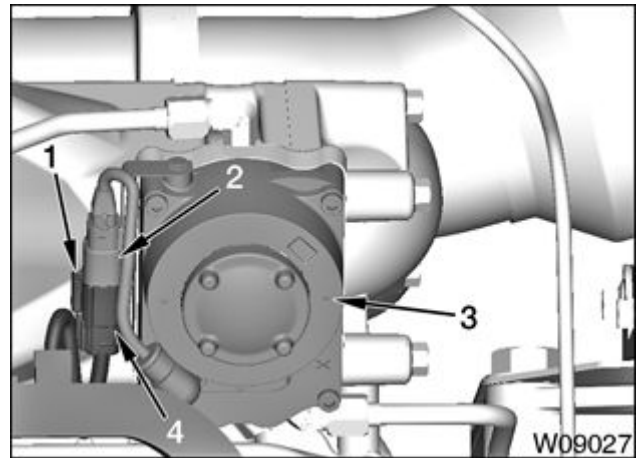
Figure 114 ECM electrical connections

1. Release lever (injector harness)
 2. Engine injector harness assembly ECM connector
 3. Red locking tab (injector harness)
 4. Engine sensor harness assembly ECM connector
 5. Release lever (engine harness)
 6. Engine injector harness assembly to engine sensor harness assembly interconnect
 7. Red locking tab (harness interconnect)
1. Connect engine injector harness assembly to engine sensor harness assembly interconnect (brake interconnect) and push in red locking tab.
 2. Connect engine sensor harness assembly connector to ECM by pushing straight in, then push down release lever until it locks in place under red locking tab.
 3. Connect engine injector harness assembly connector to ECM by pushing straight in, then push down release lever until it locks under red locking tab.
 4. Connect ground (-) cable to battery only if all electrical repairs and connector connections are complete.

EGR Temperature (EGRT) Sensor**Figure 115 EGRT sensor**

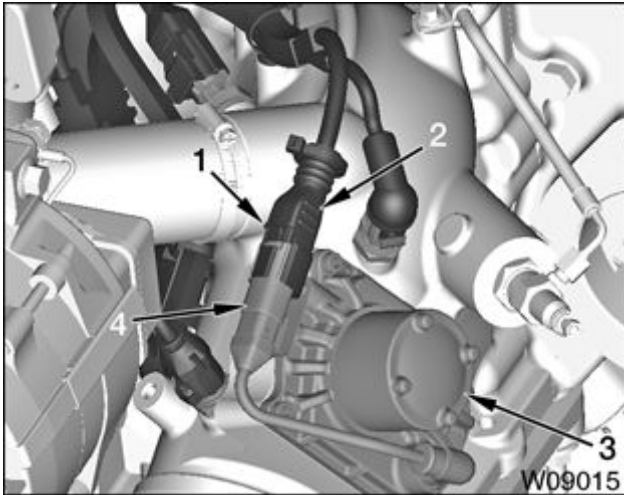
1. EGR Temperature (EGRT) sensor
2. Red locking tab
3. Electrical connector

1. Install EGRT sensor on engine throttle valve assembly and tighten to special torque (page 110).
2. Connect electrical connector by pushing in until the release lever clicks into place (click may be heard or felt).
3. Push in red locking tab on EGRT sensor electrical connector.

Exhaust Gas Recirculation (EGR) Valve Assembly Connector**Figure 116 EGR valve assembly**

1. Release lever
2. Electrical connector (EGR valve)
3. EGR valve assembly
4. Electrical connector (harness)

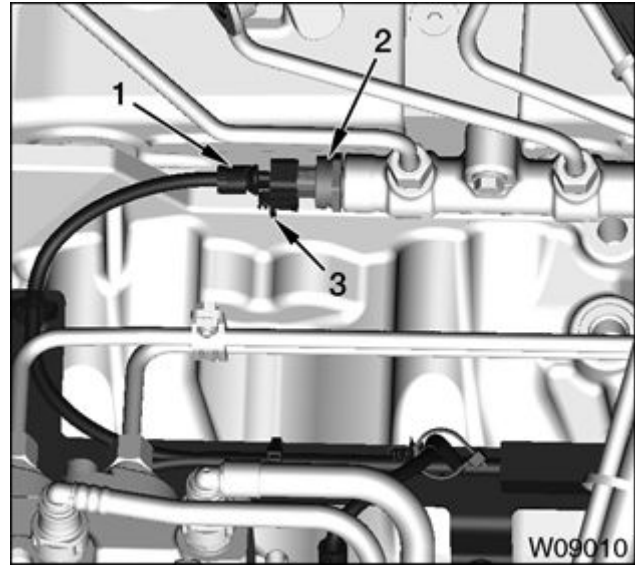
1. Connect engine sensor harness assembly electrical connector to EGR valve assembly electrical connector located at EGR valve assembly installed at rear of EGR cooler assembly. Push electrical connectors together until the release lever clicks into place (click may be heard or felt).

Engine Throttle Valve (ETV) Assembly Connector**Figure 117 ETV assembly**

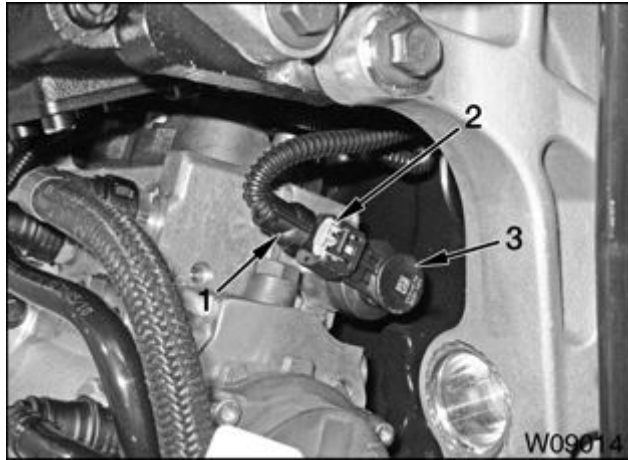
1. Release lever
 2. Electrical connector (harness)
 3. Engine Throttle Valve (ETV)
 4. Electrical connector
-
1. Connect engine sensor harness assembly electrical connector to ETV electrical connector at engine throttle valve installed on engine throttle valve assembly on air inlet at top left side of engine. Push electrical connectors together until release lever clicks into place (click may be heard or felt).

Fuel Rail Pressure (FRP) Sensor

1. If installed during removal, remove Disposable Air and Fuel Caps covering exposed rail assembly opening.

**Figure 118 FRP sensor**

1. Electrical connector
 2. Fuel Rail Pressure (FRP) sensor
 3. Yellow locking tab
-
2. Install FRP sensor at end of fuel rail assembly towards front of engine and tighten to special torque (page 110).
 3. Connect electrical connector by pushing in until the release lever clicks into place (click may be heard or felt).
 4. Push in yellow locking tab on electrical connector.

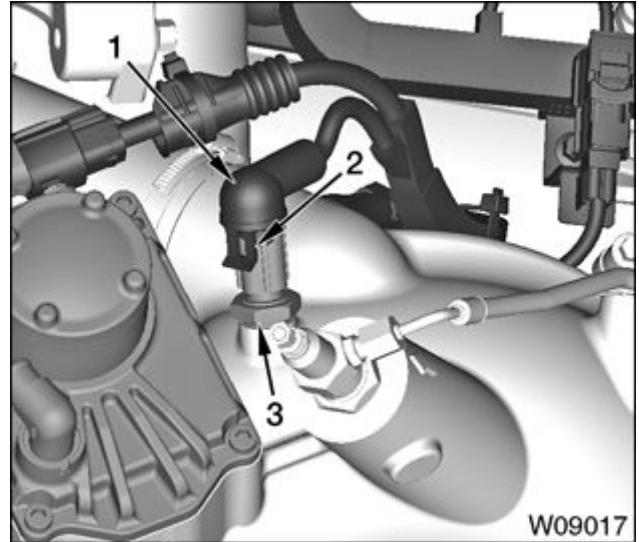
High-Pressure Fuel Pump Connector**Figure 119 High-pressure fuel pump connector**

1. Electrical connector
2. Yellow locking tab
3. High-pressure fuel pump

1. Connect electrical connector to high-pressure fuel pump installed at left forward side of engine by pushing in until the release lever clicks into place (click may be heard or felt).
2. Push in yellow locking tab on electrical connector.

Intake Manifold Pressure (IMP) Sensor

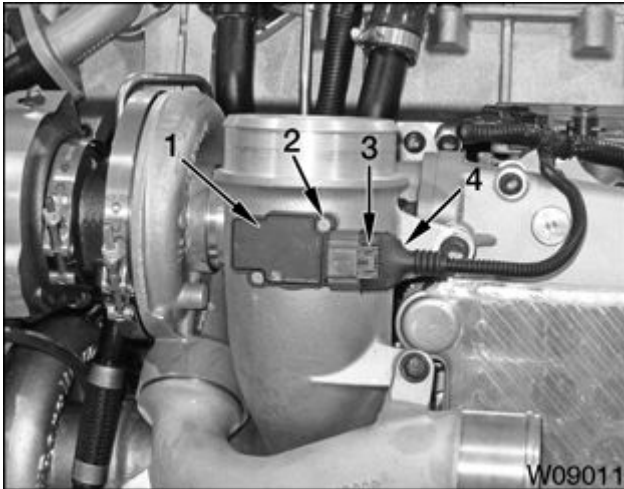
1. Lubricate new O-ring with P-80® rubber lubricant or equivalent (page 110) and install on IMP sensor.

**Figure 120 IMP sensor**

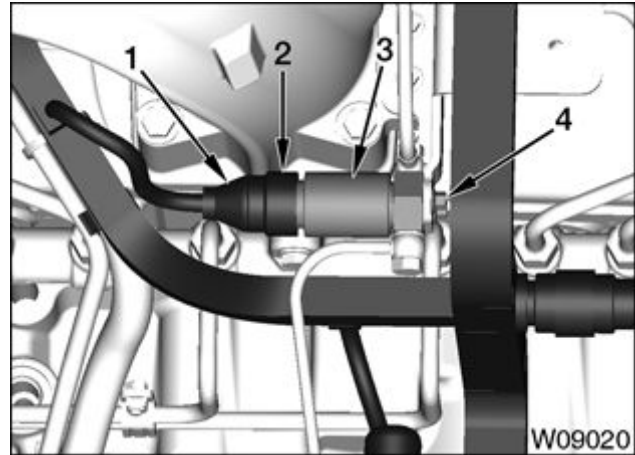
1. Electrical connector
 2. Release lever
 3. Intake Manifold Pressure (IMP) sensor
2. Install IMP sensor on engine throttle valve assembly and tighten to special torque (page 110).
 3. Connect electrical connector by pushing in until the release lever clicks into place (click may be heard or felt).

Mass Air Flow (MAF) Sensor

1. Install new O-ring on MAF sensor.

**Figure 121 MAF sensor**

1. Mass Air Flow (MAF) sensor
 2. M4 x 0.7 hex head cap screw (2)
 3. Release lever
 4. Electrical connector
2. Position MAF sensor on turbocharger air inlet duct.
- NOTE:** Do not overtighten screws; screws can snap or strip if overtightened.
3. Install two M4 x 0.7 hex head cap screws and tighten to special torque (page 110).
 4. Connect electrical connector by pushing in until the release lever clicks into place (click may be heard or felt).

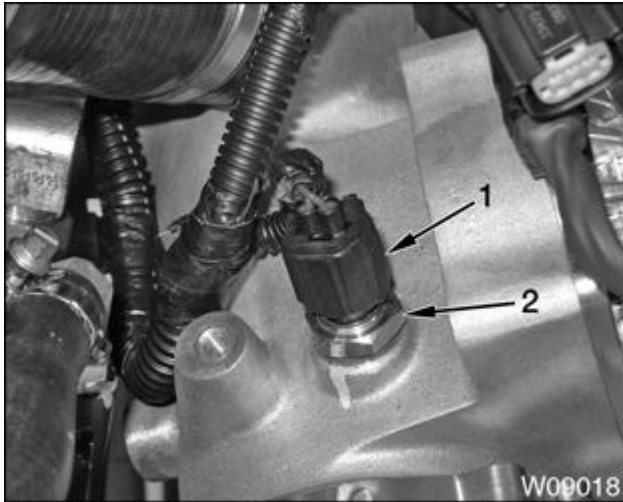
Cold Start Fuel Solenoid (CSFS) Valve Connector**Figure 122 CSFS valve**

1. Electrical connector
2. Locking collar
3. Cold Start Fuel Solenoid (CSFS) valve
4. M6 x 12 hex flange bolt (2)

Connect electrical connector to CSFS valve and turn locking collar 90° clockwise.

Charge Air Cooler Outlet Temperature (CACOT) Sensor

1. Lubricate new O-ring with P-80® rubber lubricant or equivalent (page 110) and install on CACOT sensor.

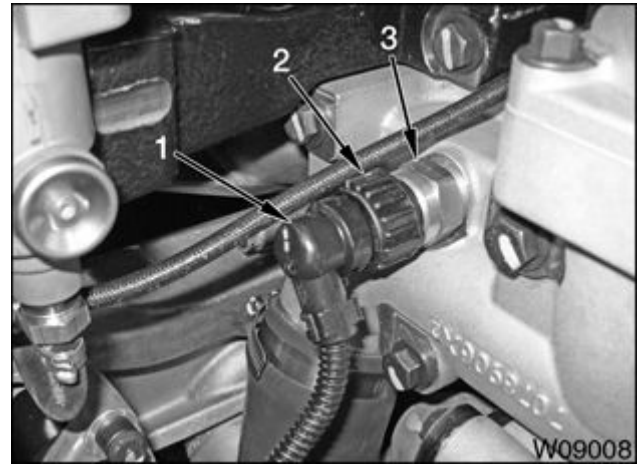
**Figure 123 CACOT sensor**

1. Electrical connector
 2. Charge Air Cooler Outlet Temperature (CACOT) sensor
2. Install CACOT sensor on engine throttle valve assembly and tighten to special torque (page 110).
 3. Connect electrical connector by pushing in until the release lever clicks into place (click may be heard or felt).

Engine Coolant Temperature 1 (ECT1) Sensor

NOTE: This engine is equipped with several temperature sensors of similar physical construction. Install a temperature sensor of the same part number as the one removed. Part number identification is embossed on the hex face of the sensor body.

1. Install new 16.7 x 24 seal ring on ECT1 sensor.

**Figure 124 ECT1 sensor**

1. Electrical connector
 2. Locking collar
 3. Engine Coolant Temperature 1 (ECT1) sensor
2. Install ECT1 sensor on thermostat housing and tighten to special torque (page 110).
 3. Connect electrical connector and turn locking collar 90° clockwise.

Engine Coolant Temperature 2 (ECT2) Sensor

NOTE: This engine is equipped with several temperature sensors of similar physical construction. Install a temperature sensor of the same part number as the one removed. Part number identification is embossed on the hex face of the sensor body.

1. Install new 16.7 x 24 seal ring on ECT2 sensor.



Figure 125 ECT2 sensor

1. Electrical connector
 2. Locking collar
 3. Engine Coolant Temperature 2 (ECT2) sensor
2. Install ECT2 sensor on coolant manifold and tighten to special torque (page 110).
 3. Connect electrical connector and turn locking collar 90° clockwise.

Engine Oil Temperature (EOT) Sensor

NOTE: This engine is equipped with several temperature sensors of similar physical construction. Install a temperature sensor of the same part number as the one removed. Part number identification is embossed on the hex face of the sensor body.

1. Install new 16.7 x 24 seal ring on EOT sensor.

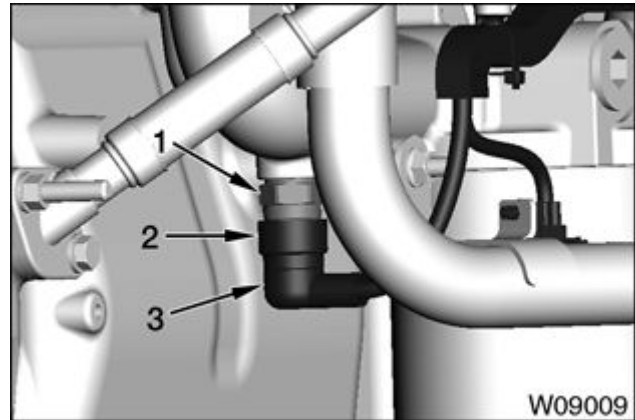


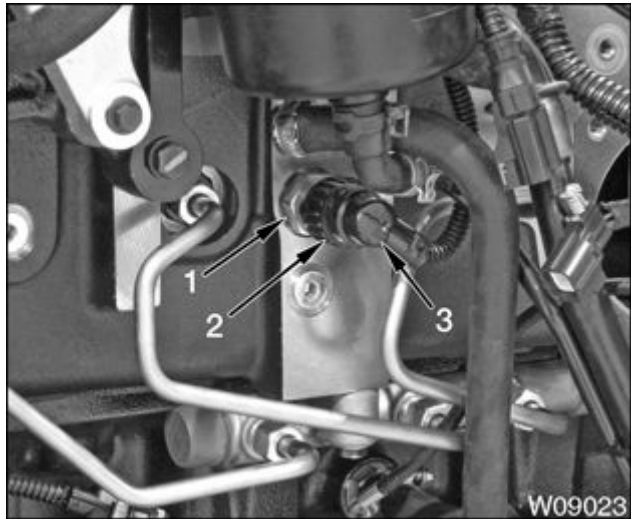
Figure 126 EOT sensor

1. Engine Oil Temperature (EOT) sensor
 2. Locking collar
 3. Electrical connector
2. Install EOT sensor in bottom of oil filter base assembly and tighten to special torque (page 110).
 3. Connect electrical connector and turn locking collar 90° clockwise.

Intake Manifold Temperature (IMT) Sensor

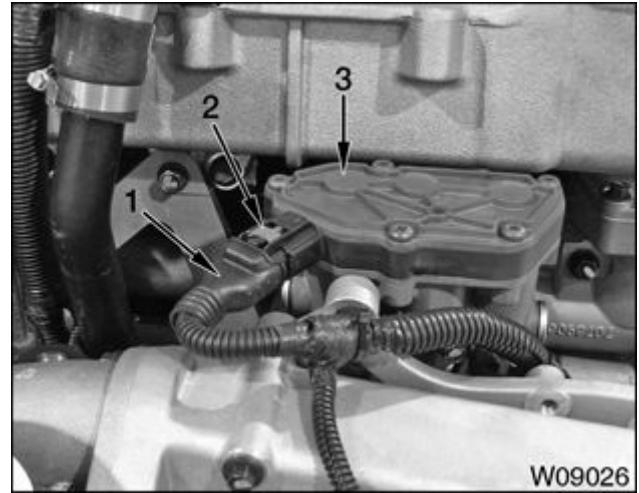
NOTE: This engine is equipped with several temperature sensors of similar physical construction. Install a temperature sensor of the same part number as the one removed. Part number identification is embossed on the hex face of the sensor body.

1. Install new 16.7 x 24 seal ring on IMT sensor.

**Figure 127 IMT sensor**

1. Intake Manifold Temperature (IMT) sensor
 2. Locking collar
 3. Electrical connector
2. Install IMT sensor on cylinder head below breather filter assembly and tighten to special torque (page 110).

3. Connect electrical connector and turn locking collar 90° clockwise.

Air Control Valve Connector**Figure 128 Air control valve**

1. Electrical connector
 2. Red locking tab
 3. Air control valve
1. Connect electrical connector to air control valve installed at right front of engine below front of EGR cooler assembly. Push in connector until the release lever clicks into place (click may be heard or felt).
 2. Push in red locking tab on electrical connector.

Special Torque

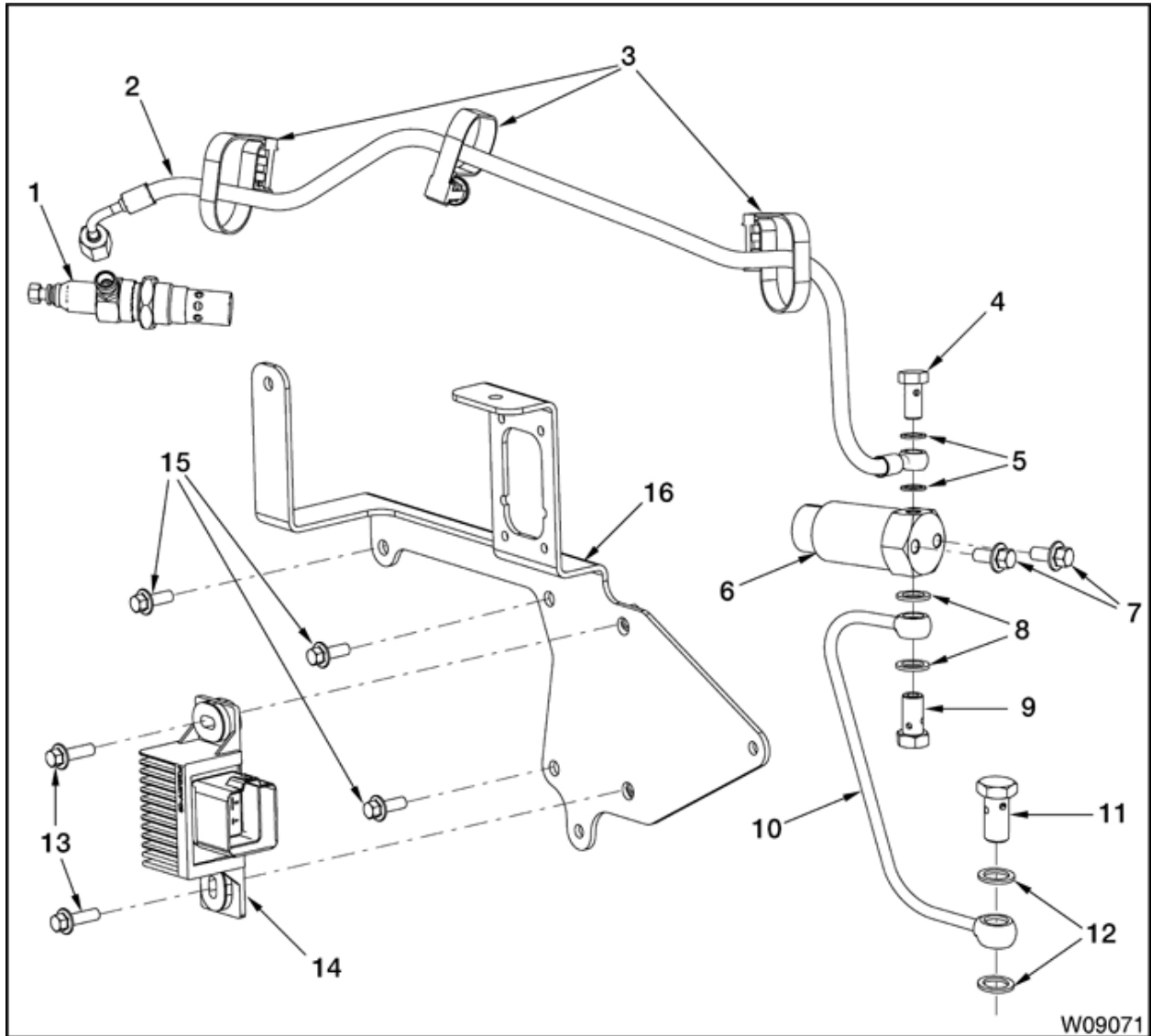
4.8 x 13 self tapping screws	4 N·m (35 lbf·in)
Charge Air Cooler Outlet (CACOT) sensor	20 N·m (15 lbf·ft)
Crankcase Pressure (CCP) sensor	12 N·m (108 lbf·in)
Engine Oil Pressure (EOP) sensor	20 N·m (15 lbf·ft)
Engine Coolant Pressure 1 (ECP1) sensor	12 N·m (108 lbf·in)
Engine Coolant Temperature 1 (ECT1) sensor	20 N·m (15 lbf·ft)
Engine Coolant Temperature 2 (ECT2) sensor	20 N·m (15 lbf·ft)
Engine Oil Temperature (EOT) sensor	20 N·m (15 lbf·ft)
EGR Temperature (EGRT) sensor	20 N·m (15 lbf·ft)
Fuel Delivery Pressure (FDP) sensor	20 N·m (15 lbf·ft)
Fuel Rail Pressure (FRP) sensor	70 N·m (52 lbf·ft)
Intake Manifold Pressure (IMP) Sensor	20 N·m (15 lbf·ft)
Intake Manifold Temperature (IMT) sensor	20 N·m (15 lbf·ft)
M4 x 0.7 hex head cap screws	0.36 N·m (3 lbf·in)
M6 x 16 hex flange bolt	9 N·m (80 lbf·in)
Oxygen Sensor (O2S)	50 N·m (37 lbf·ft)

Special Service Tools

Description	Tool Number
Disposable Air and Fuel Caps	ZTSE4891
P-80® rubber lubricant or equivalent	Obtain locally

Table of Contents

Exploded View.....	113
Removal.....	114
Cold Start Relay (CSR).....	114
Relay Support Assembly.....	115
Solenoid to Injector Tube.....	115
Filter to Solenoid Tube.....	116
Cold Start Fuel Solenoid (CSFS).....	116
Cold Start Fuel Igniter (CSFI).....	116
Installation.....	117
Cold Start Fuel Igniter (CSFI).....	117
Cold Start Fuel Solenoid (CSFS).....	117
Filter to Solenoid Tube.....	118
Solenoid to Injector Tube.....	118
Relay Support Assembly.....	119
Cold Start Relay (CSR).....	120
Special Torque.....	121

Exploded View**Figure 129 Cold start assist components**

1. Cold Start Fuel Igniter (CSFI)	7. M6 x 12 hex flange bolt (2)	13. M6 x 20 hex flange bolt (2)
2. Solenoid to injector tube	8. 10.7 x 16 ring seal (2)	14. Cold Start Relay (CSR)
3. Tie strap (3)	9. Size 6 banjo bolt	15. M6 x 16 hex flange bolt (3)
4. M8 x 1 banjo bolt	10. Filter to solenoid tube assembly	16. Relay support assembly
5. Washer (2)	11. Size 8 banjo bolt	
6. Cold Start Fuel Solenoid (CSFS)	12. 12.7 x 18 ring seal (2)	

Removal



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

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

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

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

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

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

Cold Start Relay (CSR)

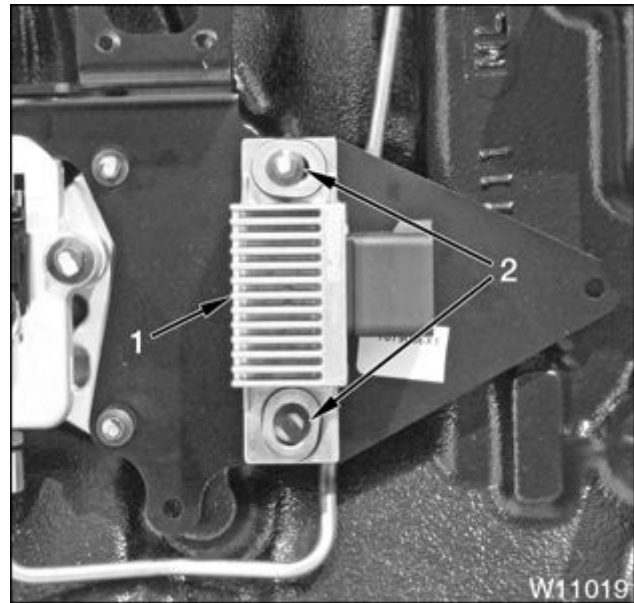
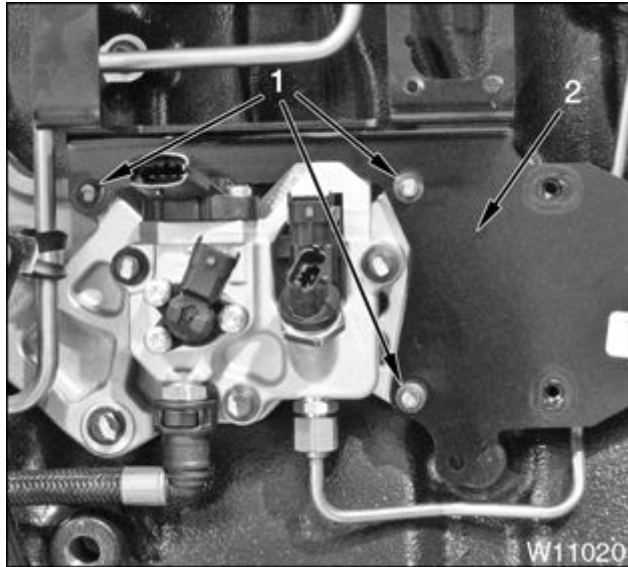


Figure 130 CSR

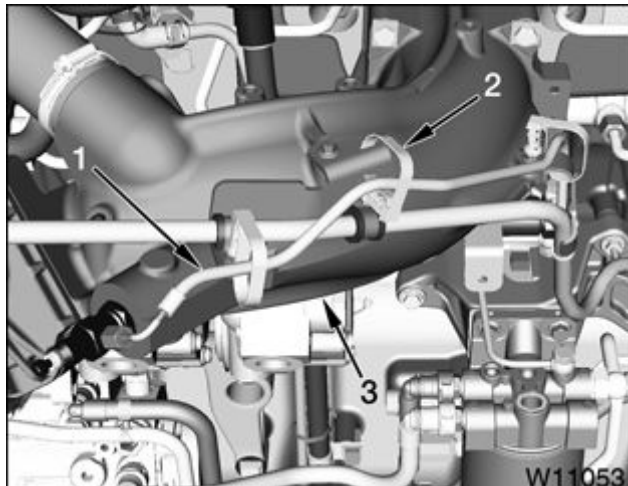
1. CSR
2. M6 x 20 hex flange bolt (2)

Remove two M6 x 20 hex flange bolts and remove CSR.

Relay Support Assembly**Figure 131 Relay support assembly**

1. M6 x 16 hex flange bolt (3)
2. Relay support assembly

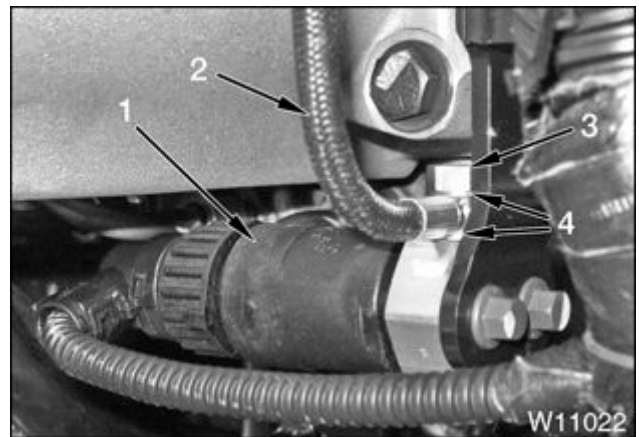
Remove three M6 x 16 hex flange bolts and relay support assembly.

Solenoid to Injector Tube**Figure 132 Solenoid to injector tube**

1. Solenoid to injector tube
2. Tie strap (3)
3. Engine throttle valve assembly

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

1. Place suitable container clearly marked **DIESEL FUEL** under Cold Start Fuel Igniter (CSFI) and solenoid to injector tube.
2. Disconnect solenoid to injector tube nut at Cold Start Fuel Igniter(CSFI).
3. Remove three tie straps and drain fuel from solenoid to injector tube into container.

**Figure 133 Solenoid to injector tube at CSFS**

1. CSFS
2. Solenoid to injector tube
3. M8 x 1 banjo bolt
4. Washer (2)

4. Remove M8 x 1 banjo bolt.
5. Remove solenoid to injector tube and two tube clamps as an assembly. Discard two washers.

Filter to Solenoid Tube

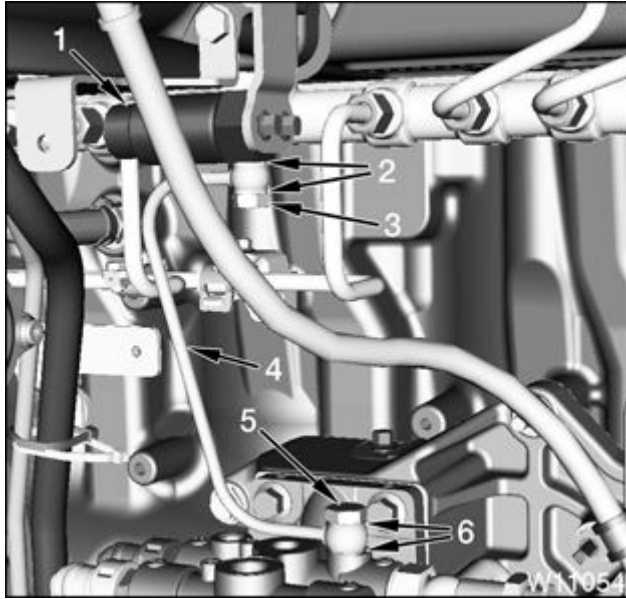


Figure 134 Filter to solenoid tube

1. CSFS
2. 10.7 x 16 ring seal (2)
3. Size 6 banjo bolt
4. Filter to solenoid tube assembly
5. Size 8 banjo bolt
6. 12.7 x 18 ring seal (2)

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

1. Place suitable container clearly marked **DIESEL FUEL** under filter to solenoid tube assembly.
2. Remove size 8 banjo bolt from fuel filter assembly and drain fuel into container.
3. Remove and discard two 12.7 x 18 ring seals.
4. Remove size 6 banjo bolt from CSFS.
5. Remove and discard two 10.7 x 16 ring seals.
6. Remove filter to solenoid tube assembly.

Cold Start Fuel Solenoid (CSFS)

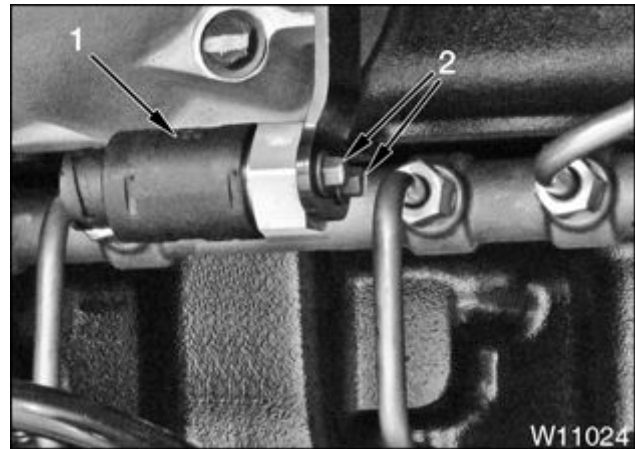


Figure 135 CSFS

1. Cold Start Fuel Solenoid (CSFS)
2. M6 x 12 hex flange bolt (2)

Remove two M6 x 12 hex flange bolts and CSFS.

Cold Start Fuel Igniter (CSFI)

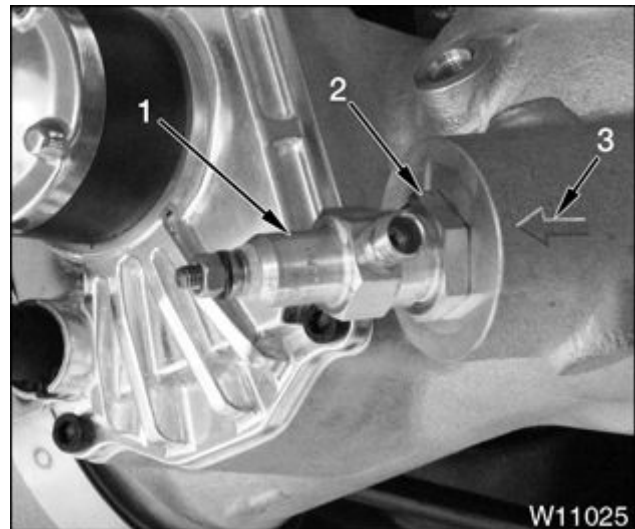


Figure 136 CSFI

1. Cold Start Fuel Igniter (CSFI)
2. CSFI locking nut (part of CSFI)
3. Alignment mark

1. Loosen CSFI locking nut.
2. Remove CSFI by rotating counterclockwise.

Installation

Cold Start Fuel Igniter (CSFI)

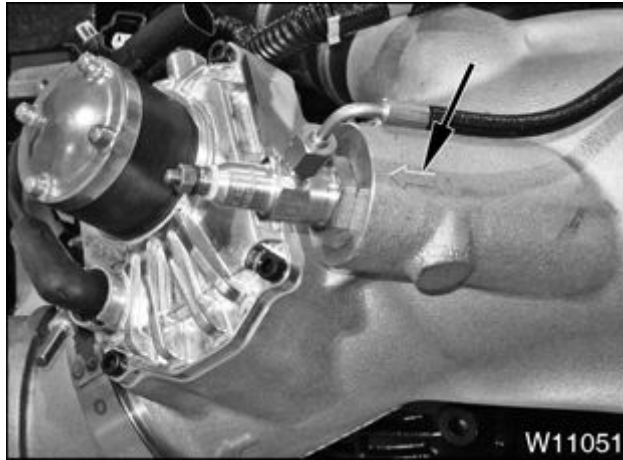


Figure 137 Alignment mark

NOTE: Use the alignment mark embossed on engine throttle valve assembly to properly orient both the Cold Start Fuel Igniter (CSFI) and connecting solenoid to injector tube.

1. Loosely install CSFI. Position CSFI so solenoid to injector tube connection is oriented with the alignment mark on engine throttle valve assembly.

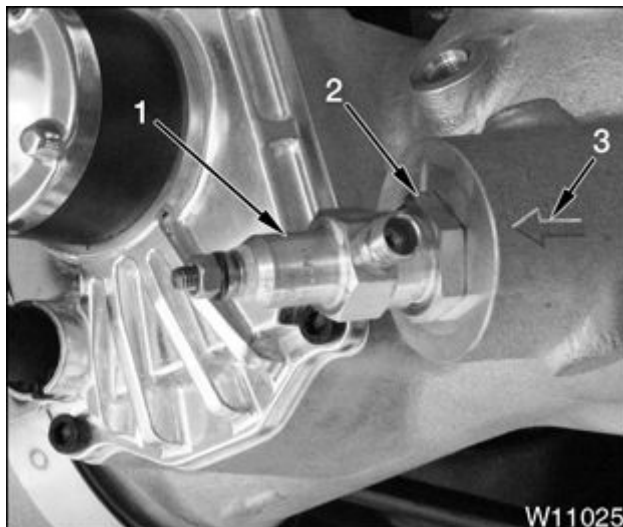


Figure 138 CSFI

1. Cold Start Fuel Igniter (CSFI)
2. CSFI locking nut (part of CSFI)
3. Alignment mark

2. If solenoid to injector tube was removed, keep CSFI loosely installed. Tighten CSFI to final torque only after installing solenoid to injector tube and ensuring proper CSFI to tube alignment. See Solenoid to Injector Tube (page 118) for installation of solenoid to injector tube.
3. Connect solenoid to injector tube nut onto loosely installed CSFI. Tighten solenoid to injector tube nut to special torque (page 121).
4. Hold CSFI with backup wrench to maintain proper orientation. Tighten CSFI locking nut to special torque (page 121).

Cold Start Fuel Solenoid (CSFS)

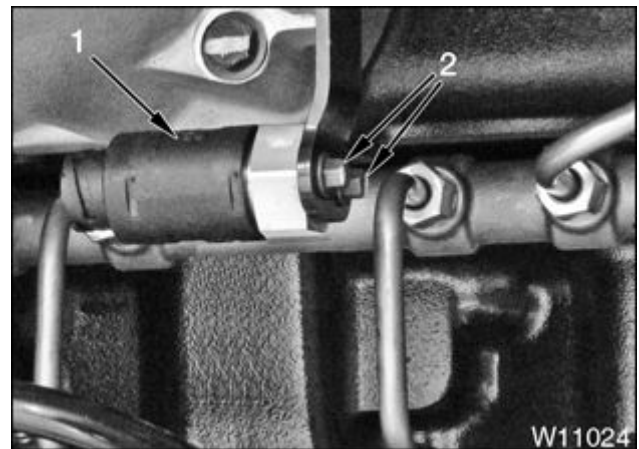
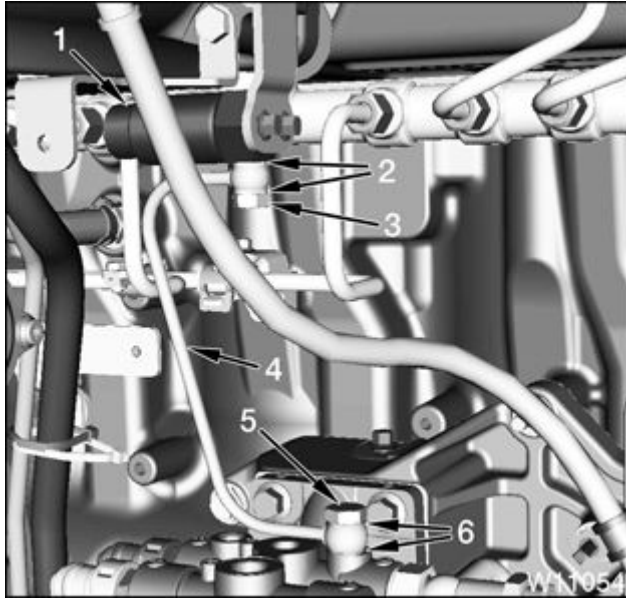


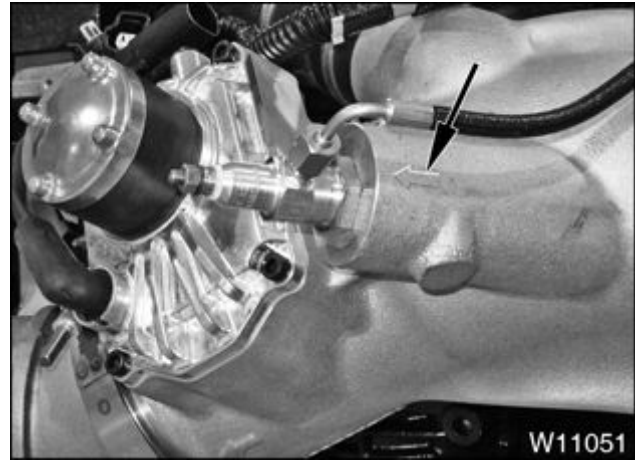
Figure 139 CSFS

1. Cold Start Fuel Solenoid (CSFS)
2. M6 x 12 hex flange bolt (2)

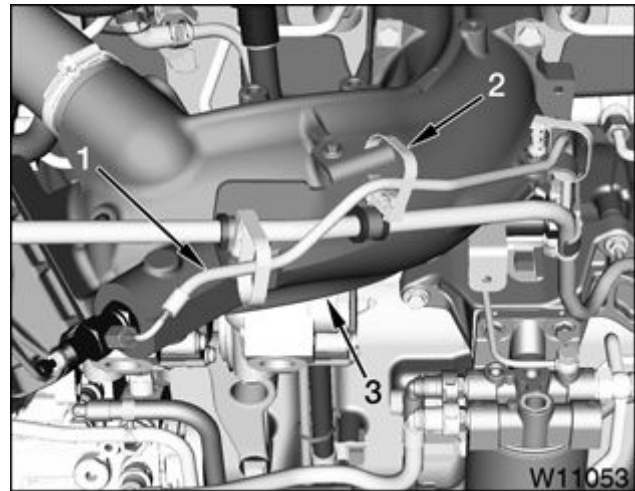
Install two M6 x 12 hex flange bolts and CSFS. Tighten bolts to special torque (page 121).

Filter to Solenoid Tube**Figure 140 Filter to solenoid tube**

1. Cold Start Fuel Solenoid (CSFS)
 2. 10.7 x 16 ring seal (2)
 3. Size 6 banjo bolt
 4. Filter to solenoid tube assembly
 5. Size 8 banjo bolt
 6. 12.7 x 18 ring seal (2)
1. Position filter to solenoid tube assembly onto CSFS. Install size 6 banjo bolt and two new 10.7 x 16 ring seals.
 2. Position filter to solenoid tube assembly onto fuel filter assembly. Install size 8 banjo bolt and two new 12.7 x 18 ring seals.
 3. Tighten size 6 and size 8 banjo bolts to special torque (page 121).

Solenoid to Injector Tube**Figure 141 Alignment mark**

NOTE: Use the alignment mark embossed on engine throttle valve assembly to properly orient both the Cold Start Fuel Igniter (CSFI) and solenoid to injector tube.

**Figure 142 Solenoid to injector tube**

1. Solenoid to injector tube
 2. Tie strap (6)
 3. Engine throttle valve assembly
1. Position solenoid to injector tube onto engine throttle valve assembly and install three tie straps. Make sure that solenoid to injector tube aligns with arrow embossed on engine throttle valve assembly.

2. If not previously done, connect solenoid to injector tube to CSFI, and tighten solenoid to injector tube nut to special torque (page 121).

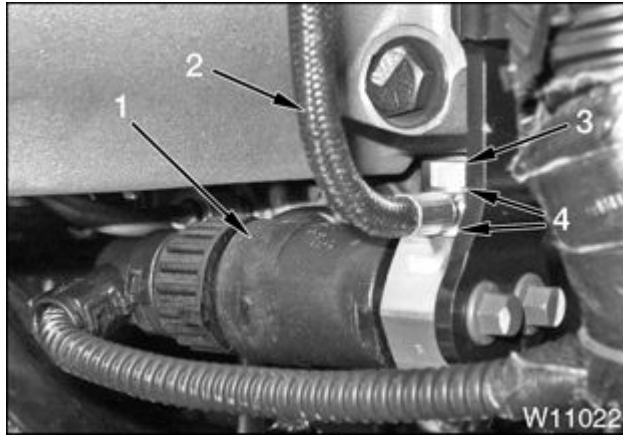


Figure 143 Solenoid to injector tube at CSFS

1. CSFS
 2. Solenoid to injector tube
 3. M8 x 1 banjo bolt
 4. Washer (2)
3. Connect solenoid to injector tube to CSFS with two new washers and M8 x 1 banjo bolt. Tighten M8 x 1 banjo bolt to special torque (page 121).
 4. Connect solenoid to injector tube to CSFI. Tighten solenoid to injector tube nut to special torque (page 121).

5. If CSFI was removed, tighten CSFI locking nut to special torque (page 121).

Relay Support Assembly

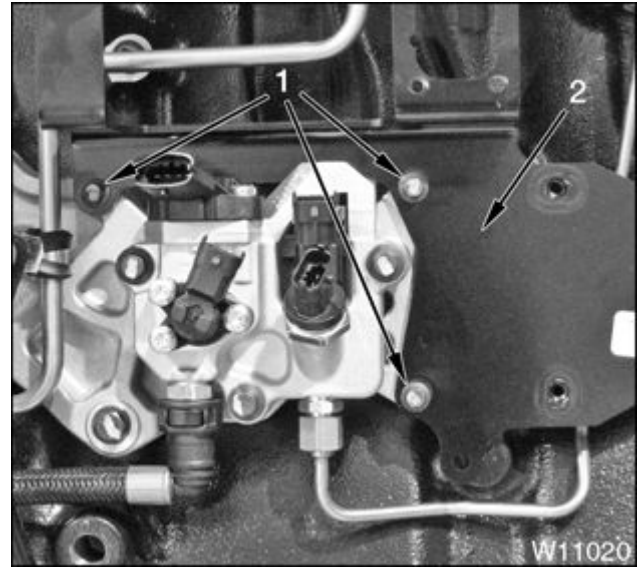
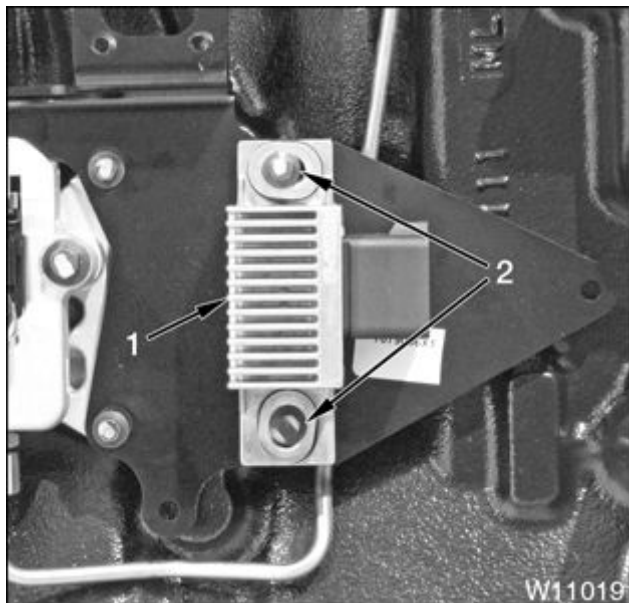


Figure 144 Relay support assembly

1. M6 x 16 hex flange bolt (3)
 2. Relay support assembly
1. Position relay support assembly and install three M6 x 16 hex flange bolts. Tighten bolts to standard torque (page 561).

Cold Start Relay (CSR)**Figure 145 CSR**

1. CSR
2. M6 x 20 hex flange bolt (2)

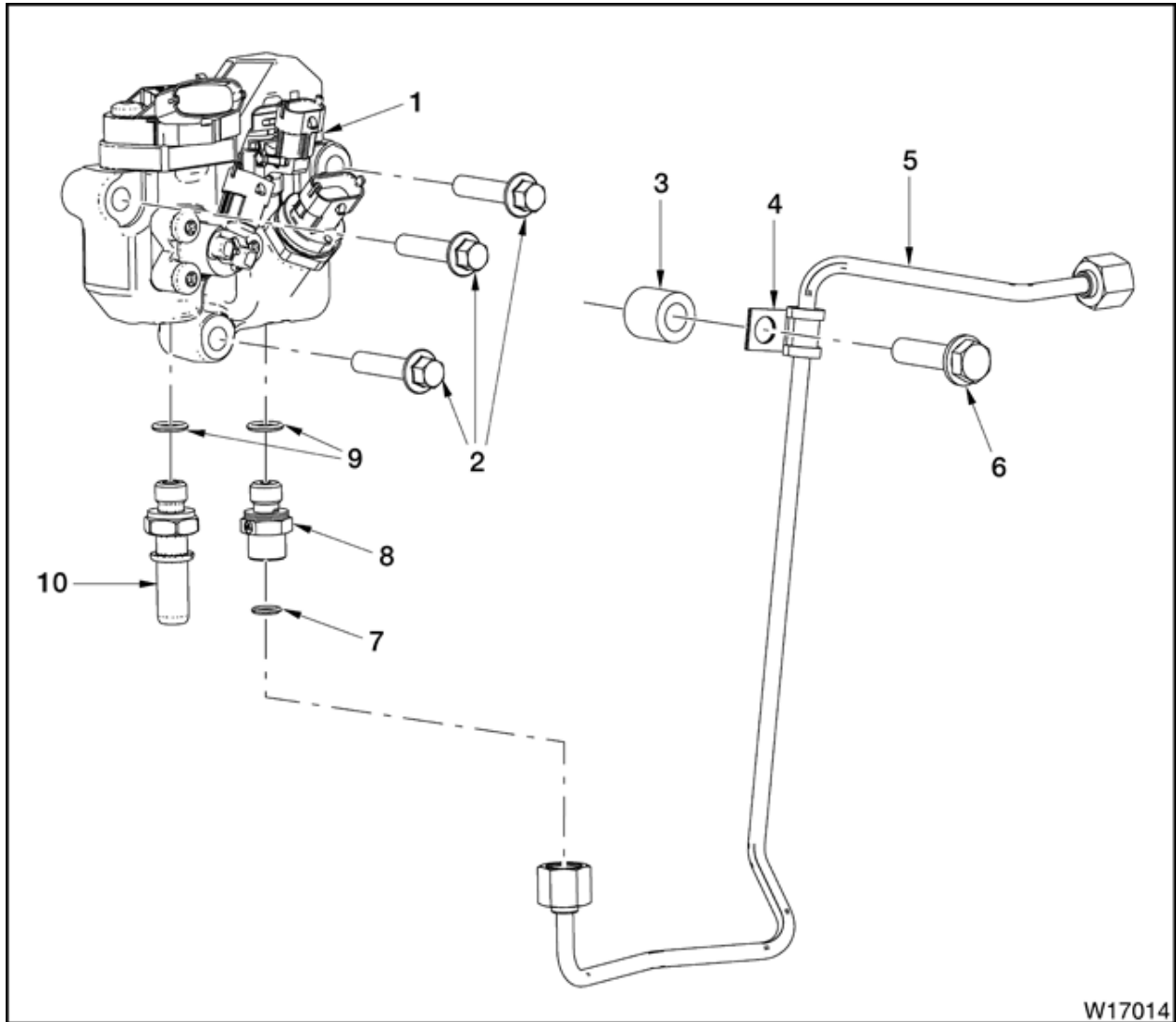
Install CSR and two M6 x 20 hex flange bolts. Tighten bolts to special torque (page 121).

Special Torque

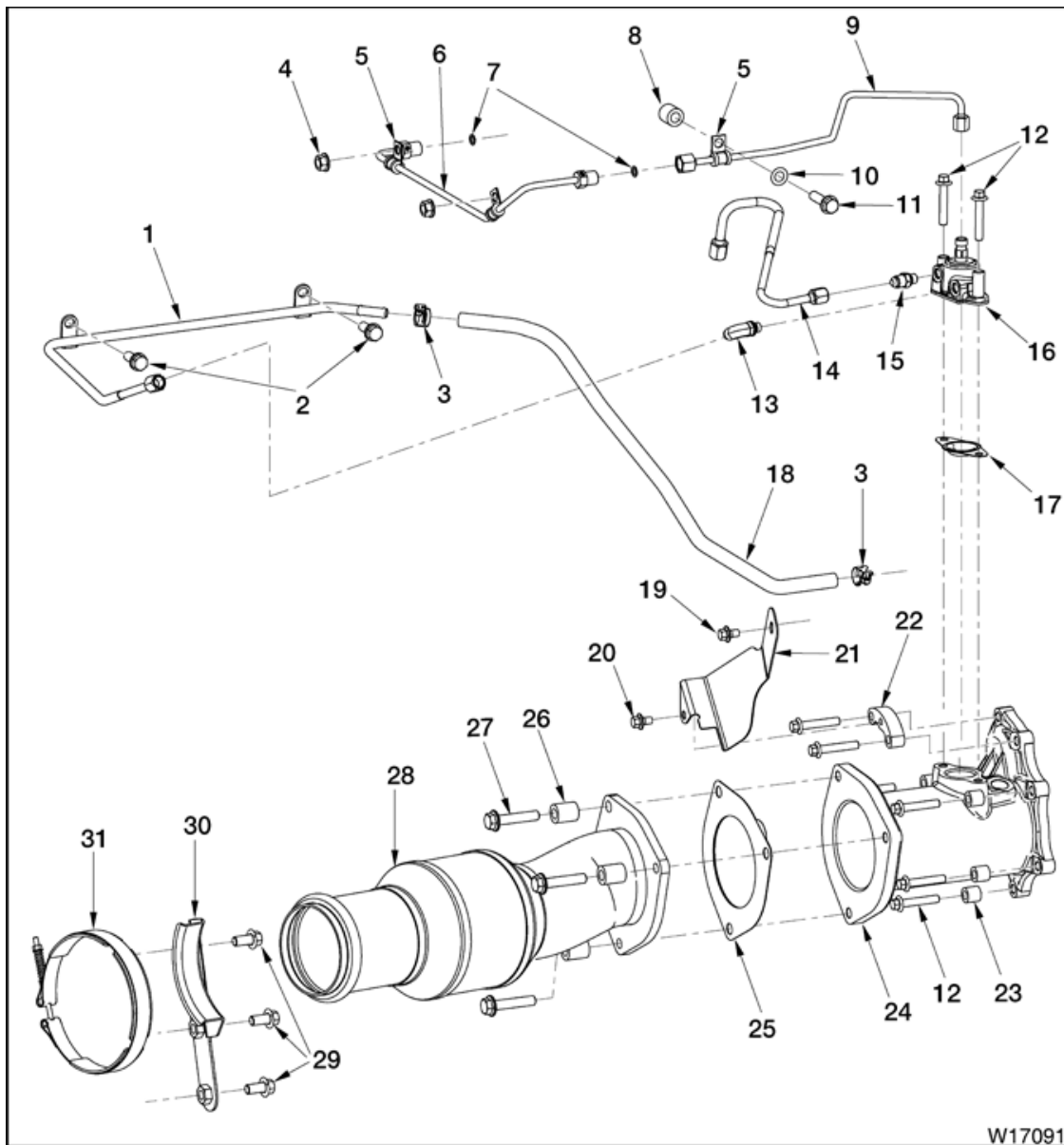
CSFI locking nut	25 N·m (18 lbf·ft)
M6 x 12 hex flange bolts (CSFS)	6 N·m (53 lbf·in)
M6 x 20 hex flange bolts (CSR)	10 N·m (88 lbf·in)
M8 x 1 banjo bolt	8 N·m (71 lbf·in)
Solenoid to injector tube nut	8 N·m (71 lbf·in)
Size 6 banjo bolt	15 N·m (92 lbf·in)
Size 8 banjo bolt	15 N·m (92 lbf·in)

Table of Contents

Exploded Views.....	125
Removal.....	127
Pre-Diesel Oxidation Catalyst (PDOC).....	127
Down Stream Injection (DSI) Assembly and Doser Fuel to Injector Tube Assembly.....	128
Injector Unit Feed Tube Assembly and Doser Fuel from Valve Tube Assembly.....	129
Doser Coolant Supply Tube Assembly and Doser Coolant Return Tube Assembly.....	130
Fuel Doser Assembly.....	131
Turbocharger Exhaust Duct.....	131
Inspection and Cleaning.....	132
Fuel Doser.....	132
Installation.....	132
Turbocharger Exhaust Duct.....	132
Fuel Doser Assembly.....	133
Doser Coolant Supply Tube Assembly and Doser Coolant Return Tube Assembly.....	134
Injector Unit Feed Tube Assembly and Doser Fuel from Valve Tube Assembly	134
Down Stream Injection (DSI) Assembly and Doser Fuel to Injector Tube Assembly.....	135
Pre-Diesel Oxidation Catalyst (PDOC).....	136
Special Torque.....	137
Special Service Tools.....	137

Exploded Views**Figure 146 Aftertreatment system components (left side of engine)**

1. Down Stream Injection (DSI) assembly	4. Single cushioned pipe clamp	7. O-ring (size 011)
2. M8 x 35 hex bolt (3)	5. Doser fuel to injector tube assembly	8. Fitting assembly
3. 19 mm spacer	6. 3/8-16 x 1 1/2 bolt	9. O-ring (2)
		10. Fitting assembly



W17091

Figure 147 Aftertreatment system components (right side of engine)

1. Doser coolant return tube assembly	11. 3/8–16 x 1 1/2 bolt	22. Heat shield spacer
2. 3/8–16 x 1 hex bolt w/washer (2)	12. M8 x 45 hi temp hex bolt (9)	23. 9 I.D. x 16 O.D. x 15 L spacer (5)
3. 3/8 CTB clamp (2)	13. Tube fitting	24. Turbo exhaust duct
4. 3/8 hex nut (2)	14. Doser coolant supply tube assembly	25. Engine brake gasket
5. Single cushioned pipe clamp (3)	15. M10 x 5/16 tube fitting	26. 11 ID x 20 OD x 24L spacer (3)
6. Injector unit feed tube assembly	16. Fuel doser	27. M10 x 50 hex bolt (3)
7. O-ring (size 011) (2)	17. HC injector gasket	28. PDOC tube assembly
8. 19 mm spacer	18. Doser coolant return hose	29. M10 x 20 hex bolt (3)
9. Doser fuel from valve tube assembly	19. M8 x 12 hex bolt	30. PDOC support assembly
10. 10.85 x 19.3 x 1.27 washer	20. M8 x 16 hex bolt	31. Clamp (PDOC)
	21. Heat shield	

Removal



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

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

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

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

! WARNING: To prevent personal injury or death, 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.

Pre-Diesel Oxidation Catalyst (PDOC)

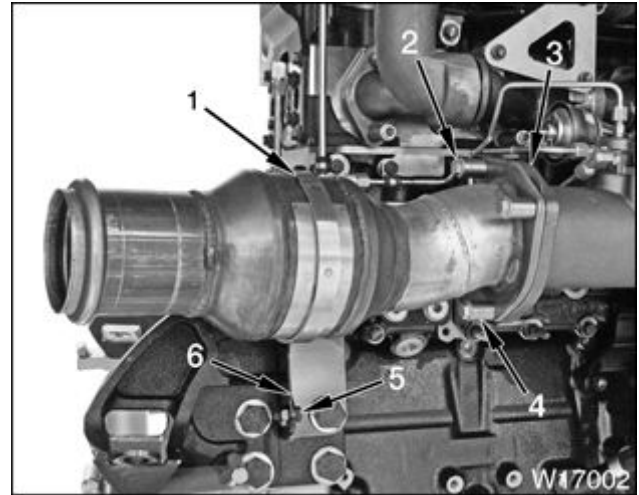


Figure 148 PDOC tube assembly

1. Clamp (PDOC)
2. M10 x 50 hex bolt (3)
3. Engine brake gasket
4. 11 ID x 20 OD x 24L spacer (3)
5. M10 x 20 hex bolt (3)
6. PDOC support assembly

1. Remove three M10 x 20 hex bolts from PDOC support assembly.
2. Remove three M10 x 50 hex bolts and three 11 ID x 20 OD x 24L spacers. Remove PDOC from turbocharger outlet. Discard engine brake gasket.
3. If required, loosen PDOC clamp and remove PDOC from PDOC support assembly.

Down Stream Injection (DSI) Assembly and Doser Fuel to Injector Tube Assembly

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

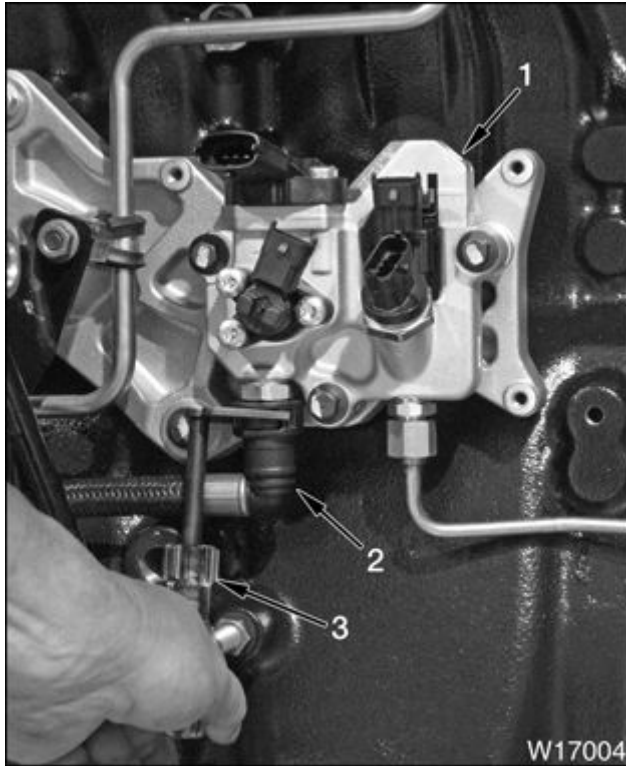


Figure 149 Fuel return tube assembly

1. DSI assembly
 2. Fuel return tube assembly
 3. Fuel line disconnect tool
1. Place suitable container clearly marked **DIESEL FUEL** under fuel return tube assembly.

2. Disconnect fuel return tube assembly from DSI assembly using Fuel Line Disconnect Tool (page 137).

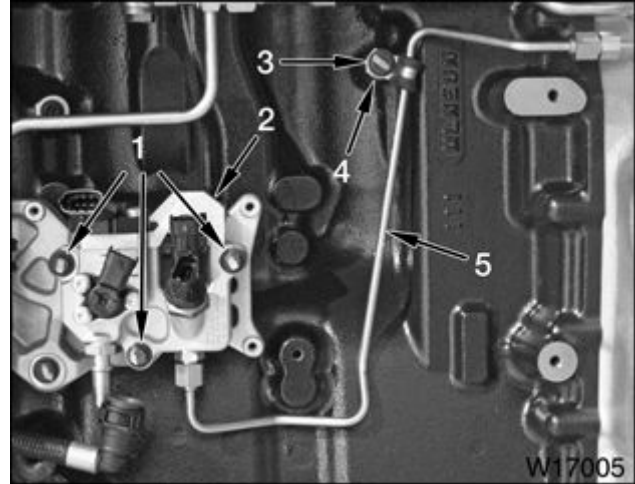


Figure 150 DSI assembly

1. M8 x 35 hex bolt (3)
 2. DSI assembly
 3. 3/8-16 x 1 1/2 bolt
 4. 19 mm spacer (under clamp)
 5. Doser fuel to injector tube assembly
3. Loosen tube nut of doser fuel to injector tube assembly at DSI assembly.
 4. Hold fitting on injector unit feed tube assembly with backup wrench and loosen tube nut on doser fuel to injector tube assembly.
 5. Remove three M8 x 35 hex bolts and remove DSI assembly.
 6. Remove 3/8-16 x 1 1/2 bolt with 19 mm spacer and remove doser fuel to injector tube assembly.

Injector Unit Feed Tube Assembly and Doser Fuel from Valve Tube Assembly

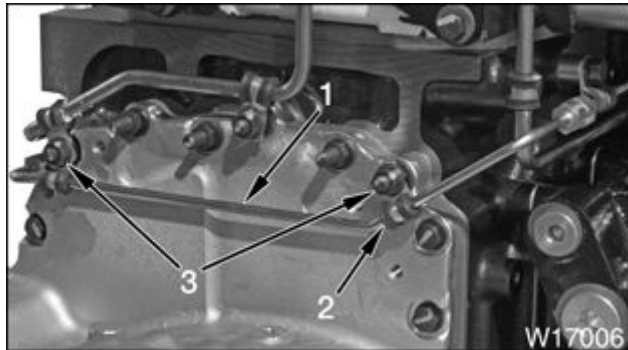


Figure 151 Injector unit feed tube assembly

1. Injector unit feed tube assembly
 2. Single cushioned pipe clamp (2)
 3. 3/8 hex nut (2)
1. Hold fitting on injector unit feed tube assembly with backup wrench and loosen tube nut on doser fuel from valve tube assembly.
 2. Remove two 3/8 hex nuts.
 3. Remove injector unit feed tube assembly with pipe clamps.

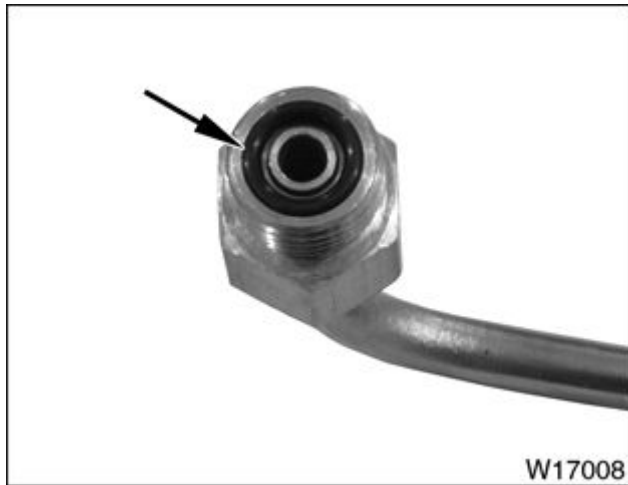


Figure 152 Injector unit feed tube assembly O-ring (size 011)

4. Remove and discard O-rings (size 011) from injector unit feed tube assembly.

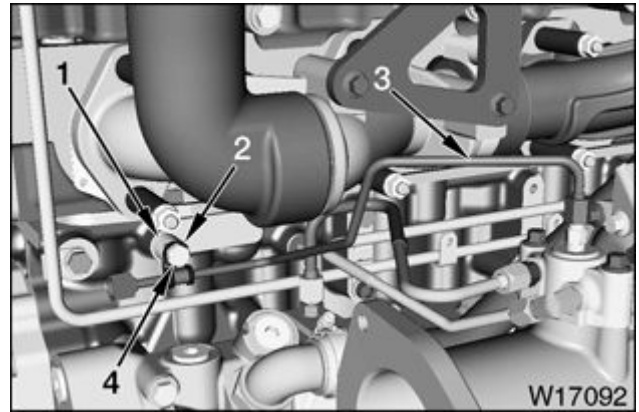


Figure 153 Doser fuel from valve tube assembly

1. 19 mm spacer
 2. 10.85 x 19.3 x 1.27 washer
 3. Doser fuel from valve tube assembly
 4. 3/8-16 x 1 1/2 bolt
5. Loosen fitting on doser fuel from valve tube assembly at fuel doser.
 6. Remove 3/8-16 x 1 1/2 bolt, 10.85 x 19.3 x 1.27 washer, and 19 mm spacer.
 7. Remove doser fuel from valve tube assembly with pipe clamp.

Doser Coolant Supply Tube Assembly and Doser Coolant Return Tube Assembly

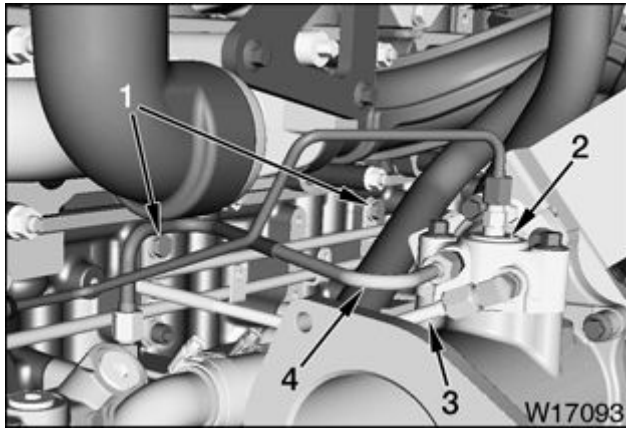


Figure 154 Doser coolant supply and return tube assemblies

1. 3/8–16 x 1 hex bolt w/washer (2)
 2. Fuel doser
 3. Doser coolant return tube assembly
 4. Doser coolant supply tube assembly
1. Loosen tube nuts at each end of doser coolant supply tube assembly and remove coolant supply tube assembly.
 2. Loosen tube nut on doser coolant return tube assembly at fuel doser.
 3. Remove two 3/8–16 x 1 hex bolts w/washers securing doser coolant return tube assembly to crankcase.

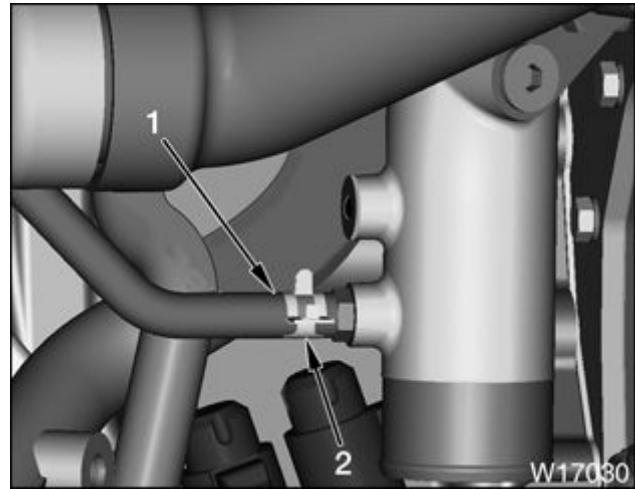
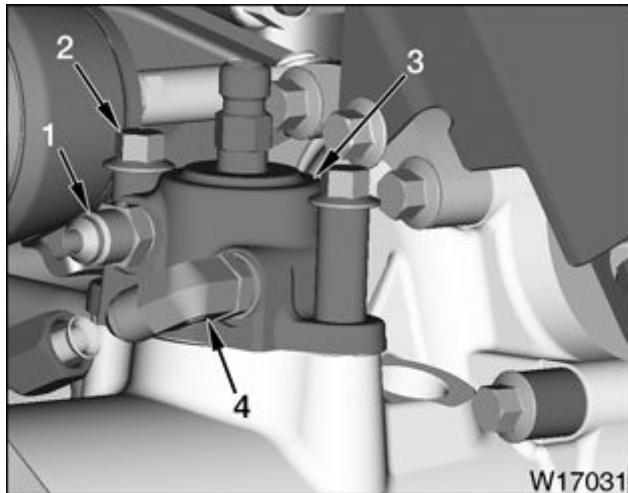
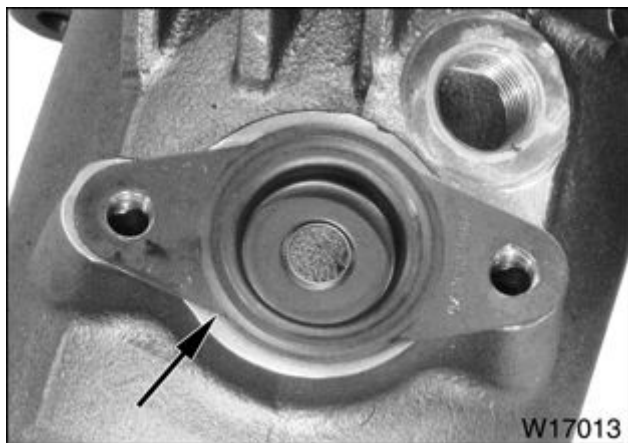


Figure 155 Doser coolant return hose

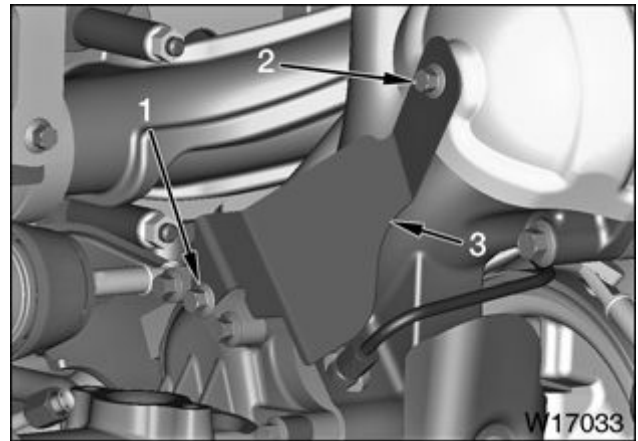
1. Doser coolant return hose
 2. 3/8 CTB clamp
4. Loosen 3/8 CTB clamp and disconnect doser coolant return hose from fitting on water pump inlet.
 5. Remove doser coolant return tube and hose. If necessary, loosen clamp and separate tube from hose.

Fuel Doser Assembly**Figure 156 Fuel doser**

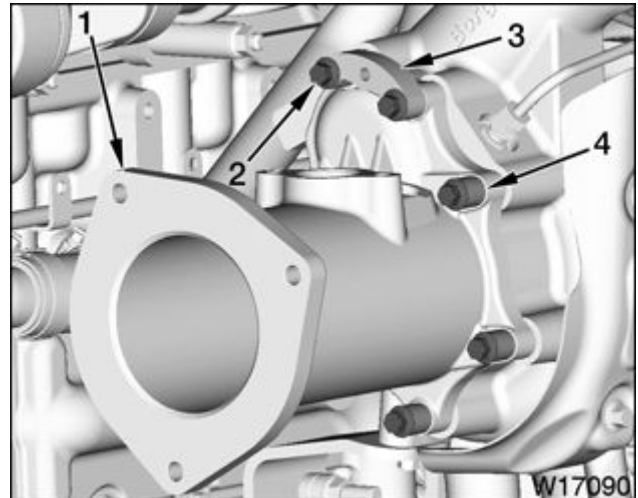
1. M10 x 5/16 tube fitting
 2. M8 x 45 hex bolt (2)
 3. Fuel doser
 4. Tube fitting (90 degree elbow)
1. If necessary, remove M10 x 5/16 tube fitting and tube fitting (90 degree elbow) from fuel doser.
 2. Remove two M8 x 45 hex bolts and discard. Remove fuel doser.

**Figure 157 HC injector gasket**

3. Remove HC injector gasket from turbocharger exhaust duct and discard.

Turbocharger Exhaust Duct**Figure 158 Heat shield**

1. M8 x 16 hex bolt
 2. M8 x 12 hex bolt
 3. Heat shield
1. Remove M8 x 16 hex bolt and M8 x 12 hex bolt. Remove heat shield.

**Figure 159 Turbocharger exhaust duct**

1. Turbocharger exhaust duct
 2. M8 x 45 hex bolt (7)
 3. Heat shield spacer
 4. 9 I.D. x 16 O.D. x 15 L spacer (5)
2. Remove seven M8 x 45 hex bolts, heat shield spacer and five 9 I.D. x 16 O.D. x 15 L spacers.

3. Remove turbocharger exhaust duct.

Inspection and Cleaning

Fuel Doser

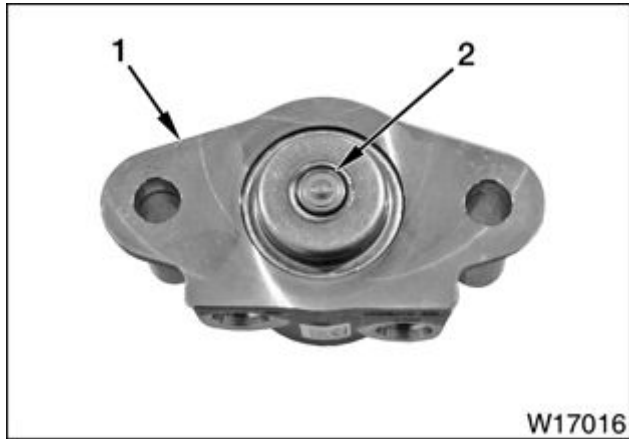


Figure 160 Fuel doser

1. Coolant housing
2. Injector nozzle tip

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

Installation

Turbocharger Exhaust Duct

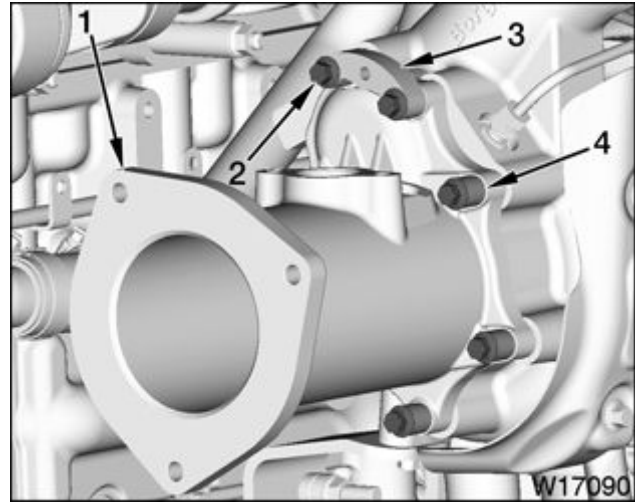


Figure 161 Turbocharger exhaust duct

1. Turbocharger exhaust duct
2. M8 x 45 bolt (7)
3. Heat shield spacer
4. 9 I.D. x 16 O.D. x 15 L spacer (5)

1. Position turbocharger exhaust duct on low-pressure turbocharger.
2. Install five M8 x 45 bolts with five 9 I.D. x 16 O.D. x 15 L spacers. Tighten bolts to standard torque (page 561).
3. Install heat shield spacer with two M8 x 45 bolts. Tighten bolts to standard torque (page 561).

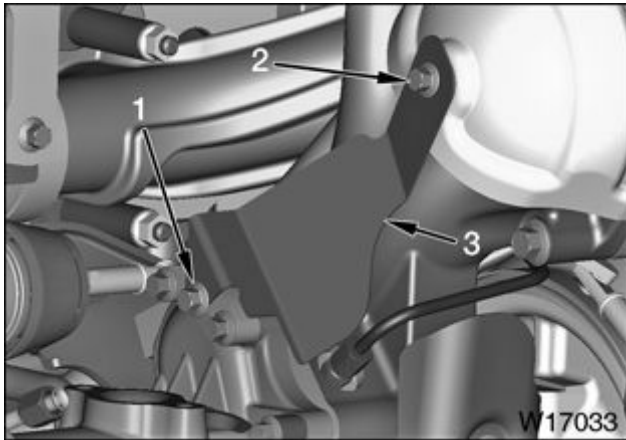


Figure 162 Heat shield

1. M8 x 16 hex bolt
 2. M8 x 12 hex bolt
 3. Heat shield
4. Install heat shield on heat shield spacer and turbocharger with M8 x 12 hex bolt and M8 x 16 hex bolt. Tighten bolts to standard torque (page 561).

Fuel Doser Assembly

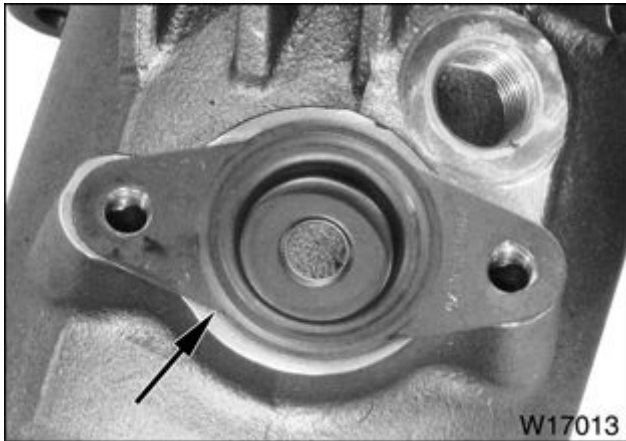


Figure 163 HC injector gasket

1. Position new HC injector gasket on turbocharger exhaust duct.

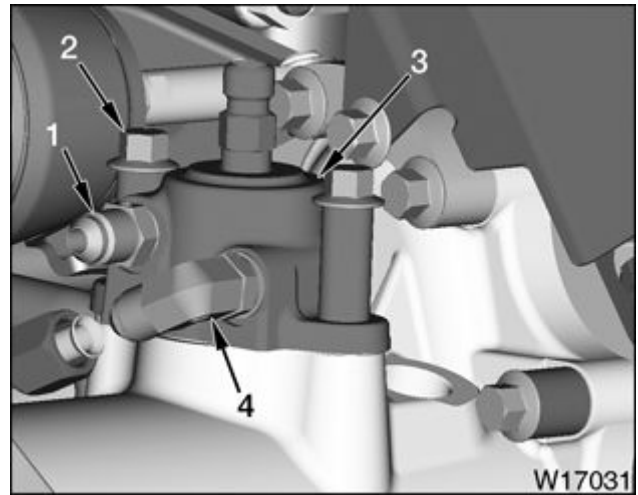


Figure 164 Fuel doser assembly

1. M10 x 5/16 tube fitting
2. M8 x 45 hex bolt (2)
3. Fuel doser
4. Tube fitting (90 degree elbow)

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

2. Install two new M8 x 45 hex bolts in two steps. Tighten both bolts first to step 1, and then both bolts to step 2 as directed in special torque (page 137).
3. If previously removed, install M10 x 5/16 tube fitting and tube fitting (90 degree elbow) into fuel doser. Tighten M10 x 5/16 tube fitting to special torque (page 137). Tighten tube fitting (90 degree elbow) finger tight. Back out tube fitting (90 degree elbow) to allow for installation of doser coolant return tube assembly. Do not tighten fitting nut at this time.

Doser Coolant Supply Tube Assembly and Doser Coolant Return Tube Assembly

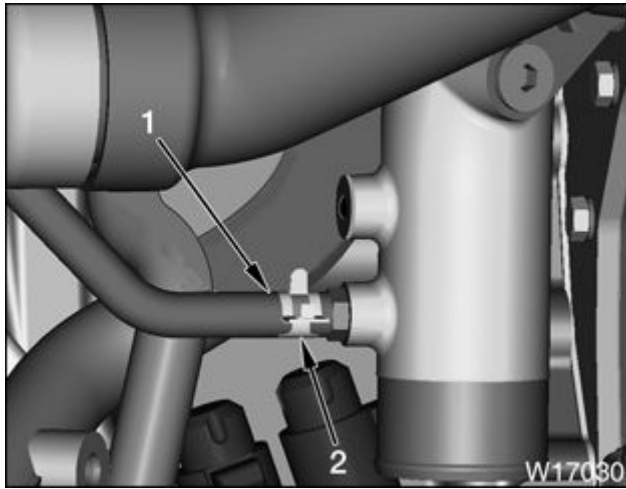


Figure 165 Doser coolant return hose

1. Doser coolant return hose
2. 3/8 CTB clamp

1. If removed, install doser coolant return hose on doser coolant return tube assembly.
2. Slide hose and tube into position on crankcase and connect hose to fitting on water pump inlet. Secure doser coolant return hose with 3/8 CTB clamp.

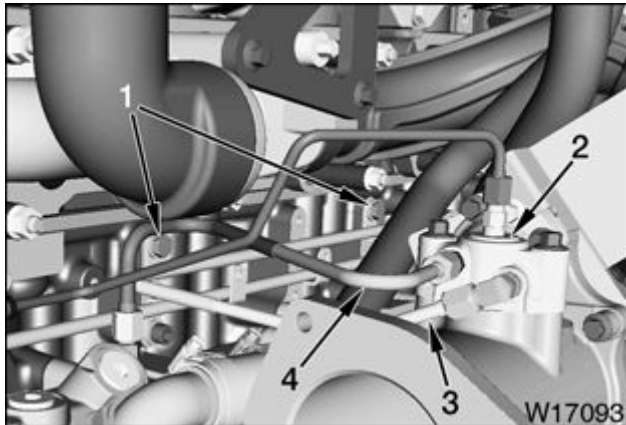


Figure 166 Doser coolant supply and return tube assemblies

1. 3/8-16 x 1 hex bolt w/washer (2)
2. Fuel doser
3. Doser coolant return tube assembly
4. Doser coolant supply tube assembly

3. Install two 3/8-16 x 1 hex bolts securing doser coolant return tube assembly to crankcase. Tighten bolts to standard torque (page 562).
4. Tighten tube nut on doser coolant return tube assembly at fuel doser to special torque (page 137). Use a backup wrench to hold 90 degree fitting and tighten jam nut to special torque (page 137).
5. Install doser coolant supply tube assembly. Tighten tube nuts to special torque (page 137).

Injector Unit Feed Tube Assembly and Doser Fuel from Valve Tube Assembly

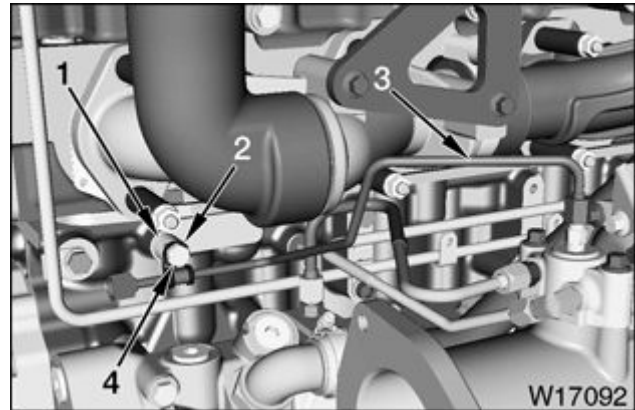


Figure 167 Doser fuel from valve tube assembly

1. 19 mm spacer
2. 10.85 x 19.3 x 1.27 washer
3. Doser fuel from valve tube assembly
4. 3/8-16 x 1 1/2 bolt
5. Fuel doser

1. Connect doser fuel from valve tube assembly to fuel doser assembly. Tighten fitting finger tight.
2. Position doser fuel from valve tube assembly on crankcase and install 3/8-16 x 1 1/2 bolt with 10.85 x 19.3 x 1.27 washer through tube clamp and 19 mm spacer. Tighten bolt to standard torque (page 562).
3. Tighten doser fuel from valve tube assembly tube nut at fuel doser to special torque (page 137).

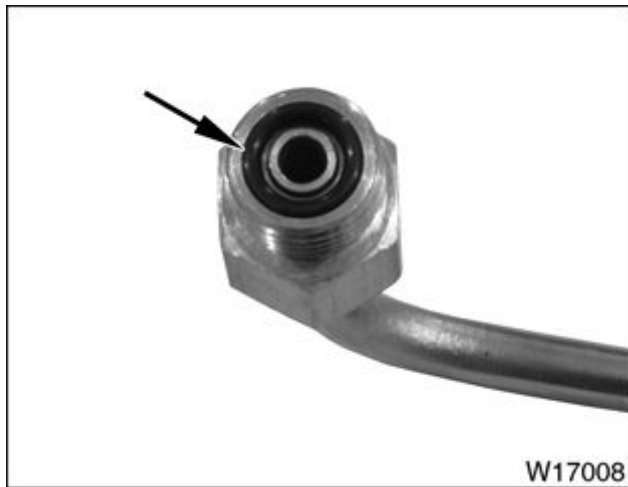


Figure 168 Injector unit feed tube assembly O-ring (size 011)

4. Install two new O-rings (size 011) in injector unit feed tube assembly.

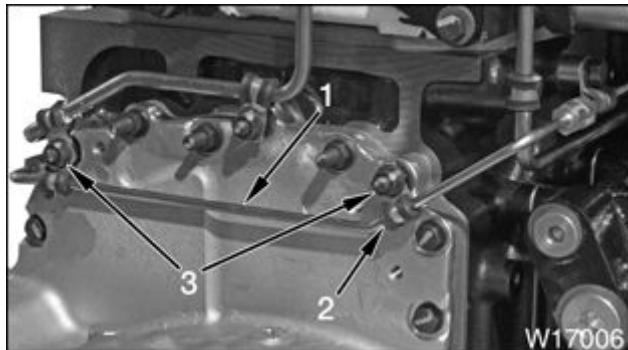


Figure 169 Injector unit feed tube assembly

1. Injector unit feed tube assembly
 2. Single cushioned pipe clamp (2)
 3. 3/8-16 nut (2)
5. Position injector unit feed tube assembly into position with single cushioned pipe clamps on flywheel housing studs. Install two 3/8-16 nuts finger tight.
 6. Connect injector unit feed tube assembly to doser fuel from valve tube assembly. Use a backup

wrench and tighten fitting to special torque (page 137).

7. Tighten 3/8-16 nuts to standard torque (page 562).

Down Stream Injection (DSI) Assembly and Doser Fuel to Injector Tube Assembly

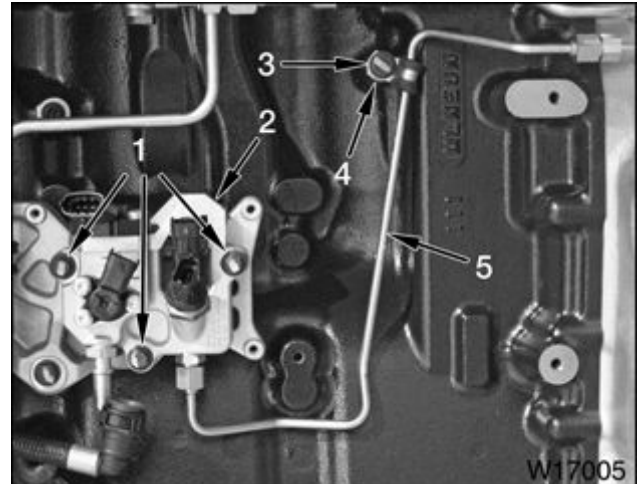


Figure 170 DSI assembly

1. M8 x 35 hex bolt (3)
 2. DSI assembly
 3. 3/8-16 x 1 1/2 bolt
 4. 19 mm spacer (under clamp)
 5. Doser fuel to injector tube assembly
1. Position DSI assembly on low-pressure fuel system support. Install three M8 x 35 hex bolts and tighten to standard torque (page 561).
 2. Connect doser fuel to injector tube assembly to DSI assembly and injector unit feed tube assembly. Tighten fittings finger tight.
 3. Install 19 mm spacer and single cushioned clamp to crankcase with 3/8-16 x 1 1/2 bolt. Tighten bolt to standard torque (page 562).
 4. Use a backup wrench and tighten doser fuel to injector tube assembly nuts to special torque (page 137).

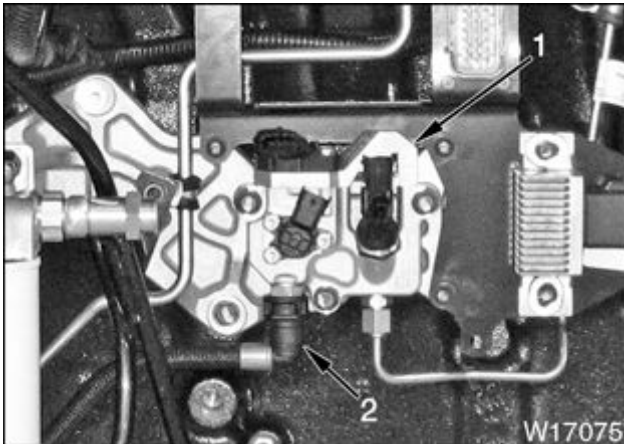


Figure 171 Fuel return tube assembly

1. DSI assembly
 2. Fuel return tube assembly
5. Push fuel return tube assembly onto fitting on DSI assembly until click is heard. Pull down on tube assembly to check for secure connection.

Pre-Diesel Oxidation Catalyst (PDOC)

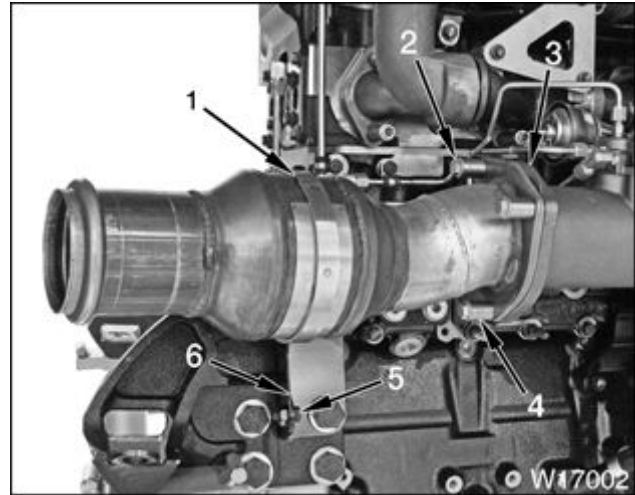


Figure 172 PDOC tube assembly

1. Clamp (PDOC)
 2. M10 x 50 bolt (3)
 3. Engine brake gasket
 4. 11 ID x 20 OD x 24L spacer (3)
 5. M10 x 20 hex bolt (3)
 6. PDOC support assembly
1. Use a new engine brake gasket and install PDOC to turbocharger outlet with three M10 x 50 bolts and three 11 ID x 20 OD x 24L spacers. Tighten bolts to standard torque (page 561).
 2. Install PDOC support assembly on PDOC base bracket. Tighten three M10 x 20 hex bolts to special torque (page 137).
 3. If removed, install clamp around PDOC support assembly and PDOC tube assembly. Tighten clamp to special torque (page 137).

Special Torque

M8 x 45 bolts (fuel doser)	Step 1: 11 N·m (8 lbf·ft)
	Step 2: 24 N·m (18 lbf·ft)
M10 x 20 hex bolts (PDOC support assembly)	62 N·m (45 lbf·ft)
M10 x 5/16 tube fitting	31 N·m (23 lbf·ft)
Clamp (PDOC)	31 N·m (23 lbf·ft)
Coolant supply tube fitting nuts	20 N·m (15 lbf·ft)
Doser coolant return tube assembly nut	20 N·m (15 lbf·ft)
Doser coolant supply tube assembly nuts	20 N·m (15 lbf·ft)
Doser fuel from valve tube nuts	24 N·m (18 lbf·ft)
Doser fuel to injector tube nuts	24 N·m (18 lbf·ft)
Injector unit feed tube fittings	20 N·m (15 lbf·ft)
Tube fitting (90 degree elbow) jam nut	20 N·m (15 lbf·ft)

Special Service Tools

Description	Tool Number
Fuel Line Disconnect Tool	ZTSE4773

Table of Contents

Exploded Views.....	141
Removal.....	145
Turbocharger Oil Drain Tube Assembly.....	145
High-Pressure (HP) Compressor Outlet Duct.....	146
Air Inlet Duct.....	146
Turbocharger to Intercooler Tube.....	147
Turbocharger Interstage Cooler (ISC) Assembly.....	148
Intercooler Support (Outer).....	150
Air Control Valve.....	150
Turbocharger Heat Shields and High-Pressure (HP) Turbocharger Wastegate Actuator.....	152
Turbocharger Oil Supply Tube Assemblies.....	153
Turbochargers.....	154
Disassembly.....	156
Turbochargers.....	156
Cleaning and Inspection.....	156
Turbochargers and Related Parts Cleaning.....	156
Turbochargers Inspection.....	156
Turbocharger Interstage Cooler Assembly (ISC) Pressure Test.....	157
Assembly.....	159
Turbochargers.....	159
Installation.....	159
Turbochargers.....	159
Turbocharger Oil Supply Tube Assemblies.....	161
Turbocharger Heat Shields and High-Pressure (HP) Turbocharger Wastegate Actuator.....	162
Air Control Valve.....	163
Intercooler Support (Outer).....	164
Turbocharger Interstage Cooler (ISC) Assembly.....	164
Turbocharger to Intercooler Tube.....	167
Air Inlet Duct.....	168
High-Pressure (HP) Compressor Outlet Duct.....	168
Turbocharger Oil Drain Tube Assembly.....	169
Special Torque.....	170
Special Service Tools.....	170

Exploded Views

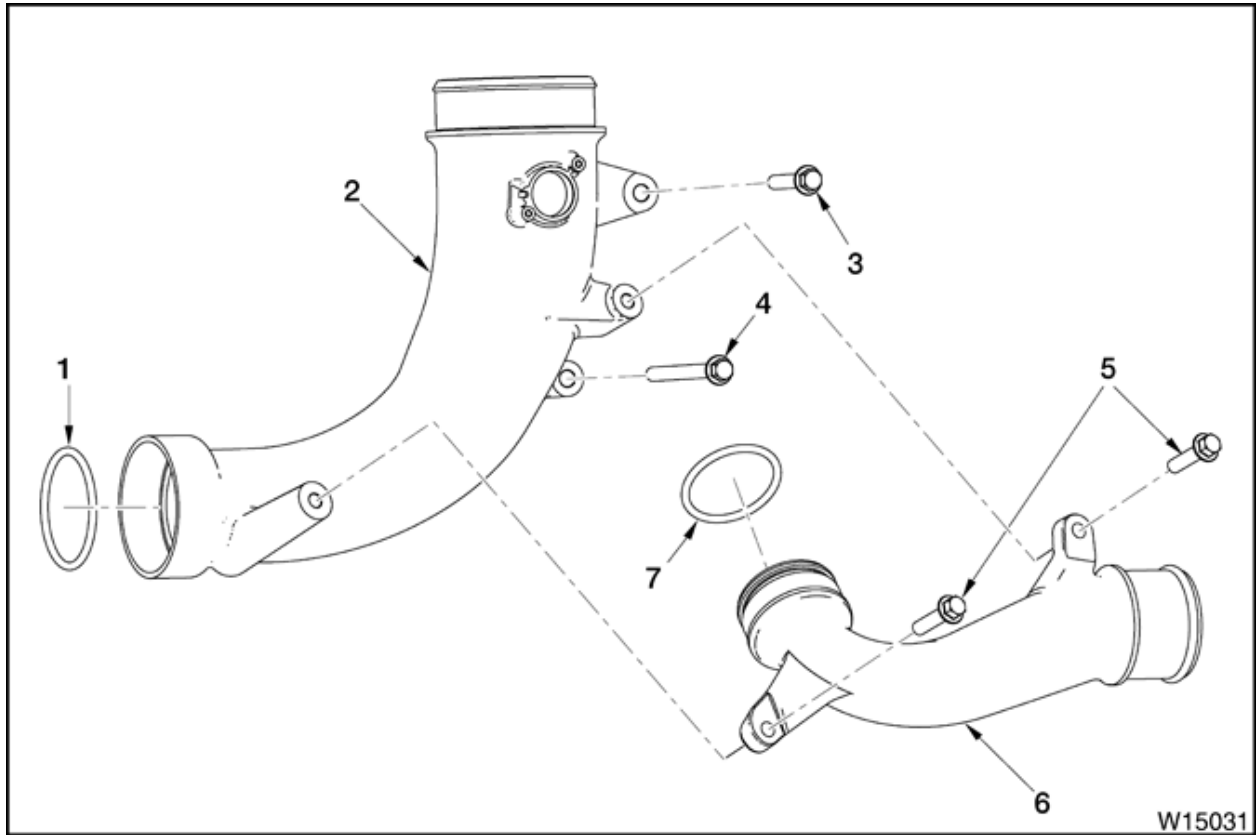
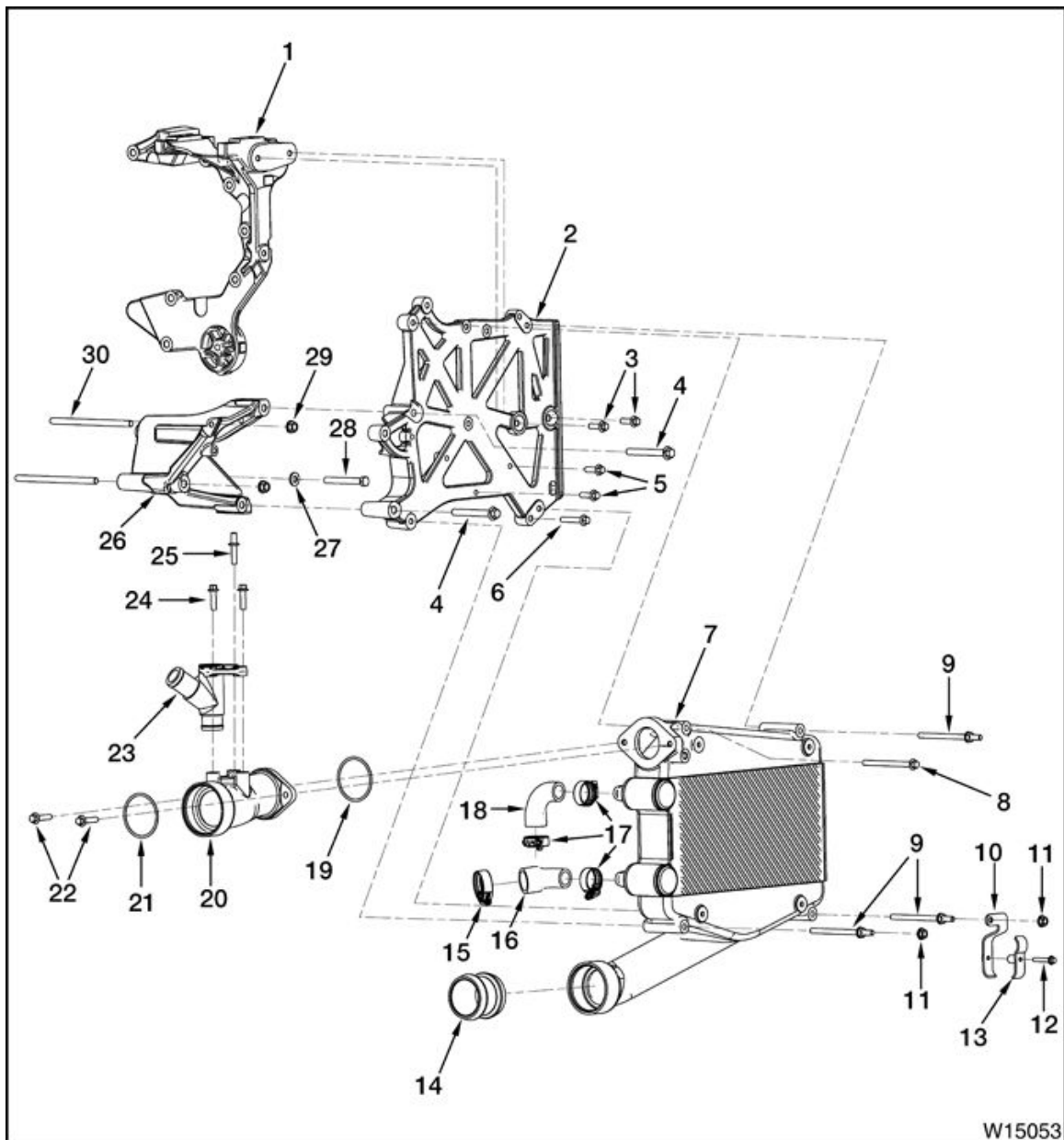


Figure 173 Turbocharger ducts

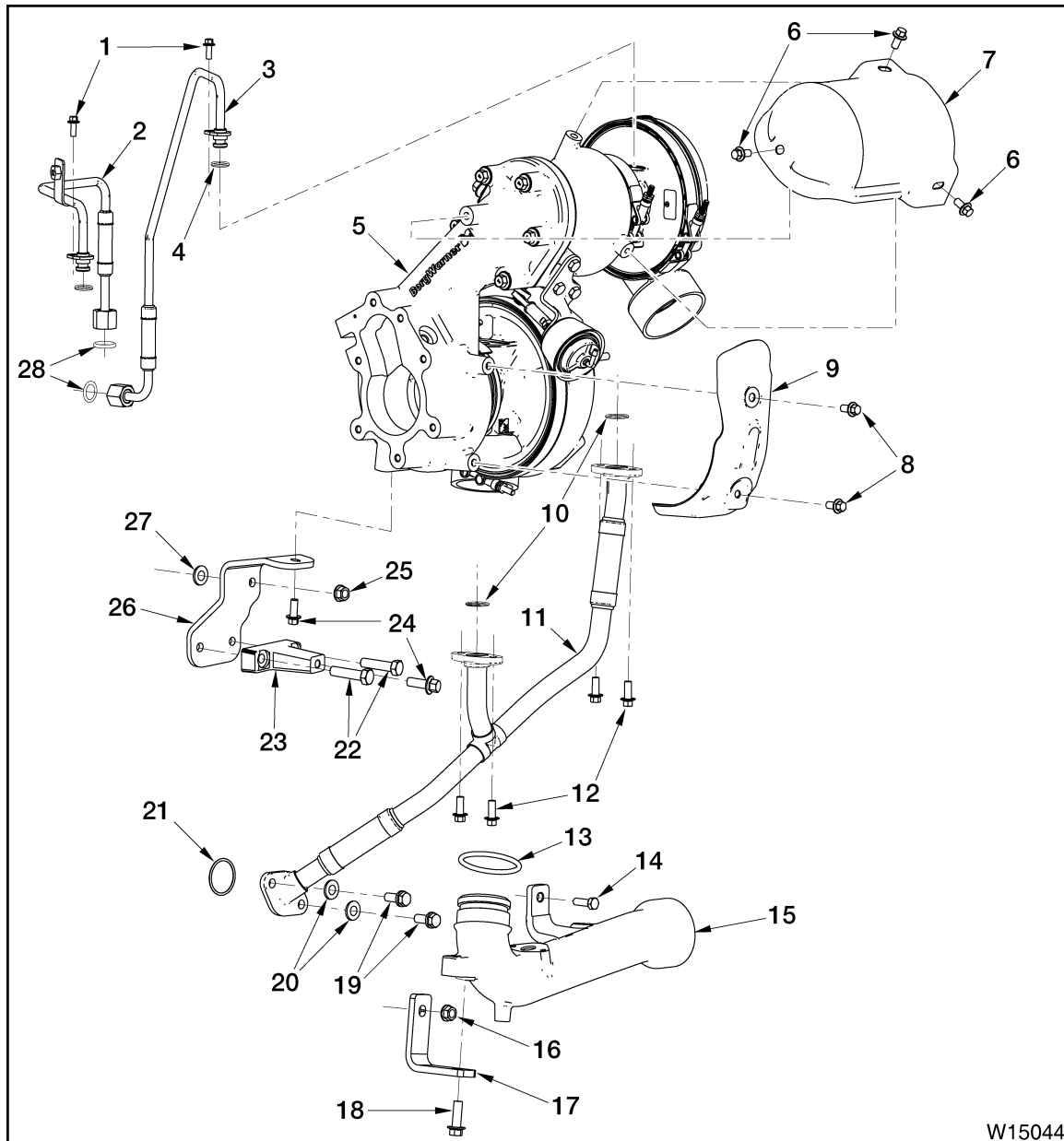
1. O-ring (size 337)	4. M10 x 110 hex flange bolt	7. O-ring (size 333)
2. Air inlet duct	5. M10 x 40 hex flange bolt (2)	
3. M10 x 55 hex flange bolt	6. HP compressor outlet duct	



W15053

Figure 174 Interstage Cooler (ISC)

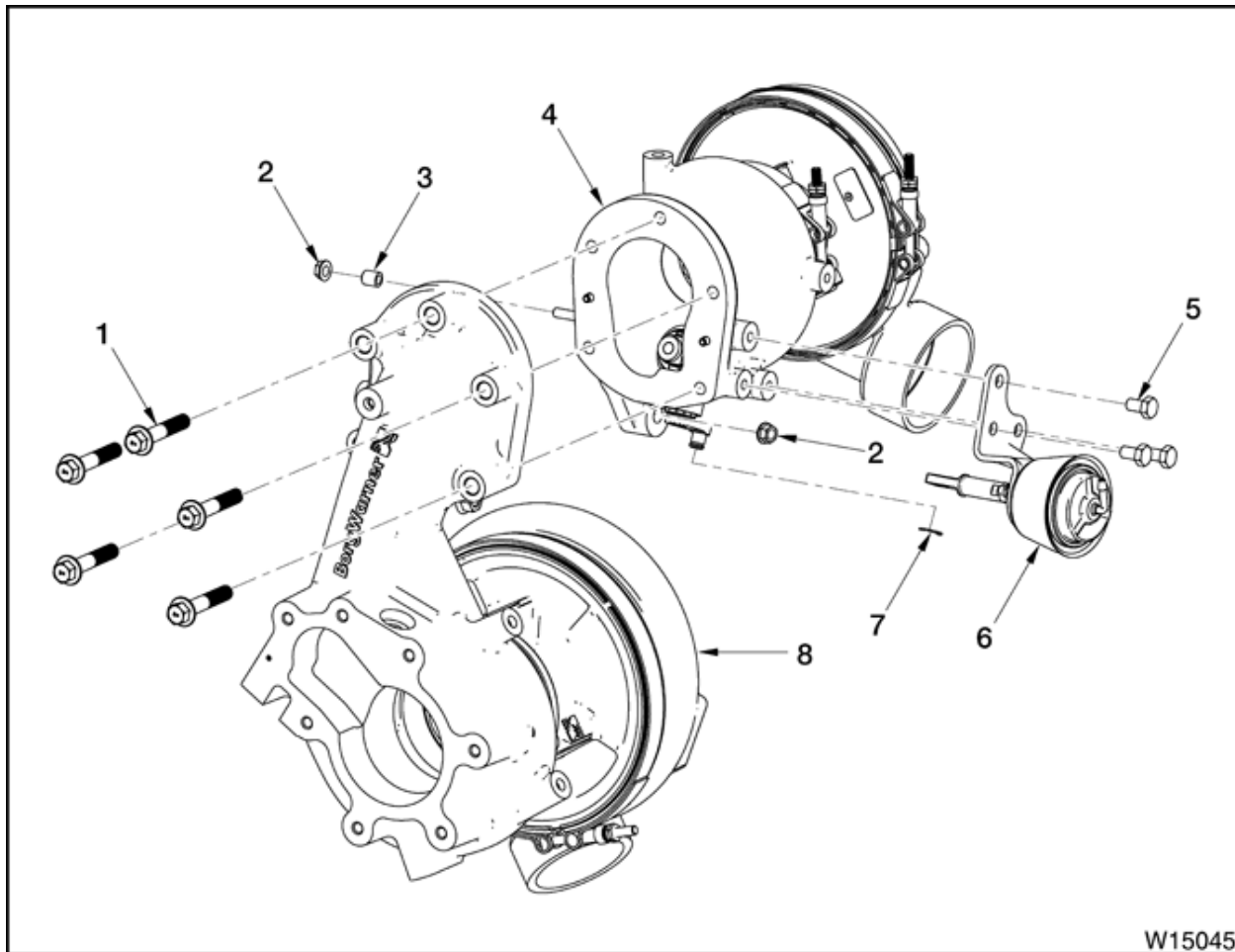
1. A/C (Freon) compressor support	11. M8 hex flange nut (2)	22. M8 x 35 hex flange bolt (2)
2. Intercooler support (outer)	12. M6 x 35 hex flange bolt	23. Heater core return adapter
3. M8 x 25 hex flange bolt (2)	13. EGR tube clamp	24. M8 x 30 hex flange bolt (2)
4. M10 x 80 hex flange bolt (2)	14. 72.2 x 60 tube seal	25. M8 x 30 stud bolt
5. M8 x 30 hex flange bolt (2)	15. SAE 24 clamp	26. Intercooler support (inner)
6. M8 x 45 hex flange bolt	16. LPCAC coolant return hose	27. 3/8 hardened washer
7. Turbocharger Interstage Cooler (ISC) assembly	17. SAE 6 clamp (3)	28. 3/8-16 x 3 hex bolt
8. M8 x 100 hex flange bolt	18. HP CAC supply and return hose	29. 3/8-16 hex flange nut (2)
9. M8 x 100 stud bolt (3)	19. 2-230 3.53 x 63.09 O-ring	30. 3/8 x 6 1/2 taperlock stud (2)
10. EGR tube support assembly	20. ISC outlet tube	
	21. O-ring (size 333)	



W15044

Figure 175 Turbocharger assembly

1. M6 x 16 hex flange bolt (2)	10. O-ring (118) (2)	20. 10.2 x 18.5 hardened washer (2)
2. LP turbocharger oil supply hose assembly	11. Turbocharger oil drain tube	21. O-ring (#128)
3. HP turbocharger oil supply hose assembly	12. M8 x 20 hex flange bolt (4)	22. 3/8-16 x 1 1/2 hex bolt (2)
4. O-ring (205) (2)	13. O-ring (size 329)	23. EGR coolant tube spacer
5. LP turbocharger assembly	14. 5/16-18 x 1 hex bolt	24. M8 x 20 hex flange bolt (2)
6. M8 x 16 hex flange bolt (3)	15. Turbocharger to intercooler tube	25. 3/8-16 hex flange nut
7. HP turbocharger heat shield	16. 3/8-16 hex flange nut	26. Turbocharger upper support
8. M8 x 16 hex flange bolt (2)	17. Turbocharger to intercooler tube support	27. 10.2 x 18.5 hardened washer
9. Turbocharger heat shield	18. M10 x 30 hex flange bolt	28. O-ring
	19. 3/8-16 x 1 hex bolt (2)	



W15045

Figure 176 High-pressure and low-pressure turbochargers

1. M10 x 55 hex flange bolt (5)	5. M8 x 14 HD hex bolt (3)	8. Low-pressure (LP) turbocharger assembly
2. M10 hex flange nut (3)	6. High-pressure (HP) turbocharger wastegate actuator	
3. 10.2 x 20.0 x 15.0 sleeve (2)	7. E clip (2)	
4. High-pressure (HP) turbocharger assembly		

Removal



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

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

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

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

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

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

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

- Engine Electrical
- Aftertreatment System

Turbocharger Oil Drain Tube Assembly

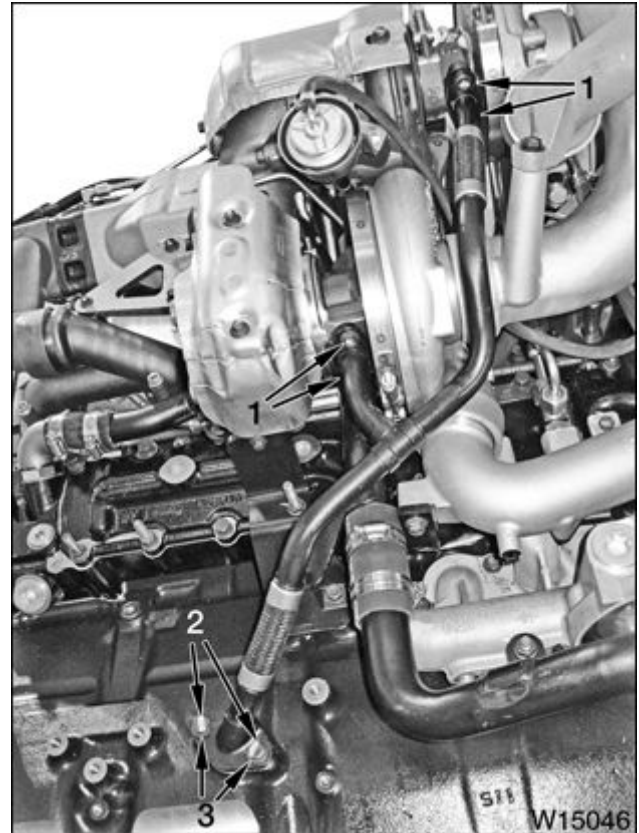
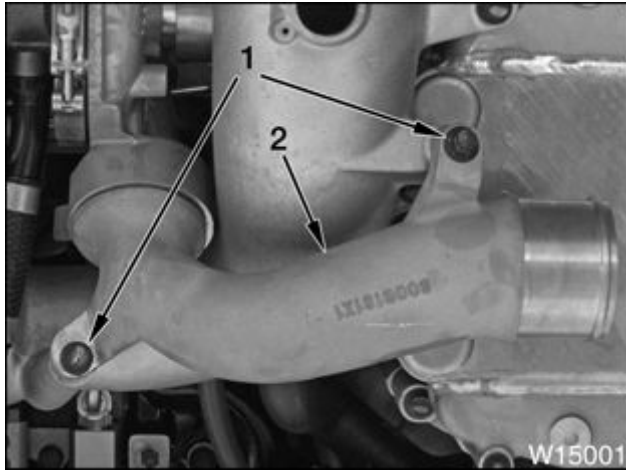


Figure 177 Turbocharger oil drain tube assembly

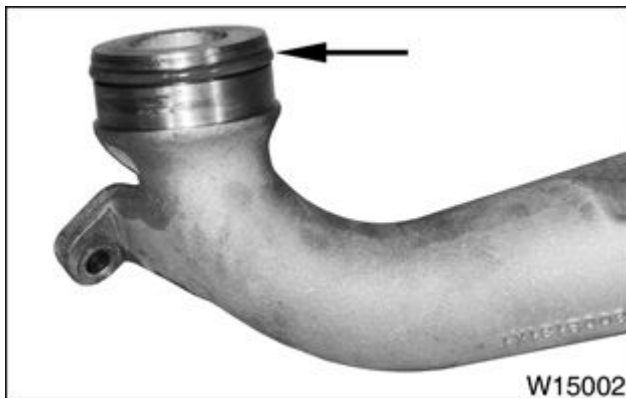
1. M8 x 20 bolt (4)
2. 3/8-16 x 7/8 bolt (2)
3. 10.2 x 18.5 hardened washer (2)

1. Remove four M8 x 20 bolts.
2. Remove two 3/8-16 x 7/8 bolts with washers and remove turbocharger oil drain tube assembly. Remove and discard O-rings (Figure 175) items 10 and 21.

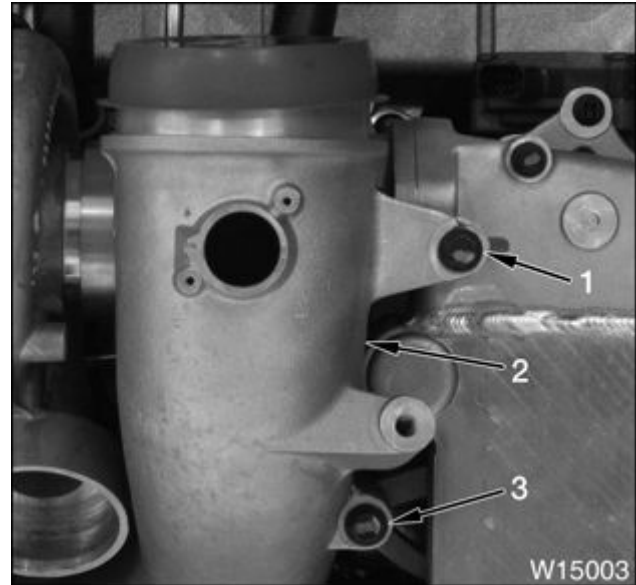
High-Pressure (HP) Compressor Outlet Duct**Figure 178 HP compressor outlet duct**

1. M10 x 40 bolt (2)
2. HP compressor outlet duct

1. Remove two M10 x 40 bolts.
2. Remove HP compressor outlet duct.

**Figure 179 HP compressor outlet duct O-ring (size 333)**

3. Remove and discard O-ring (size 333) from HP compressor outlet duct.

Air Inlet Duct**Figure 180 Air inlet duct**

1. M10 x 55 bolt
2. Air inlet duct
3. M10 x 110 bolt

1. Remove M10 x 55 and M10 x 110 bolts.
2. Remove air inlet duct from low-pressure turbocharger.

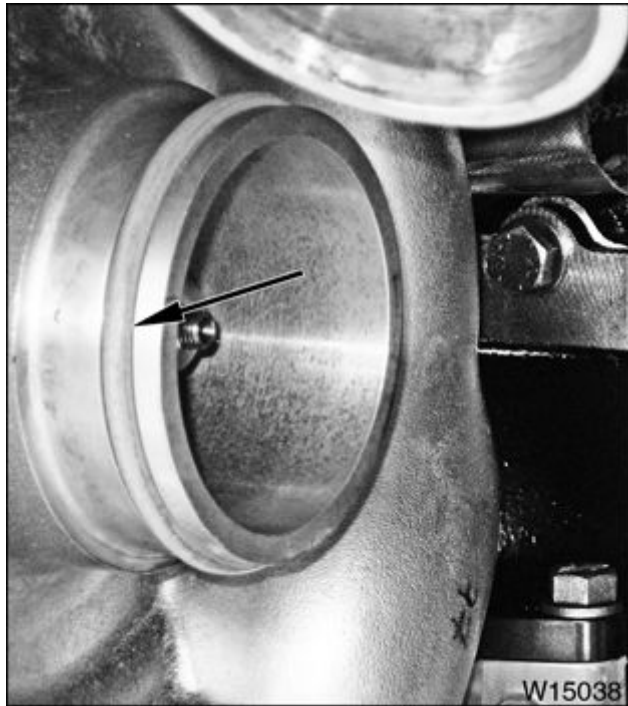


Figure 181 LP turbocharger inlet O-ring (size 337)

3. Remove and discard O-ring (size 337) from low-pressure turbocharger compressor inlet.

Turbocharger to Intercooler Tube

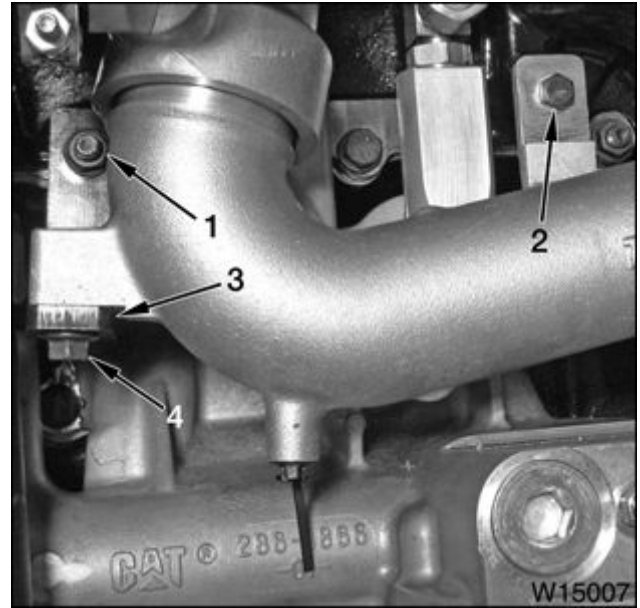


Figure 182 Turbocharger to ISC tube

1. 3/8-16 nut
 2. 5/16-18 x 1 bolt
 3. Turbocharger to intercooler tube support
 4. M10 x 30 bolt
1. Remove 3/8-16 nut, 5/16-18 x 1 bolt, and M10 x 30 bolt. Remove turbocharger to ISC tube and turbocharger to intercooler tube support.

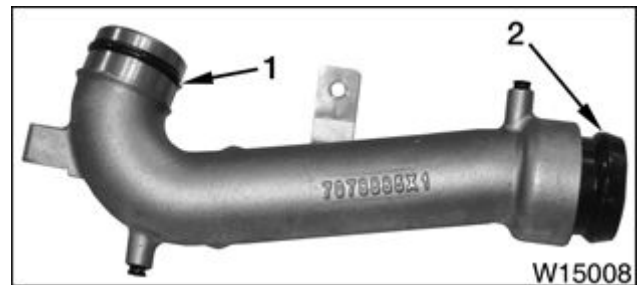
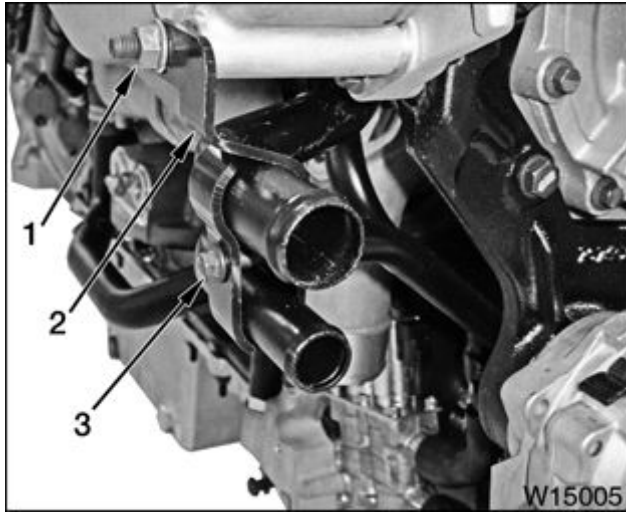


Figure 183 Turbocharger to ISC tube seals

1. O-ring (size 329)
 2. 72.2 x 60 tube seal
2. Remove and discard O-ring (size 329).
 3. Remove and discard 72.2 x 60 tube seal.

Turbocharger Interstage Cooler (ISC) Assembly**Figure 184 EGR tube support assembly**

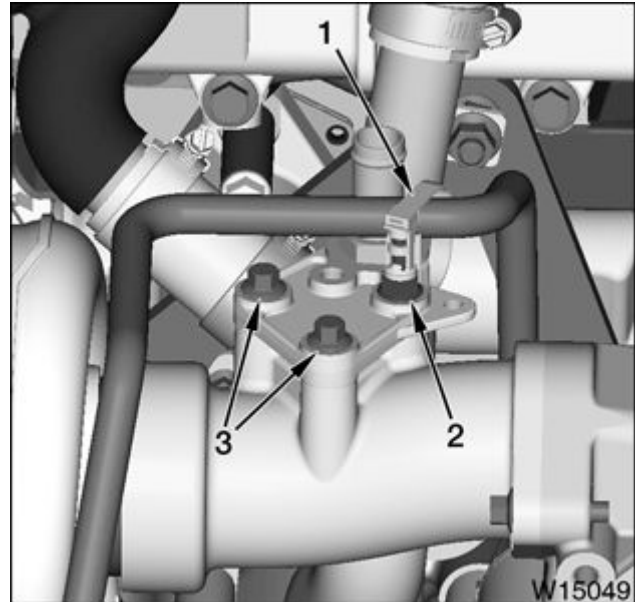
1. M8 hex flange nut
2. EGR tube support assembly
3. M6 x 35 hex flange bolt

1. Remove M6 x 35 hex flange bolt and clamp.
2. Remove M8 hex flange nut.
3. Remove EGR tube support assembly.

**Figure 185 ISC coolant hose clamps**

1. SAE 16 clamp (coolant supply)
2. SAE 16 clamp (coolant return)

4. Loosen both SAE 16 clamps on coolant supply hose and coolant return hose. Disconnect hoses from turbocharger interstage cooler assembly.

**Figure 186 Heater core return adapter**

1. Tie strap
2. M8 x 30 stud bolt
3. M8 x 30 hex flange bolt (2)
5. Remove tie strap from M8 x 30 stud bolt.
6. Remove two M8 x 30 hex flange bolts and M8 x 30 stud bolt.

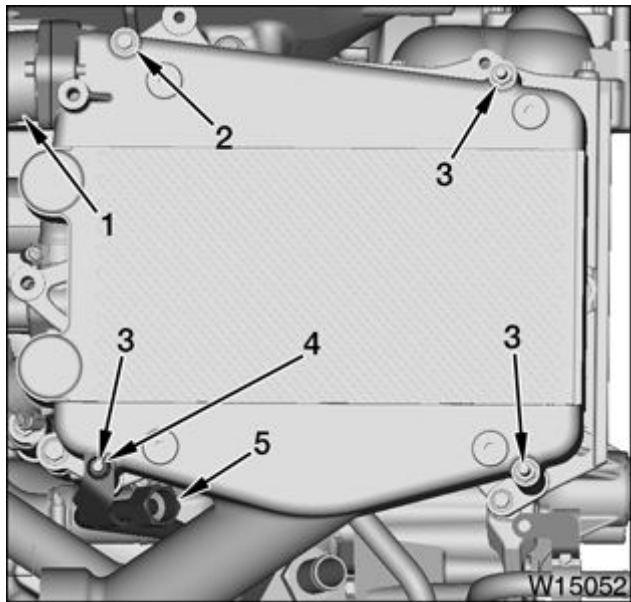


Figure 187 ISC mounting bolts

1. ISC outlet tube
 2. M8 x 100 hex flange bolt
 3. M8 x 100 x 18 stud bolt (3)
 4. M8 x 1.25 hex flange nut
 5. Oil supply tube assembly
7. Remove M8 x 1.25 hex flange nut.
 8. Remove oil supply tube assembly from M8 x 100 x 18 stud bolt.
 9. Remove three M8 x 100 x 18 stud bolts.
 10. Remove M8 x 100 hex flange bolt. Remove ISC together with ISC outlet tube.

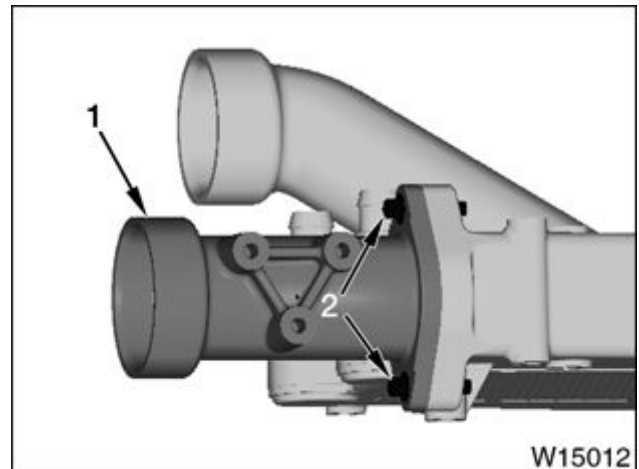


Figure 188 ISC outlet tube

1. ISC outlet tube
2. M8 x 35 hex flange bolt (2)

11. Remove two M8 x 35 hex flange bolts. Remove ISC outlet tube from ISC.

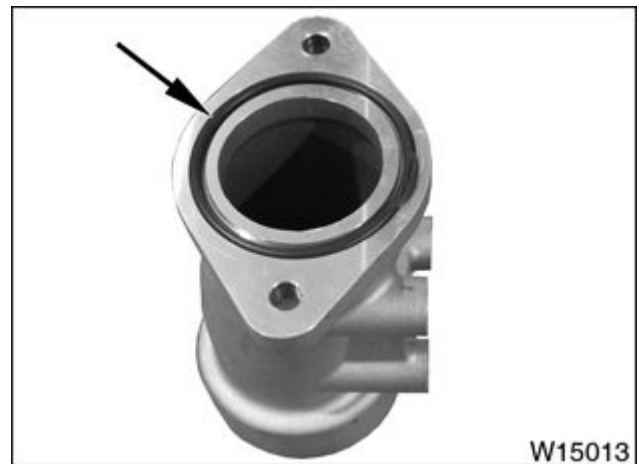


Figure 189 ISC outlet tube 2-230 3.53 x 63.09 O-ring

12. Remove and discard 2-230 3.53 x 63.09 O-ring from ISC outlet tube.

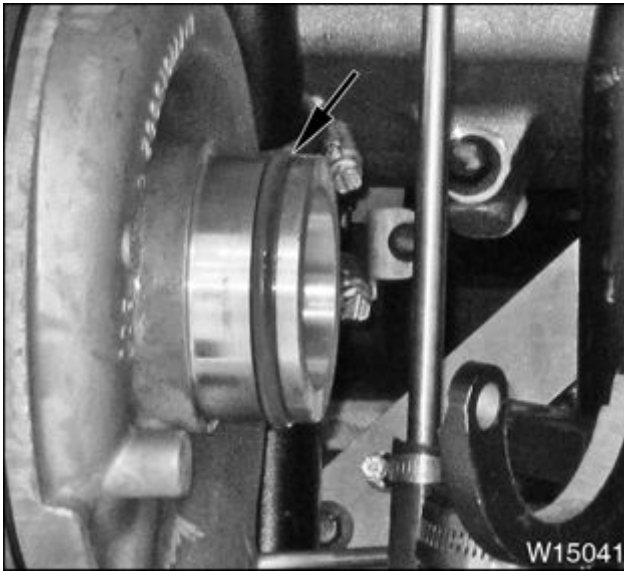


Figure 190 HP compressor O-ring (size 333)

13. Remove and discard HP compressor O-ring (size 333) from HP turbocharger.

Intercooler Support (Outer)

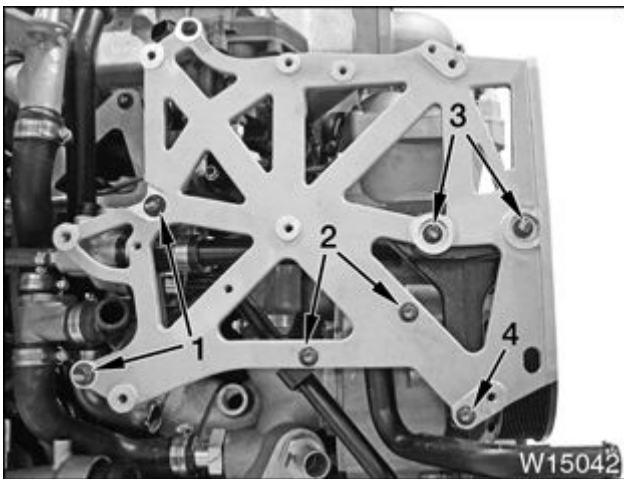


Figure 191 Intercooler support (outer)

1. M10 x 80 hex flange bolt (2)
2. M8 x 30 hex flange bolt (2)
3. M8 x 25 hex flange bolt (2)
4. M8 x 45 hex flange bolt

1. Remove two M8 x 30 hex flange bolts.
2. Remove M8 x 45 hex flange bolt, two M8 x 25 hex flange bolts, and two M10 x 80 hex flange bolts.
3. Remove intercooler support (outer).

Air Control Valve

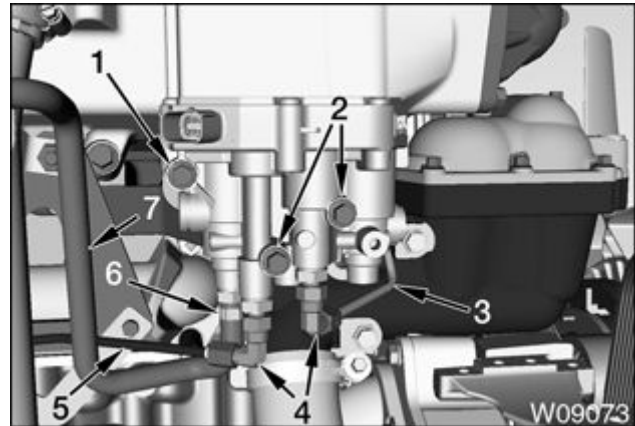


Figure 192 Air control valve

1. M8 x 65 bolt
 2. M8 x 80 bolt (2)
 3. Air supply tube assembly
 4. 90 degree flare fitting (2)
 5. Exhaust Back Pressure (EBP) tube assembly
 6. 12.3 x 7 crimp clamp
 7. High-Pressure (HP) turbocharger wastegate actuator hose
1. Disconnect EBP tube assembly from 90 degree flare fitting.
 2. Disconnect air supply tube assembly from 90 degree flare fitting.
 3. Cut 12.3 x 7 crimp clamp and disconnect HP turbocharger wastegate actuator hose from air control valve.
 4. Remove two M8 x 80 bolts and one M8 x 65 bolt. Remove air control valve.

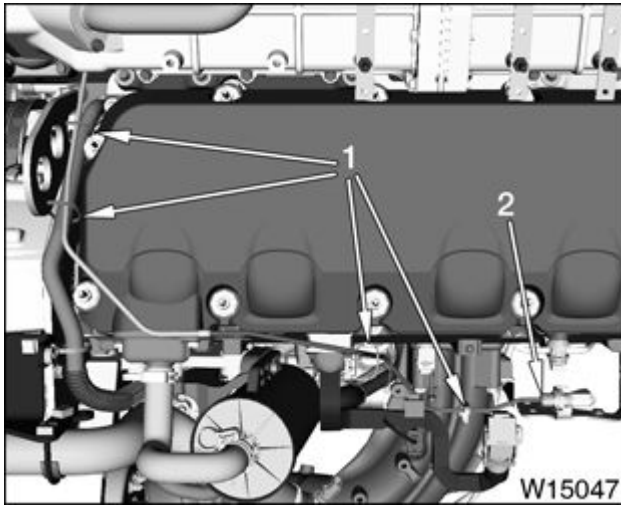


Figure 193 Air control valve air supply tube

1. Tie strap
2. Yellow collar

5. Cut four tie straps.
6. Press in yellow collar and remove air control valve air supply tube.

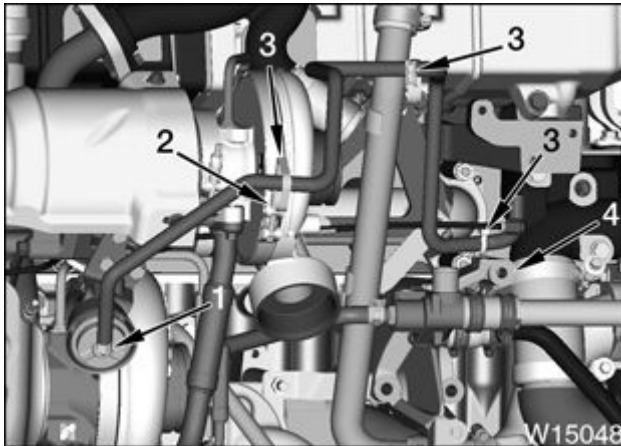


Figure 194 HP turbocharger wastegate actuator hose

1. 12.3 x 7 crimp clamp
2. V-band clamp
3. Tie strap
4. Intercooler support (inner)

7. Cut 12.3 x 7 crimp clamp from high-pressure turbocharger actuator hose.
8. Remove tie straps from V-band clamp and intercooler support.
9. Note the routing and remove wastegate actuator hose from actuator.

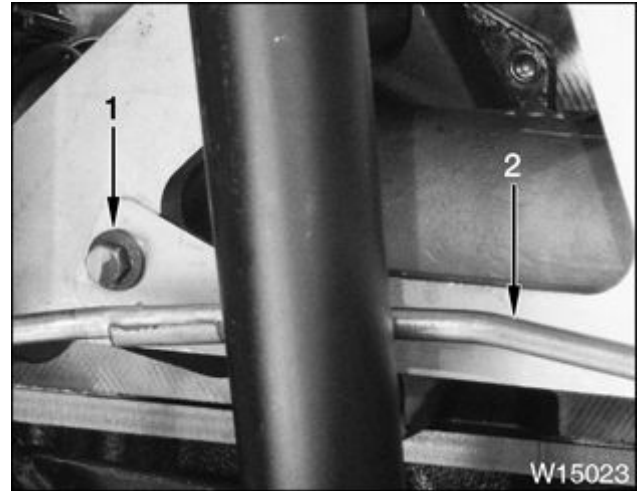


Figure 195 Exhaust Back Pressure (EBP) tube assembly

1. M6 x 12 bolt
2. EBP tube assembly

NOTE: The low pressure turbocharger oil supply tube assembly and EBP tube assembly will be removed with the turbochargers.

10. Remove M6 x 12 bolt holding EBP tube assembly to front EGR cooler support.

Turbocharger Heat Shields and High-Pressure (HP) Turbocharger Wastegate Actuator

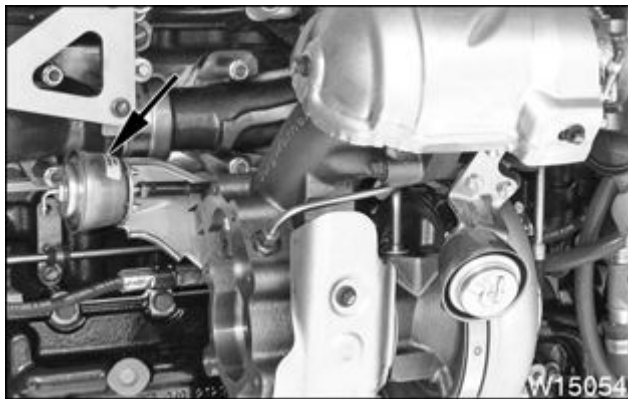


Figure 196 Low-pressure turbocharger wastegate actuator

NOTE: Early production engines were produced with a low-pressure turbocharger wastegate actuator. This actuator is non-functional, and does not need to be connected.



Figure 197 Turbocharger heat shields

1. M8 x 16 hex flange bolt (3) (high-pressure turbocharger)
2. M8 x 16 hex flange bolt (2) (low-pressure turbocharger)

1. Remove three M8 x 16 hex flange bolts. Remove heat shield from high-pressure turbocharger.
2. Remove two M8 x 16 hex flange bolts. Remove heat shield from low-pressure turbocharger.



Figure 198 HP turbocharger wastegate actuator

1. E clip
2. M8 x 14 HD hex bolt (3)
3. Remove the E clip.
4. Remove three M8 x 14 HD hex bolts from HP turbocharger wastegate actuator. Remove HP turbocharger wastegate actuator.

Turbocharger Oil Supply Tube Assemblies

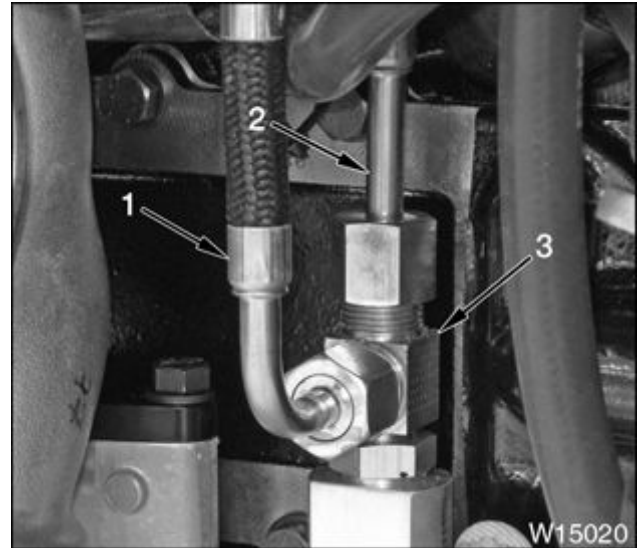


Figure 199 Turbocharger oil supply tubes at oil filter housing

1. High-pressure oil supply tube assembly
2. Low-pressure oil supply tube assembly
3. Connector
1. Disconnect high-pressure oil supply tube assembly from connector. Remove and discard O-ring.
2. Disconnect low-pressure oil supply tube assembly from connector. Remove and discard O-ring.



Figure 200 Turbocharger oil supply tube M6 x 12 bolt at high-pressure turbocharger

NOTE: The low-pressure turbocharger oil supply tube assembly and EBP tube assembly will be removed from the turbochargers after the turbochargers are removed from the engine.

3. Remove M6 x 12 bolt and pull turbocharger oil supply tube assembly from high-pressure turbocharger.

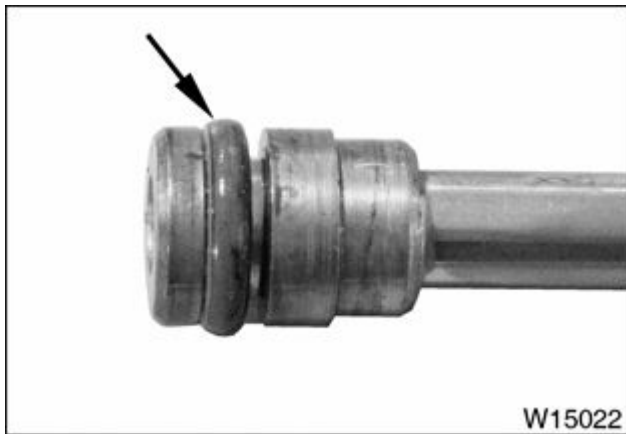


Figure 201 Turbocharger oil supply tube assembly O-ring

4. Remove and discard O-ring from high-pressure turbocharger oil supply tube assembly.

Turbochargers

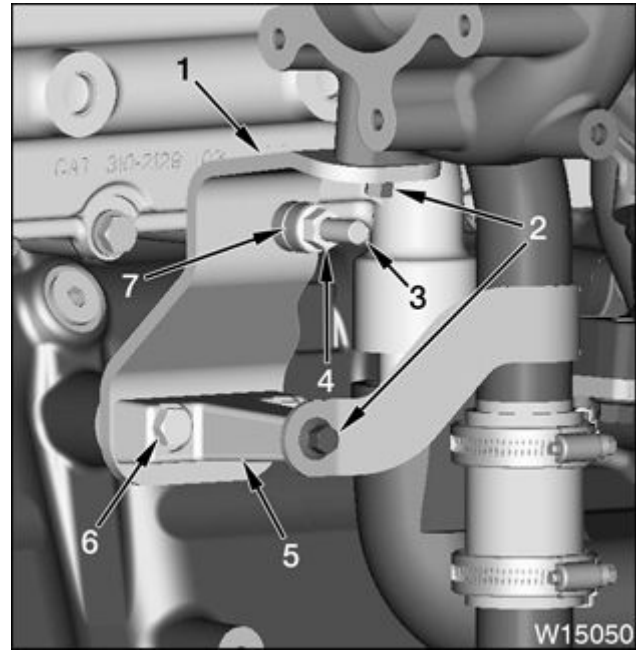


Figure 202 Turbocharger upper support

1. 10.2 x 18.5 x 2.5 hardened washer (behind support)
2. M8 x 20 hex flange bolt (2)
3. 3/8-16 x 5 1/2 stud bolt
4. 3/8-16 hex flange nut
5. EGR coolant tube spacer
6. 3/8-16 x 1 1/2 hex flange bolt (2)
7. 10.5 x 20 x 15 sleeve

1. Remove M8 x 20 hex flange bolts.
2. Remove two 3/8-16 x 1 1/2 hex flange bolts.
3. Remove EGR coolant tube spacer.
4. Remove 3/8-16 hex flange nut, 10.5 x 20 x 15 sleeve, and turbocharger upper support. Remove 10.2 x 18.5 x 2.5 hardened washer from 3/8-16 x 5 1/2 stud bolt.

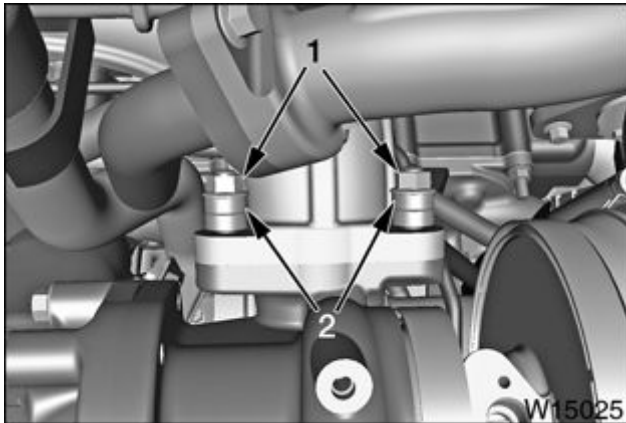


Figure 203 Turbocharger mounting (upper nuts shown)

1. M10 nut (3)
2. 10.2 x 20 x 15 sleeve (2)

NOTE: The lower M10 turbocharger mounting nut faces away from the engine.

5. Remove lower M10 nut.
6. Remove two upper M10 nuts and 10.2 x 20 x 15 sleeves.
7. Install Turbocharger Lifting Bracket (page 170) using heat shield mounting bolt bosses.
8. Remove turbochargers from exhaust manifold. Place turbochargers on clean work surface.

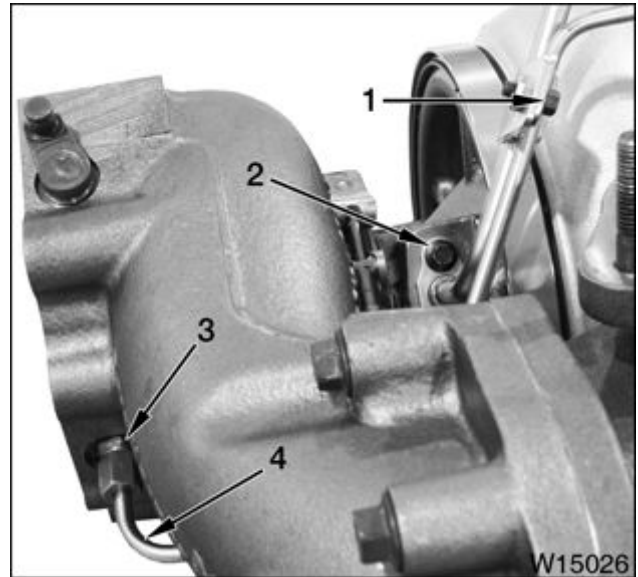


Figure 204 EBP tube assembly and low-pressure turbocharger oil supply tube assembly

1. M6 x 12 bolt (bracket)
2. M6 x 12 bolt (oil supply tube assembly)
3. M10 x M12 24 degree fitting
4. EBP tube assembly
9. Remove M6 x 12 bolt (bracket)
10. Remove M6 x 12 bolt (oil supply tube assembly) and pull low-pressure oil supply tube assembly from turbocharger. Remove and discard O-ring.
11. Loosen tube nut on EBP tube assembly and remove EBP tube.
12. If turbocharger is to be replaced or fitting is found to be leaking, remove M10 x M12 24 degree fitting.

Disassembly

Turbochargers

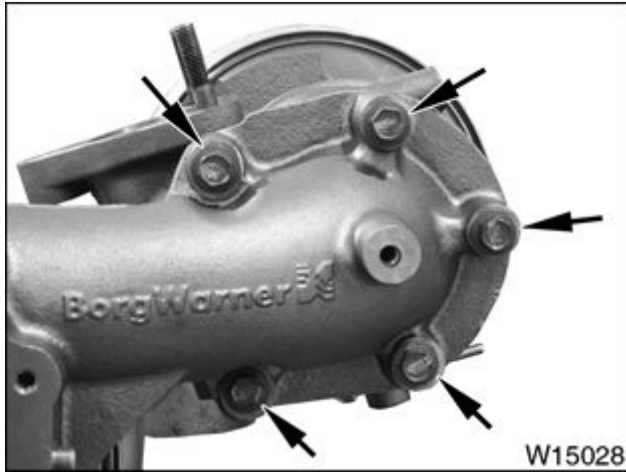


Figure 205 Low-pressure turbocharger to high-pressure turbocharger M10 x 55 hex bolts

1. If necessary, remove five M10 x 55 hex bolts.
2. Separate low-pressure turbocharger from high-pressure turbocharger.

Cleaning and Inspection

Turbochargers and Related Parts Cleaning

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

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

1. Clean piping between air intake manifold and air cleaner assembly with soap and steam clean. Dry all piping with filtered compressed air.
2. Clean Charge Air Cooler (CAC), air intake manifold, and intercooler piping with filtered compressed air.
3. Clean oil supply and oil return tubes with suitable solvent and a nylon brush. Dry tubes with filtered compressed air. Replace any damaged tubes.
4. Clean all gasket and mounting surfaces.

Turbochargers Inspection

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

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

3. Place turbochargers on a bench with the shafts in a horizontal position.

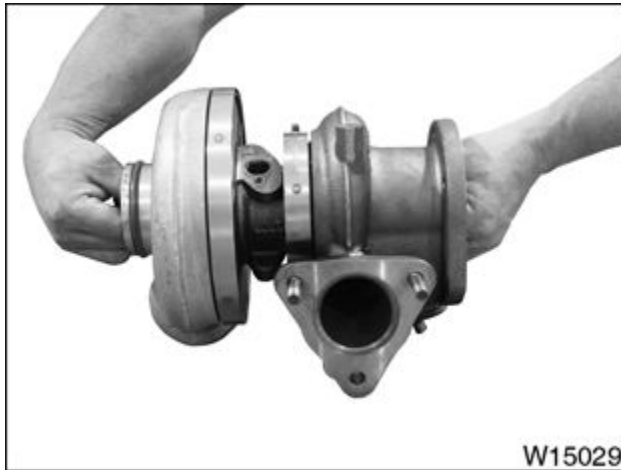


Figure 206 Free rotation of turbocharger assembly shaft (typical)

4. Turn turbine shafts by hand and check for wheel rub in each housing. The wheels must rotate freely. If there is any rubbing or interference, replace turbocharger.

Turbocharger Interstage Cooler Assembly (ISC) Pressure Test

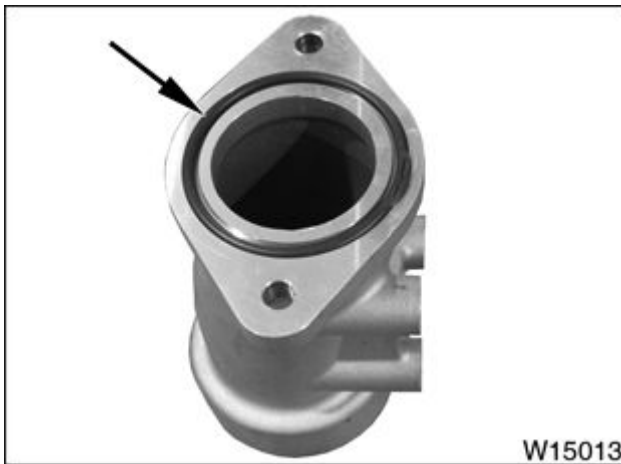


Figure 207 ISC outlet tube 2-230 3.53 x 63.09 O-ring

1. Place a new 2-230 3.53 x 63.09 O-ring in groove on ISC outlet tube.

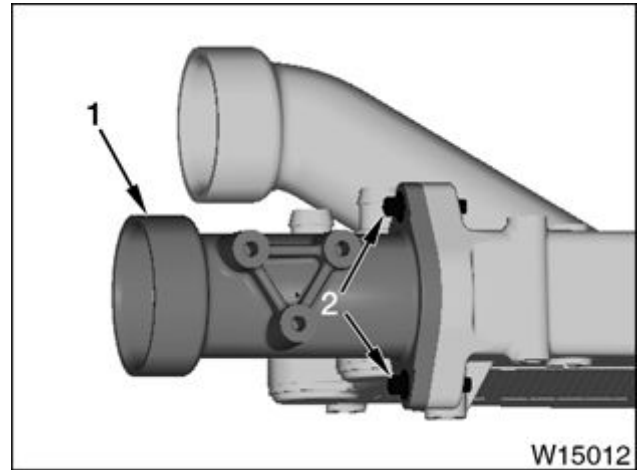


Figure 208 ISC outlet tube

1. ISC outlet tube
2. M8 x 35 hex flange bolt (2)
2. Install ISC outlet tube on ISC. Install M8 x 35 hex flange bolts. Tighten bolts to standard torque (page 561).

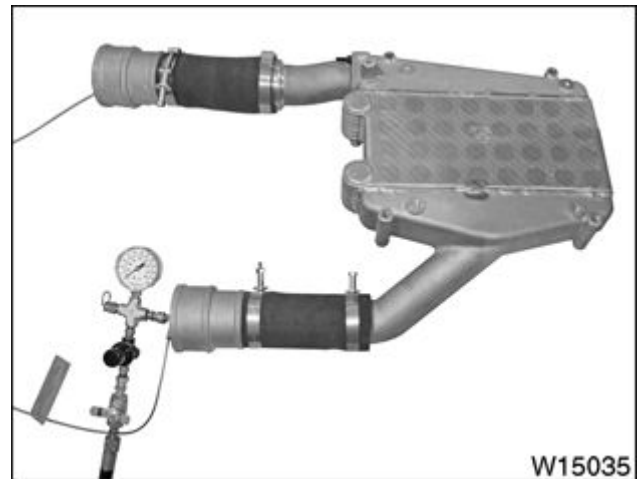


Figure 209 ISC pressure test setup

3. Attach Charge Air Cooler Tester Kit (page 170) to ISC using instructions supplied with tool and three inch couplers and clamps (obtain locally).

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

4. Pressurize ISC to 30 psi (205 kPa) and close valve on air supply line.
 5. Spray a soapy water solution on ISC, ISC outlet tube mounting flange and tester components. Verify there are no leaks from hose connections or tester components.
 6. If a leak is visually detected on ISC or tester gauge pressure drops, replace ISC.
 7. Bleed off pressure, then remove Charge Air Cooler Tester from ISC.
-

Assembly

Turbochargers

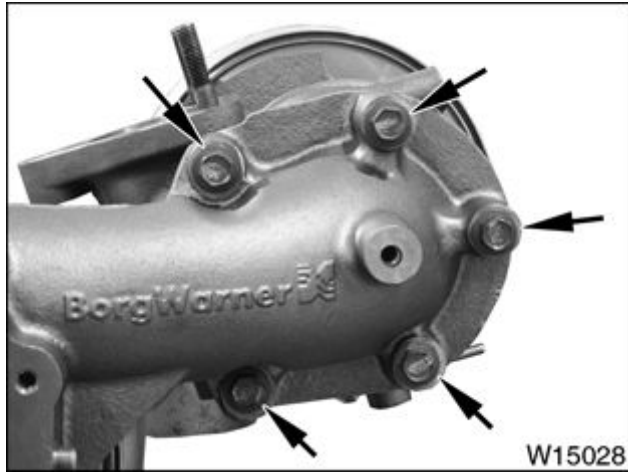


Figure 210 Low-pressure turbocharger to high-pressure turbocharger M10 x 55 hex bolts

1. Install low-pressure turbocharger on high-pressure turbocharger.

NOTE: Final tightening of the M10 x 55 hex bolts will be done after turbochargers are installed on turbocharger upper support.

2. Install five M10 x 55 hex bolts finger tight. Tighten bolts to special torque (page 170).

Installation

Turbochargers

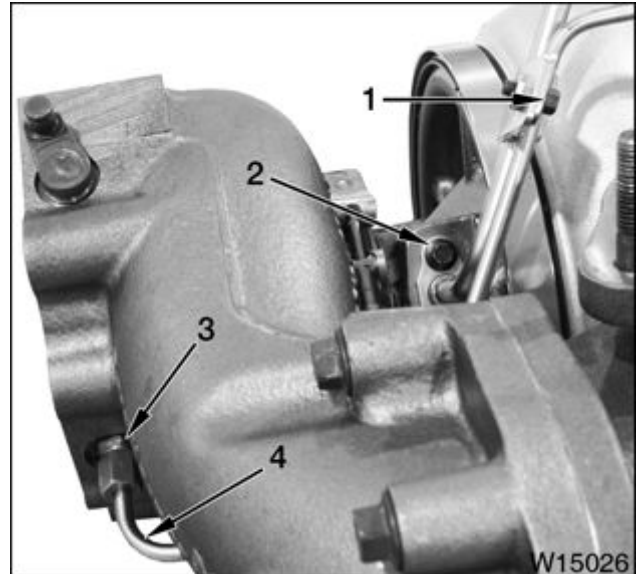


Figure 211 EBP tube assembly and low-pressure turbocharger oil supply tube assembly

1. M6 x 12 bolt (bracket)
 2. M6 x 12 bolt (oil supply tube assembly)
 3. M10 x M12 24 degree fitting
 4. EBP tube assembly
1. If removed, install M10 x M12 24 degree fitting. Tighten fitting to special torque (page 170).
 2. Install new O-ring on low pressure turbocharger oil supply tube assembly. Lubricate O-ring with clean engine oil.
 3. Install low pressure turbocharger oil supply tube assembly. Tighten M6 x 12 bolt (oil supply tube assembly) to standard torque (page 561).
 4. Install EBP tube assembly on M10 x M12 24 degree fitting. Tighten nut finger tight.
 5. Install M6 x 12 bolt (bracket). Tighten M6 x 12 bolt to standard torque (page 561).
 6. Tighten EBP tube assembly nut to special torque (page 170).

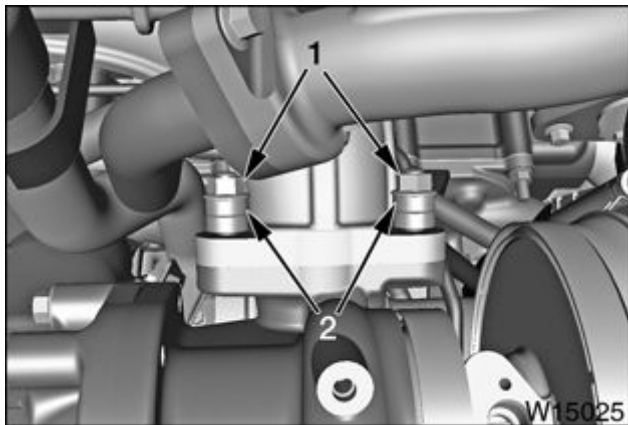


Figure 212 Turbocharger mounting (upper nuts shown)

1. M10 nut (3)
2. 10.2 x 20 x 15 sleeve (2)

NOTE: The lower M10 turbocharger mounting nut faces away from the engine. This nut does not have a sleeve behind it.

7. Install turbochargers on exhaust manifold. Install two 10.2 x 20 x 15 sleeves and three M10 nuts. Tighten nuts to standard torque (page 561).
8. Remove Turbocharger Lifting Bracket.

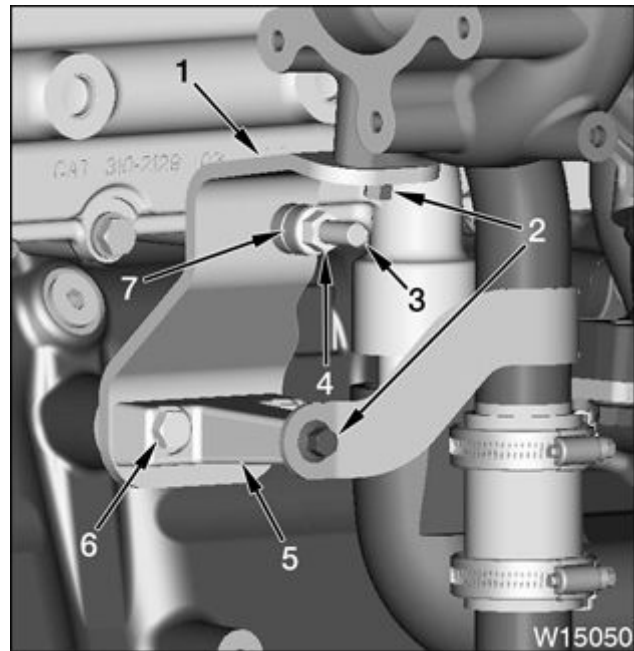


Figure 213 Turbocharger upper support

1. 10.2 x 18.5 x 2.5 hardened washer (behind support)
2. M8 x 20 hex flange bolt (2)
3. 3/8–16 x 5 1/2 stud bolt
4. 3/8–16 hex flange nut
5. EGR coolant tube spacer
6. 3/8–16 x 1 1/2 hex flange bolt (2)
7. 10.5 x 20 x 15 sleeve
9. Place 10.2 x 18.5 x 2.5 hardened washer on 3/8–16 x 5 1/2 stud bolt.
10. Position turbocharger upper support over 3/8–16 x 5 1/2 stud.
11. Install 10.5 x 20 x 15 sleeve and 3/8–16 hex flange nut. Tighten nut hand tight.
12. Install EGR coolant tube spacer with two 3/8–16 x 1 1/2 hex flange bolts. Tighten bolts and 3/8–16 nut to standard torque (page 562).
13. Install both M8 x 20 hex flange bolts. Low-pressure turbocharger may need to be moved slightly to align hole at bottom of turbocharger with hole in turbocharger upper support. Tighten bolts to standard torque (page 561).
14. If necessary, tighten five M10 x 55 bolts (Figure 210) to special torque (page 170).

Turbocharger Oil Supply Tube Assemblies

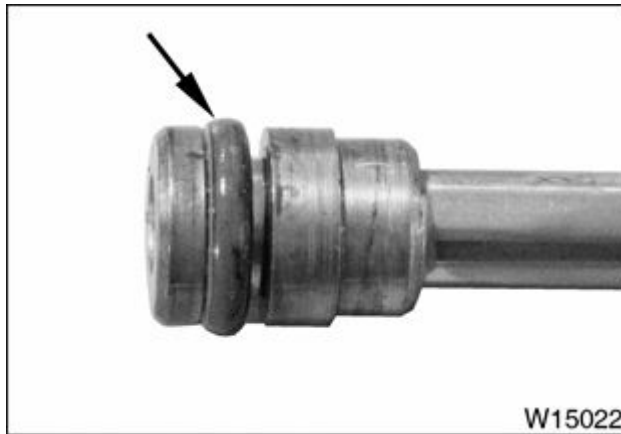


Figure 214 Turbocharger oil supply tube assembly O-ring

1. Install a new O-ring on high-pressure turbocharger oil supply tube assembly. Lubricate O-ring with clean engine oil.



Figure 215 Turbocharger oil supply tube M6 x 12 bolt at high-pressure turbocharger

2. Install high-pressure turbocharger oil supply tube assembly in turbocharger. Tighten M6 x 12 bolt to standard torque (page 561).

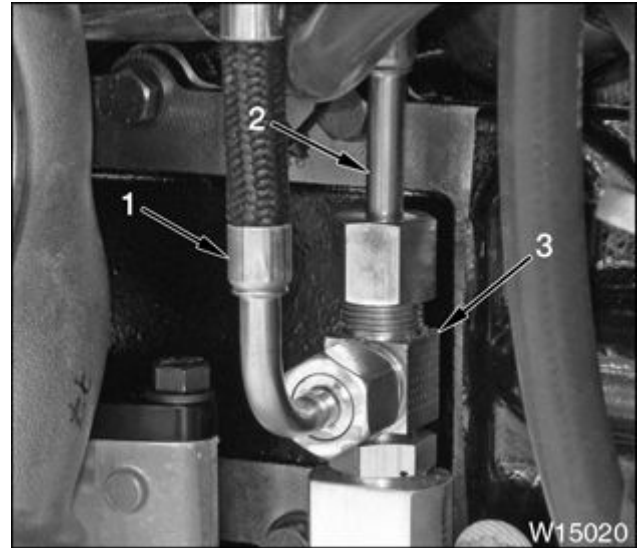


Figure 216 Turbocharger oil supply tubes at oil filter housing

1. High-pressure oil supply tube assembly
2. Low-pressure oil supply tube assembly
3. Connector

NOTE: Connector may need to be clocked for connection of high-pressure oil supply tube assembly.

3. Lubricate new O-rings, (Figure 175) item 28, with clean engine oil. Install O-rings on the connector.
4. Connect high-pressure oil supply tube assembly to connector.
5. Connect low-pressure oil supply tube assembly to connector.
6. Tighten oil supply tube nuts to special torque (page 170).

Turbocharger Heat Shields and High-Pressure (HP) Turbocharger Wastegate Actuator

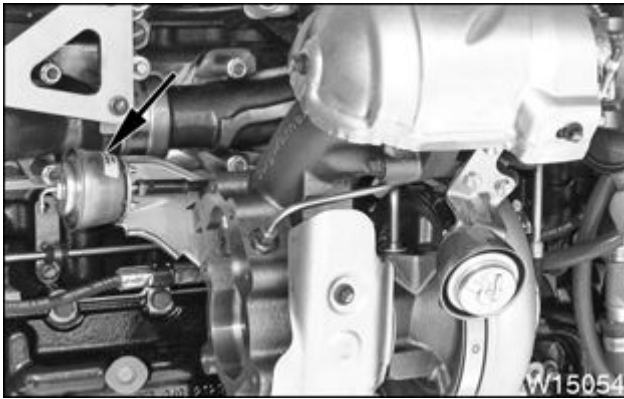


Figure 217 Low-pressure turbocharger wastegate actuator

NOTE: Early production engines were produced with a low-pressure turbocharger wastegate actuator. This actuator is non-functional, and does not need to be connected.

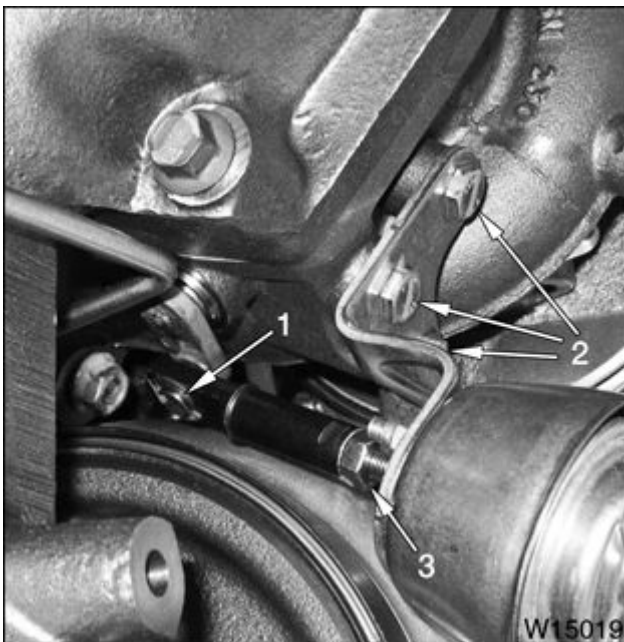


Figure 218 HP turbocharger wastegate actuator

1. E clip
2. M8 x 14 HD hex bolt (3)
3. Pushrod jam nut

1. Install HP turbocharger wastegate actuator on HP turbocharger with M8 x 14 bolts. Tighten bolts to standard torque (page 561).
2. Install E clip to secure actuator rod to pin on wastegate lever.

NOTE: Check wastegate actuator linkage movement using a hand pump or shop air regulated to no more than 345 kPa (50 psi).

3. Attach air source to wastegate actuator and operate actuator through full range and check for free movement. There should be smooth operation without binding. If operation is not smooth, loosen pushrod jam nut and retighten. Recheck movement.

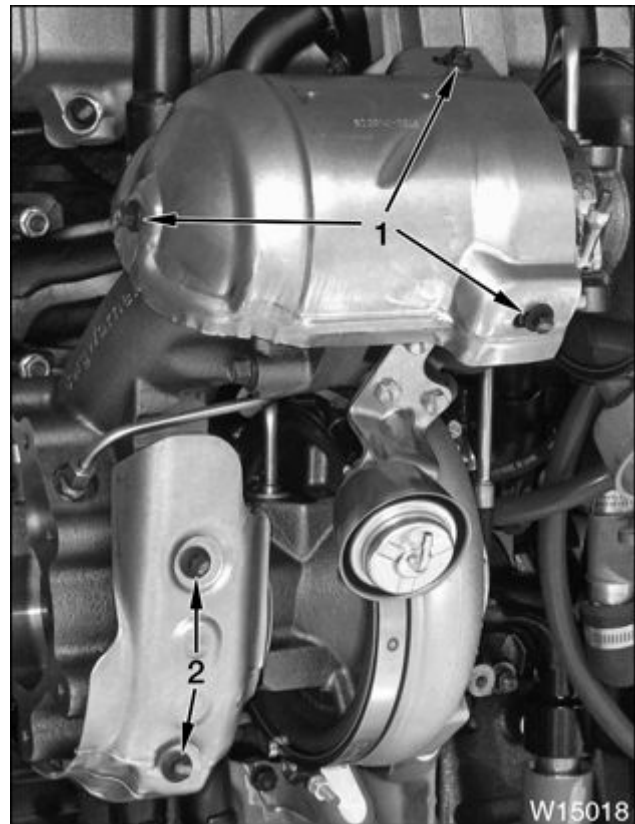


Figure 219 Turbocharger heat shields

1. M8 x 16 hex flange bolt (3) (high-pressure turbocharger)
2. M8 x 16 hex flange bolt (2) (low-pressure turbocharger)

4. Install heat shield on high-pressure turbocharger with three M8 x 16 bolts. Tighten bolts to standard torque (page 561).
5. Install heat shield on low-pressure turbocharger with two M8 x 20 bolts. Tighten bolts to standard torque (page 561).

Air Control Valve

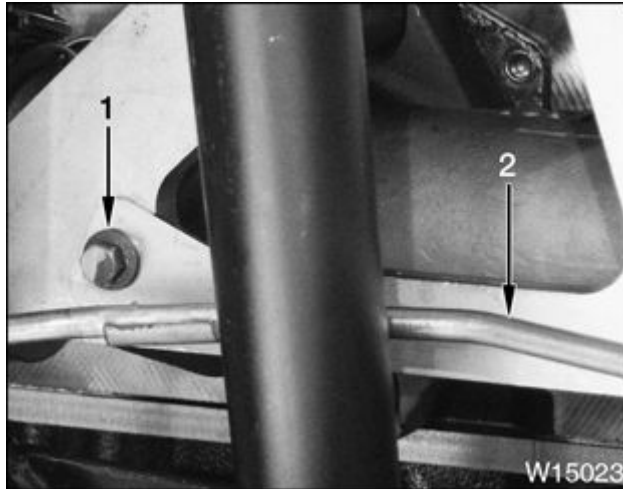


Figure 220 Exhaust Back Pressure (EBP) tube assembly

1. M6 x 12 bolt
 2. EBP tube assembly
1. Install M6 x 12 bolt through EBP tube bracket and into front EGR cooler support. Tighten bolt to standard torque (page 561).

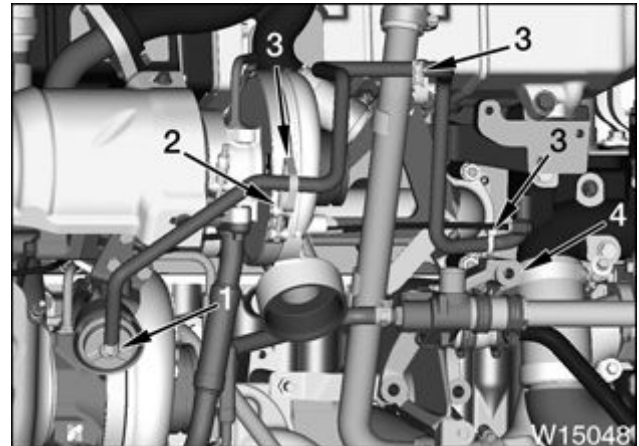


Figure 221 HP turbocharger wastegate actuator hose

1. 12.3 x 7 crimp clamp
 2. V-band clamp
 3. Tie strap
 4. Intercooler support (inner)
2. Position HP turbocharger wastegate actuator hose on engine. Secure hose to V-band clamp and intercooler support (inner) with tie straps.
 3. Place a new 12.3 x 7 crimp clamp on the end of the HP turbocharger wastegate actuator hose. Attach HP turbocharger wastegate actuator hose to actuator and secure the 12.3 x 7 crimp clamp.

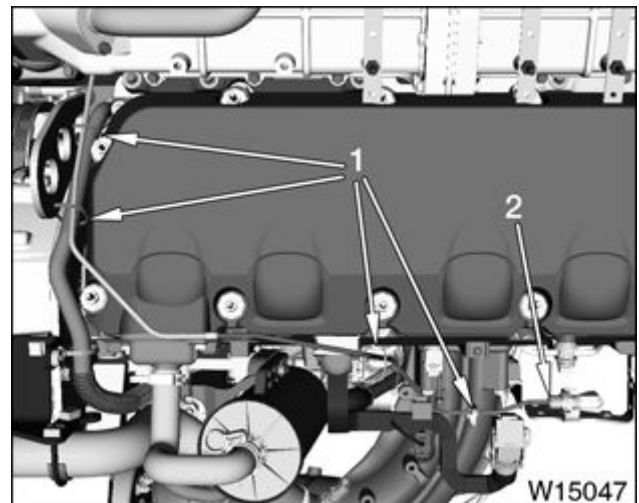


Figure 222 Air control valve air supply tube

1. Tie strap
2. Yellow collar

4. Position air control valve air supply tube in original location.
5. Press in yellow collar and insert air control valve air supply tube in fitting. Release yellow collar and pull on tube to insure good connection.
6. Install four new tie straps at locations shown.

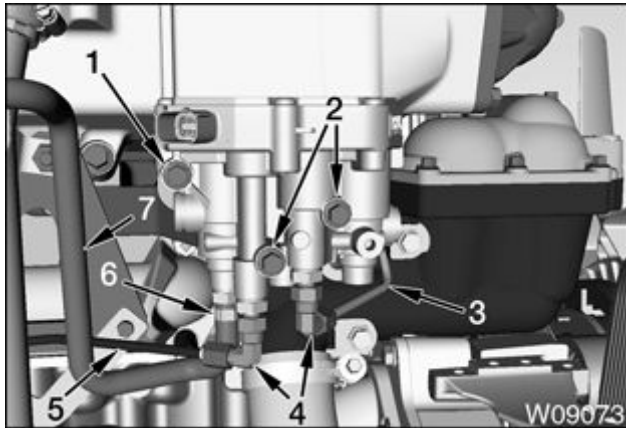


Figure 223 Air control valve

1. M8 x 65 bolt
 2. M8 x 80 bolt (2)
 3. Air supply tube assembly
 4. 90 degree flare fitting (2)
 5. Exhaust Back Pressure (EBP) tube assembly
 6. 12.3 x 7 crimp clamp
 7. High-Pressure (HP) turbocharger wastegate actuator hose
7. Install air control valve. Tighten two M8 x 80 bolts and one M8 x 65 bolt to standard torque (page 561).
 8. Connect air supply tube assembly to 90 degree flare fitting. Tighten air supply tube nut to special torque (page 170).
 9. Connect EBP tube assembly to 90 degree flare fitting. Tighten EBP tube assembly nut to special torque (page 170).
 10. Place a new 12.3 x 7 crimp clamp on the HP turbocharger wastegate actuator hose. Connect

hose to air control valve. Crimp 12.3 x 7 crimp clamp securely in position.

Intercooler Support (Outer)

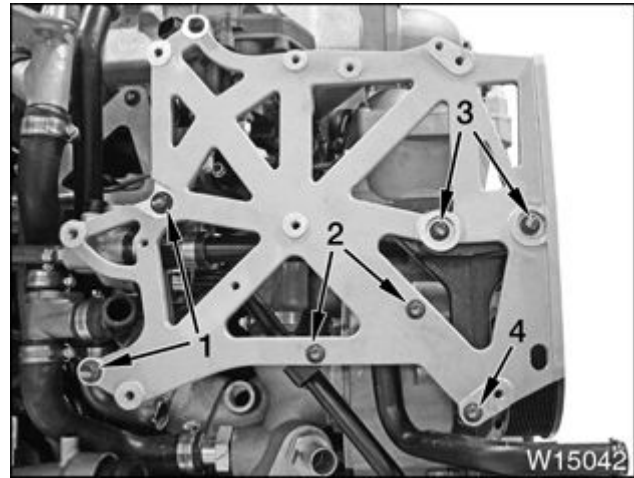


Figure 224 Intercooler support (outer)

1. M10 x 80 hex flange bolt (2)
 2. M8 x 30 hex flange bolt (2)
 3. M8 x 25 hex flange bolt (2)
 4. M8 x 45 hex flange bolt
1. Position intercooler support (outer) and install two M8 x 25 hex flange bolts, and two M10 x 80 hex flange bolts. Tighten bolts to standard torque (page 561).
 2. Install two M8 x 30 hex flange bolts. Tighten bolts to standard torque (page 561)

Turbocharger Interstage Cooler (ISC) Assembly

NOTE: The ISC outlet tube was installed with a new 2-230 3.53 x 63.09 O-ring during the "Turbocharger Interstage Cooler Assembly (ISC) Pressure Test". If this test was performed, go to step three.

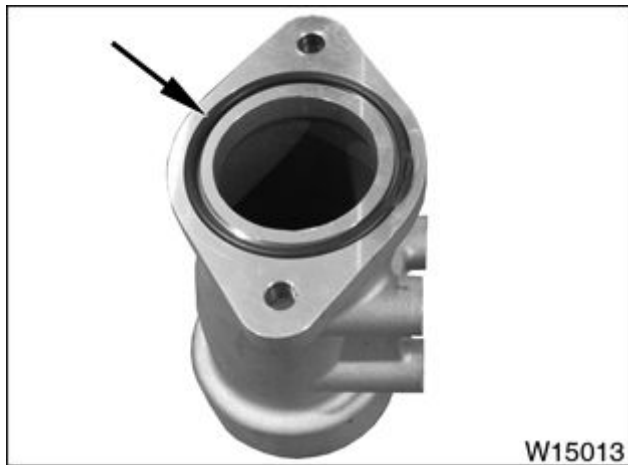


Figure 225 ISC outlet tube 2-230 3.53 x 63.09 O-ring

1. Place a new 2-230 3.53 x 63.09 O-ring in groove on ISC outlet tube.

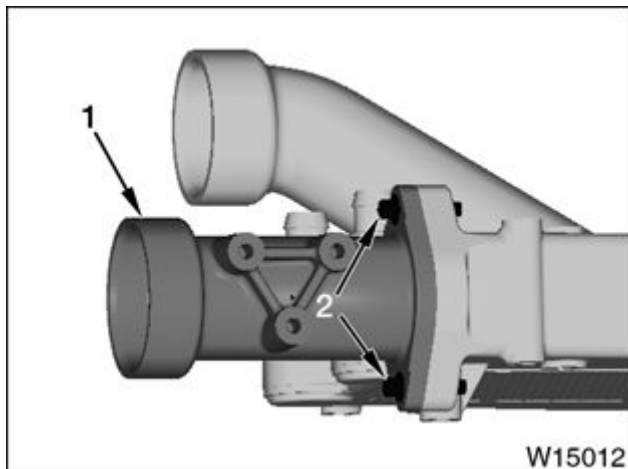


Figure 226 ISC outlet tube

1. ISC outlet tube
 2. M8 x 35 hex flange bolt (2)
2. Install ISC outlet tube on ISC. Install M8 x 35 hex flange bolts. Tighten bolts to standard torque (page 561).

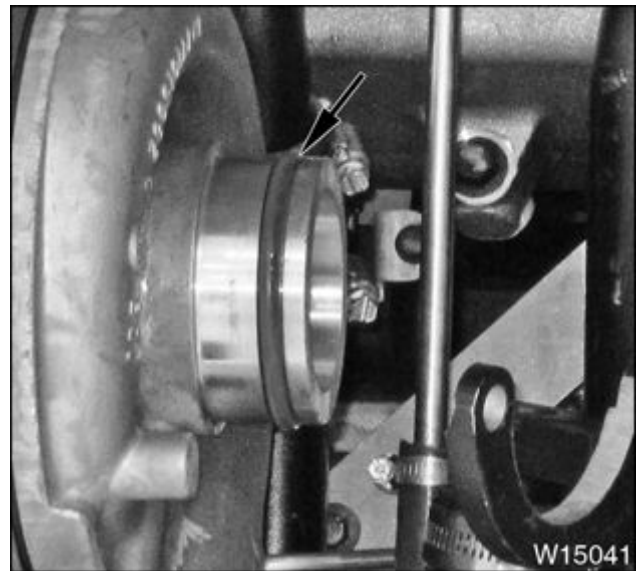


Figure 227 HP compressor O-ring (size 333)

3. Install a new HP compressor O-ring (size 333) on high-pressure turbocharger. Lubricate seal with P-80® rubber lubricant or equivalent (page 170)

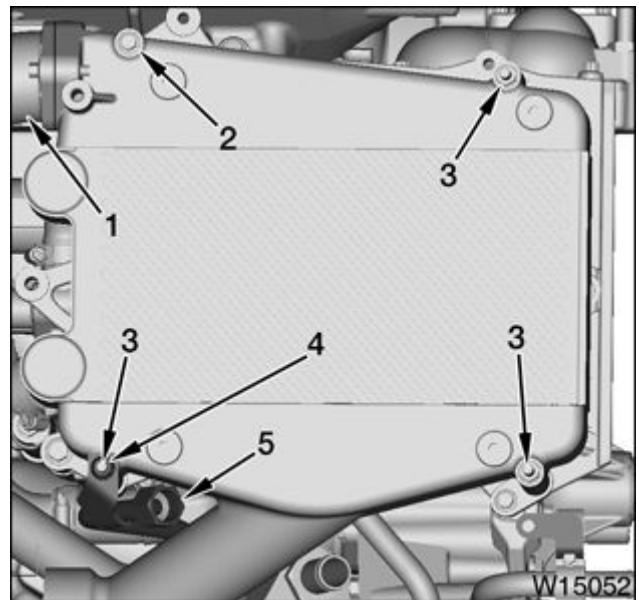


Figure 228 ISC mounting bolts

1. ISC outlet tube
2. M8 x 100 hex flange bolt
3. M8 x 100 x 18 stud bolt (3)
4. M8 x 1.25 hex flange nut
5. Oil supply tube assembly

4. Position ISC together with ISC outlet tube on intercooler support (outer). Install M8 x 100 hex flange bolt and upper M8 x 100 x 18 stud bolt finger tight.
5. Install remaining two M8 x 100 x 18 stud bolts. Tighten bolt and three stud bolts to standard torque (page 561).
6. Install oil supply tube assembly on M8 x 100 x 18 stud bolt.
7. Install M8 x 1.25 hex flange nut. Tighten nut to standard torque (page 561).



Figure 229 ISC coolant hose clamps

1. SAE 16 clamp (coolant supply)
2. SAE 16 clamp (coolant return)

8. Connect coolant hoses to fittings on ISC and secure with SAE 16 clamps.

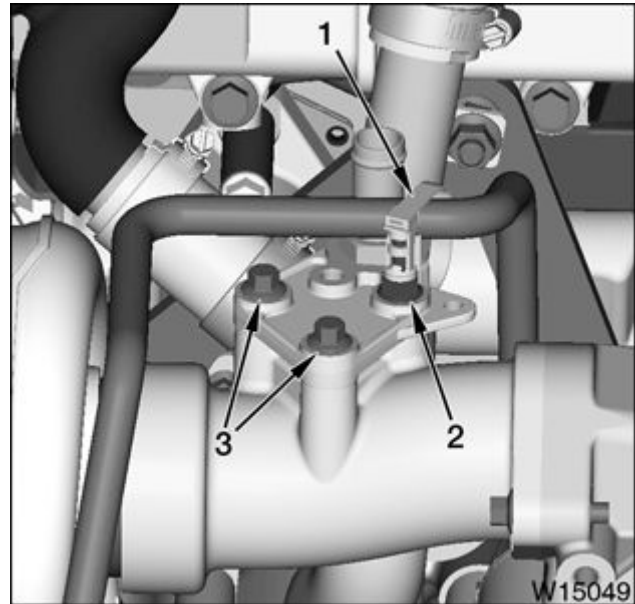


Figure 230 Heater core return adapter

1. Tie strap
 2. M8 x 30 stud bolt
 3. M8 x 30 hex flange bolt (2)
9. Install two M8 x 30 hex flange bolts and one M8 x 30 stud bolt. Tighten bolts and stud bolt to standard torque (page 561).
 10. Secure high-pressure turbocharger wastegate actuator hose to M8 x 30 stud bolt with tie strap.

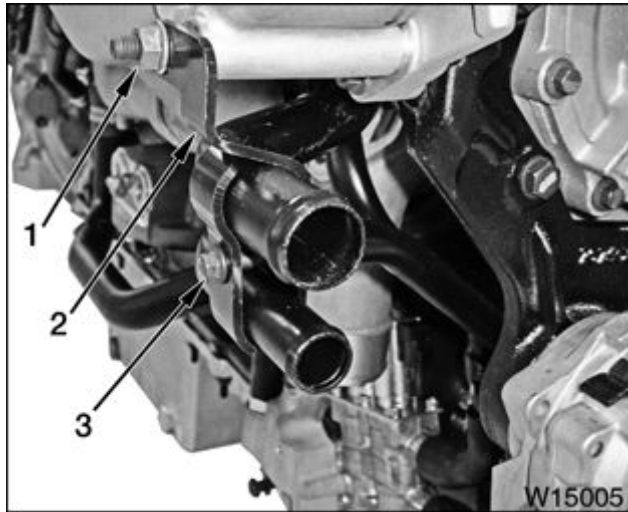


Figure 231 CAC coolant pipe bracket

1. M8 hex flange nut
 2. EGR tube support assembly
 3. M6 x 35 hex flange bolt
11. Position CAC coolant pipe bracket on M8 x 100 x 18 stud bolt and install M8 hex flange nut. Tighten nut to standard torque (page 561).
 12. Install M6 x 35 bolt. Tighten bolt to standard torque (page 561).

Turbocharger to Intercooler Tube

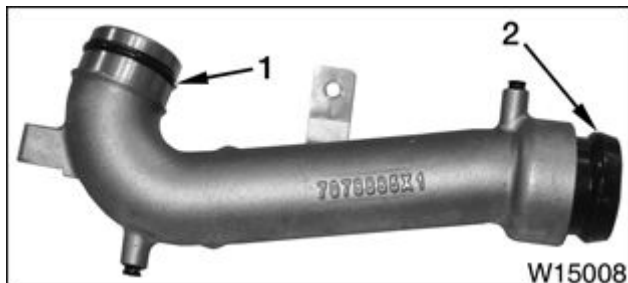


Figure 232 Turbocharger to ISC tube seals

1. O-ring (size 329)
2. 72.2 x 60 tube seal

1. Install new intake O-ring (size 329). Lubricate O-ring with P-80® rubber lubricant or equivalent (page 170).
2. Install new 72.2 x 60 tube seal using Interstage Cooler Pipe to High-Pressure Turbo Extension Tube Seal Installer (page 170). Lubricate tube seal with P-80® rubber lubricant or equivalent (page 170) to ease installation.

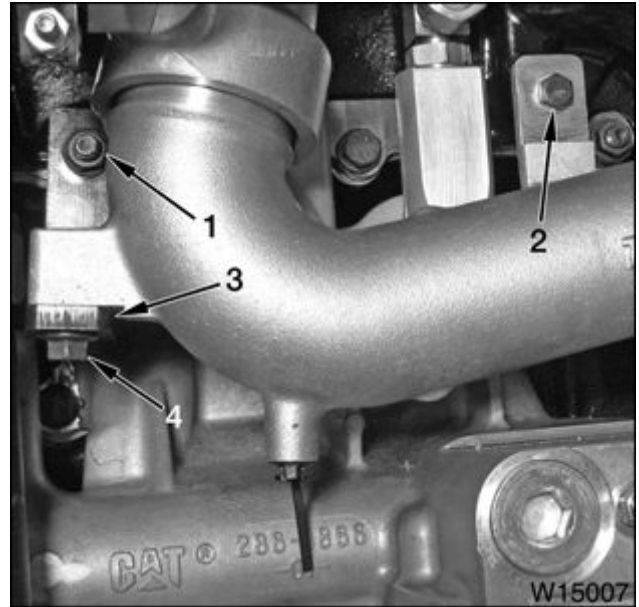


Figure 233 Turbocharger to ISC tube

1. 3/8-16 nut
 2. 5/16-18 x 1 bolt
 3. Turbocharger to intercooler tube support
 4. M10 x 30 bolt
3. Install turbocharger to intercooler tube into ISC and then into outlet of low-pressure turbocharger.
 4. Install turbocharger to intercooler tube support. Install 3/8-16 nut finger tight.
 5. Install 5/16-18 x 1 bolt. Tighten 5/16-18 x 1 bolt and 3/8-16 nut to standard torque (page 562).
 6. Install M10 x 30 bolt. Tighten M10 x 30 bolt to standard torque (page 561)

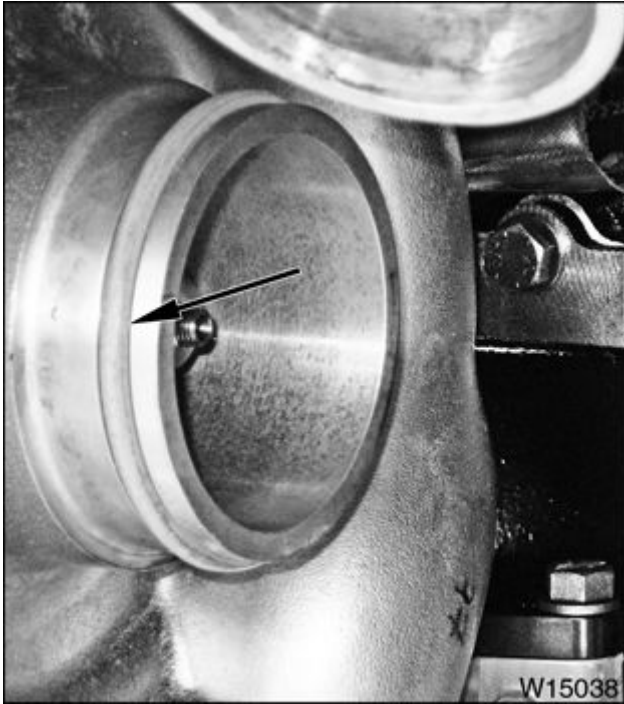
Air Inlet Duct

Figure 234 LP turbocharger inlet O-ring (size 337)

1. Install new O-ring (size 337) on compressor inlet of low-pressure turbocharger. Lubricate O-ring with P-80® rubber lubricant or equivalent (page 170).
2. Install air inlet duct on low-pressure turbocharger.

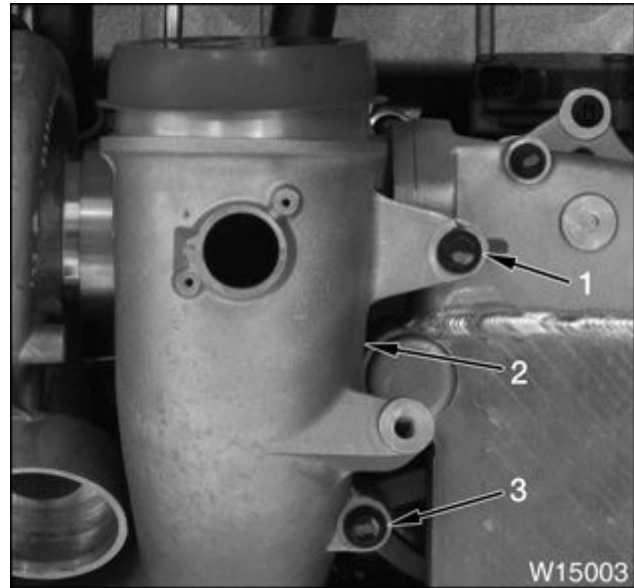


Figure 235 Air inlet duct

1. M10 x 55 bolt
 2. Air inlet duct
 3. M10 x 110 bolt
3. Install M10 x 55 and M10 x 110 bolts. Tighten both bolts to standard torque (page 561).

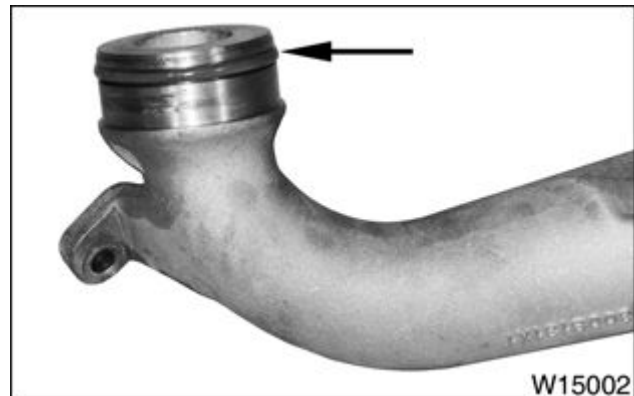
High-Pressure (HP) Compressor Outlet Duct

Figure 236 HP compressor outlet duct O-ring (size 333)

1. Install a new O-ring (size 333) on HP compressor outlet duct. Lubricate O-ring with P-80® rubber lubricant or equivalent (page 170).

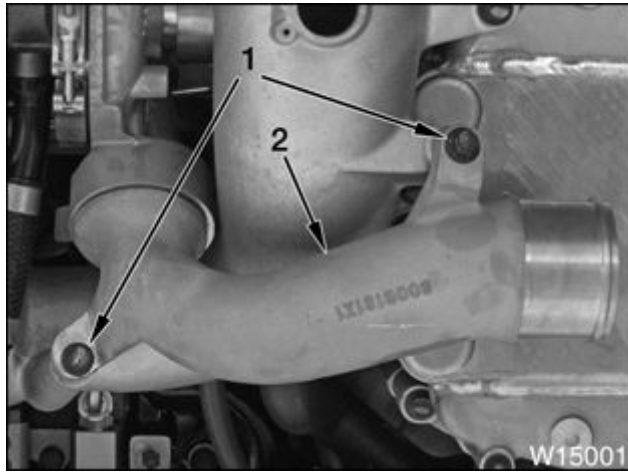


Figure 237 HP compressor outlet duct

1. M10 x 40 bolt (2)
 2. HP compressor outlet duct
2. Push HP compressor outlet duct into high-pressure turbocharger. Install two M10 x 40 bolts. Tighten bolts to standard torque (page 561).

Turbocharger Oil Drain Tube Assembly

1. Install new O-rings (Figure 175) items 10 and 21, on turbocharger oil drain tube assembly.

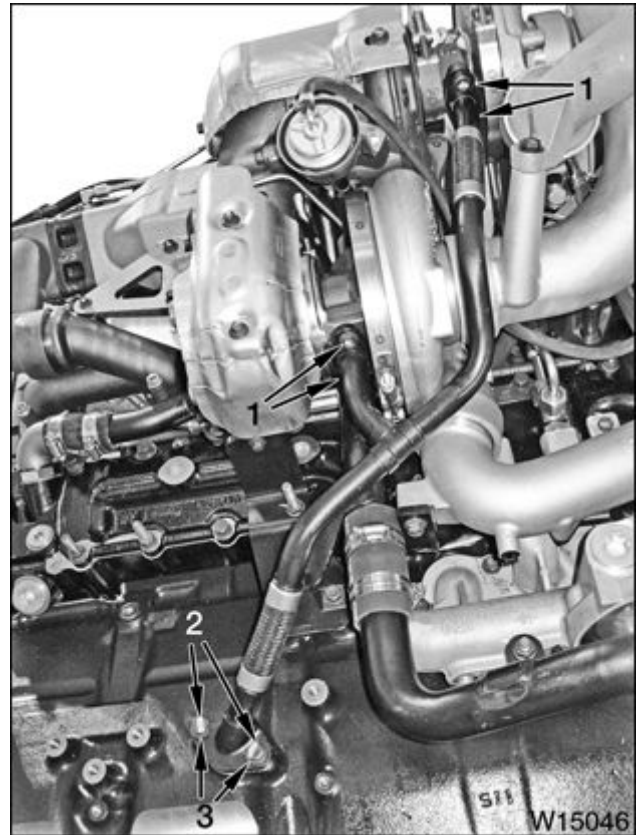


Figure 238 Turbocharger oil drain tube assembly

1. M8 x 20 bolt (4)
 2. 3/8-16 x 7/8 bolt (2)
 3. 10.2 x 18.5 hardened washer (2)
2. Install turbocharger oil drain tube assembly with four M8 x 20 bolts. Tighten bolts to standard torque (page 561).
3. Install two 3/8-16 x 7/8 bolts with 10.2 x 18.5 hardened washers. Tighten bolts to standard torque (page 562).

Special Torque

Air supply tube nut	25 N·m (18 lbf·ft)
EBP tube assembly nut	25 N·m (18 lbf·ft)
M10 x 55 hex bolts	47 N·m (35 lbf·ft)
M10 x M12 24 degree fitting	62 N·m (45 lbf·ft)
Oil supply tube nuts	31 N·m (23 lbf·ft)

Special Service Tools

Description	Tool Number
Charge Air Cooler Tester Kit	ZTSE6042
Interstage Cooler Pipe to High-Pressure Turbo Extension Tube Seal Installer	ZTSE6057
P-80® rubber lubricant or equivalent	Obtain locally
Turbocharger Lifting Bracket	ZTSE6104

Table of Contents

Exploded Views.....	173
Removal.....	175
Power Steering Pump.....	175
Air Compressor Coolant Tubes.....	175
Air Compressor	176
Cleaning.....	177
All Components.....	177
Installation.....	178
Air Compressor	178
Air Compressor Coolant Tubes.....	180
Power Steering Pump.....	180
Special Torque.....	182

Exploded Views

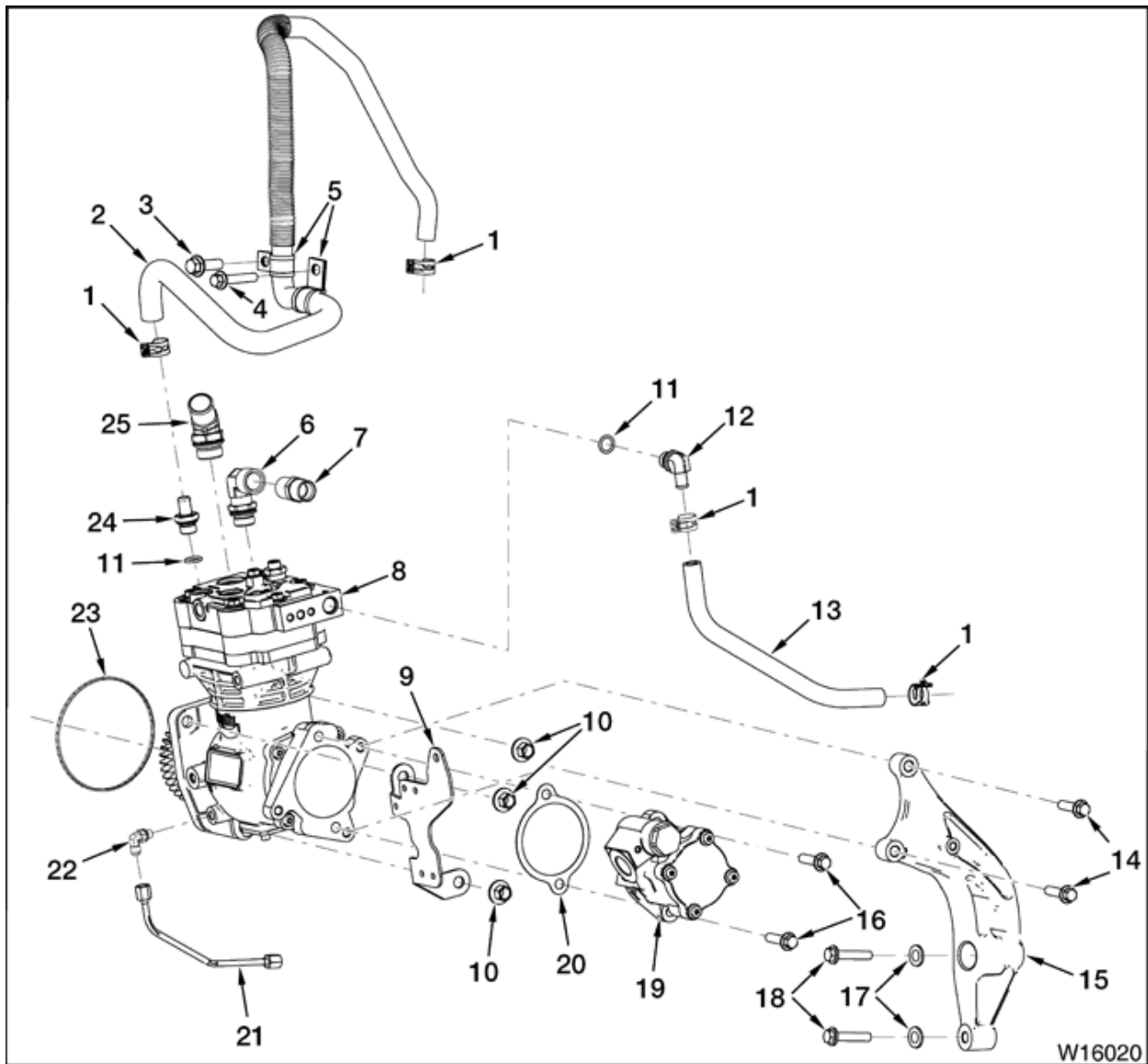


Figure 239 Air compressor system (single cylinder) with power steering pump

1. Hose clamp (4)	10. 1/2-13 hex flange nut (3)	19. Power steering pump
2. Coolant outlet tube	11. 18 mm O-ring seal (2)	20. Gasket
3. 3/8-16 hex flange nut	12. M18 adj str thd 90 degree elbow	21. Air compressor oil inlet tube assembly
4. M8 x 20 hex flange bolt	13. Coolant inlet tube	22. 45 deg flare to M10 90 degree elbow
5. Clamp (2)	14. M10 x 40 hex flange bolt (2)	23. Air compressor ring seal
6. Adapter (90 degree)	15. Air compressor support	24. M18 straight fitting
7. Spherical sleeve connector	16. M10 x 30 hex flange bolt (2)	25. 45 degree M27 x 1 adapter
8. Air compressor	17. M10 spring lock washer (2)	
9. Harness support	18. 3/8-16 x 2 hex head bolt (2)	

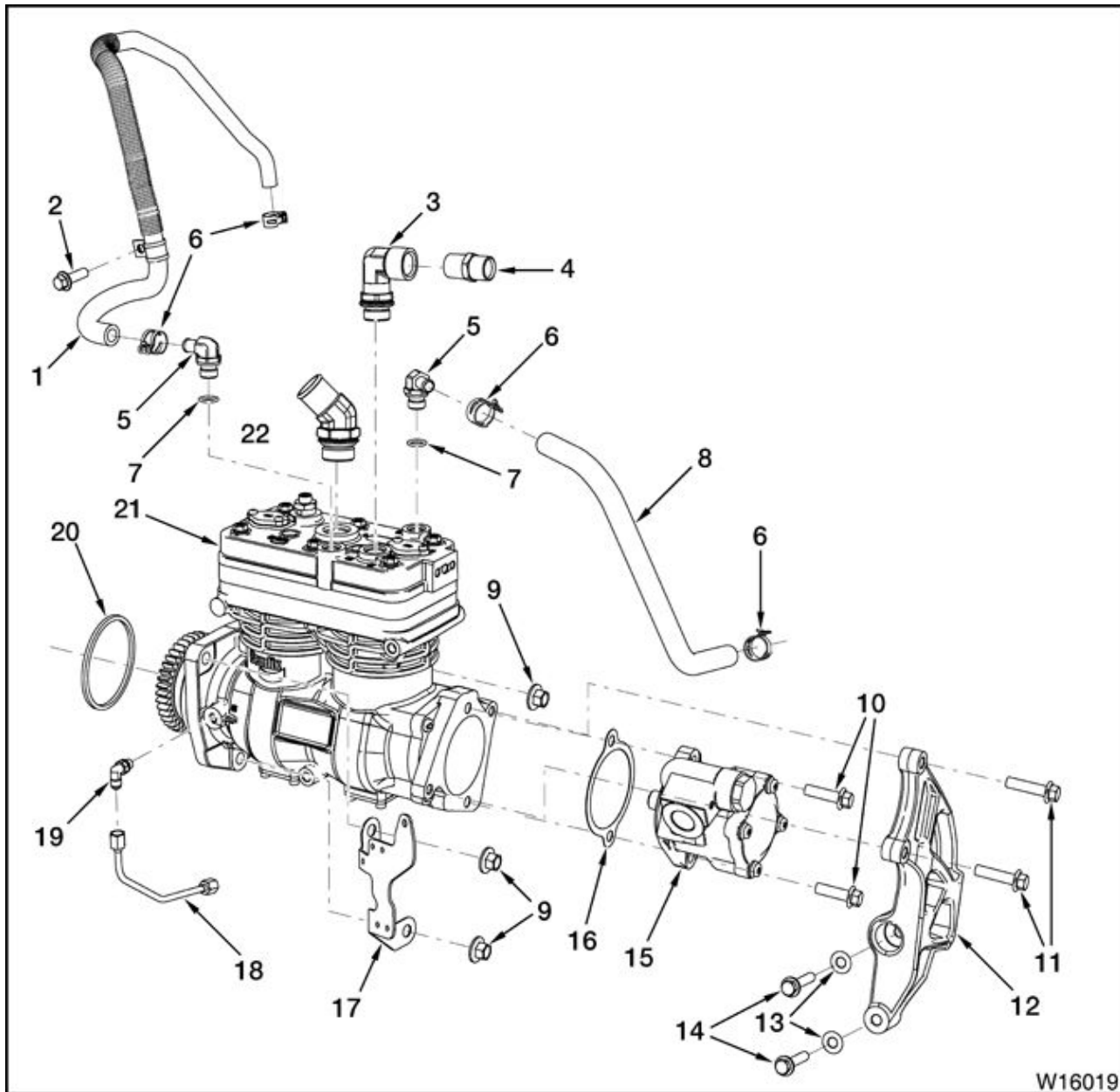


Figure 240 Optional air compressor system (twin cylinder) with power steering pump

1. Coolant outlet tube	9. 1/2-13 hex flange nut (3)	18. Air compressor oil inlet tube assembly
2. Clamp	10. M10 x 30 hex flange bolt (2)	19. 90 degree elbow, 45 degree flare to M10
3. Adapter (90 degree)	11. M10 x 40 hex flange bolt (2)	20. Air compressor ring seal
4. Spherical sleeve connector	12. Air compressor support	21. Air compressor
5. M18 adj str thd 90 degree elbow (2)	13. M10 spring lock washer (2)	22. 45 degree M27 x 1 adapter
6. Hose clamp (4)	14. 3/8-16 x 2 hex head bolt (2)	
7. 18 mm O-ring seal (2)	15. Power steering pump	
8. Coolant inlet tube	16. Gasket	
	17. Harness support	

Removal



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



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



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



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

NOTE: Air compressor and power steering pump may be removed together as an assembly or separately depending on service requirements.

Power Steering Pump

1. Remove oil level gauge tube assembly. See Oil Level Gauge and Oil Level Gauge Tube Assembly (page 435).

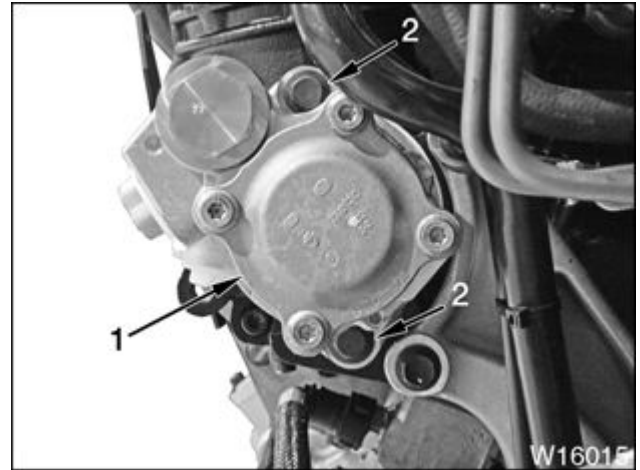


Figure 241 Power steering pump (rear view)

1. Power steering pump
 2. M10 x 30 hex flange bolt
2. Remove any tubes or hoses that may be attached to the power steering pump.
 3. Remove two M10 x 30 hex flange bolts.
 4. Remove power steering pump and discard gasket.

Air Compressor Coolant Tubes

1. Remove Engine Throttle Valve (ETV) assembly. See Air Inlet (page 287).

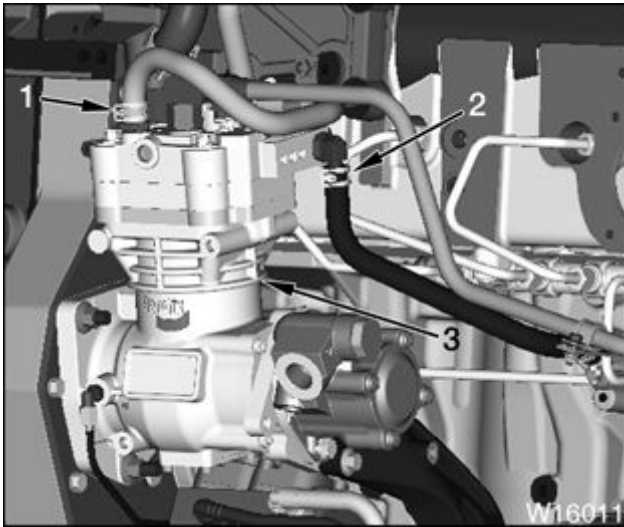


Figure 242 Air compressor coolant tubes (single cylinder)

1. Coolant outlet tube
2. Coolant inlet tube
3. Air compressor

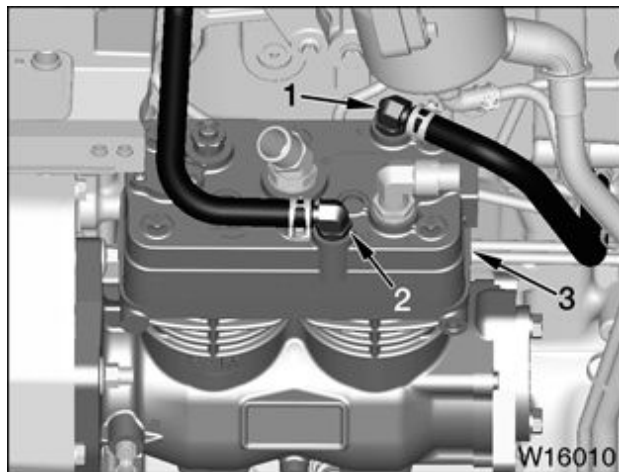


Figure 243 Air compressor coolant tubes (twin cylinder)

1. Coolant inlet tube
2. Coolant outlet tube
3. Air compressor

NOTE: If removing air compressor in chassis, clamp off coolant inlet and outlet tubes to minimize coolant loss from engine.

2. Place suitable container under air compressor to collect any residual coolant.
3. Loosen hose clamp from coolant inlet tube. Remove coolant inlet tube.
4. Loosen hose clamp from coolant outlet tube. Remove coolant outlet tube.

Air Compressor

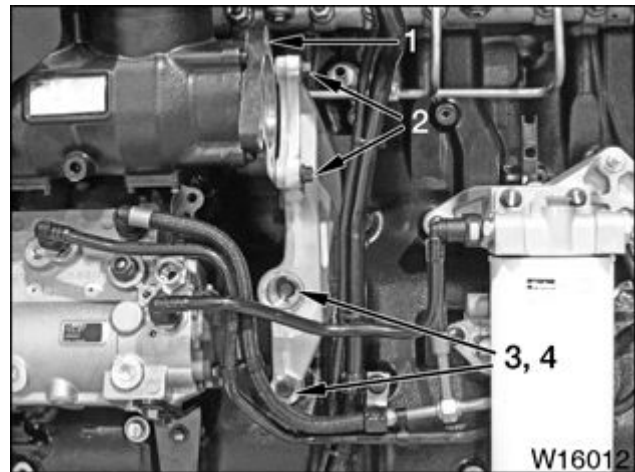


Figure 244 Air compressor support (typical)

1. Air compressor
2. M10 x 40 hex flange bolt
3. 3/8 hardened washer
4. 3/8-16 x 2 hex head bolt

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

1. Remove two M10 x 40 hex flange bolts.
2. Remove support from engine by removing two 3/8-16 x 2 hex head bolts and two 3/8 hardened washers.

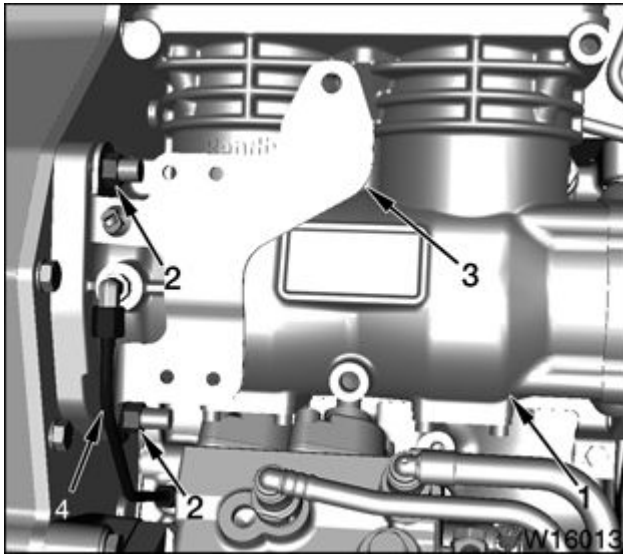


Figure 245 Air compressor/harness support (typical)

1. Air compressor
 2. 1/2-13 hex flange nut (3) (one behind compressor, not shown)
 3. Harness support
 4. Air compressor oil inlet tube assembly
-
3. Disconnect air compressor oil inlet tube assembly tube nut from connection on side of air compressor.

4. While supporting the air compressor, remove (2) 1/2-13 hex flange nuts securing harness support on outside of air compressor.
5. While continuing to support the air compressor, remove remaining 1/2-13 hex flange nut securing air compressor to the rear of the front cover plate (on back side of compressor).
6. Remove air compressor from studs.
7. Remove and discard seal.

Cleaning

All Components

1. Cover coolant, fluid and air openings to ensure dirt does not enter air compressor and power steering pump.
2. Clean foreign material from gasket surfaces of air compressor. Use a scraper to remove gasket from gasket surfaces.
3. Use only hot water to clean all hoses and tubes.

Installation

Air Compressor

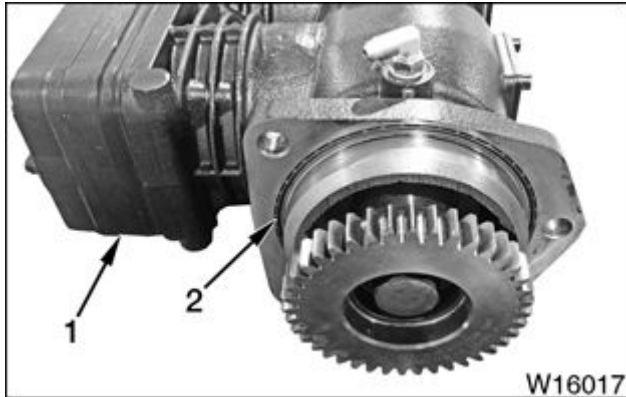


Figure 246 Air compressor seal (typical)

1. Air compressor
2. Air compressor ring seal

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

1. Install new air compressor ring seal into groove.

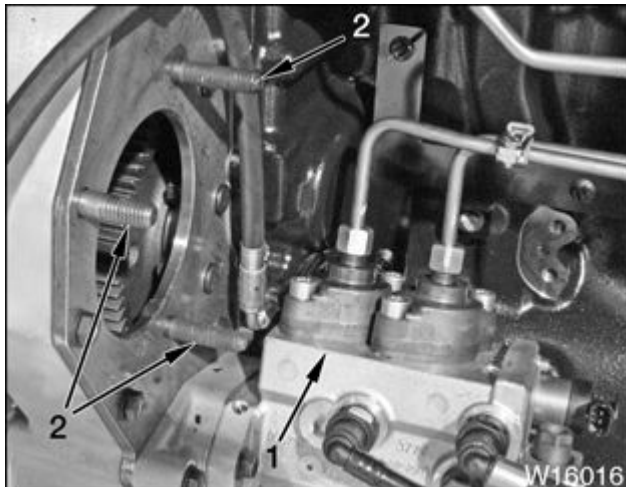


Figure 247 Air compressor mounting face

1. Fuel pump
2. 1/2 x 13 x 2.95 mounting studs

2. Position air compressor onto all three 1/2 x 13 x 2.95 mounting studs while aligning gears, and loosely install inner 1/2–13 hex flange nut.

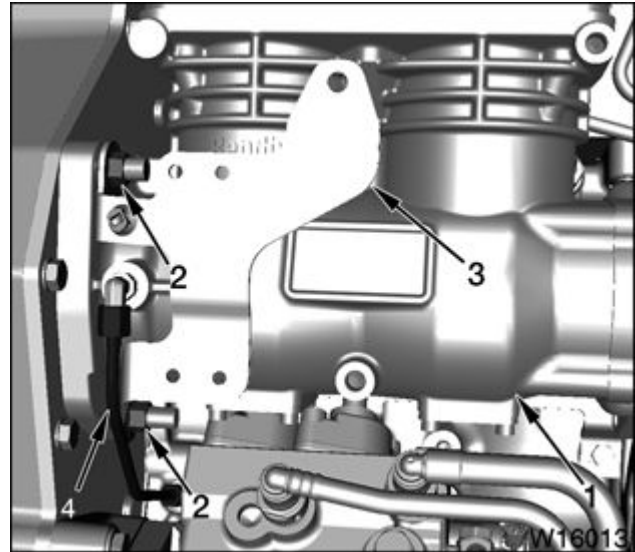


Figure 248 Air compressor/harness support (typical)

1. Air compressor
 2. 1/2–13 hex flange nut (3) (one behind compressor, not shown)
 3. Harness support
 4. Air compressor oil inlet tube assembly
3. While supporting the air compressor, position harness support over outside two studs and loosely install two 1/2–13 hex flange nuts.
 4. Tighten all nuts to special torque (page 182).

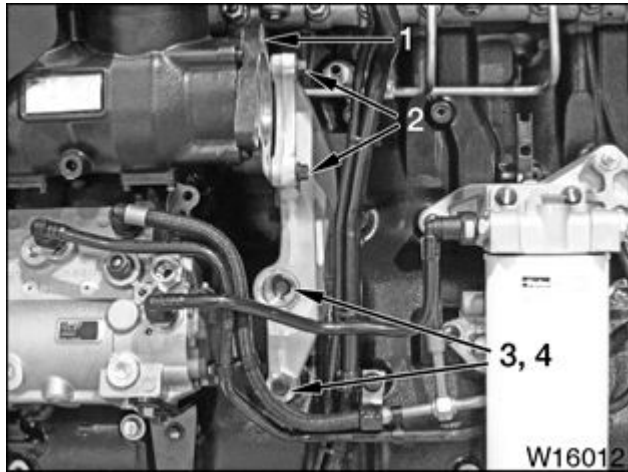


Figure 249 Air compressor support (typical)

1. Air compressor
 2. M10 x 40 hex flange bolt
 3. 3/8 hardened washer
 4. 3/8-16 x 2 hex head bolt
5. Install appropriate air compressor support (distinct supports for single and twin cylinder compressors) onto engine block using two 3/8-16 x 2 hex head bolts and two 3/8 hardened washers. Tighten to standard torque (page 562).
 6. Secure air compressor to support using two M10 x 40 hex flange bolts. Tighten bolts to standard torque (page 561).

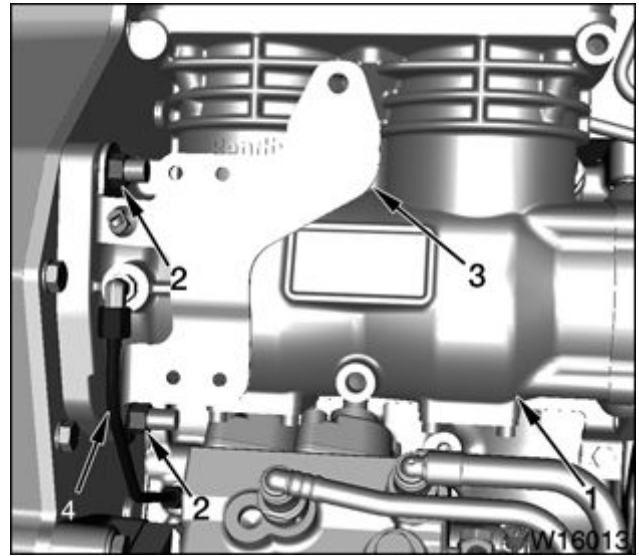


Figure 250 Air compressor oil inlet tube (typical)

1. Air compressor
 2. 1/2-13 hex flange nut (3) (one behind compressor, not shown)
 3. Harness support
 4. Air compressor oil inlet tube assembly
7. Attach air compressor oil inlet tube assembly to oil inlet connector on side of compressor. Tighten tube fitting nut to special torque (page 182).

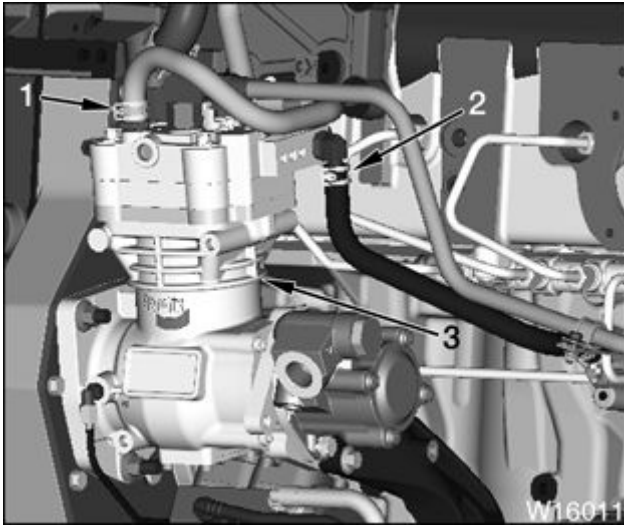
Air Compressor Coolant Tubes

Figure 251 Air compressor coolant tubes (single cylinder)

1. Coolant outlet tube
2. Coolant inlet tube
3. Air compressor

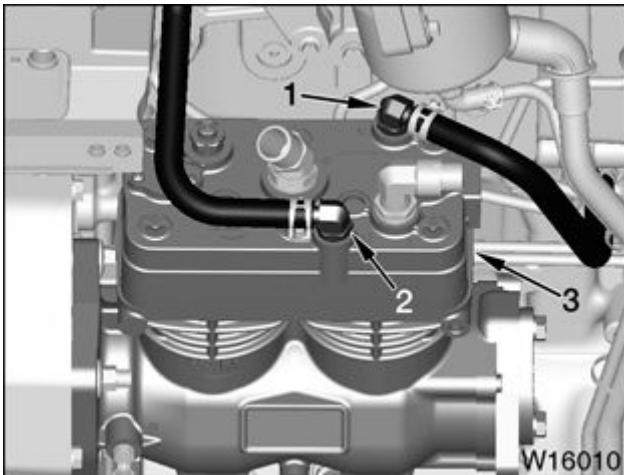


Figure 252 Air compressor coolant tubes (twin cylinder)

1. Coolant inlet tube
2. Coolant outlet tube
3. Air compressor

1. Install coolant outlet tube onto coolant return M18 straight fitting (single cylinder) or M18 90 degree fitting (twin cylinder). Tighten hose clamp.
2. Install coolant inlet tube onto coolant inlet M18 90 degree fitting. Tighten hose clamp.
3. Remove clamps that prevent coolant loss in chassis from coolant inlet and outlet tubes, if used.
4. Install Engine Throttle Valve (ETV) assembly. See Air Inlet (page 290).

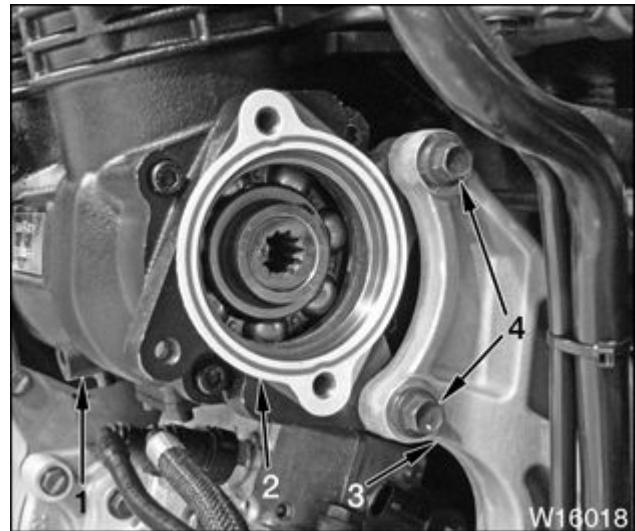
Power Steering Pump

Figure 253 Power steering pump gasket

1. Air compressor
 2. Gasket
 3. Air compressor support
 4. 3/8-16 x 2 hex head bolt
1. Position new power steering pump gasket on mating face of air compressor.

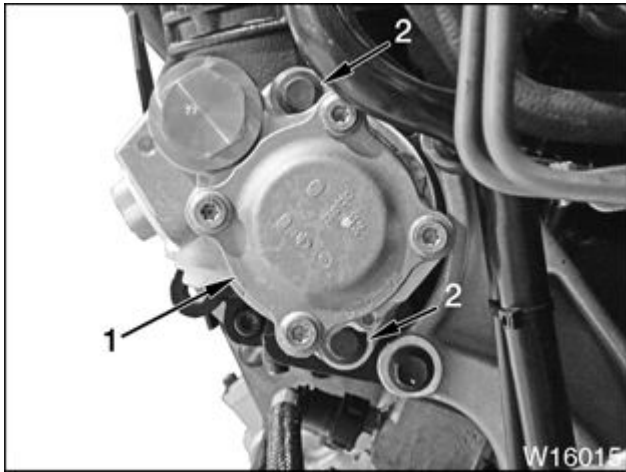


Figure 254 Power steering pump (rear view)

1. Power steering pump
2. M10 x 30 hex flange bolt

2. Align power steering pump onto gasket and secure both to air compressor with two M10 x 30 hex flange bolts. Tighten to standard torque (page 561).
3. Install oil level gauge tube assembly. See Oil Level Gauge and Oil Level Gauge Tube Assembly (page 449).

Special Torque

1/2–13 hex flange nuts (air compressor mounting)	115 N·m (77 lbf·ft)
Air compressor oil inlet tube assembly fitting nut	16 N·m (144 lbf·in)

Table of Contents

Exploded Views.....	185
Periodic Service.....	188
Fuel Filter Replacement.....	188
Removal.....	189
Pump to Rail Fuel Tube Assemblies and Rail to Injector Tube Assemblies.....	189
Fuel Rail	192
Fuel Return Tube Assembly.....	192
Fuel Filter Housing Assembly.....	193
High-Pressure Fuel Pump.....	195
Cleaning and Inspection.....	196
Installation.....	197
High-Pressure Fuel Pump.....	197
Fuel Filter Housing Assembly.....	198
Fuel Return to Tank Tube Assembly.....	199
Fuel Rail.....	200
Rail to Injector Tube Assemblies.....	201
Pump to Rail Fuel Tube Assemblies.....	202
Specifications.....	204
Special Torque.....	204
Special Service Tools.....	204

Exploded Views

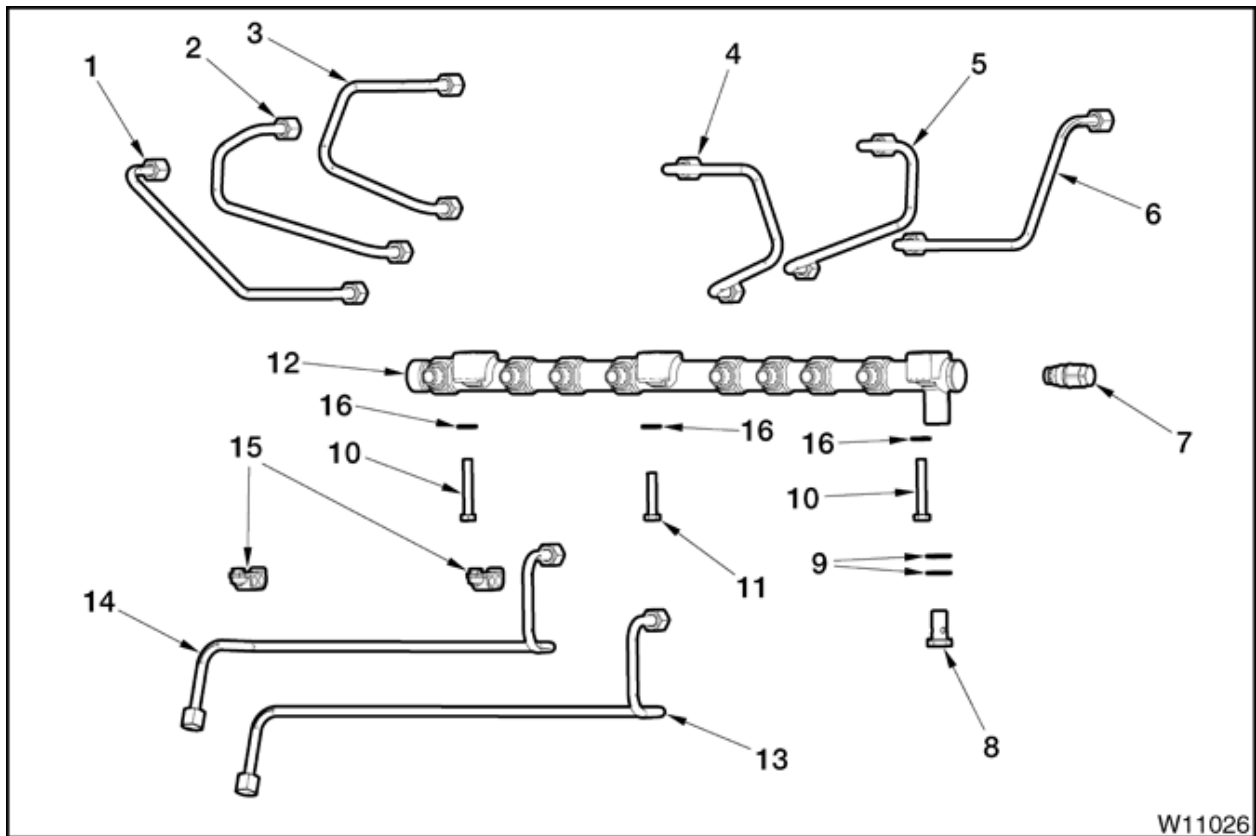


Figure 255 High-pressure fuel rail and tubes

1. Cylinder 1 rail to injector tube assembly	7. Pressure limiting valve	17. 3/8 x 1/2 Thread locking bolt
2. Cylinder 2 rail to injector tube assembly	8. M14 hex flange banjo bolt	18. 10.2 x 18.5 x 5 hardened washer
3. Cylinder 3 rail to injector tube assembly	9. 14.7 x 22 seal ring (2)	19. Pump to rail fuel tube assembly (front)
4. Cylinder 4 rail to injector tube assembly	10. 5/16-18 x 2 hex head bolt (2)	20. Fuel to rail supply clamp assembly (2)
5. Cylinder 5 rail to injector tube assembly	11. 5/16-18 x 1 1/2 hex head bolt	21. 8.8 x 17 x 1.6 mm washer (3)
6. Cylinder 6 rail to injector tube assembly	12. Fuel rail	
	13. Pump to rail fuel tube assembly (rear)	
	14. M6 x 20 hex flange bolt	
	15. High-pressure fuel line support	
	16. High-pressure fuel line clamp assembly	

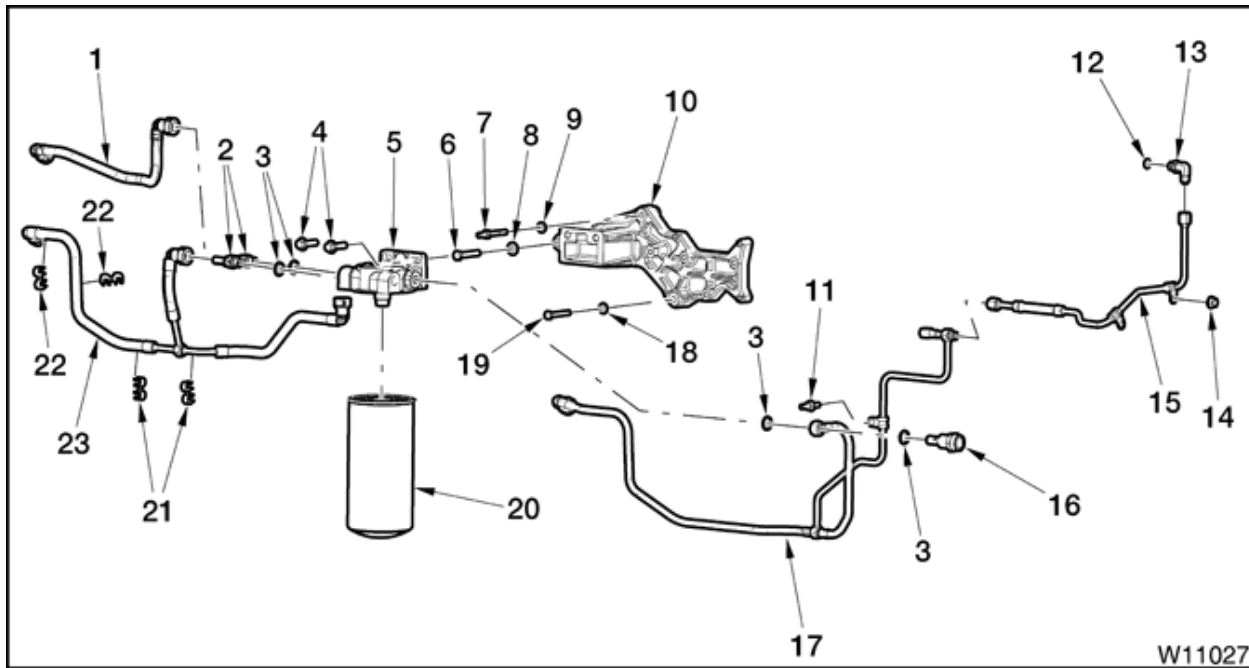


Figure 256 Fuel filter housing assembly and fuel supply and return lines

1. Fuel pump to filter tube assembly	10. LP fuel system support	17. Fuel return to tank tube assembly
2. M14 x 1.5 threaded union (2)	11. M8 stud bolt	18. 8.8 x 17 x 1.6 washer
3. 14.7 x 22 seal ring (4)	12. #906 O-ring	19. 5/16-18 x 2 hex head bolt
4. M10 x 35 hex flange bolt (2)	13. 9/16-18 x 90 degree fitting	20. Fuel filter
5. Fuel filter header assembly	14. 3/8-16 hex flange nut	21. Wiring twice clamp (2)
6. 3/8-16 x 2 hex head bolt	15. Fuel return tube assembly (from injectors)	22. C clip (2)
7. 5/16-18 stud	16. Fuel supply adapter	23. Fuel return tube assembly
8. 3/8 hardened washer		
9. 8.8 x 17 x 1.6 washer		

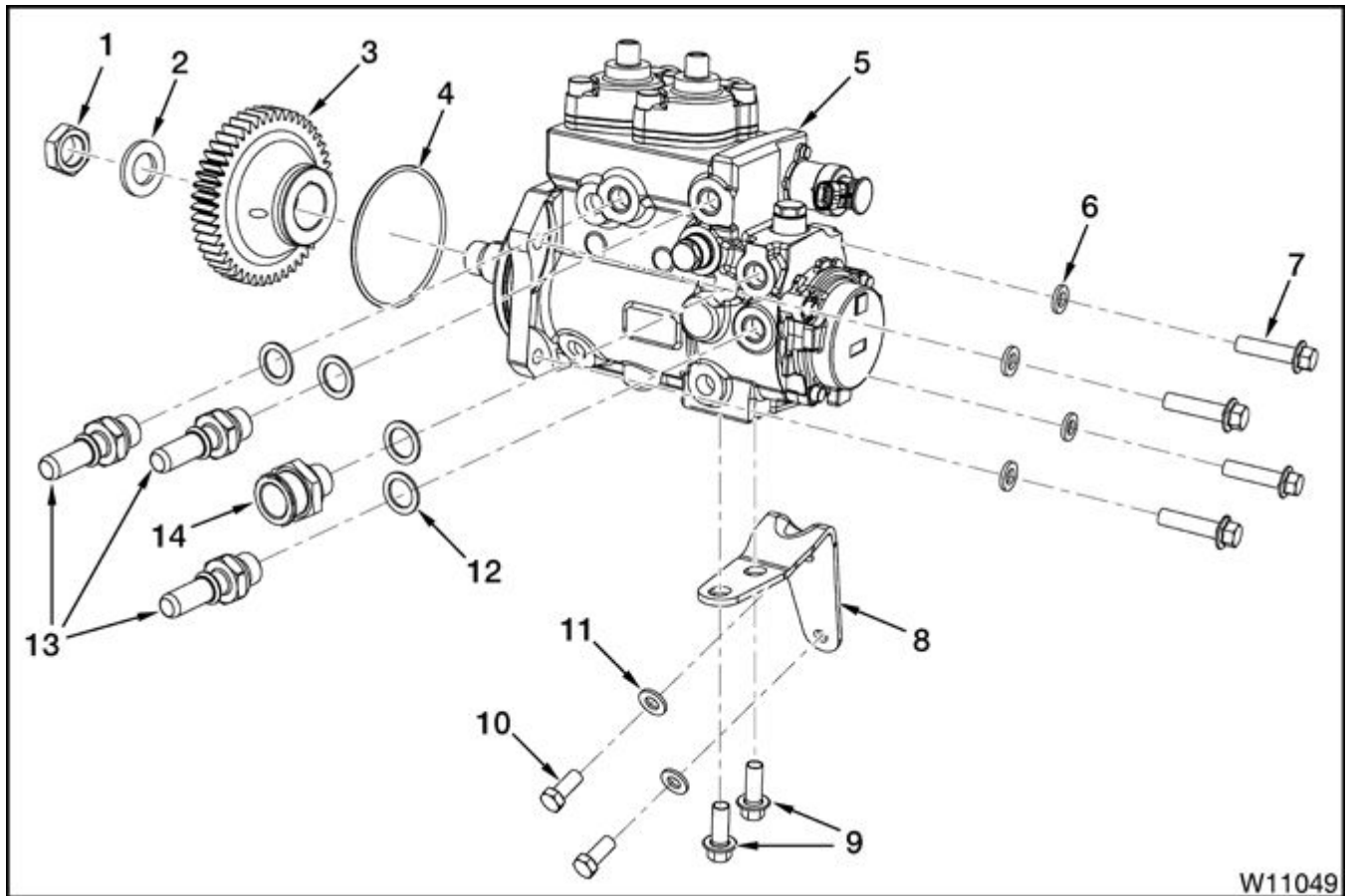


Figure 257 High-pressure fuel pump

1. M24 hex jam nut	6. Plain washer (4)	11. 3/8 hardened washer (2)
2. M25 x 44 x 4 washer	7. M10 x 40 hex flange bolt (4)	12. 16.7 x 24 ring seals (4)
3. High-pressure pump gear	8. High-pressure pump support	13. M16 x 1.5 quick connect connector (3)
4. 100 x 3.349 O-ring	9. M12 x 30 hex flange bolt (2)	14. M16 x 1.5 female connector
5. High-pressure fuel pump	10. 3/8-16 x 7/8 hex head bolt (2)	

Periodic Service



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

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

! WARNING: To prevent personal injury or death, shift 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 Filter Replacement

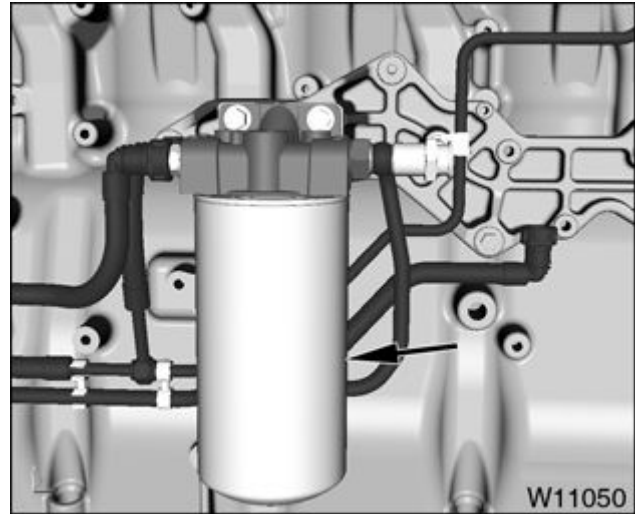


Figure 258 Fuel filter

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

1. Using appropriate filter wrench or strap, loosen and remove the fuel filter from the header and dispose of according to local regulations.
2. Lubricate the seal of the new filter with clean engine oil.
3. Secure the fuel filter to the fuel filter header assembly by turning the fuel filter clockwise until fuel filter seal contacts the header. Tighten an additional 2/3 to one full turn.
4. Prime fuel system with chassis mounted primer pump.
5. Start engine to pressurize fuel system. Inspect area around fuel filter for fuel leaks. Turn engine OFF and repair leaks as needed.

Removal

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

- Engine Electrical
- Cold Start Assist
- Aftertreatment System
- EGR System
- Oil Cooler, Filter Housing and Crankcase Ventilation
- Front Cover, High Mount Fan Drive, Cooling System, and Related Components
- Air Compressor

Pump to Rail Fuel Tube Assemblies and Rail to Injector Tube Assemblies

! WARNING: To prevent personal injury or death, engine must be OFF for at least 5 minutes before doing any work on high-pressure fuel system to allow for system depressurization.

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

1. Remove fuel filter.

CAUTION: To prevent damage to engine, plug component connections immediately after each fuel line is removed using clean fuel system caps.

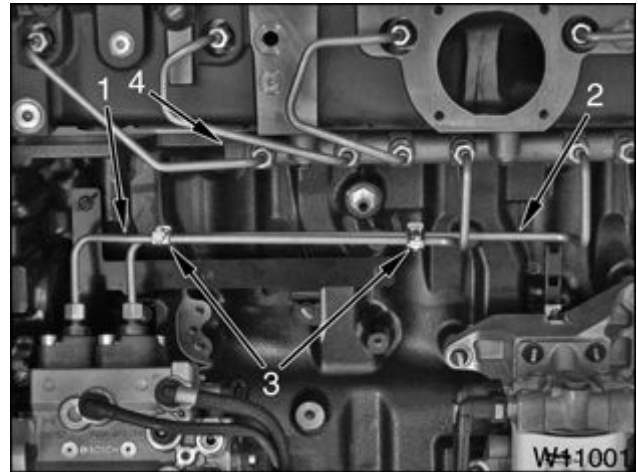


Figure 259 Pump to rail fuel tube assemblies

1. Pump to rail fuel tube assembly (Front)
2. Fuel rail
3. M6 x 20 hex flange bolt
4. Pump to rail fuel tube assembly (Rear)
5. High-pressure fuel line support
6. 3/8 x 1/2 Thread locking bolt and hardened washer
7. High-pressure fuel line clamp assembly
8. Pump to rail fuel tube clamp assembly (2)

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

2. Remove M6 x 20 hex flange bolt and high-pressure fuel line clamp assembly from pump to rail fuel tube assembly (rear).
3. Remove 3/8 x 1/2 thread locking bolt and hardened washer. Remove high-pressure fuel line support from crankcase.
4. Loosen pump to rail fuel tube assembly nuts and disconnect pump to rail fuel tube assemblies from HP fuel pump.
5. Loosen pump to rail fuel tube assembly nuts and disconnect pump to rail fuel tube assemblies from fuel rail.

! WARNING: To prevent personal injury or death, replace both pump to rail fuel tube assemblies as a set.

6. Discard the pump to rail fuel tube assemblies and pump to rail fuel tube clamp assemblies.

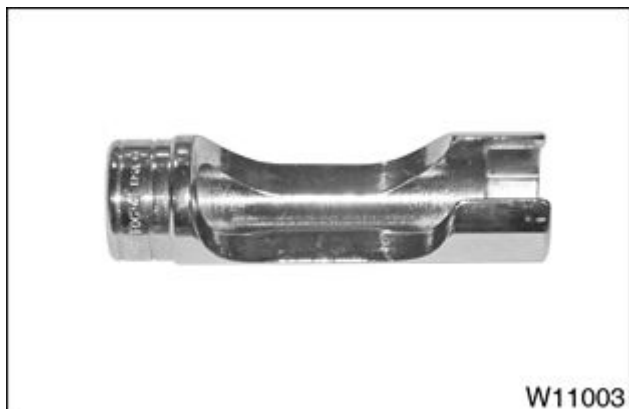


Figure 260 Fuel Line Socket

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

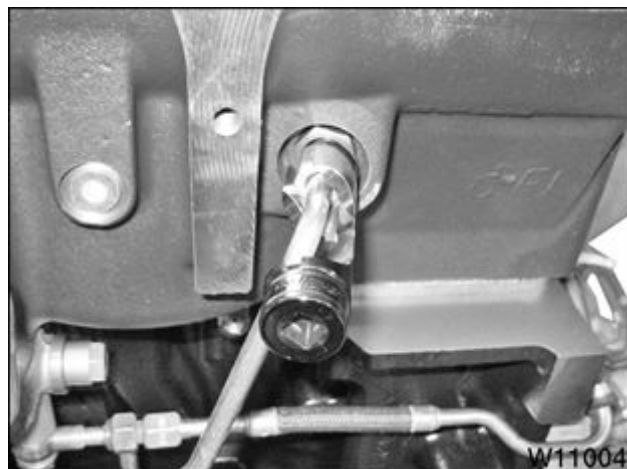


Figure 261 Rail to injector tube assembly tube nut removal (typical)

7. Using a Fuel Line Socket (page 204), loosen rail to injector tube assemblies tube nuts and disconnect rail to injector tube assemblies from HP connector assemblies.

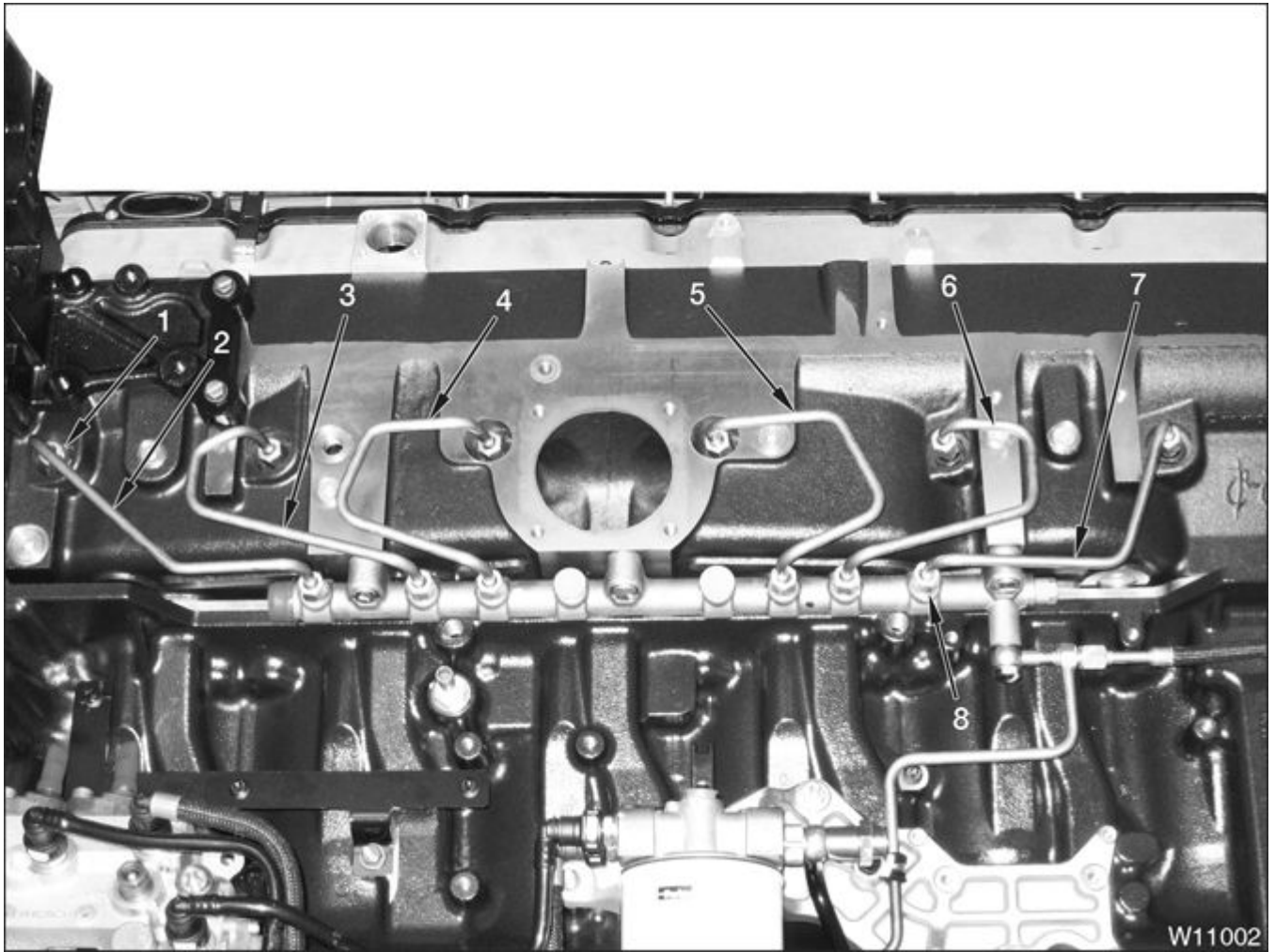


Figure 262 Rail to injector tube assemblies

1. Line tube nuts at HP connector assemblies (typical)	4. Cylinder 3 rail to injector tube assembly	7. Cylinder 6 rail to injector tube assembly
2. Cylinder 1 rail to injector tube assembly	5. Cylinder 4 rail to injector tube assembly	8. Line tube nuts at fuel rail (typical)
3. Cylinder 2 rail to injector tube assembly	6. Cylinder 5 rail to injector tube assembly	

8. Loosen rail to injector tube assemblies tube nuts and remove the rail to injector tube assemblies from fuel rail.

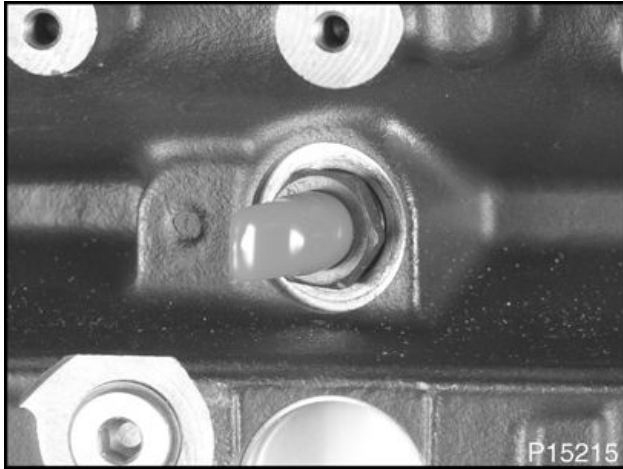


Figure 263 Fuel cap on HP connector assembly (typical)

9. Remove and discard rail to injector tube assemblies. Immediately cap open HP connector assemblies, fuel rail and high-pressure fuel pump connections with clean Disposable Air and Fuel Caps (page 204).

Fuel Rail

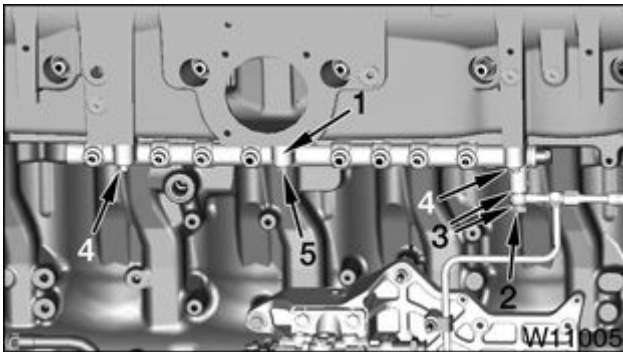


Figure 264 Fuel rail

1. Fuel rail
2. Pressure limiting valve
3. M14 hex flange banjo bolt
4. 14.7 x 22 seal ring (2)
5. 5/16-18 x 2 hex head bolt and washer (2 ea)
6. 5/16-18 x 1 1/2 hex head bolt and washer

NOTE: Pressure limiting valve is not reusable if removed from fuel rail.

1. Only if necessary, remove pressure limiting valve from fuel rail. Discard pressure limiting valve.
2. Remove the M14 hex flange banjo bolt and discard two 14.7 x 22 seal rings.
3. Remove two 5/16-18 x 2 hex head bolts, one 5/16-18 x 1 1/2 hex head bolt, three 8.8 x 17 x 1.6 washers and the fuel rail.

Fuel Return Tube Assembly

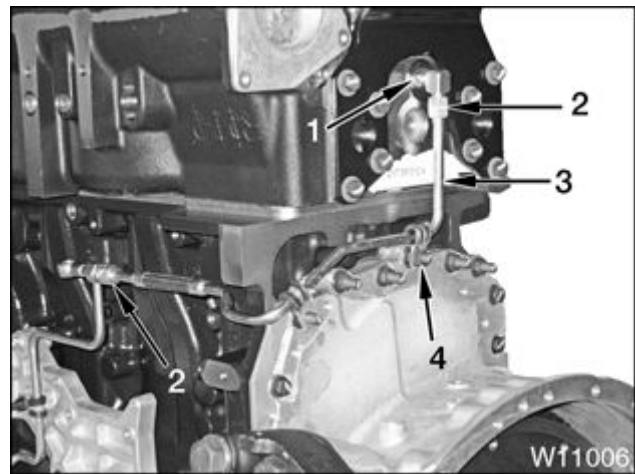


Figure 265 Fuel return tube assembly

1. 9/16-18 x 90 degree fitting assembly
2. Fuel return tube assembly tube nuts (2)
3. Fuel return tube assembly
4. 3/8-16 hex flange nut

1. Loosen fuel return tube assembly tube nuts.
2. Remove the 3/8-16 hex flange nut and the fuel return tube assembly.
3. Remove the 9/16-18 x 90 degree fitting assembly and discard the #906 O-ring.

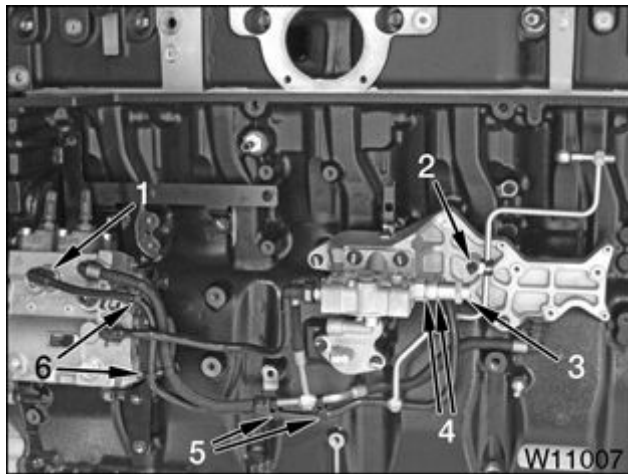


Figure 266 Fuel return to tank tube assembly

1. Fuel return to tank tube assembly HP fuel pump fitting
 2. M8 stud bolt
 3. Fuel supply adapter
 4. 14.7 x 22 seal ring (2)
 5. Wiring twice clamp (2)
 6. C clip (2)
4. Remove the fuel supply adapter and discard two seal rings.
 5. Remove two C clips from low pressure fuel lines.



Figure 267 Use of Fuel Line Disconnect Tool

6. Use Fuel Line Disconnect Tool (page 204) to disconnect all low pressure fuel line quick-connect fittings.
 - a. Slide tines of tool over release buttons on quick-connect fitting.
 - b. Pull quick-connect fitting to disconnect.
7. Disconnect the fuel return to tank tube assembly at the HP fuel pump fitting. Immediately cap openings using clean Disposable Air and Fuel Caps (page 204).
8. Release the fuel return to tank tube assembly from two wiring twice clamps.
9. Remove the M8 stud bolt and the fuel return to tank tube assembly.

Fuel Filter Housing Assembly

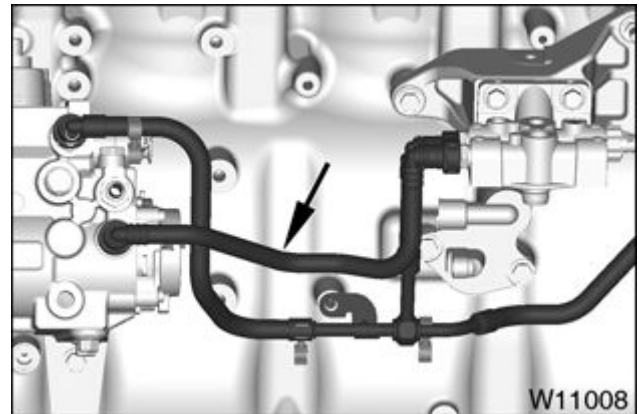


Figure 268 Fuel pump to filter tube assembly

1. Using Fuel Line Disconnect Tool (page 204), disconnect and remove Fuel pump to filter tube assembly from high-pressure fuel pump and fuel filter header assembly. Immediately cap openings using clean Disposable Air and Fuel Caps (page 204).

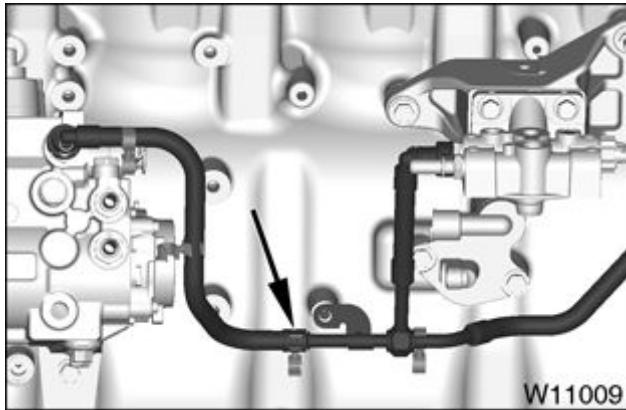


Figure 269 Fuel return tube assembly

2. If not previously removed, disconnect the fuel return tube assembly from the metering unit valve assembly. See Down Stream Injection (DSI) Assembly and Doser Fuel to Injector Tube Assembly (page 128).
3. Disconnect and remove fuel return tube assembly from high-pressure fuel pump and fuel filter header assembly. Immediately cap openings using clean Disposable Air and Fuel Caps (page 204).

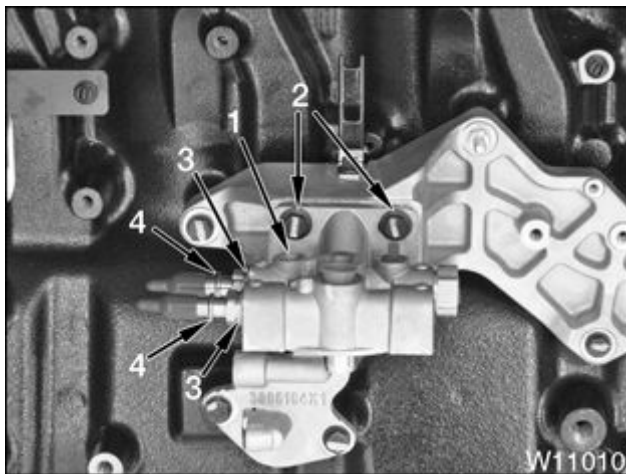


Figure 270 Fuel filter header assembly

1. Fuel filter header assembly
2. M10 x 35 hex flange bolt (2)
3. 14.7 x 22 seal ring (2)
4. M14 x 1.5 threaded union (2)

4. Remove two M10 x 35 hex flange bolts and fuel filter header assembly.
5. If fuel filter header assembly is to be replaced or fittings are found to be leaking, remove two M14 x 1.5 threaded unions from fuel filter header assembly. Discard two 14.7 x 22 ring seals.

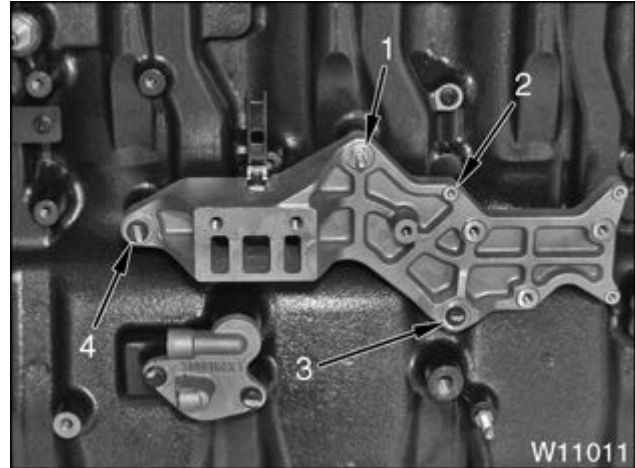
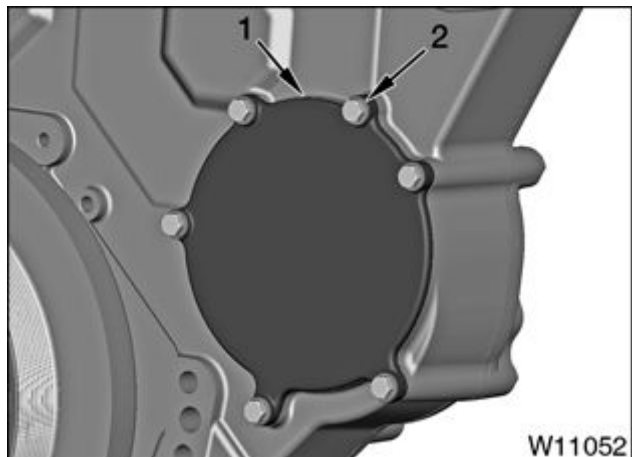


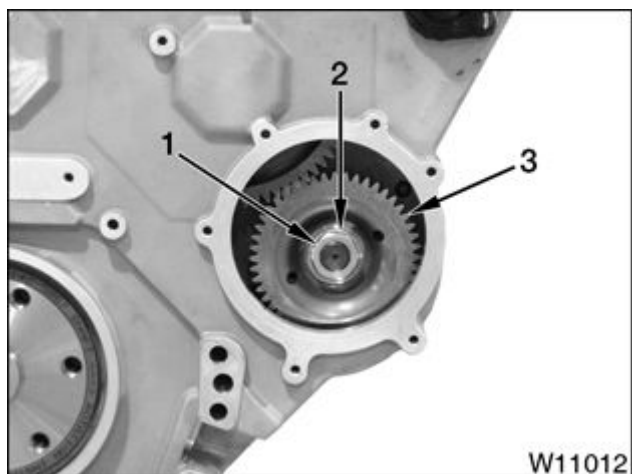
Figure 271 LP fuel system support

1. 5/16-18 stud and washer
 2. LP fuel system support
 3. 5/16-18 x 2 hex head bolt and 8.8 X 17 X 1.6 washer
 4. 3/8-16 x 2 hex head bolt and 3/8 hardened washer
6. Remove 5/16-18 stud and washer, 5/16-18 x 2 hex head bolt and 8.8 x 17 x 1.6 mm washer, 3/8-16 x 2 hex head bolt and 3/8 hardened washer and LP fuel system support.

High-Pressure Fuel Pump**Figure 272 High-pressure pump gear cover plate**

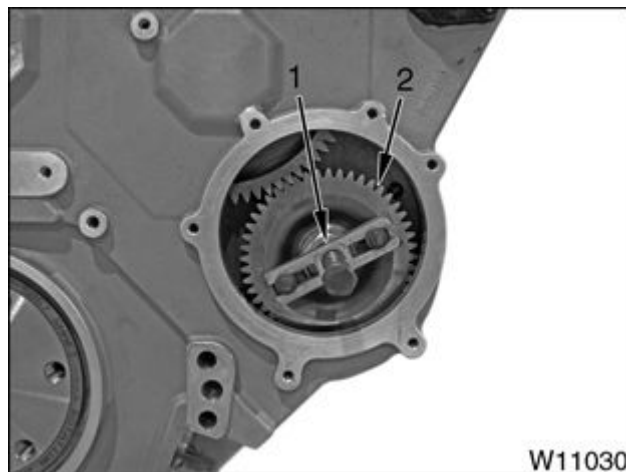
1. Cover plate
2. 5/16 x 18 x 1 hex flange bolt (6)

1. Remove six 5/16 x 18 x 1 hex flange bolts and the cover plate.
2. Remove and discard the 6.102 x 0.140 O-ring from cover plate.

**Figure 273 High-pressure pump gear**

1. M24 hex jam nut
2. M25 x 44 x 4 washer
3. High-pressure pump gear

3. Remove M24 hex jam nut and M25 x 44 x 4 washer. Reinstall the M24 hex jam nut 2 turns.

**Figure 274 High-pressure pump gear and H-bar puller**

1. H-bar puller
2. High-pressure pump gear

4. Use H-bar puller (page 204) to remove the high-pressure pump gear from the high-pressure fuel pump.
5. Remove the H-bar puller.
6. Remove the M24 hex jam nut.

NOTE: The high-pressure pump gear will be removed from inside of engine front cover after the high-pressure pump is removed from rear of front cover.

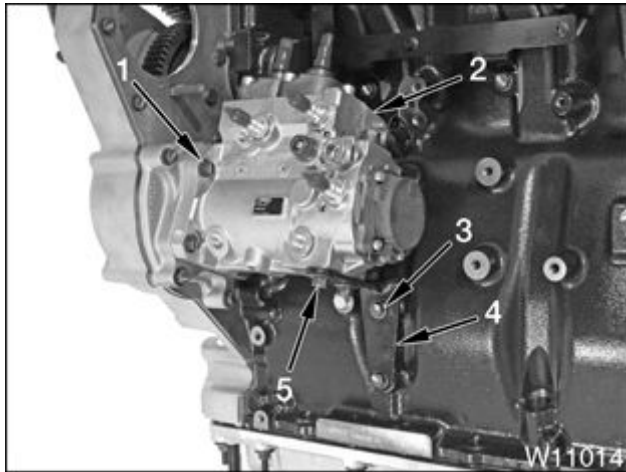


Figure 275 High-pressure fuel pump

1. M10 x 40 hex flange bolt and plain washer (4 ea)
 2. M16 x 1.5 quick connect connector (3)
 3. M16 x 1.5 female connector
 4. High-pressure fuel pump
 5. 3/8-16 x 7/8 hex head bolt and 3/8 hardened washer (2 ea)
 6. High-pressure pump support
 7. M12 x 30 hex flange bolt (2)
7. Remove two 3/8-16 x 7/8 hex head bolts, two 3/8 hardened washers, two M12 x 30 hex flange bolts and the high-pressure pump support.
 8. Remove four M10 x 40 hex flange bolts and four plain washers and the high-pressure fuel pump.
 9. Remove and discard the 100 x 3.349 O-ring from high-pressure fuel pump.
 10. Remove the high-pressure pump gear from inside the engine front cover.
- NOTE:** If high-pressure fuel pump is to be replaced or fittings are found to be leaking, continue with step 11.
11. If required, remove three M16 x 1.5 quick connect connectors and the M16 x 1.5 female connector from high-pressure fuel pump. Discard four 16.7 x 24 ring seals.

Cleaning and Inspection

1. Inspect low pressure fuel lines for kinks, obstructions or other damage. Replace if necessary.
2. Inspect low pressure fuel line quick-connect fitting O-ring seals for damage. Replace low pressure fuel lines if necessary.
3. Inspect fuel filter header assembly for damage. Replace if necessary.
4. Inspect high-pressure fuel pump input shaft and gear for wear or damage. Replace if necessary.

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

5. Clean outside surfaces of low pressure fuel lines, and fuel filter header assembly with a suitable non-caustic solvent. Dry with filtered compressed air.

Installation

High-Pressure Fuel Pump

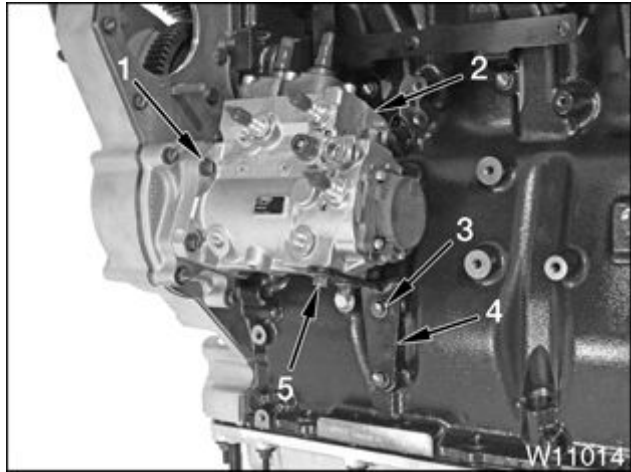


Figure 276 High-pressure fuel pump

1. M10 x 40 hex flange bolt and plain washer (4 ea)
 2. M16 x 1.5 quick connect connector (3)
 3. M16 x 1.5 female connector
 4. High-pressure fuel pump
 5. 3/8-16 x 7/8 hex head bolt and 3/8 hardened washer (2 ea)
 6. High-pressure pump support
 7. M12 x 30 hex flange bolt (2)
1. If removed, install three M16 x 1.5 quick connect connectors and the M16 x 1.5 female connector with four new 16.7 x 24 ring seals on high-pressure fuel pump. Tighten the M16 x 1.5 quick connect connectors and the M16 x 1.5 female connector to special torque (page 204).
 2. Install a new 100 x 3.349 O-ring on front of high-pressure fuel pump. Ensure the O-ring is properly seated in the respective groove before tightening the bolts.
 3. Install two High-Pressure Pump Alignment Studs (page 204) in the high-pressure pump adapter.
 4. Position the high-pressure fuel pump on the High-Pressure Pump Alignment Studs (page 204) through the engine front cover.
 5. Clean oil residue from bolt threads with non-chlorinated solvent. Apply Loctite® 242 (page 204) to threads on M10 x 40 hex flange bolts.

6. Install two plain washers and two M10 x 40 hex flange bolts. Tighten hex flange bolts to standard torque (page 561).
7. Remove two High-Pressure Pump Alignment Studs (page 204) from the high-pressure pump adapter.
8. Install two plain washers and two M10 x 40 hex flange bolts. Tighten hex flange bolts to standard torque (page 561).
9. Clean oil residue from bolt threads with non-chlorinated solvent. Apply Loctite® 242 (page 204) to threads on 3/8-16 x 7/8 bolts and M12 x 30 hex flange bolts.
10. Position the high-pressure pump support and install two 3/8 hardened washers, two 3/8-16 x 7/8 hex head bolts and two M12 x 30 hex flange bolts. Tighten the two 3/8-16 x 7/8 hex head bolts and two M12 x 30 hex flange bolts to special torque (page 204).

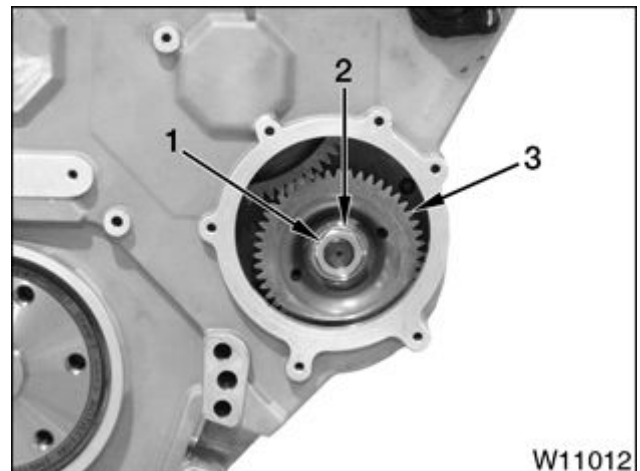


Figure 277 High-pressure pump gear

1. M24 hex jam nut
 2. M25 x 44 x 4 washer
 3. High-pressure pump gear
11. Position high-pressure pump gear on the high-pressure fuel pump shaft.
 12. Install M25 x 44 x 4 washer and M24 hex jam nut. Tighten M24 hex jam nut to special torque (page 204).
 13. Lubricate the high-pressure pump gear with 90 W gear oil (page 204).

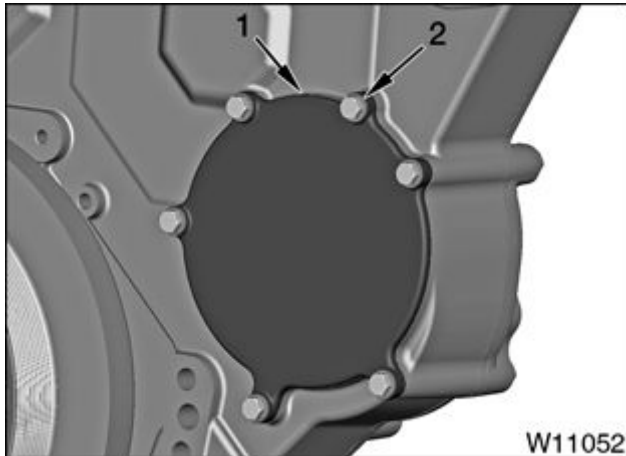


Figure 278 High-pressure pump gear cover plate

1. Cover plate
2. 5/16 x 18 x 1 hex flange bolt (6)

14. Install a new 6.102 x 0.140 O-ring into the cover plate groove.

15. Install the cover plate and six 5/16 x 18 x 1 hex flange bolts. Tighten bolts to standard torque (page 562).

Fuel Filter Housing Assembly

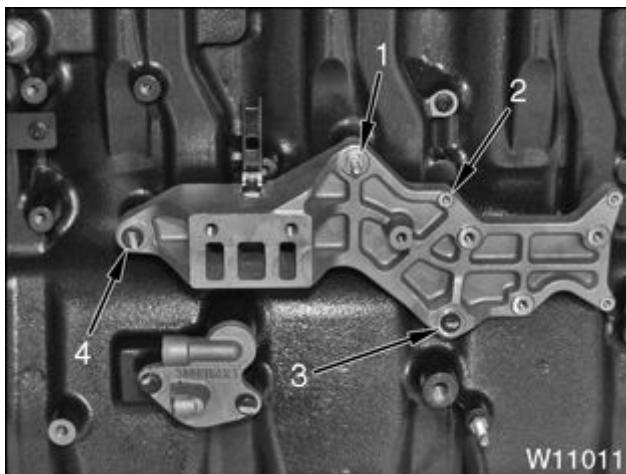


Figure 279 LP fuel system support

1. 5/16-18 stud and washer
2. LP fuel system support
3. 5/16-18 x 2 hex head bolt and 8.8 X 17 X 1.6 washer
4. 3/8-16 x 2 hex head bolt and 3/8 hardened washer

1. Position the LP fuel system support and install 5/16-18 stud and washer, 5/16-18 x 2 hex head bolt and 8.8 x 17 x 1.6 mm washer, 3/8-16 x 2 hex head bolt and 3/8 hardened washer. Tighten hex head bolts and stud to standard torque (page 562).

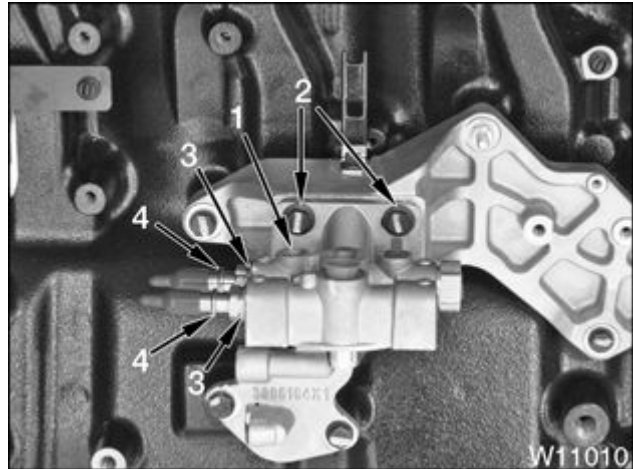


Figure 280 Fuel filter header assembly

1. Fuel filter header assembly
2. M10 x 35 hex flange bolt (2)
3. 14.7 x 22 seal ring (2)
4. M14 x 1.5 threaded union (2)

2. Position fuel filter header assembly and install two M10 x 35 hex flange bolts. Tighten hex flange bolts to special torque (page 204).

3. If fuel filter header assembly was replaced or fittings were found to be leaking, lubricate with clean fuel and install two new 14.7 x 22 seal rings and two M14 x 1.5 threaded unions to fuel filter header assembly. Tighten the M14 x 1.5 threaded unions to special torque (page 204).

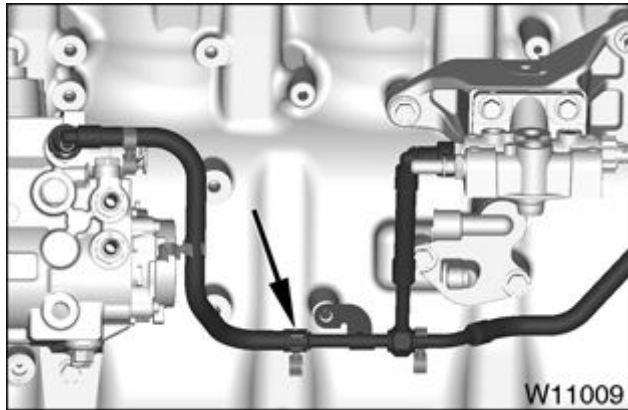


Figure 281 Fuel return tube assembly

NOTE: The fuel return tube assembly connectors will seat with an audible click. Verify connection by pulling on connector.

4. Connect fuel return tube assembly to high-pressure fuel pump and fuel filter header assembly.
5. If required, connect fuel return tube assembly to metering unit valve assembly.

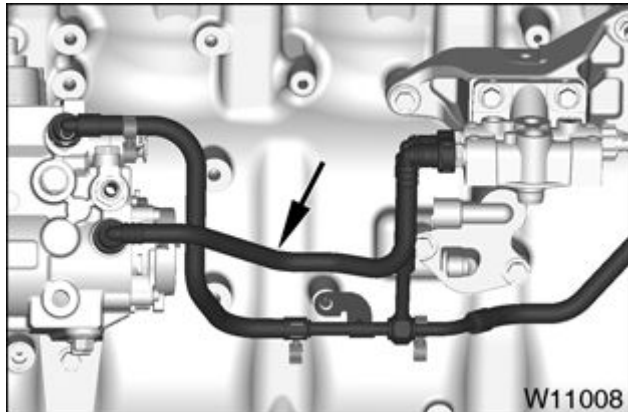


Figure 282 Fuel pump to filter tube assembly

NOTE: The Fuel pump to filter tube assembly connectors will seat with an audible click. Verify connection by pulling on connector.

6. Connect Fuel pump to filter tube assembly to high-pressure fuel pump and fuel filter header assembly.

Fuel Return to Tank Tube Assembly

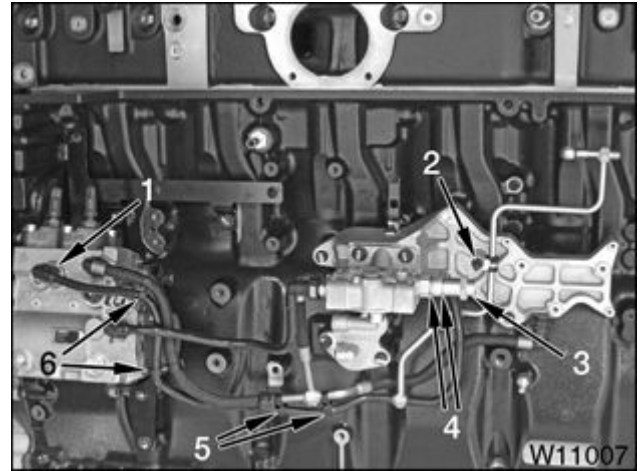


Figure 283 Fuel return to tank tube assembly

1. Fuel return to tank tube assembly HP fuel pump fitting
 2. M8 stud bolt
 3. Fuel supply adapter
 4. 14.7 x 22 seal ring (2)
 5. Wiring twice clamp (2)
 6. C clip (2)
1. Position fuel return to tank tube assembly and loosely install the M8 stud bolt.
 2. Secure the fuel return to tank tube assembly with two wiring twice clamps and two C clips.
 3. Connect the fuel return to tank tube assembly to HP fuel pump fitting.
 4. Position two new 14.7 x 22 seal rings and install the fuel supply adapter. Tighten fuel supply adapter to special torque (page 204).

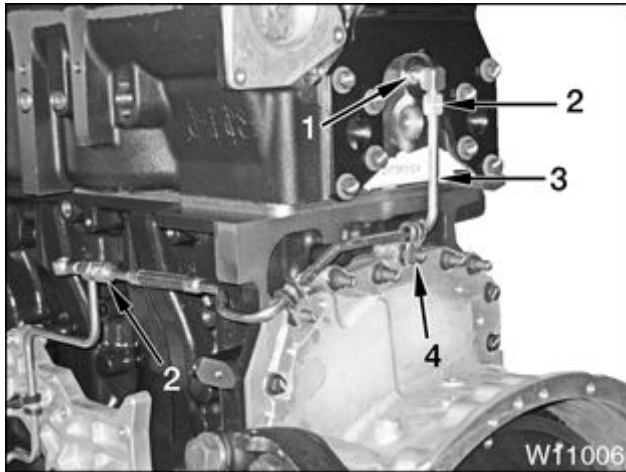


Figure 284 Fuel return tube assembly

1. 9/16-18 x 90 degree fitting assembly
 2. Fuel return tube assembly tube nuts (2)
 3. Fuel return tube assembly
 4. 3/8-16 hex flange nut
5. Install a new #906 O-ring on the 9/16-18 x 90 degree fitting assembly.
 6. Install the 9/16-18 x 90 degree fitting assembly. Loosely tighten the 9/16-18 x 90 degree fitting lock nut.
 7. Position the fuel return tube assembly and install 3/8-16 hex flange nut. Tighten hex flange nut to standard torque (page 562).
- NOTE:** Use a backup wrench when tightening fuel return tube assembly tube nuts.
8. Tighten fuel return tube assembly tube nuts. Tighten fuel return assembly tube nuts to special torque (page 204).
 9. Tighten 9/16-18 x 90 degree fitting lock nut to special torque (page 204).

Fuel Rail

NOTE: If replacing a single rail to injector tube assembly, see Rail to Injector Tube Assemblies (page 201).

NOTE: If replacing a single pump to rail fuel tube assembly, see Pump to Rail Fuel Tube Assemblies (page 202).

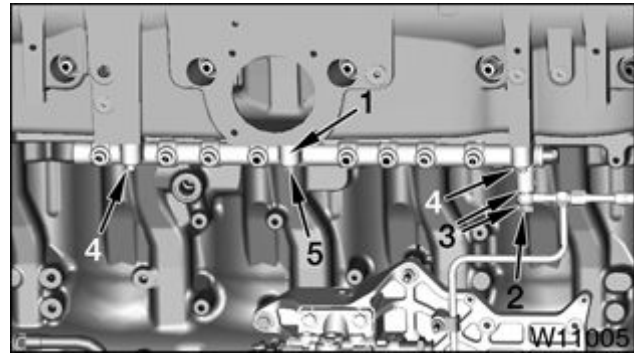
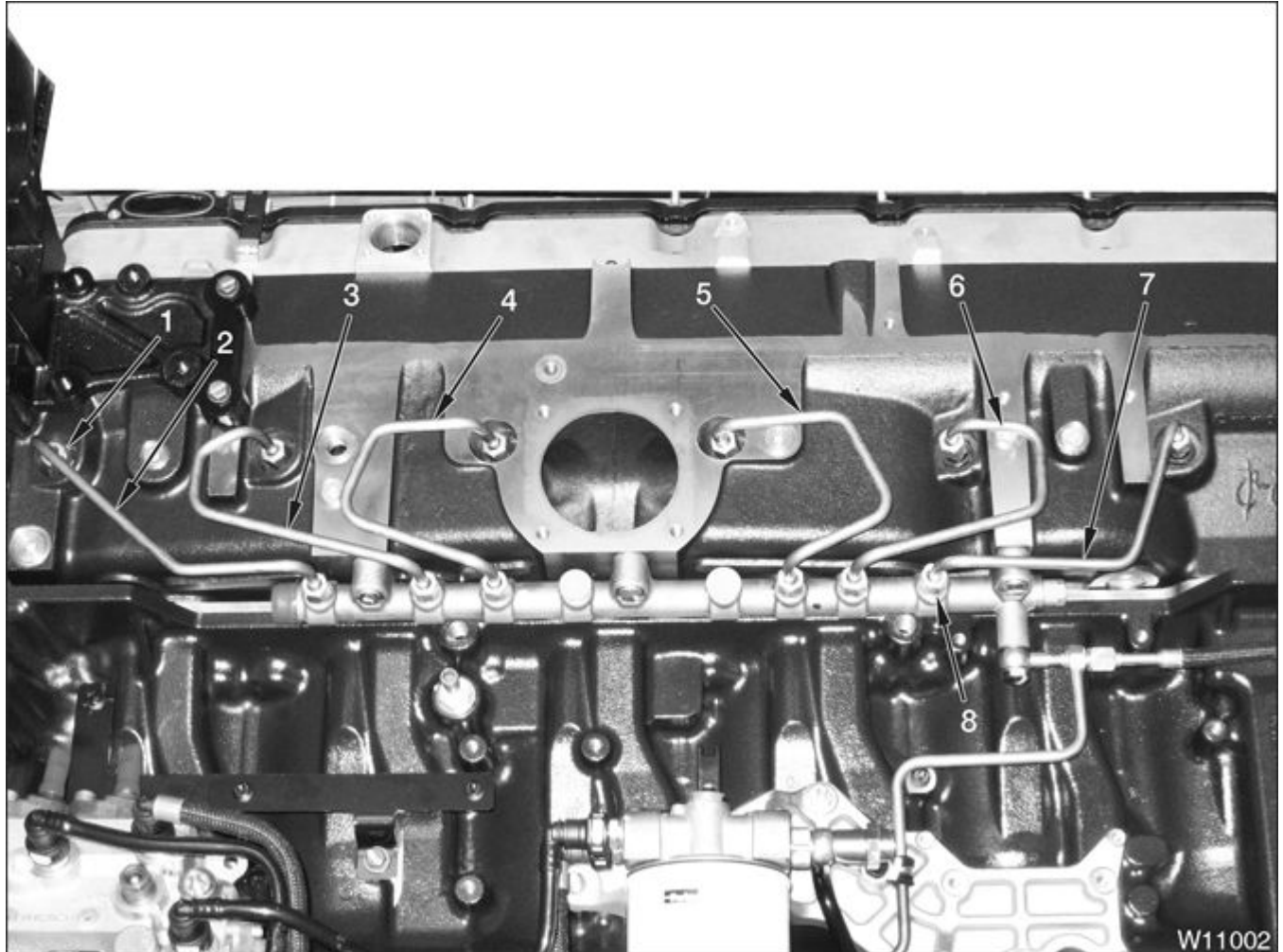


Figure 285 Fuel rail

1. Fuel rail
 2. Pressure limiting valve
 3. M14 hex flange banjo bolt
 4. 14.7 x 22 seal ring (2)
 5. 5/16-18 x 2 hex head bolt and washer (2 ea)
 6. 5/16-18 x 1 1/2 hex head bolt and washer
1. Apply Loctite® 242 (page 204) to threads on 5/16-18 x 2 hex head bolts and 5/16-18 x 1 1/2 hex head bolt.
- NOTE:** Final tightening of fuel rail hex head bolts will be done after installation of rail to injector tube assemblies and pump to rail fuel tube assemblies.
2. Position the fuel rail and install three 8.8 x 17 x 1.6 washers, two 5/16-18 x 2 hex head bolts, one 5/16-18 x 1 1/2 hex head bolt. Only hand tighten the fuel rail hex head bolts at this time.
 3. Position two new 14.7 x 22 seal rings (one on each side of banjo on fuel return to tank tube assembly) and install the M14 hex flange banjo bolt. Tighten M14 hex flange banjo bolt to special torque (page 204).
 4. Tighten the fuel drain tube M8 stud bolt (Figure 283) (item 2) to standard torque (page 561).
 5. If removed, install new pressure limiting valve. Lubricate threads and O-ring with clean diesel fuel and install pressure limiting valve finger tight.
 6. Tighten pressure limiting valve to special torque (page 204).

Rail to Injector Tube Assemblies

**Figure 286 Rail to injector tube assemblies**

1. Line tube nuts at HP connector assemblies (typical)	4. Cylinder 3 rail to injector tube assembly	7. Cylinder 6 rail to injector tube assembly
2. Cylinder 1 rail to injector tube assembly	5. Cylinder 4 rail to injector tube assembly	8. Line tube nuts at fuel rail (typical)
3. Cylinder 2 rail to injector tube assembly	6. Cylinder 5 rail to injector tube assembly	

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

NOTE: If replacing a single fuel rail to injector tube assembly, the fuel rail bolts should not be loosened.

1. If replacing more than one rail to injector tube assembly, loosen the fuel rail mounting bolts to allow the fuel rail to move horizontally.
2. Place new rail to injector tube in position on mating port and check for proper alignment at both ends. If gross misalignment (more than 2 mm [0.08 in] off center) exists, do not use tube.

Minor misalignment is allowed due to the spring back nature of the tube.

3. Install new rail to injector tube assembly(ies) to appropriate cylinder(s). Hold tube assembly firmly against inner mating cone and tighten the rail to injector tube nuts at the fuel rail and then the rail to injector tube nuts at the high-pressure connector assemblies finger tight.

NOTE: Before applying final torque, make sure the tube is centered relative to the tube nuts.

4. Tighten the rail to injector tube assembly nuts at the fuel rail to special torque (page 204).

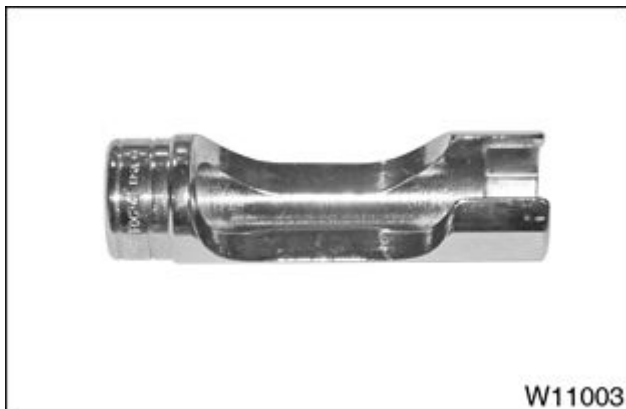


Figure 287 Fuel Line Socket

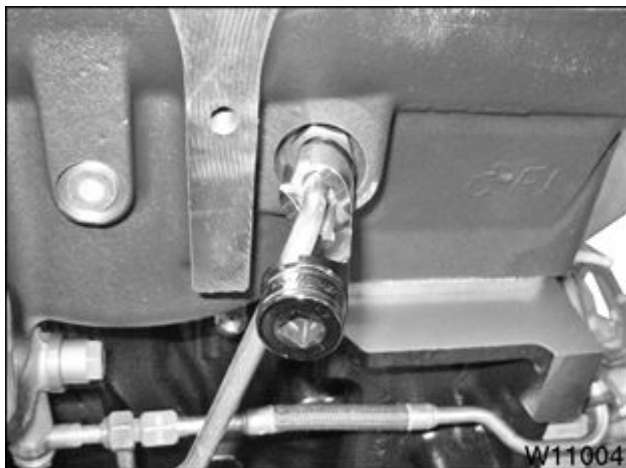


Figure 288 Rail to injector tube assembly tube nut (typical)

5. Using a Fuel Line Socket (page 204), tighten the rail to injector tube assembly nuts at the high-pressure connector to special torque (page 204).
6. If fuel rail hex head bolts were loosened, remove each bolt one at a time and re-apply Loctite® 242 (page 204) to bolt threads. Tighten the three fuel rail hex head bolts to special torque (page 204).

Pump to Rail Fuel Tube Assemblies

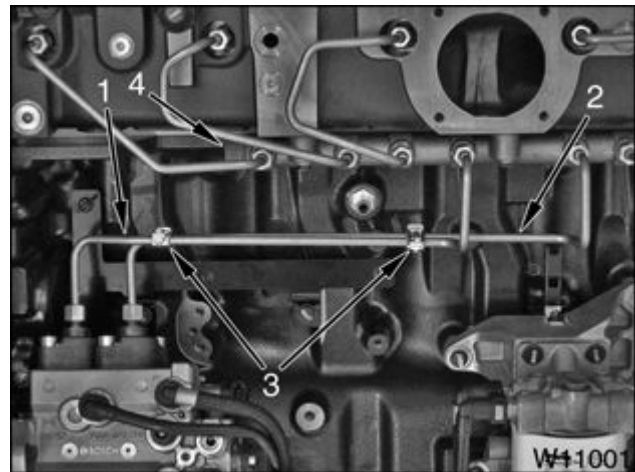


Figure 289 Pump to rail fuel tube assemblies

1. Pump to rail fuel tube assembly (Front)
2. Fuel rail
3. M6 x 20 hex flange bolt
4. Pump to rail fuel tube assembly (Rear)
5. High-pressure fuel line support
6. 3/8 x 1/2 Thread locking bolt and hardened washer
7. High-pressure fuel line clamp assembly
8. Pump to rail fuel tube clamp assembly (2)

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

⚠ WARNING: The new pump to rail fuel tube assemblies come as a set with new pump to rail fuel tube clamp assemblies already installed. If either of the new pump to rail fuel tube assemblies cannot be installed without forcing the ends into place, order a new pump to rail fuel tube assembly.

⚠ WARNING: To prevent personal injury or death, do not scratch the new pump to rail fuel tube assembly when marking the pump to rail fuel tube clamp assembly locations.

NOTE: If minor adjustment between tubes is required, mark the pump to rail fuel tube clamp assembly positions with a permanent marker prior to loosening. Install clamps in original locations.

1. Install the new pump to rail fuel tube assemblies and observe the following:
 - Check for proper alignment of tube ends with inner mating cones at fuel pump and fuel rail
 - Minor adjustment may be necessary by loosening the pump to rail fuel tube clamp assemblies
 - If gross misalignment (more than 2 mm [0.08 in] off center) exists on any one of the pump to rail fuel tube assemblies, order a new pump to rail fuel tube assembly
- Hold tube assembly firmly against inner mating cone and tighten the pump to rail fuel tube nuts at the fuel rail and then the tube nuts at the high-pressure fuel pump finger tight
2. Tighten the pump to rail fuel line assembly tube nuts at the fuel rail to special torque (page 204).
3. If pump to rail fuel tube clamp screws were loosened, tighten screws to special torque (page 204).
4. Tighten the pump to rail fuel line assembly tube nuts at the high-pressure fuel pump to special torque (page 204).
5. Install high-pressure fuel line clamp assembly on pump to rail fuel tube assembly (rear).
6. Install high-pressure fuel line support on crankcase with 3/8 x 1/2 thread locking bolt and hardened washer. Tighten bolt to 54 N·m (40 lbf·ft) and back it out 50°.
7. Attach high-pressure fuel line clamp assembly to high-pressure fuel line support with M6 x 20 hex flange bolt. Tighten bolt finger tight.
8. Tighten 3/8 x 1/2 thread locking bolt to 54 N·m (40 lbf·ft) and M6 x 20 hex flange bolt to 13 N·m (114 lbf·ft). Ensure high-pressure fuel line clamp assembly and high-pressure fuel line support remain in correct positions.

Specifications

Fuel filter filtration	4 microns

Special Torque

3/8–16 x 7/8 hex head bolt (high-pressure pump support)	48 N·m (35 lbf·ft)
9/16–18 x 90 degree fitting lock nut	37 N·m (27 lbf·ft)
Fuel filter header assembly M10 x 35 hex flange bolts	55 N·m (41 lbf·ft)
Fuel return assembly tube nuts	29 N·m (21 lbf·ft)
Fuel rail hex head bolts	30 N·m (22 lbf·ft)
Fuel supply adapter	30 N·m (22 lbf·ft)
M12 x 30 hex flange bolt (high-pressure pump support)	105 N·m (77 lbf·ft)
M14 hex flange banjo bolt	30 N·m (22 lbf·ft)
M14 x 1.5 threaded unions	30 N·m (22 lbf·ft)
M16 x 1.5 female connector	58 N·m (43 lbf·ft)
M16 x 1.5 quick connect connectors	58 N·m (43 lbf·ft)
M24 hex jam nut	285 N·m (210 lbf·ft)
Pressure limiting valve	110 N·m (81 lbf·ft)
Pump to rail fuel tube assembly clamp screws	5 N·m (44 lbf·in)
Pump to rail fuel tube assembly nuts	22.5 N·m (16.5 lbf·ft) + 90°
Rail to injector tube assembly nuts	22.5 N·m (16.5 lbf·ft) + 90°

Special Service Tools

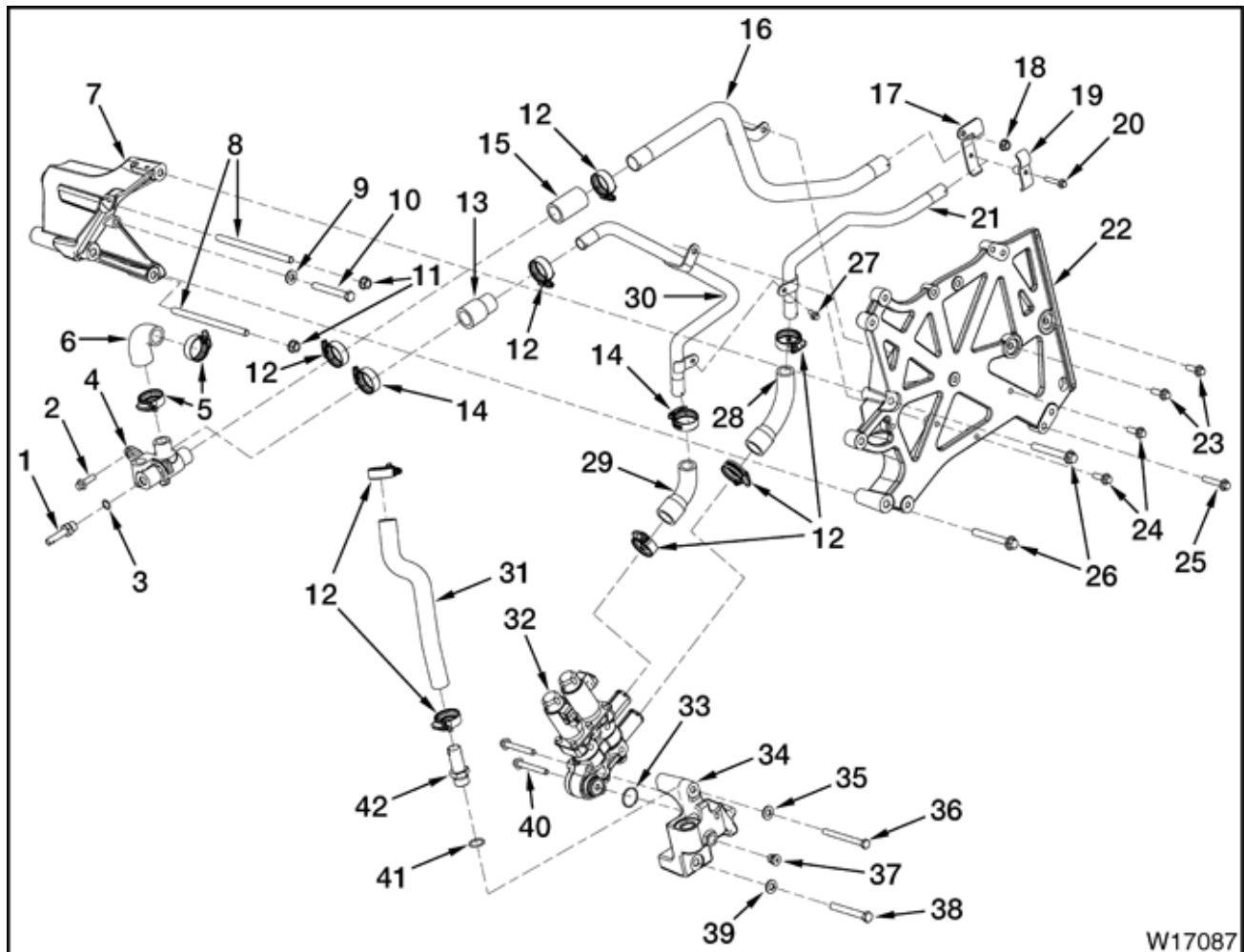
Description	Tool Number
90 W Gear Oil	Obtain locally
Disposable Air and Fuel Caps	ZTSE4891
Fuel Line Disconnect Tool	ZTSE4773
Fuel Line Socket	Snap-on FRX241
H-bar puller	Obtain locally
High-Pressure Pump Alignment Studs	ZTSE6099
Loctite® 242	Obtain locally

Table of Contents

Exploded Views.....	207
Removal.....	214
EGR Cooler Assembly Draining.....	214
Coolant Manifold, ISC Coolant Supply Tube Assembly and CCV LTR Bypass Tube Assembly.....	215
Coolant Control Valve (CCV) Assembly and Coolant Adapter.....	217
Heater Core Return Adapter and Temperature Sensor Fitting.....	218
Intercooler Support (Inner).....	218
EGRV Coolant Return Tube and EGRV Coolant Supply Tube.....	219
EGR Coolant Tube Assembly (front) and EGR2 Coolant Supply Tube Assembly.....	221
EGR Coolant Tube Assembly (rear), EGR Coolant Tube Assembly and EGR Tube Assembly.....	222
Coolant Adapter and EGR Coolant Return Tube Assembly.....	223
EGR Crossover Tube.....	224
EGR Cooler Inlet Elbow.....	225
EGR Cooler Supply Tube and EGR Valve Assembly.....	226
EGR Cooler Assembly.....	227
EGR Cooler Supports.....	228
Cleaning, Inspection, and Testing.....	229
Exhaust Gas Recirculation (EGR) System Components.....	229
EGR Valve Assembly.....	229
EGR Cooler Assembly Pressure Test.....	230
Tool Assembly.....	230
Tool Installation.....	232
EGR Cooler Leak Test.....	235
Tool Removal.....	237
Installation.....	239
EGR Cooler Supports.....	239
EGR Cooler Assembly.....	240
EGR Cooler Supply Tube and EGR Valve Assembly.....	241
EGR Cooler Inlet Elbow.....	242
EGR Crossover Tube.....	243
Coolant Adapter and EGR Coolant Return Tube Assembly.....	244
EGR Coolant Tube Assembly (rear), EGR Coolant Tube Assembly and EGR Tube Assembly.....	245
EGR Coolant Tube Assembly (front) and EGR2 Coolant Supply Tube Assembly.....	247
EGRV Coolant Return Tube and EGRV Coolant Supply Tube.....	249
Intercooler Support (Inner).....	251
Heater Core Return Adapter and Temperature Sensor Fitting.....	251
Coolant Control Valve (CCV) Assembly and Coolant Adapter.....	252
Coolant Manifold, ISC Coolant Supply Tube Assembly and CCV LTR Bypass Tube Assembly.....	253
Specifications.....	255

Special Torque.....	255
Special Service Tools.....	255

Exploded Views



W17087

Figure 290 Interstage Cooler (ISC) support and coolant lines

1. Hose fitting	16. ISC coolant supply tube assembly	30. CCV LTR bypass tube assembly
2. M8 x 25 hex flange bolt	17. EGR tube support assembly	31. CCV coolant supply hose assembly
3. O-ring	18. M8 hex flange nut	32. Coolant Control Valve (CCV) assembly
4. Coolant manifold	19. EGR tube clamp	33. O-ring (26 x 2.0)
5. SAE 16 clamp (2)	20. M6 x 35 hex flange bolt	34. Coolant adapter
6. HPCAC supply and return hose	21. CCV LTR supply tube assembly	35. 8.8 x 17 x 1.6 washer
7. Intercooler support (inner)	22. Intercooler support (outer)	36. 5/16-18 x 3 1/2 hex bolt
8. 3/8-16 x 6 1/2 taper lock stud (2)	23. M8 x 25 hex flange bolt (2)	37. Plug assembly
9. 3/8 hardened washer	24. M8 x 30 hex flange bolt (2)	38. 3/8-16 x 3 hex bolt
10. 3/8-16 x 3 hex bolt	25. M8 x 45 hex flange bolt	39. 10.2 x 18.5 hardened washer
11. 3/8-16 hex flange nut (2)	26. M8 x 80 hex flange bolt (2)	40. M8 x 60 hex flange bolt (2)
12. SAE 15/16 left clip clamp (8)	27. M6 x 16 hex flange bolt	41. O-ring (3-910)
13. Adapter hose	28. 3/4 to 1 inch elbow hose (lower)	42. Hose fitting
14. SAE 16 clamp (2)	29. 3/4 to 1 inch elbow hose (upper)	
15. 24.6 x 52 coolant hose		

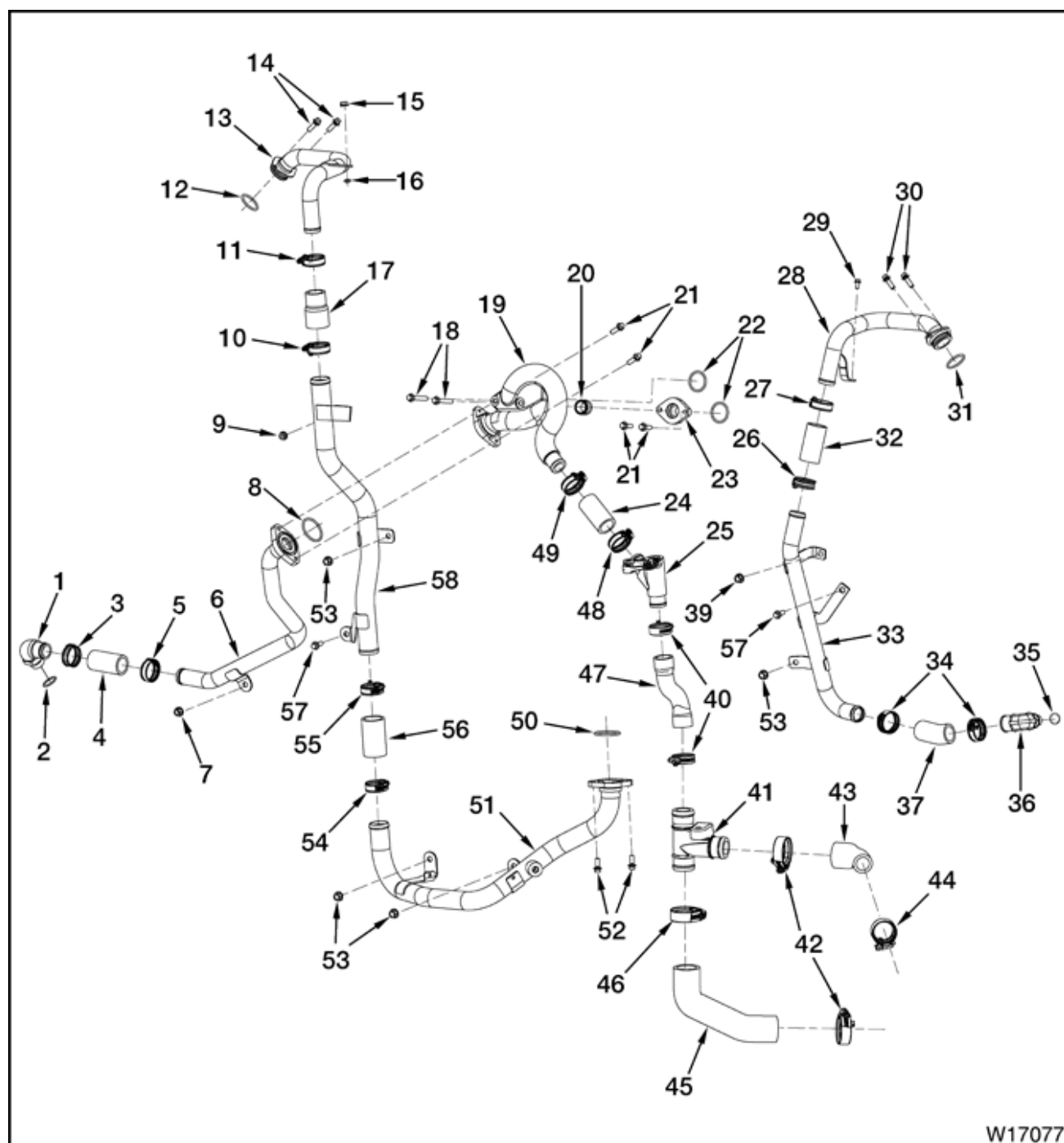


Figure 291 EGR cooler coolant lines

-
1. 1 3/16-12 x 1 1/4 hose elbow	20. EGR coolant tube seal	39. M10 hex flange nut
2. O-ring	21. M8 x 25 hex flange bolt (4)	40. Clamp SAE 24 (2)
3. SAE 24 left clip clamp	22. O-ring seal (2)	41. Temperature sensor fitting
4. Coolant hose	23. Coolant tube adapter	42. SAE 24 Clamp (2)
5. SAE 24 clamp	24. EGR coolant hose assembly	43. LPCAC coolant return hose
6. EGR coolant return tube assembly	25. Heater core return adapter	44. SAE 6 clamp
7. 3/8 hex flange nut	26. SAE 24 left clip clamp	45. Formed 1.2 inch hose
8. O-ring seal (2-225)	27. SAE 24 clamp	46. SAE 24 left clip clamp
9. M8 hex flange nut	28. EGR coolant tube assembly	47. Heater core return hose
10. SAE 24 left clip clamp	29. M6 x 12 hex flange bolt	48. SAE 24 clamp
11. SAE 24 clamp	30. M8 x 25 hex flange bolt (2)	49. SAE 24 left clip clamp
12. O-ring seal (2-221)	31. O-ring seal (2-221)	50. O-ring seal (2-225)
13. EGR coolant tube assembly (rear)	32. 31.75 x 69 coolant hose	51. EGR tube assembly
14. M8 x 25 hex flange bolt (2)	33. EGR2 coolant supply tube assembly	52. M8 x 20 hex flange bolt (2)
15. M8 hex flange nut	34. Clamp SAE 24 (2)	53. 3/8-16 hex flange nut (4)
16. 8.8 x 16 x 2 hardened washer	35. O-ring	54. SAE 24 left clip clamp
17. Adapter hose	36. 90 degree fitting assembly (on water pump outlet pipe)	55. SAE 24 clamp
18. M8 x 55 hex flange bolt (2)	37. 1 1/4 inch formed hose	56. 37.1 x 77 coolant hose
19. EGR cooler adapter assembly	38. M8 x 20 hex flange bolt	57. M8 x 20 hex flange bolt (2)
		58. EGR coolant tube assembly
-

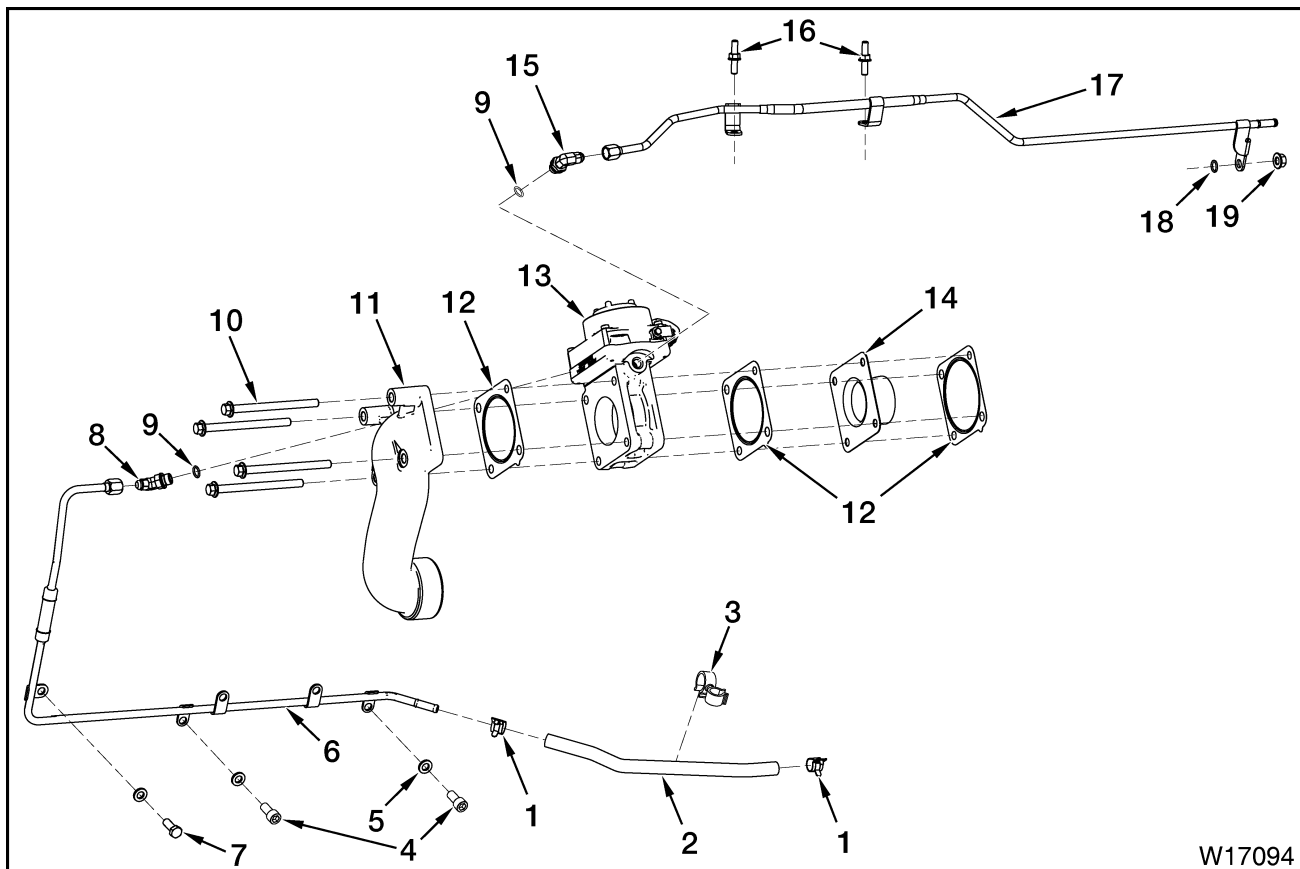
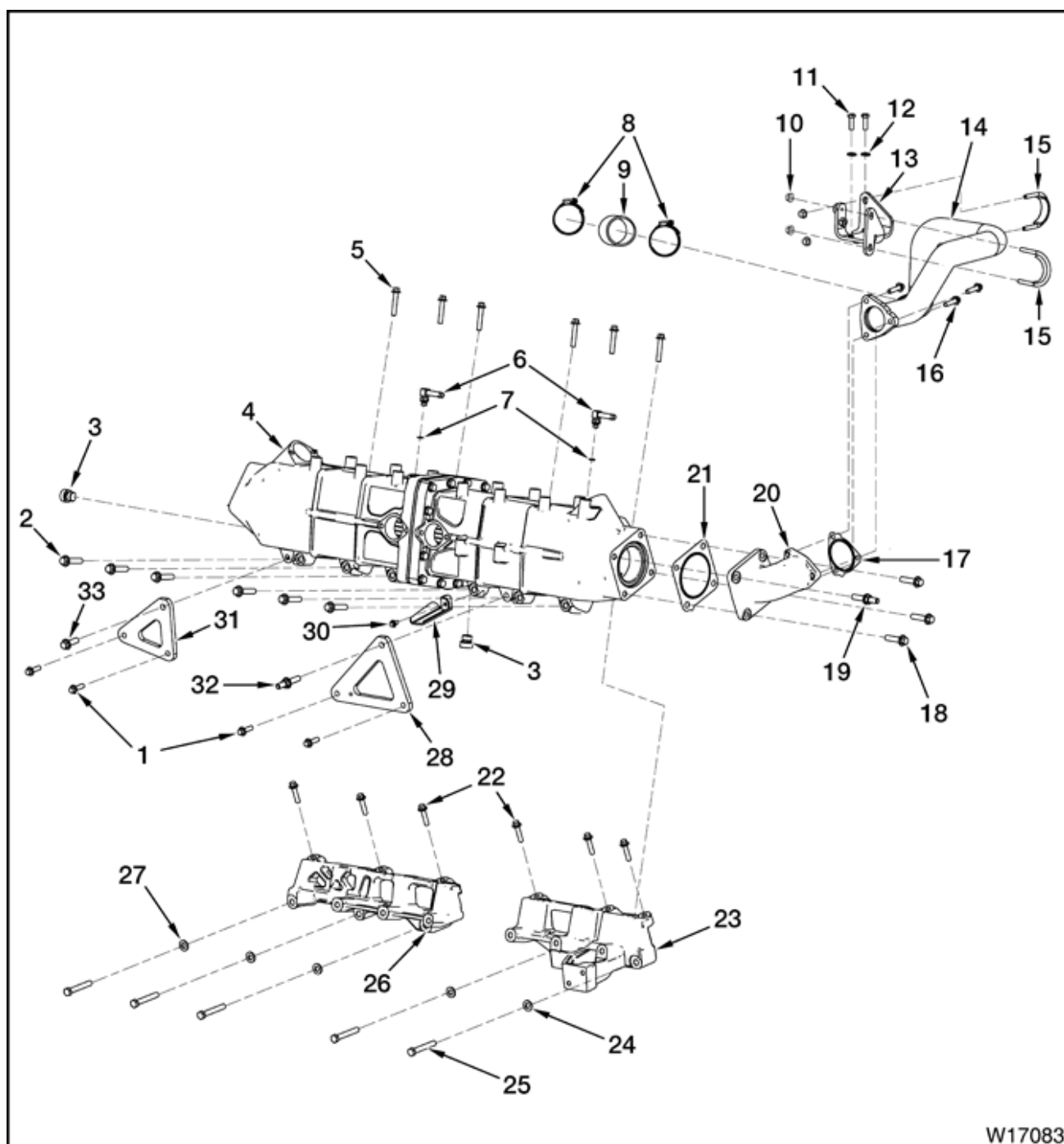


Figure 292 EGR valve and coolant lines

1. 3/8 CTB clamp (2)	7. 3/8-16 x 1 bolt	14. EGRC inlet gas shield
2. EGRV coolant supply hose	8. Fitting (45 degree)	15. M14 37 degree flare fitting (90 degree)
3. C clip	9. O-ring (M14) (2)	16. M8 stud bolt (2)
4. 3/8-16 x 3/4 socket head screw (2)	10. M10 x 130 high temp bolt (4)	17. EGRV coolant return tube
5. 10.2 x 18.5 hardened washer (3)	11. EGR cooler supply tube	18. 10.8 x 21 x 2.5 washer
6. EGRV coolant supply tube	12. EGR gasket (3)	19. M10 hex flange nut
	13. EGR valve assembly	

This page left intentionally blank



W17083

Figure 293 EGR cooler assemblies

-
1. M8 x 27 high temp bolt (4)	12. 5/16 hardened washer (2)	23. EGR cooler support (front)
2. M10 x 45 hex flange bolt (6)	13. EGR tube support	24. 3/8 hardened washer (2)
3. M18 plug assembly (2)	14. EGR crossover tube	25. 3/8–16 x 2 1/2 hex head bolt (5)
4. EGR cooler assembly	15. Liner and U bolt assembly (2)	26. EGR cooler support (rear)
5. M8 x 45 hex flange bolt (6)	16. M8 x 30 hex flange bolt (3)	27. 3/8 hardened washer (3)
6. M10 90 degree 3/8 hose fitting (2)	17. Exhaust gasket	28. EGR cooler support (front)
7. O-ring (2)	18. M10 x 40 hex flange bolt (3)	29. EGR coolant drain guide
8. Clamp (2)	19. M10 x 20 x 35 hex flange stud bolt	30. M6 x 12 hex flange bolt
9. EGR supply hose	20. EGR cooler inlet elbow	31. EGR cooler support (rear)
10. M8 hex flange lock nut (4)	21. EGR gasket	32. M10 x 20 x 35 stud bolt
11. 5/16–18 x 1 hex bolt (2)	22. M8 x 35 hex flange bolt (6)	33. M10 x 30 hex flange bolt
-

Removal



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

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

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

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

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

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

- Engine Electrical
- Turbochargers
- Air Compressor and Power Steering

EGR Cooler Assembly Draining

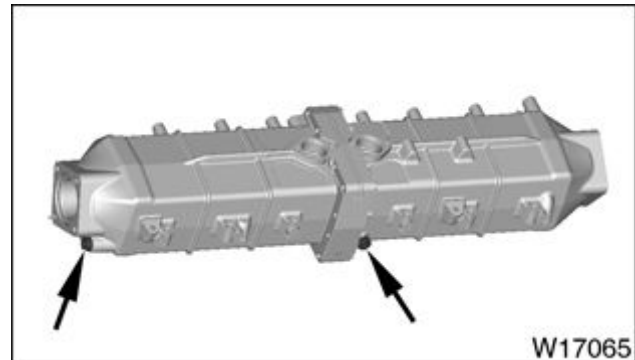


Figure 294 EGR cooler assembly M18 (drain) plugs (cooler assembly removed for clarity)

NOTE: The rear M18 plug assembly will drain coolant from the rear half of the EGR cooler assembly and the front M18 plug assembly near the center will drain the front half of the EGR cooler assembly.

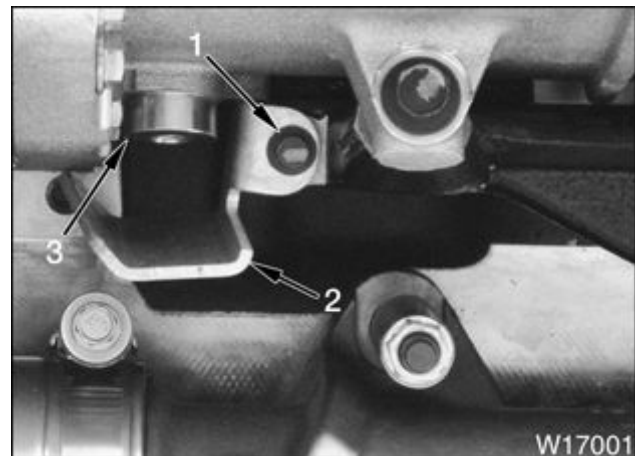


Figure 295 EGRC coolant drain guide

1. M6 x 12 hex flange bolt
2. EGRC coolant drain guide
3. M18 O-ring boss plug

CAUTION: To prevent engine damage, the EGRC coolant drain guide must be installed during reassembly before running the engine. The EGRC coolant drain guide also acts as a heat shield and provides protection from heat damage to the M18 O-ring boss plug O-ring.

1. Remove M6 x 12 hex flange bolt and EGRC coolant drain guide.

2. Place a suitable container below front M18 O-ring boss plug. Remove plug and drain coolant.
3. Place a suitable container below rear M18 O-ring boss plug. Remove plug and drain coolant.



Figure 296 EGR cooler M18 plug assembly O-ring

4. Remove O-rings from M18 plug assemblies and discard O-rings.
5. Lubricate with P-80® rubber lubricant or equivalent (page 255). Install new O-rings on M18 plug assemblies and install plugs in EGR cooler assembly. Tighten plugs to special torque (page 255).

Coolant Manifold, ISC Coolant Supply Tube Assembly and CCV LTR Bypass Tube Assembly

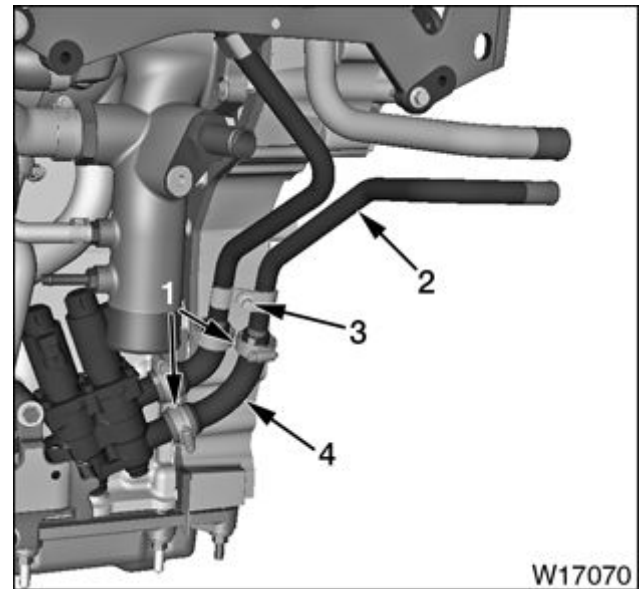


Figure 297 CCV LTR supply tube assembly

1. SAE 16 left clip clamp (2)
 2. CCV LTR supply tube assembly
 3. M6 x 16 hex flange bolt
 4. 3/4 to 1 inch elbow hose (lower)
-
1. Remove M6 x 16 hex flange bolt.
 2. Loosen SAE 16 left clip clamps. Remove CCV LTR supply tube assembly from 3/4 to 1 inch elbow hose (lower).
 3. Remove 3/4 to 1 inch elbow hose (lower) from Coolant Control Valve (CCV).

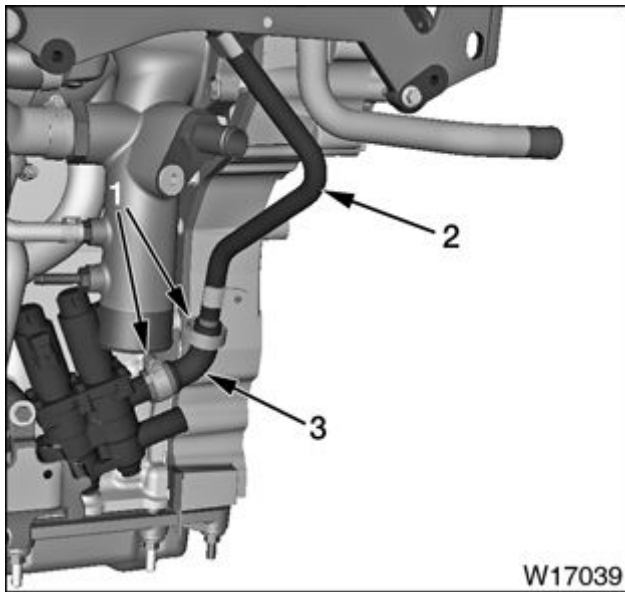


Figure 298 CCV LTR bypass tube assembly

1. SAE 16 left clip clamp (2)
2. CCV LTR bypass tube assembly
3. 3/4 to 1 inch elbow hose (upper)

NOTE: The CCV LTR bypass tube assembly will be removed with coolant manifold.

4. Loosen SAE 15/16 left clip clamp on 3/4 to 1 inch elbow hose (upper) and disconnect CCV LTR bypass tube assembly from CCV.

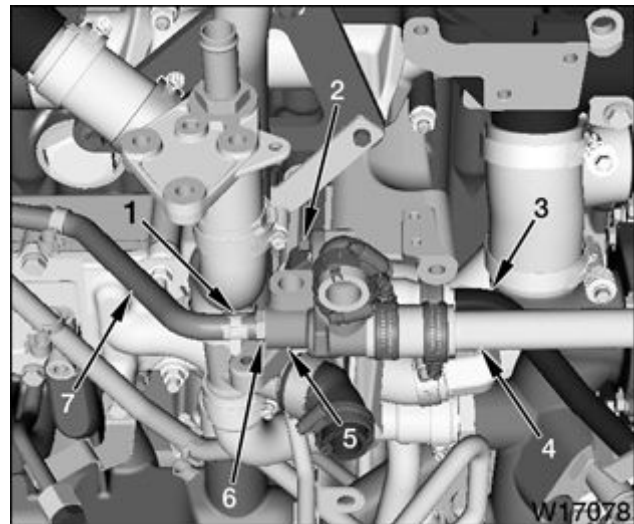


Figure 299 Coolant manifold

1. 3/8 CTB clamp
2. M8 x 25 hex flange bolt
3. CCV LTR bypass tube assembly
4. ISC coolant supply tube assembly
5. Coolant manifold
6. Hose fitting
7. EGRV coolant hose

5. Loosen 3/8 CTB clamp and disconnect EGRV coolant hose from hose fitting.
6. Remove M8 x 25 hex flange bolt.
7. Remove coolant manifold with ISC coolant supply tube assembly and CCV LTR bypass tube assembly.
8. If necessary, remove ISC coolant supply tube assembly and CCV LTR bypass tube assembly from coolant manifold.

Coolant Control Valve (CCV) Assembly and Coolant Adapter

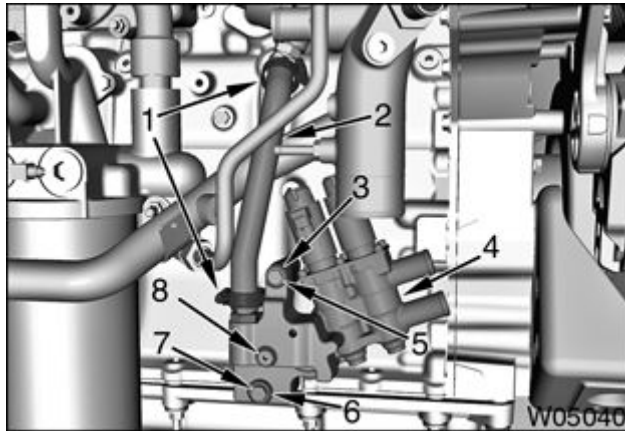


Figure 300 CCV assembly and coolant adapter

1. SAE 15/16 left clip clamp (2)
 2. CCV supply hose assembly
 3. 8.8 x 17 x 1.6 washer
 4. CCV assembly
 5. 5/16-18 x 3 1/2 hex bolt
 6. 10.2 x 18.5 x 5 hardened washer
 7. 3/8-16 x 3 hex bolt
 8. Plug assembly
1. Loosen upper SAE 15/16 left clip clamp.
 2. Remove 5/16-18 x 3 1/2 hex bolt and 8.8 x 17 x 1.6 washer.
 3. Remove 3/8-16 x 3 hex bolt with 10.2 x 18.5 x 5 hardened washer.
 4. Remove CCV and coolant adapter with CCV supply hose assembly.

5. If necessary, loosen remaining SAE 15/16 left clip clamp and remove CCV supply hose assembly.

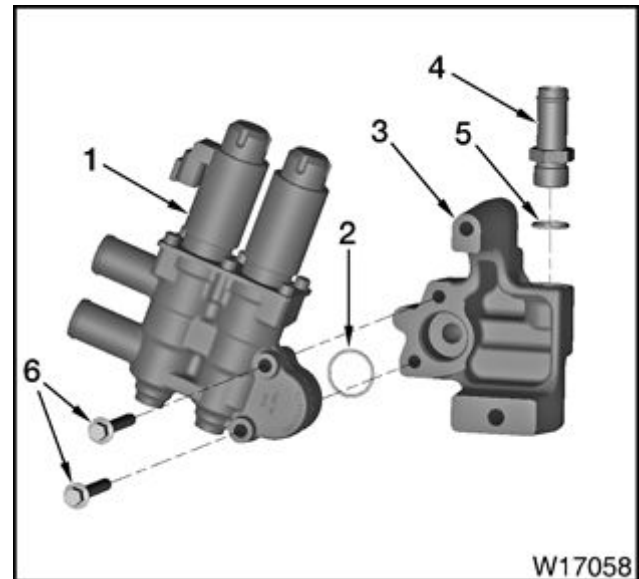


Figure 301 CCV assembly and coolant adapter (exploded view)

1. CCV assembly
 2. O-ring (26 x 2.0)
 3. Coolant adapter
 4. Hose fitting
 5. O-ring (3-910)
 6. M8 x 60 hex flange bolt (2)
6. Remove two M8 x 60 hex flange bolts and separate coolant adapter from CCV assembly. Remove and discard O-ring (26 x 2.0).

Heater Core Return Adapter and Temperature Sensor Fitting

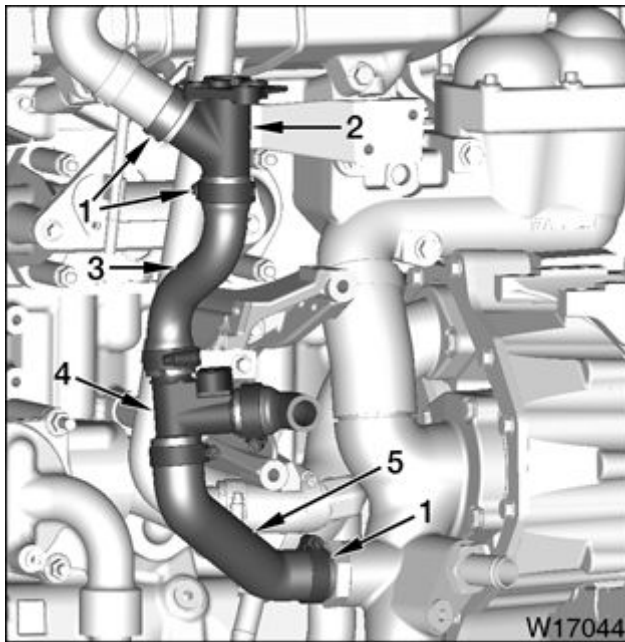


Figure 302 Heater core return adapter and temperature sensor fitting

1. SAE 24 clamp (3)
 2. Heater core return adapter
 3. Heater core return hose
 4. Temperature sensor fitting
 5. Formed 1.2 inch hose
1. Loosen SAE 24 clamp at top of heater core return adapter.
 2. Loosen SAE 24 clamp at bottom of formed 1.2 inch hose.
 3. Disconnect heater core return adapter from EGR coolant hose assembly.
 4. Disconnect formed 1.2 inch hose from hose fitting. Remove heater core return adapter and temperature sensor fitting with hoses attached.
 5. Loosen remaining SAE 24 clamps and disassemble components as needed.

Intercooler Support (Inner)

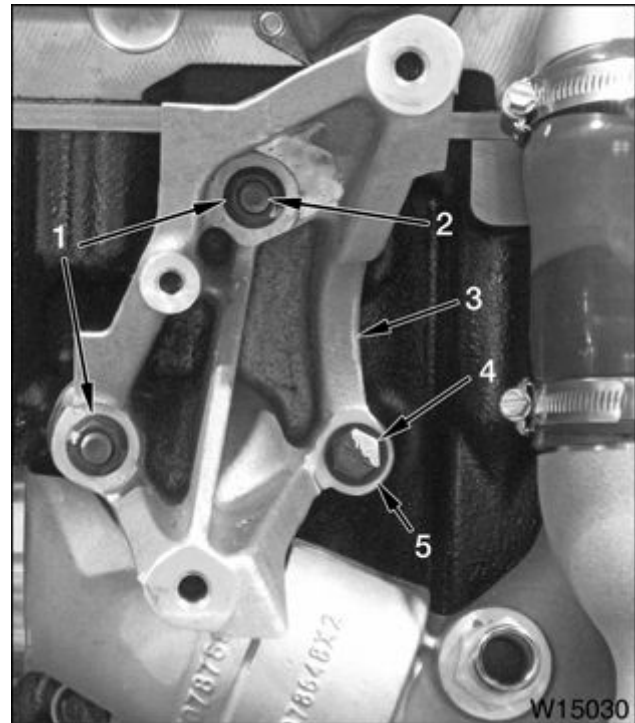
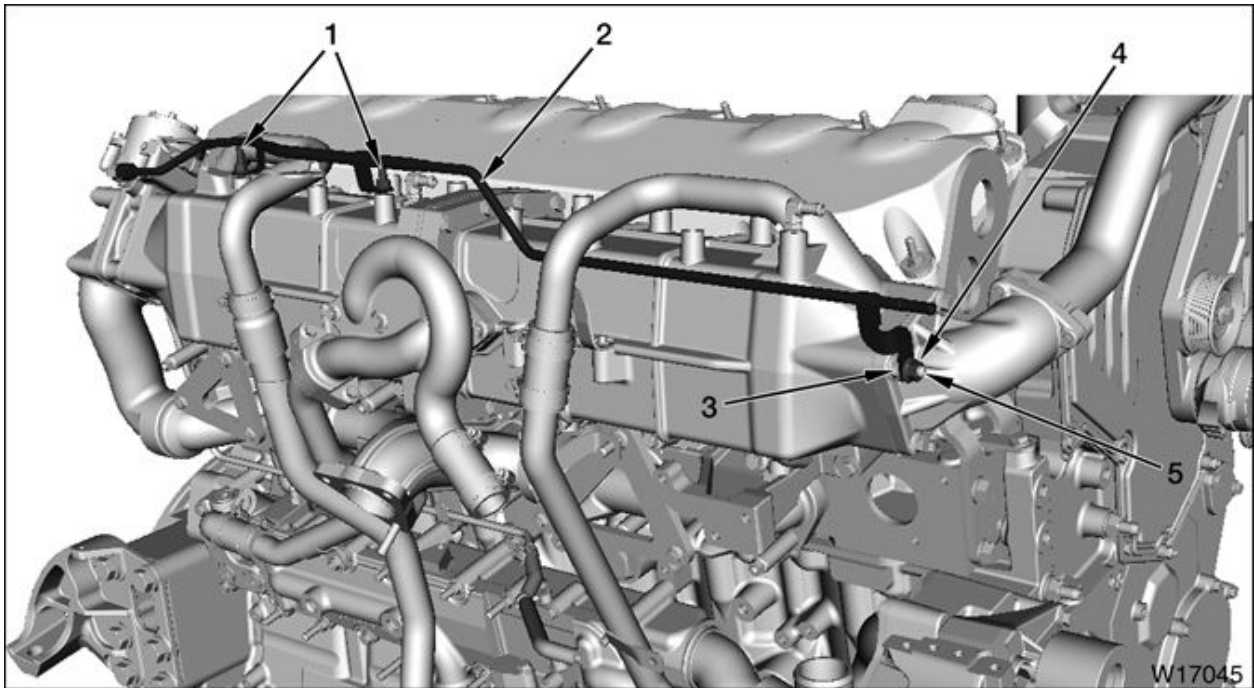


Figure 303 Intercooler support

1. 3/8-16 hex flange nut (2)
 2. 3/8-16 x 6 1/2 taper lock stud (2)
 3. Intercooler support
 4. 3/8-16 x 3 hex bolt
 5. 3/8 hardened washer
1. Remove two 3/8-16 hex flange nuts.
 2. Remove 3/8-16 x 3 hex bolt and 3/8 hardened washer.
 3. Remove intercooler support from 3/8-16 x 6 1/2 taper lock studs.
 4. Remove two 3/8-16 x 6 1/2 taper lock studs from crankcase if necessary.

EGRV Coolant Return Tube and EGRV Coolant Supply Tube**Figure 304 EGRV coolant return tube**

1. M8 stud bolt (2)	3. 10.8 x 21 x 2.5 washer	5. M10 x 20 x 35 hex flange stud bolt
2. EGRV coolant return tube	4. M10 hex flange nut	
-
1. Loosen tube nut on EGRV coolant return tube at EGR valve.	3. Remove M10 hex flange nut. Remove EGRV coolant return tube and 10.8 x 21 x 2.5 washer.
2. Remove two M8 stud bolts securing EGRV coolant return tube at top of EGR cooler assembly.	

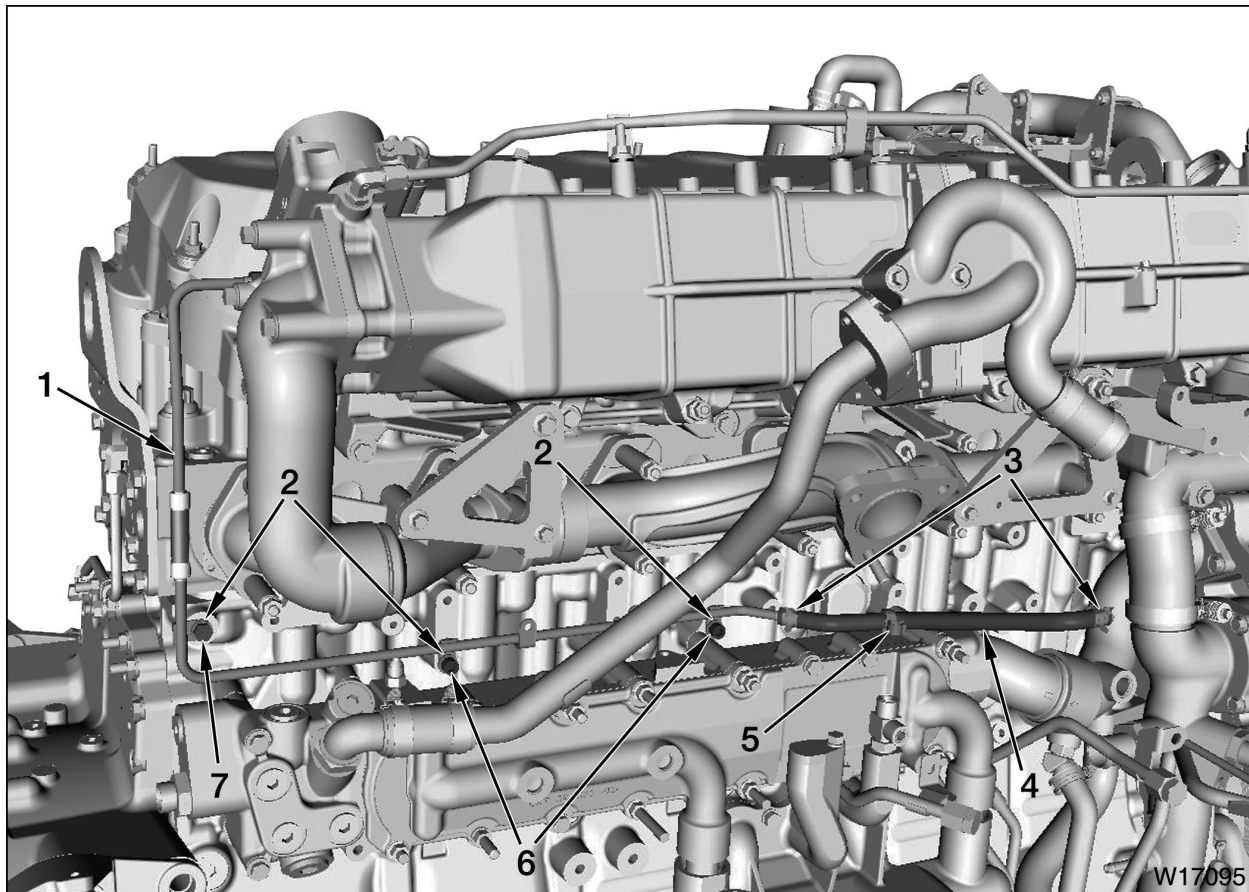


Figure 305 EGRV coolant supply tube

1. EGRV coolant supply tube	4. EGRV coolant supply hose	7. 3/8-16 x 1 hex bolt
2. 10.2 x 18.5 hardened washer	5. C clip	
3. 3/8 CTB clamp	6. 3/8-16 x 3/4 socket head screw	
-
4. Remove one 3/8-16 x 1 hex bolt, two 3/8-16 x 3/4 socket head screws and three 10.2 x 18.5 hardened washers securing EGRV coolant supply tube to engine. Remove EGRV coolant supply tube and EGRV coolant supply hose.
 5. Loosen tube nut on EGRV coolant supply tube at EGR valve.
 6. If required, loosen 3/8 CTB clamp and remove EGRV coolant supply hose from EGRV coolant supply tube.

EGR Coolant Tube Assembly (front) and EGR2 Coolant Supply Tube Assembly

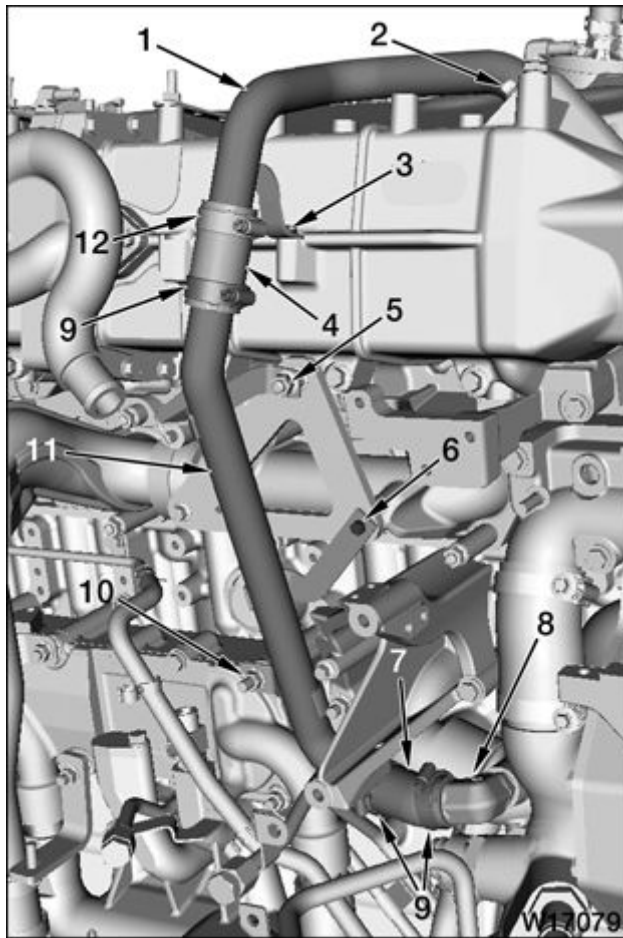


Figure 306 EGR coolant tube assembly (front)

1. EGR coolant tube assembly (front)
2. M8 x 25 hex flange bolt (2)
3. M6 x 12 hex flange bolt
4. 31.75 x 69 coolant hose
5. M10 hex flange nut
6. M8 x 27 hex flange bolt
7. 1 1/4 inch formed hose
8. 90 degree fitting assembly (on water pump outlet pipe)
9. SAE 24 clamp (3)
10. 3/8-16 hex flange nut
11. EGR2 coolant supply tube assembly
12. SAE 24 left clip clamp

1. Remove two M8 x 25 hex flange bolts at EGR coolant tube assembly.
2. Remove M6 x 12 hex flange bolt, loosen SAE 24 left clip clamp and remove EGR coolant tube assembly (front).
3. Remove M10 hex flange nut, M8 x 27 hex flange bolt and 3/8-16 hex flange nut. Loosen SAE 24 clamp at 90 degree fitting assembly and remove EGR2 coolant supply tube assembly. If necessary, loosen remaining SAE 24 clamps and remove 31.75 x 69 coolant hose and 1 1/4 inch formed hose.
4. Loosen SAE 24 clamp on 1 1/4 inch formed hose at 90 degree fitting assembly.
5. Loosen nut on 90 degree fitting assembly and remove fitting.



Figure 307 EGR coolant tube assembly O-ring seal (2-221)

6. Remove and discard O-ring seal (2-221).

EGR Coolant Tube Assembly (rear), EGR Coolant Tube Assembly and EGR Tube Assembly

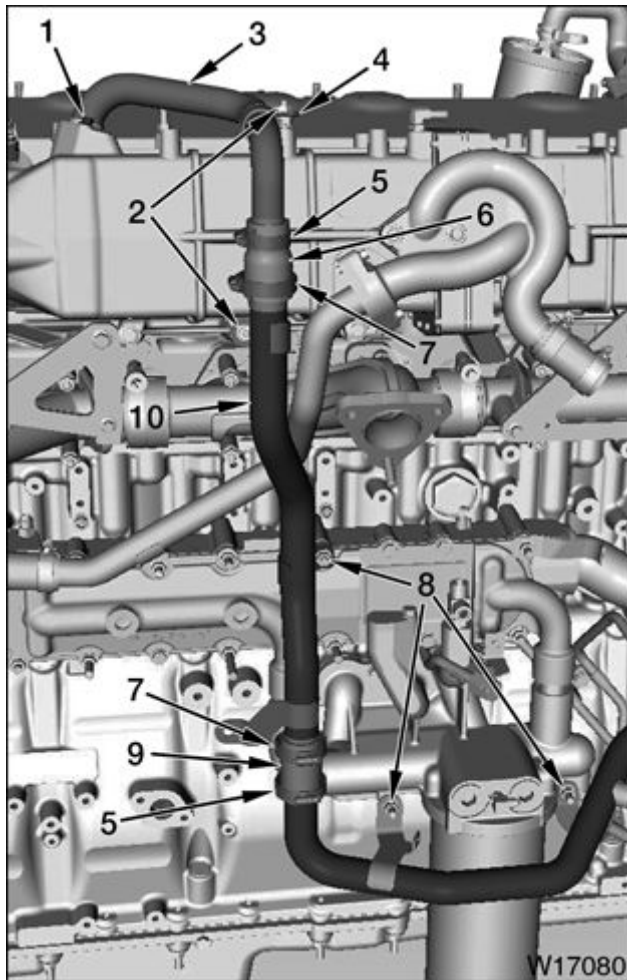


Figure 308 EGR coolant tube assembly (rear)

1. M8 x 20 hex flange bolt (2)
2. M8 hex flange nut (2)
3. EGR coolant tube assembly (rear)
4. 8.8 x 16 x 2 hardened washer (under bracket)
5. SAE 24 clamp (2)
6. Adapter hose
7. SAE 24 left clip clamp (2)
8. 3/8-16 hex flange nut (3)
9. 37.1 x 77 coolant hose
10. EGR coolant tube assembly

1. Remove two M8 x 20 hex flange bolts at top of EGR coolant tube assembly (rear).
2. Remove M8 hex flange nut from stud bolt on EGR cooler.
3. Loosen clamps on adapter hose. Remove EGR coolant tube assembly (rear), clamps, and adapter hose.



Figure 309 EGR coolant tube assembly O-ring seal (2-221)

4. Remove and discard O-ring seal (2-221).
5. Remove 8.8 x 16 x 2 hardened washer (under bracket) from stud of EGR cooler.
6. Remove M8 hex flange nut from upper bracket (below adapter hose) and 3/8-16 hex flange nut on bracket at oil cooler module.
7. Loosen two SAE 24 clamps on 37.1 x 77 coolant hose. Remove EGR coolant tube assembly, SAE 24 clamps, and 37.1 x 77 coolant hose.
8. Remove two 3/8-16 hex flange nuts.

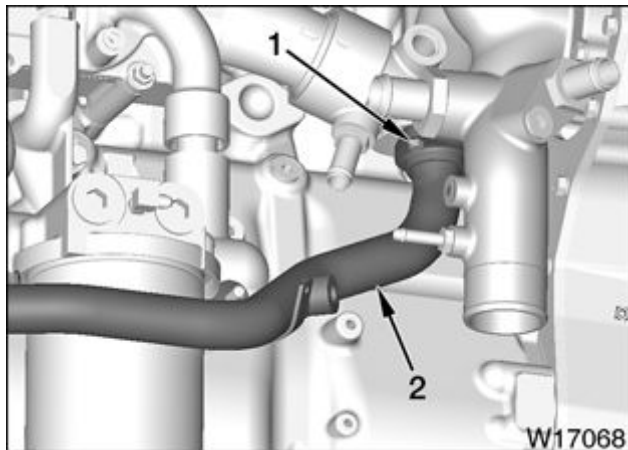


Figure 310 EGR tube assembly

1. M8 x 20 hex flange bolt (2)
2. EGR tube assembly

9. Remove two M8 x 20 hex flange bolts from EGR tube assembly. Remove EGR tube assembly.



Figure 311 EGR tube assembly O-ring seal (2-225) (typical)

10. Remove and discard O-ring seal (2-225) from groove in EGR tube assembly.

Coolant Adapter and EGR Coolant Return Tube Assembly

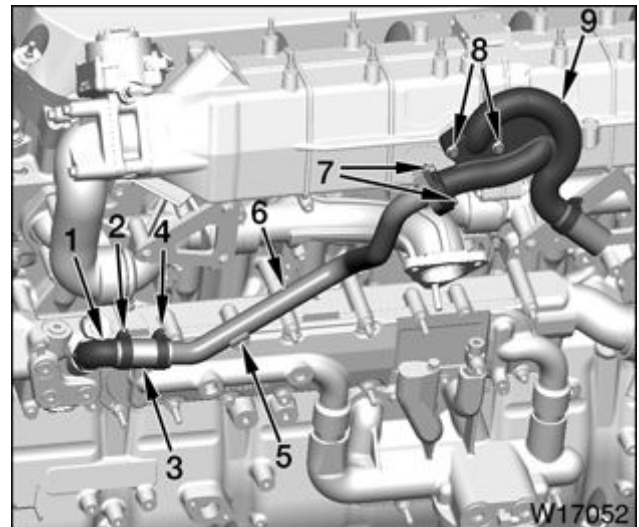


Figure 312 Coolant adapter and EGR coolant return tube assembly

1. 1 3/16-12 x 1 1/4 inch hose elbow
2. SAE 24 left clip clamp
3. Coolant hose
4. SAE 24 clamp
5. 3/8 hex flange nut
6. EGR coolant return tube assembly
7. M8 x 25 hex flange bolt (2)
8. M8 x 55 hex flange bolt (2)
9. Coolant adapter

1. Loosen SAE 24 left clip clamp and SAE 24 clamp. Remove 3/8 hex flange nut.
2. Remove two M8 x 25 hex flange bolts. Remove EGR coolant return tube assembly. Remove and discard O-ring seal (2-225) from groove in EGR coolant return tube assembly.
3. Remove two M8 x 55 hex flange bolts. Remove coolant adapter from EGR cooler.
4. If required, loosen locknut and remove 1 3/16-12 x 1 1/4 inch hose elbow from oil cooler assembly.

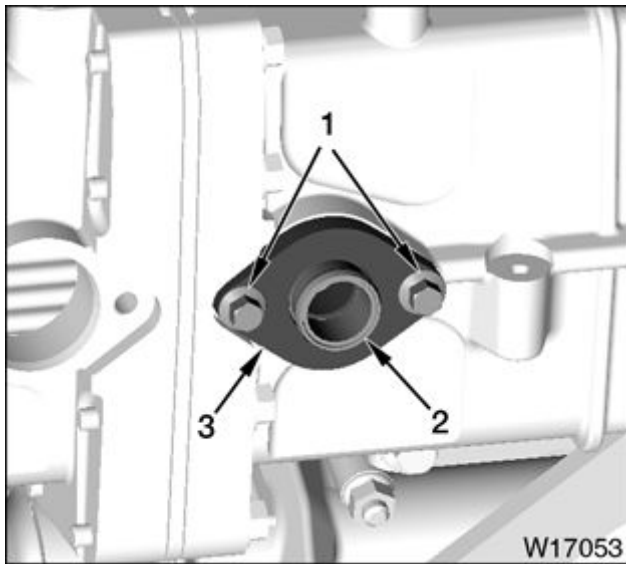


Figure 313 Coolant tube adapter

1. M8 x 25 hex flange bolt (2)
 2. EGR coolant tube seal
 3. Coolant tube adapter
5. Inspect EGR coolant tube seal for reuse. If damaged, pull EGR coolant tube seal out of coolant tube adapter and discard.
 6. Remove two M8 x 25 hex flange bolts. Remove coolant tube adapter from EGR cooler. Remove and discard O-ring seal from coolant tube adapter.

EGR Crossover Tube

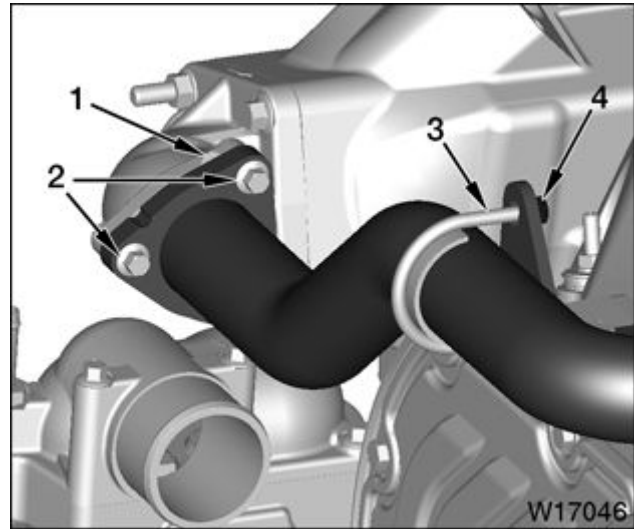


Figure 314 EGR crossover tube at EGR cooler inlet elbow

1. Exhaust gasket
 2. M8 x 30 hex flange bolt (3)
 3. Liner and U bolt assembly
 4. M8 hex flange lock nut (2)
1. Remove three M8 x 30 hex flange bolts.
 2. Remove two M8 hex flange lock nuts, and liner and U bolt assembly.

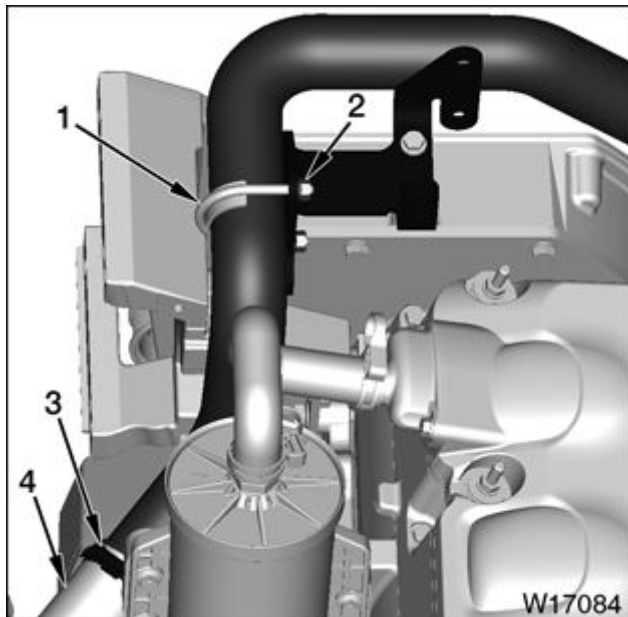


Figure 315 EGR crossover tube at engine throttle valve assembly

1. Liner and U bolt assembly
 2. M8 hex flange lock nut (2)
 3. Clamp (2)
 4. EGR supply hose
3. Remove two M8 hex flange lock nuts, and liner and U bolt assembly.
 4. Loosen two clamps and remove EGR crossover tube with exhaust gasket and EGR supply hose. Discard exhaust gasket.

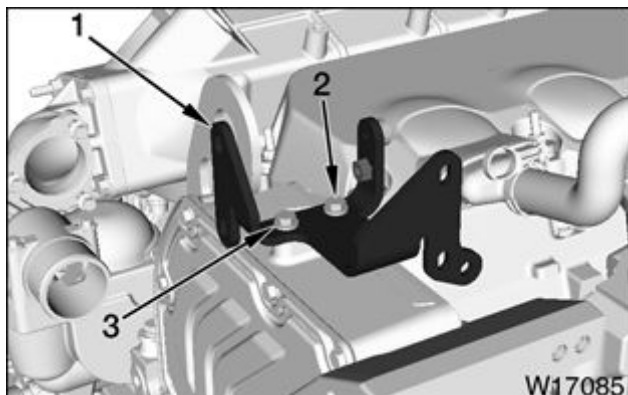


Figure 316 EGR tube support

1. EGR tube support
2. 5/16-18 x 1 hex bolt (2)
3. 5/16 hardened washer (2)

5. Remove two 5/16-18 x 1 hex bolts and two 5/16 hardened washers.
6. Remove EGR tube support.

EGR Cooler Inlet Elbow

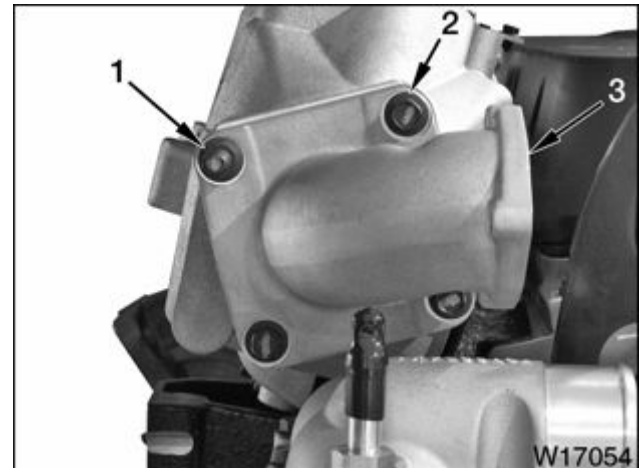


Figure 317 EGR cooler inlet elbow

1. M10 x 20 x 35 hex flange stud bolt
 2. M10 x 40 hex flange bolt (3)
 3. EGR cooler inlet elbow
1. Remove M10 x 20 x 35 hex flange stud bolt and three M10 x 40 hex flange bolts.
 2. Remove EGR cooler inlet elbow.

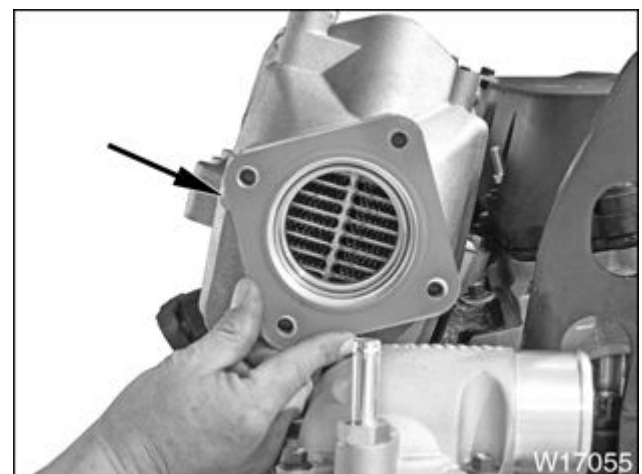


Figure 318 EGR gasket

3. Remove and discard EGR gasket.

EGR Cooler Supply Tube and EGR Valve Assembly

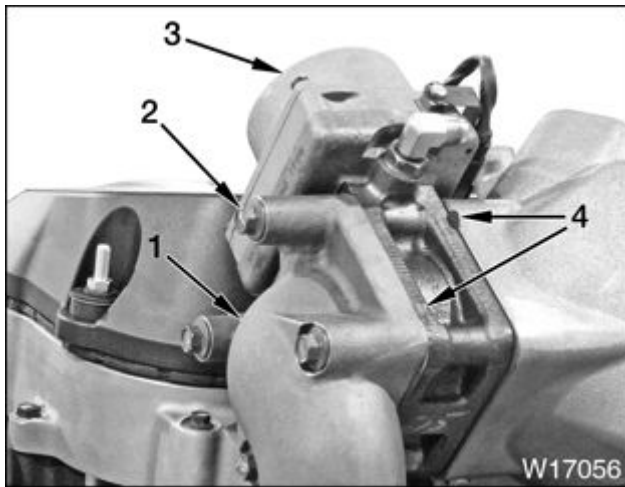


Figure 319 EGR cooler supply tube and EGR valve assembly

1. EGR cooler supply tube
 2. M10 x 130 high temp bolt (4)
 3. EGR valve assembly
 4. EGR gasket (2)
1. Remove two M10 x 130 high temp bolts and install Alignment Pins (page 255) into rear of EGR cooler assembly finger tight.
 2. Remove remaining M10 x 130 high temp bolts.
 3. Remove EGR cooler supply tube and EGR valve assembly. Discard two EGR gaskets.

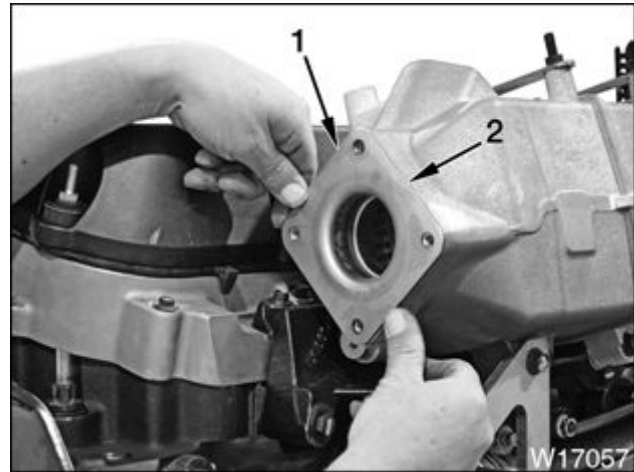


Figure 320 EGRC inlet gas shield and gasket

1. EGRC inlet gas shield
2. EGR gasket (under EGRC inlet gas shield)

4. Remove EGRC inlet gas shield and discard EGR gasket.

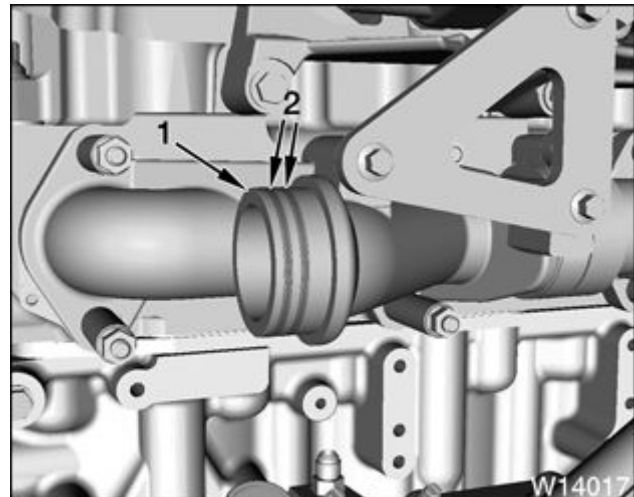


Figure 321 Exhaust manifold ring seals

1. Exhaust manifold
2. Ring seal (4)

5. Remove the four ring seals from the exhaust manifold to EGR cooler supply tube joint and discard.

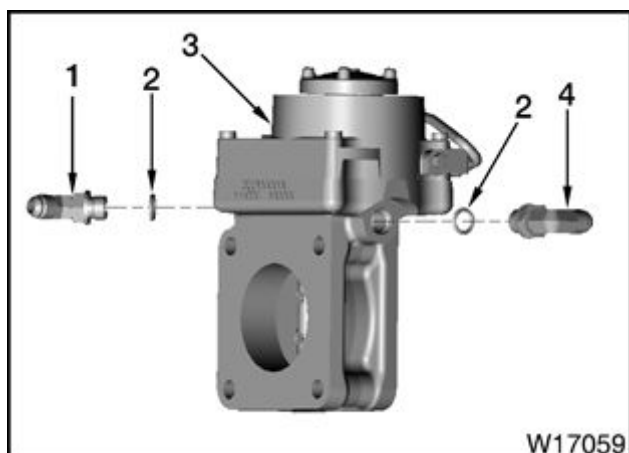


Figure 322 EGR valve assembly and coolant fittings

1. Fitting (45 degree)
 2. O-ring (M14) (2)
 3. EGR valve assembly
 4. M14 37 degree flare fitting (90 degree)
6. If required, remove two fitting (45 degree) from EGR valve assembly. Remove and discard O-ring (M14).
 7. If required, remove M14 37 degree flare fitting (90 degree) from EGR valve assembly. Remove and discard O-ring (M14).

EGR Cooler Assembly

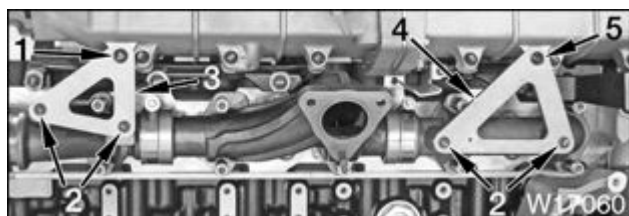


Figure 323 EGR cooler supports

1. M10 x 30 hex flange bolt
 2. M8 x 27 high temp bolt (4)
 3. EGR cooler support (rear)
 4. EGR cooler support (front)
 5. M10 x 20 x 35 hex flange stud bolt
1. Remove M10 x 30 hex flange bolt and two M8 x 27 high temp bolts at EGR cooler support (rear). Remove EGR cooler support (rear).

2. Remove M10 x 20 x 35 hex flange stud bolt and two M8 x 27 high temp bolts at EGR cooler support (front). Remove EGR cooler support (front).

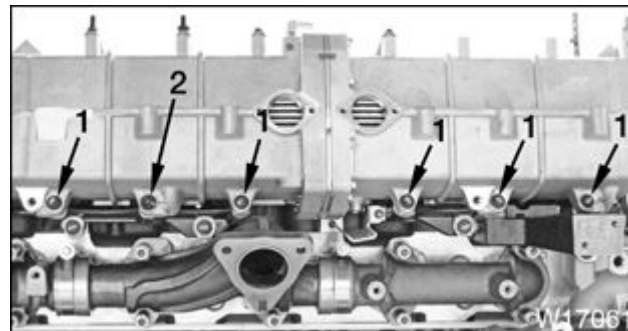


Figure 324 EGR cooler assembly lower bolts

1. M10 x 45 hex flange bolt (5)
2. M10 x 45 stud bolt

3. Remove five M10 x 45 hex flange bolts and M10 x 45 stud bolt from bottom of EGR cooler assembly.

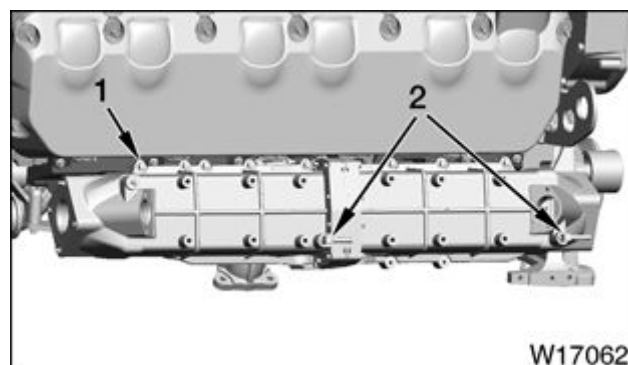
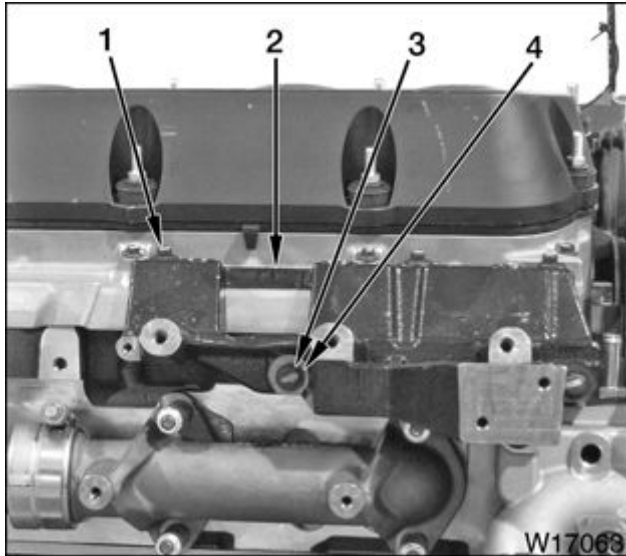


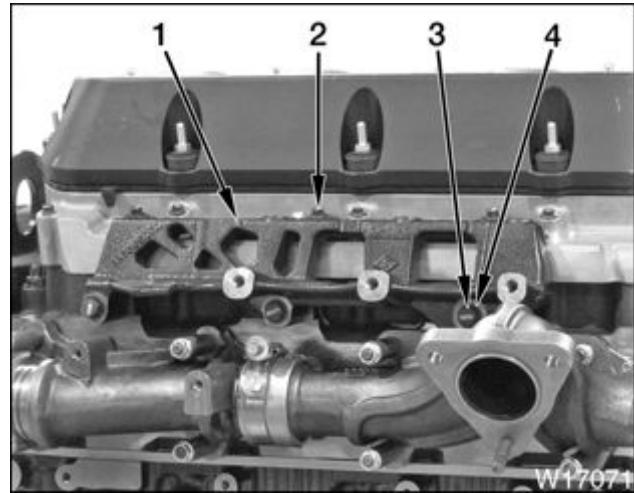
Figure 325 EGR cooler assembly upper bolts

1. M8 x 45 hex flange bolts (6)
2. M10 90 degree 3/8 hose fitting (2)

4. If required, remove two M10 90 degree 3/8 hose fittings from EGR cooler.
5. With help from an assistant or using EGR Cooler Lifting Tool (page 255) and hoist, hold EGR cooler assembly to prevent it from falling and remove six M8 x 45 hex flange bolts. Lift EGR cooler assembly from engine.

EGR Cooler Supports**Figure 326 EGR cooler support (front)**

1. M8 x 35 hex flange bolt (3)
 2. EGR cooler support (front)
 3. 3/8-16 x 2 1/2 hex head bolt (2)
 4. 3/8 hardened washer (2)
1. Remove two 3/8-16 x 2 1/2 hex head bolts and two 3/8 hardened washers from EGR cooler support (front).
 2. Hold EGR cooler support (front) and remove three M8 x 35 hex flange bolts from top of EGR cooler support (front). Remove EGR cooler support (front).

**Figure 327 EGR cooler support (rear)**

1. EGR cooler support (rear)
 2. M8 x 35 hex flange bolt (3)
 3. 3/8-16 x 2 1/2 hex head bolt (3)
 4. 3/8 hardened washer (3)
3. Remove three 3/8-16 x 2 1/2 hex head bolts and three 3/8 hardened washers from EGR cooler support (rear).
 4. Hold EGR cooler support (rear) and remove three M8 x 35 hex flange bolts from top of EGR cooler support (rear). Remove EGR cooler support (rear).

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).

Exhaust Gas Recirculation (EGR) System Components

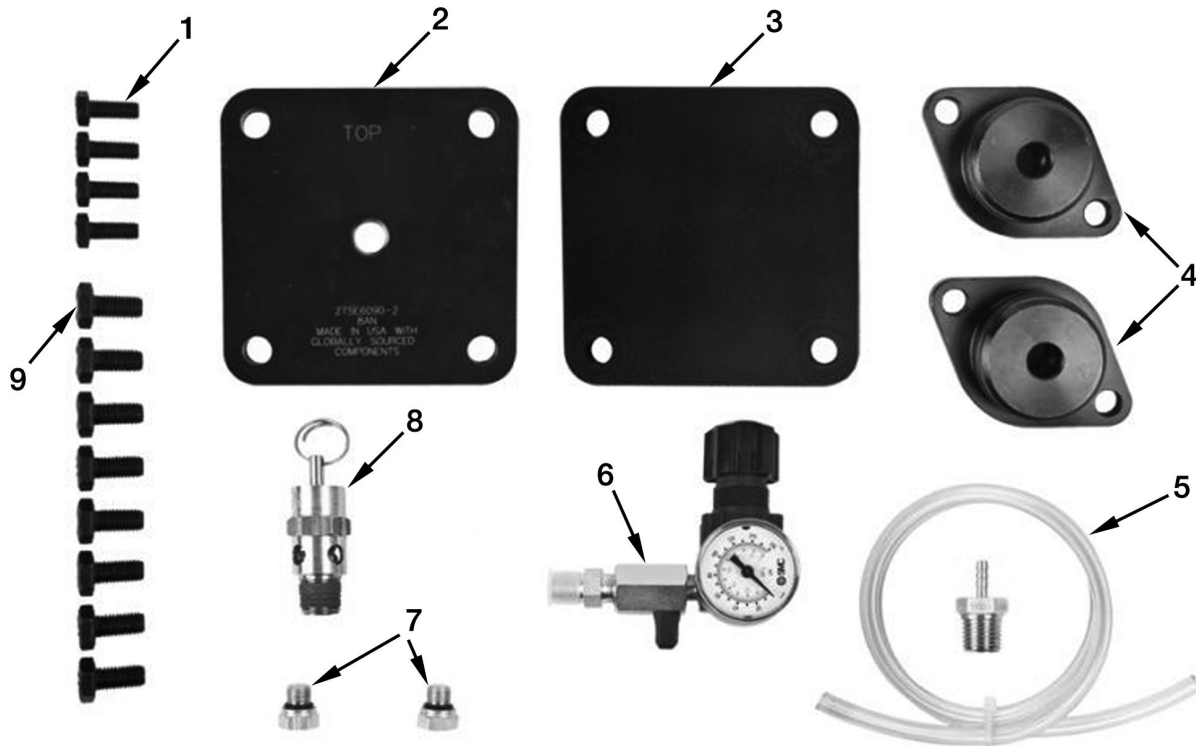
NOTE: To maintain and ensure peak engine performance, it is critical to do the following cleaning and inspecting procedures.

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

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.
3. Clean all mating surfaces to ensure proper gasket sealing.

NOTE: Refer to MaxxForce® 15 *Engine Diagnostic Manual* for functional check of EGR valve assembly.

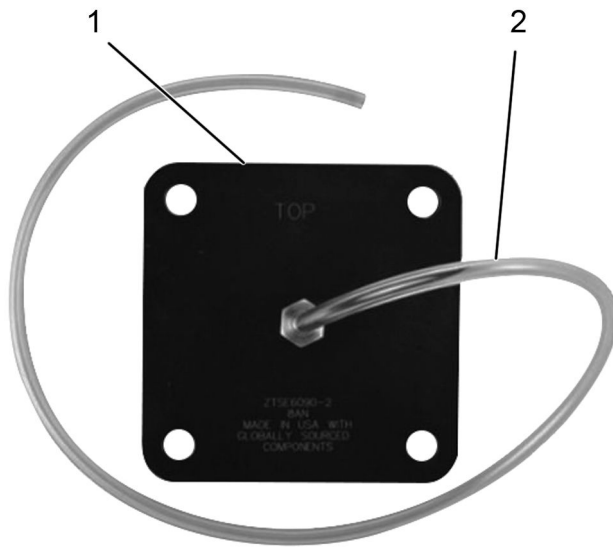
EGR Cooler Assembly Pressure Test**Tool Assembly****Figure 328 EGR Cooler Pressure Test Kit contents**

1. M8 hex bolt (4)	4. Test Plug with O-ring ZTSE6090-1	7. M10 Plug with O-ring ZTSE6090-3
2. Test Plate Assembly (with port) ZTSE6090-2	5. Hose Assembly ZTSE6090-5	8. Safety Relief Valve ZTSE6090-6
3. Test Plate Assembly (without port) ZTSE6090-4	6. Air Pressure Regulator Assembly ZTSE6090-7	9. M10 hex bolt (8)

NOTE: In addition to the EGR Cooler Pressure Test Kit (page 255), you will need;

- Container suitable for water (obtain locally)
- Spray bottle with soapy water solution (obtain locally)
- Teflon® tape or equivalent sealant (obtain locally)

1. Apply Teflon® tape or equivalent to threads of Hose Assembly.



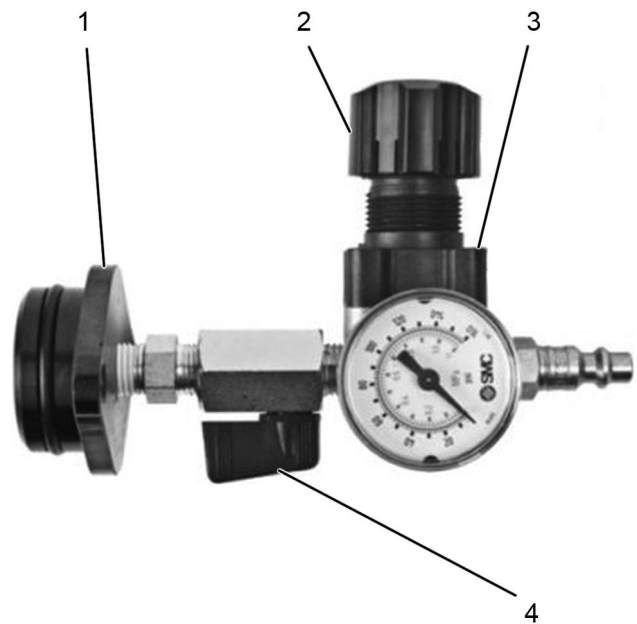
0000045716

Figure 329 EGR Cooler Test Plate Assembly (with port)

1. EGR Cooler Test Plate Assembly (with port)
2. Hose Assembly

NOTE: Hose Assembly should be installed into TOP side of the EGR Cooler Test Plate Assembly (with port).

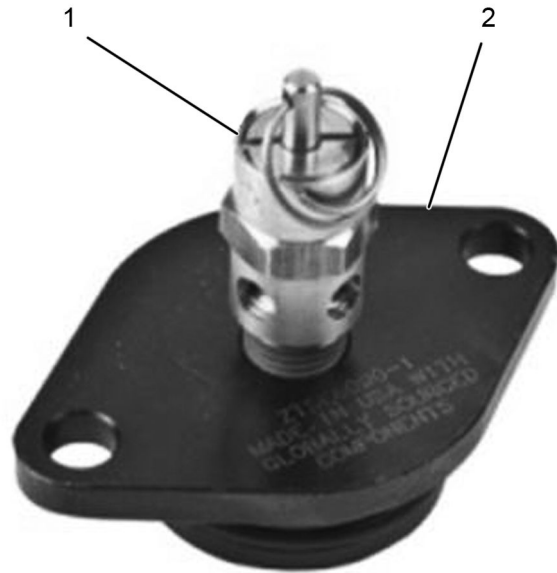
2. Install Hose Assembly ZTSE6090-5 into threaded port of EGR Cooler Test Plate Assembly (with port) ZTSE6090-2.
3. Apply Teflon® tape or equivalent to threads of Air Pressure Regulator Assembly.



0000045718

Figure 330 Air Pressure Regulator Assembly

1. Test Plug with O-ring
 2. Adjustment knob
 3. Air Pressure Regulator Assembly
 4. Valve
4. Install Air Pressure Regulator Assembly into the threaded port of one of the Test Plugs with O-ring.
 5. Apply Teflon® tape or equivalent if necessary to threads of Safety Relief Valve.



0000045720

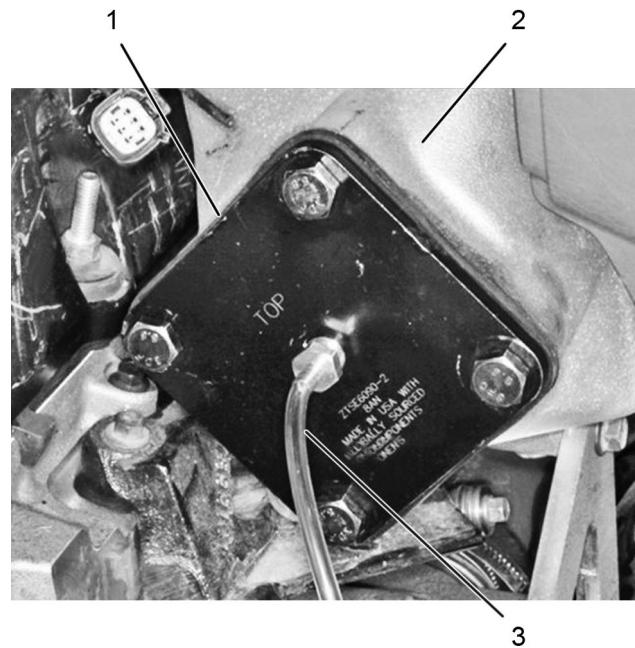
Figure 331 Safety Relief Valve

1. Safety Relief Valve
2. Test Plug with O-ring

6. Install Safety Relief Valve into the threaded port of the other Test Plug with O-ring.

Tool Installation

1. Remove two M10 90-degree 3/8 hose fittings and O-rings from deaeration ports on top of EGR Cooler assembly. Save fittings. Inspect O-rings and replace if necessary.



0000045731

Figure 332 Rear of EGR cooler assembly

1. Test Plate Assembly (with port)
2. High-Temperature (HT) EGR cooler
3. Hose Assembly

NOTE: Make sure gasket mating surfaces on Test Plate Assemblies and EGR cooler assembly are clean, free of contaminants, and not damaged.

2. Install Test Plate Assembly (with port) and Hose Assembly to EGR valve location of EGR cooler assembly – High-Temperature (HT) EGR cooler. Make sure Test Plate Assembly (with port) sealing surface is towards EGR cooler assembly. Tighten four M10 hex bolts to 20.3 N·m (15 lbf·ft).

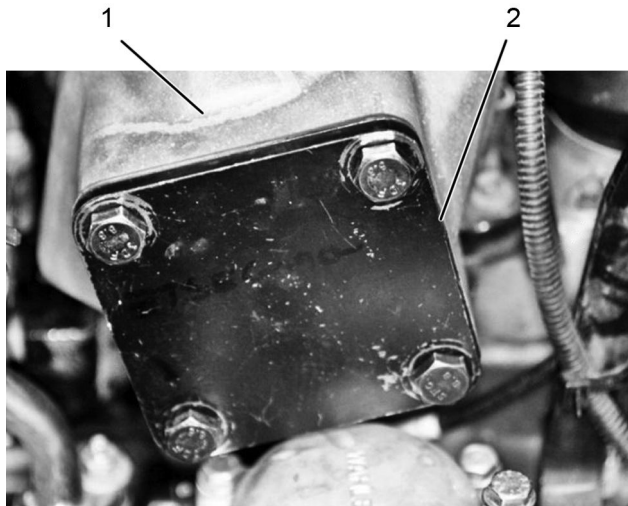


Figure 333 Front of EGR cooler assembly

1. Low-Temperature (LT) EGR cooler
 2. Test Plate Assembly (without port)
3. Install Test Plate Assembly (without port) to EGR cooler inlet elbow location of EGR cooler assembly – Low-Temperature (LT) EGR cooler. Make sure Test Plate Assembly (without port) sealing surface is towards EGR cooler assembly. Tighten four M10 hex bolts to 20.3 N·m (15 lbf·ft).

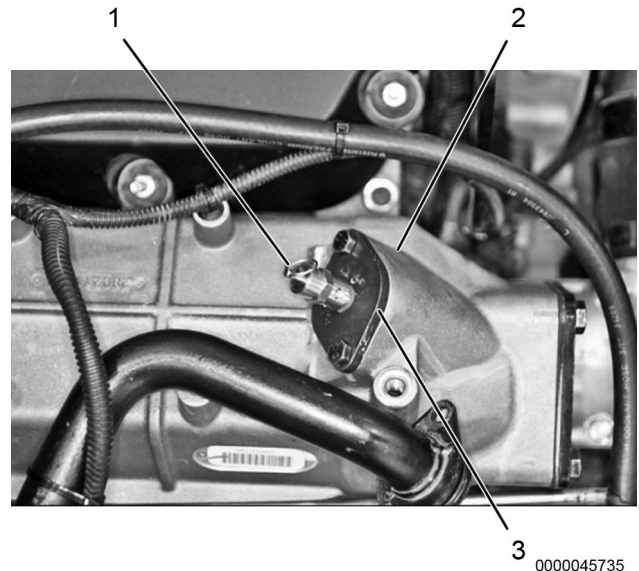


Figure 334 Top front of EGR cooler assembly

1. Safety Relief Valve
 2. Low-Temperature (LT) EGR cooler
 3. Test Plug with O-ring
4. Install Test Plug with O-ring and Safety Relief Valve to the upper coolant passage of the Low-Temperature (LT) EGR cooler. Tighten two M8 hex bolts to 13.6 N·m (120 lbf·in).

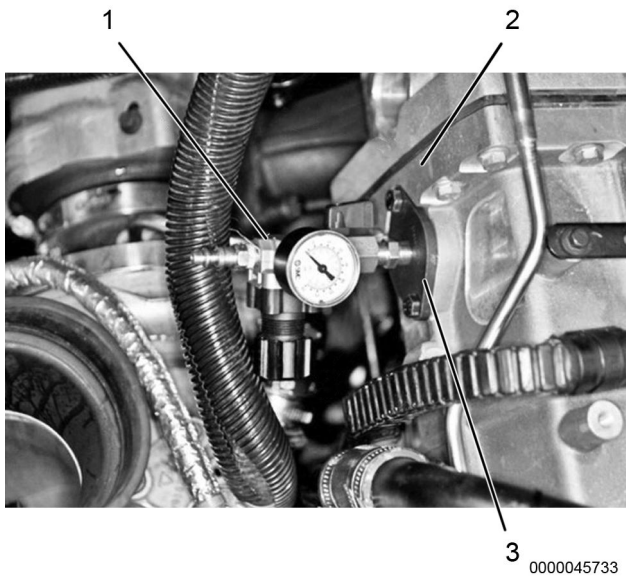


Figure 335 Side of EGR cooler assembly

1. Air Pressure Regulator Assembly
 2. LT EGR cooler
 3. Test Plug with O-ring
5. Install Test Plug with O-ring and Air Pressure Regulator Assembly to the lower coolant passage of the LT EGR cooler. Tighten two M8 hex bolts to 13.6 N·m (120 lbf·in).

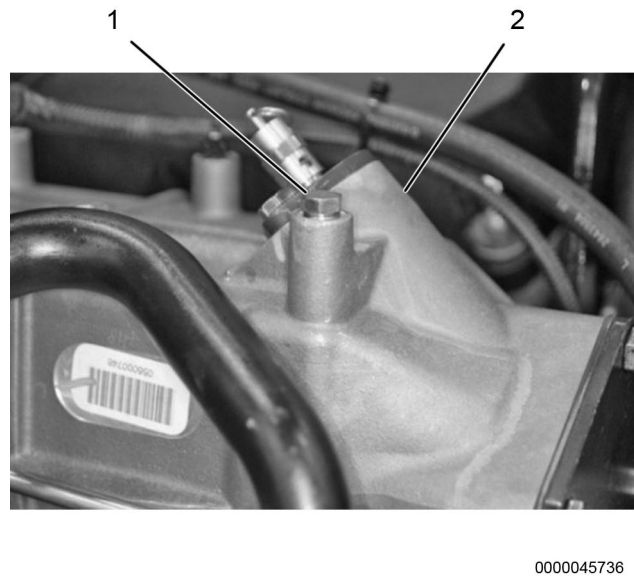


Figure 336 Top of LT EGR cooler assembly

1. M10 Plug with O-ring
 2. LT EGR cooler
6. Install M10 Plug with O-ring into the LT EGR cooler deaeration port. Tighten to 4 N·m (35 lbf·in).

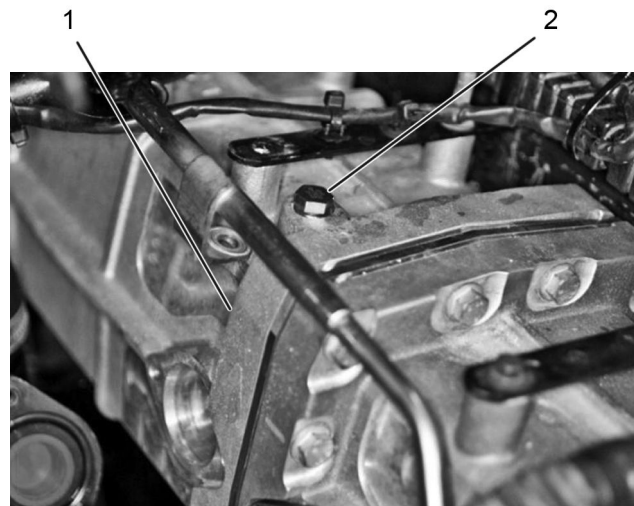


Figure 337 Top of HT EGR cooler assembly

1. HT EGR cooler
2. M10 Plug with O-ring

7. Install M10 Plug with O-ring ZTSE6090-3 into the HT EGR cooler deaeration port. Tighten to 4 N·m (35 lbf·in).

EGR Cooler Leak Test

CAUTION: To prevent component damage, do not exceed the given pressure testing limits. Make sure pressure regulator is set to 310 kPa (45 psi) before opening valve.

! WARNING: To prevent personal injury or death, wear safety glasses with side shields. Limit compressed air pressure to 310 kPa (45 psi).

1. Rotate adjustment knob on Air Pressure Regulator Assembly clockwise to close regulator.
2. Close valve on Air Pressure Regulator Assembly.



0000045721

Figure 338 Shop air connection

3. Connect shop air to Air Pressure Regulator Assembly.
4. Set the maximum air pressure by rotating adjustment knob on Air Pressure Regulator Assembly counterclockwise until the air pressure gauge reads 310 kPa (45 psi).



0000045722

Figure 339 Air Pressure Regulator Assembly

5. Verify air pressure is set to a maximum 310 kPa (45 psi). Slowly open valve on Air Pressure Regulator Assembly to pressurize the coolant passage of EGR cooler assembly.



0000045723

Figure 340 Hose in container of water

0000045725

Figure 341 Center section of EGR cooler

6. Submerge the open end of Hose Assembly into a container of water to a depth of 0.375 in below the waterline. Inspect for air bubbles coming from Hose Assembly ZTSE6090-5. While the EGR cooler assembly is pressurized, observe the container of water for a maximum of five minutes:
 - If the water is bubbling, that portion of the EGR cooler is leaking. Replace the EGR cooler assembly according to the procedure in the “Exhaust Gas Recirculation (EGR) System” section of the *Engine Service Manual*.
 - If water is not bubbling, proceed to step 7.
7. While the EGR cooler assembly is pressurized, spray the center section of the EGR cooler assembly with a soapy water solution and observe the area:
 - If the soapy water solution on the area is bubbling, then there is a leak at the mating surface. Replace the EGR cooler assembly according to the procedure in the “Exhaust Gas Recirculation (EGR) System” section of the *Engine Service Manual*.
 - If no bubbling is detected, proceed to step 8.



0000045726

Figure 342 Air Pressure Regulator Assembly adjustment knob

8. Release the air pressure from EGR cooler assembly by rotating the adjustment knob on the Air Pressure Regulator Assembly clockwise until the air pressure gauge reads 0 kPa (0 psi).
9. Verify air pressure reads 0 kPa (0 psi). Close valve on Air Pressure Regulator Assembly.



0000045721

Figure 343 Shop air hose removal

10. Disconnect shop air from Air Pressure Regulator Assembly.

NOTE: Do not disassemble Safety Relief Valve or Air Pressure Regulator Assembly from Test Plugs with O-ring.

11. Remove Test Plug with O-ring from upper coolant passage of the LT EGR cooler and install it to the upper coolant passage of the HT EGR cooler. Tighten two M8 hex bolts to 13.6 N·m (120 lbf·in).
12. Remove Test Plug with O-ring from lower coolant passage of the LT EGR cooler and install it to the lower coolant passage of the HT EGR cooler. Tighten two M8 hex bolts to 13.6 N·m (120 lbf·in).
13. Repeat steps 3 through 10 to leak test the HT EGR cooler.

Tool Removal

1. Remove M10 Plugs with O-ring from EGR cooler assembly deaeration ports. Store for reuse.
2. If necessary, install two M10 90-degree 3/8 hose fittings with O-rings in EGR cooler assembly deaeration ports. Tighten to 8 N·m (71 lbf·in).

NOTE: It is not necessary to disassemble Safety Relief Valve and Air Pressure Regulator Assembly from Test Plugs with O-ring. Store each plug as an assembly for reuse.

3. Remove two Test Plugs with O-ring from EGR cooler assembly coolant passages. Store plug assemblies and four M8 hex bolts for reuse.
4. Remove Test Plate Assembly (without port) from EGR cooler assembly. Store plate and four M10 hex bolts for reuse.

NOTE: It is not necessary to disassemble Hose Assembly from Test Plate Assembly (with port). Store hose and plate as an assembly for reuse.

5. Remove Test Plate Assembly (with port) from EGR cooler assembly. Store hose, plate, and four M10 hex bolts for reuse.
 6. Inspect sealing surfaces for damage on the Test Plate Assembly (without port) and Test Plate Assembly (with port). Replace if necessary.
 7. Inspect O-rings for damage on two M10 Plugs with O-ring and two Test Plugs with O-ring. Replace if necessary.
-

Installation

EGR Cooler Supports

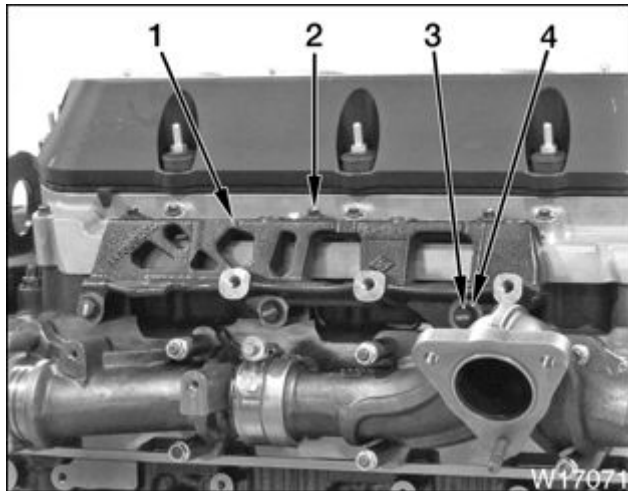


Figure 344 EGR cooler support (rear)

1. EGR cooler support (rear)
 2. M8 x 35 hex flange bolt (3)
 3. 3/8-16 x 2 1/2 hex head bolt (3)
 4. 3/8 hardened washer (3)
1. Place EGR cooler support (rear) on cylinder head. Install three M8 x 35 hex flange bolts on top of EGR cooler support (rear) and three 3/8-16 x 2 1/2 hex head bolts with three 3/8 hardened washers at bottom of EGR cooler support (rear). Tighten 3/8-16 x 2 1/2 hex head bolts and M8 x 35 hex flange bolts to standard torque (page 561).

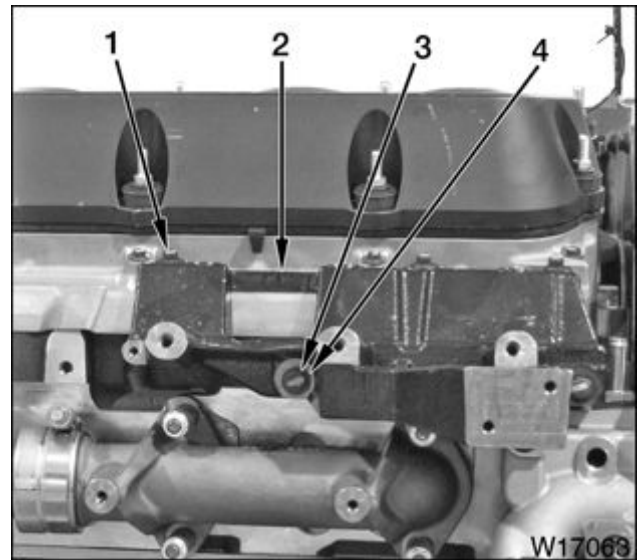


Figure 345 EGR cooler support (front)

1. M8 x 35 hex flange bolt (3)
 2. EGR cooler support (front)
 3. 3/8-16 x 2 1/2 hex head bolt (2)
 4. 3/8 hardened washer (2)
2. Place EGR cooler support (front) on cylinder head. Install three M8 x 35 hex flange bolts on top of EGR cooler support (front) and two 3/8-16 x 2 1/2 hex head bolts with two 3/8 hardened washers at bottom of EGR cooler support (front). Tighten 3/8-16 x 2 1/2 hex head bolts and M8 x 35 hex flange bolts to standard torque (page 561).

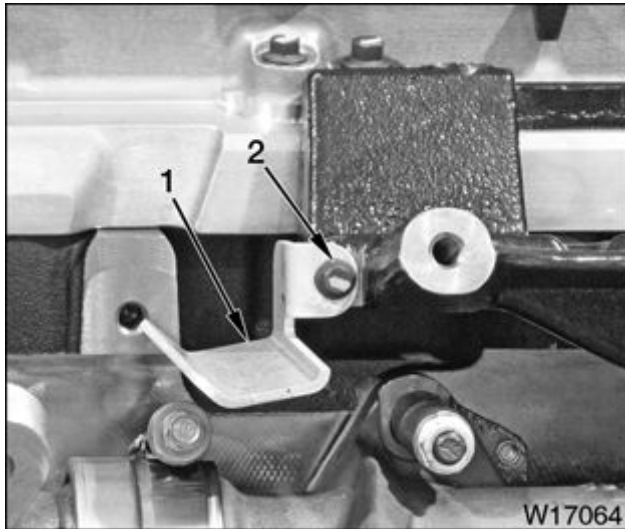


Figure 346 EGRC coolant drain guide

1. EGRC coolant drain guide
2. M6 x 12 hex flange bolt

CAUTION: To prevent engine damage, the EGRC coolant drain guide must be installed during reassembly before running the engine. The EGRC coolant drain guide also acts as a heat shield and provides protection from heat damage to the M18 O-ring boss plug O-ring.

3. Install EGRC coolant drain guide on EGR cooler support (front) with M6 x 12 hex flange bolt. Tighten bolt to standard torque (page 561).

EGR Cooler Assembly

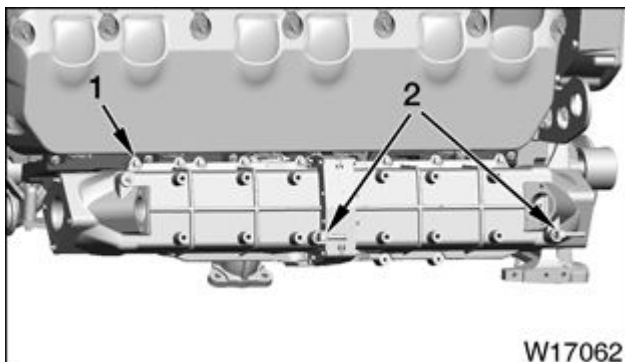


Figure 347 EGR cooler assembly upper bolts

1. M8 x 45 hex flange bolts (6)
2. M10 90 degree 3/8 hose fitting (2)

1. With help from an assistant or using EGR Cooler Lifting Tool (page 255) and hoist, lift EGR cooler assembly onto engine. Install six M8 x 45 hex flange bolts finger tight.
2. If previously removed, install two M10 90 degree 3/8 hose fittings into EGR cooler. Fittings should point to front of engine. Hold fittings with backup wrench and tighten nut to special torque (page 255).

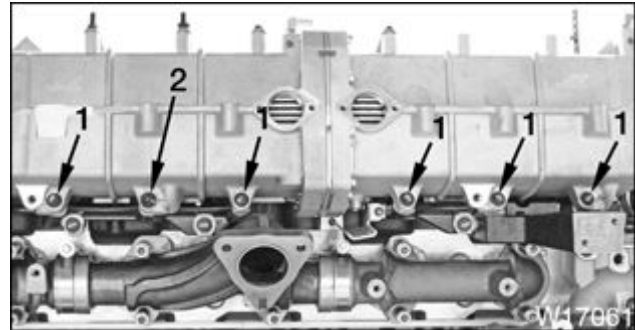


Figure 348 EGR cooler assembly lower bolts

1. M10 x 45 hex flange bolt (5)
2. M10 x 45 stud bolt
3. Install five M10 x 45 hex flange bolts and M10 x 45 stud bolt into bottom of EGR cooler assembly. Tighten bolts finger tight.

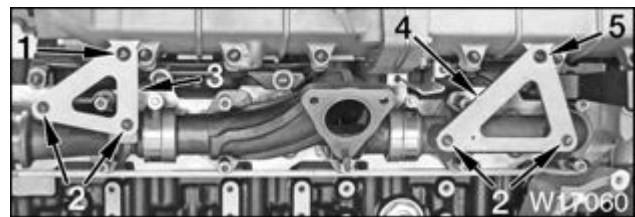


Figure 349 EGR cooler supports

1. M10 x 30 hex flange bolt
2. M8 x 27 high temp bolt (4)
3. EGR cooler support (rear)
4. EGR cooler support (front)
5. M10 x 20 x 35 hex flange stud bolt
4. Install EGR cooler support (rear) with M10 x 30 hex flange bolt and two M8 x 27 high temp bolts. Tighten bolts finger tight.
5. Install EGR cooler support (front) with M10 x 20 x 35 hex flange stud bolt and two M8 x 27 high temp

bolts. Tighten stud bolt and high temp bolts finger tight.

6. Tighten M10 x 45 hex flange bolts and M10 x 45 stud bolt to standard torque (page 561).
7. Tighten M8 x 45 hex flange bolts to standard torque (page 561).
8. Tighten M8 x 27 high temp bolts to special torque (page 255).
9. Tighten M10 x 30 hex flange bolt and M10 x 20 x 35 hex flange stud bolt to standard torque (page 561).

EGR Cooler Supply Tube and EGR Valve Assembly

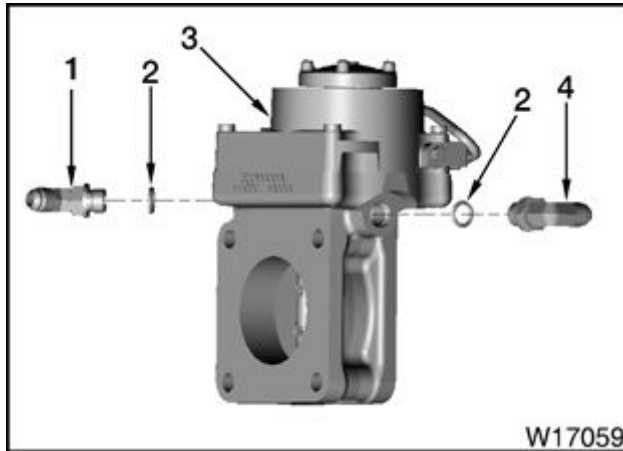


Figure 350 EGR valve assembly and coolant fittings

1. Fitting (45 degree)
 2. O-ring (M14) (2)
 3. EGR valve assembly
 4. M14 37 degree flare fitting (90 degree)
1. If removed, install new O-ring (M14) on M14 37 degree flare fitting (90 degree). Lubricate O-ring (M14) with P-80® rubber lubricant or equivalent (page 255). Install M14 37 degree flare fitting (90 degree) into EGR valve assembly. After connecting EGRV coolant return tube to fitting, tighten fitting to special torque (page 255).
 2. If removed, install new O-ring (M14) on fitting (45 degree). Lubricate O-ring (M14) with P-80®

rubber lubricant or equivalent (page 255). Install fitting (45 degree) into EGR valve assembly. After connecting EGRV coolant supply tube to fitting, tighten fitting to special torque (page 255).

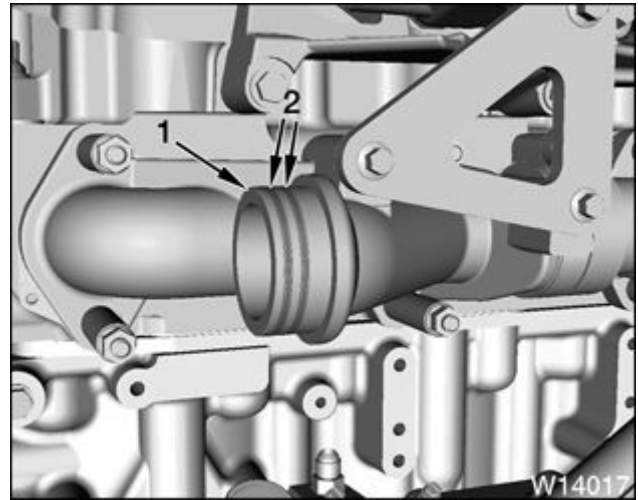


Figure 351 Exhaust manifold ring seals

1. Exhaust manifold
2. Ring seal (4)

3. Install four new rings seals on exhaust manifold joint.

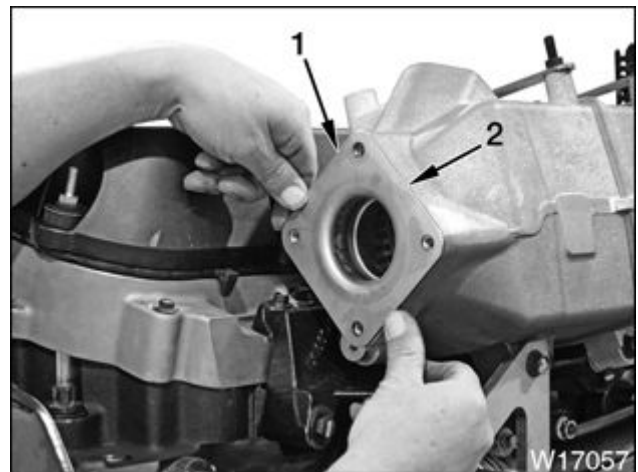


Figure 352 EGRC inlet gas shield and gasket

1. EGRC inlet gas shield
2. EGR gasket (under EGRC inlet gas shield)

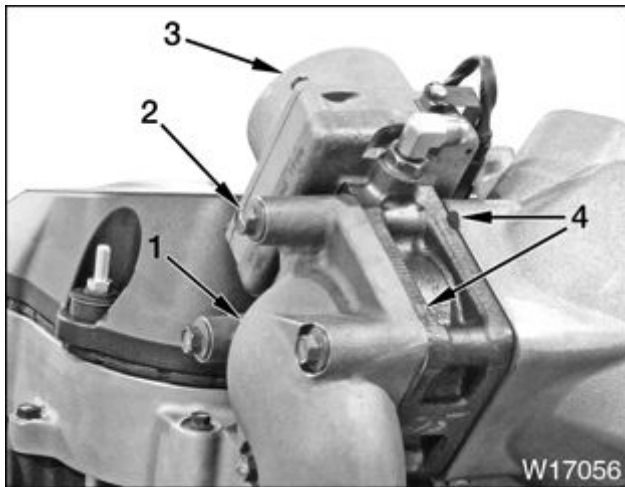


Figure 353 EGR cooler supply tube and EGR valve assembly

1. EGR cooler supply tube
 2. M10 x 130 high temp bolt (4)
 3. EGR valve assembly
 4. EGR gasket (2)
4. Install Alignment Pins (page 255) into rear of EGR cooler assembly finger tight. Assemble new EGR gasket, EGRC inlet gas shield, new EGR gasket, EGR valve assembly, and new EGR gasket on Alignment Pins.
 5. Install EGR cooler supply tube onto EGR valve assembly and exhaust manifold. Install two M10 x 130 high temp bolts finger tight. Remove Alignment Pins and install remaining two M10 x 130 high temp bolts. Tighten bolts to special torque (page 255).

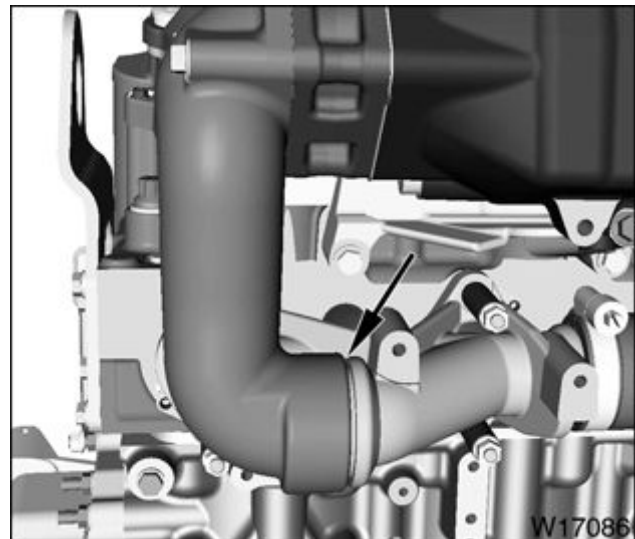


Figure 354 EGR cooler supply tube to exhaust manifold gap

6. Ensure gap between EGR cooler supply pipe and exhaust manifold is within specification (page 255). Adjust position of exhaust manifold or EGR cooler assembly if necessary.

EGR Cooler Inlet Elbow

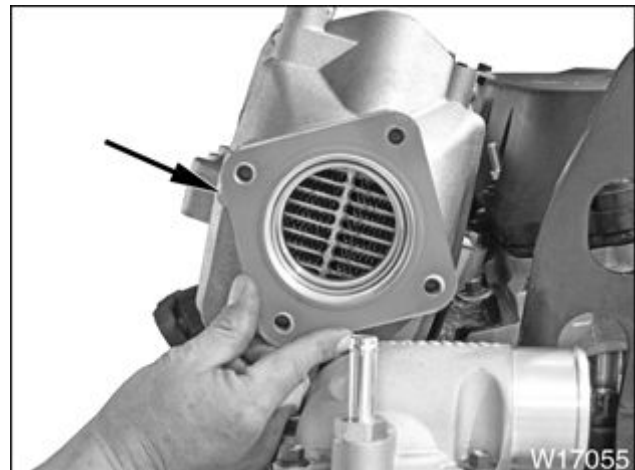


Figure 355 EGR gasket

1. Place a new EGR gasket on EGR cooler assembly.

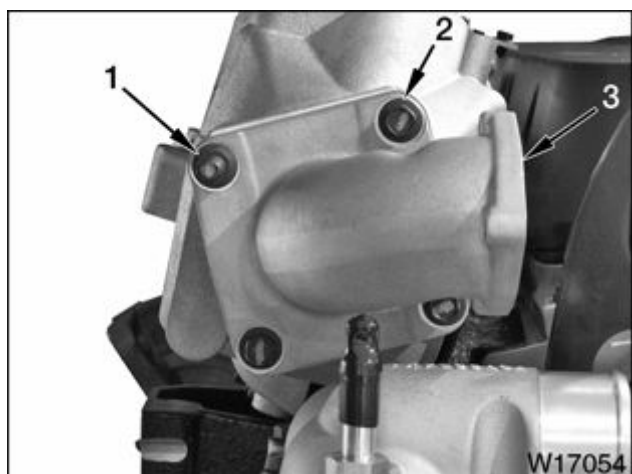


Figure 356 EGR cooler inlet elbow

1. M10 x 20 x 35 hex flange stud bolt
 2. M10 x 40 hex flange bolt (3)
 3. EGR cooler inlet elbow
2. Install EGR cooler inlet elbow with one M10 x 20 x 35 hex flange stud bolt and three M10 x 40 hex flange bolts. Tighten bolts and stud bolt to standard torque (page 561).

EGR Crossover Tube

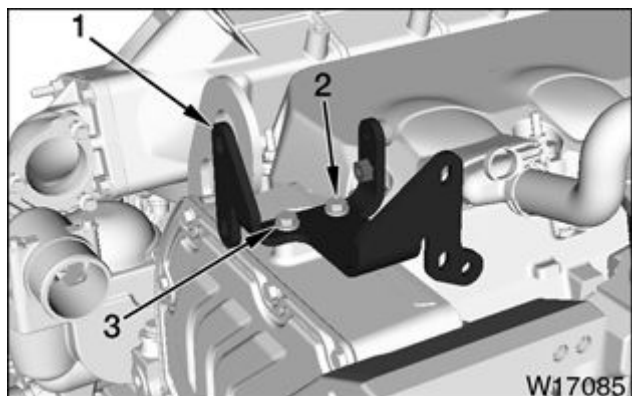


Figure 357 EGR tube support

1. EGR tube support
2. 5/16–18 x 1 hex bolt (2)
3. 5/16 hardened washer (2)

1. Install EGR tube support on front cover with two 5/16–18 x 1 hex bolts and two 5/16 hardened washers. Tighten bolts to standard torque (page 562).

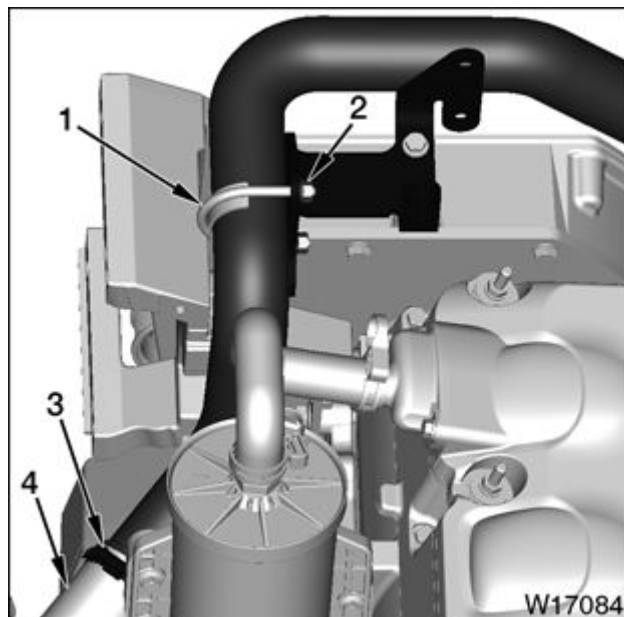


Figure 358 EGR crossover tube at engine throttle valve assembly

1. Liner and U bolt assembly
 2. M8 hex flange lock nut (2)
 3. Clamp (2)
 4. EGR supply hose
2. Assemble EGR supply hose and EGR crossover tube to engine throttle valve assembly. Do not tighten clamps at this time.
3. Install EGR crossover tube to EGR cooler inlet elbow with new gasket (Figure 356), (item 1). Tighten three M8 x 30 hex flange bolts to standard torque (page 561).
4. Tighten two clamps on EGR supply hose to special torque (page 255).
5. Install liner and U bolt assembly over EGR crossover tube with two M8 hex flange lock nuts. Tighten nuts to special torque (page 255).

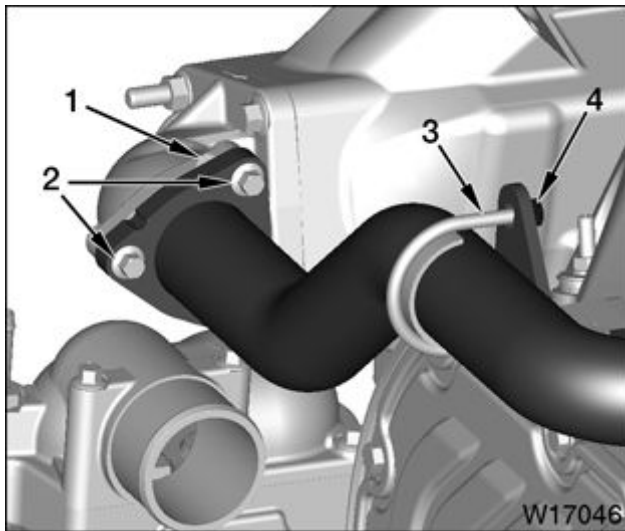


Figure 359 EGR crossover tube at EGR cooler inlet elbow

1. Exhaust gasket
 2. M8 x 30 hex flange bolt (3)
 3. Liner and U bolt assembly
 4. M8 hex flange lock nut (2)
6. Install liner and U bolt assembly over EGR crossover tube with two M8 hex flange lock nuts. Tighten nuts to special torque (page 255).

Coolant Adapter and EGR Coolant Return Tube Assembly

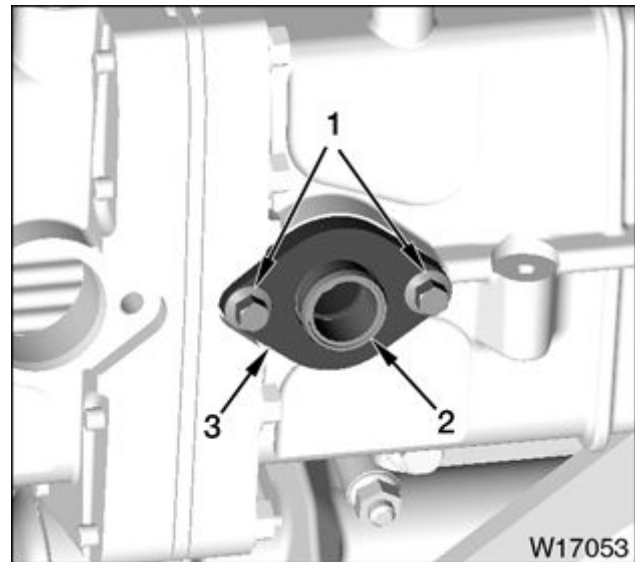


Figure 360 Coolant tube adapter

1. M8 x 25 hex flange bolt (2)
 2. EGR coolant tube seal
 3. Coolant tube adapter
1. Install new O-ring seal (Figure 291) (item 20) on coolant tube adapter. Lubricate O-ring seal with P-80® rubber lubricant or equivalent (page 255).
 2. Install coolant tube adapter into EGR cooler assembly with two M8 x 25 hex flange bolts. Tighten bolts to standard torque (page 561).
 3. Install new EGR coolant tube seal if original was damaged and discarded. Lubricate EGR coolant tube seal with P-80® rubber lubricant or equivalent (page 255). Push EGR coolant tube seal into coolant tube adapter.

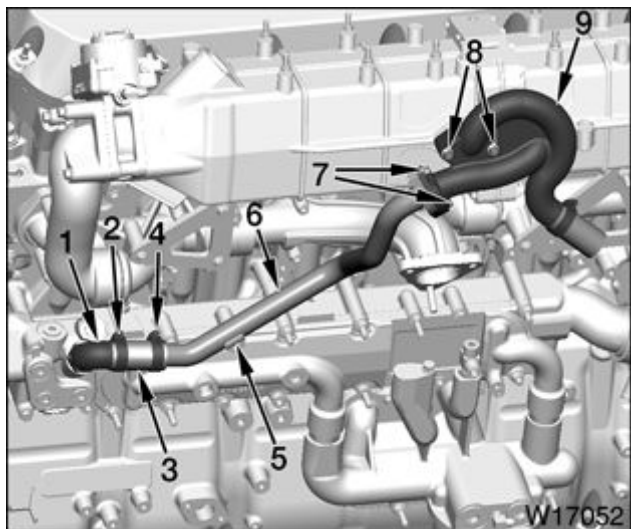


Figure 361 Coolant adapter and EGR coolant return tube assembly

1. 1 3/16-12 x 1 1/4 inch hose elbow
 2. SAE 24 left clip clamp
 3. Coolant hose
 4. SAE 24 clamp
 5. 3/8 hex flange nut
 6. EGR coolant return tube assembly
 7. M8 x 25 hex flange bolt (2)
 8. M8 x 55 hex flange bolt (2)
 9. Coolant adapter
4. If required, install a new O-ring on 1 3/16-12 x 1 1/4 inch hose elbow. Lubricate O-ring with P-80® rubber lubricant or equivalent (page 255). Make sure O-ring and back-up washer are at top of O-ring groove. Rotate locknut until it contacts back-up washer. Install 1 3/16-12 x 1 1/4 inch hose elbow in oil cooler until back-up washer contacts spot faced surface of port, and opening is toward front of engine. Tighten locknut on 1 3/16-12 x 1 1/4 inch hose elbow to special torque (page 255).
 5. Install a new O-ring (2-225) in groove (Figure 360) on EGR coolant return tube assembly.
 6. Pre-assemble EGR coolant return tube assembly to coolant adapter. Tighten two M8 x 25 hex flange bolts to standard torque (page 561).

7. Install coolant hose on EGR coolant return tube assembly. Do not tighten two SAE 24 left clip clamps at this time.
8. Install a new O-ring seal on coolant adapter. Lubricate O-ring seal with P-80® rubber lubricant or equivalent (page 255).
9. Install coolant adapter onto EGR cooler assembly with two M8 x 55 hex flange bolts. Tighten M8 x 55 hex flange bolts to standard torque (page 561).
10. Install coolant hose on 1 3/16-12 x 1 1/4 inch hose elbow and EGR coolant return tube assembly on oil cooler stud.
11. Install 3/8 hex flange nut. Tighten nut to standard torque (page 562).
12. Tighten clamps to special torque (page 255).

EGR Coolant Tube Assembly (rear), EGR Coolant Tube Assembly and EGR Tube Assembly



Figure 362 EGR coolant tube assembly O-ring seal (2-221)

1. Install a new O-ring seal (2-221) on EGR coolant tube assembly (rear).



Figure 363 EGR tube assembly O-ring seal (2-225) (typical)

2. Install a new O-ring seal (2-225) in groove on EGR tube assembly.

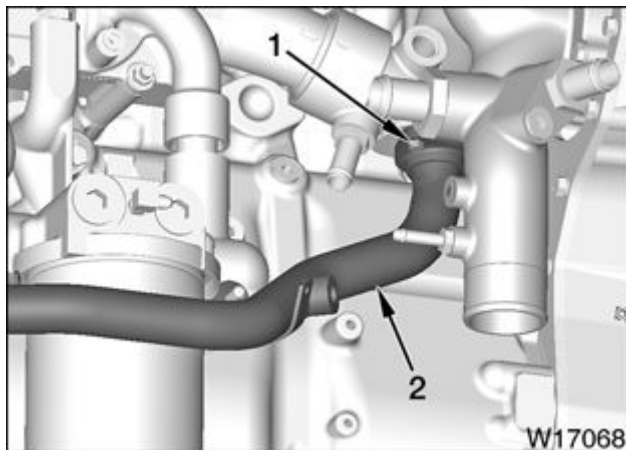


Figure 364 EGR tube assembly

1. M8 x 20 hex flange bolt (2)
 2. EGR tube assembly
3. Install EGR tube assembly with two M8 x 20 hex flange bolts. Tighten bolts to standard torque (page 561).

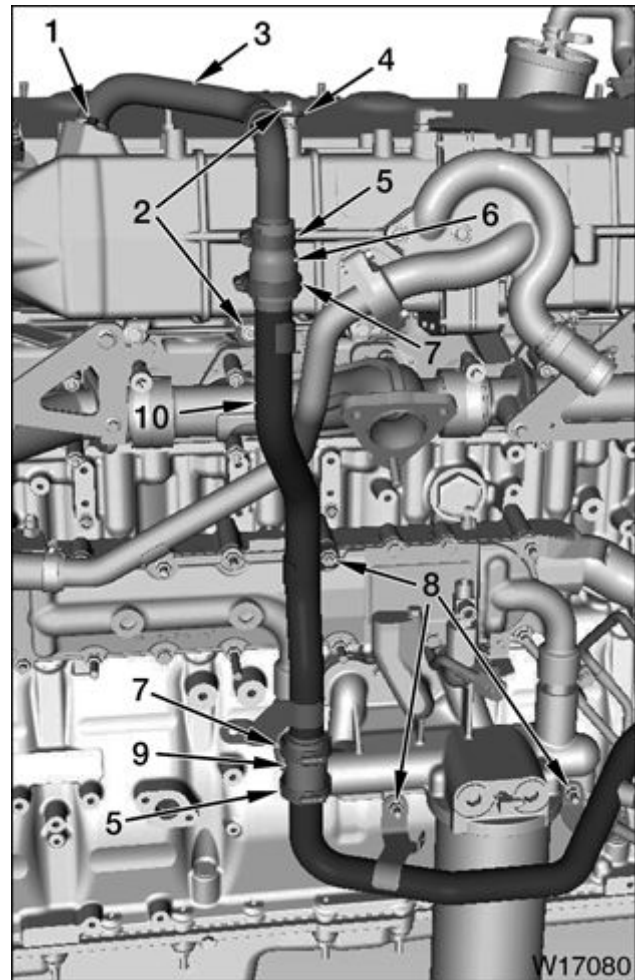


Figure 365 EGR coolant tube assembly (rear)

1. M8 x 20 hex flange bolt (2)
 2. M8 hex flange nut (2)
 3. EGR coolant tube assembly (rear)
 4. 8.8 x 16 x 2 hardened washer (under bracket)
 5. SAE 24 clamp (2)
 6. Adapter hose
 7. SAE 24 left clip clamp (2)
 8. 3/8-16 hex flange nut (3)
 9. 37.1 x 77 coolant hose
 10. EGR coolant tube assembly
4. Install two 3/8-16 hex flange nuts at oil filter base assembly. Tighten nuts to standard torque (page 562).
 5. Install EGR coolant tube assembly to EGR tube assembly with 37.1 x 77 coolant hose and two clamps.

6. Install 3/8–16 hex flange nut at oil cooler module and M8 hex flange nut at upper bracket on EGR coolant tube assembly. Tighten nuts to standard torque (page 561).
7. Place 8.8 x 16 x 2 hardened washer (under bracket) on stud of EGR cooler.
8. Install EGR coolant tube assembly (rear), clamps, and adapter hose. Tighten two M8 x 20 hex flange bolts and M8 hex flange nut to standard torque (page 561).
9. Tighten clamps to special torque (page 255).

EGR Coolant Tube Assembly (front) and EGR2 Coolant Supply Tube Assembly



Figure 366 EGR coolant tube assembly O-ring seal (2-221)

1. Install a new O-ring seal (2-221) on EGR coolant tube assembly (front)

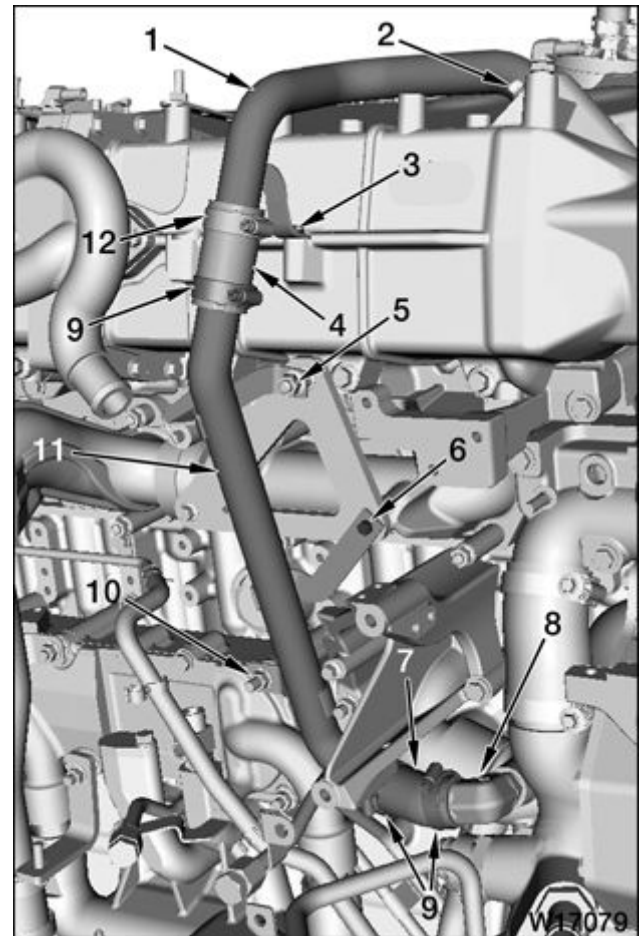


Figure 367 EGR coolant tube assembly (front)

1. EGR coolant tube assembly (front)
 2. M8 x 25 hex flange bolt (2)
 3. M6 x 12 hex flange bolt
 4. SAE 24 left clip clamp
 5. 31.75 x 69 coolant hose
 6. SAE 24 clamp (3)
 7. M10 hex flange nut
 8. EGR2 coolant supply tube assembly
 9. 1 1/4 inch formed hose
 10. 90 degree fitting assembly (on water pump outlet pipe)
2. Lubricate with P-80® rubber lubricant or equivalent (page 255) and install a new O-ring on 90 degree fitting assembly and install fitting. Do not tighten fitting nut at this time.
 3. Assemble EGR coolant tube assembly (front) to EGR2 coolant supply tube assembly with 31.75

- x 69 coolant hose and clamps. Do not tighten clamps at this time.
4. Install 1 1/4 inch formed hose and SAE 24 clamps on bottom of EGR2 coolant supply tube assembly and install assembly on 90 degree fitting assembly. Install and tighten two M8 x 25 hex flange bolts and M6 x 12 hex flange bolt to standard torque (page 561). Install and tighten 3/8 hex flange nut to standard torque (page 562).
 5. Install and tighten M10 hex flange nut to standard torque (page 562).
 6. Tighten 90 degree fitting assembly nut (on water pump outlet pipe) to special torque (page 255).
 7. Tighten three SAE 24 clamps and SAE 24 left clip clamp to special torque (page 255).
-

EGRV Coolant Return Tube and EGRV Coolant Supply Tube

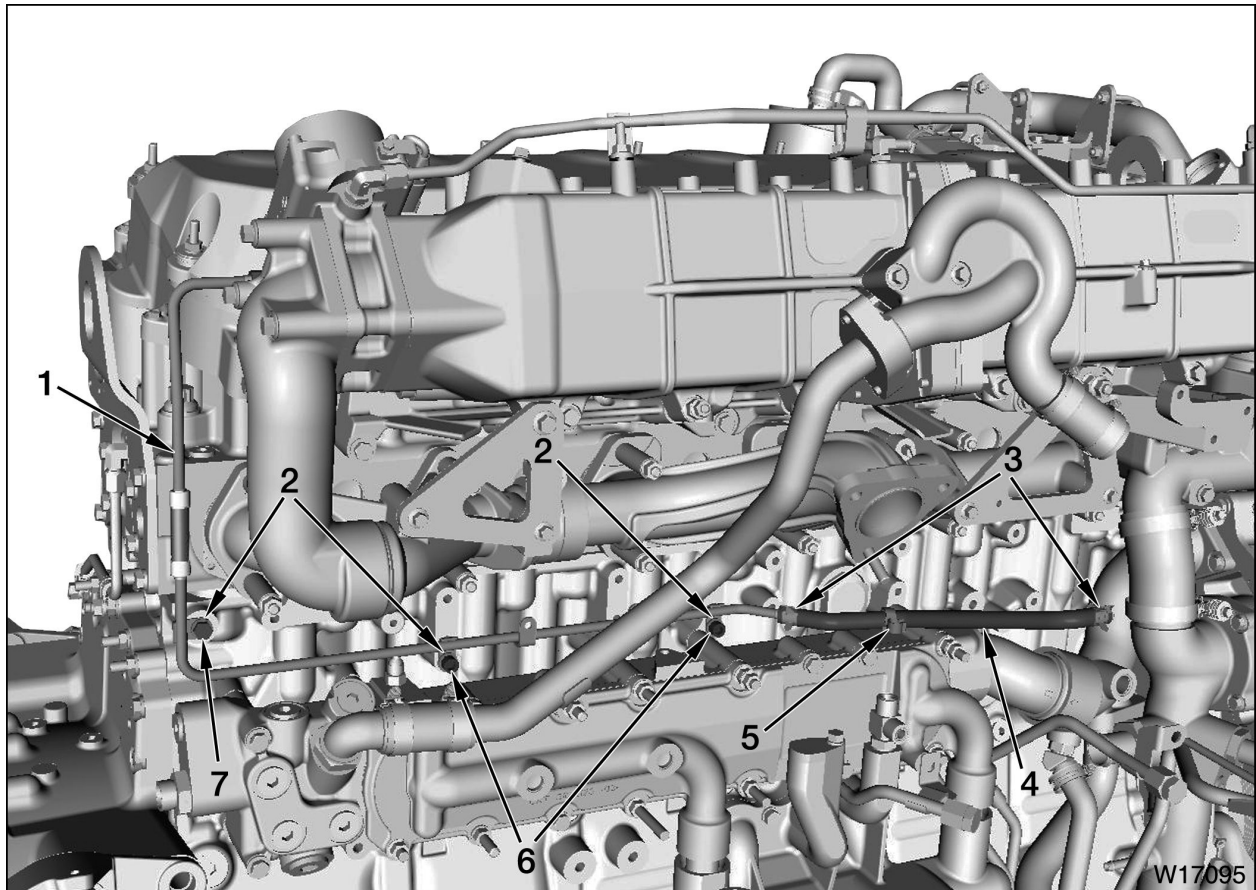


Figure 368 EGRV coolant supply tube

1. EGRV coolant supply tube
2. 10.2 x 18.5 hardened washer
3. 3/8 CTB clamp
4. EGRV coolant supply hose
5. C clip
6. 3/8-16 x 3/4 socket head screw
7. 3/8-16 x 1 hex bolt

1. Connect EGRV coolant supply tube nut to EGR valve but do not tighten nut at this time.
2. Install EGRV coolant supply tube. Secure tube to engine with three 10.2 x 18.5 hardened washers, two 3/8–16 x 3/4 socket head screws and one 3/8–16 x 1 hex bolt. Tighten bolts to standard torque (page 562). Tighten EGRV coolant supply tube nut at EGR valve to special torque (page 255).
3. If removed, connect EGRV coolant supply hose to EGRV coolant supply tube with 3/8 CTB clamp.

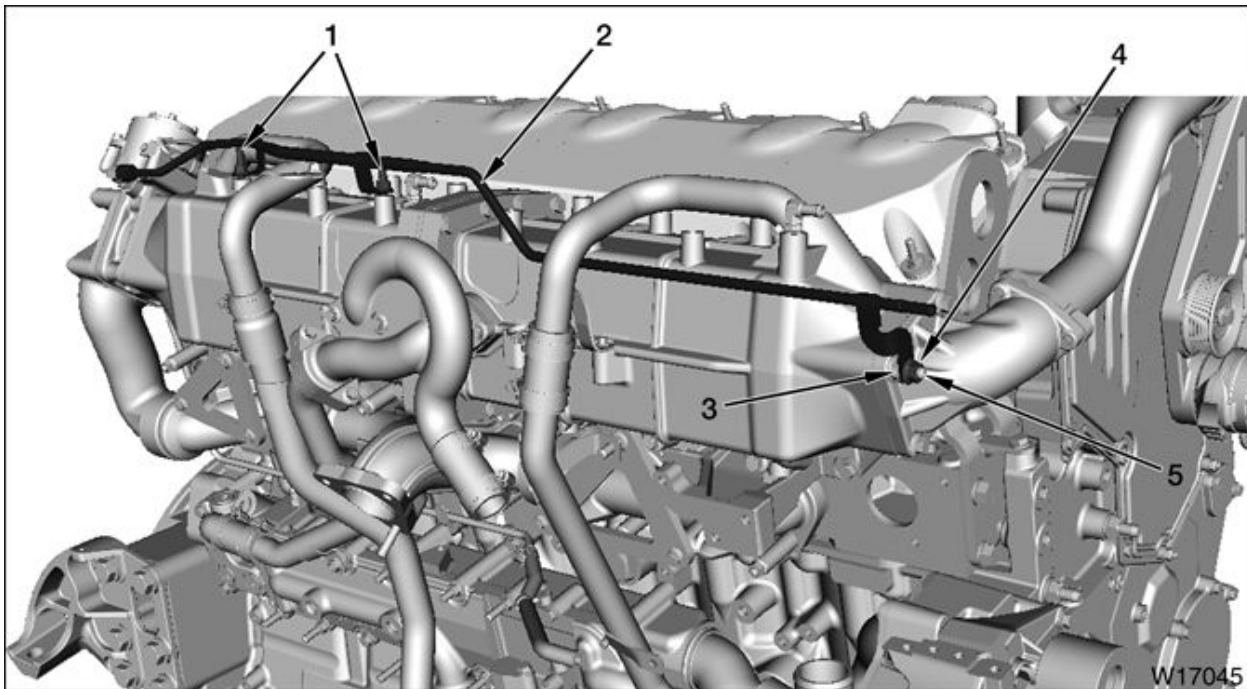
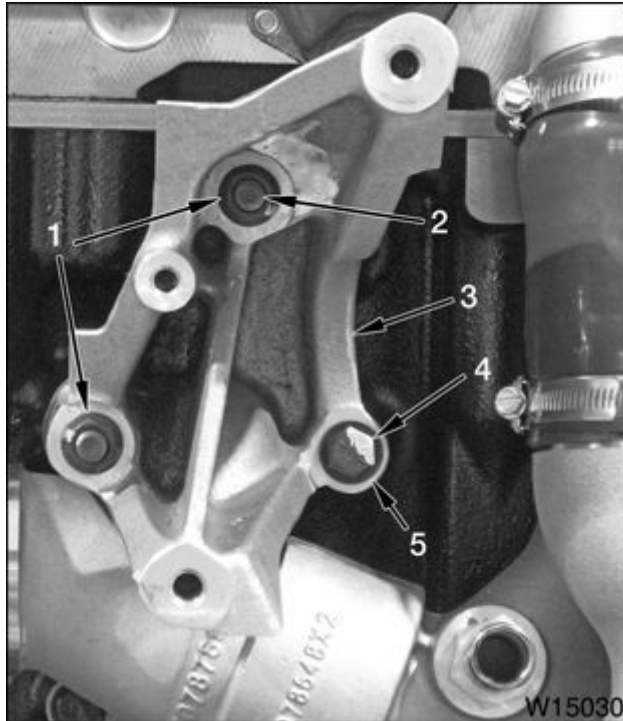
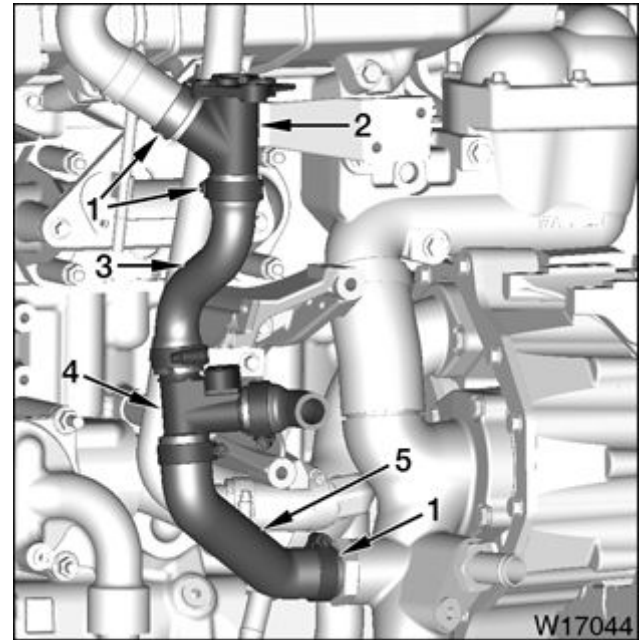


Figure 369 EGRV coolant return tube

1. M8 stud bolt (2)	3. 10.8 x 21 x 2.5 washer	5. M10 x 20 x 35 hex flange stud bolt
2. EGRV coolant return tube	4. M10 hex flange nut	6. torque (page 561). Tighten EGRV coolant return tube nut at EGR valve to special torque (page 255).
4. Place 10.8 x 21 x 2.5 washer on M10 x 20 x 35 hex flange stud bolt.
 5. Place EGRV coolant return tube forward bracket on M10 x 20 x 35 hex flange stud bolt.
 6. Install EGRV coolant return tube on engine with two M8 stud bolts. Tighten stud bolts to standard

Intercooler Support (Inner)**Figure 370 Intercooler support**

1. 3/8–16 hex flange nut (2)
 2. 3/8–16 x 6 1/2 taper lock stud (2)
 3. Intercooler support
 4. 3/8–16 x 3 hex bolt
 5. 3/8 hardened washer
1. If removed, install two 3/8–16 x 6 1/2 taper lock studs into crankcase. Tighten studs to standard torque (page 562).
 2. Install intercooler support on 3/8–16 x 6 1/2 taper lock studs. Place 3/8 hardened washer on 3/8–16 x 3 hex bolt and install bolt. Tighten bolt to standard torque (page 562).
 3. Install two 3/8–16 hex flange nuts. Tighten nuts to standard torque (page 562).

Heater Core Return Adapter and Temperature Sensor Fitting**Figure 371 Heater core return adapter and temperature sensor fitting**

1. SAE 24 clamp (3)
 2. Heater core return adapter
 3. Heater core return hose
 4. Temperature sensor fitting
 5. Formed 1.2 inch hose
1. Loosely assemble heater core return adapter, heater core return hose, temperature sensor fitting, and formed 1.2 inch hose with six SAE 24 clamps.
 2. Install assembly on engine. Tighten SAE 24 clamps to special torque (page 255).

Coolant Control Valve (CCV) Assembly and Coolant Adapter

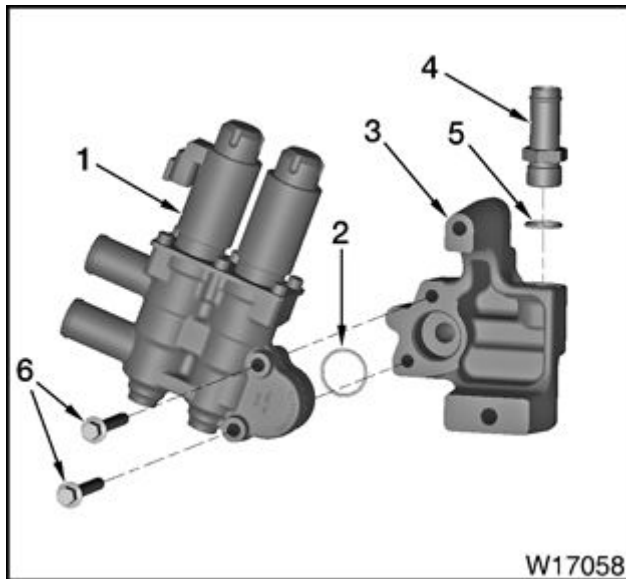


Figure 372 CCV assembly and coolant adapter (exploded view)

1. CCV assembly
 2. O-ring (26 x 2.0)
 3. Coolant adapter
 4. Hose fitting
 5. O-ring (3-910)
 6. M8 x 60 hex flange bolt (2)
1. Assemble coolant adapter to CCV assembly with a new O-ring (26 x 2.0). Tighten two M8 x 60 hex flange bolts to standard torque (page 561).
 2. If previously removed, install hose fitting on coolant adapter with a new O-ring (3-910). Tighten to special torque (page 255).

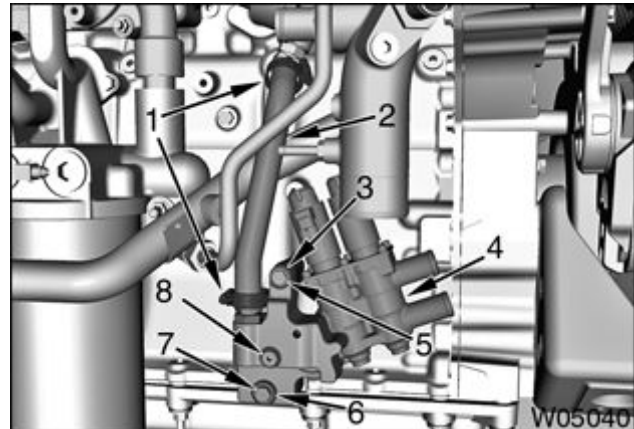


Figure 373 CCV assembly and coolant adapter

1. SAE 15/16 left clip clamp (2)
 2. CCV supply hose assembly
 3. 8.8 x 17 x 1.6 washer
 4. CCV assembly
 5. 5/16-18 x 3 1/2 hex bolt
 6. 10.2 x 18.5 x 5 hardened washer
 7. 3/8-16 x 3 hex bolt
 8. Plug assembly
3. If removed, install CCV supply hose assembly on hose fitting. Do not tighten SAE 15/16 left clip clamp at this time.
 4. Install CCV supply hose assembly and CCV on engine with 5/16-18 x 3 1/2 hex bolt and 8.8 x 17 x 1.6 washer. Tighten bolt to standard torque (page 562).
 5. Install 3/8-16 x 3 hex head bolt and 10.2 x 18.5 x 5 hardened washer. Tighten bolt to standard torque (page 562).
 6. Ensure correct orientation of CCV supply hose assembly and tighten two SAE 15/16 left clip clamps to special torque (page 255).

Coolant Manifold, ISC Coolant Supply Tube Assembly and CCV LTR Bypass Tube Assembly

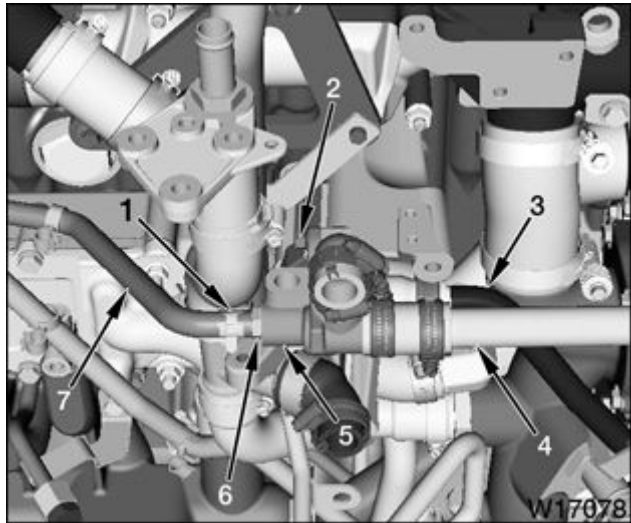


Figure 374 Coolant manifold

1. 3/8 CTB clamp
 2. M8 x 25 hex flange bolt
 3. CCV LTR bypass tube assembly
 4. ISC coolant supply tube assembly
 5. Coolant manifold
 6. Hose fitting
 7. EGRV coolant hose
1. Install coolant manifold on intercooler support (inner) with M8 x 25 hex flange bolt. Tighten bolt to standard torque (page 561).
 2. Connect EGRV coolant hose to hose fitting with 3/8 CTB clamp.

3. If removed, install ISC coolant supply tube assembly and CCV LTR bypass tube assembly to coolant manifold. Ensure tubes are positioned correctly and tighten SAE 15/16 left clip clamps to special torque (page 255).

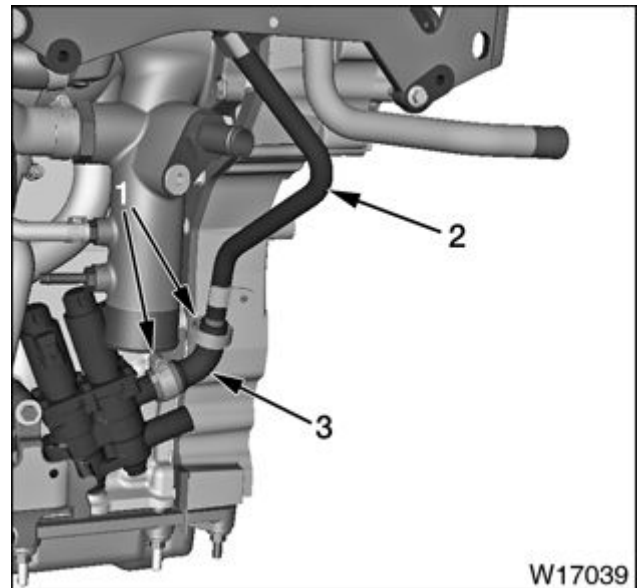


Figure 375 CCV LTR bypass tube assembly

1. SAE 15/16 left clip clamp (2)
 2. CCV LTR bypass tube assembly
 3. 3/4 to 1 inch elbow hose (upper)
4. Connect CCV LTR bypass tube assembly and 3/4 to 1 inch elbow hose (upper) to CCV assembly.
 5. Tighten two SAE 15/16 left clip clamps to special torque (page 255).

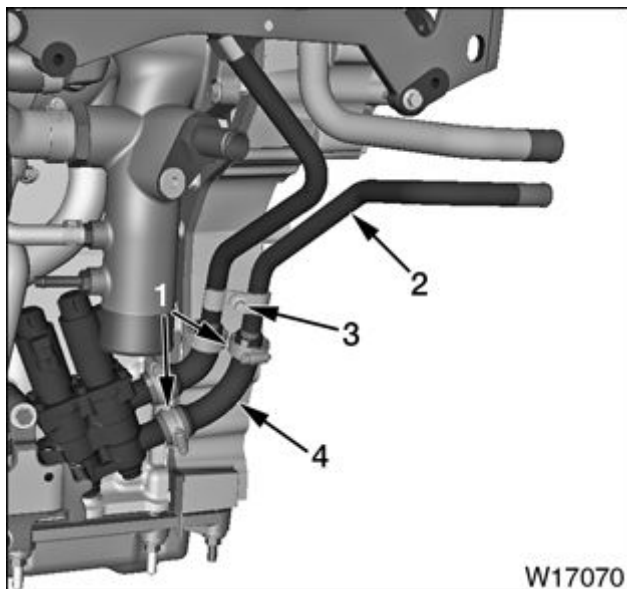


Figure 376 CCV LTR supply tube assembly

1. SAE 15/16 left clip clamp (2)
2. CCV LTR supply tube assembly
3. M6 x 16 hex flange bolt
4. 3/4 to 1 inch elbow hose (lower)

6. Connect CCV LTR supply tube assembly and 3/4 to 1 inch elbow hose (lower) to CCV with two SAE 15/16 left clip clamps. Do not tighten clamps at this time.
7. Install M6 x 16 hex flange bolt. Tighten bolt to standard torque (page 561).
8. Tighten two SAE 15/16 left clip clamps to special torque (page 255).

Specifications

EGR cooler supply tube to exhaust manifold gap	2 - 4.5 mm (0.079 - 0.177 in)

Special Torque

90 degree fitting assembly (on water pump outlet pipe)	58 N·m (43 lbf·ft)
Clamp (EGR supply hose)	4 N·m (24 lbf·in)
EGRV coolant return tube nut	26 N·m (19 lbf·ft)
EGRV coolant supply tube nut	26 N·m (19 lbf·ft)
Fitting (45 degree on EGR valve)	35 N·m (26 lbf·ft)
1 3/16-12 x 1 1/4 inch hose elbow lock nut (90 degree on rear of oil cooler)	250 N·m (184 lbf·ft)
Hose fitting (on coolant adapter)	48 N·m (35 lbf·ft)
M8 x 27 high temp bolt	24 N·m (18 lbf·ft)
M8 hex flange lock nut	8.2 N·m (72 lbf·in)
M10 x 130 high temp bolt	48 N·m (35 lbf·ft)
M10 90 degree 3/8 hose fitting (nut)	8 N·m (71 lbf·in)
M14 37 degree flare fitting (90 degree) (on EGR valve)	35 N·m (26 lbf·ft)
M18 plug assembly	24 N·m (18 lbf·ft)
SAE 15/16 left clip clamp	Step 1: 5.8 N·m (51 lbf·in) Wait 5 seconds Step 2: 5.8 N·m (51 lbf·in)
SAE 24 clamp	Step 1: 8.3 N·m (73 lbf·in) Wait 5 seconds Step 2: 8.3 N·m (73 lbf·in)
SAE 24 left clip clamp	Step 1: 8.3 N·m (73 lbf·in) Wait 5 seconds Step 2: 8.3 N·m (73 lbf·in)

Special Service Tools

Description	Tool Number
Air pressure regulator	Obtain locally
Alignment Pins	ZTSE4945 1-2
EGR Cooler Pressure Test Kit	ZTSE6090
EGR Cooler Lifting Tool	ZTSE6105
P-80® rubber lubricant or equivalent	Obtain locally

Table of Contents

Exploded Views.....	259
Removal.....	263
Engine Oil Cooler Assembly and Oil Filter Base Assembly.....	263
Breather Tube and Valve Cover Adapter.....	267
Breather Draft Tube and Breather Drain Tube.....	268
Breather Filter Assembly and Oil Breather Support.....	269
Disassemble.....	270
Oil Filter Base Assembly Pressure Valves.....	270
Cleaning, Inspection, and Testing.....	270
Engine Oil Cooler Assembly Cleaning.....	270
Assemble.....	271
Oil Filter Base Assembly Pressure Valves.....	271
Installation.....	272
Breather Filter Assembly and Oil Breather Support.....	272
Breather Draft Tube and Breather Drain Tube.....	272
Breather Tube and Valve Cover Adapter.....	273
Engine Oil Cooler Assembly and Oil Filter Base Assembly.....	274
Special Torque.....	279
Special Service Tools.....	279

Exploded Views

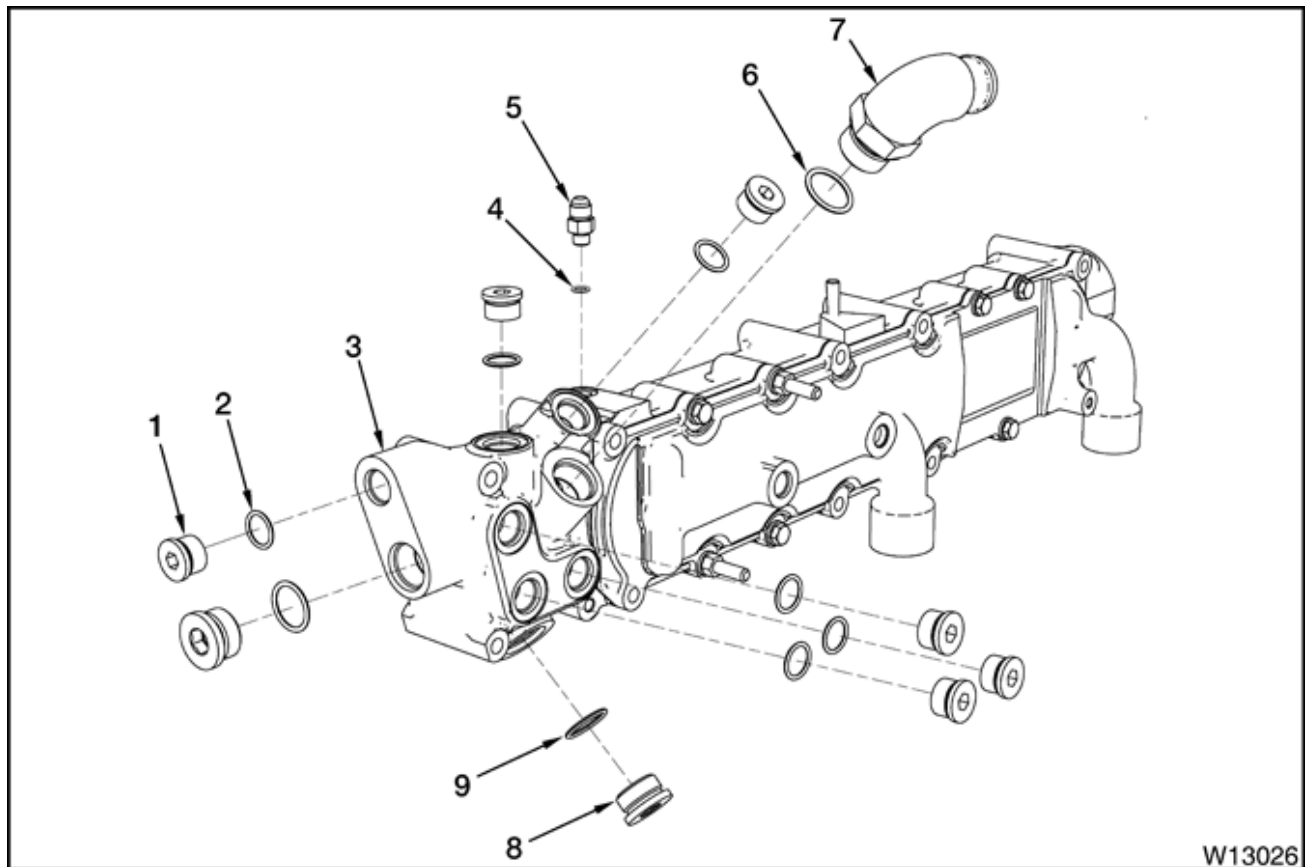
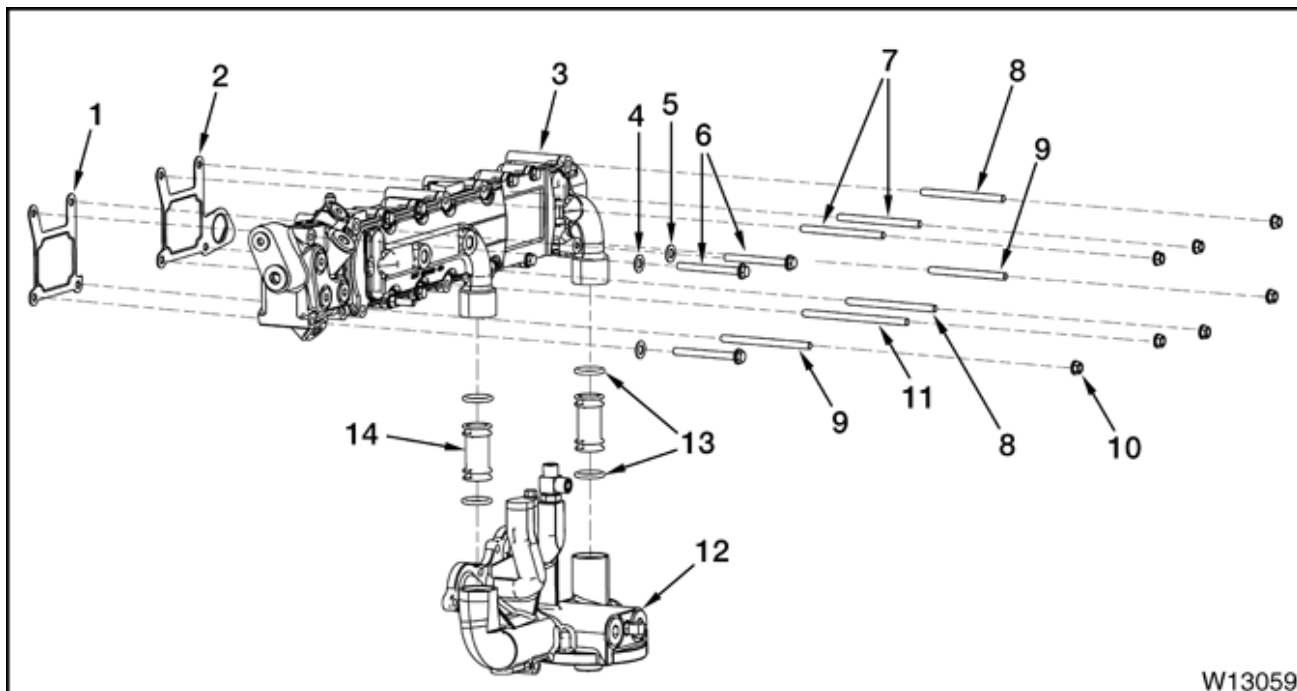


Figure 377 Engine oil cooler assembly

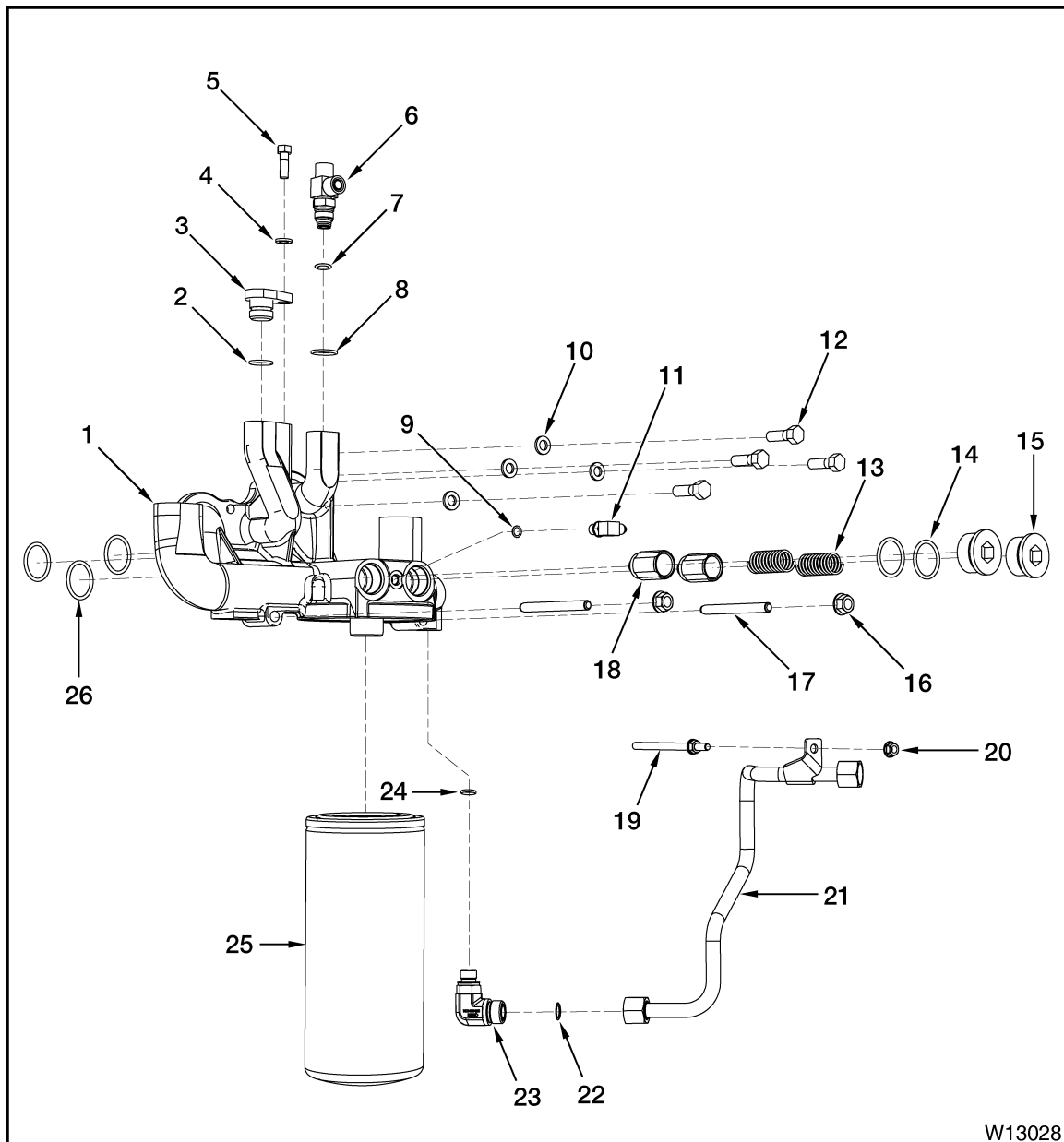
1. O-ring boss plug (7/8-14) (6)	5. 7/16-20 x 37 fitting	8. O-ring boss plug (1 3/16-12) (2)
2. O-ring (6)	6. O-ring	9. O-ring (2)
3. Engine oil cooler assembly	7. 1 3/16-12 x 1 1/4 inch hose elbow	
4. O-ring		



W13059

Figure 378 Engine oil cooler assembly to oil filter base assembly

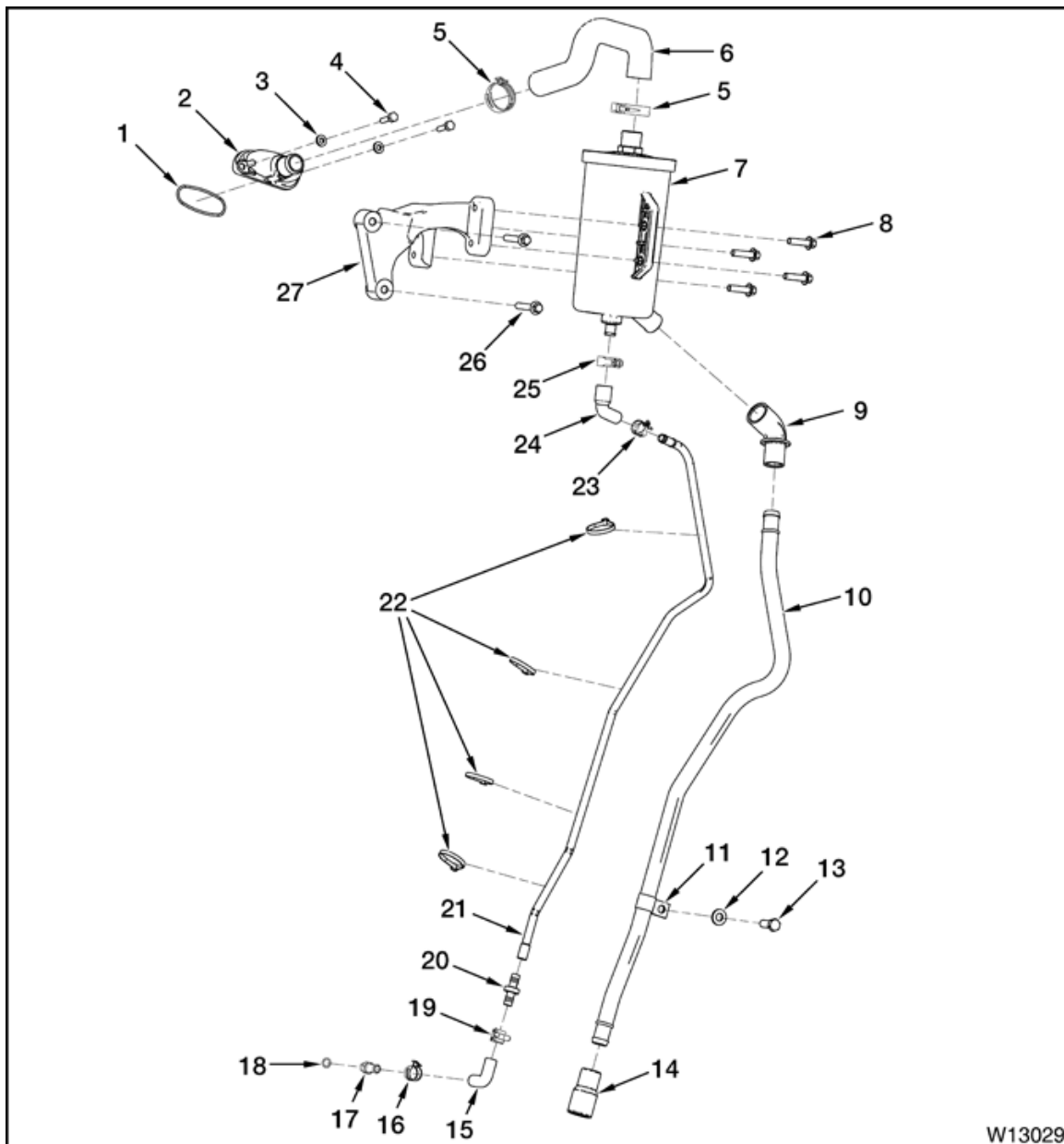
1. Oil cooler gasket (back)	6. 3/8-16 x 4 bolt (3)	12. Oil filter base assembly
2. Oil cooler gasket (front)	7. 3/8-16 x 5 1/8 taperlock stud (2)	13. O-ring (4)
3. Engine oil cooler assembly	8. 3/8-16 x 5 1/2 stud (2)	14. Tube (2)
4. 3/8 hardened washer (2)	9. 3/8-16 x 4 3/4 stud (2)	
5. 10.2 x 18.5 x 2.5 hardened washer	10. 3/8-16 hex flange nut (7)	
	11. 3/8-16 x 6 1/2 taperlock stud	



W13028

Figure 379 Oil filter base assembly

1. Oil filter base assembly	10. 10.2 x 18.5 hardened washer (4)	19. M8 x 100 stud bolt
2. O-ring seal	11. 90 degree fitting	20. M8 x 1.25 hex flange nut
3. Plug	12. 3/8-16 x 1.125 hex bolt (4)	21. Oil supply tube assembly
4. 10.2 x 18.5 hardened washer	13. Spring (2)	22. O-ring
5. 3/8-16 x 1.125 hex bolt	14. O-ring (2)	23. 90 degree elbow assembly
6. Connector	15. O-ring boss plug (1 5/16-12) (2)	24. O-ring seal
7. O-ring (Size 018)	16. 3/8-16 hex flange nut (2)	25. Oil filter
8. O-ring	17. 3/8-16 x 4 taperlock stud (2)	26. O-ring (3)
9. O-ring	18. Plunger (2)	



W13029

Figure 380 Breather assembly

1. O-ring	10. Breather draft tube	19. CTB 3/8 dia clamp
2. Valve cover adapter	11. Clip	20. Check valve
3. 7.2 x 14.5 hardened washer (2)	12. 1/2 hardened washer	21. Breather drain tube
4. 1/4 x 20 x 0.875 hex bolt (2)	13. 3/8-16 x 1 hex flange bolt	22. Cable lock strap (4)
5. CTB 1 dia clamp (2)	14. 1 to 3/4 tube connector	23. CT 3/8 preload clamp
6. Breather tube	15. Rubber elbow	24. Rubber elbow
7. Breather filter assembly	16. CT 3/8 open clamp	25. CTB 21 mm clamp
8. M8 x 30 hex flange bolt (4)	17. 7/16-20 STR to 3/8 fitting	26. M8 x 45 hex flange head bolt (2)
9. 110 degree elbow	18. Size 904 O-ring	27. Oil breather support

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 “Safety Information” section of this manual.

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

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

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

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

- Engine Electrical
- Aftertreatment System
- Turbocharger
- Fuel System
- EGR System

Engine Oil Cooler Assembly and Oil Filter Base Assembly

! WARNING: To prevent personal injury or death, contain and dispose of engine fluids in a proper container according to applicable regulations.

CAUTION: To prevent component damage, remove engine oil cooler and oil filter base together as an assembly.

CAUTION: To prevent engine damage, ensure that all coolant has been drained from oil cooler assembly. Excess residual coolant may result in oil contamination.

1. If oil cooler was not previously drained of coolant, place a coolant drain pan under engine oil cooler assembly.

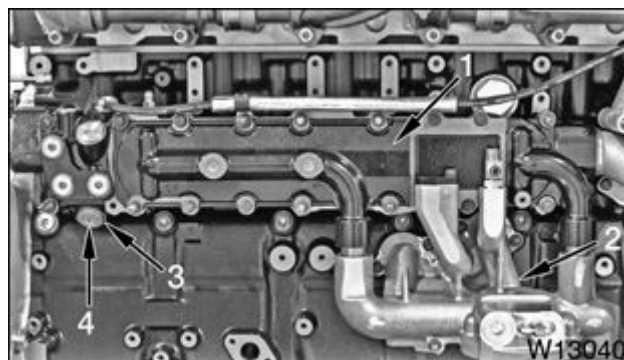


Figure 381 Engine oil cooler assembly drain plug

1. Engine oil cooler assembly
 2. Oil filter base assembly
 3. O-ring
 4. O-ring boss plug (1 3/16–12)
2. Remove O-ring boss plug (1 3/16–12) and drain coolant. Remove and discard O-ring.
 3. Inspect O-ring boss plug (1 3/16–12) and replace if necessary.
 4. Install new O-ring on O-ring boss plug (1 3/16–12). Lubricate O-ring with P-80® rubber lubricant or equivalent (page 279).
 5. Install O-ring boss plug (1 3/16–12) and tighten to special torque (page 279).

6. Place an oil drain pan under engine oil cooler assembly and oil filter base assembly.
7. Use an oil filter removal tool (page 279) to remove oil filter.

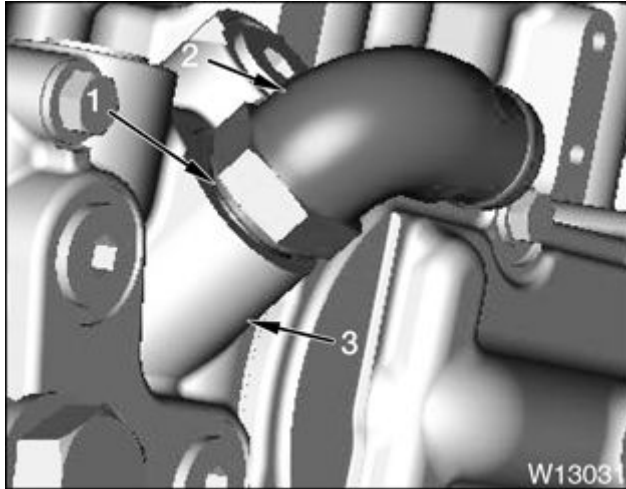


Figure 382 1 3/16-12 x 1 1/4 inch hose elbow

1. O-ring
 2. 1 3/16-12 x 1 1/4 inch hose elbow
 3. Engine oil cooler assembly
8. If required, remove 1 3/16-12 x 1 1/4 inch hose elbow. See Coolant Adapter and EGR Coolant Return Tube Assembly (page 223).

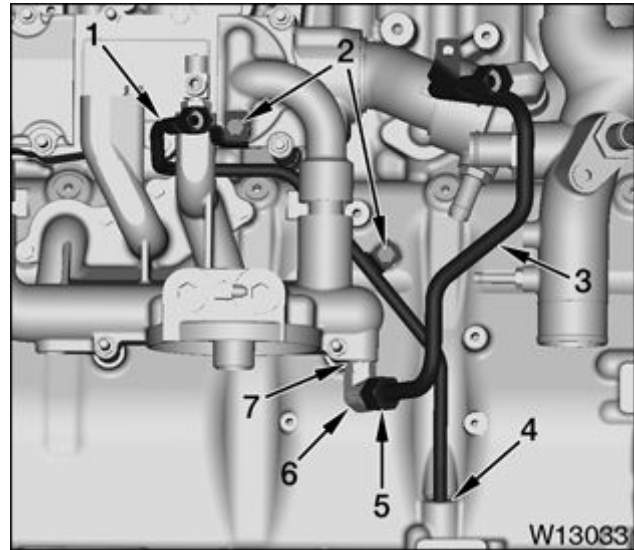


Figure 383 Oil supply tube assembly and oil drain tube assembly

1. Oil drain tube assembly
 2. 3/8-16 x 1/2 bolt (2)
 3. Oil supply tube assembly
 4. O-ring
 5. O-ring seal
 6. 90 degree elbow assembly
 7. O-ring seal
9. Loosen tube nut at 90 degree elbow assembly and remove oil supply tube assembly.
 10. If required, remove 90 degree elbow assembly. Remove and discard O-ring seal and O-ring from 90 degree elbow assembly.
 11. Remove two 3/8-16 x 1/2 bolts. Remove oil drain tube assembly. Remove and discard O-ring from bottom of oil drain tube assembly.

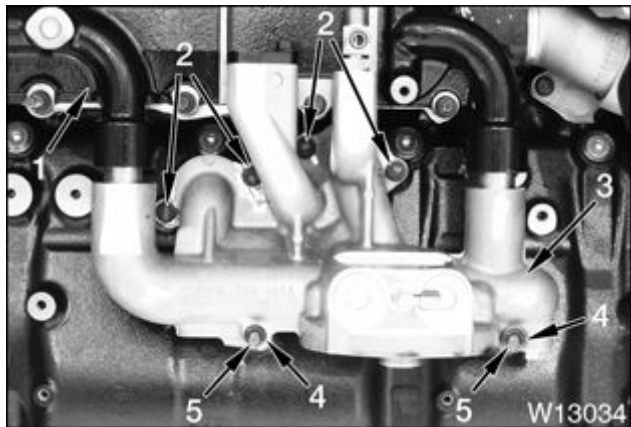


Figure 384 Oil filter base assembly

1. Engine oil cooler assembly
 2. 3/8-16 x 1.125 hex bolt (4) and 10.2 x 18.5 hardened washer (4)
 3. Oil filter base assembly
 4. 3/8-16 hex flange nut (2)
 5. 3/8-16 x 4 taperlock stud (2)
12. Remove four 3/8-16 x 1.125 hex bolts and four 10.2 x 18.5 hardened washers.
 13. Remove two 3/8-16 hex flange nuts and two 3/8-16 x 4 taperlock studs.
 14. Do not attempt removal of oil filter base assembly at this time. Oil filter base assembly and engine oil cooler assembly will be removed together.

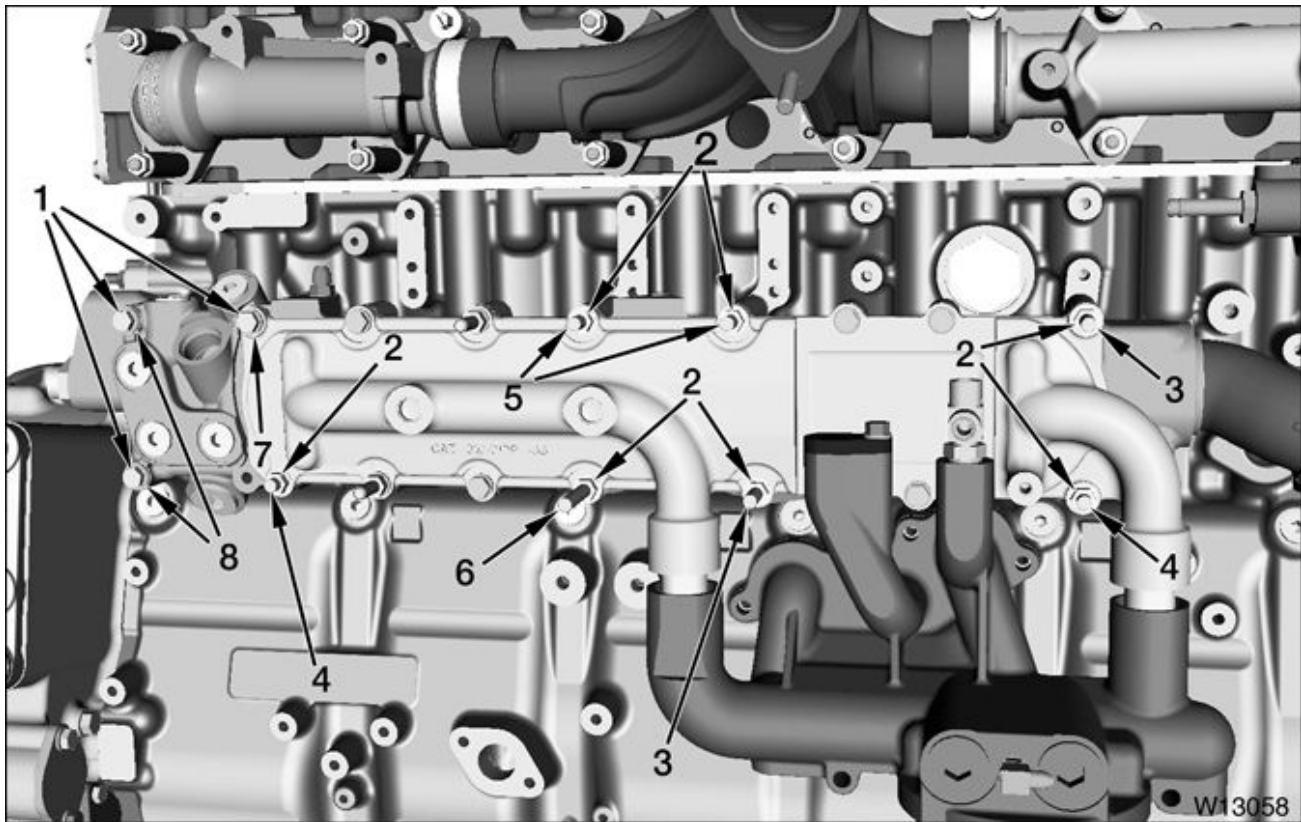


Figure 385 Engine oil cooler assembly fasteners

1. 3/8-16 x 4 hex head bolt (3)	4. 3/8-16 x 4 3/4 stud (2)	7. 10.2 x 18.5 x 2.5 hardened washer
2. 3/8-16 hex flange nut (7)	5. 3/8-16 x 5 1/8 taper lock stud (2)	8. 3/8 hardened washer (2)
3. 3/8-16 x 5 1/2 stud (2)	6. 3/8-16 x 6 1/2 taper lock stud	
-
15. Remove three 3/8-16 x 4 hex head bolts, two 3/8 hardened washers and one 10.2 x 18.5 x 2.5 hardened washer.
 16. Remove seven 3/8-16 hex flange nuts.
 17. Remove two 3/8-16 x 5 1/2 studs, two 3/8-16 x 4 3/4 studs and one 3/8-16 x 6 1/2 taper lock stud.
 18. With help from an assistant, properly support oil filter base assembly and engine oil cooler assembly before removing final fasteners.
 19. Remove two 3/8-16 x 5 1/8 taper lock studs.
 20. Remove oil filter base assembly and engine oil cooler assembly and place on suitable workbench.

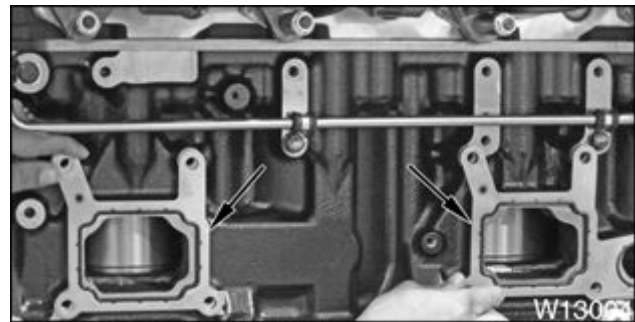


Figure 386 Oil cooler gaskets

21. Remove and discard two oil cooler gaskets.
22. Separate oil filter base assembly from engine oil cooler assembly.

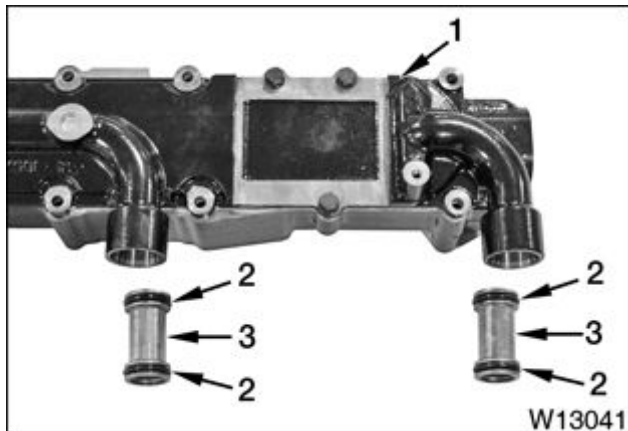


Figure 387 Connecting tubes

1. Engine oil cooler assembly
2. O-ring (4)
3. Tube (2)

23. Remove two tubes. Remove and discard four O-rings

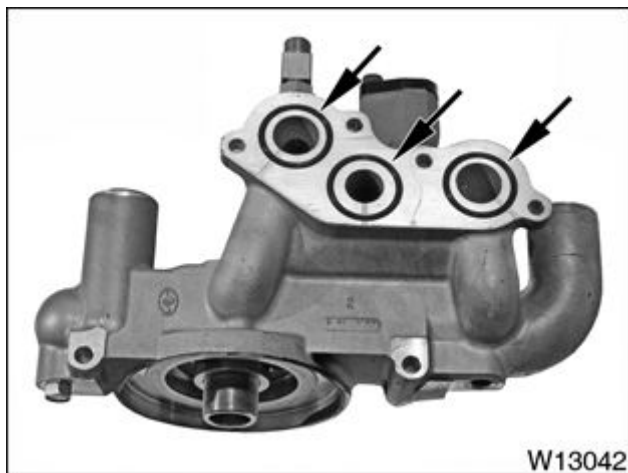


Figure 388 Oil filter base assembly O-rings

24. Remove and discard three O-rings from back side of oil filter base assembly.

Breather Tube and Valve Cover Adapter

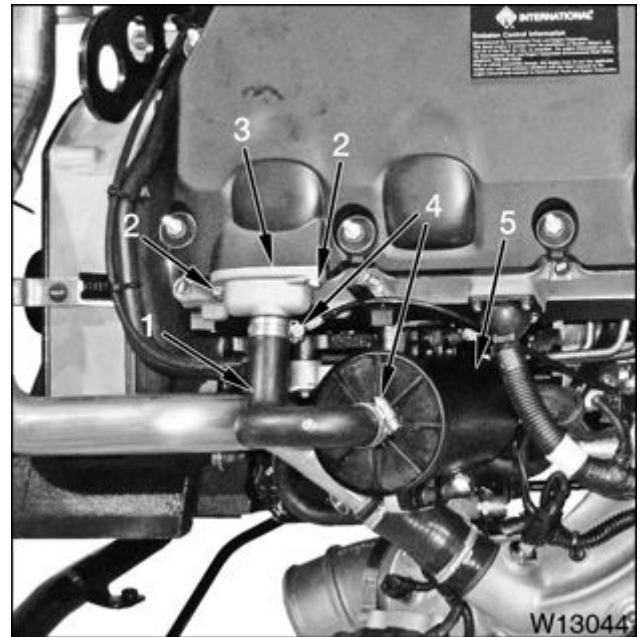


Figure 389 Breather tube and valve cover adapter

1. Breather tube
2. 1/4 x 20 x 0.875 hex bolt (2) and 7.2 x 14.5 hardened washer (2)
3. Valve cover adapter
4. CTB 1 dia clamp (2)
5. Breather filter assembly

1. Loosen two CTB 1 dia clamps.
2. Disconnect end of breather tube from valve cover adapter.
3. Disconnect other end of breather tube from breather filter assembly and remove breather tube.
4. Remove two 1/4 x 20 x 0.875 hex bolts and two 7.2 x 14.5 hardened washers.
5. Remove valve cover adapter.



Figure 390 Valve cover adapter O-ring

6. Inspect valve cover adapter O-ring and replace if necessary.

Breather Draft Tube and Breather Drain Tube

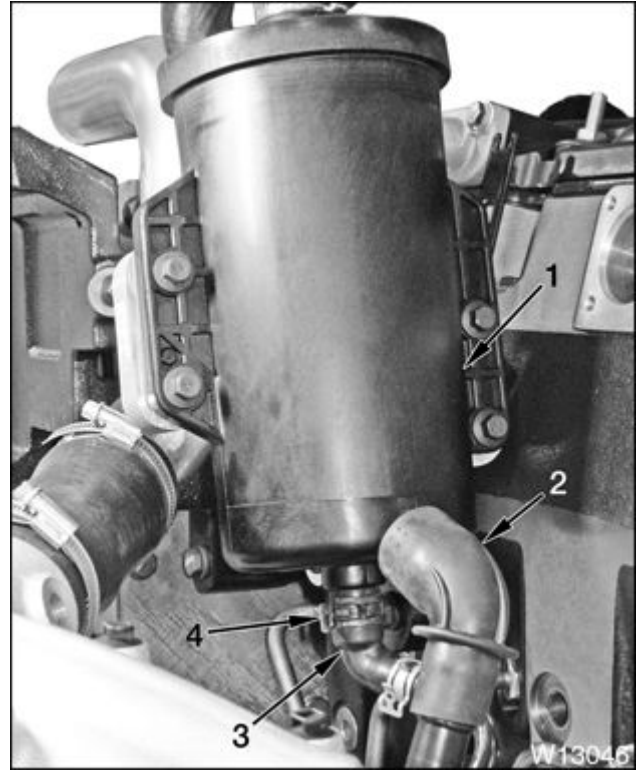


Figure 391 Tube connections at breather filter assembly

1. Breather filter assembly
 2. 110 degree elbow
 3. Rubber elbow
 4. CTB 21 mm clamp
-
1. Disconnect 110 degree elbow from breather filter assembly.
 2. Loosen CTB 21 mm clamp and disconnect rubber elbow from breather filter assembly.

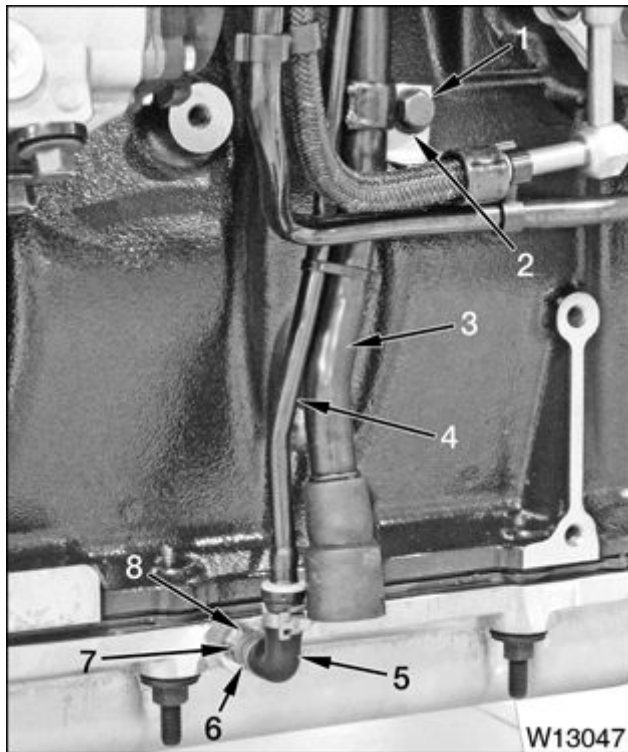


Figure 392 Tube connections at oil pan

1. 3/8-16 x 1 hex flange bolt
 2. 1/2 hardened washer
 3. Breather draft tube
 4. Breather drain tube
 5. Rubber elbow
 6. CT 3/8 open clamp
 7. 7/16-20 STR to 3/8 fitting
 8. Size 904 O-ring
3. Remove 3/8-16 x 1 hex flange bolt and 1/2 hardened washer.
 4. Loosen CT 3/8 open clamp and disconnect rubber elbow from 7/16-20 STR to 3/8 fitting at oil pan.
 5. Remove breather draft tube and breather drain tube from engine by snaking out together. Breather draft tube and breather drain tube are connected to each another by four cable lock straps.
 6. If required, remove 7/16-20 STR to 3/8 fitting from oil pan. Remove and discard size 904 O-ring.

Breather Filter Assembly and Oil Breather Support

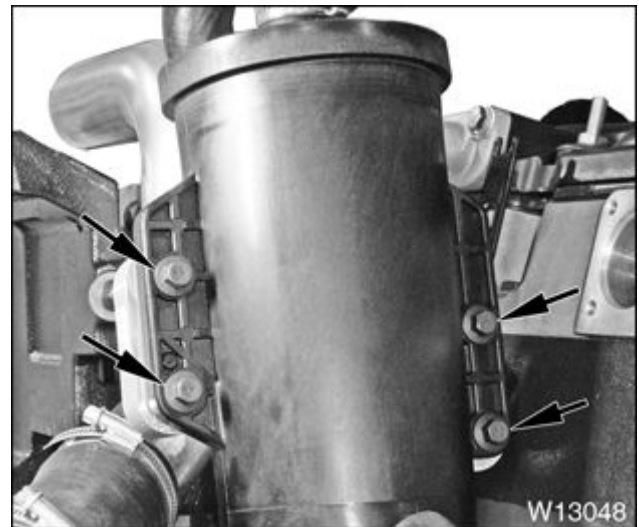


Figure 393 Breather filter assembly M8 x 30 hex flange mounting bolts

1. Remove four M8 x 30 hex flange bolts.
2. Remove breather filter assembly.

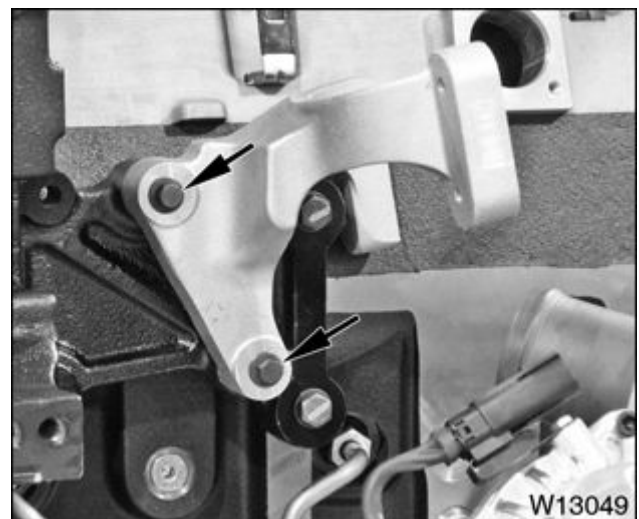


Figure 394 Oil breather support M8 x 45 hex flange mounting bolts

3. Remove two M8 x 45 hex flange head bolts.
4. Remove oil breather support.

Disassemble



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

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

Oil Filter Base Assembly Pressure Valves

NOTE: Component disassembly shown for one oil filter base assembly plunger; other is similar.

! WARNING: To prevent personal injury or death, use care when releasing pressure valve O-ring boss plug. Plug is under spring tension.

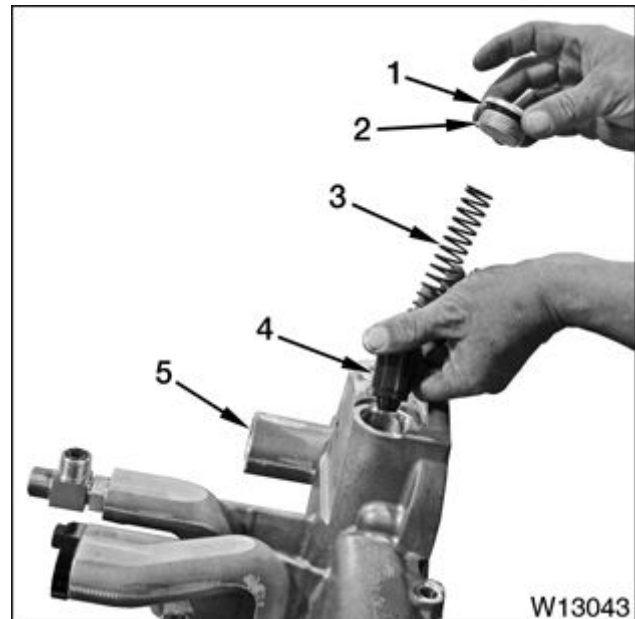


Figure 395 Oil filter base assembly plunger

1. O-ring
2. O-ring boss plug (1 5/16–12)
3. Spring
4. Plunger
5. Oil filter base assembly

1. Using 5/8 hex key (page 279), remove O-ring boss plug (1 5/16–12). Plug is under spring tension.
2. Remove and discard O-ring from O-ring boss plug (1 5/16–12).
3. Remove spring.
4. Remove plunger.

Cleaning, Inspection, and Testing

Engine Oil Cooler Assembly Cleaning

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

CAUTION: To prevent engine damage, replace engine oil cooler assembly if an engine bearing fails. Trapped bearing debris within engine oil cooler assembly can cause further engine damage.

1. Engine oil cooler assembly can be cleaned, then dried with filtered compressed air.
 - a. Clean engine oil cooler assembly with brake cleaner.
 - b. Flush and drain engine oil cooler assembly to remove any residues.
 - c. Dry engine oil cooler assembly thoroughly using filtered compressed air.

CAUTION: To prevent engine damage, completely drain and dry engine oil cooler assembly. Excess residual solvent can cause damage.

Assemble



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

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

Oil Filter Base Assembly Pressure Valves

! WARNING: To prevent personal injury or death, use care when releasing pressure valve O-ring boss plug. Plug is under spring tension.

NOTE: Component assembly shown for one oil filter base assembly plunger; other is similar

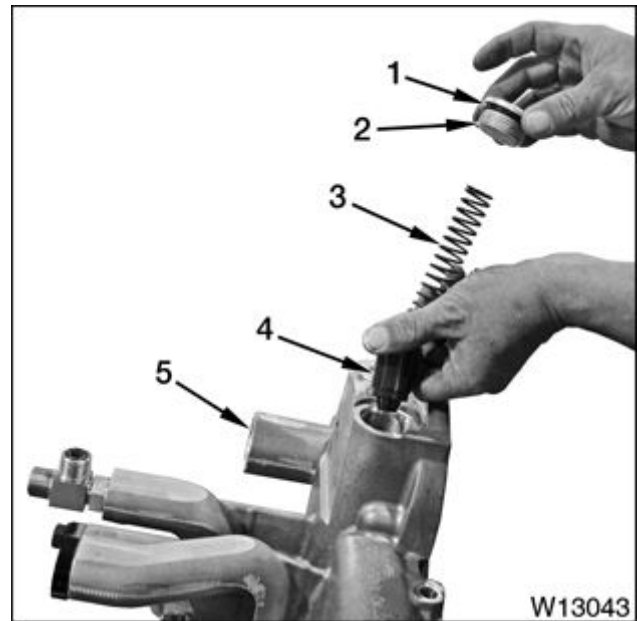


Figure 396 Oil filter base assembly plunger

1. O-ring
2. O-ring boss plug (1 5/16–12)
3. Spring
4. Plunger
5. Oil filter base assembly

1. Install plunger.
2. Install spring.
3. Lubricate new O-ring with P-80® rubber lubricant or equivalent (page 279) and install on O-ring boss plug (1 5/16–12).
4. Apply pressure to O-ring boss plug to compress spring into oil filter base assembly.
5. Using 5/8 hex key (page 279), install O-ring boss plug (1 5/16–12). Tighten to special torque (page 279).

Installation

Breather Filter Assembly and Oil Breather Support

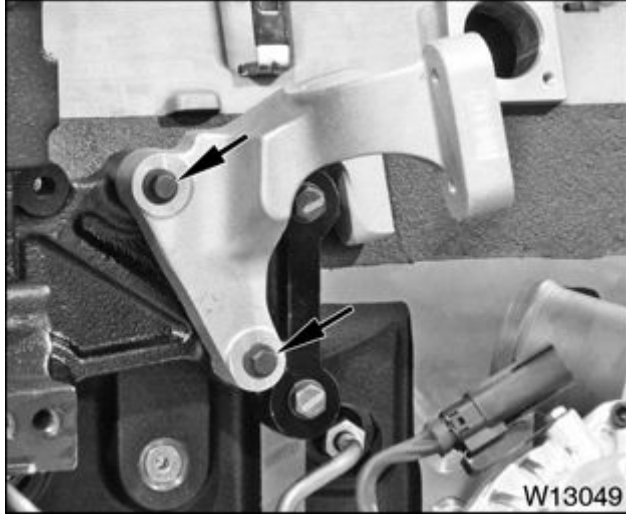


Figure 397 Oil breather support M8 x 45 hex flange mounting bolts

1. Position oil breather support.
2. Install two M8 x 45 hex flange head bolts and tighten to standard torque (page 561).

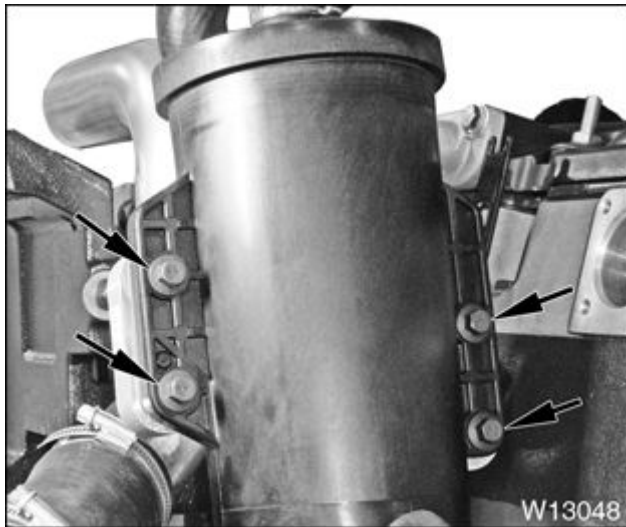


Figure 398 Breather filter assembly M8 x 30 hex flange mounting bolts

3. Position new breather filter assembly.

4. Install four M8 x 30 hex flange bolts and tighten to standard torque (page 561).

Breather Draft Tube and Breather Drain Tube

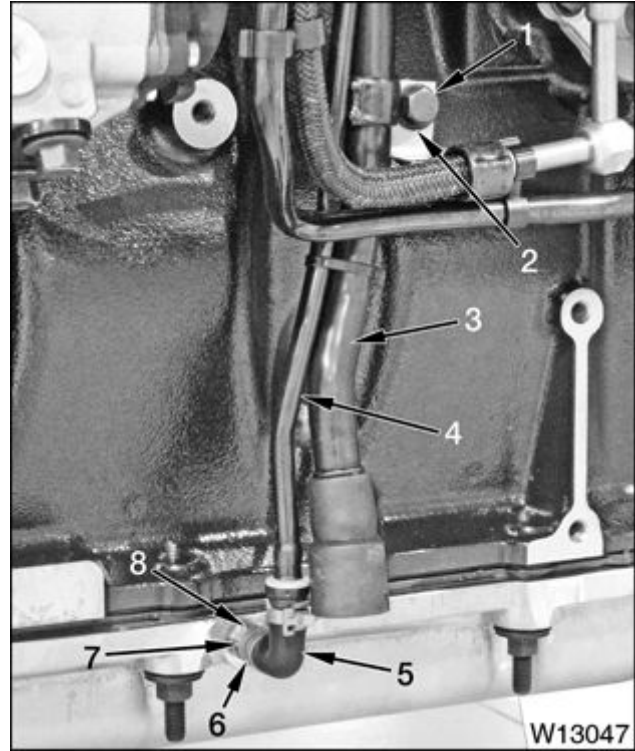


Figure 399 Tube connections at oil pan

1. 3/8-16 x 1 hex flange bolt
2. 1/2 hardened washer
3. Breather draft tube
4. Breather drain tube
5. Rubber elbow
6. CT 3/8 open clamp
7. 7/16-20 STR to 3/8 fitting
8. Size 904 O-ring

1. If 7/16-20 STR to 3/8 fitting into oil pan was removed, lubricate with clean engine oil and install new size 904 O-ring onto 7/16-20 STR to 3/8 fitting.
2. Install 7/16-20 STR to 3/8 fitting into oil pan and tighten to special torque (page 279).
3. Position breather draft tube and breather drain tube on engine. Breather draft tube and breather drain tube are connected to each other by four cable lock straps.

4. Loosen CT 3/8 open clamp and connect rubber elbow onto 7/16–20 STR to 3/8 fitting at oil pan. Release clamp.
5. Install 3/8–16 x 1 hex flange bolt and 1/2 hardened washer. Tighten bolt to standard torque (page 562).

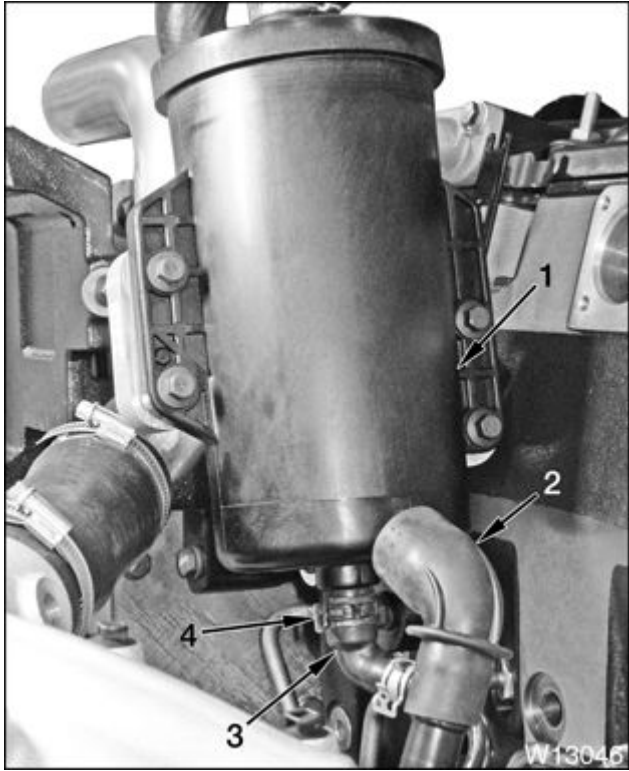


Figure 400 Tube connections at breather filter assembly

1. Breather filter assembly
 2. 110 degree elbow
 3. Rubber elbow
 4. CTB 21 mm clamp
6. Loosen CTB 21 mm clamp and connect rubber elbow onto breather filter assembly. Tighten clamp.
 7. Connect 110 degree elbow onto breather filter assembly.

Breather Tube and Valve Cover Adapter



Figure 401 Valve cover adapter O-ring

1. Inspect valve cover adapter O-ring and replace if necessary.

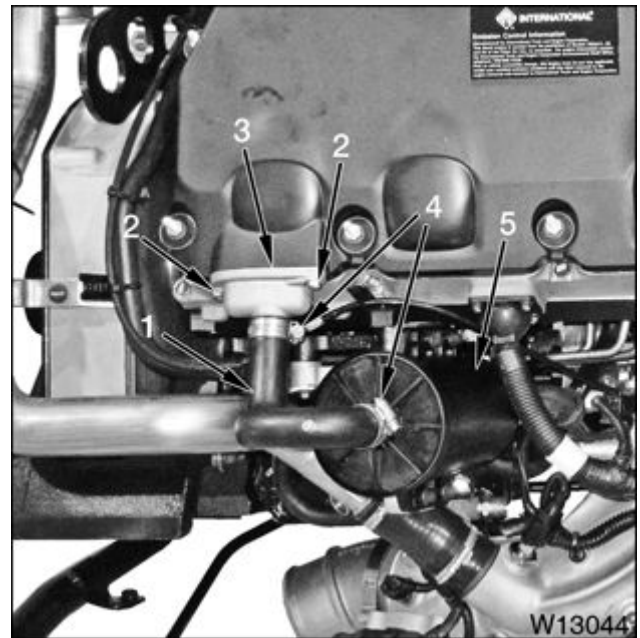


Figure 402 Breather tube and valve cover adapter

1. Breather tube
2. 1/4 x 20 x 0.875 hex bolt (2) and 7.2 x 14.5 hardened washer (2)
3. Valve cover adapter
4. CTB 1 dia clamp (2)
5. Breather filter assembly

2. Position valve cover adapter.
3. Install two 1/4 x 20 x 0.875 hex bolts and two 7.2 x 14.5 hardened washers. Tighten to standard torque (page 562).
4. Slide one end of breather tube with two CTB 1 dia clamps onto breather filter assembly.
5. Slide other end of breather tube onto valve cover adapter.
6. Position two loosened CTB 1 dia clamps at each end of breather tube. Tighten clamps until snug.

Engine Oil Cooler Assembly and Oil Filter Base Assembly

! WARNING: To prevent personal injury or death, contain and dispose of engine fluids in a proper container according to applicable regulations.

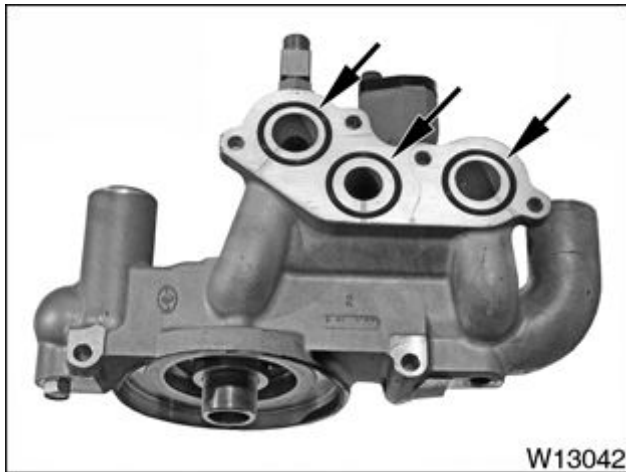


Figure 403 Oil filter base assembly O-rings

1. Lubricate three O-rings with P-80® rubber lubricant or equivalent (page 279) and install into backside of oil filter base assembly.

CAUTION: To prevent component damage, install engine oil cooler and oil filter base together as an assembly.

2. On a suitable workbench, align oil filter base assembly with engine oil cooler assembly.

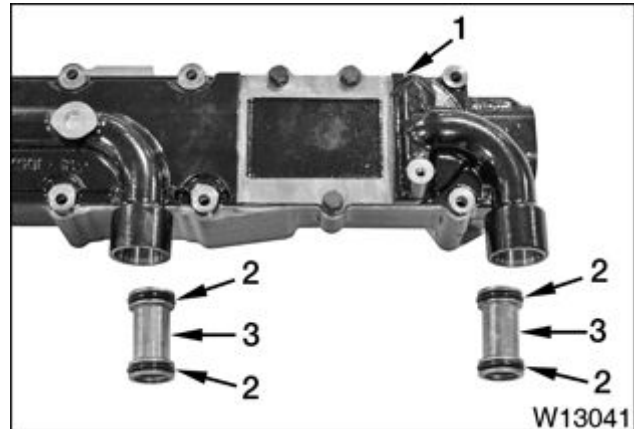


Figure 404 Connecting tubes

1. Engine oil cooler assembly
2. O-ring (4)
3. Tube (2)
3. Lubricate two new O-rings with clean engine oil and install onto one of the tubes. Repeat for other tube.
4. Slide two tubes into engine oil cooler assembly. Slide other end of tubes into oil filter base assembly. Oil filter base assembly and engine oil cooler assembly will be installed as a connected unit.

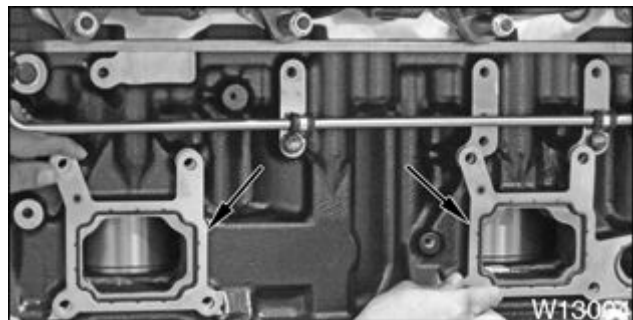


Figure 405 Oil cooler gaskets

5. On engine, install two oil cooler gaskets. Position as shown.

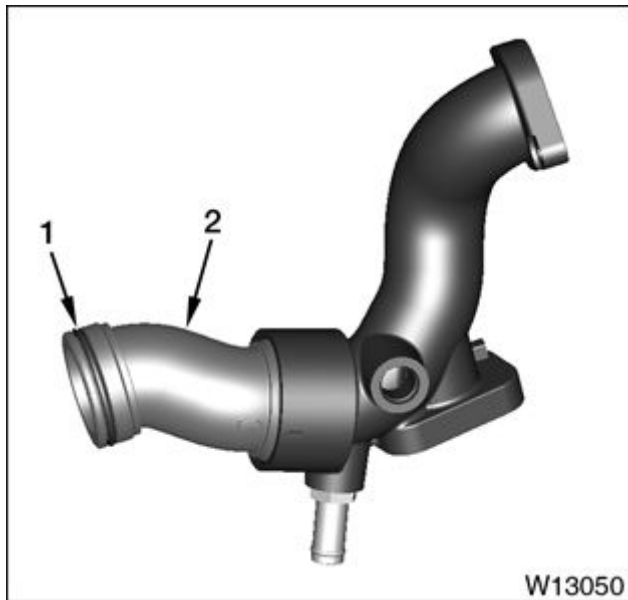


Figure 406 Water outlet connector (shown removed from engine to highlight O-ring location)

1. O-ring
2. Water outlet connector

6. Prior to oil filter base assembly and engine oil cooler assembly installation onto engine, inspect water outlet connector O-ring. Replace as necessary.
7. Lubricate water outlet connector O-ring with P-80® rubber lubricant or equivalent (page 279).
8. With help from an assistant, properly support oil filter base assembly and engine oil cooler assembly, and position on engine. Slide onto water outlet connector and align fastener openings.

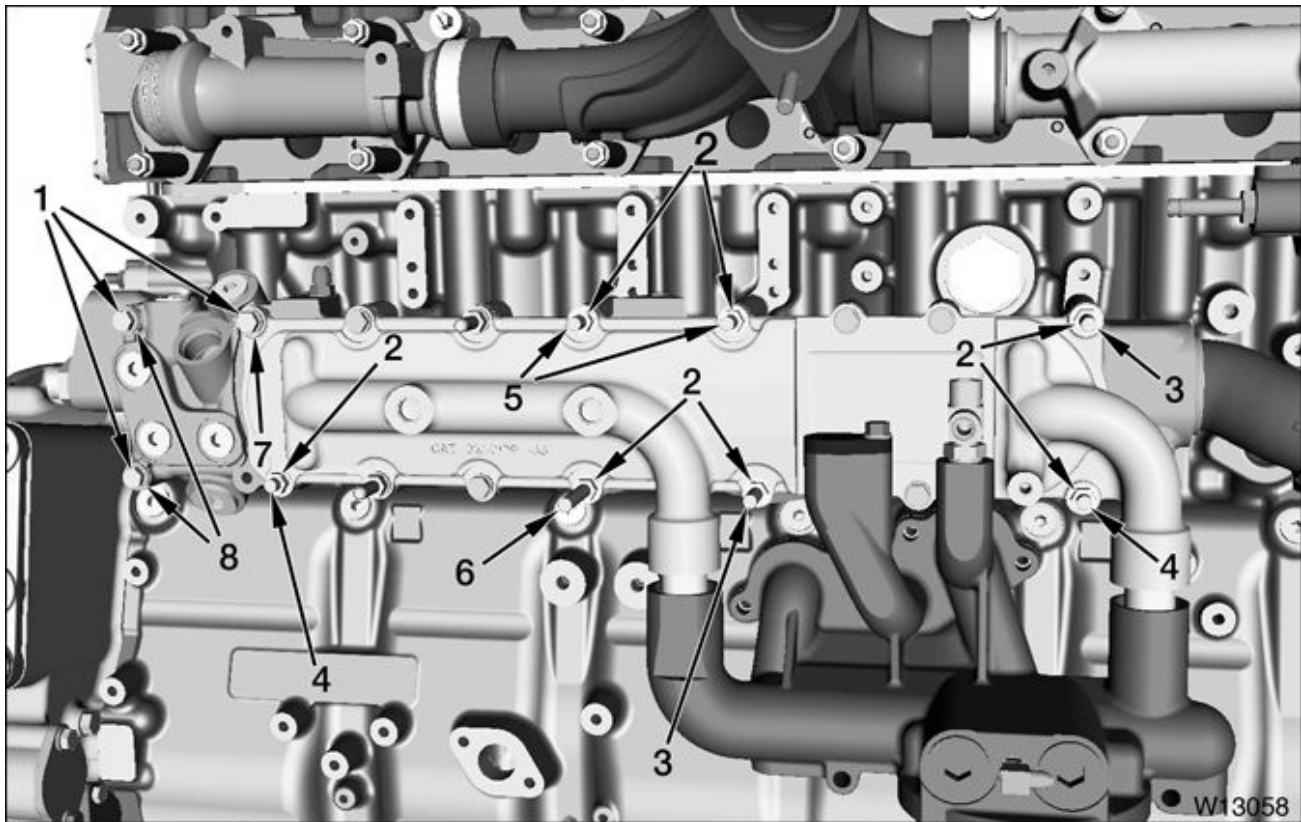


Figure 407 Engine oil cooler assembly fasteners

1. 3/8–16 x 4 hex head bolt (3)	4. 3/8–16 x 4 3/4 stud (2)	7. 10.2 x 18.5 x 2.5 hardened washer
2. 3/8–16 hex flange nut (7)	5. 3/8–16 x 5 1/8 taper lock stud (2)	8. 3/8 hardened washer (2)
3. 3/8–16 x 5 1/2 stud (2)	6. 3/8–16 x 6 1/2 taper lock stud	
-
9. Install two 3/8–16 x 5 1/8 taperlock studs. Tighten studs until they bottom out to special torque (page 279).
 10. Install two 3/8–16 x 5 1/2 studs, two 3/8–16 x 4 3/4 studs and one 3/8–16 x 6 1/2 taper lock stud. Tighten studs until they bottom out to special torque (page 279).
 11. Install seven 3/8–16 hex flange nuts and tighten to standard torque (page 562).
 12. Install two 3/8 hardened washers, one 10.2 x 18.5 x 2.5 hardened washer, and three 3/8–16 x 4 bolts. Tighten bolts to standard torque (page 562).

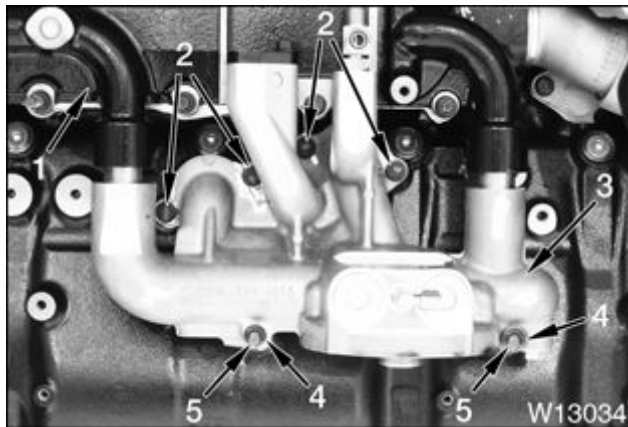


Figure 408 Oil filter base assembly

1. Engine oil cooler assembly
 2. 3/8–16 x 1.125 hex bolt (4) and 10.2 x 18.5 hardened washer (4)
 3. Oil filter base assembly
 4. 3/8–16 hex flange nut (2)
 5. 3/8–16 x 4 taperlock stud (2)
13. Install two 3/8–16 x 4 taperlock studs. Tighten studs until they bottom out to standard torque (page 562).
 14. Install two 3/8–16 hex flange nuts and tighten to standard torque (page 562).
 15. Install four 10.2 x 18.5 hardened washers and four 3/8–16 x 1.125 hex bolts. Tighten bolts to standard torque (page 562).

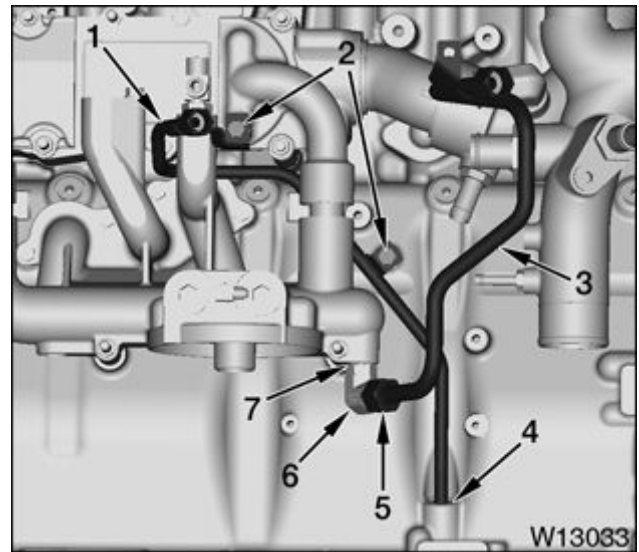


Figure 409 Oil supply tube assembly and oil drain tube assembly

1. Oil drain tube assembly
 2. 3/8-16 x 1/2 bolt (2)
 3. Oil supply tube assembly
 4. O-ring
 5. O-ring seal
 6. 90 degree elbow assembly
 7. O-ring seal
16. Install new O-ring on bottom of oil drain tube assembly. Lubricate O-ring with P-80® rubber lubricant or equivalent (page 279). Install oil drain tube assembly in crankcase. Install two 3/8-16 x 1/2 bolts. Tighten bolts to standard torque (page 562).
 17. If removed, lubricate O-ring and O-ring seal with P-80® rubber lubricant or equivalent (page 279) and install O-ring and O-ring seal onto 90 degree elbow assembly. Install 90 degree elbow assembly into oil filter base assembly hand tight.
 18. Position oil supply tube assembly on engine.
 19. Hand tighten oil supply tube assembly connection to 90 degree elbow assembly.
 20. Using back up wrench, tighten 90 degree elbow assembly jam nut to special torque (page 279).
 21. Using back up wrench, tighten oil supply tube assembly nut to special torque (page 279).

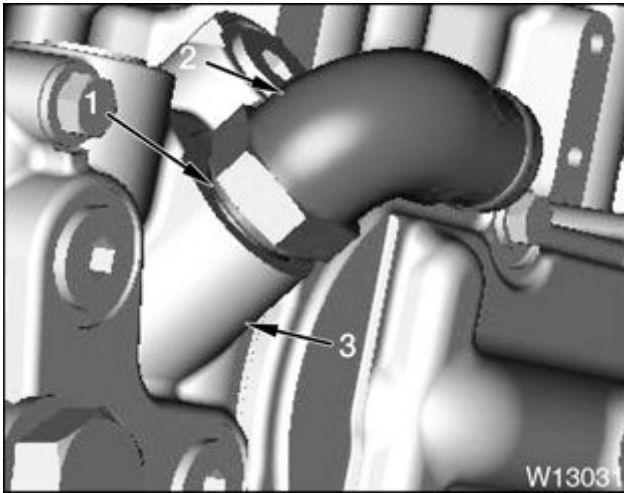


Figure 410 1 3/16-12 x 1 1/4 inch hose elbow

1. O-ring
 2. 1 3/16-12 x 1 1/4 inch hose elbow
 3. Engine oil cooler assembly
22. If removed, install 1 3/16-12 x 1 1/4 inch hose elbow. See Coolant Adapter and EGR Coolant Return Tube Assembly (page 244).

23. Lubricate new oil filter gasket with clean engine oil.

CAUTION: To prevent engine damage, do not over tighten oil filter.

24. Install new oil filter on oil filter base assembly.

25. Hand tighten oil filter until oil filter gasket contacts oil filter base assembly, then tighten one full additional turn.

26. After all other service is completed and all oil lines are properly connected, fill engine with proper grade and viscosity engine oil.

CAUTION: To prevent engine damage, do not operate engine if oil level is above or below proper operating range.

27. Ensure oil level is within appropriate range prior to operation.

Special Torque

3/8–16 x 4 3/4 stud	35 N·m (26 lbf·ft)
3/8–16 x 5 1/8 taperlock stud	35 N·m (26 lbf·ft)
3/8–16 x 5 1/2 stud	35 N·m (26 lbf·ft)
3/8–16 x 6 1/2 taperlock stud	35 N·m (26 lbf·ft)
7/16–20 STR to 3/8 fitting	23 N·m (17 lbf·ft)
90 degree elbow assembly jam nut (oil filter base assembly)	28 N·m (20 lbf·ft)
O-ring boss plug (7/8–14)	100 N·m (74 lbf·ft)
O-ring boss plug (1 3/16–12)	100 N·m (74 lbf·ft)
O-ring boss plug (1 5/16–12)	100 N·m (74 lbf·ft)
Oil supply tube assembly nut	28 N·m (21 lbf·ft)

Special Service Tools

5/8 hex key	Obtain locally
Oil Cooler Test Kit (includes two test plugs)	ZTSE6092
Oil filter removal tool	Obtain locally
P-80® rubber lubricant or equivalent	Obtain locally

Table of Contents

Exploded Views.....	283
Removal.....	285
Exhaust Manifold.....	285
Air Inlet.....	287
Cleaning, Inspection, and Testing.....	289
All Components.....	289
Exhaust Manifold.....	289
Air Inlet.....	289
Installation.....	290
Air Inlet.....	290
Exhaust Manifold.....	291
Specifications.....	294
Special Torque.....	294
Special Service Tools.....	294

Exploded Views

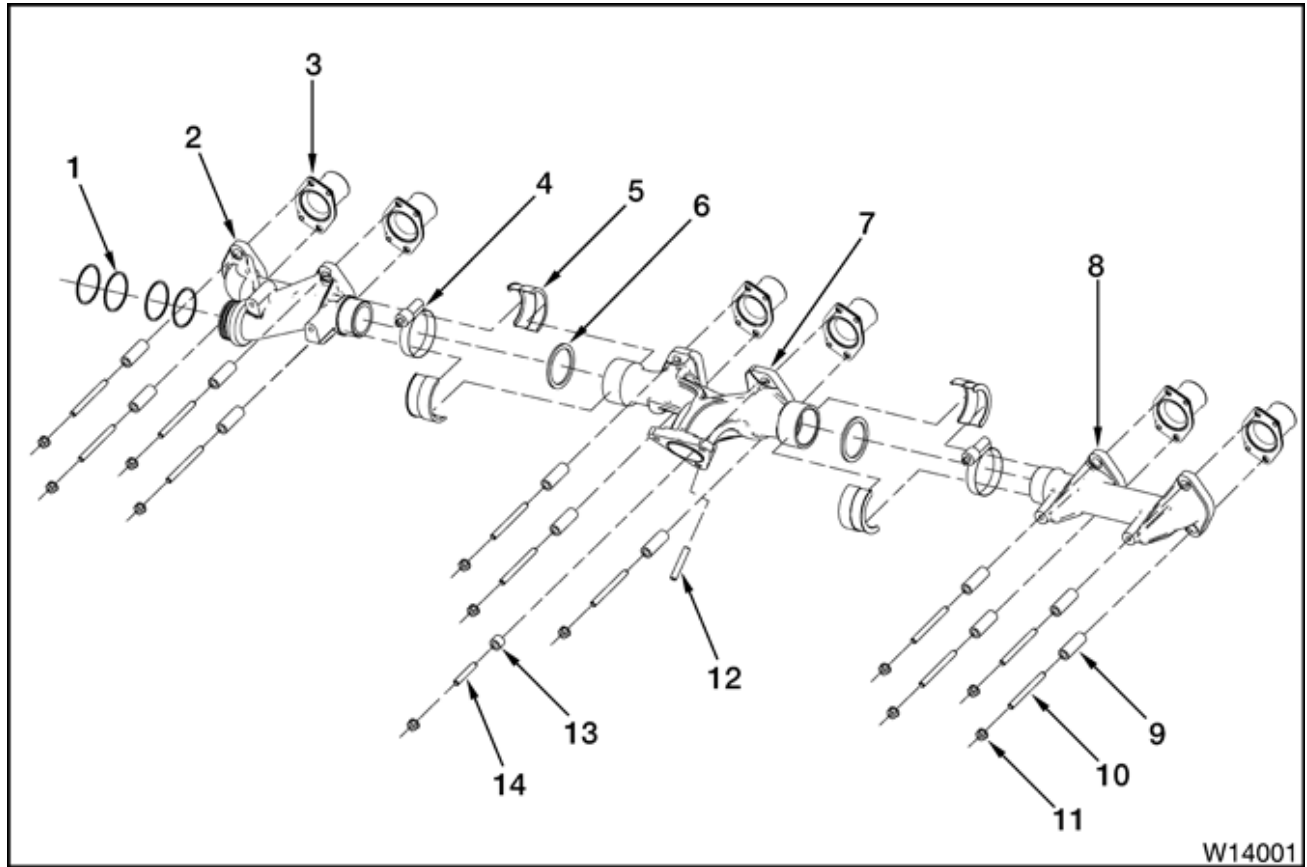
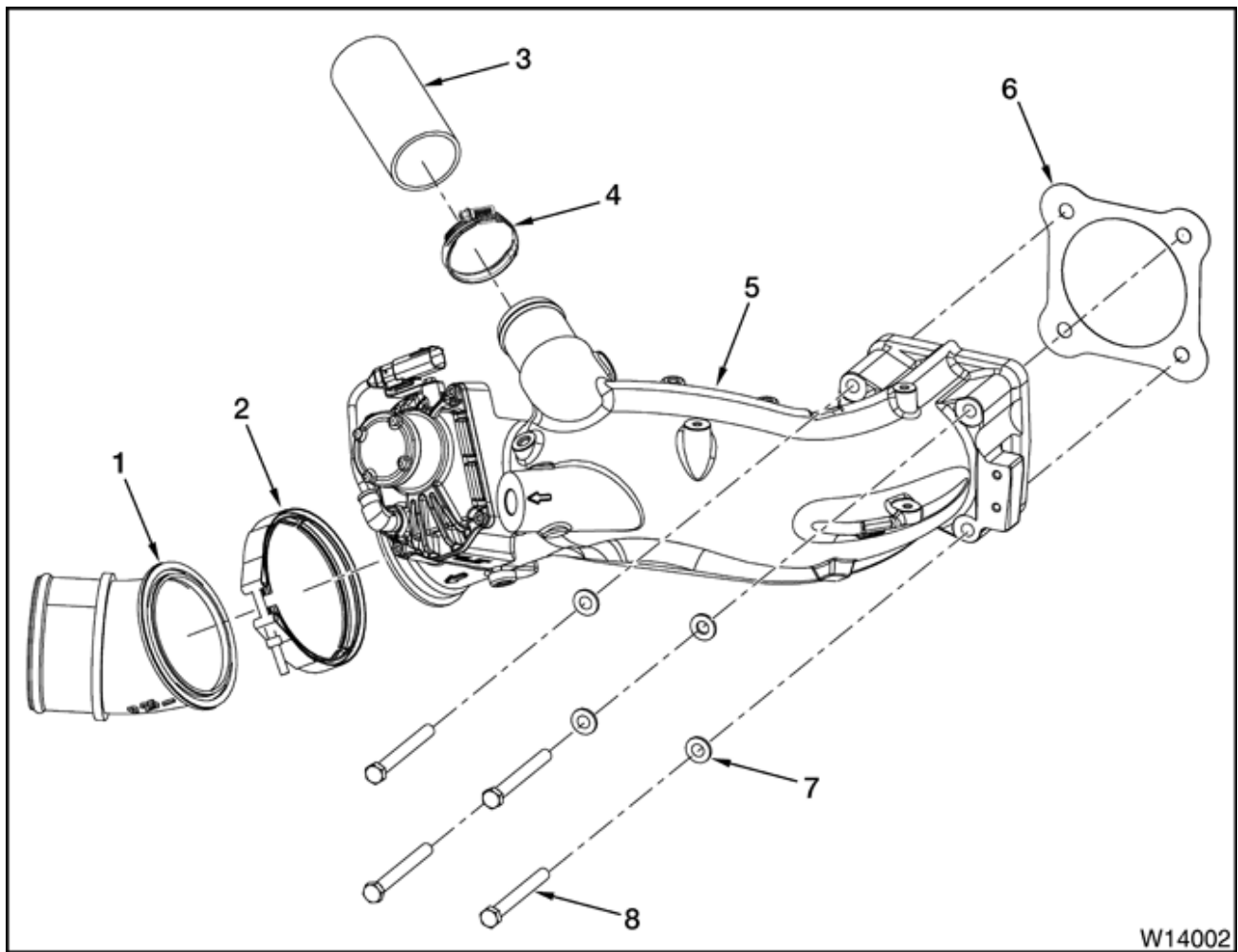


Figure 411 Exhaust manifold assembly

1. Ring seal (4)	6. Packing (2)	11. 3/8-16 hex flange lock nut (12)
2. Exhaust manifold	7. Center exhaust manifold	12. M10 x 45 stud
3. Exhaust sleeve gasket (6)	8. Exhaust manifold	13. 11.13 x 19.05 x 13.5 spacer
4. Ring seal clamp (2)	9. 11.13 x 19.05 x 53 spacer (11)	14. 3/8-16 x 2.3 taperlock stud
5. Shield (4)	10. 3/8-16 x 4 taperlock stud (11)	



W14002

Figure 412 Air inlet

1. Intake throttle elbow	4. Clamp (EGR supply hose)	7. 3/8 hardened washer (4)
2. Intake throttle clamp	5. Engine throttle valve assembly	8. 3/8-16 x 3-1/2 hex head bolt (4)
3. EGR supply hose	6. Throttle body gasket	

Removal



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

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

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

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

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

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

- Engine Electrical
- Cold Start Assist
- Aftertreatment System
- Turbochargers
- Oil Cooler, Filter Housing and Crankcase Ventilation
- Exhaust Gas Recirculation (EGR) System

Exhaust Manifold

CAUTION: To prevent engine damage, do not reuse exhaust manifold taperlock studs and nuts.

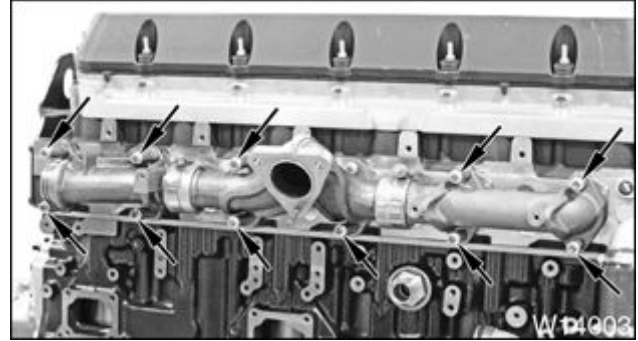


Figure 413 Exhaust manifold 3/8-16 hex flange lock nuts and 11.13 x 19.05 x 53 spacers

1. Remove and discard eleven 3/8-16 hex flange lock nuts. Remove eleven 11.13 x 19.05 x 53 spacers.

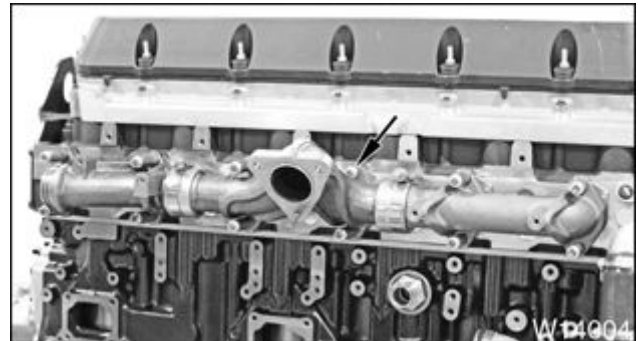


Figure 414 Exhaust manifold 3/8-16 hex flange lock nut and 11.13 x 19.05 x 13.5 spacer

2. Remove and discard 3/8-16 hex flange lock nut. Remove 11.13 x 19.05 x 13.5 spacer.
3. Remove the exhaust manifold assembly from engine.

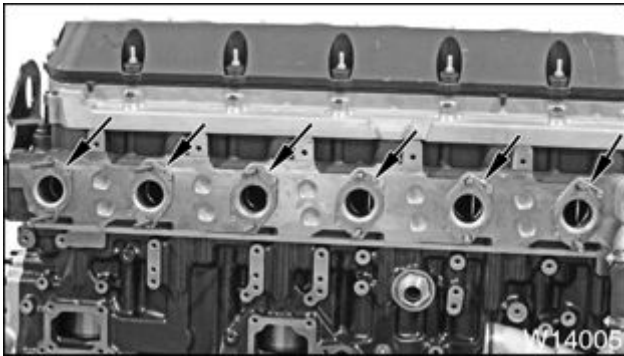


Figure 415 Exhaust sleeve gaskets

4. Remove and discard six exhaust sleeve gaskets.

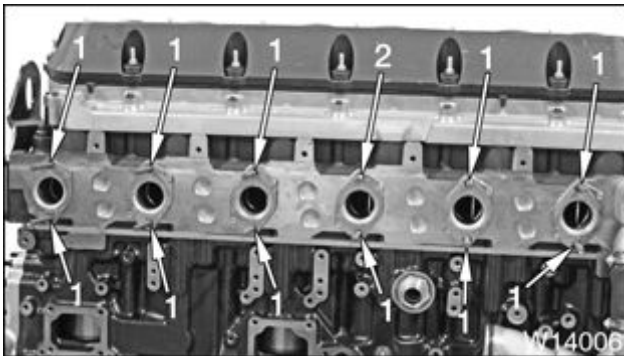


Figure 416 Exhaust manifold taperlock studs

1. 3/8-16 x 4 taperlock stud (11)
 2. 3/8-16 x 2.3 taperlock stud
5. Remove and discard eleven 3/8-16 x 4 taperlock studs and one 3/8-16 x 2.3 taperlock stud.

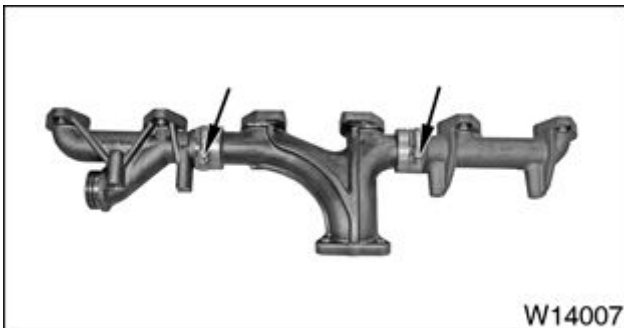


Figure 417 Exhaust manifold ring seal clamps

6. Remove two ring seal clamps.

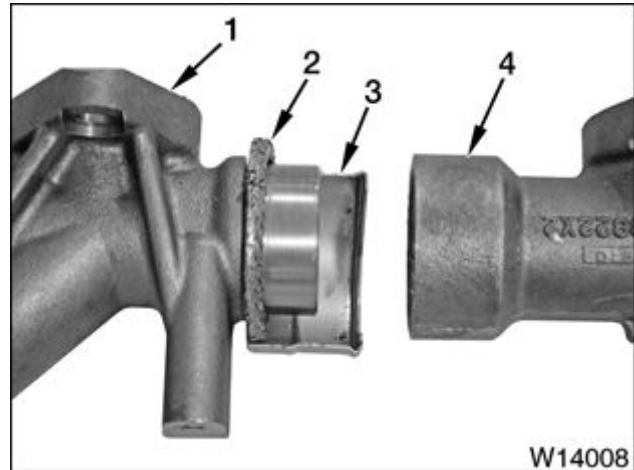


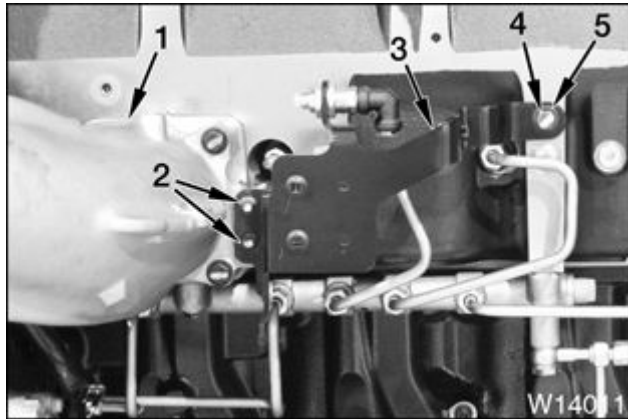
Figure 418 Exhaust manifold packing and shield (typical)

1. Exhaust manifold
 2. Packing
 3. Shield
 4. Center exhaust manifold
7. Separate and remove four shield halves.
 8. Disconnect two exhaust manifolds from center exhaust manifold.
 9. Remove both packings.

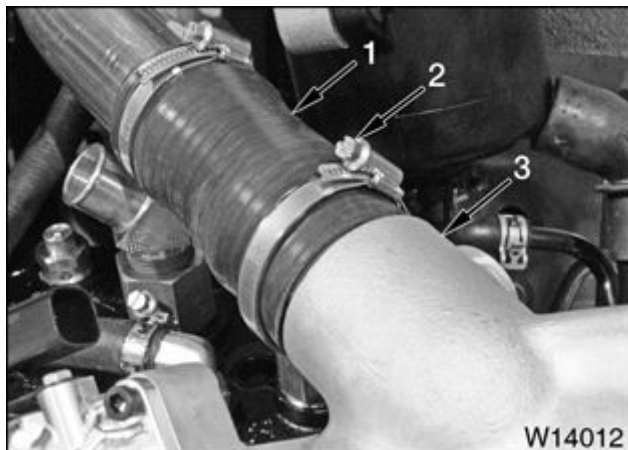


Figure 419 Exhaust manifold ring seals

10. Remove and discard four ring seals.

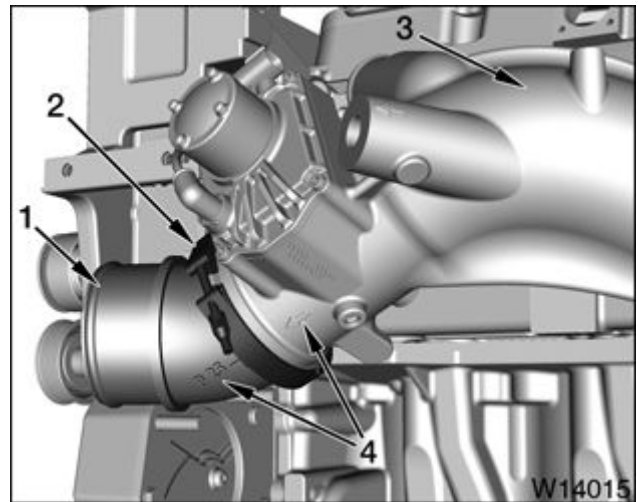
Air Inlet**Figure 420 ECM harness support**

1. Engine throttle valve assembly
 2. M6 x 30 hex flange bolt (2)
 3. ECM harness support
 4. 3/8-16 x 1 hex bolt
 5. 3/8 hardened washer
1. If not previously removed, remove ECM harness support.
 - a. Remove two M6 x 30 hex flange bolts.
 - b. Remove 3/8-16 x 1 hex bolt and 3/8 hardened washer.
 - c. Remove ECM harness support.

**Figure 421 EGR supply hose**

1. EGR supply hose
2. Clamp (EGR supply hose)
3. Engine throttle valve assembly

2. If not previously disconnected, disconnect EGR supply hose from engine throttle valve assembly.
 - a. Loosen EGR supply hose clamp at engine throttle valve assembly.
 - b. Slide back clamp and disconnect EGR supply hose from engine throttle valve assembly.

**Figure 422 Intake throttle elbow**

1. Intake throttle elbow
 2. Intake throttle clamp
 3. Engine throttle valve assembly
 4. Alignment marks
3. Remove intake throttle clamp fastening intake throttle elbow to engine throttle valve assembly.
 4. Remove intake throttle elbow.
 5. Remove and discard intake throttle elbow O-ring.

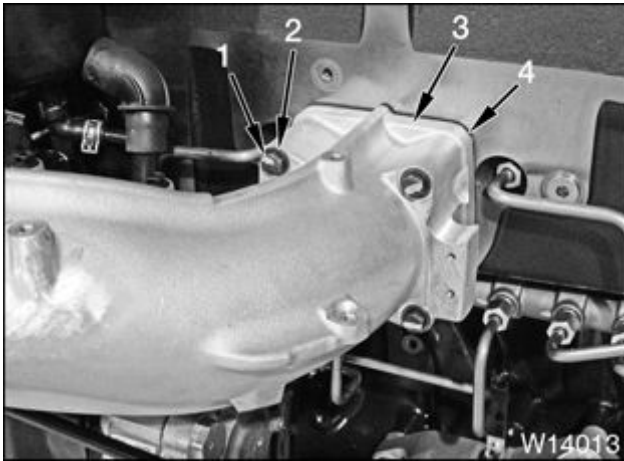


Figure 423 Engine throttle valve assembly

1. 3/8-16 x 3-1/2 hex head bolt (4)
 2. 3/8 hardened washer (4)
 3. Engine throttle valve assembly
 4. Throttle body gasket
6. Remove two 3/8-16 x 3-1/2 hex head bolts and two 3/8 hardened washers and install two engine throttle valve assembly Alignment Studs (page 294) into cylinder head.
 7. Remove two remaining 3/8-16 x 3-1/2 hex head bolts and two 3/8 hardened washers.
 8. Remove engine throttle valve assembly.
 9. Remove and discard throttle body gasket.
-

Cleaning, Inspection, and Testing

All Components

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

CAUTION: To prevent engine damage, do not use air tools or abrasive pads to clean aluminum parts.

Exhaust Manifold

NOTE: The cast iron exhaust manifold sections may be cleaned with steam or suitable non-caustic solvents.

CAUTION: To prevent engine damage, do not grind or machine exhaust manifold to compensate for warpage.

1. Scrape excess scale and rust from exhaust manifold surfaces.
2. Inspect exhaust manifolds for cracks and damage. Replace if necessary.
3. Clean cylinder head to exhaust manifold gasket surfaces.
4. Install exhaust manifold without exhaust sleeve gaskets onto cleaned cylinder head mating surface. See Exhaust Manifold (page 293).

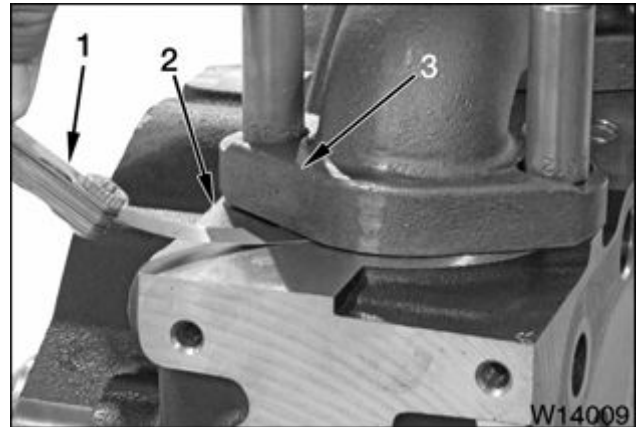


Figure 424 Exhaust manifold warpage measurement

1. Feeler gauge
2. Cylinder head
3. Exhaust manifold
5. Using a 0.24 mm (0.01 in) feeler gauge (page 294), measure gap between cylinder head and exhaust manifold mating surfaces. If feeler gauge passes through any gap, replace the defective exhaust manifold.
6. Remove exhaust manifold assembly.

Air Inlet

NOTE: Engine throttle valve assembly may be cleaned with steam or suitable non-caustic solvents.

1. Clean cylinder head to engine throttle valve assembly gasket surfaces.
2. Inspect engine throttle valve assembly for cracks or damage. Replace if necessary.

Installation

Air Inlet

1. Install two engine throttle valve assembly Alignment Studs (page 294) into cylinder head.
2. Position new throttle body gasket on Alignment Studs.
3. Position engine throttle valve assembly in place on cylinder head surface by sliding over Alignment Studs.

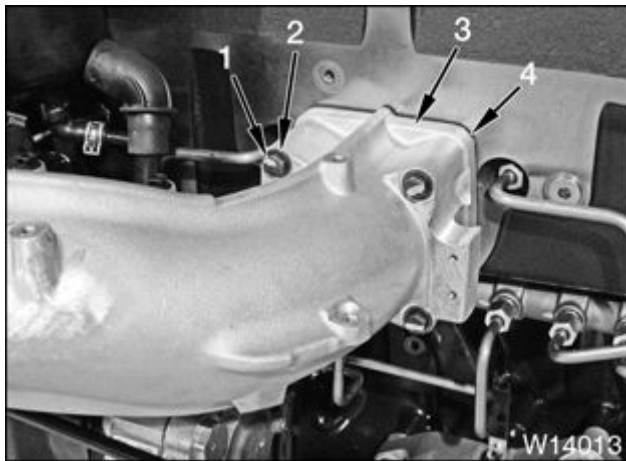


Figure 425 Engine throttle valve assembly

1. 3/8-16 x 3-1/2 hex head bolt (4)
 2. 3/8 hardened washer (4)
 3. Engine throttle valve assembly
 4. Throttle body gasket
4. Install two 3/8-16 x 3-1/2 hex head bolts and two 3/8 hardened washers hand tight.
 5. Remove two engine throttle valve assembly Alignment Studs.
 6. Install remaining two 3/8-16 x 3-1/2 hex head bolts and two 3/8 hardened washers hand tight.
 7. Tighten all four installed 3/8-16 x 3-1/2 hex head bolts to special torque (page 294).
 8. Install new intake throttle elbow O-ring. Lubricate O-ring with P-80® rubber lubricant or equivalent (page 294).

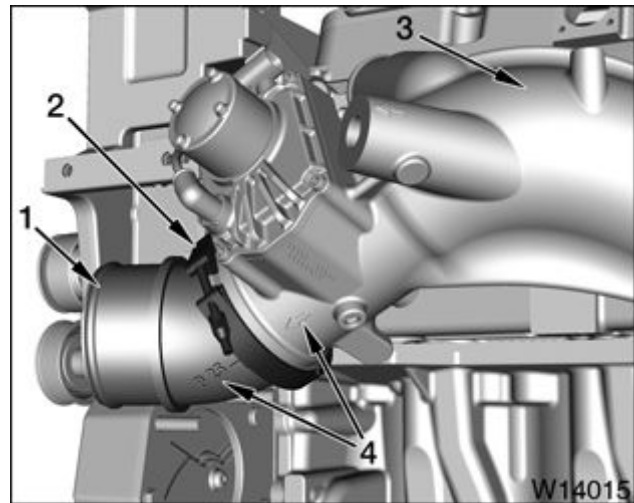


Figure 426 Intake throttle elbow

1. Intake throttle elbow
 2. Intake throttle clamp
 3. Engine throttle valve assembly
 4. Alignment marks
9. Position intake throttle elbow on end of engine throttle valve assembly. Use alignment marks to ensure proper orientation.
 10. Install intake throttle clamp. Tighten clamp to special torque (page 294).

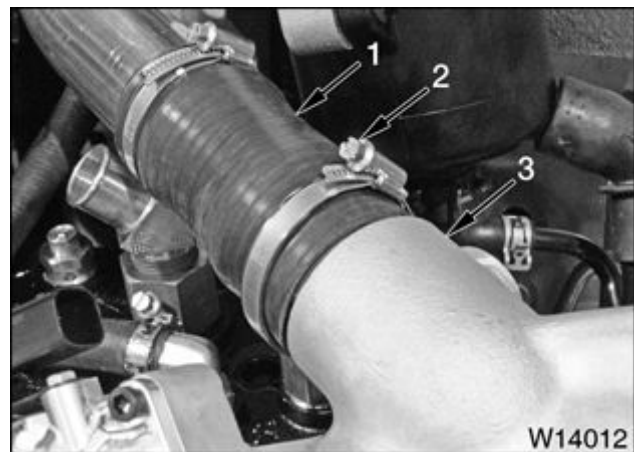


Figure 427 EGR supply hose

1. EGR supply hose
2. Clamp (EGR supply hose)
3. Engine throttle valve assembly

11. With clamp loose on EGR supply hose, slide EGR supply hose onto engine throttle valve assembly.
12. Position clamp and tighten to special torque (page 294).

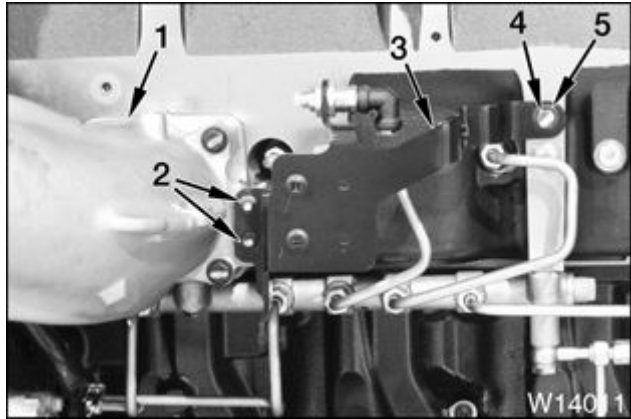


Figure 428 ECM harness support

1. Engine throttle valve assembly
2. M6 x 30 hex flange bolt (2)
3. ECM harness support
4. 3/8-16 x 1 hex bolt
5. 3/8 hardened washer

13. Position ECM harness support in place.
14. Install two M6 x 30 hex flange bolts. Tighten to standard torque (page 561).
15. Install 3/8-16 x 1 hex bolt and 3/8 hardened washer. Tighten to standard torque (page 562).

Exhaust Manifold

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

CAUTION: To prevent engine damage, do not reuse exhaust manifold taperlock studs and nuts.

CAUTION: To prevent engine damage, do not apply anti-seize compound to fastener threads.

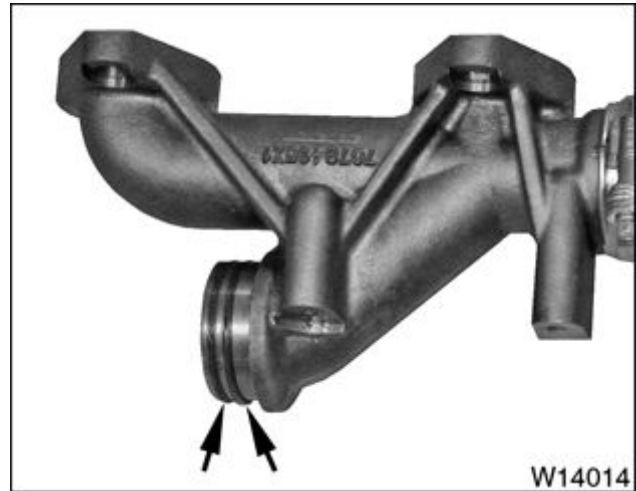


Figure 429 Exhaust manifold ring seals

1. Install four new ring seals. Orient each set of ring seals so ring seal gaps are 180 degrees from one another. Lubricate O-rings with P-80® rubber lubricant or equivalent (page 294).

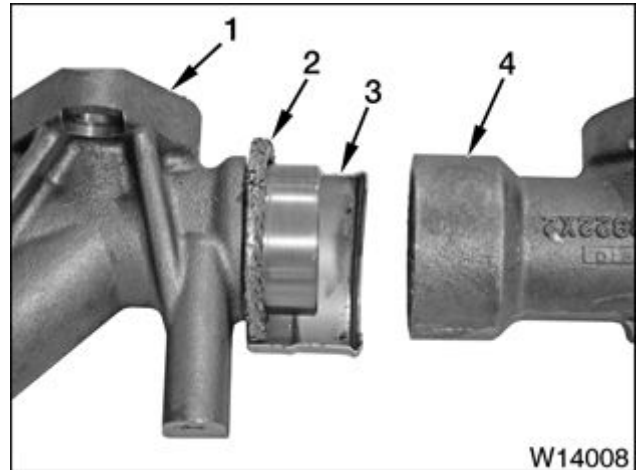


Figure 430 Exhaust manifold packing and shield (typical)

1. Exhaust manifold
 2. Packing
 3. Shield
 4. Center exhaust manifold
2. Install packing on both exhaust manifolds (front shown, rear similar).
 3. Connect exhaust manifolds to center exhaust manifold.

4. Position shield halves at each exhaust manifold connection to center exhaust manifold.

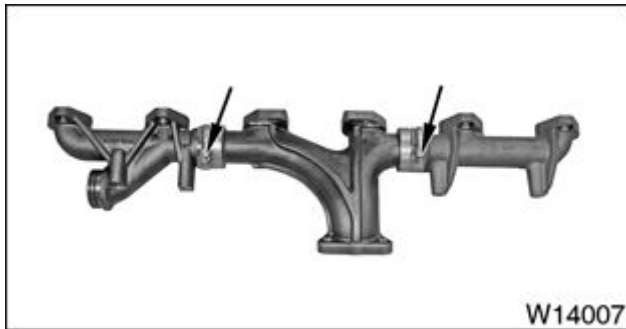


Figure 431 Exhaust manifold ring seal clamps

NOTE: Loosely assemble exhaust manifold assembly to permit positioning movements when installing onto engine.

5. Loosely install two ring seal clamps over shields. Do not tighten to final torque.

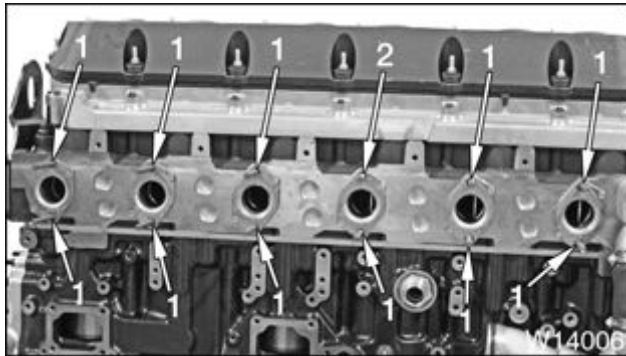


Figure 432 Exhaust manifold 3/8-16 x 4 taperlock studs and 3/8-16 x 2.3 taperlock stud

CAUTION: To prevent engine damage, taperlock studs are directional and must be installed with tapered end into cylinder head.

6. Install eleven new 3/8-16 x 4 taperlock studs and one new 3/8-16 x 2.3 taperlock stud with tapered

ends into cylinder head. Tighten until taperlock studs bottom out at special torque (page 294).

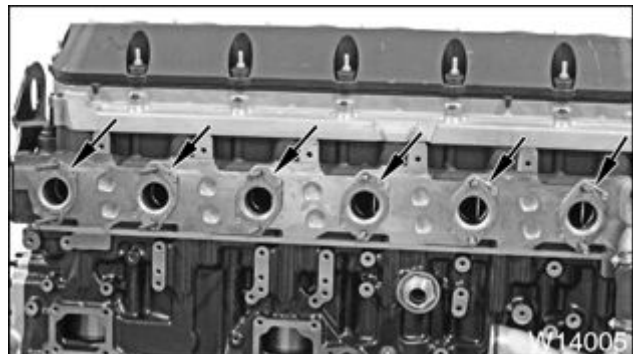


Figure 433 Exhaust sleeve gaskets

7. Clean cylinder head to ensure there is no residual gasket material at exhaust sleeve gasket mating surfaces.
8. Install six new exhaust sleeve gaskets over taperlock studs.

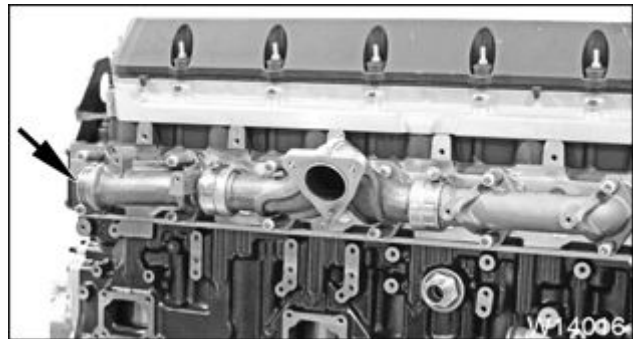


Figure 434 Exhaust manifold open end position

9. Position exhaust manifold assembly over taperlock studs and onto engine so that open end of the exhaust manifold assembly is at rear of the engine

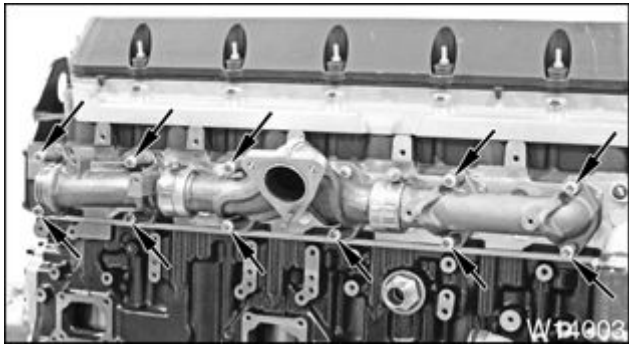


Figure 435 Exhaust manifold 3/8-16 hex flange lock nuts and 11.13 x 19.05 x 53 spacers

10. Install eleven 11.13 x 19.05 x 53 spacers. Loosely install eleven new 3/8-16 hex flange lock nuts. Do not tighten to final torque.

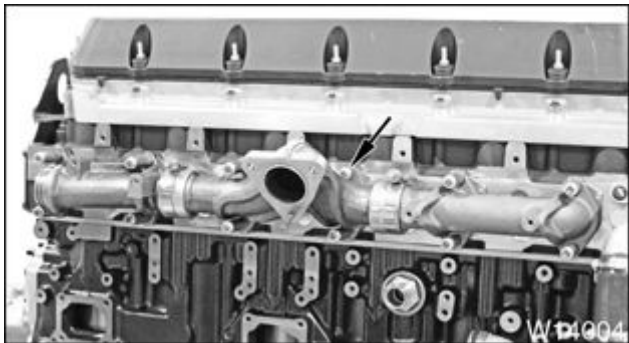


Figure 436 Exhaust manifold 3/8-16 hex flange lock nut and 11.13 x 19.05 x 13.5 spacer

11. Install 11.13 x 19.05 x 13.5 spacer. Loosely install new 3/8-16 hex flange lock nut. Do not tighten to final torque.

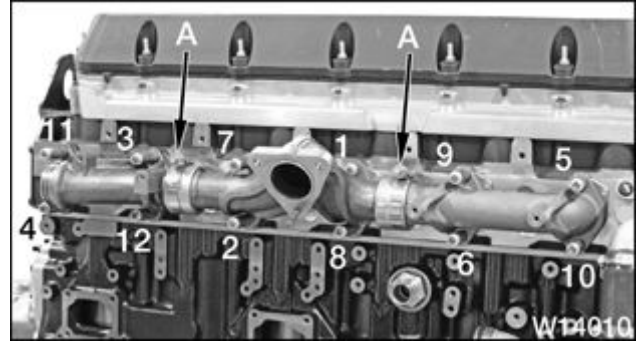


Figure 437 Exhaust manifold tightening sequence

12. Torque exhaust manifold assembly fasteners to following sequence:
- Torque 3/8-16 hex flange lock nuts 1 through 12 to 38 N·m (28 lbf·ft).
 - Tighten ring seal clamps (A) to 5 N·m (44 lbf·in).
 - Tighten ring seal clamps (A) to 10 N·m (89 lbf·in).

Specifications

Exhaust manifold maximum allowable warpage	0.24 mm (0.01 in)

Special Torque

EGR supply hose clamp	4 N·m (35 lbf·in)
Intake throttle clamp	8 N·m (71 lbf·ft)
Ring seal clamps	See tightening steps in procedure (page 293)
3/8–16 hex flange lock nuts	See tightening steps in procedure (page 293)
3/8–16 x 2.3 taperlock stud	35 N·m (26 lbf·ft)
3/8–16 x 3–1/2 hex head bolts	48 N·m (35 lbf·ft)
3/8–16 x 4 taperlock studs	35 N·m (26 lbf·ft)

Special Service Tools

Alignment Stud (engine throttle valve assembly)	ZTSE6109
Feeler gauge (0.24 mm (0.01 in))	Obtain locally
P-80® rubber lubricant or equivalent	Obtain locally

Table of Contents

Exploded Views.....	297
Removal.....	304
Fan Drive (High or Low Mount Fan).....	304
Thermostat Housing and Thermostats.....	306
Water Pump Inlet and Water Outlet Pipe.....	307
Belt Tensioners and Idler Pulleys.....	309
A/C (Freon) Compressor Support.....	310
Water Pump.....	311
Damper.....	311
Front Engine Mount Support.....	312
Crankshaft Front Seal.....	312
Front Cover	312
Timing Gears and Supports.....	315
Cleaning, Inspection, and Testing.....	324
Front Cover.....	324
Timing Gears.....	324
Installation.....	325
Timing Gears and Supports.....	325
Front Cover	332
Camshaft Gear.....	335
Timing Gear Lash.....	336
Crankshaft Front Seal.....	339
Front Engine Mount Support.....	339
Damper.....	340
Water Pump.....	340
A/C (Freon) Compressor Support.....	341
Belt Tensioners and Idler Pulleys.....	342
Water Pump Inlet and Water Outlet Pipe.....	342
Thermostat Housing and Thermostats.....	344
Fan Drive (High and Low Mount Fan).....	345
Specifications.....	348
Special Torque.....	348
Special Service Tools.....	349

Exploded Views

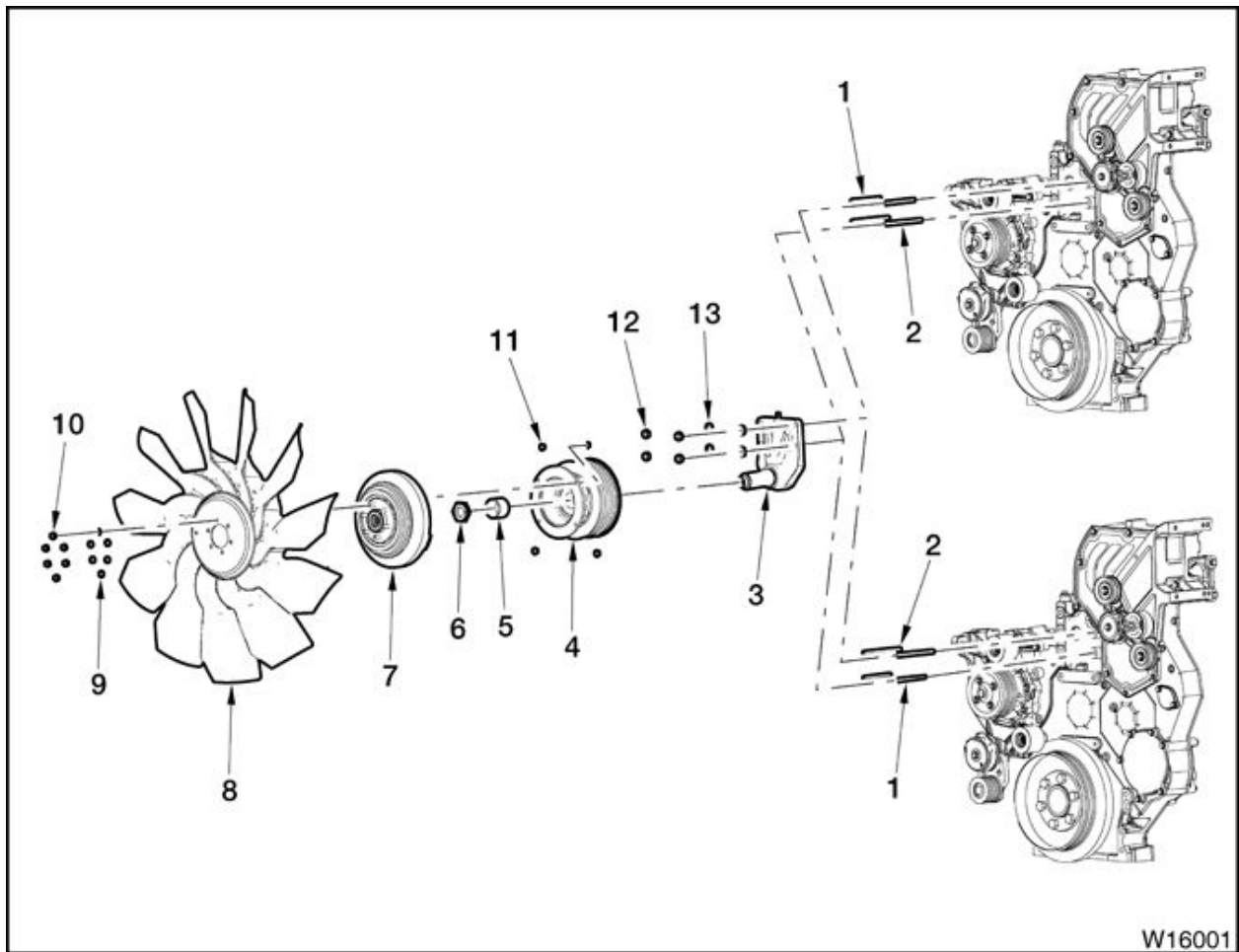


Figure 438 High and low mount fan drive system (Typical)

1. 1/2-13 x 2.72 taperlock stud (2)	6. Nut assembly	11. M8 hex flange nut (4)
2. 1/2-13 x 5 5/8 taperlock stud (2)	7. Fan clutch	12. 1/2-13 hex nut (4)
3. Horton® fan bracket	8. Fan	13. 13.5 x 25.5 hardened washer (4)
4. Pulley	9. 3/8 lock washer (6)	
5. Spacer	10. 3/8-24 nut (6)	

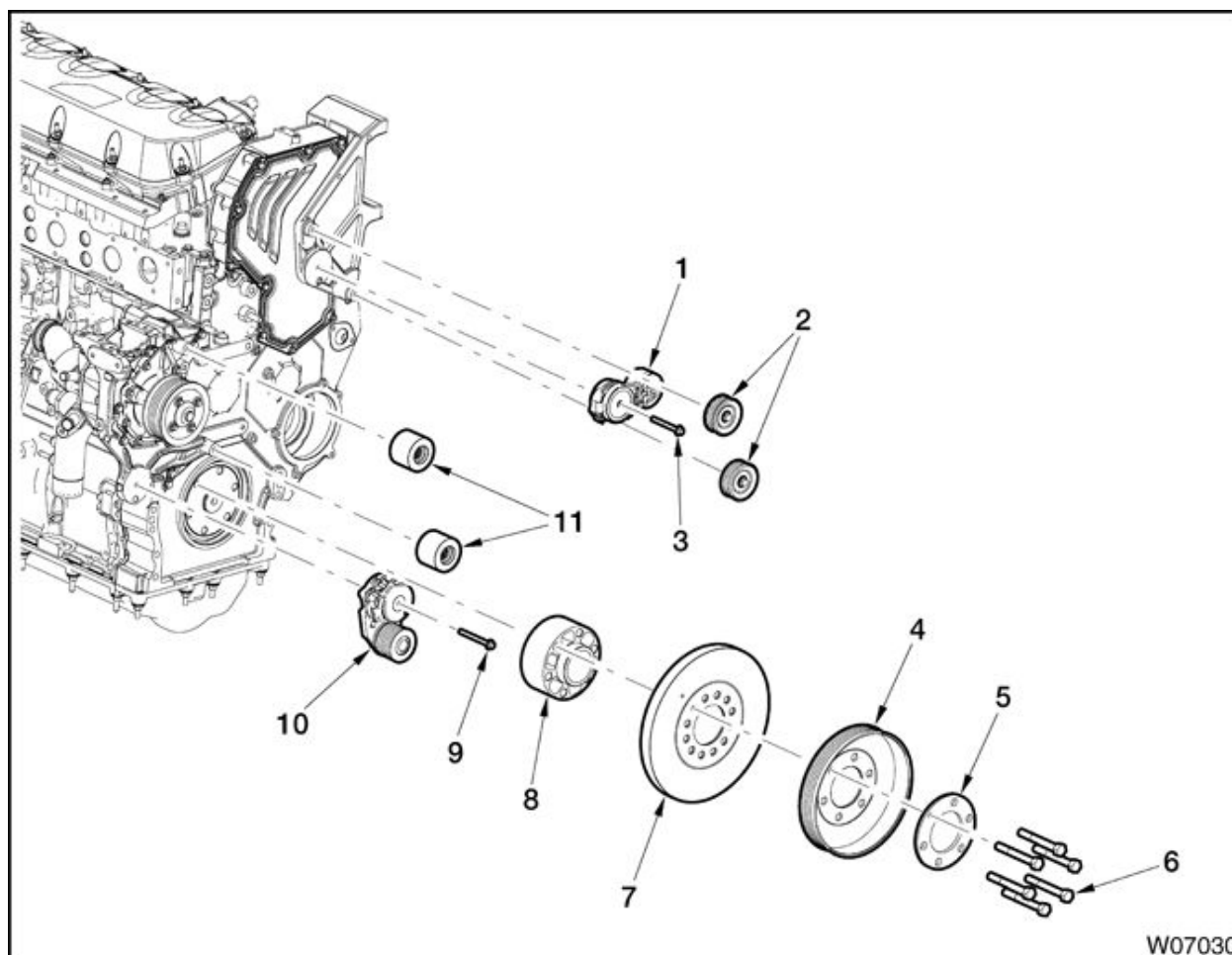
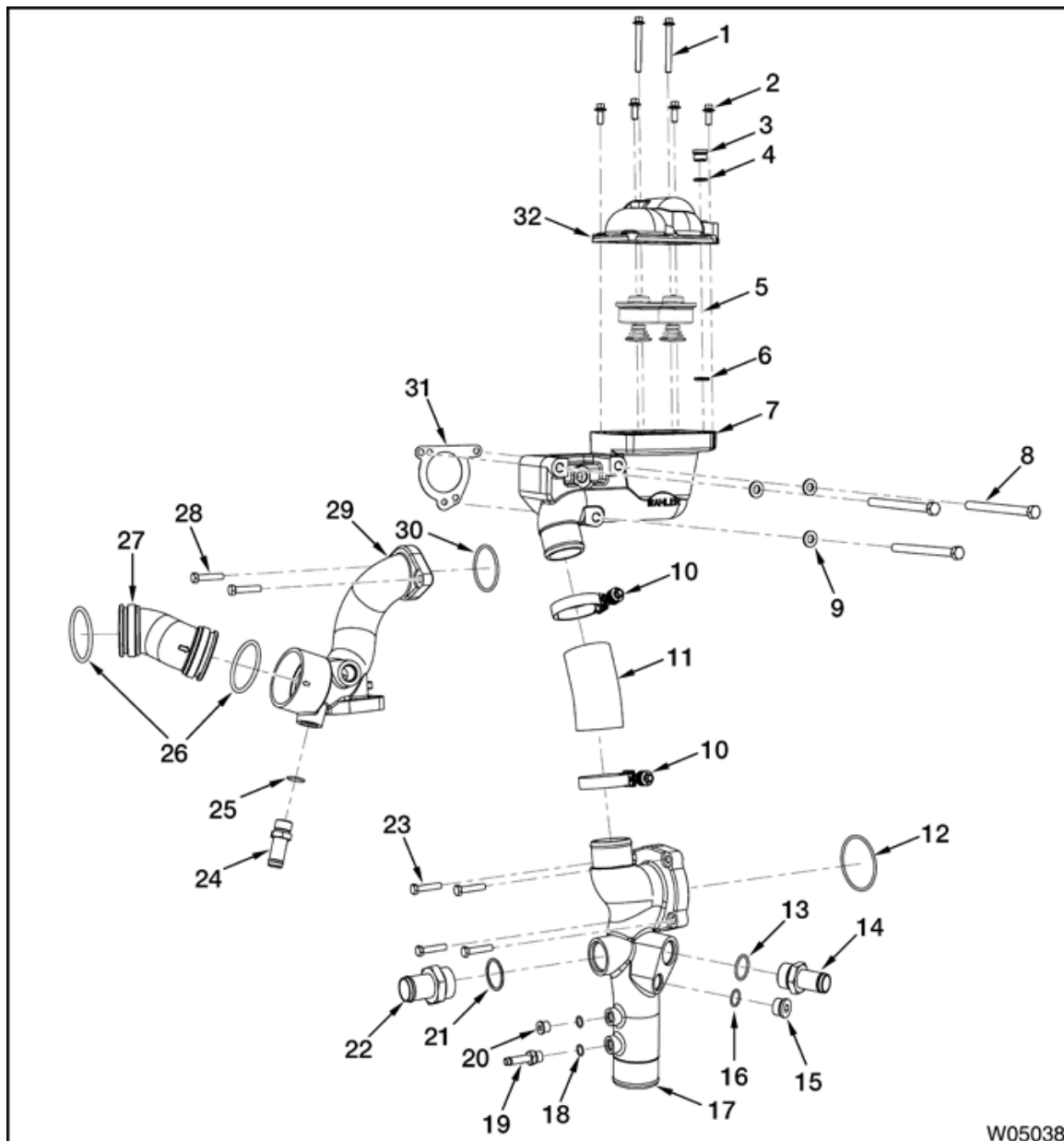


Figure 439 Tensioner pulleys, idler pulleys and crankshaft damper

1. Belt tensioner (upper)	5. 131.57 x 163.6 x 8 mm spacer	9. M10 x 70-10.9 countersunk screw
2. Idler pulley, grooved (2)	6. 5/8-18 x 4.5 hex flange bolt (6)	10. Tensioner (lower)
3. M10 x 90 hex flange bolt	7. Damper	11. Idler pulley assembly, flat (2)
4. Crankshaft pulley (12 groove)	8. Crankshaft adapter	



W05038

Figure 440 Thermostat, water inlet and water outlet pipe assemblies

1. M8 x 70 hex flange bolt (2)	13. O-ring (hose fitting assembly (1 1/4–11))	24. Hose fitting assembly (3/4–14)
2. M8 x 25 hex flange bolt (4)	14. Hose fitting assembly (1 1/4–11)	25. O-ring (hose fitting assembly (3/4–14))
3. O-ring boss plug (3/4–16)	15. Hex plug 7/8–14	26. O-ring (water outlet connector) (2)
4. O-ring (3/4–16 O-ring boss plug)	16. O-ring (7/8–14 plug assembly)	27. Water outlet connector
5. Thermostat (2)	17. Water pump inlet	28. 5/16–18 x 1 1/2 hex flange bolt (2)
6. O-ring (thermostat housing)	18. O-ring (2)	29. Water outlet pipe
7. Thermostat housing	19. Hose fitting assembly (9/16–16)	30. O-ring (water pump outlet pipe)
8. 3/8–16 x 4.25 hex bolt (3)	20. O-ring boss plug (9/16–16)	31. Regulator cover gasket
9. 3/8 hardened washer (3)	21. O-ring (Coolant connector (1 1/2–11))	32. Thermostat housing cover
10. Clamp (2)	22. Coolant connector (1 1/2–11)	
11. Water pump inlet hose	23. 5/16–18 x 1 1/2 hex bolt (4)	
12. 234 EPDM O-ring seal		

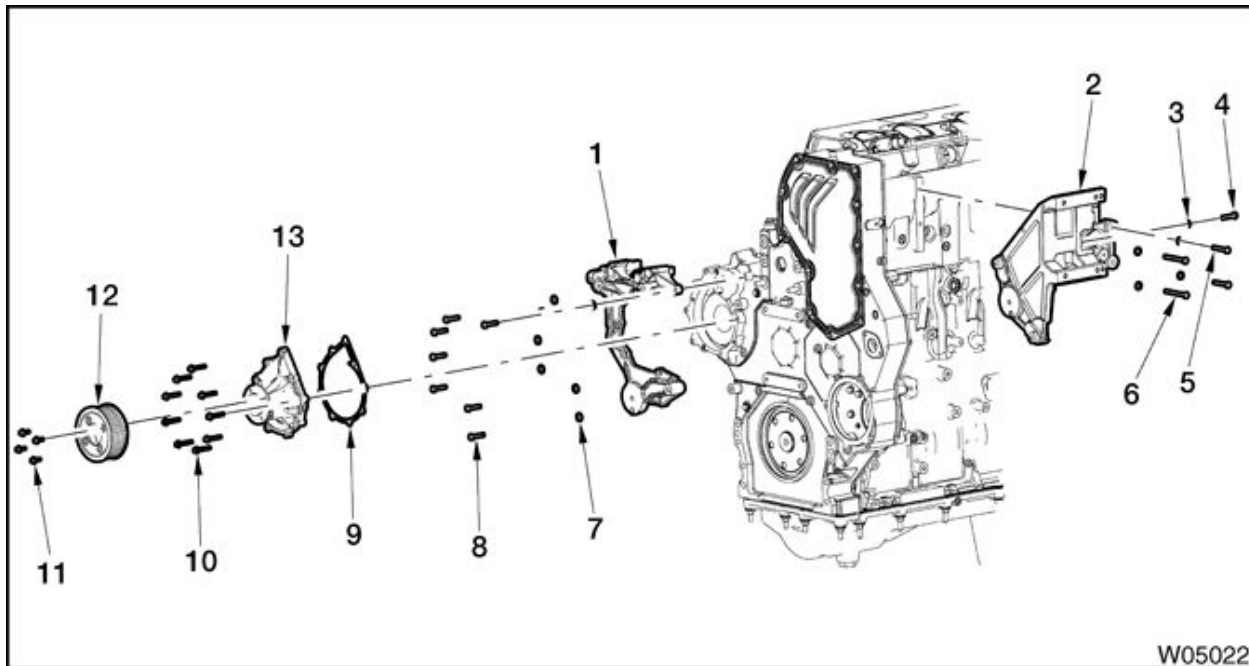
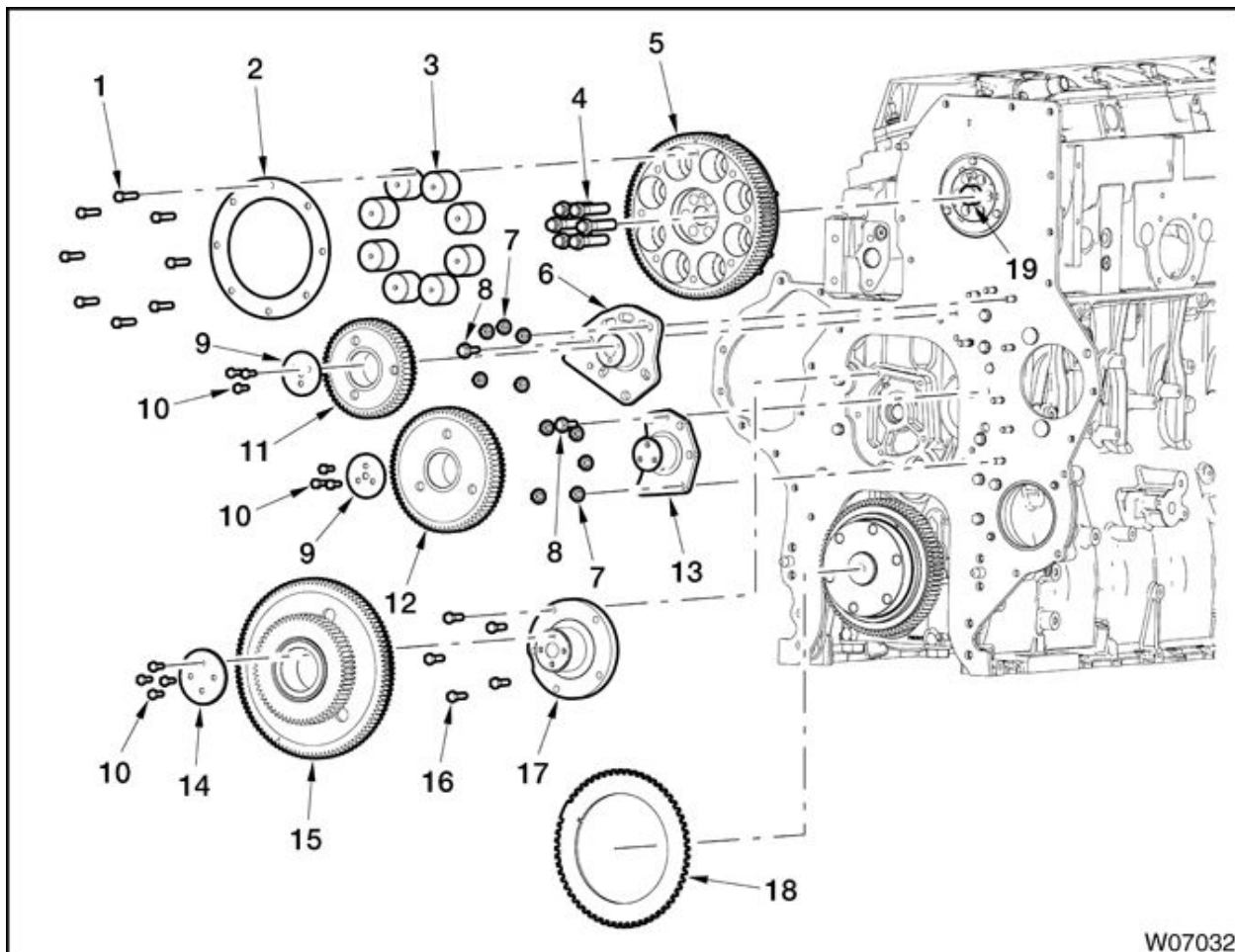


Figure 441 Water pump, freon compressor support and alternator bracket

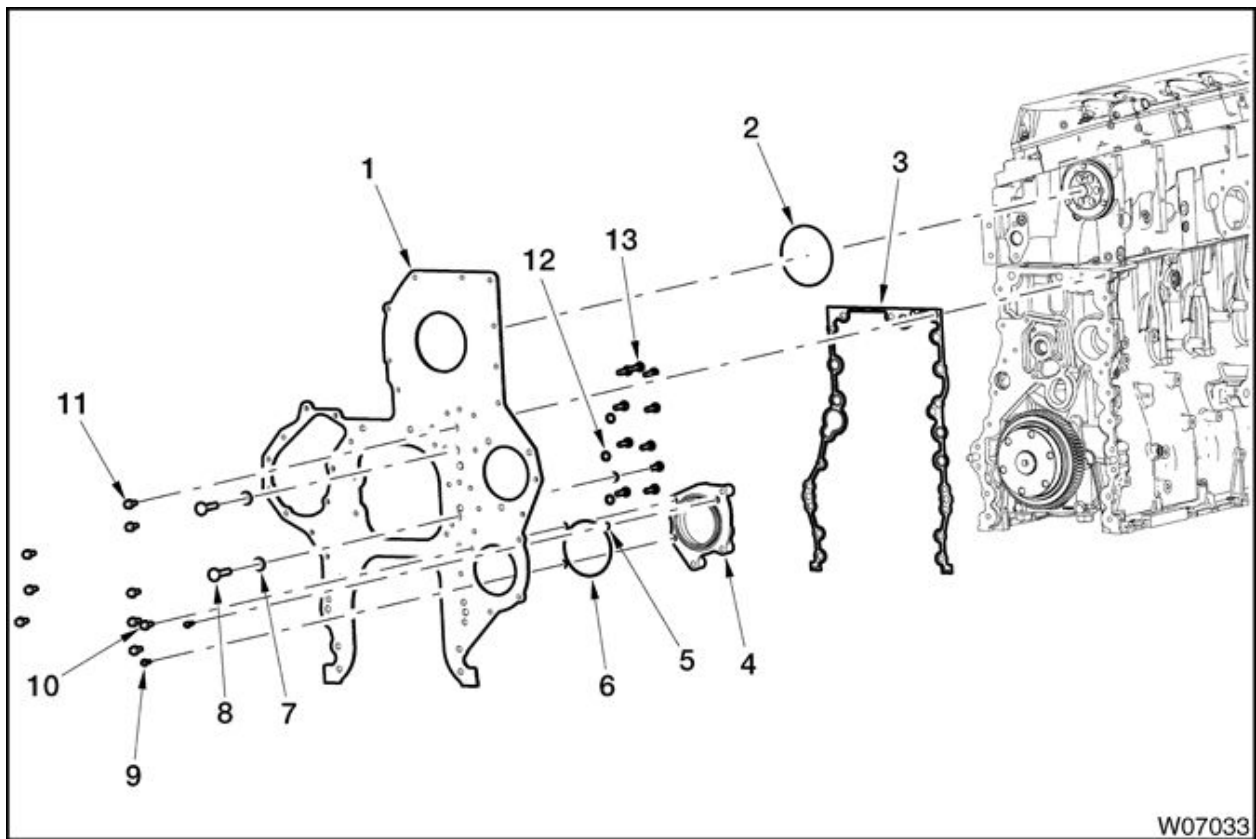
1. A/C (Freon) compressor support	5. 3/8-16 x 2 hex flange bolt (2)	10. M8 x 45-10.9 hex flange bolt (9)
2. Alternator bracket	6. 3/8-16 x 3 hex flange bolt (2)	11. M8 x 20 hex flange bolt (4)
3. 10.2 x 18.5 x 2.5 hardened washer (5)	7. 3/8 hardened washer (7)	12. Water pump pulley
4. 3/8-16 x 1 3/4 hex head bolt	8. 3/8-16 x 1 1/2 hex flange bolt (7)	13. Water pump
	9. Water pump gasket	



W07032

Figure 443 Timing gears

1. 3/8-16 x 1.75 hex bolt (8)	9. Bushing flange (2)	16. 5/16-18 x 0.875 hex locking bolt (5)
2. Damper cover plate	10. 5/16-18 x 0.875 hex locking bolt (10)	17. 105/63-teeth cluster gear support
3. Damper (8)	11. 56-teeth gear assembly	18. Crankshaft timing ring
4. 5/8-11 x 3, 12 point socket head bolt (6)	12. 71-teeth gear assembly	19. Dowel pin
5. Camshaft gear	13. 71-teeth gear support assembly	
6. 56-teeth gear support assembly	14. Bushing flange	
7. 3/8-16 hex flange nut (10)	15. 105/63-teeth cluster gear assembly	
8. 3/8-16 x 1.5 hex flange locking bolt (2)		



W07033

Figure 444 Front cover plate

1. Front cover plate	7. Sealing washer (large) (2)	12. THK washer (small) (7)
2. O-ring (camshaft retainer)	8. Self clinching stud (large)	13. Self clinching stud (small) (10)
3. Front cover plate gasket	9. M6 x 20 mm hex flange bolt (2)	
4. High-pressure pump adapter	10. 3/8-16 x 1 thread locking hex flange locking bolt	
5. 906 O-ring (3)	11. 3/8-16 x 1 hex flange bolt (8)	
6. O-ring		

Removal



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

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

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

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

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

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

- Engine Electrical
- Fuel System
- Exhaust Gas Recirculation (EGR) System
- Fuel System
- Air Compressor and Power Steering
- Oil Pan, Oil Pickup Tube and Oil Pump
- Flywheel and Flywheel Housing

Fan Drive (High or Low Mount Fan)

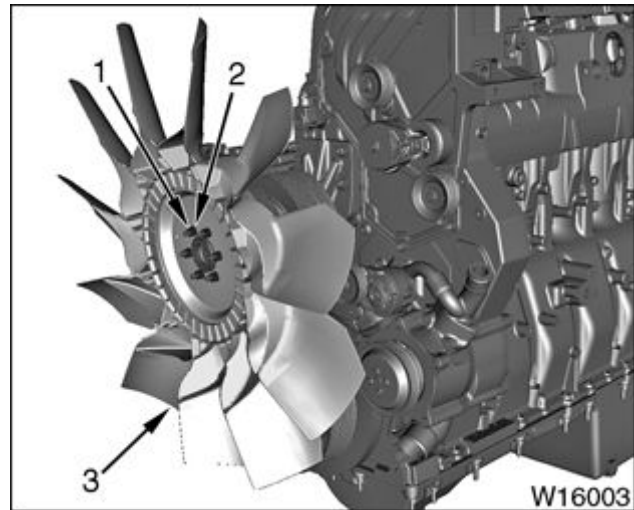


Figure 445 Fan

1. 3/8–24 hex nut (6)
2. 3/8 lock washer (6)
3. Fan

1. Remove six 3/8–24 hex nuts and six 3/8 lock washers.
2. Remove the fan.

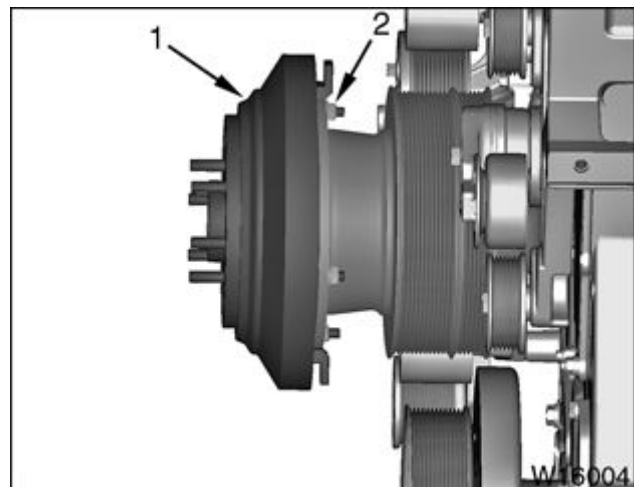


Figure 446 Fan clutch

1. Fan clutch
2. M8 hex flange nut (4)

3. Remove four M8 hex flange nuts and the fan clutch.

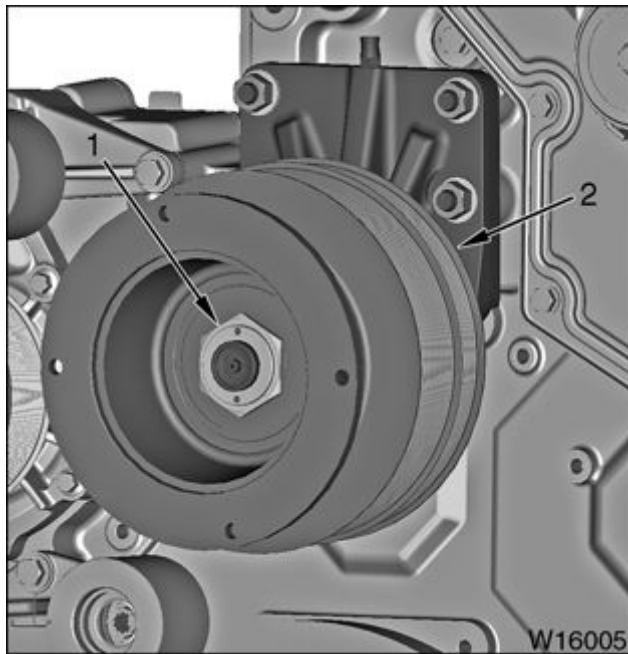


Figure 447 Fan pulley

1. Nut assembly
2. Pulley

4. Remove the nut assembly.

NOTE: The spacer is located behind the nut assembly.

5. Remove the spacer and then the pulley.

NOTE: For high mount fan, do steps 6 and 7, then skip steps 8 and 9.

NOTE: For low mount fan, skip steps 6 and 7, then do steps 8 and 9.

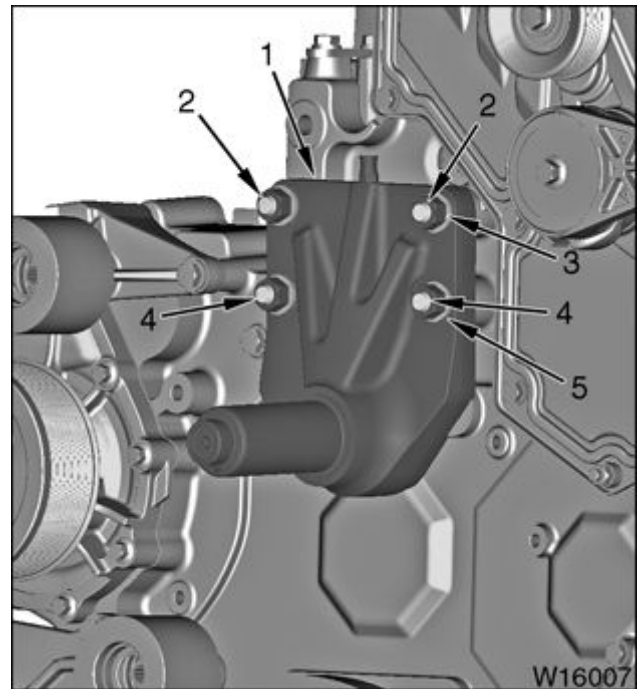


Figure 448 High mount Horton® fan bracket (typical)

1. Horton® fan bracket
2. 1/2-13 x 2.72 taperlock stud (2)
3. 1/2-13 hex nut (4)
4. 1/2-13 x 5 5/8 taperlock stud (2)
5. 13.5 x 25.5 hardened washer (4)
6. Remove four 1/2-13 hex nuts, four 13.5 x 25.5 hardened washers, and the Horton® fan bracket.
7. If required for replacement, remove two 1/2-13 x 2.72 taperlock studs and two 1/2-13 x 5 5/8 taperlock studs.

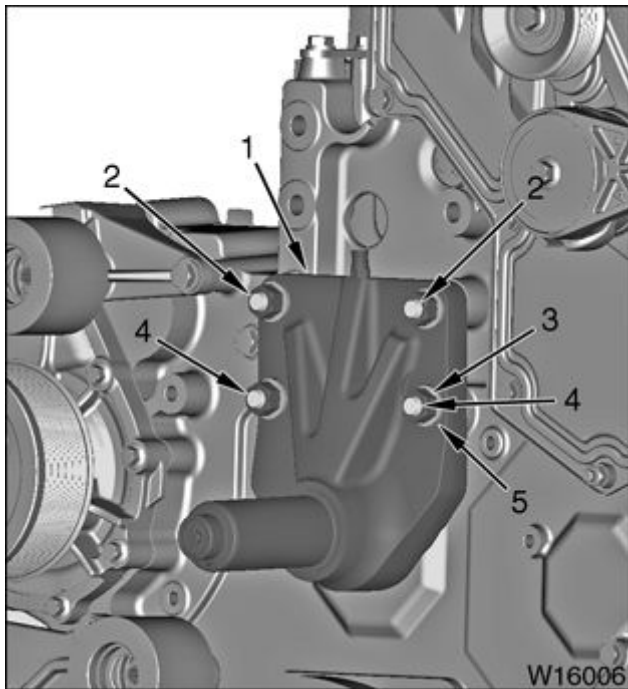


Figure 449 Low mount Horton® fan bracket (typical)

1. Horton® fan bracket
 2. 1/2-13 x 5 5/8 taperlock stud (2)
 3. 1/2-13 hex nut (4)
 4. 1/2-13 x 2.72 taperlock stud (2)
 5. 13.5 x 25.5 hardened washer (4)
8. Remove four 1/2-13 hex nuts, four 13.5 x 25.5 hardened washers, and the Horton® fan bracket.
 9. If required for replacement, remove two 1/2-13 x 3 taperlock studs and two 1/2-13 x 5 5/8 taperlock studs.

Thermostat Housing and Thermostats

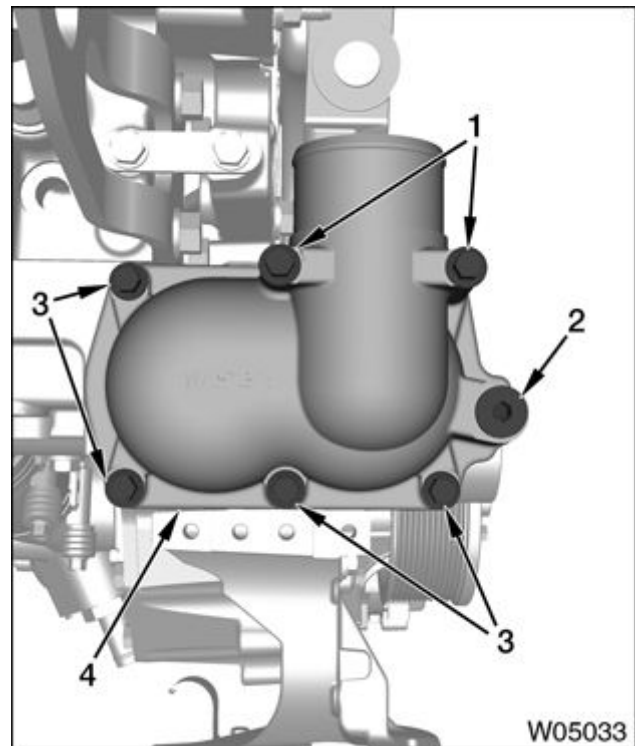


Figure 450 Thermostat housing cover

1. M8 x 70 hex flange bolt (2)
 2. O-ring boss plug (3/4-16)
 3. M8 x 25 hex flange bolt (4)
 4. Thermostat housing cover
1. Remove two M8 x 70 hex flange bolts, four M8 x 25 hex flange bolts, and the thermostat housing cover.
 2. If required when replacing the thermostat housing cover, remove the 3/4-16 O-ring boss plug and discard the O-ring.

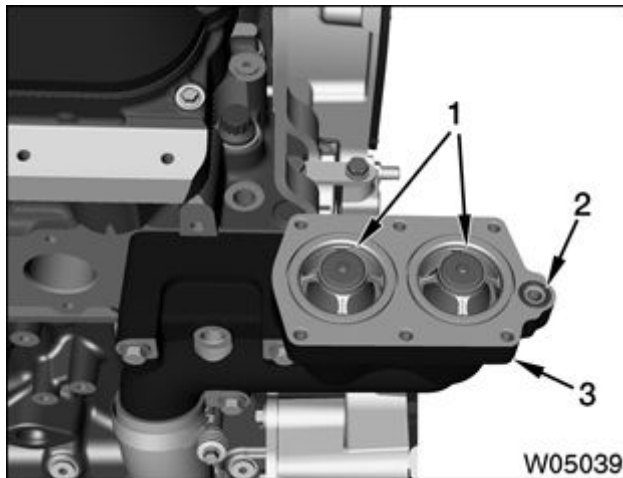


Figure 451 Thermostat

1. Thermostat
2. O-ring
3. Thermostat housing

3. Remove and discard O-ring.
4. Remove and discard the thermostats from thermostat housing assembly.



Figure 452 Thermostat housing

1. 3/8-16 x 4.25 hex flange bolt (3)
2. Thermostat housing
3. Water pump inlet hose
4. Hose clamp (2)

5. Loosen two hose clamps.
6. Remove three 3/8-16 x 4.25 hex flange bolts.

7. Remove the thermostat housing.
8. Remove the water pump inlet hose.

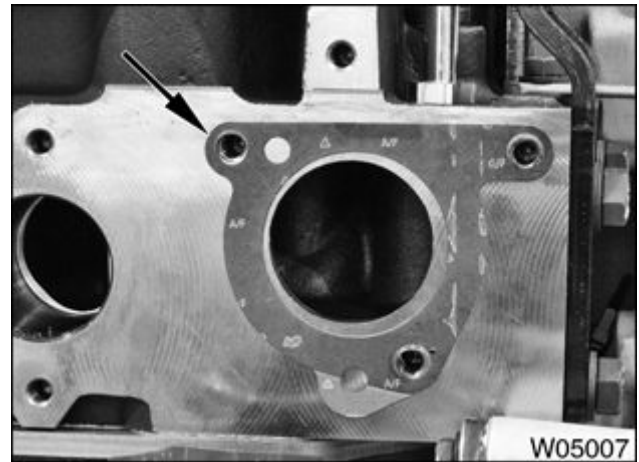


Figure 453 Regulator cover gasket

9. Remove and discard regulator cover gasket.

Water Pump Inlet and Water Outlet Pipe

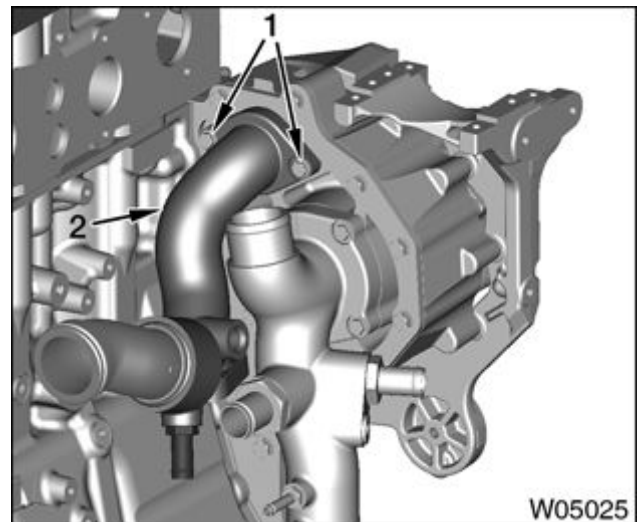


Figure 454 Water outlet pipe

1. 5/16-18 x 1 1/2 hex flange bolt (2)
2. Water outlet pipe

1. Remove two 5/16-18 x 1 1/2 hex flange bolts and the water outlet pipe assembly.

2. Remove and discard the O-ring from between the water pump outlet pipe and the front cover.

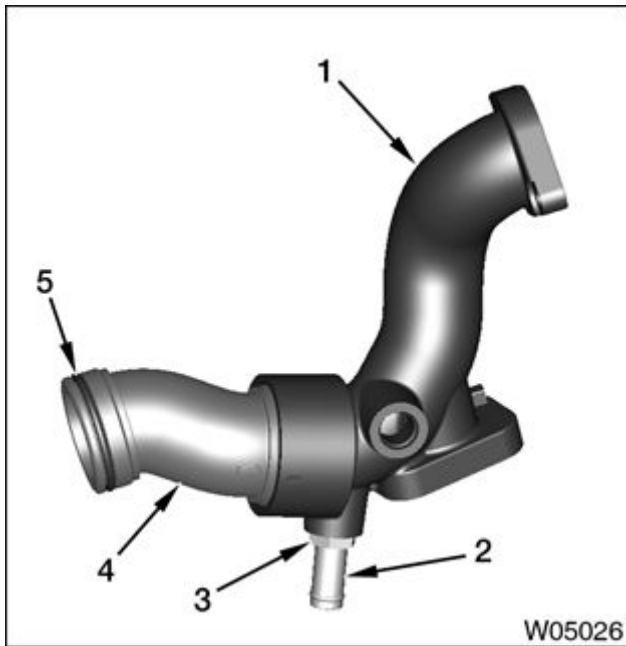


Figure 455 Water outlet pipe assembly

1. Water outlet pipe
 2. Hose fitting assembly (3/4–14)
 3. O-ring (located on hose fitting assembly (3/4–14))
 4. Water outlet connector
 5. O-ring (2) (both ends of item 4)
3. If required for replacement, remove the hose fitting assembly (3/4–14) and its O-ring.

4. Separate the water outlet connector from the water outlet pipe.

5. Remove and discard two O-rings.

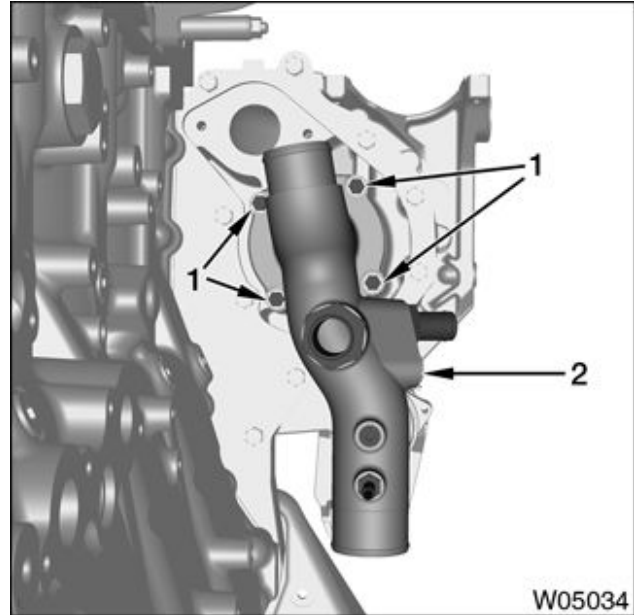


Figure 456 Water pump inlet

1. 5/16–18 x 1 1/2 hex flange bolt (4)
 2. Water pump inlet
6. Remove four 5/16–18 x 1 1/2 hex flange bolts and the water pump inlet.
 7. Remove and discard the O-ring from between the water pump inlet and the front cover.

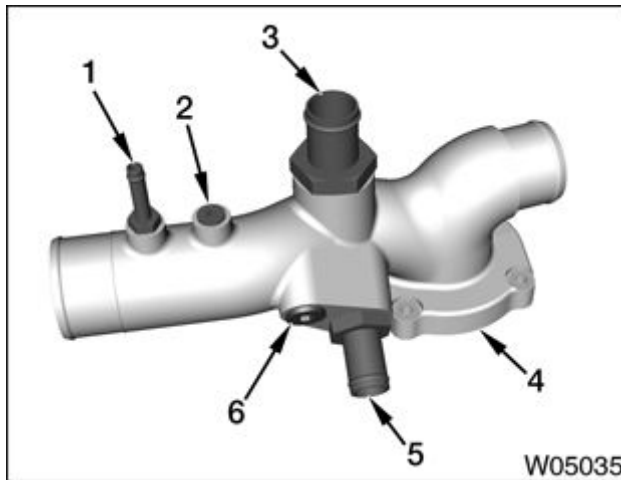


Figure 457 Water pump inlet

1. Hose fitting assembly (9/16-16)
2. O-ring boss plug assembly (9/16-16)
3. Coolant connector (1 1/2-11)
4. Water pump inlet
5. Hose fitting assembly (1 1/4-11)
6. 7/8-14 plug assembly

NOTE: Only remove the fittings, connector and plug (steps 8-17) if components are damaged, leaking or being replaced.

8. Remove the hose fitting assembly (1 1/4-11).
9. Remove and discard O-ring from the hose fitting assembly (1 1/4-11).
10. Remove the coolant connector (1 1/2-11).
11. Remove and discard O-ring from coolant connector (1 1/2-11).
12. Remove the hose fitting assembly (9/16-16).
13. Remove and discard O-ring from the hose fitting assembly (9/16-16).
14. Remove the O-ring boss plug assembly (9/16-16).
15. Remove and discard O-ring from the O-ring boss plug assembly (9/16-16).
16. Remove the 7/8-14 plug assembly.

17. Remove and discard O-ring from the 7/8-14 plug assembly.

Belt Tensioners and Idler Pulleys

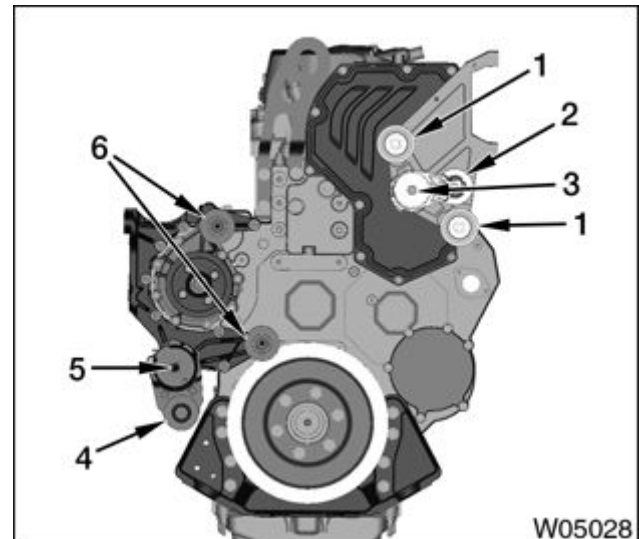


Figure 458 Belt tensioners and idler pulleys

1. Idler pulley, grooved (2)
2. Belt tensioner (upper)
3. M10 x 90 hex flange bolt
4. Tensioner (lower)
5. M10 x 70-10.9 countersunk screw
6. Idler pulley, flat (2)

NOTE: The bolts are integral to two grooved and two flat idler pulleys and cannot be removed.

1. Remove two grooved idler pulleys.
2. Remove two flat idler pulleys.

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

3. Remove M10 x 90 hex flange bolt and upper belt tensioner.
4. Remove M10 x 70-10.9 countersunk screw and lower tensioner.

A/C (Freon) Compressor Support

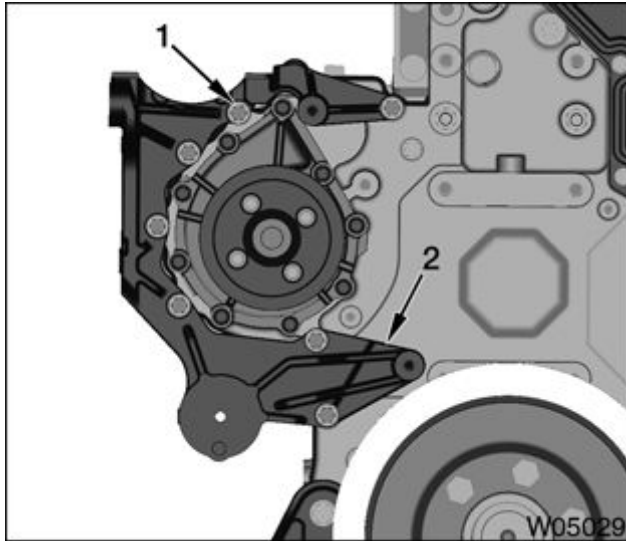


Figure 459 A/C (Freon) compressor support

1. 3/8–16 x 1 1/2 hex head bolt (7) and 3/8 hardened washer (7)
 2. A/C (Freon) compressor support
1. Remove seven 3/8–16 x 1 1/2 hex head bolts, seven 3/8 hardened washers, and the A/C (Freon) compressor support.

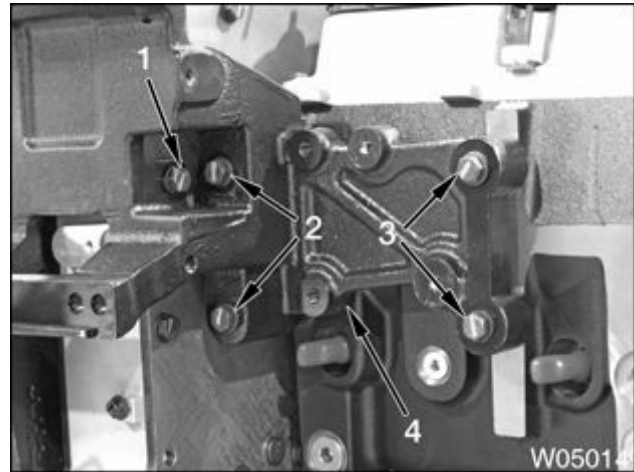


Figure 460 Alternator bracket

1. 3/8–16 x 1 3/4 hex head bolt and hardened washer
 2. 3/8–16 x 3 hex head bolt (2) and hardened washer (2)
 3. 3/8–16 x 2 hex head bolt (2) and hardened washer (2)
 4. Alternator bracket
2. Remove one 3/8–16 x 1 3/4 hex head bolt, two 3/8–16 x 3 hex head bolts, two 3/8–16 x 2 hex head bolts, five 10.2 x 18.5 x 2.5 hardened washers, and remove the alternator bracket.

Water Pump

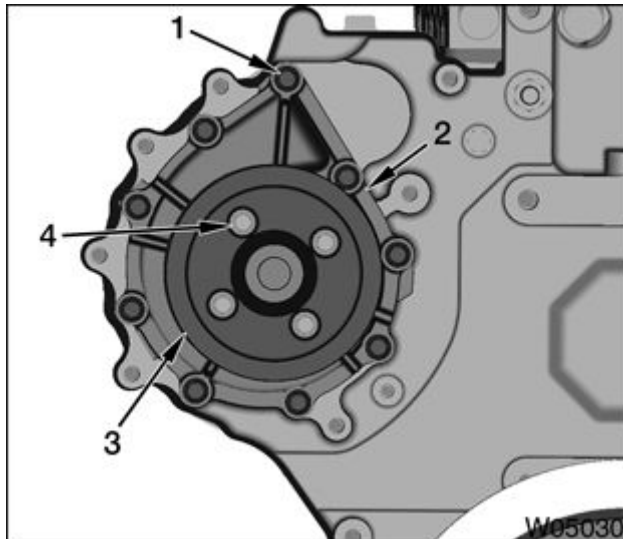


Figure 461 Water pump

1. M8 x 45–10.9 hex flange bolt (9)
2. Water pump
3. Water pump pulley
4. M8 x 20 hex flange bolt (4)

1. Remove four M8 x 20 hex flange bolts and water pump pulley.
2. Remove nine M8 x 45–10.9 hex flange bolts and the water pump.

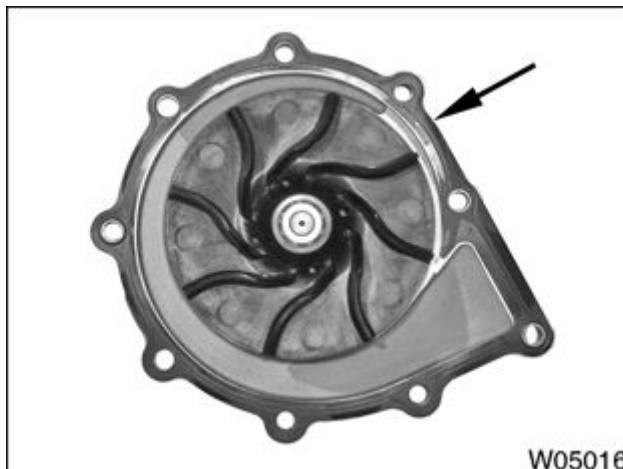


Figure 462 Water pump gasket

3. Remove and discard the water pump gasket.

Damper

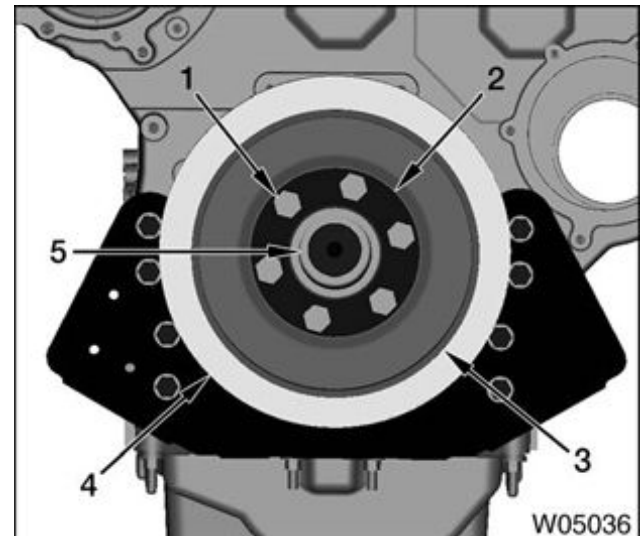


Figure 463 Damper

1. 5/8–18 x 4.5 hex flange bolt (6)
2. 131.57 x 163.6 x 8 mm spacer
3. Crankshaft pulley (12 groove)
4. Damper
5. Crankshaft adapter

⚠ WARNING: To prevent personal injury or death, support the vibration damper when removing bolts. The damper can easily slide off the end of the crankshaft.

1. Remove six 5/8–18 x 4.5 hex flange bolts.
2. Remove 131.57 x 163.6 x 8 mm spacer.
3. Remove 12 groove crankshaft pulley.
4. Remove damper.
5. Remove crankshaft adapter.

Front Engine Mount Support

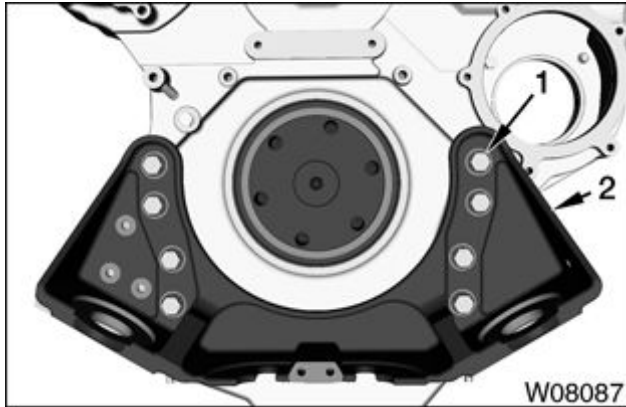


Figure 464 Front engine mount support

1. 1/2–13 x 5 in hex flange bolt (8)
 2. Front engine mount support
1. Remove eight 1/2–13 x 5 in hex flange bolts and the front engine mount support.

Crankshaft Front Seal

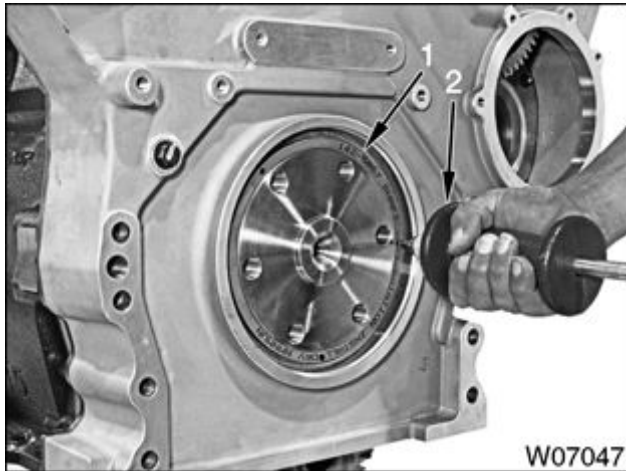


Figure 465 Crankshaft front seal

1. Crankshaft front seal
2. Slide hammer

! WARNING: To prevent personal injury or death, wear safety glasses with side shields when doing the following procedure.

1. With an awl and hammer, punch three holes 120° apart in crankshaft front seal.
2. Use Slide Hammer Kit (page 349) with correct size screw in one of the three holes.
3. Slide hammer until one side of seal begins to pull out of cover. Move slide hammer to next hole and repeat until crankshaft front seal and wear sleeve is removed completely.

NOTE: If wear sleeve does not come out with the front seal, continue with steps 4-6 to extract the wear sleeve. If both come out together, skip steps 4-6.

4. With an awl and hammer, punch three holes 120° apart in front wear sleeve.
5. Use Slide Hammer Kit (page 349) with correct size screw in one of the three holes.
6. Slide hammer until one side of wear sleeve begins to pull out of cover. Move slide hammer to next hole and repeat until front wear sleeve is removed completely.

Front Cover

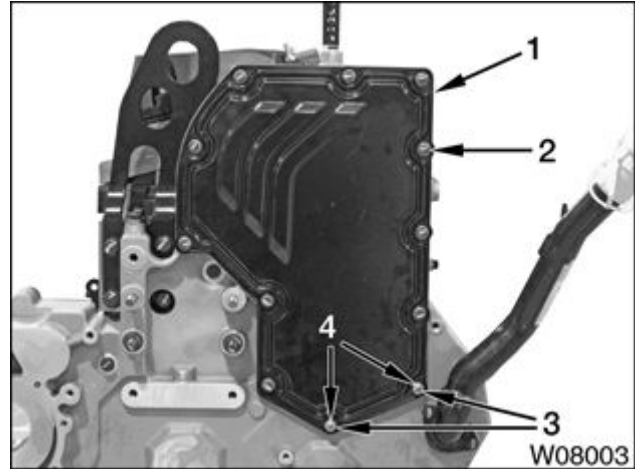


Figure 466 Camshaft gear cover

1. Camshaft gear cover
 2. 5/16–18 x 1 hex flange bolt (10)
 3. 5/16–18 hex lock nut (2)
 4. 8.8 x 16 x 10 spacer (2)
1. Remove two 5/16–18 hex lock nuts, two 8.8 x 16 x 10 spacers, ten 5/16–18 x 1 hex flange bolts, and the camshaft gear cover.



Figure 467 Camshaft gear cover gasket

2. Inspect the camshaft gear cover gasket for damage. If the gasket is damaged, remove and discard the camshaft gear cover gasket.

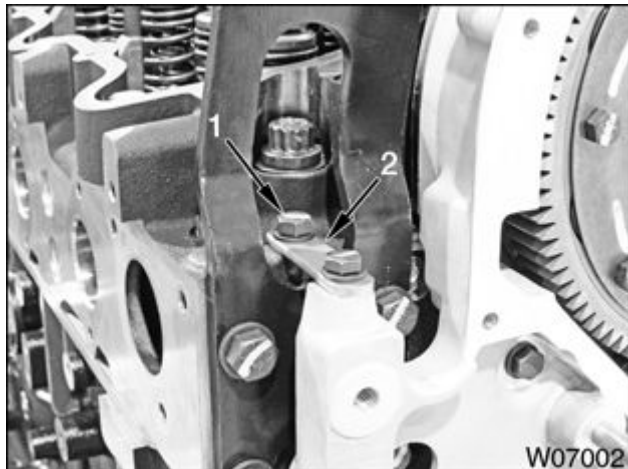


Figure 468 Front cover strap

1. 3/8-16 x 1 hex flange bolt (2)
 2. Front cover strap
3. Remove two 3/8-16 x 1 hex flange bolts and the front cover strap.

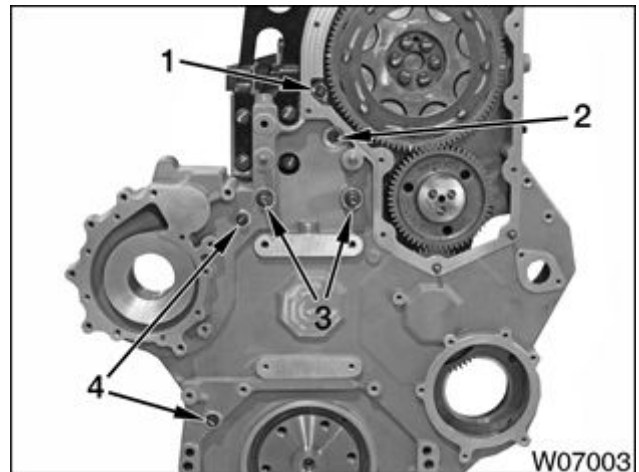


Figure 469 Front cover assembly front fasteners

1. 3/8-16 x 2 1/4 hex flange bolt
2. 3/8-16 x 1 3/4 hex flange bolt
3. 1/2-13 hex flange nut (2)
4. 3/8-16 x 4 1/4 hex flange bolt (2)

4. Remove two 1/2-13 hex flange nuts from front cover assembly.
5. Remove two 3/8-16 x 4 1/4 hex flange bolts, one 3/8-16 x 2 1/4 hex flange bolt, and one 3/8-16 x 1 3/4 hex flange bolt from front cover assembly.

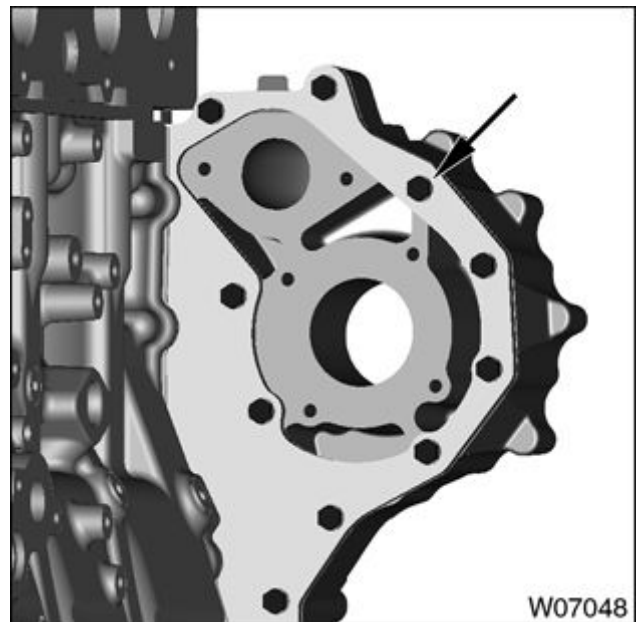


Figure 470 Front cover assembly right side rear 3/8-16 x 1 1/4 hex flange bolts

6. Remove ten 3/8–16 x 1 1/4 hex flange bolts.

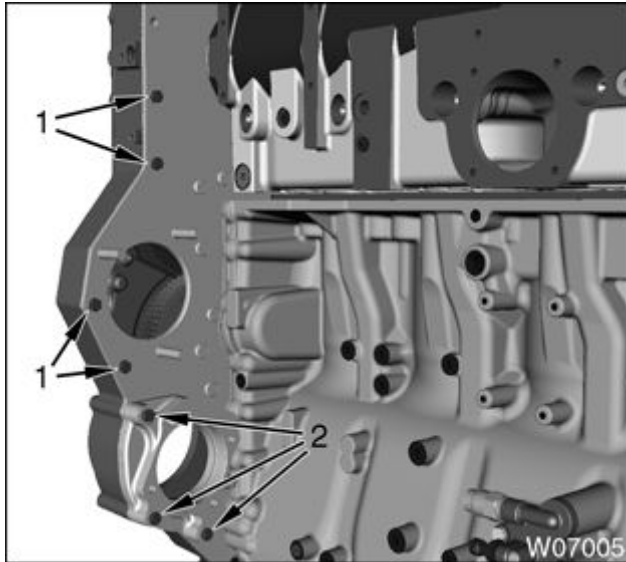


Figure 471 Front cover left side rear fasteners

1. 3/8–16 x 1 1/4 hex flange bolt (4)
2. 3/8–16 x 2 1/2 hex flange bolt (3)

7. Remove four 3/8–16 x 1 1/4 hex flange bolts.
8. Remove three 3/8–16 x 2 1/2 hex flange bolts.

NOTE: Valve cover is shown removed for clarity.

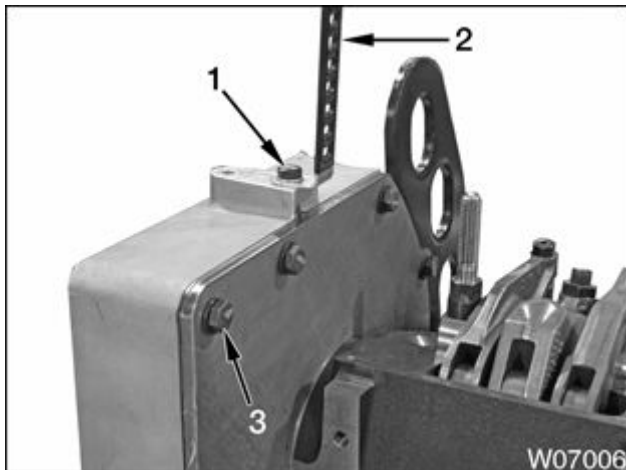


Figure 472 Front cover top rear fasteners

1. 5/16–18 x 3/4 hex flange bolt (if equipped)
2. Wiring harness bracket (if equipped)
3. 3/8–16 x 1 1/4 hex flange bolt (4)

9. Remove four 3/8–16 x 1 1/4 hex flange bolts.

10. Remove the front cover from crankcase dowels.

NOTE: If the front cover is being replaced, perform steps 11–13.

11. If equipped, remove 5/16–18 x 3/4 hex flange bolt and the wiring harness bracket.



Figure 473 Camshaft cover studs

12. If required, remove two camshaft cover studs with O-rings. Discard two O-rings.



Figure 474 Front cover stud

13. If required, remove 1/2–13 x 2.72 stud.

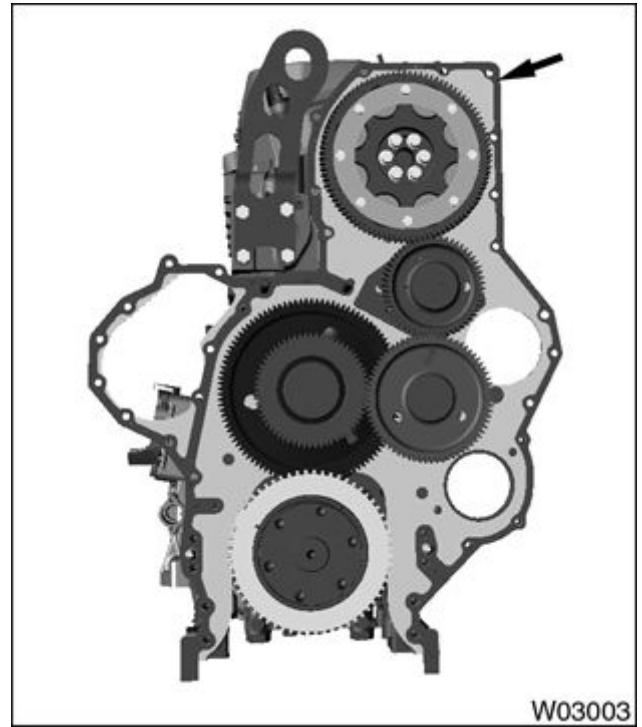


Figure 475 Front cover gasket

14. Remove front cover gasket from crankcase dowels. Discard front cover gasket.

Timing Gears and Supports

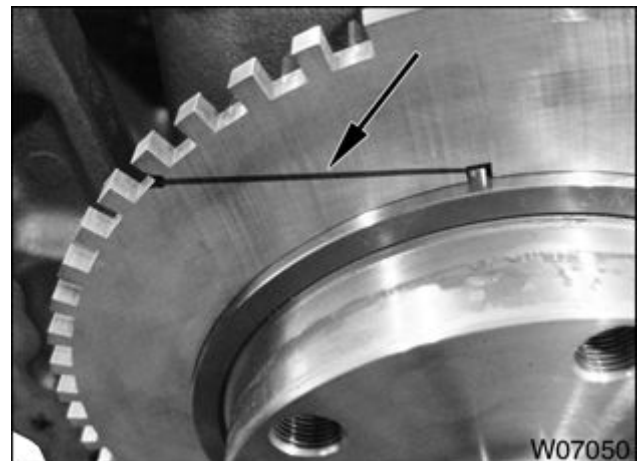


Figure 476 Crankshaft timing ring cut line

1. Prepare to cut the crankshaft timing ring. Count five slots from the left or right of the solid portion of crankshaft timing ring and draw a line from the

bottom of the slot to the slot on the inner diameter of the crankshaft timing ring.

2. Using an abrasive cutting disk (page 349) , cut the crankshaft timing ring along the line from the outer edge toward the inner slot along the line. It is not necessary to cut completely through to the inner slot.
3. Remove the crankshaft timing ring from the crankshaft.

⚠ WARNING: To prevent personal injury or death, wear heat insulated gloves when handling heated components.

4. Using heat insulated gloves (page 349) remove the crankshaft timing ring.

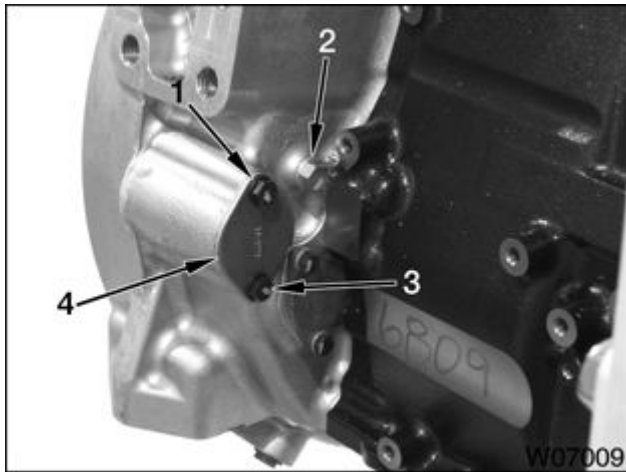


Figure 477 Flywheel locking bolt

1. 3/8–16 x 3 hex flange bolt
 2. Plug (flywheel locking port)
 3. 3/8–16 x 1 hex flange bolt
 4. Plate (flywheel access)
5. Remove the 3/8–16 x 3 hex flange bolt, 3/8–16 x 1 hex flange bolt and plate (flywheel access).
 6. Remove the plug (flywheel locking port)

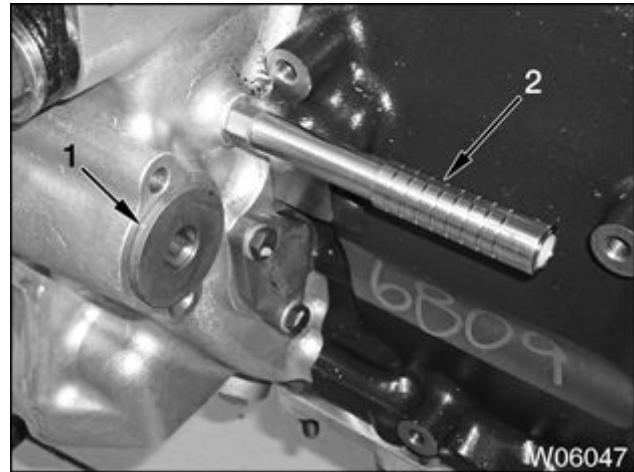


Figure 478 Right front of flywheel housing

1. Engine Rotation Tool
2. Timing Pin

7. Install the Timing Pin (page 349) into the flywheel locking port.
8. Install the Engine Rotation Tool (page 349).

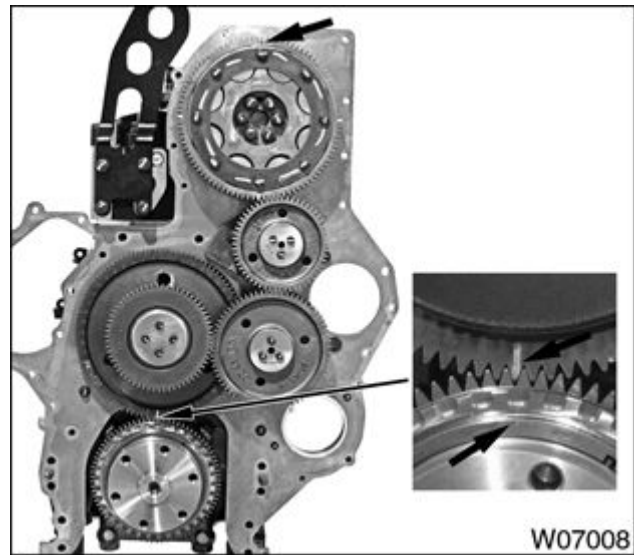


Figure 479 Timing mark alignment

NOTE: The crankshaft gear timing mark is an inverted "V" and the camshaft gear timing mark is a round hole (drill point).

9. Slowly rotate the crankshaft until the crankshaft gear and 105/63-teeth cluster gear assembly timing marks are aligned and the camshaft gear

timing mark is in the 12 o'clock position. The Timing Pin (page 349) will slide into a hole in the flywheel when the timing marks align.

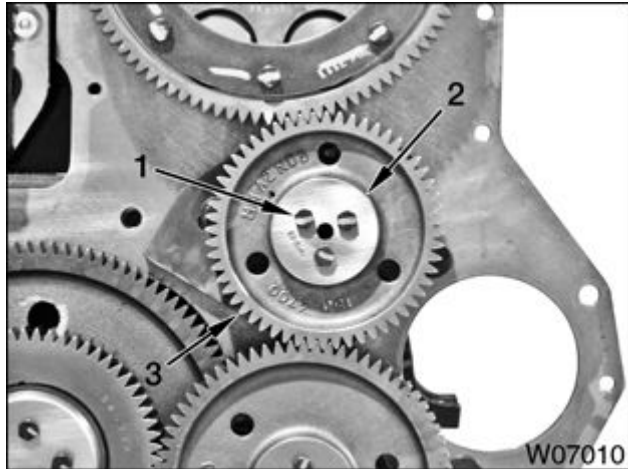


Figure 480 56-teeth gear assembly

1. 5/16–18 x 0.875 hex locking bolt (3)
2. Bushing flange
3. 56-teeth gear assembly

10. Remove three 5/16–18 x 0.875 hex locking bolts and the bushing flange.
11. Remove the 56-teeth gear assembly.

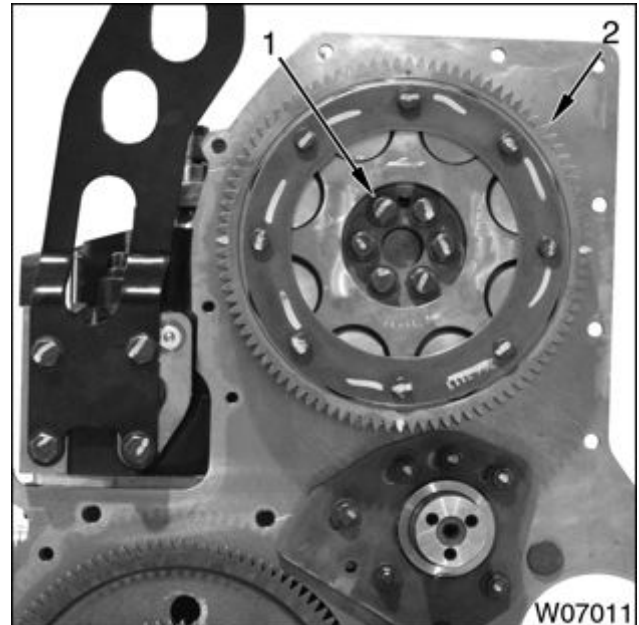


Figure 481 Camshaft timing gear assembly

1. 5/8–11 x 3, 12 point socket head bolt (6)
2. Camshaft gear assembly

12. Using a 5/8 inch 12 point socket, remove six 5/8–11 x 3, 12 point socket head bolts.
13. Remove the camshaft gear assembly.

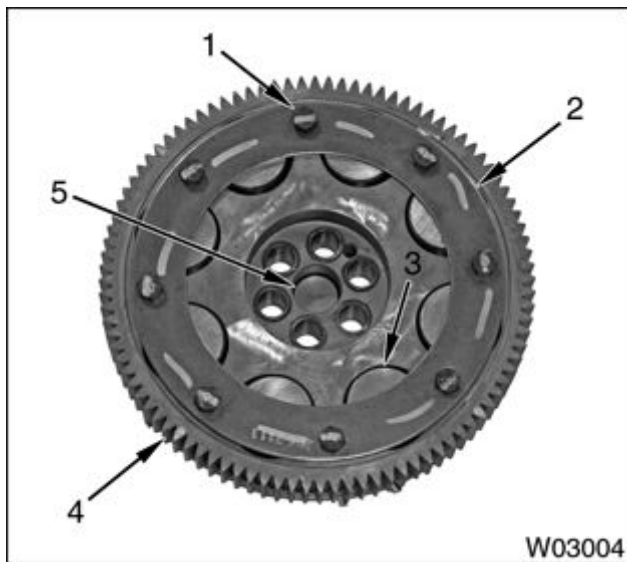


Figure 482 Camshaft gear assembly

1. 3/8–16 x 1.75 hex bolt (8)
2. Damper cover plate
3. Damper (8)
4. Camshaft gear
5. Dowel pin

NOTE: Only the 3/8–16 x 1.75 hex bolts are available individually as service parts. If the gear or dampers need replacement, the entire camshaft gear assembly should be replaced.

If required for cleaning and inspection, do steps 14–15.

14. Remove eight 3/8–16 x 1.75 hex bolts and the damper cover plate.

15. Remove eight dampers.

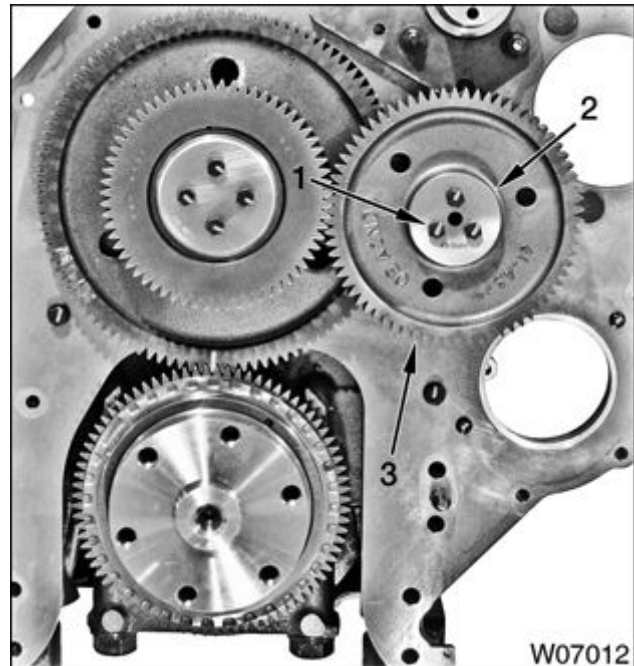


Figure 483 71-teeth gear assembly

1. 5/16–18 x 0.875 hex locking bolt (3)
2. Bushing flange
3. 71-teeth gear assembly

16. Remove three 5/16–18 x 0.875 hex locking bolts and the bushing flange.

17. Remove the 71-teeth gear assembly.

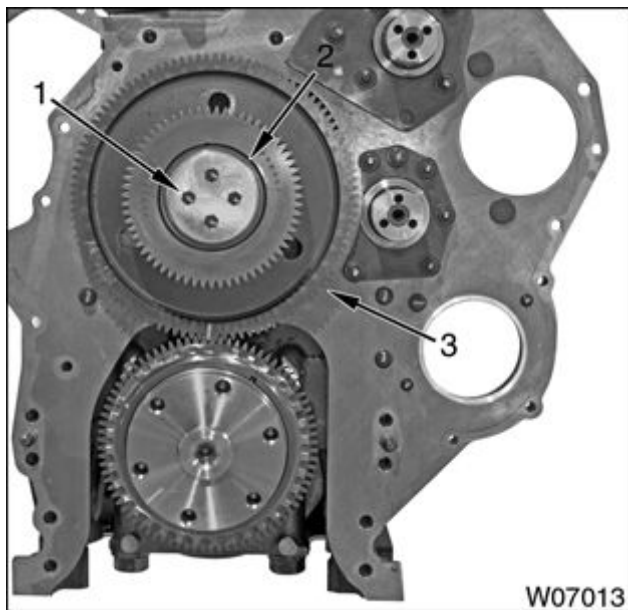


Figure 484 105/63-teeth cluster gear assembly

1. 5/16–18 x 0.875 hex locking bolt (4)
2. Bushing flange
3. 105/63-teeth cluster gear assembly

18. Remove four 5/16–18 x 0.875 hex locking bolts and the bushing flange.
19. Remove the 105/63-teeth cluster gear assembly.

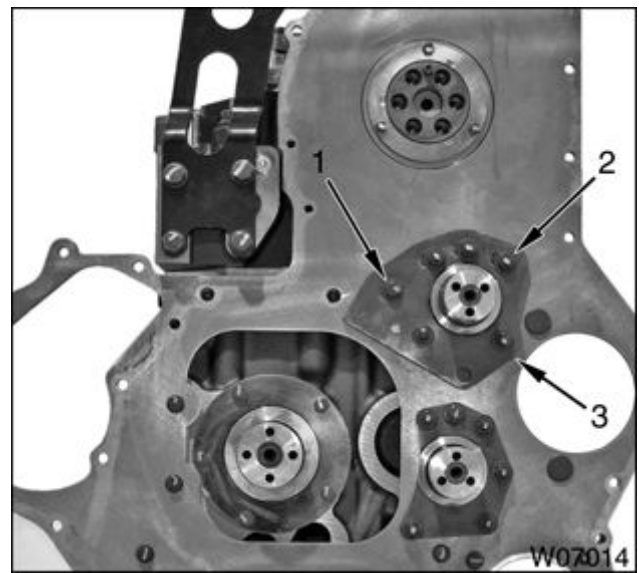


Figure 485 56-teeth gear support assembly

1. 3/8–16 x 1.5 hex flange locking bolt
2. 3/8–16 hex flange nut (5)
3. 56-teeth gear support assembly

20. Remove 3/8–16 x 1.5 hex flange locking bolt and five 3/8–16 hex flange nuts.
21. Remove 56-teeth gear support assembly.

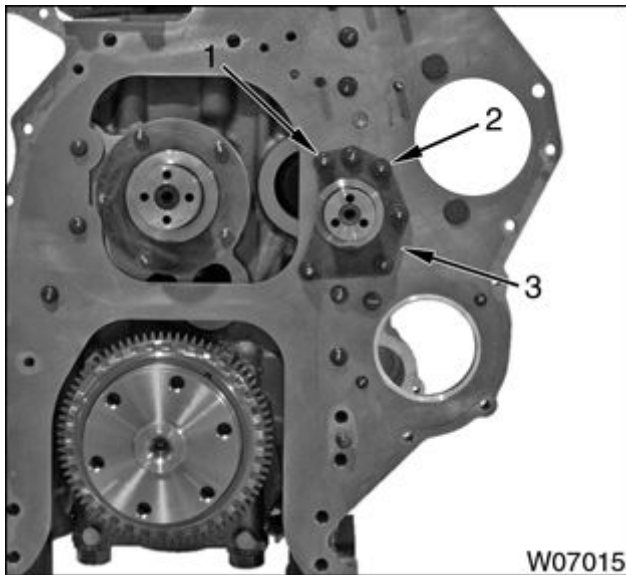


Figure 486 71-teeth gear support assembly

1. 3/8–16 x 1.5 hex flange locking bolt
 2. 3/8–16 hex flange nut (5)
 3. 71-teeth gear support assembly
22. Remove 3/8–16 x 1.5 hex flange locking bolt and five 3/8–16 hex flange nuts.
23. Remove 71-teeth gear support assembly.



Figure 487 High-pressure pump adapter

1. M6 x 20 mm hex flange bolt (2)
2. High-pressure pump adapter
3. 3/8–16 x 1 thread locking hex flange locking bolt

24. Remove 3/8–16 x 1 thread locking hex flange locking bolt and two M6 x 20 mm hex flange bolts.

25. Remove high-pressure pump adapter.



Figure 488 High-pressure pump adapter O-rings

1. 906 O-ring (3)
2. O-ring
3. High-pressure pump adapter

26. Remove and discard one O-ring and three 906 O-rings.

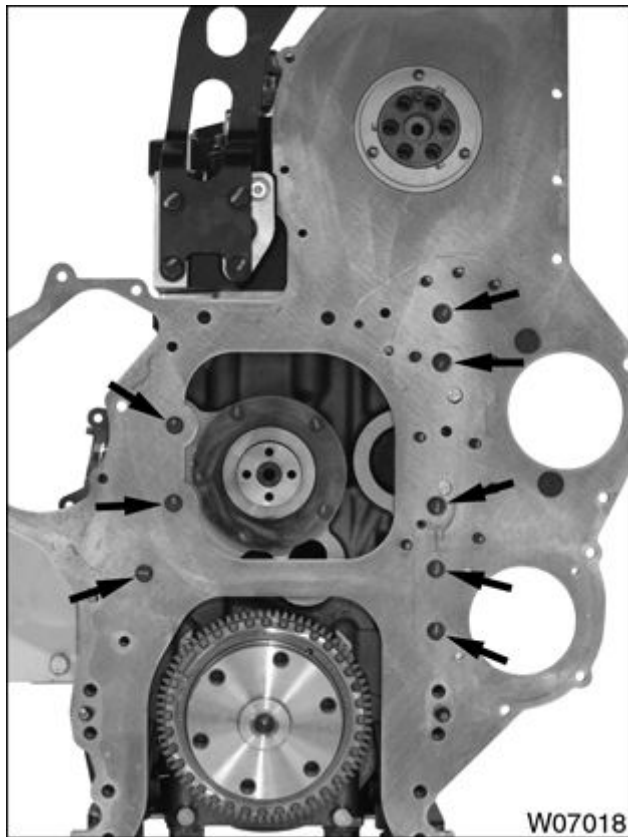


Figure 489 Front cover plate 3/8-16 x 1 hex flange bolts

27. Remove eight 3/8-16 x 1 hex flange bolts and the front cover plate.

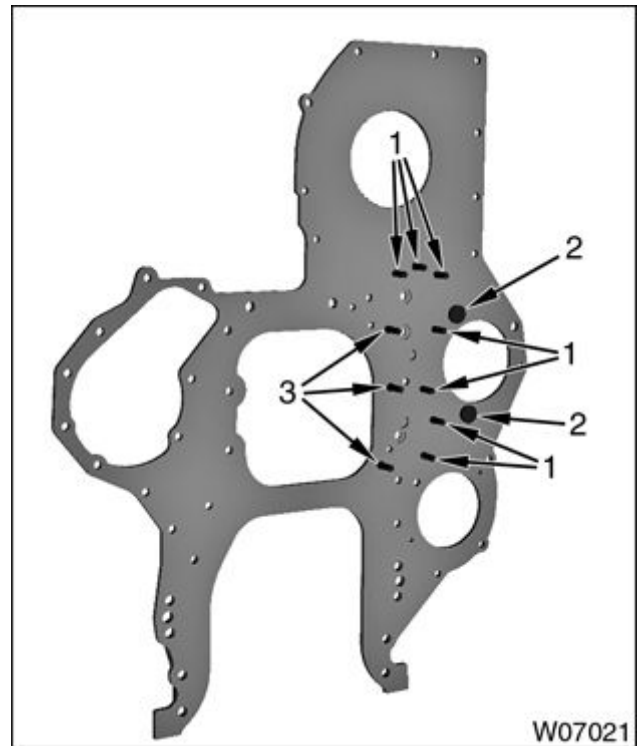


Figure 490 Front cover plate stud locations

1. Self clinching stud with 10.85 x 19.3 x 1.27 mm THK washer (small) (7)
2. Self clinching stud with sealing washer (large) (2)
3. Self clinching stud (small) (3)

NOTE: It is only necessary to replace a self clinching stud washer when replacing a self clinching stud.

28. If any self clinching stud is damaged, press out the self clinching stud. Remove and discard the 10.85 x 19.3 x 1.27 mm THK washer on a small self clinching stud or the sealing washer on a large self clinching stud.

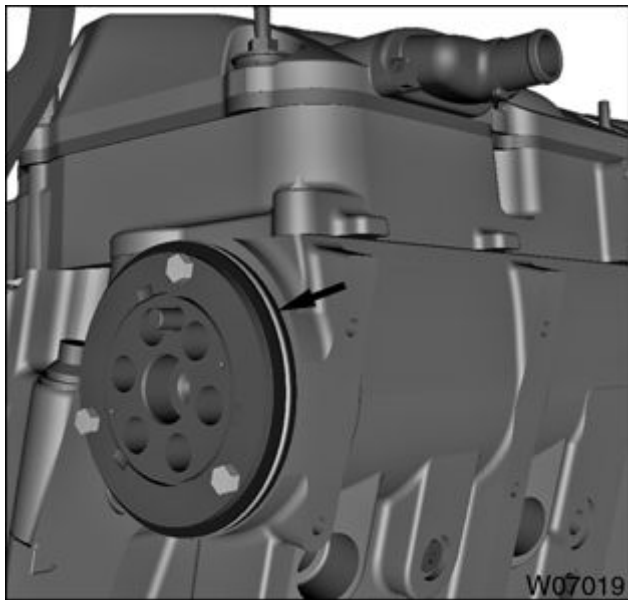


Figure 491 Camshaft seal plate O-ring seal

29. Remove the camshaft seal plate O-ring seal.

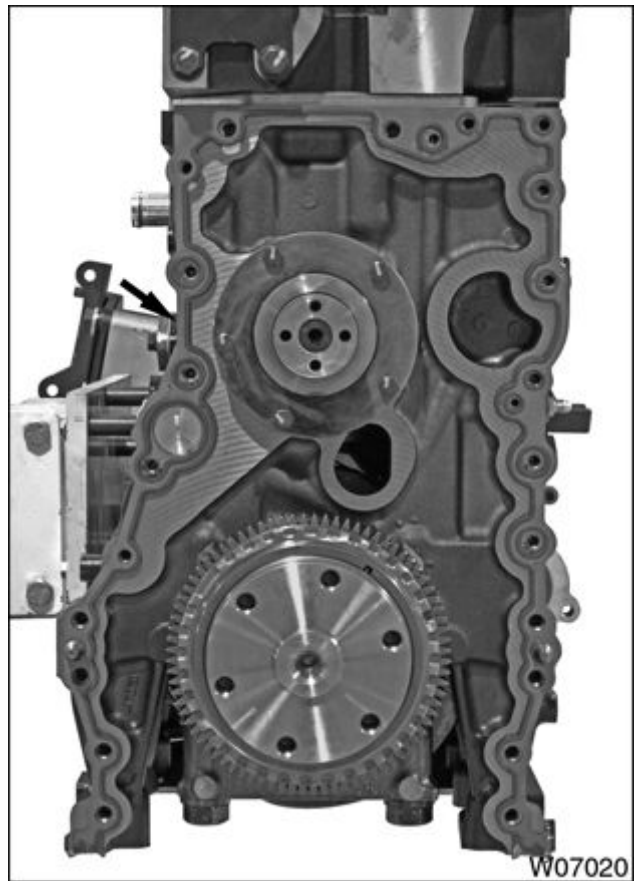


Figure 492 Front cover plate gasket

30. Remove and discard the front cover plate gasket.

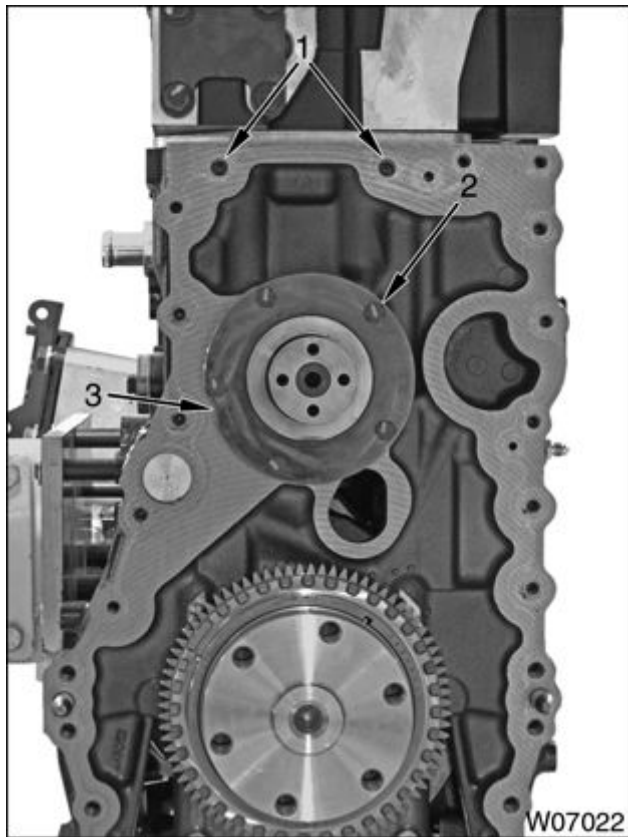


Figure 493 105 & 63 teeth gears support

1. 1/2–13 x 5 5/8 taperlock stud (2)
2. 3/8–16 x 1.25 locking hex bolt (5)
3. 105 & 63 teeth gears support

31. If required, remove two 1/2–13 x 5 5/8 taperlock studs.
32. Remove five 3/8–16 x 1.25 locking hex bolts and the 105 & 63 teeth gears support.

Cleaning, Inspection, and Testing**Front Cover**

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

1. Clean water pump, coolant elbows, thermostat housing, front engine mount support, and front cover with a suitable non-caustic solvent.
2. Blow parts dry using filtered compressed air.
3. Clean coolant and oil seal mating surfaces on the crankcase, cylinder head, water pump, coolant elbow, thermostat housing, and front cover.
4. Clean the bolt threads and bolt holes for the high-pressure pump adapter bolts.
5. Clean the bolt threads and bolt holes for the front cover plate bolts.
6. Inspect coolant elbow, vibration damper, and front cover for damage, contamination, or excessive wear. Replace parts if required.
7. Inspect automatic belt tensioner and pulley to make sure tensioner arm and pulley are properly in line with the fan drive belt and not coming apart. Make sure tensioner arm is not binding and pulley bearing is not loose. Replace belt tensioner if required.

8. Inspect water pump. Wiggle water pump hub and shaft. If water pump bearing has excess play, replace water pump. Inspect water pump housing for coolant leaks. Replace water pump if leaking.

Timing Gears

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

1. Wash timing gears and supports with a stiff brush and suitable non-caustic solvent. Dry all with filtered compressed air.
 2. Inspect timing gears for irregular wear pattern and worn or damaged teeth. Replace as necessary.
 3. Clean the nut, bolt, and self clinching stud threads and bolt holes for the 105 & 63 teeth, 71-teeth, and 56-teeth gear support fasteners.
 4. Clean the bolt threads and bolt holes for the 105 & 63 teeth, 71-teeth, and 56-teeth gear support bushing flange bolts.
 5. Clean the bolt threads and bolt holes for the damper cover plate bolts.
 6. Inspect timing gear supports for worn or damaged bearing surfaces. Replace as necessary.
-

Installation

Timing Gears and Supports

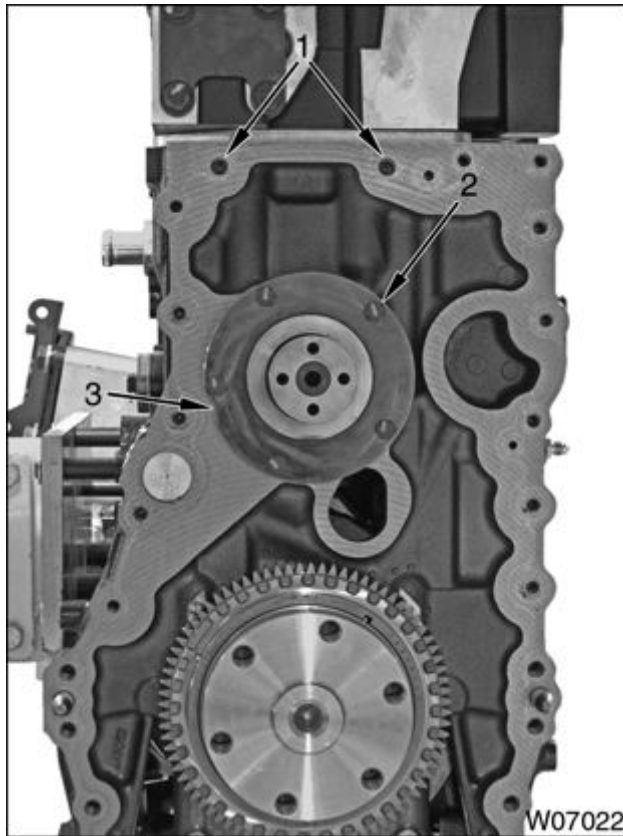


Figure 494 105 & 63 teeth gears support

1. 1/2-13 x 5 5/8 taperlock stud (2)
 2. 3/8-16 x 1.25 locking hex bolt (5)
 3. 105 & 63 teeth gears support
1. If previously removed, install two 1/2-13 x 5 5/8 taperlock studs with short chamfered end into crankcase. Tighten taperlock studs fully into the crankcase until they bottom out.

2. Apply Loctite® 242 (page 349) to threads on five 3/8-16 x 1.25 locking hex bolts.

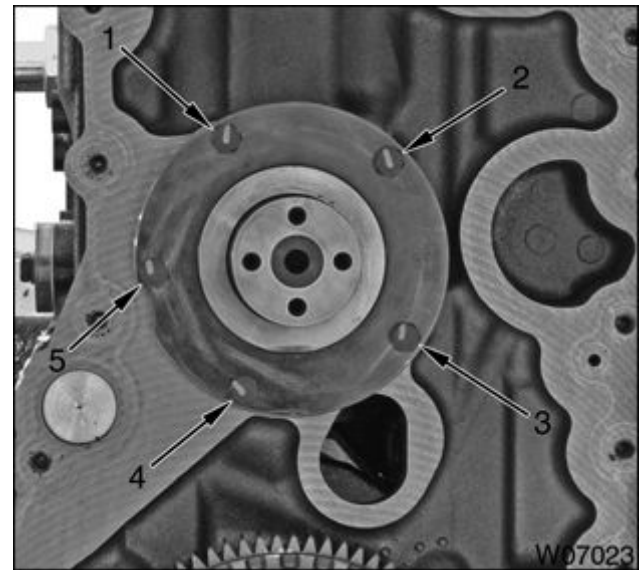


Figure 495 105 & 63 teeth gears support locking hex bolt torque locations

3. Position 105 & 63 teeth gears support and loosely install five 3/8-16 x 1.25 locking hex bolts. Tighten locking hex bolts in the following sequence to special torque:
 - a. Tighten the five locking hex bolts in location sequence 1, 3, 4, 5, 2 to 20 N·m (27 lbf·ft).
 - b. Tighten the five locking hex bolts in location sequence 1, 2, 3, 4, 5 to 56 N·m (41 lbf·ft).
 - c. Retighten locking hex bolt location 1 to 56 N·m (41 lbf·ft).

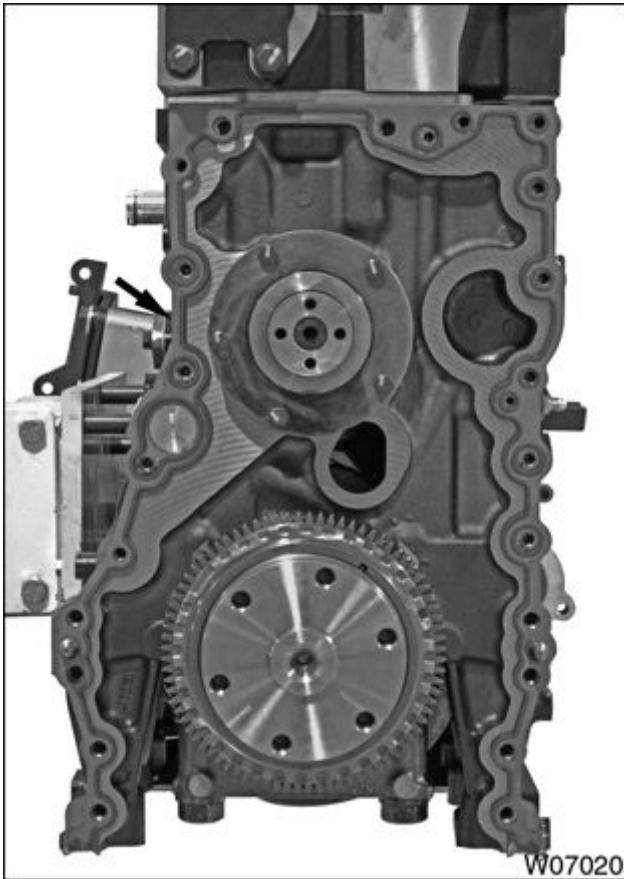


Figure 496 Front cover plate gasket

4. Install a new front cover plate gasket.

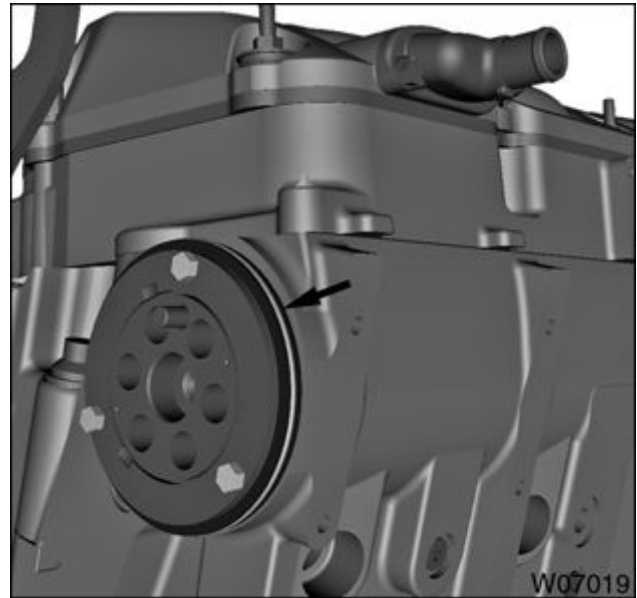


Figure 497 Camshaft seal plate O-ring seal

NOTE: Do steps 5 and 6 if not previously done during camshaft or cylinder head repairs.

5. Lubricate the camshaft seal plate O-ring seal with clean engine oil.
6. Install a new camshaft seal plate O-ring seal on the camshaft seal plate.

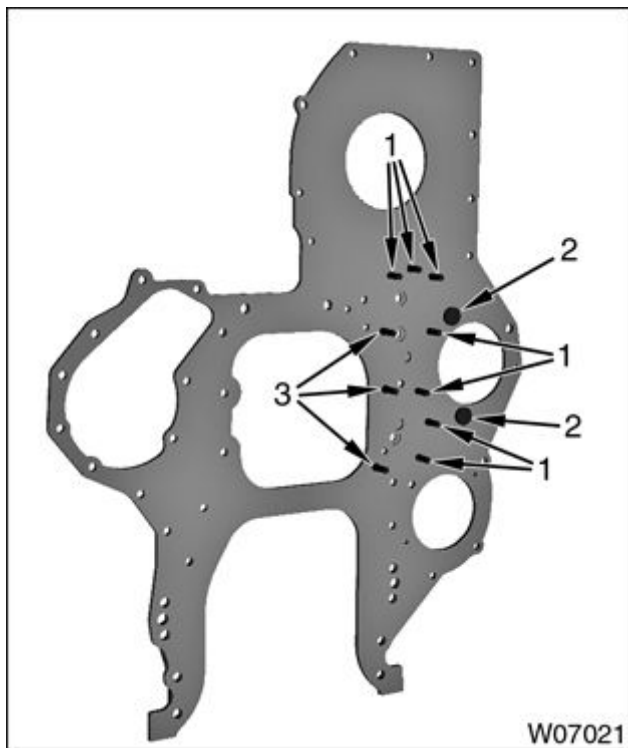


Figure 498 Front cover plate stud locations

1. Self clinching stud with 10.85 x 19.3 x 1.27 mm THK washer (small) (7)
 2. Self clinching stud with sealing washer (large) (2)
 3. Self clinching stud (small) (3)
7. If any large self clinching stud was removed, install the sealing washer on the large self clinching stud.
 8. If any small self clinching stud was removed, install a new 10.85 x 19.3 x 1.27 mm THK washer on the small self clinching stud.
 9. If any self clinching stud was removed, press in the self clinching stud.

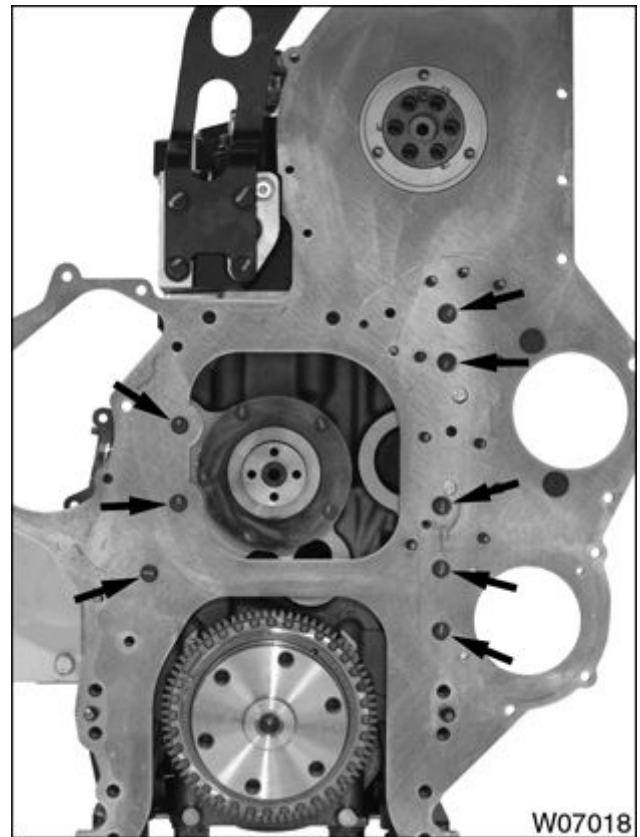


Figure 499 Front cover plate 3/8-16 x 1 hex flange bolts

10. Apply Loctite® 242 (page 349) to threads on eight 3/8-16 x 1 thread locking hex flange bolts.
11. Position front cover plate and install eight 3/8-16 x 1 thread locking hex flange bolts. Tighten the eight 3/8-16 x 1 thread locking hex flange bolts in two stages to special torque:
 - a. Tighten the eight 3/8-16 x 1 thread locking hex flange bolts to 56 N·m (41 lbf·ft).
 - b. Retighten the eight 3/8-16 x 1 thread locking hex flange bolts to 56 N·m (41 lbf·ft).

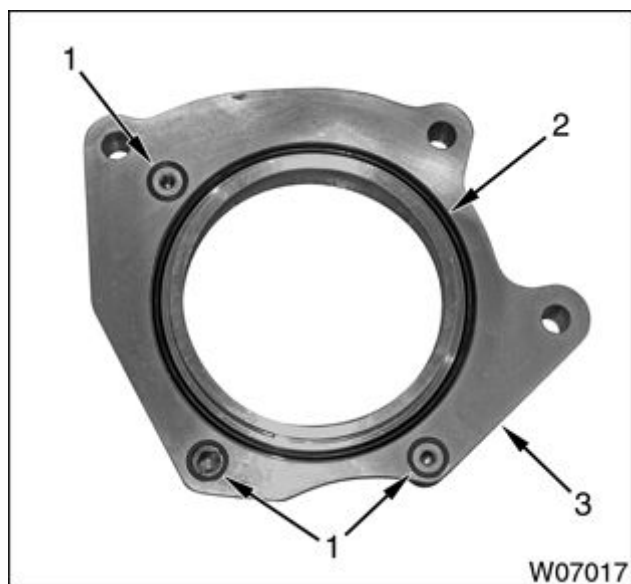


Figure 500 High-pressure pump adapter O-rings

1. 906 O-ring (3)
2. O-ring
3. High-pressure pump adapter

12. Install one new O-ring and three new 906 O-rings into the high-pressure pump adapter.

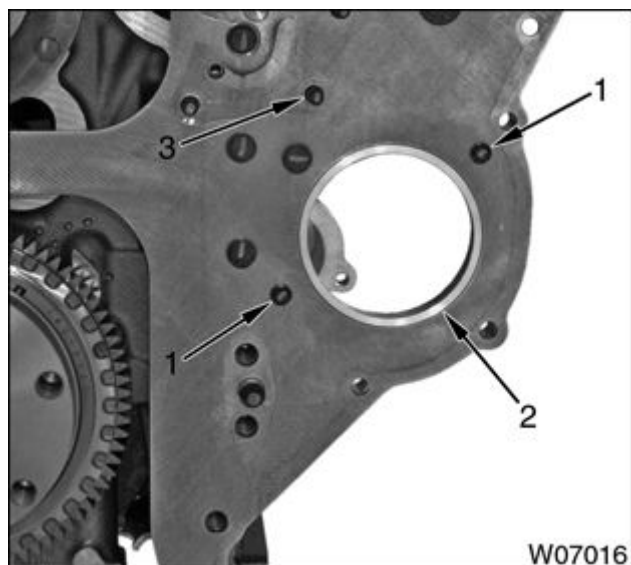


Figure 501 High-pressure pump adapter

1. M6 x 20 mm hex flange bolt (2)
2. High-pressure pump adapter
3. 3/8-16 x 1 thread locking hex flange locking bolt

13. Apply Loctite® 242 (page 349) to threads on M6 x 20 mm hex flange bolts and 3/8-16 x 1 thread locking hex flange locking bolt.

14. Position high-pressure pump adapter and install 3/8-16 x 1 thread locking hex flange locking bolt and two M6 x 20 mm hex flange bolts. Tighten the M6 x 20 mm hex flange bolts to standard torque (page 561). Tighten the 3/8-16 x 1 thread locking hex flange locking bolt to standard torque (page 562).

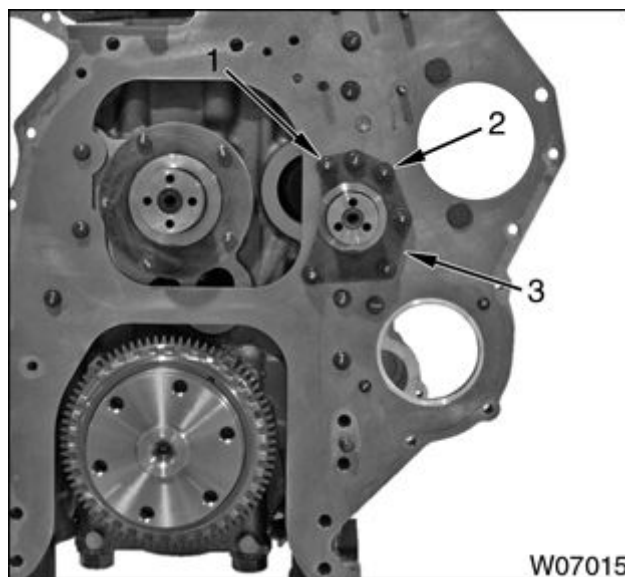


Figure 502 71-teeth gear support assembly

1. 3/8-16 x 1.5 hex flange locking bolt
2. 3/8-16 hex flange nut (5)
3. 71-teeth gear support assembly

15. Apply Loctite® 242 (page 349) to threads on 3/8-16 x 1.5 hex flange locking bolt and self clinching studs that support 71-teeth gear support assembly.

16. Position 71-teeth gear support assembly and install 3/8-16 x 1.5 hex flange locking bolt and five 3/8-16 hex flange nuts. Tighten the 3/8-16 x 1.5 hex flange locking bolt and five 3/8-16 hex flange nuts to special torque (page 348).

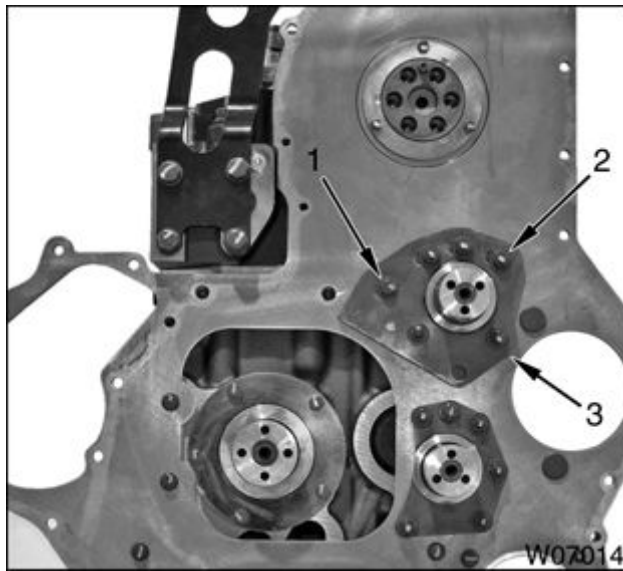


Figure 503 56-teeth gear support assembly

1. 3/8–16 x 1.5 hex flange locking bolt
2. 3/8–16 hex flange nut (5)
3. 56-teeth gear support assembly

NOTE: Do not apply Loctite® 242 to the threads of 56-teeth gear support mounting bolt or studs at this time. Do not tighten mounting bolt or nuts at this time.

17. Position 56-teeth gear support assembly and loosely install 3/8–16 x 1.5 hex flange locking bolt and five 3/8–16 hex flange nuts without use of Loctite®.

NOTE: If not already done, do steps 18–23.

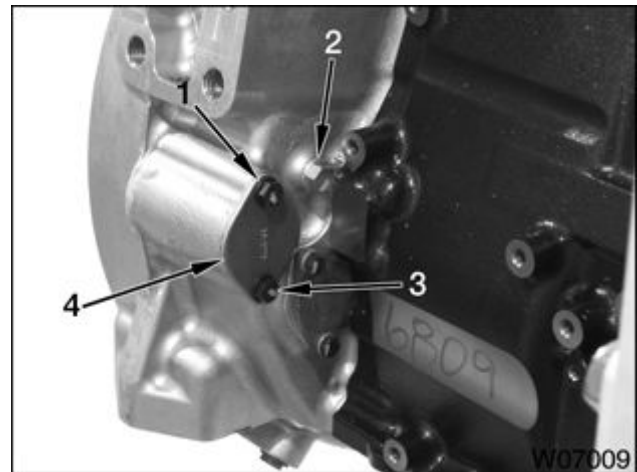


Figure 504 Flywheel locking port

1. 3/8–16 x 3 hex flange bolt
2. Plug (flywheel locking port)
3. 3/8–16 x 1 hex flange bolt
4. Plate (flywheel access)

18. Remove 3/8–16 x 3 hex flange bolt, 3/8–16 x 1 hex flange bolt, and plate (flywheel access).

19. Remove and discard the seal.

20. Remove the plug (flywheel locking port)

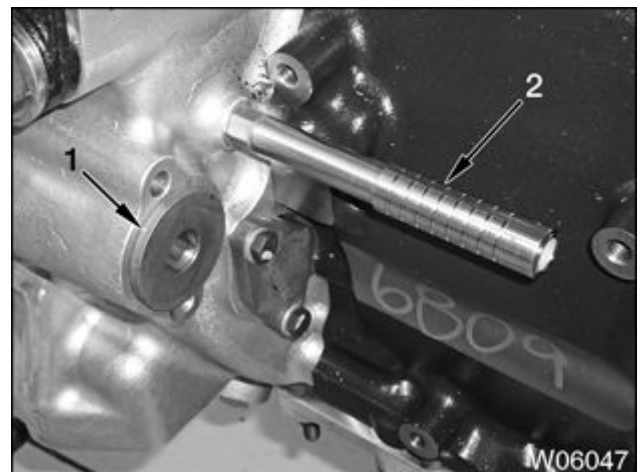


Figure 505 Right front of flywheel housing

1. Engine Rotation Tool
2. Timing Pin

21. Install the Timing Pin (page 349).

22. Install the Engine Rotation Tool (page 349).

23. Slowly rotate the crankshaft. The Timing Pin will slide into a threaded hole in the flywheel when the crankshaft is at Top Dead Center (TDC).

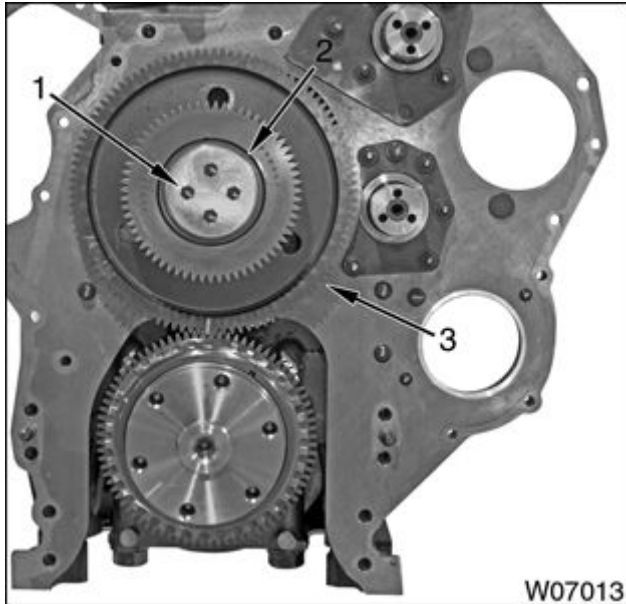


Figure 506 105/63-teeth cluster gear assembly

1. 5/16–18 x 0.875 hex locking bolt (4)
 2. Bushing flange
 3. 105/63-teeth cluster gear assembly
24. Lubricate the 105 & 63 teeth gears support shaft and the 105/63-teeth cluster gear teeth with 90 weight gear oil (page 349).

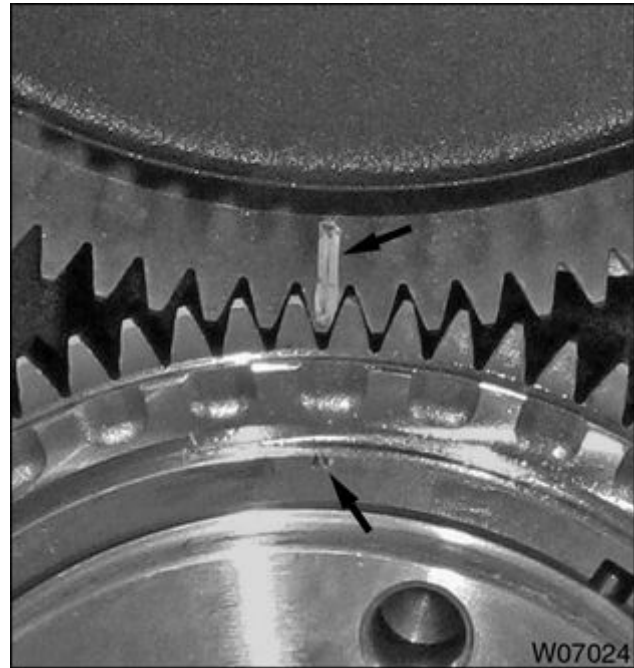


Figure 507 Crankshaft gear to 105/63-teeth cluster gear assembly timing alignment

25. Position the 105/63-teeth cluster gear assembly on the 105 & 63 teeth gears support shaft while aligning the timing marks.
26. Apply Loctite® 242 (page 349) to threads on four 5/16–18 x 0.875 hex locking bolts.
27. Position the bushing flange and install four 5/16–18 x 0.875 hex locking bolts. Tighten the 5/16–18 x 0.875 hex locking bolts to standard torque (page 562).

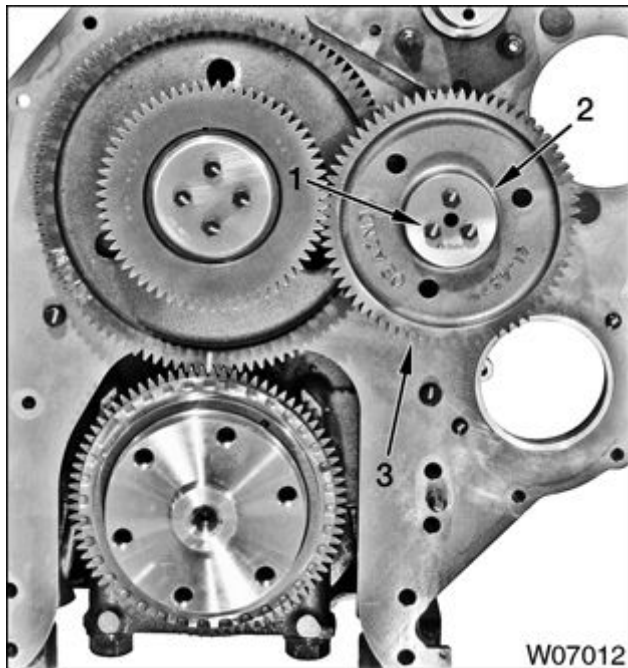


Figure 508 71-teeth gear assembly

1. 5/16–18 x 0.875 hex locking bolt (3)
 2. Bushing flange
 3. 71-teeth gear assembly
28. Lubricate the 71-teeth gear support shaft and the 71-teeth gear teeth with 90 weight gear oil (page 349).
 29. Position the 71-teeth gear assembly on the 71-teeth gear support shaft.
 30. Apply Loctite® 242 (page 349) to threads on three 5/16–18 x 0.875 hex locking bolts.
 31. Position the bushing flange and install three 5/16–18 x 0.875 hex locking bolts. Tighten the 5/16–18 x 0.875 hex locking bolts to standard torque (page 562).

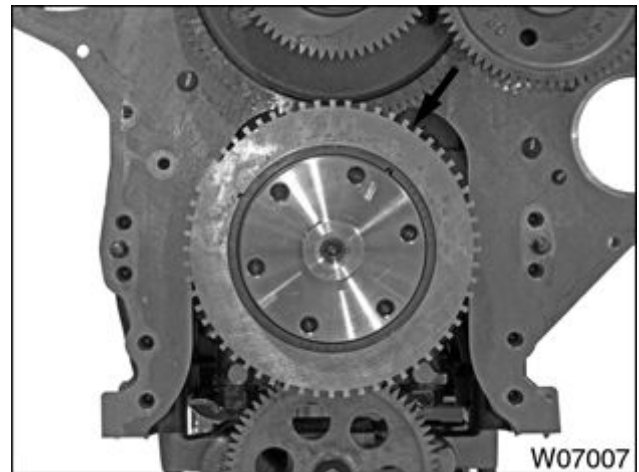


Figure 509 Crankshaft timing ring

CAUTION: To prevent engine damage, do not heat crankshaft timing ring above 204 °C (400 °F).

NOTE: Monitor the crankshaft timing ring temperature using an infrared thermometer (thermo gun) (page 349).

Heat crankshaft timing ring on a hot plate (page 349), or other controlled heat source, until the timing ring is between 177 °C (350 °F) and 191 °C (375 °F).

! WARNING: To prevent personal injury or death, wear heat insulated gloves when handling heated components.

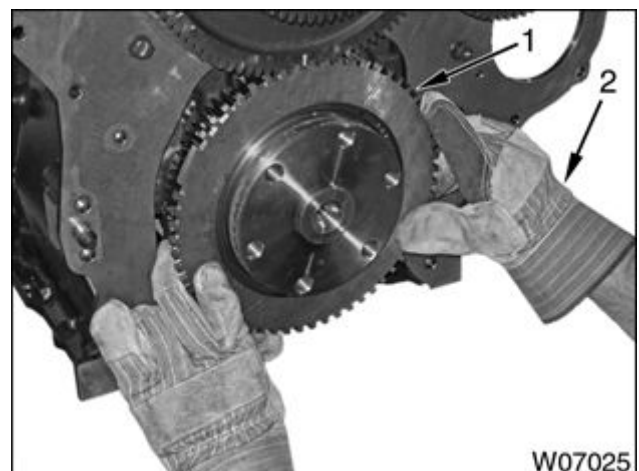


Figure 510 Crankshaft timing ring install

1. Crankshaft timing ring
2. Heat insulated gloves

32. Using heat insulated gloves (page 349) install the crankshaft timing ring while aligning the ring notch to the crankshaft timing pin. Hold in place 30 seconds.

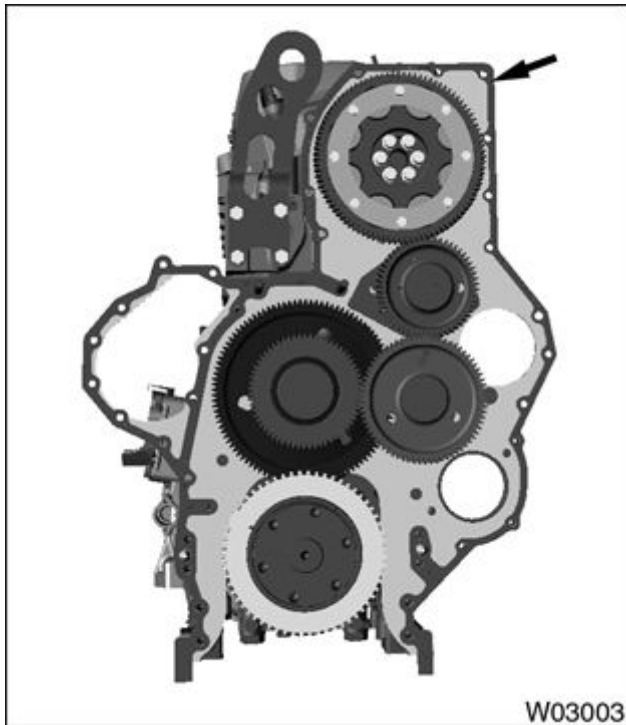
Front Cover

Figure 511 Front cover gasket

1. Install a new front cover gasket over crankcase dowels.



Figure 512 Front cover stud

2. If previously removed, install 1/2–13 x 2.72 stud in the front cover. Tighten the 1/2–13 x 2.72 stud until fully threaded into the front cover.
3. Position the front cover on the two crankcase threadlock studs and slide the front cover over the crankcase dowels.

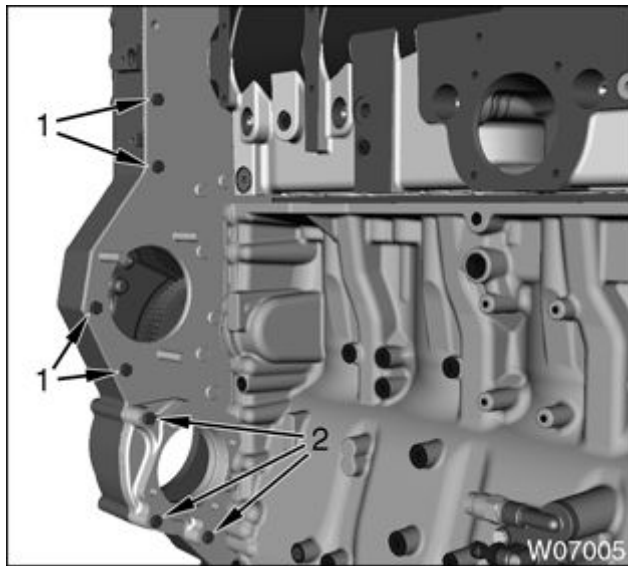


Figure 513 Front cover left side rear fasteners

1. 3/8-16 x 1 1/4 hex flange bolt (4)
2. 3/8-16 x 2 1/2 hex flange bolt (3)

4. Install four 3/8-16 x 1 1/4 hex flange bolts. Tighten the 3/8-16 x 1 1/4 hex flange bolts to standard torque (page 562).
5. Install three 3/8-16 x 2 1/2 hex flange bolts. Tighten the 3/8-16 x 2 1/2 hex flange bolts to standard torque (page 562).

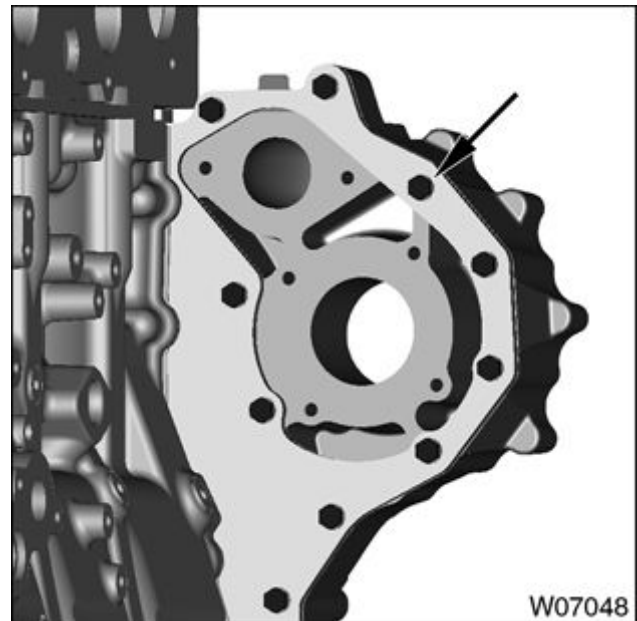


Figure 514 Front cover assembly right side rear 3/8-16 x 1 1/4 hex flange bolts

6. Install ten 3/8-16 x 1 1/4 hex flange bolts. Tighten the 3/8-16 x 1 1/4 hex flange bolts to standard torque (page 562).

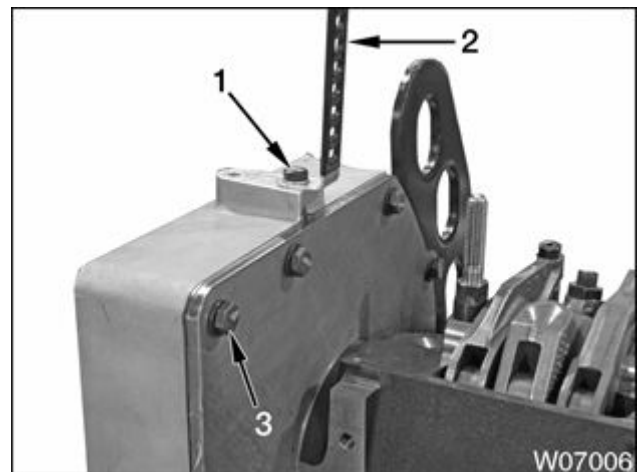


Figure 515 Front cover top rear fasteners

1. 5/16-18 x 3/4 hex flange bolt (if equipped)
2. Wiring harness bracket (if equipped)
3. 3/8-16 x 1 1/4 hex flange bolt (4)

NOTE: Valve cover is shown removed for clarity.

7. Install four 3/8–16 x 1 1/4 hex flange bolts. Tighten the 3/8–16 x 1 1/4 hex flange bolts to standard torque (page 562).
8. If equipped, install wiring harness bracket and 5/16–18 x 3/4 hex flange bolt. Tighten the 5/16–18 x 3/4 hex flange bolt to standard torque (page 562).

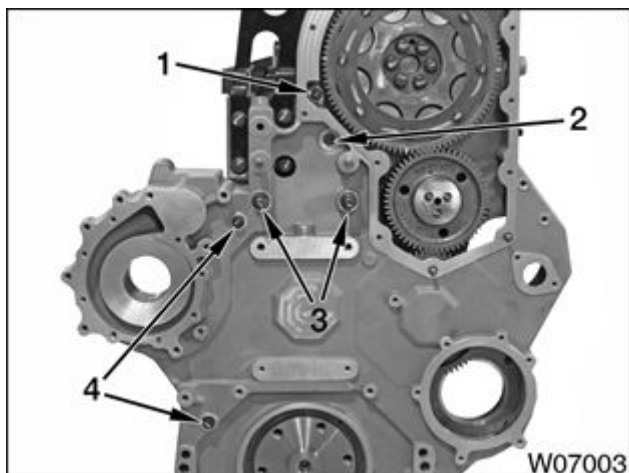


Figure 516 Front cover assembly front fasteners

1. 3/8–16 x 2 1/4 hex flange bolt
 2. 3/8–16 x 1 3/4 hex flange bolt
 3. 1/2–13 hex flange nut (2)
 4. 3/8–16 x 4 1/4 hex flange bolt (2)
9. Install two 3/8–16 x 4 1/4 hex flange bolts, one 3/8–16 x 2 1/4 hex flange bolt, and one 3/8–16 x 1 3/4 hex flange bolt in front cover assembly. Tighten the 3/8 hex flange bolts to standard torque (page 562).
 10. Install two 1/2–13 hex flange nuts on front cover assembly. Tighten the 1/2–13 hex flange nuts to standard torque (page 562).

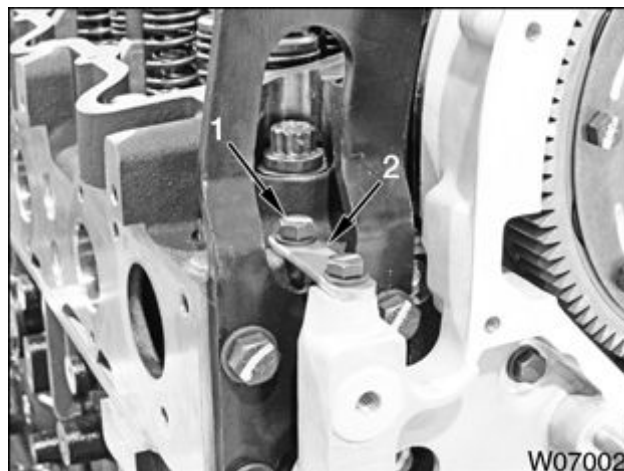


Figure 517 Front cover strap

1. 3/8–16 x 1 hex flange bolt (2)
2. Front cover strap

11. Position front cover strap and install two 3/8–16 x 1 hex flange bolts. Tighten the 3/8–16 x 1 hex flange bolts to standard torque (page 562).

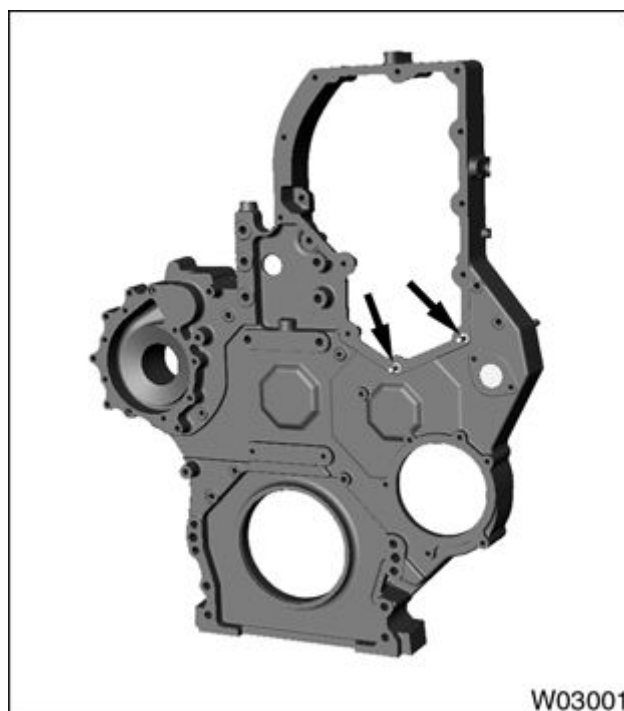


Figure 518 Camshaft cover studs

12. If the front cover is being replaced, install two new O-rings and two camshaft cover studs. Tighten

the camshaft cover studs to special torque (page 348).

Camshaft Gear

NOTE: If the damper cover plate was removed, do steps 1–2.

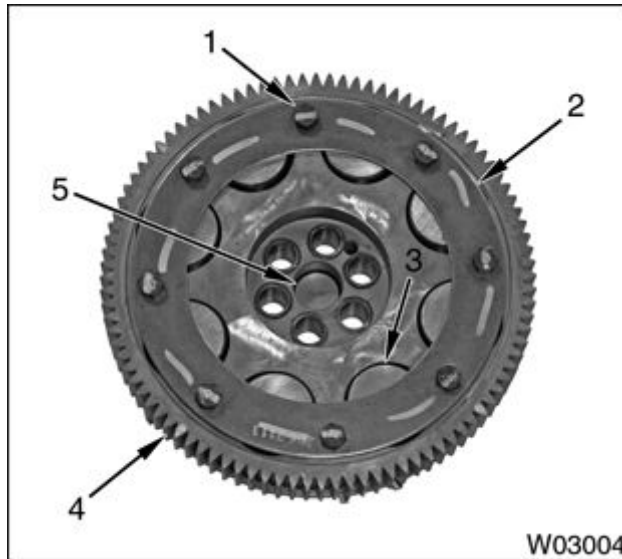


Figure 519 Camshaft gear assembly

1. 3/8–16 x 1.75 hex bolt (8)
2. Damper cover plate
3. Damper (8)
4. Camshaft gear
5. Dowel pin

1. Install the eight dampers.
2. Install damper cover plate and eight 3/8–16 x 1.75 hex bolts. Tighten the 3/8–16 x 1.75 hex bolts to special torque (page 348).

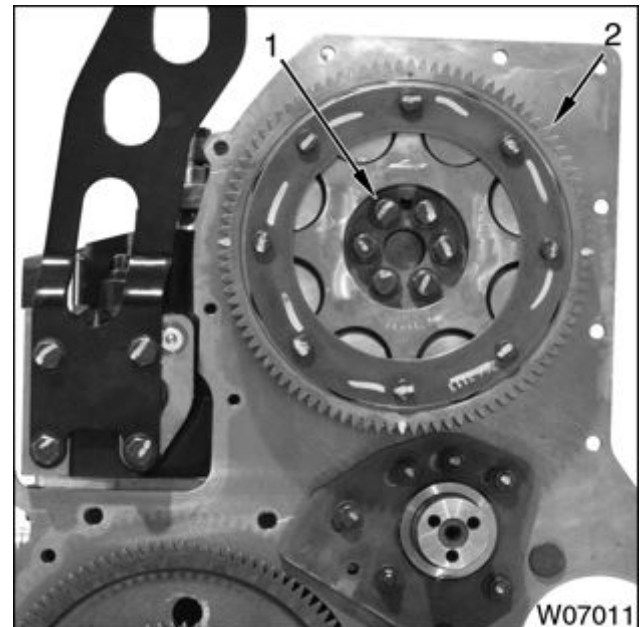


Figure 520 Camshaft gear assembly

1. 5/8–11 x 3, 12 point socket head bolt (6)
2. Camshaft gear assembly
3. Position the camshaft gear assembly on the camshaft aligning hole in gear to timing pin in camshaft.
4. Using a 5/8 inch 12 point socket, install six 5/8–11 x 3, 12 point socket head bolts. Tighten the 5/8–11 x 3, 12 point socket head bolts to special torque (page 348).

Timing Gear Lash

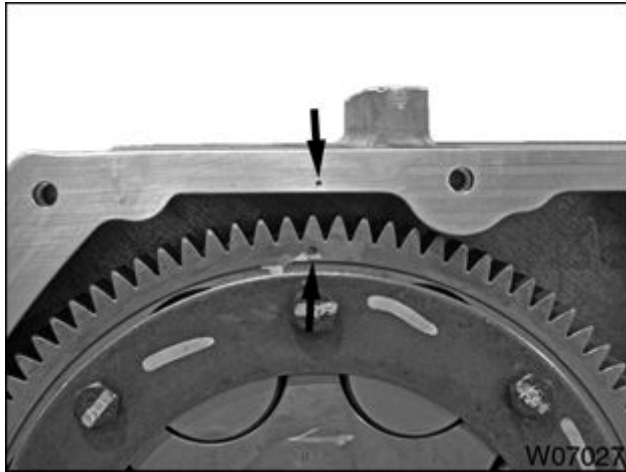


Figure 521 Camshaft timing marks

1. Turn the camshaft timing gear assembly until the timing mark on the camshaft gear lines up with the timing mark on the front cover.

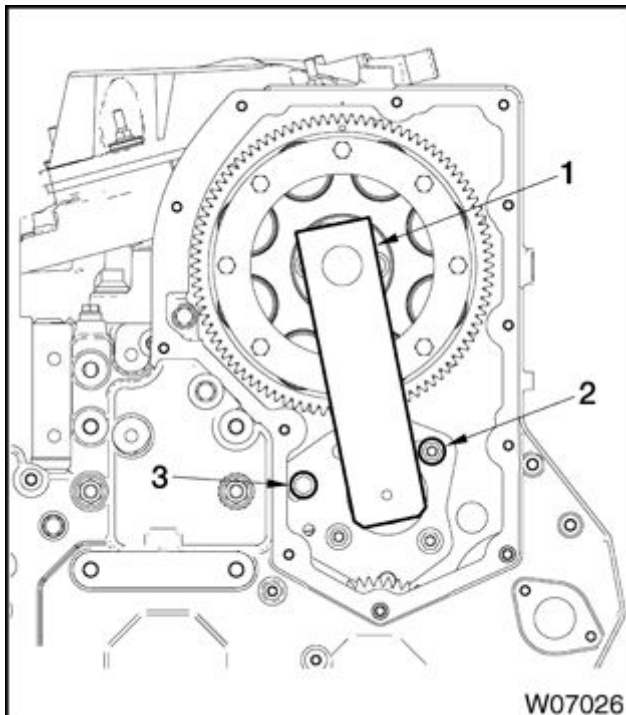


Figure 522 Idler gear backlash adjustment

1. Idler Assembly Adjuster
2. 3/8-16 x 1.5 hex flange locking bolt
3. 3/8-16 hex flange nut (5)

2. Install the Idler Assembly Adjuster (page 349) in the center of the camshaft gear assembly and the center of the 56-teeth gear support assembly.
3. Lightly tighten the 3/8-16 x 1.5 hex flange locking bolt and five 3/8-16 hex flange nuts on the 56-teeth gear support assembly.

NOTE: The Idler Assembly Adjuster will be free to move in and out without binding when the Idler Assembly Adjuster is correctly seated.

4. Using a rubber mallet (page 349), lightly tap the Idler Assembly Adjuster on each side to seat the tool. Continue until the 56-teeth gear support assembly is located such that the Idler Assembly Adjuster is free to move in and out without binding.

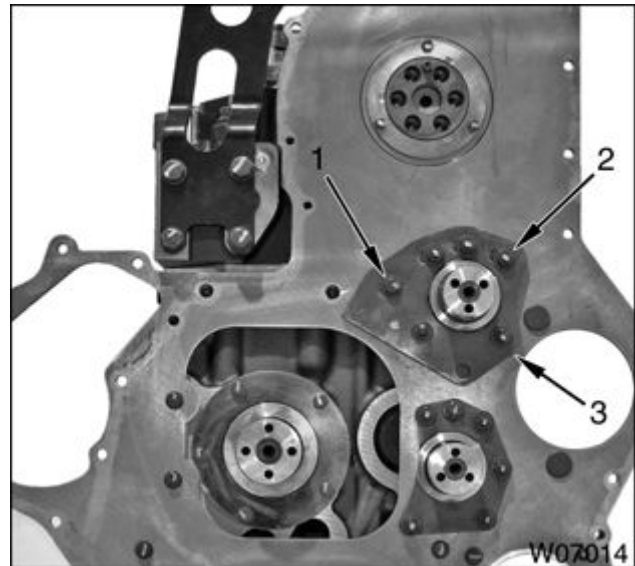


Figure 523 56-teeth gear support assembly

1. 3/8-16 x 1.5 hex flange locking bolt
 2. 3/8-16 hex flange nut (5)
 3. 56-teeth gear support assembly
5. Tighten the 3/8-16 x 1.5 hex flange locking bolt and five 3/8-16 hex flange nuts to special torque (page 348).

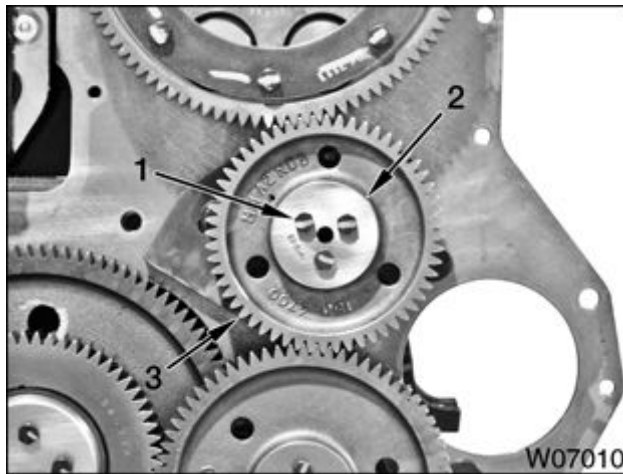


Figure 524 56-teeth gear assembly

1. 5/16-18 x 0.875 hex locking bolt (3)
 2. Bushing flange
 3. 56-teeth gear assembly
6. Position the 56-teeth gear assembly on the 56-teeth gear support shaft.
 7. Position the bushing flange and install three 5/16-18 x 0.875 hex locking bolts. Tighten the 5/16-18 x 0.875 hex locking bolts to standard torque (page 562).

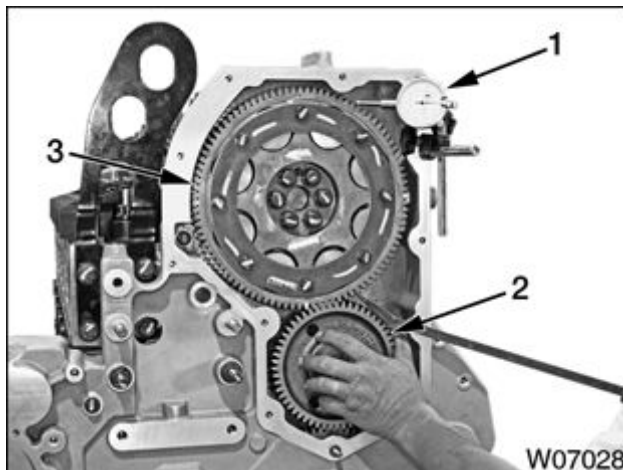


Figure 525 Idler gear backlash check

1. Dial indicator and bracket
2. 56-teeth gear assembly
3. Camshaft gear assembly

8. Using a dial indicator and bracket (page 349), measure the backlash between the 56-teeth gear assembly and the camshaft gear assembly while the 56-teeth gear assembly is held stationary.
9. If idler gear backlash is outside Specifications (page 348):
 - a. Remove the 56-teeth gear assembly.
 - b. Loosen the 3/8-16 x 1.5 hex flange locking bolt and five 3/8-16 hex flange nuts.
 - c. Repeat steps 1-8 until a correct backlash reading is achieved.
10. Remove the 56-teeth gear assembly.

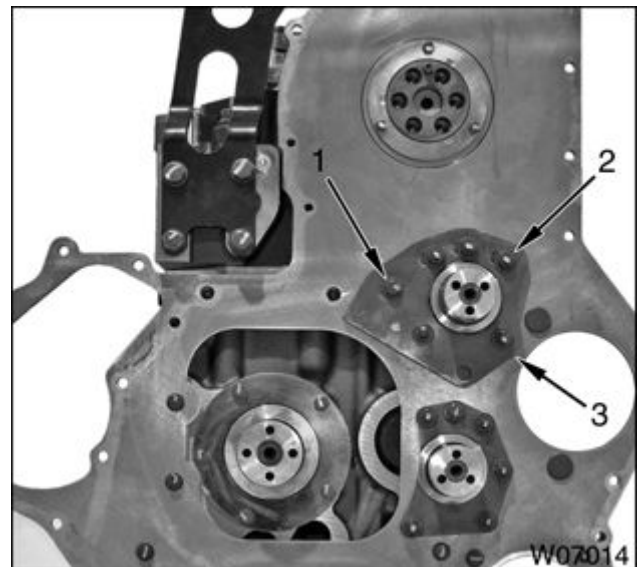


Figure 526 56-teeth gear support assembly

1. 3/8-16 x 1.5 hex flange locking bolt
 2. 3/8-16 hex flange nut (5)
 3. 56-teeth gear support assembly
11. Remove the 3/8-16 x 1.5 hex flange locking bolt.
 12. Apply Loctite® 242 (page 349) to threads on 3/8-16 x 1.5 hex flange locking bolt.
 13. Reinstall and tighten the 3/8-16 x 1.5 hex flange locking bolt to special torque (page 348).
 14. Remove one 3/8-16 hex flange nut.
 15. Apply Loctite® 242 (page 349) to threads on self clinching stud.

16. Reinstall and tighten the 3/8–16 hex flange nut to special torque (page 348).
17. Repeat steps 14–16 until all five nuts are tightened with Loctite® 242 (page 349) applied.

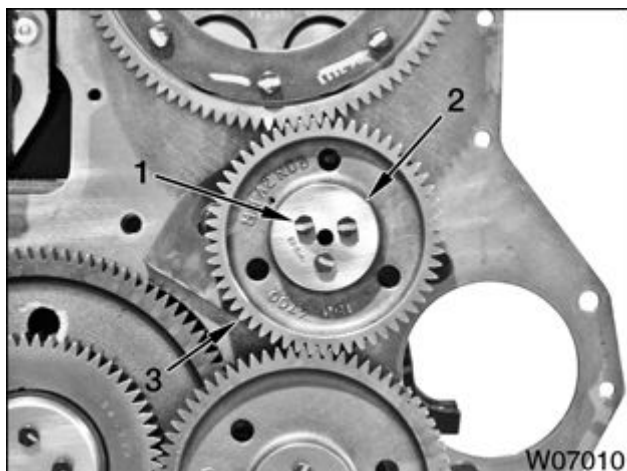


Figure 527 56-teeth gear assembly

1. 5/16–18 x 0.875 hex locking bolt (3)
 2. Bushing flange
 3. 56-teeth gear assembly
18. Lubricate the 56-teeth gear support shaft and the 56-teeth gear teeth with 90 weight gear oil (page 349).
 19. Position the 56-teeth gear assembly on the 56-teeth gear support shaft.
 20. Apply Loctite® 242 (page 349) to threads on three 5/16–18 x 0.875 hex locking bolts.
 21. Position the bushing flange and install three 5/16–18 x 0.875 hex locking bolts. Tighten the 5/16–18 x 0.875 hex locking bolts to standard torque (page 562).
 22. Remove the Timing Pin (page 349) from the flywheel housing.
 23. Remove the Engine Rotation Tool (page 349) from the flywheel housing.

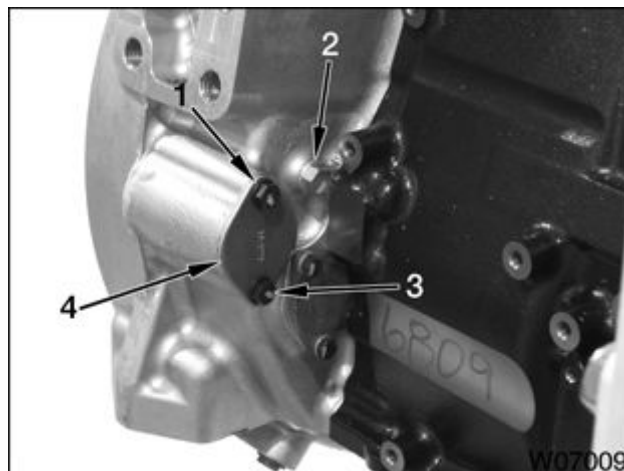


Figure 528 Flywheel locking plug and plate

1. 3/8–16 x 3 hex flange bolt
 2. Plug (flywheel locking port)
 3. 3/8–16 x 1 hex flange bolt
 4. Plate (flywheel access)
24. Install a new flywheel access plate seal.
 25. Install flywheel access plate, 3/8–16 x 3 hex flange bolt and 3/8–16 x 1 hex flange bolt. Tighten the 3/8–16 hex flange bolts to standard torque (page 562).
 26. Install the plug (flywheel locking port). Tighten plug to special torque (page 348).

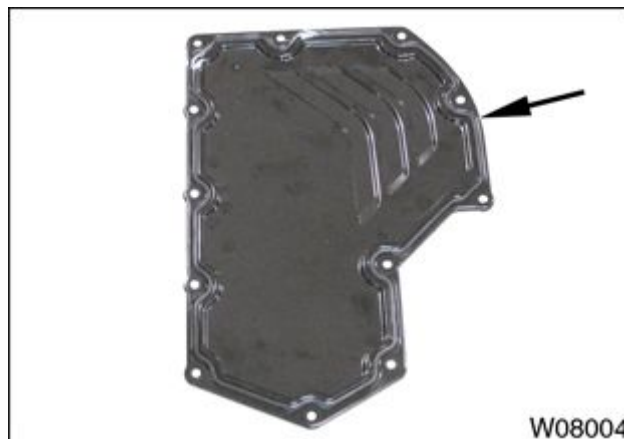


Figure 529 Camshaft gear cover gasket

27. If the gasket was discarded, install a new camshaft gear cover gasket.

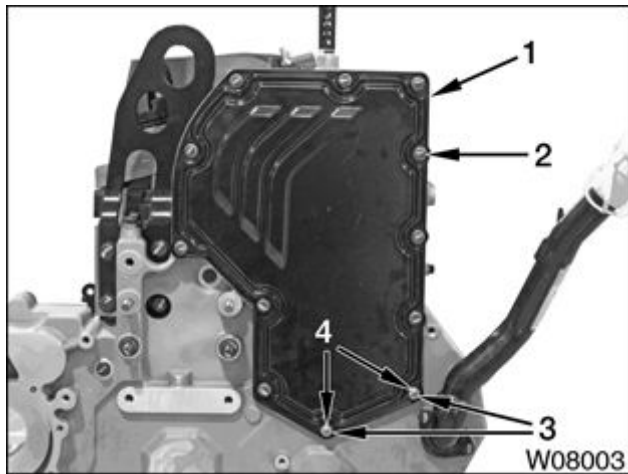


Figure 530 Camshaft gear cover

1. Camshaft gear cover
2. 5/16–18 x 1 hex flange bolt (10)
3. 5/16–18 hex lock nut (2)
4. 8.8 x 16 x 10 spacer (2)

28. Install the camshaft gear cover and install two 5/16–18 hex lock nuts, two 8.8 x 16 x 10 spacers, and ten 5/16–18 x 1 hex flange bolts. Tighten the 5/16–18 hex lock nuts and ten 5/16–18 x 1 hex flange bolts to standard torque (page 562).

Crankshaft Front Seal

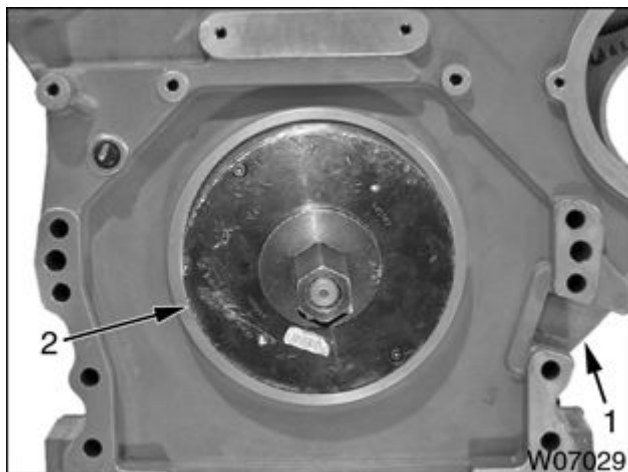


Figure 531 Crankshaft front seal

1. Front cover assembly
2. Front Crankshaft Seal Installer

CAUTION: To avoid damage to the crankshaft front seal, do not touch inner seal lip or allow oil or grease on any part of the seal during installation.

1. Using Front Crankshaft Seal Installer (page 349), install new crankshaft front seal into front cover assembly.
 - a. Install inner hub of tool to crankshaft flange. Use two bolts provided with tool.
 - b. Install crankshaft front seal to inner hub of tool such that arrow on seal, as viewed from front of engine is clockwise.
 - c. Install pressing hub and nut, then tighten nut to install crankshaft front seal. When tool bottoms out, seal is fully installed.

Front Engine Mount Support

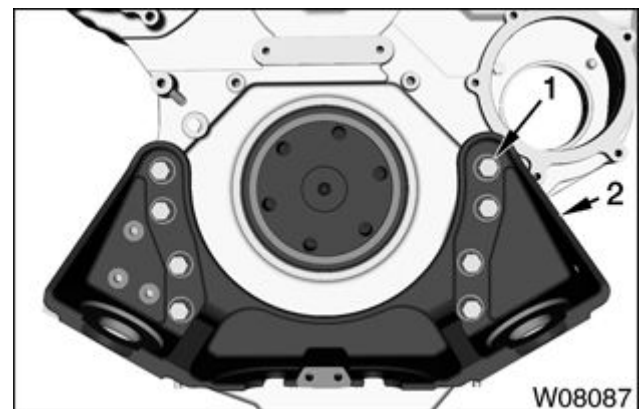


Figure 532 Front engine mount support

1. 1/2–13 x 5 in hex flange bolt (8)
2. Front engine mount support

1. Install front engine mount support and eight 1/2–13 x 5 in hex flange bolts. Tighten 1/2–13 x 5 in hex flange bolts to special torque (page 348).

Damper

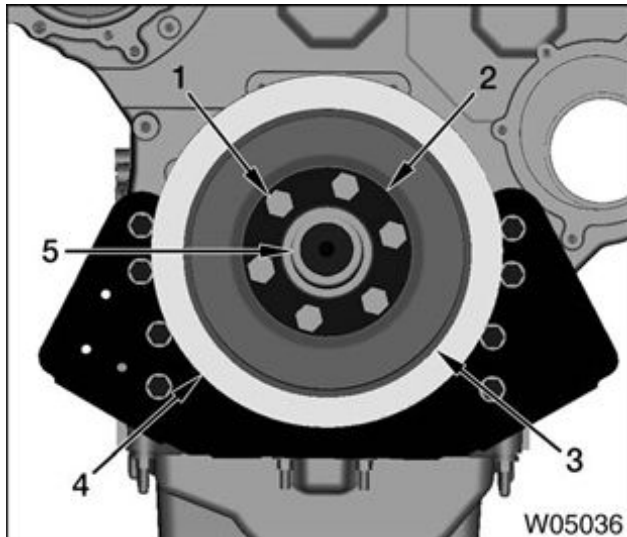


Figure 533 Damper

1. 5/8-18 x 4.5 hex flange bolt (6)
2. 131.57 x 163.6 x 8 mm spacer
3. Crankshaft pulley (12 groove)
4. Damper
5. Crankshaft adapter

⚠ WARNING: To prevent personal injury or death, support the vibration damper when removing bolts. The damper can easily slide off the end of the crankshaft.

1. Assemble the 131.57 x 163.6 x 8 mm spacer, 12 groove crankshaft pulley, damper and crankshaft adapter on one of the 5/8-18 x 4.5 hex bolts. Place assembly on front of crankshaft and start 5/8-18 x 4.5 hex bolt by hand.
2. Install remaining 5/8-18 x 4.5 hex bolts. Tighten 5/8-18 x 4.5 hex bolts to standard torque (page 562).

Water Pump

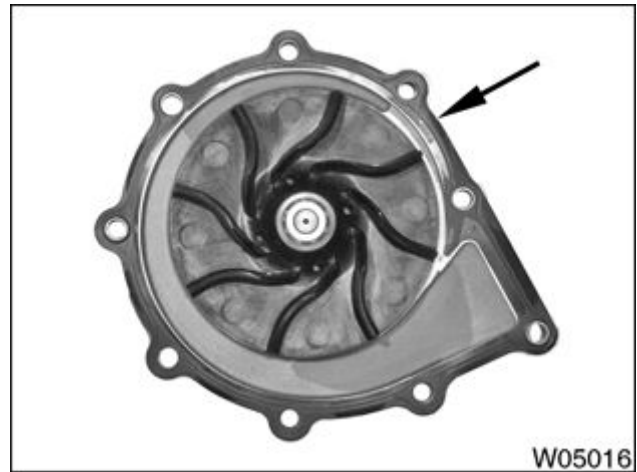


Figure 534 Water pump gasket

1. Install a new water pump gasket on the water pump.

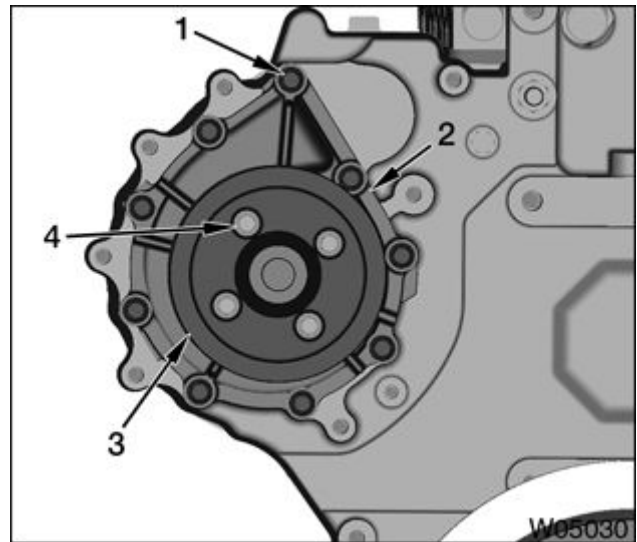


Figure 535 Water pump

1. M8 x 45-10.9 hex flange bolt (9)
 2. Water pump
 3. Water pump pulley
 4. M8 x 20 hex flange bolt (4)
2. Install water pump and nine M8 x 45-10.9 hex flange bolts. Tighten the M8 x 45-10.9 bolts to standard torque (page 561).

3. Install water pump pulley and four M8 x 20 hex flange bolts. Tighten the M8 x 20 hex flange bolts to standard torque (page 561).

A/C (Freon) Compressor Support

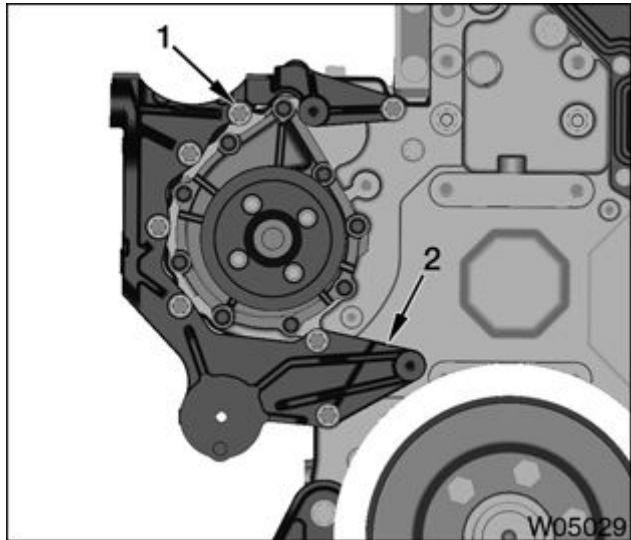


Figure 536 A/C (Freon) compressor support

1. 3/8–16 x 1 1/2 hex head bolt (7) and 3/8 hardened washer (7)
 2. A/C (Freon) compressor support
1. Install A/C (Freon) compressor support, seven 3/8 hardened washers and seven 3/8–16 x 1 1/2 hex

head bolts. Tighten 3/8–16 x 1 1/2 hex head bolts to standard torque (page 562).

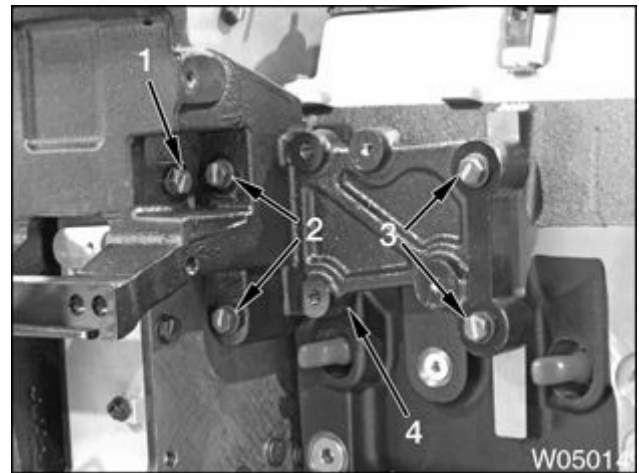


Figure 537 Alternator bracket

1. 3/8–16 x 1 3/4 hex head bolt and hardened washer
 2. 3/8–16 x 3 hex head bolt (2) and hardened washer (2)
 3. 3/8–16 x 2 hex head bolt (2) and hardened washer (2)
 4. Alternator bracket
2. Install alternator bracket, five 10.2 x 18.5 x 2.5 hardened washers, one 3/8–16 x 1 3/4 hex head bolt, two 3/8–16 x 3 hex head bolts, and two 3/8–16 x 2 hex head bolts. Tighten 3/8 hex head bolts to standard torque (page 562).

Belt Tensioners and Idler Pulleys

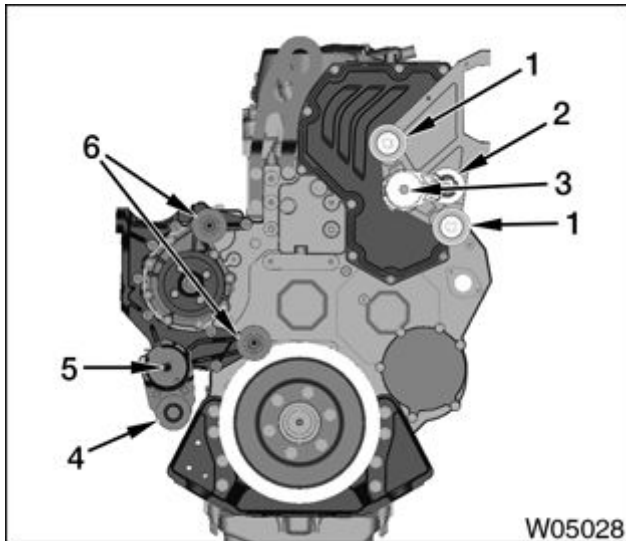


Figure 538 Belt tensioners and idler pulleys

1. Idler pulley, grooved (2)
2. Belt tensioner (upper)
3. M10 x 90 hex flange bolt
4. Tensioner (lower)
5. M10 x 70–10.9 countersunk screw
6. Idler pulley, flat (2)

1. Install two grooved idler pulleys. Tighten grooved idler pulleys to special torque (page 348).
2. Install two flat idler pulleys. Tighten flat idler pulleys to special torque (page 348).

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

3. Install upper belt tensioner and M10 x 90 hex flange bolt. Tighten M10 x 90 hex flange bolt to special torque (page 348).
4. Install lower tensioner and M10 x 70–10.9 countersunk screw. Tighten M10 x 70–10.9 countersunk screw to special torque (page 348).

Water Pump Inlet and Water Outlet Pipe

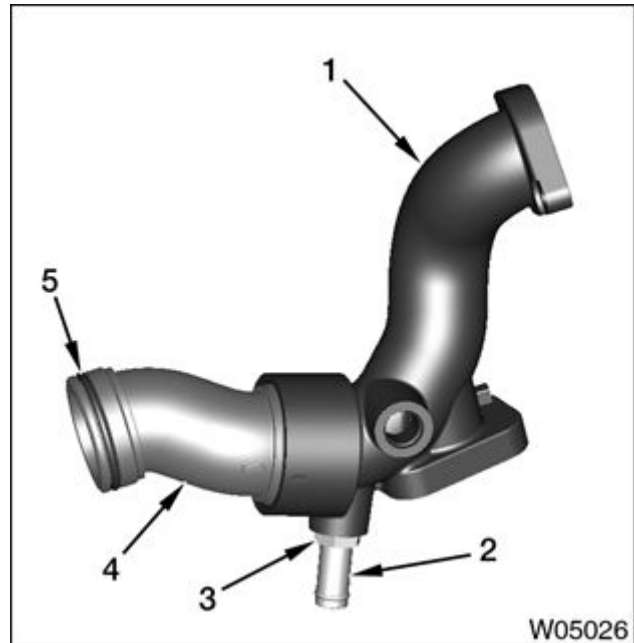


Figure 539 Water outlet pipe assembly

1. Water outlet pipe
2. Hose fitting assembly (3/4–14)
3. O-ring (located on hose fitting assembly (3/4–14))
4. Water outlet connector
5. O-ring (2) (both ends of item 4)

Lubricate water outlet connector O-rings with P-80® rubber lubricant or equivalent (page 349).

1. Install two new O-rings on the water outlet connector.
2. Install the water outlet connector in the water outlet pipe.

Lubricate hose fitting assembly (3/4–14) O-ring with P-80® rubber lubricant or equivalent (page 349).

3. Install a new O-ring on the hose fitting assembly (3/4–14).
4. Install the hose fitting assembly (3/4–14). Tighten hose fitting assembly to special torque (page 348).

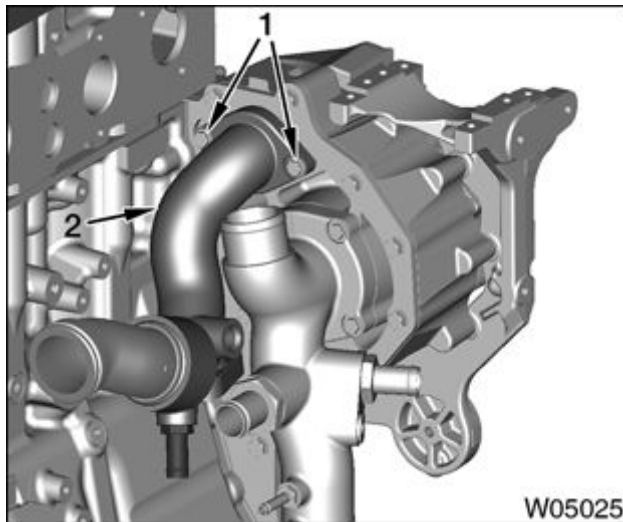


Figure 540 Water outlet pipe

1. 5/16-18 x 1 1/2 hex flange bolt (2)
2. Water outlet pipe

Lubricate 7/8-14 plug assembly with P-80® rubber lubricant or equivalent (page 349).

5. Install a new O-ring on the water pump outlet pipe.
6. Install water outlet pipe and two 5/16-18 x 1 1/2 hex flange bolts. Tighten the 5/16-18 x 1 1/2 hex flange bolts to standard torque (page 562).

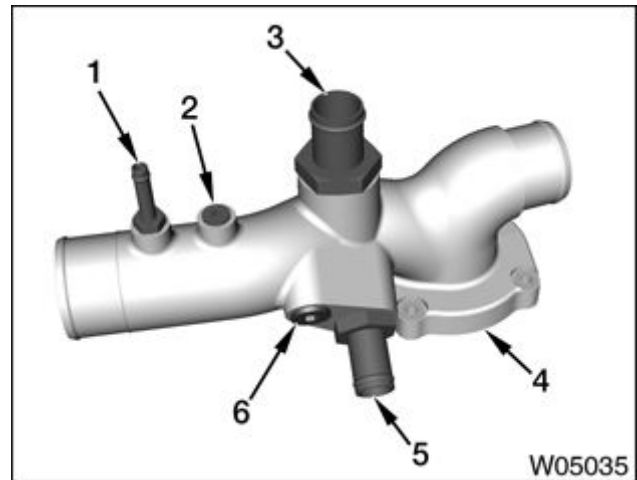


Figure 541 Water pump inlet

1. Hose fitting assembly (9/16-16)
2. O-ring boss plug assembly (9/16-16)
3. Coolant connector (1 1/2-11)
4. Water pump inlet
5. Hose fitting assembly (1 1/4-11)
6. 7/8-14 plug assembly

Lubricate hose fitting assembly (9/16-16) O-ring with P-80® rubber lubricant or equivalent (page 349).

7. Install new O-ring on the hose fitting assembly (9/16-16).
8. Install the hose fitting assembly (9/16-16). Tighten the hose fitting assembly to special torque (page 348).

Lubricate O-ring boss plug assembly (9/16-16) O-rings with P-80® rubber lubricant or equivalent (page 349).

9. Install new O-ring on the O-ring boss plug assembly (9/16-16).
10. Install the O-ring boss plug assembly (9/16-16). Tighten the O-ring boss plug assembly to special torque (page 348).

Lubricate coolant connector (1 1/2-11) O-ring with P-80® rubber lubricant or equivalent (page 349).

11. Install a new O-ring on the coolant connector (1 1/2-11).
12. Install the coolant connector (1 1/2-11). Tighten the coolant connector to special torque (page 348).

Lubricate hose fitting assembly (1 1/4–11) O-ring with P-80® rubber lubricant or equivalent (page 349).

13. Install a new O-ring on the hose fitting assembly (1 1/4–11).

14. Install the hose fitting assembly (1 1/4–11). Tighten the hose fitting assembly to special torque (page 348).

Lubricate 7/8–14 plug assembly O-ring with P-80® rubber lubricant or equivalent (page 349).

15. Install a new O-ring on the 7/8–14 plug assembly.

16. Install the 7/8–14 plug assembly. Tighten the 7/8–14 plug assembly to special torque (page 348).

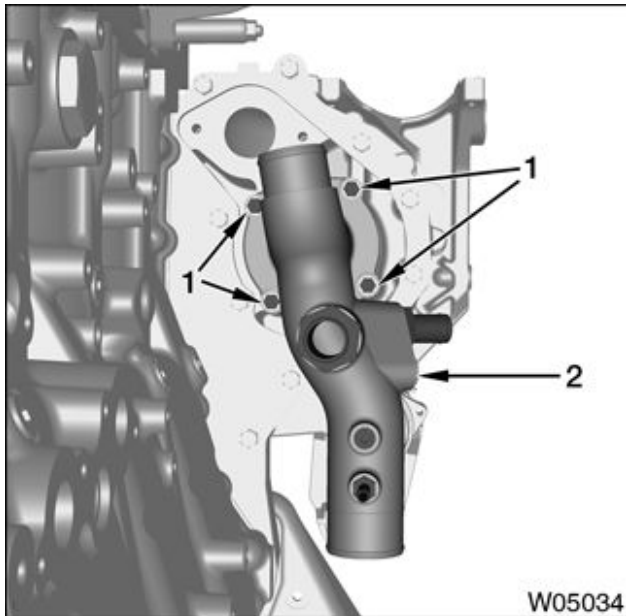


Figure 542 Water pump inlet

1. 5/16–18 x 1 1/2 hex flange bolt (4)
2. Water pump inlet

Lubricate water pump inlet O-ring with P-80® rubber lubricant or equivalent (page 349).

17. Install a new O-ring on the water pump inlet.

18. Install water pump inlet and four 5/16–18 x 1 1/2 hex flange bolts. Tighten the 5/16–18 x 1 1/2 hex flange bolts to standard torque (page 562).

Thermostat Housing and Thermostats



Figure 543 Thermostat housing

1. 3/8–16 x 4.25 hex flange bolt (3)
2. Thermostat housing
3. Water pump inlet hose
4. Hose clamp (2)

1. Install the regulator gasket, thermostat housing, and three 3/8–16 x 4.25 hex flange bolts. Tighten the 3/8–16 x 4.25 hex flange bolts to standard torque (page 562).

2. Connect the water pump inlet hose.

3. Position and tighten two hose clamps.

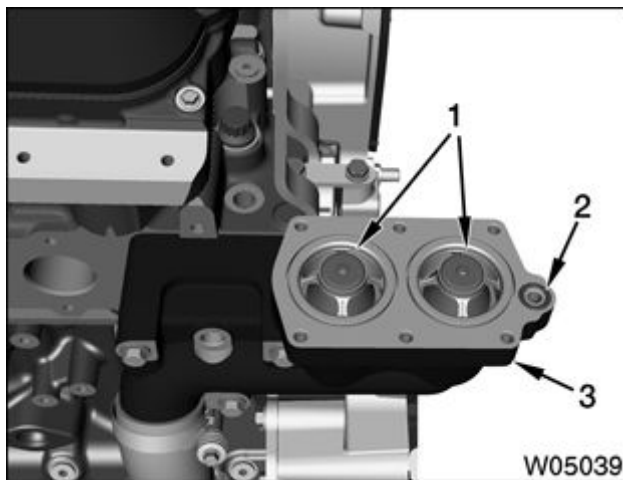


Figure 544 Thermostat

1. Thermostat
2. O-ring
3. Thermostat housing

4. Install a new thermostats in thermostat housing.

Lubricate thermostat housing O-ring with P-80® rubber lubricant or equivalent (page 349).

5. Install a new O-ring in the thermostat housing.

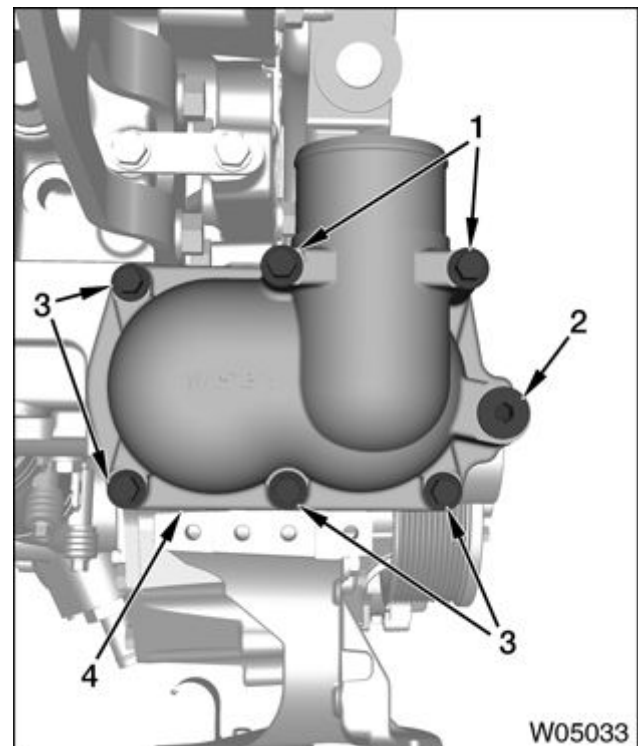


Figure 545 Thermostat housing cover

1. M8 x 70 hex flange bolt (2)
2. O-ring boss plug (3/4–16)
3. M8 x 25 hex flange bolt (4)
4. Thermostat housing cover

Lubricate O–ring boss plug (3/4–16) O–ring with P-80® rubber lubricant or equivalent (page 349).

6. Install a new O-ring and the O-ring boss plug (3/4–16). Tighten the 3/4–16 O-ring boss plug to special torque (page 348).
7. Install thermostat housing cover, four M8 x 25 hex flange bolts, and two M8 x 70 hex flange bolts. Tighten the M8 hex flange bolts to standard torque (page 561).

Fan Drive (High and Low Mount Fan)

NOTE: For high mount fan, do steps 1 and 2, then skip steps 3 and 4.

NOTE: For low mount fan, skip steps 1 and 2, then do steps 3 and 4.

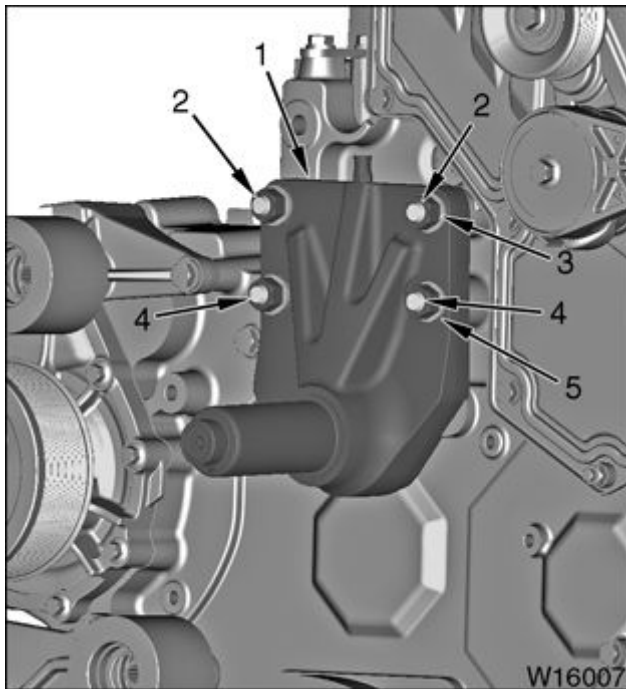


Figure 546 High mount Horton® fan bracket (typical)

1. Horton® fan bracket
2. 1/2-13 x 2.72 taperlock stud (2)
3. 1/2-13 hex nut (4)
4. 1/2-13 x 5 5/8 taperlock stud (2)
5. 13.5 x 25.5 hardened washer (4)

1. Install two 1/2-13 x 2.72 taperlock studs. Tighten the taperlock studs until they bottom out in the front cover.
2. Position the Horton® fan bracket and install four 13.5 x 25.5 hardened washers and four 1/2-13 hex nuts. Tighten 1/2-13 hex nuts to special torque (page 348).

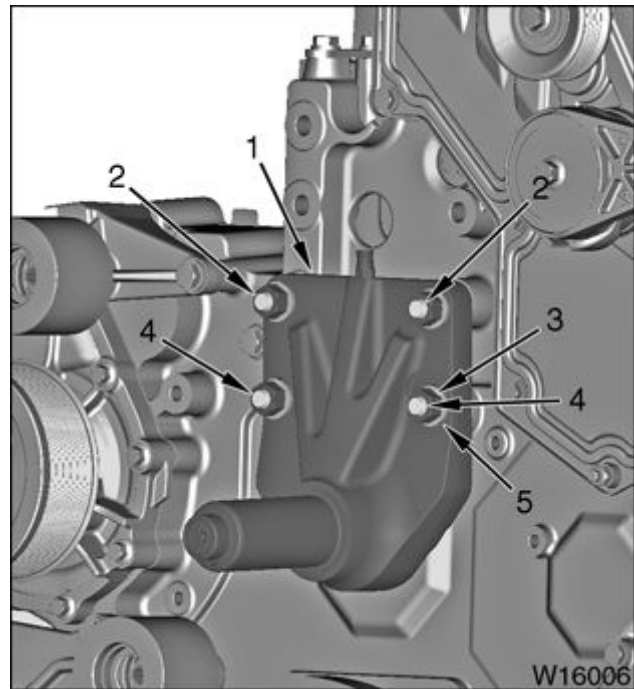


Figure 547 Low mount Horton® fan bracket (typical)

1. Horton® fan bracket
2. 1/2-13 x 5 5/8 taperlock stud (2)
3. 1/2-13 hex nut (4)
4. 1/2-13 x 2.72 taperlock stud (2)
5. 13.5 x 25.5 hardened washer (4)

3. Install two 1/2-13 x 2.72 taperlock studs. Tighten the taperlock studs until they bottom out in the front cover.
4. Install the Horton® fan bracket.
5. Position the Horton® fan bracket and install four 13.5 x 25.5 hardened washers, and four 1/2-13 hex nuts. Tighten 1/2-13 hex nuts to special torque (page 348).

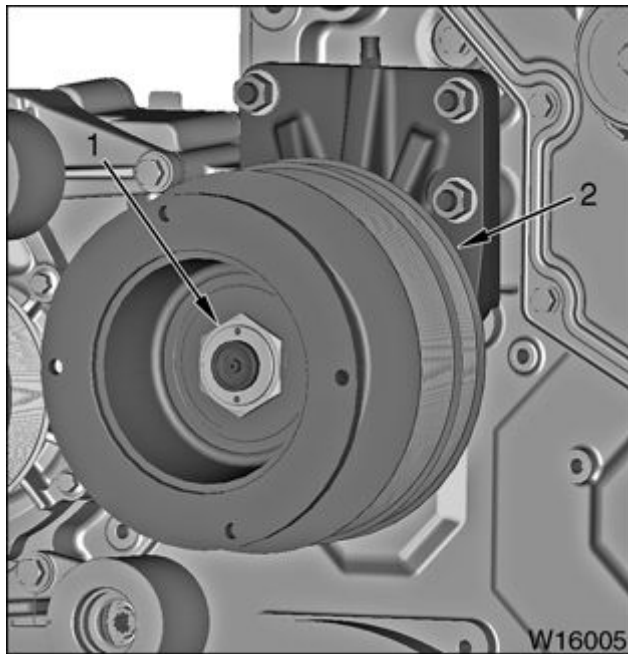


Figure 548 Fan pulley

1. Nut assembly
2. Pulley

6. Install the spacer (Figure 438) (item 5) and the pulley.
7. Install the nut assembly. Tighten nut assembly to special torque (page 348).

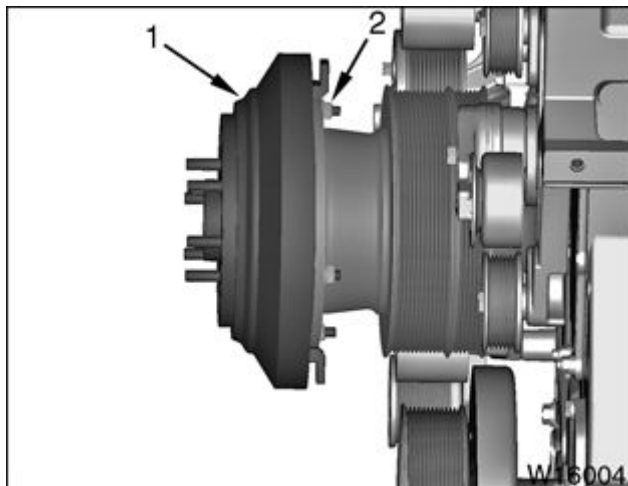


Figure 549 Fan clutch

1. Fan clutch
2. M8 hex flange nut (4)

8. Install the fan clutch and four M8 hex flange nuts. Tighten M8 hex flange nuts to special torque (page 348).

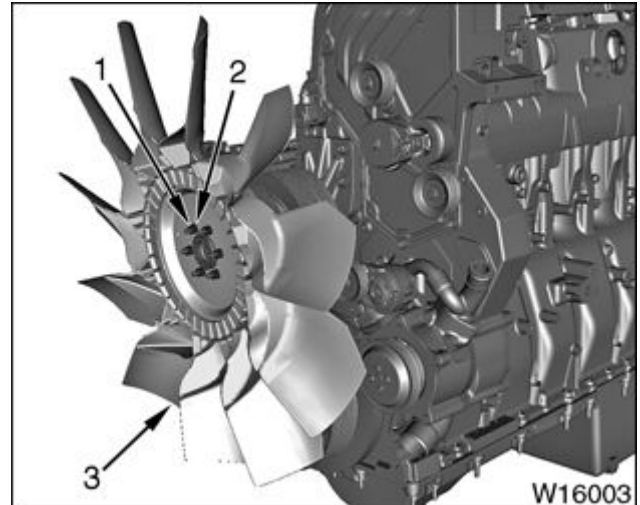


Figure 550 Fan

1. 3/8-24 hex nut (6)
2. 3/8 lock washer (6)
3. Fan

9. Install the fan blade.
10. Install six 3/8 lock washers and six 3/8-24 hex nuts. Tighten six 3/8-24 hex nuts to special torque (page 348).

Specifications

Idler gear backlash	0.102 – 0.33 mm (0.0040 – 0.0130 inch)

Special Torque

1/2–13 hex nuts (fan bracket)	79 N·m (58 lbf·ft)
3/8–24 hex nuts (fan)	35 N·m (26 lbf·ft)
3/8–16 x 1.75 hex bolts	66 N·m (49 lbf·ft)
7/8–14 plug assembly	50 N·m (37 lbf·ft)
56-teeth gear support assembly bolt	56 N·m (41 lbf·ft)
56-teeth gear support assembly nuts	56 N·m (41 lbf·ft)
71-teeth gear support assembly bolt	56 N·m (41 lbf·ft)
71-teeth gear support assembly nuts	56 N·m (41 lbf·ft)
105 & 63 teeth gears support bolts	See tightening steps in procedure (page 325)
Camshaft cover studs	18 N·m (25 lbf·ft)
Camshaft gear assembly 5/8-11 x 3 (12 point) bolts	240 N·m (175 lbf·ft)
Coolant connector (1 1/2–11)	145 N·m (107 lbf·ft)
Front engine mount support bolts	100 N·m (74 lbf·ft)
Front cover plate 3/8-16 x 1 thread locking hex flange bolts	See tightening steps in procedure (page 325)
Idler pulleys (grooved)	50 N·m (37 lbf·ft)
Idler pulleys (flat)	50 N·m (37 lbf·ft)
Hose fitting assembly (3/4–14)	50 N·m (37 lbf·ft)
Hose fittings (9/16–16)	18 N·m (13 lbf·ft)
Hose fitting (1 1/4–11)	104 N·m (77 lbf·ft)
M8 hex flange nuts (fan clutch)	30 N·m (22 lbf·ft)
M10 x 70 counter sunk screw (lower tensioner)	41 N·m (30 lbf·ft)
M10 x 90 hex flange bolt (belt tensioner)	50 N·m (37 lbf·ft)
Nut assembly (fan pulley)	176 N·m (130 lbf·ft)
O-ring boss plug (3/4–16)	50 N·m (37 lbf·ft)
O-ring boss plug assembly (9/16–16)	18 N·m (156 lbf·in)
Plug (flywheel locking port)	23 N·m (17 lbf·ft)

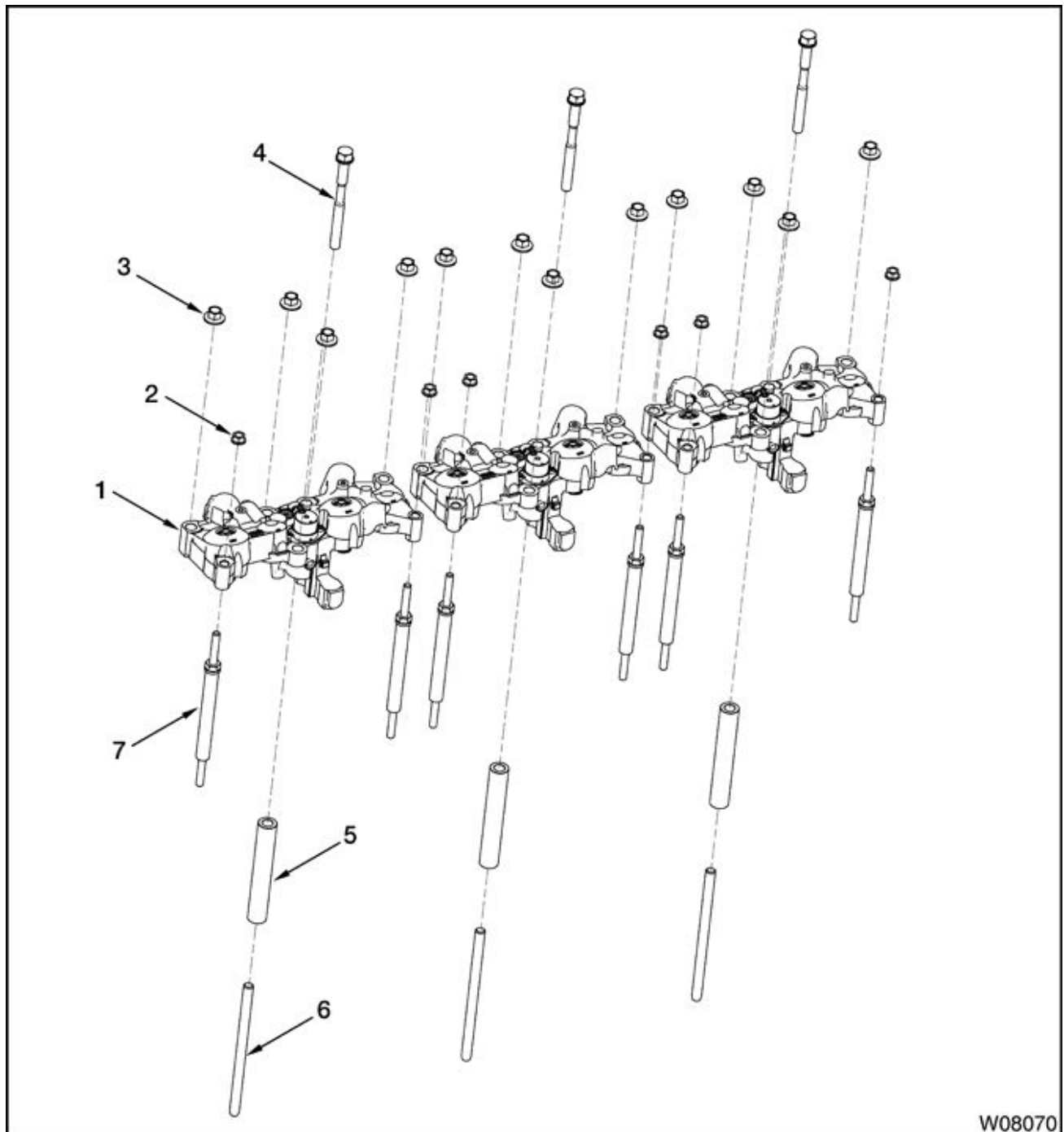
Special Service Tools

Description	Tool Number
90 weight gear oil	Obtain locally
100 °C (212 °F) thermo-melt crayon	Obtain locally
Abrasive cutting disk	Obtain locally
Dial indicator and bracket	Obtain locally
Engine Rotation Tool	ZTSE6112
Front and Rear Crankshaft Seal Installer	ZTSE6119
Idler Assembly Adjuster	ZTSE6116
Infrared thermometer (thermo gun)	Obtain locally
Heat insulated gloves	Obtain locally
Hot plate	Obtain locally
Loctite® 242	Obtain locally
P-80® rubber lubricant or equivalent	Obtain locally
Propane torch	Obtain locally
Rubber mallet	Obtain locally
Slide hammer kit	ZTSE1879
Timing Pin	ZTSE6108

Table of Contents

Exploded Views.....	353
Periodic Service.....	356
Engine Brake Lash Adjustment.....	356
Removal.....	360
Valve Brake Actuator Assembly.....	360
Lost Motion Pedestal.....	361
Cleaning and Inspection.....	363
Valve Brake Actuator Assembly.....	363
Installation.....	364
Lost Motion Pedestal.....	364
Valve Brake Actuator Assembly.....	364
Specifications.....	368
Special Torque.....	368
Special Service Tools.....	368

Exploded Views



W08070

Figure 551 Engine brake

1. Valve brake actuator assembly (3)	3. 1/2-13 hex flange nut (12)	6. 1/2-13 x 2.2 taperlock stud (3)
2. 3/8-16 hex nut (6)	4. 1/2-13 x 5.65 hex bolt (3)	7. Spacer assembly (6)
	5. Support (3)	

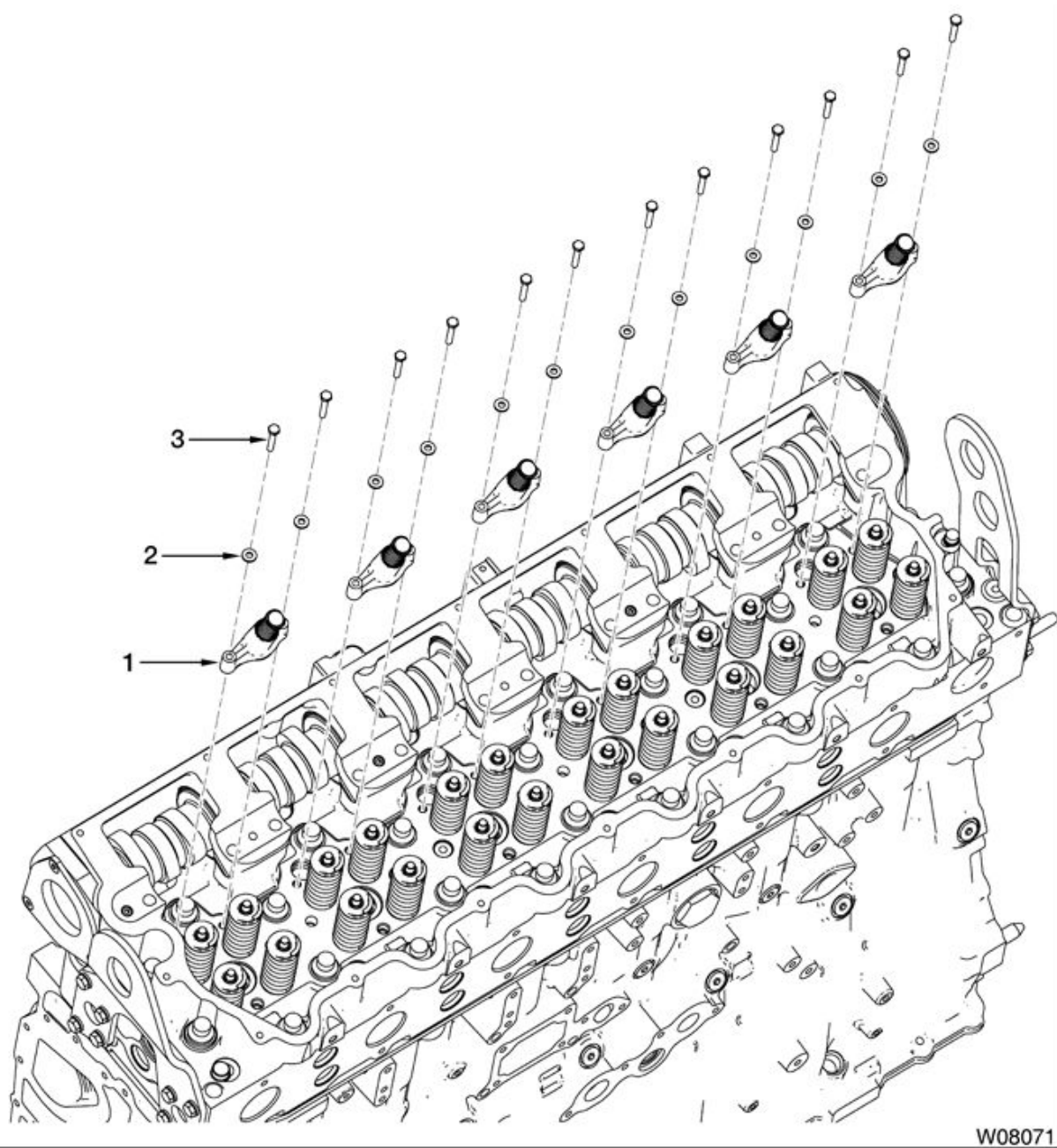


Figure 552 Lost motion pedestal

1. Lost motion pedestal assembly (6)	2. 1/4 hardened washer (12)
	3. 1/4-20 x 1 1/2 bolt (12)

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, make sure engine is stationary and has cooled before removing components or performing adjustments.

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

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

NOTE: If valve cover is removed for any reason, verify slave piston lash adjuster jam nuts are tight. If any are loose, verify and reset brake lash adjustment.

NOTE: The engine brake lash adjustment is not the same as a valve lash adjustment. Read through carefully and understand the difference. For valve lash adjustment, see Valve Lash Adjustment (page 379).

Engine Brake Lash Adjustment

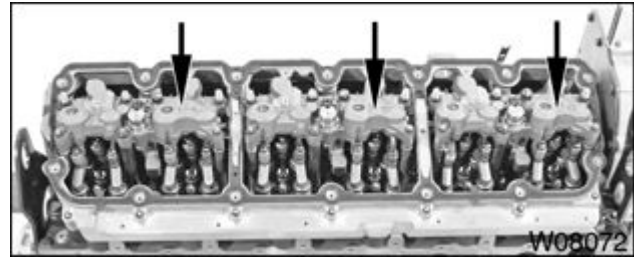


Figure 553 Valve brake actuator assemblies

The engine compression brake consists of three identical valve brake actuator assemblies; each valve brake actuator assembly is positioned over two cylinders.

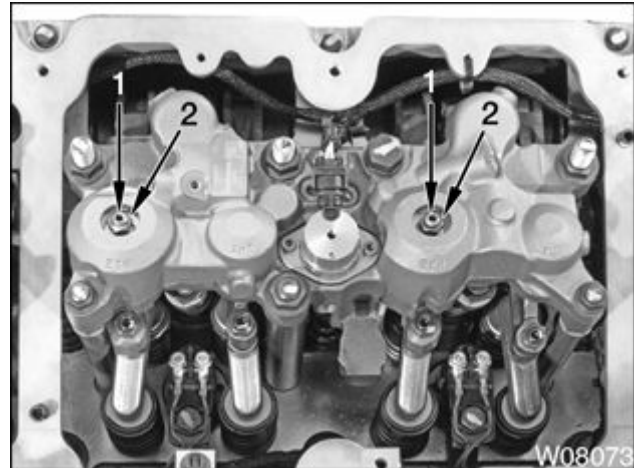


Figure 554 Slave piston lash adjusters and jam nuts (typical)

1. Slave piston lash adjuster (2)
2. Slave piston lash adjuster jam nut (2)

Each valve brake actuator assembly is adjusted using a pair of slave piston lash adjusters. Each slave piston lash adjuster is held in position by a slave piston lash adjuster jam nut.

CAUTION: To prevent engine damage, make sure that engine valve lash is within specification prior to adjusting lash for the engine brake. See Valve Lash Adjustment (page 379).

NOTE: Engine brake lash adjustment must be performed while engine is stationary and uniformly cool between 4° C and 38° C (40° F and 100° F).

NOTE: There are two holes in the front surface of the flywheel used to pin (lock in place) the engine. Each of these flywheel holes are in alignment with a port at either the left or right front of the flywheel housing assembly. The two flywheel lock holes are at different distances from the center of the flywheel, so only one of the flywheel holes is engaged at each port location. Installing the timing pin in either port will lock the flywheel at TDC compression of cylinder 1 or 6. Engine brake lash adjustment is performed on cylinders 1, 3, and 5 when cylinder 1 is at TDC compression and on cylinders 2, 4, and 6 when cylinder 6 is at TDC compression. Either port location may be used for the engine brake lash adjustment. It is suggested to use the right side locking port as that location is next to the tool port used to rotate the engine.

Table 1

Crank Angle for TDC Compression	Cam Angle	Brake Lash Adjustment at:
#1 TDC = 0 degrees	#1 TDC = 0 degrees	Cylinders: 1, 3, and 5
#6 TDC = 360 degrees	#6 TDC = 180 degrees	Cylinders: 2, 4, and 6

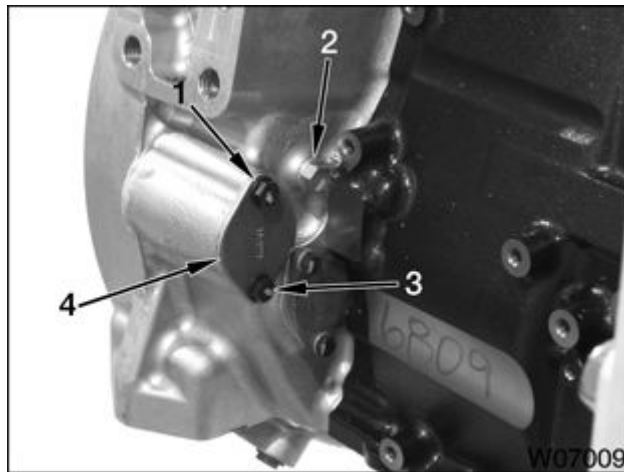


Figure 555 Flywheel locking port and rotation tool guide (right side)

1. 3/8–16 x 3 hex flange bolt
2. Plug (right flywheel locking port)
3. 3/8–16 x 1 hex flange bolt
4. Plate (rotation tool guide)

1. Using Engine Rotation Tool (page 368) and Timing Pin (page 368), lock flywheel in position to perform engine brake lash adjustment.
 - a. Remove 3/8–16 x 3 hex flange bolt, 3/8–16 x 1 hex flange bolt, and plate (rotation tool guide). Discard plate seal.
 - b. Install engine rotation tool through opening that was covered by the plate.
 - c. Remove plug from flywheel locking port.
 - d. Install timing pin into flywheel locking port.
 - e. Using 1/2 inch drive ratchet, rotate engine rotation tool in the direction of normal engine rotation (counterclockwise as viewed from the flywheel end of the engine looking forward). The timing pin is under constant spring tension and will engage the appropriate hole in the flywheel when the crankshaft is at correct top dead center (TDC) position.
 2. Determine which cylinder (1 or 6) is currently at TDC compression. At cylinder 1 position, attempt to move the exhaust and intake rocker arm assemblies by hand. If both rocker arm assemblies (exhaust and intake) are in free float and can be moved by hand, then cylinder 1 is at TDC compression. If the rocker arm assemblies cannot be moved and the valves are slightly open, then cylinder 1 is on the exhaust stroke and companion cylinder 6 is at TDC compression.
 3. Engine brake lash adjustment is performed on cylinders 1, 3, and 5 when cylinder 1 is at TDC compression and on cylinders 2, 4, and 6 when cylinder 6 is at TDC compression (Table 1).
- CAUTION:** To prevent engine damage, back out slave piston lash adjusters. If slave piston lash adjusters are not backed out, binding between exhaust rockers and slave piston may occur during lash adjustment.
4. On appropriate cylinders, loosen slave piston lash adjuster jam nut and back out slave piston lash adjuster using 5/32 hex key wrench (page 368) so that slave piston is not in contact with exhaust rocker arm.

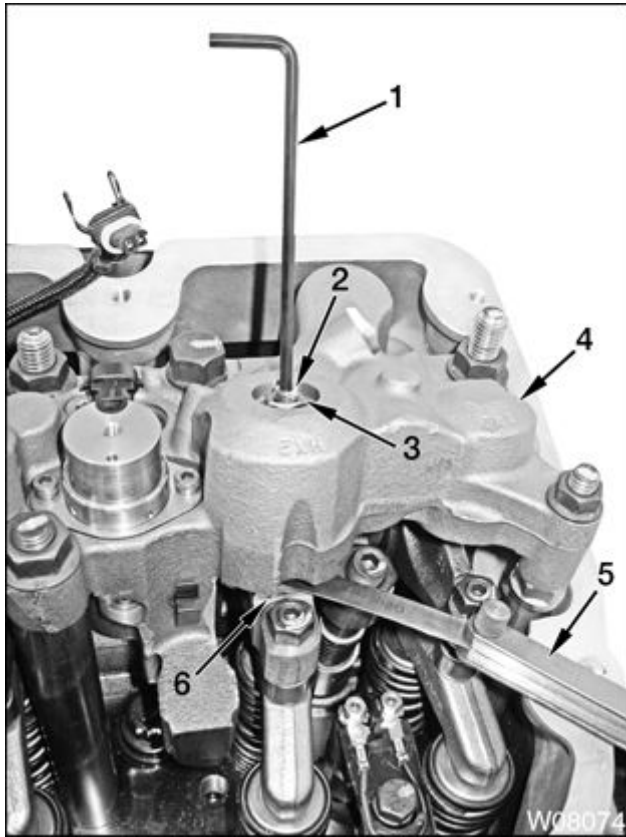


Figure 556 Valve brake actuator assembly lash adjustment (typical)

1. 5/32 hex key wrench
 2. Slave piston lash adjuster
 3. Slave piston lash adjuster jam nut
 4. Valve brake actuator assembly
 5. Lash gauge
 6. Exhaust rocker arm
5. Place a Lash gauge 0.686 mm (0.027 in.) (page 368) between valve brake actuator assembly slave piston and exhaust rocker arm.
 6. Using 5/32 hex key wrench, turn slave piston lash adjuster clockwise while sliding feeler gauge slightly back and forth.
 7. Continue turning slave piston lash adjuster until a slight drag is felt on feeler gauge.
 8. Remove feeler gauge.
 9. While maintaining position of slave piston lash adjuster with 5/32 hex key wrench, tighten slave piston lash adjuster jam nut to special torque (page 368).
 10. Verify valve brake actuator assembly lash adjustment is still at specification (page 368). If too tight or loose, repeat procedure.
 11. After adjustment is made at all three cylinders for the current flywheel lock position, remove timing pin from flywheel locking port.
 12. To perform engine brake lash adjustments on remaining three cylinder positions:
 - a. Using 1/2 inch drive ratchet, rotate engine rotation tool a few times in the direction of normal engine rotation (counterclockwise as viewed from the flywheel end of the engine looking forward). The flywheel locking hole will no longer be aligned with the locking port
 - b. Install timing pin into flywheel locking port.
 - c. Using 1/2 inch drive ratchet, rotate engine rotation tool in the direction of normal engine rotation (counterclockwise as viewed from the flywheel end of the engine looking forward). Rotate until crankshaft travels a full revolution (360 degrees) placing the companion cylinder at TDC compression. The timing pin is under constant spring tension and will engage the flywheel hole once the crankshaft rotation to the next cylinder 1 and 6 TDC position is reached (Table 1).
 - d. Confirm the companion cylinder is now at TDC compression by attempting to move the rocker arm assemblies at cylinder 1. The cylinder 1 rocker arm assemblies should now react opposite of when the timing pin was first installed. If the first time both rocker arm assemblies were in free float and able to be moved by hand indicating cylinder 1 was at TDC compression, now the rocker arm assemblies should not move indicating that cylinder 1 is on the exhaust stroke and companion cylinder 6 is at TDC compression; and vice versa.
 13. Perform steps 3 through 10 for cylinders at the current flywheel lock position.
 14. After adjustment is made at all three cylinders, remove timing pin from flywheel locking port.

15. Install plug into flywheel locking port. Tighten plug to special torque (page 368).
16. Remove engine rotation tool.
17. Install a new seal on plate that covers opening for rotation tool guide.

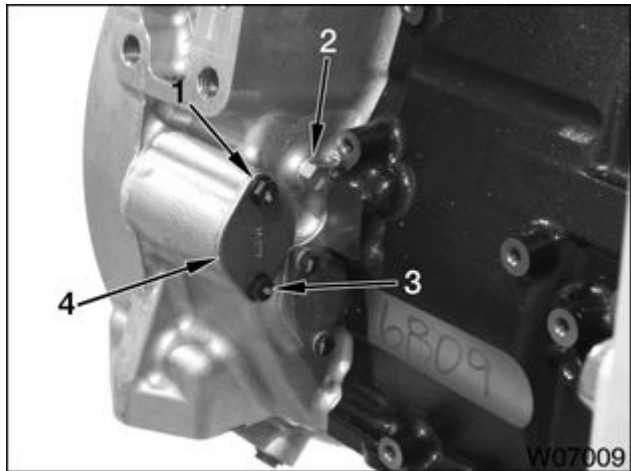


Figure 557 Flywheel locking port and rotation tool guide

1. 3/8–16 x 3 hex flange bolt
 2. Plug (flywheel locking port)
 3. 3/8–16 x 1 hex flange bolt
 4. Plate (rotation tool guide)
-
18. Install plate with new seal, 3/8–16 x 3 hex flange bolt, and 3/8–16 x 1 hex flange bolt. Tighten 3/6–16 hex flange bolts to standard torque (page 562).

Removal

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

- Engine Electrical
- Aftertreatment System
- Turbocharger
- Fuel System
- EGR System
- Front Cover, High Mount Fan Drive, Cooling System, Related Components
- Flywheel and Flywheel Housing

Valve Brake Actuator Assembly

NOTE: The engine compression brake consists of three identical valve brake actuator assemblies; each valve brake actuator assembly is positioned over two cylinders. This procedure details removal of one of the three valve brake actuator assemblies. Removal of others is similar.

1. If not previously performed, remove valve cover. See Valve Cover (page 384).

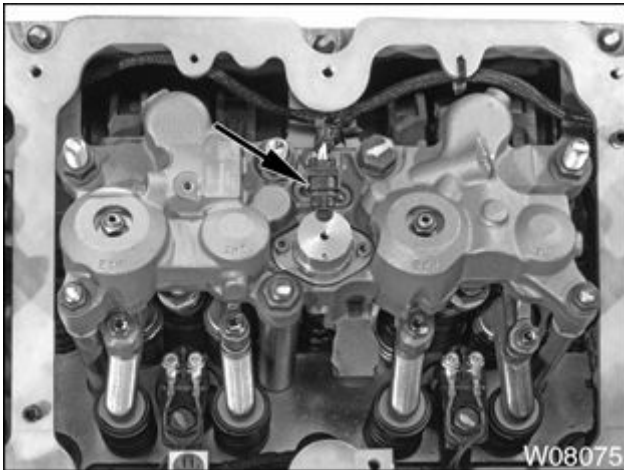


Figure 558 Valve brake actuator assembly electrical connector

2. Disconnect valve brake actuator assembly electrical connector.

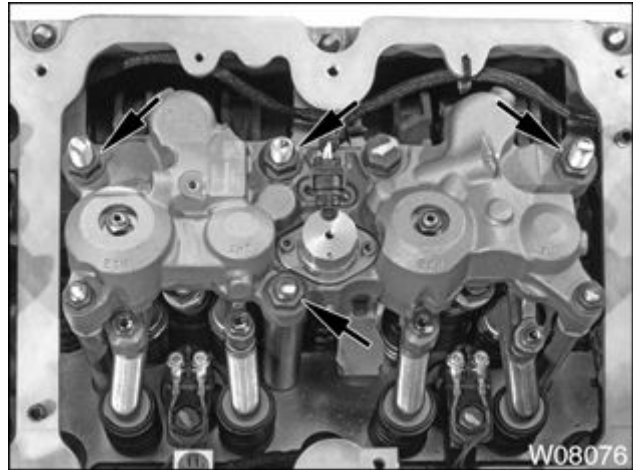


Figure 559 Valve brake actuator assembly 1/2-13 hex flange nuts

3. Remove four 1/2-13 hex flange nuts.

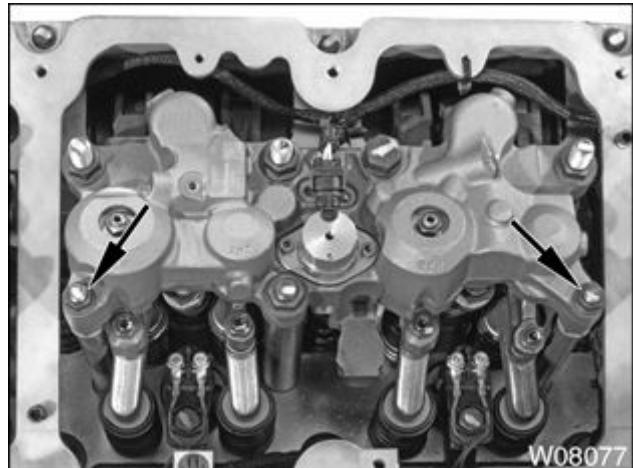


Figure 560 Valve brake actuator assembly 3/8-16 hex nuts

4. Remove two 3/8-16 hex nuts.



Figure 561 Valve brake actuator assembly
1/2-13 x 5.65 hex bolt

5. Remove 1/2-13 x 5.65 hex bolt.
6. Remove valve brake actuator assembly by sliding off studs. Place valve brake actuator assembly facing up on a clean dry work area.

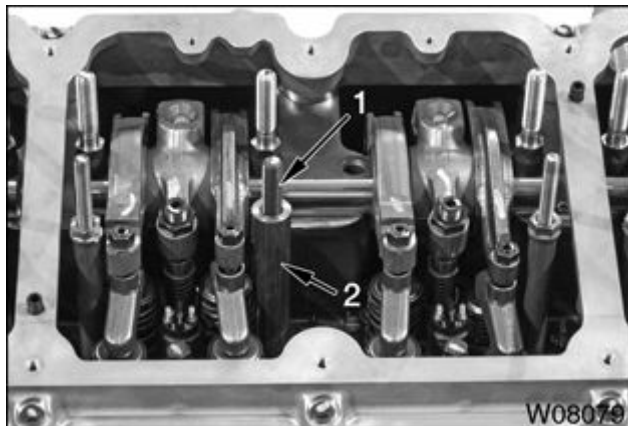


Figure 562 Support and 1/2-13 x 2.2 taperlock stud

1. 1/2-13 x 2.2 taperlock stud
2. Support

7. Remove support and 1/2-13 x 2.2 taperlock stud.

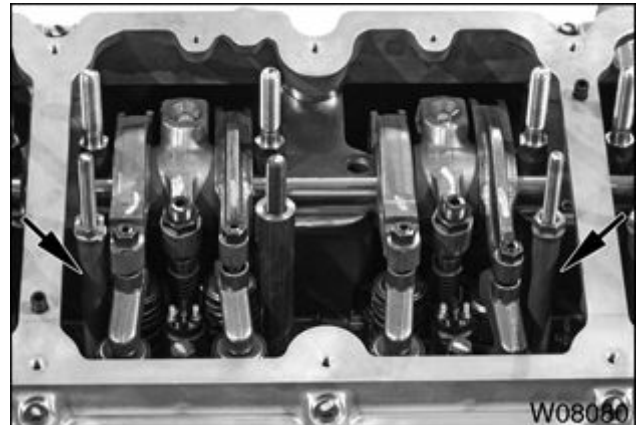


Figure 563 Spacer assemblies

8. Remove two spacer assemblies.

Lost Motion Pedestal

The engine contains six lost motion pedestal assemblies, one at top of each cylinder among valve springs. This procedure details removal of one of the six lost motion pedestal assemblies. Removal of others is similar.

1. If not previously performed, remove rocker arms to access the lost motion pedestals. See Rocker Arms (page 391).

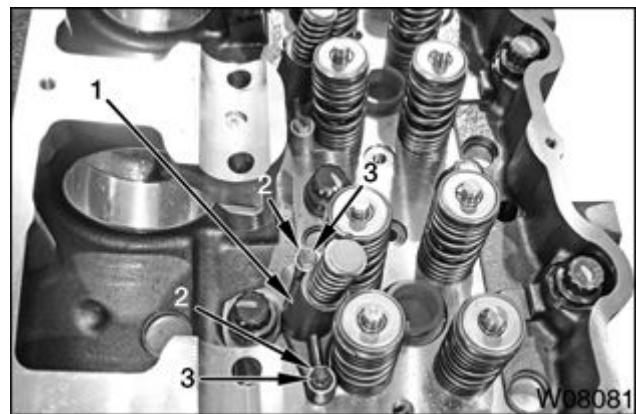
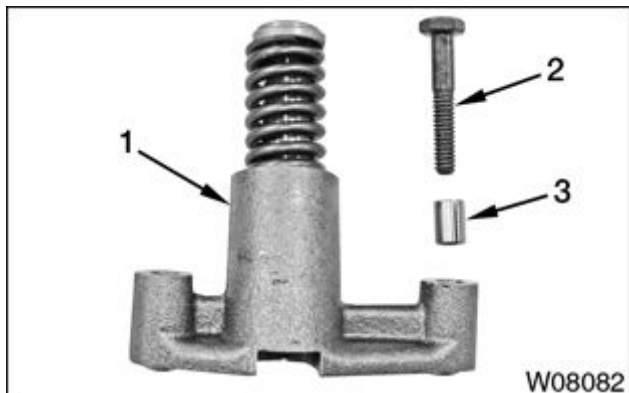


Figure 564 Lost motion pedestal assembly

1. Lost motion pedestal assembly
2. 1/4 hardened washer (2)
3. 1/4-20 x 1 1/2 bolt (2)

2. Remove two 1/4-20 x 1 1/2 bolts and two 1/4 hardened washers.

3. Remove lost motion pedestal assembly.



NOTE: 1/4-20 x 1 1/2 bolt through holes of lost motion pedestal assembly contain dowel sleeve bushings. New bushings come as part of new lost motion pedestal assembly and should not be left in engine during removal.

Figure 565 Lost motion pedestal assembly

1. Lost motion pedestal assembly
2. 1/4-20 x 1 1/2 bolt (2)
3. Dowel sleeve bushing (2)

Cleaning and Inspection

Valve Brake Actuator Assembly

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

1. Clean external surface of valve brake actuator assembly, lost motion pedestal, cylinder head, valve bridges, and slave piston with a suitable non-caustic solvent.
2. Clean any oil and debris from fastener threads and fastener openings. Clean bolt hole threads
3. Blow all parts dry using filtered compressed air.
4. Inspect all valve brake actuator assembly piston and valve bridge contact surfaces. Look for pitting and material transfer deformation. Replace pitted or deformed parts if necessary. Polished surfaces are acceptable.
5. Inspect housing of each valve brake actuator assembly for cracks. Replace any suspect assemblies.

will ensure proper torque is reached when tightening fasteners.

Installation

Lost Motion Pedestal

NOTE: The 1/4–20 x 1 1/2 bolt through holes of lost motion pedestal assembly contain dowel sleeve bushings. New bushings come as part of a new lost motion pedestal assembly. There should be no dowel sleeve bushings in engine prior to installation.

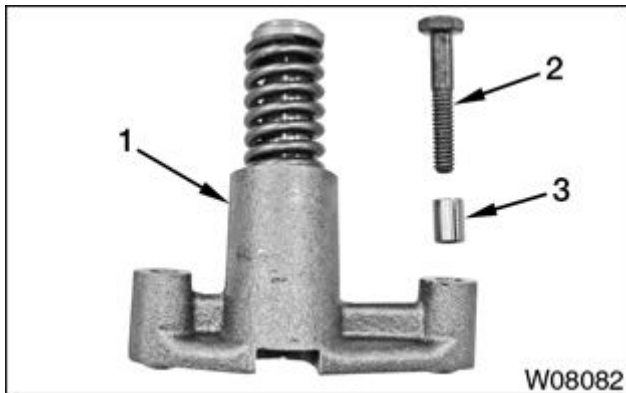


Figure 566 Lost motion pedestal assembly dowel sleeve bushing

1. Lost motion pedestal assembly
2. 1/4–20 x 1 1/2 bolt (2)
3. Dowel sleeve bushing (2)

1. Make sure lost motion pedestal assembly contains both dowel sleeve bushings.

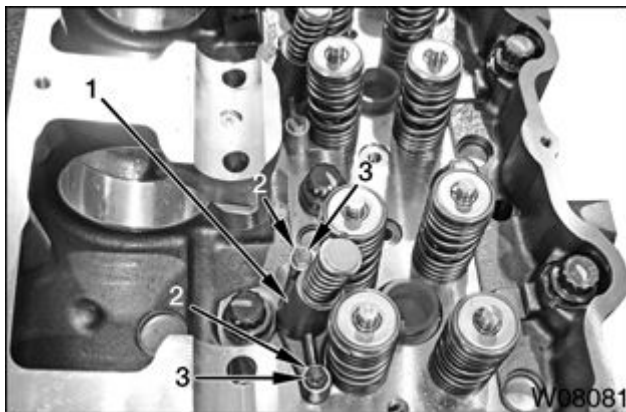


Figure 567 Lost motion pedestal assembly

1. Lost motion pedestal assembly
2. 1/4 hardened washer (2)
3. 1/4–20 x 1 1/2 bolt (2)

2. Position lost motion pedestal assembly on engine as pictured. Make sure orientation is as shown.
3. Install two 1/4 hardened washers and two 1/4–20 x 1 1/2 bolts. Tighten bolts to special torque (page 368).

Valve Brake Actuator Assembly

NOTE: The engine compression brake consists of three identical valve brake actuator assemblies; each valve brake actuator assembly is positioned over two cylinders. This procedure details installation of one of the three valve brake actuator assemblies. Installation of others is similar.

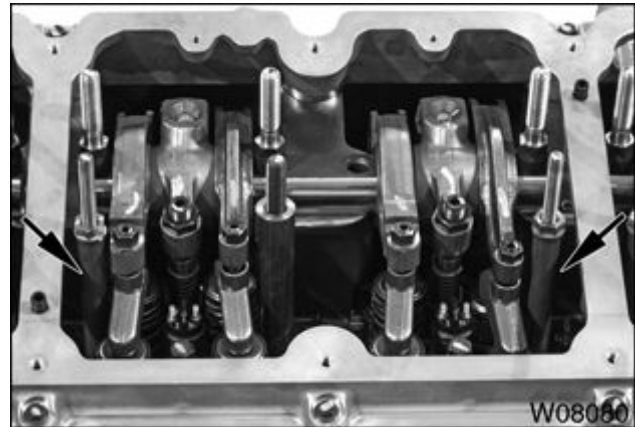


Figure 568 Spacer assemblies

1. Install two spacer assemblies. Tighten to special torque (page 368).

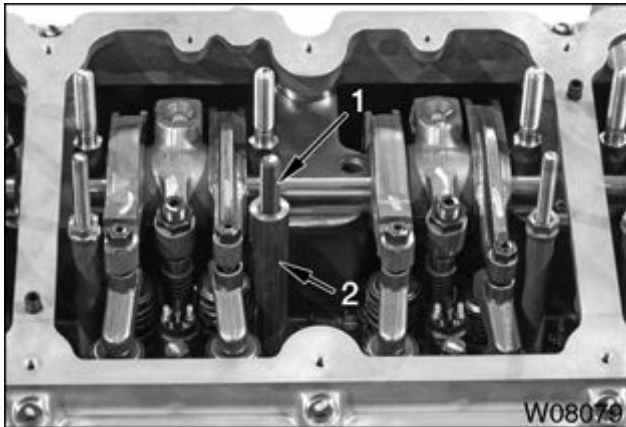


Figure 569 Support and 1/2-13 x 2.2 taperlock stud

1. 1/2-13 x 2.2 taperlock stud
2. Support

2. Install support and 1/2-13 x 2.2 taperlock stud. Tighten stud to special torque (page 368).

CAUTION: To prevent engine damage, loosen all slave piston lash adjuster jam nuts and back out all slave piston lash adjusters so that slave pistons are fully seated at top of the bore (slave pistons stop moving). If slave piston lash adjusters are not backed out, binding between exhaust rockers and slave piston may occur during installation.

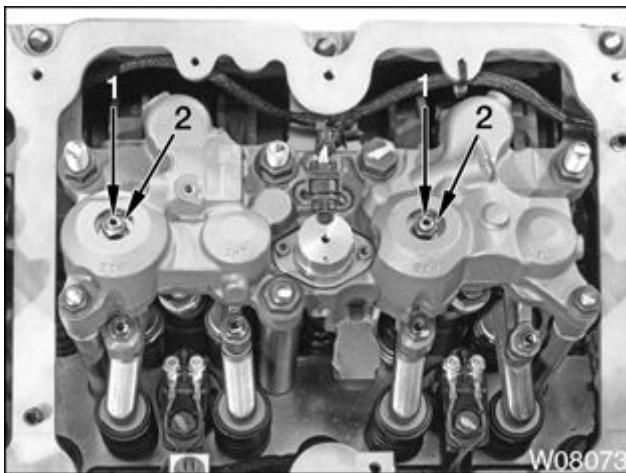


Figure 570 Slave piston lash adjusters and jam nuts

1. Slave piston lash adjuster (2)
2. Slave piston lash adjuster jam nut (2)

3. On valve brake actuator assembly, loosen two slave piston lash adjuster jam nuts and back out two slave piston lash adjusters using 5/32 hex key wrench (page 368) so that slave pistons are fully seated at top of the bore (slave pistons stop moving).

CAUTION: To prevent damage to electrical harness, make sure electrical connector and harness are out of the way during installation of valve brake actuator assembly. Do not torque any valve brake actuator assembly fasteners without checking positioning of electrical harness and connection.

CAUTION: Do not apply rust preventive onto the solenoid or solenoid connector.

NOTE: Ensure that the fans are on before using this material.

NOTE: Wear nitrile gloves with 11" cuff for this operation

4. Apply Rust Preventive to all top surfaces and on the sides of the Brake Actuator Assembly with silicone basting brush.

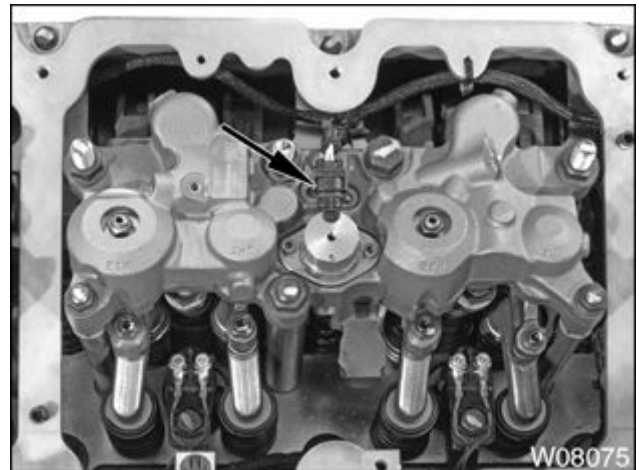


Figure 571 Valve brake actuator assembly electrical connector

5. Install valve brake actuator assembly by sliding over studs. Make sure electrical harness and connector are out of the way.
6. Connect valve brake actuator assembly electrical connector.

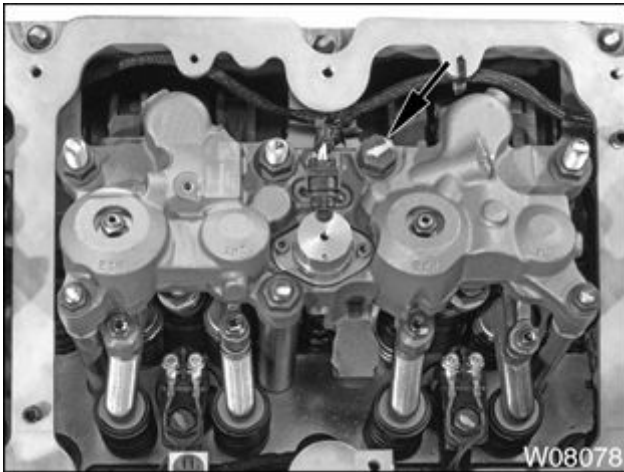


Figure 572 Valve brake actuator assembly
1/2-13 x 5.65 hex bolt

7. Install 1/2-13 x 5.65 hex bolt hand tight.



Figure 574 Valve brake actuator assembly
1/2-13 hex flange nuts

9. Install four 1/2-13 hex flange nuts hand tight.

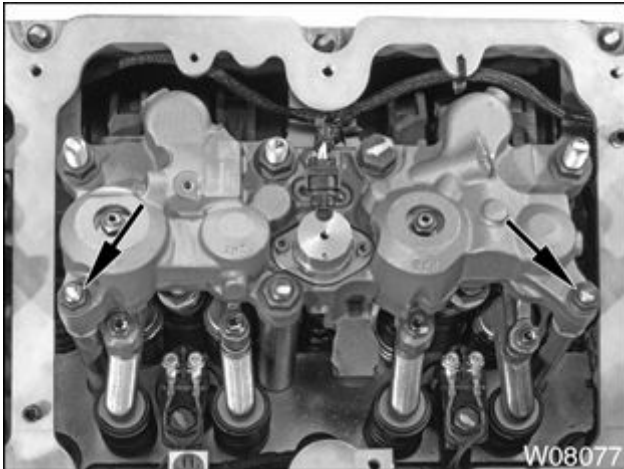


Figure 573 Valve brake actuator assembly
3/8-16 hex nuts

8. Install two 3/8-16 hex nuts hand tight.



Figure 575 Valve brake actuator assembly
torque sequence

10. Tighten valve brake actuator assembly fasteners in sequence to proper torque specifications:
- Tighten 1/2-13 x 5.65 hex bolt (1) to special torque (page 368).
 - Tighten four 1/2-13 hex flange nuts (2, 3, 4, 5) to special torque (page 368).
 - Tighten two 3/8-16 hex nuts (6, 7) to special torque (page 368).

11. Perform lash adjustment on each installed valve brake actuator assembly. See Engine Brake Lash Adjustment (page 356).
-

Specifications

Engine brake rocker lash	0.15 mm $\pm$ 0.05 mm (0.006 in $\pm$ 0.002 in)
Engine brake slave piston (cold)	0.686 mm $\pm$ 0.05 mm (0.027 in $\pm$ 0.002 in)

Special Torque

1/4–20 x 1 1/2 bolt	15 N·m (11 lbf·ft)
1/2–13 hex flange nut	See sequence in procedure (page 364) 105 N·m (77 lbf·ft)
1/2–13 x 2.2 taperlock stud	65 N·m (48 lbf·ft)
1/2–13 x 5.65 hex bolt	See sequence in procedure (page 366) 105 N·m (77 lbf·ft)
3/8–16 hex nut	See sequence in procedure (page 364) 47 N·m (35 lbf·ft)
Plug (flywheel locking port)	23 N·m (17 lbf·ft)
Slave piston lash adjuster jam nut	15 N·m (11 lbf·ft)
Spacer assembly	47 N·m (35 lbf·ft)

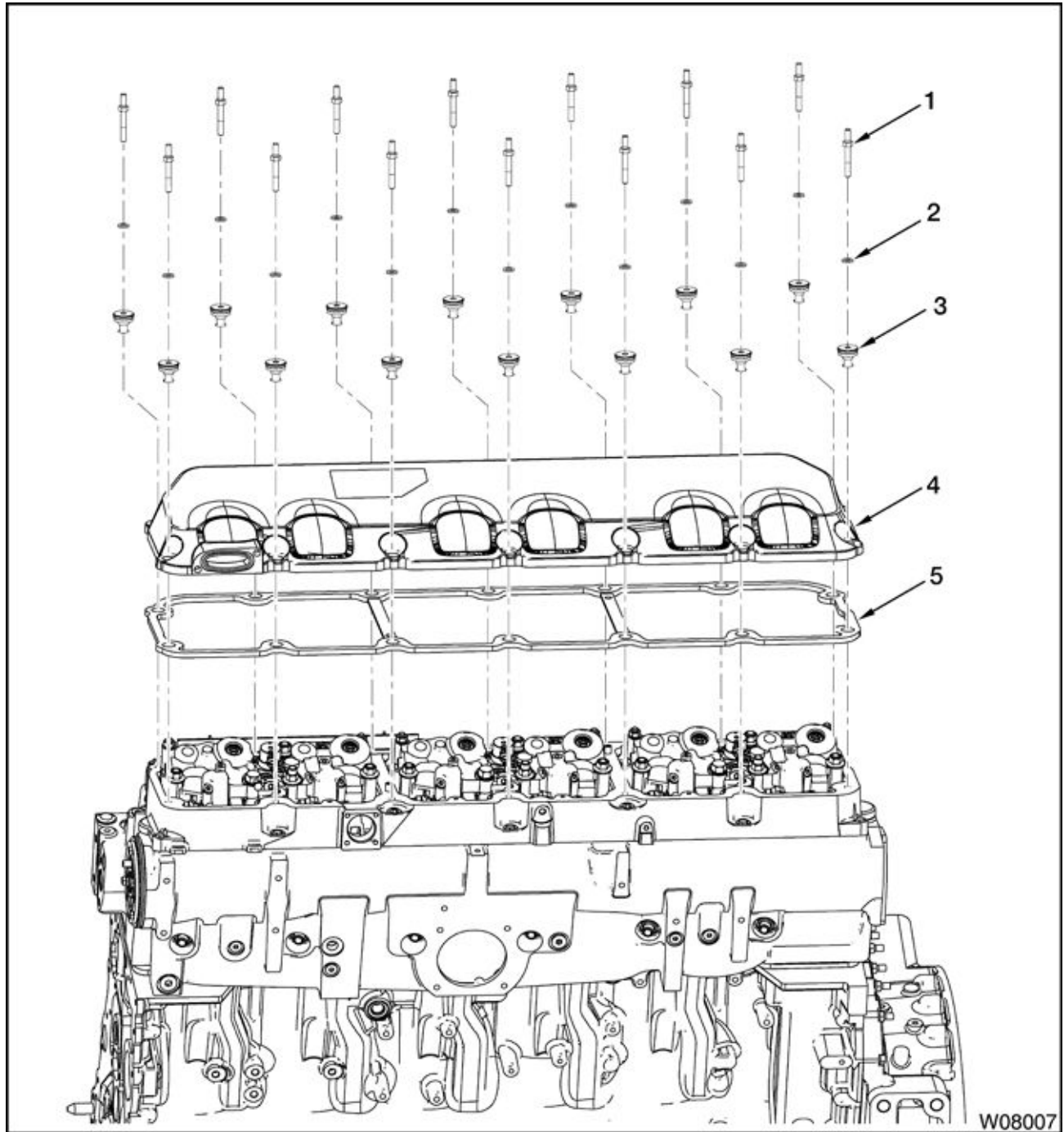
Special Service Tools

Description	Tool Number
5/32 hex key wrench	Obtain locally
Engine Rotation Tool	ZTSE6112
Lash gauge 0.686 mm (0.027 in.)	Obtain locally
Timing Pin	ZTSE6108

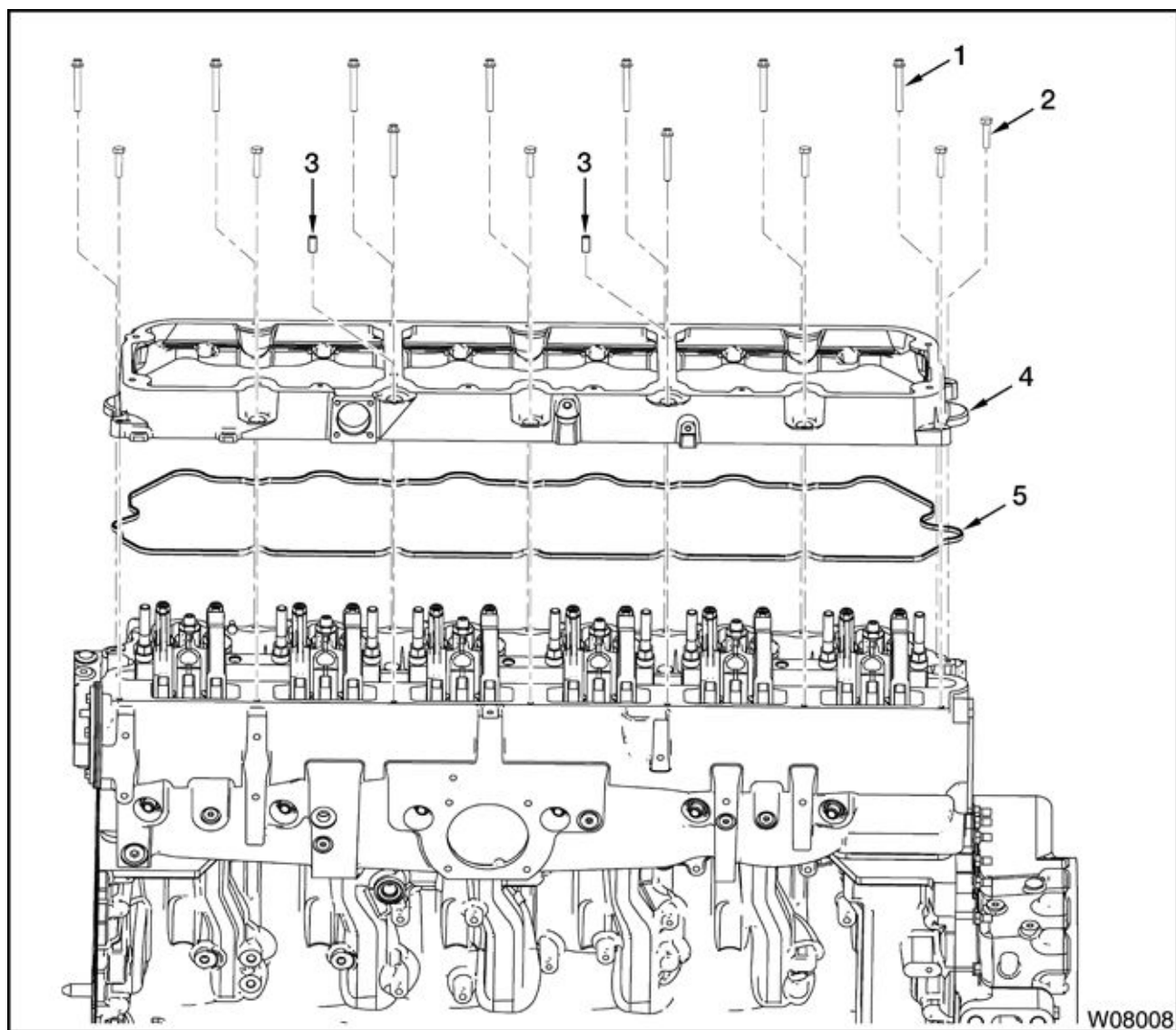
Table of Contents

Exploded Views.....	371
Periodic Service.....	379
Valve Lash Adjustment.....	379
Removal.....	384
Valve Cover.....	384
Valve Cover Base.....	387
Engine Brakes.....	390
Fuel Injectors.....	390
Rocker Arms.....	391
Camshaft and Bearings.....	393
Camshaft.....	393
Camshaft Bearings.....	396
Cylinder Head.....	397
Replacing O-ring Boss Plugs and Cylinder head Cup Plugs.....	400
O-ring boss plugs.....	400
Cup plugs.....	400
Cleaning, Inspection, and Testing.....	402
Camshaft Lobes and Journals Measurement.....	402
Cylinder Head and Crankcase Components.....	402
Camshaft Bearings.....	403
Fuel Injector Bore.....	403
Fuel Injector Harness.....	403
Measuring Valve Seat Leakage.....	403
Measuring Rocker Shaft.....	404
Inspection and Measurement of Rocker Arms.....	404
Measuring Cylinder Head Warpage.....	405
Measuring Cylinder Head Thickness.....	405
Inspecting Cylinder Head for Cracks.....	406
Installation.....	407
Cylinder Head.....	407
Camshaft and Bearings.....	410
Camshaft Bearings.....	410
Camshaft.....	412
Rocker Arms.....	415
Fuel Injectors.....	416
Engine Brakes.....	418
Valve Cover Base.....	418
Valve Cover.....	423
Specifications.....	425
Special Torque.....	426

Special Service Tools.....427

Exploded Views**Figure 576 Valve cover**

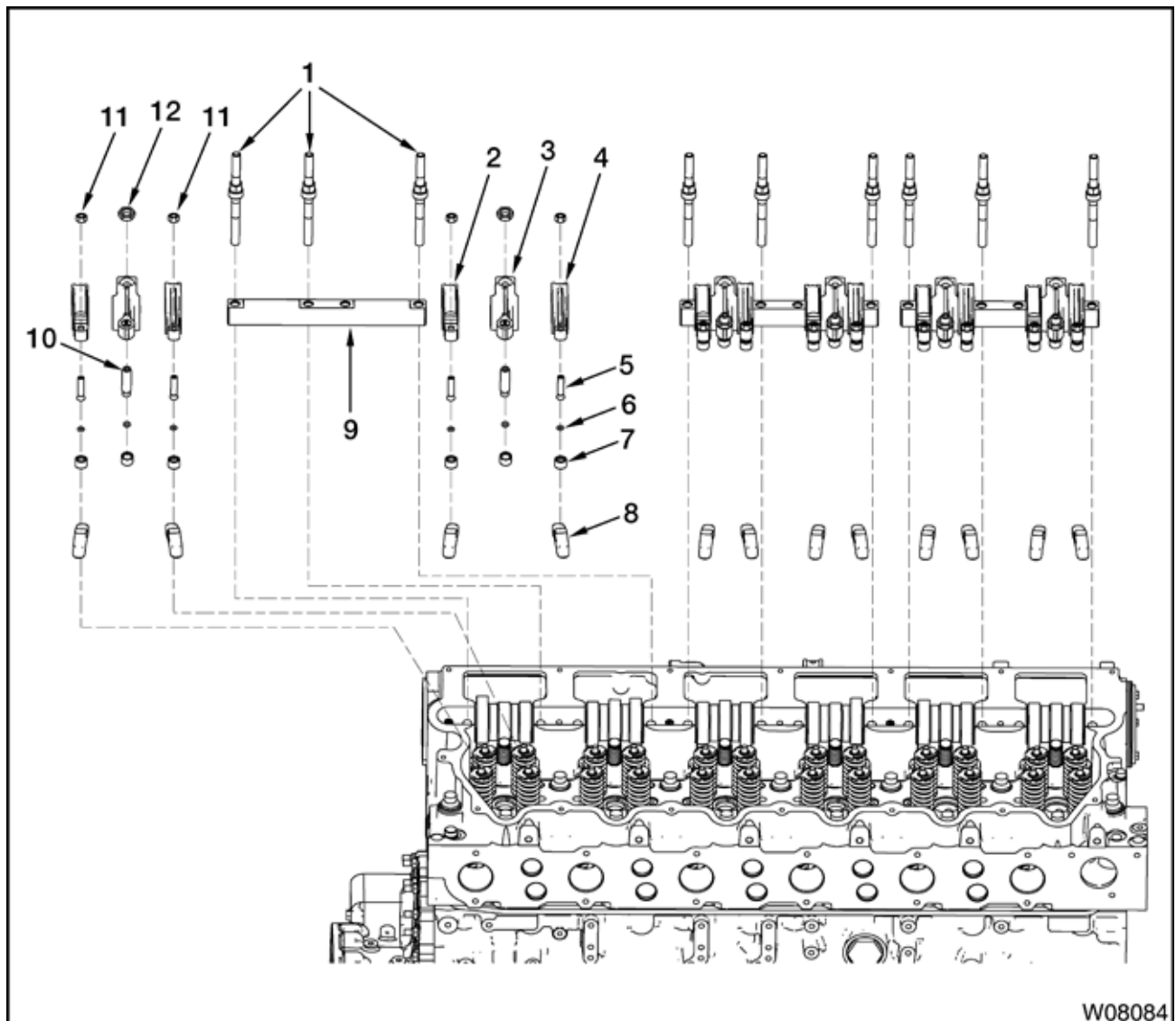
1. 5/16 - 18 stud (14)	3. Valve cover grommet (14)
2. 8.8 X 16 X 2 hardened washer (14)	4. Valve cover assembly
	5. Valve cover gasket



W08008

Figure 577 Valve cover base

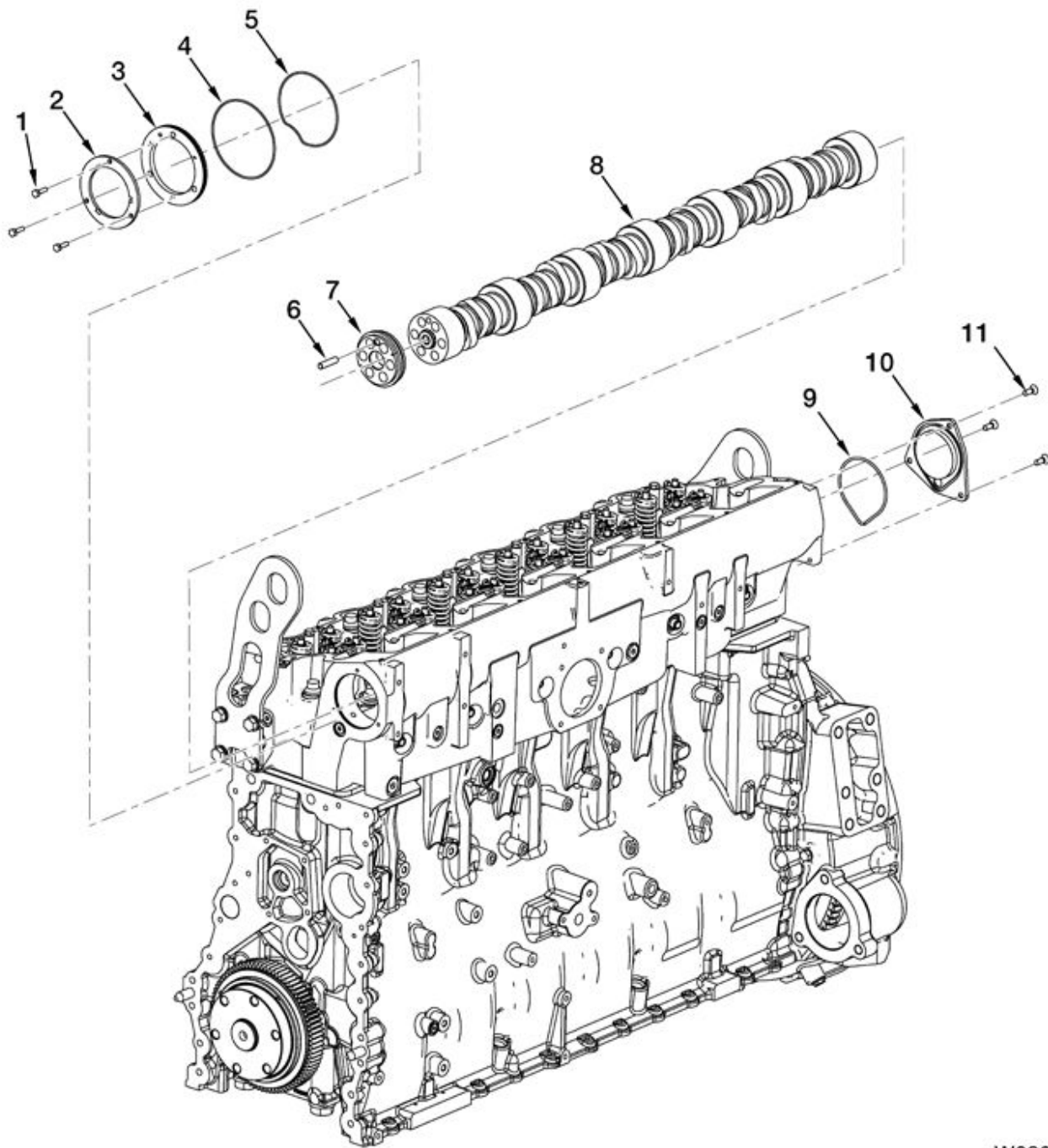
1. 5/16 - 18 X 2.36 hex flange bolt (9)	2. 5/16 - 18 X 1 - 1/4 hex flange bolt (6)	4. Valve cover base
	3. Spring pin (2)	5. Valve cover gasket



W08084

Figure 578 Rocker arms, rocker shafts and valve bridges

1. Hex flange stud (9)	5. Arm adjustment screw 3/8 - 24 X 1.2 (valve) (12)	10. Arm adjustment screw 9/16 - 18 (engine brake) (6)
2. Valve rocker arm assembly (exhaust) (6)	6. O-ring seal (18)	11. 3/8 - 24 nut (valve lash adjuster) (12)
3. Engine brake rocker arm assembly (6)	7. Pivot foot (18)	12. 9/16 - 18 nut (engine brake lash adjuster) (6)
4. Valve rocker arm assembly (intake) (6)	8. Valve bridge (12)	
	9. Rocker shaft assembly (3)	



W03006

Figure 579 Camshaft

1. 1/4 - 20 X 0.87 hex locking bolt (3)	5. O-ring (camshaft seal plate to cylinder head)	9. O-ring (rear camshaft cover)
2. Thrust bearing plate	6. Dowel pin	10. Cover (rear camshaft)
3. Camshaft seal plate	7. Camshaft drive adapter assembly	11. 5/16 - 18 X 0.87 Torx screw (3)
4. O-ring (camshaft seal plate to front cover plate)	8. Camshaft	

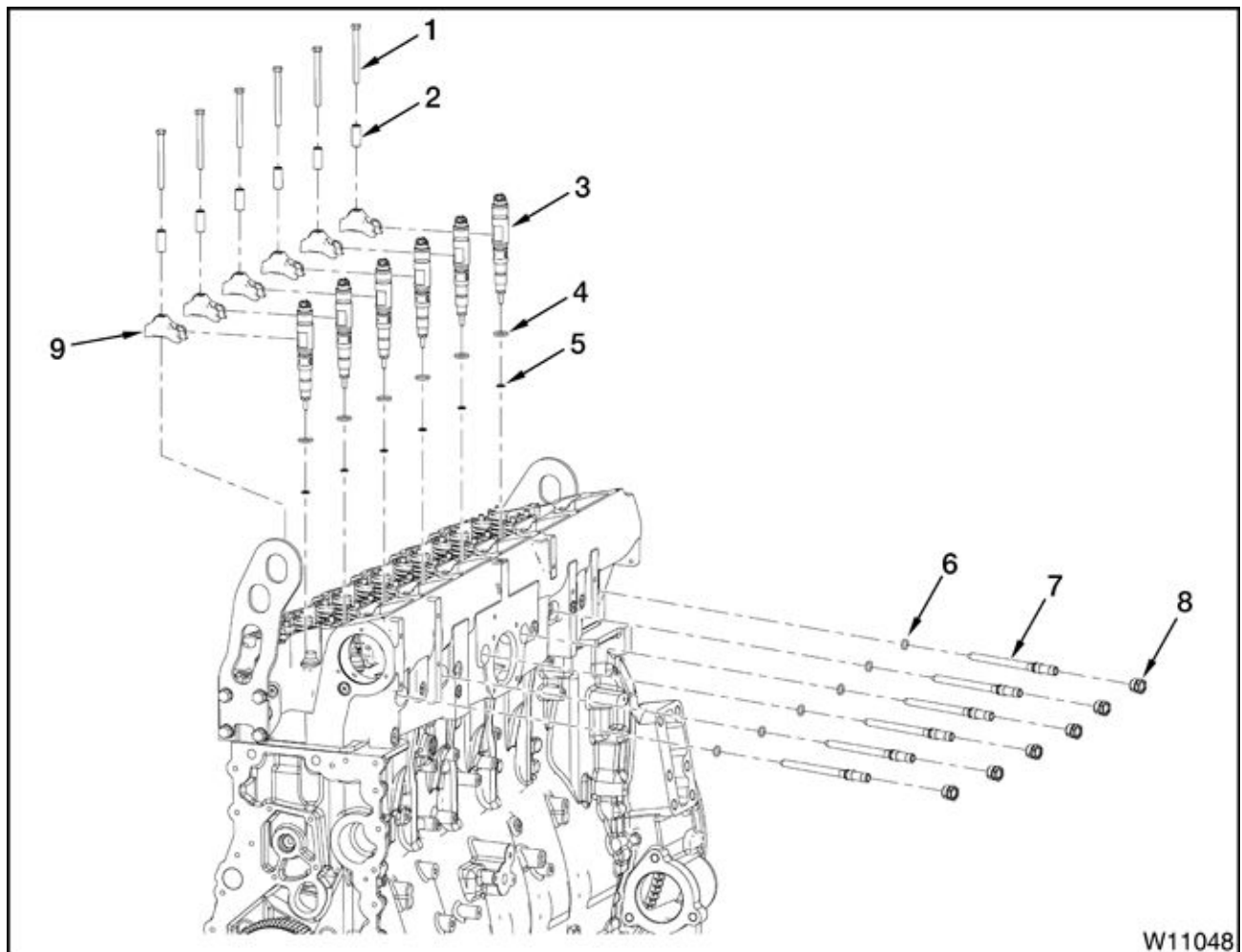
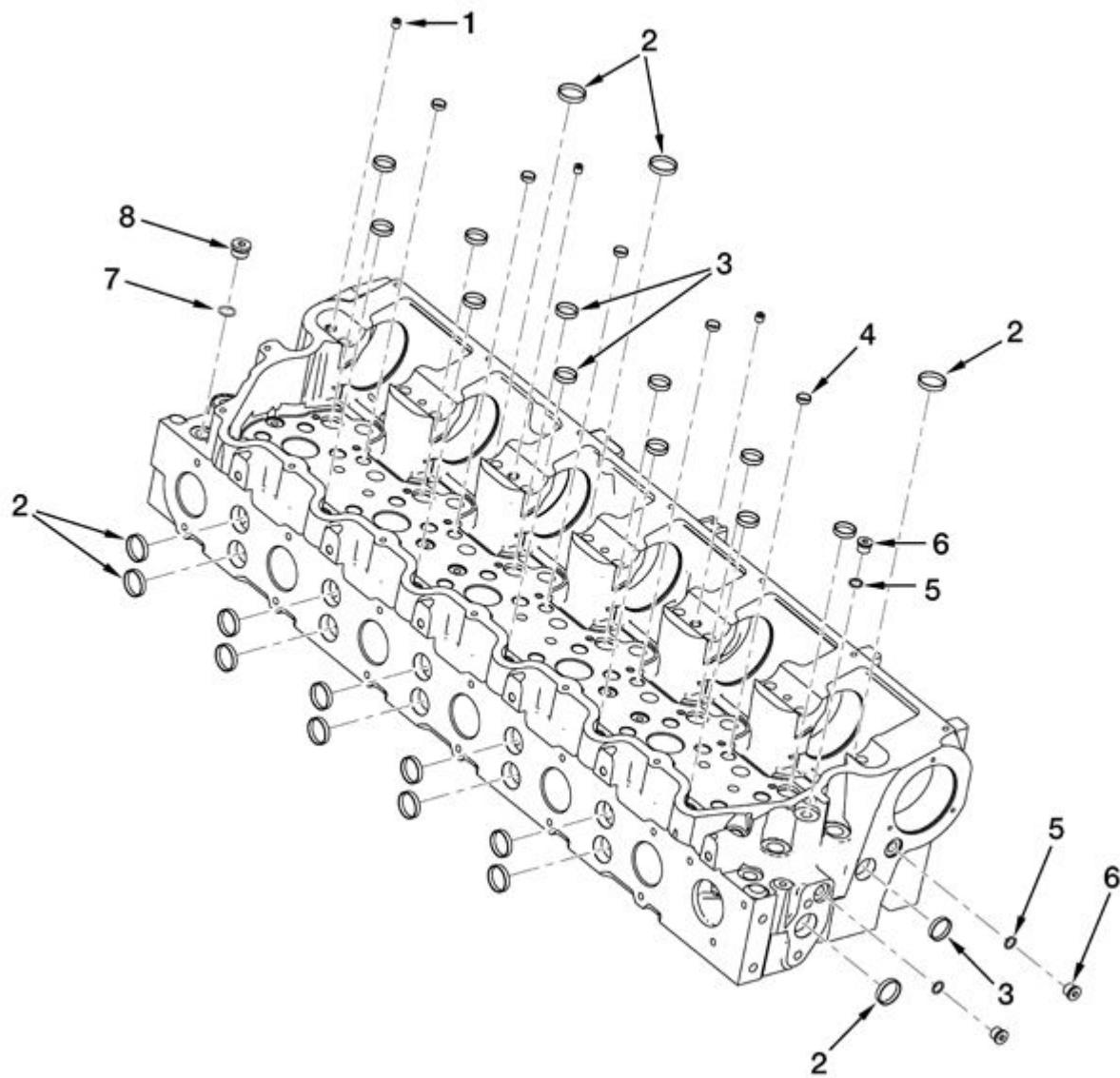


Figure 580 Fuel injectors and high-pressure connector assemblies

1. 3/8 - 16 X 4 hex bolt (6)	5. Combustion gasket (6)	8. High-pressure connector retaining nut (6)
2. 9.8 X 15.85 X 37.6 spacer (6)	6. 13.5 X 3 O-ring (6)	9. Injector clamp (6)
3. Injector assembly (6)	7. High-pressure connector body (6)	
4. 3 X 20.9 ID O-ring (6)		



W08011

Figure 582 Front, top and RH cup plugs and O-ring boss plugs

1. 10 mm pipe plug (3)	4. Cup plug (22 mm) (5)	6. O-ring boss plug (9/16 - 18) (3)
2. Cup plug (1 - 7/32 in) (14)	5. O-ring (9/16 O-ring boss plug) (3)	7. Ring seal (3/4 O-ring boss plug)
3. Cup plug (1 in) (12)		8. O-ring boss plug 3/4 - 16)

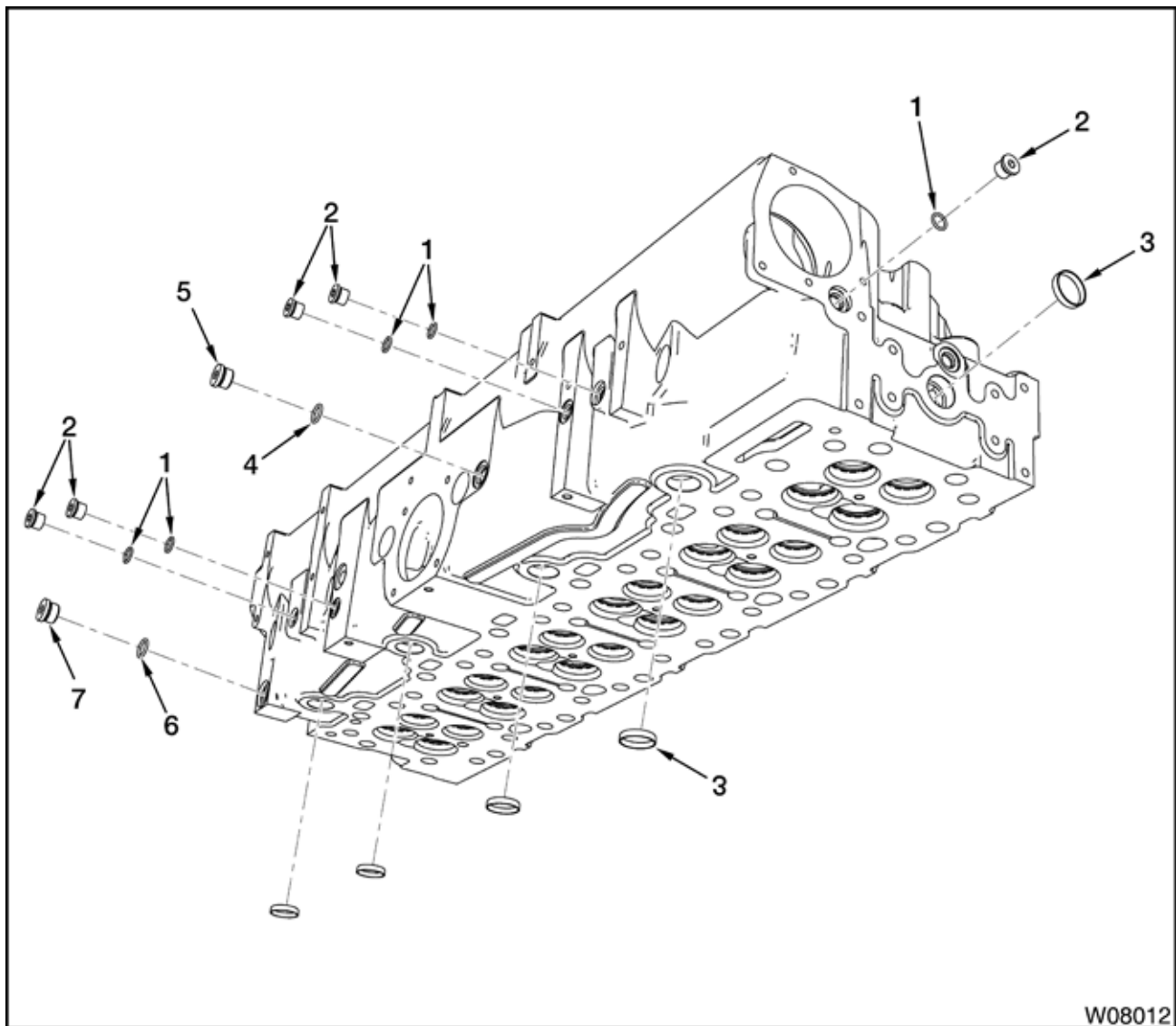


Figure 583 Rear, bottom and LH cup plugs and O-ring boss plugs

1. O-ring (9/16 O-ring boss plug) (5)	3. Cup plug (1 - 7/32 in) (5)	6. Ring seal (7/8 O-ring boss plug)
2. O-ring boss plug (9/16 - 18) (5)	4. Ring seal (3/4 O-ring boss plug)	7. O-ring boss plug (7/8 - 14)
	5. O-ring boss plug (3/4 - 16)	

Periodic Service



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

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

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

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

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

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

Valve Lash Adjustment

CAUTION: To prevent engine damage, an engine brake lash adjustment must be performed after the valve lash procedure is completed, and the valve brake actuator assembly has been reinstalled. See Engine Brake Lash Adjustment (page 356).

NOTE: Valve lash adjustment must be performed while engine is stationary and uniformly cool between 4° C and 38° C (40° F and 100° F).

1. Remove Valve Cover (page 384).
2. Remove three Valve Brake Actuator Assemblies (page 360).
3. Remove camshaft gear cover. See Front Cover (page 312).

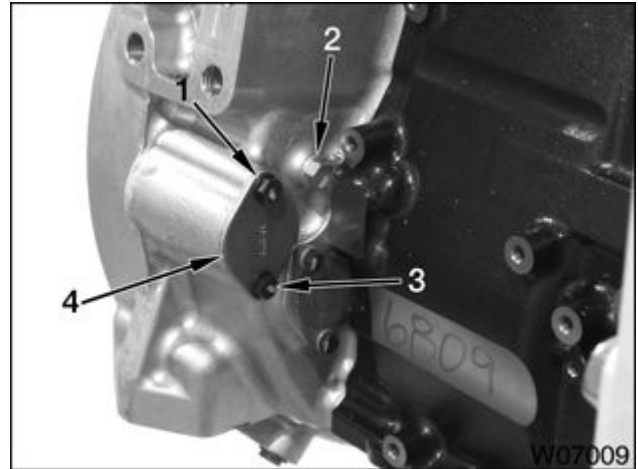


Figure 584 Flywheel locking port

1. 3/8–16 x 3 hex flange bolt
2. Plug (flywheel locking port)
3. 3/8–16 x 1 hex flange bolt
4. Plate (flywheel access)

NOTE: There are two holes in the front surface of the flywheel used to pin (lock in place) the engine. Each of these flywheel holes are in alignment with a port at either the left or right front of the flywheel housing assembly. The two flywheel lock holes are at different distances from the center of the flywheel, so only one of the flywheel holes is engaged at each port location. Installing the timing pin in either port will lock the flywheel at TDC compression of cylinder 1 or 6. It is suggested to use the right side locking port as that location is next to the tool port used to rotate the engine.

4. Remove 3/8–16 x 3 hex flange bolt, 3/8–16 x 1 hex flange bolt, and plate (rotation tool guide). Discard plate seal.
5. Remove plug from flywheel locking port.

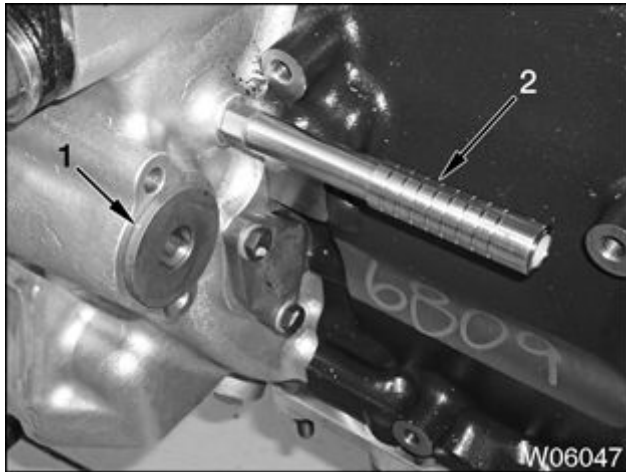


Figure 585 Right front of flywheel housing

1. Engine Rotation Tool
 2. Timing Pin
6. Install Engine Rotation Tool (page 427) through opening that was covered by the plate.
 7. Install Timing Pin (page 427) into flywheel locking port.
 8. Using 1/2 inch drive ratchet, rotate engine rotation tool in the direction of normal engine rotation (counterclockwise as viewed from the flywheel end of the engine looking forward). The timing pin is under constant spring tension and will engage the appropriate hole in the flywheel when the crankshaft is at top dead center (TDC) position.

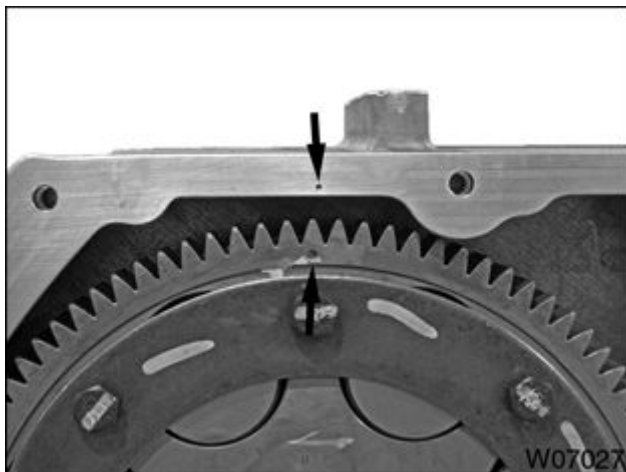


Figure 586 Cylinder #1 compression timing marks

9. If the camshaft timing mark is at 12 o'clock, then cylinder #1 is at TDC on compression stroke. If the camshaft timing mark is at 6 o'clock, then cylinder #6 is at TDC on compression stroke. Lock the flywheel when cylinder #1 is at TDC on compression stroke.

NOTE: If the rocker arm shafts have been removed for service, do steps 6 and 7 prior to installing them. If adjusting valve lash as periodic service, skip steps 6 and 7.

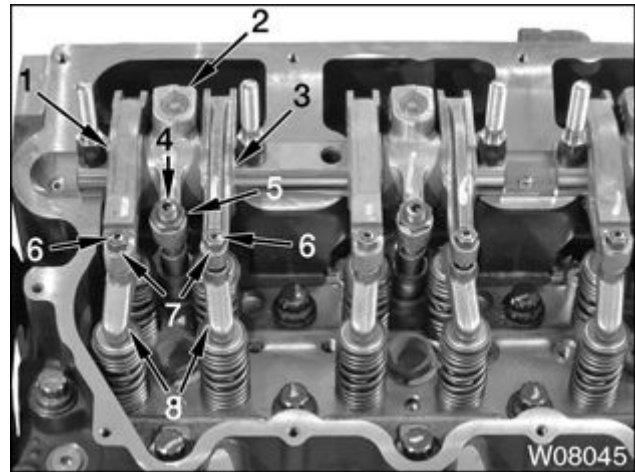


Figure 587 Rocker arm assembly components (typical)

1. Exhaust rocker arm assembly
 2. Engine brake rocker arm assembly
 3. Intake rocker arm assembly
 4. Engine brake arm adjustment screw assembly (typical)
 5. Engine brake arm adjustment nut (typical)
 6. Valve arm adjustment screw assembly (typical) (2 per cylinder)
 7. Valve arm adjustment nut (typical) (2 per cylinder)
 8. Valve bridges (typical) (2 per cylinder)
10. Loosen twelve valve arm adjustment nuts and six engine brake arm adjustment nuts.
 11. Turn the twelve valve arm adjustment screws and the six engine brake arm adjustment screws counter clockwise until the adjustment arm foot contacts the rocker arm assembly.



Figure 588 Lash gauge on exhaust valve bridge

12. Lightly tap each rocker arm in Table 1 (page 381) at the top of the adjustment screw with a soft faced mallet and make sure that the roller seats against the base circle of the camshaft. Measure each rocker arm lash in Table 1 prior to adjustment. Use Lash Gauge (page 427) to measure the exhaust valve lash. If the current rocker arm lash in Table 1 is within the specifications (page 425) do not adjust the rocker arm lash. If the current rocker arm lash in Table 1 is outside the specifications (page 425) adjust the rocker arm lash.
13. Loosen adjustment nuts and adjust the lash for the rocker arms in Table 1 (page 381).
14. Tighten the adjustment nuts to special torque (page 426). Verify the rocker arm lash measurements after tightening the valve arm adjustment nuts and engine brake arm adjustment nuts.

Table 1

Cylinder Number	Rocker arm
1	Intake
1	Exhaust
2	Intake
2	Engine brake
3	Exhaust
4	Intake
5	Exhaust
6	Engine brake

NOTE: The camshaft gear timing mark will be at the 3 o'clock (90 degrees) after the crankshaft is rotated 180 degrees.

15. Remove the timing pin and using Engine Rotation Tool (page 427) rotate the crankshaft 180 degrees in a clockwise direction (as viewed from the front of the engine).
16. Lightly tap the rocker arm in Table 2 (page 381) at the top of the adjustment screw with a soft faced mallet and make sure that the roller seats against the base circle of the camshaft. Measure the Table 2 rocker arm lash prior to adjustment. If the current Table 2 rocker arm lash is within the specifications (page 425), do not adjust the rocker arm lash. If the current Table 2 rocker arm lash is outside the specifications (page 425), adjust the rocker arm lash.
17. Loosen adjustment nuts and adjust the lash for the rocker arm in Table 2 (page 381).
18. Tighten the adjustment nut to special torque (page 426). Verify the rocker arm lash measurements after tightening the valve arm adjustment nuts and engine brake arm adjustment nuts.

Table 2

Cylinder Number	Rocker arm
4	Engine brake

NOTE: The camshaft gear timing mark will be at the 6 o'clock (180 degrees) after the crankshaft is rotated an additional 180 degrees.

19. Using Engine Rotation Tool (page 427), rotate the crankshaft an additional 180 degrees in a

clockwise direction (as viewed from the front of the engine) (cylinder #6 at TDC compression).

20. Install the Timing Pin (page 427) and lock the flywheel.
21. Lightly tap each rocker arm in Table 3 (page 382) at the top of the adjustment screw with a soft faced mallet and make sure that the roller seats against the base circle of the camshaft. Measure each Table 3 rocker arm lash prior to adjustment. If the current Table 3 rocker arm lash is within the specifications (page 425), do not adjust the rocker arm lash. If the current Table 3 rocker arm lash is outside the specifications (page 425), adjust the rocker arm lash.
22. Loosen adjustment nuts and adjust the lash for the rocker arms in Table 3.
23. Tighten the adjustment nuts to special torque (page 426). Verify the rocker arm lash measurements after tightening the valve arm adjustment nuts and engine brake arm adjustment nuts.

Table 3

Cylinder Number	Rocker arm
1	Engine brake
2	Exhaust
3	Intake
4	Exhaust
5	Intake
5	Engine brake
6	Intake
6	Exhaust

NOTE: The camshaft gear timing mark will be at the 9 o'clock (270 degrees) after the crankshaft is rotated an additional 180 degrees in a clockwise direction (as viewed from the front of the engine).

24. Remove the Timing Pin (page 427), and using Engine Rotation Tool (page 427), rotate the crankshaft an additional 180 degrees.
25. Lightly tap each rocker arm in Table 4 (page 382) at the top of the adjustment screw with a soft faced mallet and make sure that the roller seats against the base circle of the camshaft. Measure the Table 4 rocker arm lash prior to adjustment.

If the current Table 4 rocker arm lash is within the specifications (page 425), do not adjust the rocker arm lash. If the current Table 4 rocker arm lash is outside the specifications (page 425), adjust the rocker arm lash.

26. Loosen adjustment nuts and adjust the lash for the rocker arm in Table 4.
27. Tighten the adjustment nut to special torque (page 426). Verify the rocker arm lash measurements after tightening the valve arm adjustment nuts and engine brake arm adjustment nuts.

Table 4

Cylinder Number	Rocker arm
3	Engine brake

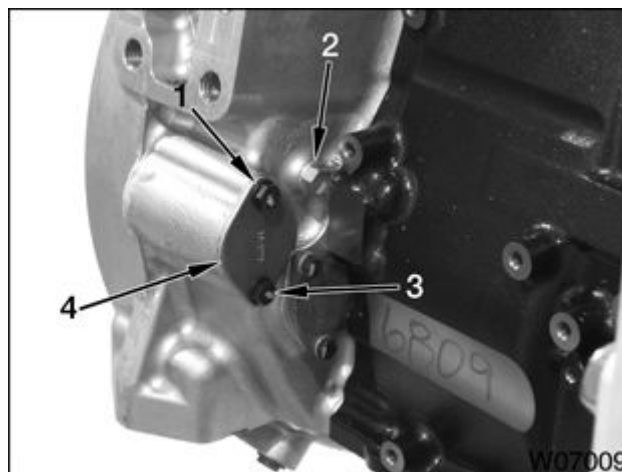


Figure 589 Flywheel locking port

1. 3/8-16 x 3 hex flange bolt
 2. Plug (flywheel locking port)
 3. 3/8-16 x 1 hex flange bolt
 4. Plate (flywheel access)
28. Install three engine brake assemblies and do engine brake lash adjustment. See Valve Brake Actuator Assembly (page 364).
 29. Remove the Engine Rotation Tool.
 30. Install a new flywheel access plate seal.
 31. Install the plate (flywheel access), 3/8-16 x 3 hex flange bolt and 3/8-16 x 1 hex flange bolt. Tighten 3/6-16 hex flange bolts to standard torque (page 562).

- 32. Install the plug (flywheel locking port). Tighten the access plug to standard torque (page 562).
- 33. Install camshaft gear cover. See Front Cover (page 332).
- 34. Install valve cover. See Valve Cover (page 423).

Removal

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

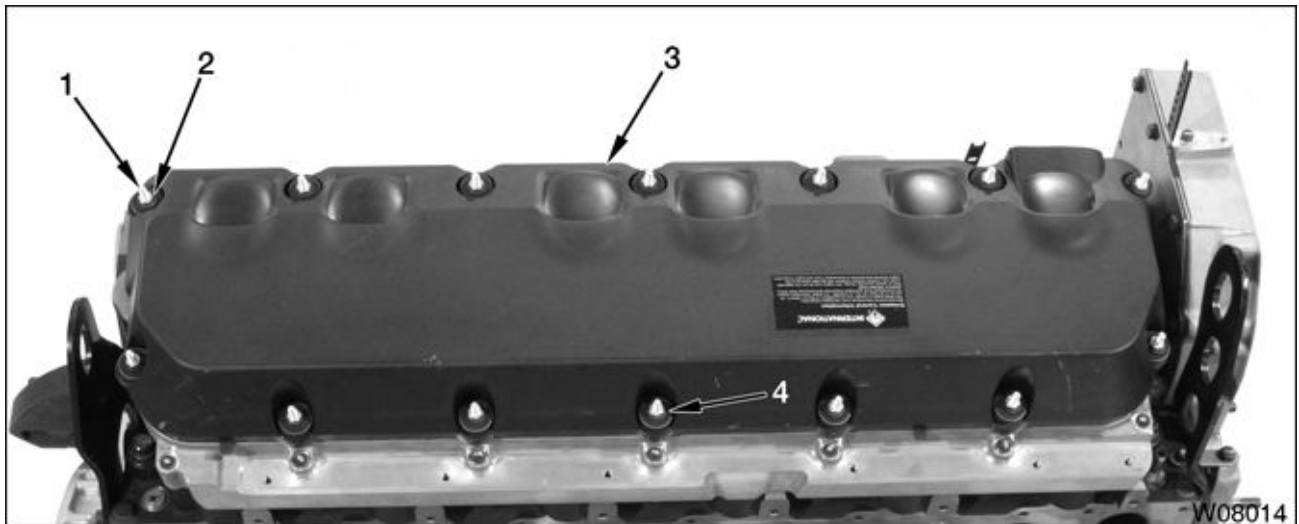
- Engine Electrical
- Turbochargers
- Air Compressor and Power Steering Pump
- Fuel System
- Oil Cooler, Filter Housing, and Crankcase Ventilation
- Exhaust Gas Recirculation (EGR) System
- Air Inlet and Exhaust Manifolds
- Front Cover, High Mount Fan Drive, Cooling System, and Related Components

Valve Cover

1. Disconnect the engine oil pressure (EOP) sensor, mass air flow (MAF) sensor, turbocharger boost controller, charge air pressure sensor, charge air cooler temperature sensor, engine coolant temperature (ECT) sensor, engine coolant pressure, and coolant control valve (CCV) electrical connectors. See Engine Electrical, Removal (page 76).
2. Cut and remove the tie straps from the top and right side of the engine sensor harness assembly. See Engine Sensor Harness Assembly (page 88).

NOTE: Note the routing of the engine sensor harness assembly for reinstallation.

3. Move the engine sensor harness assembly to the top of the engine and position the harness assembly to the left side of the engine to gain access to cylinder head components.

**Figure 590 Valve Cover**

1. 5/16 - 18 stud (14)	2. 8.8 X 16 X 2 hardened washer (14)	3. Valve cover assembly
		4. Valve cover grommet (14)

CAUTION: To prevent engine damage, do not use air tools to remove or install valve cover.

5. Remove the valve cover assembly.
4. Remove fourteen 5/16 - 18 studs, fourteen hardened washers and fourteen valve cover grommets.

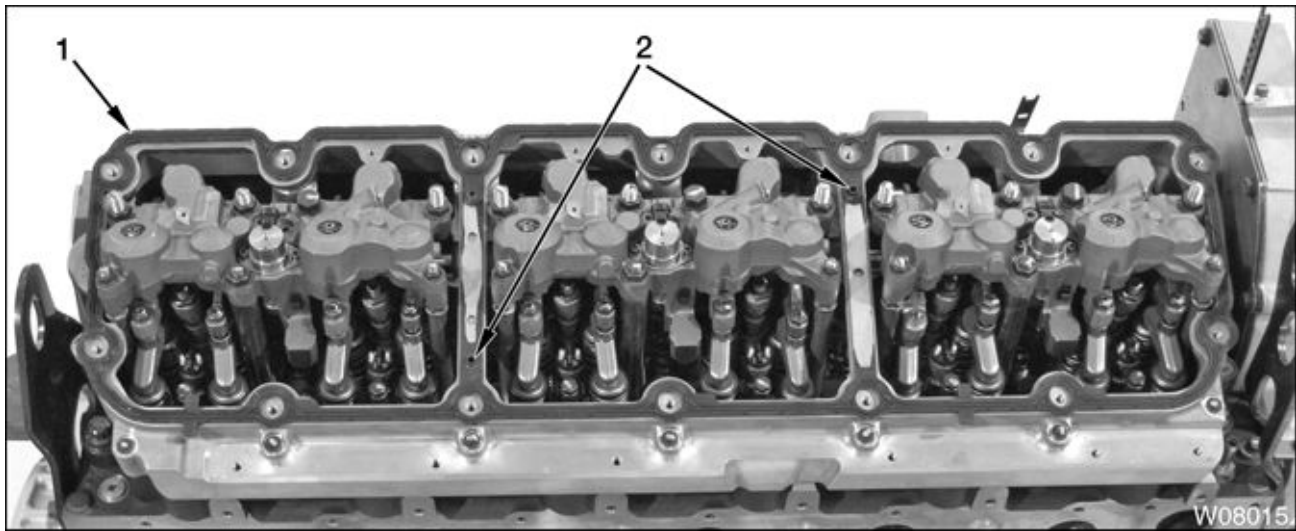


Figure 591 Valve cover gasket

1. Valve cover gasket
 2. Spring pin (2)
-
6. Remove the valve cover gasket from the two spring pins.
 7. Inspect valve cover gasket for damage. If damaged, discard the valve cover gasket.
 8. If required, remove the two spring pins.

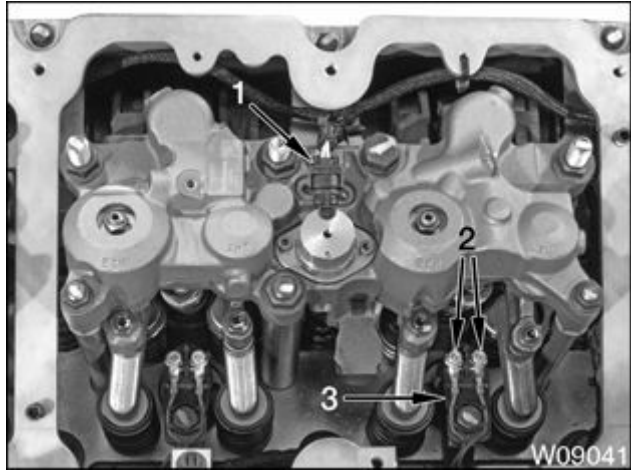
Valve Cover Base

Figure 592 Under valve cover (UVC) harness connections (typical)

1. Engine brake electrical connector (3)
2. Injector harness nut (12)
3. Fuel injector connector bracket (6)

NOTE: The injector harness nuts are part of the under valve cover (UVC) harness and cannot be separated.

1. Disconnect three engine brake electrical connectors and twelve injector harness nuts.
2. Remove six fuel injector connector brackets from the fuel injector clamp bolt.

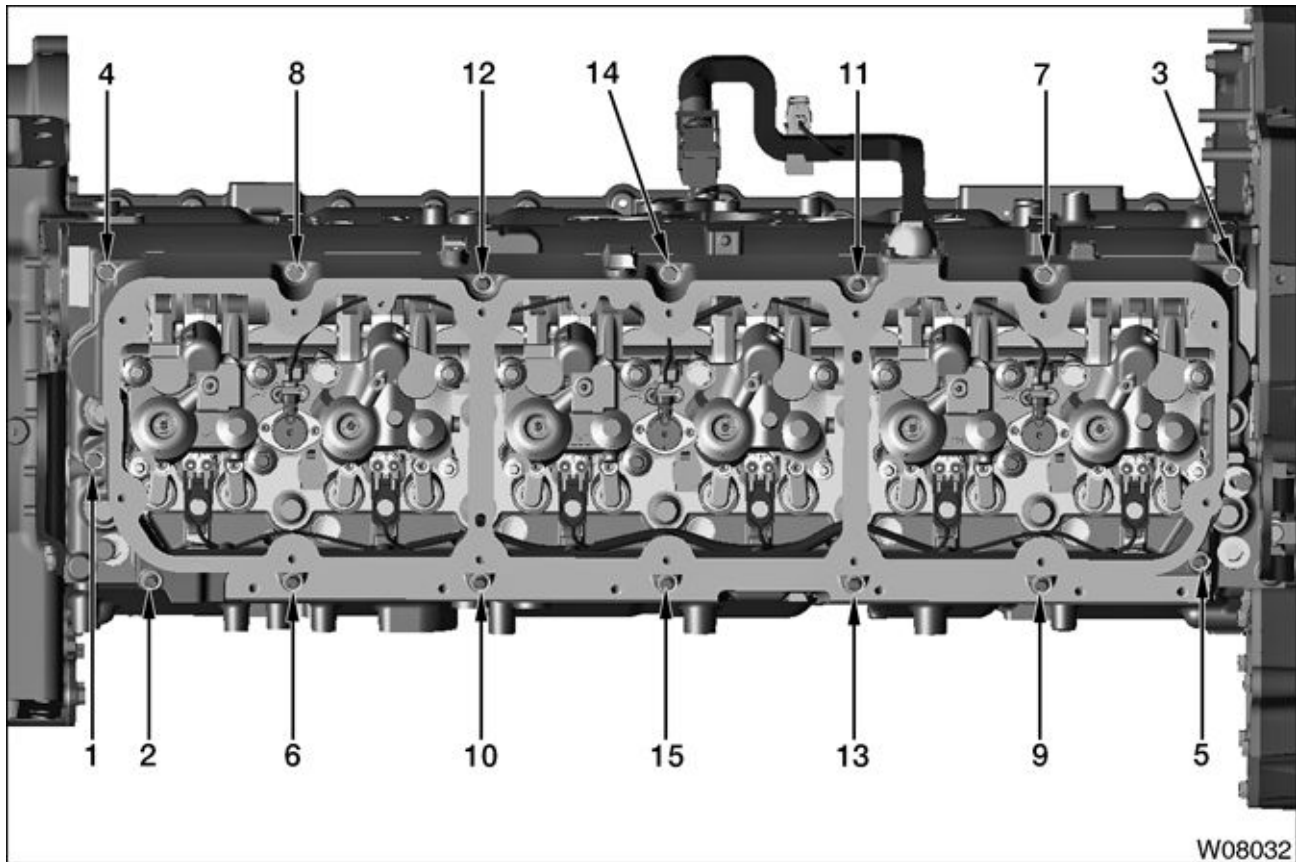


Figure 593 Valve cover base bolts removal sequence

3. Remove six 5/16 - 18 X 1 - 1/4 hex flange bolts and nine 5/16 - 18 X 2.36 hex flange bolts in the sequence shown.

NOTE: Make sure that the UVC harness and connections do not abrade or become damaged during valve cover base removal.

4. Remove the valve cover base from the cylinder head.

NOTE: Do steps 5 and 6 only if the UVC harness or valve cover base is being replaced.

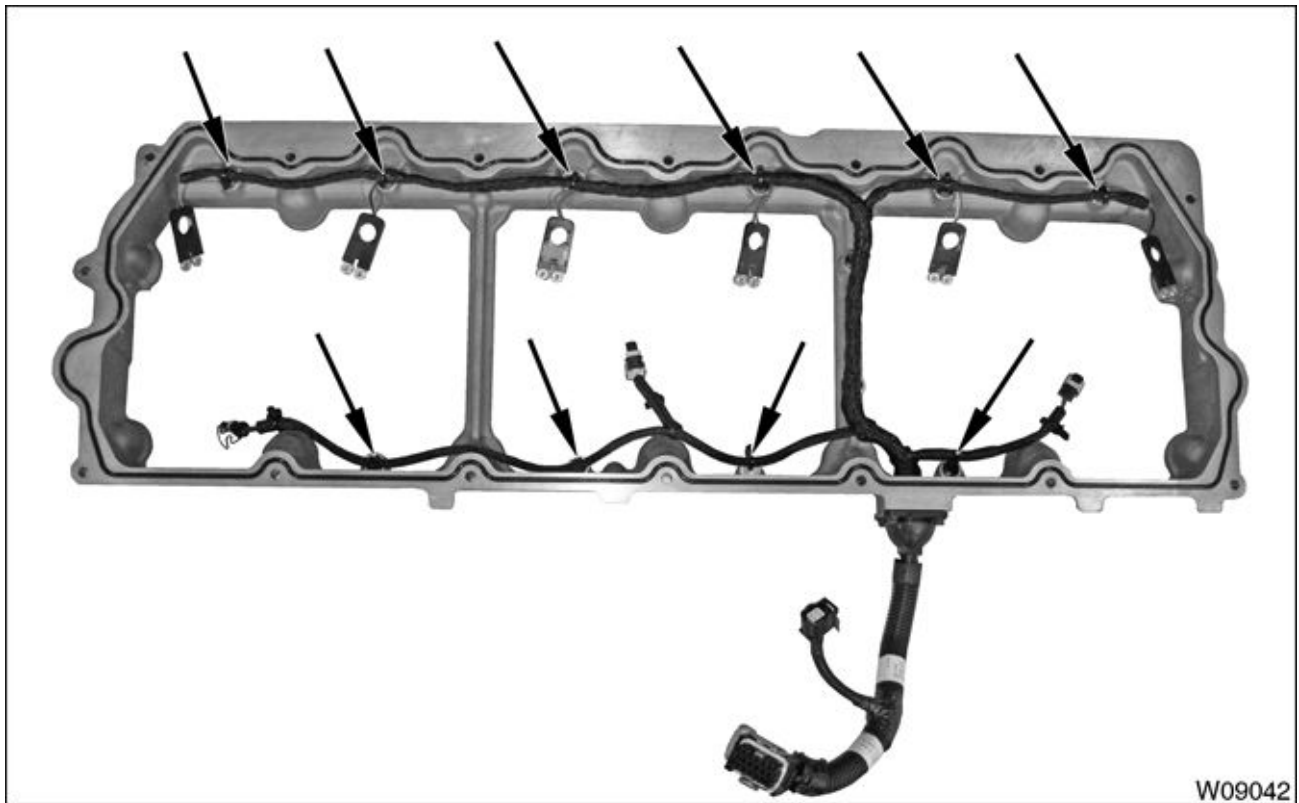


Figure 594 UVC harness tie strap locations

5. Cut ten UVC harness tie straps

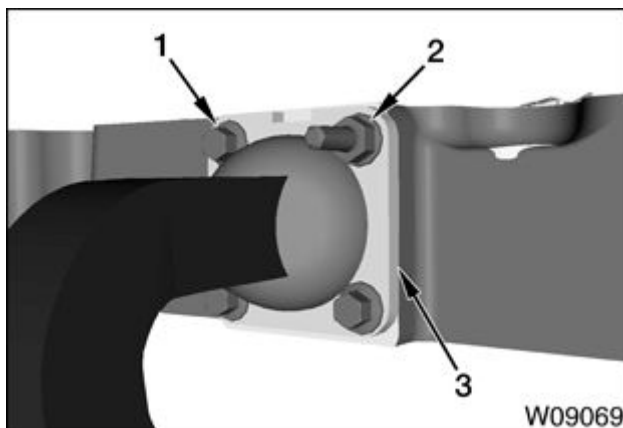


Figure 595 UVC harness bolts

1. M6 X 20 hex flange bolt (3)
2. M6 X 16 stud bolt
3. UVC harness

NOTE: Make sure that the UVC harness and connections do not abrade or become damaged during removal or installation from valve cover base.

6. Remove three M6 X 20 hex flange bolts and one M6 X 16 stud bolt. Remove the UVC harness.

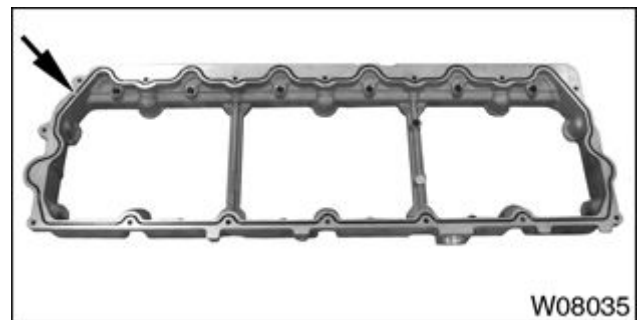


Figure 596 Valve cover base gasket

7. Inspect valve cover base gasket for damage. If damaged, remove and discard valve cover base gasket.

Engine Brakes

1. Remove the three engine brake assemblies. See Valve Brake Actuator Assembly (page 360).
2. Remove the six lost motion pedestals. See Lost Motion Pedestal (page 361).
3. Remove three supports, three 1/2 - 13 X 2.2 taperlock studs and six spacer assemblies. See Valve Brake Actuator Assembly (page 360).

Fuel Injectors

CAUTION: To prevent engine damage, remove injectors before removing cylinder head.

CAUTION: To prevent engine damage, do not use power tools on the high-pressure connector retaining nuts.

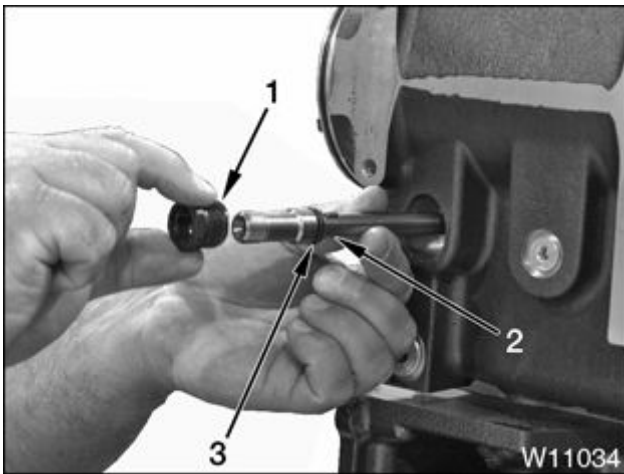


Figure 597 High-pressure connector (typical)

1. High-pressure connector retaining nut (6)
 2. High-pressure connector body (6)
 3. 13.5 X 3 O-ring (6)
1. Using High-Pressure Connector Installer/Remover (page 427), remove six high-pressure connector retaining nuts.
 2. Using High-Pressure Connector Installer/Remover (page 427), remove and discard six high-pressure connector body and O-ring assemblies.
 3. Cover cylinder head high-pressure connector body bores with appropriate size plugs from Disposable Air and Fuel Caps (page 427).

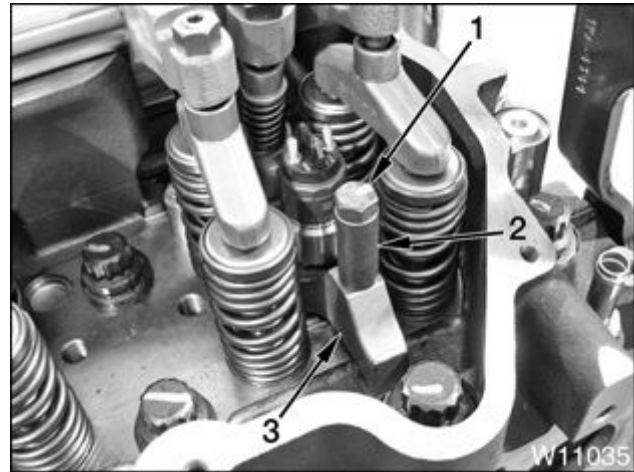


Figure 598 Injector clamp (typical)

1. 3/8 - 16 X 4 hex bolt (6)
 2. 9.8 X 15.85 X 37.6 spacer (6)
 3. Injector clamp (6)
4. Remove six 3/8 - 16 X 4 hex bolts, six 9.8 X 15.85 X 37.6 spacers and six injector clamps.

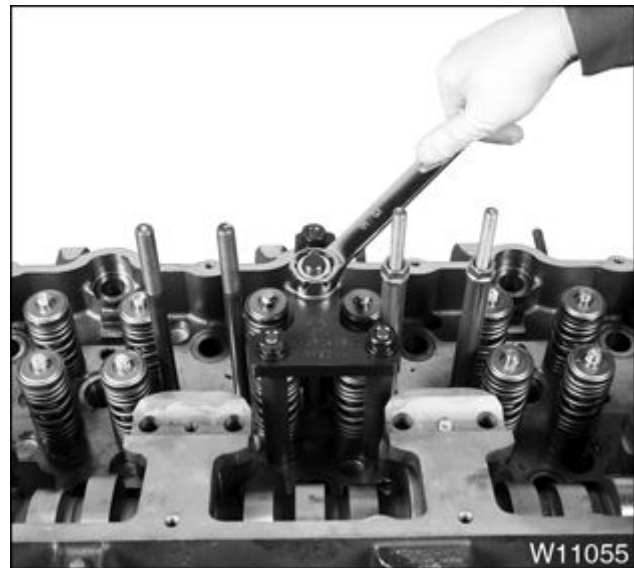


Figure 599 Injector removal

5. Install Injector Removal Kit (page 427) , on cylinder head and remove six fuel injectors.

NOTE: Make sure that no combustion gasket remains in the injector bore after the injector is removed.

6. Cover cylinder head injector bore with appropriate size plugs from Disposable Air and Fuel Caps (page 427).

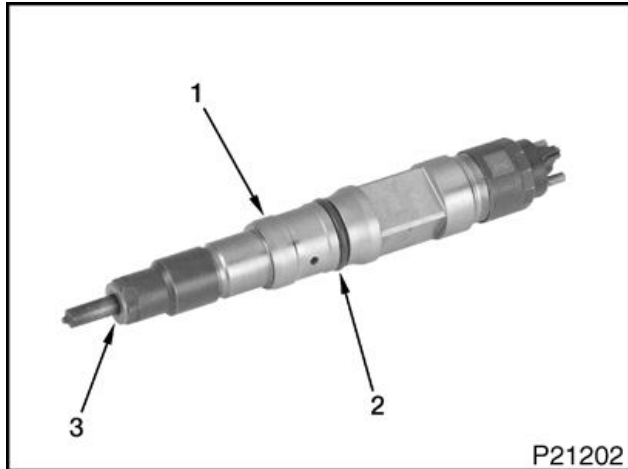


Figure 600 Injector seals (typical)

1. Injector
2. O-ring
3. Combustion gasket

7. Using a small hand tool, remove and discard combustion gasket. Wipe injector nozzle with a lint free cloth. Do not remove O-ring at this time.

CAUTION: To prevent engine damage, do not clean fuel injectors with solvents or brake cleaner.

8. Clean injector tip with Fuel Injector Tip Cleaning Brush (page 427).
9. Insert injector into Fuel Injector Cups and Rack (page 427).

Rocker Arms

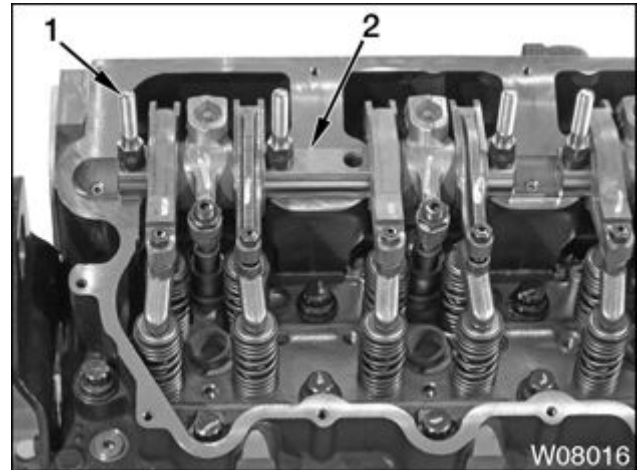


Figure 601 Rocker arm assembly (typical)

1. Hex flange stud (9)
2. Rocker arm assembly (3)

CAUTION: To prevent engine damage, use permanent markers to identify internal components and their orientation. Do not use paint or temporary markers.

1. Mark the rocker arm assemblies location and orientation.

! WARNING: To prevent personal injury or death, the rocker arm assembly should be kept level when removed or installed on engine. Rocker arms can move or slide off the rocker shaft after the hex flange studs are removed.

2. Remove nine hex flange studs and three rocker arm assemblies.

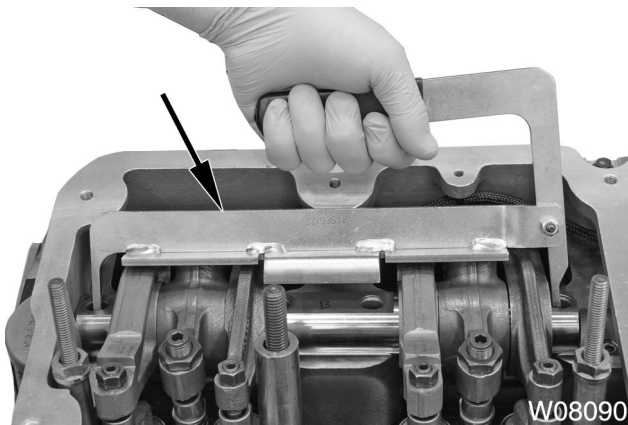


Figure 602 Rocker Arm Lifting Bracket Assembly

3. Remove rocker arm assembly from cylinder head using Rocker Arm Lifting Bracket Assembly (page 427).

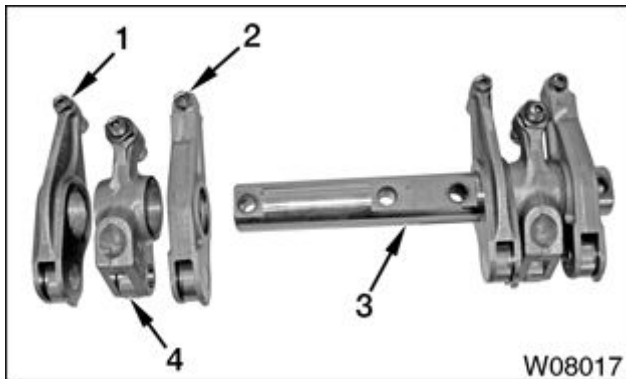


Figure 603 Rocker arm assembly (typical)

1. Valve rocker arm assembly (exhaust) (6)
2. Valve rocker arm assembly (intake) (6)
3. Rocker shaft assembly (3)
4. Engine brake rocker arm assembly (6)

CAUTION: To prevent engine damage, use permanent markers to identify internal components and their orientation. Do not use paint or temporary markers.

4. Mark each rocker arm's location.
5. Remove two exhaust rocker arm assemblies, two engine brake rocker arm assemblies and two intake rocker arm assemblies from each rocker shaft assembly.

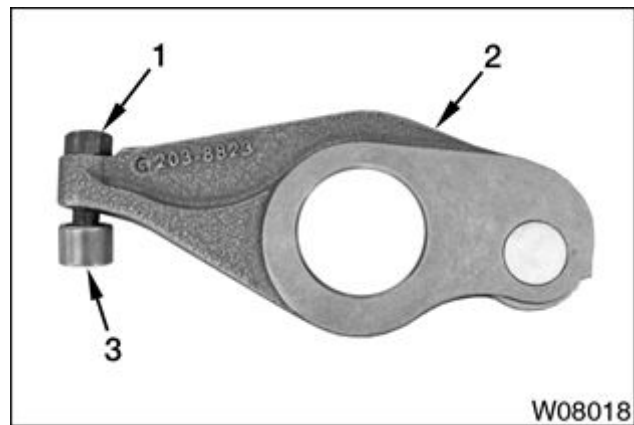


Figure 604 Rocker arm (typical)

1. Arm adjustment nut (typical)
2. Rocker arm assembly (typical)
3. Arm adjustment screw assembly (typical)
6. If required, remove the 3/8 - 24 nut and arm adjustment screw assembly 3/8 - 24 X 1.2 from the valve rocker arm assemblies.
7. If required, remove the 9/16 -18 nut and arm adjustment screw assembly 9/16 -18 from the engine brake rocker arm assemblies.

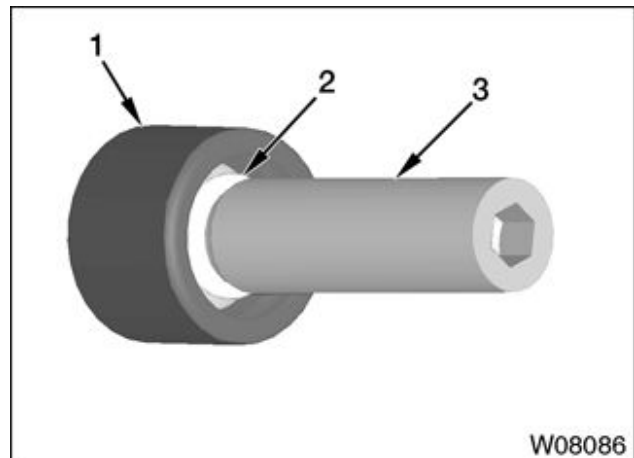


Figure 605 Arm adjustment screw (typical)

1. Pivot foot (typical)
2. O-ring seal (typical)
3. Arm adjustment screw (typical)
8. Inspect arm adjustment screw, pivot foot and O-ring seal for wear or heat damage.

- a. If O-ring seal is torn, out of position or melted, remove pivot foot and remove and discard O-ring seal. Assemble adjustment screw assembly using existing arm adjustment screw and pivot foot with new O-ring seal.
- b. If the arm adjustment screw or pivot foot is worn or damaged, assemble a new arm adjustment screw assembly using a new arm adjustment screw, pivot foot and O-ring seal.

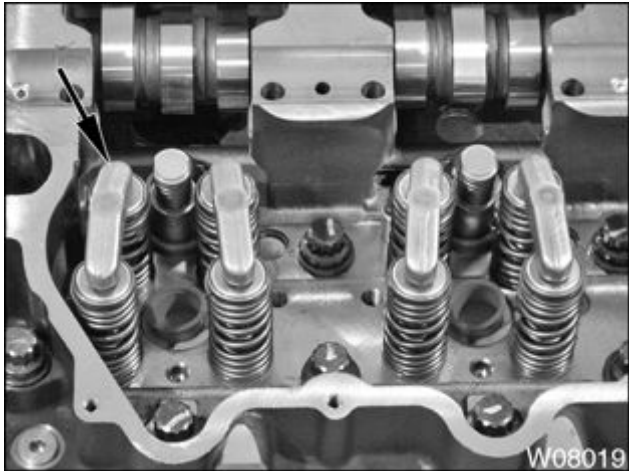


Figure 606 Valve bridges (typical)

CAUTION: To prevent engine damage, use permanent markers to identify internal components and their orientation. Do not use paint or temporary markers.

9. Mark each valve bridge's location and orientation.
10. Remove twelve valve bridges.

Camshaft and Bearings

Camshaft

CAUTION: To prevent engine damage, use permanent markers to identify internal components and their orientation. Do not use paint or temporary markers.

1. Obtain Camshaft Remover/Installer (page 427).

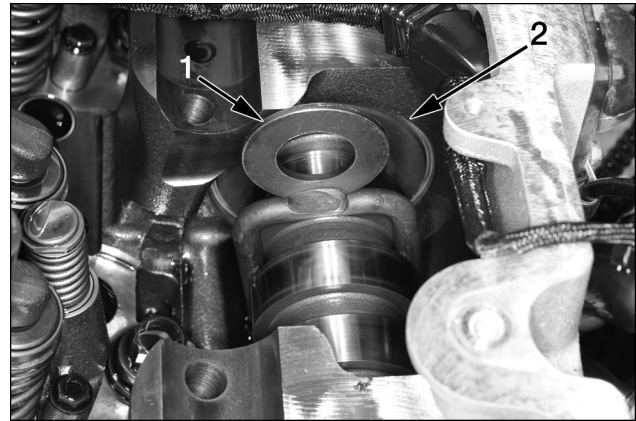


Figure 607 Camshaft Position Retainer

1. Camshaft Position Retainer
2. Main bearing journal

NOTE: The Camshaft Position Retainer is used to prevent the camshaft from moving or slipping inside the camshaft bore. If the camshaft moves or slips out of the bore it could cause damage to the camshaft, camshaft bushings and other valve train components.

2. Install Camshaft Position Retainer between engine brake lobe and intake lobe to prevent camshaft from moving.

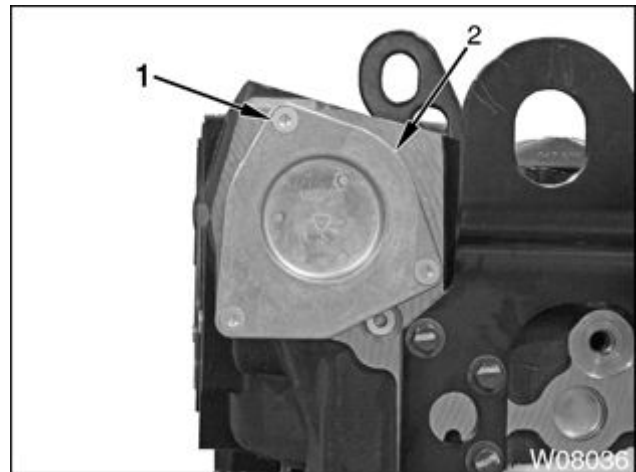


Figure 608 Rear camshaft cover removal

1. 5/16 - 18 X 0.87 Torx screw (3)
2. Cover (camshaft rear)

3. Remove three 5/16 - 18 X 0.87 Torx screws and the rear camshaft cover.

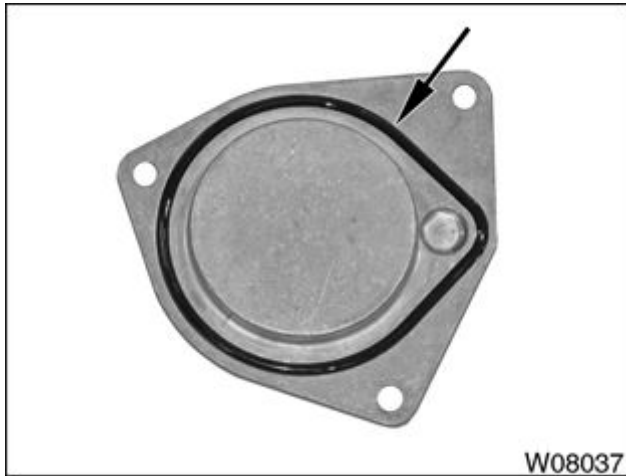


Figure 609 Rear camshaft cover O-ring

4. Remove and discard the rear camshaft cover O-ring.

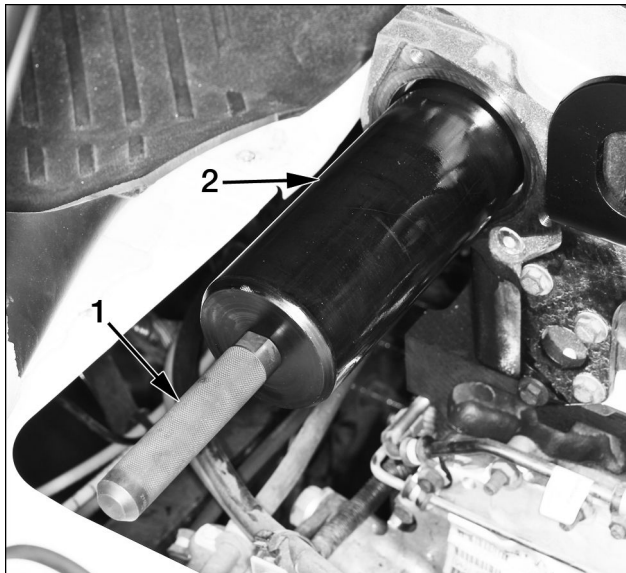


Figure 610 Rear of cylinder head

1. Short Handle
 2. Nose Cone
5. Install Nose Cone and the Short Handle onto rear of camshaft.

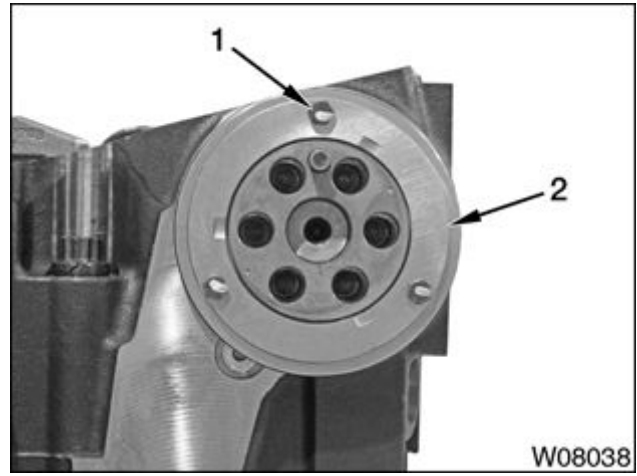


Figure 611 Thrust bearing plate bolts

1. 1/4 - 20 X 0.87 hex locking bolt (3)
 2. Thrust bearing plate
6. Remove three 1/4 - 20 X 0.87 hex locking bolts from the thrust bearing plate.

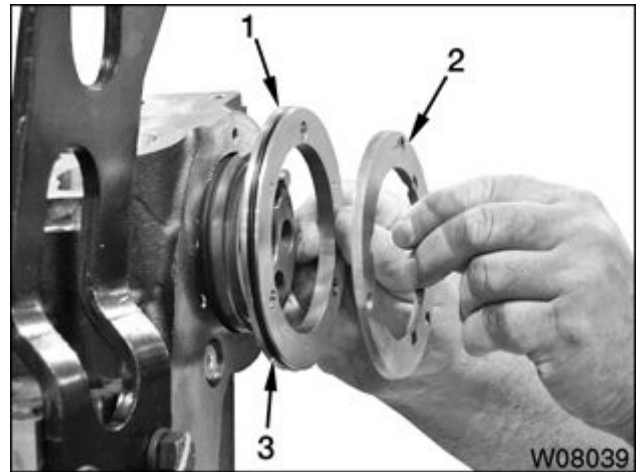


Figure 612 Camshaft thrust bearing and camshaft seal plates

1. Camshaft seal plate
 2. Thrust bearing plate
 3. O-ring (camshaft seal plate to front cover plate)
7. Remove thrust bearing plate.
 8. Remove the camshaft seal plate.
 9. Remove and discard the camshaft seal plate to front cover plate O-ring.

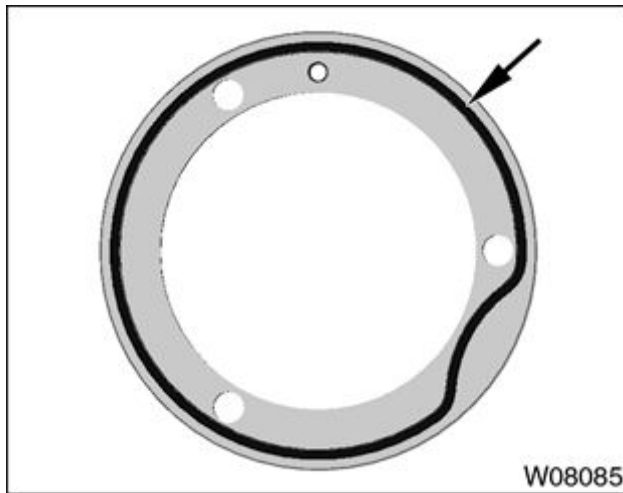


Figure 613 Camshaft seal plate to cylinder head O-ring

10. Remove and discard the camshaft seal plate to cylinder head O-ring.

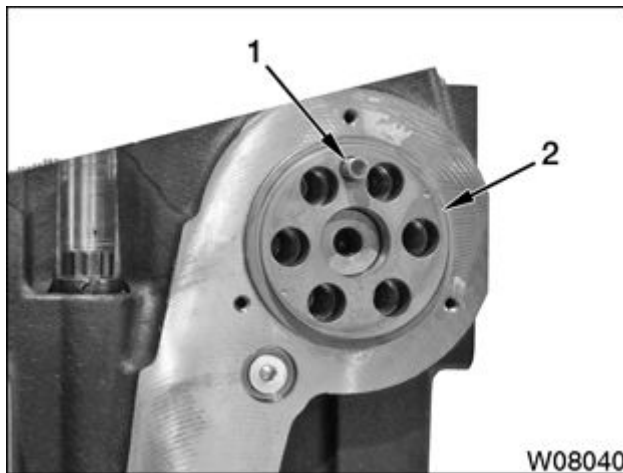


Figure 614 Camshaft drive adapter assembly

1. Dowel pin
2. Camshaft drive adapter assembly

11. Remove camshaft drive adapter assembly by hand.

12. If required, remove dowel pin.

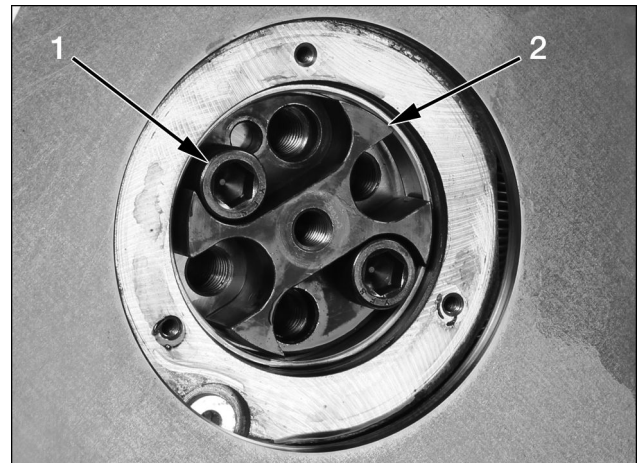


Figure 615 Front of camshaft

1. 5/8 x 1 1/4 socket head bolt (2)
2. Front Camshaft Adapter

13. Install Front Camshaft Adapter on front of camshaft with two 5/8 x 1 1/4 socket head bolts. Tighten bolts securely.

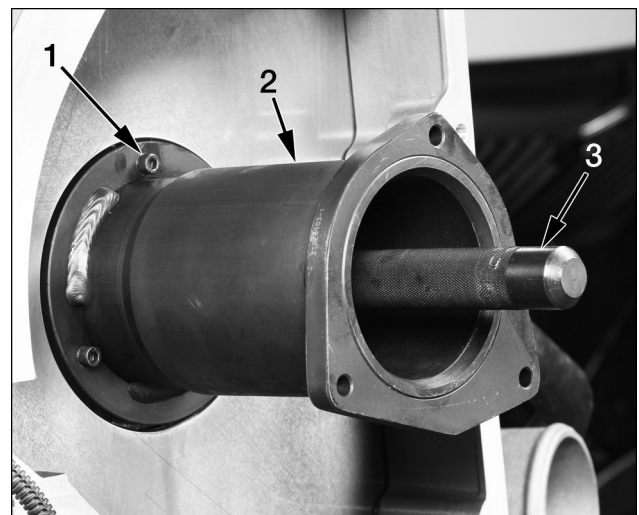


Figure 616 Front of cylinder head

1. 1/4 x 1 bolt (3)
2. Guide Assembly
3. Long Handle

14. Install the Long Handle onto the Front Camshaft Adapter.

15. Install Guide Assembly to the cylinder head with three 1/4 x 1 bolts. Tighten bolts finger tight.

! WARNING: Be prepared, the camshaft is heavy. To prevent personal injury or death, keep all body parts clear of pinch points and contact points in case the camshaft falls. Use assistance when needed to remove the camshaft.

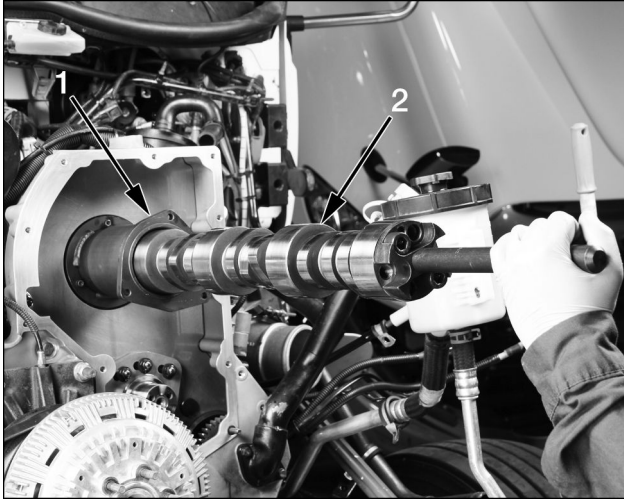


Figure 617 Camshaft removal

1. Guide Assembly
2. Camshaft

NOTE: To aid in camshaft removal, apply engine oil to camshaft journals, outside of Nose Cone and inside of Guide Assembly.

16. Remove Camshaft Position Retainer (Figure 607), and carefully remove camshaft from front of engine by slowly rotating the camshaft while pulling lightly.

Camshaft Bearings

NOTE: Do not remove the camshaft bearings (steps 2-6) unless they are out of Specifications (page 425).

1. Inspect the camshaft bearings. See Camshaft Bearings (page 403).

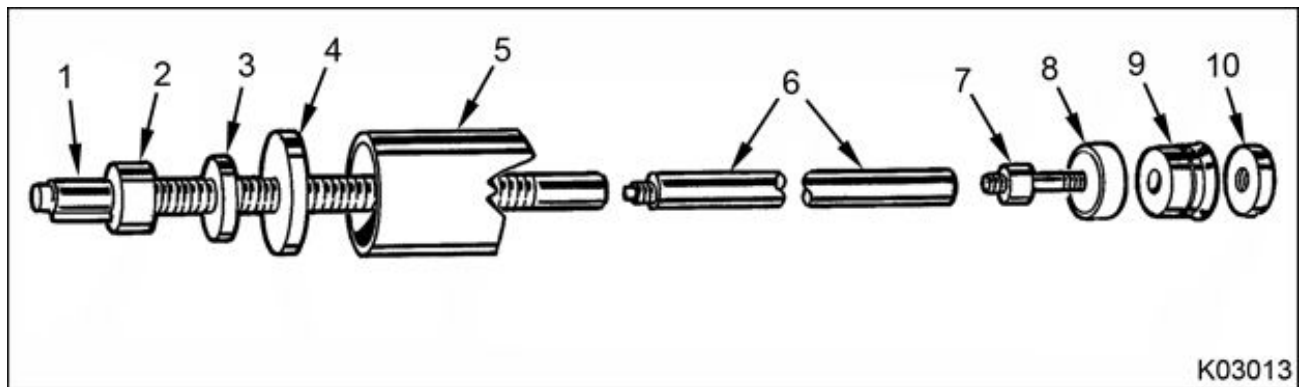


Figure 618 Cam Bushing Installation and Removal Tools

1. Puller screw	6. Extension tube	10. Backup nut
2. Pulling nut	7. Puller screw extension	
3. Thrust bearing	8. Camshaft bearing (not part of tool)	
4. Pulling plate	9. Expanding collet	
5. Pulling spacer		

2. Install the expanding collet into the rear (number 7 bearing) camshaft bearing from rear of engine.
3. Place the puller screw extension through expanding collet (from front of engine). Install backup nut on puller screw extension and tighten backup nut until collet expands into camshaft bearing.
4. Assemble the Cam Bushing Installer (page 427) and install extension tube onto the puller screw extension.
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. Working from the rear of the engine and removing the next rearmost camshaft bearing, repeat steps 1 through 4 for the remaining six camshaft bearings.

NOTE: Make sure pulling spacer is squarely mounted on the cylinder head before tightening pulling nut.

Cylinder Head

CAUTION: To prevent engine damage, remove injectors before removing cylinder head.

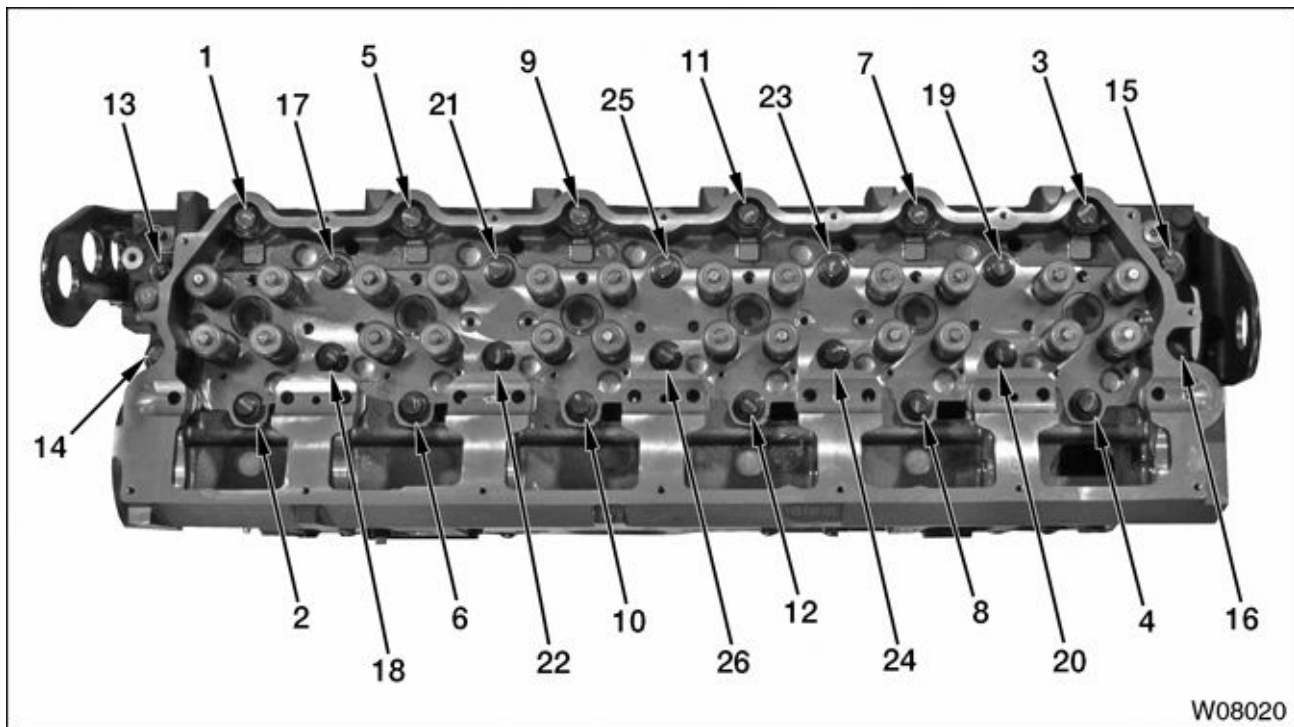


Figure 619 Cylinder head bolt loosening sequence

1. Use 3/4 inch 12 Point Socket (page 427) loosen and remove ten 3/4 - 16 X 8.5, sixteen 3/4 - 16 X 7.638 12 point bolts and twenty-six 20 X 33.5 X 5 hardened washers in sequence.



Figure 620 Cylinder head removal

2. Using Cylinder Head Lifting Brackets (page 427), lift cylinder head using a suitable lifting device.

CAUTION: To prevent engine damage, do not scratch gasket surface of cylinder head.

NOTE: Place cylinder head on wood blocks to protect valves and bottom deck surface.

3. Place cylinder head on a clean non-metallic surface. Support cylinder head with wooden blocks.

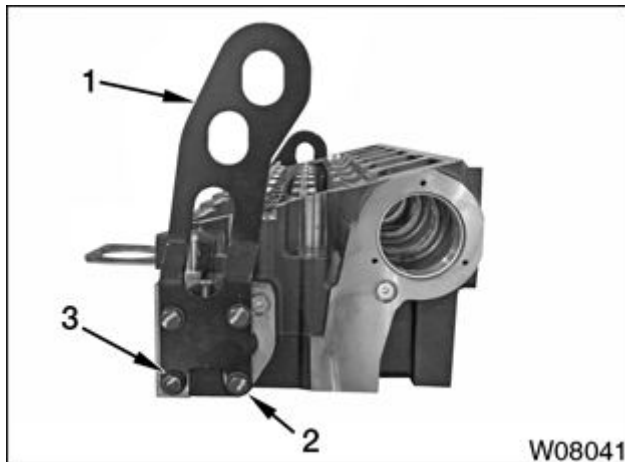


Figure 621 Front lifting eye

1. Lifting eye (front)
2. 1/2 - 13 X 1.25 hex bolt (4)
3. 13.5 X 25.5 X 3 hardened washer (4)

4. If required, remove four 1/2 - 13 X 1.25 hex bolts, four 13.5 X 25.5 X 3 hardened washers and the front lifting eye.

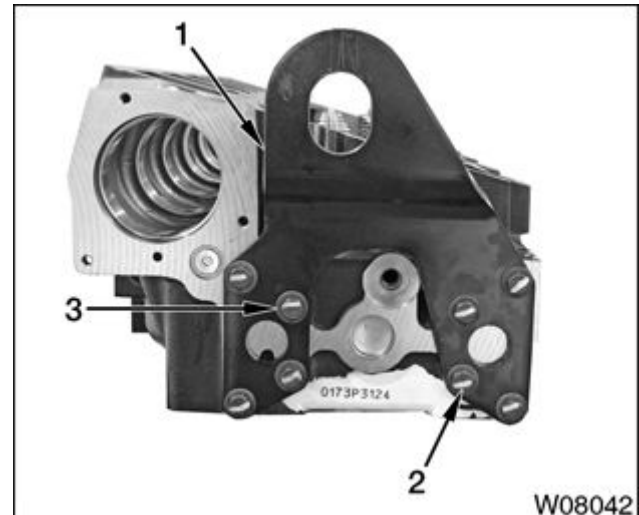


Figure 622 Rear lifting eye

1. Lifting eye (rear)
2. 3/8 - 16 X 1 hex bolt (8)
3. 10.2 X 18.5 X 2.5 hardened washer (8)

5. If required, remove eight 3/8 - 16 X 1 hex bolts, eight 10.2 X 18.5 X 2.5 hardened washers and the rear lifting eye.

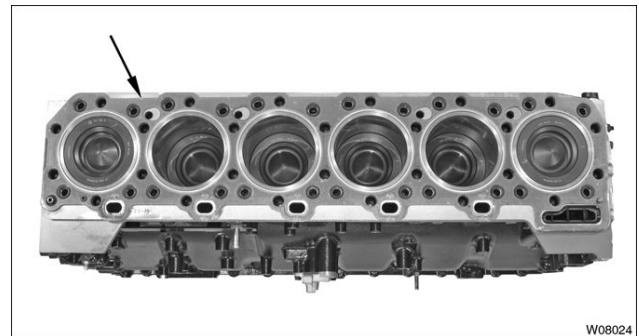


Figure 623 Cylinder head gasket removal

6. Remove and discard cylinder head gasket from the spacer plate.

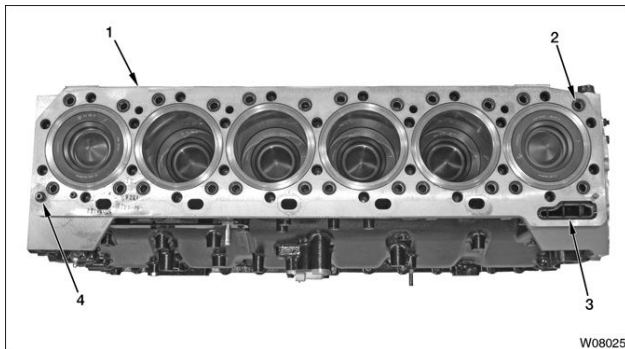


Figure 624 Spacer plate removal

1. Spacer plate
 2. Seal ring (24)
 3. Coolant passage insert assembly (used as an oil drain passage in this application)
 4. O-ring
7. Remove the O-ring from the front dowel pin.
 8. Remove the spacer plate.
 9. Remove twenty-four seal rings and the coolant passage insert assembly.

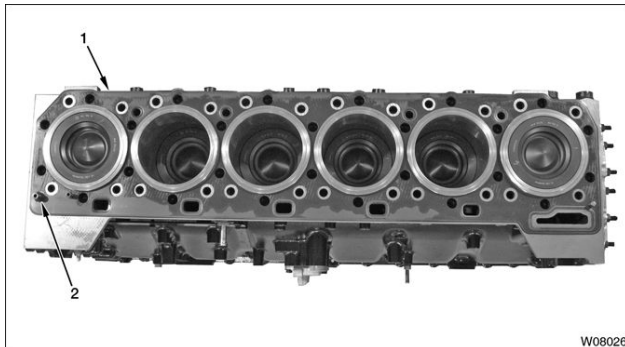


Figure 625 Spacer plate gasket removal

1. Spacer plate gasket
 2. O-ring
10. Remove the O-ring from the front dowel pin.
 11. Remove and discard the spacer plate gasket.
 12. If damaged, remove three dowel pins. See Crankcase Dowel Pins, Plugs and Fittings (page 508).

Replacing O-ring Boss Plugs and Cylinder head Cup Plugs

O-ring boss plugs

NOTE: O-ring boss plugs should only be removed if the O-ring boss plug or O-ring is leaking.

NOTE: O-ring boss plugs are used in various sizes and locations on the cylinder head. The procedure is the same for all O-ring boss plugs, but the torque specification is size-dependent; use the correct special torque (page 426) for the O-ring boss plug size.

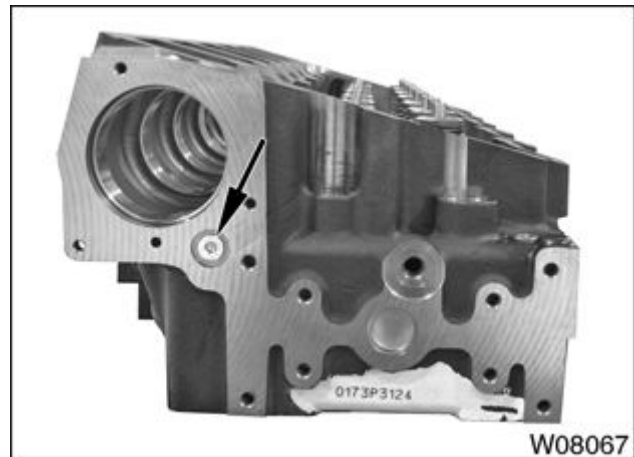


Figure 626 O-ring boss plug (typical)

1. Remove the O-ring boss plug.
2. Remove and discard the O-ring boss plug O-ring.
3. Lubricate O-ring boss plug O-ring with P-80® rubber lubricant or equivalent (page 427).
4. Install a new O-ring on the O-ring boss plug.
5. Install the O-ring boss plug. Tighten the O-ring boss plug to special torque (page 426).

Cup plugs

NOTE: Cylinder head cup plugs should only be removed if the cup plug is leaking.

NOTE: Cylinder head cup plugs are used in various sizes and locations on the cylinder head. The procedure is the same for all cup plugs.

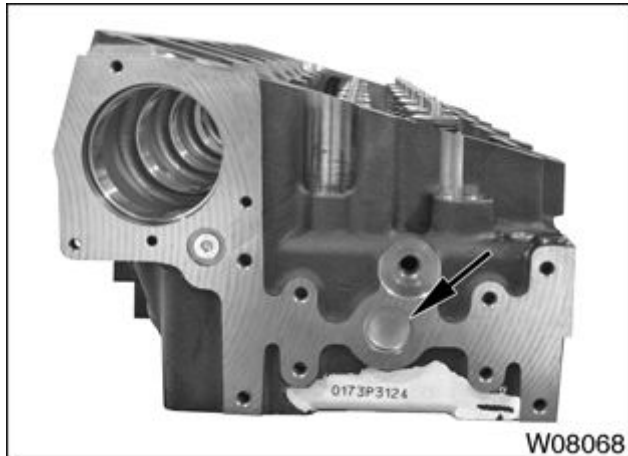


Figure 627 Cylinder head cup plug (typical)

1. Using a hammer and punch, punch a hole in the cylinder head cup plug.
2. Using a Slide hammer and appropriate size screw (page 427), remove the cylinder head cup plug.
3. Discard the cylinder head cup plug.
4. Apply Loctite® 120541 Core Plug Sealant (page 427) to the outer surface of the cylinder head cup plug.
5. Drive cup plug into the cylinder head using a punch approximately 6mm (0.25 in.) smaller in diameter than the plug being installed.
6. Recess cup plugs to just below machined surface or machined lead in chamfer.

Cleaning, Inspection, and Testing

Camshaft Lobes and Journals Measurement

1. Use a soft bristle brush and a suitable solvent to clean the camshaft.
2. Inspect camshaft for scuffed, scored, and cracked lobes. Replace camshaft if necessary.

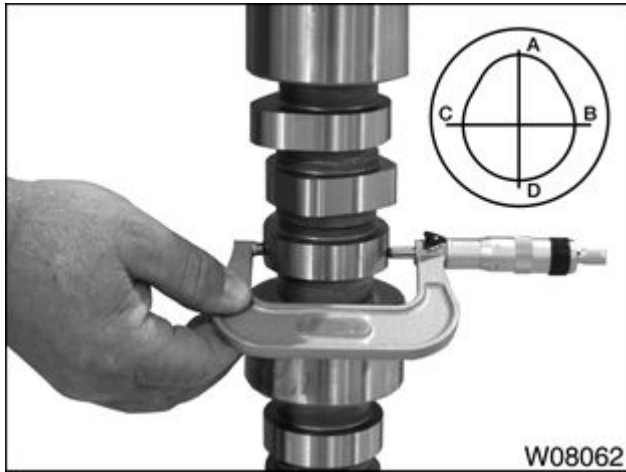


Figure 628 Camshaft lobe measurement

3. Measure across each intake and exhaust camshaft lobe from points A-D and B-C using an 2–3 inch micrometer (page 427).
4. Subtract measurement B-C from measurement A-D. This is lobe lift.
5. If any camshaft lobe lift measurement is 0.13 mm (0.005 in) or more below Specifications (page 425), replace camshaft.

NOTE: Due to the profile of the engine brake lobe, a dial indicator must be used to measure the lift.

6. Place the camshaft on V-blocks (page 427) and zero the dial indicator at the lowest spot.
7. Rotate the camshaft and measure the lift of the engine brake lobes.
8. If any journal measurement is below Specifications (page 425), replace the camshaft.

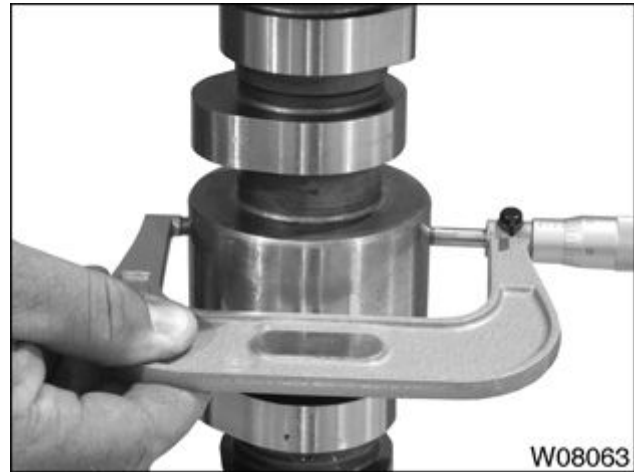


Figure 629 Camshaft journal measurement

9. Measure the diameter of each camshaft journal using a 3–4 inch micrometer (page 427).
10. If any journal measurement is below Specifications (page 425), replace the camshaft.

Cylinder Head and Crankcase Components

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

CAUTION: To prevent engine damage, do not use chlorinated solvents on bolts or crankcase tapped holes. Parts should be clean, dry, and free of any chemicals other than engine oil.

CAUTION: To prevent engine damage, do not scratch gasket surface of cylinder head.

1. Use a scraper and wire brush to remove deposits and gasket material from valve heads and gasket surface.
2. Use a suitable non-chlorinated solvent to remove dirt, grease, and deposits from removed parts.
3. Clean all bolt holes. Make sure gasket surfaces, and oil return passages are clean. Clean all surfaces and ports with steam, and then dry with filtered compressed air.
4. Clean all bolts with a suitable non-chlorinated solvent and dry thoroughly.

CAUTION: To prevent engine damage, clean and dry threads in crankcase bolt holes with filtered compressed air. Dirt or oil in holes may cause binding and incorrect torque readings.

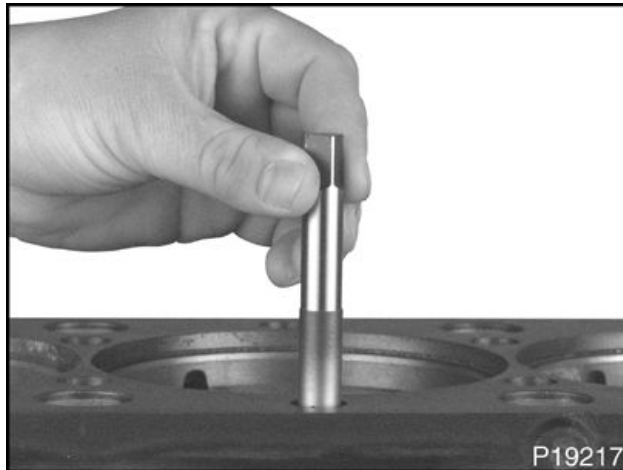


Figure 630 Head bolt bottoming tap

5. Clean cylinder head bolt holes in crankcase with Head and Main Bolt Bottoming Tap Kit (page 427).
6. Clean out debris with filtered compressed air.

Camshaft Bearings

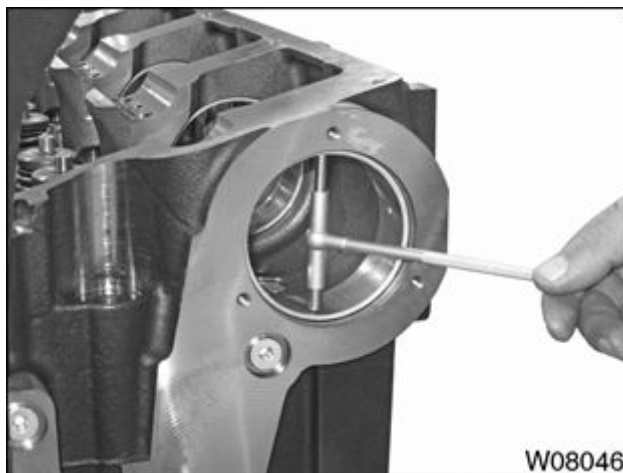


Figure 631 Camshaft bearing check (typical)

1. With camshaft removed, use a telescoping gauge set (page 427) and a 3–4 inch micrometer (page 427) to measure camshaft bearing inside diameter. If inside diameter does not meet Specifications (page 425), install new camshaft bearings

Fuel Injector Bore

1. Use Injector Sleeve Brushes (page 427) in injector bore to remove deposits.

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

2. Use filtered compressed air to clean out debris from injector bores.

Fuel Injector Harness

Inspect injector wire harness for kinked wires or terminals. Replace harness if kinks are found. Kinked wires can result in oil leak between the harness protective foam covering and the wires.

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, cylinder head assembly should be replaced.

Measuring Rocker Shaft

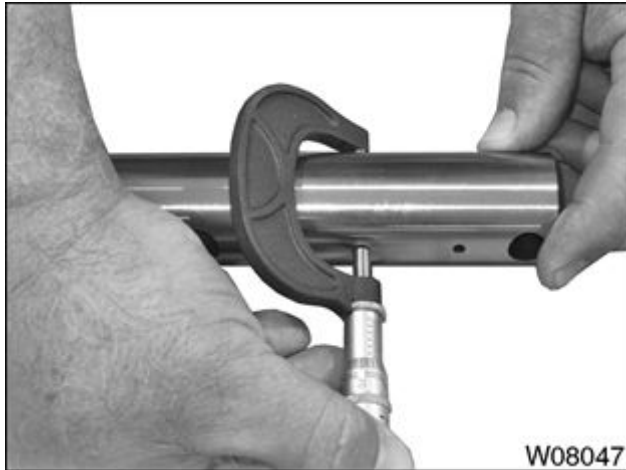


Figure 632 Rocker arm shaft measurement

1. Inspect rocker shaft for scoring, pitting, and wear. Replace rocker arm shaft 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 1–2 inch micrometer (page 427). This dimension will be used as a baseline for shaft diameter.
3. Measure each of the six rocker arm contact areas of rocker arm shaft with a micrometer. If the difference between the baseline measurement and any of the contact area measurements is greater than Specifications (page 425), replace the rocker shaft and inspect all rocker arms (page 404).
4. Repeat steps 1 to 3 for each rocker shaft.

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.

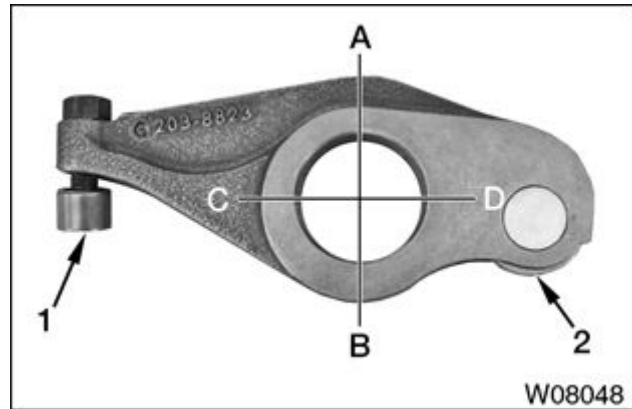


Figure 633 Rocker arm bore measurement (typical)

1. Valve lash adjuster screw
2. Rocker arm roller

NOTE: Rocker arms must be labeled and installed in their original locations to maintain proper wear patterns.

2. Use a telescoping gauge (page 427) and 1–2 inch micrometer (page 427) 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 rocker arm bore out of round Specifications (page 425), replace rocker arm.
3. If either measurement exceeds rocker arm bore diameter Specifications (page 425), replace rocker arm.
4. Inspect eighteen rocker arm rollers for scoring, pitting, or signs of excessive wear. Replace rocker arms if necessary.
5. Inspect valve lash adjuster screw for wear. Replace adjuster screw if excessively worn.

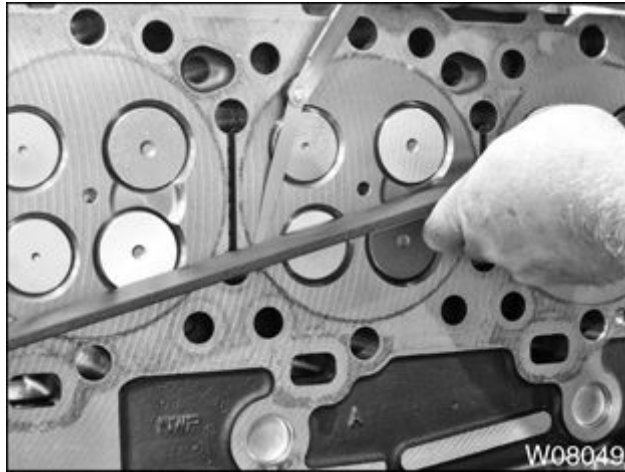
Measuring Cylinder Head Warpage

Figure 634 Cylinder head warpage measurement (typical)

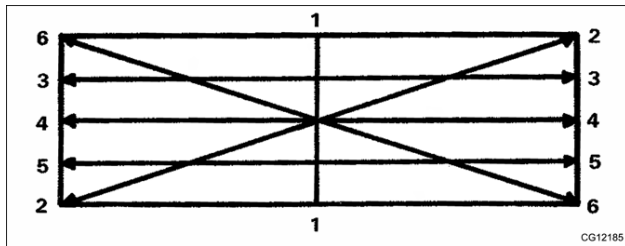


Figure 635 Cylinder head warpage measurement pattern

Use a straight edge (page 427) and feeler gauge set (page 427) to measure cylinder head gasket surface for warpage. If warpage exceeds cylinder head gasket surface flatness Specifications (page 425), replace cylinder head.

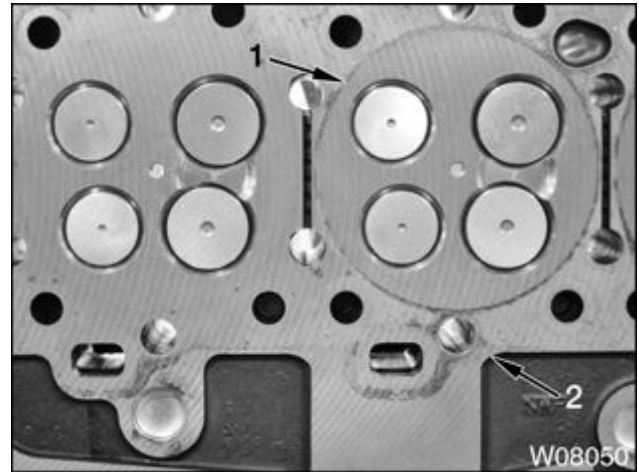


Figure 636 Cylinder head deck brinelling

1. Brinelling (indentation area)
2. Cylinder head deck

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 425)

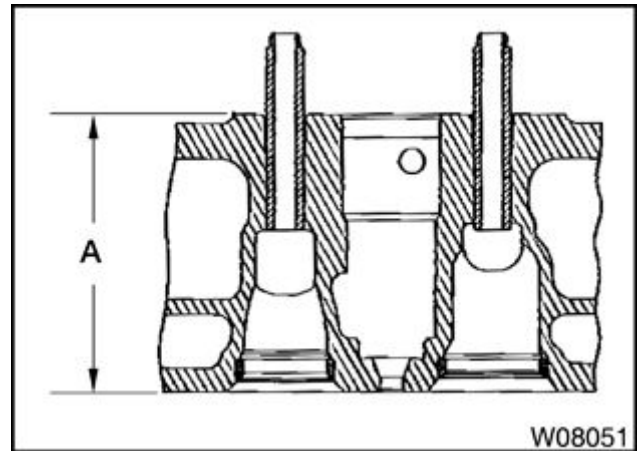
Measuring Cylinder Head Thickness

Figure 637 Cylinder head thickness measurement

Use a 6–7 inch micrometer (page 427) to measure cylinder head thickness at six locations (as shown at each set of valves). All cylinder head thickness measurements must equal or exceed minimum

Specifications (page 425) after resurfacing. Replace cylinder head if under minimum specification.

Inspecting Cylinder Head for Cracks

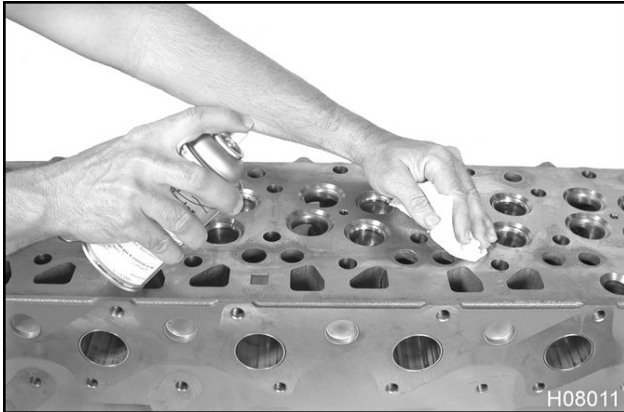


Figure 638 Spraying cleaner on cylinder head (typical)

NOTE: Cylinder head crack inspection can be performed with or without valves installed.

1. Spray cleaner, from dye penetrant kit (page 427), on cylinder head gasket surface and wipe dry.

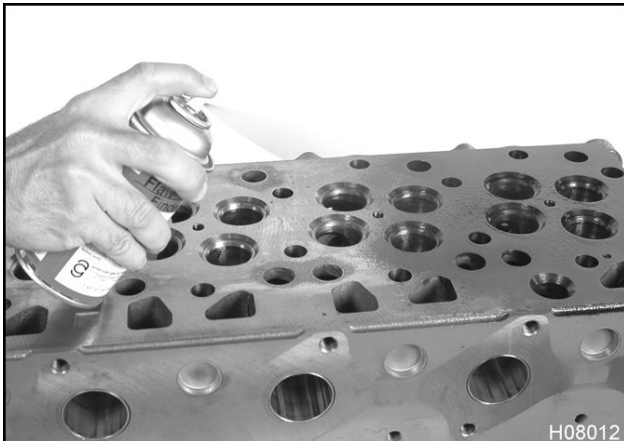


Figure 639 Spraying dye penetrant on cylinder head (typical)

2. Spray dye penetrant, from dye penetrant kit (page 427), on cylinder head gasket surface. Leave dye penetrant on for 1 to 10 minutes.

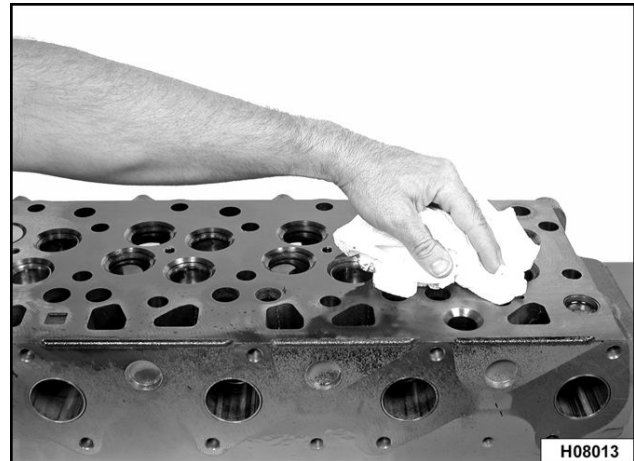


Figure 640 Wiping dye penetrant off cylinder head (typical)

3. Wipe off dye penetrant after 1 to 10 minutes. Dye will remain in any cracks in the cylinder head.



Figure 641 Spraying developer on cylinder head (typical)

4. Spray developer, from dye penetrant kit, on cylinder head gasket surface. Allow developer to dry for 5 to 15 minutes.

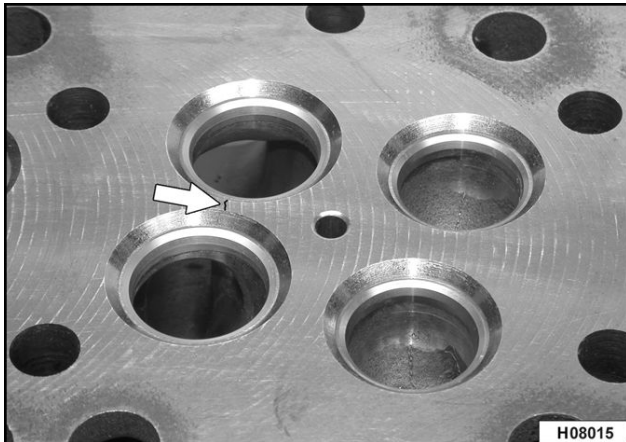


Figure 642 Crack in cylinder head (example)

NOTE: Any cracks will show up as purple lines against the white developer. If any cracks are present, replace cylinder head.

Installation

Cylinder Head

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

CAUTION: To prevent engine damage, 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.

CAUTION: To prevent engine damage, clean and blow dry threads in the crankcase bolt holes with filtered compressed air. Dirt or oil in holes may cause binding or an incorrect torque reading.

CAUTION: To prevent engine damage, remove debris from cylinder head. If debris is not removed, a faulty seal between the cylinder head and gasket will cause oil, coolant, and compression leaks. Do not apply sealant to head gasket surfaces.

1. If removed, install three dowel pins into top of crankcase. See Crankcase Dowel Pins, Plugs and Fittings (page 516).

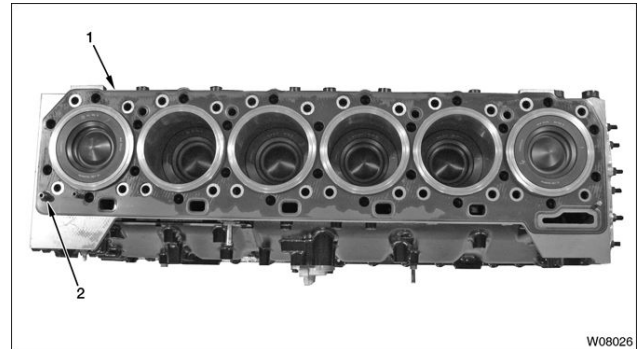


Figure 643 Spacer plate gasket installation

1. Spacer plate gasket
2. O-ring

2. Install the O-ring on the front dowel pin.
3. Install a new spacer plate gasket.

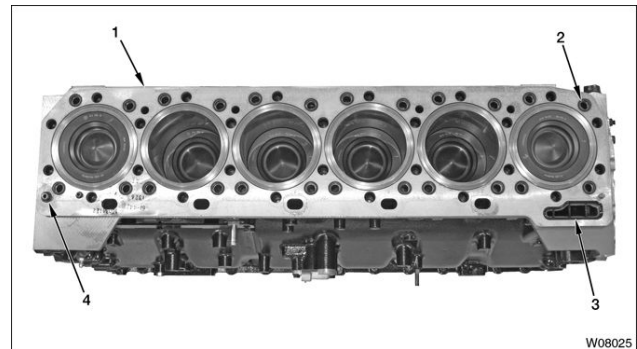


Figure 644 Spacer plate installation

1. Spacer plate
2. Seal ring (24)
3. Coolant passage insert assembly (used as an oil drain passage in this application)
4. O-ring

4. Select the appropriate spacer plate thickness. See Cylinder Sleeve Protrusion Measurement (page 488).
5. Install the spacer plate.
6. Install the O-ring on the front dowel pin.
7. Install twenty four seal rings and the coolant passage insert assembly.

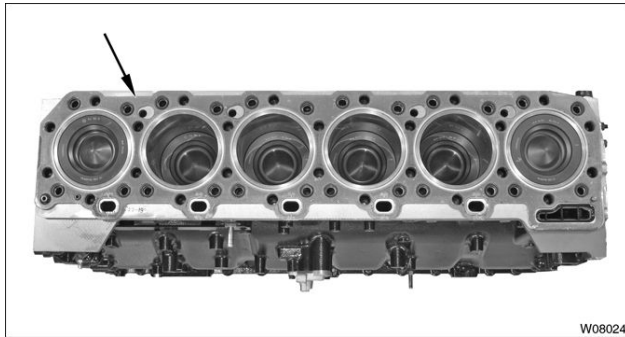


Figure 645 Cylinder head gasket installation

8. Install a new cylinder head gasket on the spacer plate.

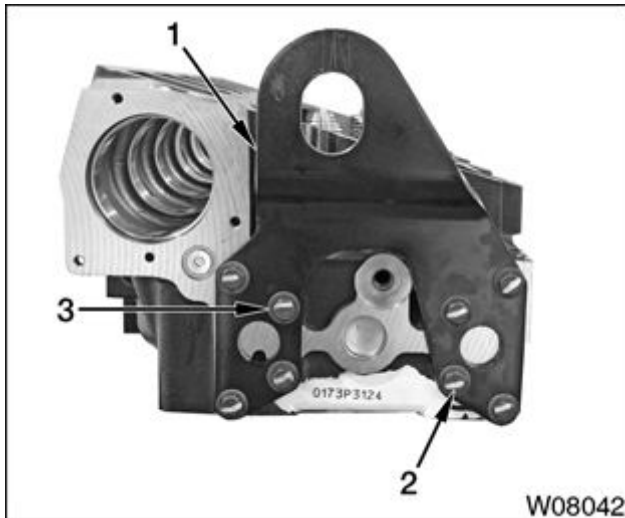


Figure 646 Rear lifting eye

1. Lifting eye (rear)
 2. 3/8 - 16 X 1 hex bolt (8)
 3. 10.2 X 18.5 X 2.5 hardened washer (8)
9. If removed, install the rear lifting eye, eight 10.2 X 18.5 X 2.5 hardened washers and eight 3/8 - 16 X 1 hex bolts. Tighten the 1/2 - 13 X 1.25 hex bolts to standard torque (page 562).

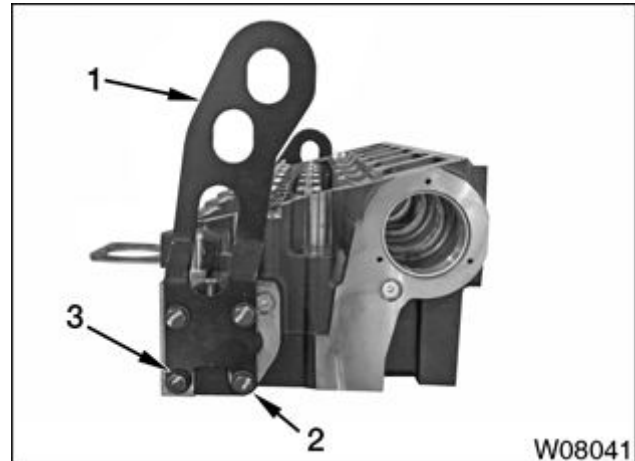


Figure 647 Front lifting eye

1. Lifting eye (front)
2. 1/2 - 13 X 1.25 hex bolt (4)
3. 13.5 X 25.5 X 3 hardened washer (4)

10. If removed, install the front lifting eye, four 13.5 X 25.5 X 3 hardened washers and four 1/2 - 13 X 1.25 hex bolts. Tighten the 1/2 - 13 X 1.25 hex bolts to standard torque (page 562).

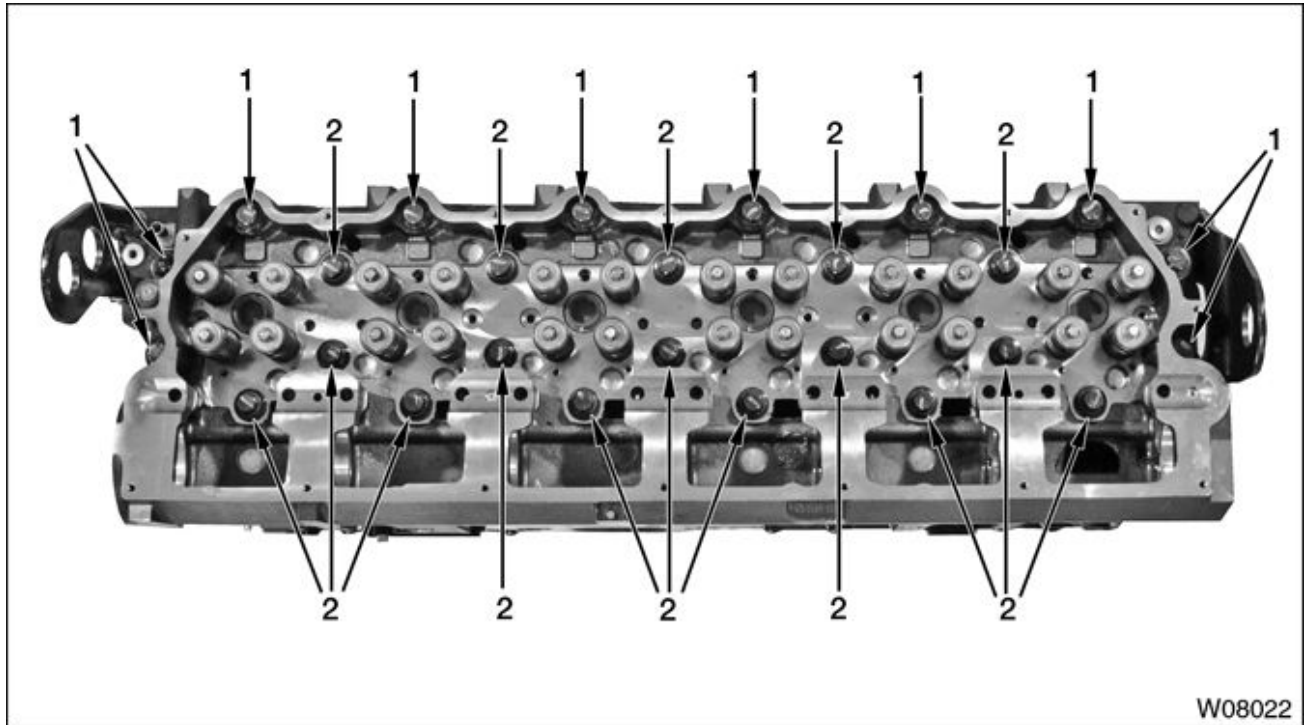


Figure 648 Cylinder head installation

CAUTION: To prevent engine damage, do not drop or slide cylinder head on cylinder head gasket. This will damage the cylinder head gasket and dowel pins.

CAUTION: To prevent engine damage, do not scratch gasket surface of cylinder head.

11. Using Cylinder Head Lifting Brackets (page 427), install the cylinder head over the three dowel pins and onto the crankcase.



W08022

Figure 649 Cylinder head bolt locations

1. 3/4 - 16 X 8.5 12 point bolt and washer (10 each)	2. 3/4 - 16 X 7.638 12 point bolt and washer (16 each)

CAUTION: To prevent engine damage, install new head bolts.

12. Lubricate both sides of the hardened washers and bolt heads and the bolt threads with Molykote Paste Lubricant 6V-4876 (page 427).

13. Loosely install twenty six new 20 X 33.5 X 5 hardened washers, ten new 3/4 - 16 X 8.5 and sixteen new 3/4 - 16 X 7.638 12 point bolts.

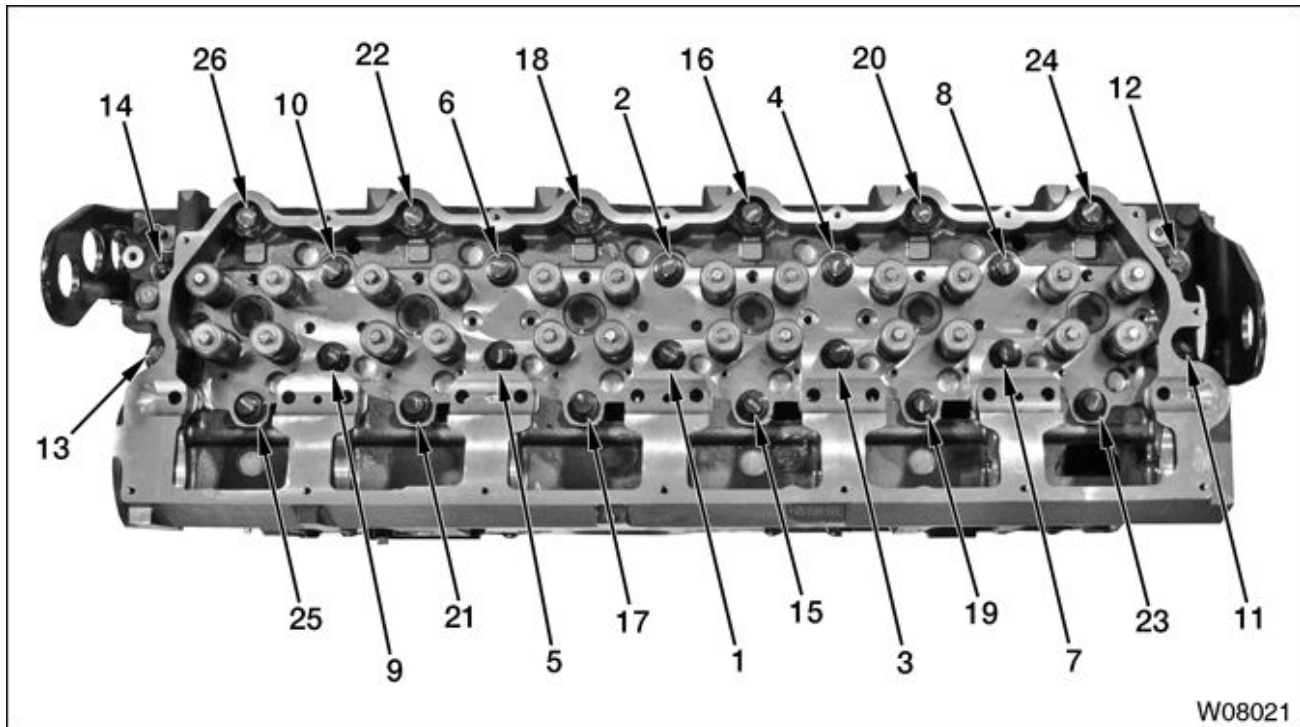


Figure 650 Cylinder head bolt tightening sequence

14. Using a 3/4 inch 12 Point Socket (page 427) tighten 12 point bolts in three stages.

- a. Tighten the 12 point bolts in the sequence shown to 270 N·m (200 lbf·ft).
- b. Tighten the 12 point bolts in the sequence shown to 450 N·m (330 lbf·ft).
- c. Retighten the 12 point bolts in the sequence shown to 450 N·m (330 lbf·ft).

Camshaft and Bearings

Camshaft Bearings

1. If removed install new camshaft bearings.

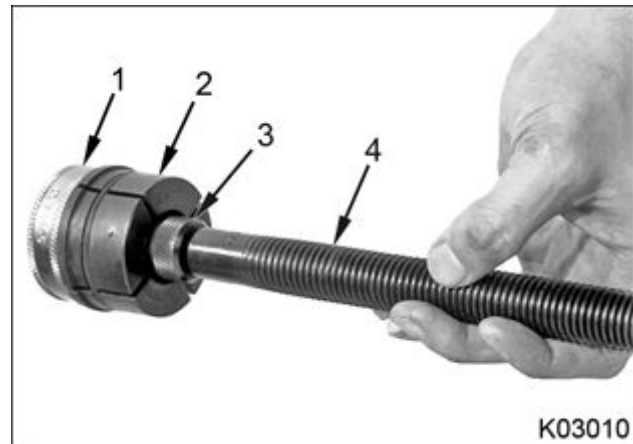


Figure 651 Camshaft Bushing Installer

1. Backup nut
 2. Expanding collet
 3. Puller screw extension
 4. Puller shaft
2. Install a new camshaft bearing on the Cam Bushing Installer (page 427).
 3. Tighten expanding collet by turning backup nut until camshaft bearing is held securely.



Figure 652 Camshaft bearing oil slot location mark

4. Mark each camshaft bearing oil slot location on the backup nut of the Cam Bushing Installer to insure bearing oil slot gets installed in the optimum bearing lubrication position.

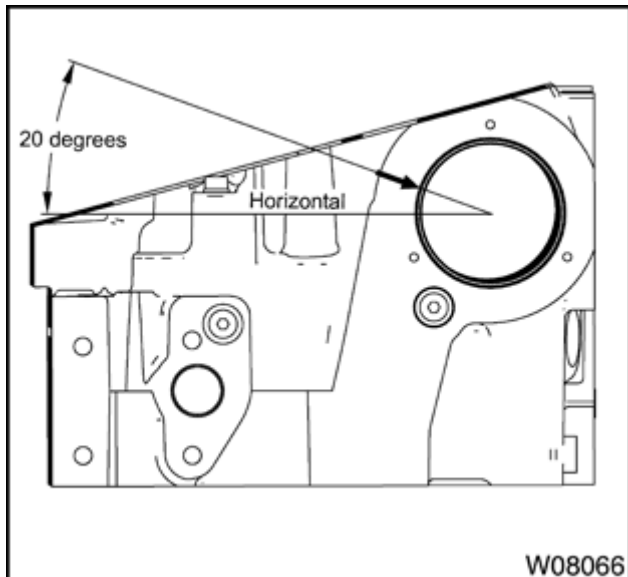


Figure 653 Camshaft bearing joint location

CAUTION: To prevent engine damage, the camshaft bearing joint must be oriented as shown when viewed from the front of the cylinder head.

5. Install the rear camshaft bearing (number 7) through rear of the cylinder head. Make sure the camshaft bearing is pulled completely into the

cylinder head. Align camshaft bearing oil slots with oil holes in the cylinder head for each bearing location.

6. Pull camshaft bearing in place with proper oil slot and bearing joint orientation from the front of the cylinder head by turning the pulling nut on the puller screw.
7. Remove the Cam Bushing Installer (page 427) and verify camshaft bearing oil slot and annulus alignment.
8. Working from the next rearmost camshaft bearing, repeat steps 2 through 7 until all 7 bearings are installed in the cylinder head.

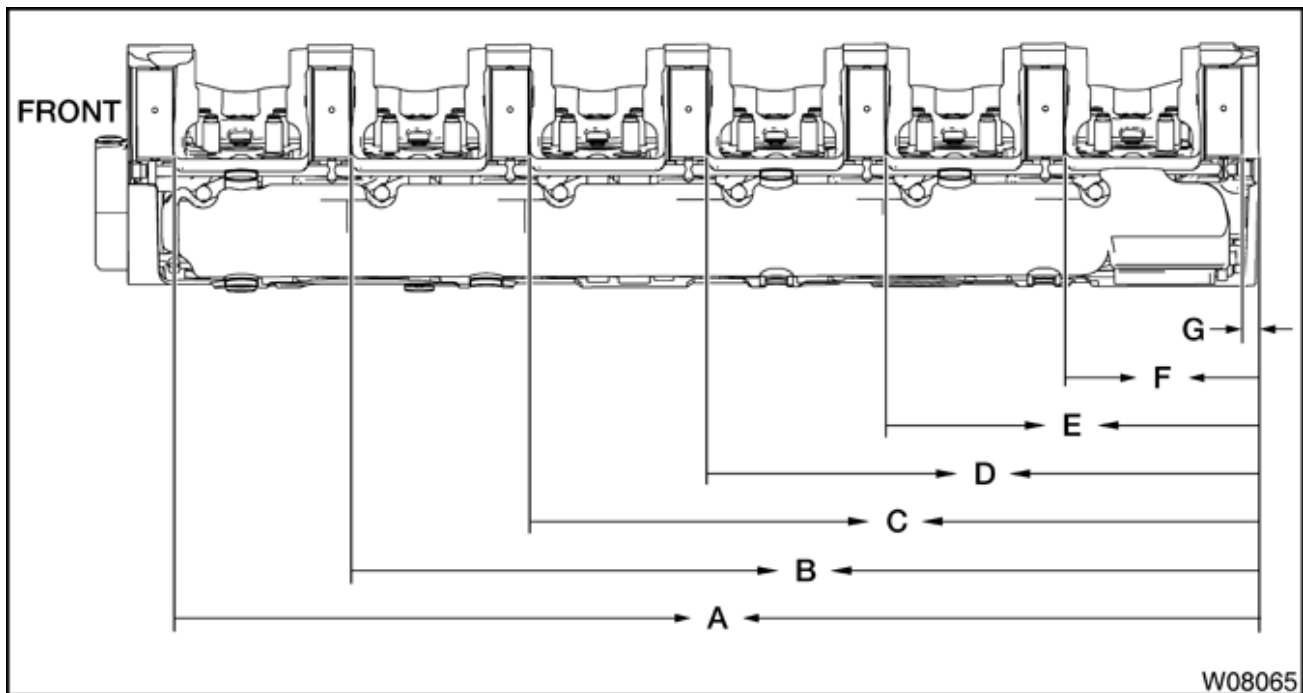


Figure 654 Camshaft bearing offset from rear of cylinder head

a. 1034.8 - 1035.8 mm (40.74 - 40.78 inch)	d. 520.5 - 521.5 mm (20.49 - 20.53 inch)	g. 7.5 - 8.5 mm (0.29 - 0.33 inch)
b. 863.3 - 864.3 mm (33.99 - 34.03 inch)	e. 349.0 - 350.0 mm (13.74 - 13.78 inch)	
c. 691.9 - 692.9 mm (27.24 - 27.28 inch)	f. 177.6 - 178.6 mm (6.99 - 7.03 inch)	

9. Make sure that each camshaft bearing is correctly positioned by measuring from the rear of the cylinder head to the rear face of each bearing.
10. If any bearing is incorrectly positioned, use the Cam Bushing Installer (page 427) to correctly position the bearing.

Camshaft

1. Obtain the Camshaft Remover/Installer (page 427).

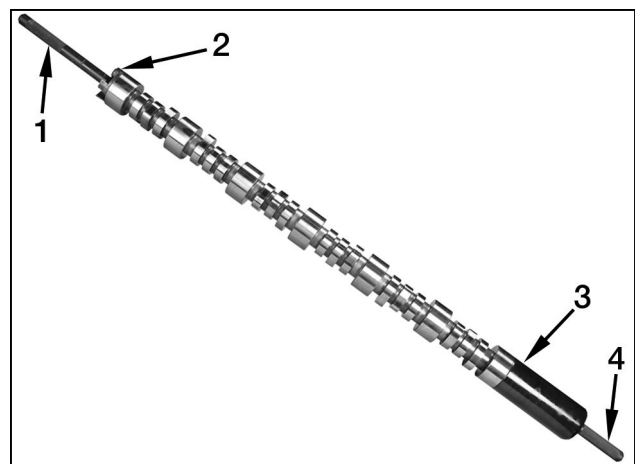


Figure 655 Camshaft with tools installed

1. Long Handle
2. Front Camshaft Adapter
3. Nose Cone
4. Short Handle

2. Install Front Camshaft Adapter and Long Handle onto front of camshaft.
3. Install the Nose Cone and Short Handle onto rear of camshaft.
4. Install the Guide Assembly to front of cylinder head with three 1/4 x 1 bolts. Tighten bolts finger tight.

NOTE: Apply clean engine oil to outside of Nose Cone, inside of Guide Assembly, camshaft lobes and bearings to aid in camshaft installation.

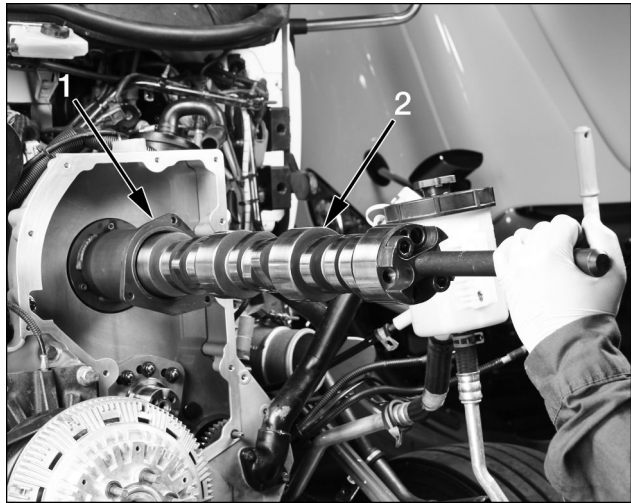


Figure 656 Camshaft installation

1. Guide Assembly ZTSE6103-1
 2. Camshaft
5. Carefully slide the camshaft through the Guide Assembly into the cylinder head while slowly rotating and pushing the camshaft lightly

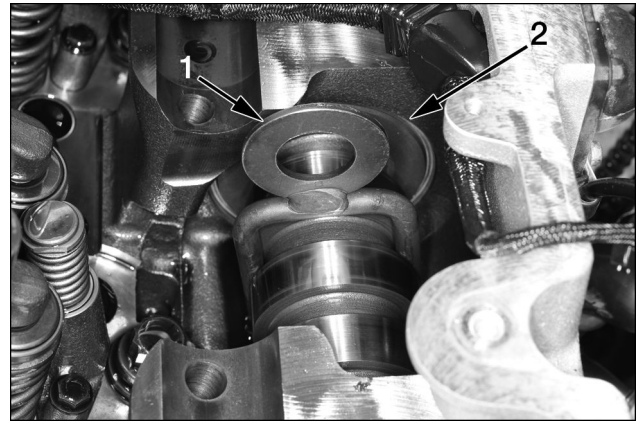


Figure 657 Camshaft Position Retainer

1. Camshaft Position Retainer
 2. Main bearing journal
6. Install Camshaft Position Retainer between engine brake lobe and intake lobe to prevent the camshaft from moving.
 7. Leave Camshaft Position Retainer in position and remove all other tools.

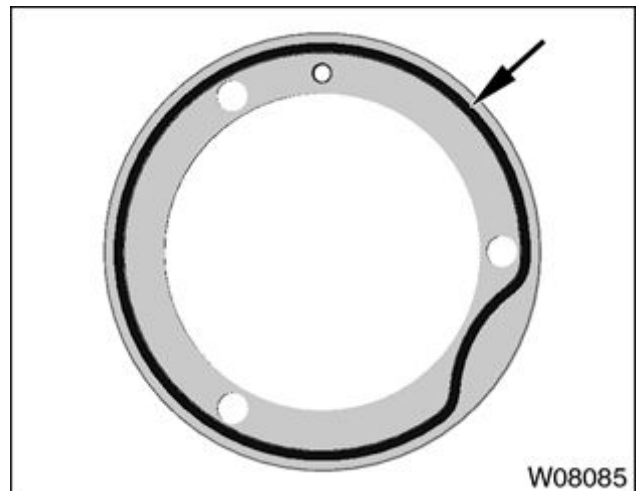


Figure 658 Camshaft seal plate to cylinder head O-ring

NOTE: Lubricate the camshaft seal plate to cylinder head O-ring with clean engine oil prior to installation.

8. Install a new camshaft seal plate to cylinder head O-ring into the camshaft seal plate.

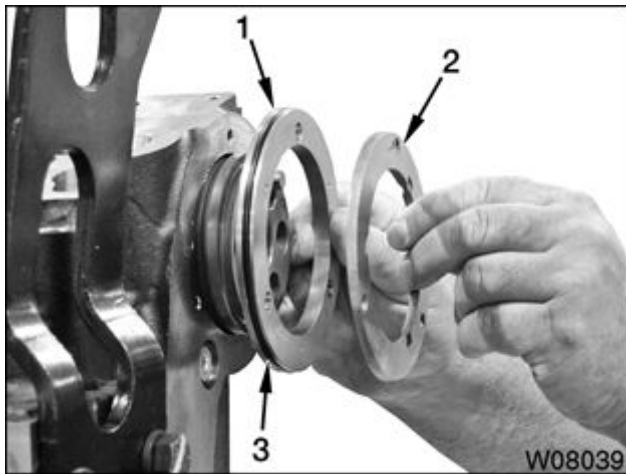


Figure 659 Camshaft thrust bearing and camshaft seal plates

1. Camshaft seal plate
2. Thrust bearing plate
3. O-ring (camshaft seal plate to front cover plate)

NOTE: Lubricate the camshaft seal plate to front cover plate O-ring with clean engine oil prior to installation.

9. Install a new camshaft seal plate to front cover plate O-ring.

CAUTION: Make sure that the camshaft seal plate to cylinder head O-ring is oriented so that deviation in the O-ring path is inboard of the O-ring boss plug and is in contact with the cylinder head sealing surface. Incorrect orientation will cause the camshaft seal plate to cylinder head O-ring to cross the O-ring boss plug and the O-ring will not seal.

10. Install the camshaft seal plate.
11. Install thrust bearing plate.

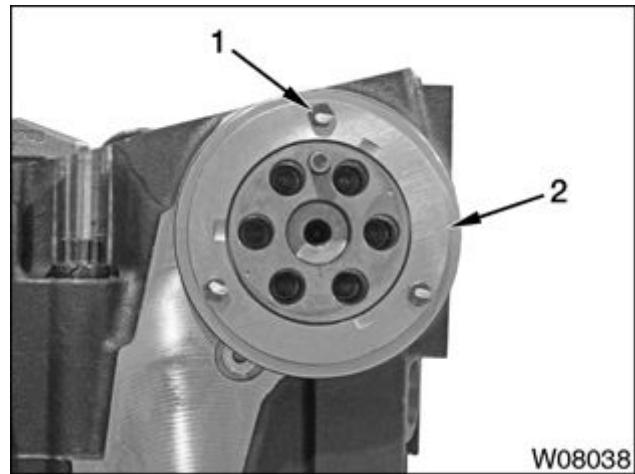


Figure 660 Thrust bearing plate bolts

1. 1/4 - 20 X 0.87 hex locking bolt (3)
2. Thrust bearing plate

12. Apply Loctite® 242 (page 427) to the 1/4 - 20 X 0.87 hex locking bolt threads.
13. Install three 1/4 - 20 X 0.87 hex locking bolts in the thrust bearing plate. Tighten the 1/4 - 20 X 0.87 hex locking bolts to standard torque (page 562).

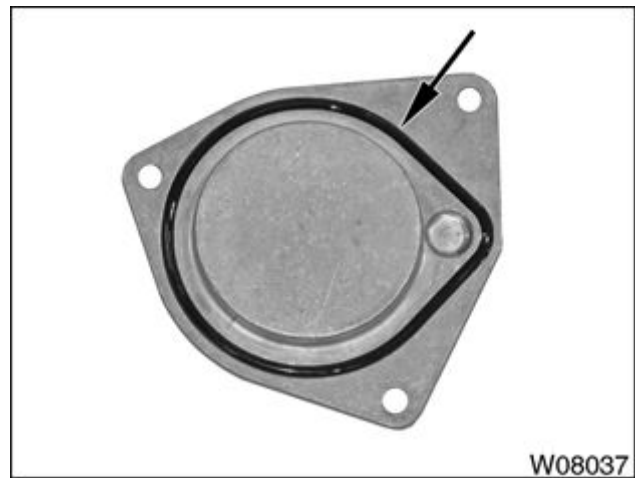


Figure 661 Rear camshaft cover O-ring

NOTE: Lubricate the rear camshaft cover O-ring with clean engine oil prior to installation.

14. Install a new rear camshaft cover O-ring.

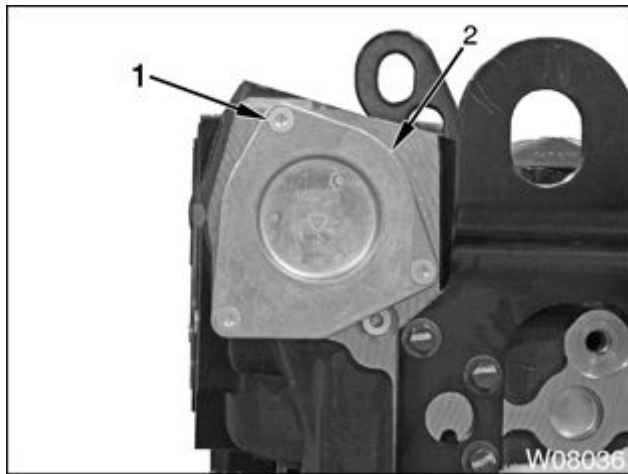


Figure 662 Rear camshaft cover installation

1. 5/16 - 18 X 0.87 Torx screw (3)
 2. Cover (camshaft rear)
15. Install the rear camshaft cover and three 5/16 - 18 X 0.87 Torx screws. Tighten the 5/16 - 18 X 0.87 Torx screws to special torque (page 426).
 16. Remove Camshaft Position Retainer from camshaft (Figure 657).

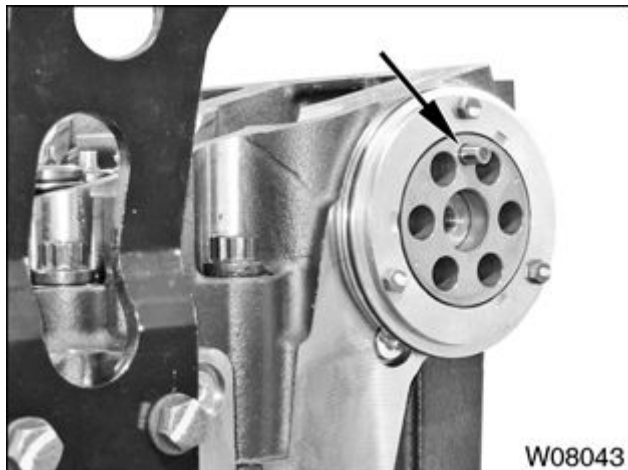


Figure 663 Camshaft dowel pin position

17. Turn the camshaft to position the dowel pin at the top of the camshaft rotation.

Rocker Arms

1. Install six lost motion pedestals. See Lost Motion Pedestals (page 364).

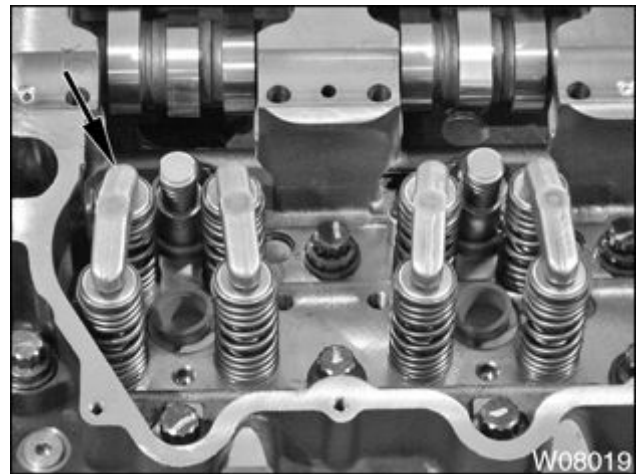


Figure 664 Valve bridges (typical)

2. Install twelve valve bridges in their original location.

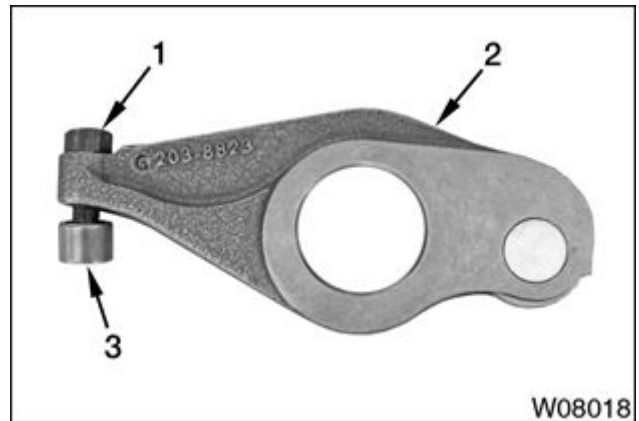


Figure 665 Rocker arm (typical)

1. Arm adjustment nut (typical)
 2. Rocker arm assembly (typical)
 3. Arm adjustment screw assembly (typical)
3. If removed, loosely install the 3/8 - 24 nut and arm adjustment screw assembly 3/8 - 24 X 1.2 in the valve rocker arm assemblies.
 4. If removed, loosely install the 9/16 - 18 nut and arm adjustment screw assembly 9/16 - 18 in the engine brake rocker arm assemblies.

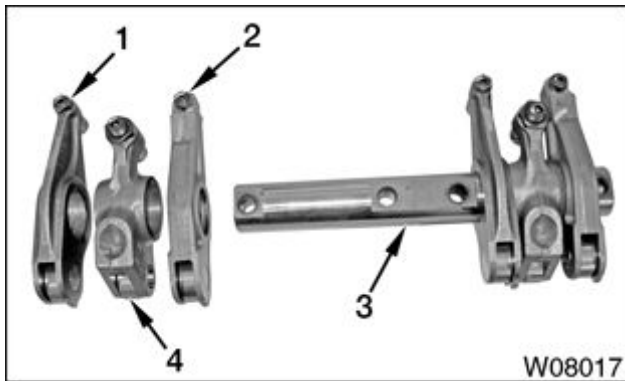


Figure 666 Rocker arm assembly (typical)

1. Valve rocker arm assembly (exhaust) (6)
2. Valve rocker arm assembly (intake) (6)
3. Rocker shaft assembly (3)
4. Engine brake rocker arm assembly (6)

NOTE: Lubricate the rocker arm assembly bearing bores with clean engine oil prior to installation.

5. Install two exhaust rocker arm assemblies, two engine brake rocker arm assemblies, and two intake rocker arm assemblies on each rocker shaft assembly in their original locations.

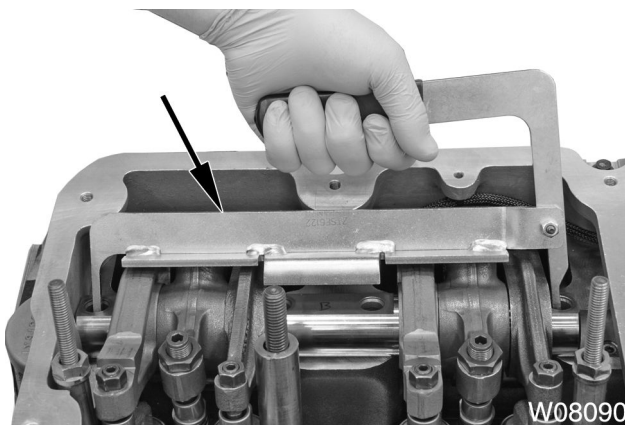


Figure 667 Rocker Arm Lifting Bracket Assembly

6. Install rocker arm assembly in original location on cylinder head using Rocker Arm Lifting Bracket Assembly (page 427).

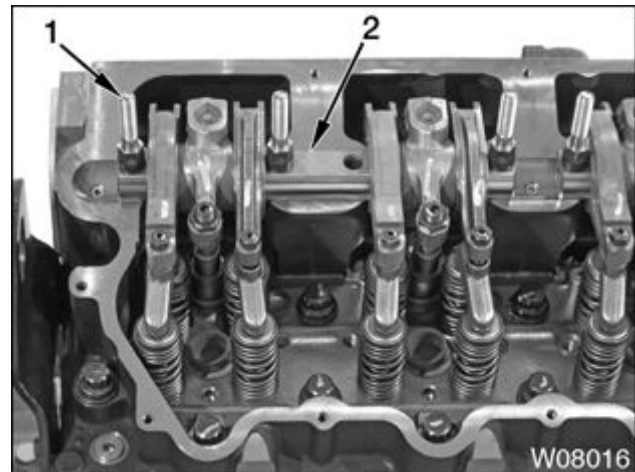


Figure 668 Rocker arm assembly (typical)

1. Hex flange stud (9)
2. Rocker arm assembly (3)

! WARNING: To prevent personal injury or death, the rocker arm assembly should be kept level when removed or installed on engine. Rocker arms can move or slide off the rocker shaft after the hex flange studs are removed.

7. Install nine hex flange studs into the locations shown.
8. Tighten the hex flange studs to 50 N·m (37 lbf·ft).
9. Tighten the hex flange studs an additional 45 degrees (1/8 turn).
10. Adjust the valve rocker arm and the engine brake rocker arm lash using procedures in Valve Lash Adjustment (page 379).

Fuel Injectors

CAUTION: To prevent engine damage, do not use power tools.

CAUTION: To prevent engine damage, install new injector O-ring and sealing washer before installing injector.

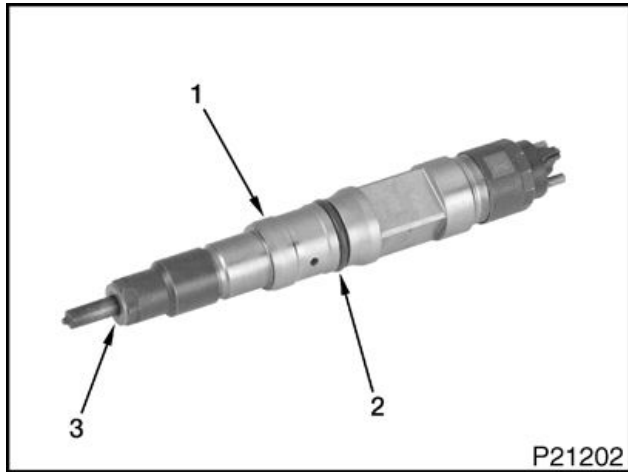


Figure 669 Injector seals (typical)

1. Injector
2. O-ring
3. Combustion gasket

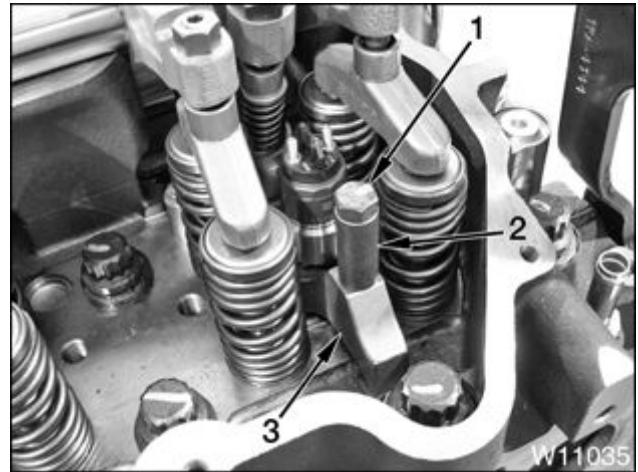


Figure 670 Injector clamp (typical)

1. 3/8 - 16 X 4 hex bolt (6)
2. 9.8 X 15.85 X 37.6 spacer (6)
3. Injector clamp (6)

1. Remove and discard O-ring from each fuel injector.
2. Install a new O-ring on each fuel injector. Lubricate O-ring with clean engine oil.
3. Install a new combustion gasket on each fuel injector.
4. Remove Disposable Air and Fuel Caps (page 427) from cylinder head injector bore.

CAUTION: To prevent engine damage, align injector correctly with cylinder head so injector tube inlet port aligns with pressure pipe holes in cylinder head; do not twist injector when inserting injector into cylinder head.

5. Install injectors so injector tube inlet port aligns with pressure pipe holes in cylinder head.

6. Install six injector clamps, six 9.8 X 15.85 X 37.6 spacers, and six 3/8 - 16 X 4 hex bolts. Tighten 3/8 - 16 X 4 hex bolts to 36 N·m (24 lbf·ft) to seat the injector.
7. Back off 3/8 - 16 X 4 hex bolts, just until loose enough to allow injectors to move freely.

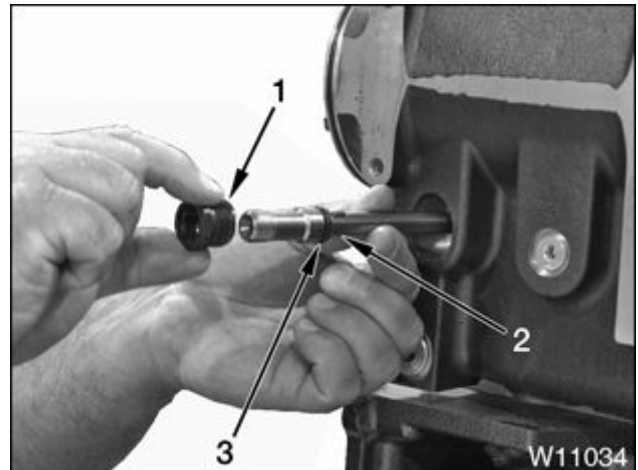


Figure 671 High-pressure connector (typical)

1. High-pressure connector retaining nut (6)
2. High-pressure connector body (6)
3. 13.5 X 3 O-ring (6)

8. Lubricate the 13.5 X 3 O-rings on the high-pressure connector bodies with clean engine oil.
9. Install six new high-pressure connector body and 13.5 X 3 O-ring assemblies.
10. Lubricate the high-pressure connector retaining nut threads with clean engine oil.
11. Using High-Pressure Connector Installer / Remover Tool (page 427), install six high-pressure connector retaining nuts. Tighten high-pressure connector retaining nuts to 55 N·m (40 lbf·ft) and then loosen completely. Tighten retaining nuts again to 10 N·m (88 lbf·in).
12. Tighten six 3/8 - 16 X 4 injector clamp hex bolts to 49 N·m (36 lbf·ft).
13. Tighten six high-pressure connector retaining nuts to 62 N·m (45 lbf·ft).

Engine Brakes

1. Install three supports, three 1/2 - 13 X 2.2 taperlock studs, and six spacer assemblies. See Valve Brake Actuator Assembly (page 364).
2. If not already done, install the six lost motion pedestals. See Lost Motion Pedestals (page 364).
3. Install the three engine brake assemblies. See Valve Brake Actuator Assembly (page 364).

Valve Cover Base

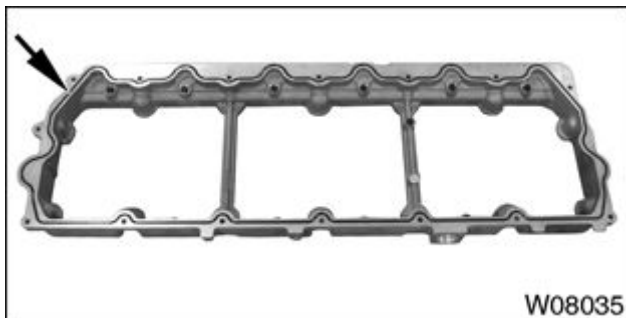


Figure 672 Valve cover base gasket

NOTE: If discarded, use a new valve cover base gasket.

1. If required, install a new valve cover base gasket into the valve cover base.

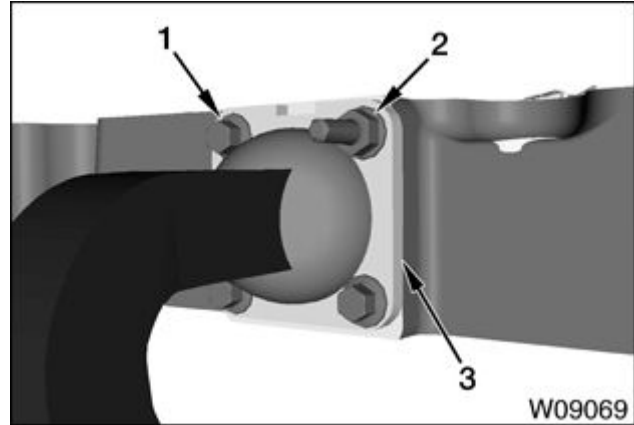


Figure 673 UVC harness bolts

1. M6 X 20 hex flange bolt (3)
2. M6 X 16 stud bolt
3. UVC harness

NOTE: Make sure that the UVC harness and connections do not abrade or become damaged during removal or installation from valve cover base.

NOTE: Do steps 2 through 4 only if the UVC harness was removed.

2. Install the UVC harness into the valve cover base.
3. Install three M6 X 20 hex flange bolts and one M6 x 16 stud bolt. Tighten hex flange bolts and stud bolt to standard torque (page 561).

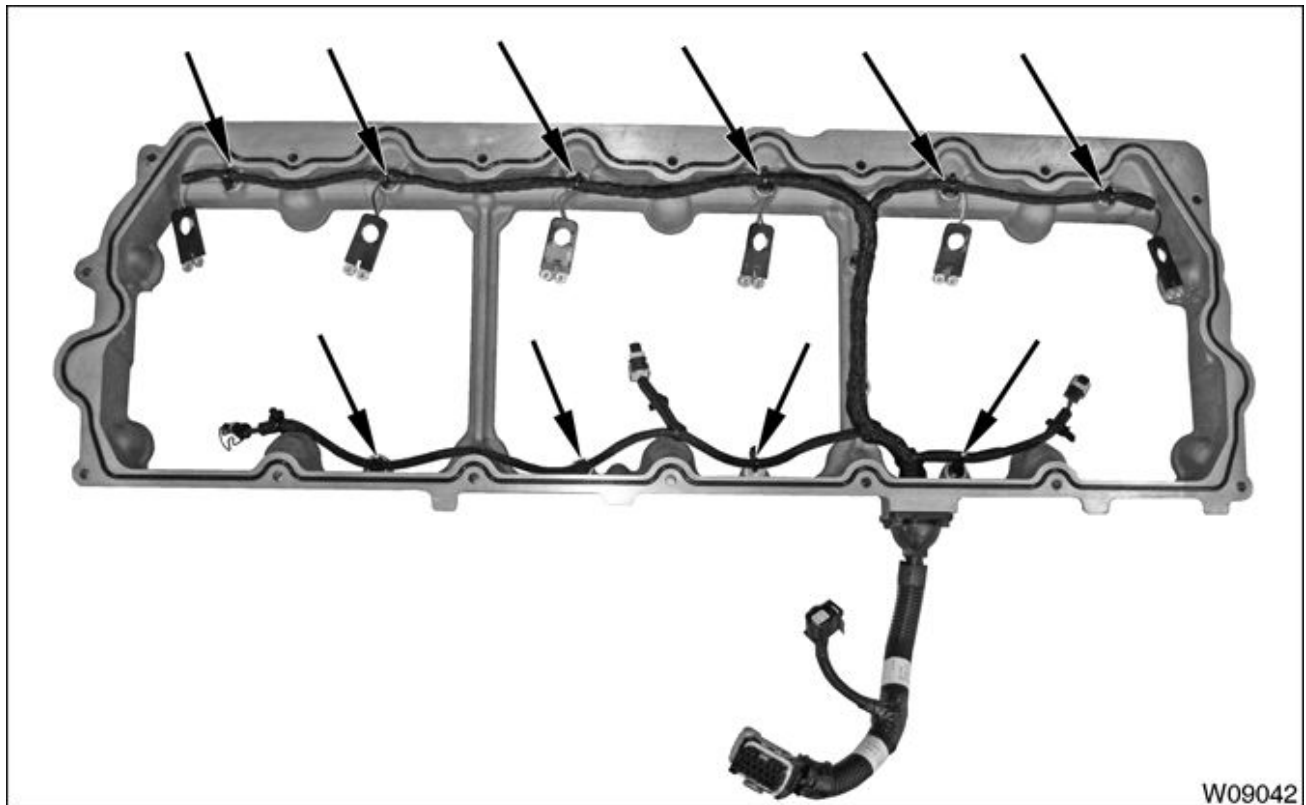


Figure 674 UVC harness tie strap locations

4. Install ten UVC harness tie straps

NOTE: Make sure that the UVC harness and connections do not abrade or become damaged during valve cover base installation.

5. Position the valve cover base on the cylinder head.

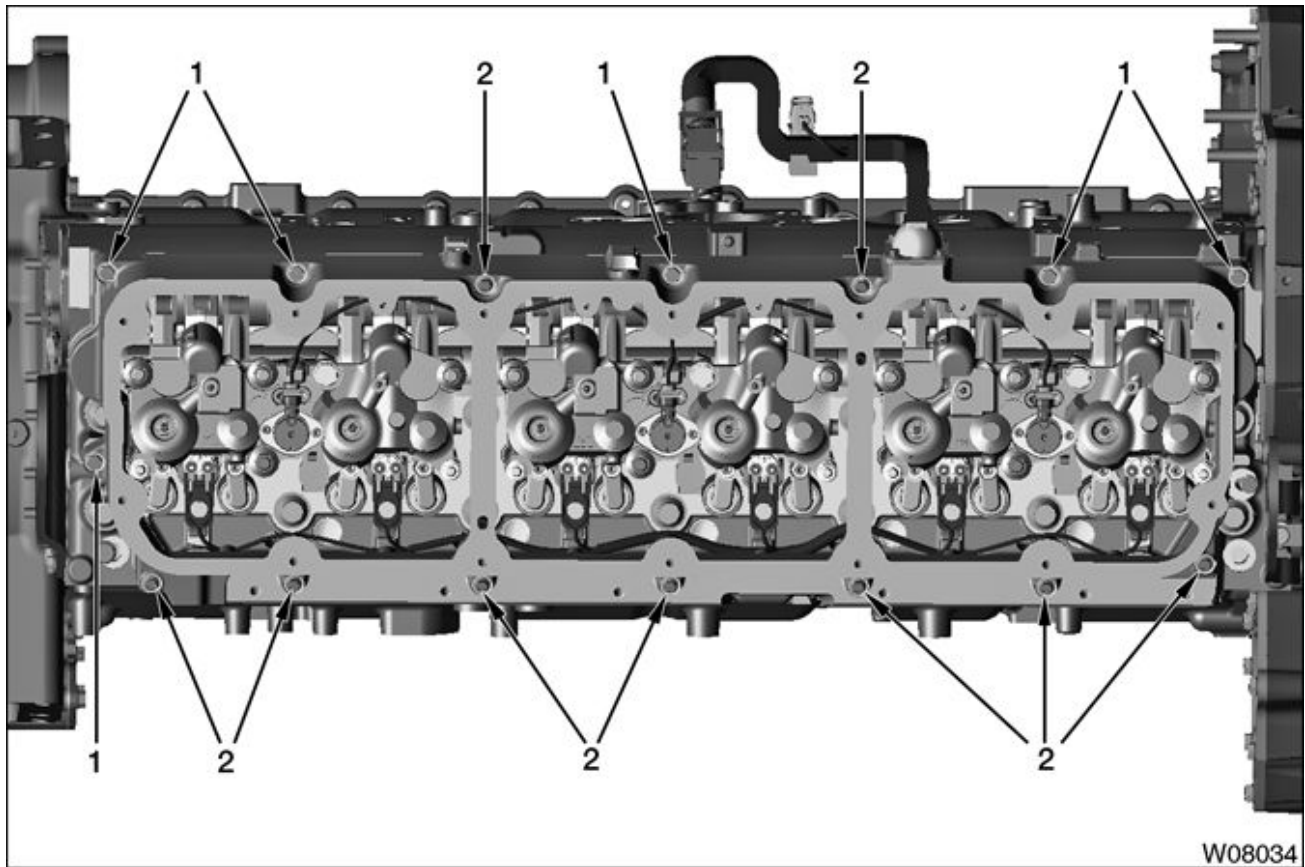


Figure 675 Valve cover base bolts

1. 5/16 - 18 X 1 - 1/4 hex flange bolt (6)	2. 5/16 - 18 X 2.36 hex flange bolt (9)
6. Loosely install six 5/16 - 18 X 1 - 1/4 hex flange bolts and nine 5/16 - 18 X 2.36 hex flange bolts.

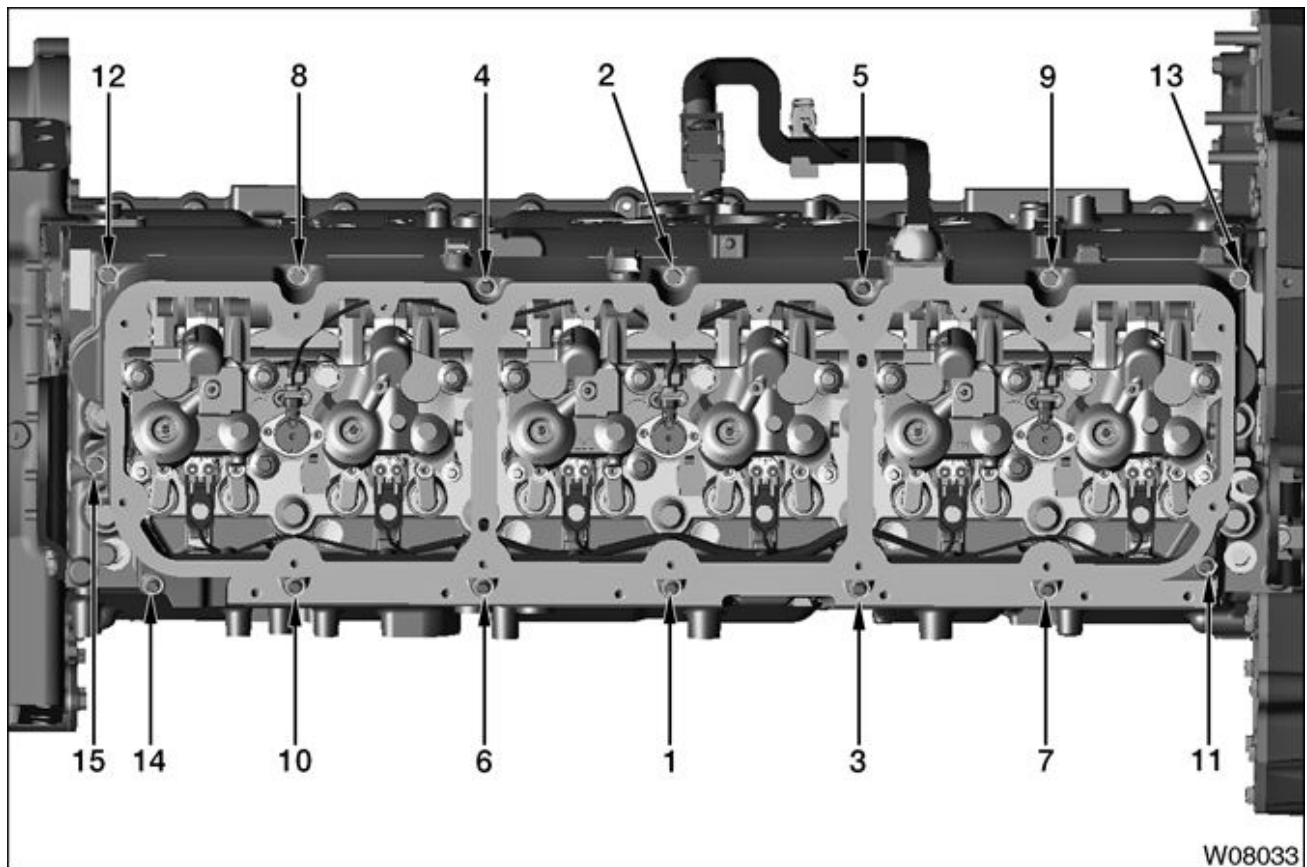


Figure 676 Valve cover base bolts tightening sequence

7. Tighten six 5/16 - 18 X 1 - 1/4 hex flange bolts and nine 5/16 - 18 X 2.36 hex flange bolts to standard torque (page 562) in the sequence shown.

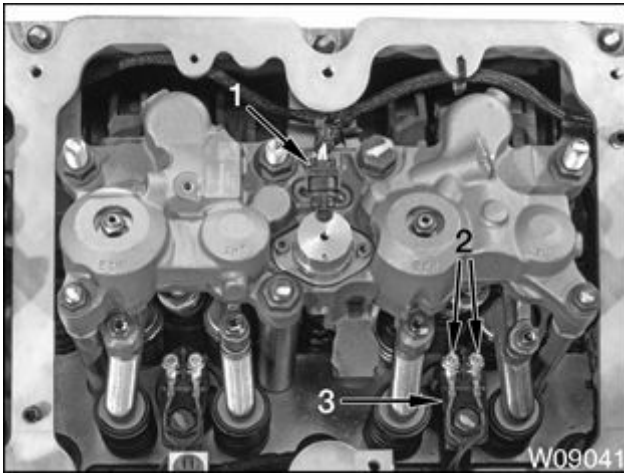


Figure 677 Under valve cover (UVC) harness connections (typical)

1. Engine brake electrical connector (3)
2. Injector harness nut (12)
3. Fuel injector connector bracket (6)

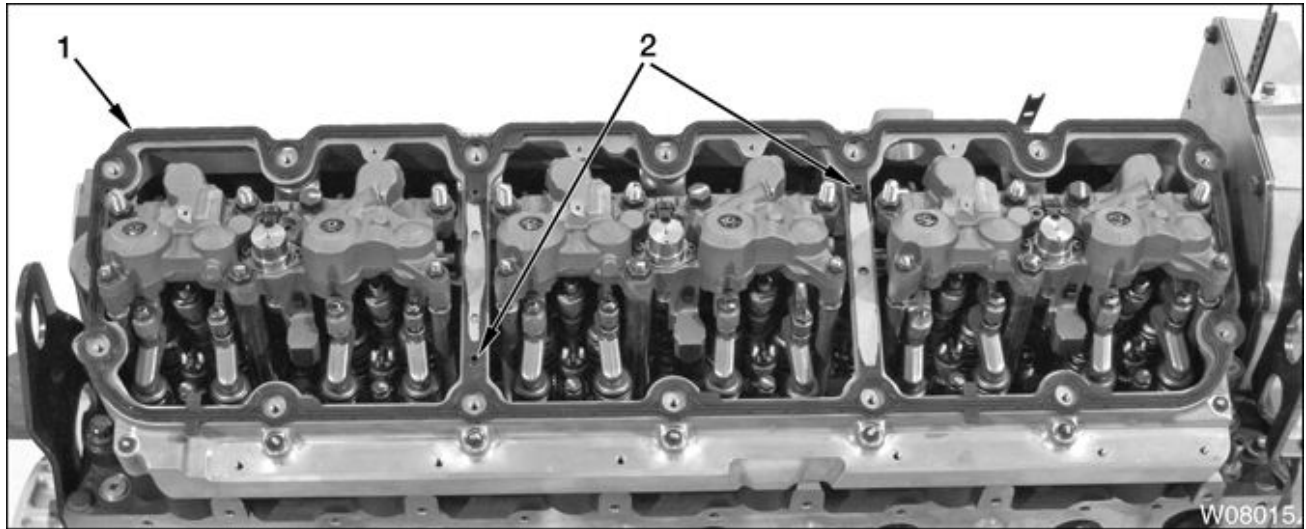
8. Connect three engine brake electrical connectors.

CAUTION: To prevent engine damage, hold injector harness terminals to prevent twisting or turning while tightening the injector harness nuts. Kinked harness terminals can result in an oil leak path between the protective cover and the wire.

CAUTION: To prevent engine damage, use a torque wrench to tighten injector harness nuts to special torque (page 426).

NOTE: The injector harness nuts are part of the under valve cover (UVC) harness and cannot be separated.

9. Position six fuel injector connector brackets on the fuel injector clamp bolt.
10. Connect twelve injector harness nuts to the fuel injectors. Tighten the injector harness nuts to special torque (page 426).

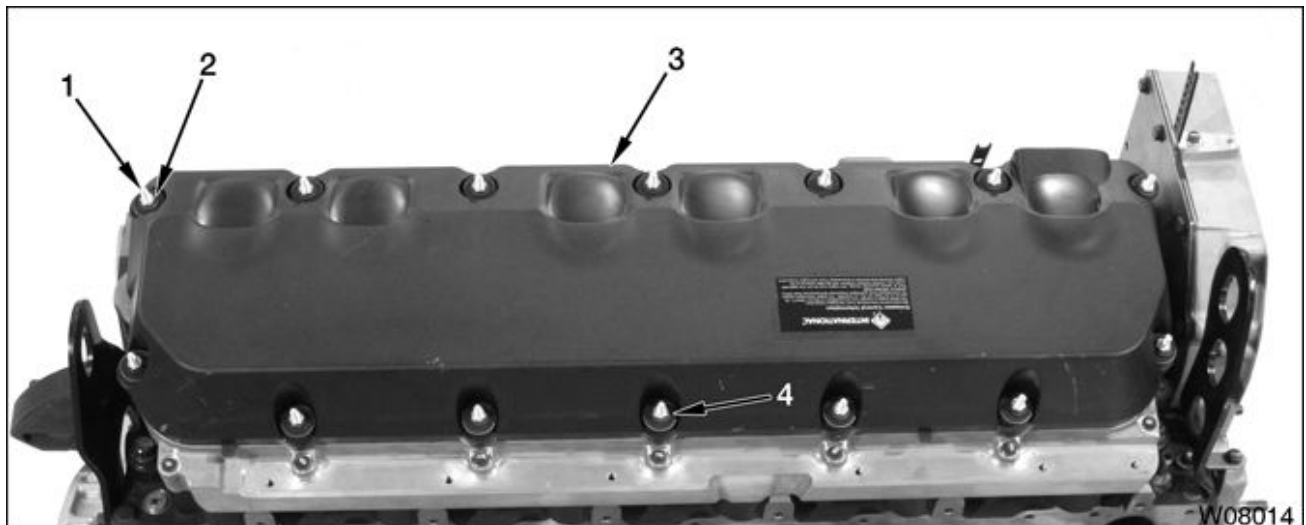
Valve Cover**Figure 678 Valve cover gasket**

1. Valve cover gasket
2. Spring pin (2)

1. If removed install the two spring pins.

NOTE: If discarded use a new valve cover gasket.

2. Install the valve cover gasket on the two spring pins.

**Figure 679 Valve cover assembly**

1. 5/16 - 18 stud (14)
2. 8.8 X 16 X 2 hardened washer (14)
3. Valve cover assembly
4. Valve cover grommet (14)

CAUTION: To prevent engine damage, do not use air tools to remove or install valve cover.

3. Place valve cover assembly on cylinder head.
4. Install fourteen of each valve cover grommets, hardened washers and 5/16 - 18 studs. Tighten 5/16 - 18 studs to special torque (page 426).

Specifications

Cylinder Head, Camshaft and Valve Train

Camshaft

Camshaft bearing installed inside diameter	84.925 – 85.045 mm (3.3435 – 3.3482 in)
Camshaft bearing joint orientation	19.5 – 20.5 degrees above the right side horizontal bearing diameter facing the right side of the engine
Camshaft journal diameter	84.83 – 84.87 mm (3.3397 – 3.3413 in)
Camshaft lobe lift (engine brake)	Tall lobe 4.925 mm (0.193 in) Short lobe 4.539 mm (0.178 in)
Camshaft lobe lift (exhaust valve)	8.515 mm (0.3352 in)
Camshaft lobe lift (intake valve)	9.431 mm (0.3713 in)
Dowel pin (camshaft drive adapter assembly) installed height	12 – 13 mm (0.472 – 0.511 in)
Engine brake rocker lash	0.15 mm ± 0.05 mm (0.006 in ± 0.002 in)
Engine brake slave piston	0.686 mm ± 0.05 mm (0.027 in ± 0.002 in)
Exhaust valve lash	0.80 mm ± 0.076 mm (0.030 in ± 0.003 in)
Intake valve lash	0.40 mm ± 0.076 mm (0.015 in ± 0.003 in)

Cylinder Head

Brinelling indentation maximum depth	0.05 mm (0.002 in)
Cylinder head gasket surface flatness	0.13 mm (0.005 in) (overall) 0.05 mm (0.002 in) (maximum for any 150 mm (6 in) span)
Cylinder head thickness	119.50 – 120.15 mm (4.705 – 4.730 in)

Rocker Arm and Shaft

Rocker arm bore diameter (max)	40.080 mm (1.5780 in)
Rocker arm bore out of round (max)	0.03 mm (0.001 in)
Rocker arm shaft allowable wear	0.010 mm (0.0004 in)

Special Torque

Cylinder head bolts	See tightening steps in procedure (page 410)
Engine brake rocker arm adjustment nuts	100 N·m (74 lbf·ft)
High-pressure connector retaining nuts	See tightening steps in procedure (page 418)
Injector harness nuts	1.5 N·m (13 lbf·in)
Injector hold down clamp hex bolts	See tightening steps in procedure (page 417)
O-ring boss plug (9/16–18)	35 N·m (26 lbf·ft)
O-ring boss plug (3/4–16)	60 N·m (44 lbf·ft)
O-ring boss plug (7/8–14)	115 N·m (85 lbf·ft)
Rear camshaft cover Torx screws	13 N·m (120 lbf·in)
Rocker arm shaft hex flange studs	See tightening steps in procedure (page 416)
Valve cover 5/16 - 18 studs with grommet elements	25 N·m (18 lbf·ft)
Valve rocker arm adjustment nuts	38 N·m (28 lbf·ft)

Special Service Tools

Description	Tool Number
1–2 inch Micrometer	Obtain locally
2–3 inch Micrometer	Obtain locally
3–4 inch Micrometer	Obtain locally
3/4 inch 12 point socket	Obtain locally
6–7 inch Micrometer	Obtain locally
Camshaft Remover/Installer	ZTSE6103
Cam Bushing Installer (used for both installation and removal)	ZTSE6113
Cylinder Head Lifting Brackets	ZTSE6106
Dye penetrant kit	Obtain locally
Disposable Air and Fuel Caps	ZTSE4891
Engine Rotation Tool	ZTSE6112
Feeler gauge set	Obtain locally
Fuel Injector Tip Cleaning Brush	ZTSE4301
Fuel Injector Cups and Rack	ZTSE4299B
Head and Main Bolt Bottoming Tap Kit (3/4 x 16 and 7/8 x 14 taps)	ZTSE6117
High-Pressure Connector Installer/Remover	ZTSE6115
Injector Removal Kit	ZTSE6102
Injector Sleeve Brushes	ZTSE4751
Lash Gauge	ZTSE6076–7
Loctite® 120541 Core Plug Sealant	Obtain locally
Loctite® 242	Obtain locally
Molykote paste lubricant 6V-4876	Obtain locally
P-80® rubber lubricant or equivalent	Obtain locally
Pressure regulator	Obtain locally
Rocker Arm Lifting Bracket Assembly	ZTSE6122
Slide Hammer Kit	ZTSE1879
Straight edge	Obtain locally
Telescoping gauge set	Obtain locally
Timing Pin	ZTSE6108
V-bolcks	Obtain locally

Table of Contents

Exploded Views.....	431
Removal.....	435
Oil Filler Pipe Assembly.....	435
Oil Level Gauge and Oil Level Gauge Tube Assembly (Early Production).....	435
Oil Level Gauge and Oil Level Gauge Tube Assembly (Late Production).....	436
Oil Pan.....	438
Oil Pick Up Tube and Oil Sending Tube Assemblies.....	439
Oil Pump.....	440
Oil Pan Plate Assembly.....	441
Cleaning and Inspection.....	442
Oil Pan.....	442
Oil Pick Up Tube.....	442
Oil Sending Tube Assembly.....	442
Installation.....	443
Oil Pan Plate Assembly.....	443
Oil Pump.....	443
Oil Pick Up Tube and Oil Sending Tube Assemblies.....	444
Oil Pan.....	445
Oil Level Gauge and Oil Level Gauge Tube Assembly (Late Production).....	448
Oil Level Gauge and Oil Level Gauge Tube Assembly (Early Production).....	450
Oil Filler Pipe Assembly.....	451
Special Torque.....	452
Special Service Tools.....	452

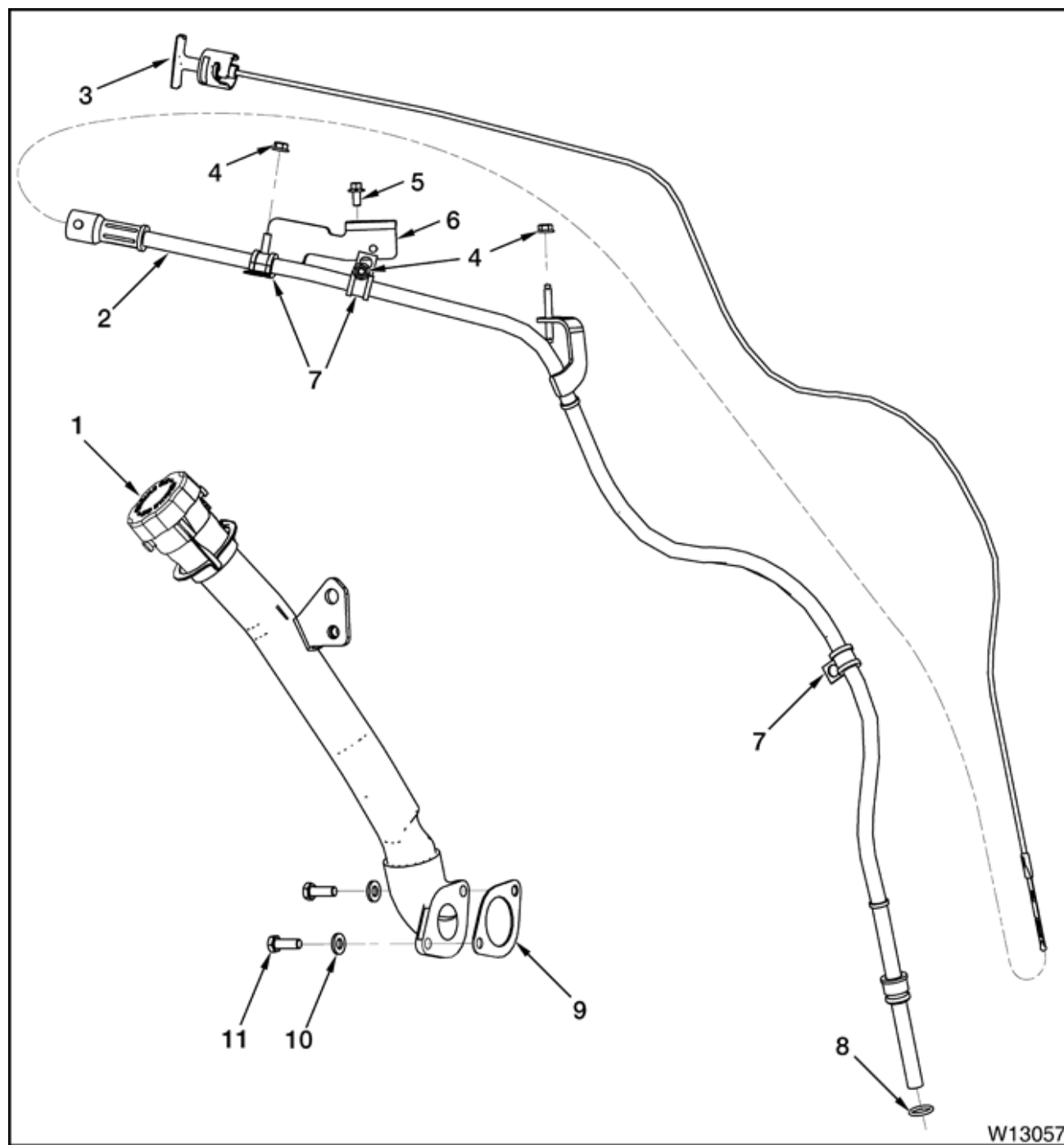


Figure 681 Oil filler pipe and oil level gauge tube assembly (late production)

1. Oil filler pipe assembly	5. M6 x 12 bolt	9. Oil fill pipe gasket
2. Oil level gauge tube assembly	6. Oil level gauge support	10. 8.8 x 17 x 1.6 washer (2)
3. Oil level gauge assembly	7. Cushioned clamp	11. 5/16-18 x 7/8 hex bolt (2)
4. M6 nut	8. O-ring (oil level gauge tube)	



Figure 682 Oil pan

1. Oil pan gasket	5. 10.2 x 25.5 x 2.5 washer (24)	9. O-ring (1 5/16–12 oil drain plug)
2. Oil pan	6. 3/8–16 x 2 x 3/4 stud bolt (24)	10. O-ring boss plug (7/16–20)
3. O-ring (1 1/8–12 oil drain plug)	7. Sleeve bushing assembly (24)	11. O-ring (7/16–20 O-ring boss plug)
4. Oil drain plug (1 1/8–12)	8. Oil drain plug (1 5/16–12)	

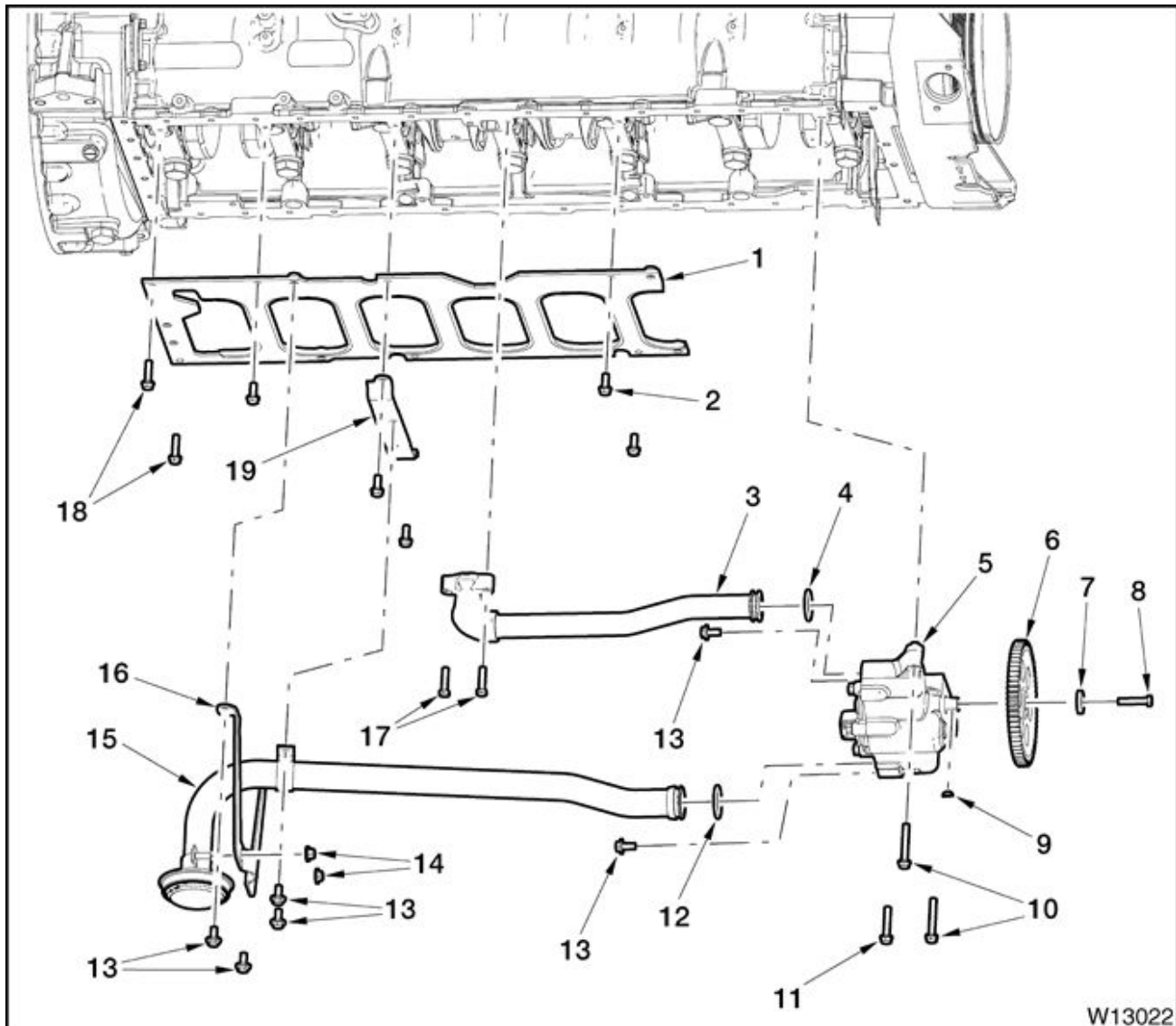


Figure 683 Oil pump, oil pick up tube assembly and oil sending tube

1. Oil pan plate assembly	7. 10.2 x 35 x 6 hardened washer	13. 3/8-16 x 0.875 hex flange bolt
2. 3/8-16 x 1 hex flange bolt (5)	8. 3/8-16 x 1 3/4 hex bolt	14. 3/8-16 hex flange lock nut
3. Tube assembly (oil sending)	9. Woodruff key	15. Oil pick up tube assembly
4. O-ring (oil sending tube assembly)	10. 3/8-16 x 2 1/2 hex flange bolt	16. Tube support
5. Oil pump assembly	11. 3/8-16 x 2 hex flange bolt	17. 3/8-16 x 1.5 hex bolt
6. 69-teeth oil pump gear	12. O-ring (oil pick up tube assembly)	18. 3/8-16 x 1.5 hex flange bolt
		19. Tube support assembly

Removal



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

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

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

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

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

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

Oil Filler Pipe Assembly

1. Remove 5/16–18 x 1 hex flange bolt holding oil fill tube to oil level gauge tube assembly.



Figure 684 Oil filler pipe assembly

1. Oil filler pipe assembly
2. 5/16–18 x 7/8 hex flange bolt and 8.8 x 17 x 1.6 washer
2. Remove two 5/16–18 x 7/8 hex flange bolts, two 8.8 x 17 x 1.6 washers and oil filler pipe assembly.

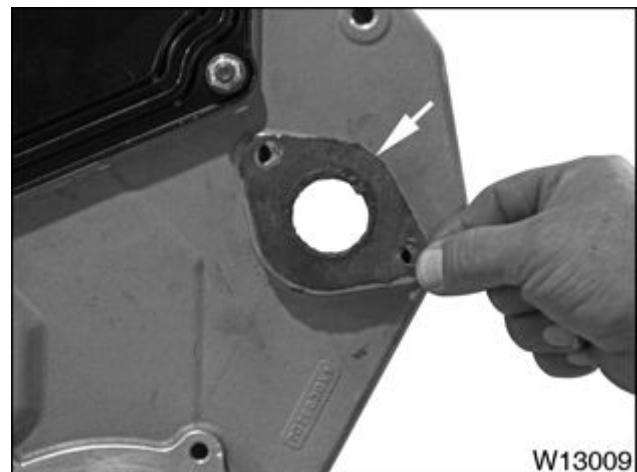


Figure 685 Oil filler pipe assembly gasket

3. Remove and discard oil filler pipe assembly gasket.

Oil Level Gauge and Oil Level Gauge Tube Assembly (Early Production)

1. Remove oil level gauge assembly.

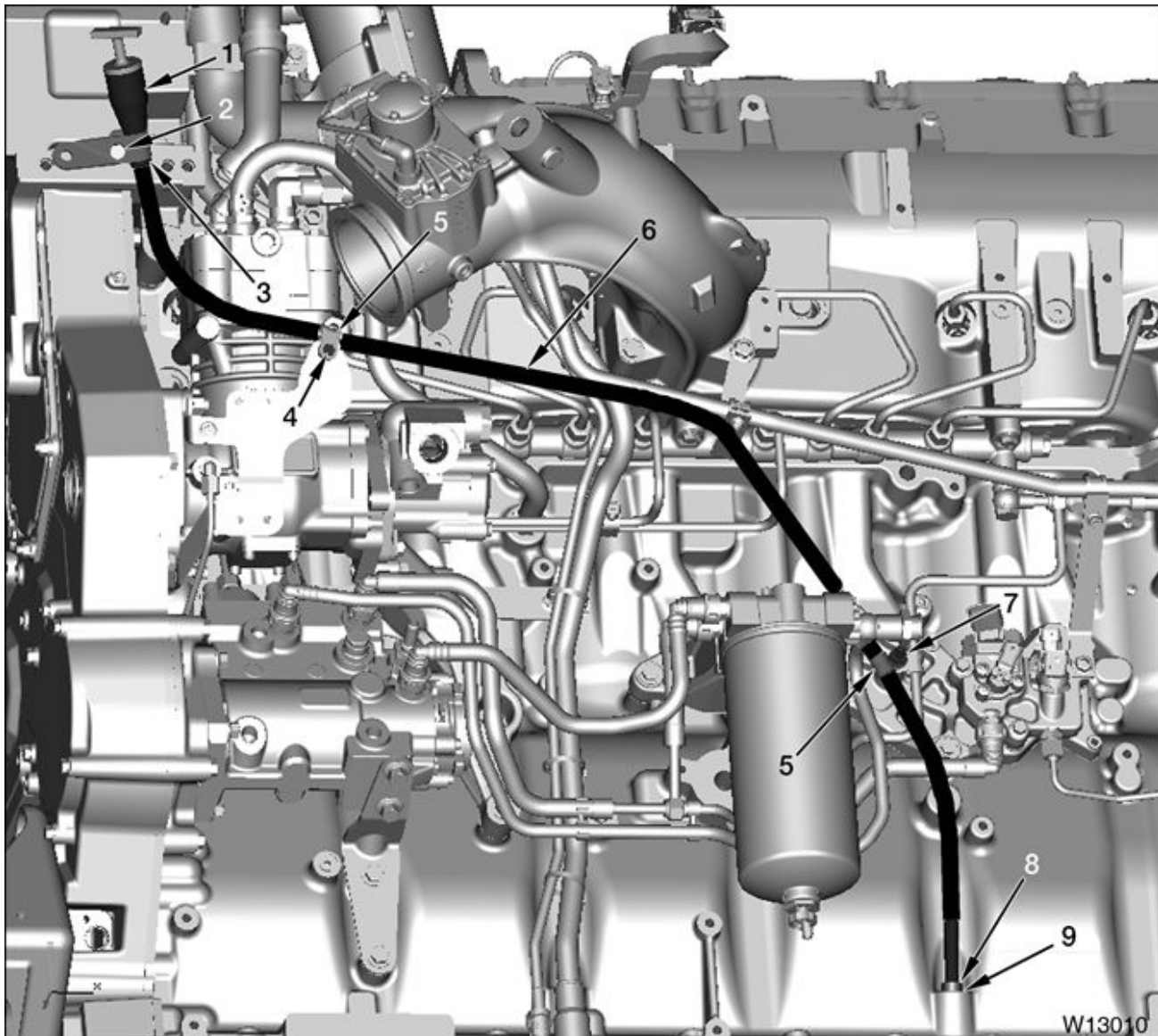


Figure 686 Oil level gauge tube assembly (early production)

1. Oil level gauge assembly	4. M8–16–10.9 hex flange bolt	7. M8 x 1.25 hex flange nut
2. 5/16–18 x 1 hex flange bolt	5. P-clip (2)	8. Oil level gauge tube adapter
3. P-clip	6. Oil level gauge tube assembly	9. O-ring (in adapter groove)

NOTE: The M8 x 1.25 hex flange nut is located behind fuel supply adapter.

- Remove M8–16–10.9 hex flange bolt and M8 x 1.25 hex flange nut. Slide oil level gauge tube assembly and adapter out of crankcase as an assembly.
- If required, remove P-clips, oil level gauge tube adapter, and O-ring from oil level gauge tube.

Oil Level Gauge and Oil Level Gauge Tube Assembly (Late Production)

- Remove oil level gauge assembly.

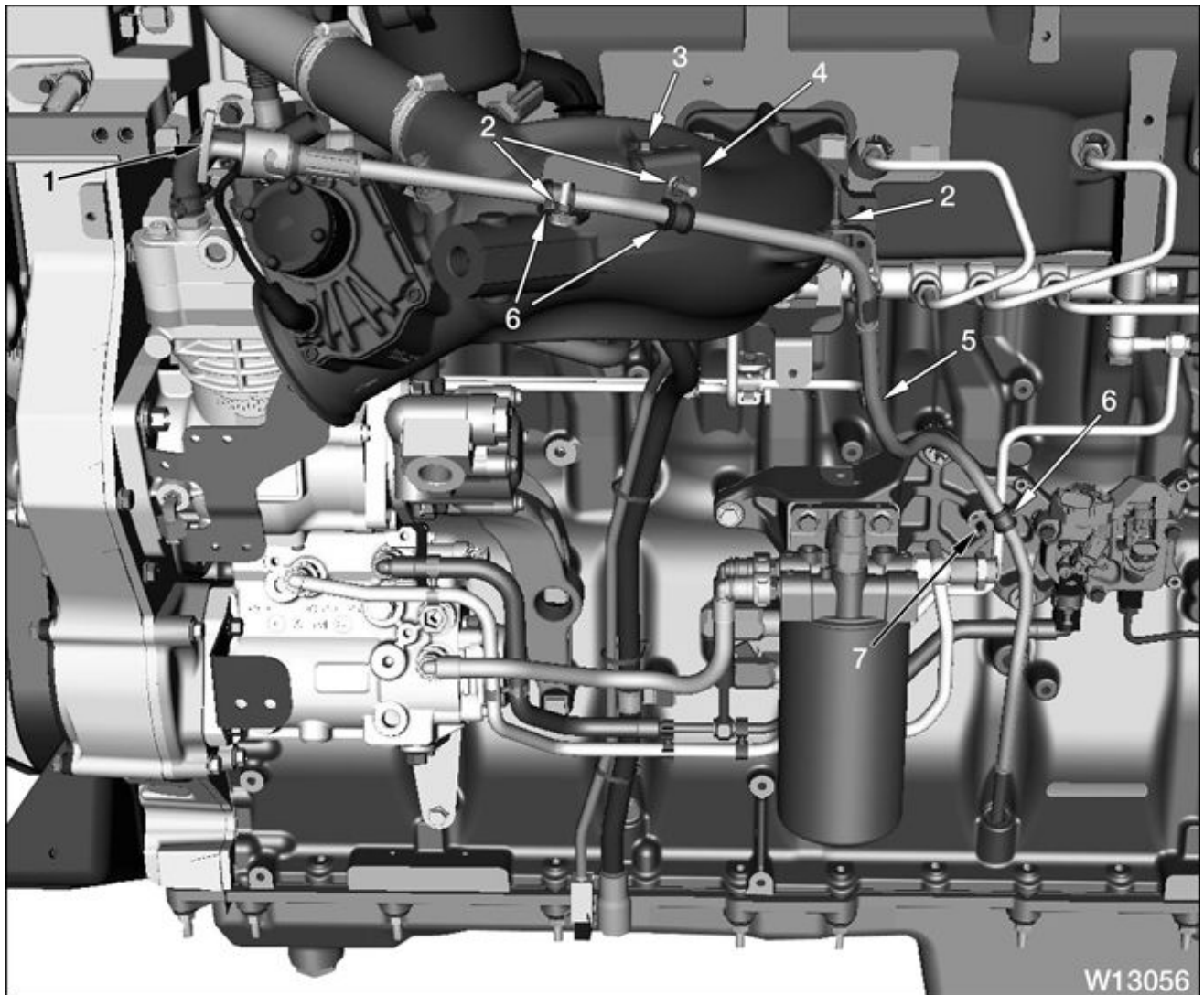


Figure 687 Oil level gauge tube assembly (late production)

1. Oil level gauge assembly	4. Oil level gauge support	7. M8 x 1.25 nut
2. M6 nut	5. Oil level gauge tube assembly	
3. M6 x 12 bolt	6. Cushioned clamp	
2. Remove M6 x 12 bolt and M8 x 1.25 nut. Slide oil level gauge tube assembly out of crankcase as an assembly.
3. If required, remove cushioned clamp, oil level gauge support, and O-ring from oil level gauge tube.

Oil Pan

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

NOTE: If not previously done, drain engine oil by doing steps 1-3. If oil is already drained, skip to step 4.

1. Place oil drain pan under engine oil pan.

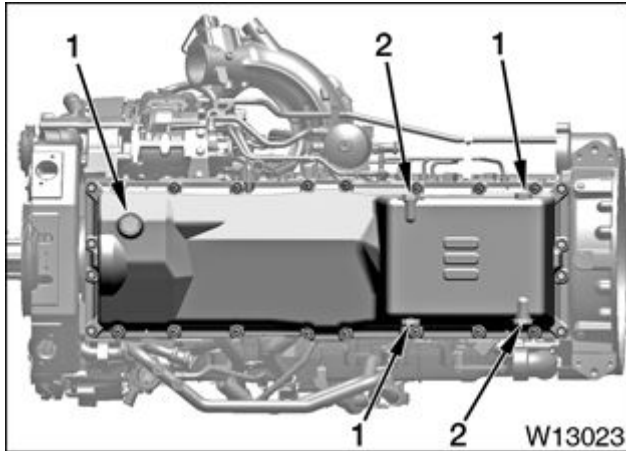


Figure 688 Oil drain plugs

1. 1 1/8–12 oil drain plug
 2. 1 5/16–12 oil drain plug
2. Remove 1 1/8–12 oil drain plug and O-ring and the lowest 1 5/16–12 oil drain plug and O-ring. Drain oil into a suitable container.

3. Discard O-rings.

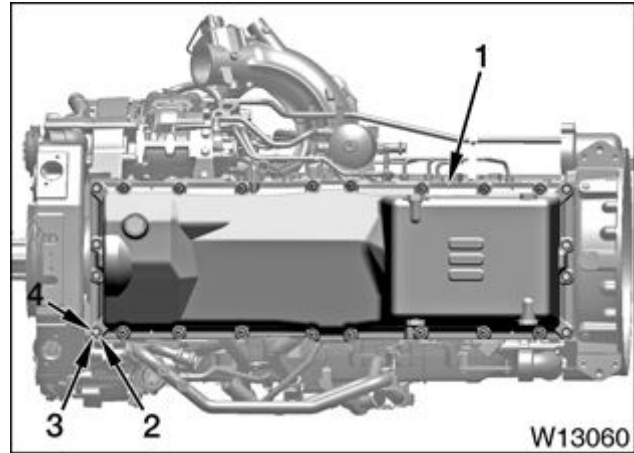


Figure 689 Oil pan retainers

1. Oil pan
 2. 3/8–16 x 2 x 3/4 stud bolt (24)
 3. 10.2 x 25.5 x 2.5 washer (24)
 4. Sleeve bushing assembly (24)
4. Remove 24 3/8–16 x 2 x 3/4 stud bolts and 24 10.2 x 25.5 x 2.5 washers.
 5. Remove 24 sleeve bushing assemblies.
 6. Remove oil pan.

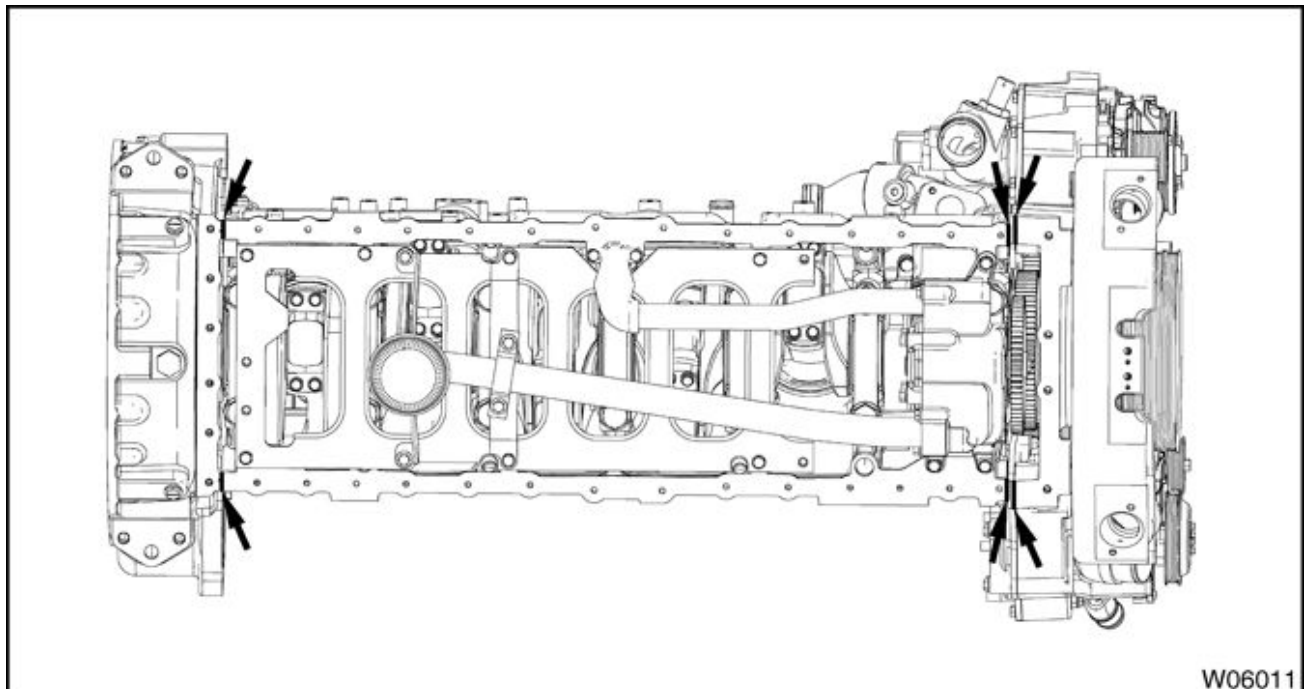


Figure 690 RTV sealer locations

7. Cut RTV sealer between oil pan gasket and crankcase at the six locations shown.
8. Remove oil pan gasket.
9. Inspect oil pan gasket for damage. If it is not cracked and the sealing surface is in good condition, the oil pan gasket is reusable. If damaged, discard oil pan gasket.

Oil Pick Up Tube and Oil Sending Tube Assemblies

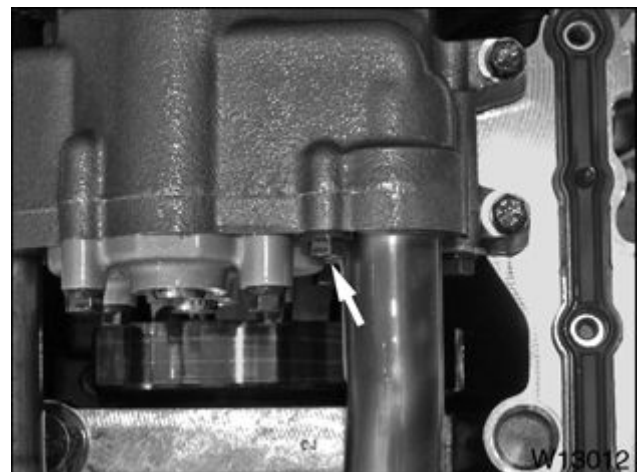
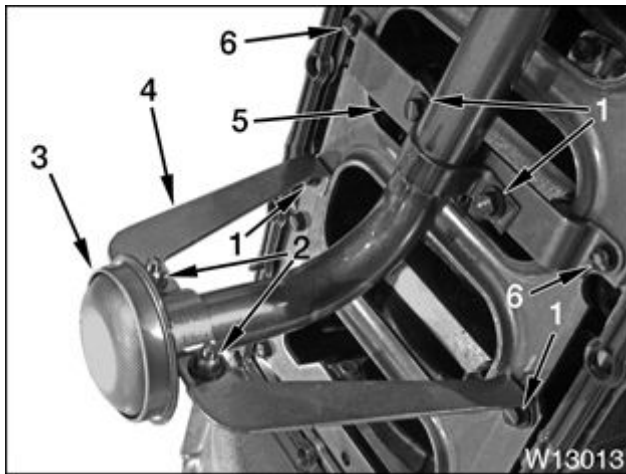
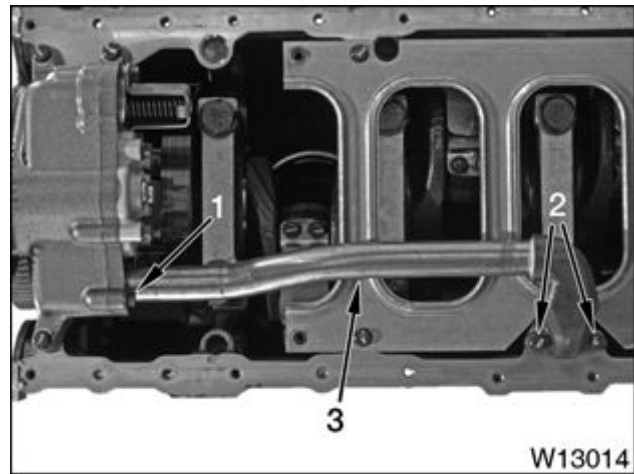


Figure 691 Oil pick up tube bolt

1. Remove 3/8–16 x 0.875 hex flange bolt from oil pump.

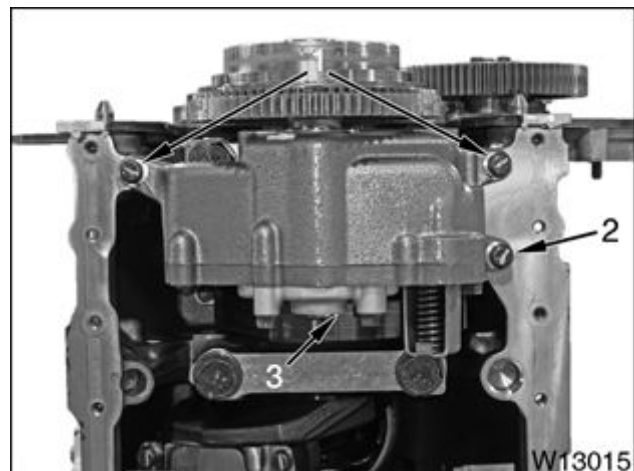
**Figure 692 Oil pick up tube and support bracket**

1. 3/8-16 x 0.875 hex flange bolt
 2. 3/8-16 hex flange lock nut
 3. Oil pick up tube assembly
 4. Tube support
 5. Tube support assembly
 6. 3/8-16 x 1 hex flange bolt
2. Remove two 3/8-16 x 0.875 hex flange bolts from oil pick up tube assembly at tube support assembly.
 3. Remove two 3/8-16 hex flange lock nuts and oil pick up tube assembly.
 4. Remove and discard O-ring at the end of oil pick up tube assembly.
 5. Remove two 3/8-16 x 0.875 hex flange bolts and tube support.
 6. Remove two 3/8-16 x 1 hex flange bolts and tube support assembly.

**Figure 693 Oil sending tube assembly**

1. 3/8-16 x 0.875 hex flange bolt
 2. 3/8-16 x 1.5 hex bolt
 3. Oil sending tube assembly
7. Remove 3/8-16 x 0.875 hex flange bolt from oil pump.
 8. Remove two 3/8-16 x 1.5 hex bolts and oil sending tube assembly.
 9. Remove and discard O-ring at the end of oil sending tube assembly.

Oil Pump

**Figure 694 Oil Pump**

1. 3/8-16 x 2 1/2 hex flange bolt
2. 3/8-16 x 2 hex flange bolt
3. Oil pump

1. Remove two 3/8–16 x 2 1/2 hex flange bolts, one 3/8–16 x 2 hex flange bolt, and oil pump.

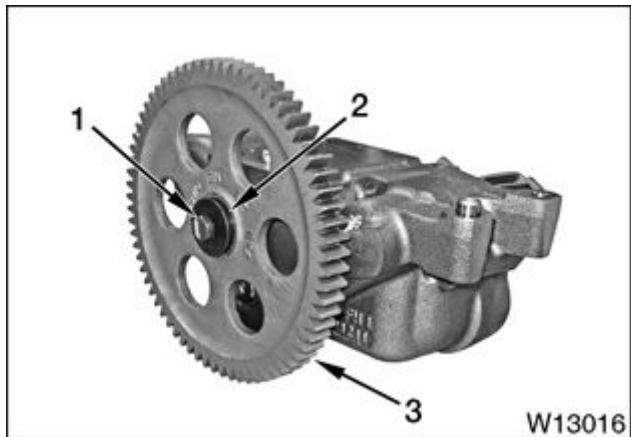


Figure 695 69-teeth Oil Pump Gear

1. 3/8–16 x 1 3/4 hex bolt
2. 10.2 x 35 x 6 hardened washer
3. 69-teeth oil pump gear

2. Remove 3/8–16 x 1 3/4 hex bolt, 10.2 x 35 x 6 hardened washer, and 69-teeth oil pump gear.
3. If required, remove the woodruff key from the oil pump shaft.

Oil Pan Plate Assembly

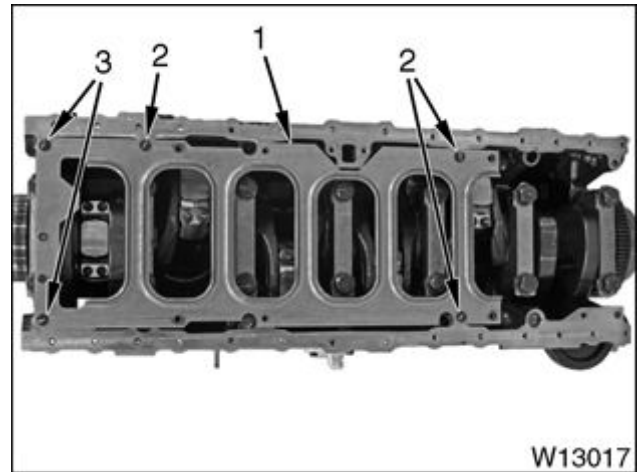


Figure 696 Oil pan plate assembly

1. Oil pan plate assembly
2. 3/8–16 x 1 hex flange bolt
3. 3/8–16 x 1.5 hex flange bolt

1. Remove three 3/8–16 x 1 hex flange bolts, two 3/8–16 x 1.5 hex flange bolts, and oil pan plate assembly.

Cleaning and Inspection

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

Oil Pan

1. Inspect bottom of oil pan for metallic debris or other evidence of engine damage. Investigate any abnormalities as required.
2. Clean oil pan with non-caustic solvent.
3. Dry with filtered compressed air.
4. Look for warping, dents, and cracking. Replace oil pan if necessary.

Oil Pick Up Tube

1. Clean oil pick up tube and support with non-caustic solvent.
2. Dry with filtered compressed air.
3. Inspect oil pick up tube and support for cracking. Replace if necessary.

Oil Sending Tube Assembly

1. Clean oil sending tube assembly with non-caustic solvent.
 2. Clean mating crankcase threads of oil residue.
-

Installation

Oil Pan Plate Assembly

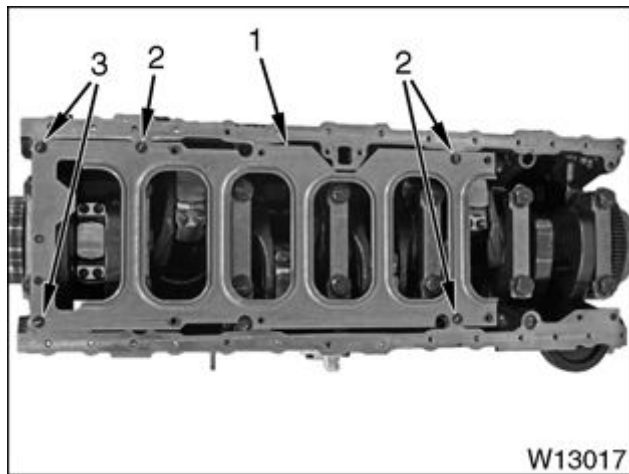


Figure 697 Oil pan plate assembly

1. Oil pan plate assembly
 2. 3/8-16 x 1 hex flange bolt
 3. 3/8-16 x 1.5 hex flange bolt
1. Install oil pan plate assembly, three 3/8-16 x 1 hex flange bolts, and two 3/8-16 x 1.5 hex flange bolts. Tighten 3/8-16 x 1 hex flange bolts and 3/8-16 x 1.5 hex flange bolts to standard torque (page 562).

Oil Pump

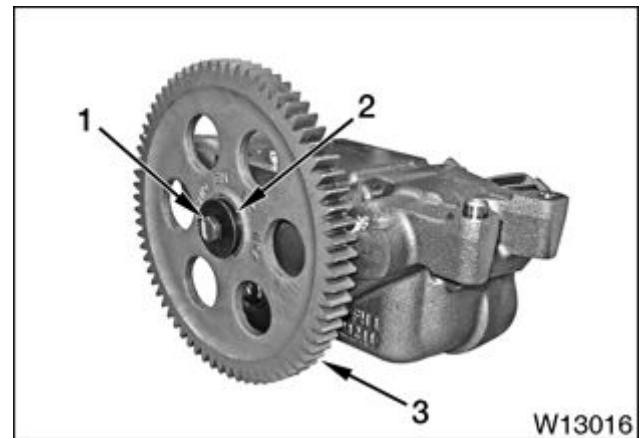


Figure 698 69-teeth Oil Pump Gear

1. 3/8-16 x 1 3/4 hex bolt
 2. 10.2 x 35 x 6 hardened washer
 3. 69-teeth oil pump gear
1. If removed, install the woodruff key into oil pump shaft.
 2. Install 69-teeth oil pump gear, 10.2 x 35 x 6 hardened washer, and 3/8-16 x 1 3/4 hex bolt. Tighten 3/8-16 x 1 3/4 hex bolt to special torque (page 452).

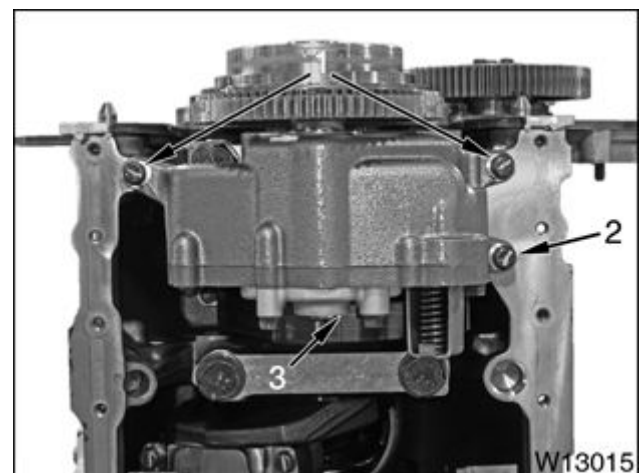


Figure 699 Oil Pump

1. 3/8-16 x 2 1/2 hex flange bolt
2. 3/8-16 x 2 hex flange bolt
3. Oil pump

3. Install oil pump, two 3/8–16 x 2 1/2 hex flange bolts, and one 3/8–16 x 2 hex flange bolt. Tighten 3/8–16 x 2 1/2 hex flange bolts and one 3/8–16 x 2 hex flange bolt to standard torque (page 562).

Oil Pick Up Tube and Oil Sending Tube Assemblies

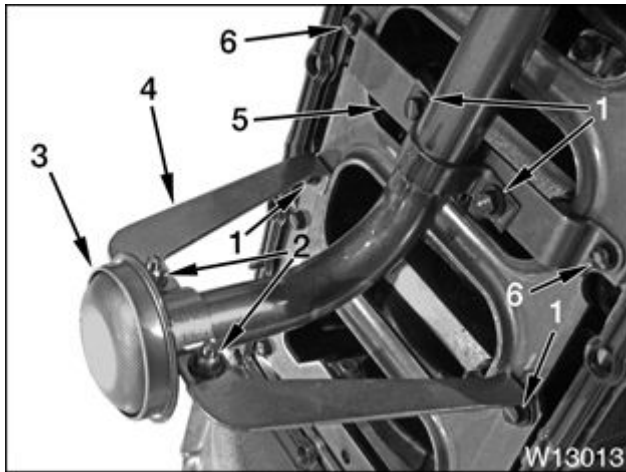


Figure 700 Oil pick up tube and support bracket

1. 3/8–16 x 0.875 hex flange bolt
 2. 3/8–16 hex flange lock nut
 3. Oil pick up tube assembly
 4. Tube support
 5. Tube support assembly
 6. 3/8–16 x 1 hex flange bolt
1. Install tube support assembly and two 3/8–16 x 1 hex flange bolts. Tighten 3/8–16 x 1 hex flange bolts to standard torque (page 562).
 2. Install tube support and two 3/8–16 x 0.875 hex flange bolts. Tighten 3/8–16 x 0.875 hex flange bolts to standard torque (page 562).
 3. Lubricate new O-ring for oil pick up tube assembly with clean engine oil.
 4. Install new lubricated O-ring on oil pick up tube assembly.
 5. Install oil pick up tube assembly into oil pump and tube support, and install two 3/8–16 hex flange lock nuts. Tighten 3/8–16 hex flange lock nuts to standard torque (page 562).
 6. Install two 3/8–16 x 0.875 hex flange bolts to oil pick up tube assembly at tube support assembly.

Tighten 3/8–16 x 0.875 hex flange bolts to standard torque (page 562).

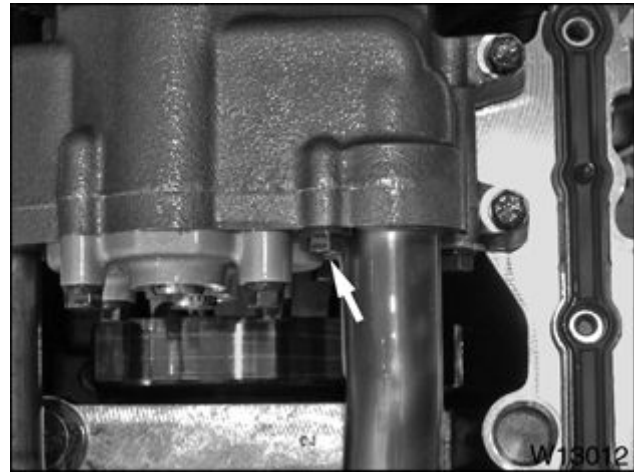


Figure 701 Oil pick up tube bolt

7. Install 3/8–16 x 0.875 hex flange bolt to oil pump. Tighten 3/8–16 x 0.875 hex flange bolt to standard torque (page 562).

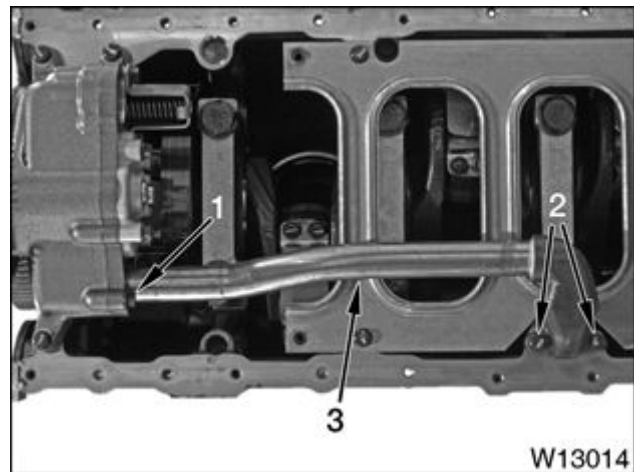


Figure 702 Oil sending tube assembly

1. 3/8–16 x 0.875 hex flange bolt
 2. 3/8–16 x 1.5 hex bolt
 3. Oil sending tube assembly
8. Lubricate new O-ring for oil sending tube assembly with clean engine oil.
 9. Install new lubricated O-ring on oil sending tube assembly.

10. Install oil sending tube in oil pump and install two 3/8–16 x 1.5 hex bolts into crankcase. Tighten 3/8–16 x 1.5 hex bolts to standard torque (page 562).
11. Install 3/8–16 x 0.875 hex flange bolt to oil pump. Tighten 3/8–16 x 0.875 hex flange bolt to standard torque (page 562).

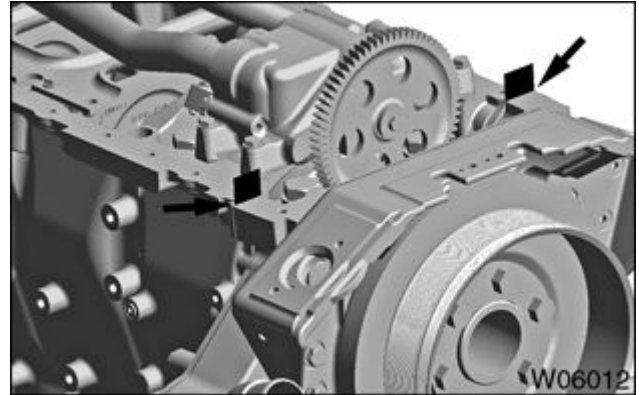
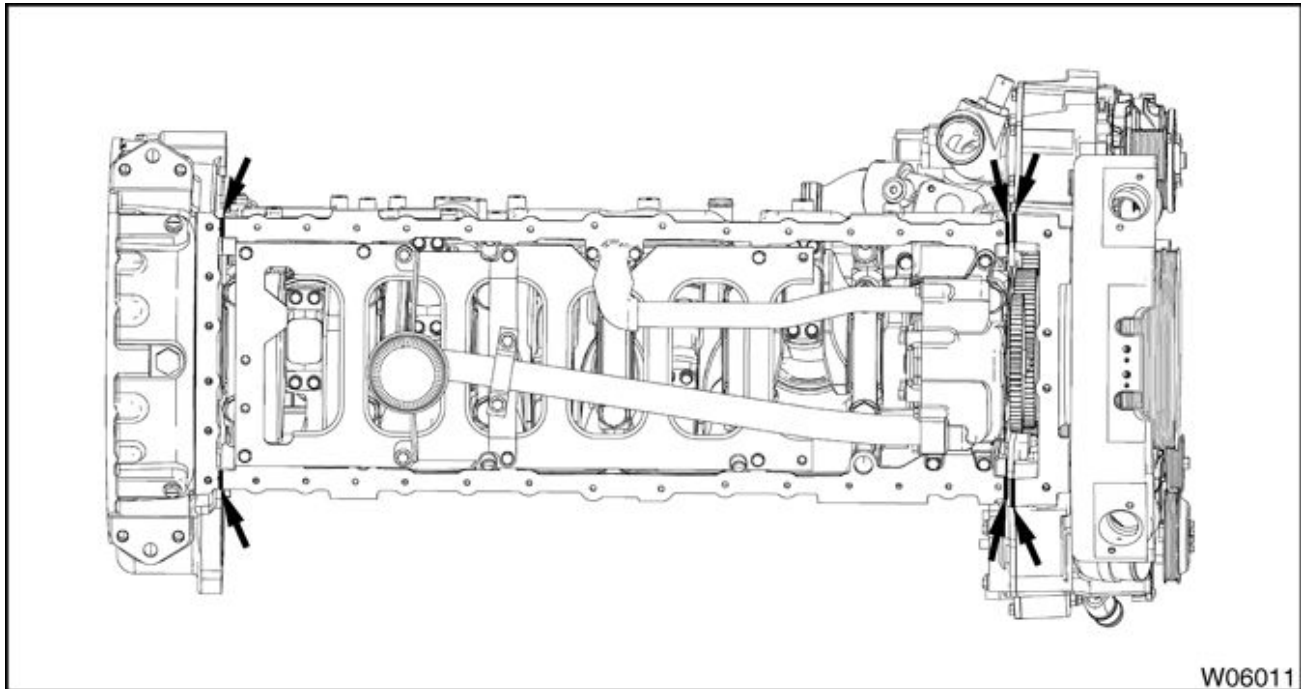
Oil Pan

Figure 703 Front cover gasket protrusion (typical)

1. Trim any protruding gasket material from front cover gasket, front cover plate gasket, or flywheel housing gasket flush with crankcase surface.



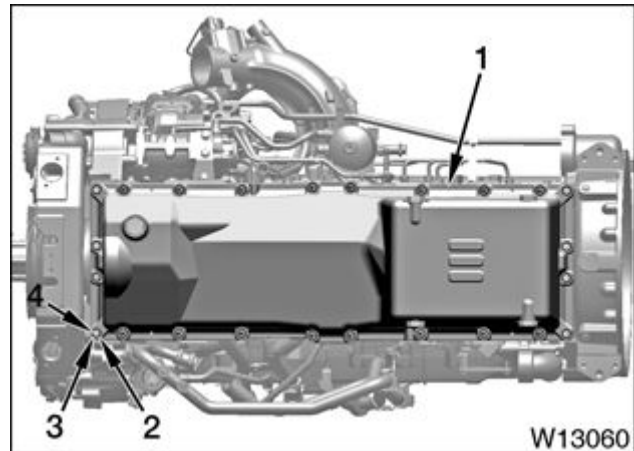
W06011

Figure 704 RTV sealer locations

2. Apply a 9 mm (0.35 in) bead of Wacker A-442 RTV sealer (page 452) to the six locations shown.

NOTE: If original gasket was discarded, use new oil pan gasket.

3. Install oil pan gasket inserting the rubber dowels in gasket with the holes in crankcase.



W13060

Figure 705 Oil pan retainers

1. Oil pan
 2. 3/8-16 x 2 x 3/4 stud bolt (24)
 3. 10.2 x 25.5 x 2.5 washer (24)
 4. Sleeve bushing assembly (24)
4. Position oil pan on oil pan gasket.
 5. Install 24 sleeve bushing assemblies; one at each mounting hole location.

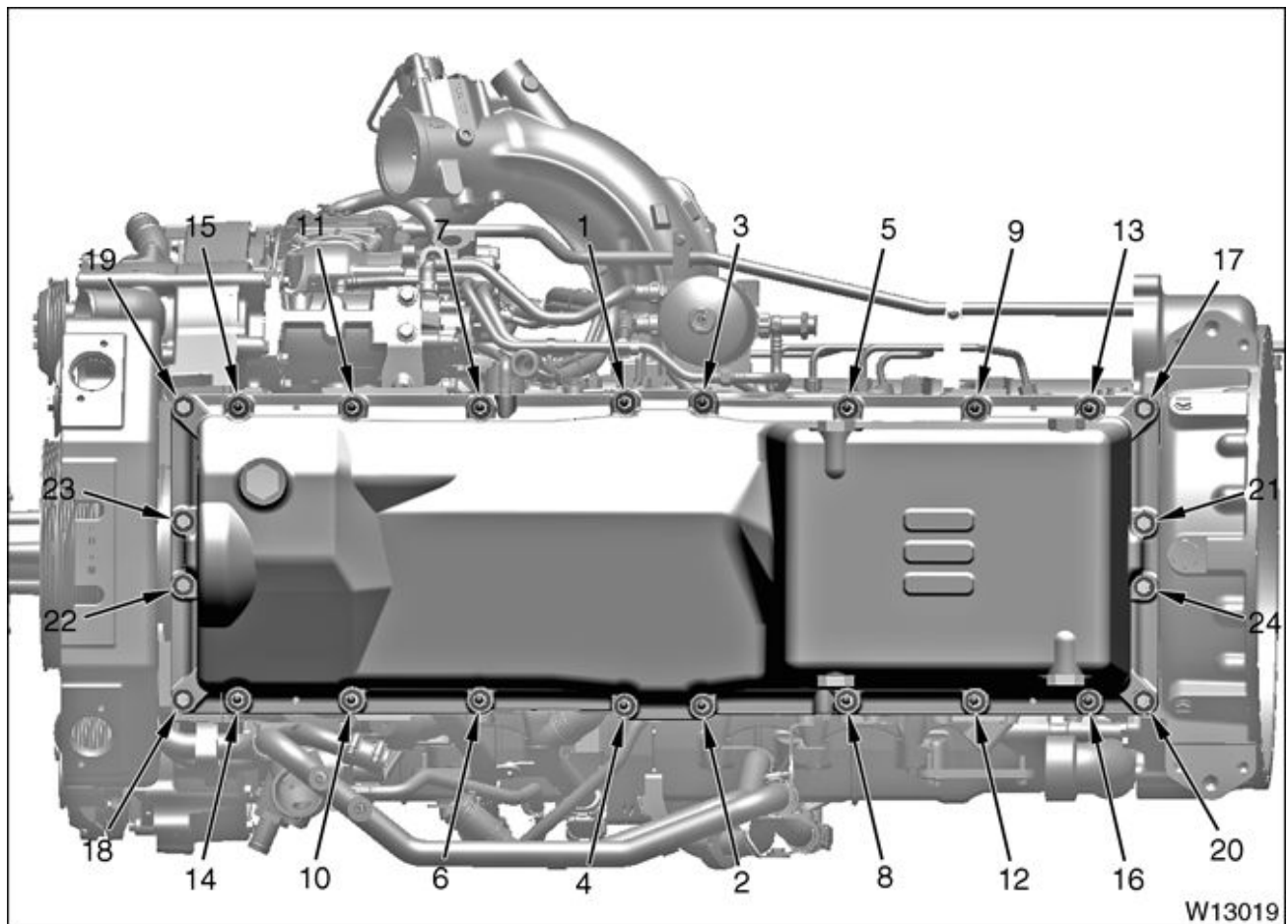


Figure 706 Oil pan stud bolt tightening sequence

6. Install 24 10.2 x 25.5 x 2.5 washers and 24 3/8–16 x 2 x 3/4 stud bolts at each mounting hole location. Tighten stud bolts to 25 N·m (220 lbf·in) in the sequence shown.

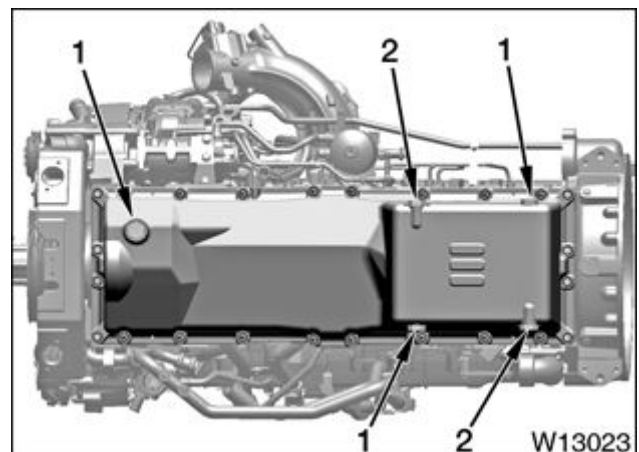


Figure 707 Oil drain plugs

1. 1 1/8–12 oil drain plug
2. 1 5/16–12 oil drain plug

7. Install one O-ring and 1 1/8–12 oil drain plug, and one O-ring and 1 5/16–12 oil drain plug. Tighten 1 1/8–12 drain plug to special torque (page 452). Tighten 1 5/16–12 drain plug to special torque (page 452).
8. If removed, install one O-ring and 1 1/8–12 oil drain plug. Tighten 1 1/8–12 oil drain plug to special torque (page 452).

Oil Level Gauge and Oil Level Gauge Tube Assembly (Late Production)

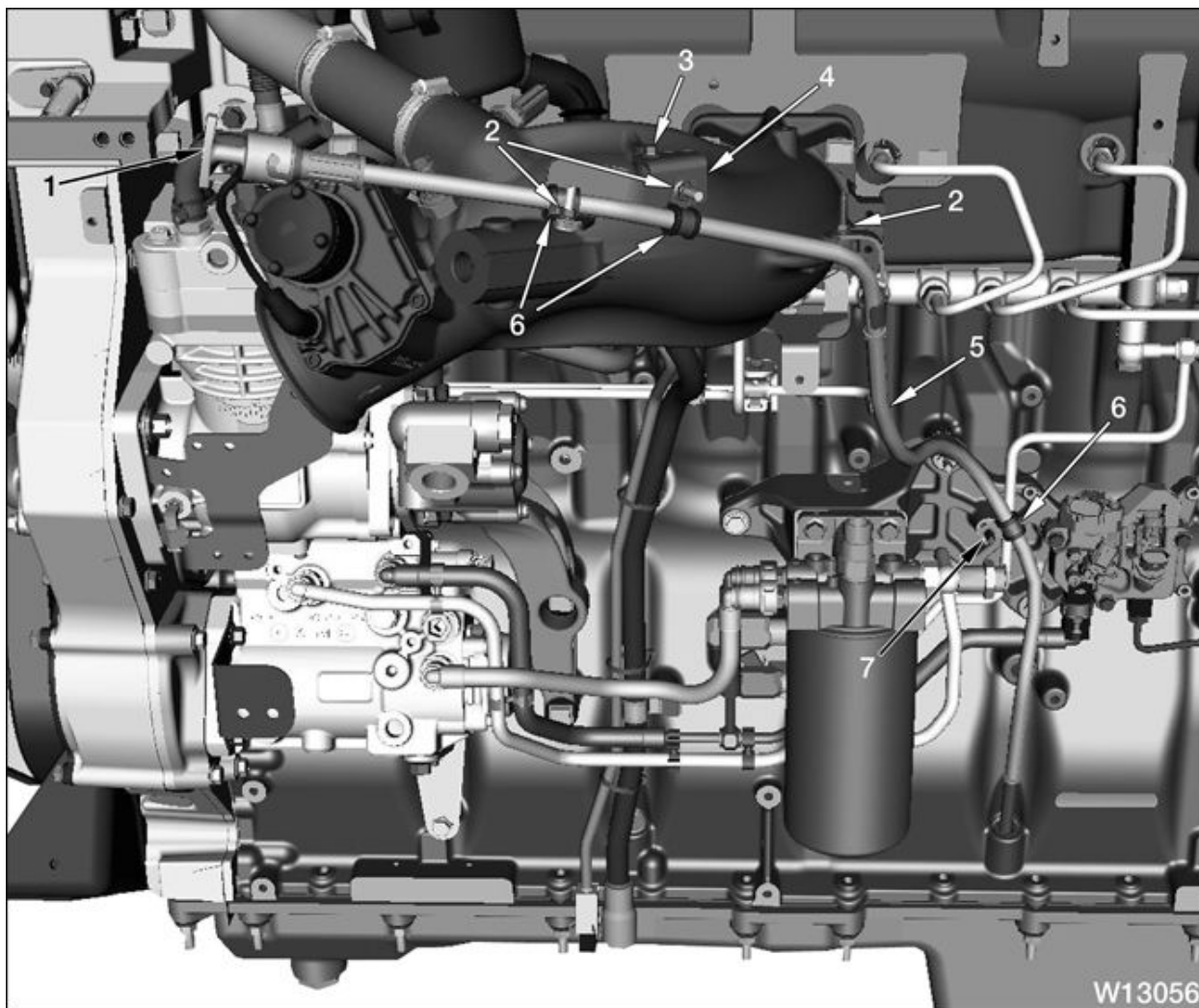


Figure 708 Oil level gauge tube assembly (late production)

1. Oil level gauge assembly	4. Oil level gauge support	7. M8 x 1.25 nut
2. M6 nut	5. Oil level gauge tube assembly	
3. M6 x 12 bolt	6. Cushioned clamp	

-
1. If removed, install cushioned clamp, oil level gauge support, and O-ring on oil level gauge tube.
 2. Slide oil level gauge tube assembly into crankcase. Install M8 x 1.25 nut and M6 x 12 bolt. Tighten in order to standard torque (page 561).
 1. M8 x 1.25 nut
 2. M6 x 12 bolt
 3. Install oil level gauge assembly into oil level gauge tube assembly.

Oil Level Gauge and Oil Level Gauge Tube Assembly (Early Production)

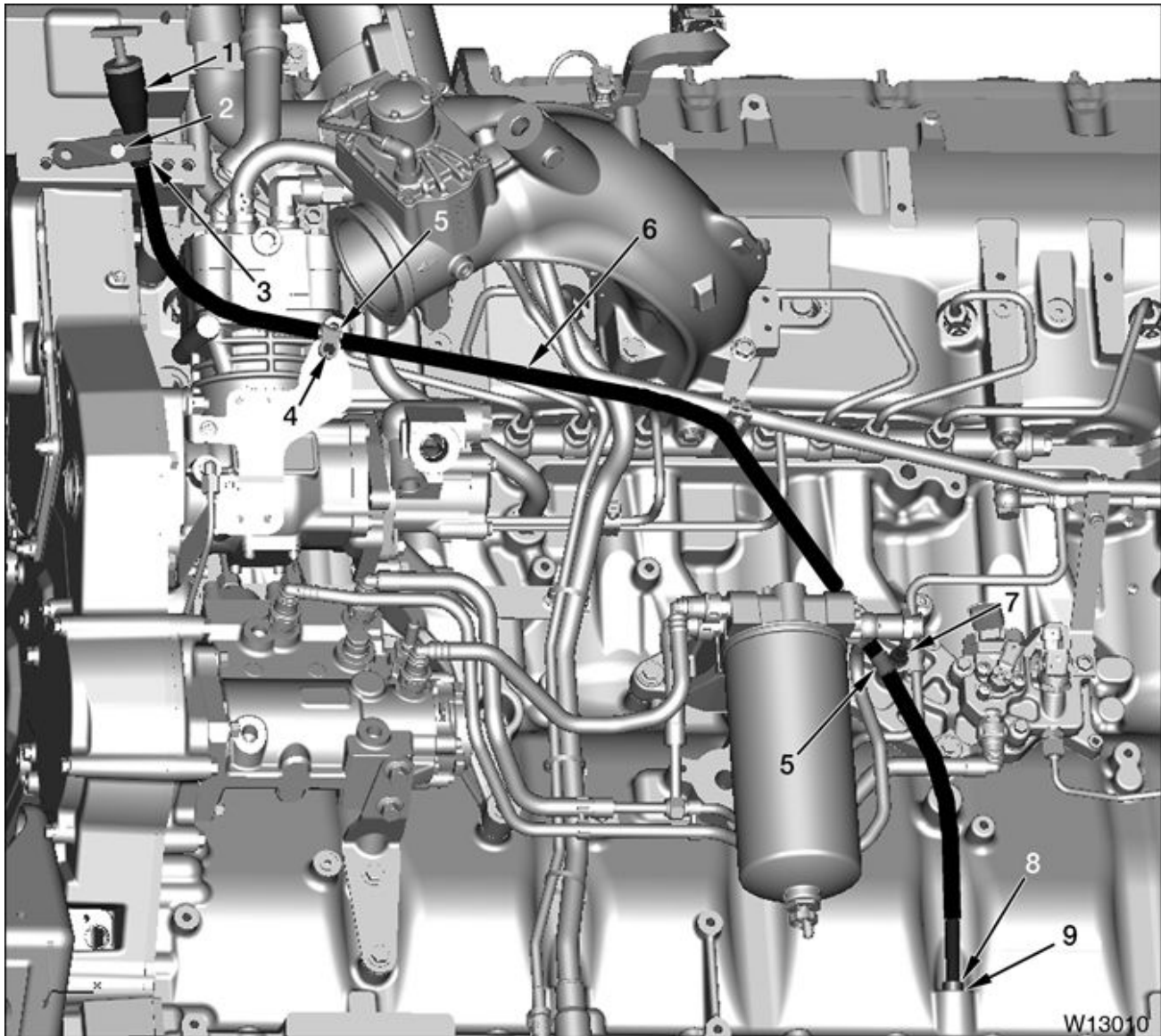


Figure 709 Oil level gauge tube assembly (early production)

1. Oil level gauge assembly	4. M8-16-10.9 hex flange bolt	7. M8 x 1.25 hex flange nut
2. 5/16-18 x 1 hex flange bolt	5. P-clip (2)	8. Oil level gauge tube adapter
3. P-clip	6. Oil level gauge tube assembly	9. O-ring (in adapter groove)

1. If removed, install P-clips, O-ring, and oil level gauge tube adapter on oil level gauge tube.

NOTE: The M8 x 1.25 hex flange nut is located behind fuel supply adapter.

2. Slide oil level gauge tube assembly and adapter into crankcase as an assembly. Install M8-16-10.9 hex flange bolt and M8 x 1.25 hex flange nut. Tighten M8-16-10.9 hex flange bolt and M8 x 1.25 hex flange nut to standard torque (page 561).

3. Install oil level gauge assembly into oil level gauge tube assembly.

Oil Filler Pipe Assembly

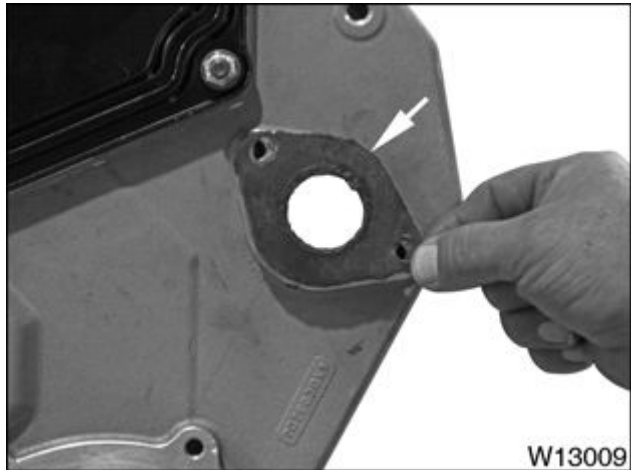


Figure 710 Oil filler pipe assembly gasket

1. Install a new oil filler pipe assembly gasket.



Figure 711 Oil filler pipe assembly

1. Oil filler pipe assembly
2. 5/16–18 x 7/8 hex flange bolt and 8.8 x 17 x 1.6 washer
2. Install oil filler pipe assembly, two 8.8 x 17 x 1.6 washers, and two 5/16–18 x 7/8 hex flange bolts. Tighten 5/16–18 x 7/8 hex flange bolts to standard torque (page 562).
3. Install 5/16–18 x 1 hex flange bolt holding oil fill tube to oil level gauge tube assembly. Tighten 5/16–18 x 1 hex flange bolt to standard torque (page 562).

Special Torque

1 1/8–12 oil drain plugs	70 N·m (50 lbf·ft)
1 5/16–12 oil drain plugs	90 N·m (65 lbf·ft)
3/8–16 x 1 3/4 hex bolt (oil pump gear)	56 N·m (41 lbf·ft)
3/8–16 x 2 x 3/4 stud bolts (oil pan)	See special torque and sequence (page 447)

Special Service Tools

Description	Tool Number
Wacker A-442 RTV sealer	Obtain locally

Table of Contents

Exploded Views.....	455
Removal.....	458
Preliminary Checks — Flywheel Assembly.....	458
Rear Engine Mounts.....	458
Flywheel Assembly.....	459
Crankshaft Rear Seal.....	460
Flywheel Housing.....	460
Clean, Inspect, and Measure.....	464
All Components.....	464
Flywheel Assembly Face Runout (Axial Eccentricity).....	464
Flywheel Assembly Bore Runout (Radial Eccentricity).....	464
Flywheel Housing Face Runout (Axial Eccentricity).....	465
Flywheel Housing Bore Runout (Radial Eccentricity).....	466
Recondition.....	467
Flywheel Assembly.....	467
Installation.....	469
Flywheel Housing.....	469
Crankshaft Rear Seal.....	472
Flywheel Assembly.....	473
Rear Engine Mounts.....	475
Specifications.....	476
Special Torque.....	476
Special Service Tools.....	476

Exploded Views

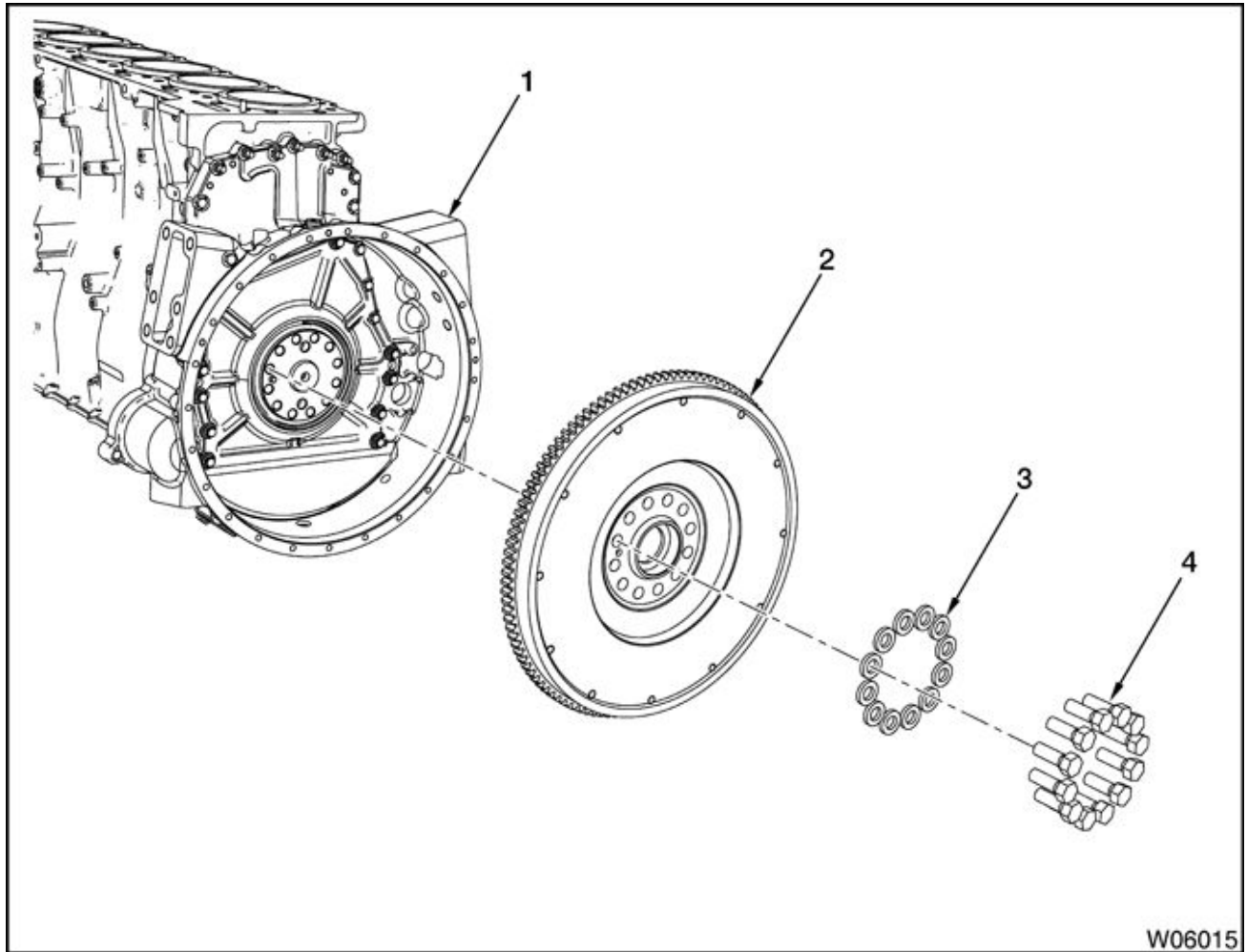
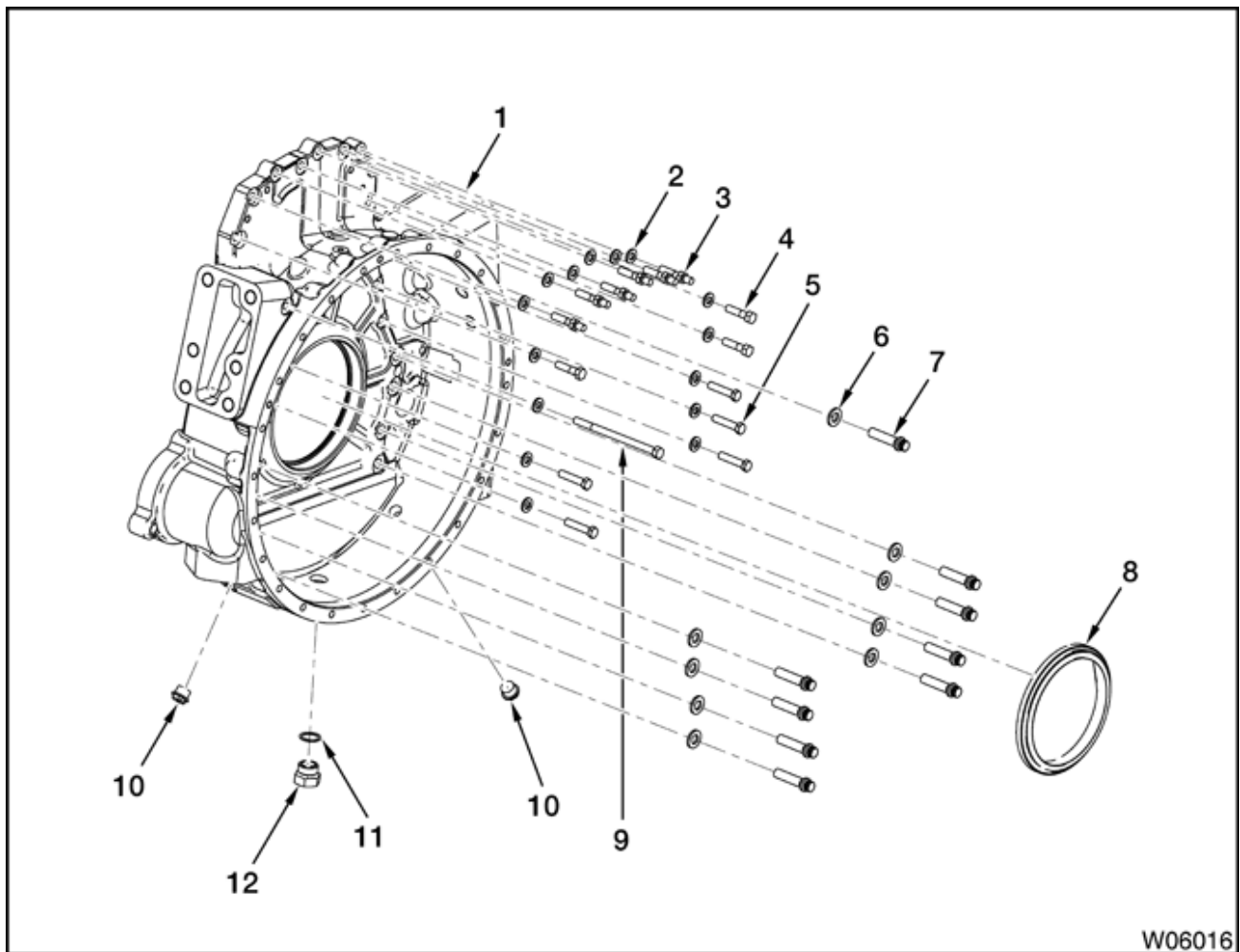


Figure 712 Flywheel assembly

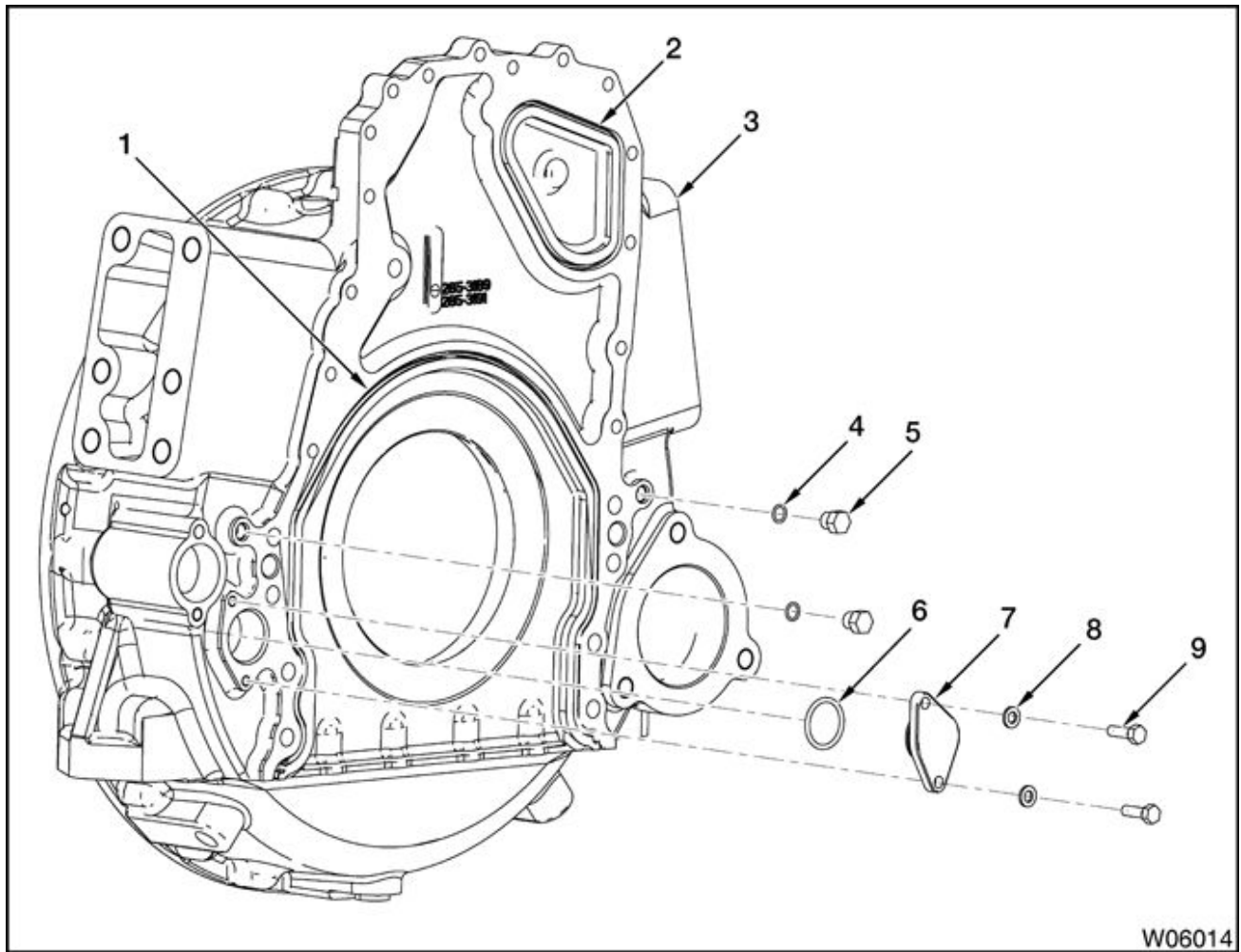
1. Flywheel housing	3. 17 x 30 x 5 hardened washer (12)	4. 5/16-18 x 1.75 hex bolt (12)
2. Flywheel assembly		



W06016

Figure 713 Flywheel housing (transmission side)

1. Flywheel housing	5. 3/8-16 x 1 3/4 bolt (5)	10. Flywheel housing drain plug (2)
2. 10.2 x 18.5 hardened washer (15)	6. 13.5 x 25.5 hardened washer (9)	11. 23.47 x 2.95 O-ring
3. 3/8 x 16 stud (6)	7. 12 PT 1/2-13 x 1.75 bolt (9)	12. 1-1/16-1 hex plug
4. 3/8-16 x 1 1/2 bolt (3)	8. Crankshaft rear seal	
	9. 3/8-16 x 5.75 hex bolt	



W06014

Figure 714 Flywheel housing (engine side)

1. Flywheel housing gasket	4. O-ring (2)	7. Access cover
2. Flywheel housing gasket	5. Plug (2)	8. 8.8 x 16.2 hardened washer (2)
3. Flywheel housing	6. O-ring	9. 5/16-18 x 1 bolt (2)

Removal



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

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

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

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

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

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

- Aftertreatment System
- Oil Pan, Oil Pickup Tube and Oil Pump

Preliminary Checks — Flywheel Assembly

1. Inspect flywheel assembly for cracks around webbing and bolt holes.
2. Inspect flywheel assembly for heat cracks and extensive scoring.
3. Inspect all ring gear teeth for starter pinion damage.
4. Replace flywheel assembly if necessary.

Rear Engine Mounts

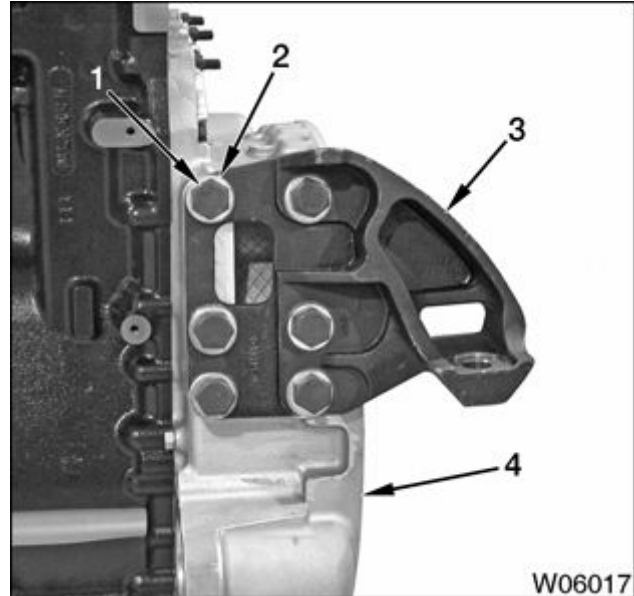


Figure 715 Left offset engine mounting support

1. 3/4 x 2 hex head bolt (6)
 2. 3/4 hardened washer (6)
 3. Left offset engine mounting support
 4. Flywheel housing
1. Remove six 3/4 x 2 hex head bolts and six 3/4 hardened washers.
 2. Remove left offset engine mounting support.

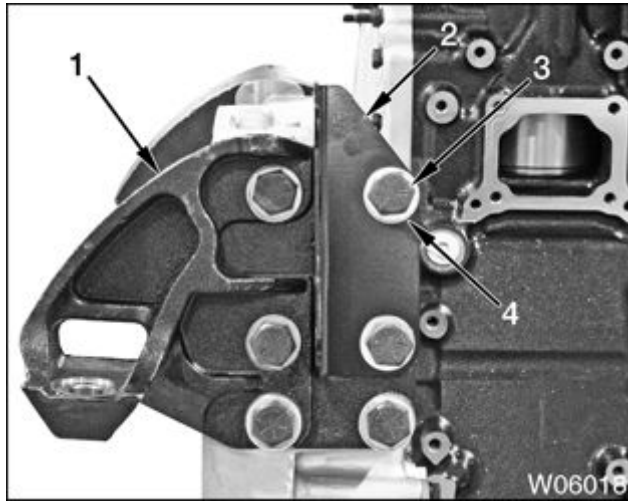


Figure 716 Right offset engine mounting support

1. Right offset engine mounting support
 2. PDO support
 3. 3/4 x 2 hex head bolt (6)
 4. 3/4 hardened washer (6)
3. Remove six 3/4 x 2 hex head bolts and six 3/4 hardened washers.
 4. Remove PDO support.
 5. Remove right offset engine mounting support.

Flywheel Assembly

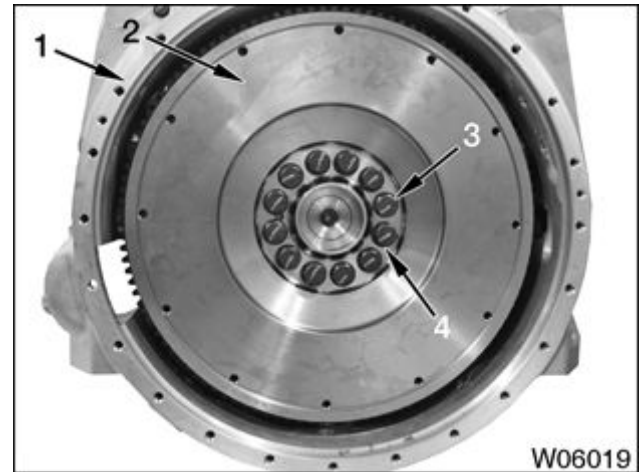


Figure 717 Flywheel assembly

1. Flywheel housing
 2. Flywheel assembly
 3. 5/16–18 x 1.75 hex bolt (12)
 4. 17 x 30 x 5 hardened washer (12)
1. Remove two 5/16–18 x 1.75 hex bolts and two 17 x 30 x 5 hardened washers 180° from each other.
 2. Install two guide pins (page 476) in place of two removed 5/16–18 x 1.75 hex bolts.
 3. Remove remaining ten 5/16–18 x 1.75 hex bolts and ten 17 x 30 x 5 hardened washers.

! WARNING: To prevent personal injury or death, get assistance or use a suitable lifting device to remove or install flywheel assembly. Flywheel assembly weighs approximately 40 kg (80 lb).

4. Properly support flywheel assembly, then slide flywheel assembly out of flywheel housing and off guide pins.
5. Remove guide pins.

Crankshaft Rear Seal

⚠ WARNING: To prevent personal injury or death, wear safety glasses with side shields when doing following procedure.

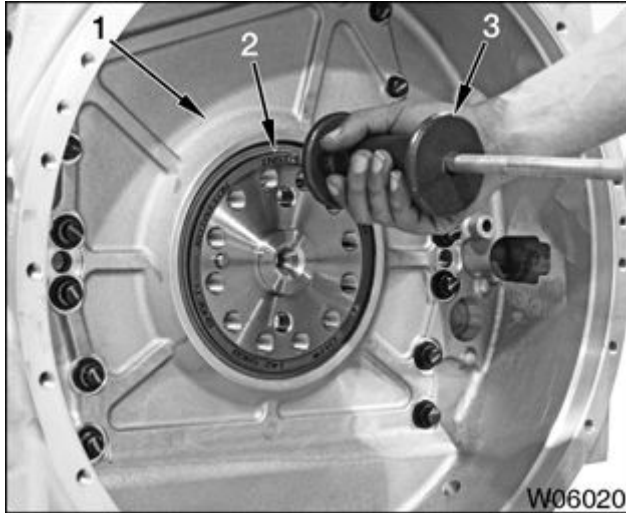


Figure 718 Crankshaft rear seal removal

1. Flywheel housing
 2. Crankshaft rear seal
 3. Slide hammer
1. With an awl and hammer, punch two holes 180° apart in crankshaft rear seal.
 2. Thread a slide hammer (page 476) with correct size screw into one of the two holes.
 3. Use slide hammer until one side of seal begins to pull out of flywheel housing. Move slide hammer to other hole and repeat until crankshaft rear seal is completely removed.
 4. Discard crankshaft rear seal.

Flywheel Housing

⚠ WARNING: To prevent personal injury or death, get assistance or use a suitable lifting device to remove or install flywheel housing. Flywheel housing weighs approximately 27 kg (60 lb).

1. If not performed previously, remove four 3/8–16 x 2 x 3/4 stud bolts and four 10.2 x 25.5 x 2.5 washers fastening oil pan to flywheel housing. See Oil Pan (page 436).

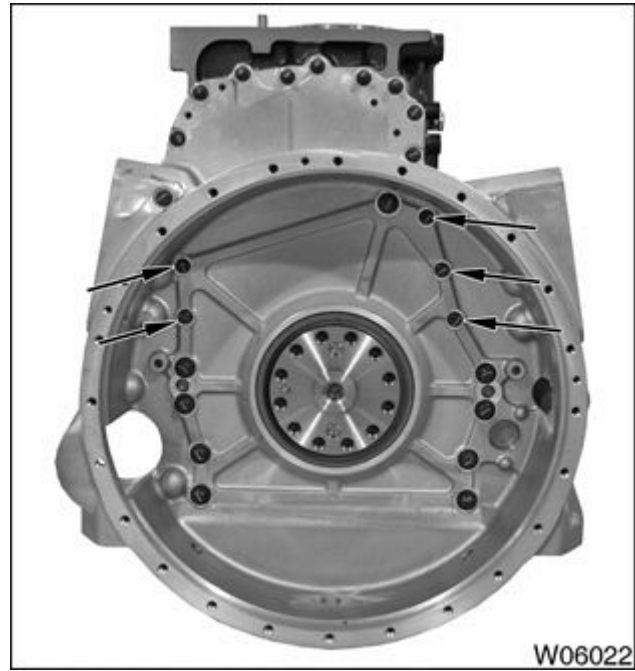


Figure 719 Flywheel housing 3/8–16 x 1 3/4 bolts and 10.2 x 18.5 hardened washers

2. Remove five 3/8–16 x 1 3/4 bolts and five 10.2 x 18.5 hardened washers.

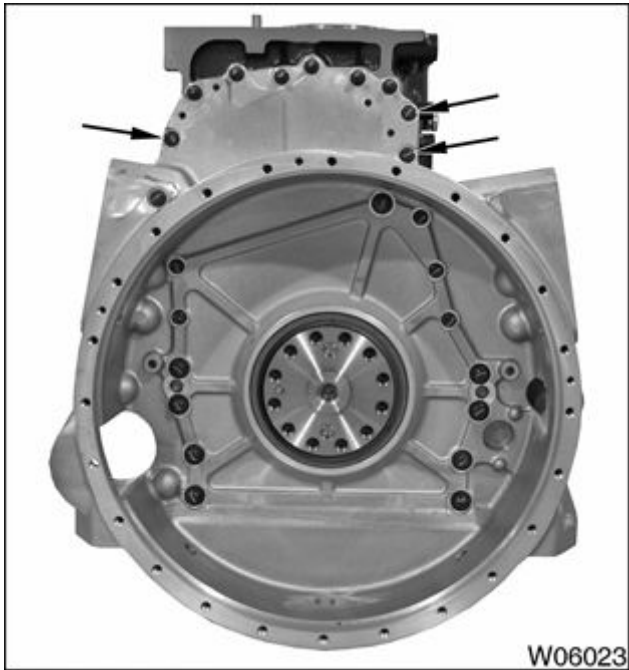


Figure 720 Flywheel housing 3/8-16 x 1 1/2 bolts and 10.2 x 18.5 hardened washers

3. Remove three 3/8-16 x 1 1/2 bolts and three 10.2 x 18.5 hardened washers.

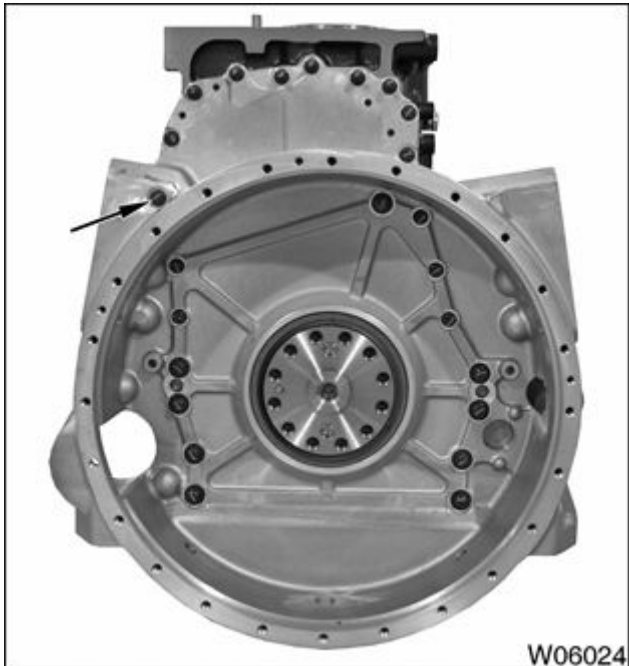


Figure 721 Flywheel housing 3/8-16 x 5.75 hex bolt and 10.2 x 18.5 hardened washer

4. Remove 3/8-16 x 5.75 hex bolt and 10.2 x 18.5 hardened washer.

! WARNING: To prevent personal injury or death, get assistance or use a suitable lifting device to remove or install flywheel housing. Flywheel housing weighs approximately 27 kg (60 lb).

5. Properly support flywheel housing before removing final fasteners.

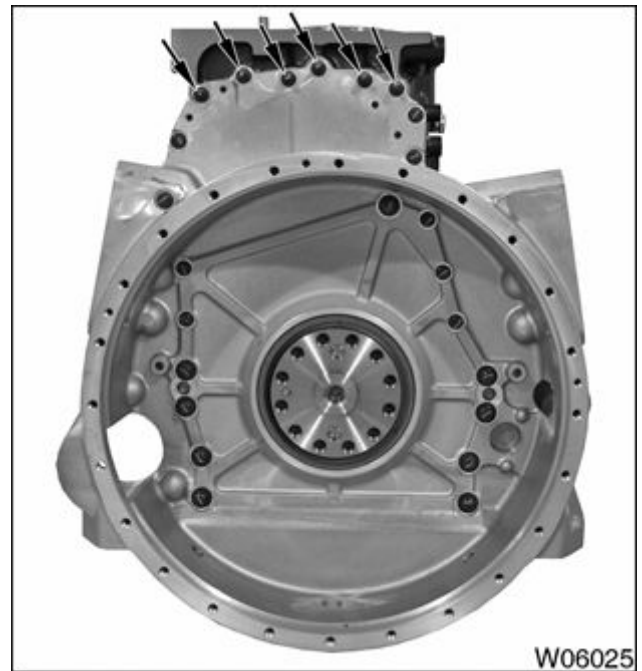


Figure 722 Flywheel housing 3/8 x 16 studs and 10.2 x 18.5 hardened washers

6. Remove six 3/8 x 16 studs and six 10.2 x 18.5 hardened washers.

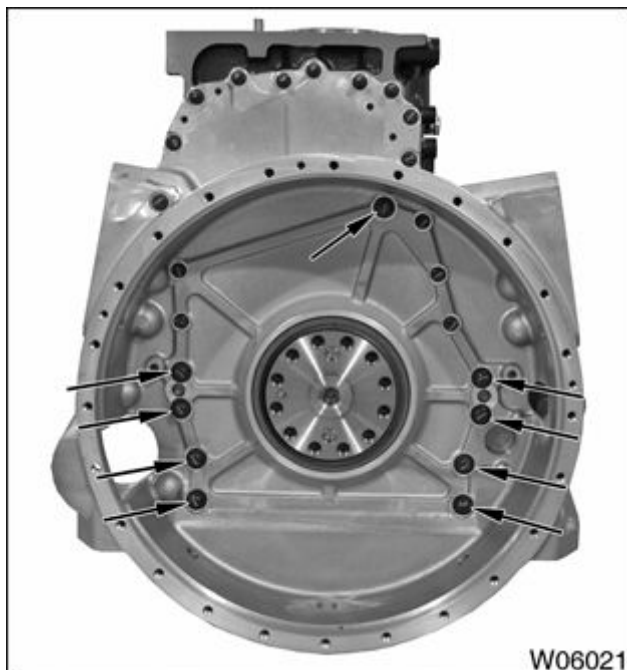


Figure 723 Flywheel housing 12 PT 1/2-13 x 1.75 bolts and 13.5 x 25.5 hardened washers

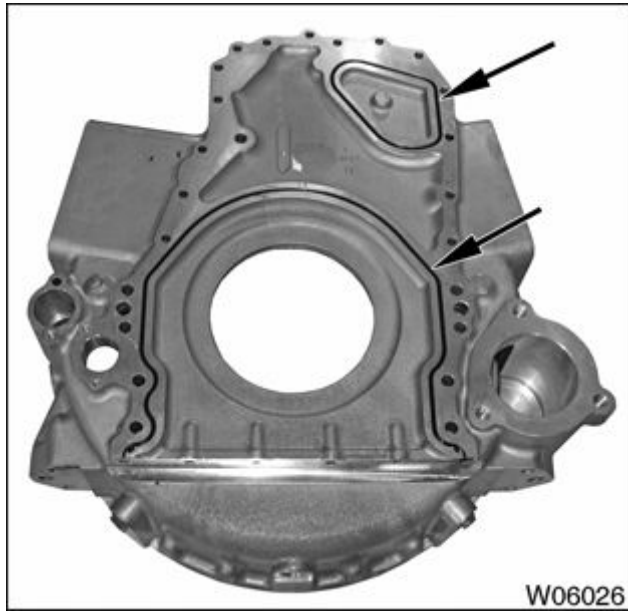
7. Remove nine 12 PT 1/2-13 x 1.75 bolts and nine 13.5 x 25.5 hardened washers.

CAUTION: To prevent engine damage, do not use excessive force when separating flywheel assembly from crankcase; each gasket location contains silicone sealant. It may be necessary to gently pry apart at gasket seal locations.



Figure 724 Flywheel housing dowel openings

8. With flywheel housing properly supported, remove flywheel housing from crankcase by sliding off two alignment dowels that extend approximately 19 mm (0.75 in) into flywheel housing.



9. Remove and discard two flywheel housing gaskets.

Figure 725 Flywheel housing gaskets

Clean, Inspect, and Measure

All Components

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

1. Clean flywheel assembly, 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. Inspect flywheel assembly for cracks, heat checks, and extensive scoring. Replace or resurface as required.
4. Clean and inspect crankshaft and crankcase where flywheel assembly and flywheel housing mount.

NOTE: Do the following four flywheel housing and flywheel runout measurements after installation of flywheel housing and flywheel.

Flywheel Assembly Face Runout (Axial Eccentricity)

CAUTION: To prevent engine damage, check runout of flywheel assembly surface for correct alignment of engine to transmission. Failure to ensure runout is within specification may reduce life of clutch or transmission.

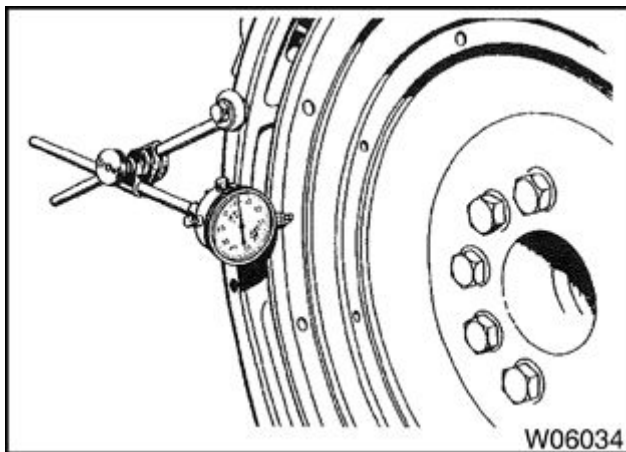


Figure 726 Flywheel assembly face runout

1. Attach dial indicator (page 476) to face of flywheel housing.

NOTE: Always put a force on crankshaft in same direction before dial indicator is read. This will remove any crankshaft end play.

2. Place indicator tip against flywheel assembly face and set dial indicator to zero.
3. Turn flywheel at intervals of 90 degrees and read dial indicator.
4. Take measurements at all four points in a complete revolution. Difference between highest and lowest reading must be within specification (page 476), which is maximum permissible face runout (axial eccentricity) of flywheel assembly.

Flywheel Assembly Bore Runout (Radial Eccentricity)

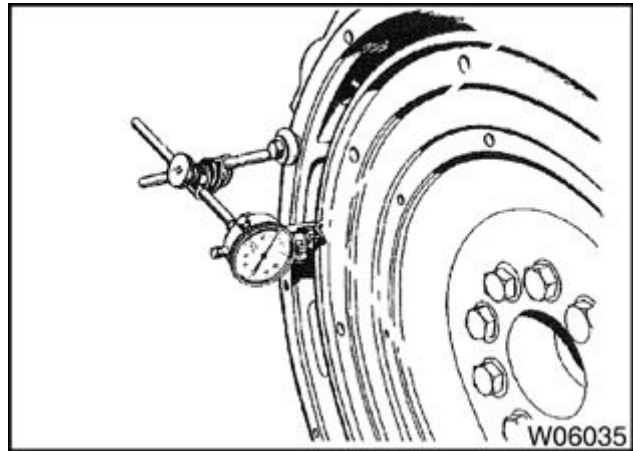


Figure 727 Flywheel assembly bore runout

1. Attach dial indicator (page 476) to face of flywheel housing. Adjust universal attachment (page 476) so dial indicator makes contact on the edge of flywheel assembly.
2. Set dial indicator to zero.
3. Turn flywheel assembly at intervals of 90 degrees and read dial indicator.
4. Take measurements at all four points in a complete revolution. Difference between highest and lowest reading must be within specification (page 476), which is maximum permissible bore runout (radial eccentricity) of flywheel assembly.

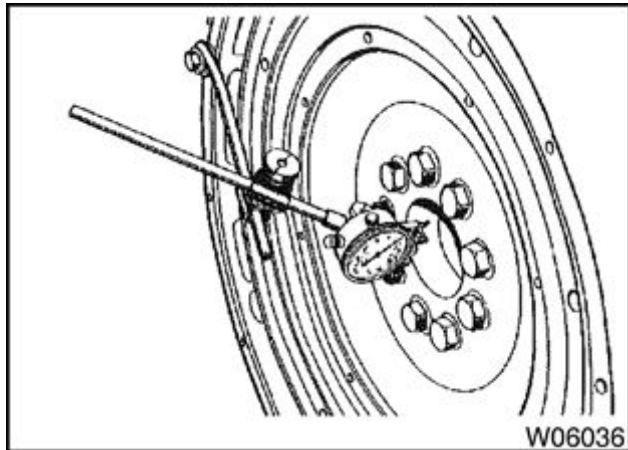


Figure 728 Flywheel assembly pilot bearing bore runout

5. Adjust position of dial indicator (page 476) to measure bore of the pilot bearing opening in flywheel assembly.
6. Set dial indicator to zero.
7. Turn flywheel assembly at intervals of 90 degrees and read dial indicator.
8. Take measurements at all four points in a complete revolution. Difference between highest and lowest reading must be within specification (page 476), which is maximum permissible pilot bearing bore runout (radial eccentricity) of flywheel assembly.

Flywheel Housing Face Runout (Axial Eccentricity)

NOTE: Bearing clearance must be removed by tapping crankshaft towards rear with rubber mallet before setting zero on dial indicator. Bearing clearance must be removed in order to receive correct measurements.

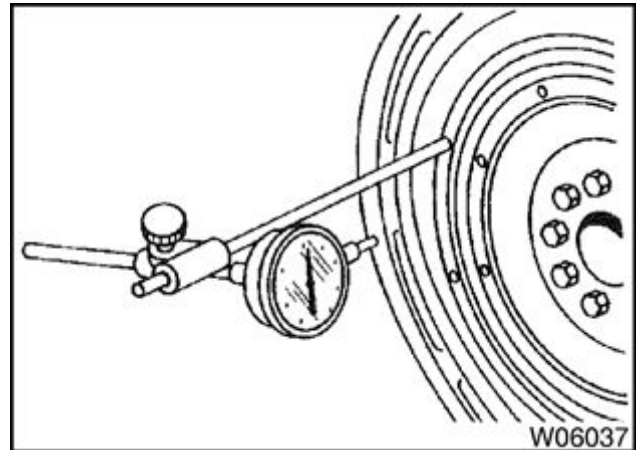


Figure 729 Flywheel housing face runout

1. Attach dial indicator (page 476) to flywheel assembly so anvil of dial indicator will contact face of flywheel housing.

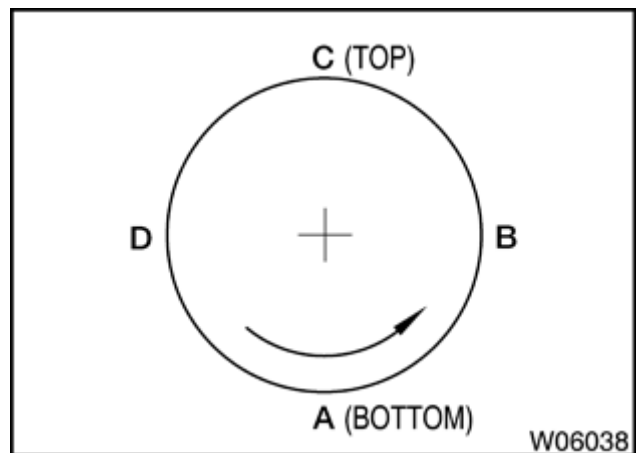


Figure 730 Flywheel housing face runout measuring locations

2. Rotate flywheel assembly so that dial indicator is at bottom (location A).
3. Use a rubber mallet (page 476) and tap crankshaft toward rear before setting dial indicator to zero.
4. Turn flywheel assembly at intervals of 90 degrees. Use a rubber mallet and tap crankshaft toward rear before reading dial indicator at locations (B), (C) and (D).
5. Difference between highest and lowest reading must be within specification (page 476), which

is maximum permissible face runout (axial eccentricity) of flywheel housing.

Flywheel Housing Bore Runout (Radial Eccentricity)

- 1. Make a copy of chart (Figure 733) to record your measurements.

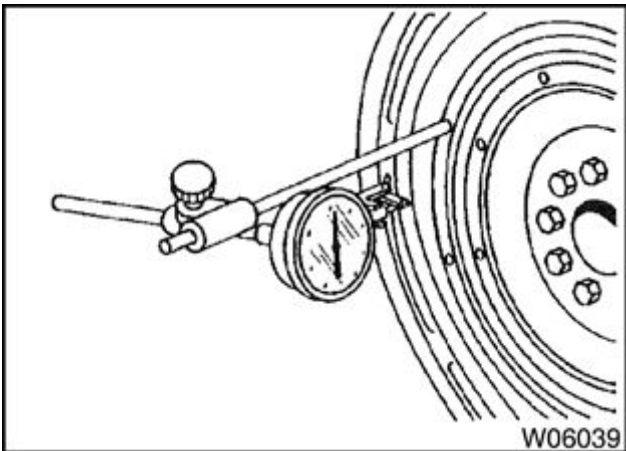


Figure 731 Flywheel housing bore runout

- 2. Attach dial indicator (page 476) to flywheel assembly so anvil of dial indicator will contact bore of flywheel housing.

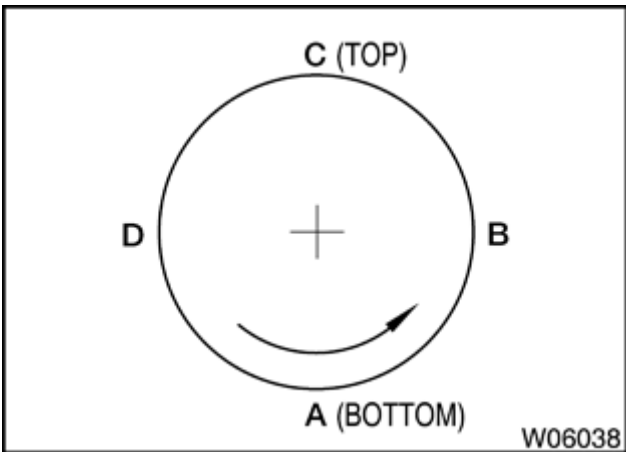


Figure 732 Flywheel housing bore runout measuring locations

- 3. Rotate flywheel assembly so that dial indicator is at top (location C).
- 4. Set dial indicator to zero.

- 5. Push crankshaft upward against top of bearing. Record measurement as bearing clearance on line 1 in column (C).

NOTE: Correct placement of appropriate measurements is necessary for making later calculations.

CHART FOR DIAL INDICATOR MEASUREMENTS					
	Position of dial indicator				
	Line No.	A	B	C	D
Correction for bearing clearance	1	0			
Dial Indicator Reading	2	0			
Total of Line 1 & 2	3	0			
the total horizontal eccentricity.					

W06040

Figure 733 Flywheel housing bore runout chart

- 6. Divide bearing clearance measurement obtained at position C (top) by two. Enter result on line 1 (bearing clearance) in columns (B) and (D).
- 7. Turn flywheel assembly to put dial indicator at bottom position (A).
- 8. Set dial indicator to zero.
- 9. Turn flywheel assembly counterclockwise 90 degrees to put dial indicator at position (B). Record measurement on line 2 (dial indicator reading) in column (B).
- 10. Turn flywheel assembly counterclockwise 90 degrees to put dial indicator at top position (C). Record measurement on line 2 (dial indicator reading) in column (C).
- 11. Turn flywheel assembly counterclockwise 90 degrees to put dial indicator at top position (D). Record measurement on line 2 (dial indicator reading) in column (D).
- 12. Complete line 3 of chart by adding lines 1 and 2 for each column.
- 13. Result in line 3 of column (C) is vertical eccentricity.
- 14. Subtract higher result in line 3 of either column (B) or (D) from lower result in line 3 of either column (B) or (D). Record subtraction result in area of chart marked total horizontal eccentricity.

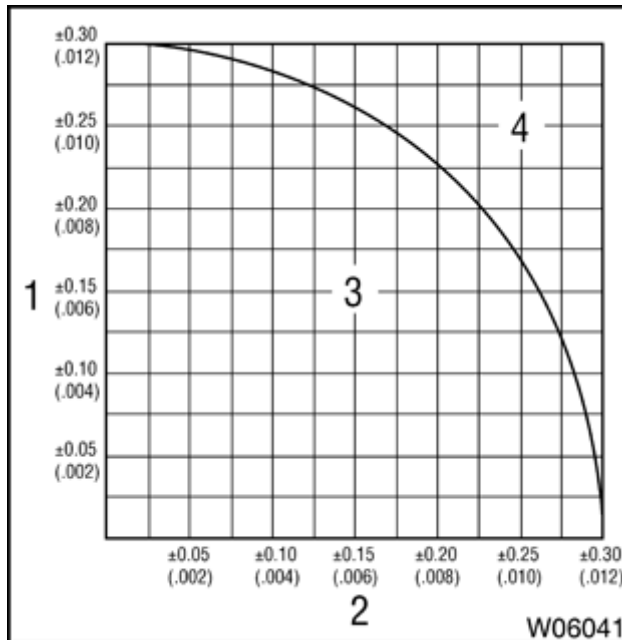


Figure 734 Flywheel housing bore runout graph

1. Total vertical eccentricity (mm (inch))
2. Total horizontal eccentricity (mm (inch))
3. Acceptable value
4. Unacceptable value

15. Using graph, find intersection of eccentricity lines (vertical and horizontal).

16. If point of intersection is in "Acceptable" range, bore is in alignment. If point of intersection is in "Unacceptable" range, flywheel housing must be changed.

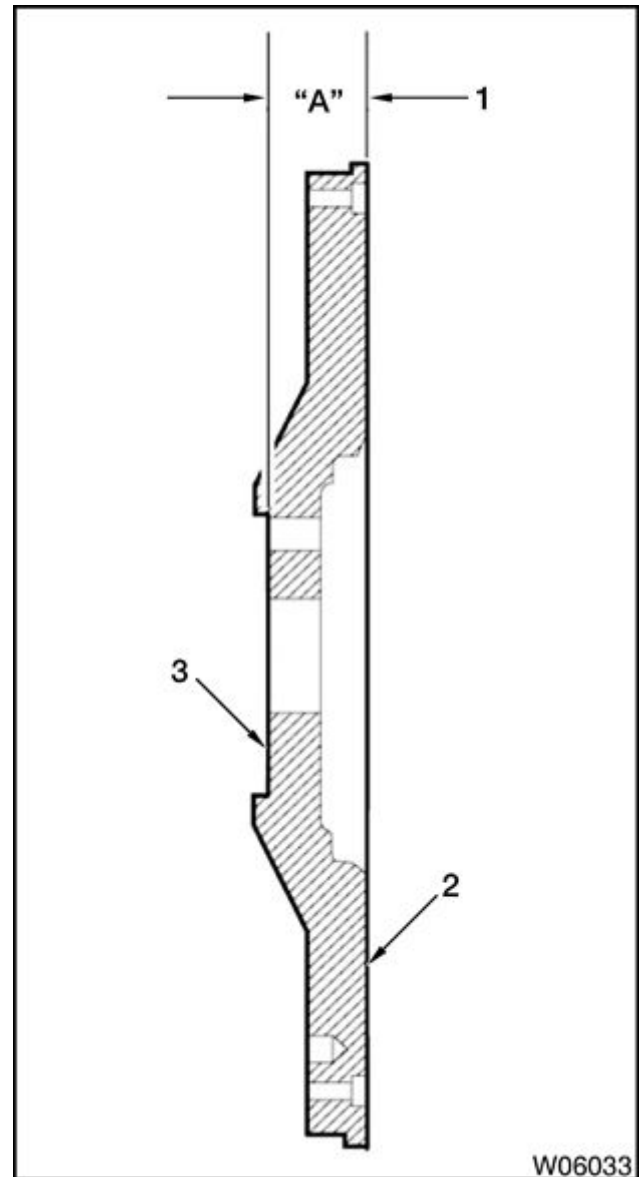


Figure 735 Flywheel assembly surface dimension (typical)

1. Flywheel assembly thickness (dimension "A")
2. Clutch disc mounting face
3. Crankshaft flange mounting face

NOTE: Flywheel assembly resurfacing information is provided for guidance only. Navistar Inc. assumes no responsibility either for results of any work performed in accordance with this information or for ability of service personnel to detect cracks.

Recondition

Flywheel Assembly

NOTE: Flywheel assemblies used with manual transmissions may be resurfaced to correct minor wear and scoring. If flywheel assembly meets following requirements it can be resurfaced.

! WARNING: To prevent personal injury or death, do not machine flywheel assembly beyond minimum thickness specified for resurfacing.

⚠ WARNING: To prevent personal injury or death, carefully examine flywheel assembly for any cracks or heat checks before and after resurfacing. Cracks in flywheel assembly can cause it to separate. If there are any questions, do not reuse flywheel assembly.

1. Check flywheel assembly for cracks and damage. Replace flywheel assembly if required.
2. With micrometer (page 476), measure flywheel assembly thickness and compare to minimum required thickness specification (dimension "A") (page 476). Discard flywheel assembly if below minimum thickness specification or if flywheel

assembly will be below minimum thickness after resurfacing.

3. Resurface flywheel assembly. See Resurfacing Machine operators manual for instructions on flywheel assembly resurfacing procedure.
 4. Check flywheel assembly for cracks and damage after resurfacing. Replace flywheel assembly if required.
 5. Measure flywheel assembly thickness after resurfacing and compare to minimum required thickness specification (dimension "A") (page 476). Discard flywheel assembly if below minimum thickness specification.
-

Installation

Flywheel Housing

⚠ WARNING: To prevent personal injury or death, get assistance or use a suitable lifting device to remove or install flywheel housing. Flywheel housing weighs approximately 27 kg (60 lb).

1. Thoroughly clean mating surfaces of flywheel housing and crankcase. Remove all residual silicone sealant.

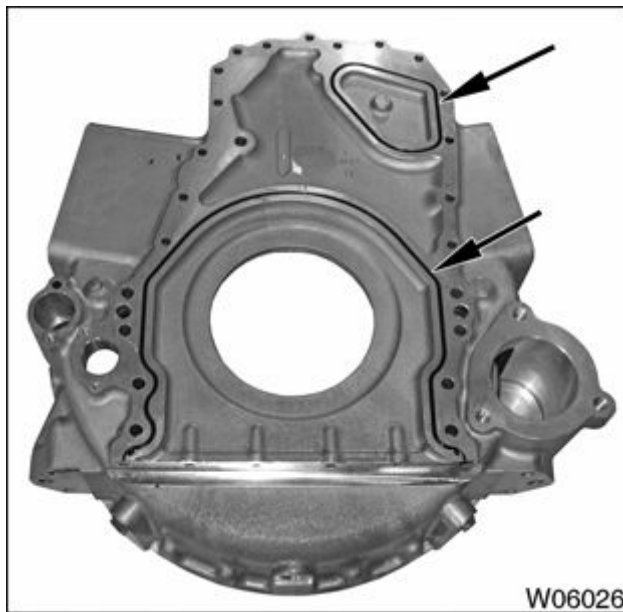


Figure 736 Flywheel housing gaskets

2. Install two new flywheel housing gaskets into rear of flywheel housing.
3. Apply thin bead of Silicone Sealant (page 476) to both flywheel gaskets.



Figure 737 Flywheel housing dowel openings

4. Verify flywheel housing alignment dowels are installed into crankcase and are not damaged. Replace as necessary. Dowels extend past end of block by approximately 19 mm (0.75 in).

⚠ WARNING: To prevent personal injury or death, get assistance or use a suitable lifting device to remove or install flywheel housing. Flywheel housing weighs approximately 27 kg (60 lb).

5. With flywheel housing properly supported, remove flywheel housing from crankcase by sliding off two alignment dowels that extend approximately 19 mm (0.75 in) into flywheel housing.
6. With flywheel housing properly supported, position flywheel housing onto crankcase by sliding over two alignment dowels. Continue supporting flywheel housing until several fasteners are installed.

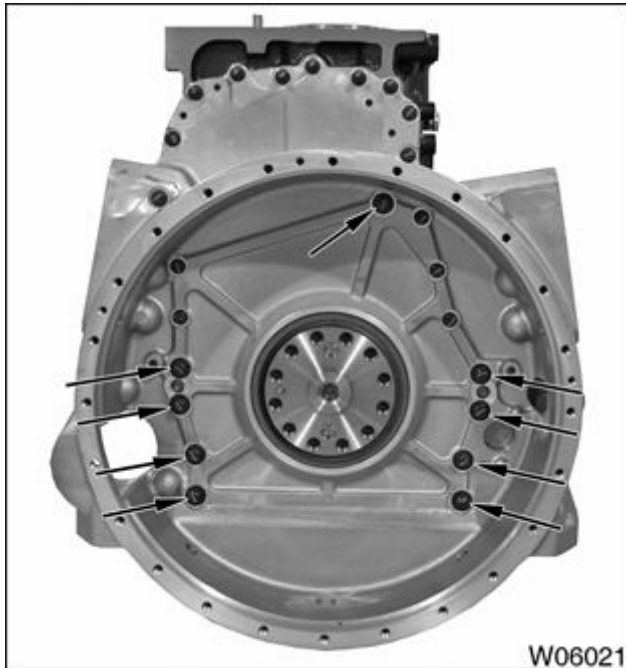


Figure 738 Flywheel housing 12 PT 1/2-13 x 1.75 bolts and 13.5 x 25.5 hardened washers

7. Install nine 12 PT 1/2-13 x 1.75 bolts and nine 13.5 x 25.5 hardened washers hand tight. Do not torque bolts at this time.

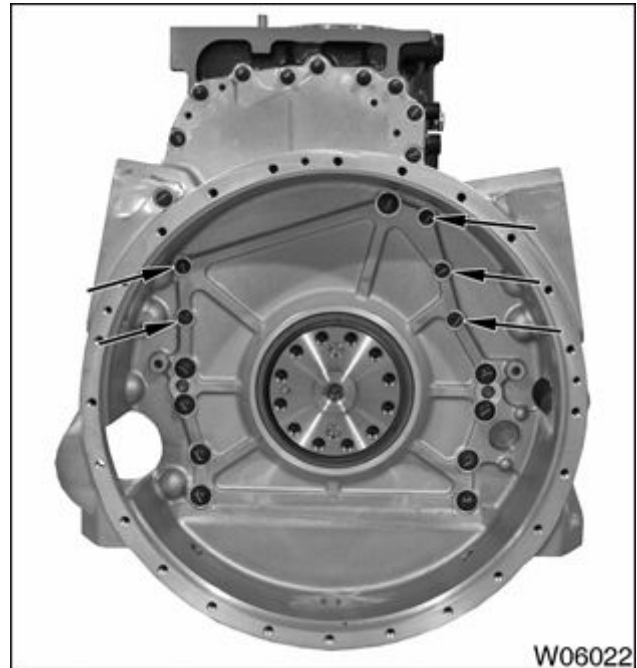


Figure 739 Flywheel housing 5 3/8-16 x 1 3/4 bolts and 10.2 x 18.5 hardened washers

8. Install five 3/8-16 x 1 3/4 bolts and five 10.2 x 18.5 hardened washers hand tight. Do not torque bolts at this time.
-

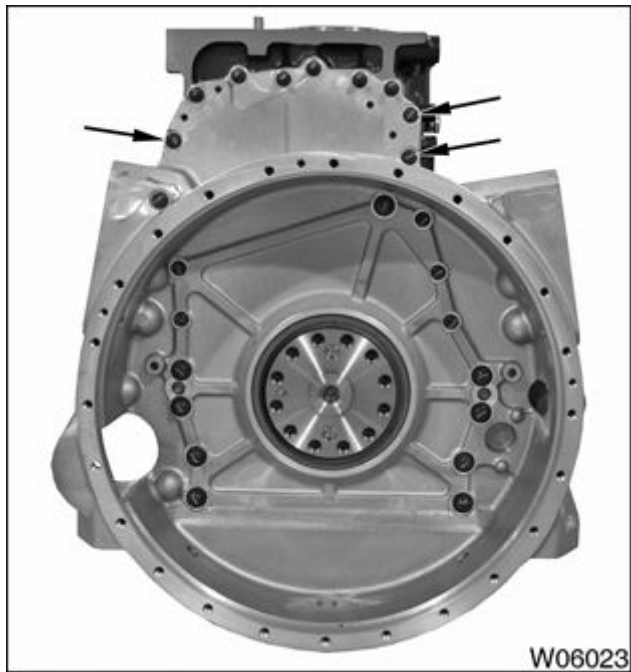


Figure 740 Flywheel housing 3/8-16 x 1 1/2 bolts and 10.2 x 18.5 hardened washers

9. Install three 3/8-16 x 1 1/2 bolts and three 10.2 x 18.5 hardened washers hand tight. Do not torque bolts at this time.

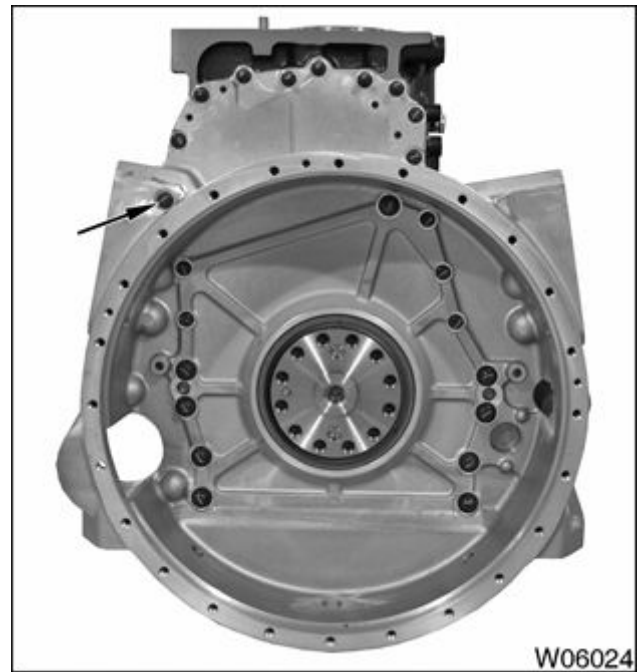


Figure 741 Flywheel housing 3/8-16 x 5.75 hex bolt and 10.2 x 18.5 hardened washer

10. Install 3/8-16 x 5.75 hex bolt and 10.2 x 18.5 hardened washer hand tight. Do not torque bolts at this time.

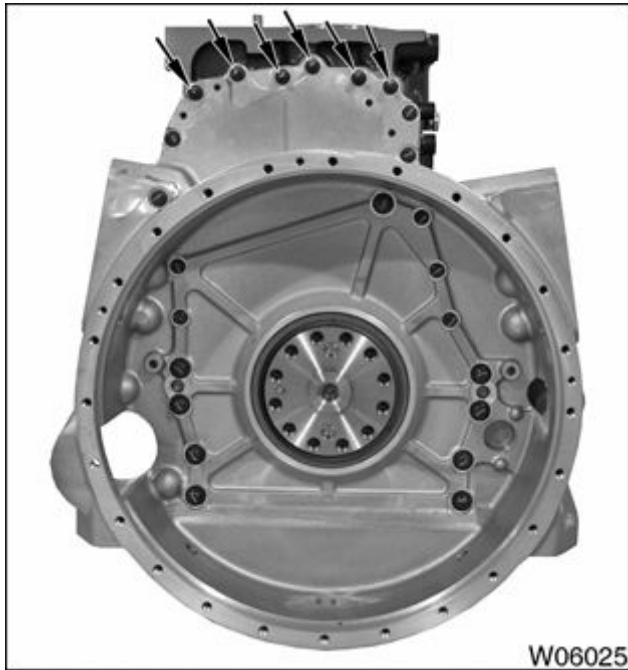


Figure 742 Flywheel housing 3/8 x 16 studs and 10.2 x 18.5 hardened washers

11. Install six 3/8 x 16 studs with six 10.2 x 18.5 hardened washers under stud heads hand tight.

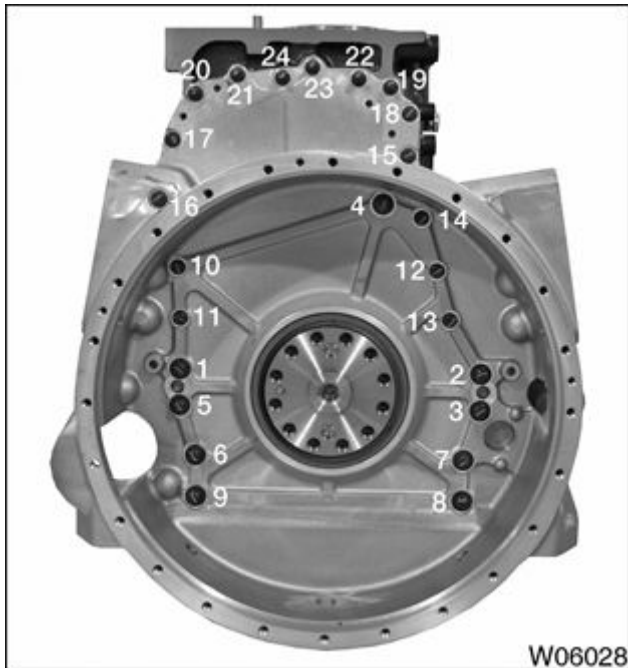


Figure 743 Flywheel housing torque sequence

12. Torque flywheel housing fasteners using torque sequence of (Figure 743) to following torque values:

- A. Torque fasteners 1 through 9 to 100 N·m (73 lbf·ft)
- B. Torque fasteners 10 through 24 to 40 N·m (30 lbf·ft)
- C. Torque fasteners 1 through 9 to 135 N·m (100 lbf·ft)
- D. Torque fasteners 10 through 24 to 55 N·m (40 lbf·ft)

Crankshaft Rear Seal

CAUTION: To prevent engine damage, keep all parts clean from contaminants; contaminants may cause rapid wear and shortened component life.

1. Inspect crankshaft surface and flywheel housing for any imperfections that may prevent proper crankshaft rear seal installation.

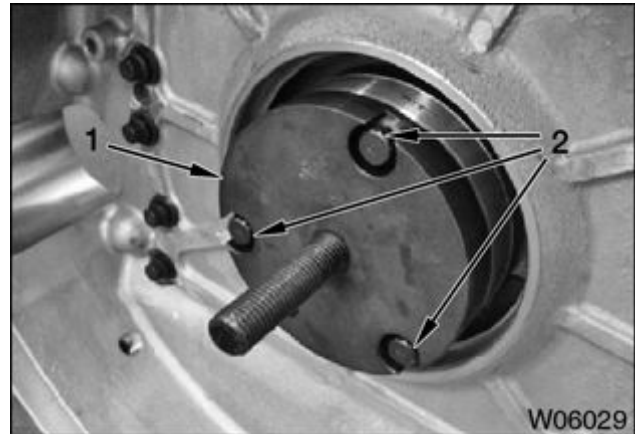


Figure 744 Rear seal installer

1. Rear seal installer inner hub
 2. Rear seal installer inner hub bolt (3)
2. Using tools from Front and Rear Crankshaft Seal Installer Kit (page 476), install rear seal installer inner hub to crankshaft flange using three rear seal installer inner hub bolts.

CAUTION: To avoid damage to crankshaft rear seal, do not touch inner seal lip or allow oil/grease on any part of seal during installation.

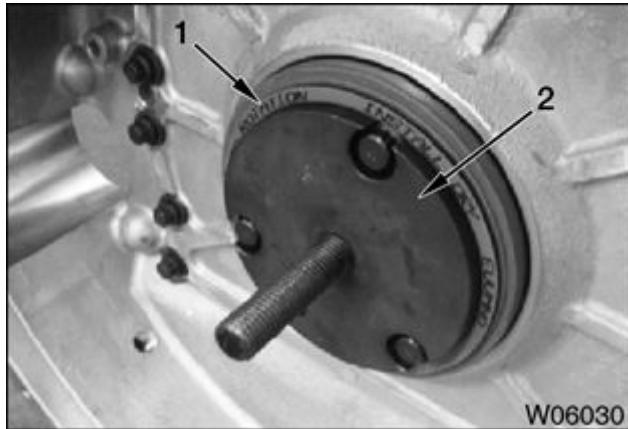


Figure 745 Rear seal installation

1. Crankshaft rear seal
2. Rear seal installer inner hub
3. Install new crankshaft rear seal over rear seal installer inner hub. Install crankshaft rear seal so that directional arrow located on seal matches direction of engine rotation (counterclockwise, as viewed looking into flywheel housing).



Figure 746 Rear seal installer pressing hub

1. Rear seal installer pressing hub
2. Rear seal installer pressing hub washer
3. Rear seal installer pressing hub nut

4. Using tools from Front and Rear Crankshaft Seal Installer Kit (page 476), install rear seal installer pressing hub over rear seal installer inner hub using included washer and nut. Lubricate nut threads and washer to aid in removal.

CAUTION: To prevent engine damage, do not use air tools to tighten rear seal installer pressing hub nut.

5. Tighten rear seal installer pressing hub nut to complete installation of crankshaft rear seal. When tool bottoms out, seal is fully seated.
6. Remove tools and inspect for proper installation.

Flywheel Assembly

! WARNING: To prevent personal injury or death, inspect flywheel assembly for cracks or heat checks after resurfacing. Do not install flywheel assembly if damaged or questionable. Resurfacing information is provided for guidance only. Navistar Inc. does not assume responsibility for work done by service personnel.

! WARNING: To prevent personal injury or death, get assistance or use a suitable lifting device to remove or install flywheel assembly. Flywheel assembly weighs approximately 40 kg (80 lb).

1. Install two guide pins (page 476) in two 5/16–18 x 1.75 hex bolt mounting holes 180° from each other.

CAUTION: To prevent engine damage, flywheel assembly must be installed with chamfered side of outer ring gear teeth facing toward starting motor.

2. Properly support flywheel assembly, then slide flywheel assembly into flywheel housing and onto guide pins.

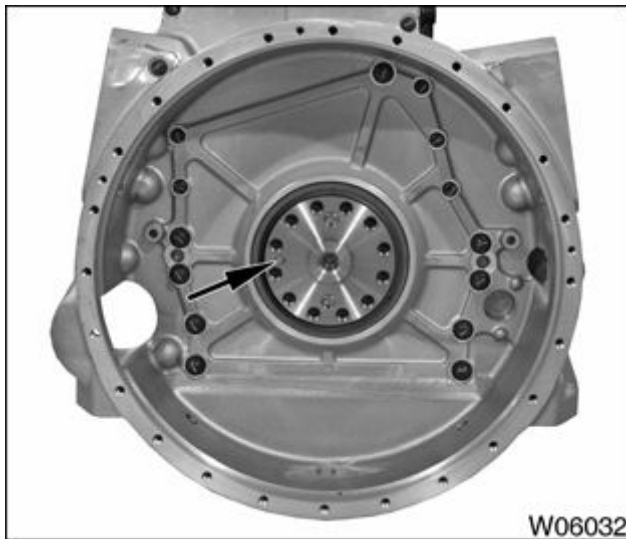


Figure 747 Flywheel assembly guide dowel

3. Ensure flywheel assembly is in proper position on crankshaft flange. Flywheel assembly is properly positioned when guide dowel on crankshaft flange aligns with opening in flywheel assembly.
4. Lubricate threads of twelve 5/16–18 x 1.75 hex bolts with clean engine oil or moly paste thread lubricant (page 476).
5. Install ten 5/16–18 x 1.75 hex bolts and ten 17 x 30 x 5 hardened washers hand tight.
6. Remove guide pins (page 476).
7. Install two 5/16–18 x 1.75 hex bolts and two 17 x 30 x 5 hardened washers hand tight where guide pins were located.

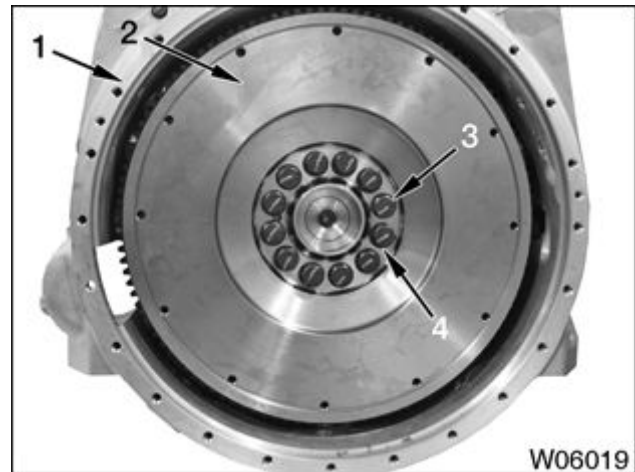


Figure 748 Flywheel assembly

1. Flywheel housing
2. Flywheel assembly
3. 5/16–18 x 1.75 hex bolt (12)
4. 17 x 30 x 5 hardened washer (12)
8. Tighten twelve 5/16–18 x 1.75 hex bolts to special torque (page 476).
9. Perform measurement tests on flywheel assembly and flywheel housing to verify installed parts are within specifications. See Clean, Inspect, and Measure (page 464).

Rear Engine Mounts

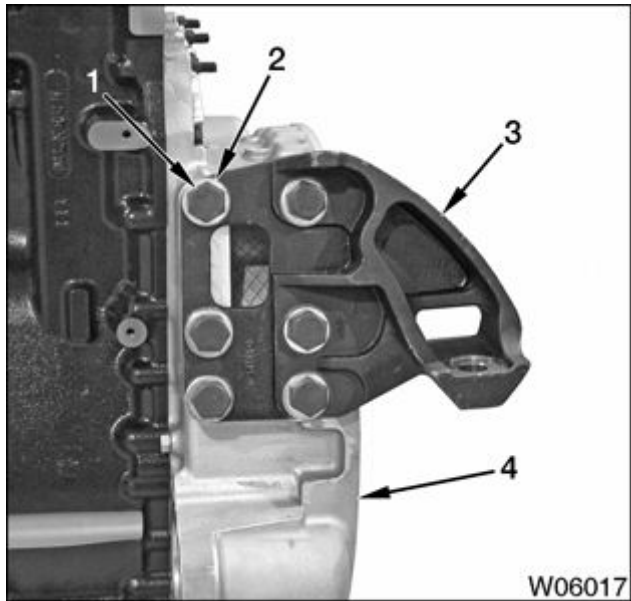


Figure 749 Left offset engine mounting support

1. 3/4 x 2 hex head bolt (6)
 2. 3/4 hardened washer (6)
 3. Left offset engine mounting support
 4. Flywheel housing
1. Position left offset engine mounting support on flywheel housing.
 2. Install six 3/4 x 2 hex head bolts and six 3/4 hardened washers.
 3. Tighten six 3/4 x 2 hex head bolts to special torque (page 476).

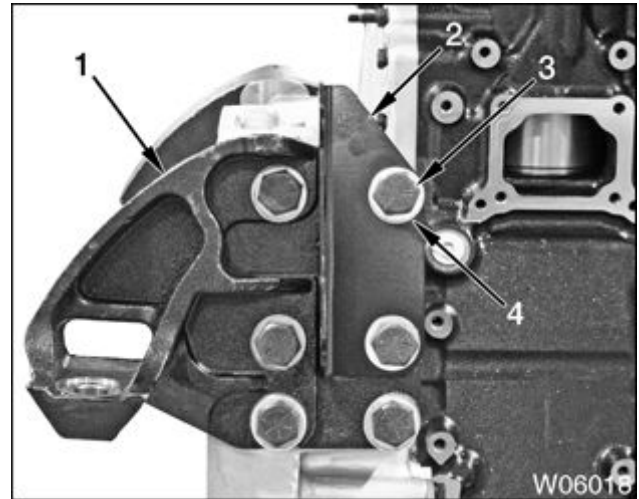


Figure 750 Right offset engine mounting support

1. Right offset engine mounting support
 2. PDO support
 3. 3/4 x 2 hex head bolt (6)
 4. 3/4 hardened washer (6)
4. Position right offset engine mounting support and PDO support on flywheel housing.
 5. Install six 3/4 x 2 hex head bolts and six 3/4 hardened washers.
 6. Tighten six 3/4 x 2 hex head bolts to special torque (page 476).

Specifications

Flywheel assembly maximum bore runout	0.15 mm (0.006 in)
Flywheel assembly maximum face runout	0.13 mm (0.005 in)
Flywheel assembly maximum pilot bearing bore runout	0.13 mm (0.005 in)
Flywheel assembly minimum thickness (dimension "A")	46 mm (1.811 in)
Flywheel housing maximum bore runout	See procedure (page 466)
Flywheel housing maximum face runout	0.38 mm (0.015 in)

Special Torque

Flywheel housing bolts	See tightening steps in procedure (page 469)
3/4 x 2 hex head bolts (rear engine mount)	135 N·m (100 lbf·ft)
5/16–18 x 1.75 hex bolts (flywheel assembly)	270 N·m (200 lbf·ft)

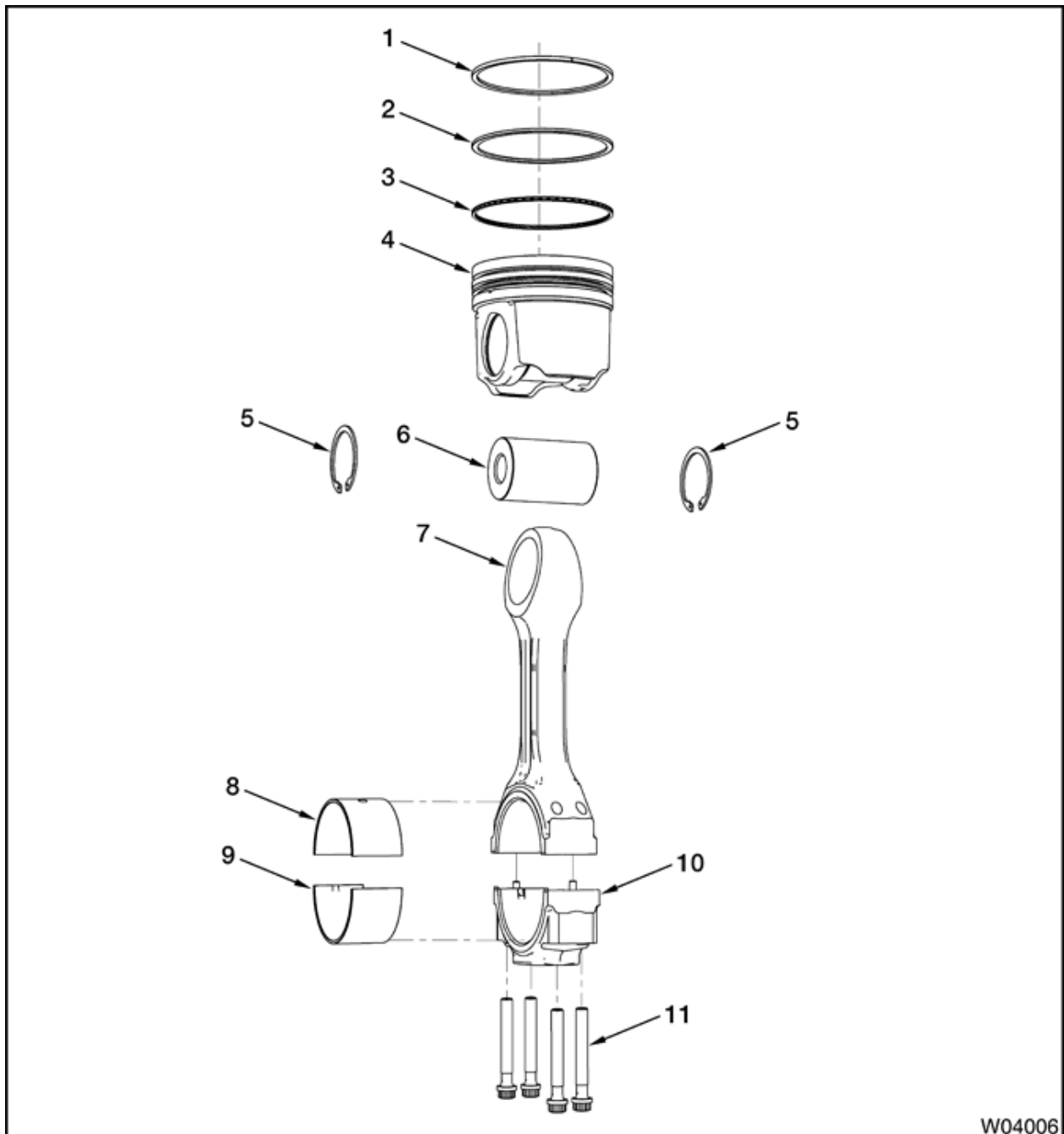
Special Service Tools

Description	Tool Number
Dial indicator	Obtain locally
Dial indicator universal attachment	Obtain locally
Front and Rear Crankshaft Seal Installer Kit	ZTSE6119
Guide pin	Obtain locally
Micrometer	Obtain locally
Moly paste thread lubricant	Obtain locally
Rubber mallet	Obtain locally
Silicone Sealant	Wacker T-442 RTV
Slide hammer	Obtain locally

Table of Contents

Exploded Views.....	479
Removal.....	481
Preliminary Checks.....	481
Piston and Connecting Rod.....	482
Piston Disassembly.....	483
Cylinder Sleeves.....	484
Cleaning and Inspection.....	485
Cleaning.....	485
Piston Inspection.....	485
Piston Ring Inspection.....	486
Connecting Rod Inspection.....	486
Connecting Rod Bore Check.....	487
Piston Pin Inspection.....	487
Cylinder Sleeve Bore Inspection.....	488
Cylinder Sleeve Projection Measurement.....	488
Installation.....	492
Cylinder Sleeves.....	492
Piston Assembly.....	492
Piston and Connecting Rod.....	493
Specifications.....	496
Special Torque.....	497
Special Service Tools.....	497

Exploded Views



W04006

Figure 751 Piston and connecting rod

1. Top piston ring (keystone) (6)	6. Piston pin (6)	10. Connecting rod cap (6)
2. Intermediate piston ring (6)	7. Connecting rod (6)	11. M11 x 84 12 point bolt (24)
3. Oil piston ring (6)	8. Connecting rod upper bearing (6)	
4. Piston (6)	9. Connecting rod lower bearing (6)	
5. Piston pin retaining ring (12)		

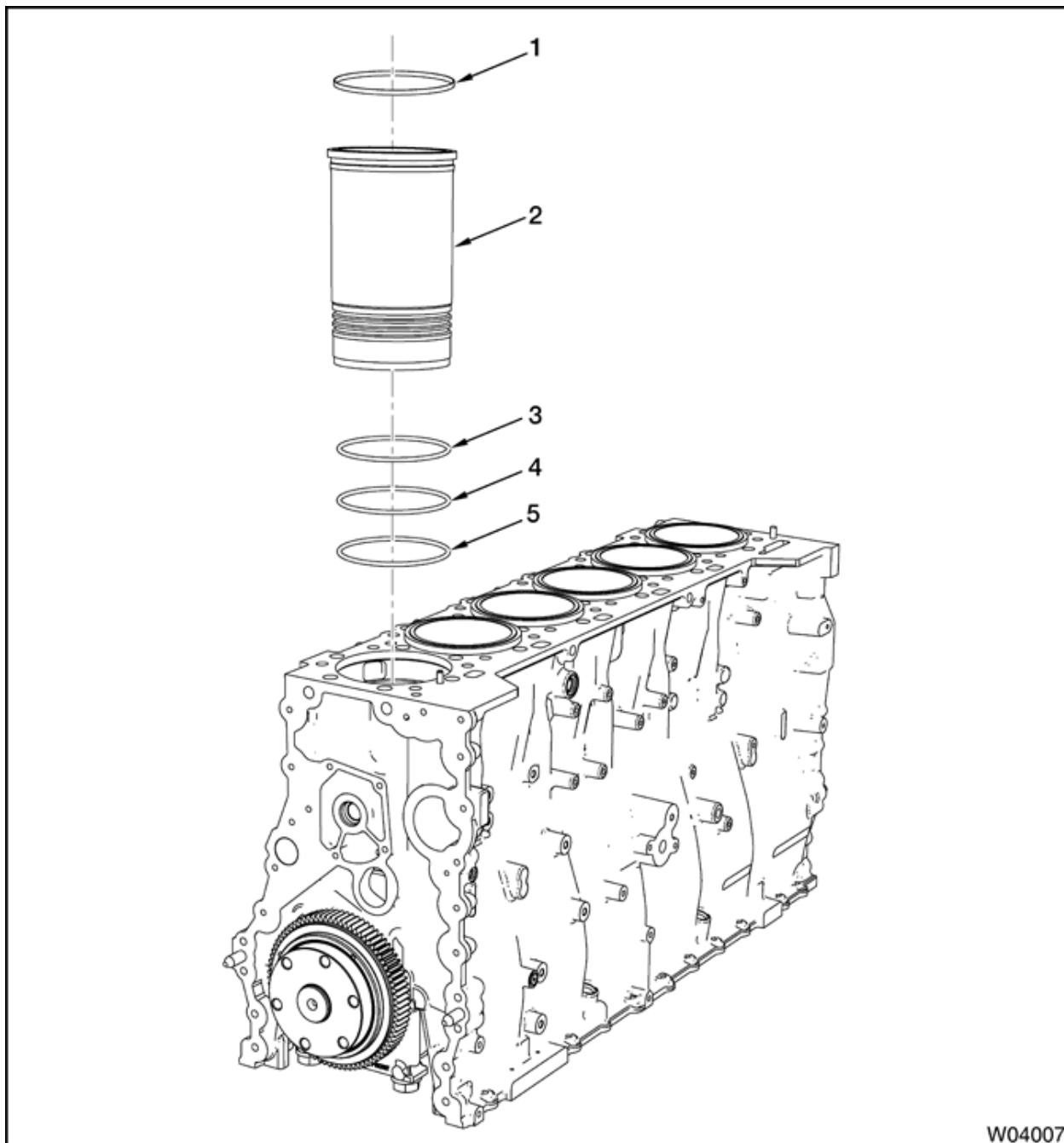


Figure 752 Cylinder sleeve

1. Cylinder lining band	3. O-ring (green)	5. O-ring (black)
2. Cylinder sleeve	4. O-ring (orange)	

Removal



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



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



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



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



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

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

- Engine Electrical
- Cold Start Assist
- Aftertreatment System
- Engine Braking System
- Turbochargers
- Fuel System
- Oil Cooler, Filter Housing, and Crankcase Ventilation
- Exhaust Gas Recirculating (EGR) System
- Air Inlet and Exhaust Manifold
- Cylinder Head, Camshaft, and Valve Train
- Flywheel and Flywheel Housing (as needed)
- Oil Pan and Oil Suction Tube

Preliminary Checks

NOTE: Evaluate piston protrusion before removing any piston and connecting rod assemblies. This helps identify bent or twisted connecting rods.



Figure 753 Checking piston protrusion (typical)

NOTE: Piston protrusion readings are done in line with piston pin, eliminating rocking movement of piston at any other position of measurement.

1. Check piston protrusion as follows:

- a. Make sure crankcase deck surface is clean.
- b. Zero dial indicator with magnetic base (page 497) on crankcase deck surface.
- c. Position dial indicator tip over piston head at 3 o'clock position (over piston pin).
- d. Rotate crankshaft in direction of normal rotation to raise piston to its maximum outward protrusion at cylinder Top Dead Center (TDC).
- e. With a wooden or plastic hammer handle, gently tap down on piston in-line with piston pin to eliminate clearances.
- f. Read this protrusion on dial indicator.
- g. Reposition dial indicator tip on piston head at 9 o'clock position (over piston pin).
- h. Rotate crankshaft to raise piston to its maximum protrusion
- i. Gently tap down on piston in-line with piston pin, to eliminate clearances.
- j. Read this protrusion on dial indicator.
- k. Average the two readings. Replace piston and connecting rod if protrusion is not within specification (page 496).

Piston and Connecting Rod

CAUTION: To prevent engine damage, check for a carbon ridge on top of cylinder sleeves. If found, remove carbon ridge with a razor knife before removing rod and piston assemblies.

1. Scrape carbon ridge from top of cylinder bore, if necessary. Use care not to damage sleeve bore surface.

CAUTION: To prevent engine damage, use permanent marker to identify internal components or their orientation. Do not use paint or temporary markers.

2. Rotate crankshaft to position journals for removal of connecting rod assemblies. Mark connecting rod locations.

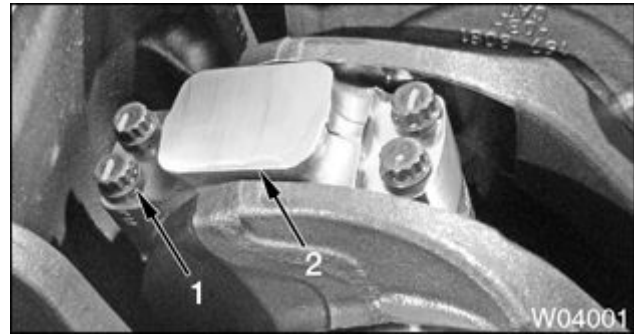


Figure 754 Connecting rod cap

1. M11 x 84 12 point bolt (24)
2. Connecting rod cap

NOTE: When removed, make sure matching connecting rod and connecting rod cap numbers stay together as a set. A cap from one connecting rod is not interchangeable with any other connecting rod.

3. Using a 12 point 14 mm socket (page 497), remove four M11 x 84 12 point bolts and connecting rod cap. Save bolts for reuse during connecting rod bore check procedure.

CAUTION: To prevent engine damage, do not damage piston cooling jet when removing connecting rod and piston assembly. If jet is bent during piston assembly removal, replace jet.

4. Remove piston and connecting rod assemblies from cylinder sleeves as follows:
 - a. If reusing piston, use a permanent marker to mark each piston and rod assembly with cylinder number and direction.
 - b. Rotate engine to a vertical position.
 - c. Use a wooden or plastic handle and push piston and connecting rod assembly from cylinder sleeve, being careful not to damage crankshaft journal.
 - d. Once piston rings are free of cylinder bore, remove piston and connecting rod assembly from cylinder sleeve.



Figure 755 Correct connecting rod and cap joint fit

CAUTION: To prevent engine damage, use permanent markers to identify internal components or their orientation. Do not use paint or temporary markers.

NOTE: Each connecting rod cap will have etched numbers on it that match the numbers on the connecting rod. Assemble the connecting rod and cap with the numbers on the same side.

5. Remove connecting rod upper and lower bearing shells by pushing out. Mark connecting rod bearing shells for position and orientation and set aside for inspection.

Piston Disassembly

! WARNING: To prevent personal injury or death, wear safety glasses with side shields when removing piston pin retaining rings.

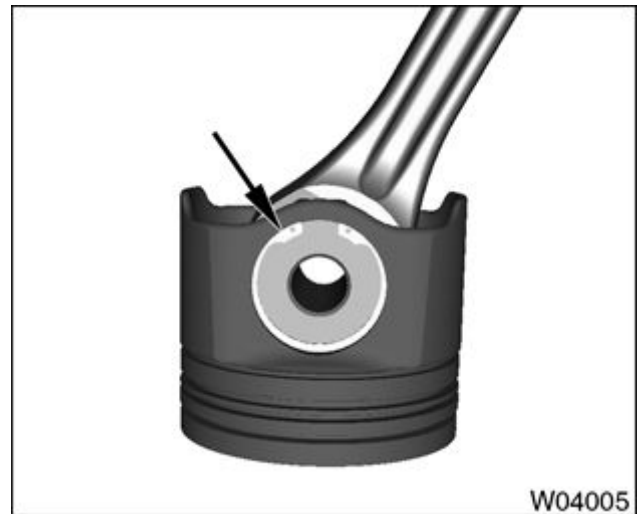


Figure 756 Piston pin retaining ring

1. Remove piston pin retaining rings.

CAUTION: To prevent engine damage, do not mark piston pin for cylinder and location on outer diameter; place mark only on flat end or tapered inside surface.

2. Remove piston pin from its bore by hand and separate connecting rod from piston.



Figure 757 Piston ring removal

NOTE: Only expand piston rings enough to fit over top of piston.

NOTE: Keep piston rings organized for each cylinder.

3. Using piston ring expansion pliers (page 497), remove top piston (keystone) ring, intermediate piston ring, and oil piston ring assembly.

Cylinder Sleeves

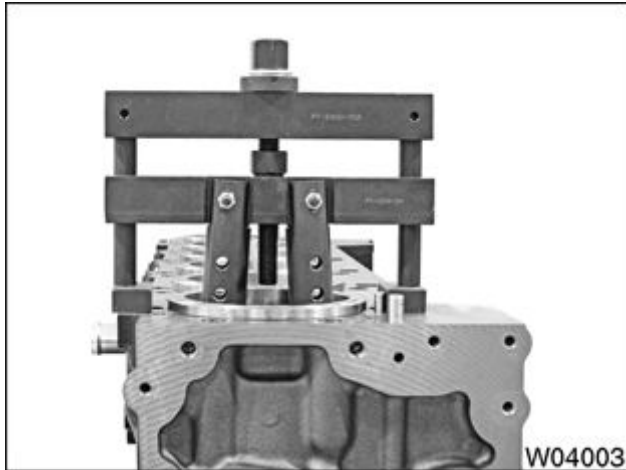


Figure 758 Cylinder sleeve removal

CAUTION: To prevent engine damage, use permanent markers to identify internal components or their orientation. Do not use paint or temporary markers.

CAUTION: To prevent engine damage, do not damage piston cooling jet when removing cylinder sleeve. If jet is bent during cylinder sleeve removal, replace jet.

1. Remove six cylinder sleeves from crankcase as follows:
 - a. Mark cylinder sleeves with cylinder number and orientation and set aside for inspection.
 - b. Insert Cylinder Sleeve Puller (page 497) into cylinder sleeve.

- c. Engage removal tool hooks under bottom edge of cylinder sleeve.
- d. Position removal tool feet diagonally on crankcase deck surface.
- e. Turn threaded shaft clockwise to extract cylinder sleeve and set aside for inspection.

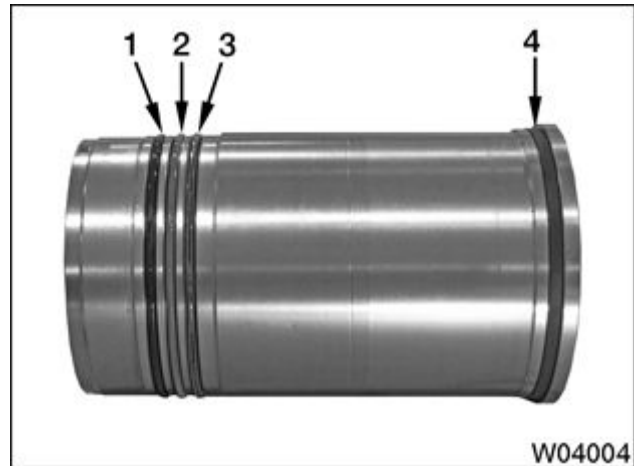


Figure 759 Cylinder sleeve O-rings

1. O-ring (black)
 2. O-ring (orange)
 3. O-ring (green)
 4. Cylinder lining band
2. Remove and discard O-rings and cylinder lining band from each cylinder sleeve.

Cleaning and Inspection

Cleaning

1. Use a soap and water solution to clean pistons. Soak piston first, and then clean with a non-metallic brush.
2. Clean piston ring grooves thoroughly.
3. The following disassembled components may be cleaned using a suitable solvent:
 - Piston pins
 - Piston pin retaining rings
4. Thoroughly clean connecting rod bolt holes and threads.

Piston Inspection

1. Inspect pistons for scuffed or scored skirts, cracked or worn ring lands, and cracked or scuffed pin bores. Replace damaged pistons.



Figure 760 Measuring piston ring groove (top / keystone cross section)

NOTE: The top piston ring groove is keystone shaped and must be measured using special gauge pins.

2. Install Piston Gauge Pins (page 497) in the top compression ring groove. Make sure the gauge pins are parallel.
3. With pistons at room temperature 20 °C (68 °F) measure the diameter of the piston over the gauge pins using an outside micrometer.

4. If the top compression ring groove measurement exceeds specification (page 496) replace the piston.



Figure 761 Ring groove side clearance check

5. Check side clearance of intermediate and oil piston ring grooves as follows:
 - a. Place edge of a new intermediate piston ring in its respective ring groove. Roll taper face intermediate ring around ring groove to ensure ring is free in its groove.
 - b. With edge of intermediate piston ring in its respective ring groove, use a feeler gauge (page 497) to measure side clearance between ring and groove.
 - c. Compare intermediate piston ring side clearance to specification (page 496). Excessive side clearance indicates ring groove wear and requires piston replacement.
6. Check side clearance of oil piston ring groove as follows:
 - a. Place edge of a new oil piston ring in its respective ring groove. Roll bevelled oil scraper ring all around ring groove to ensure ring is free in its groove.
 - b. With edge of oil piston ring in the bevelled oil piston ring groove, use a feeler gauge (page 497) to measure side clearance between ring and groove.
 - c. Compare oil piston ring side clearance to specification (page 496). Excessive side

clearance indicates ring groove wear and requires piston replacement.



Figure 762 Piston skirt diameter

7. Using a 4–5 inch micrometer (page 497), measure diameter of piston at intervals given in Specifications (page 496). If measurements do not meet specification, replace piston.

Piston Ring Inspection

CAUTION: To prevent engine damage, install new piston rings if a piston is removed. Faulty piston rings cannot always be detected visually.

1. Inspect new piston rings for cleanliness.

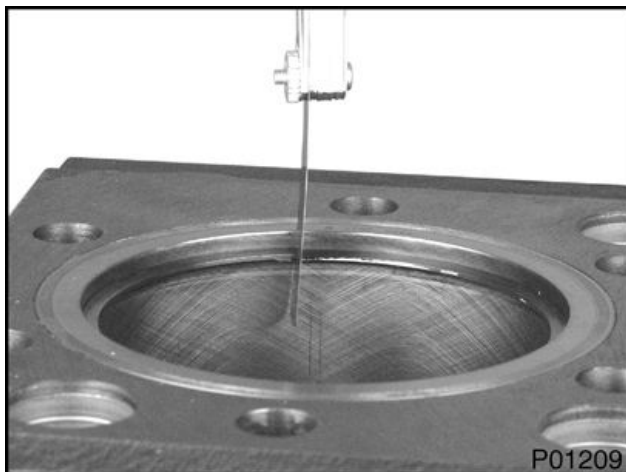


Figure 763 Piston ring end gap clearance in cylinder bore (typical)

2. Before installing new piston rings, check ring gap for each ring as follows:
 - a. Push piston ring down into cylinder bore. Make sure the piston ring is square with cylinder wall. An inverted piston head can be used to push piston ring to desired location of measurement (usually at top of piston stroke).
 - b. Use a feeler gauge (page 497) to measure gap between ends of each piston ring.
 - c. If gap does not meet specification (page 496), select another ring or recheck cylinder sleeve wear.

Connecting Rod Inspection

1. Inspect connecting rod bolt threads for nicks or damage. Replace as required.
2. Inspect connecting rod and cap mating surfaces and bearing bore for any indication of damage. Bore must be smooth and free of scoring or nicks. Replace connecting rod if necessary.

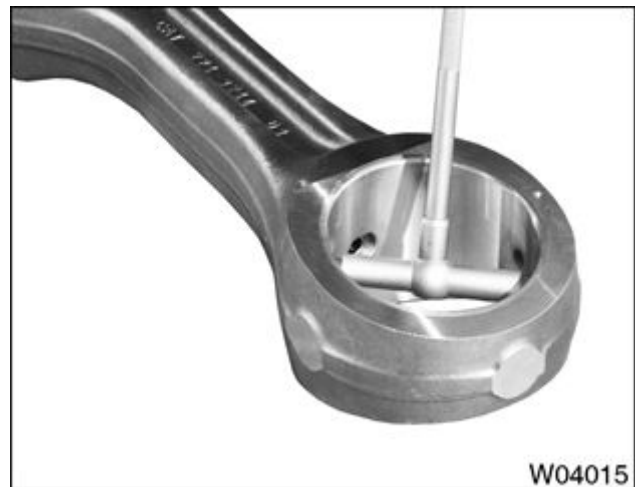


Figure 764 Inside diameter of piston pin bore

3. Inspect connecting rod piston pin bore for wear as follows:
 - a. Using a telescoping gauge (page 497) and a micrometer (page 497), measure piston pin bore at two locations 90° apart.
 - b. If inside diameter of piston pin bore exceeds specification (page 496), replace connecting rod.

Connecting Rod Bore Check

CAUTION: To prevent engine damage, do not use air powered tools to install connecting rod bolts; this can seize rod bolts.

1. Lubricate used connecting rod M11 x 84 12 point bolts with clean engine oil. Assemble cap to connecting rod without bearing shell. Tighten bolts to special torque (page 497).

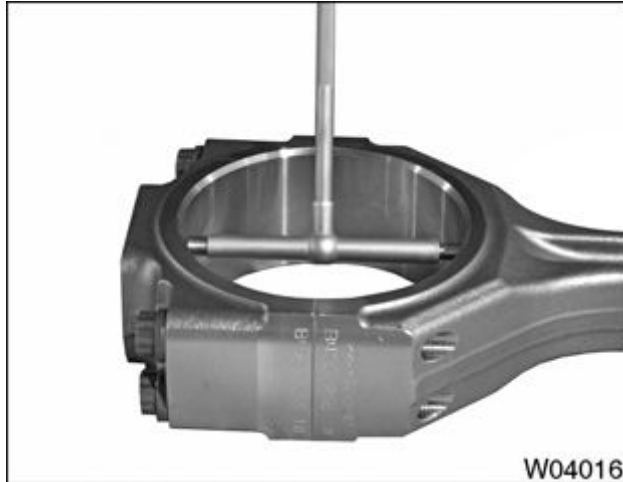


Figure 765 Measurement of connecting rod bore

2. Using a telescoping gauge (page 497) and a 3–4 inch micrometer (page 497), measure connecting rod bearing bore diameter in three locations. If connecting rod bearing bore diameter does not meet specification (page 496), replace connecting rod.
3. After all connecting rod bores are inspected, disassemble connecting rods and discard used M11 x 84 12 point bolts.
4. With connecting rod cap removed, inspect surface finish of connecting rod bearing bore. Bore must be smooth and free of scoring, nicks, or burrs. Replace connecting rod as necessary.

Piston Pin Inspection

1. Inspect piston pins for scoring or wear. Replace as necessary.



Figure 766 Piston pin wear

2. Using a 2–3 inch micrometer (page 497), measure piston pin outside diameter at two locations 90° apart.
3. Measure center area and each end of pin. If outside diameter of any piston pin is less than minimum specification (page 496), replace piston pin.

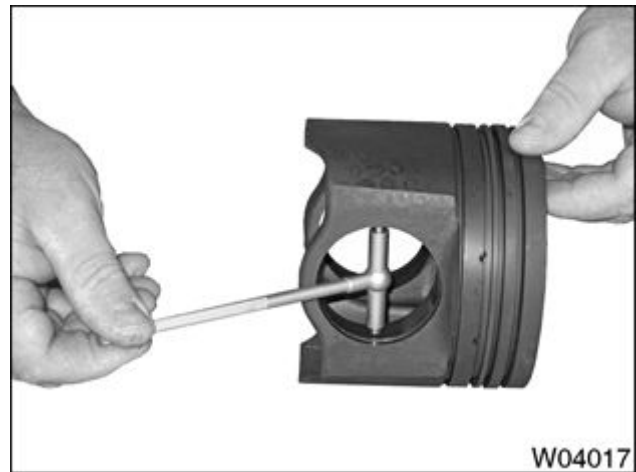


Figure 767 Inside diameter measurement of piston pin bore

4. Using a telescoping gauge (page 497) and 2–3 inch micrometer (page 497), measure each piston pin bore inside diameter at two locations 90° apart. If piston pin bore inside diameter is not within specification (page 496), replace piston.

5. To check piston pin running clearance, subtract outside diameter of piston pin from inside diameter of piston pin bore. If clearance exceeds specification (page 496), replace piston pin and check piston pin clearance using new piston pin.

Cylinder Sleeve Bore Inspection

1. Install six cylinder sleeves (without seal rings) into crankcase.



Figure 768 Cylinder sleeve bore measurement

2. Using a dial bore gauge (page 497), measure the cylinder sleeve inside diameter at 120° intervals at four different depths of cylinder sleeve. If cylinder

sleeve inside diameter is not within specification (page 496), replace cylinder sleeve.

Cylinder Sleeve Projection Measurement

NOTE: The following procedure does not require use of an H bar to hold sleeves while making sleeve projection measurements.

1. Clean the cylinder liner flange and the cylinder block surface. Remove any nicks on the top of the cylinder block.
2. Install the cylinder liner in the cylinder block with seals and bands. See Cylinder Sleeves (page 492).
3. Place a new spacer gasket and clean spacer plate on crankcase.

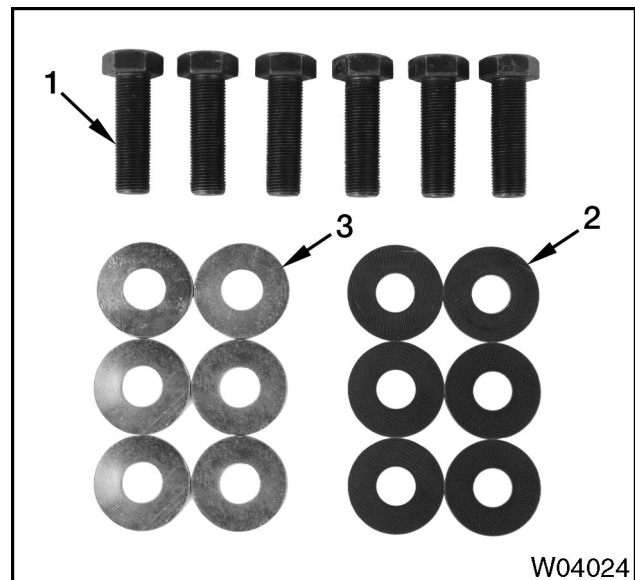


Figure 769 Sleeve projection measurement bolts and washers

1. Bolt (6) (PN 7H-3598)
2. Soft washer (6) (PN 7K-1977)
3. Hard washer (6) (PN 8F-1484)

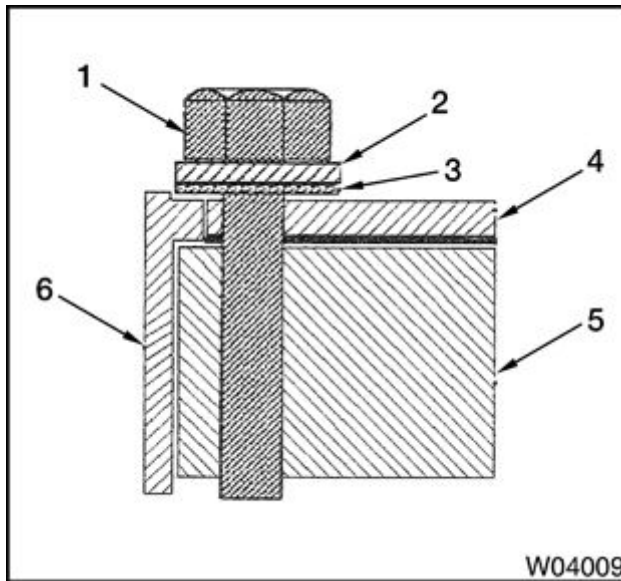


Figure 770 Sleeve projection components

1. Bolt
 2. Hard washer
 3. Soft washer
 4. Spacer plate
 5. Crankcase
 6. Cylinder sleeve
4. Secure cylinder sleeve into crankcase with six bolts, six hard washers, and six soft washers as shown in (Figure 770). Tighten hold-down bolts to special torque (page 497).

NOTE: The soft washer is made of cotton fabric impregnated with resin. The washers will not damage the sealing surfaces of the cylinder block. Replace theses washers as they wear out.



Figure 771 Dial Indicator with Base

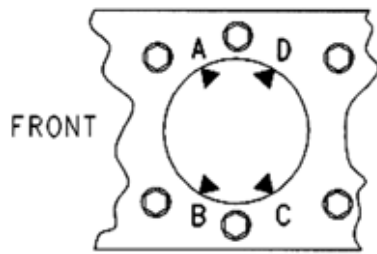
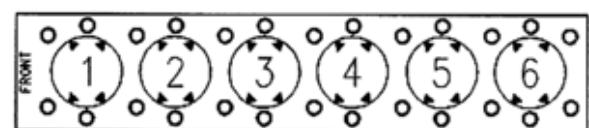
5. Place Dial Indicator with Base (page 497) on surface of spacer plate.
6. Position dial indicator tip on spacer plate adjacent to cylinder sleeve flange. Zero dial indicator.
7. Carefully pivot dial indicator until tip is resting on cylinder sleeve flange.
8. Measure and record cylinder sleeve protrusion at four locations evenly spaced around each cylinder sleeve as shown on sleeve projection measurement worksheet (Figure 772).
9. Add the four readings for each cylinder. Then divide the sum by four in order to find the average.

NOTE: If the liner projection changes around the cylinder liner, turn the cylinder liner to a different position within the bore. If the liner projection is not within specifications, move the cylinder liner to a different bore. Inspect the top face of the cylinder block.

NOTE: A thinner spacer plate should be installed if the liner projection measurements are below the specifications. This spacer plate should also be installed if the liner projection measurements are low within a range. These spacer plates are 0.076 mm (0.0030 inch) thinner than the regular spacer plate. The thinner spacer plates will increase the liner projection. This will increase the crush of the fire ring. Use these spacer plates to compensate for low liner projections that are less than the 0.076 mm (0.0030 inch). Use these spacer plates if the inspection of the top deck reveals no measurable damage directly under the liner flanges but the average liner projection is less than 0.076 mm (0.0030 inch). Do not exceed the maximum liner projection of 0.152 mm (0.0060 inch). The excessive liner projection will contribute to cracking of the liner flange.

10. Once the liner projection is correct, remove the six bolts, and move onto the next cylinder liner.

11. If any of the measurements are not within specification (page 496), fit new cylinder sleeve and repeat the procedure.
 12. If after trying all available new cylinder sleeves and specification still cannot be met, contact Tech Central at 1-800-336-4500.
 13. Remove six cylinder sleeves and continue with installation.
-

Liner Projection Measurements																																																																																																																																																							
Date _____	Miles, Km Hours _____	Engine Serial Number _____	Vehicle Serial Number _____																																																																																																																																																				
 FRONT  FRONT																																																																																																																																																							
Liner Projection Max 0.15 mm (.006 in) Min 0.03 mm (.001 in) <table border="1" style="width: 100%; border-collapse: collapse;"> <tr><td>1A</td><td>_____</td></tr> <tr><td>1B</td><td>_____</td></tr> <tr><td>1C</td><td>_____</td></tr> <tr><td>1D</td><td>_____</td></tr> <tr><td>SUM 1</td><td>_____</td></tr> <tr><td>AVG 1</td><td>_____</td></tr> <tr><td colspan="2"> </td></tr> <tr><td>2A</td><td>_____</td></tr> <tr><td>2B</td><td>_____</td></tr> <tr><td>2C</td><td>_____</td></tr> <tr><td>2D</td><td>_____</td></tr> <tr><td>SUM 2</td><td>_____</td></tr> <tr><td>AVG 2</td><td>_____</td></tr> <tr><td colspan="2"> </td></tr> <tr><td>3A</td><td>_____</td></tr> <tr><td>3B</td><td>_____</td></tr> <tr><td>3C</td><td>_____</td></tr> <tr><td>3D</td><td>_____</td></tr> <tr><td>SUM 3</td><td>_____</td></tr> <tr><td>AVG 3</td><td>_____</td></tr> <tr><td colspan="2"> </td></tr> <tr><td>4A</td><td>_____</td></tr> <tr><td>4B</td><td>_____</td></tr> <tr><td>4C</td><td>_____</td></tr> <tr><td>4D</td><td>_____</td></tr> <tr><td>SUM 4</td><td>_____</td></tr> <tr><td>AVG 4</td><td>_____</td></tr> <tr><td colspan="2"> </td></tr> <tr><td>5A</td><td>_____</td></tr> <tr><td>5B</td><td>_____</td></tr> <tr><td>5C</td><td>_____</td></tr> <tr><td>5D</td><td>_____</td></tr> <tr><td>SUM 5</td><td>_____</td></tr> <tr><td>AVG 5</td><td>_____</td></tr> <tr><td colspan="2"> </td></tr> <tr><td>6A</td><td>_____</td></tr> <tr><td>6B</td><td>_____</td></tr> <tr><td>6C</td><td>_____</td></tr> <tr><td>6D</td><td>_____</td></tr> <tr><td>SUM 6</td><td>_____</td></tr> <tr><td>AVG 6</td><td>_____</td></tr> </table> Max Variation Each Cylinder Max 0.051 mm (.002 in) <table border="1" style="width: 100%; border-collapse: collapse;"> <tr><td>Max 1A-1D</td><td>_____</td></tr> <tr><td>Min 1A-1D</td><td>_____</td></tr> <tr><td>Variation</td><td>_____</td></tr> <tr><td>Max 2A-2D</td><td>_____</td></tr> <tr><td>Min 2A-2D</td><td>_____</td></tr> <tr><td>Variation</td><td>_____</td></tr> <tr><td>Max 3A-3D</td><td>_____</td></tr> <tr><td>Min 3A-3D</td><td>_____</td></tr> <tr><td>Variation</td><td>_____</td></tr> <tr><td>Max 4A-4D</td><td>_____</td></tr> <tr><td>Min 4A-4D</td><td>_____</td></tr> <tr><td>Variation</td><td>_____</td></tr> <tr><td>Max 5A-5D</td><td>_____</td></tr> <tr><td>Min 5A-5D</td><td>_____</td></tr> <tr><td>Variation</td><td>_____</td></tr> <tr><td>Max 6A-6D</td><td>_____</td></tr> <tr><td>Min 6A-6D</td><td>_____</td></tr> <tr><td>Variation</td><td>_____</td></tr> </table> Max Variation of AVG Between Adjacent Liners Max 0.051 mm (.002 in) <table border="1" style="width: 100%; border-collapse: collapse;"> <tr><td>AVG 1</td><td>_____</td></tr> <tr><td>AVG 2</td><td>_____</td></tr> <tr><td>Variation</td><td>_____</td></tr> <tr><td>AVG 2</td><td>_____</td></tr> <tr><td>AVG 3</td><td>_____</td></tr> <tr><td>Variation</td><td>_____</td></tr> <tr><td>AVG 3</td><td>_____</td></tr> <tr><td>AVG 4</td><td>_____</td></tr> <tr><td>Variation</td><td>_____</td></tr> <tr><td>AVG 4</td><td>_____</td></tr> <tr><td>AVG 5</td><td>_____</td></tr> <tr><td>Variation</td><td>_____</td></tr> <tr><td>AVG 5</td><td>_____</td></tr> <tr><td>AVG 6</td><td>_____</td></tr> <tr><td>Variation</td><td>_____</td></tr> </table>				1A	_____	1B	_____	1C	_____	1D	_____	SUM 1	_____	AVG 1	_____			2A	_____	2B	_____	2C	_____	2D	_____	SUM 2	_____	AVG 2	_____			3A	_____	3B	_____	3C	_____	3D	_____	SUM 3	_____	AVG 3	_____			4A	_____	4B	_____	4C	_____	4D	_____	SUM 4	_____	AVG 4	_____			5A	_____	5B	_____	5C	_____	5D	_____	SUM 5	_____	AVG 5	_____			6A	_____	6B	_____	6C	_____	6D	_____	SUM 6	_____	AVG 6	_____	Max 1A-1D	_____	Min 1A-1D	_____	Variation	_____	Max 2A-2D	_____	Min 2A-2D	_____	Variation	_____	Max 3A-3D	_____	Min 3A-3D	_____	Variation	_____	Max 4A-4D	_____	Min 4A-4D	_____	Variation	_____	Max 5A-5D	_____	Min 5A-5D	_____	Variation	_____	Max 6A-6D	_____	Min 6A-6D	_____	Variation	_____	AVG 1	_____	AVG 2	_____	Variation	_____	AVG 2	_____	AVG 3	_____	Variation	_____	AVG 3	_____	AVG 4	_____	Variation	_____	AVG 4	_____	AVG 5	_____	Variation	_____	AVG 5	_____	AVG 6	_____	Variation	_____
1A	_____																																																																																																																																																						
1B	_____																																																																																																																																																						
1C	_____																																																																																																																																																						
1D	_____																																																																																																																																																						
SUM 1	_____																																																																																																																																																						
AVG 1	_____																																																																																																																																																						
2A	_____																																																																																																																																																						
2B	_____																																																																																																																																																						
2C	_____																																																																																																																																																						
2D	_____																																																																																																																																																						
SUM 2	_____																																																																																																																																																						
AVG 2	_____																																																																																																																																																						
3A	_____																																																																																																																																																						
3B	_____																																																																																																																																																						
3C	_____																																																																																																																																																						
3D	_____																																																																																																																																																						
SUM 3	_____																																																																																																																																																						
AVG 3	_____																																																																																																																																																						
4A	_____																																																																																																																																																						
4B	_____																																																																																																																																																						
4C	_____																																																																																																																																																						
4D	_____																																																																																																																																																						
SUM 4	_____																																																																																																																																																						
AVG 4	_____																																																																																																																																																						
5A	_____																																																																																																																																																						
5B	_____																																																																																																																																																						
5C	_____																																																																																																																																																						
5D	_____																																																																																																																																																						
SUM 5	_____																																																																																																																																																						
AVG 5	_____																																																																																																																																																						
6A	_____																																																																																																																																																						
6B	_____																																																																																																																																																						
6C	_____																																																																																																																																																						
6D	_____																																																																																																																																																						
SUM 6	_____																																																																																																																																																						
AVG 6	_____																																																																																																																																																						
Max 1A-1D	_____																																																																																																																																																						
Min 1A-1D	_____																																																																																																																																																						
Variation	_____																																																																																																																																																						
Max 2A-2D	_____																																																																																																																																																						
Min 2A-2D	_____																																																																																																																																																						
Variation	_____																																																																																																																																																						
Max 3A-3D	_____																																																																																																																																																						
Min 3A-3D	_____																																																																																																																																																						
Variation	_____																																																																																																																																																						
Max 4A-4D	_____																																																																																																																																																						
Min 4A-4D	_____																																																																																																																																																						
Variation	_____																																																																																																																																																						
Max 5A-5D	_____																																																																																																																																																						
Min 5A-5D	_____																																																																																																																																																						
Variation	_____																																																																																																																																																						
Max 6A-6D	_____																																																																																																																																																						
Min 6A-6D	_____																																																																																																																																																						
Variation	_____																																																																																																																																																						
AVG 1	_____																																																																																																																																																						
AVG 2	_____																																																																																																																																																						
Variation	_____																																																																																																																																																						
AVG 2	_____																																																																																																																																																						
AVG 3	_____																																																																																																																																																						
Variation	_____																																																																																																																																																						
AVG 3	_____																																																																																																																																																						
AVG 4	_____																																																																																																																																																						
Variation	_____																																																																																																																																																						
AVG 4	_____																																																																																																																																																						
AVG 5	_____																																																																																																																																																						
Variation	_____																																																																																																																																																						
AVG 5	_____																																																																																																																																																						
AVG 6	_____																																																																																																																																																						
Variation	_____																																																																																																																																																						
Max Variation of AVG Under One Cylinder Head Max 0.102 mm (.004 in) <table border="1" style="width: 100%; border-collapse: collapse;"> <tr><td>Max AVG 1-6</td><td>_____</td></tr> <tr><td>Min AVG 1-6</td><td>_____</td></tr> <tr><td>Variation</td><td>_____</td></tr> </table>				Max AVG 1-6	_____	Min AVG 1-6	_____	Variation	_____																																																																																																																																														
Max AVG 1-6	_____																																																																																																																																																						
Min AVG 1-6	_____																																																																																																																																																						
Variation	_____																																																																																																																																																						

W04010

Figure 772 Sleeve projection measurement worksheet

Installation

Cylinder Sleeves

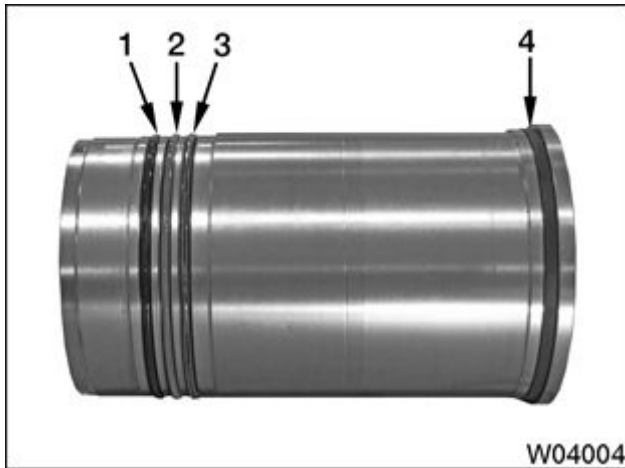


Figure 773 Cylinder sleeve O-rings

1. O-ring (black)
2. O-ring (orange)
3. O-ring (green)
4. Cylinder lining band

NOTE: If reusing cylinder sleeves, they must go into their original bore locations. If installing new sleeves, use locations as determined during cylinder sleeve projection measurement.

1. Lubricate new O-rings with P-80® rubber lubricant or equivalent (page 497). Install O-rings on cylinder sleeve.

NOTE: The cylinder lining band is designed to swell slightly after contact with engine oil. Install cylinder sleeve in crankcase immediately after installing cylinder lining band on sleeve.

2. Dip new cylinder lining band in clean engine oil and install on cylinder sleeve. Install cylinder sleeve immediately in crankcase. Cylinder lining band will swell slightly to center cylinder sleeve in crankcase.

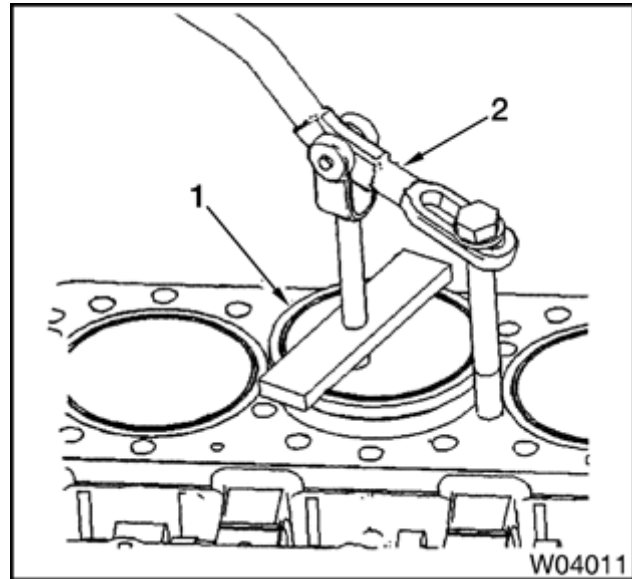


Figure 774 Cylinder sleeve installation

1. Cylinder sleeve
2. Cylinder Sleeve Installer

3. Place cylinder sleeve in crankcase. Push cylinder sleeve into crankcase using a cylinder sleeve installer.

Piston Assembly

! WARNING: To prevent personal injury or death, wear safety glasses with side shields when doing the following procedure.



Figure 775 Piston ring installation

CAUTION: To prevent engine damage, install piston rings correctly. Top piston ring is marked “up-1” on the upper surface to indicate installation in the upper piston ring groove with the marking facing up toward crown of piston. Intermediate piston ring is marked “up-2” on the upper surface to indicate installation in the middle piston ring groove with the marking facing up toward crown of piston.

NOTE: Only expand piston rings enough to fit over top of piston.

1. Using piston ring expansion pliers (page 497), install piston rings.
 - a. Install expansion spring component of oil piston ring into bottom piston groove.
 - b. Install oil scraper ring component of oil piston ring over expansion spring with the gap 180° from the spring wire latch.
 - c. Install intermediate ring into intermediate piston ring groove. Make sure ring is installed with identification mark facing up toward piston crown.
 - d. Install top piston (keystone) ring into top piston groove. Make sure ring is installed with identification mark facing up toward piston crown.
2. Space ring gaps approximately 120° apart after ring installation.
3. Connect piston to connecting rod as follows:
 - a. Lubricate connecting rod piston pin bore, piston pin bore, and piston pin with clean engine oil.
 - b. Set piston crown down, so mark (indicating front of engine) made during removal is at 6 o'clock position.
 - c. Hold connecting rod so that matching engraved numbers on rod and rod cap face the 3 o'clock position of piston when installed.
 - d. Place connecting rod into piston.

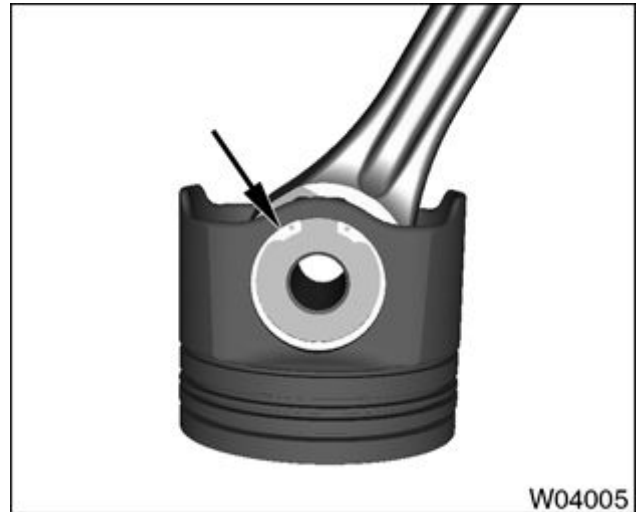


Figure 776 Piston pin retaining ring

- e. Using a pair of pliers, install first circlip at one end of piston pin bore.
- f. Slide piston pin through bored holes, stopping at installed circlip.
- g. Using a pair of pliers, install second circlip.

Piston and Connecting Rod

1. Turn crankshaft so crank pin on the cylinder to receive piston installation is at bottom of its stroke.
2. Lightly coat piston and piston rings with clean engine oil.
3. Coat cylinder sleeve walls, crankshaft journals, and Piston Cope (ring compressor) (page 497) with clean engine oil.
4. Place piston in Piston Cope (ring compressor) (page 497).
5. Install connecting rod bearing shells in connecting rod and cap. Coat bearing shells with clean engine oil.

CAUTION: To prevent engine damage, do not damage piston cooling jet when installing connecting rod and piston assembly. If jet is bent during piston assembly installation, replace jet.

NOTE: Before installing piston and connecting rod assembly, make sure all piston cooling jets are installed and pointing into cylinder bores.

NOTE: There is no mark indicating front of engine on piston. New service pistons can be installed in either direction. Use the mark made during removal if installing used pistons.

6. Carefully put piston and piston ring compressor combination, and connecting rod assembly in cylinder sleeve. Make sure locking tangs of bearing shells are on same side as piston cooling jet.

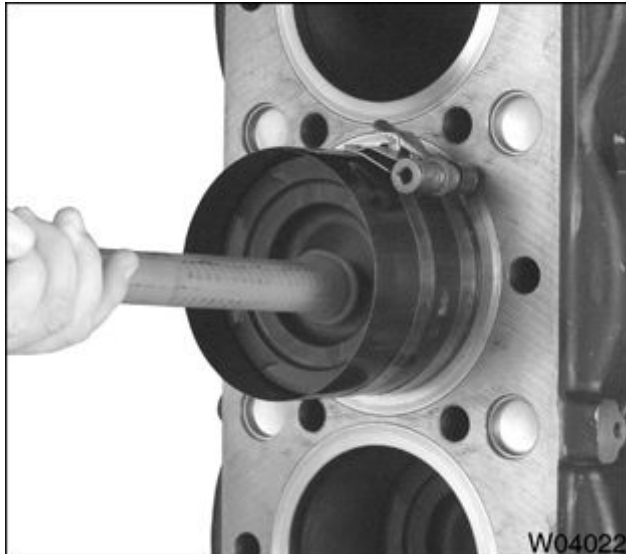


Figure 777 Installation of piston in cylinder bore

7. Once piston and connecting rod assembly have been inserted in cylinder sleeve, use a (wood or plastic) drift to tap piston into cylinder sleeve. Guide connecting rod in place on crankshaft.

CAUTION: To prevent engine damage, lightly lubricate bolt threads and mating surfaces of bolt flanges with clean engine oil. Too much oil will cause hydrostatic lock and give incorrect torque reading.

8. Apply clean engine oil to bolt threads for connecting rod and upper and lower bearing shell in cap before installing screws.



Figure 778 Correct connecting rod and cap joint fit

9. Assemble cap to connecting rod. Make sure etched identification code on cap is on same side and matches code on connecting rod.

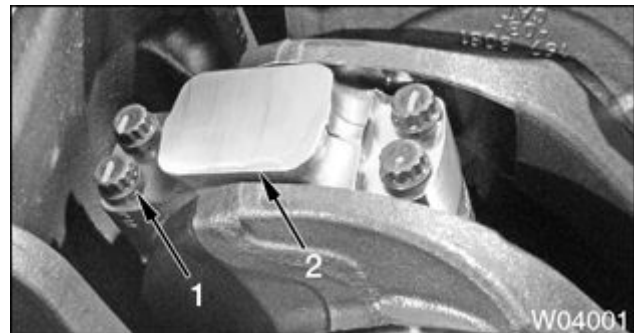


Figure 779 Connecting rod cap

1. M11 x 84 12 point bolt (24)
2. Connecting rod cap

CAUTION: To prevent engine damage, install new M11 x 84 12 point bolts.

CAUTION: To prevent engine damage, do not use air powered tools to install connecting rod bolts; this can seize rod bolts.

CAUTION: To prevent engine damage, do not rotate crankshaft until M11 x 84 12 point bolts are fully tightened, as this may cause bearing shells to rotate in place.

10. Install four new M11 x 84 12 point bolts.

11. Using a 12 point 14 mm socket (page 497) tighten M11 x 84 12 point bolts evenly to special torque (page 497). Torque all four bolts to initial torque first. Do the final bolt rotation after all four bolts are at initial torque.
 12. Repeat installation procedure for remaining connecting rod and piston assemblies.
-

Specifications

Connecting Rods

Piston pin bore inside diameter	60.035 ± 0.008 mm (2.3635 ± 0.0003 in)
Connecting rod bearing bore diameter (crankshaft end)	103.2 ± 0.013 mm (4.0629 ± 0.0005 in)

Piston and Pin

Skirt diameter measured 78 mm from piston crown	137.065 + 0.015 mm (5.3962 ± 0.0005 in)
Piston protrusion measured from crankcase deck to piston	8.627 ± 0.208 mm (0.339 ± 0.008 in)
Piston pin bore inside diameter	60.085 – 60.105 mm (2.365 – 2.3663 in)
Piston pin running clearance	0.105 – 0.135 mm (0.0041 – 0.0053 in)
Piston pin outside diameter	59.975 ± 0.005 mm (2.3612 ± 0.0001 in)

Piston Rings

Top ring

Ring gap	0.35 ± 0.05 mm (0.0137 ± 0.0019 in)
Top compression ring groove width, measure over 3.4 mm (0.1338 in) gauge pins	135.561 – 135.798 mm (5.337 to 5.3463 in)

Intermediate ring

Ring gap	0.70 ± 0.10 mm (0.0275 ± 0.0039 in)
Side clearance	0.037 – 0.093 mm (0.0014 – 0.0036 in)*

Oil ring

Ring gap	0.45 ± 0.15 mm (0.0177 ± 0.0059 in)
Side clearance	0.027 – 0.073 mm (0.0010 – 0.0028 in)

Sleeve dimensions

Sleeve inside diameter	137.185 ± 0.025 mm (5.4009 ± 0.0009 in)
Sleeve projection	0.025 – 0.152 mm (0.0010 – 0.0060 in)
Maximum average variation between adjacent sleeves	0.051 mm (0.0020 in)
Maximum variation between all sleeves	0.102 mm (0.0040 in)
Maximum variation in each sleeve	0.051 mm (0.0020 in)

Special Torque

M11 x 84 12 point bolts (connecting rod bolts)	Initial	70 ± 4 N·m (52 ± 3 lbf·ft)
	Final	additional 60° (1/6 turn)
Cylinder sleeve projection hold-down bolts	Step 1: Tighten all to 95 N·m (70 lbf·ft)	
	Step 2: Retighten all to 95 N·m (70 lbf·ft)	

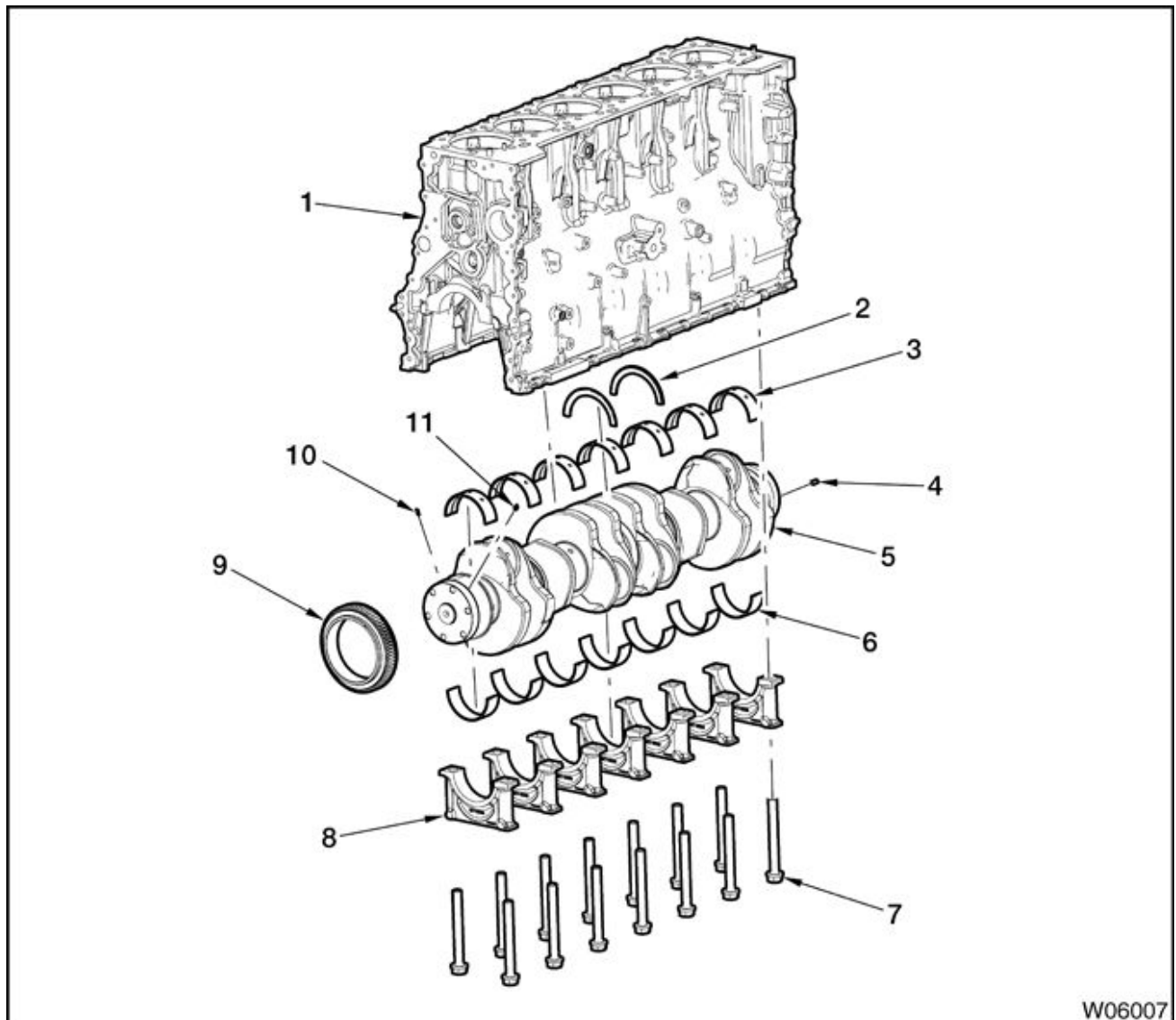
Special Service Tools

Description	Tool Number
2–3 inch micrometer	Obtain locally
3–4 inch micrometer	Obtain locally
4–5 inch micrometer	Obtain locally
12 Point 14 mm socket	Obtain locally
Cylinder Sleeve Puller	ZTSE2536
Dial bore gauge	Obtain locally
Dial Indicator with Base	Part of ZTSE2515A
Feeler gauge	Obtain locally
P-80® Rubber lubricant or equivalent	Obtain locally
Piston Cope (ring compressor)	ZTSE6118
Piston Gauge Pin (3.4 mm (0.1338 in.))	Obtain locally
Piston ring expansion pliers	Obtain locally
Telescoping gauge set	Obtain locally

Table of Contents

Exploded Views.....	501
Removal.....	504
Crankshaft Bearing Caps, Crankshaft, and Main Bearings.....	505
Piston Cooling Jet.....	507
Crankcase Dowel Pins, Plugs and Fittings.....	508
Cleaning, Inspection, and Testing.....	511
Crankshaft End Play.....	511
Crankcase.....	511
Crankshaft.....	512
Main Bearings.....	513
Piston Cooling Jet.....	515
Installation.....	516
Crankcase Dowel Pins, Plugs and Fittings.....	516
Piston Cooling Jet.....	518
Crankshaft Bearing Caps, Crankshaft, and Main Bearings.....	519
Specifications.....	526
Special Torque.....	526
Special Service Tools.....	527

Exploded Views



W06007

Figure 780 Crankcase and crankshaft

1. Crankcase	5. Crankshaft	9. Crankshaft gear
2. Thrust plate bearing (2)	6. Main lower bearing (7)	10. 5 x 10 hardened dowel pin (crankshaft timing ring)
3. Main upper bearing (with oil hole) (7)	7. 7/8-14 x 7.75 hex flange bolt (14)	11. Dowel pin (0.25 X 0.50 inch)
4. Dowel pin (9.55 X 19.1 mm)	8. Crankshaft bearing cap (7)	

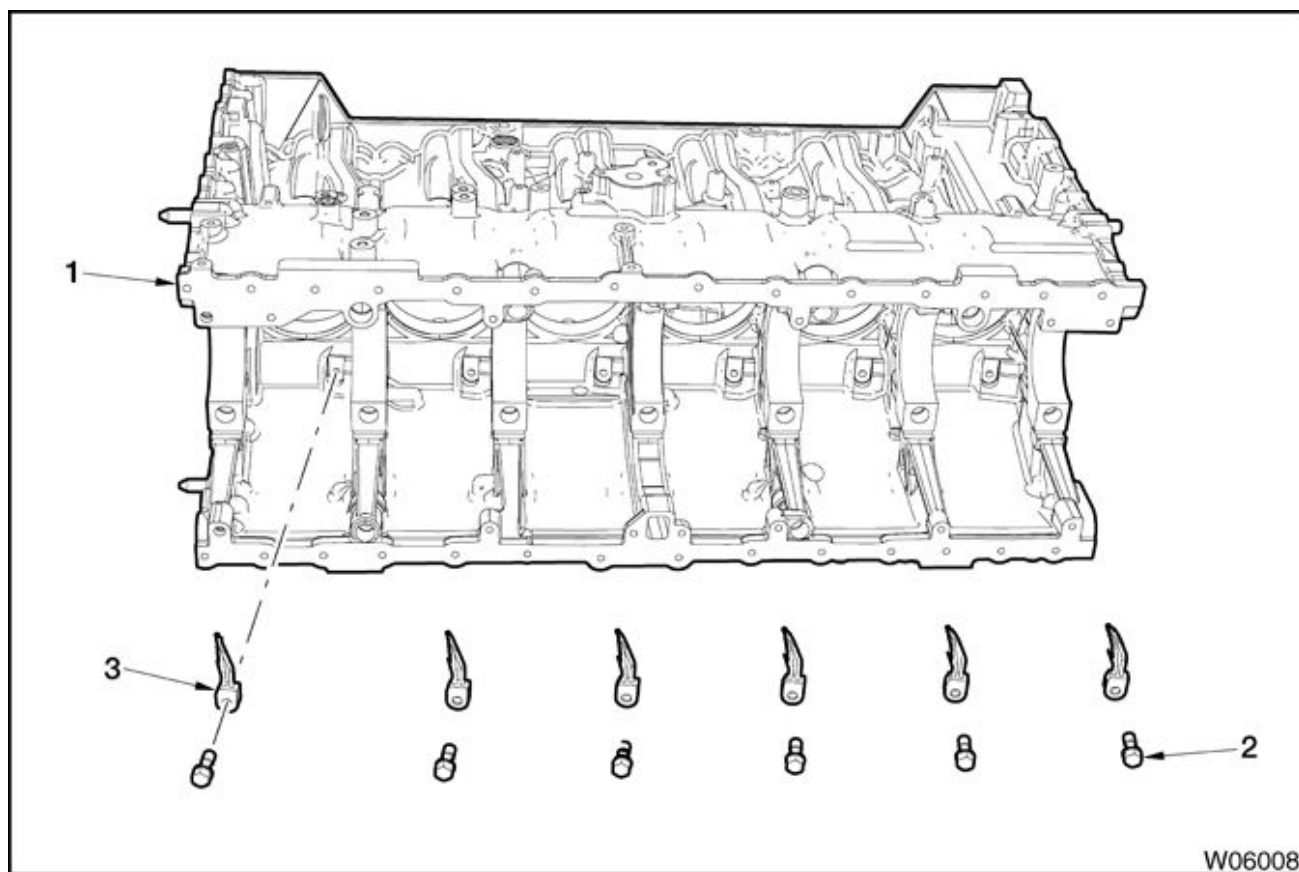
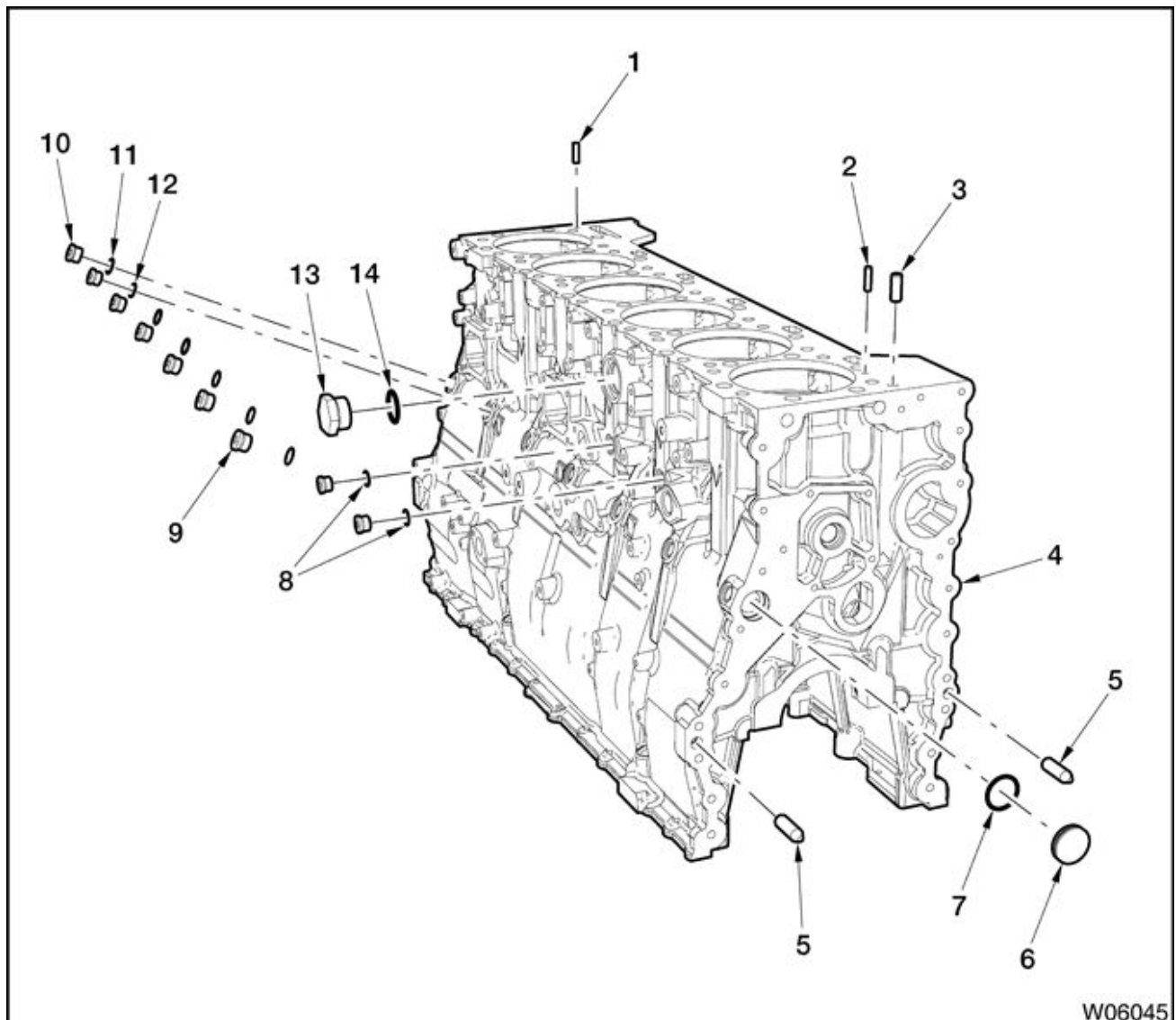


Figure 781 Piston Cooling Jets

1. Crankcase

2. Cooling jet bolt (6)

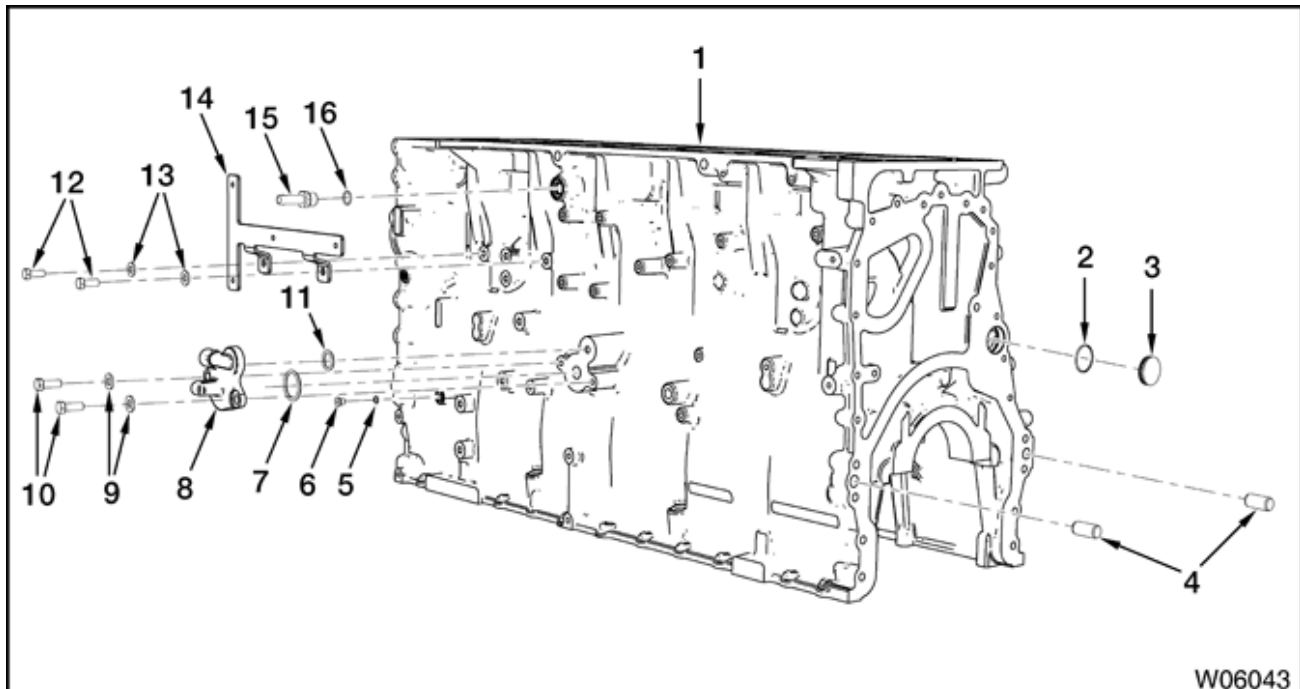
3. Piston cooling jet (6)



W06045

Figure 782 Crankcase Dowel Pins, Plugs and Fittings (Right Side, Top and Front)

1. Dowel pin (9.55 X 31.8 mm solid)	5. Dowel pin (15.88 X 50 mm solid) (2)	11. Ring seal (O-ring boss plug 7/8-14)
2. Dowel pin (6.35 X 30.2 mm solid)	6. Plug	12. O-ring (blue) (oil) (O-ring boss plug 3/4-14) (6)
3. Dowel pin (12.725 X 33 mm hollow)	7. O-ring (plug)	13. O-ring boss plug assembly (1-5/8-12)
4. Crankcase	8. O-ring (black) (coolant) (O-ring boss plug 3/4-14) (2)	14. O-ring (O-ring boss plug assembly)
	9. O-ring boss plug (3/4-14) (8)	
	10. O-ring boss plug (7/8-14)	



W06043

Figure 783 Crankcase Dowel Pins, Plugs and Fittings (Left Side and Rear)

1. Crankcase	6. O-ring boss plug (7/16 - 20)	13. 3/8 Washer (plain) (2)
2. O-ring (plug)	7. O-ring size 220	14. Harness support
3. Plug	8. Oil pressure sensor support	15. Hose fitting (3/4-16)
4. Dowel pin (15.88 X 31.8 mm solid) (2)	9. 3/8 Washer (hardened) (2)	16. O-ring (3/4-16 hose fitting)
5. O-ring (7/16 - 20 O-ring boss plug)	10. 3/8-16 x 1 hex bolt (2)	
	11. O-ring size 221	
	12. 3/8-16 x 7/8 hex bolt (2)	

Removal



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

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

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

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

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

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

- Engine Electrical
- Cold Start Assist
- Aftertreatment System
- Engine Braking System
- Turbochargers
- Air Compressor and Power Steering Pump
- Fuel System
- Oil Cooler and Filter Housing
- Exhaust Gas Recirculating (EGR) System
- Intercooler Elbow and Exhaust Manifolds
- Front Cover, High Mount Fan Drive, Cooling System, and Related Components
- Cylinder Head, Camshaft, and Valve Train
- Flywheel and Flywheel Housing
- Oil Pan and Oil Suction Tube
- Oil Pump, Low Mount Fan Drive, and Timing Gears
- Power Cylinders

Crankshaft Bearing Caps, Crankshaft, and Main Bearings

1. Position engine so that bottom of crankshaft bearing caps are facing upwards.
2. Measure crankshaft end play. See Crankshaft End Play (page 511).

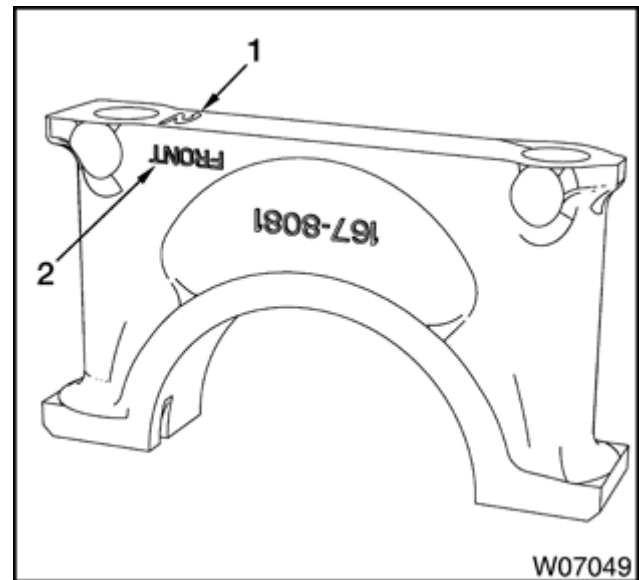


Figure 784 Crankshaft bearing cap marks (typical)

1. Crankshaft bearing cap stamp on #2 crankshaft bearing cap
2. Front of engine casting

NOTE: Each crankcase bearing cap is identified for location and orientation as shown in (Figure 784).

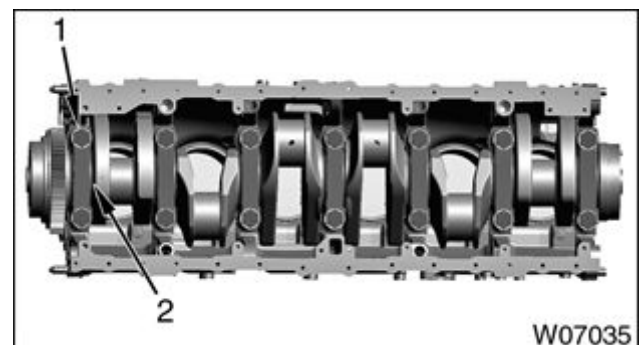


Figure 785 Crankshaft bearing caps

1. 7/8–14 x 7.75 hex flange bolt (14)
2. Crankshaft bearing cap (7)

NOTE: Crankshaft bearing caps may need to be cleaned to see stamped numbers.

NOTE: Crankshaft bearing cap bolts are not reusable, due to permanent deformation caused when bolts are tightened to the yield point (torque-to-yield).

3. Remove 14 7/8–14 x 7.75 hex flange bolts and seven crankshaft bearing caps. Save bolts for main bearing inspection procedure. See Main Bearing Inspection Procedure (page 513).

CAUTION: To prevent engine damage, use permanent markers to identify internal components or their orientation. Do not use paint or temporary markers.

4. Remove lower main bearings from crankshaft bearing caps one at a time by pushing out. Mark each for location and set aside for inspection.

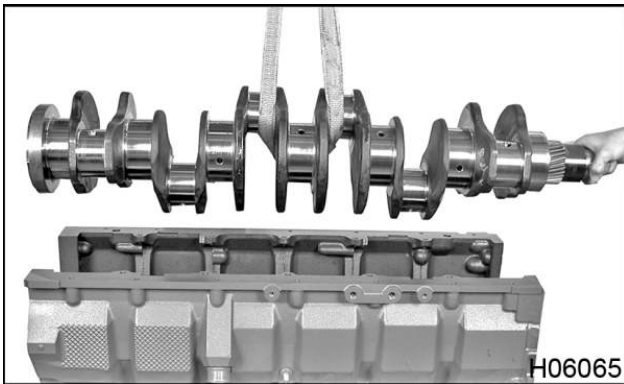


Figure 786 Crankshaft removal (typical)

! WARNING: To prevent personal injury or death, use a correct size lifting sling and hoist with a safety latch on hook.

CAUTION: To prevent engine damage, do not bend, drop or mar crankshaft.

5. Attach a heavy duty strap (page 527) to crankshaft. Lift crankshaft up and out of crankcase and set aside for inspection.

CAUTION: To prevent engine damage, use permanent markers to identify internal components or their orientation. Do not use paint or temporary markers.

6. Remove upper main bearings and upper main bearing thrust washers from crankcase one at a

time by pushing out, mark each for location and set aside for inspection.

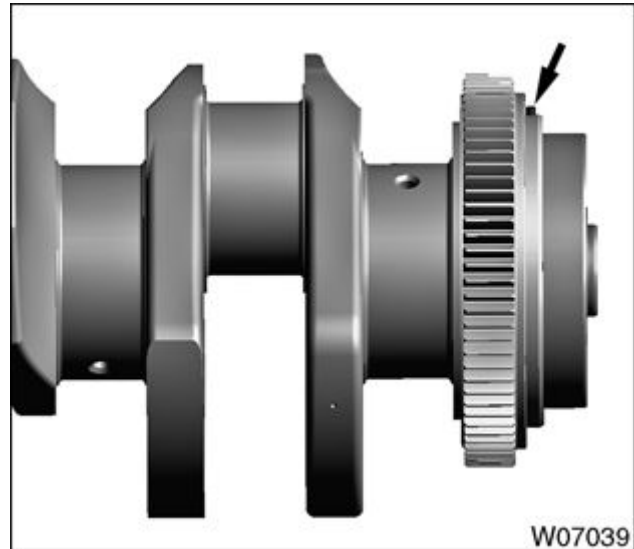


Figure 787 Crankshaft timing ring dowel pin

CAUTION: To prevent engine damage, do not bend, drop or mar crankshaft.

7. If required, remove the crankshaft timing ring 5 x 10 hardened dowel pin from crankshaft.

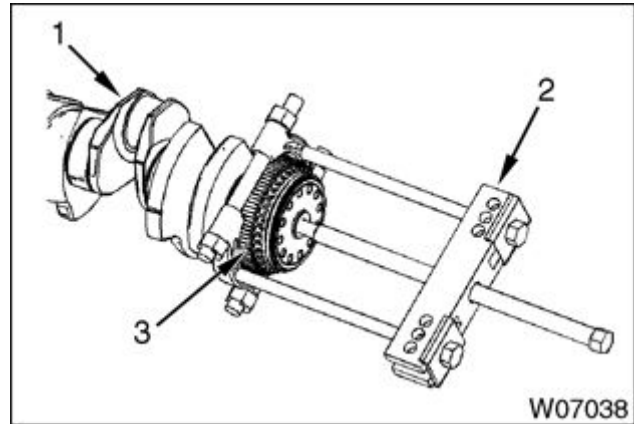


Figure 788 Crankshaft gear removal

1. Crankshaft
2. Gear remover
3. Crankshaft gear

CAUTION: To prevent engine damage, do not bend, drop or mar crankshaft.

8. If required, using Gear remover (page 527), remove the crankshaft gear from crankshaft.

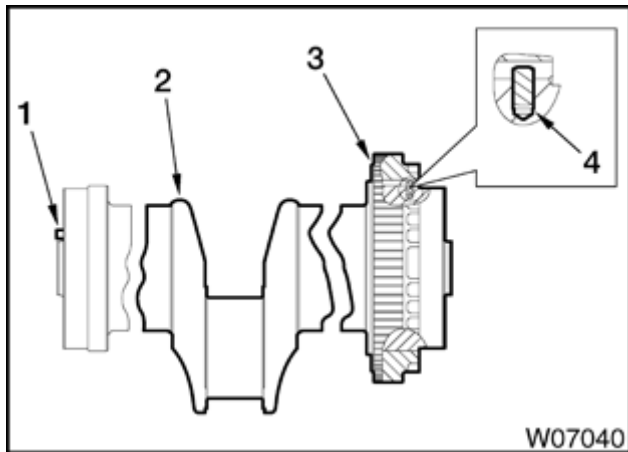


Figure 789 Crankshaft gear dowl

1. Crankshaft rear dowl pin (9.55 X 19.1 mm)
2. Crankshaft
3. Crankshaft gear
4. Crankshaft gear dowl pin (0.25 X 0.5 mm)

9. If required, remove the crankshaft front dowl pin and crankshaft rear dowl pin from crankshaft.

Piston Cooling Jet

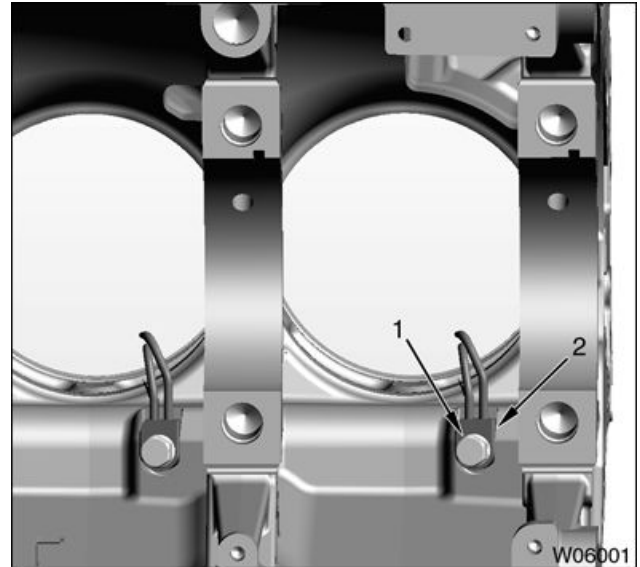
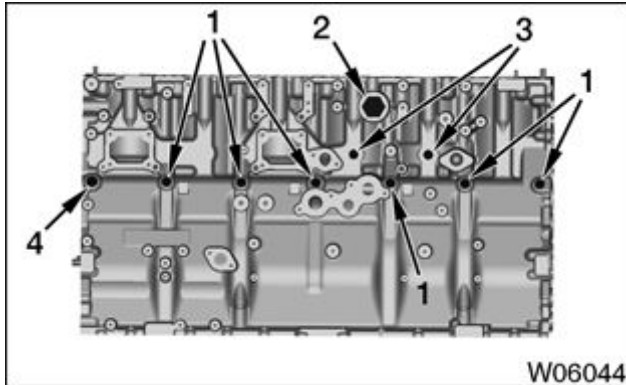


Figure 790 Piston cooling jet (typical)

1. Cooling jet bolt (6)
2. Piston cooling jet (6)

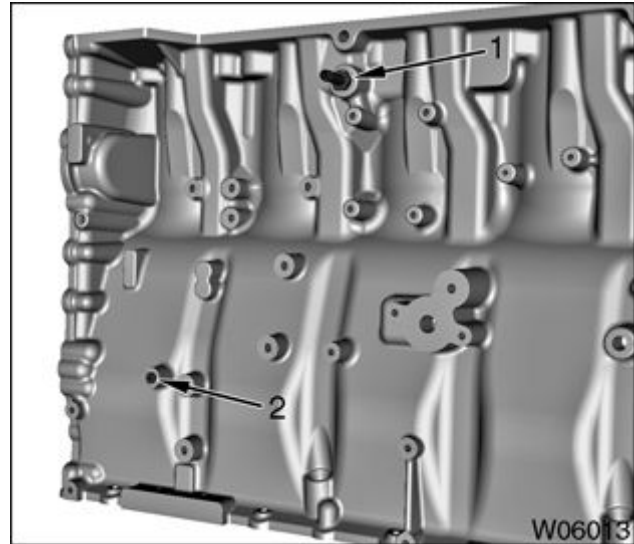
CAUTION: To prevent engine damage, do not bend the piston cooling jets because the piston cooling jets are precision aligned with a coolant passage in the pistons and will not function properly if bent.

1. Remove six cooling jet bolts and six piston cooling jets.

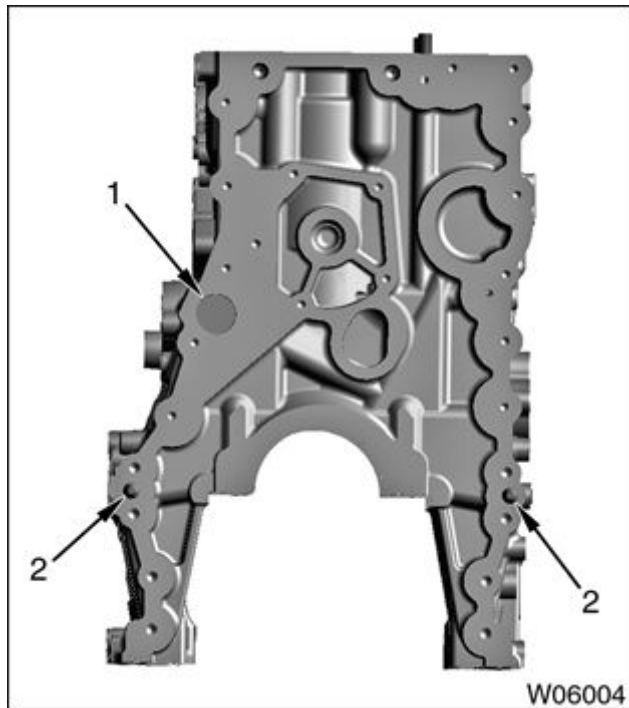
Crankcase Dowel Pins, Plugs and Fittings**Figure 791 Right side crankcase**

1. O-ring boss plug assembly (3/4–14 with blue O-ring) (oil) (6)
 2. O-ring boss plug assembly (1-5/8 – 12)
 3. O-ring boss plug assembly (3/4–14 with black O-ring) (coolant) (2)
 4. O-ring boss plug (7/8–14)
1. Remove eight O-ring boss plugs (3/4–14).
 2. Remove and discard the O-rings (six blue and two black).
 3. Remove O-ring boss plug assembly (1-5/8 – 12).
 4. Remove and discard the O-ring.
 5. Remove O-ring boss plug (7/8–14).

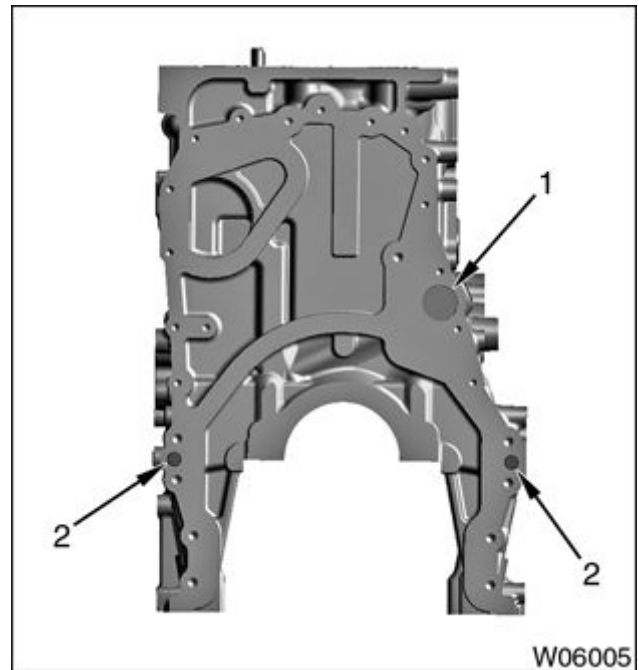
6. Remove and discard O-ring.

**Figure 792 Left side crankcase**

1. Hose fitting (3/4–16) with o-ring
 2. O-ring boss plug (crankcase left side) with o-ring
7. Remove the 3/4–16 hose fitting.
 8. Remove and discard the O-ring.
 9. Remove O-ring boss plug (crankcase left side).
 10. Remove and discard the O-ring.

**Figure 793 Front crankcase**

1. Plug and O-ring
 2. Dowel pin (15.88 X 50 mm solid) (2)
11. Drill center of plug with 29/64th drill bit (page 527) and tap with 1/2 x 20 in. tap (page 527).
 12. Remove plug with Slide Hammer Kit (page 527). Remove and discard the O-ring.
 13. If required, remove two dowel pins (15.88 X 50 mm solid).

**Figure 794 Rear crankcase**

1. Plug and O-ring
 2. Dowel pin (15.88 X 31.8 mm solid) (2)
14. Drill center of plug with 29/64th drill bit (page 527) and tap with 1/2 x 20 in. tap (page 527).
 15. Remove plug with Slide Hammer Kit (page 527). Remove and discard the O-ring.
 16. If required, remove two dowel pins (15.88 X 31.8 mm solid).

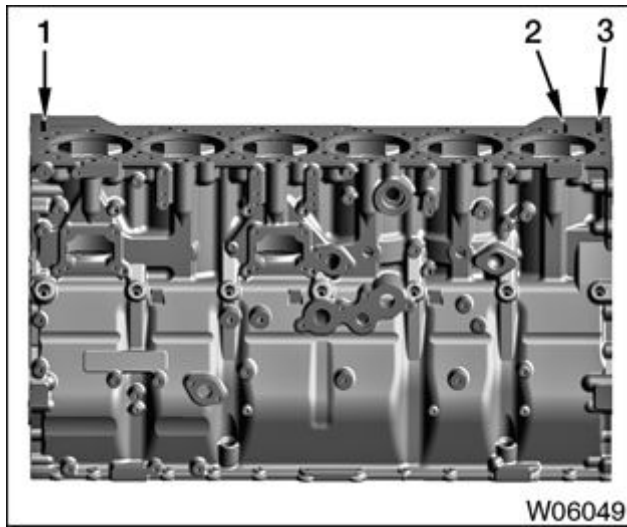


Figure 795 Top crankcase

1. Dowel pin (9.55 X 31.8 mm solid)
2. Dowel pin (6.35 X 30.2 mm solid)
3. Dowel pin (12.725 X 33 mm hollow)

17. If required, remove three dowel pins.

Cleaning, Inspection, and Testing

Crankshaft End Play

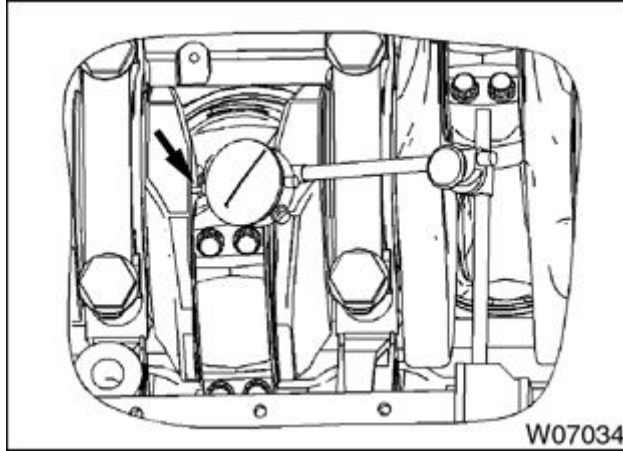


Figure 796 Crankshaft end play

1. Rotate crankshaft to insure crankshaft turns freely. If not, determine cause and repair before proceeding.
2. Check crankshaft end play as follows:
 - a. Mount dial indicator with magnetic base (page 527) on crankcase with indicator tip on a machined surface of the crankshaft as shown.
 - b. Move crankshaft forward with pry bar and zero the dial indicator. Pry between rear or front crankshaft counterweight and crankcase.
 - c. Move crankshaft back and forth while reading dial indicator. Compare dial indicator reading with specifications (page 526).
 - d. If end play exceeds specified limits, replace main bearing thrust washers.

Crankcase

CAUTION: To prevent engine damage, do not use chlorinated solvents on bolts or crankcase tapped holes. Parts should be clean, dry, and free of any chemicals other than engine oil.

NOTE: Thoroughly clean and inspect crankcase before and after reconditioning.

1. Clean crankcase in a chemical bath or hot tank. This removes all carbonized material and mineral deposits in coolant passages.

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

CAUTION: To prevent engine damage, do not use solvents or a wire brush to clean the mating surface of crankcase and crankshaft bearing caps.

2. If a hot tank is not available, do the following steps:
 - a. Use non-metallic stiff bristle brushes and scrapers to clean gasket material from machined surfaces of crankcase.
 - b. Clean crankcase in solvent.
 - c. Dry with filtered compressed air.

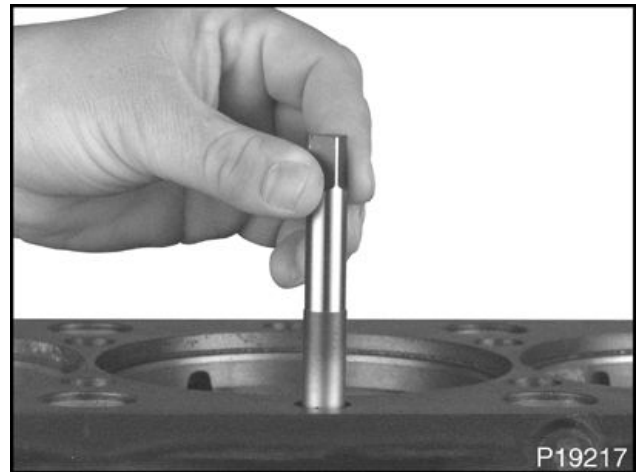


Figure 797 Cylinder head bolt holes

CAUTION: To prevent engine damage, clean and dry threads in the crankcase bolt holes with filtered compressed air. Dirt or oil in holes may cause binding and incorrect torque readings.

3. Clean cylinder head bolt holes with Head and Main Bolt Bottoming Tap Kit (page 527).
4. Clean crankcase bearing cap bolt holes with Head and Main Bolt Bottoming Tap Kit (page 527).

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

5. Clean out debris with filtered compressed air from cylinder head and bearing cap bolt holes.

Crankshaft

1. Clean and inspect crankshaft and main bearings.
2. Clean crankshaft with a suitable solvent.

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

3. Dry with filtered compressed air.
4. Use a stiff nylon brush to clean oil passages in crankshaft. Loosen accumulated dirt, sludge, and deposits.
5. Flush oil passages with a suitable solvent.
6. Inspect crankshaft journals (main and connecting rod) for scratches, grooves, and scoring.
7. Inspect main bearings for scratches, grooves, scoring, pitting, and inconsistent coloring.

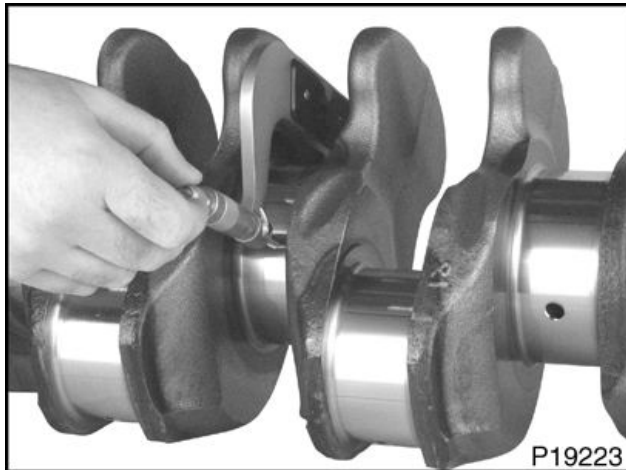


Figure 798 Measurement of crankshaft main bearing journal

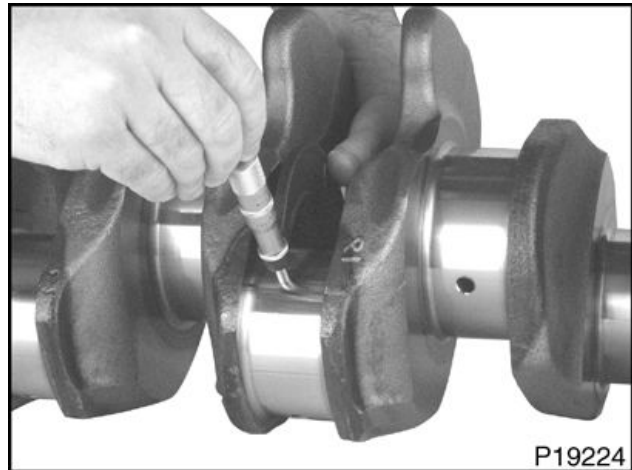


Figure 799 Measurement of crankshaft connecting rod bearing journal

CAUTION: To prevent engine damage, do not rework bearings or bearing caps to reduce journal-to-bearing running clearances. Install new or factory remanufactured crankshaft.

8. Use a 3–4 inch micrometer (page 527) to measure diameter of each connecting rod journal, and a 4–5 inch micrometer (page 527) to measure diameter of each main journal. Measure each journal at both sides next to fillet radius at two directions 90° apart. Move micrometer over entire width of journal. If journal wear exceeds specification (page 526), machine or replace crankshaft.

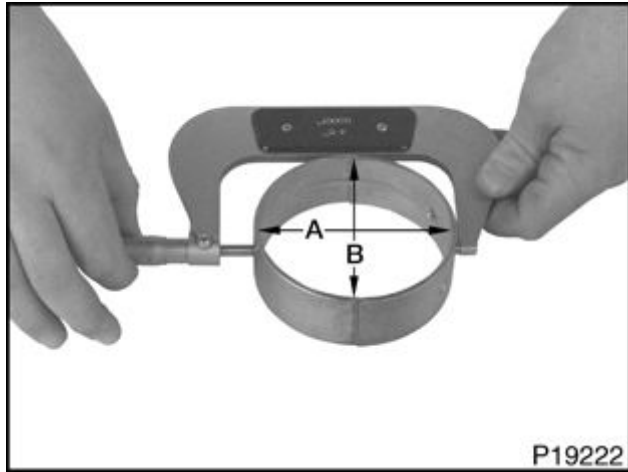
Main Bearings

Figure 800 Main bearing free spread measurement

1. Inspect each main bearing. If any bearing is found to be scored, chipped or worn, replace all bearings.
2. Using a flat surface, place matching upper and lower main bearings together as shown.
3. Using a 5–6 inch micrometer (page 527), measure and note dimensions A and B as shown.
4. Calculate difference between dimensions A and B. If difference exceeds free spread specification (page 526), replace main bearings.
5. Install upper main bearings into crankcase and lower main bearings into crankshaft bearing caps in their original positions and orientation.

CAUTION: To prevent engine damage, install crankshaft bearing caps in the original orientation.

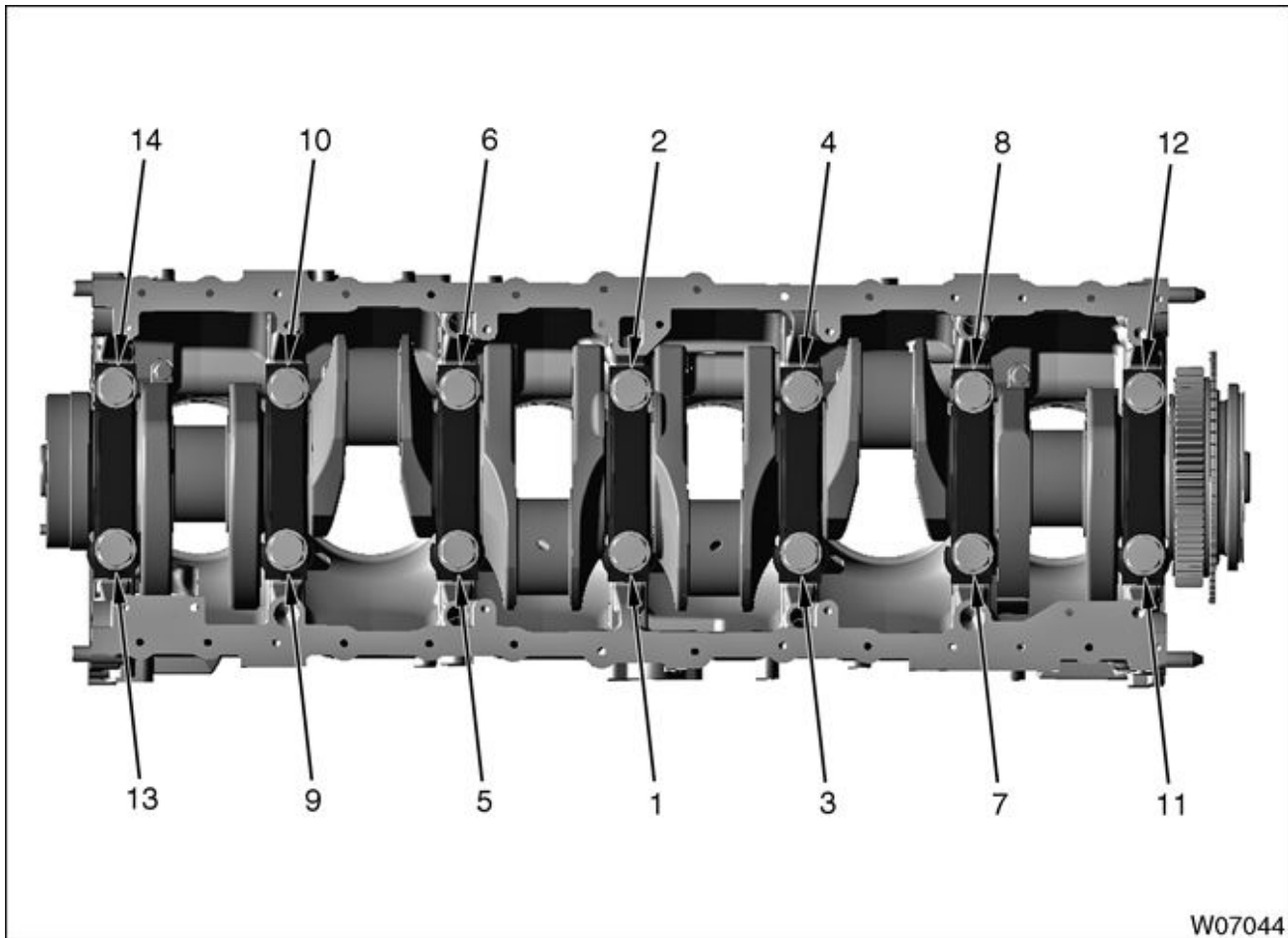


Figure 801 Crankshaft bearing cap bolt tightening sequence

6. With crankshaft still removed, install seven crankshaft bearing caps and 14 previously removed hex collar bolts. Do not use new bolts for this inspection procedure.
7. Tighten the 14 previously removed 7/8–14 x 7.75 hex flange bolts as follows.
 - a. Tighten the 14 previously removed 7/8–14 x 7.75 hex flange bolts in the sequence shown to 258 N·m (190 lbf·ft).
 - b. Tighten the 14 previously removed 7/8–14 x 7.75 hex flange bolts in the sequence shown an additional 120 degrees.

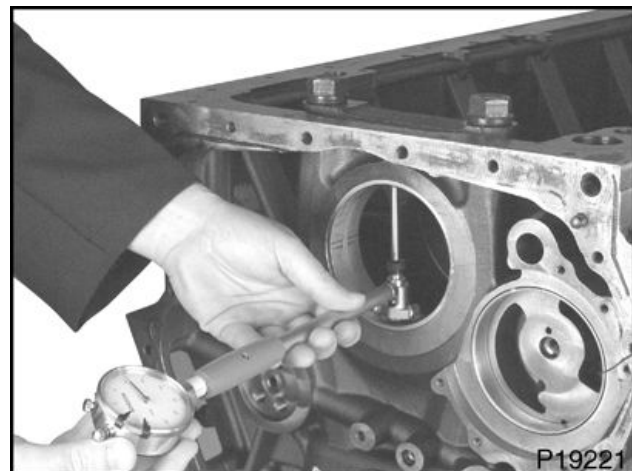


Figure 802 Main bearing installed diameter measurement (typical)

8. Using a dial bore gauge (page 527), measure main bearing installed inside diameter. If measurement does not meet specification (page 526), replace main bearings.
9. Remove 14 7/8–14 x 7.75 hex flange bolts, seven crankshaft bearing caps, upper main bearings, and lower main bearings. Save used 14 7/8–14 x 7.75 hex flange bolts to be used later during main bearing clearance inspection.

Piston Cooling Jet

CAUTION: To prevent engine damage, do not bend the piston cooling jets because the piston cooling jets are precision aligned with a coolant passage in the pistons and will not function properly if bent.

1. Hold each piston cooling jet under running water. Water should stream from jet end.

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

2. Clear blocked piston cooling jets using filtered compressed air. Replace piston cooling jet if blockage cannot be cleared.
3. Replace any cracked or bent piston cooling jets.

Installation

Crankcase Dowel Pins, Plugs and Fittings

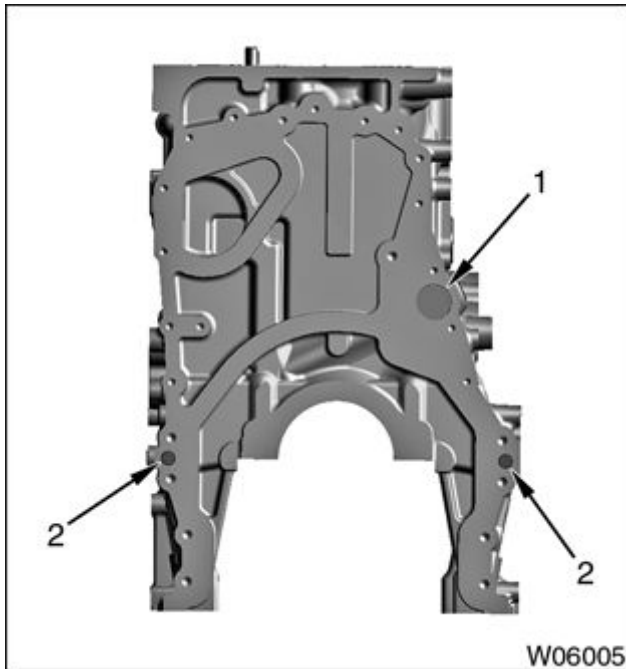


Figure 803 Rear crankcase

1. Plug
 2. Dowel pin (15.88 X 31.8 mm solid) (2)
1. Lubricate new O-ring and rear crankcase plug bore with clean engine oil.
 2. Install lubricated O-ring into the plug ring groove.
 3. Install plug into the rear of the crankcase to depth specified specification (page 526).
 4. Install two dowel pins (15.88 X 31.8 mm solid) into the rear of the crankcase.

5. Measure the protrusion of the dowels and make sure the protrusion is within specification (page 526).

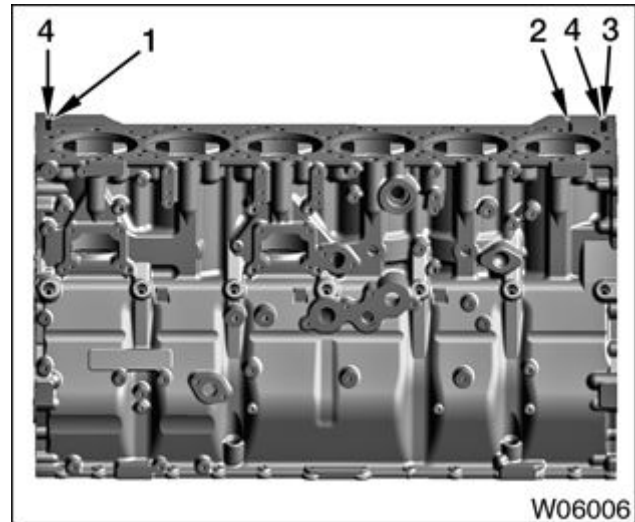


Figure 804 Top crankcase

1. Dowel pin (9.55 X 31.8 mm solid) (rear)
 2. Dowel pin (6.35 X 30.2 mm solid)
 3. Dowel pin (12.725 X 33 mm hollow) (front)
 4. Loctite® 609
6. Apply Loctite® 609 Retaining Compound (page 527) to the two top crankcase dowel pin locations as indicated in (Figure 804).
 7. Install three dowel pins to specified protrusions specification (page 526).
 8. Measure the protrusion of the dowels and make sure the protrusion is within specification (page 526).

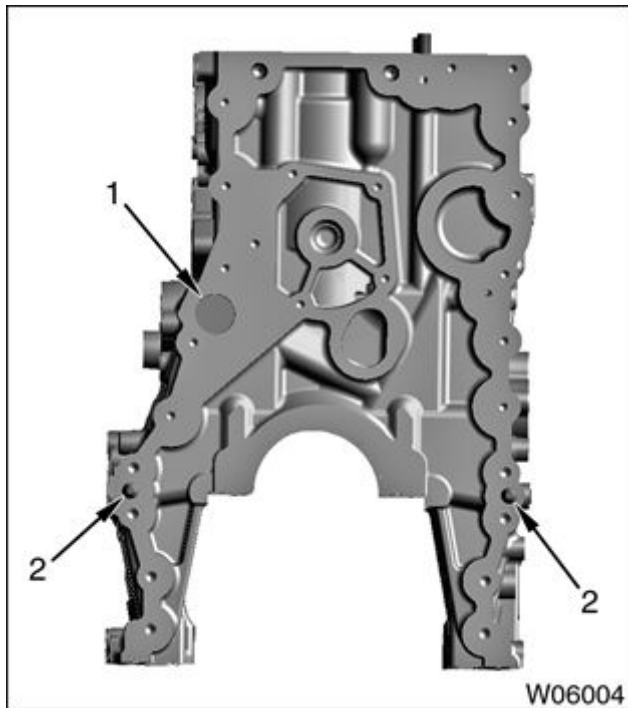


Figure 805 Front crankcase

1. Plug with o-ring
 2. Dowel pin (15.88 X 50 mm solid) (2)
9. Lubricate new O-ring and front crankcase plug bore with clean engine oil.
 10. Install lubricated O-ring into the plug ring groove.
 11. Install plug into the front of the crankcase to depth specified (page 526).
 12. Install two dowel pins (15.88 X 50 mm solid) to specified (page 526) protrusion.
 13. Measure the protrusion of the dowels and make sure the protrusion is within specification (page 526).

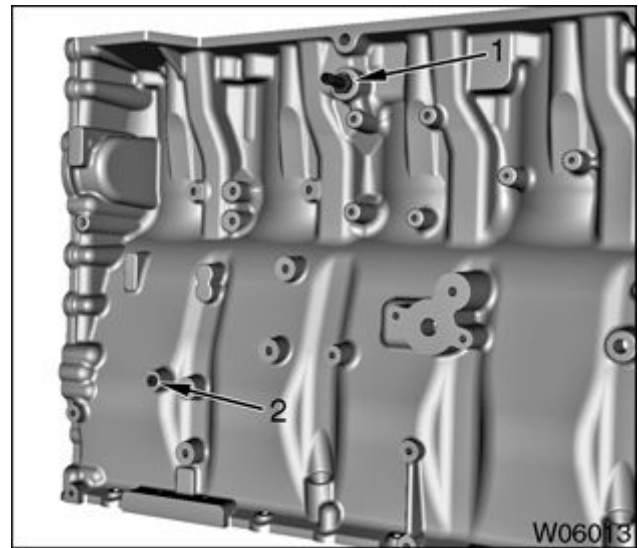


Figure 806 Left side crankcase

1. Hose fitting (3/4–16) with o-ring
 2. O-ring boss plug (7/16–20)
14. Install a new O-ring on the 3/4–16 hose fitting.
 15. Install 3/4–16 hose fitting into left side of crankcase as shown. Tighten 3/4–16 hose fitting to special torque (page 526).
 16. Install a new O-ring on the O-ring boss plug (7/16–20).
 17. Install O-ring boss plug (7/16–20) into left side of crankcase as shown. Tighten O-ring boss plug (7/16–20) to special torque (page 526).

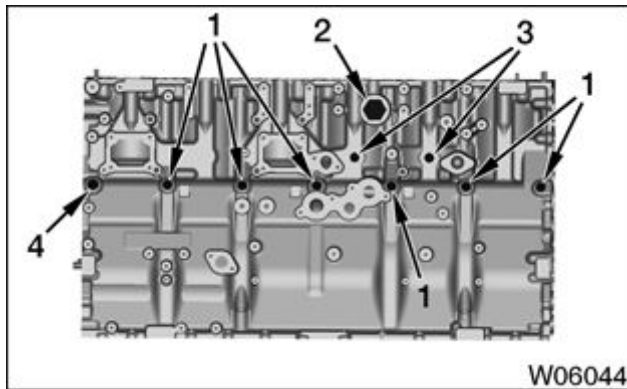


Figure 807 Right side crankcase

1. O-ring boss plug assembly (3/4–14 with blue O-ring) (oil) (6)
 2. O-ring boss plug assembly (1-5/8 – 12)
 3. O-ring boss plug assembly (3/4–14 with black O-ring) (coolant) (2)
 4. O-ring boss plug (7/8–14)
18. Lubricate two black O-rings with clean engine oil.
 19. Install two new O-rings on the O-ring boss plugs (3/4–14).
 20. Lubricate six blue O-rings with P-80 lubricant (page 527)
 21. Install eight new O-rings on the O-ring boss plugs (3/4–14).
 22. Install six and two O-ring boss plugs (3/4–14) in the locations shown. Tighten O-ring boss plugs (3/4–14) to special torque (page 526).
 23. Install a new O-ring on the O-ring boss plug assembly (1-5/8 – 12).
 24. Install O-ring boss plug assembly (1-5/8 – 12) into right side of crankcase as shown. Tighten O-ring boss plug assembly (1-5/8 – 12) to special torque (page 526).
 25. Install a new O-ring on the O-ring boss plug (7/8–14).

26. Install O-ring boss plug (7/8–14) into right side of crankcase as shown. Tighten O-ring boss plug (7/8–14) to special torque (page 526).

Piston Cooling Jet

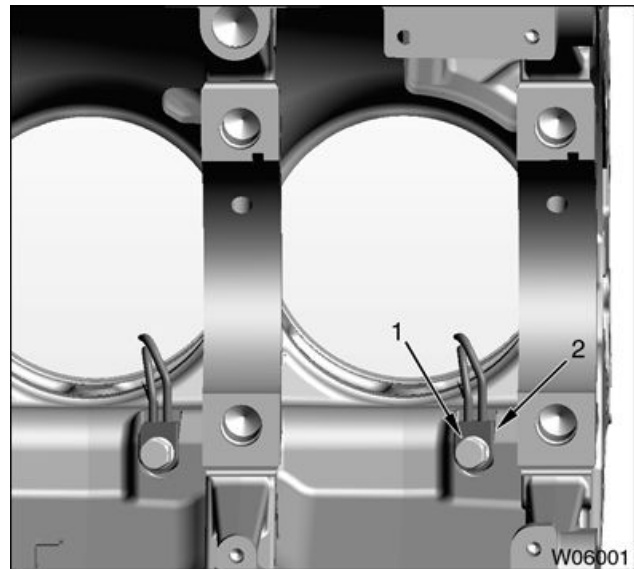


Figure 808 Piston cooling jet (typical)

1. Cooling jet bolt (6)
2. Piston cooling jet (6)

CAUTION: To prevent engine damage, do not bend the piston cooling jets because the piston cooling jets are precision aligned with a coolant passage in the pistons and will not function properly if bent.

CAUTION: To prevent engine damage, piston cooling jets must be installed with open end of jets facing piston.

1. Install six cooling jets and six piston cooling jet bolts. Tighten six piston cooling jet bolts to special torque (page 526).

Crankshaft Bearing Caps, Crankshaft, and Main Bearings

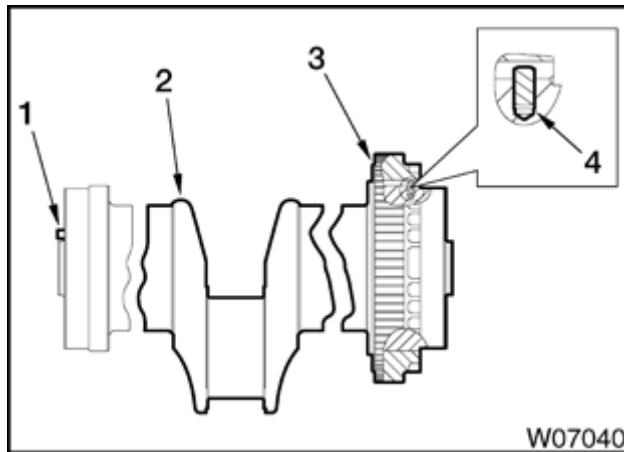


Figure 809 Crankshaft gear dowel

1. Crankshaft rear dowel pin (9.55 X 19.1 mm)
 2. Crankshaft
 3. Crankshaft gear
 4. Crankshaft gear dowel pin (0.25 X 0.5 inch)
1. If removed, install the crankshaft gear dowel pin (0.25 X 0.5 inch) and crankshaft rear dowel pin (9.55 X 19.1 mm) in crankshaft to result in protrusion specified (page 526).
 2. Measure the protrusion of the dowel pins and make sure the protrusion is within specification.

⚠ WARNING: To prevent personal injury or death, wear heat insulated gloves when handling heated components.

CAUTION: To prevent engine damage, do not heat crankshaft gear above 149 °C (300 °F)

NOTE: Monitor the temperature of the crankshaft gear using an Infrared thermometer (thermo gun) (page 527).

3. Heat crankshaft gear on a hot plate (page 527) or other controlled heat source to 149 °C (300 °F).
4. Install heated crankshaft gear on the crankshaft while wearing heat insulated gloves (page 527).

Make sure dowel pin groove on gear aligns with dowel pin in crankshaft. Crankshaft gear should slide on the crankshaft with only slight hand pressure. Hold the crankshaft gear (while thoroughly seated with the gap between the crankshaft flange front face and crankshaft gear rear face less than specification (page 526)) until it cools on the crankshaft (approximately 30 seconds).

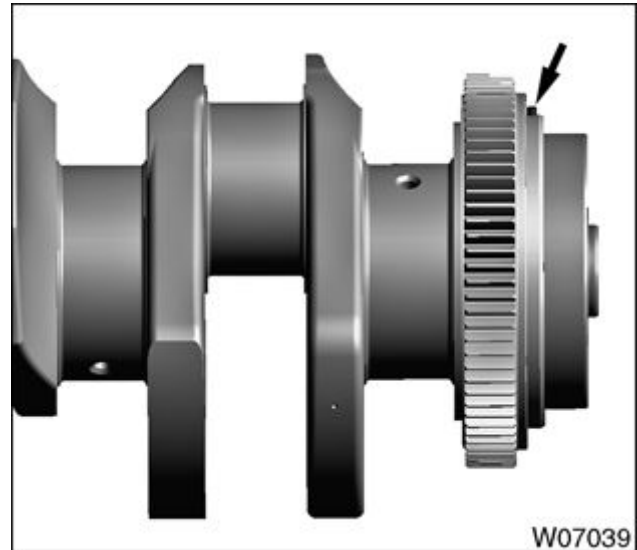


Figure 810 Crankshaft timing ring 5 x 10 hardened dowel pin

5. If removed, install the crankshaft timing ring 5 x 10 hardened dowel pin in crankshaft to result in the protrusion specified. See specifications (page 526).
6. Measure the protrusion of the dowel and make sure the protrusion is within specifications (page 526).

NOTE: Make sure crankshaft and bearings have been inspected per instructions in this section before proceeding.

7. Use a lint-free cloth to wipe crankcase bearing saddles free of oil.

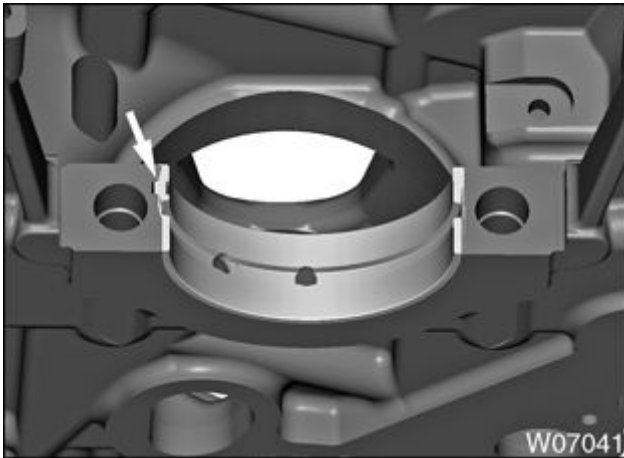


Figure 811 Main bearing installation

NOTE: If new main bearings are not being installed, reinstall the main bearings in their original locations and clean location markings from the bearing surface.

NOTE: When inserting main bearings, make sure oil is not between back side of bearing and crankcase bearing saddles.

8. Install upper main bearings in crankcase. Make sure locking tabs on bearings are snapped into saddle, and oil holes in bearings line up with oil holes in crankcase.

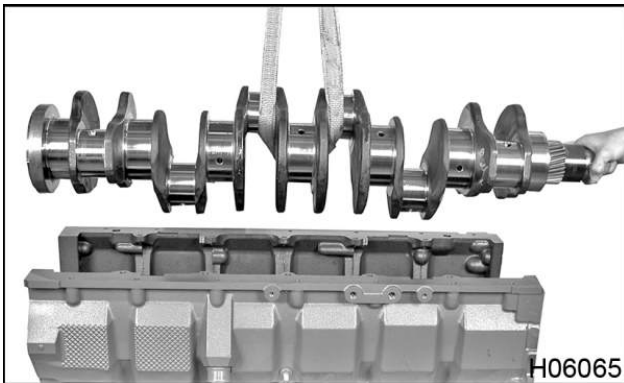


Figure 812 Crankshaft installation (typical)

! WARNING: To prevent personal injury or death, use a correct size lifting sling and hoist with a safety latch on hook.

CAUTION: To prevent engine damage, do not bend, drop or mar crankshaft.

CAUTION: To prevent engine damage, orient the crankshaft with the #1 and #6 connecting rod journals within 15 degrees of BDC for installation of the crankshaft into the crankcase.

CAUTION: To prevent engine damage, make sure that there is no interference between the crankshaft and crankcase while positioning the crankshaft in the crankcase.

9. Attach a heavy duty strap (page 527) to crankshaft. Lower crankshaft down into crankcase.



Figure 813 Thrust plate bearing installation

NOTE: Make sure oil grooves on thrust plate bearings face outward towards crankshaft thrust surface.

10. Install two thrust plate bearings into crankcase at No. 4 main location the oil grooves on thrust plate bearings facing outward towards crankshaft thrust surface as follows:
 - a. Set thrust plate bearings on top of crankshaft at No. 4 main journal.
 - b. Allow thrust plate bearings to pivot around crankshaft and down into position.
11. Install seven lower main bearings in seven crankshaft bearing caps. Make sure locking tabs on bearings are snapped into saddle.
12. Place a piece of Plastigage® (page 527) on the lower bearing surfaces.

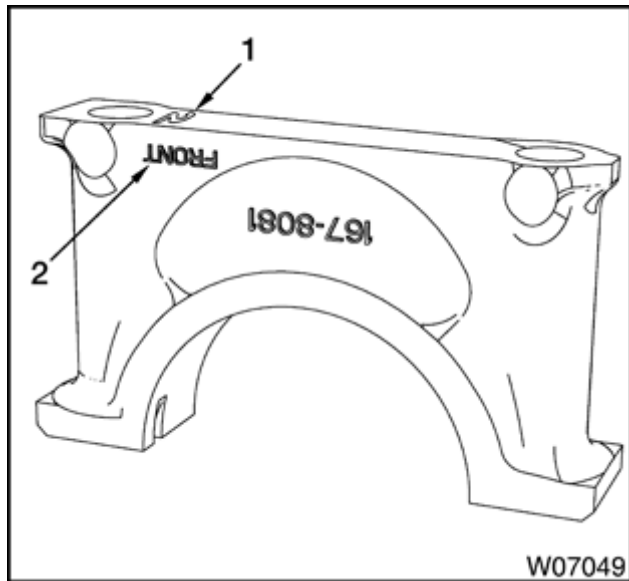


Figure 814 Crankshaft bearing cap marks (typical)

1. Crankshaft bearing cap stamp on #2 crankshaft bearing cap
2. Front of engine casting

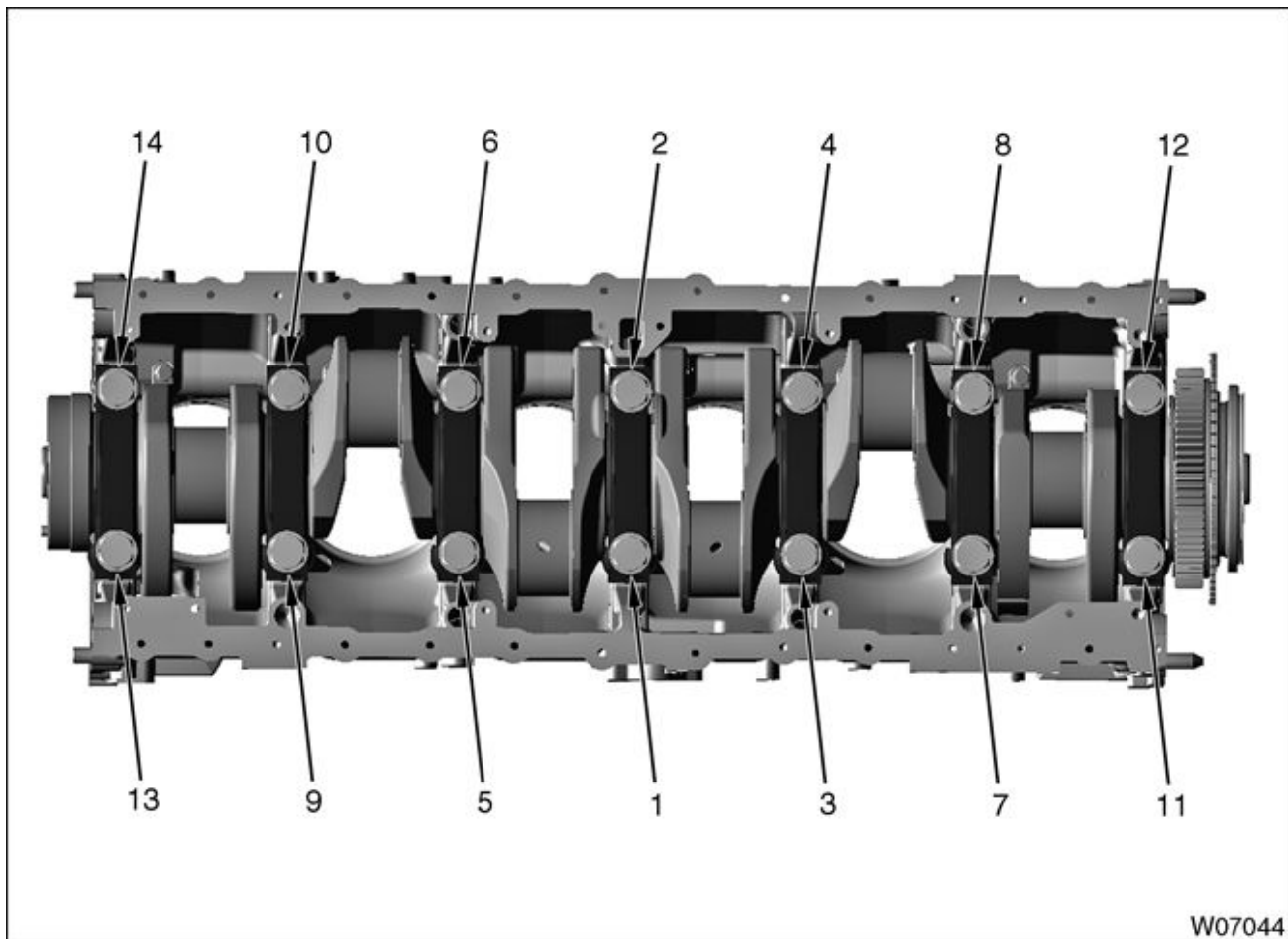


Figure 815 Crankshaft bearing cap bolt tightening sequence

13. Install seven crankshaft bearing caps in correct location and orientation per markings on the bearing caps. Lubricate with clean engine oil and install the 14 previously removed 7/8–14 x 7.75 hex flange bolts. Per the following:
 - a. Install the No. 4 crankshaft bearing cap and tap into place with a hammer.
 - b. Working from the center outward, install the remaining crankshaft bearing caps and tap into place with a hammer.
 - c. Tighten the 14 7/8–14 x 7.75 hex flange bolts in the sequence shown to 300 N·m (221 lbf·ft).
 - d. Tighten the 14 7/8–14 x 7.75 hex flange bolts in the sequence shown an additional 90 degrees.

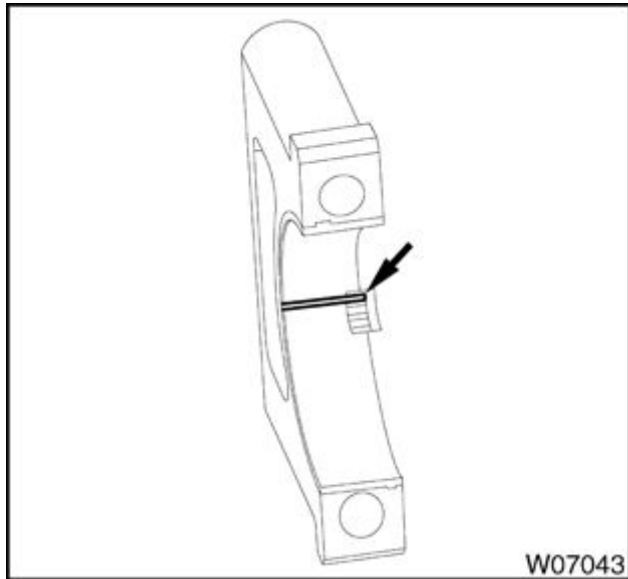


Figure 816 Plastigage® Measurement

14. Remove 14 7/8–14 x 7.75 hex flange bolts and seven crankshaft bearing cap, one set at a time.
15. Using the Plastigage® scale, determine the crankshaft main bearing clearance for each set of main bearings.
16. Compare the main bearing clearance measured and make sure that the clearance is within specification (page 526).
17. If any main bearing clearance is outside specification (page 526), install a new crankshaft.
18. Clean the plastic gage from the main bearing and the crankshaft.
19. Discard the used 14 7/8–14 x 7.75 hex flange bolts.
20. Lubricate all main bearings

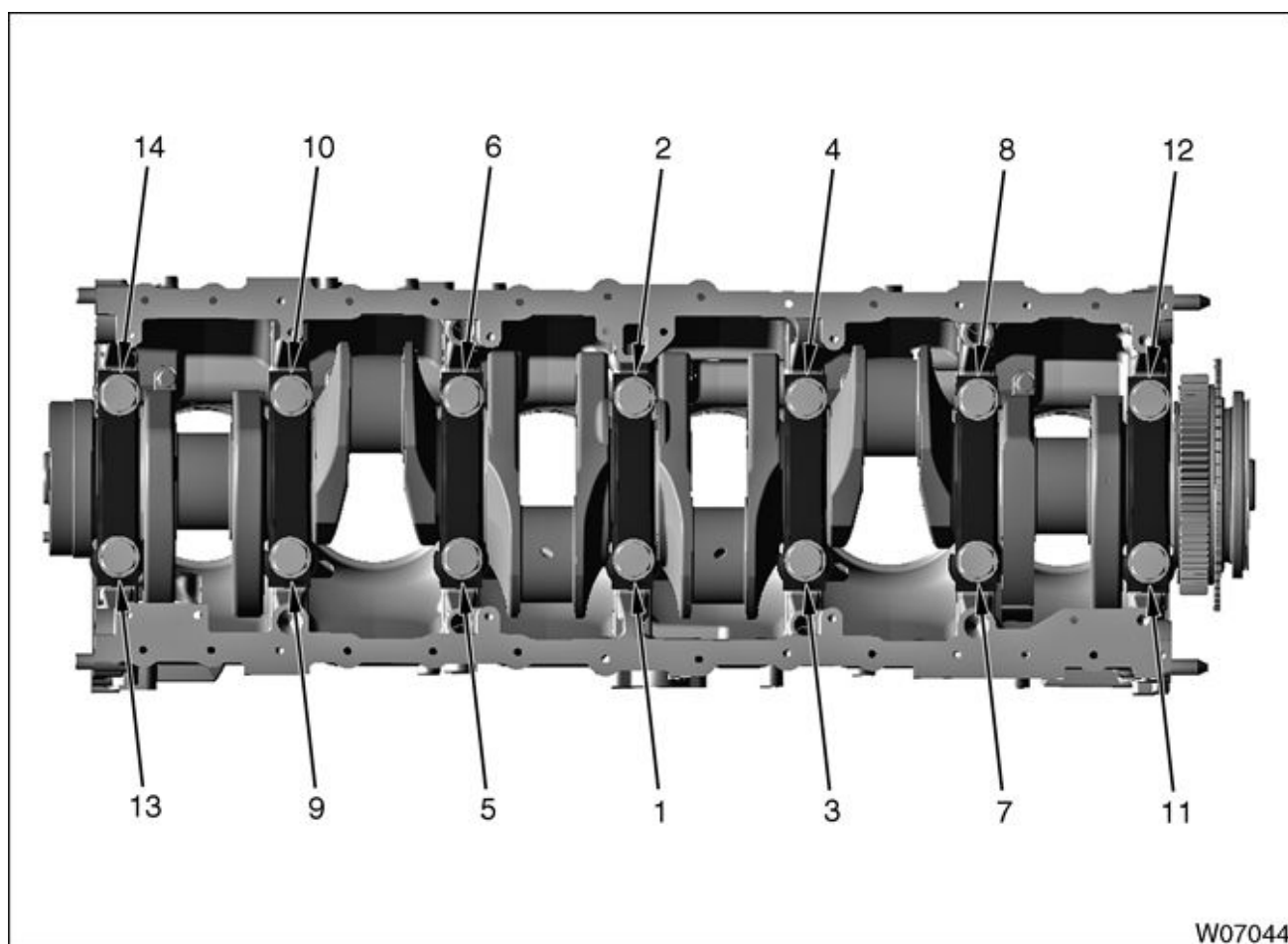


Figure 817 Crankshaft bearing cap bolt tightening sequence

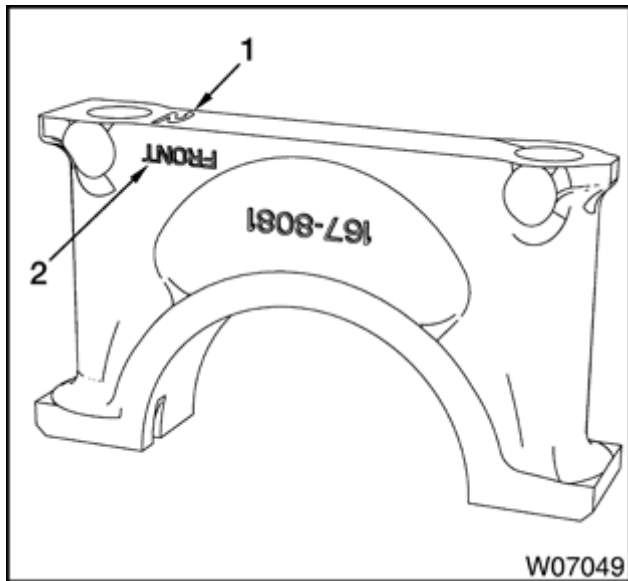


Figure 818 Crankshaft bearing cap marks (typical)

1. Crankshaft bearing cap stamp on #2 crankshaft bearing cap
2. Front of engine casting

NOTE: Each crankcase bearing cap is identified for location and orientation as shown in (Figure 818).

21. Install seven crankshaft bearing caps in correct location and orientation per the markings on the bearing caps. Lubricate the 14 new 7/8–14 x 7.75 hex flange bolts with clean engine oil and install.
 - a. Install the No. 4 crankshaft bearing cap and tap into place with a hammer.
 - b. Working from the center outward, install the remaining crankshaft bearing caps and tap into place with a hammer.
 - c. Tighten the 14 7/8–14 x 7.75 hex flange bolts in the sequence shown to 300 N·m (221 lbf·ft).
 - d. Tighten the 14 7/8–14 x 7.75 hex flange bolts in the sequence shown an additional 90 degrees.
22. Make sure that the crankshaft rotates freely.
23. Measure crankshaft end play. See specifications (page 526).

Specifications

Crankshaft Specifications

Main Bearing:

Crankshaft main bearing clearance	0.076 – 0.186 mm (0.0030 – 0.0073 in)
Main bearing free spread	130.79 – 131.79 mm (5.1492 – 5.1885 in)
Main bearing installed diameter	120.718 – 120.768 mm (4.7527 – 4.7463 in)

Crankshaft:

Crankshaft flange front face to crankshaft gear rear face gap	0.1 mm (0.0039 in) Max
Crankshaft gear dowel pin protrusion	3.6 – 4.6 mm (0.14 – 0.18)
Crankshaft rear dowel pin max protrusion	6.4 mm (0.25 in)
Crankshaft timing ring 5 x 10 hardened dowel pin protrusion	4.4 – 5.4 mm (0.173 – 0.212 in)
End play Maximum service	0.11 – 0.57 mm (0.0043 – 0.0224 in)
Journal diameter	120.630 – 120.670 mm (4.7492 – 4.7508 in)

Crankcase:

Dowel pin (15.88 X 31.8 mm solid) protrusion	36.8 – 37.8 mm (1.45 – 1.49 in)
Top crankcase (rear) dowel pin (9.55 X 31.8 mm solid) protrusion	18.0 – 19.0 mm (0.71 – 0.75 in)
Top crankcase dowel pin (6.35 X 30.2 mm solid) protrusion	15.5 – 16.5 mm (0.61 – 0.65 in)
Top crankcase (front) dowel pin (12.725 X 33 mm hollow) protrusion	19.5 – 20.5 mm (0.76 – 0.81 in)
Dowel pin protrusion (to flywheel housing)	18.6 – 19.6 mm (0.73 – 0.77 in)
Plug (front and rear of crankcase) depth	1.0 – 3.0 mm (0.04 – 0.12 in)

Special Torque

Main bearing cap 7/8–14 x 7.75 hex flange bolts	See tightening procedure and sequence (page 525)
Piston cooling jet bolts	40 N·m (30 lbf·ft)
Hose fitting (3/4–16)	60 N·m (44 lbf·ft)
O-ring boss plug (7/16 – 20)	23 N·m (17 lbf·ft)
O-ring boss plugs (3/4–14)	60 N·m (44 lbf·ft)
O-ring boss plug (7/8–14)	115 N·m (85 lbf·ft)
O-ring boss plug assembly (1-5/8 – 12)	290 N·m (214 lbf·ft)

Special Service Tools

Description	Tool Number
1/2 x 20 in. tap	Obtain locally
29/64 th drill bit	Obtain locally
3–4 inch micrometer	Obtain locally
4–5 inch micrometer	Obtain locally
5–6 inch micrometer	Obtain locally
Dial bore gauge	Obtain locally
Dial indicator with magnetic base	Obtain locally
Gear remover	Obtain locally
Head and Main Bolt Bottoming Tap Kit (3/4 x 16 and 7/8 x 14 taps)	ZTSE6117
Heat insulated gloves	Obtain locally
Heavy duty strap	Obtain locally
Hot plate	Obtain locally
Infrared thermometer (thermo gun)	Obtain locally
Loctite® 609	Obtain locally
Plastigage®	Obtain locally
P-80® Rubber lubricant or equivalent	Obtain locally
Slide Hammer Kit	ZTSE1879

Table of Contents

Abbreviations and Acronyms.....	531

Abbreviations and Acronyms

A or amp – Ampere

AAT – Ambient Air Temperature

ABDC – After Bottom Dead Center

ABS – Antilock Brake System

AC – Alternating Current

A/C – Air Conditioner

ACC – Air Conditioner Control

ACCEL – 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

CCOSS – Crankcase Oil Separator Speed

CCP – Crankcase Pressure Sensor

CCS – Cruise Control Switches

CCV – Coolant Control Valve

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
DTM – 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
EGBP – Exhaust Gas Back Pressure

EGC – Electronic Gauge Cluster
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

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
GND – Ground (electrical)
GPC – Glow Plug Control
GPD – Glow Plug Diagnostic
GPR – Glow Plug Relay
GVW – Gross Vehicle Weight

H₂O – 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 – Inlet Air Heater
IAHC – Inlet Air Heater Control
IAHD – Inlet Air Heater Diagnostic
IAHR – Inlet Air Heater Relay
IAT – Inlet Air Temperature
IC – Integrated Circuit
ICG1 – Injector Control Group 1
ICG2 – Injector Control Group 2
ICP – Injection Control Pressure
ICPR – Injection Control Pressure Regulator
ID – Inside Diameter
IDM – Injector Driver Module
IGN – Ignition
ILO – Injector Leak Off
IMP – Intake Manifold Pressure
IMT – Intake Manifold Temperature
in – Inch
inH₂O – Inch of water
inHg – Inch of mercury
INJs – Injectors
IPR – Injection Pressure Regulator
IPR PWR – Injection Pressure Regulator Power
ISC – Interstage Cooler
ISIS® – International® Service Information System
IST – Idle Shutdown Timer
ITP – Internal Transfer Pump
ITV – Intake Throttle Valve

ITVH – Intake Throttle Valve High control
ITVL – Intake Throttle Valve Low control
ITVP – Intake Throttle Valve Position
IVS – Idle Validation Switch

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
lb – Pound
lbf – Pounds of force
lb/s – Pounds per second
lbf ft – Pounds of force per foot
lbf in – Pounds of force per inch
lbm – Pounds of mass
L/h – Liters per hour
L/m – Liters per minute
LPCAC – Low Pressure Charge Air Cooler
L/s – Liters per second
LSD – Low Sulfur Diesel

m – Meter
MAF – Mass Air Flow
MAF GND – Mass Air Flow Ground
MAG – Magnetic
MAP – Manifold Absolute Pressure
MAP/IAT – Manifold Absolute Pressure / Inlet 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
m/s – Meters per second
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

PDOC – Pre-Diesel Oxidation Catalyst
PID – Parameter Identifier
P/N – Part Number
ppm – Parts per million
PROM – Programmable Read Only Memory
psi – Pounds per square inch
psia – Pounds per square inch absolute
psig – Pounds per square inch gauge
pt – Pint
PTO – Power Takeoff
PWM – Pulse Width Modulate
PWR – Power (voltage)

qt – Quart

RAM – Random Access Memory
RAPP – Remote Accelerator Pedal Position
RAS – Resume / Accelerate Switch (speed control)
REPTO – Rear Engine Power Takeoff
rev – Revolution
RFI – Radio Frequency Interference
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
TC1TOP – Turbocharger 1 Turbine Outlet Pressure
TC1WC – Turbocharger 1 Wastegate Control
TC2CIS – Turbocharger 2 Compressor Inlet Sensor
TC2TOP – Turbocharger 2 Turbine Outlet Pressure
TC2WC – Turbocharger 2 Wastegate Control
TCAPE – Truck Computer Analysis of Performance and Economy
TCM – Transmission Control Module
TDC – Top Dead Center
TDE – Transmission Driving Engaged
TOP – Transmission Oil Pressure
TOSS – Transmission Output Shaft Speed
TOT – Transmission Oil Temperature
TTS – Transmission Tailshaft Speed

ULSD – Ultra Low Sulfur Diesel
UVC – Under Valve Cover

V – Volt
VBAT or B+ – Battery Voltage
VC – Volume Control
VEPS – Vehicle Electronics Programming System
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

WEL – Warn Engine Lamp

WIF – Water In Fuel

WIFL – Water In Fuel Lamp

WTEC – World Transmission Electronically Controlled
automatic transmissions (Allison)

WTSL – Wait to Start Lamp

XCS – Transference

XMSN – Transmission

Table of Contents

Terminology.....539

 Terms.....539

Terminology

Terms

Accelerator Pedal Position (APP) sensor – A potentiometer sensor that indicates the position of the throttle pedal.

Accessory work – The work per cycle required to drive engine accessories (normally, only those essential to engine operation).

Actuator – A device that performs work in response to an input signal.

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

Aeration – The entrainment of air or combustion gas in coolant, lubricant, or fuel.

Aftercooler (Charge Air Cooler) – A heat exchanger mounted in the charge air path between the turbocharger and engine intake manifold. The aftercooler reduces the charge air temperature by transferring heat from the charge air to a cooling medium (usually air).

Aftertreatment Fuel Doser (AFTFD) – A part of the Down Stream Injection (DSI) unit that sends pressurized fuel to the Aftertreatment Fuel Injector (AFI) to inject fuel into the exhaust pipe.

Aftertreatment (AFT) system – A part of the exhaust system that processes engine exhaust to meet emission requirements and traps particulate matter (soot) to prevent it from leaving the tailpipe.

Air Control Valve (ACV) – Contains the LP turbocharger wastegate control port, HP turbocharger wastegate control port, the EBPV control port, and the TC1TOP port. Although these components are integral to the ACV, each circuit is controlled by the ECM. The ACV controls compressed air for each control valve.

Air Inlet Temperature (AIT) sensor – A thermistor sensor that monitors intake air temperature.

Ambient temperature – The environmental air temperature in which a unit is operating. In general, the temperature is measured in the shade (no solar radiation) and represents the air temperature for other engine cooling performance measurement purposes.

Air entering the radiator may or may not be the same ambient due to possible heating from other sources or recirculation. (SAE J1004 SEP81)

Ampere (amp) – The standard unit for measuring the strength of an electrical current. The flow rate of a charge in a conductor or conducting medium of one coulomb per second. (SAE J1213 NOV82)

Analog – A continuously variable voltage.

Analog to digital converter (A/D) – A circuit in the ECM processing section that converts an analog signal (DC or AC) to a usable digital signal for the microprocessor.

American Trucking Association (ATA) Datalink – A serial datalink specified by the American Trucking Association and the SAE.

Boost pressure – 1. The pressure of the charge air leaving the turbocharger.

2. Inlet manifold pressure that is greater than atmospheric pressure. Obtained by turbocharging.

Bottom Dead Center (BDC) – The lowest position of the piston during the stroke.

Brake Horsepower (bhp) – The power output from an engine, not the indicated horsepower. The power output of an engine, sometimes-called flywheel horsepower is less than the indicated horsepower by the amount of friction horsepower consumed in the engine.

Brake Horsepower (bhp) net – Net brake horsepower is measured with all engine components. The power of an engine when configured as a fully equipped engine. (SAE J1349 JUN90)

Calibration – 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.

Catalyst – A substance that produces a chemical reaction without undergoing a chemical change itself.

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 –

- The auto-ignition quality of diesel fuel.
- A rating applied to diesel fuel similar to octane rating for gasoline.
- A measure of how readily diesel fuel starts to burn (self-ignites) at high compression temperature.

Diesel fuel with a high cetane number self-ignites shortly after injection into the combustion chamber. Therefore, it has a short ignition delay time. Diesel fuel with a low cetane number resists self-ignition. Therefore, it has a longer ignition delay time.

Charge air – Dense, pressurized, heated air discharged from the turbocharger.

Charge Air Cooler (CAC) – See **Aftercooler**.

Charge Air 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 a sensor to provide feedback to the ECM. The ECM uses the sensor to continuously monitor variables and adjust to match engine requirements.

Cloud point – The point when wax crystals occur in fuel, making fuel cloudy or hazy. Usually below -12 °C (10 °F).

Cold cranking ampere rating (battery rating) – The sustained constant current (in amperes) needed to produce a minimum terminal voltage under a load of 7.2 volts per battery after 30 seconds.

Cold Start Fuel Ignitor (CSFI) – The CSFI heats the intake air by vaporizing and igniting fuel in the air inlet.

Cold Start Fuel Solenoid (CSFS) – As the engine is cranked, the ECM energizes the CSFS valve, introducing fuel into the CSFI, which ignites and warms the air being drawn into the engine.

Cold Start Relay (CSR) – The CSR provides voltage to the CSFI, and is controlled by the ECM.

Controller Area Network (CAN) – A J1939 high speed communication link.

Coolant – A fluid used to transport heat from one point to another.

Coolant level switch – A switch sensor used to monitor coolant level.

Coolant Flow Valve (CFV) – The CFV is ECM controlled and redirects coolant through the fuel cooler, based on EFT, when directed.

Coolant Mixer Valve (CMV) – Controls coolant flow through the low-temperature radiator.

Continuous Monitor Test – An ECM function that continuously monitors the inputs and outputs to ensure that readings are within set limits.

Crankcase – The housing that encloses the crankshaft, connecting rods, and allied parts.

Crankcase breather – A vent for the crankcase to release excess interior air pressure.

Crankcase Oil Separator Speed (CCOSS) sensor – The CCOSS sensor sends the ECM information about the speed of the crankcase oil separator internal components.

Crankcase pressure – The force of air inside the crankcase against the crankcase housing.

Crankshaft Position (CKP) sensor – A magnetic pickup sensor that determines crankshaft position and speed.

Current – The flow of electrons passing through a conductor. Measured in amperes.

Damper – A device that reduces the amplitude of torsional vibration. (SAE J1479 JAN85)

Deaeration – The removal or purging of gases (air or combustion gas) entrained in coolant or lubricating oil.

Deaeration tank – A separate tank in the cooling system used for one or more of the following functions:

- Deaeration
- Coolant reservoir (fluid expansion and afterboil)
- Coolant retention
- Filling
- Fluid level indication (visible)

Diagnostic Trouble Code (DTC) – 2010 model year vehicles no longer utilize DTC identification by number. DTCs are now identified using the Suspect Parameter Number (SPN) and Failure Mode Indicator (FMI) identifiers only.

Diesel Particulate Filter (DPF) – A diesel particulate filter, sometimes called a DPF, is a device designed to remove diesel particulate matter or soot from the exhaust gas of a diesel engine.

Diesel Oxidation Catalyst (DOC) – A DOC is part of the diesel exhaust Aftertreatment system. DOCs are devices that use a chemical process to break down pollutants in the exhaust stream into less harmful components. More specifically, DOCs utilize rare metals such as palladium and platinum to reduce hydrocarbon based Soluble Organic Fraction (SOF) and carbon monoxide content of diesel exhaust by simple oxidation. The DOC can be used during an active regeneration to create higher exhaust temperatures, thereby reducing soot in the DPF.

Digital Multimeter (DMM) – An electronic meter that uses a digital display to indicate a measured value. Preferred for use on microprocessor systems because it has a very high internal impedance and will not load down the circuit being measured.

Disable – A computer decision that deactivates a system and prevents operation of the system.

Displacement – The stroke of the piston multiplied by the area of the cylinder bore multiplied by the number of cylinders in the engine.

Down Stream Injection (DSI) – The DSI system injects fuel into the exhaust system to increase temperature of the exhaust gases, and is necessary for DPF regeneration.

Driver (high side) – A transistor within an electronic module that controls the power to an actuator circuit.

Driver (low side) – A transistor within an electronic module that controls the ground to an actuator circuit.

Dual Stage Turbocharger – An assembly of two turbochargers (low-pressure and high-pressure) in series to provide a wide range of charge air pressures efficiently.

Duty cycle – A control signal that has a controlled on/off time measurement from 0 to 100%. Normally used to control solenoids.

EGR Cooler – A cooler that allows heat to dissipate from the exhaust gasses before they enter the intake manifold.

Engine Control Module (ECM) – An electronic processor that monitors and controls the engine.

Engine 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 3 (ECB3) solenoid – The ECB3 solenoid controls pressure entering the brake oil gallery from the high-pressure oil rail gallery.

Engine Compression Brake Pressure (ECBP) sensor – A high-pressure sensor that provides a feedback signal to the ECM indicating brake control pressure.

Engine Coolant Level (ECL) sensor – A switch sensor that monitors coolant level.

Engine Coolant Temperature 1 (ECT1) sensor – A thermistor sensor that detects engine coolant temperature.

Engine Coolant Temperature 2 (ECT2) sensor – A thermistor sensor that detects engine coolant temperature.

Engine Fuel Temperature (EFT) sensor – A thermistor sensor that measures fuel temperature.

Engine lamp – An instrument panel lamp that comes on when DTCs are set. DTCs can be read as flash codes (red and amber instrument panel lamps).

Engine OFF tests – Tests that are done with the ignition switch ON and the engine OFF.

Engine Oil Pressure (EOP) sensor – A variable capacitance sensor that measures oil pressure.

Engine Oil Temperature (EOT) sensor – A thermistor sensor that measures oil temperature.

Engine rating – Engine rating includes **Rated hp** and **Rated rpm**.

Engine RUNNING tests – Tests done with the engine running.

Engine Throttle Valve (ETV) and Engine Throttle Position Sensor – The ETV valve is used to control airflow during a regeneration process of the aftertreatment system. The ETV valve is also used to ensure a smooth engine shut down by restricting airflow to the engine at shut down.

Engine Warning Protection System (EWPS) – Safeguards the engine from undesirable operating conditions to prevent engine damage and to prolong engine life.

Exhaust Back Pressure (EBP) – The pressure present in the exhaust system during the exhaust period.

Exhaust Back Pressure Valve (EBPV) – A valve that regulates the amount of air pressure applied to the EBPV pneumatic actuator.

Exhaust brake – A brake device using engine exhaust back pressure as a retarding medium.

Exhaust Gas Recirculation (EGR) – A system used to recirculate a portion of the exhaust gases into the power cylinder in order to reduce oxides of nitrogen.

Exhaust Gas Temperature (EGT) – The temperature of exhaust gases.

Exhaust Gas Recirculation Temperature (EGRT) sensor – A thermistor sensor that detects the exhaust gas temperature entering the EGR cooler.

Exhaust Gas Recirculation (EGR) valve – The EGRV controls the flow of exhaust gases to the intake manifold. The EGRV is integrated with an EGR Position (EGRP) sensor.

Exhaust manifold – Exhaust gases flow through the exhaust manifold to the turbocharger exhaust inlet and are directed to the EGR cooler.

Exhaust Manifold Pressure (EMP) sensor – A variable capacitance sensor used to indicate air pressure in the exhaust manifold.

Exhaust Manifold Temperature (EMT) sensor – A thermistor style sensor used to indicate air temperature in the exhaust manifold.

Fault detection/management – An alternate control strategy that reduces adverse effects that can be caused by a system failure. If a sensor fails, the ECM substitutes a good sensor signal or assumed sensor value in its place. A lit amber instrument panel lamp signals that the vehicle needs service.

Failure Mode Indicator (FMI) – Identifies the fault or condition effecting the individual component.

Filter restriction – A blockage, usually from contaminants, that prevents the flow of fluid through a filter.

Flash code – See **Diagnostic Trouble Code (DTC)**.

Fuel doser – Injects fuel into the exhaust system to increase temperature of the exhaust gases.

Fuel inlet restriction – A blockage, usually from contaminants, that prevents the flow of fluid through the fuel inlet line.

Fuel pressure – The force that the fuel exerts on the fuel system as it is pumped through the fuel system.

Fuel 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 – Generates a digital on/off signal that indicates speed and timing.

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 – Unburned or partially burned fuel molecules.

Idle speed –

- Low idle is minimum rpm at no load.
- High idle is maximum rpm at no load.

Injection Pressure Regulator (IPR) valve – A valve that is used to maintain desired injection control pressure.

Injection Control Pressure (ICP) sensor – Provides a feedback signal to the ECM indicating injection control pressure.

Inlet Air Heater (IAH) – The IAH is primarily used to assist in starting the engine during cold weather. In addition, it helps to reduce white smoke emissions by heating the incoming air.

Intake manifold – A collection of tubes through which the fuel-air mixture flows from the fuel injector to the intake valves of the cylinders.

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 through the Fuel Volume Control Valve (FVCV). The ITP also provides fuel for cooling and lubrication of the HPFP. Fuel is rerouted as pump return flow through the HPFP cooling and lubrication valve. Pressure is

maintained at the inlet of the HPFP piston pump by an ITP regulator.

International NGV Tool Utilized for Next Generation Electronics (INTUNE) – The diagnostics software for chassis related components and systems.

Interstage Cooler (ISC) – Uses cooled coolant to lower the charged air temperature that exits from the turbocharger low-pressure compressor and enters the turbocharger high-pressure compressor.

Low speed digital inputs – Switched sensor inputs that generate an on/off (high/low) signal to the ECM. The input to the ECM from the sensor could be from a high input source switch (usually 5 or 12 volts) or from a grounding switch that grounds the signal from a current limiting resistor in the ECM that creates a low signal (0 volts).

Low temperature radiator thermostat – Coolant flow to the low temperature radiator is regulated by the low temperature radiator thermostat.

Lubricity – Lubricity is the ability of a substance to reduce friction between solid surfaces in relative motion under loaded conditions.

Lug (engine) – A condition when the engine is operating at or below maximum torque speed.

Manifold Absolute Pressure (MAP) – Boost pressure in the manifold that is a result of the turbocharger.

Manifold Absolute Pressure (MAP) sensor – A variable capacitance sensor that measures boost pressure.

Manometer – A double-leg liquid-column gauge, or a single inclined gauge, used to measure the difference between two fluid pressures. Typically, a manometer records in inches of water.

Mass Air Flow – The intake airflow in an engine.

Mass Air Flow (MAF) sensor – The MAF sensor is used for closed loop control of the EGR valve and ITV. The ECM monitors the MAF signal so that the ECM can control the EGR and intake throttle systems.

MasterDiagnostics® (MD) – The diagnostics software for engine related components and systems.

Magnehelic Gauge – A gauge that measures pressure in inches of water.

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

Metering unit valve assembly – The Metering unit valve assembly provides a metered amount of fuel to the 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 resistance. One ohm is the value of resistance through which a potential of one volt will maintain a current of one ampere. (SAE J1213 NOV82)

On demand test – A self test that the technician initiates using the EST and is run from a program in the processor.

Output Circuit Check (OCC) – An On demand test done during an Engine OFF self test to check the continuity of selected actuators.

Oxides of Nitrogen (NO_x) – 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 is done. Compare with **Torque**.

Power TakeOff (PTO) – Accessory output, usually from the transmission, used to power a hydraulic pump for a special auxiliary feature (garbage packing, lift equipment, etc).

Pulse Width Modulate (PWM) – The time that an actuator, such as an injector, remains energized.

Random Access Memory (RAM) – Computer memory that stores information. Information can be written to and read from RAM. Input information (current engine speed or temperature) can be stored in RAM to be compared to values stored in Read Only Memory (ROM). All memory in RAM is lost when the ignition switch is turned off.

Rated gross horsepower – Engine gross horsepower at rated speed as declared by the manufacturer. (SAE J1995 JUN90)

Rated horsepower – Maximum brake horsepower output of an engine as certified by the engine manufacturer. The power of an engine when configured as a basic engine. (SAE J1995 JUN90)

Rated net horsepower – Engine net horsepower at rated speed as declared by the manufacturer. (SAE J1349 JUN90)

Rated speed – The speed, as determined by the manufacturer, at which the engine is rated. (SAE J1995 JUN90)

Rated torque – Maximum torque produced by an engine as certified by the manufacturer.

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

Reference voltage (V_{REF}) – A 5 volt reference supplied by the ECM to operate the engine sensors.

Reserve capacity – Time in minutes that a fully charged battery can be discharged to 10.5 volts at 25 amperes.

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

ServiceMaxx™ software – Diagnostics software for engine related components and systems.

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

Signal ground – The common ground wire to the ECM for the sensors.

Speed Control Command Switches (SCCS) – A set of switches used for cruise control, Power TakeOff (PTO), and remote hand throttle system.

Steady state condition – An engine operating at a constant speed and load and at stabilized temperatures and pressures. (SAE J215 JAN80)

Strategy – A plan or set of operating instructions that the microprocessor follows for a desired goal. Strategy is the computer program itself, including all equations and decision making logic. Strategy is always stored in ROM and cannot be changed during calibration.

Stroke – Stroke is the movement of the piston from Top Dead Center (TDC) to Bottom Dead Center (BDC).

Substrate – Material that supports the washcoating or catalytic materials.

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 air flow from air entrance through air exit in a system. Usually measured in inches (millimeters) of water. (SAE J1004 SEP81)

Tachometer output signal – Engine speed signal for remote tachometers.

Thermistor – A semiconductor device. A sensing element that changes resistance as the temperature changes.

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) – Truck Computer Analysis of Performance and Economy is a computer program that simulates the performance and fuel economy of trucks.

Turbocharger – A turbine driven compressor mounted to the exhaust manifold. The turbocharger increases the pressure, temperature and density of intake air to charge air.

Turbocharger 1 Turbine Outlet Pressure (TC1TOP) sensor – A variable capacitance sensor that monitors exhaust back-pressure.

Turbocharger 2 Compressor Inlet (TC2CIS) sensor – The TC2CIS sensor includes a thermistor sensor that monitors the temperature of charge air entering the HP turbocharger. This sensor also monitors boost pressure for the LP turbocharger.

Turbocharger Wastegate Control (TCWC) solenoid – Controls the TCWC actuator by regulating the amount of charge air pressure supplied to the TCWC

actuator. The TCWC solenoid is controlled by signals from the ECM in response to engine speed, required fuel quantity, boost, exhaust back-pressure, and altitude.

Turbocharger 1 Wastegate Control (TC1WC) solenoid – Controls the TC1WC actuator by regulating the amount of charge air pressure supplied to the TC1WC actuator. The TC1WC solenoid is controlled by signals from the ECM in response to engine speed, required fuel quantity, boost, exhaust back-pressure, and altitude. The TC1WC actuator is part of the turbocharger assembly.

Turbocharger 2 Wastegate Control (TC2WC) solenoid – Controls the TC2WC actuator by regulating the amount of charge air pressure supplied to the wastegate actuator. The TC2WC solenoid is controlled by signals from the ECM in response to engine speed, required fuel quantity, boost, exhaust back-pressure, and altitude. The TC2WC actuator is part of the turbocharger assembly.

Variable capacitance sensor – A variable capacitance sensor measures pressure. The pressure forces a ceramic material closer to a thin metal disc in the sensor, changing the capacitance of the sensor.

Vehicle Electronic System Programming System – The computer system used to program electronically controlled vehicles.

Vehicle Retarder Enable/Engage – Output from the ECM to a vehicle retarder.

Vehicle Speed Sensor (VSS) – Normally a magnetic pickup sensor mounted in the tailshaft housing of the transmission, used to indicate ground speed.

Viscosity – The internal resistance to the flow of any fluid.

Viscous fan – A fan drive that is activated when a thermostat, sensing high air temperature, forces fluid through a special coupling. The fluid activates the fan.

Volt (v) – A unit of electromotive force that will move a current of one ampere through a resistance of one Ohm.

Voltage – Electrical potential expressed in volts.

Voltage drop – Reduction in applied voltage from the current flowing through a circuit or portion of the circuit current multiplied by resistance.

Voltage ignition – Voltage supplied by the ignition switch when the key is ON.

Water In Fuel (WIF) sensor – A switch sensor that measures the amount of water in the fuel.

Washcoat – A layer of alumina applied to the substrate in a monolith-type converter.

Table of Contents

Fuel System.....	551
Exhaust Gas Recirculation (EGR) System.....	551
Air Inlet and Exhaust Manifolds.....	551
Front Cover, High Mount Fan Drive, Cooling System, and Related Components.....	551
Engine Brake.....	551
Cylinder Head, Camshaft and Valve Train.....	552
Flywheel and Flywheel Housing.....	553
Power Cylinders.....	554
Crankcase and Crankshaft.....	555

Fuel System

Fuel filter filtration	4 microns

Exhaust Gas Recirculation (EGR) System

EGR cooler supply tube to exhaust manifold gap	2 - 4.5 mm (0.079 - 0.177 in)

Air Inlet and Exhaust Manifolds

Exhaust manifold maximum allowable warpage	0.24 mm (0.01 in)

Front Cover, High Mount Fan Drive, Cooling System, and Related Components

Idler gear backlash	0.102 – 0.33 mm (0.0040 – 0.0130 inch)

Engine Brake

Engine brake rocker lash	0.15 mm ± 0.05 mm (0.006 in ± 0.002 in)
Engine brake slave piston (cold)	0.686 mm ± 0.05 mm (0.027 in ± 0.002 in)

Cylinder Head, Camshaft and Valve Train

Camshaft

Camshaft bearing installed inside diameter	84.925 – 85.045 mm (3.3435 – 3.3482 in)
Camshaft bearing joint orientation	19.5 – 20.5 degrees above the right side horizontal bearing diameter facing the right side of the engine
Camshaft journal diameter	84.83 – 84.87 mm (3.3397 – 3.3413 in)
Camshaft lobe lift (engine brake)	Tall lobe 4.925 mm (0.193 in) Short lobe 4.539 mm (0.178 in)
Camshaft lobe lift (exhaust valve)	8.515 mm (0.3352 in)
Camshaft lobe lift (intake valve)	9.431 mm (0.3713 in)
Dowel pin (camshaft drive adapter assembly) installed height	12 – 13 mm (0.472 – 0.511 in)
Engine brake rocker lash	0.15 mm ± 0.05 mm (0.006 in ± 0.002 in)
Engine brake slave piston	0.686 mm ± 0.05 mm (0.027 in ± 0.002 in)
Exhaust valve lash	0.80 mm ± 0.076 mm (0.030 in ± 0.003 in)
Intake valve lash	0.40 mm ± 0.076 mm (0.015 in ± 0.003 in)

Cylinder Head

Brinelling indentation maximum depth	0.05 mm (0.002 in)
Cylinder head gasket surface flatness	0.13 mm (0.005 in) (overall) 0.05 mm (0.002 in) (maximum for any 150 mm (6 in) span)
Cylinder head thickness	119.50 – 120.15 mm (4.705 – 4.730 in)

Rocker Arm and Shaft

Rocker arm bore diameter (max)	40.080 mm (1.5780 in)
Rocker arm bore out of round (max)	0.03 mm (0.001 in)
Rocker arm shaft allowable wear	0.010 mm (0.0004 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 assembly maximum bore runout	0.15 mm (0.006 in)
Flywheel assembly maximum face runout	0.13 mm (0.005 in)
Flywheel assembly maximum pilot bearing bore runout	0.13 mm (0.005 in)
Flywheel assembly minimum thickness (dimension "A")	46 mm (1.811 in)
Flywheel housing maximum bore runout	See procedure (page 466)
Flywheel housing maximum face runout	0.38 mm (0.015 in)

Power Cylinders

Connecting Rods

Piston pin bore inside diameter	60.035 ± 0.008 mm (2.3635 ± 0.0003 in)
Connecting rod bearing bore diameter (crankshaft end)	103.2 ± 0.013 mm (4.0629 ± 0.0005 in)

Piston and Pin

Skirt diameter measured 78 mm from piston crown	137.065 + 0.015 mm (5.3962 ± 0.0005 in)
Piston protrusion measured from crankcase deck to piston	8.627 ± 0.208 mm (0.339 ± 0.008 in)
Piston pin bore inside diameter	60.085 – 60.105 mm (2.365 – 2.3663 in)
Piston pin running clearance	0.105 – 0.135 mm (0.0041 – 0.0053 in)
Piston pin outside diameter	59.975 ± 0.005 mm (2.3612 ± 0.0001 in)

Piston Rings

Top ring

Ring gap	0.35 ± 0.05 mm (0.0137 ± 0.0019 in)
Top compression ring groove width, measure over 3.4 mm (0.1338 in) gauge pins	135.561 – 135.798 mm (5.337 to 5.3463 in)

Intermediate ring

Ring gap	0.70 ± 0.10 mm (0.0275 ± 0.0039 in)
Side clearance	0.037 – 0.093 mm (0.0014 – 0.0036 in)*

Oil ring

Ring gap	0.45 ± 0.15 mm (0.0177 ± 0.0059 in)
Side clearance	0.027 – 0.073 mm (0.0010 – 0.0028 in)

Sleeve dimensions

Sleeve inside diameter	137.185 ± 0.025 mm (5.4009 ± 0.0009 in)
Sleeve projection	0.025 – 0.152 mm (0.0010 – 0.0060 in)
Maximum average variation between adjacent sleeves	0.051 mm (0.0020 in)
Maximum variation between all sleeves	0.102 mm (0.0040 in)
Maximum variation in each sleeve	0.051 mm (0.0020 in)

Crankcase and Crankshaft

Crankshaft Specifications
Main Bearing:

Crankshaft main bearing clearance	0.076 – 0.186 mm (0.0030 – 0.0073 in)
Main bearing free spread	130.79 – 131.79 mm (5.1492 – 5.1885 in)
Main bearing installed diameter	120.718 – 120.768 mm (4.7527 – 4.7463 in)

Crankshaft:

Crankshaft flange front face to crankshaft gear rear face gap	0.1 mm (0.0039 in) Max
Crankshaft gear dowel pin protrusion	3.6 – 4.6 mm (0.14 – 0.18)
Crankshaft rear dowel pin max protrusion	6.4 mm (0.25 in)
Crankshaft timing ring 5 x 10 hardened dowel pin protrusion	4.4 – 5.4 mm (0.173 – 0.212 in)
End play Maximum service	0.11 – 0.57 mm (0.0043 – 0.0224 in)
Journal diameter	120.630 – 120.670 mm (4.7492 – 4.7508 in)

Crankcase:

Dowel pin (15.88 X 31.8 mm solid) protrusion	36.8 – 37.8 mm (1.45 – 1.49 in)
Top crankcase (rear) dowel pin (9.55 X 31.8 mm solid) protrusion	18.0 – 19.0 mm (0.71 – 0.75 in)
Top crankcase dowel pin (6.35 X 30.2 mm solid) protrusion	15.5 – 16.5 mm (0.61 – 0.65 in)
Top crankcase (front) dowel pin (12.725 X 33 mm hollow) protrusion	19.5 – 20.5 mm (0.76 – 0.81 in)
Dowel pin protrusion (to flywheel housing)	18.6 – 19.6 mm (0.73 – 0.77 in)
Plug (front and rear of crankcase) depth	1.0 – 3.0 mm (0.04 – 0.12 in)

Table of Contents

General Torque.....	559
Bolt Identification.....	559
General Torque Guidelines.....	560
Standard Torque Charts.....	561
Using a Torque Wrench Extension.....	563
Special Torques.....	564
Mounting Engine on Stand.....	564
Engine Electrical.....	564
Cold Start Assist.....	564
Aftertreatment System.....	565
Turbochargers.....	565
Air Compressor and Power Steering.....	565
Fuel System.....	566
Exhaust Gas Recirculation (EGR) System.....	567
Oil Cooler, Filter Housing and Crankcase Ventilation.....	567
Air Inlet and Exhaust Manifolds.....	568
Front Cover, High Mount Fan Drive, Cooling System, Related Components.....	569
Engine Brake.....	570
Cylinder Head, Camshaft and Valve Train.....	570
Oil Pan, Oil Pickup Tube and Oil Pump.....	570
Flywheel and Flywheel Housing.....	571
Power Cylinders.....	571
Crankcase and Crankshaft.....	571

General Torque

Bolt Identification

INTERNATIONAL Class	ISO R 898 I	MATERIAL	THERMAL TREATMENT	HEAD MARKING	
				Preferred	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 819 Metric fasteners – Classification and identification

INTERNATIONAL designation	MATERIAL	THERMAL TREATMENT	HEAD MARKING	
			Preferred	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 820 Special fasteners – Classification and identification

General Torque Guidelines

CAUTION: To prevent engine damage, do not substitute fasteners. All original equipment fasteners are hardened and phosphate coated.

NOTE: Inspect parts for cleanliness and defects before assembly.

Many conditions affect torque and the results of torque applications. The major purpose in tightening a fastener to a specified torque is to obtain a clamping load which exceeds any possible loading imposed on parts.

New phosphate coated fasteners do not require oil lubrication during assembly and torque application. Reused fasteners (even if originally phosphate

coated) do require oil lubrication to threads and under head area for correct torque application.

Threads that are dry, excessively rough, battered, or filled with dirt require considerable effort just to rotate. Then when the clamping load is developed or the bolt tension is applied, the torque reading mounts rapidly (due to thread friction) to the specified torque value. However, the desired bolt tension and correct clamping load is not achieved. This condition can lead to failure of the fastener to maintain component integrity. The correct bolt tension and clamping effect can never be attained if the fastener is dry. Fastener threads must be new condition phosphate coated or have a film of clean lubricant (engine oil) to be considered lubricated.

Standard Torque Charts

CAUTION: To prevent engine damage, do not use this standard torque chart with other International brand engines or engines made by other manufacturers.

Standard torque chart provides tightening values for all hardware that do not require special torque.

Standard Torque Values – Class 10.9 Metric Flange Head Bolts and Studs

Thread Diameter (mm)	Thread Pitch (mm)	Torque
6	1	13 N·m (115 lbf·in)
8	1.25	31 N·m (23 lbf·ft)
10	1.5	62 N·m (45 lbf·ft)
12	1.75	107 N·m (79 lbf·ft)
14	2	172 N·m (127 lbf·ft)
15	2	216 N·m (159 lbf·ft)
16	2	266 N·m (196 lbf·ft)
18	2.5	368 N·m (272 lbf·ft)
20	2.5	520 N·m (384 lbf·ft)

Example: Tighten four M6 x 12 pulley bolts to standard torque. What is the size and standard torque for these four bolts?

M6 x 12 refers to the bolts thread diameter and length. These bolts have a thread diameter of 6 mm and are 12 mm long.

To find the standard torque for a M6 x 12 bolt look at the torque chart above. We see the standard torque for a 6 mm thread diameter class 10.9 bolt should be 13 N·m (115 lbf·in).

Standard Torque Values – Standard (SAE) Flange Head Bolts and Studs

Thread Diameter (mm)	Thread Pitch (in)	Torque
1/4	20	12 N·m (107 lbf·in)
1/4	28	14 N·m (123 lbf·in)
5/16	18	25 N·m (220 lbf·in)
3/8	16	47 N·m (35 lbf·ft)
7/16	14	70 N·m (50 lbf·ft)
1/2	13	105 N·m (75 lbf·ft)
9/16	12	160 N·m (120 lbf·ft)
5/8	11	215 N·m (160 lbf·ft)
3/4	10	370 N·m (275 lbf·ft)
7/8	9	620 N·m (460 lbf·ft)
1	8	900 N·m (660 lbf·ft)

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.

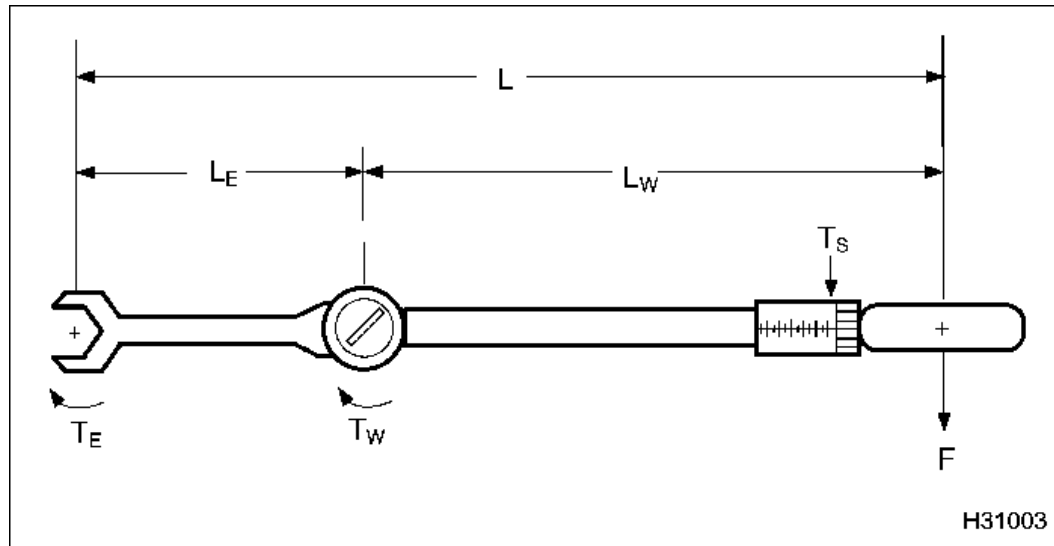


Figure 821 Torque wrench and extension

- F - Force applied by technician
- L - Total length through which force is applied to fastener
- T_W - Torque applied at end of torque wrench

$$T_s = T_E (L_W / (L_W + L_E))$$

- T_s - Torque wrench setting
- T_E - Torque specified at fastener
- L_W - Length of torque wrench
- L_E - Length of extension

Example: A component requires a specified torque value of 65 lbf·ft and a 6 inch extension is required to

reach it. What should the torque wrench setting (T_s) be to compensate for the extension?

- Torque specified at fastener (T_E) = 65 lbf·ft
- Length of torque wrench (L_W) = 12 inches
- Length of extension (L_E) = 6 inches

$$T_s = T_E (L_W / (L_W + L_E))$$

$$T_s = 65 \text{ lbf·ft} (12 \text{ inches} / (12 \text{ inches} + 6 \text{ inches}))$$

$$T_s = 65 \text{ lbf·ft} (12 \text{ inches} / (18 \text{ inches}))$$

$$T_s = 65 \text{ lbf·ft} (0.666)$$

$$T_s = 43.33 \text{ lbf·ft}$$

Special Torques

Mounting Engine on Stand

1-1/8 – 12 oil drain plugs	70 N·m (50 lbf·ft)
1 3/16–12 O-ring boss plug	135 N·m (100 lbf·ft)
1-5/16–12 oil drain plugs	90 N·m (65 lbf·ft)
M18 O-ring boss plugs	24 N·m (18 lbf·ft)
Plug assembly (coolant adapter)	23 N·m (17 lbf·ft)

Engine Electrical

4.8 x 13 self tapping screws	4 N·m (35 lbf·in)
Charge Air Cooler Outlet (CACOT) sensor	20 N·m (15 lbf·ft)
Crankcase Pressure (CCP) sensor	12 N·m (108 lbf·in)
Engine Oil Pressure (EOP) sensor	20 N·m (15 lbf·ft)
Engine Coolant Pressure 1 (ECP1) sensor	12 N·m (108 lbf·in)
Engine Coolant Temperature 1 (ECT1) sensor	20 N·m (15 lbf·ft)
Engine Coolant Temperature 2 (ECT2) sensor	20 N·m (15 lbf·ft)
Engine Oil Temperature (EOT) sensor	20 N·m (15 lbf·ft)
EGR Temperature (EGRT) sensor	20 N·m (15 lbf·ft)
Fuel Delivery Pressure (FDP) sensor	20 N·m (15 lbf·ft)
Fuel Rail Pressure (FRP) sensor	70 N·m (52 lbf·ft)
Intake Manifold Pressure (IMP) Sensor	20 N·m (15 lbf·ft)
Intake Manifold Temperature (IMT) sensor	20 N·m (15 lbf·ft)
M4 x 0.7 hex head cap screws	0.36 N·m (3 lbf·in)
Oxygen Sensor (O2S)	50 N·m (37 lbf·ft)

Cold Start Assist

CSFI locking nut	25 N·m (18 lbf·ft)
M6 x 12 hex flange bolts (CSFS)	6 N·m (53 lbf·in)
M6 x 20 hex flange bolts (CSR)	10 N·m (88 lbf·in)
M8 x 1 banjo bolt	8 N·m (71 lbf·in)
Solenoid to injector tube nut	8 N·m (71 lbf·in)
Size 6 banjo bolt	15 N·m (92 lbf·in)
Size 8 banjo bolt	15 N·m (92 lbf·in)

Aftertreatment System

M8 x 45 bolts (fuel doser)	Step 1: 11 N·m (8 lbf·ft)
	Step 2: 24 N·m (18 lbf·ft)
M10 x 20 hex bolts (PDOC support assembly)	62 N·m (45 lbf·ft)
M10 x 5/16 tube fitting	31 N·m (23 lbf·ft)
Clamp (PDOC)	31 N·m (23 lbf·ft)
Coolant supply tube fitting nuts	20 N·m (15 lbf·ft)
Doser coolant return tube assembly nut	20 N·m (15 lbf·ft)
Doser coolant supply tube assembly nuts	20 N·m (15 lbf·ft)
Doser fuel from valve tube nuts	24 N·m (18 lbf·ft)
Doser fuel to injector tube nuts	24 N·m (18 lbf·ft)
Injector unit feed tube fittings	20 N·m (15 lbf·ft)
Tube fitting (90 degree elbow) jam nut	20 N·m (15 lbf·ft)

Turbochargers

Air supply tube nut	25 N·m (18 lbf·ft)
EBP tube assembly nut	25 N·m (18 lbf·ft)
M10 x 55 hex bolts	47 N·m (35 lbf·ft)
M10 x M12 24 degree fitting	62 N·m (45 lbf·ft)
Oil supply tube nuts	31 N·m (23 lbf·ft)

Air Compressor and Power Steering

1/2–13 hex flange nuts (air compressor mounting)	115 N·m (77 lbf·ft)
Oil intake tube assembly fitting nuts	16 N·m (144 lbf·in)

Fuel System

3/8–16 x 7/8 hex head bolt (high-pressure pump support)	48 N·m (35 lbf·ft)
9/16–18 x 90 degree fitting lock nut	37 N·m (27 lbf·ft)
Fuel filter header assembly M10 x 35 hex flange bolts	55 N·m (41 lbf·ft)
Fuel return assembly tube nuts	29 N·m (21 lbf·ft)
Fuel rail hex head bolts	30 N·m (22 lbf·ft)
Fuel supply adapter	30 N·m (22 lbf·ft)
M12 x 30 hex flange bolt (high-pressure pump support)	105 N·m (77 lbf·ft)
M14 hex flange banjo bolt	30 N·m (22 lbf·ft)
M14 x 1.5 threaded unions	30 N·m (22 lbf·ft)
M16 x 1.5 quick connect connectors	58 N·m (43 lbf·ft)
M24 hex jam nut	285 N·m (210 lbf·ft)
Pressure limiting valve	110 N·m (81 lbf·ft)
Pump to rail fuel tube assembly clamp screws	5 N·m (44 lbf·in)
Pump to rail fuel line tube assembly nuts	22.5 N·m (16.5 lbf·ft) + 90°
Rail to injector tube assembly nuts	22.5 N·m (16.5 lbf·ft) + 90°

Exhaust Gas Recirculation (EGR) System

90 degree fitting assembly (on water pump outlet pipe)	58 N·m (43 lbf·ft)
Clamp (EGR supply hose)	4 N·m (2 lbf·ft)
EGRV coolant return tube nut	26 N·m (19 lbf·ft)
EGRV coolant supply tube nut	26 N·m (19 lbf·ft)
Fitting (45 degree on EGR valve)	35 N·m (26 lbf·ft)
1 3/16-12 x 1 1/4 inch hose elbow lock nut (90 degree on rear of oil cooler)	250 N·m (184 lbf·ft)
Hose fitting (on coolant adapter)	48 N·m (35 lbf·ft)
M8 x 27 high temp bolt	24 N·m (18 lbf·ft)
M8 hex flange lock nut	8.2 N·m (72 lbf·in)
M10 x 130 high temp bolt	48 N·m (35 lbf·ft)
M10 90 degree 3/8 hose fitting (nut)	8 N·m (71 lbf·in)
M14 37 degree flare fitting (90 degree) (on EGR valve)	35 N·m (26 lbf·ft)
M18 plug assembly	24 N·m (18 lbf·ft)
SAE 15/16 left clip clamp	Step 1: 5.8 N·m (51 lbf·in) Wait 5 seconds Step 2: 5.8 N·m (51 lbf·in)
SAE 24 clamp	Step 1: 8.3 N·m (73 lbf·in) Wait 5 seconds Step 2: 8.3 N·m (73 lbf·in)
SAE 24 left clip clamp	Step 1: 8.3 N·m (73 lbf·in) Wait 5 seconds Step 2: 8.3 N·m (73 lbf·in)

Oil Cooler, Filter Housing and Crankcase Ventilation

3/8–16 x 4 3/4 stud	35 N·m (26 lbf·ft)
3/8–16 x 5 1/8 taperlock stud	35 N·m (26 lbf·ft)
3/8–16 x 5 1/2 stud	35 N·m (26 lbf·ft)
3/8–16 x 6 1/2 taperlock stud	35 N·m (26 lbf·ft)
7/16–20 STR to 3/8 fitting	23 N·m (17 lbf·ft)
90 degree elbow assembly jam nut (oil filter base assembly)	28 N·m (20 lbf·ft)
O-ring boss plug (7/8–14)	100 N·m (74 lbf·ft)
O-ring boss plug (1 3/16–12)	100 N·m (74 lbf·ft)
O-ring boss plug (1 5/16–12)	100 N·m (74 lbf·ft)
Oil supply tube assembly nut	28 N·m (21 lbf·ft)

Air Inlet and Exhaust Manifolds

EGR supply hose clamp	4 N·m (35 lbf·in)
Intake throttle clamp	8 N·m (71 lbf·ft)
Ring seal clamps	See tightening steps in procedure (page 293)
3/8–16 hex flange lock nuts	See tightening steps in procedure (page 293)
3/8–16 x 2.3 taperlock stud	35 N·m (26 lbf·ft)
3/8–16 x 3–1/2 hex head bolts	48 N·m (35 lbf·ft)
3/8–16 x 4 taperlock studs	35 N·m (26 lbf·ft)

Front Cover, High Mount Fan Drive, Cooling System, Related Components

1/2–13 hex nuts (fan bracket)	79 N·m (58 lbf·ft)
3/8–24 hex nuts (fan)	35 N·m (26 lbf·ft)
3/8–16 x 1.75 hex bolts	66 N·m (49 lbf·ft)
7/8–14 plug assembly	50 N·m (37 lbf·ft)
56-teeth gear support assembly bolt	56 N·m (41 lbf·ft)
56-teeth gear support assembly nuts	56 N·m (41 lbf·ft)
71-teeth gear support assembly bolt	56 N·m (41 lbf·ft)
71-teeth gear support assembly nuts	56 N·m (41 lbf·ft)
105 & 63 teeth gears support bolts	See tightening steps in procedure (page 325)
Camshaft cover studs	18 N·m (25 lbf·ft)
Camshaft gear assembly 5/8-11 x 3 (12 point) bolts	240 N·m (175 lbf·ft)
Coolant connector (1 1/2–11)	145 N·m (107 lbf·ft)
Front engine mount support bolts	100 N·m (74 lbf·ft)
Front cover plate 3/8-16 x 1 thread locking hex flange bolts	See tightening steps in procedure (page 325)
Idler pulleys (grooved)	50 N·m (37 lbf·ft)
Idler pulleys (flat)	50 N·m (37 lbf·ft)
Hose fitting assembly (3/4–14)	50 N·m (37 lbf·ft)
Hose fittings (9/16–16)	18 N·m (13 lbf·ft)
Hose fitting (1 1/4–11)	104 N·m (77 lbf·ft)
M8 hex flange nuts (fan clutch)	30 N·m (22 lbf·ft)
M10 x 70 counter sunk screw (lower tensioner)	41 N·m (30 lbf·ft)
M10 x 90 hex flange bolt (belt tensioner)	50 N·m (37 lbf·ft)
Nut assembly (fan pulley)	176 N·m (130 lbf·ft)
O-ring boss plug (3/4–16)	50 N·m (37 lbf·ft)
O-ring boss plug assembly (9/16–16)	18 N·m (13 lbf·ft)
Plug (flywheel locking port)	23 N·m (17 lbf·ft)

Engine Brake

1/4–20 x 1 1/2 bolt	15 N·m (11 lbf·ft)
1/2–13 hex flange nut	See sequence in procedure (page 364) 105 N·m (77 lbf·ft)
1/2–13 x 2.2 taperlock stud	65 N·m (48 lbf·ft)
1/2–13 x 5.65 hex bolt	See sequence in procedure (page 364) 105 N·m (77 lbf·ft)
3/8–16 hex nut	See sequence in procedure (page 364) 47 N·m (35 lbf·ft)
Plug (flywheel locking port)	23 N·m (17 lbf·ft)
Slave piston lash adjuster jam nut	15 N·m (11 lbf·ft)
Spacer assembly	47 N·m (35 lbf·ft)

Cylinder Head, Camshaft and Valve Train

Cylinder head bolts	See tightening steps in procedure (page 410)
Engine brake rocker arm adjustment nuts	100 N·m (74 lbf·ft)
High-pressure connector retaining nuts	See tightening steps in procedure (page 418)
Injector harness nuts	1.5 N·m (13 lbf·in)
Injector hold down clamp hex bolts	See tightening steps in procedure (page 417)
O-ring boss plug (9/16–18)	35 N·m (26 lbf·ft)
O-ring boss plug (3/4–16)	60 N·m (44 lbf·ft)
O-ring boss plug (7/8–14)	115 N·m (85 lbf·ft)
Rear camshaft cover Torx screws	13 N·m (10 lbf·ft)
Rocker arm shaft hex flange studs	See tightening steps in procedure (page 416)
Valve cover 5/16 - 18 studs with grommet elements	25 N·m (18 lbf·ft)
Valve rocker arm adjustment nuts	38 N·m (28 lbf·ft)

Oil Pan, Oil Pickup Tube and Oil Pump

1 1/8–12 oil drain plugs	70 N·m (50 lbf·ft)
1 5/16–12 oil drain plugs	90 N·m (65 lbf·ft)
3/8–16 x 1 3/4 hex bolt (oil pump gear)	56 N·m (41 lbf·ft)
3/8–16 x 2 x 3/4 stud bolts (oil pan)	See special torque and sequence (page 447)

Flywheel and Flywheel Housing

Flywheel housing bolts	See tightening steps in procedure (page 469)	
3/4 x 2 hex head bolts (rear engine mount)		135 N·m (100 lbf·ft)
5/16–18 x 1.75 hex bolts (flywheel assembly)		270 N·m (200 lbf·ft)

Power Cylinders

M11 x 84 12 point bolts (connecting rod bolts)	Initial	70 ± 4 N·m (52 ± 3 lbf·ft)
	Final	additional 60° (1/6 turn)
Cylinder sleeve projection hold-down bolts		Step 1: Tighten all to 95 N·m (70 lbf·ft)
		Step 2: Retighten all to 95 N·m (70 lbf·ft)

Crankcase and Crankshaft

Main bearing cap 7/8–14 x 7.75 hex flange bolts	See tightening procedure and sequence (page 525)	
Piston cooling jet bolts		40 N·m (30 lbf·ft)
Hose fitting (3/4–16)		60 N·m (44 lbf·ft)
O-ring boss plug (7/16 – 20)		23 N·m (17 lbf·ft)
O-ring boss plugs (3/4–14)		60 N·m (44 lbf·ft)
O-ring boss plug (7/8–14)		115 N·m (85 lbf·ft)
O-ring boss plug assembly (1-5/8 – 12)		290 N·m (214 lbf·ft)

Table of Contents

Special Tools.....	575
Mounting Engine on Stand.....	575
Engine Electrical.....	575
Aftertreatment System.....	575
Turbochargers.....	575
Fuel System.....	576
Exhaust Gas Recirculation (EGR) System.....	576
Oil Cooler, Filter Housing and Crankcase Ventilation.....	576
Air Inlet and Exhaust Manifolds.....	576
Front Cover, High Mount Fan Drive, Cooling System, and Related Components.....	577
Engine Brake.....	577
Cylinder Head, Camshaft and Valve Train.....	578
Oil Pan , Oil Suction Tube and Oil Pump.....	579
Flywheel and Flywheel Housing.....	579
Power Cylinders.....	579
Crankcase and Crankshaft.....	580
Special Tools	581
Essential Tools.....	581

Special Tools

For concerns or ordering information regarding special tools for the MaxxForce® 15 engine, refer to the Service Resource Center on ISIS®, or call 1-800-365-0088.

Mounting Engine on Stand

Description	Tool Number
Disposable Air and Fuel Caps	ZTSE4891
Engine Adapter Mounting Plate	OTC205060
Universal Adapter Plates	OTC205061

Engine Electrical

Description	Tool Number
Disposable Air and Fuel Caps	ZTSE4891
P-80® Rubber Lubricant or equivalent	Obtain locally

Aftertreatment System

Description	Tool Number
Fuel Line Disconnect Tool	ZTSE4773

Turbochargers

Description	Tool Number
Charge Air Cooler Tester Kit	ZTSE6042
Interstage Cooler Pipe to High-Pressure Turbo Extension Tube Seal Installer	ZTSE6057
P-80 ® Rubber Lubricant or equivalent	Obtain locally
Turbocharger Lifting Bracket	ZTSE6104

Fuel System

Description	Tool Number
90 W Gear Oil	Obtain locally
Disposable Air and Fuel Caps	ZTSE4891
Fuel Line Disconnect Tool	ZTSE4773
Fuel Line Socket	Snap-on FRX241
	Obtain locally
H-bar puller	Obtain locally
High-pressure pump alignment studs	ZTSE6099
Loctite® 242	Obtain locally

Exhaust Gas Recirculation (EGR) System

Description	Tool Number
Air Pressure Regulator	Obtain locally
Alignment Pins	ZTSE4945 1–2
EGR Cooler Pressure Test Kit	ZTSE6090
EGR Cooler Lifting Tool	ZTSE6105
P-80® Rubber Lubricant or equivalent	Obtain locally

Oil Cooler, Filter Housing and Crankcase Ventilation

Description	Tool Number
5/8 hex key	Obtain locally
Oil Cooler Test Kit (includes two test plugs)	ZTSE6092
Oil filter removal tool	Obtain locally
P-80® Rubber Lubricant or equivalent	Obtain locally

Air Inlet and Exhaust Manifolds

Description	Tool Number
Alignment Stud (engine throttle valve assembly)	ZTSE6109
Feeler gauge (0.24 mm (0.01 in)	Obtain locally
P-80® rubber lubricant or equivalent	Obtain locally

Front Cover, High Mount Fan Drive, Cooling System, and Related Components

Description	Tool Number
90 weight gear oil	Obtain locally
100 °C (212 °F) thermo-melt crayon	Obtain locally
Abrasive cutting disk	Obtain locally
Dial indicator and bracket	Obtain locally
Engine Rotation Tool	ZTSE6112
Front and Rear Crankshaft Seal Installer	ZTSE6119
Idler Assembly Adjuster	ZTSE6116
Infrared thermometer (thermo gun)	Obtain locally
Heat insulated gloves	Obtain locally
Hot plate	Obtain locally
Loctite® 242	Obtain locally
P-80® rubber lubricant or equivalent	Obtain locally
Propane torch	Obtain locally
Rubber mallet	Obtain locally
Slide Hammer Kit	ZTSE1879
Timing Pin	ZTSE6108

Engine Brake

Description	Tool Number
5/32 hex key wrench	Obtain locally
Engine Rotation Tool	ZTSE6112
Lash gauge 0.686 mm (0.027 in.)	Obtain locally
Timing Pin	ZTSE6108

Cylinder Head, Camshaft and Valve Train

Description	Tool Number
1–2 inch Micrometer	Obtain locally
2–3 inch Micrometer	Obtain locally
3–4 inch Micrometer	Obtain locally
3/4 inch 12 point socket	Obtain locally
6–7 inch Micrometer	Obtain locally
Camshaft Remover/Installer	ZTSE6103
Cam Bushing Installer (used for both installation and removal)	ZTSE6113
Cylinder Head Lifting Brackets	ZTSE6106
Dye penetrant kit	Obtain locally
Disposable Air and Fuel Caps	ZTSE4891
Engine Rotation Tool	ZTSE6112
Feeler gauge set	Obtain locally
Fuel Injector Tip Cleaning Brush	ZTSE4301
Fuel Injector Cups and Rack	ZTSE4299B
Head and Main Bolt Bottoming Tap Kit (3/4 x 16 and 7/8 x 14 taps)	ZTSE6117
High-Pressure Connector Installer/Remover	ZTSE6115
Injector Removal Kit	ZTSE6102
Injector Sleeve Brushes	ZTSE4751
Lash Gauge	ZTSE6076–7
Loctite® 120541 Core Plug Sealant	Obtain locally
Loctite® 242	Obtain locally
Molykote paste lubricant 6V-4876	Obtain locally
P-80® lubricant	Obtain locally
Pressure regulator	Obtain locally
Rocker Arm Lifting Bracket Assembly	ZTSE6122
Slide Hammer Kit	ZTSE1879
Straight edge	Obtain locally
Telescoping gauge set	Obtain locally
Timing Pin	ZTSE6108
V-bolcks	Obtain locally

Oil Pan , Oil Suction Tube and Oil Pump

Description	Tool Number
Wacker A-442 RTV sealer	Obtain locally

Flywheel and Flywheel Housing

Description	Tool Number
Dial indicator	Obtain locally
Dial indicator universal attachment	Obtain locally
Front and Rear Crankshaft Seal Installer Kit	ZTSE6119
Guide pin	Obtain locally
Micrometer	Obtain locally
Moly paste thread lubricant	Obtain locally
Rubber mallet	Obtain locally
Silicone Sealant	Wacker T-442 RTV
Slide Hammer Kit	ZTSE1879

Power Cylinders

Description	Tool Number
2–3 inch micrometer	Obtain locally
3–4 inch micrometer	Obtain locally
4–5 inch micrometer	Obtain locally
12 Point 14 mm socket	Obtain locally
Cylinder Sleeve Puller	ZTSE2536
Dial bore gauge	Obtain locally
Dial Indicator with Base	Part of ZTSE2515A
Feeler gauge	Obtain locally
P-80® Rubber lubricant or equivalent	Obtain locally
Piston Cope (ring compressor)	ZTSE6118
Piston ring expansion pliers	Obtain locally
Telescoping gauge set	Obtain locally

Crankcase and Crankshaft

Description	Tool Number
1/2 x 20 in. tap	Obtain locally
29/64 th drill bit	Obtain locally
3–4 inch micrometer	Obtain locally
4–5 inch micrometer	Obtain locally
5–6 inch micrometer	Obtain locally
Dial bore gauge	Obtain locally
Dial indicator with magnetic base	Obtain locally
Gear remover	Obtain locally
Head and Main Bolt Bottoming Tap Kit (3/4 x 16 and 7/8 x 14 taps)	ZTSE6117
Heat insulated gloves	Obtain locally
Heavy duty strap	Obtain locally
Hot plate	Obtain locally
Infrared thermometer (thermo gun)	Obtain locally
Loctite® 609	Obtain locally
Plastigage®	Obtain locally
P-80® Rubber lubricant or equivalent	Obtain locally
Slide Hammer Kit	ZTSE1879

Special Tools

Essential Tools

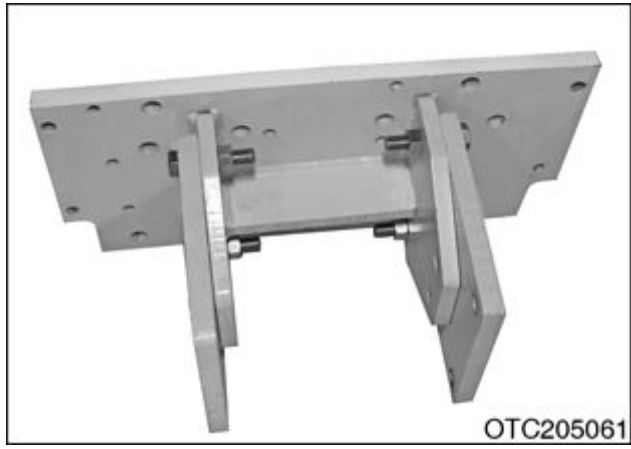


Figure 822 OTC205060 Engine Adapter Mounting Plate and OTC205061 Universal Adapter Plates

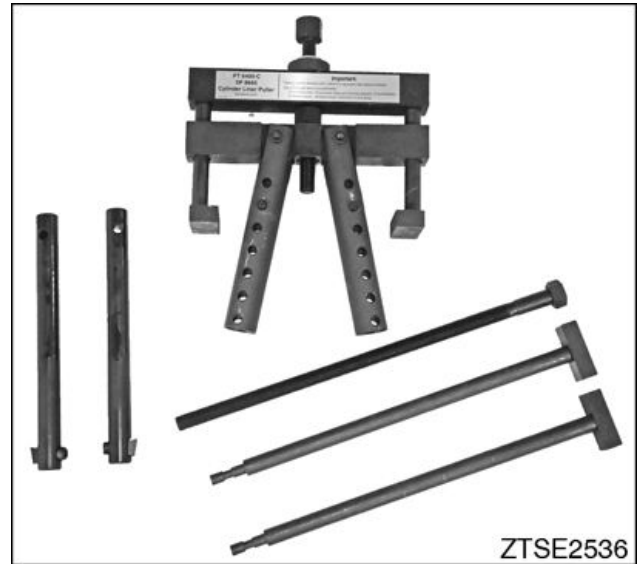


Figure 824 ZTSE2536 Cylinder Sleeve Puller

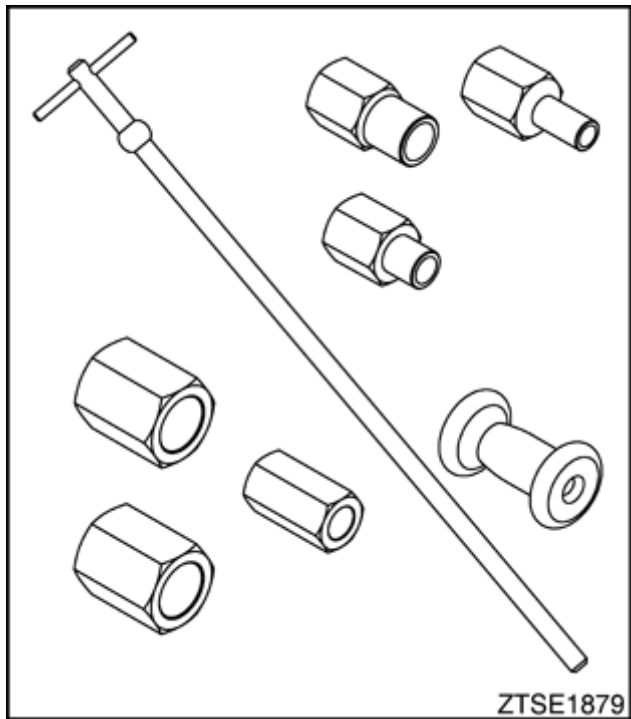


Figure 823 ZTSE1879 Slide Hammer Kit



Figure 825 ZTSE4299B Fuel Injector Cups and Rack

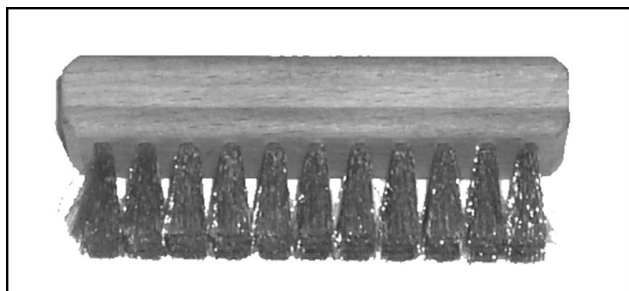


Figure 826 ZTSE4301 Fuel Injector Tip Cleaning Brush

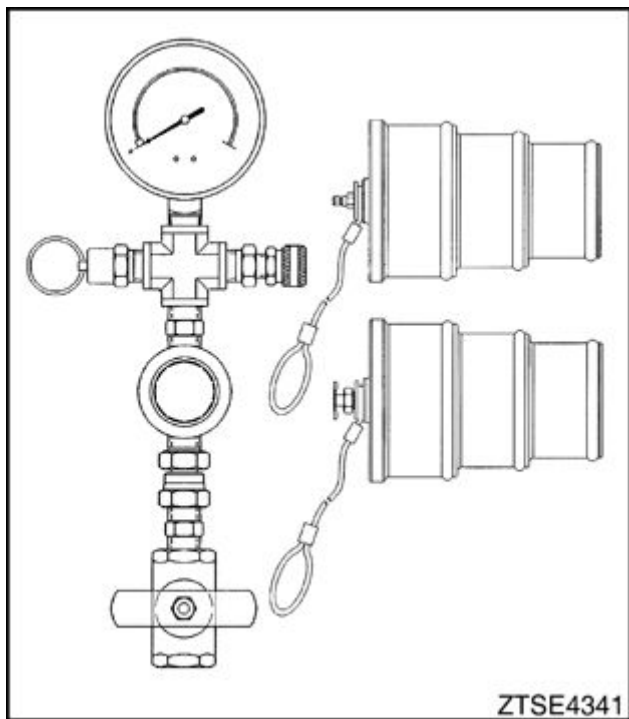


Figure 827 ZTSE4341 Charge Air Cooler Test Kit

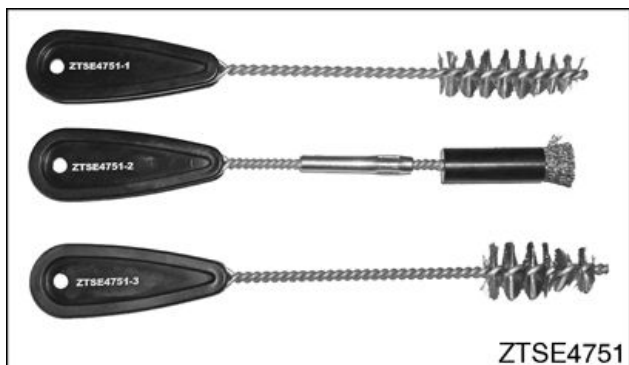


Figure 828 ZTSE4751 Injector Sleeve Brushes

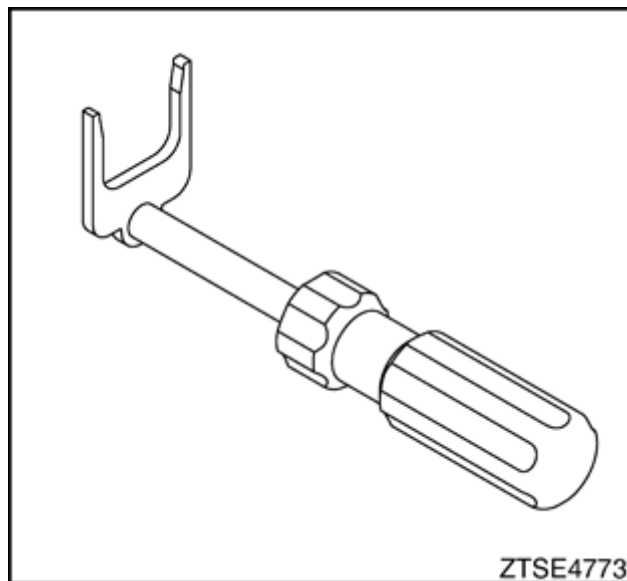


Figure 829 ZTSE4773 Fuel Line Disconnect Tool

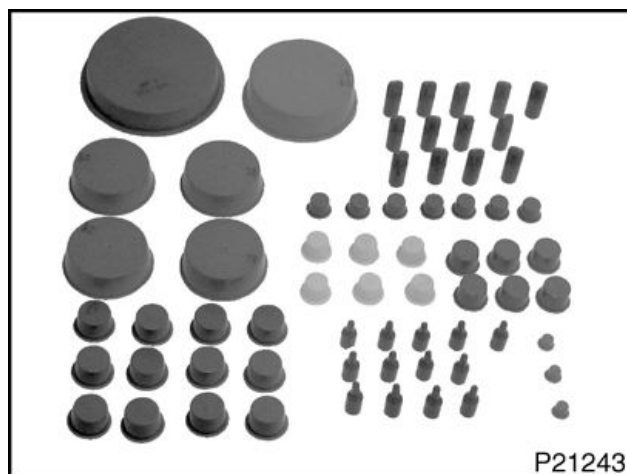


Figure 830 ZTSE4891 Disposable Air and Fuel Caps



Figure 831 ZTSE4945 1-2 Alignment Pins



Figure 832 ZTSE6057 Interstage Cooler Pipe to High-Pressure Turbo Extension Tube Seal Installer

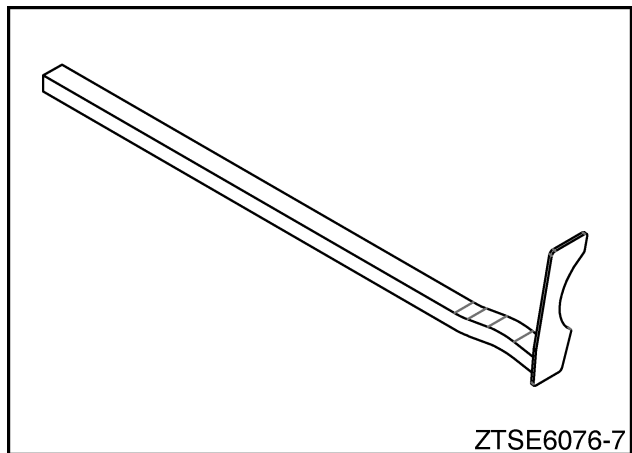


Figure 833 ZTSE6076-7 Lash Gauge

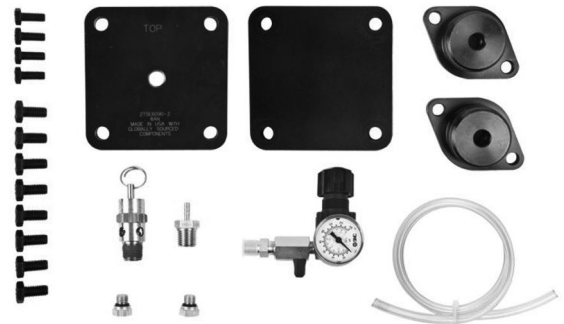


Figure 834 ZTSE6090 EGR Cooler Pressure Test Kit

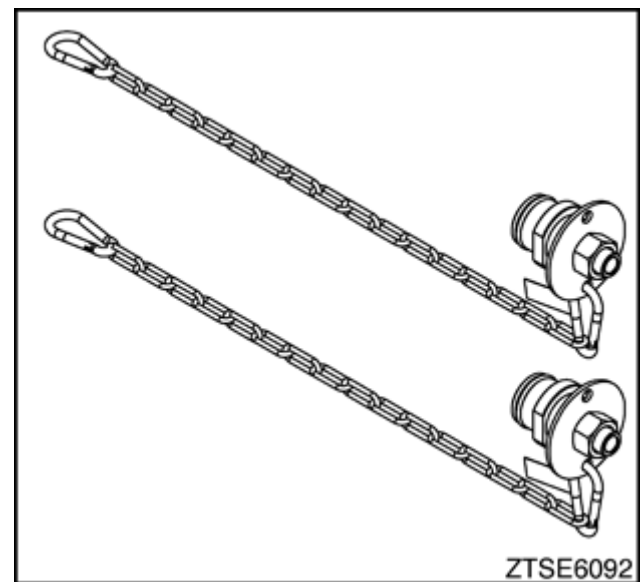


Figure 835 ZTSE6092 Oil Cooler Test Plugs



Figure 836 ZTSE6095 Injector Cup Remover



Figure 837 ZTSE6099 High-Pressure Pump Alignment Studs

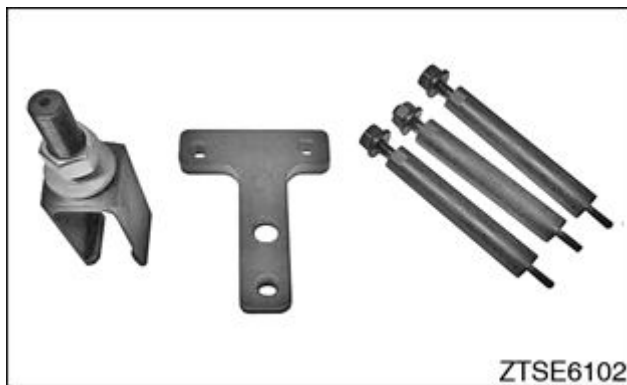


Figure 838 ZTSE6102 Injector Removal Kit

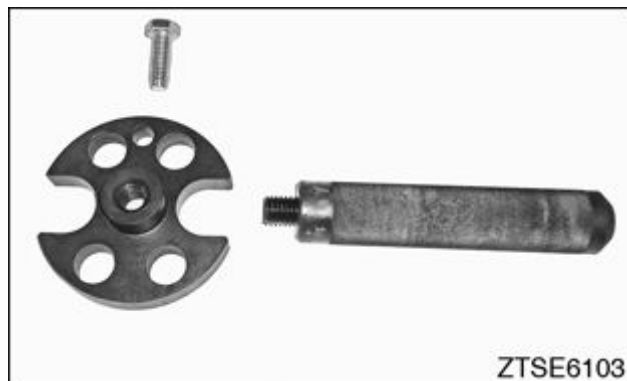


Figure 839 ZTSE6103 Camshaft Remover and Installer



Figure 840 ZTSE6104 Turbocharger Lifting Bracket

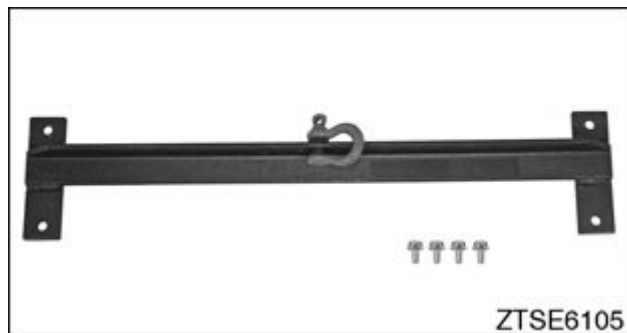


Figure 841 ZTSE6105 EGR Cooler Lifting Tool

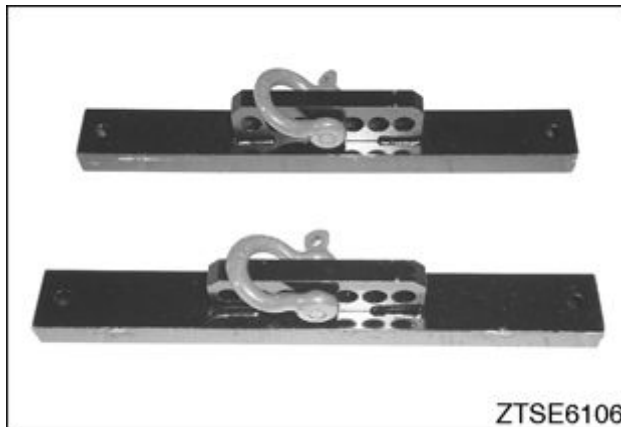


Figure 842 ZTSE6106 Cylinder Head Lifting Bracket



Figure 845 ZTSE6112 Engine Rotation Tool



Figure 843 ZTSE6108 Timing Pin

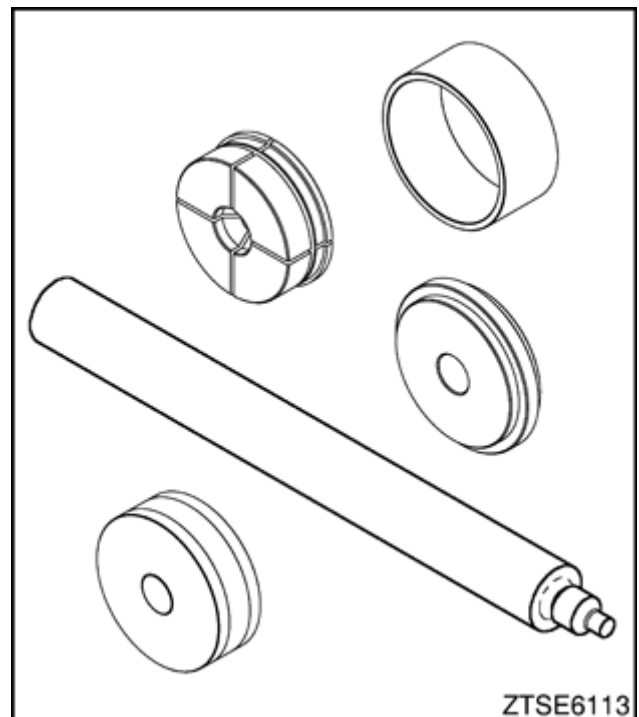


Figure 846 ZTSE6113 Cam Bushing Installer



Figure 844 ZTSE6109 Alignment Stud (engine throttle valve assembly)

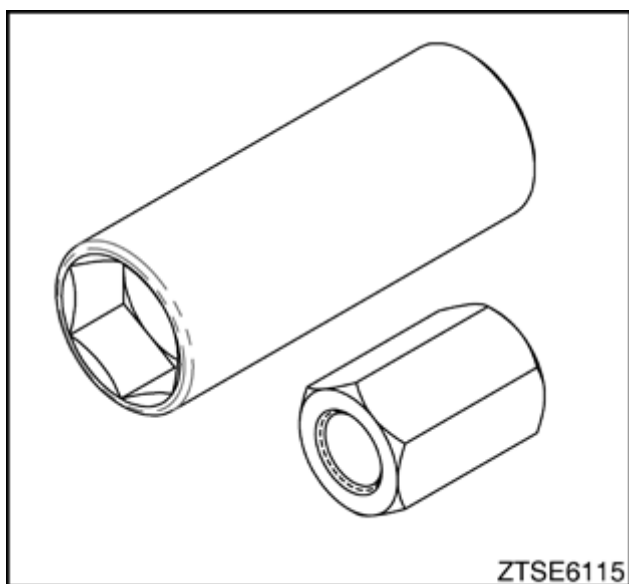


Figure 847 ZTSE6115 High-Pressure Connector Installer/Remover

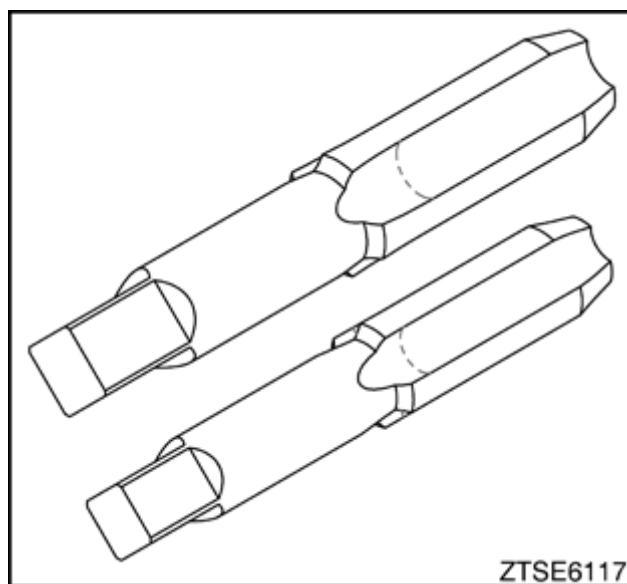


Figure 849 ZTSE6117 Head and Main Bolt Bottoming Tap Kit

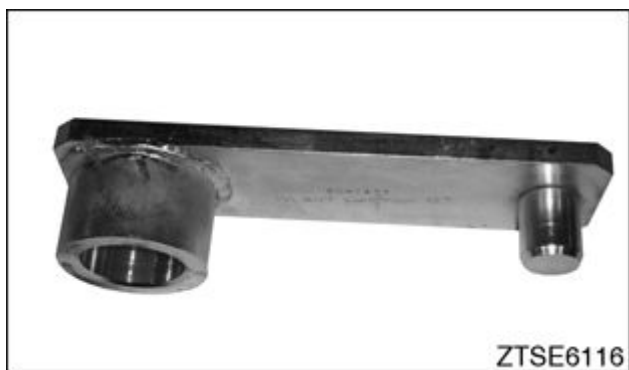


Figure 848 ZTSE6116 Idler Assembly Adjuster



Figure 850 ZTSE6118 Piston Cope (ring compressor)
