

SERVICE MANUAL

INTERNATIONAL® VT 365

DIESEL ENGINE

2004-2006 Model Years

EGES-295-2

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Foreword

International Truck and Engine Corporation 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.

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

This manual includes necessary information and specifications for technicians to maintain International® diesel engines. See vehicle manuals and Technical Service Information (TSI) bulletins for additional information.

Technical Service Literature

1171814R2	<i>VT 365 Engine Operation and Maintenance Manual</i>
EGES-295-2	<i>VT 365 Engine Service Manual</i>
EGES-240	<i>VT 365 Engine Diagnostic Manual</i>
EGED-245	VT 365 Hard Start and No Start Diagnostic Form
EGED-250	VT 365 Performance Diagnostics Form
EGED-320-1	VT 365 Electronic Control System Diagnostic Form
CGE-575	Engine Diagnostic Trouble Codes

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: The following order information is for technical service literature only.

International Truck and Engine Corporation

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Service Diagnosis

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

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

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

Prerequisites for Effective Diagnosis

- Availability of gauges and diagnostic test equipment
- Availability of current information for engine application and engine systems
- Knowledge of the principles of operation for engine application and engine systems
- Knowledge to understand and do procedures in diagnostic and service publications

Technical Service Literature required for Effective Diagnosis

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

Safety Information

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

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

Disregard for Safety Instructions, Warnings, Cautions, and Notes in this manual can lead to injury, death or damage to the engine or vehicle.

SAFETY TERMINOLOGY

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

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

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

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

SAFETY INSTRUCTIONS

Vehicle

- Make sure the vehicle is in neutral, the parking brake is set, and the wheels are blocked before doing any work or diagnostic procedures on the engine or vehicle.

Work area

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

Safety equipment

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

Protective measures

- Wear protective glasses and safety shoes.

- Wear appropriate hearing protection.
- Wear correct work clothing.
- Do not wear rings, watches, or other jewelry.
- Restrain long hair.

Fire prevention

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

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

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

Batteries

Batteries produce highly flammable gas during and after charging.

- Always disconnect the main negative battery cable first.
- Always connect the main negative battery cable last.
- Avoid leaning over batteries.
- Protect your eyes.
- Do not expose batteries to open flames or sparks.
- Do not smoke in workplace.

Compressed air

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

Tools

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

- Check for frayed power cords before using power tools.

Fluids under pressure

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

Fuel

- Do not over fill the fuel tank. Over fill creates a fire hazard.

- Do not smoke in the work area.
- Do not refuel the tank when the engine is running.

Removal of tools, parts, and equipment

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

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Engine Identification

Engine Serial Number

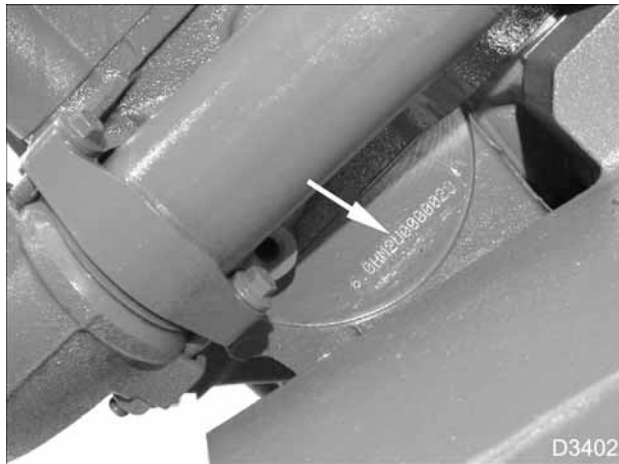


Figure 1 Engine serial number

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

The engine serial number is also on an identification sticker on the valve cover.

Engine serial number examples

6.0HM2Y0000500

6.0HA2U0000508

Engine serial number codes

6.0 – Engine displacement

H – Diesel, turbocharged, Charge Air Cooled, and electronically controlled

M2 – Truck

A2 – Service

U – USA

Y – USA Huntsville

7 digit suffix – Engine serial number sequence

Emission Labels (2004 and 2005 Model Years)

Two emission labels are on the right valve cover:

- 50 – State Exhaust Emissions Label
- U.S. Federal Family Emission Limits Label

 2004 VT 365 ENGINE FAMILY 4NVXH0365AEB		CURB IDLE, FUEL RATE @ ADVERTISED POWER, AND INJECTION TIMING ARE NON-ADJUSTABLE.
EMISSION CONTROL INFORMATION ENGINE MANUFACTURED BY: INTERNATIONAL TRUCK AND ENGINE CORPORATION		EM CONTROL SYSTEM: -ECM, TC, CAC, DI, OC, EGR
INTERNATIONAL®		DISPLACEMENT: 6.0L
THIS ENGINE HAS A PRIMARY INTENDED SERVICE APPLICATION AS A LIGHT HEAVY-DUTY DIESEL ENGINE AND CONFORMS TO U.S. EPA, CALIFORNIA, CANADIAN, AND AUSTRALIAN ADR-30 REGULATIONS FOR 2004 MODEL YEAR AND IS CERTIFIED TO OPERATE ON DIESEL FUEL.		1844849C1
MODEL	ADV. BHP@RPM	LB-FT TORQUE@RPM
A175 ()	175 @ 2600	460 @ 1400
A200 ()	200 @ 2600	520 @ 1400
A215 ()	215 @ 2600	540 @ 1400
A230 ()	230 @ 2600	620 @ 1500

D3410A

Figure 2 50 – State Exhaust Emissions Label (example)

The 50 – State Exhaust Emissions Label includes the following:

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

 INTERNATIONAL® VT365 ENGINE	U.S. FED. FAMILY EMISSION LIMITS	
	NMHC+NOx	PART.
FAMILY 4NVXH0365AEB	2.8	–
1845586C1		

D3406a

Figure 3 U.S. Federal Family Emission Limits label (example)

The U.S. Federal Family Emission Limits Label identifies the engine family and emission limits established by the manufacturer and certified by the EPA.

Emission Label (2006) Model Year

One emission label is on the right valve cover.

 2006 VT 365 ENGINE FAMILY GNV XH0365AEC EMISSION CONTROL INFORMATION ENGINE MANUFACTURED BY: INTERNATIONAL TRUCK AND ENGINE CORPORATION INTERNATIONAL®			CURB IDLE, FUEL RATE @ ADVERTISED POWER, AND INJECTION TIMING ARE NON-ADJUSTABLE. EM CONTROL SYSTEM: -ECM, TC, CAC, DI, OC, EGR DISPLACEMENT: 6.0L		
THIS ENGINE HAS A PRIMARY INTENDED SERVICE APPLICATION AS A LIGHT HEAVY-DUTY DIESEL ENGINE AND CONFORMS TO U.S. EPA, CALIFORNIA, CANADIAN AND AUSTRALIAN ADR-30 REGULATIONS FOR 2006 MODEL YEAR AND IS CERTIFIED TO OPERATE ON DIESEL FUEL 1872922C1					
MODEL	ADV. BHP@RPM	LB-FT TORQUE@RPM			
A175 ()	175 @ 2600	460 @ 1400			
A200 ()	200 @ 2600	520 @ 1400			
A215 ()	215 @ 2600	540 @ 1400			
A230 ()	230 @ 2600	620 @ 1400			
A230HT ()	230 @ 2600	620 @ 1500			

D3413

Figure 4 50 – State Exhaust Emissions Label (example)

The 50 – State Exhaust Emissions Label includes the following:

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

Engine accessories

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

- Air compressor (for brake or suspension system)
- Air conditioning compressor
- Alternator
- Cooling fan clutch
- Variable Geometry Turbocharger (VGT)
- Power steering / fuel pump
- Starter motor

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

Engine Description

Table 1 Engine Features and Specifications

International® VT 365 engine features and specifications

Engine	Diesel, 4 cycle
Configuration	4 OHV/1 Cam-in-Crankcase-V8
Displacement	365 cu. in (6.0L)
Bore and stroke	95 mm x 105 mm (3.74 in x 4.134 in)
Compression ratio	18.0:1
Aspiration	VGT turbocharged and Charge Air Cooling (CAC)
Rated power @ rpm ¹	175 bhp @ 2600 rpm
Peak torque @ rpm ¹	460 lbf•ft @ 1400 rpm
Engine rotation, facing flywheel	Counterclockwise
Combustion system	Digital Direct Injection (DDI)
Total engine weight (auto with oil)	459 kg (1094 lb)
Cooling system capacity (engine only)	10.2 liters (10.8 qts)
Lube system capacity (including filter)	18 liters (19 qts)
Lube system capacity (dry)	21.8 liters (23 qts)
Firing order	1–2–7–3–4–5–6–8

¹ Base rating shown. See Appendix A for other ratings.

Major features

Air Management System (AMS)

- Variable Geometry Turbocharger (VGT)
- Exhaust Gas Recirculation (EGR) system
- Chassis mounted Charge Air Cooling (CAC)

Digital Direct fuel Injection (DDI)

Two piece crankcase

One piece cylinder head with four valves per cylinder

Dual timing

Rear gear train

Closed crankcase ventilation

Oil cooler

The firing order is 1-2-7-3-4-5-6-8. When viewing the engine from the rear (flywheel end), the right side cylinders are numbered 1, 3, 5, and 7. Number one is the front position. The left side is numbered 2, 4, 6, and 8.

A two piece crankcase has been specially designed to withstand the loads of diesel operation. The lower crankcase has integral main bearing caps. Coolant and oil passages are cast and machined in the crankcase and front cover housing.

The crankshaft has five main bearings with fore and aft thrust controlled at the upper half of the number 4 main bearing. Two connecting rods are attached to each crankshaft journal. The piston pin moves freely inside the piston and rod. Piston pin retaining rings secure the piston pin within the piston.

One piece aluminum alloy pistons are fitted with one keystone cut compression ring, one rectangular intermediate compression ring, and a two piece oil control ring. The combustion bowl (in the piston crown) reduces exhaust emissions.

The camshaft is supported by five insert bushings pressed into the crankcase. Two cam lobes, cam followers, push rods and valve bridges control four valves per cylinder. The camshaft is gear driven from the rear end of the crankshaft. A thrust flange is located between the camshaft gear and the crankcase. Camshaft thrust is controlled with the rear surface of the number 5 cam journal and the cam gear.

Hydraulic cam followers maintain zero valve lash and minimize engine noise. This eliminates periodic adjustment of valve lash. The hydraulic cam followers have rollers which provide excellent cam lobe and cam follower durability.

The lubrication system uses a crankshaft driven gerotor pump mounted on the front cover. The oil pressure regulator is built into the front cover and is accessible from outside the engine. Lube oil is routed through an oil cooler equipped with a pressure controlled bypass valve. Lube oil moves through passages in the crankcase to lubricate all internal components and to supply the piston cooling tubes and high pressure pump reservoir. The VGT and air compressor use external oil lines.

The VGT is electronically controlled and hydraulically actuated. The VGT provides boost control at low and high speeds for improved throttle response.

An exhaust gas recirculation valve allows water cooled exhaust gases to be fed into the inlet air stream to reduce exhaust emissions.

A closed crankcase breather system recirculates crankcase vapors back into the intake air system.

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

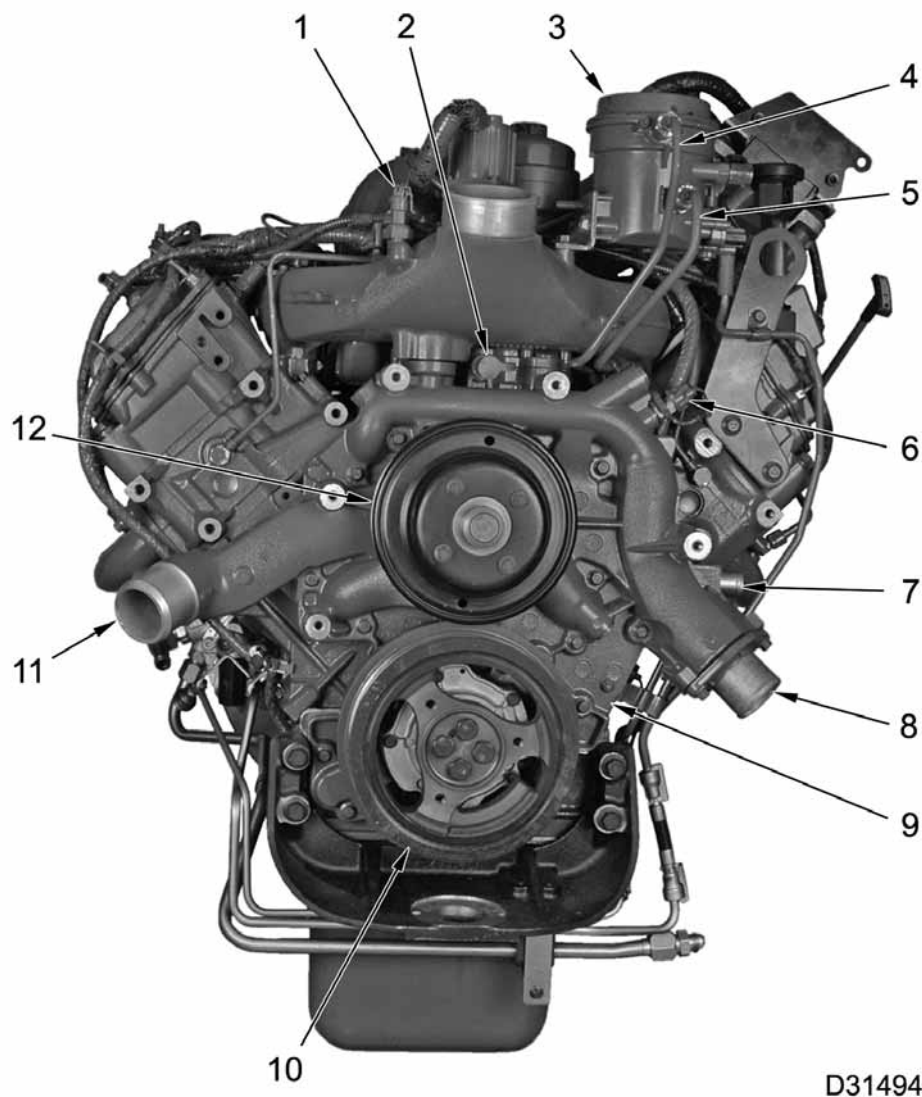
Engine operation is controlled by two engine mounted control modules:

- Electronic Control Module (ECM)
- Injector Drive Module (IDM)

The ECM receives signals from engine and chassis mounted sensors. The ECM controls engine operation with the following actuators:

- IPR
- VGT control valve
- EGR
- Glow plug relay

The IDM controls fuel injector operation using data from the ECM.

Engine Component Locations

D31494

Figure 5 Engine components – Front

1. Manifold Absolute Pressure (MAP) sensor	5. Fuel supply	9. Front cover assembly
2. Lube oil pressure test port	6. Engine Coolant Temperature (ECT) sensor	10. Crankshaft vibration damper
3. Fuel filter assembly	7. Port for coolant deaeration tank	11. Coolant inlet
4. Fuel return	8. Coolant outlet and thermostat	12. Water pump pulley

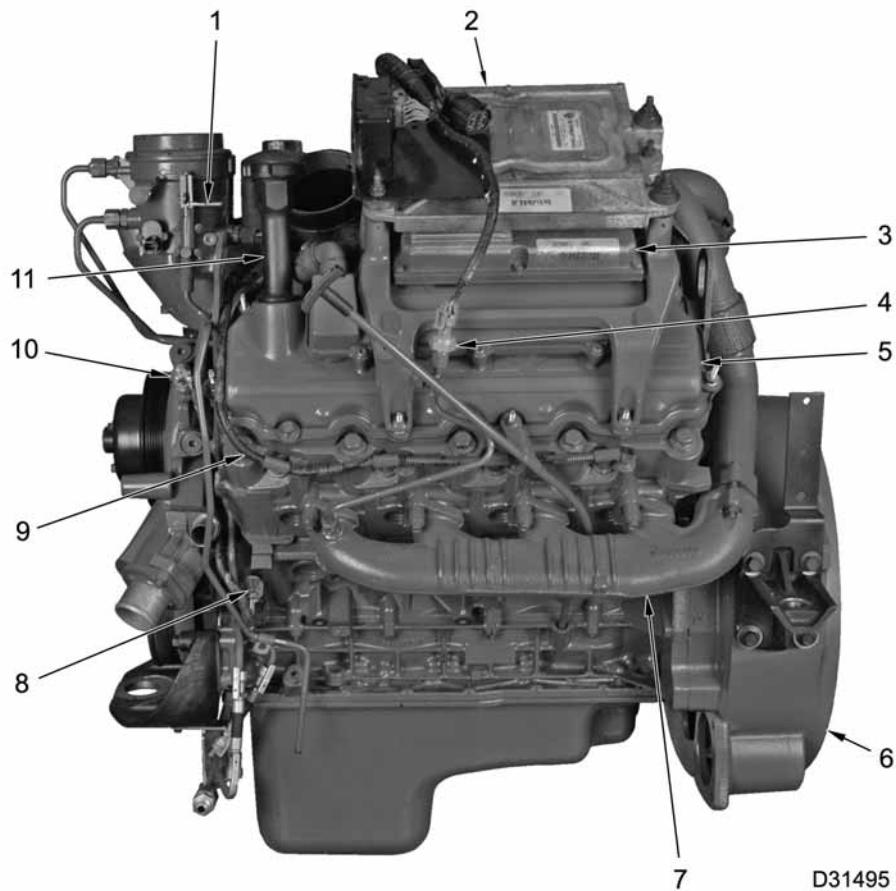
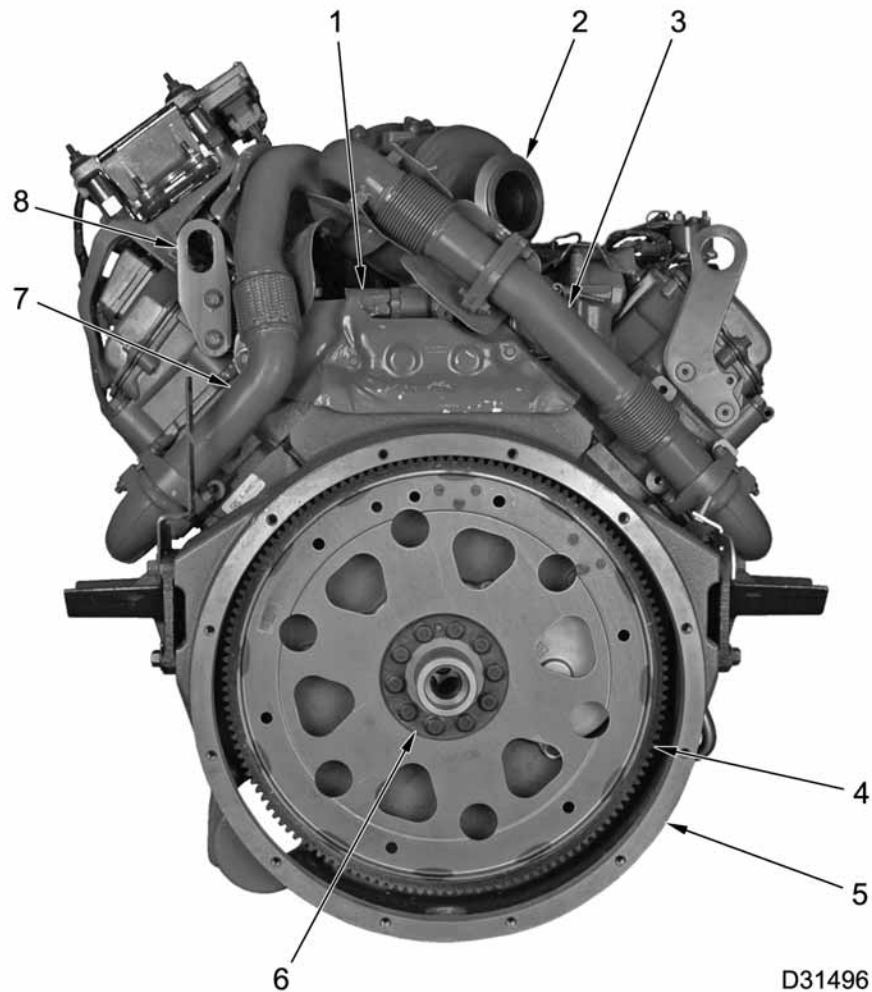


Figure 6 Engine components – Left

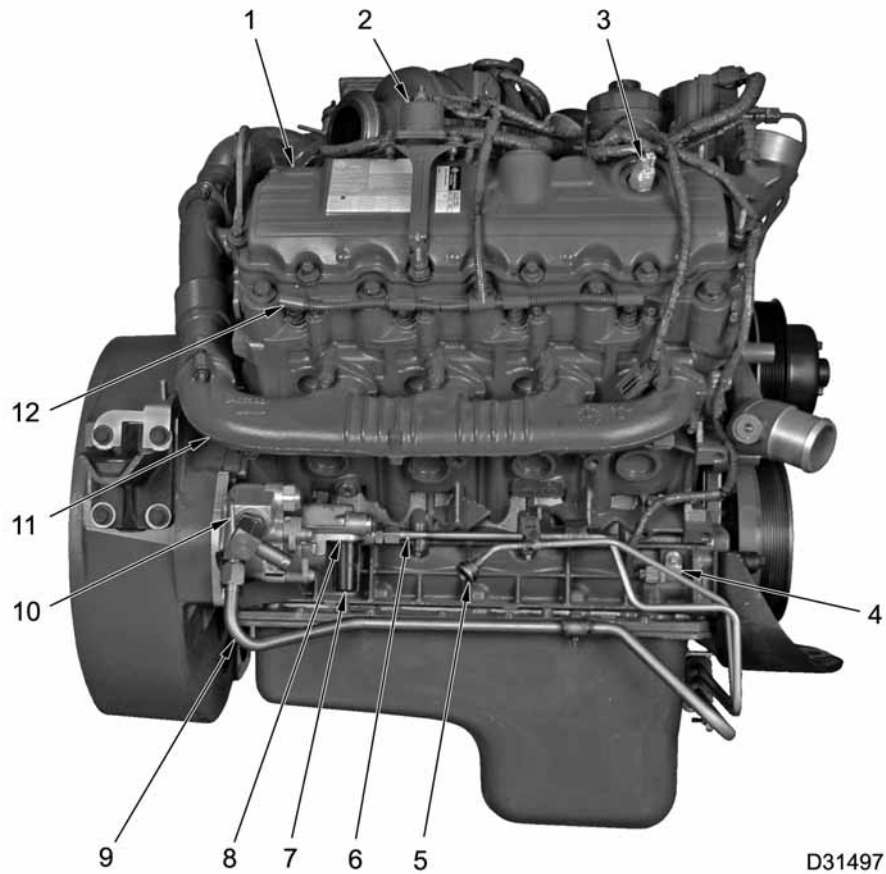
1. Fuel filter drain lever	5. Valve cover	10. Engine Coolant Temperature (ECT) sensor
2. Engine Control Module (ECM)	6. Rear cover	11. Lube oil fill tube
3. Injector Driver Module (IDM)	7. Exhaust manifold	
4. Exhaust Back Pressure (EBP) sensor	8. Camshaft Position (CMP) sensor	
	9. Glow plug harness	



D31496

Figure 7 Engine components – Rear

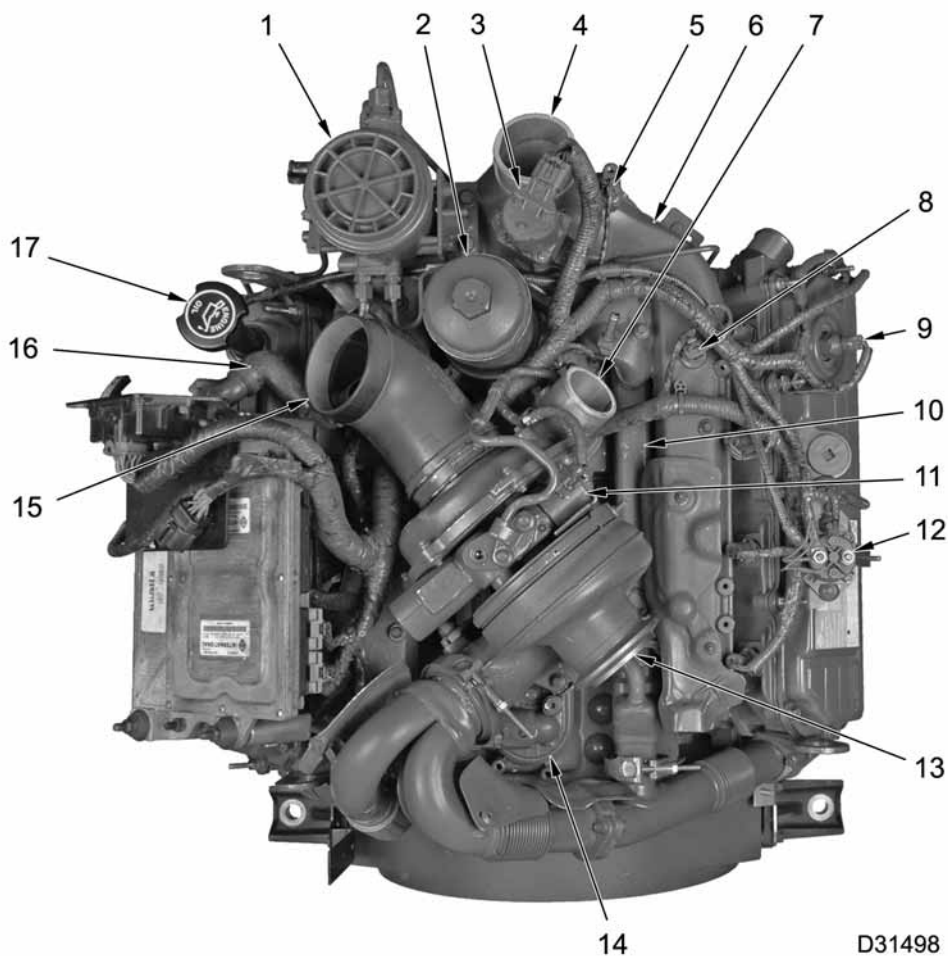
1. Injection Pressure Regulator (IPR valve)	4. Flywheel or flexplate assembly	7. Shielded exhaust tube assembly, left
2. Turbocharger exhaust outlet	5. Rear cover assembly	8. Lifting eye (3)
3. Exhaust tube assembly, right	6. Reinforcement ring	



D31497

Figure 8 Engine components – Right

1. Valve cover	5. Fuel return line	11. Exhaust Manifold
2. Glow plug relay	6. Fuel supply line	12. Glow plug harness
3. Injection Control Pressure (ICP) sensor	7. Fuel filter strainer	
4. Crankshaft Position (CKP) sensor	8. Fuel supply pump (transfer)	
	9. Power steering line	
	10. Power steering pump	

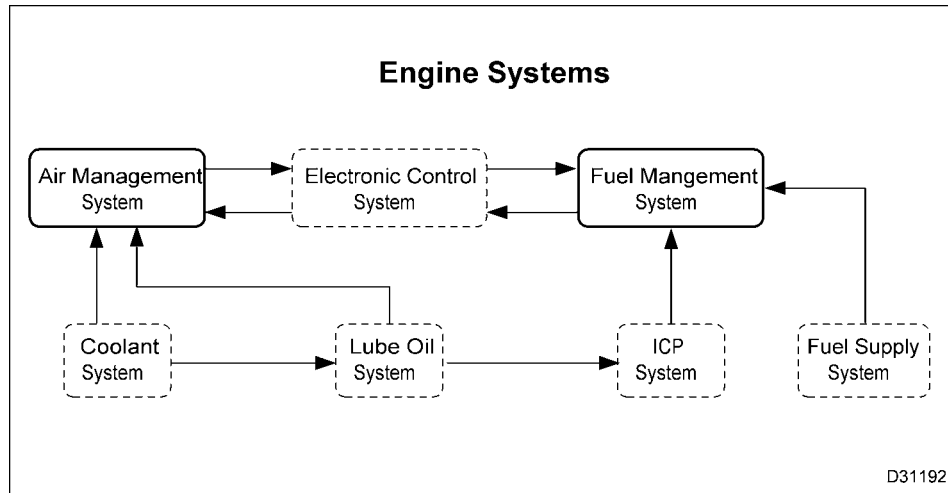


D31498

Figure 9 Engine components – Top

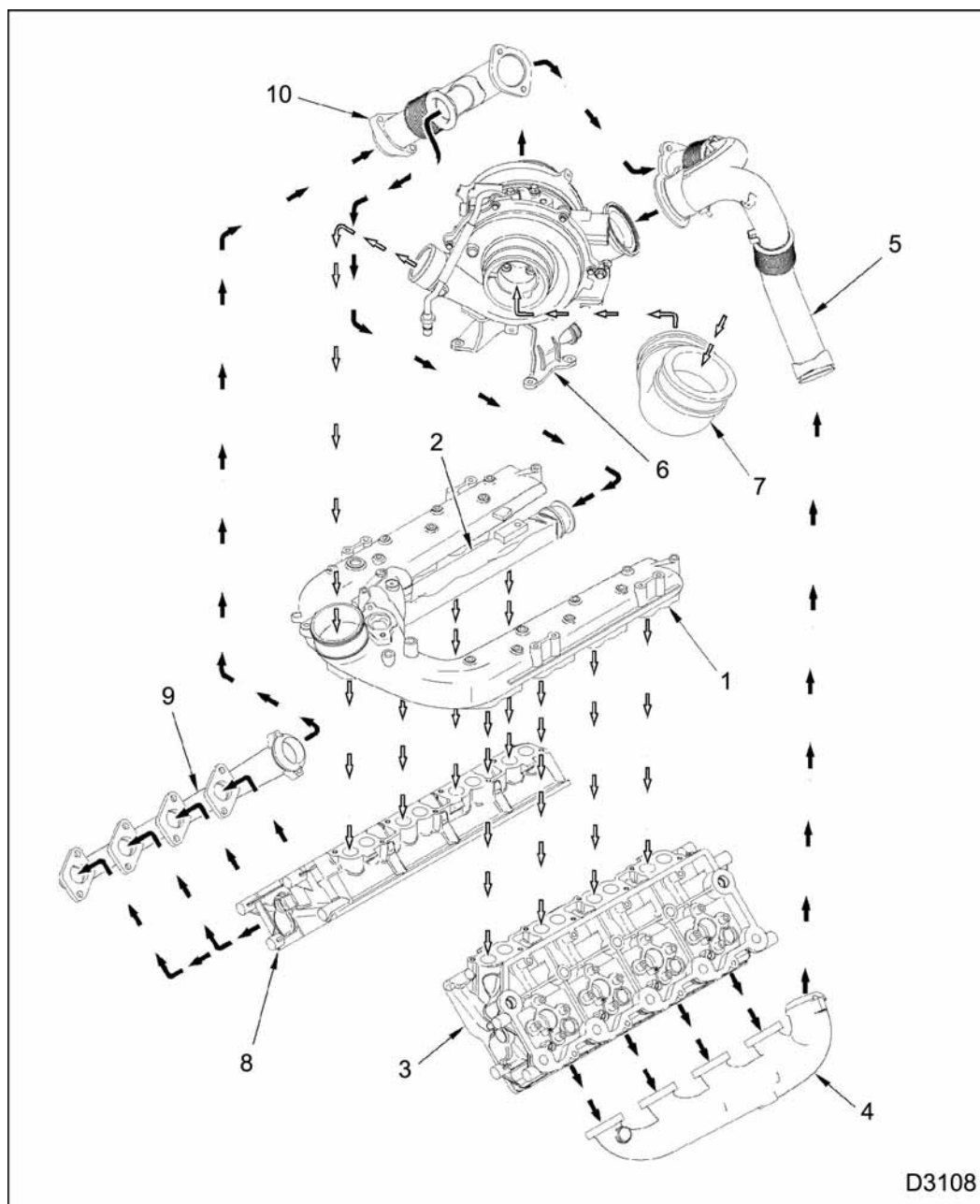
1. Fuel filter assembly	6. Intake manifold	12. Glow plug relay
2. Oil filter housing	7. Compressor outlet	13. VGT
3. Exhaust Gas Recirculation (EGR) valve	8. Manifold Air Temperature (MAT) sensor	14. High-pressure oil pump cover
4. Intake manifold air inlet	9. ICP sensor	15. Air inlet duct
5. Manifold Absolute Pressure (MAP) sensor	10. EGR cooler	16. Breather hose assembly with pitot tube
	11. VGT control valve	17. Lube oil fill

Engine Systems



The primary engine systems are Air Management and Fuel Management, which share some subsystems or have a subsystem that contributes to their operation.

- The Electronic Control System controls the Air Management System and Fuel Management System.
- The Coolant System provides heat transfer for EGR gases and lubrication oil.
- The ICP system uses lube oil for hydraulic fluid to actuate the fuel injectors.
- The Fuel Supply System pressurizes fuel for transfer to the fuel injectors.
- The Lube Oil System provides lubrication and heat transfer to engine components.

Air Management System (AMS)

D3108

Figure 11 Air Management System (AMS)

1. Intake manifold	5. Shielded tube exhaust assembly	9. Right exhaust manifold
2. EGR cooler	6. VGT with mounting bracket	10. Exhaust tube assembly, right
3. Left cylinder head	7. Air inlet duct	
4. Left exhaust manifold	8. Right cylinder head	

The Air Management system includes the following:

- Air filter assembly
- Closed crankcase breather
- Chassis mounted Charged Air Cooler (CAC)
- Variable Geometry Turbocharger (VGT)
- Intake manifold
- Exhaust Gas Recirculation (EGR) system
- Exhaust system
- Catalytic converter– dependent on application
- Catalyzed Diesel Particulate Filter (CDPF) – dependent on application

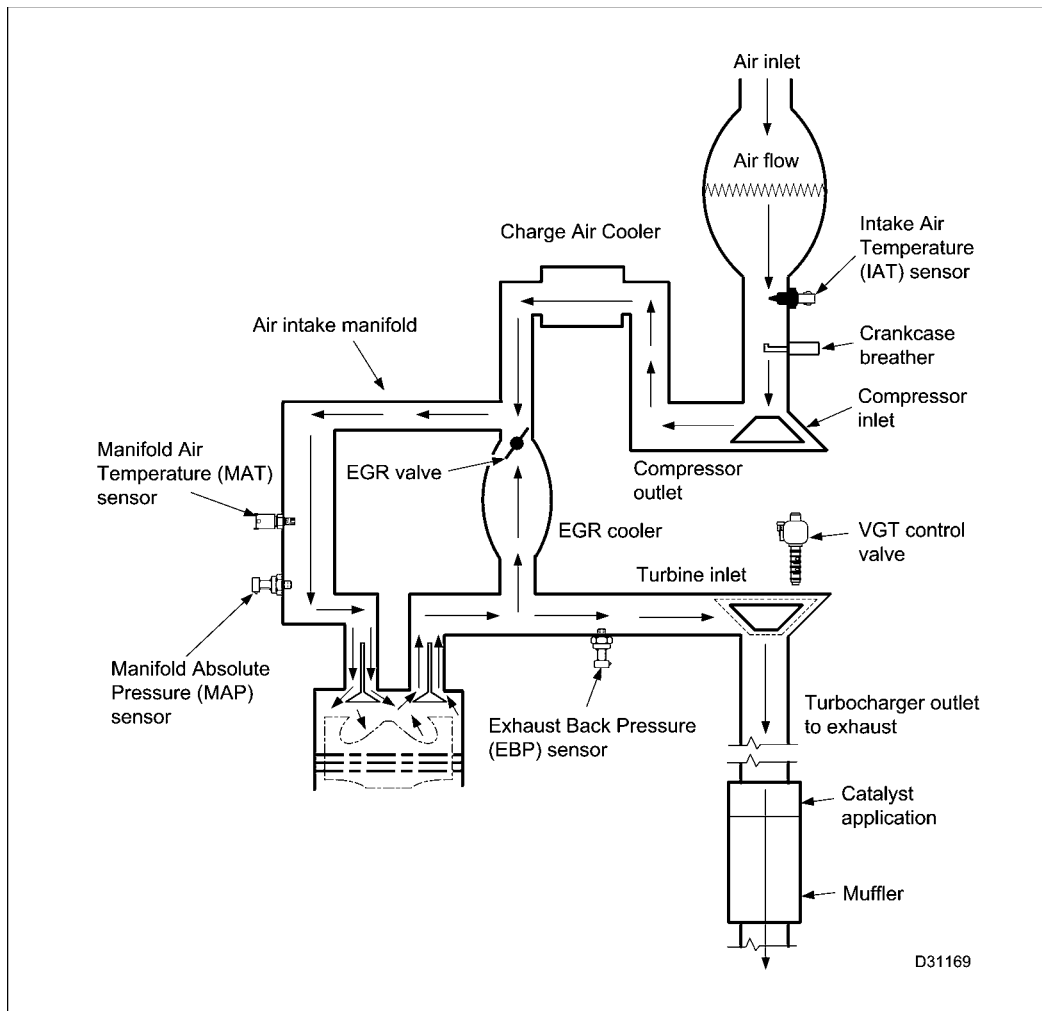


Figure 12 Air flow diagram

Air flow

Air enters and flows through the air filter assembly and mixes with air from crankcase ventilation. The VGT compresses the air mixture before it enters the Charge Air Cooler (CAC). Cooled compressed air flows from the CAC into the air intake manifold that directs air to the intake ports for each cylinder head.

After combustion, hot exhaust gas is forced through the exhaust manifolds to the EGR cooler and VGT.

- Some hot exhaust gas is cooled in the EGR cooler and flows through the EGR control valve back through the air intake manifold to mix with filtered air. This reduces nitrogen oxide (NOx) emissions and noise.

- The rest of the hot exhaust gas expands and flows to the VGT, spins the turbine wheel, and flows from the VGT outlet to the engine exhaust pipe.
- The VGT compressor wheel, on the same shaft as the turbine wheel, compresses the mixture of filtered air and air from crankcase ventilation.

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

The VGT modifies more efficient exhaust flow characteristics.

Charge Air Cooler (CAC)

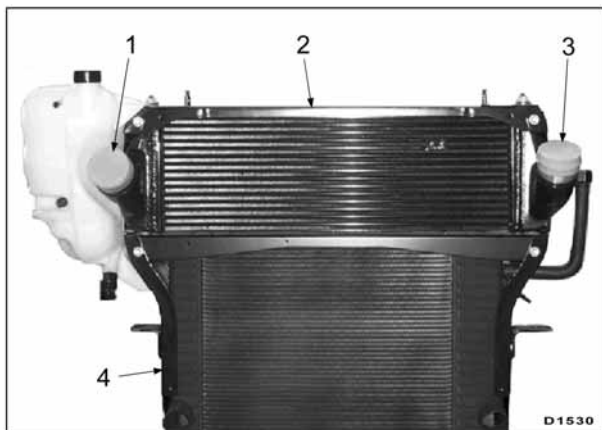


Figure 13 Charge Air Cooler

1. Air outlet
2. Charge Air Cooler
3. Air inlet
4. Radiator

The CAC cooler is mounted on top of the radiator. Air from the VGT is pushed through a network of heat exchanger tubes before entering the air intake manifold. Outside air flowing over the tubes and fins cools the charged air. Charged air is cooler and denser than the uncooled air; cooler and denser air improves the fuel-to-air ratio during combustion, resulting in improved emission control and power output.

Variable Geometry Turbocharger (VGT)

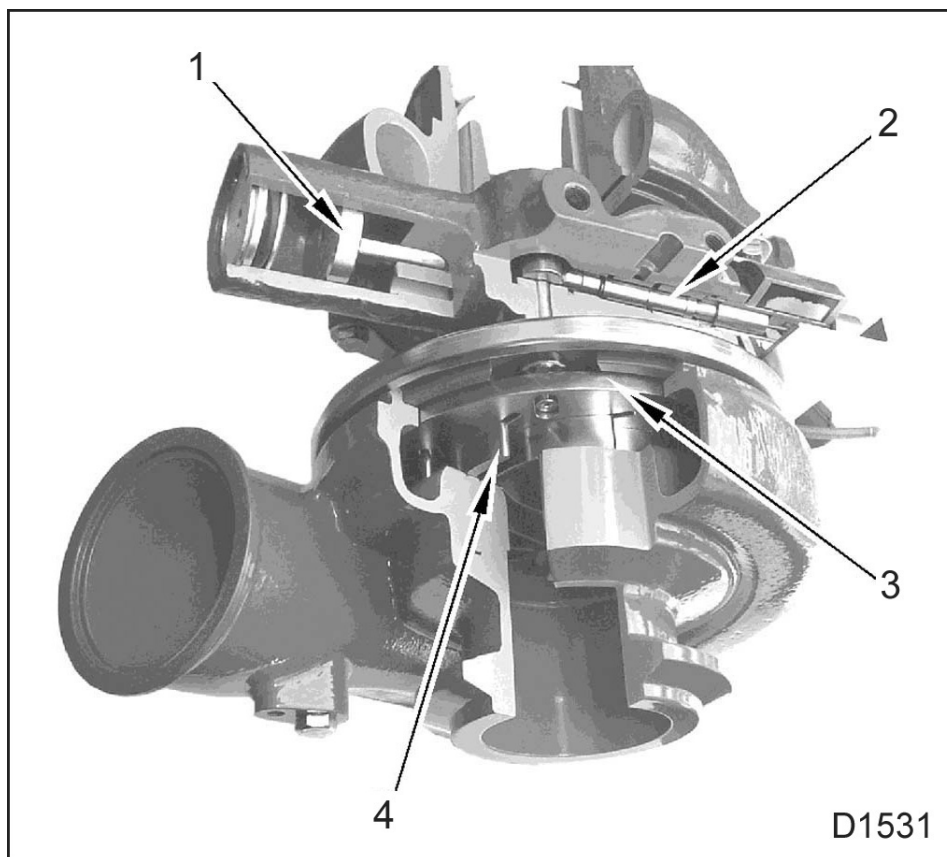


Figure 14 VGT

1. Actuator	3. Unison ring
2. VGT control valve	4. Vanes

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

VGT closed loop system

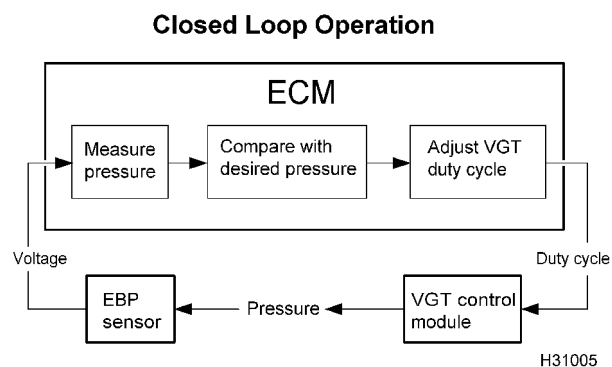


Figure 15 VGT closed loop system

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

VGT control

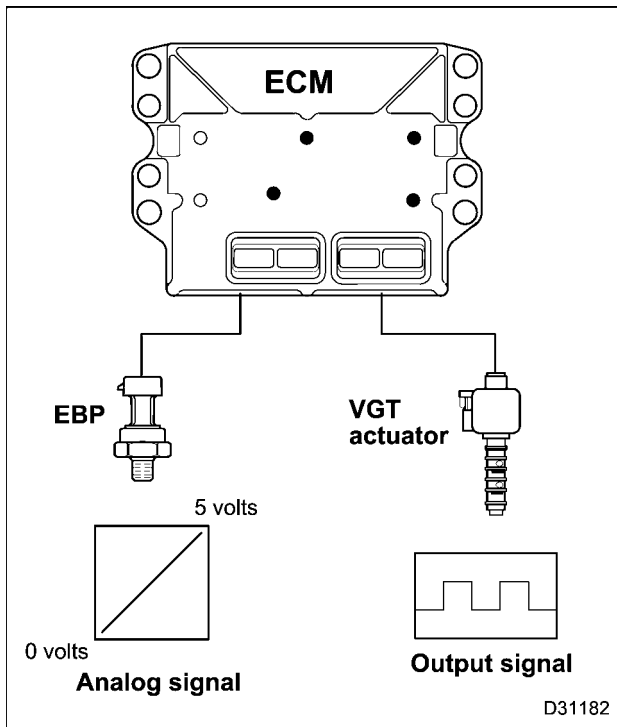


Figure 16 VGT control

The solenoid receives a pulse width modulated signal from the ECM that indicates the on / off time that the control valve is energized. The control valve directs lube oil flow to both sides of the piston in the actuator housing. Directing oil to different sides of the piston increases or decreases exhaust back pressure.

Actuated vanes are mounted around the inside circumference of the turbine housing. A unison ring

links all the vanes. When the unison ring moves, all vanes move to the same position. Unison ring movement occurs when either side of the actuator piston is pressurized by engine oil.

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

Exhaust Gas Recirculation (EGR) System

The EGR system includes the following:

- EGR drive module
- EGR valve
- EGR cooler
- Air intake manifold
- Exhaust tube assembly, right

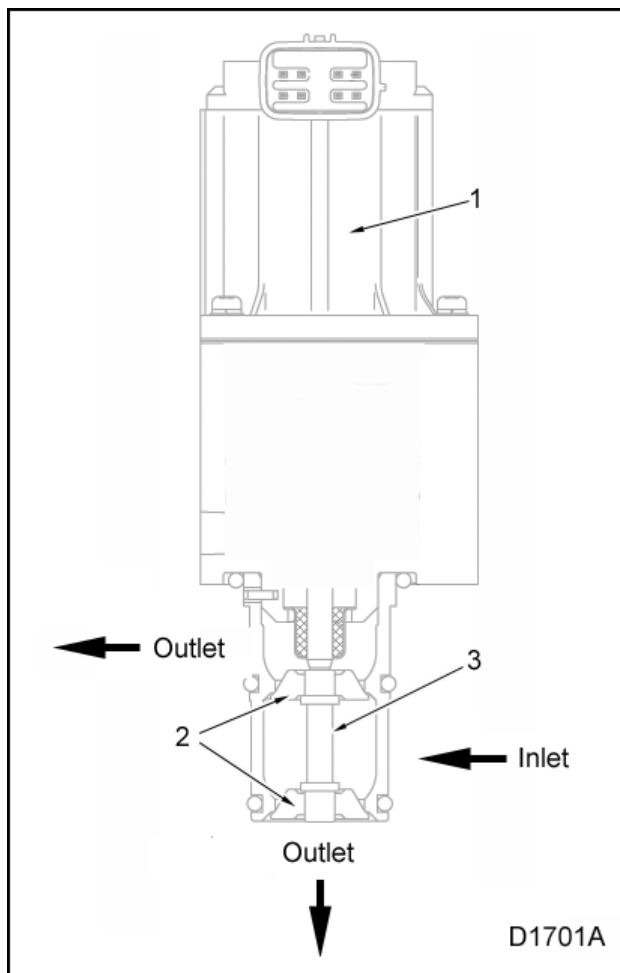
The Exhaust Gas Recirculation (EGR) system reduces Nitrogen Oxide (NO_x) emissions.

NO_x forms during a reaction between nitrogen and oxygen at high temperature during combustion. Combustion starts when fuel is injected into the cylinder before or slightly after the piston reaches top-dead-center.

EGR flow

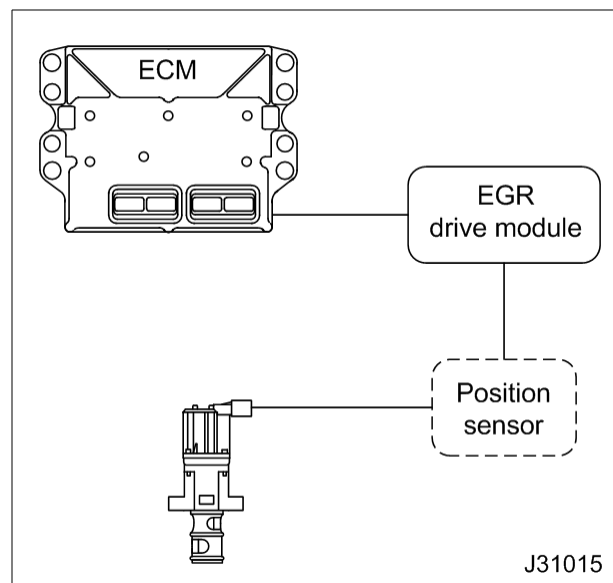
Some exhaust from the right exhaust tube assembly flows into the EGR cooler. Exhaust from the EGR cooler flows into a passage in the air intake manifold that intersects with the EGR valve.

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

EGR valve**Figure 17 EGR valve**

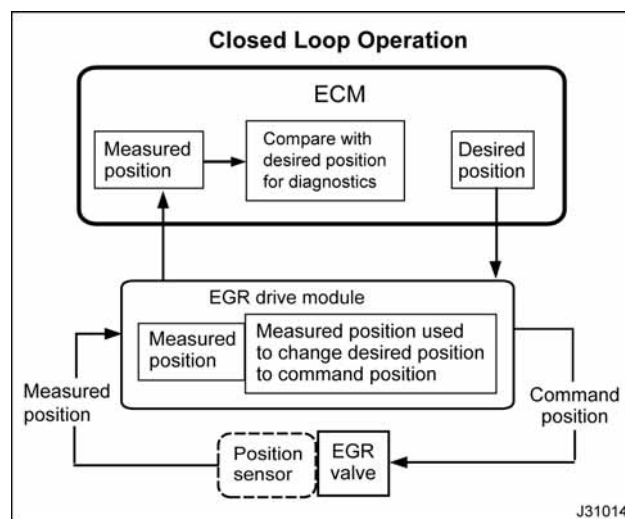
1. Actuator coil
2. Valve heads (2)
3. Common shaft

A DC motor, in EGR valve, moves and controls the position of a two head valve assembly.

**Figure 18 EGR control**

The EGR valve, installed in the top front of the air intake manifold, has three major components: a two head valve assembly, a DC motor, and an Integrated Circuit (IC). The IC has three Hall effect position sensors that monitor valve movement.

The EGR drive module, mounted on the EGR drive module mounting bracket above the ECM/IDM assembly, controls the DC motor.

**Figure 19 EGR closed loop operation**

The EGR system is closed loop control, using EGR position signals.

The EGR drive module receives the desired EGR valve position from the ECM across the CAN 2 datalink to activate the EGR valve for exhaust gas recirculation. The EGR drive module provides feedback to the ECM on the valve position, interprets the ECM command, and sends the command using three pulse width modulated signals to the DC motor.

Exhaust System

The exhaust system includes the following:

- Exhaust valves
- Exhaust manifolds
- Turbocharger

- Exhaust piping
- Muffler and catalytic converter – dependent on application
- Catalyzed Diesel Particulate Filter (CDPF) – if equipped.

The exhaust system removes exhaust gases from the engine. Exhaust gases exit from exhaust ports, through exhaust valves, and flow into the exhaust manifolds. Expanding exhaust gases are directed through the exhaust tubes. The right exhaust tube directs some exhaust gases into the Exhaust Gas Recirculation (EGR) cooler. Exhaust gases flowing into the VGT drive the turbine wheel. Exhaust gases exit the VGT and flow into the exhaust piping, through the muffler and catalytic converter or CDPF, and out the discharge pipe to the atmosphere.

Fuel Management System

Fuel Injection

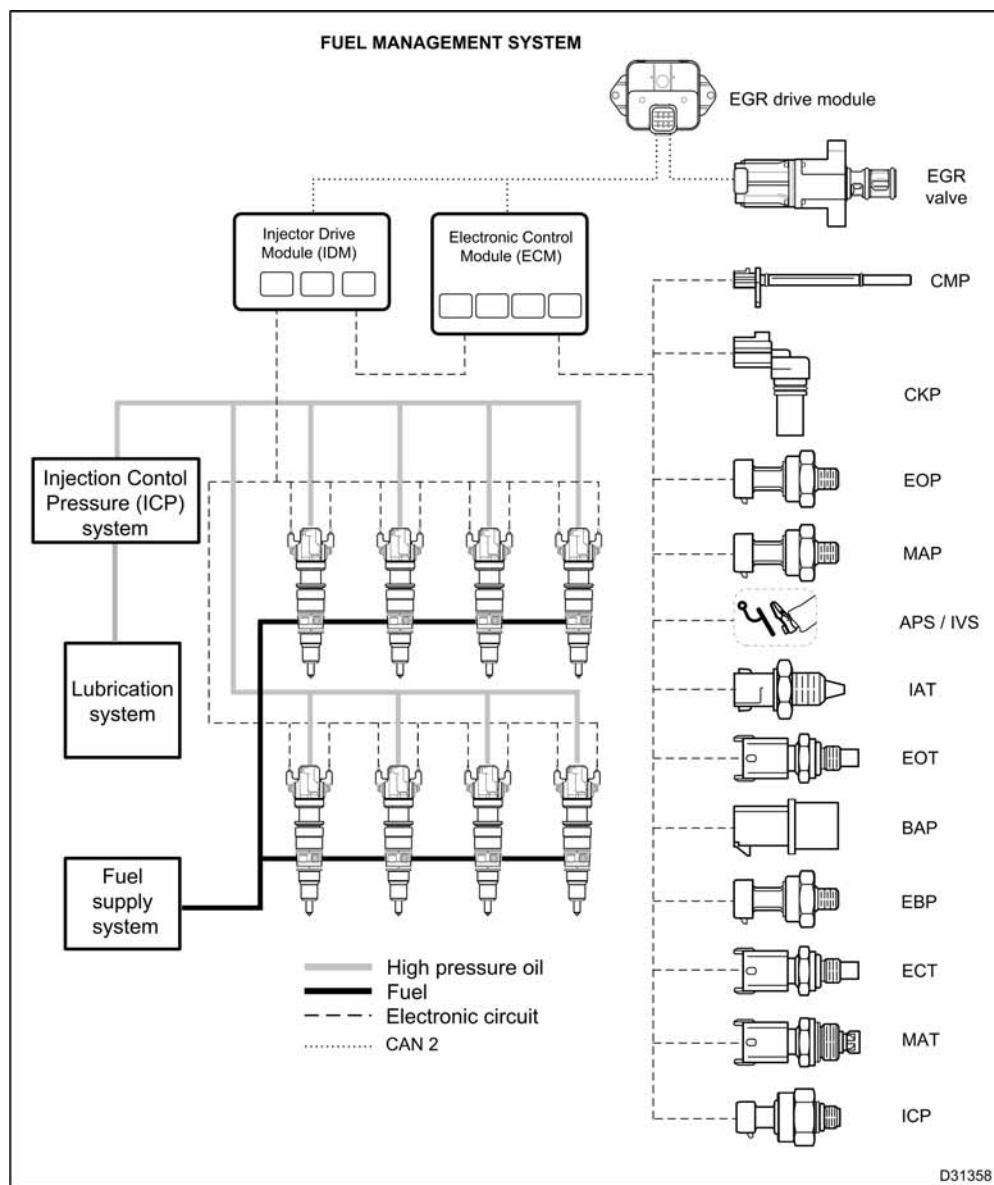


Figure 20 Fuel management system

The fuel management system includes the following:

- Injection Control Pressure (ICP) system
- Lubrication system
- Fuel injectors
- Electronic control system
- Fuel supply system

ICP Closed Loop System

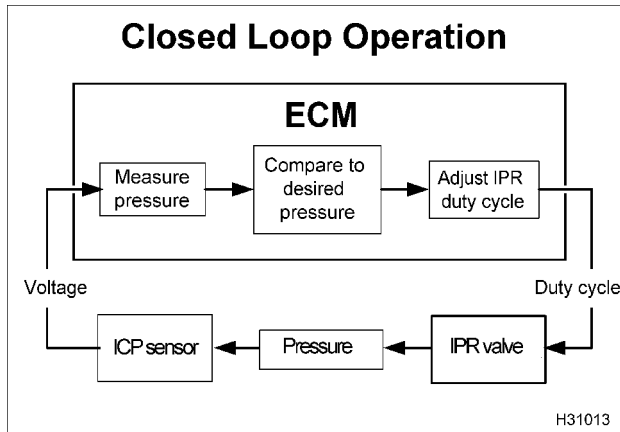


Figure 22 ICP closed loop system

The ICP is a closed loop system that uses the ICP sensor to provide feedback to the ECM. The ECM uses the ICP sensor to continuously monitor ICP and adjust the duty cycle to the IPR to match engine requirements.

ICP control

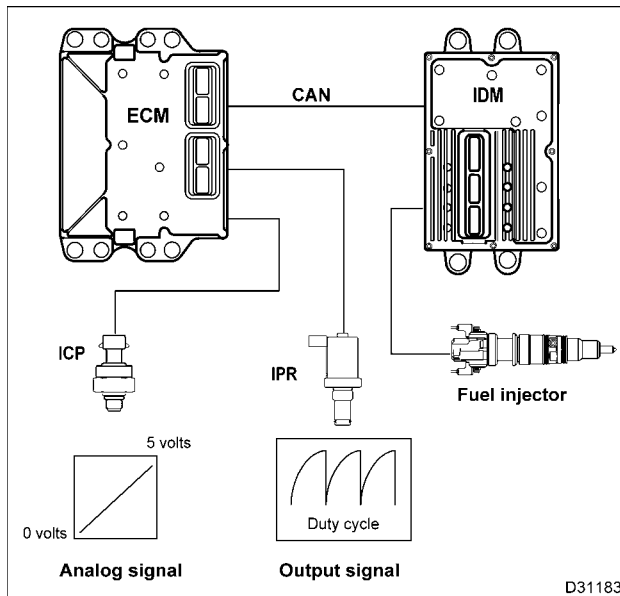


Figure 23 ICP control

ICP system operation

The solenoid receives a pulse width modulated signal from the ECM that indicates the on/off time the control valve is energized. The pulse is modulated to control ICP pressure in the range of 3 to 20 MPa (500 to 3,000 psi).

The IPR valve is mounted in the high-pressure pump cover. The IPR valve maintains the desired ICP by dumping excess oil out the bottom of the high-pressure pump cover.

High-pressure oil is routed to the IPR valve and ICP sensor through the discharge tube and passages in the high-pressure pump cover.

As the demand for ICP increases, the ECM increases the pulse width to the IPR solenoid. When ICP demand decreases, the ECM decreases the (duty cycle) to the solenoid, allowing oil to flow from the drain orifice.

The ECM sets Diagnostic Trouble Codes (DTCs), if the ICP electrical signal is out of range. DTCs are also set if an ICP signal corresponds to an out of range value for injection control pressure for a given operating condition.

The ECM will ignore ICP signals that are out of range. The IPR valve will operate from preprogrammed default values. This is called an Open Loop Operation.

Fuel Injectors

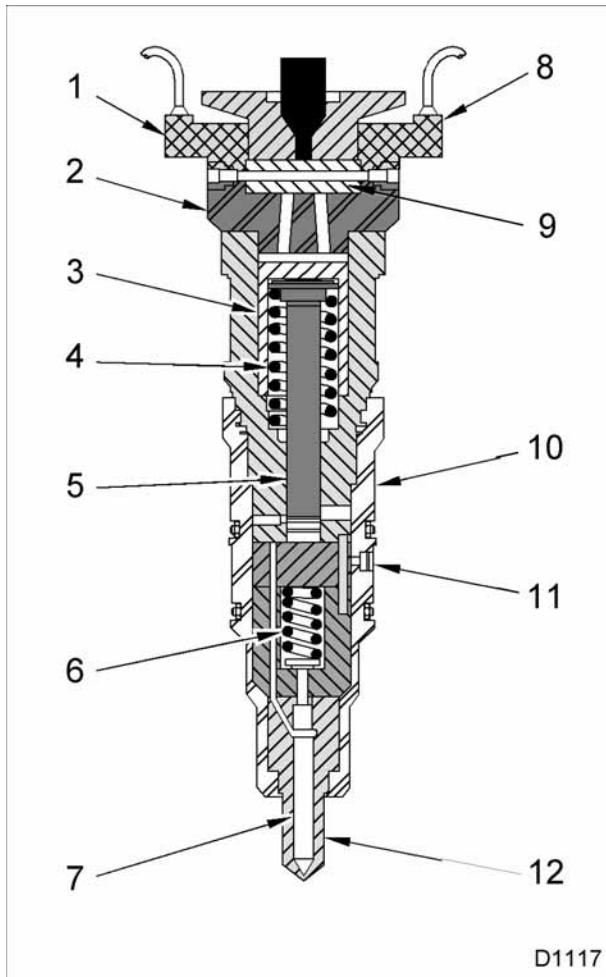


Figure 24 Fuel Injector

1. CLOSE coil
2. Control valve body
3. Intensifier piston
4. Piston return spring
5. Plunger
6. Valve opening pressure spring
7. Needle
8. OPEN coil
9. Spool valve (control valve)
10. Casenut
11. Fuel strainer (3)
12. Nozzle assembly

Fuel injector features

Two 48 volt 20 amp coils control a spool valve that directs oil flow in and out of the injector. The injector coils are turned on for approximately 800 (micro second or millionth of a second). Each injector has a single four pin connector that passes through the rocker arm carrier

Injector coils and spool valve

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

- When the spool valve is open oil flows into the injector from the high pressure oil rail.
- When the spool valve is closed oil drains back to the crankcase.

Intensifier piston

When the spool valve is open, high pressure oil enters the injector, pushing down the intensifier piston and plunger. Since the intensifier piston is 7.1 times greater in surface area than the plunger, the injection pressure is also 7.1 times greater than ICP pressure on the plunger.

Plunger and barrel

Fuel pressure builds between the plunger and the barrel. When the intensifier piston pushes the plunger down, the plunger increases fuel pressure in the barrel 7.1 times greater than ICP. The plunger has tungsten carbide coating to reduce scuffing and poor performance.

Injector needle

The injector needle opens inward, off its seat when fuel pressure overcomes the Valve Opening Pressure (VOP) - approximately 21 MPa (3100 psi). Fuel is atomized at high pressure through the nozzle tip.

Fuel injector operation

The injection operation has three stages:

- Fill stage
- Main injection
- End of main injection

Fill stage

During the fill stage both coils are de-energized and the spool valve is closed. High pressure oil from the high pressure oil rail is dead headed at the spool valve.

Low pressure fuel fills the port below the plunger. The needle control spring holds the needle on its seat to prevent fuel from entering the combustion chamber.

Main injection (Step 1)

A pulse width current energizes the OPEN coil. Magnetic force moves the spool open. High-pressure oil flows past the spool valve into the intensifier piston chamber. Oil pressure overcomes the force of the intensifier piston spring and the intensifier starts to move. An increase in fuel pressure under the plunger seats the fuel inlet check ball. Fuel pressure starts to build once the plunger passes the fuel spill port of the barrel. Force on the needle begins to build.

Main injection (Step 2)

The pulse width controlled current to the OPEN coil is shut off, but the spool valve remains open. High pressure oil from high-pressure oil rail continues to flow past the spool valve. The intensifier piston and plunger continue to move and fuel pressure increases in the barrel. When fuel pressure rises above the VOP - about 21 MPa (3100 psi) - the needle lifts of its seat and injection begins.

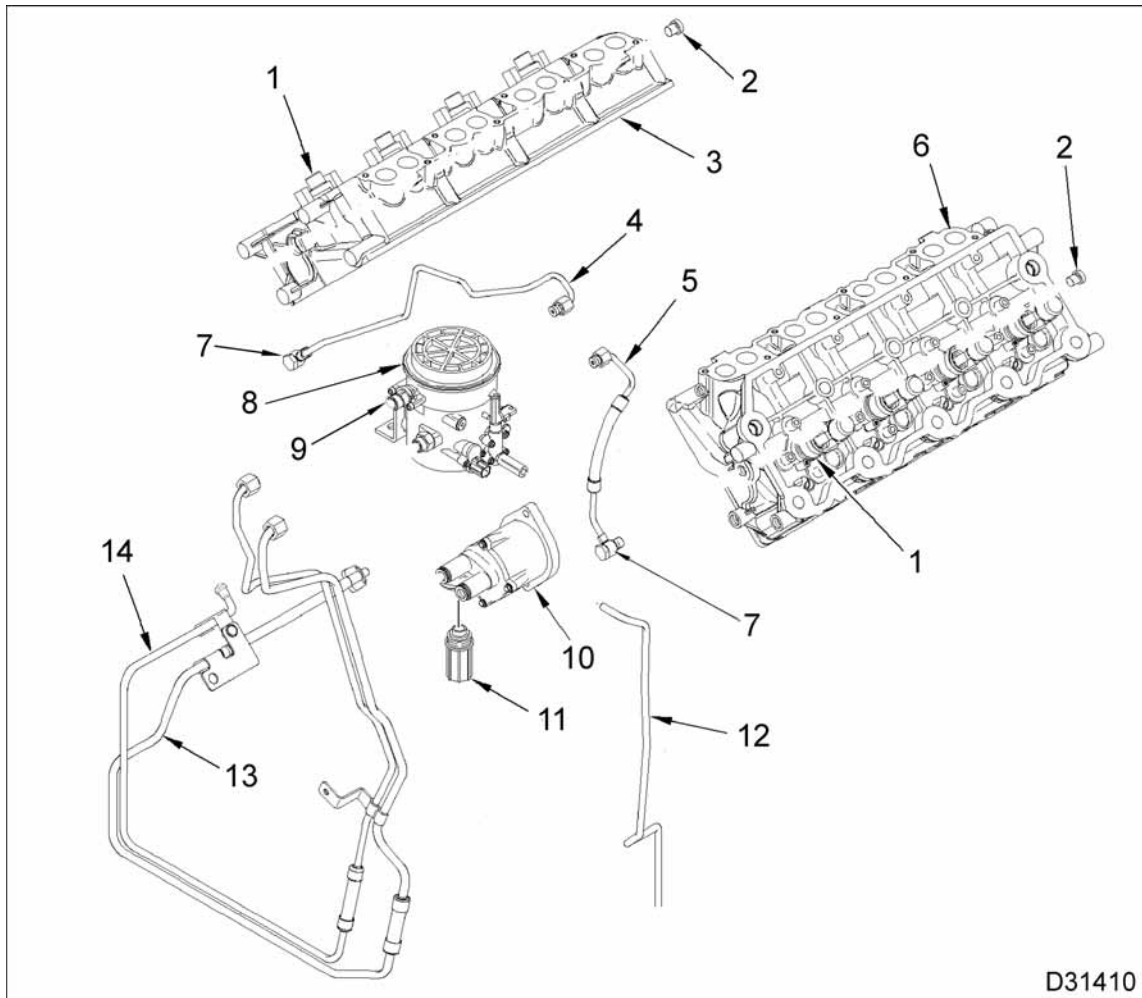
End of main injection (Step 1)

When the Injector Drive Module (IDM) determines that the correct injector On Time has been reached (meaning the correct amount of fuel has been delivered), the IDM sends pulse width controlled current to the CLOSE coil of the injector. The current energizes the CLOSE coil and magnetic force closes the spool valve. High pressure oil is dead headed against the spool valve.

End of main injection (Step 2)

The pulse width controlled current to the CLOSE coil is shut off, but the spool valve remains closed. The intensifier piston and plunger return to their initial position. Oil above the intensifier piston flows past the spool valve through the exhaust ports. Fuel pressure decreases until the needle control spring forces the needle back onto its seat.

Fuel Supply System



D31410

Figure 25 Fuel supply system

1. Fuel injector assembly (8)	7. 12 mm banjo bolt with check valve (2)	12. Fuel filter water drain tube assembly
2. Plug assembly, fuel rail (2)	8. Fuel filter housing assembly	13. Fuel supply line
3. Cylinder head (right)	9. Fuel filter regulator valve assembly	14. Fuel return line
4. Fuel supply line (right cylinder head)	10. Fuel and power steering pump assembly (gear driven)	
5. Fuel supply line (left cylinder head)	11. Fuel filter prestrainer	
6. Cylinder head (left)		

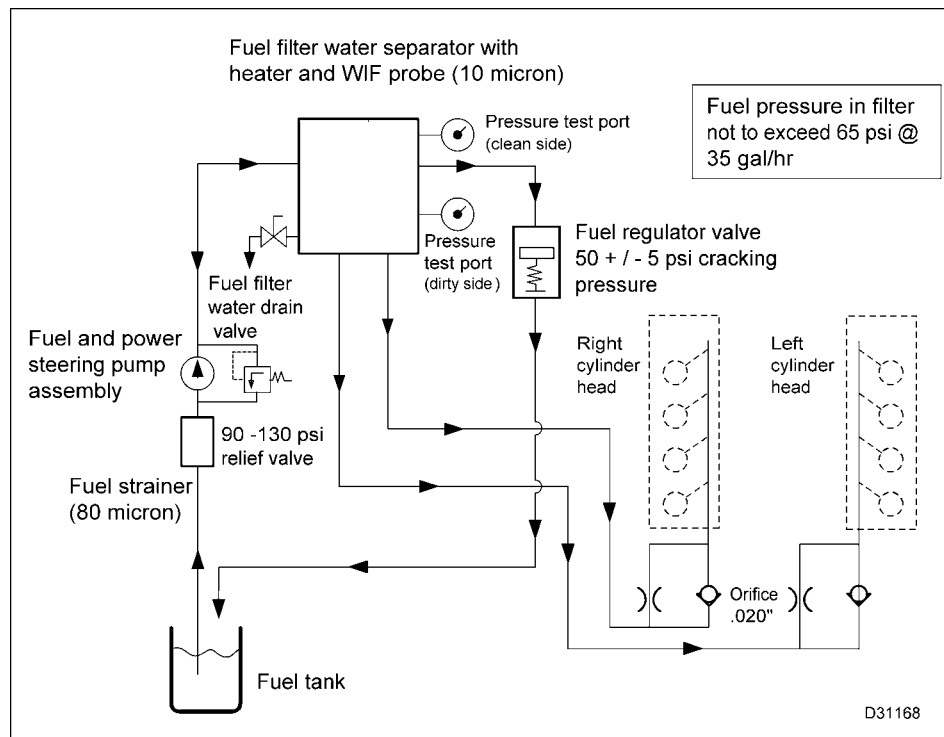


Figure 26 Fuel system schematic

The fuel supply system includes the following:

- Check valve banjo bolts
- Fuel tank(s)
- Fuel filter and housing
- Fuel supply lines
- Fuel passages in cylinder heads
- Fuel pressure regulator and fuel return lines
- Fuel supply pump (transfer)

Fuel Flow

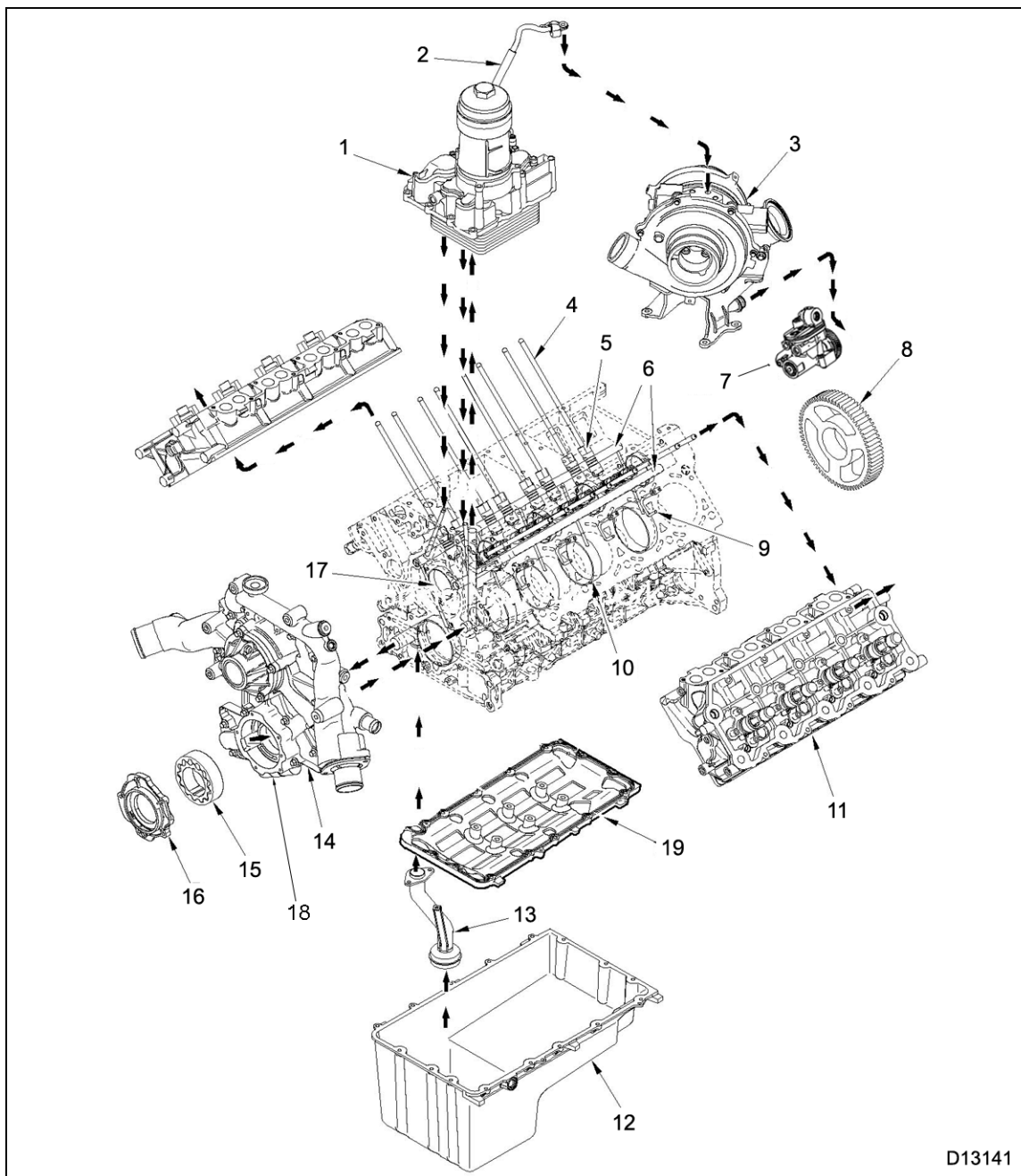
The fuel pump draws fuel from the fuel tank(s). Fuel passes through an 80 micron strainer on the pump. The fuel pump pressurizes and transfers fuel to the base of the fuel filter housing.

- The fuel filter housing regulates fuel pressure and relieves excessive pressure back to the fuel tank(s) through a fuel line connected to the top of the fuel filter housing. The fuel pressure regulator is calibrated to open at 345 kPa (50 psi) but at high rpm, low load pressure could reach more than 517 kPa (75 psi).

- The fuel is conditioned as it passes through a 10 micron filter to a standpipe in the center of the fuel filter housing.
- An optional electric heating element in the fuel filter housing warms the fuel to prevent waxing.
- A sensor in the base of the fuel housing detects water in the fuel. When enough water accumulates in the bottom of the housing, the sensor sends a signal to light the optional Water In Fuel (WIF) lamp on the instrument panel.
- A fuel drain valve on the housing is used to eliminate contaminants (usually water) from the fuel housing.
- Filtered fuel flows from the fuel filter housing to both cylinder heads through fuel lines.

Fuel flows past check valves through passages in the cylinder heads that intersect with the fuel injectors.

Lubrication System



D13141

Figure 27 Lubrication system

1. Oil cooler cover with filter base	7. High-pressure oil pump assembly	13. Oil pick up tube
2. VGT oil supply line	8. Camshaft gear	14. Front cover housing
3. VGT	9. Piston cooling tube (8)	15. Gerotor assembly
4. Push rod (16)	10. Main bearing insert (10)	16. Gerotor housing cover
5. Valve lifter (16)	11. Cylinder head (2)	17. Cam bushing (5)
6. Main lube oil gallery (2)	12. Lower oil pan	18. Oil regulator valve
		19. Upper oil pan

EGES295-2

Read all safety instructions in the "Safety Information" section of this manual before doing any procedures.

Follow all warnings, cautions, and notes.

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Oil Flow

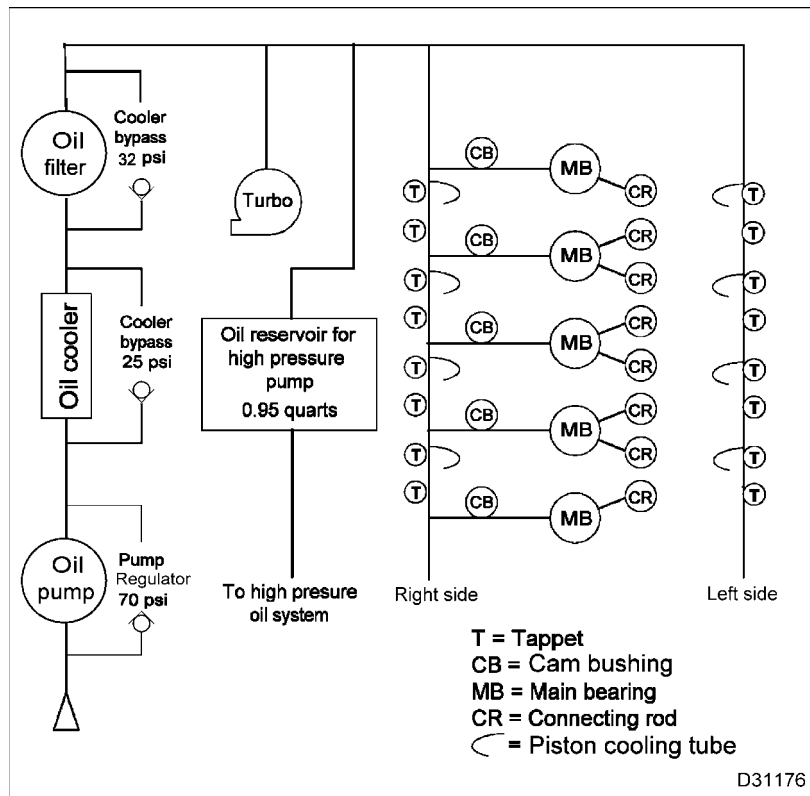


Figure 28 Lubrication system schematic

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

Oil is drawn from the oil pan through the pickup tube, upper oil pan, lower crankcase, and the front cover to the gerotor oil pump.

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

The gerotor pump pressurizes lube oil. Pressurized lube oil flows from the front cover through a passage in the lower crankcase. Lube oil from the lower crankcase flows through a passage in the upper crankcase to the oil cooler base. Passages in the oil cooler base direct lube oil and coolant.

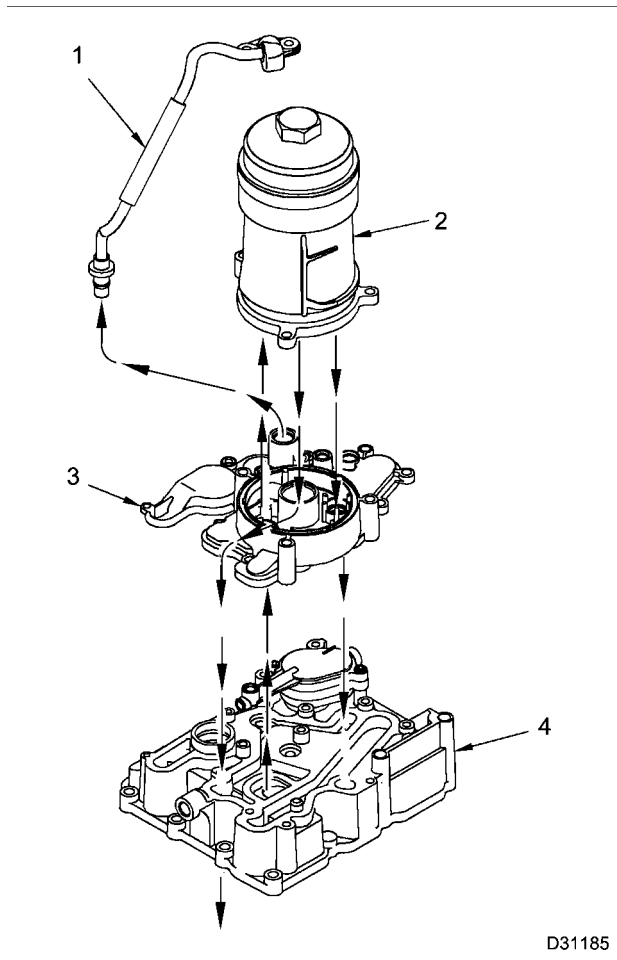


Figure 29 Oil cooler base and oil filter base

1. VGT oil supply tube assembly
2. Oil filter housing
3. Oil filter base assembly
4. Oil cooler cover

Lube oil is routed from the front of the oil cooler cover to the back where it enters the oil cooler. Lube oil is cooled as it flows from the back of the oil cooler to the front into the oil filter housing.

- If the oil cooler is restricted, a bypass valve in the oil filter base will open and allow oil to bypass the oil cooler going directly to the oil filter housing.

Oil flows to the oil filter element. Oil passes through the outside of the element to the inside of the element, down the stand pipe, back into the oil filter base, and into the oil cooler base.

The oil filter base directs filtered oil in four ways:

- One passage supplies filtered oil to the oil temperature sensor, oil pressure sensor, oil supply tube for the VGT, and oil supply for the air compressor (optional).

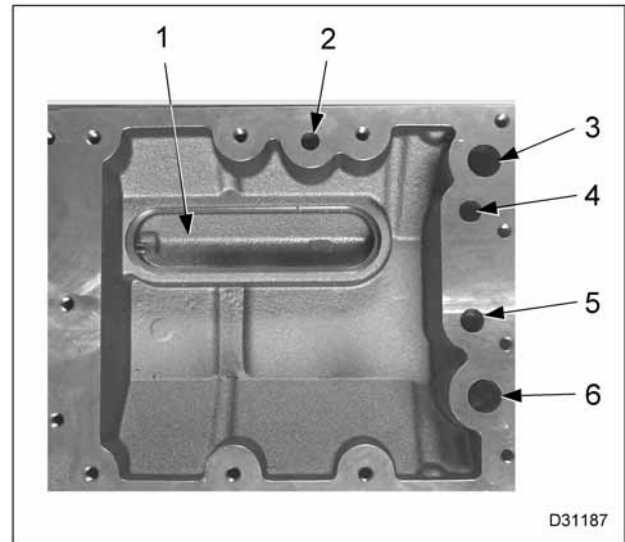


Figure 30 Oil reservoir in crankcase

1. Oil feed to high pressure pump
2. Oil filter drain to pan
3. Oil feed to oil cooler cover
4. Oil feed to left side of main lube oil gallery
5. Oil feed to right side of main lube oil gallery
6. Coolant feed to oil cooler

- A second passage supplies filtered oil to the reservoir in the crankcase for the high pressure pump and ICP system.

Two other passages supply filtered oil for the following:

Left side

- Main lube oil gallery
- Push rod and rocker arms
- Piston cooling tubes

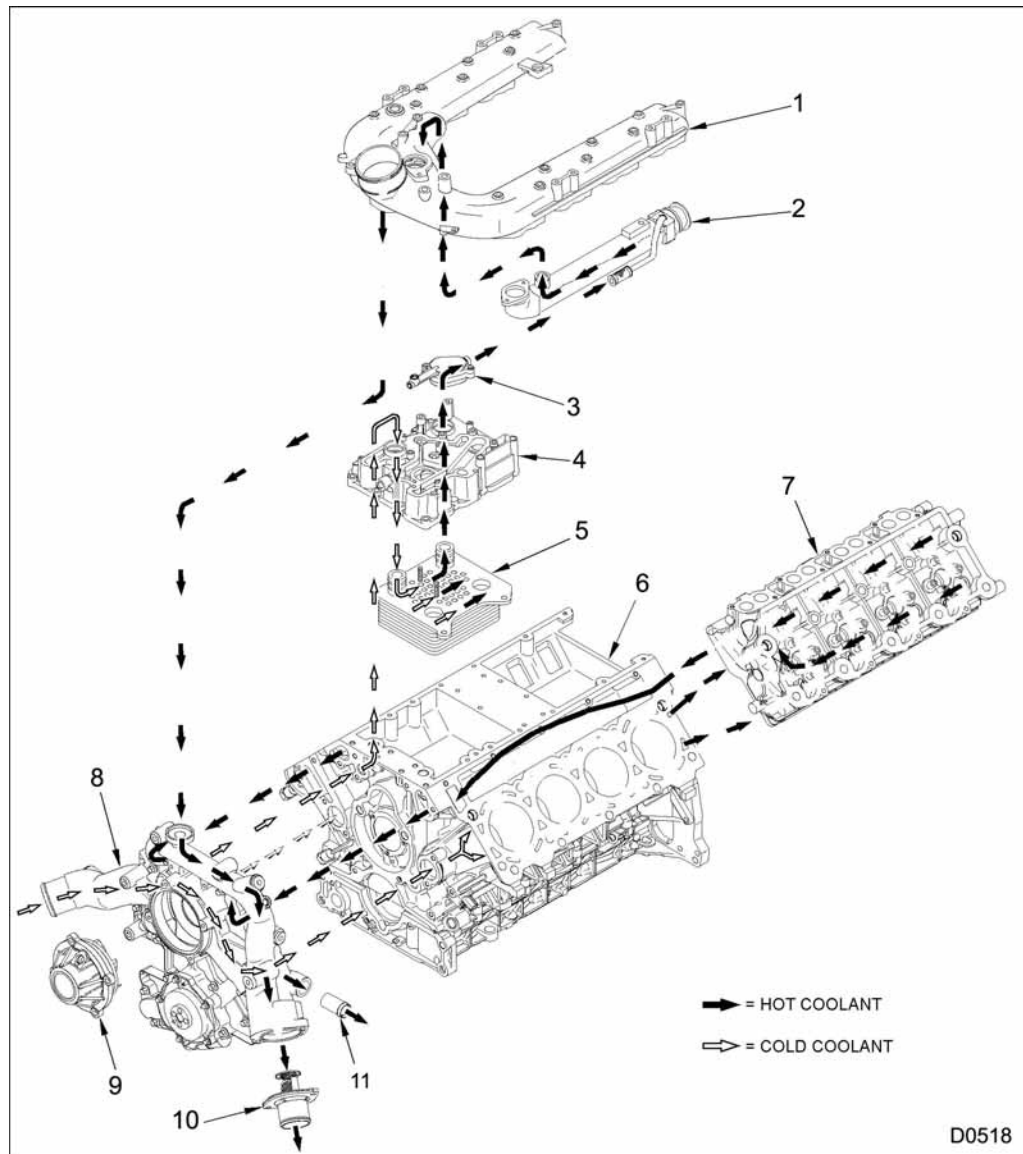
Right Side

- Main lube oil gallery
- Push rod and rocker arms
- Piston cooling tubes

- Cam bushings
- Crankshaft main bearings
- Connecting rod bearings

When the oil filter is removed, oil flows from a drain valve in the oil filter base back to the oil pan.

Cooling System

**Figure 31 Engine cooling system components**

1. Intake manifold	6. Crankcase	11. Coolant deaeration fitting (to deaeration tank)
2. EGR cooler	7. Cylinder head	
3. Coolant outlet cap	8. Front cover housing	
4. Oil cooler cover	9. Water pump	
5. Oil cooler (not serviced separately)	10. Thermostat assembly	

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

The centrifugal water pump (hub and impeller) is mounted in the pump housing of the front cover. The water pump has a built in reservoir to catch small amounts of coolant that may seep past the seal.

CAUTION: The water pump impeller may be damaged if dropped or hit by a hard object.

Front cover housing flow

The water pump draws coolant from the radiator through inlet of the front cover housing. Coolant flows from the water pump through three passages in the front cover.

- Two passages (left and right) direct coolant into the crankcase (front to rear) to cool the cylinder walls and the cylinder heads.
- The third passage directs coolant through a passage in the crankcase to the oil cooler cover.

NOTE: If an oil cooler seal is damaged, weep holes in the oil filter base allow coolant to seep from the cooler cover.

Coolant returns to the water pump through three passages in the front cover.

- Two passages (left and right) from the crankcase direct coolant to the front cover.
- A third passage directs coolant from the intake manifold to the front cover.

Return coolant is directed to the thermostat in the front cover.

- If the thermostat is open, coolant flows to the radiator.
- If the thermostat is closed, coolant returns to the water pump through a bypass passage in the front cover, because the radiator outlet is blocked.

As the engine reaches operating temperatures, the thermostat opens and directs coolant to the radiator. This also restricts the bypass opening.

Crankcase and cylinder head flow

Coolant flows through passages in the front cover to the left and right sides of the crankcase. Coolant flows through the front of both sides of the crankcase, evenly distributing coolant around the cylinders, and exits the rear of the crankcase flowing up to the cylinder heads.

Coolant flows from the rear of the cylinder heads to the front of the cylinder heads, exits down a passage in the crankcase, and returns to the front cover.

Oil cooler and EGR cooler flow

The front cover directs coolant to a passage in the crankcase. Coolant flows from the crankcase to the front of the oil cooler cover. The oil cooler and the oil filter base direct coolant to the front of the oil cooler.

Coolant flows through the oil cooler from the front to rear and exits through the EGR cooler supply port.

Coolant flows from the rear of the EGR cooler to the front returning to the front cover through a passage in the intake manifold.

- The deaeration port is on top of the intake manifold.
- For engines equipped with an air compressor the deaeration point is at the air compressor and intake manifold.

NOTE: Earlier engines have a single line from the air compressor to the deaeration tank. Later engines have two lines. One from the intake and one from the air compressor that intersect one line to the deaeration tank.

Electronic Control System

Electronic Control System Components

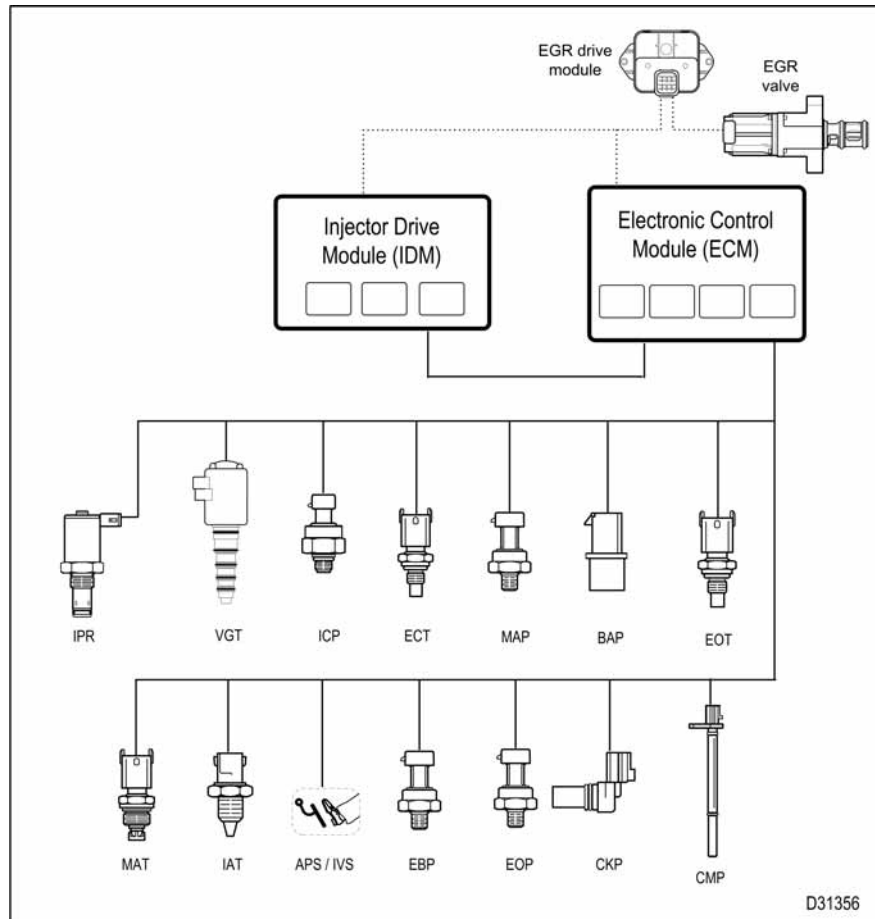


Figure 32

Operation and function

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

- Provides Reference Voltage (V_{REF})
- Conditions input signals
- Processes and stores control strategies
- Controls actuators

1. Reference voltage (V_{REF})

The ECM supplies a 5 volt V_{REF} signal to input sensors in the electronic control system. By comparing

the 5 volt V_{REF} signal sent to the sensors with their respective returned signals, the ECM determines pressures, positions, and other variables important to engine and vehicle functions.

The ECM supplies two independent circuits for V_{REF} :

- V_{REF} A supplies 5 volts to engine sensors
- V_{REF} B supplies 5 volts to vehicle sensors

2. 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.

3. Microprocessor

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

Continuous calculations in the ECM occur at two different levels or speeds: Foreground and Background.

- Foreground calculations are much 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 a slower rates. Engine temperature is an example.

Diagnostic Trouble Codes (DTCs) are generated 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 to achieve the correct performance of the engine.

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 by turning the ignition switch to OFF or when ECM power 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 conditions. Temporary information in RAM is lost when the ignition switch is turned OFF or when ECM

power is interrupted. RAM information includes the following:

- Engine temperature
- Engine rpm
- Accelerator pedal position

4. 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, these drivers complete a ground or power circuit to an actuator.

Actuators are controlled in three ways (determined by the kind of actuator):

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

ECM Control of Engine Operation

The ECM controls engine operation with the following:

- VGT control valve
- EGR valve
- IPR valve
- Glow plug relay

VGT control valve

The VGT control valve is an actuator mounted on the top right side of the VGT. The VGT control valve, a variable position valve, controls vane position in the turbine housing. Vane position is controlled by a switching voltage source in the ECM. The ground circuit is supplied directly from battery ground at all times.

Actuator control is achieved by setting a pulse width modulated signal in response to engine speed, desired fuel quantity, boost or exhaust back pressure and altitude.

Exhaust Gas Recirculation (EGR) valve

The EGR valve controls the flow of exhaust gases into the intake manifold.

The EGR drive module controls the DC motor in the EGR valve.

The EGR drive module receives the desired EGR valve position from the ECM across the CAN 2 datalink to activate the EGR valve for exhaust gas recirculation.

The EGR drive module provides feedback to the ECM on the valve position. When an EGR control error is detected, the EGR drive module sends a message to the ECM and a DTC is set.

Injection Pressure Regulator (IPR)

The IPR valve controls pressure in the Injection Control Pressure (ICP) system. The IPR valve is a variable position valve controlled by the ECM. This regulated pressure actuates the fuel injectors. The valve position is controlled by switching the ground circuit in the ECM. The voltage source is supplied by the ignition switch.

Glow plug relay

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

Injection Drive Module (IDM)

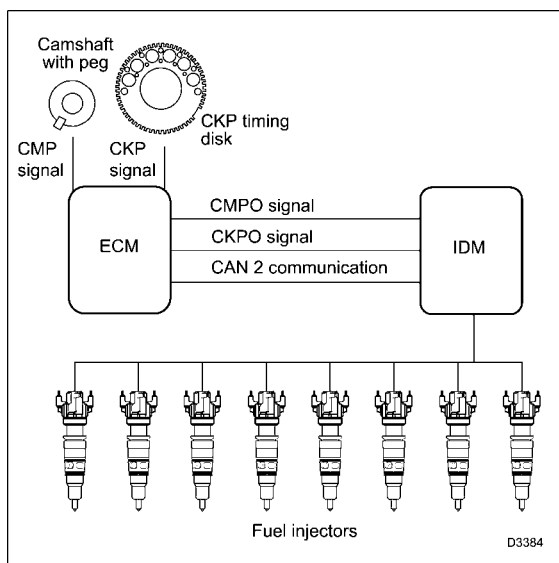


Figure 33 Injection Drive Module (IDM)

The IDM has three functions:

- Electronic distributor for injectors
- Power source for injectors
- IDM and injector diagnostics

Electronic distributor for injectors

The IDM distributes current to the injectors. The IDM controls fueling to the engine by sending high voltage pulses to the OPEN and CLOSE coils of the injector. The IDM uses information from the ECM to determine the timing and quantity of fuel for each injector.

The ECM uses CMP and CKP input signals to calculate engine speed and position. The ECM conditions both input signals and supplies the IDM with CMP and CKP output signals. The IDM uses CMP and CKP output signals to determine the correct sequence for injector firing.

The ECM sends information (fuel volume, EOT, and ICP) through the CAN 2 link to the IDM; the IDM uses this information to calculate the injection cycle.

Injector Power Source

The IDM creates a constant 48 volt (DC) supply to all injectors by making and breaking a 12 volt source across a coil in the IDM. The 48 volts created by the collapsed field is stored in capacitors until used by the injectors.

The IDM controls when the injector is turned on and how long the injector is active. The IDM first energizes the OPEN coil, then the CLOSE coil. The low side driver supplies a return circuit to the IDM for each injector coil (open and close). The high side driver controls the power supply to the injector. During each injection event, the low and high side drivers are switched on and off for each coil.

IDM and injector diagnostics

The IDM determines if an injector is drawing enough current. The IDM sends a fault to the ECM, indicating potential problems in the wiring harness or injector, and the ECM will set a DTC. The IDM also does self diagnostic checks and sets a DTC to indicate failure of the IDM.

On demand tests can be done using the Electronic Service Tool (EST). The EST sends a request to the ECM, the ECM sends a request to the IDM to do a

test. Some tests generate a DTC when a problem exists. Other tests require the technician to evaluate parameters, if a problem exists.

Engine and Vehicle Sensors

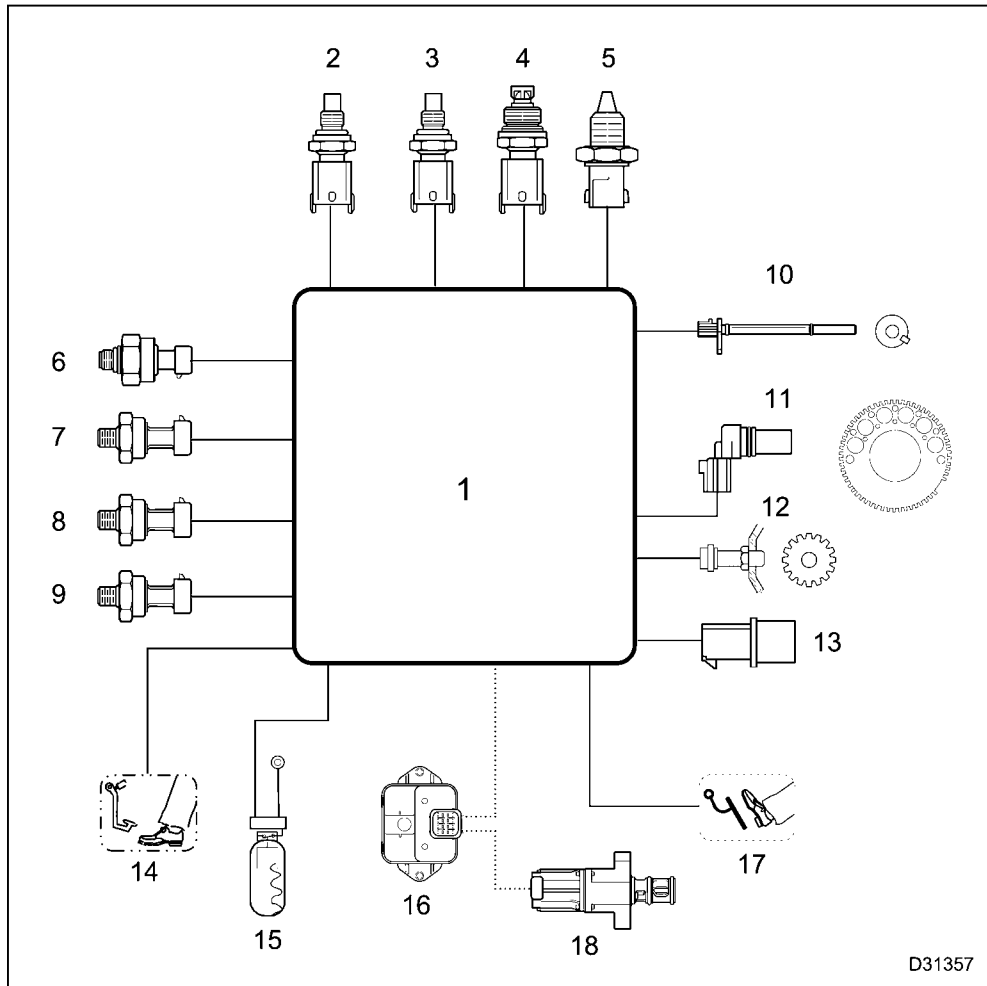


Figure 34 Engine and Vehicle Sensors

1. Electronic Control Module (ECM)	8. Engine Oil Pressure (EOP)	14. Driveline Disengagement Switch (DDS)
2. Engine Oil Temperature (EOT)	9. Manifold Absolute Pressure (MAP)	15. Engine Coolant Level (ECL)
3. Engine Coolant Temperature (ECT)	10. Camshaft Position (CMP)	16. Exhaust Gas Recirculation (EGR) drive module
4. Manifold Air Temperature (MAT)	11. Crankshaft Position (CKP)	17. Accelerator Position Sensor (APS)
5. Intake Air Temperature (IAT)	12. Vehicle Speed Sensor (VSS)	18. EGR valve
6. Injection Control Pressure (ICP)	13. Barometric Absolute Pressure (BAP)	
7. Exhaust Back Pressure (EBP)		

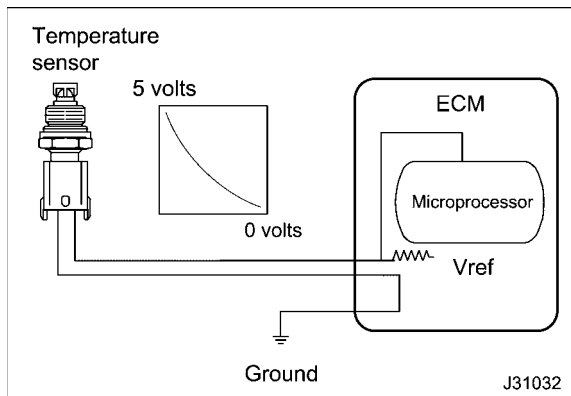


Figure 35 Thermistor

Thermistors

- ECT
- EOT
- IAT
- MAT

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

The top half of the voltage divider is the current limiting resistor that is internal to the ECM. A thermistor sensor has two electrical contacts: signal return and ground. The output of a thermistor sensor is a non-linear analog signal.

Engine Coolant Temperature (ECT)

The ECT sensor detects engine coolant temperature.

The ECT signal is monitored by the ECM for operation of the instrument panel temperature gauge, coolant temperature compensation, optional Engine Warning Protection System (EWPS), glow plugs, and the wait to start lamp. The ECM will use ECT sensor input as a backup, if EOT sensor values are out of range.

The ECT sensor is installed in the left side of the front cover.

Engine Oil Temperature (EOT)

The EOT sensor detects engine oil temperature.

The EOT signal is monitored by the ECM to control EGR, VGT, and for engine fueling calculations throughout the operating range of the engine. The EOT signal allows the ECM and IDM to compensate for differences in oil viscosity, due to temperature changes.

The EOT sensor is installed in the oil filter base.

Intake Air Temperature (IAT)

The IAT signal is monitored by the ECM to control timing and fuel rate during cold starts.

The IAT sensor is chassis mounted in the air filter housing.

Manifold Air Temperature (MAT)

The MAT sensor detects intake manifold air temperature.

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

The MAT sensor is installed in the right front of the intake manifold.

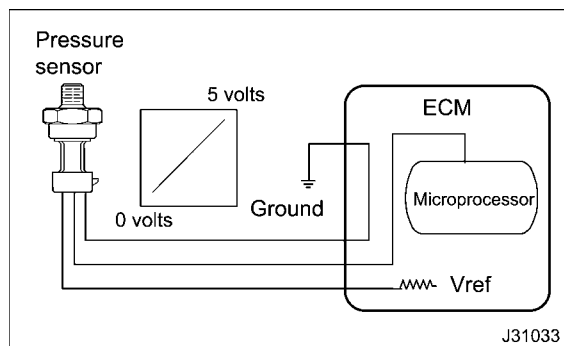


Figure 36 Variable capacitance sensor

Variable capacitance sensors

- BAP
- EBP
- EOP
- ICP
- MAP

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

The sensor is connected to the ECM by three wires:

- V_{REF}
- Signal return
- Signal ground

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

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

Barometric Absolute Pressure (BAP)

The BAP sensor detects altitude.

The BAP sensor provides information to the ECM for control of fuel quantity, fuel timing, glow plug operation, and adjustment of the VGT to compensate for density changes.

The BAP sensor is mounted behind the instrument panel.

Engine Oil Pressure (EOP)

The EOP sensor 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 filter base.

Exhaust Back Pressure (EBP)

The EBP sensor measures exhaust back pressure before the turbocharger.

The EBP sensor provides feedback to the ECM for closed loop control of the VGT and for EGR position calculations.

The EBP sensor is mounted on a bracket on the left side of the engine below the ECM.

Injection Control Pressure (ICP)

The ICP sensor, a micro-strain gauge sensor, measures injection control pressure.

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

The ICP sensor is installed in the right high-pressure oil rail.

Manifold Absolute Pressure (MAP)

The MAP sensor detects intake manifold boost pressure.

The MAP signal is monitored by the ECM for EGR position and engine fueling calculations.

The MAP sensor is installed in the top front of the intake manifold.

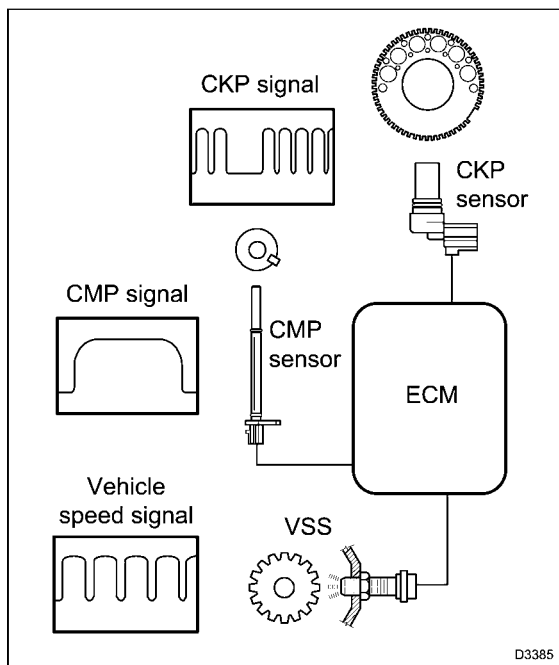


Figure 37 Magnetic pickups

Magnetic pickup sensors

- CKP
- CMP
- VSS

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

Crankshaft Position (CKP) sensor

The CKP sensor indicates crankshaft speed and position.

The CKP sensor provides the ECM with a signal that indicates crankshaft speed and position. As the crankshaft turns the CKP sensor detects a 60 tooth timing disk on the crankshaft. Teeth 59 and 60 are missing. By comparing the CKP signal with the CMP signal, the ECM calculates engine rpm and timing requirements.

The CKP is installed in the front right side of the lower crankcase.

Camshaft Position (CMP)

The CMP sensor indicates camshaft speed and position.

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

The CMP sensor is installed in the front left side of the crankcase.

Vehicle Speed Sensor (VSS)

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

The VSS is installed in left side of the transmission.

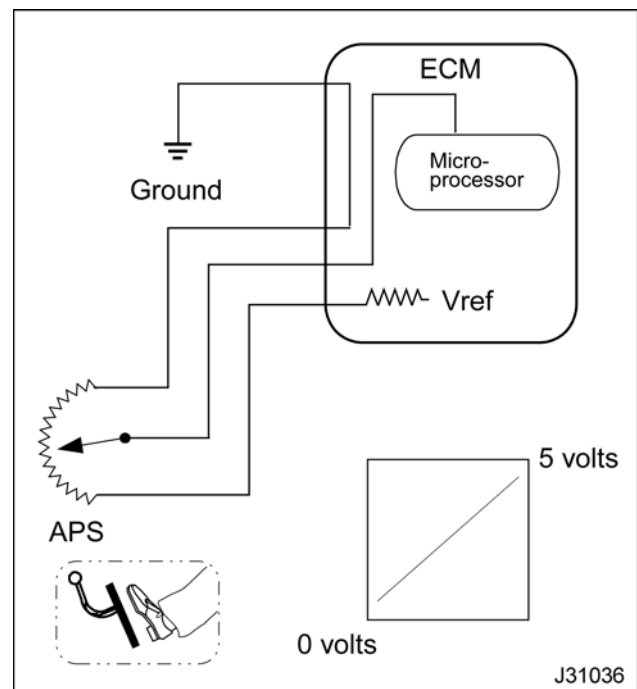


Figure 38 Potentiometer

Potentiometers

- APS

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.

Accelerator Position Sensor (APS)

The APS provides the ECM with a feedback signal (linear analog voltage) that indicates the operator's demand for power. The APS is mounted in the accelerator pedal. In the same application, a remote accelerator or throttle device can be used in addition to the accelerator pedal.

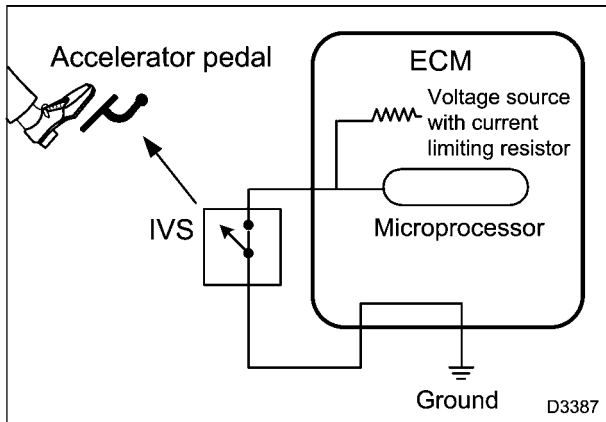


Figure 39 Switch

Switches

- DDS
- ECL
- IVS

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

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 switch functions as the DDS.

Engine Coolant Level (ECL)

The ECL switch is used in plastic deaeration tanks. When the magnetic switch is open, the tank is full.

The ECL lamp on the instrument panel signals the operator if engine coolant is low. ECL is part of the Engine Warning Protection System (EWPS)

Idle Validation Switch (IVS)

The IVS is a redundant switch that provides the ECM with a signal that verifies when the APS is in the idle position.

Glow Plug Control System

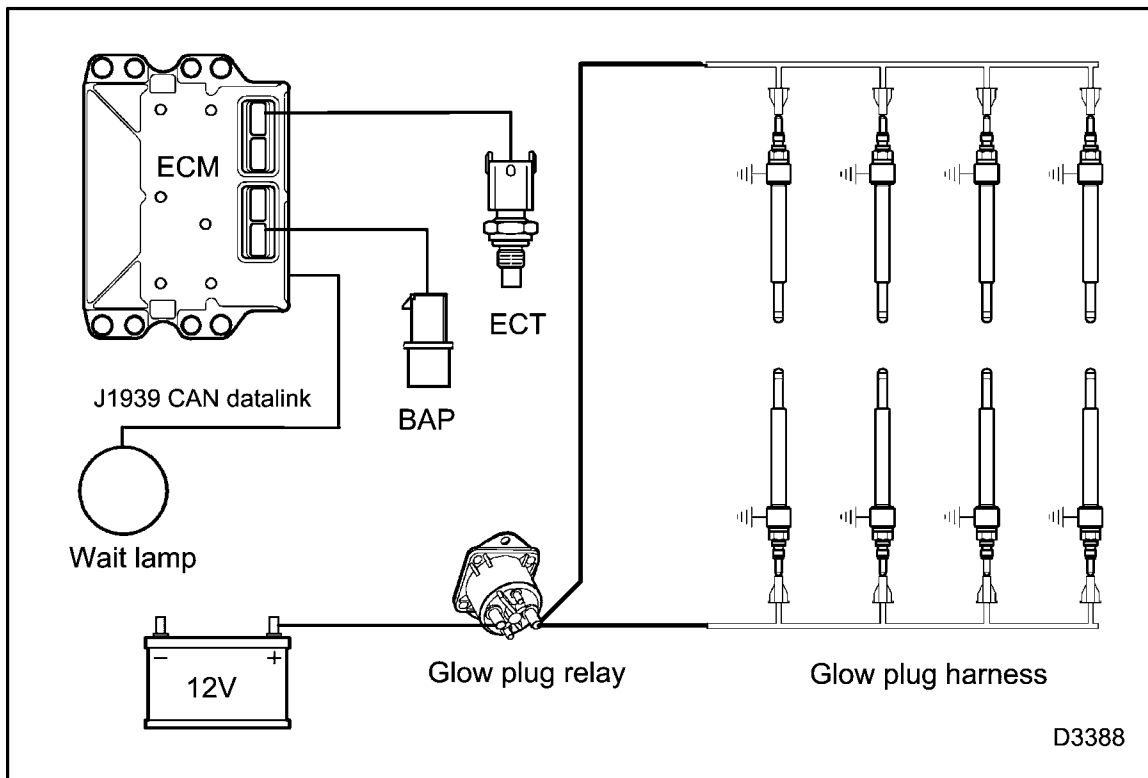


Figure 40 Glow plug control system

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

The Electronic Control Module (ECM) is programmed to energize the glow plugs (through the glow plug relay), while monitoring programmed conditions for engine coolant temperature and atmospheric pressure.

The ECM monitors battery voltage and uses information from the Barometric Absolute Pressure (BAP) sensor and Engine Coolant Temperature (ECT) sensor to determine the amount of time that the WAIT TO START lamp is ON and the activation time of the glow plugs. The ECM controls the WAIT TO START

lamp and the activation of the glow plugs separately. The glow plugs are self limiting and do not require cycling on and off. The glow plug relay will only cycle on and off repeatedly if system voltage is greater than 14.0 volts.

Glow plugs are activated for a longer time, if the engine is cold or the barometric pressure is low (high altitude).

The engine is ready to start when the WAIT TO START lamp is turned off by the ECM. The glow plugs can remain on up to 120 seconds, while the engine is running, to reduce exhaust emissions during engine warm-up.

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Mounting Engine

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

NOTE: Before mounting the engine on the engine stand, do steps 1 through 5.

1. Remove fuel and power steering lines from the pump assembly.

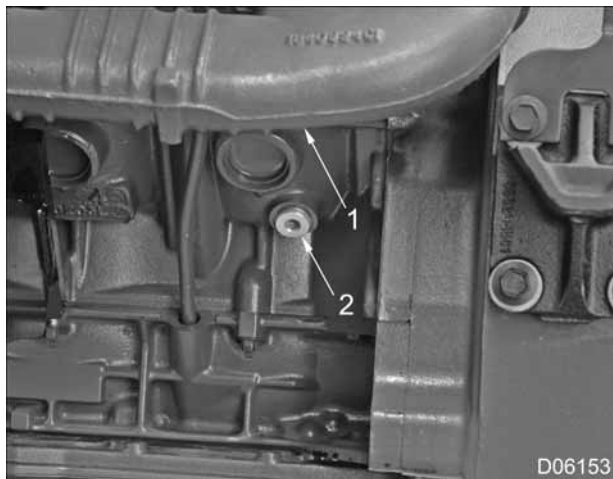


Figure 41 Left side coolant drain plug

1. Exhaust manifold
2. Coolant drain plug

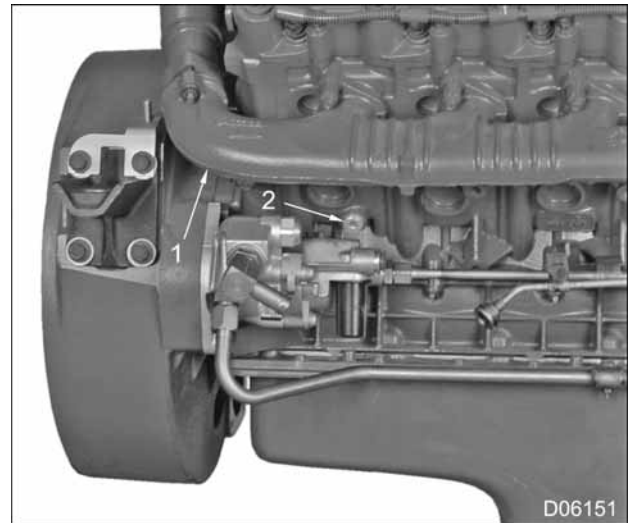


Figure 42 Right side coolant drain plug

1. Exhaust manifold
 2. Coolant drain plug
2. Remove two coolant drain plugs and drain coolant from crankcase into a suitable container. The coolant drain plugs are in the rear of the crankcase, below the exhaust manifolds.
 3. Remove oil pan drain plug and drain oil into a suitable container.
 4. After fluids are drained from the engine, reinstall plugs.
 5. Torque oil pan drain plug to the special torque (Table 2).

! WARNING: To prevent personal injury or death, attach the hoist hook lifting bracket to the engine lifting eyes before lifting the engine.

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

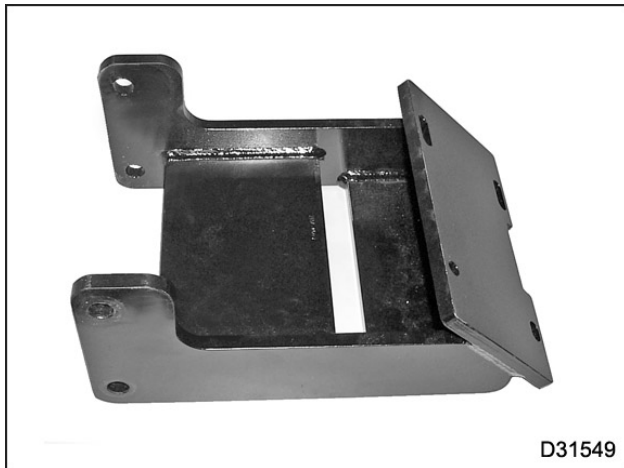


Figure 43 Engine Stand Mounting Bracket

! WARNING: To prevent personal injury or death, use only grade 8 bolts to secure Engine Stand Mounting Bracket to engine and engine lift stand. Other grade bolts may shear, causing the engine to fall off engine or engine lift stand.

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

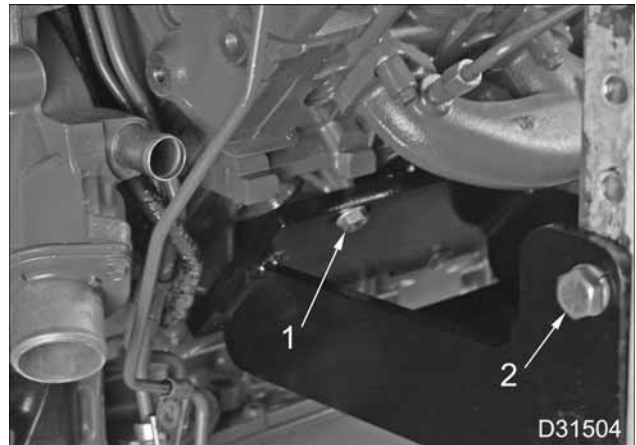


Figure 44 Mounting bolts for Engine Stand Mounting Bracket

1. Grade 8 mounting bolts (4) to engine block
2. Grade 8 mounting bolts (4) to engine lift stand
7. Position Engine Stand Mounting Bracket (Table 3) on right side of engine. Secure bracket plate with four grade 8 mounting bolts and washers.
8. Mount engine on engine lift stand using four grade 8 mounting bolts.

Special Torque

Table 2 Oil Pan Drain Plug

Oil pan drain plug	25 ± 5 N·m (18 ± 4 lbf·ft)

Special Service Tools

Table 3 Mounting Engine on Stand

Description	TOOL NUMBER
Engine Stand Mounting Bracket	ZTSE4507

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Description

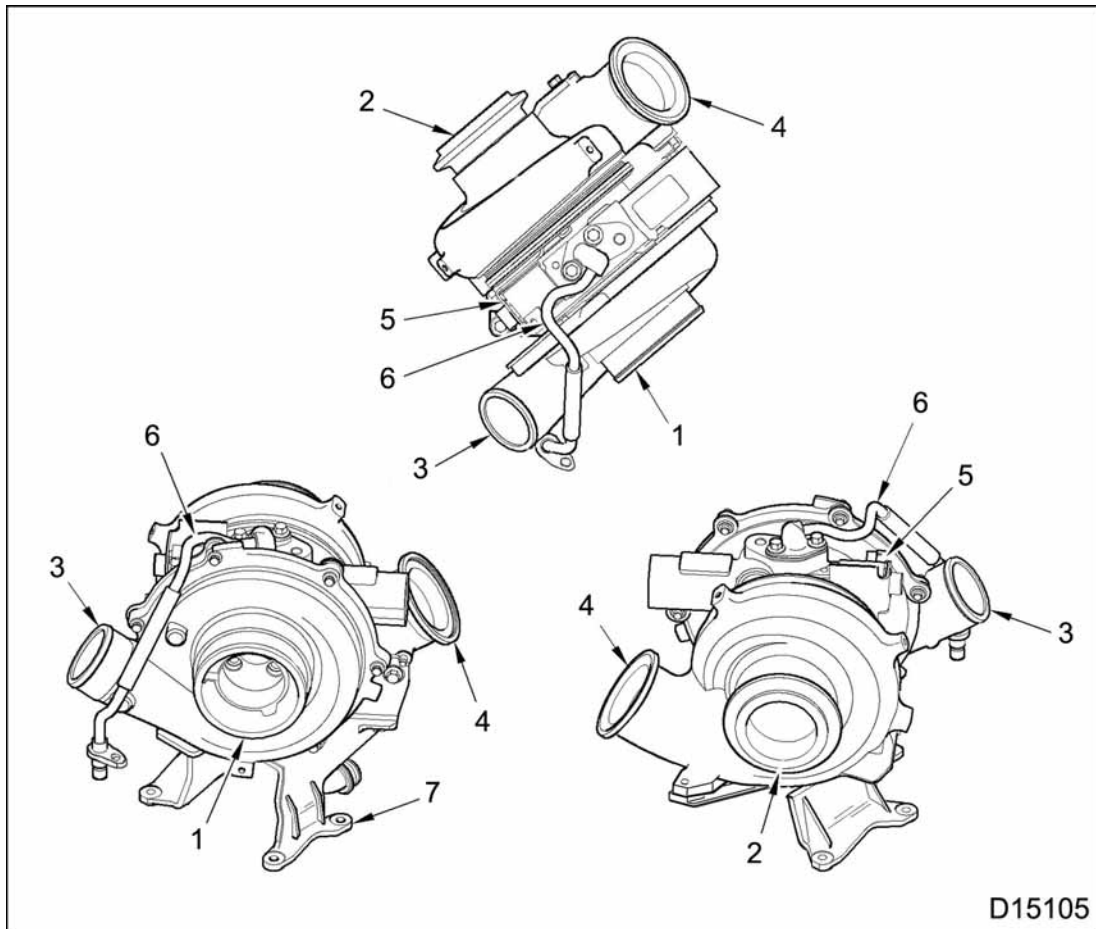


Figure 45 Turbocharger components

1. Air inlet	4. Exhaust inlet	7. Turbocharger mounting bracket
2. Exhaust outlet	5. Turbocharger control valve	
3. Compressor outlet	6. Oil supply tube	

Operation

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

The VGT is a closed loop system that uses the Exhaust Back Pressure (EBP) sensor to provide feedback to the Electronic Control Module (ECM). The ECM uses the EBP sensor to continuously

monitor EBP and adjust the duty cycle to the VGT to match engine requirements.

The solenoid receives a pulse width modulated signal from the ECM that indicates the on / off time that the control valve is energized. The control valve directs lube oil flow to both sides of the piston in the actuator housing. Directing oil to different sides of the piston increases or decreases exhaust back pressure.

Actuated vanes are mounted around the inside circumference of the turbine housing. A unison ring links all the vanes. When the unison ring moves, all vanes move to the same position. Unison ring

ELECTRONICALLY CONTROLLED VARIABLE GEOMETRY TURBOCHARGER (VGT)

movement occurs when either side of the actuator piston is pressurized by engine oil.

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

The VGT is an exhaust driven centrifugal air compressor that uses signals from the ECM to control intake manifold pressure. The VGT uses a set of moveable vanes in the turbine housing to change the flow of exhaust gases through the VGT. These vanes can be positioned to change the angle or direction of flow to the turbine wheel depending on engine operating conditions. As power demands increase, exhaust gas velocity increases in direct relation, as does intake manifold boost pressure. Conversely, as the flow of exhaust gas diminishes, intake manifold boost pressure is also reduced at the same rate.

Vaness mounted around the internal circumference of the turbine housing are connected to a unison ring. When the unison ring moves, all vanes move to the same position. The unison ring moves, when either side of the actuator piston receives pressurized engine oil, regulated by the control valve, part of a Pulse Width Modulated (PWM) circuit regulated by the ECM. An increase in duty cycle of the PWM circuit routes oil through the control valve in a way that will cause piston movement that increases manifold pressure. Decreasing the pulse width will

direct oil such that the manifold pressure will be decreased. The VGT control is a closed loop system using the EBP sensor to provide feedback to the ECM. The ECM provides a duty cycle in response to engine speed, engine load, manifold pressure, and barometric pressure in order to adjust the duty cycle to match the requirements of the engine.

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

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

Removal

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

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

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

! WARNING: To prevent personal injury or possible 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 a hand cleaner, and wash with soap and water. Wash or discard clothing and rags contaminated with engine fluids.

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

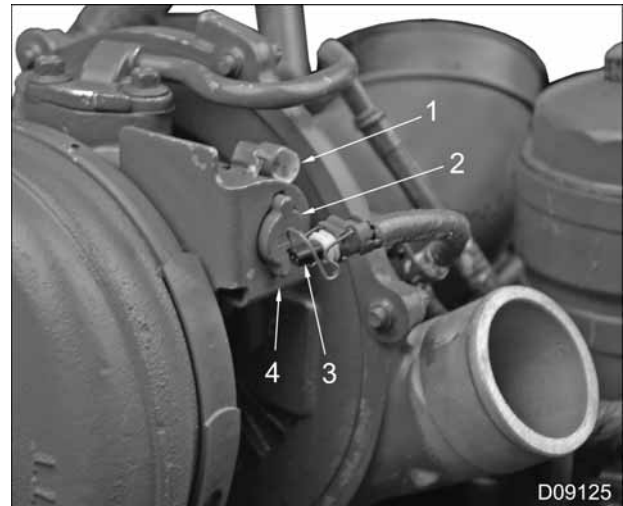


Figure 46 Disconnection of VGT control valve

1. VGT control valve connection
2. VGT control valve
3. VGT control valve connector
4. VGT control valve bracket

1. Disconnect the engine harness electrical connector from the VGT control valve.

VGT Control Valve Removal (If required)

NOTE: The VGT control valve should only be removed for cleaning and inspection, when troubleshooting VGT problems.

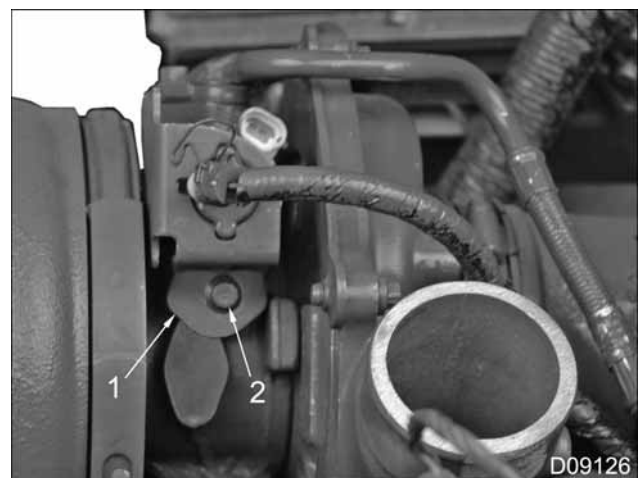


Figure 47 Retaining bolt for VGT control valve

1. VGT control valve bracket
2. Retaining bolt

ELECTRONICALLY CONTROLLED VARIABLE GEOMETRY TURBOCHARGER (VGT)

1. Remove the retaining bolt and control valve bracket for VGT control valve.



Figure 48 VGT control valve

2. Remove VGT control valve from turbocharger center housing.

VGT and Components

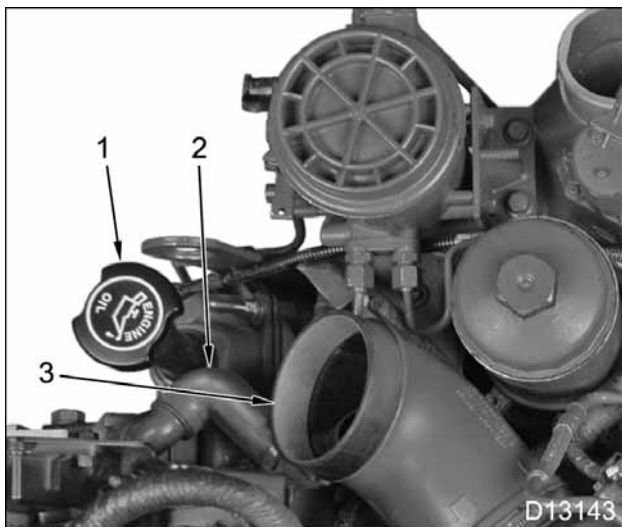


Figure 49 Air inlet duct

1. Lube oil fill extension tube
2. Air inlet duct
3. Air inlet duct clamp

1. Remove oil fill extension tube and put a cap in the oil fill hole of the valve cover to keep out foreign material.



Figure 50 Air inlet duct

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

2. Loosen the air inlet duct clamp.
3. Remove air inlet duct and clamp. Put a cap over the opening of the VGT air inlet, to keep out foreign material.

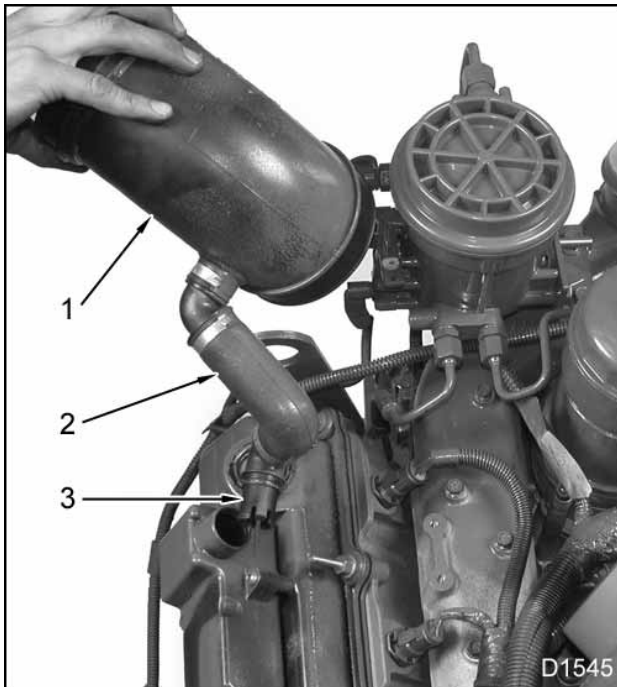


Figure 51 Breather tube and pitot tube

1. Air inlet duct
 2. Breather hose
 3. Pitot tube
4. Remove air inlet duct breather hose by turning breather hose and pitot tube enough to align hold clips with opening, to remove from the crankcase breather cover.
 5. Put caps in the opening of the breather cover vent hole, to keep out foreign material.



Figure 52 Oil supply tube to VGT

1. Oil supply tube
 2. Mounting bolt (2)
6. Remove two M8 x 20 bolts from the oil supply tube mounted on top of the VGT and swing oil supply tube out of the way.
 7. Remove oil supply tube gasket and discard.
 8. Put a cap over oil supply inlet to the VGT, to keep out foreign material.



Figure 53 Oil supply tube for VGT to oil cooler cover assembly

1. Oil supply tube
2. Mounting bolt

ELECTRONICALLY CONTROLLED VARIABLE GEOMETRY TURBOCHARGER (VGT)

9. Disconnect oil supply tube from engine by removing the M8 x 20 flange head bolt.
10. Remove oil supply tube from oil cooler cover assembly.

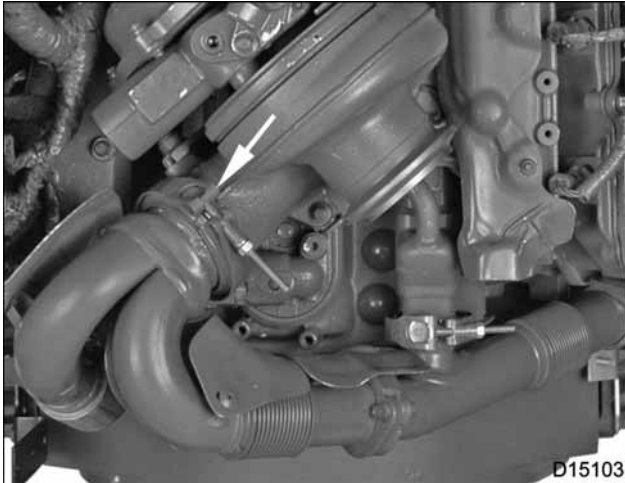


Figure 54 Exhaust adapter V-clamp for VGT

11. Remove exhaust adapter V-clamp.
12. Cover all openings to the VGT when piping is removed, to keep out foreign material.

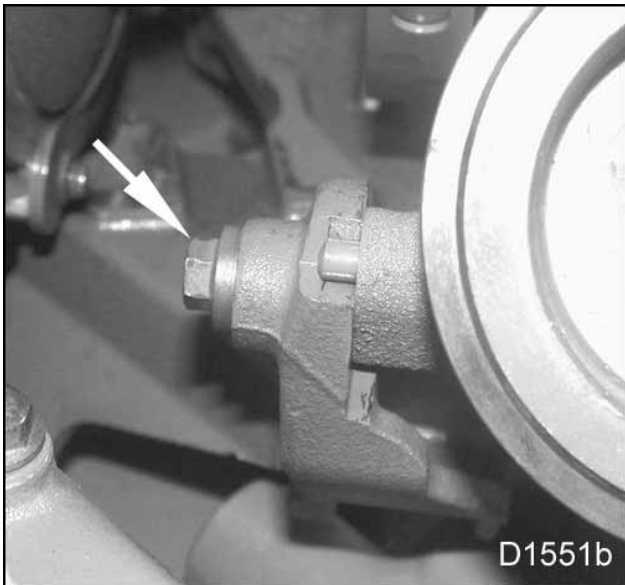


Figure 55 Center mounting bolt and spacer for VGT

13. Remove M8 x 30 flange head bolt and spacer securing the VGT to the center of mounting bracket.

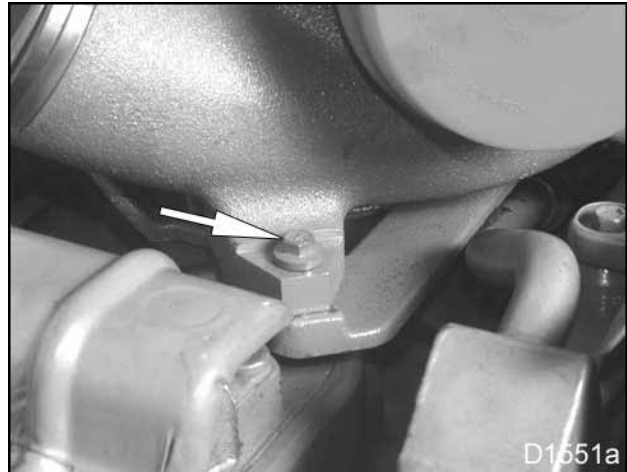


Figure 56 Rear mounting bolt for VGT

14. Remove M8 x 30 flange head bolt securing the VGT to the rear of mounting bracket.

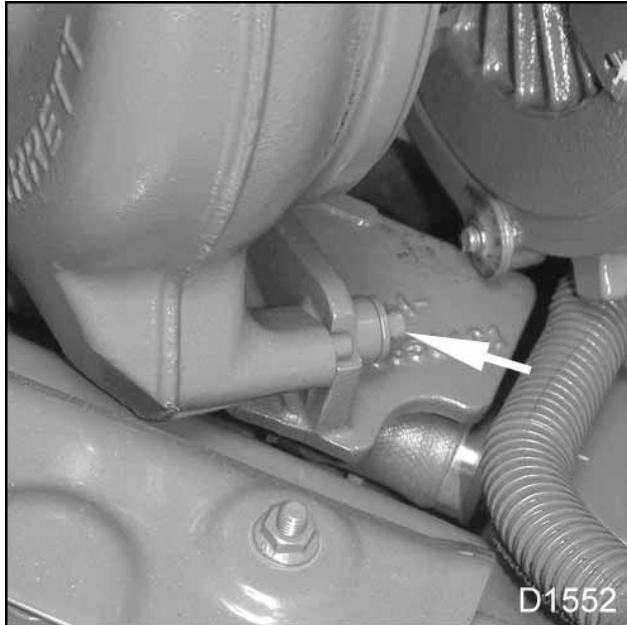


Figure 57 Front mounting bolt and spacer for VGT

15. Remove one M8 x 30 flange head bolt and spacer securing the VGT to the front of mounting bracket.

NOTE: If removing the VGT only, cap off oil drain line to keep out foreign material.

16. Lift the VGT assembly up and off the engine. Make sure all openings in the VGT assembly are capped.

NOTE: Use Compressor Inlet Cap and Exhaust Outlet Cap. (Table 6). If plastic caps are not available, cover openings with tape.

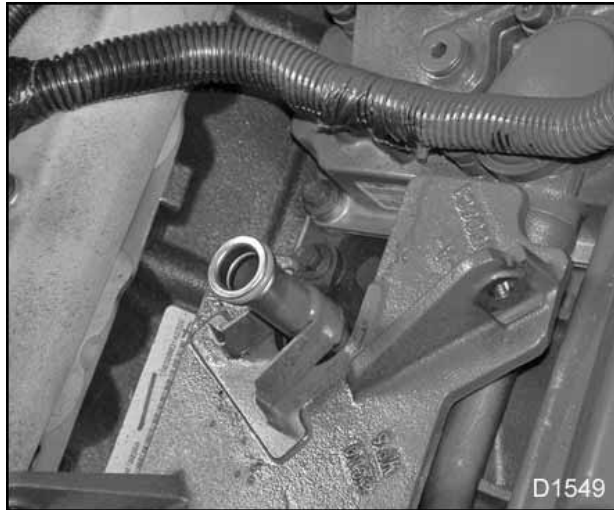


Figure 58 Oil drain tube for VGT



Figure 59 Removal of oil drain tube for VGT

17. Pull oil drain tube out of high-pressure oil pump cover.
18. Put a cap over opening in the high-pressure oil pump cover to keep out foreign material.
19. Remove two O-rings on the oil drain tube and discard.

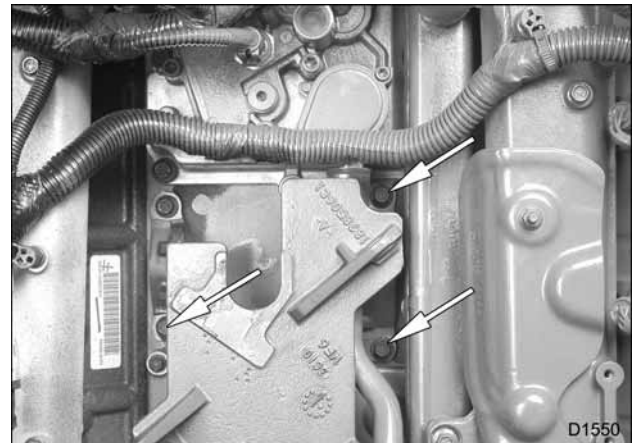


Figure 60 VGT bracket bolts

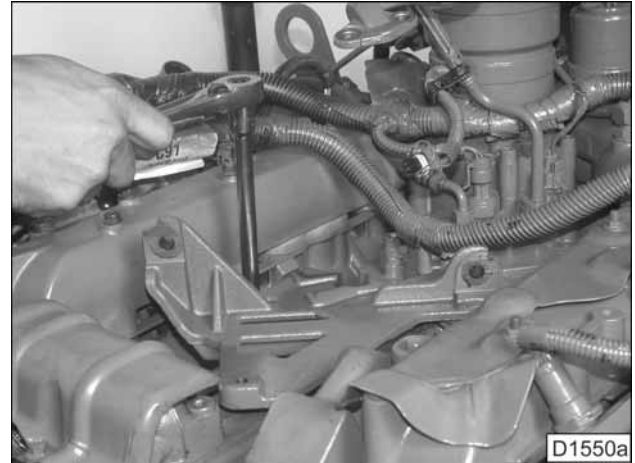
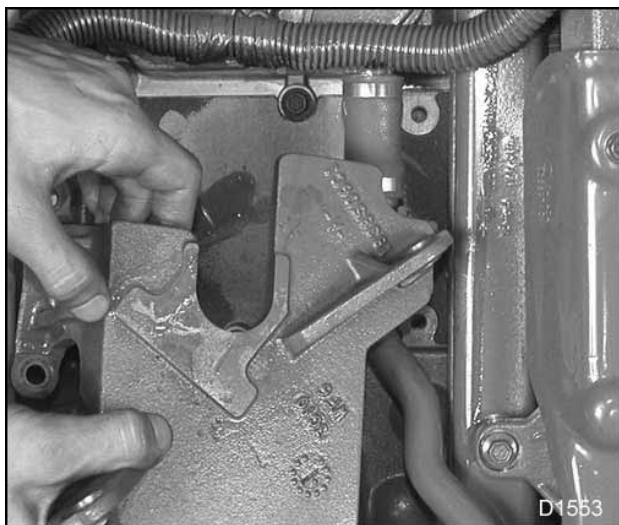


Figure 61 Removal of VGT bracket bolts

20. Remove four M8 x 20 VGT bracket bolts.

ELECTRONICALLY CONTROLLED VARIABLE GEOMETRY TURBOCHARGER (VGT)



21. Lift up the left side of the bracket first so the right side can clear the EGR cooler coolant inlet tube.

Figure 62 VGT mounting bracket

Cleaning and Inspection

VGT Assembly

 **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).

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

Clean the VGT assembly and bracket with a suitable solvent and nylon brush. Dry with filtered compressed air.

Related Components

1. Rinse out inside of oil supply tube, if removed from the oil filter base.
2. Clean VGT mounting bracket, exhaust piping, and oil drain pipe.

Inspection

NOTE: Replace VGT if blades are bent. Do not straighten bent wheel blades.

1. Inspect the compressor impeller and turbine wheel for blade erosion, bending, breakage or deposits. Replace VGT if damaged.

NOTE: Compressor impeller and turbine wheel deposits can be caused by the following:

- High air inlet restriction allows oil to transfer from the VGT center housing, resulting in oil deposits.
 - Excessive oil consumption can result in turbine wheel carbon deposits.
 - Engine over fueling can cause excessive operating temperatures, which can melt aluminum parts. Deposits on the turbine wheel indicate failure.
 - Oil from crankcase breather (mounted on top of the left valve cover). Oil from the breather is normal for this engine.
2. Inspect the turbine and compressor housings for wheel rubbing. Replace the VGT if wheels rub.
 3. Inspect oil drain and supply lines for kinking, clogging, restrictions, and deterioration. Discard both sets of O-rings.

ELECTRONICALLY CONTROLLED VARIABLE GEOMETRY TURBOCHARGER (VGT)

Check Free Rotation and Housing Rub

1. Put VGT on a bench with the shaft in a horizontal position.

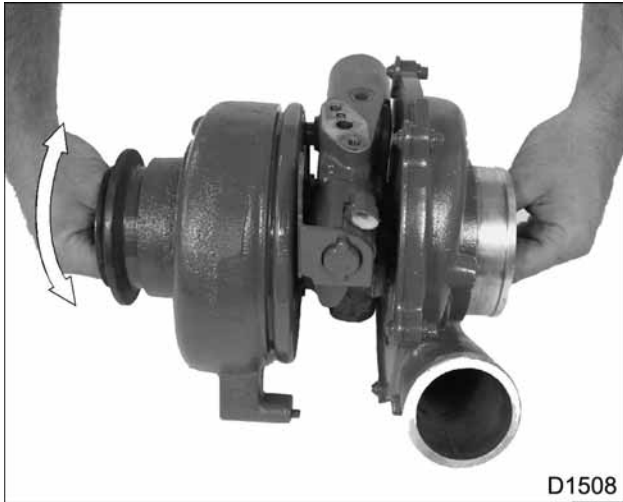


Figure 63 Free rotation of VGT shaft

2. Turn VGT shaft by hand; the shaft must spin freely. Contact with the turbine and compressor housings is not acceptable.

Check Axial End Play

1. With VGT in a stable position, push the impeller shaft toward the turbine housing as far as it will

go. Put tip of dial indicator (Table 6) on end of the compressor side of the shaft and zero the indicator.

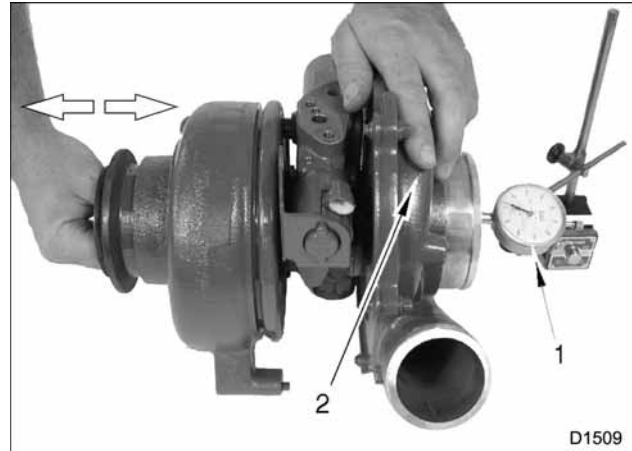


Figure 64 Axial end play

1. Dial indicator with magnetic base
2. Compressor housing
2. Move shaft back toward the dial indicator.
3. If measurement exceeds specifications, (Table 4) replace VGT.

Installation

Variable Geometry Turbocharger (VGT) and Components

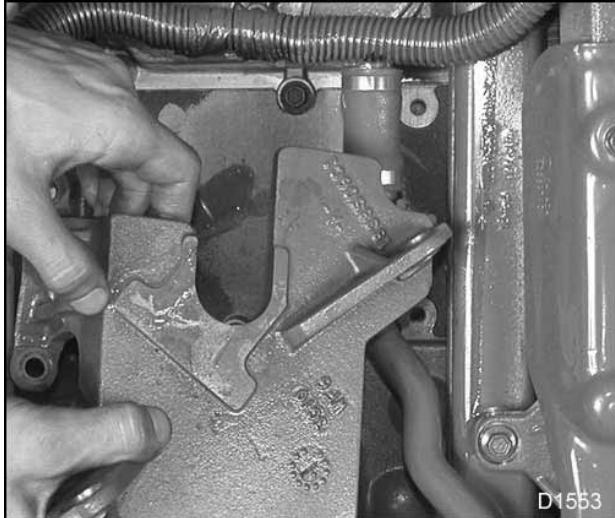


Figure 65 VGT bracket

1. Place VGT bracket in engine valley by putting right side of bracket under EGR cooler coolant inlet tube. Then lower left side over bolt holes.

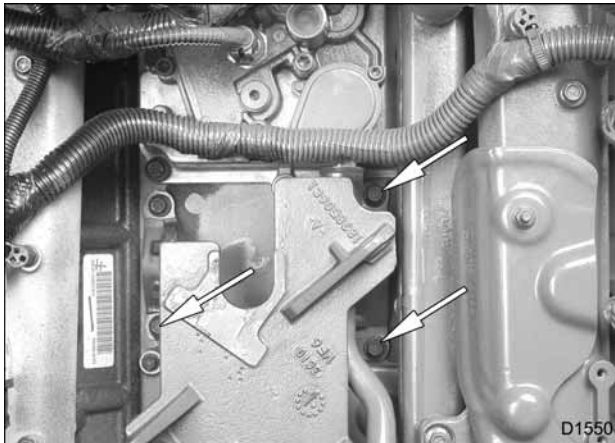


Figure 66 VGT bracket bolts

2. Install four M8 x 20 mounting bolts to secure VGT bracket to crankcase. Tighten bolts to the standard torque (Standard Torques, page 375).



Figure 67 Lubrication for O-rings on oil drain tube for VGT

3. Install two new oil drain tube O-rings and lubricate both O-rings with clean engine oil.
4. Remove cap and install drain tube in the high-pressure oil pump cover.

NOTE: If not immediately installing the VGT, install a cover over the oil drain tube.

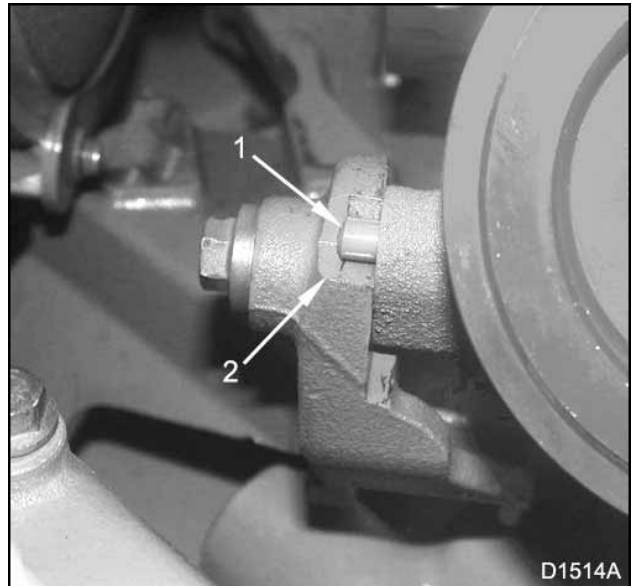


Figure 68 VGT alignment dowels and bosses

1. Alignment dowel
2. Alignment boss

ELECTRONICALLY CONTROLLED VARIABLE GEOMETRY TURBOCHARGER (VGT)

5. Use alignment dowels to position VGT on bosses of forward and middle mounting brackets.
6. Remove the oil drain tube cap (if it was installed) and lower VGT on mounting brackets and on oil drain tube.
7. Coat bolt threads for three M8 x 30 flange head bolts with anti-seize compound and secure VGT to mounting bracket.
8. Tighten bolts to the special torque (Table 5).

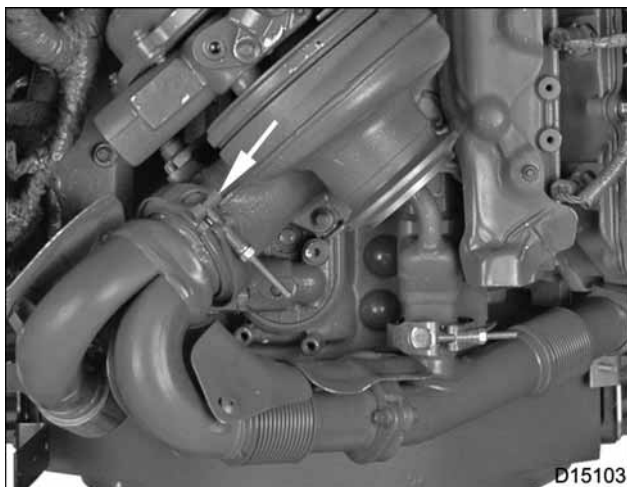


Figure 69 Exhaust adapter V-clamp for VGT

9. Remove the exhaust outlet cover, install exhaust piping, and tighten VGT exhaust adapter V-clamp to the special torque (Table 5).
10. Remove cover on oil supply port on the oil cooler cover assembly.
11. Install and lubricate a new O-ring on oil supply tube.



Figure 70 Oil supply tube for VGT to oil cooler cover assembly

1. Oil supply tube
2. Mounting bolt

12. Install VGT oil supply tube in oil supply line port in the oil cooler cover assembly.
13. Install and tighten the M8 x 20 flange head bolt. Torque the oil supply tube bolt to the standard torque (Standard Torques, page 375).

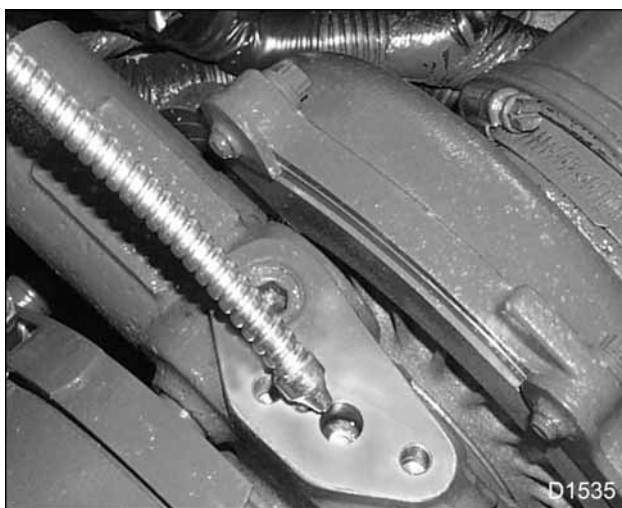


Figure 71 Prelubrication of VGT bearings

CAUTION: To prevent engine damage, prelubricate VGT bearings when installing the VGT.

14. Prelubricate the oil inlet hole of the VGT with clean engine oil and spin compressor wheel several times to coat bearings with oil. Refill the oil inlet hole up to oil supply tube mounting surface.



Figure 72 Oil supply tube for VGT

1. Oil supply tube
2. Mounting bolt (2)

15. Position oil supply tube over a new gasket and secure with two M8 x 20 bolts.
16. Tighten to the standard torque (Standard Torques, page 375). Alternate tightening between both bolts until the correct torque is reached.

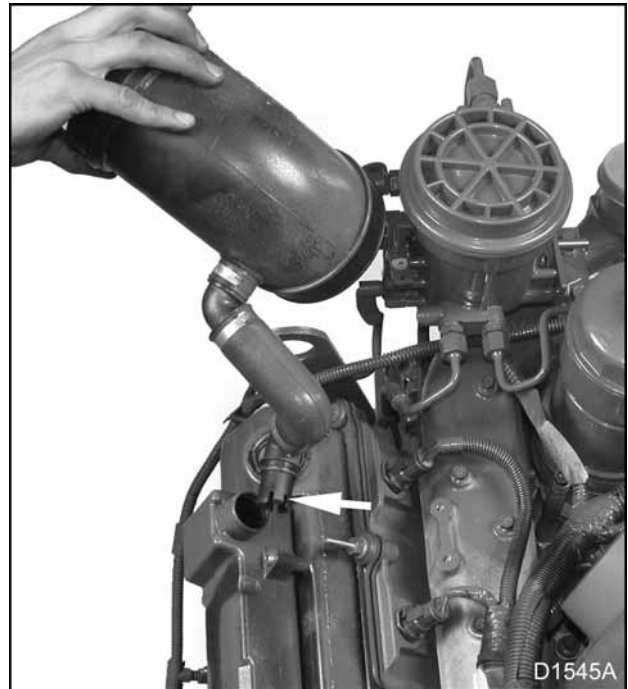


Figure 73 Breather tube with pitot tube in crankcase breather

17. Remove cap and press pitot tube in the crankcase breather until it locks in place.

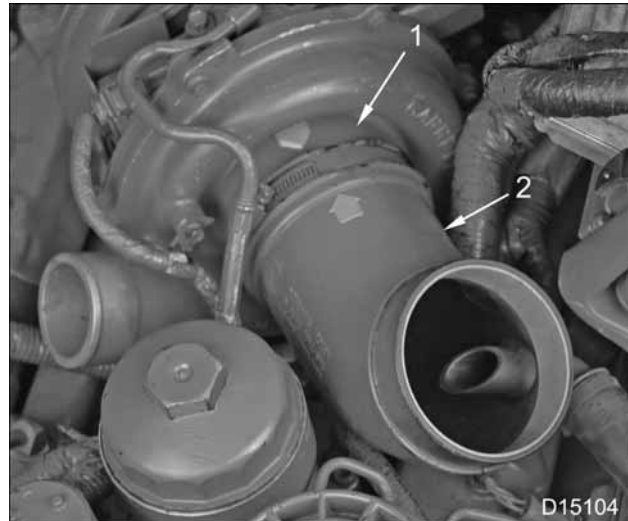


Figure 74 Air inlet duct to VGT

1. VGT
2. Air inlet duct

ELECTRONICALLY CONTROLLED VARIABLE GEOMETRY TURBOCHARGER (VGT)

18. Remove cap and align the arrow on the inlet duct with the mark on the inlet housing opening on VGT and press on the VGT.
19. Secure air inlet duct to VGT by tightening hose clamp to the special torque (Table 5).

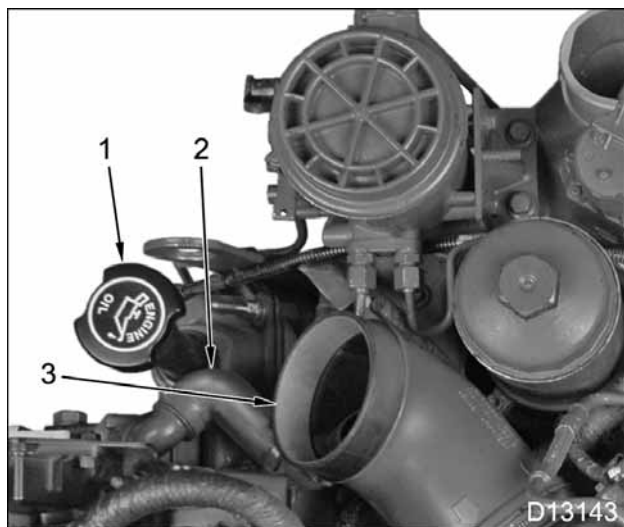


Figure 75 Air inlet duct

1. Lube oil fill extension tube
2. Breather hose
3. Air inlet duct

20. Remove cap from the valve cover and thread the oil fill extension tube in the valve cover and torque to the special torque (Table 5).

Control Valve (If previously removed)



Figure 76 O-ring lubrication

1. During reassembly, lubricate new O-rings with clean engine oil. Make sure O-rings are seated correctly – not twisted or distorted.



Figure 77 VGT control valve

2. Install control valve carefully to avoid twisting or cutting O-rings.

NOTE: Do not use the retaining bolt to draw the control valve into the housing. Push the VGT control valve in by hand to seat securely before installing bracket and bolt.

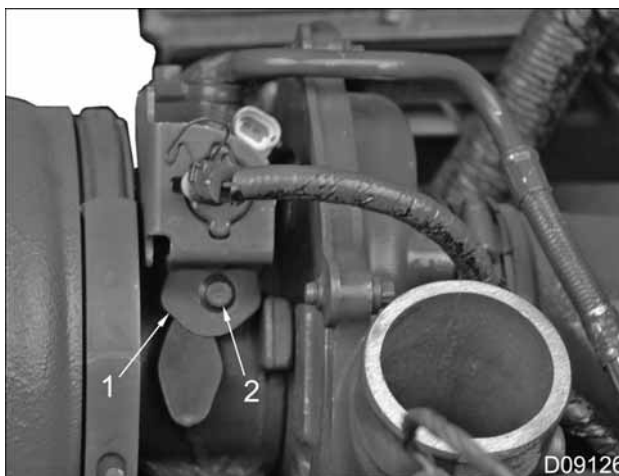


Figure 78 Retaining bolt for VGT Control valve

1. VGT control valve bracket
2. Retaining bolt

3. Install control valve bracket and retaining bolt and tighten bolt to standard torque (Standard Torques, page 375).

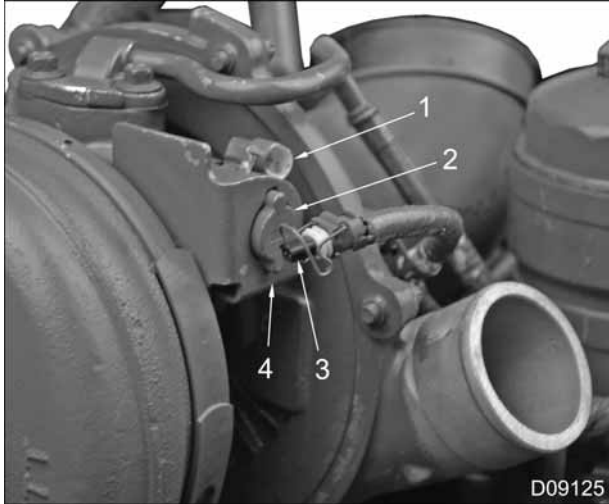


Figure 79 VGT control valve

1. VGT control valve connection
2. VGT control valve
3. VGT control valve connector
4. VGT control valve bracket

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

1. Connect the VGT control valve to the electrical harness.
2. Reinstall all safety guards, shields, and covers.
3. Make sure all tools, cleanliness covers, loose parts, and service equipment are removed from the engine work area.

ELECTRONICALLY CONTROLLED VARIABLE GEOMETRY TURBOCHARGER (VGT)

Specifications

Table 4 Variable Geometry Turbocharger (VGT) Shaft

Maximum turbine shaft axial end play	0.091 mm (0.0036 in)
Maximum turbine shaft radial shaft movement (play)	0.5 mm (0.02 in)

Special Torque

Table 5 VGT Bolts and Clamps

Air inlet duct hose clamp	4 to 5 N·m (36 to 48 lbf·in)
Oil fill extension tube	14 ± 1 N·m (124 ± 9 lbf·in)
VGT to mounting bracket bolts	31 ± 4 N·m (23 ± 3 lbf·ft)
VGT exhaust adapter V-clamp	12 N·m (108 lbf·in)

Special Service Tools

Table 6 Turbocharger

Description	Tool Number
Cap Kit (All)	ZTSE4610
Dial Indicator with Magnetic Base	Obtain locally
Intake Guard	ZTSE4548

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Component Exploded Views

Intake Manifold

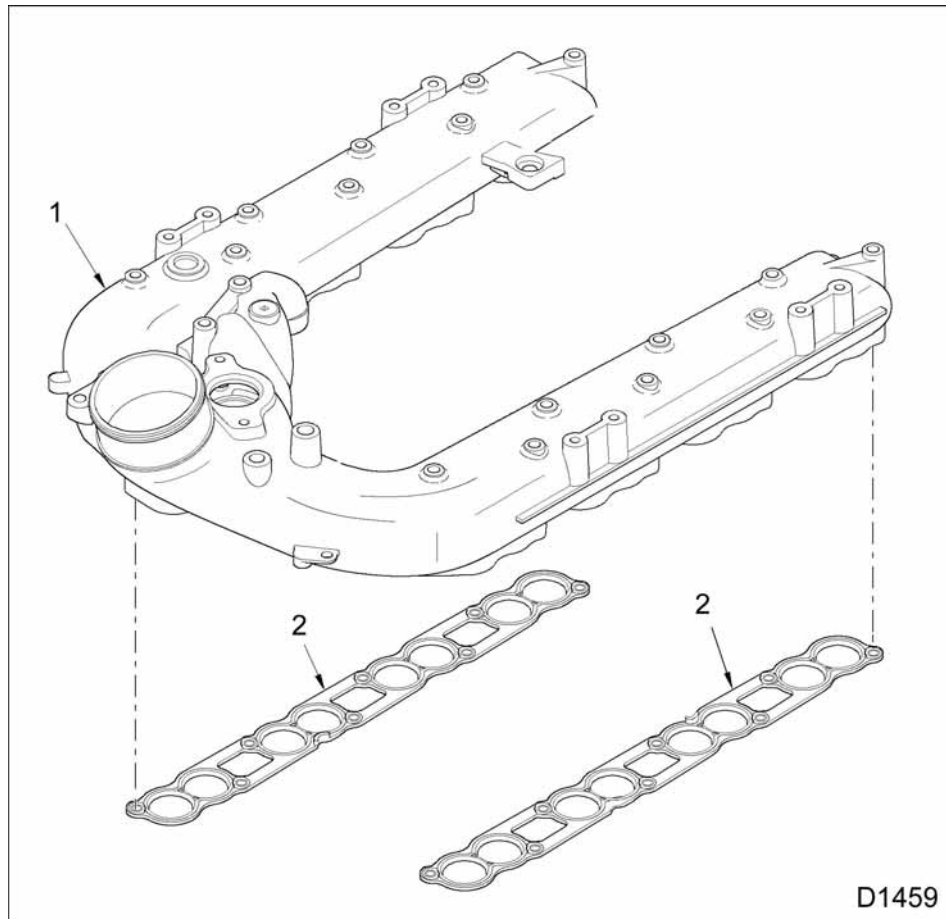
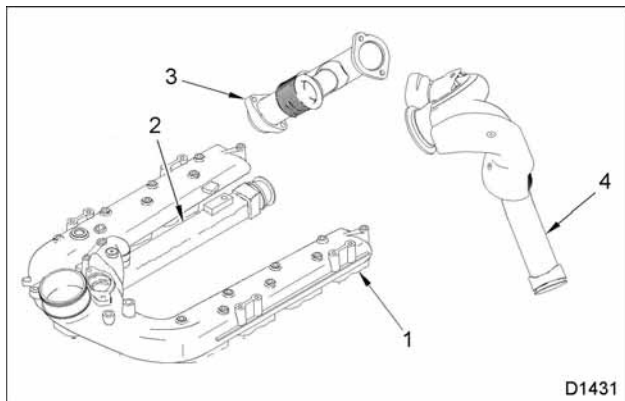
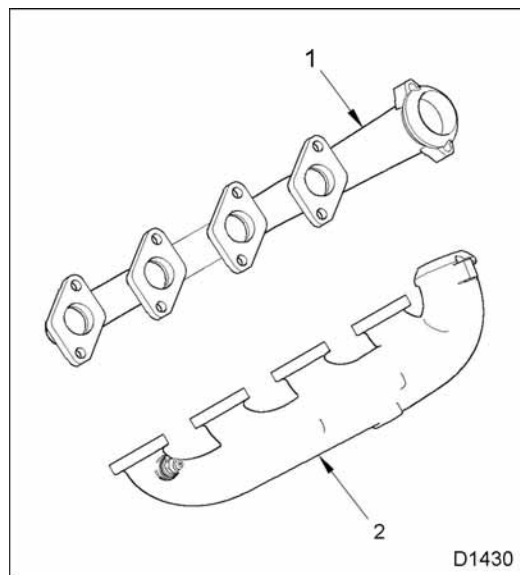


Figure 80 Intake manifold and gaskets

1. Intake manifold
2. Intake manifold gasket (2)

Exhaust Gas Recirculation Components**Figure 81 Exhaust Gas Recirculation Components (EGR)**

1. Intake manifold assembly
2. EGR cooler
3. Exhaust tube assembly (right side)
4. Shielded tube exhaust assembly (left side)

**Figure 82 Exhaust manifolds**

1. Exhaust manifold (right)
2. Exhaust manifold (left)

Removal

Exhaust Manifolds and Tubing

Left Exhaust Manifold and Tubing

! 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.

NOTE: Engine fluids (oil, fuel and coolant) are a threat to the environment. Recycle or dispose of engine fluids according to local regulations. Never put engine fluids in the trash, pour fluids on the ground, in sewers or bodies of water.

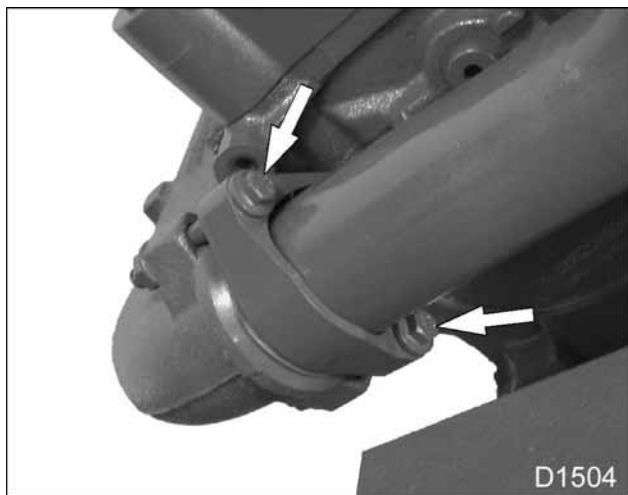


Figure 83 Manifold mounting bolts for shielded tube exhaust assembly

1. Remove two M8 x 60 bolts securing the shielded tube exhaust assembly on left exhaust manifold.

NOTE: Install caps (Table 9) to cover all openings. If plastic caps are not available, cover with tape.



Figure 84 Exhaust tube bolts (upper right)

2. Remove two M8 x 30 bolts securing the shielded tube exhaust assembly. Discard exhaust tube gasket.

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

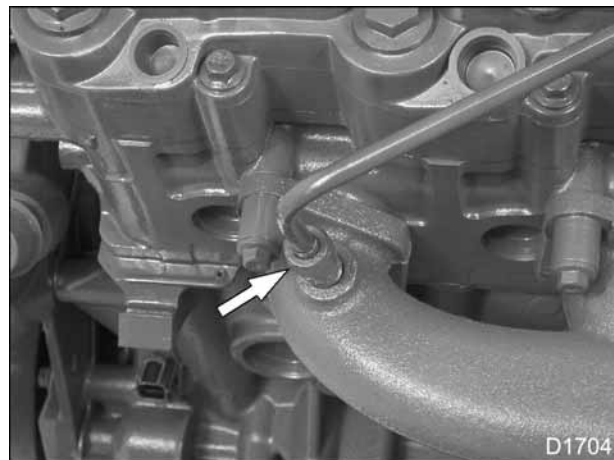


Figure 85 Tube fitting for EBP sensor

3. Remove tube fitting for EBP sensor and pull tube from exhaust manifold.

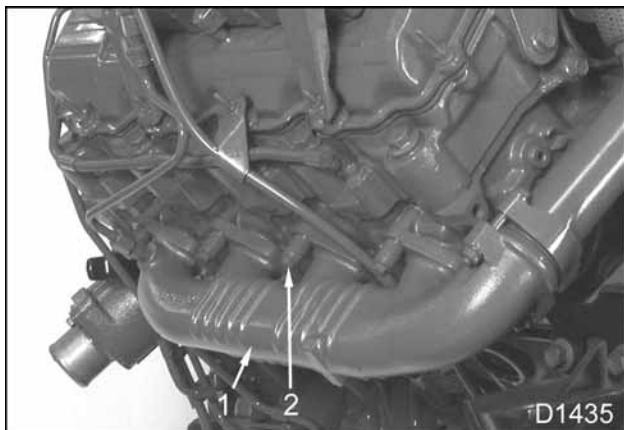


Figure 86 Mounting bolts and spacers for left exhaust manifold

1. Exhaust manifold
 2. Exhaust manifold mounting bolt and spacer (8)
4. Remove eight M8 x 40 exhaust manifold bolts and remove manifold.
 5. Remove and discard manifold gasket.

Right Exhaust Manifold and Tubing

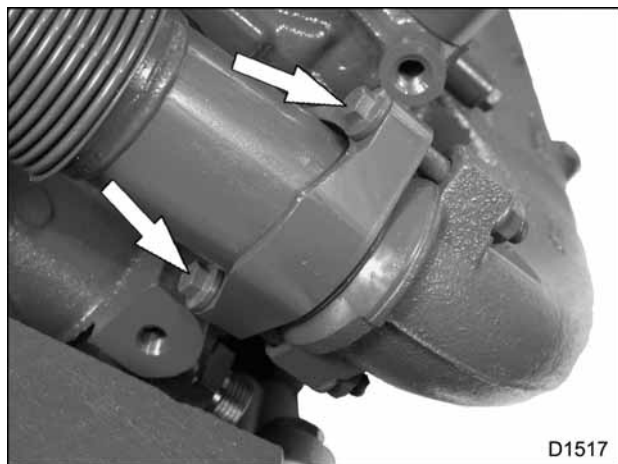


Figure 87 Right exhaust tube assembly

1. Remove two M8 x 60 bolts connecting the right exhaust tube assembly to the right exhaust manifold.

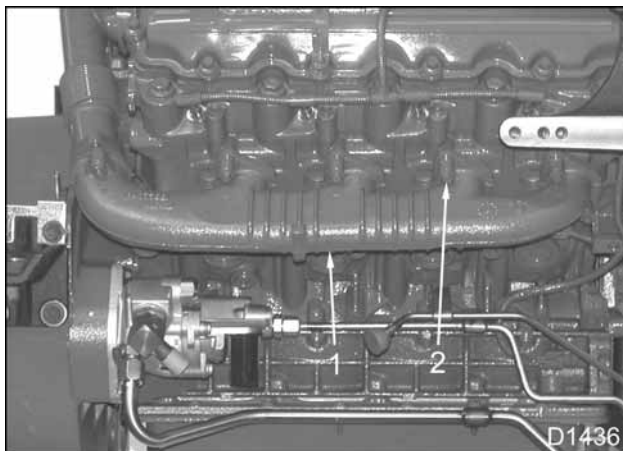


Figure 88 Mounting bolts and spacers for right exhaust manifold

1. Exhaust manifold
 2. Prevailing torque bolt and spacer (8)
2. Remove eight M8 x 40 prevailing torque bolts and remove manifold.
 3. Remove and discard manifold gasket.

Exhaust Gas Recirculation (EGR) Valve

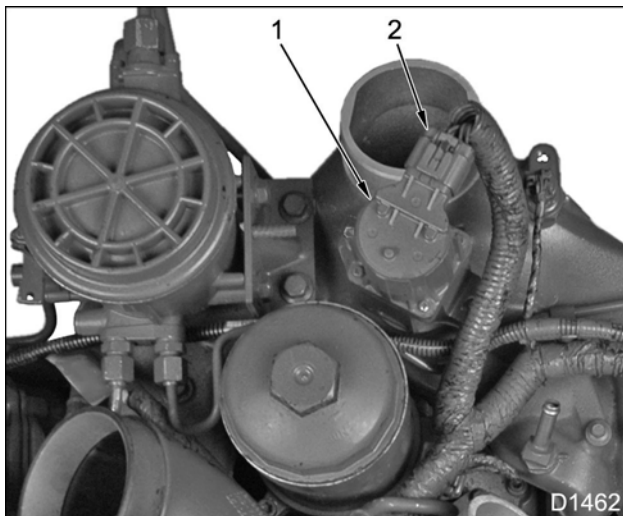


Figure 89 EGR valve and 8-pin electrical connector

1. EGR valve
2. 8-pin electrical connector

1. Disconnect 8-pin electrical connector from EGR valve.

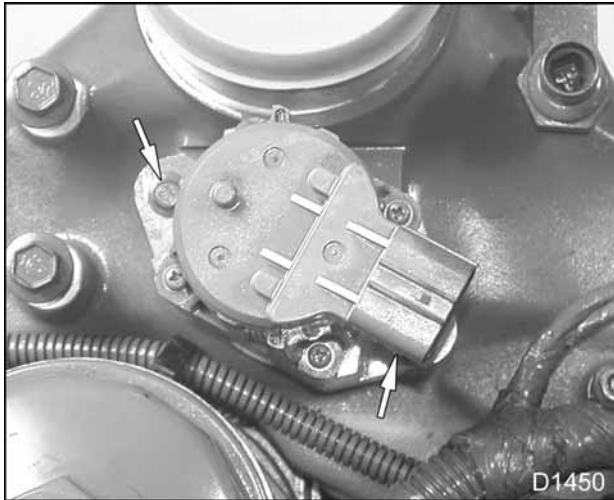


Figure 90 EGR valve retaining bolts

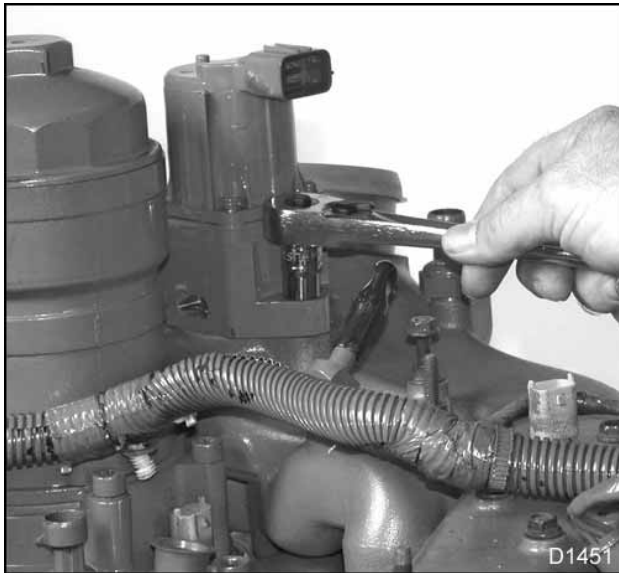


Figure 91 EGR valve retaining bolts

2. Remove two M6 x 35 EGR valve retaining bolts.
3. Turn the EGR valve counterclockwise.

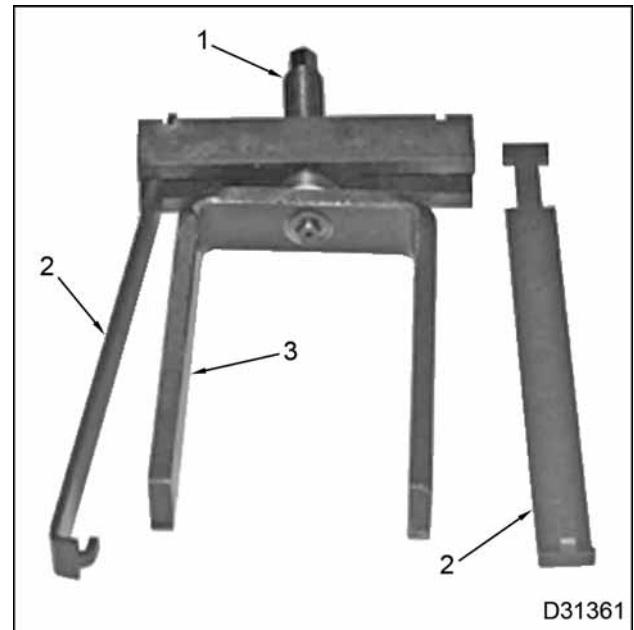


Figure 92 EGR Valve Puller

1. Screw
2. J arm with tab
3. Puller legs

4. Install the EGR valve puller (Table 9).

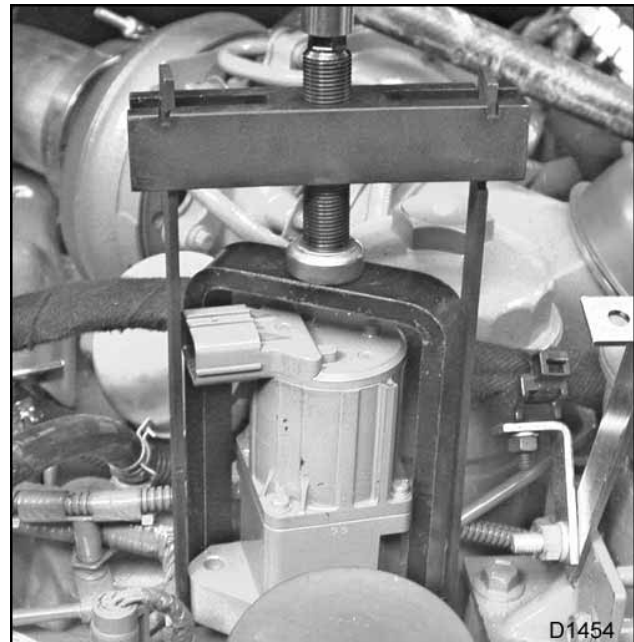


Figure 93 EGR valve puller installed

5. Slip the pin of each J-arm under and in the bolt hole of the EGR mounting flange and hook the top end in the puller beam.
6. Position the puller legs over the EGR bolt holes in the intake manifold.



Figure 94 EGR valve removed

7. Turn threaded shaft clockwise to remove EGR valve.

CAUTION: To prevent engine damage, after removing the EGR valve, vacuum loose carbon deposits and debris from inside the intake manifold.

8. Remove and discard three O-rings.

Intake Manifold and EGR Cooler

NOTE: Before removing intake manifold, remove the following components:

- Fuel Filter Housing and Lines
- VGT

See “Fuel System” and “Electronically Controlled VGT” sections for removal procedures.

! 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, blow out or vacuum dirt and debris under the intake manifold. This prevents dirt and debris from entering intake ports when the manifold is removed.

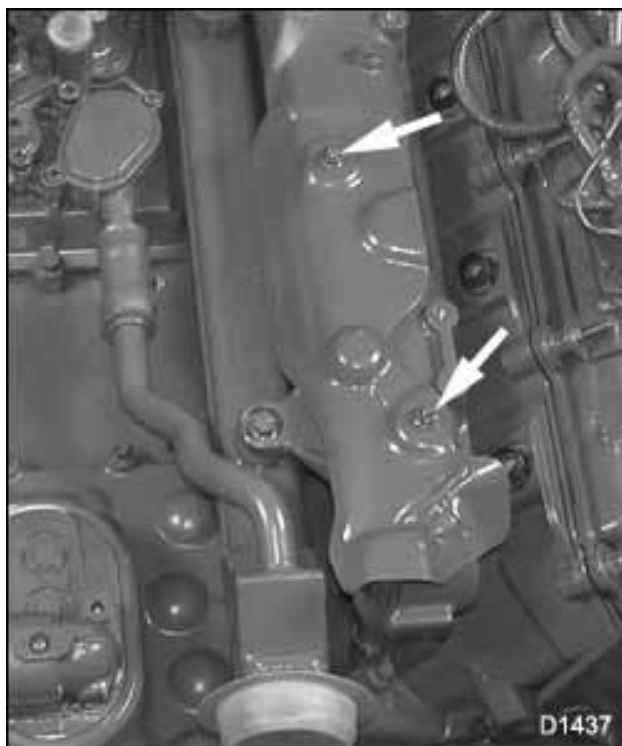


Figure 95 Intake heat shield mounting nuts (right side)

1. Remove two M6 intake heat shield nuts on the right side of the intake manifold.
2. Remove heat shield.

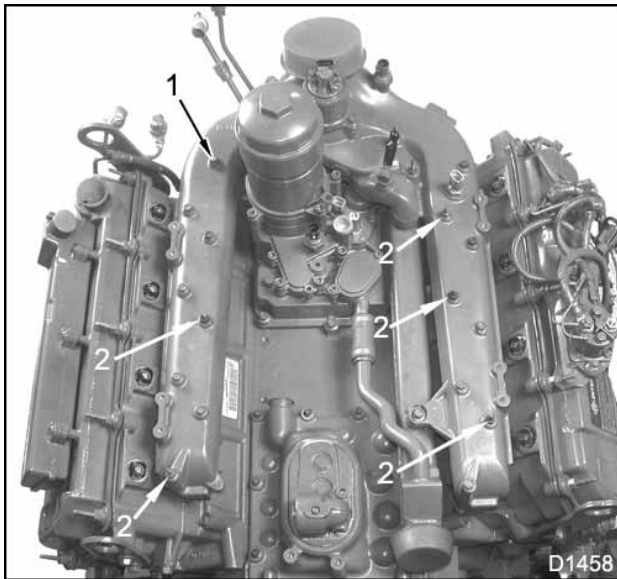


Figure 96 Dog point bolts stud bolts

1. Bolt (M6 x 95 dog point) (11)
 2. Bolt (M6 x 95) stud (5)
3. Remove 11 dog point bolts and 5 stud bolts.

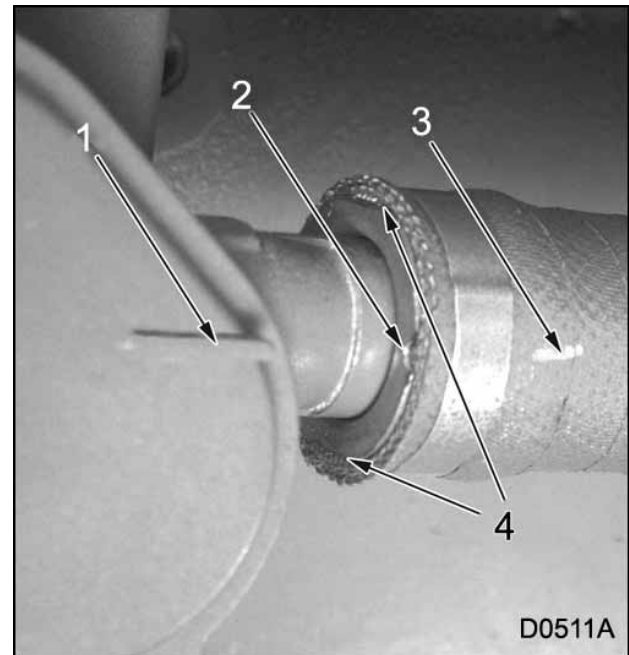


Figure 97 EGR coolant inlet coupling

1. Index feature on coolant supply port cover
 2. Recess
 3. Single index mark
 4. Flat edge representing dual index marks
4. Align single index mark (if visible) or one of the recesses on the end of the EGR inlet coolant coupling (Figure 97) with index feature located on coolant supply port cover.

This aligns the detentes inside the coupling with the raised slide-off area of the coolant supply port.

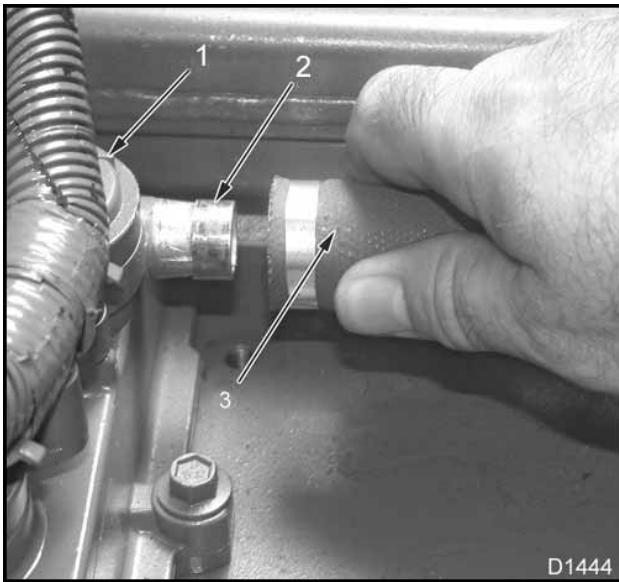


Figure 98 EGR coolant inlet coupling removal from coolant supply port

1. Index feature on EGR coolant supply cover
 2. Coolant supply port
 3. EGR coolant inlet coupling
5. Slide the coupling off the port.
 6. Slide EGR coolant inlet coupling toward rear of engine, away from coolant supply port.

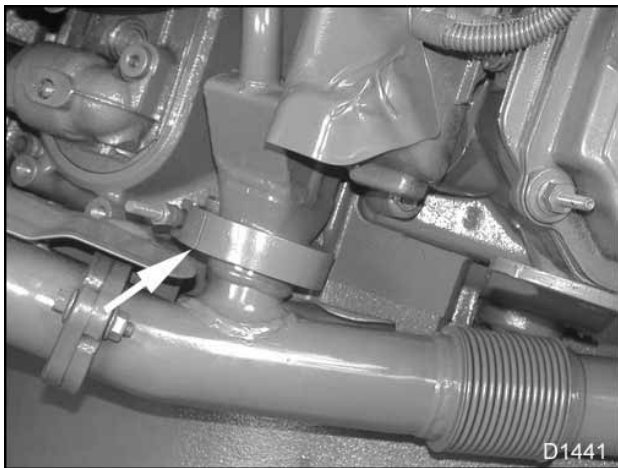


Figure 99 V-clamp on EGR Cooler

7. Remove V-clamp from EGR cooler.

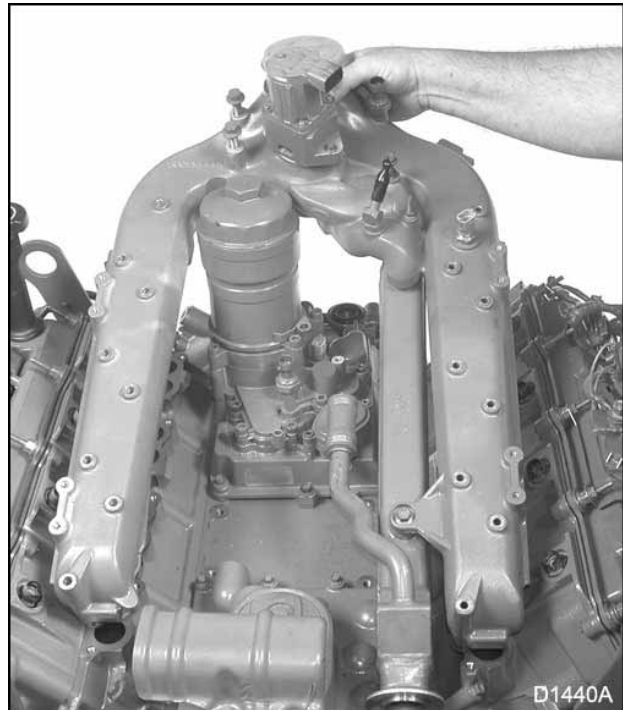


Figure 100 Intake manifold and EGR cooler

8. Lift intake manifold assembly straight up to remove.
 9. Remove and save steel gasket for EGR cooler.
- NOTE:** The EGR cooler will be bolted to the intake manifold.
10. Put protective magnetic covers over intake ports in cylinder head (Table 9).

Exhaust Gas Recirculation (EGR) Cooler

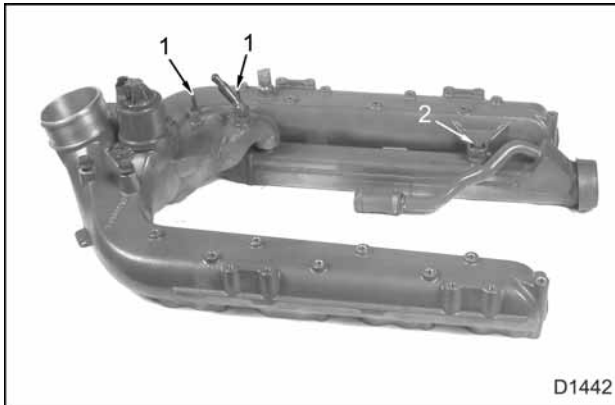


Figure 101 EGR cooler retaining bolts

1. Bolt (M6 x 20) stud (2)
2. Bolt (M6 x 16)

1. Put intake manifold on workbench.
2. Remove two M6 x 20 stud bolts and one M8 x 16 bolt securing the EGR cooler to the intake manifold.

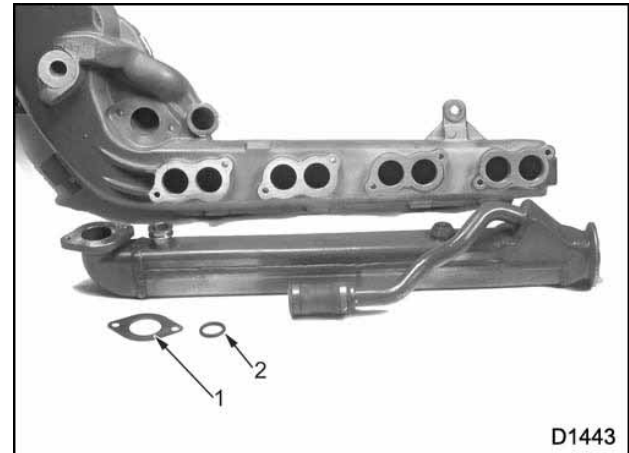


Figure 102 EGR cooler assembly

1. EGR cooler to intake manifold gasket
2. EGR cooler O-ring

3. Remove cooler assembly and discard gasket.
4. Remove O-ring.
5. Remove and save boss grommets.

Cleaning, Inspection, and Testing

Intake and Exhaust Manifolds

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

Clean contact areas of EGR O-ring in the intake manifold, using Injector Sleeve Brush (Table 9). Make sure carbon above and below contact areas can be vacuumed from the intake manifold. Vacuum loose carbon debris.

Exhaust Gas Recirculation (EGR) Valve

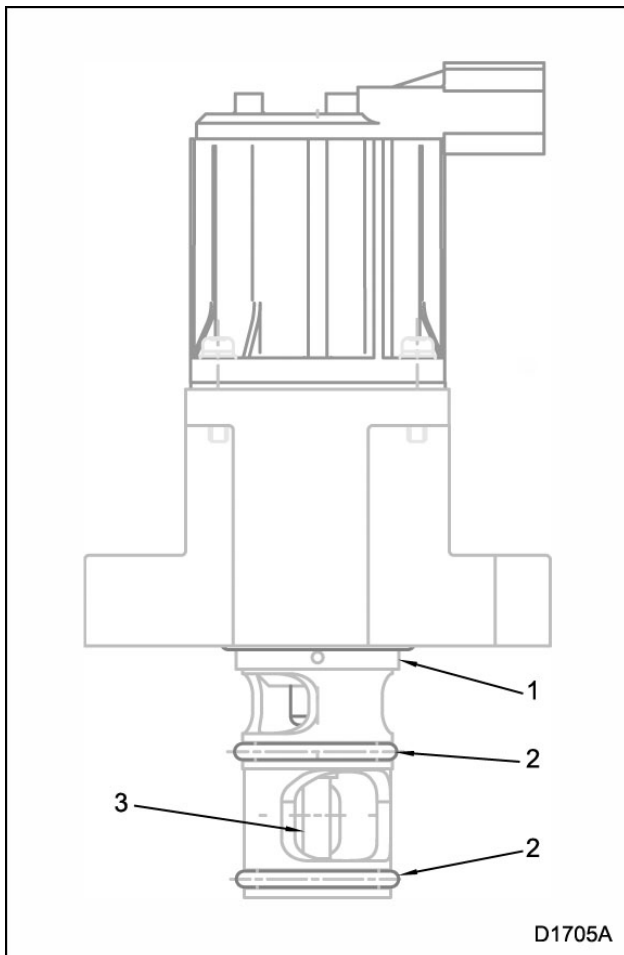


Figure 103 EGR valve assembly

1. Large O-ring
2. Valve group O-rings (2)
3. Common pintle shaft

Check the pintle shaft and frame for misalignment. Remove both O-rings and large O-ring (if not removed) and discard. For electrical inspections, see *Engine Diagnostic Manual* EGES-240.

Manifold Warp Test for Right and Left Exhaust Manifold

1. Use a straightedge and feeler gauge to check seating surface flatness for right and left exhaust manifolds.
2. Check for flatness – across left and right and diagonally. See “Intake and Exhaust manifolds” (Table 7).
3. If specifications are not met, replace right or left exhaust manifold.

Intake Manifold

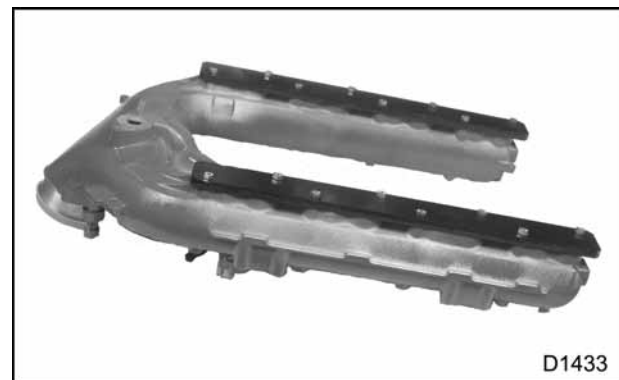


Figure 104 Test plates installed on intake manifold

1. Install Intake Manifold Pressure Plates (Table 9) .

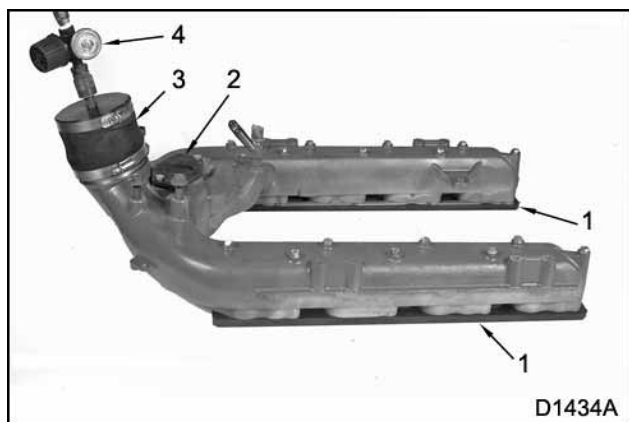


Figure 105 Set up for intake manifold pressure test

1. Test plate
 2. Intake Manifold Pressure Test Plug
 3. Intake Manifold Pressure Test Cap
 4. Air supply pressure regulator
2. Install Intake Manifold Pressure Test Plug (Table 9) in EGR orifice.
 3. Install Intake Manifold Pressure Test Cap (Table 9) on air intake.

! 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).

4. Submerge intake manifold assembly in water.
5. Use a regulated filtered air supply and pressurize to 172 to 207 kPa (25 to 30 psi). Inspect for leaks in the intake plenum, EGR, and coolant passages. Replace intake manifold, if necessary.
6. Inspect intake manifold gasket seal beads for defects. Replace gasket, if necessary.

Exhaust Gas Recirculation (EGR) Cooler

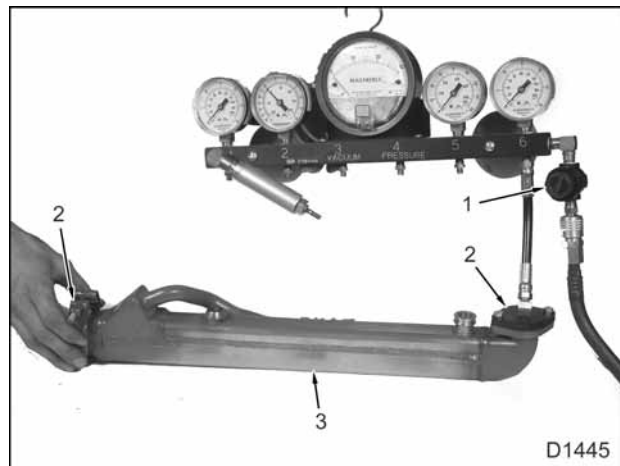


Figure 106 EGR cooler with pressure test plates installed

1. Air pressure regulator assembly
 2. EGR cooler test plates
 3. Cooler assembly
1. Install EGR cooler test plates (Table 9) to each end of the EGR cooler assembly.
- ! WARNING:** To prevent personal injury or death, wear safety glasses with side shields. Limit compressed air pressure to 207 kPa (30 psi).
2. Attach an air pressure regulator to the EGR cooler. Connect to shop air supply and adjust air pressure to approximately 172 to 207 kPa (25 to 30 psi).
 3. Completely submerge EGR cooler in sink or large container of water. Inspect for air bubbles coming from coolant passages.
 4. Reinstall EGR cooler assembly, if leaks are not detected. If leaks are detected, install new cooler assembly.

Installation

Exhaust Gas Recirculation (EGR) Cooler

1. Place new O-ring on the EGR cooler to manifold seal tube and lubricate O-ring with clean engine oil before assembly.

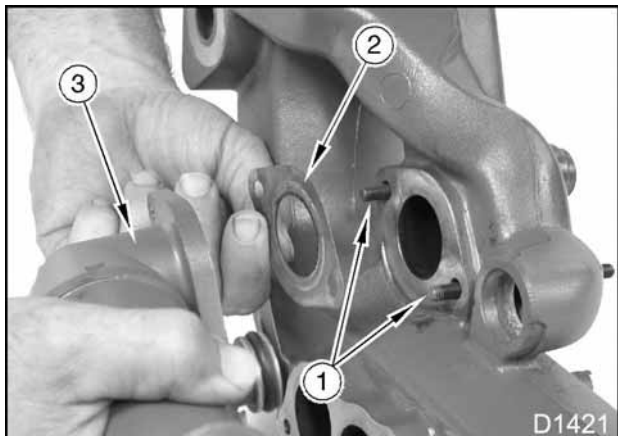


Figure 107 EGR cooler connection to intake manifold

1. Stud bolt (M6 x 20) (2)
2. EGR cooler to manifold gasket
3. EGR cooler

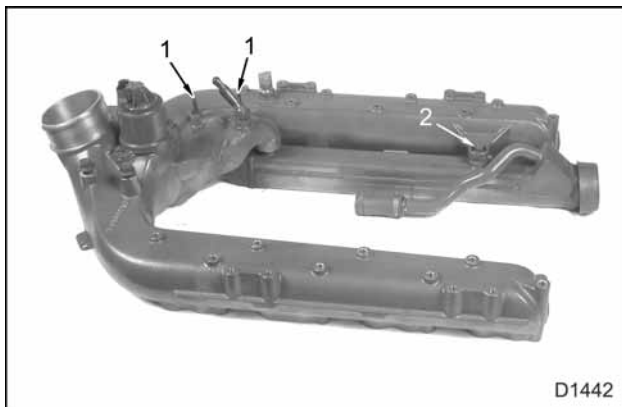


Figure 108 EGR cooler retaining bolts

1. Bolt (M6 x 20) stud (2)
 2. Bolt (M6 x 16)
2. Install a new EGR cooler gasket and connect the EGR cooler to the intake manifold. Install and hand tighten two M6 x 20 stud bolts.

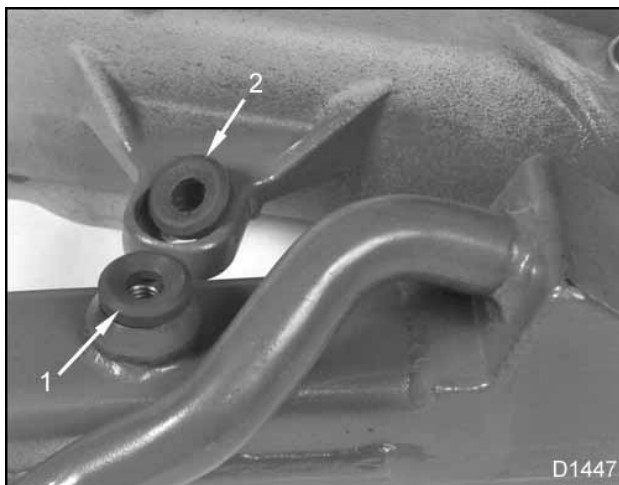


Figure 109 Bosses between EGR cooler and intake manifold

1. Boss grommet
2. Intake manifold bolt tab grommet

3. Set a grommet on the EGR cooler boss, align the intake manifold bolt tab over the grommet, and set a grommet in the bolt tab cavity.

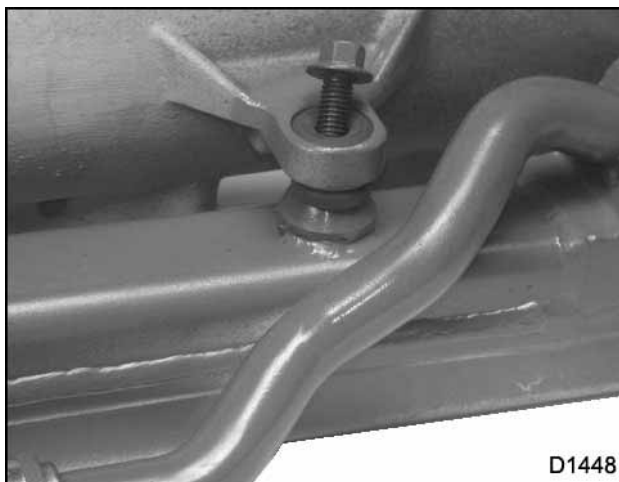


Figure 110 EGR rear mount bolt

4. Insert and hand tighten one M8 x 15 hex washer bolt.

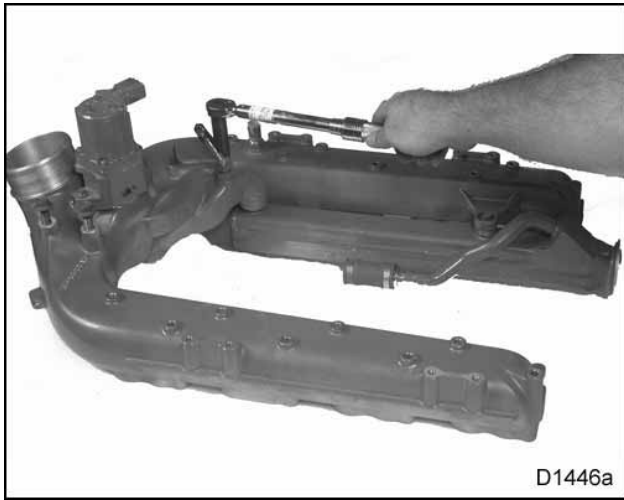


Figure 111 EGR cooler retaining bolts

5. Tighten all three fasteners to the standard torque (Standard Torques, page 375).

Intake Manifold and EGR Cooler



Figure 112 Front module seal

1. Install a new front module seal between the intake manifold and front cover module.

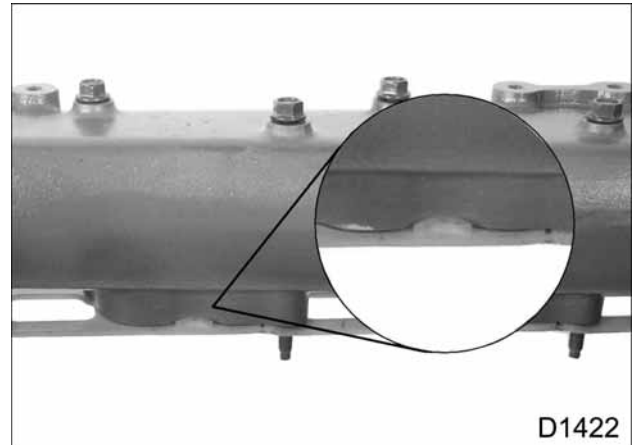


Figure 113 Intake manifold gasket with centering tab

2. Position a new intake manifold gasket on each side of intake manifold and run two bolts through each side to hold gaskets. Make sure centering tabs are facing up in the manifold, while positioned inboard toward the engine valley.
3. Remove protective magnetic covers (Table 9) from cylinder head intake ports.

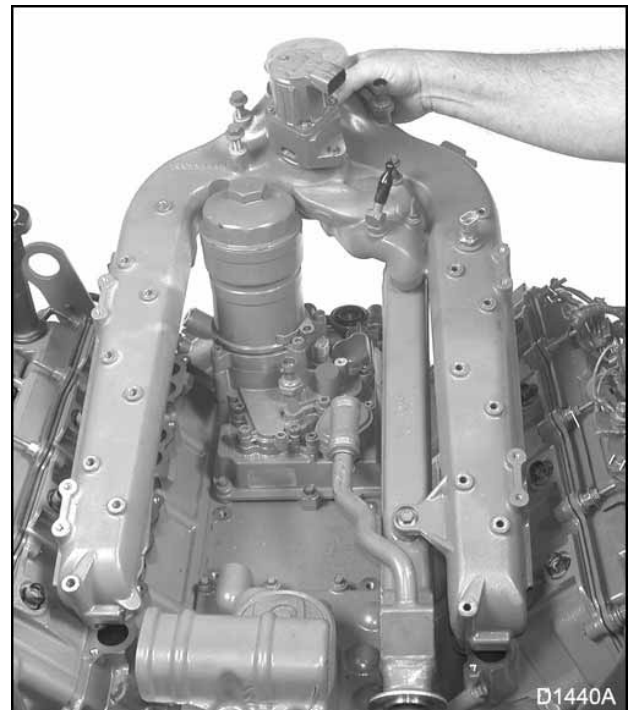


Figure 114 Intake manifold and EGR cooler assembly

4. Position intake manifold on cylinder heads.

5. Loosely install 11 dog point bolts and 5 stud bolts.

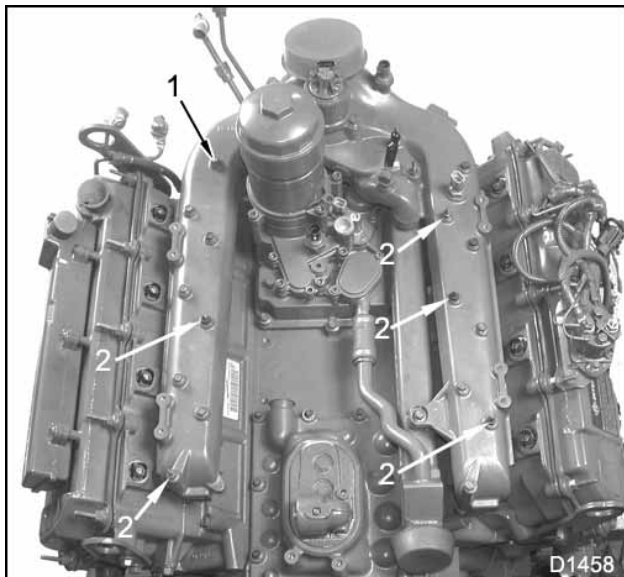


Figure 115 Dog point bolts and stud bolts

1. Bolt (M6 x 95 dog point) (11)
2. Bolt (M6 x 95) stud (5)

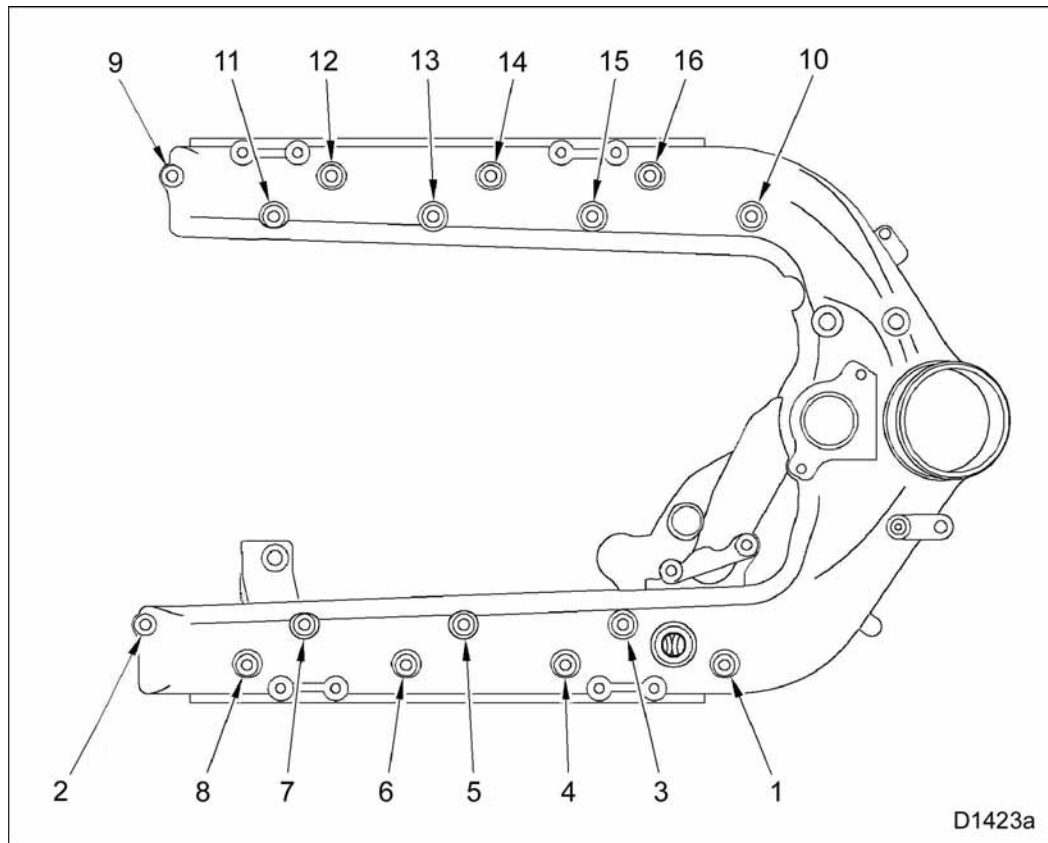


Figure 116 Torque sequence for intake manifold mounting bolts

6. Torque dog point bolts and stud bolts to the special torque value (Table 8) (Figure 116).

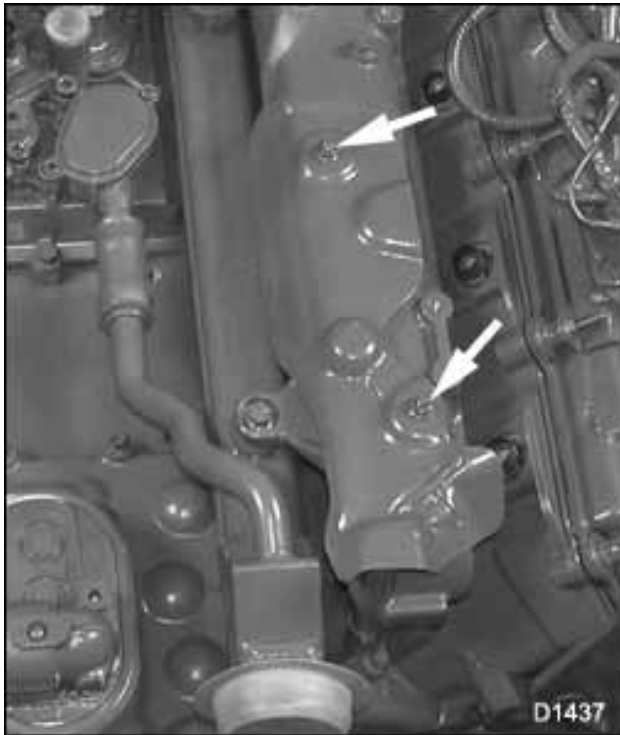


Figure 117 Heat shield mounting nuts (right side)

7. If equipped, install intake heat shield and two M6 nuts on right side of intake manifold and tighten to the special torque (Table 8).

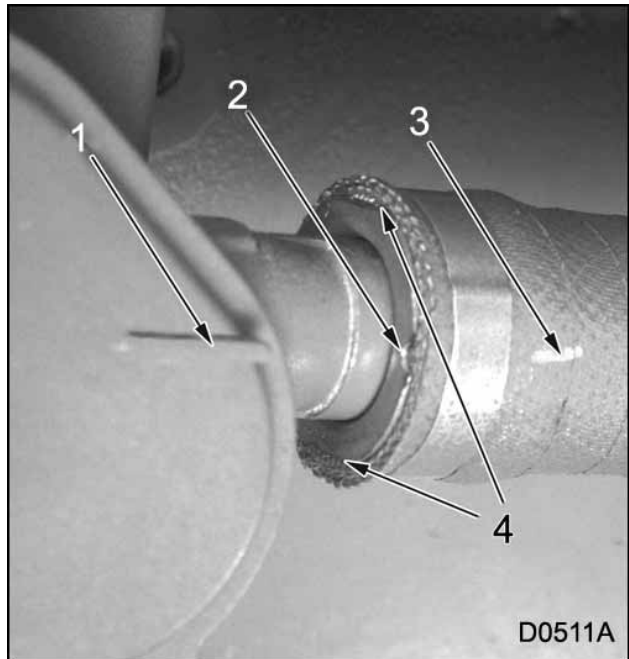


Figure 118 EGR coolant inlet coupling alignment (unlocked position)

1. EGR coolant supply port cover mark
 2. Recess
 3. Single index mark
 4. Flat edge representing dual index marks
8. Connect the EGR coolant inlet coupling by aligning the single index mark (if visible) or recess on the end of the coupling with index feature on the oil cooler cover (Figure 118).

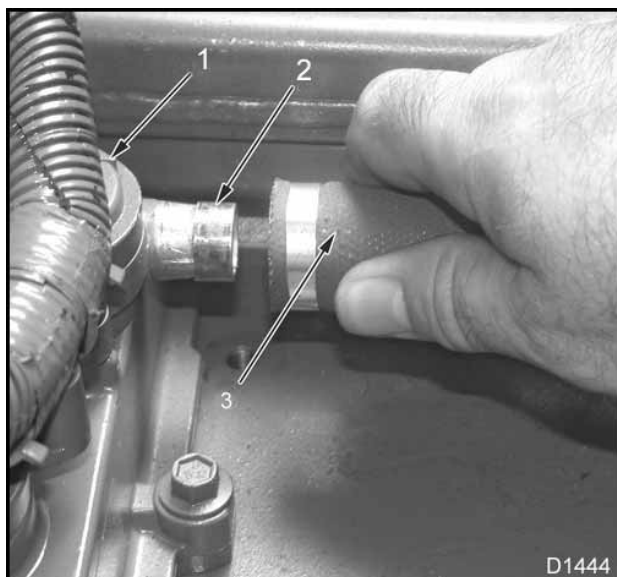


Figure 119 EGR coolant inlet coupling to coolant supply port

1. Index feature on oil cooler cover
 2. Coolant supply port
 3. EGR coolant inlet coupling
9. Slide EGR coolant inlet coupling toward the front of the engine on coolant supply port up to the face of the oil cooler cover.
 10. To lock, rotate the coupling either way until single index mark (if visible) or recess no longer aligns with index feature on oil cooler cover.
 11. Attempt to slide EGR coolant inlet coupling off coolant supply port to verify locked position.

Exhaust Manifolds and Tubing

Right Exhaust Manifold

NOTE: When installing exhaust manifolds, only use prevailing torque hex flange bolts having an interference thread.

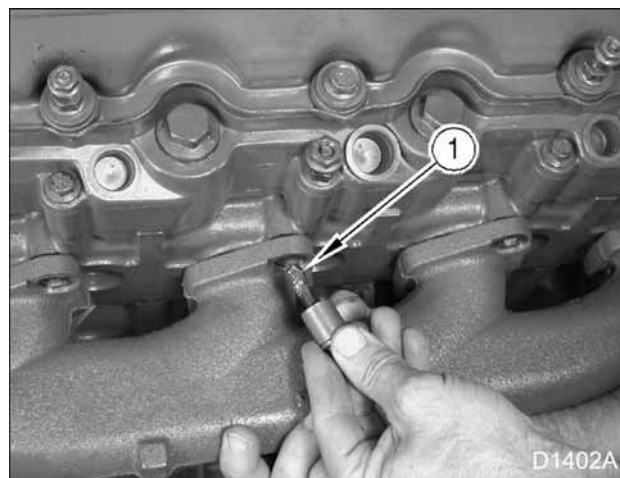


Figure 120 Right exhaust manifold bolt and spacer

1. Anti-seize compound
1. Apply anti-seize compound to all bolt threads.

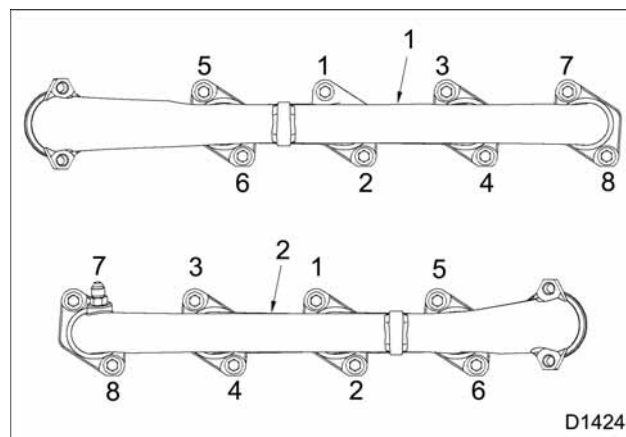


Figure 121 Torque sequence for exhaust manifold mounting bolts

1. Right exhaust manifold
 2. Left exhaust manifold
2. Position exhaust manifold gasket.
 3. Install right exhaust manifold, using eight M8 x 40 prevailing torque hex flange bolts and spacers. Start with the second bolt from the rear on top. The hole diameter is smaller, to allow alignment of the remaining bolts.
 4. Tighten bolts to the special torque (Table 8) and in the specified sequence (Figure 121).

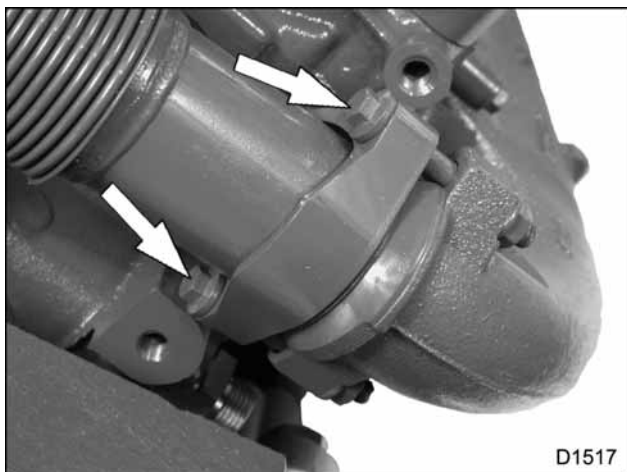


Figure 122 Mounting bolts for right exhaust tube

5. Apply anti-seize compound to two M8 x 60 bolts securing the right exhaust tube assembly to the exhaust manifold flange with two prevailing torque nuts. Loosely assembly bolts and nuts.

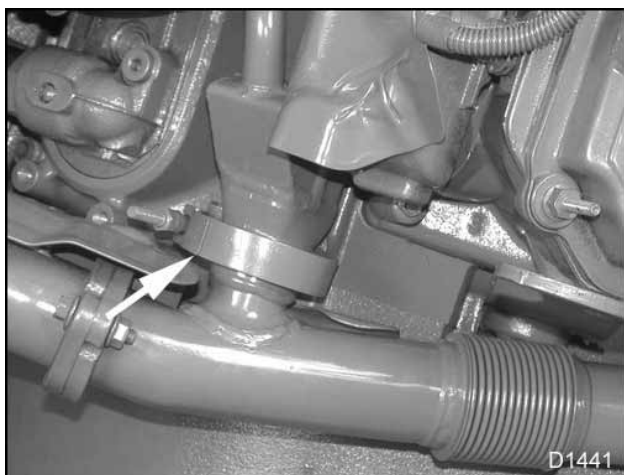


Figure 123 EGR cooler V-clamp

6. Install steel gasket for EGR cooler.
7. Attach right exhaust tube assembly to EGR cooler assembly with V-clamp. Do not tighten V-clamp.

Left Exhaust Manifold



Figure 124 Bolt and spacer for left exhaust manifold

1. Anti-seize compound

1. Apply anti-seize compound to all bolt threads.
2. Position exhaust manifold gasket.
3. Install left exhaust manifold, using eight M8 x 40 prevailing torque hex flange bolts and spacers. Start with the second bolt from the rear on top. The hole diameter is smaller, to allow alignment of the remaining bolts.
4. Tighten bolts to specified torque (Table 8) and in the specified sequence (Figure 121).

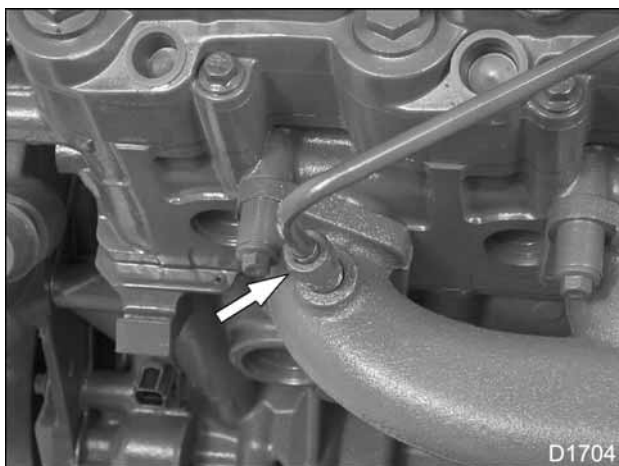


Figure 125 EBP sensor tube fitting

5. Apply anti-seize compound to the threads of the EBP sensor tube fitting.
6. Install EBP sensor tube to exhaust manifold and tighten fitting to the special torque (Table 8).



Figure 126 Exhaust tube bolts (upper right)

7. Apply anti-seize compound to the threads of two M8 x 30 bolts and prevailing torque nuts.
8. Install a new exhaust tube gasket and secure the shielded tube exhaust assembly (upper right side) to the right exhaust tube assembly. Loosely assemble bolts and nuts.

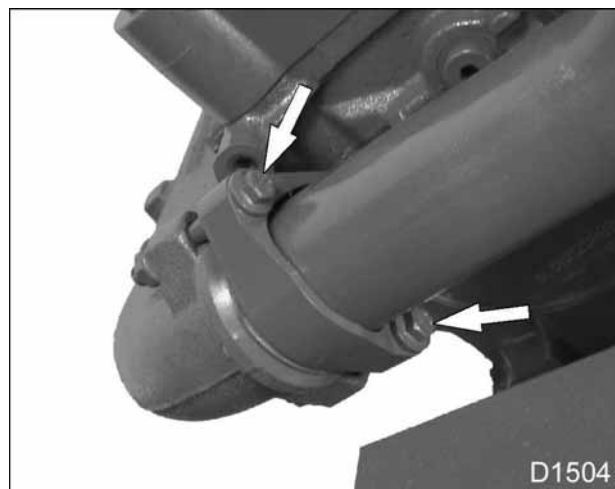


Figure 127 Mounting bolts for shielded tube exhaust assembly on left exhaust manifold

9. Apply anti-seize compound to two M8 x 60 bolts securing the shielded tube exhaust assembly to the exhaust manifold flange. Loosely assemble bolts and nuts.
10. For VGT installation procedure, see (Installation, page 67).
11. After VGT installation, torque all bolts for VGT tubing in the following order:
 - a. Shielded exhaust tube assembly at right exhaust tube (upper flange)
 - b. Turbocharger exhaust adapter V-clamp
 - c. EGR cooler V-clamp
 - d. Shielded exhaust tube assembly at left manifold
 - e. Exhaust tube assembly at right manifold

See (Table 8) for special torque specifications.

Exhaust Gas Recirculation (EGR) Valve

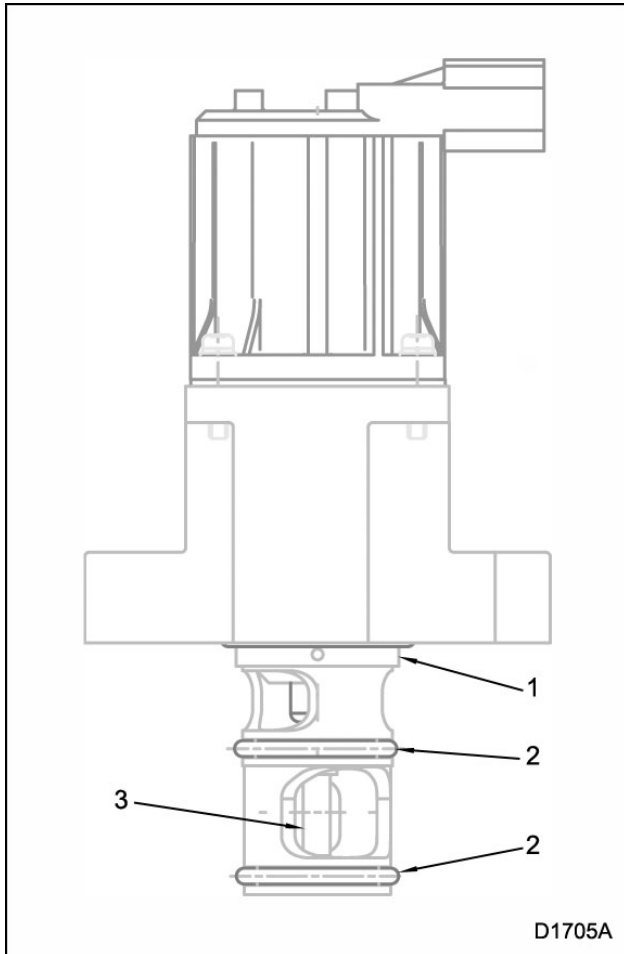


Figure 128 EGR valve assembly

1. Large O-ring
2. Valve group O-rings (2)
3. Common pintle shaft

1. Install a large O-ring on the EGR valve.
2. Lubricate two new valve group O-rings with a solution of dish washing soap and water (approximately 50/50 mix) and install O-rings on EGR valve.



Figure 129 Seat EGR valve

3. When installing the EGR valve into the intake manifold, make sure the valve is completely seated by hand before installing bolts.

NOTE: Failing to completely seat the EGR valve into the intake manifold, before inserting the mounting bolts, may cause damage to the EGR valve.

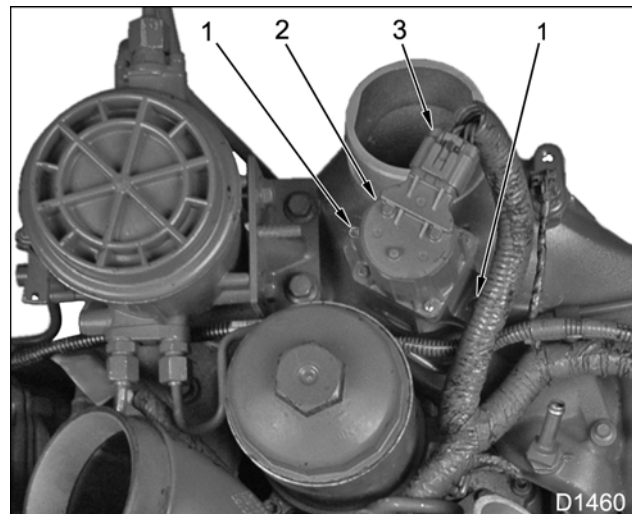


Figure 130 Installation of EGR valve

1. M6 x 35 bolt
2. EGR valve
3. 8-pin electrical connector

4. Thread two M6 x 35 bolts by hand and tighten, alternating between both bolts to the standard torque (Standard Torques, page 375).
5. Connect 8-pin electrical connector to EGR valve.
6. Reinstall all safety guards, shields, and covers.
7. Make sure all tools, cleanliness covers, loose parts, and service equipment are removed from the engine work area.

Specifications

Table 7 Intake and Exhaust Manifolds

Exhaust Manifold	
Maximum allowable warpage	0.08 mm (0.003 in)
Intake Manifold	
Maximum allowable clearance	Between ports: 0.13 mm (0.005 in)
	Total: 0.25 mm (0.010 in)

Special Torque

Table 8 Manifolds and Exhaust Gas Recirculation (EGR)

Intake manifold, M6 x 95 hex flange bolt or stud bolt dog point	11 ± 1 N·m (96 ± 10 lbf·in)
Intake heat shield, M6 hex flange nut	11 ± 3 N·m (96 ± 24 lbf·in)
Exhaust manifold hex flange bolts ¹	38 ± 4 N·m (28 ± 3 lbf·ft) (Figure 122)
EBP tube assembly ¹	30 ± 1 N·m (22 ± 1 lbf·ft)
EBP tube connector ¹	14 - 15 N·m (120 - 132 lbf·in)
Shielded exhaust tube to exhaust manifold (left side) ¹	27 ± 4 N·m (20 ± 3 lbf·ft)
Shielded tube exhaust to right side exhaust tube ¹	27 ± 4 N·m (20 ± 3 lbf·ft)
Exhaust tube to exhaust manifold (right side) ¹	27 ± 4 N·m (20 ± 3 lbf·ft)
Turbocharger exhaust adapter V-clamp	12 N·m (108 lbf·in)
EGR cooler V-clamp	6 N·m (48 lbf·in)

¹ Apply anti-seize compound to bolt threads before assembly.

Special Service Tools**Table 9 Manifolds and Exhaust Gas Recirculation (EGR)**

Description	Tool Number
Anti-Seize Compound	Obtain locally
Cap Kit (All)	ZTSE4610
EGR Cooler Pressure Test Plates	ZTSE4545
EGR Valve Puller	ZTSE4669
Feeler Gauge	Obtain locally
Injector Sleeve Brush	ZTSE43041
Intake Manifold Pressure Test Plates	ZTSE4527
Intake Manifold Pressure Test Plug (Replaces EGR Valve)	ZTSE4544
Intake Manifold Pressure Test Cap	ZTSE4554
Intake Port Covers (cylinder heads)	ZTSE4559
Pressure Test Adaptor (intake)	ZTSE4554
Straightedge	Obtain locally

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Cylinder Head Components

NOTE: Before removing cylinder heads, remove the following components:

- Fuel filter assembly and lines
See "Fuel System."
- VGT assembly
See "Variable Geometry Turbocharger (VGT) Assembly."
- Electronic Control Module (ECM), Injector Driver Module (IDM), and mounting bracket
See "Engine Electrical."
- Exhaust Gas Recirculation (EGR) drive module and EGR drive module mounting bracket
See "Engine Electrical."
- Glow plug relay and bracket
See "Engine Electrical"
- Intake manifold
See "Manifolds and Exhaust Gas Recirculation (EGR)"
- Flywheel and rear cover (if removing cam followers)
See "Rear Cover, Flywheel, and Power Steering Gear Drive."
- Branch tube assembly (if removing cam followers)
See "High-pressure Oil Pump."

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

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

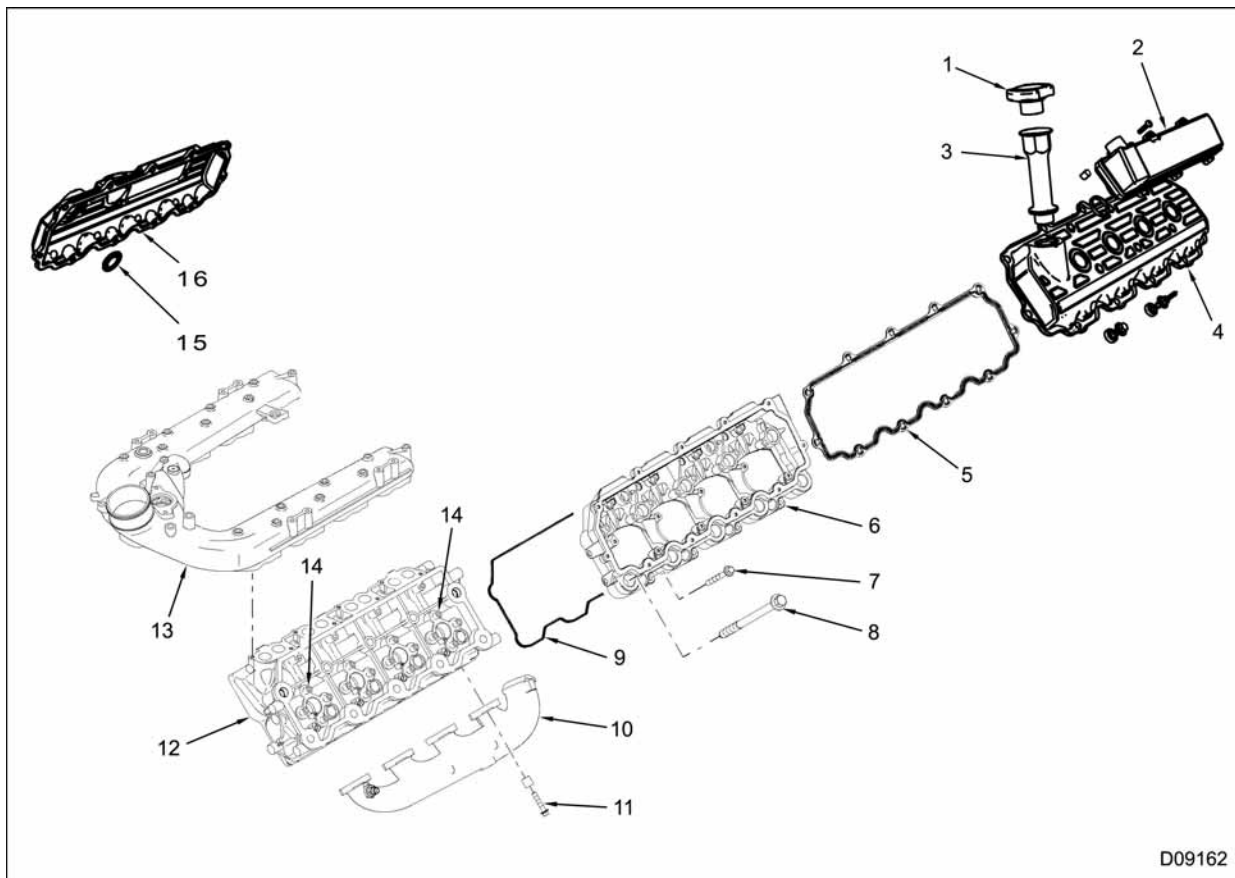
 **WARNING:** To prevent personal injury or death, do not let engine fluids stay on your skin. Clean skin and nails using hand cleaner and wash with soap and water. Wash or discard clothing and rags contaminated with engine fluids.

NOTE: Engine fluids (oil, fuel, and coolant) are a threat to the environment. Recycle or dispose of engine fluids according to local regulations. Never put engine fluids in the trash, pour fluids on the ground, in sewers or bodies of water.

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

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

Exploded Views



D09162

Figure 131 Cylinder head and related components (typical)

1. Oil fill cap	7. Rocker arm carrier mounting bolt	13. Intake manifold
2. Breather housing	8. Cylinder head bolt	14. Dowel
3. Oil fill extension	9. Rocker arm carrier gasket	15. Valve cover gasket (ICP sensor)
4. Valve cover (left side)	10. Exhaust manifold (left side)	16. Valve cover (right side)
5. Valve cover gasket	11. Exhaust manifold bolts	
6. Rocker arm carrier	12. Cylinder head (left side)	

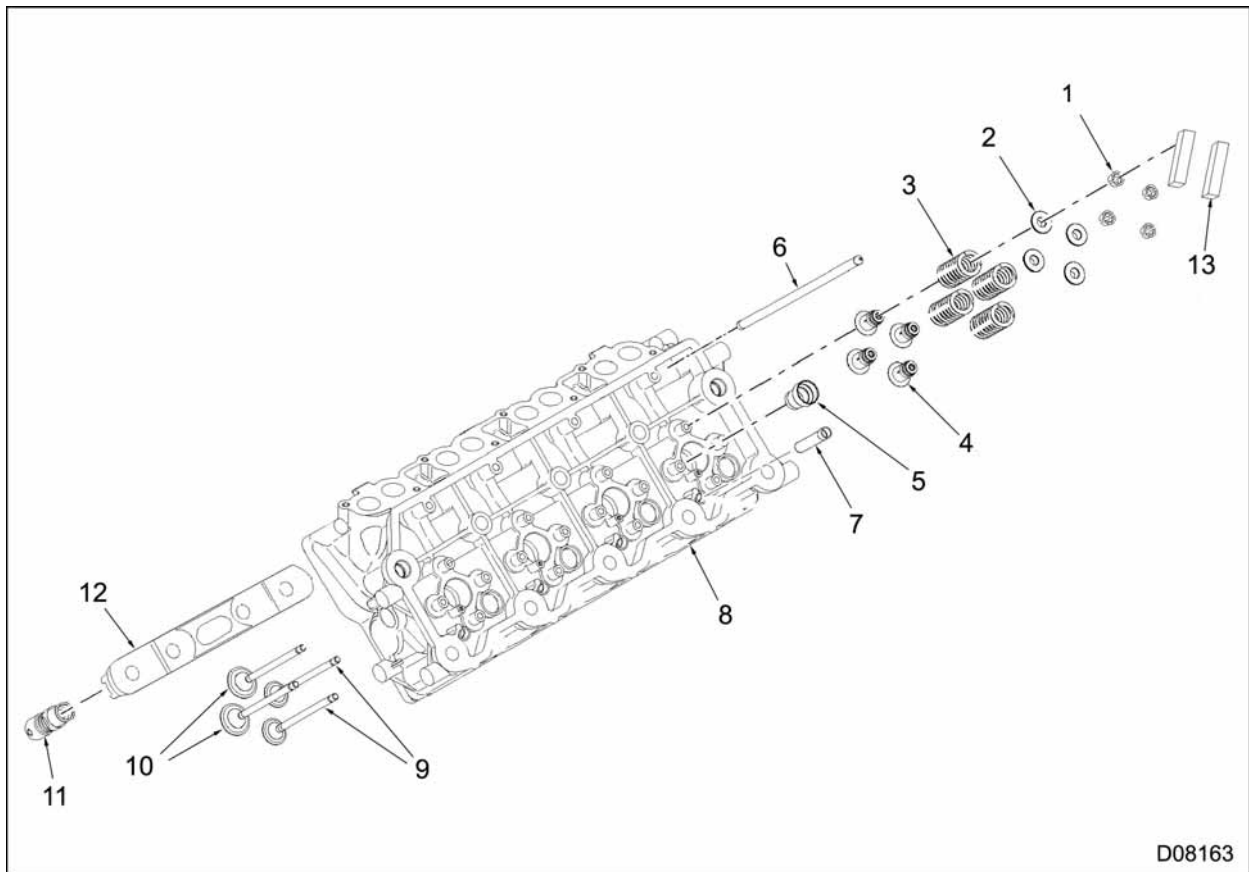


Figure 132 Cylinder head components (typical)

1. Valve retainer key (32)	6. Push rod (8)	11. Hydraulic cam follower (8)
2. Valve spring retainer (16)	7. Glow plug sleeve (4)	12. Cam follower guide (2)
3. Valve spring (16)	8. Cylinder head	13. Valve bridge (8)
4. Valve stem oil seal (16)	9. Exhaust valve (8)	
5. Fuel injector sleeve (4)	10. Intake valve (8)	

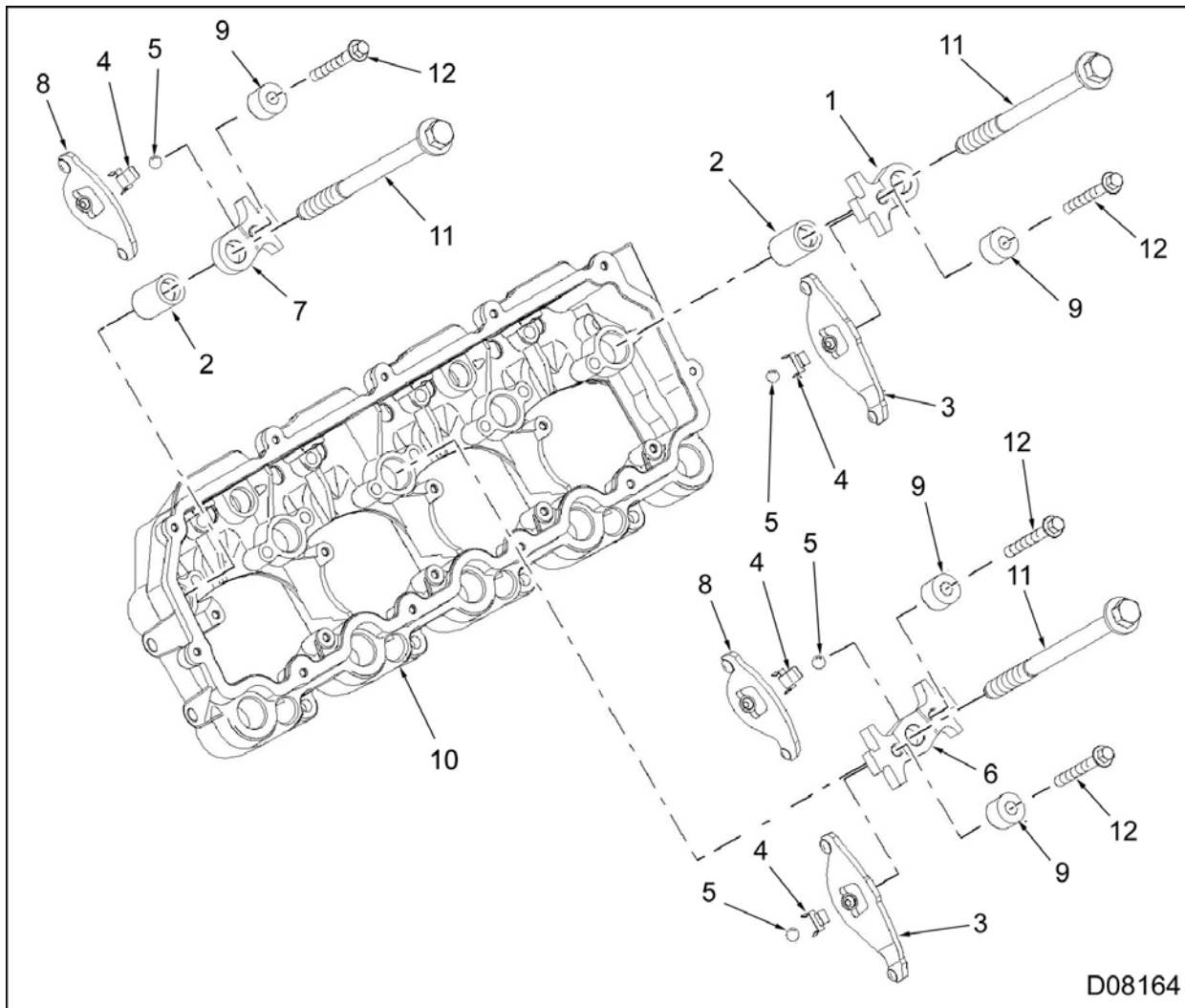


Figure 133 Rocker arm carrier components (typical)

1. Exhaust fulcrum plate	5. Ball, 3/8 chrome (8)	10. Rocker arm carrier
2. Dowel sleeve bushing (end fulcrums only)	6. Dual rocker fulcrum plate (3)	11. Head bolt
3. Exhaust rocker arm (4)	7. Intake fulcrum plate	12. Fulcrum bolt (8)
4. Rocker arm clip	8. Intake rocker arm (4)	
	9. Fulcrum bolt spacer (8)	

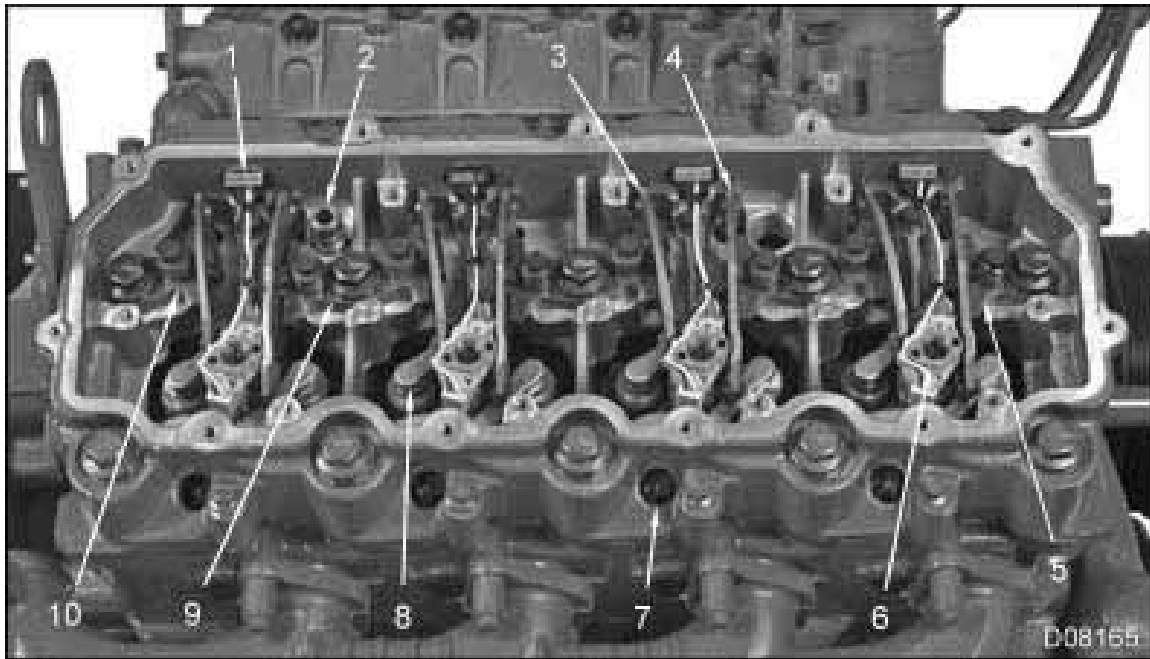


Figure 134 Rocker arm carrier and cylinder head components (typical)

1. Injector harness connector (4)	5. Exhaust fulcrum plate	9. Fulcrum plate (dual) (3)
2. Case-to-head tube assembly	6. Injector assembly (4)	10. Intake fulcrum plate
3. Intake rocker arm (4)	7. Glow plug (4)	
4. Exhaust rocker arm (4)	8. Valve bridge (8)	

Removal

Valve Covers, ICP Sensor, and Rear Heat Shield

Injection Control Pressure (ICP) Sensor (right high-pressure oil rail)

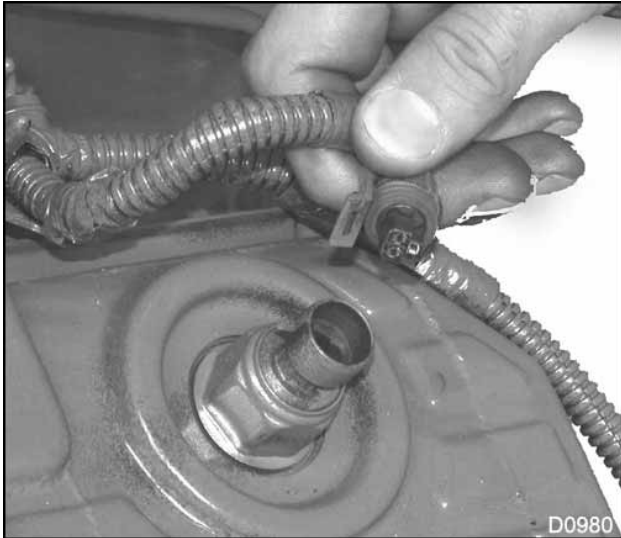


Figure 135 Electrical connector removed from ICP sensor

1. Disconnect electrical connector from ICP sensor in the right high-pressure oil rail.

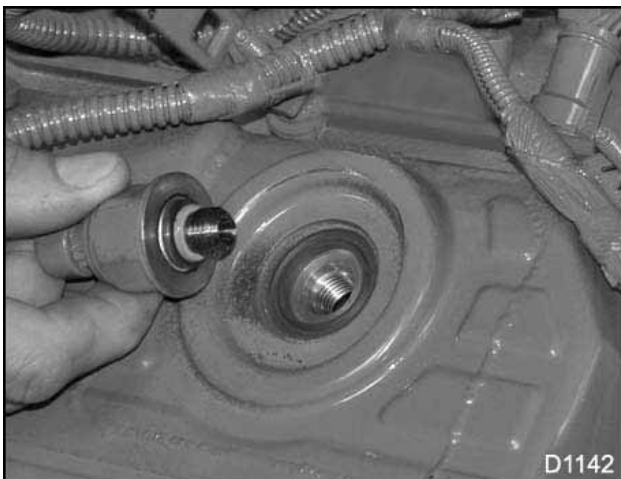


Figure 136 ICP Sensor and O-ring

2. Remove the ICP sensor.
3. Remove O-ring from ICP sensor and discard O-ring.



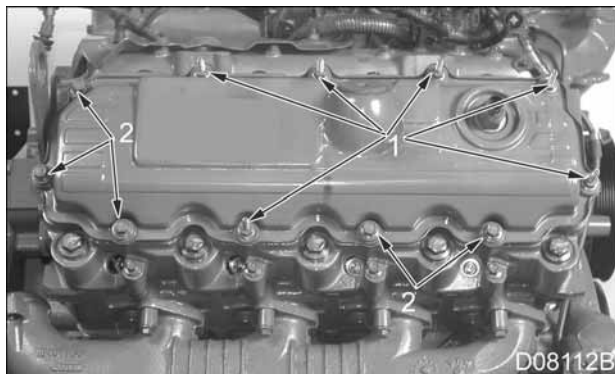
Figure 137 Valve cover seal ring for ICP sensor

1. Valve cover seal ring for ICP sensor
2. Oil rail ICP sensor opening

NOTE: The ICP sensor may be removed before or after removing the right valve cover. The valve cover seal ring for the ICP sensor (under the valve cover) can be removed only after removing valve cover. If the ICP sensor is removed, for replacement or troubleshooting, the valve cover seal ring can be reused.

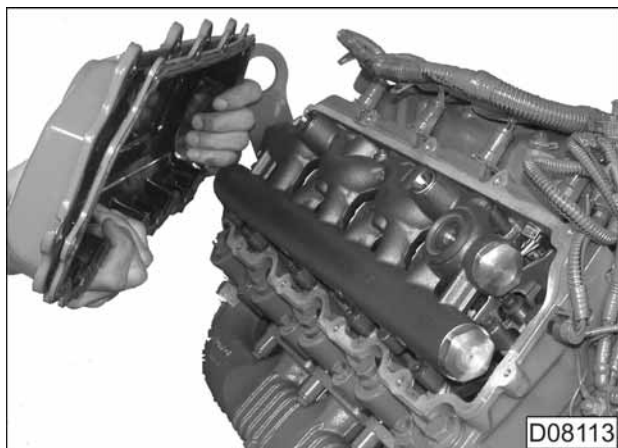
Valve Covers

CAUTION: To prevent engine damage, do not use air tools when removing and installing valve covers.

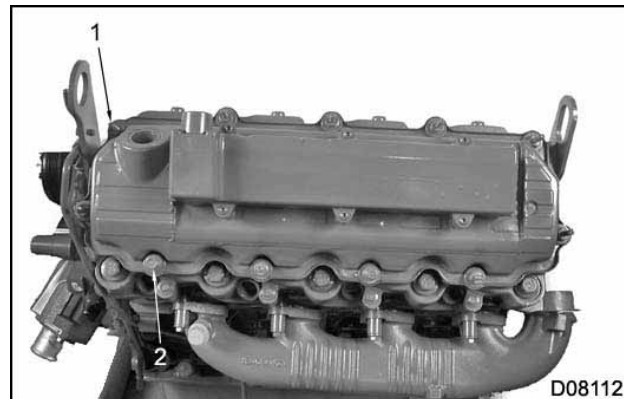
Right Valve Cover**Figure 138 Mounting bolts and studs**

1. Stud (6)
2. Bolt (5)

1. Remove five mounting bolts and six studs.

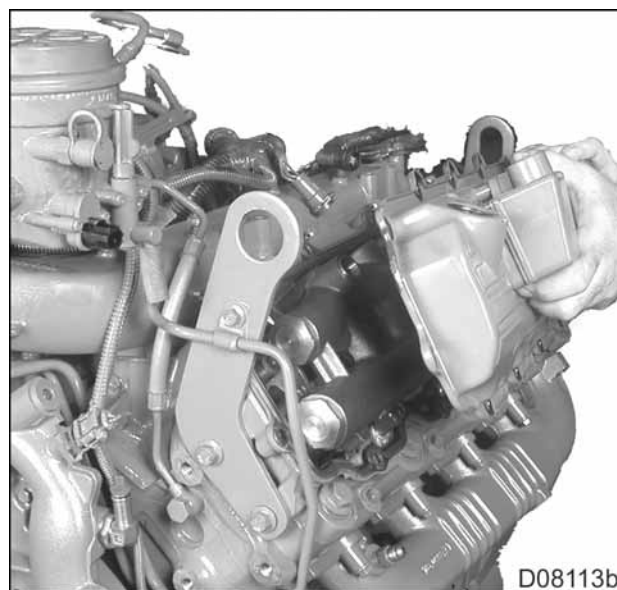
**Figure 139 Right valve cover**

2. Remove right valve cover.
3. Remove right valve cover gasket. Keep gasket for cleaning and inspection.

Left Valve Cover**Figure 140 Mounting bolts and studs**

1. Bolt (1)
2. Stud (10)

4. Remove one mounting bolt and 10 studs.

**Figure 141 Left valve cover with breather housing attached**

5. Remove left valve cover with breather cover attached.

NOTE: Unless replacing the breather housing, leave breather housing on the left valve cover.

6. Remove the left valve cover gasket. Keep gasket for cleaning and inspection.

Breather Housing

NOTE: Remove the breather housing for replacement only. The breather housing may be removed with the left valve cover on or off the engine.

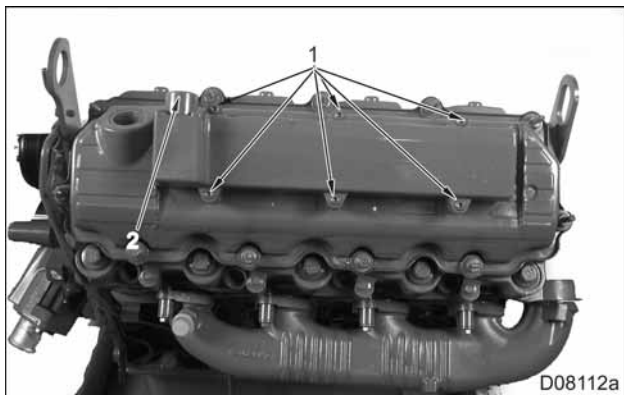


Figure 142 Mounting bolts for breather housing

1. Bolt (6)
2. Breather opening

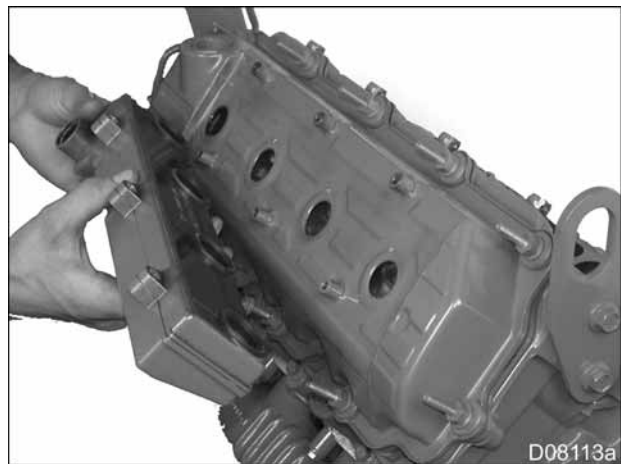


Figure 143 Breather housing

7. Remove six bolts from breather housing.
8. Remove breather housing. Save housing for inspection.

9. Remove four breather opening gaskets. Keep gaskets for cleaning and inspection

ICP Sensor (right high-pressure oil rail)



Figure 144 Valve Cover Seal Ring for ICP Sensor

1. Valve cover seal ring for ICP sensor
2. Oil rail ICP sensor opening

1. Remove and discard valve cover seal ring.

High-pressure Oil Rail Assembly

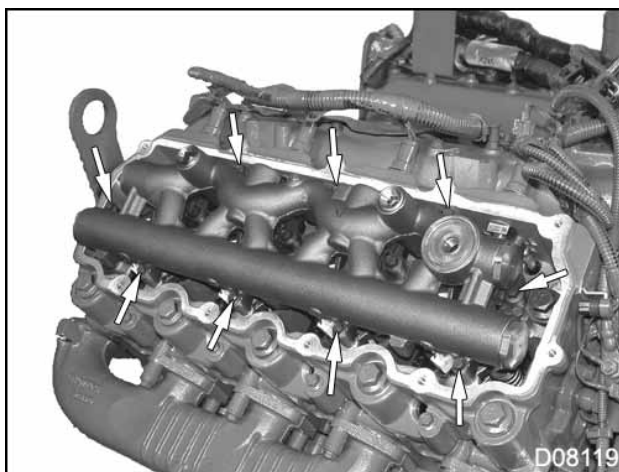


Figure 145 Oil rail assembly bolts

1. Loosen and remove nine M6 x 40 hex head bolts holding the oil rail assembly to the rocker arm carrier.



Figure 146 Crankcase-to-head tube plug

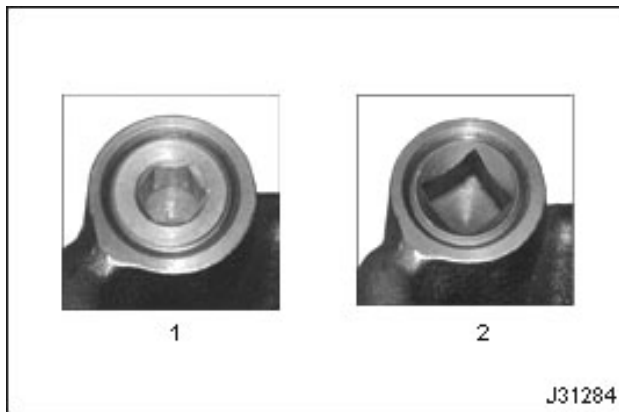


Figure 147 Crankcase-to-head tube plugs

1. Hex socket
2. Square socket

NOTE: The square socket identifies the short crankcase-to-head tube plug. The hex socket identifies the longer crankcase-to-head tube plug (with check valve).

NOTE: The square socket short crankcase-to-head tube plug and crankcase-to-head tube assembly is not available for service.

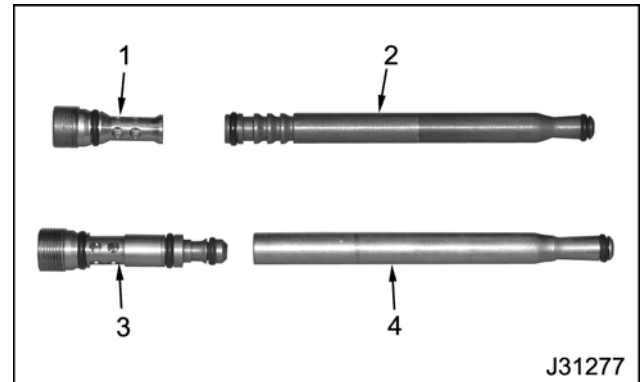


Figure 148 Crankcase-to-head tube assemblies

1. Crankcase-to-head tube plug (short)
 2. Crankcase-to-head tube (used with item 1)
 3. Crankcase-to-head tube plug (long – with check valve)
 4. Crankcase-to-head tube (used with item 3)
2. Remove the crankcase-to-head tube assembly from right and left high-pressure oil rails.
 3. Discard crankcase-to-head tube assemblies.

NOTE: The crankcase-to-head tube, used with the long crankcase-to-head tube plug may remain in the crankcase.

- If crankcase-to-head tube remains in the crankcase, continue with step 4.
- If both crankcase-to-head tube assemblies were removed, continue with step 6.

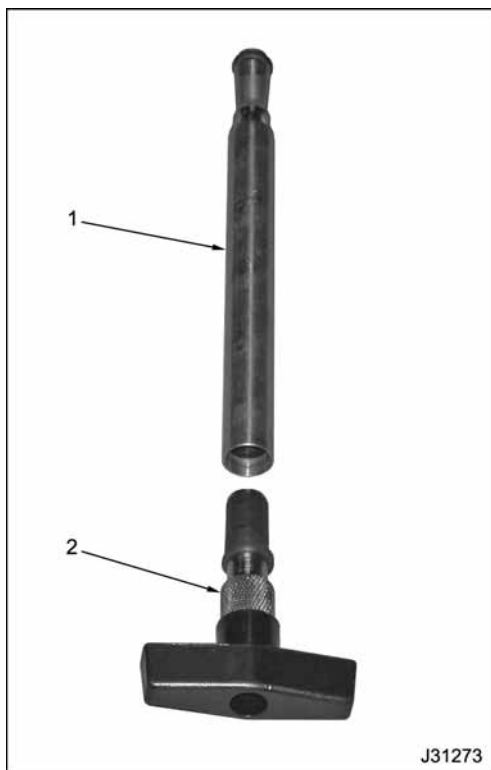


Figure 149 Crankcase-to-head tube and Crankcase-to-head Removal Tool

1. Crankcase-to-head tube
2. Crankcase-to-head Removal Tool

4. Insert the Crankcase-to-head Removal Tool (Table 12) into the crankcase-to-head tube, tighten T-handle, and pull out tube.
5. Discard crankcase-to-head tube.

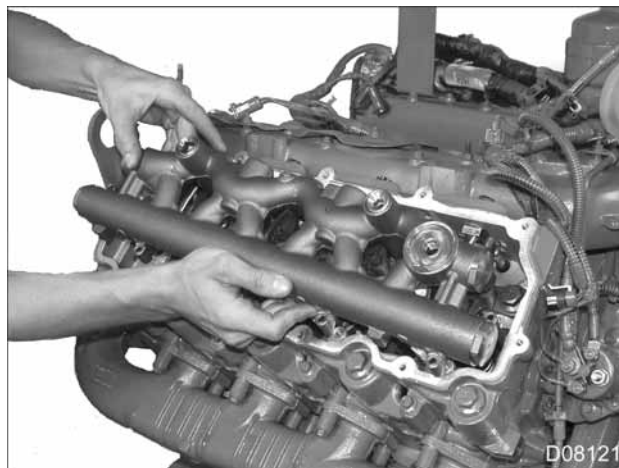


Figure 150 Removal of oil rail assembly

6. Lift oil rail assembly straight away from fuel injectors. Allow oil to drain back to the sump or other suitable container.

CAUTION: To prevent engine damage, do not remove 1-1/4 x 20 UNF oil rail end plugs or the Acoustic Wave Attenuator (AWA) bottom port fitting. Service parts are not available.

Fuel Injectors

NOTE: Do not drain the fuel rail, if removing an injector from chassis.

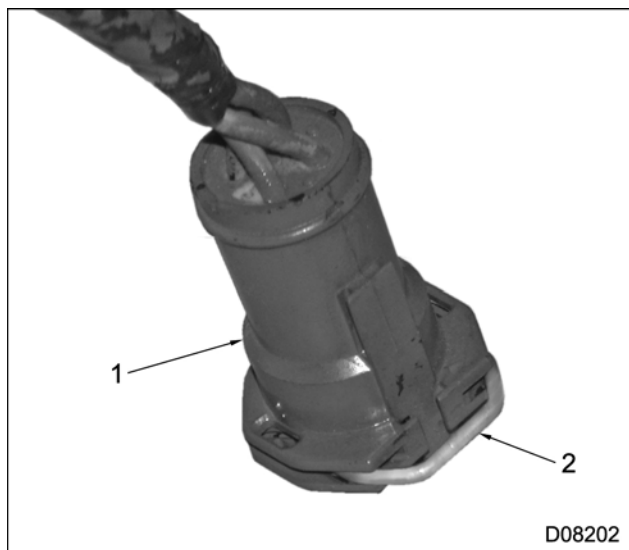


Figure 151 Engine Harness connector to injector connector

1. Connector
2. Spring loaded metal clip

1. Push in the spring loaded metal clip in the engine harness connector to the fuel injector connector and remove engine harness connector.



Figure 152 Injector connector removal

1. Injector Connector Remover
2. Injector connector

2. Install the Injector Connector Remover (Table 12).
3. Push Injector Connector Release Tool to pop loose the spring clips on the injector connector and remove connector from rocker arm carrier.



Figure 153 Fuel Injector Hold Down Wrench



Figure 154 Removal of fuel injector hold down clamp assembly

1. Fuel injector assembly
2. Fuel injector hold down clamp assembly
3. Fuel Injector Hold Down Wrench

CAUTION: To prevent damage to fuel injector assemblies, do not use air power tools to remove or install injectors.

4. Use the Fuel Injector Hold Down Wrench (Table 12) to remove the hold down clamp assembly.

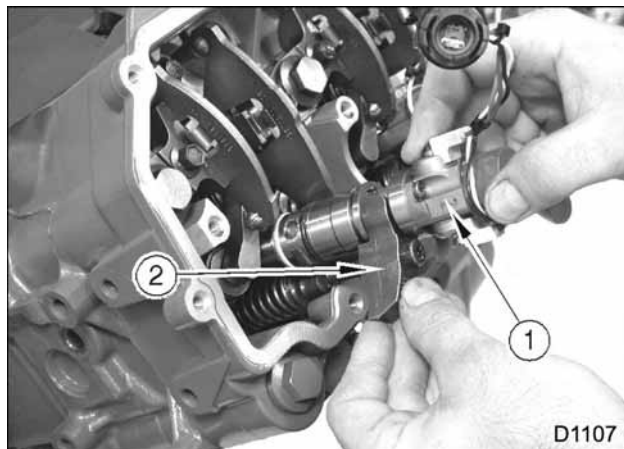


Figure 155 Fuel Injector assembly

1. Fuel injector assembly
2. Fuel injector hold down clamp assembly

5. Remove fuel injector from cylinder head bore by lifting injector and hold down clamp assembly straight up and out.

6. Put fuel injectors in the Fuel Injector Rack Holder (Table 12).

Rocker Arm Carrier

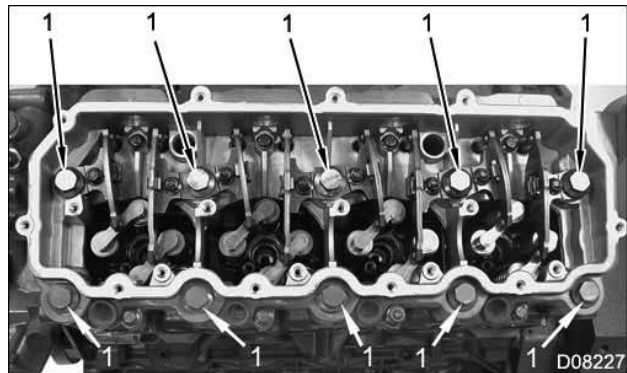


Figure 156 Cylinder head bolts (typical)

1. M14 x 193 bolts (10)

1. Using a circular pattern loosen and remove ten M14 x 193 bolts from cylinder head. Begin with the outer bolts and move inward.

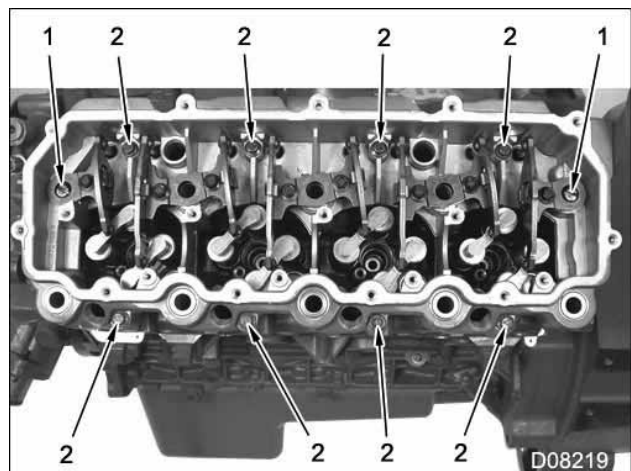


Figure 157 2004 and 2005 Model Year (eight M8 mounting bolts for rocker arm carrier)

1. Alignment guide (2)
2. M8 x 50 bolt (8)

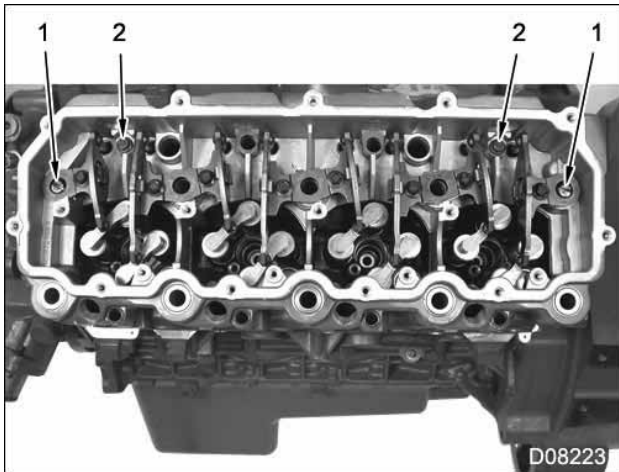


Figure 158 2005 Model Year (two M8 mounting bolts for rocker arm carrier)

1. Alignment guide (2)
2. M8 x 50 bolt (2)

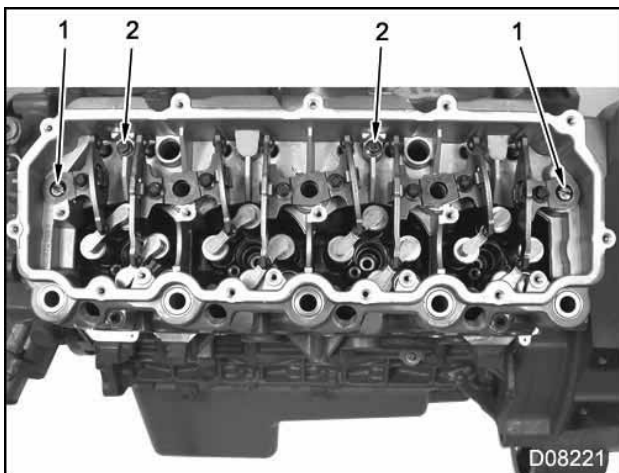


Figure 159 2006 Model Year (two M10 mounting bolts for rocker arm carrier)

1. Alignment guide (2)
 2. M10 x 50 bolt (2)
2. Remove bolts from rocker arm carrier.

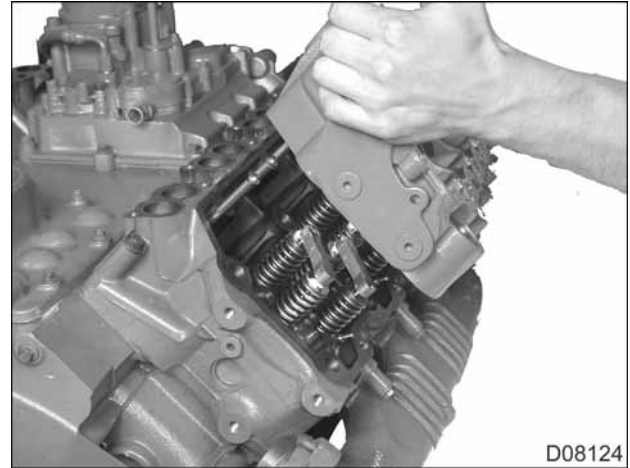


Figure 160 Rocker arm carrier

3. Lift rocker arm carrier assembly from cylinder head and set aside for disassembly, cleaning, inspection, and assembly.

Valve Bridges and Pushrods

CAUTION: To prevent engine damage, do not use paint to identify internal components or their orientation. Use permanent markers only.

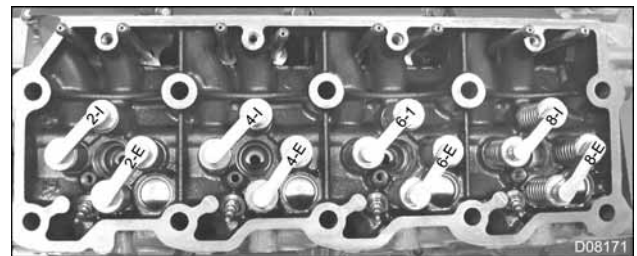
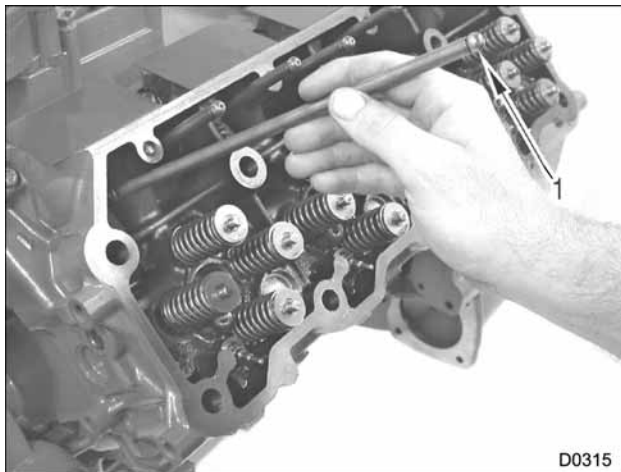


Figure 161 Valve bridge (left cylinder head)

1. Identify each valve bridge and corresponding valve set so they can be installed in their original locations.

Example: **2 - I**

- Cylinder number **2** as counted from the front of engine
- **I** = Intake, **E** = Exhaust

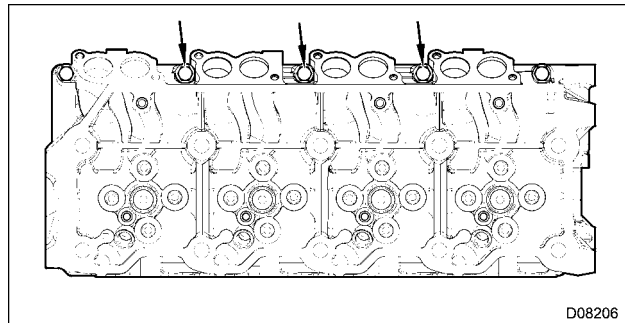
**Figure 162 Pushrods**

1. Pushrod
2. Remove and identify all pushrods; they must be installed to their original positions.

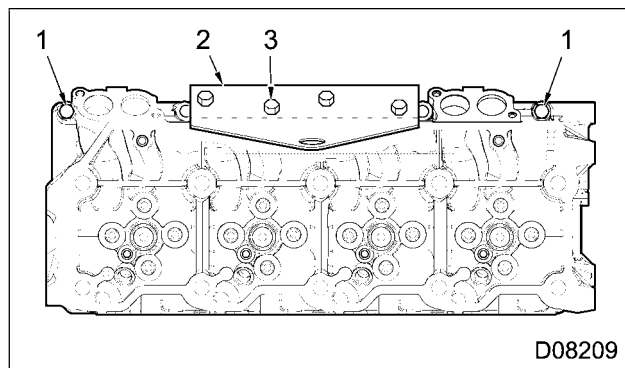
Cylinder Heads**Figure 163 Glow plug removal**

1. Remove glow plugs.

! WARNING: To prevent personal injury or death, make sure the cylinder head lifting bracket is mounted on the center of cylinder head. Also make sure the lifting hook has a safety latch.

**Figure 164 Removal of middle M8 x 70 bolts**

2. Remove three middle M8 x 70 bolts – cylinder head to crankcase.

**Figure 165 Cylinder head lifting bracket**

1. M8 x 70 bolt – cylinder head to crankcase
2. Cylinder head lifting bracket
3. Lifting bracket mounting bolt (4)
3. Position lifting bracket on cylinder head and install four lifting bracket mounting bolts.

NOTE: The lifting bracket allows the cylinder head to be removed squarely from the crankcase.

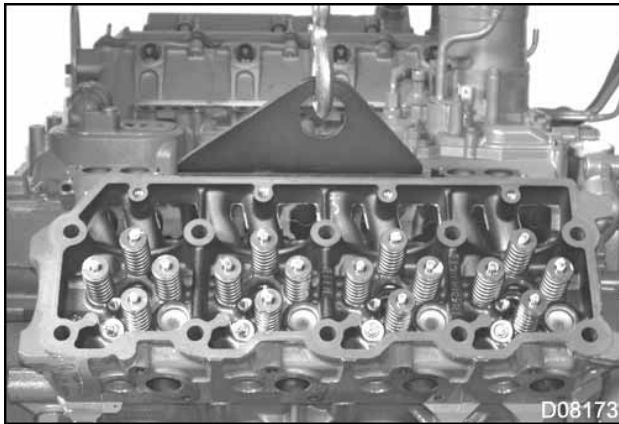


Figure 166 Cylinder head removal

4. Attach a lifting hoist hook or suitable lifting sling to lifting bracket.
5. Remove the two remaining M8 x 70 bolts – cylinder head to crankcase.
6. Lift cylinder head from the crankcase.

CAUTION: Do not damage cylinder head locating dowel sleeves.

7. Put cylinder head on suitable surface.

CAUTION: Do not scratch cylinder head surface.

8. Remove and discard cylinder head gasket.

Hydraulic Cam Followers

NOTE: If cam followers must be removed, the rear cover and the high-pressure oil pump cover must be removed to gain access to the rear engine tube assembly. See "Rear Cover, Flywheel, and Power Steering gear Drive."

CAUTION: To prevent engine damage, keep cam followers and push rods in the order removed. Install cam followers and push rods to original positions.

NOTE: If the valve train operates quietly and hydraulic cam followers function satisfactorily, do not service cam followers.

1. Remove the M6 x 15 bolt with washer from each roller follower guide.

NOTE: Identify orientation of each cam follower and guide during disassembly.

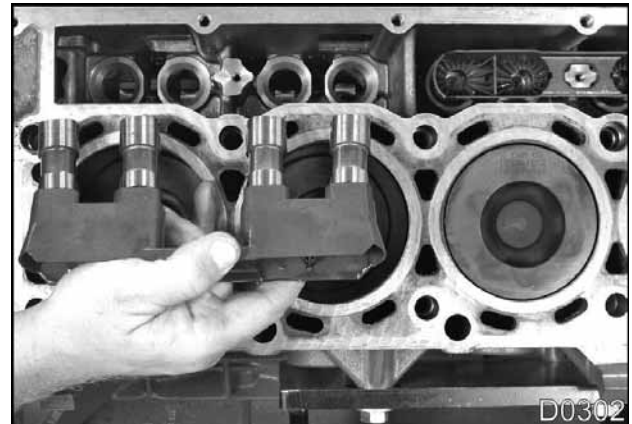


Figure 167 Cam followers and roller follower guides

2. Remove cam followers and roller follower, lifting the guide straight up. A hand tool may be required.

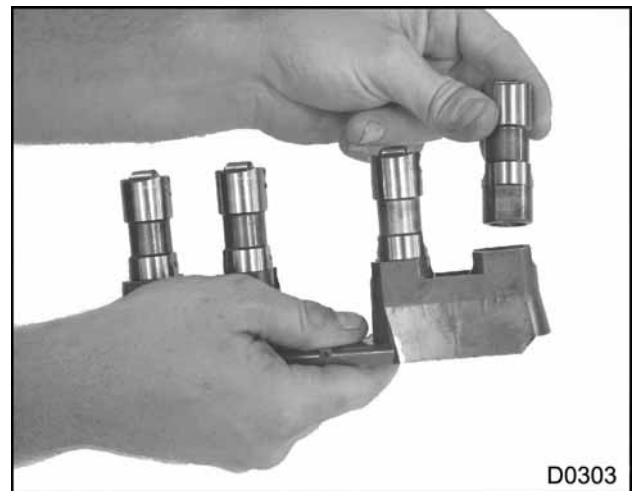


Figure 168 Cam follower removal from roller follower guide

3. Remove cam followers from roller follower guide.

Removing Valves from Cylinder Head

NOTE: Valve removal is required, if valves need replacement or seats need reconditioning. Valve seat reconditioning is not required, if the cylinder head passes the mineral spirits test. See Cleaning, Inspections, and Testing in this section.

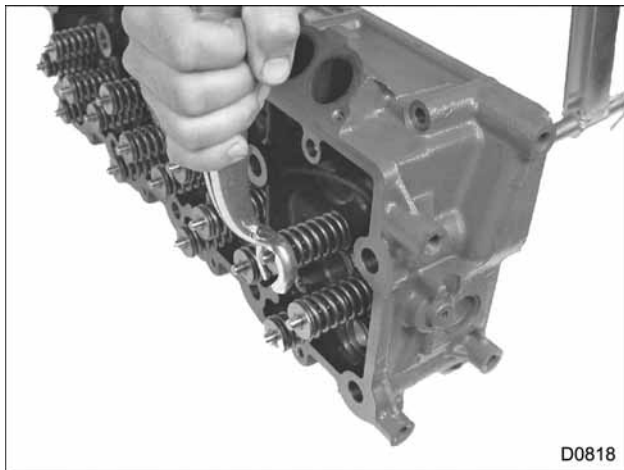


Figure 169 Valve spring compression



Figure 171 Valve spring retainer

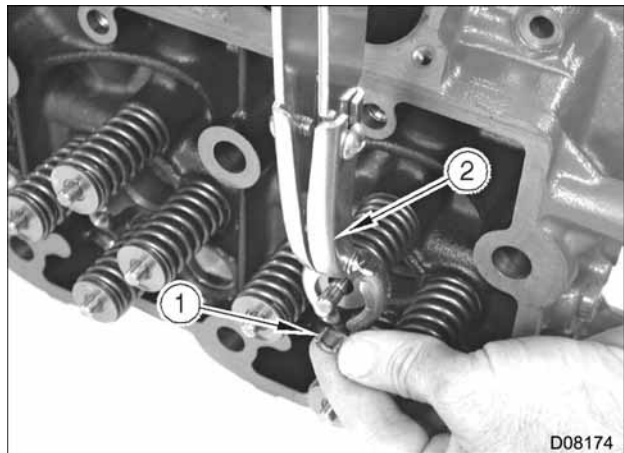


Figure 170 Valve retainer key

1. Valve retainer key
2. Valve Spring Compressor

1. Use a "C" Type Valve Spring Compressor (Table 12), to compress valve springs. Remove valve retainer keys. A small magnet is useful.

2. Remove valve spring retainer.



Figure 172 Valve spring

3. Remove valve spring.

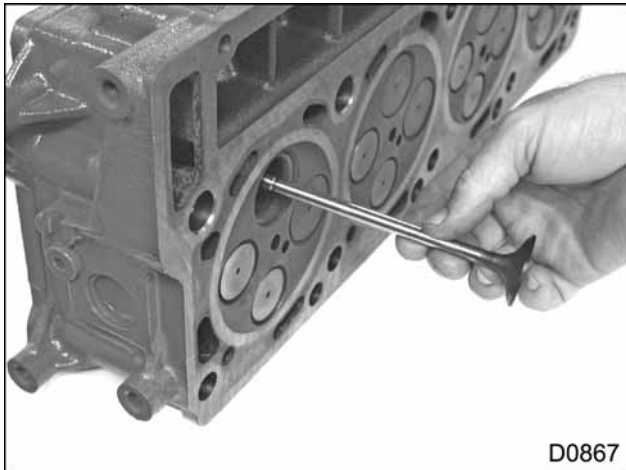


Figure 173 Valve

4. Remove valve from cylinder head.



Figure 174 Valve stem oil seal

5. Remove valve stem oil seal and discard. Valve stem seals are not reusable. Use pliers to remove seal from end of valve stem guide.

Fuel Injector Sleeve Removal

CAUTION: To prevent engine damage, if replacing fuel injector sleeves in chassis, put a small plug in the bottom of the injector sleeve before cutting threads. The plug will prevent small metal chips from entering the combustion chamber.

NOTE: Fuel injector sleeve removal is not required unless the sleeve has been damaged. See Cleaning, Inspection and Testing in this section, to determine if sleeve replacement is required.



Figure 175 Lubrication of Injector Sleeve Remover (Thread tap)

NOTE: The fuel injector sleeve is made of stainless steel. Lubrication of the Injector Sleeve Remover is required.

1. Lubricate Injector Sleeve Remover (Table 12).



Figure 176 Fuel injector sleeve tapped

2. Thread Injector Sleeve Remover (thread tap) into fuel injector sleeve. Cut threads at least 3/4 inch deep to accommodate the injector sleeve remover.

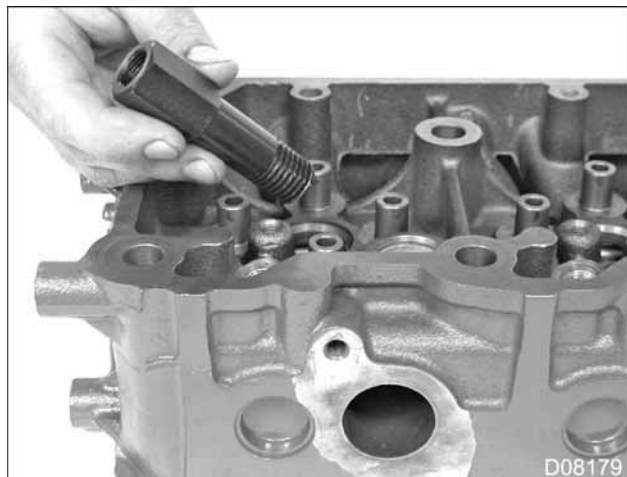


Figure 177 Injector Sleeve Remover (Slide hammer adapter)

3. Install Injector Sleeve Remover (slide hammer adapter) (Table 12) in the threads cut in the fuel injector sleeve and tighten.



Figure 178 Slide hammer

4. Thread the slide hammer (Table 12) in the injector sleeve remover.

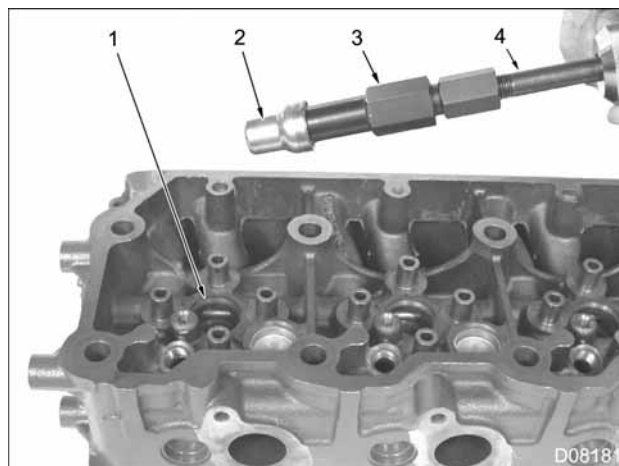


Figure 179 Fuel injector sleeve removal

1. Fuel injector bore
2. Fuel injector sleeve
3. Injector Sleeve Remover
4. Slide hammer
5. Using the slide hammer, remove fuel injector sleeve.

Glow Plug Sleeve Removal

NOTE: In-chassis removal of glow plug sleeves is only practical on the front two cylinders.

CAUTION: To prevent engine damage, if replacing glow plug sleeves in chassis, put a small plug in the bottom of the glow plug sleeve before cutting threads. The plug will prevent small metal chips from entering the combustion chamber.

NOTE: Glow plug sleeve removal is not required unless sleeves are damaged. If sleeve replacement is required, see Cleaning, Inspection, and Testing in this section.



Figure 180 Glow plug sleeve remover (Thread tap)

1. Lubricate Glow Plug Sleeve Remover (thread tap) (Table 12).

NOTE: The glow plug sleeve is made of stainless steel. Lubricate the Glow Plug Sleeve Remover (thread tap) to get the threads started – otherwise excessive force would be necessary.

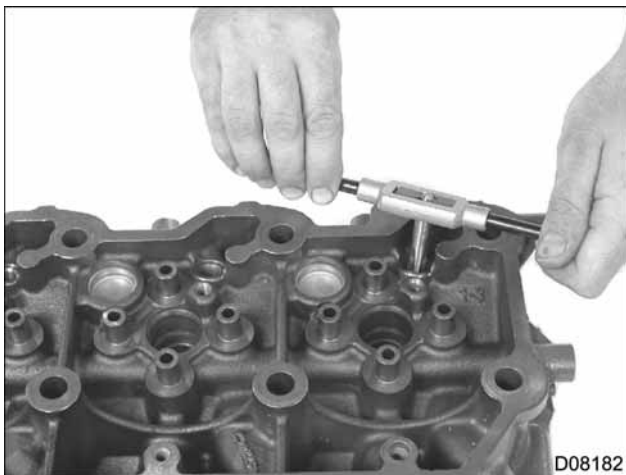


Figure 181 Glow plug sleeve tapped

2. Cut threads in the glow plug sleeve – at least 1/2 inch deep for the Glow Plug Sleeve Remover (bolt and sleeve adapter) (Table 12).

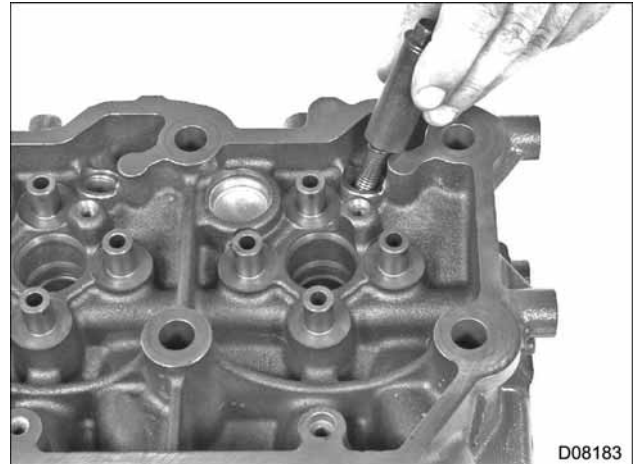


Figure 182 Glow Plug Sleeve Remover

3. Thread the Glow Plug Sleeve Remover into glow plug sleeve (Table 12).



Figure 183 Removal of glow plug sleeve

4. Use a wrench to turn the bolt of the Glow Plug Sleeve Remover until the glow plug sleeve is extracted.

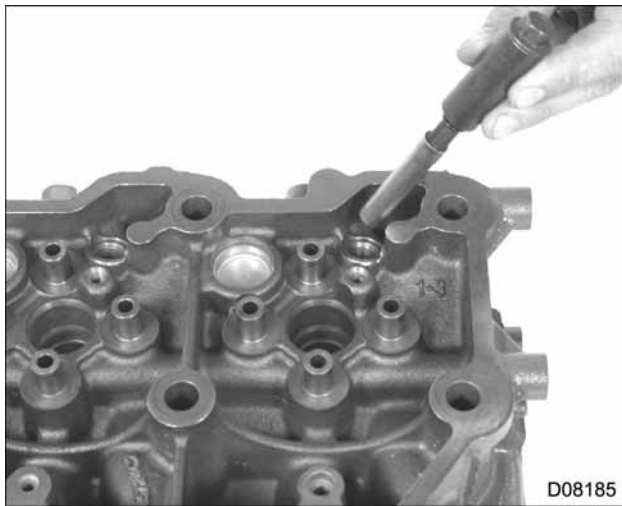


Figure 184 Glow plug sleeve

5. Remove glow plug sleeve.

Rocker Arm Carrier Fulcrum Removal

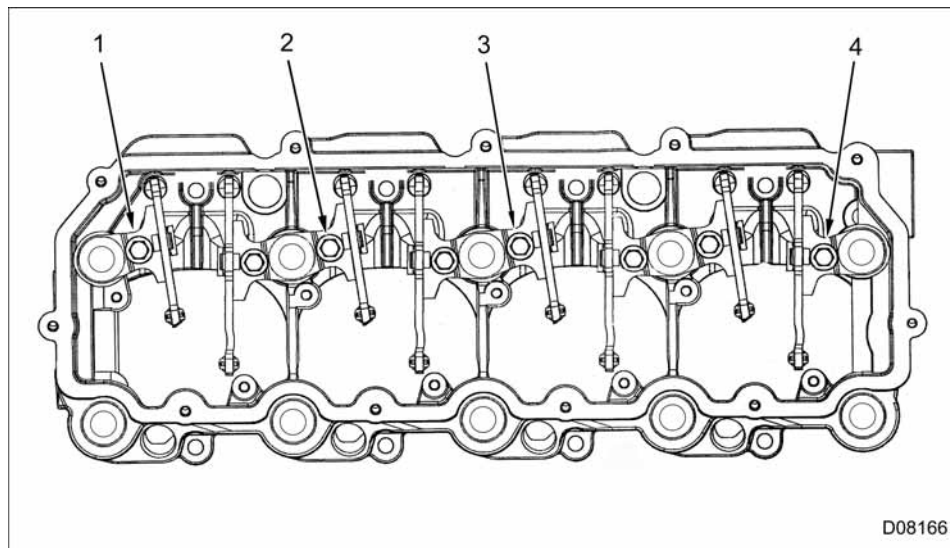


Figure 185 Rocker arm fulcrum plates

1. Intake fulcrum plate	2. Mounting bolt and spacer (8 each)	3. Dual rocker fulcrum plate (3)
		4. Exhaust fulcrum plate
-
1. Remove eight M8 x 65 bolts and spacers holding rocker arm fulcrums to the rocker arm carrier.
 2. Remove – as assemblies – the intake fulcrum plate, three dual rocker fulcrum plates, and exhaust fulcrum plate from the rocker arm carrier. Do steps 3 through 6 to disassemble.

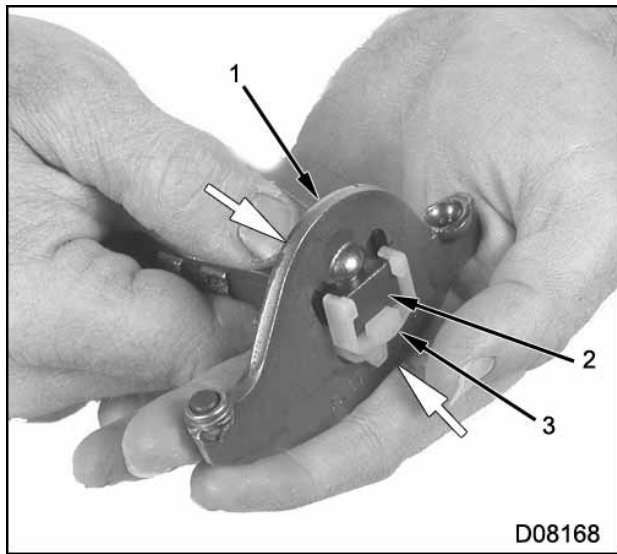


Figure 186 Separation of rocker arm from fulcrum plate (typical)

1. Rocker arm
 2. Fulcrum plate
 3. Rocker arm clip
3. Put rocker arm and fulcrum plate assembly upside down in your palm.
 4. Push up on the rocker arm with palm and forward on the fulcrum plate with thumb of opposite hand.

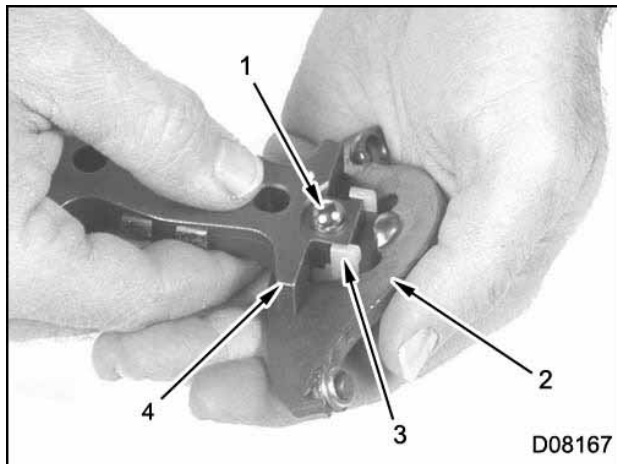


Figure 187 Rocker arm separated (typical)

1. Fulcrum plate
2. Rocker arm ball
3. Rocker arm
4. Rocker arm clip

5. Remove the rocker arm and rocker arm ball.

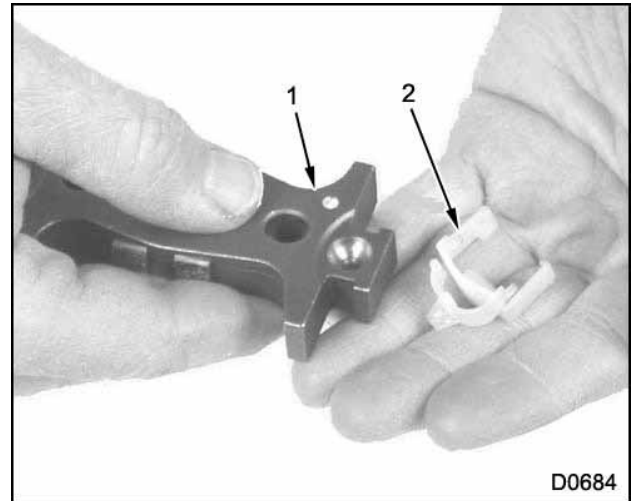


Figure 188 Rocker arm clip removed (typical)

1. Fulcrum plate
2. Rocker arm clip

6. Remove and discard rocker arm clip.

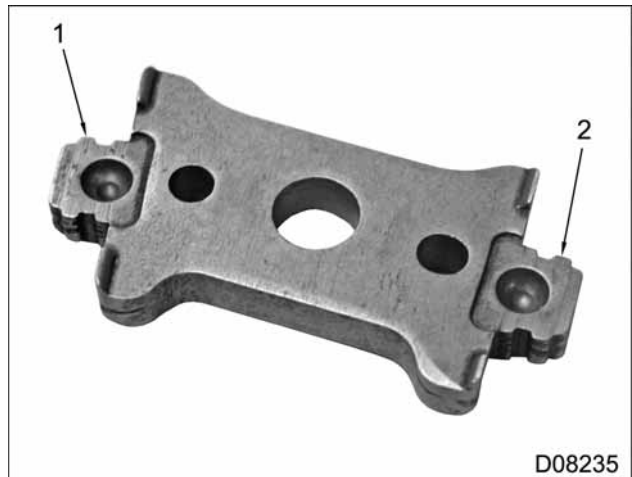


Figure 189 New rocker arm fulcrum (dual)

1. Exhaust end
2. Intake end

NOTE: Earlier rocker arm fulcrums are no longer serviceable; new rocker arm fulcrums and clips are required.

Cleaning, Inspection, and Testing

Cylinder Head and Crankcase Components

1. With valves installed to protect seats, use a scraper and wire brush to remove deposits and gasket material from valve heads and gasket surface. Do not damage gasket surface of cylinder head.
2. Use a suitable solvent to remove dirt, grease, and deposits from removed parts.

! 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).

3. Clean all bolt holes, Make sure gasket surfaces, oil return, and coolant passages are clean. After rinsing thoroughly with hot water, dry with filtered compressed air.

CAUTION: To prevent engine damage, new head bolts and a new cylinder head gasket must be used when installing the cylinder head. Even if one bolt was removed, a new cylinder head gasket and new bolts are required.

4. Clean all bolts (except head bolts) with a suitable solvent and dry thoroughly. New head bolts must be installed.
5. Clean crankcase threads.

NOTE: Dirt in threads or damaged threads may cause binding, resulting in a false torque reading.

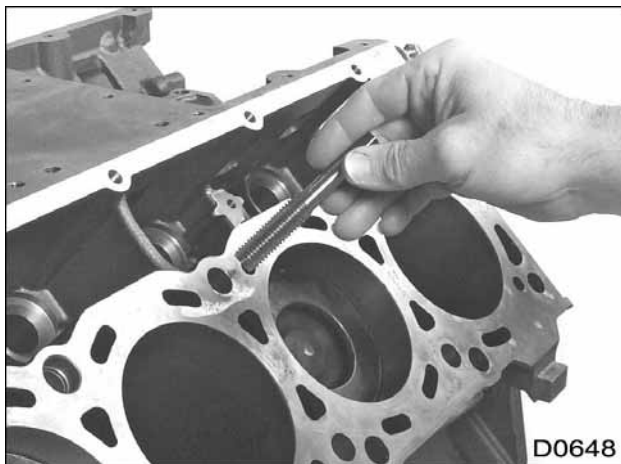


Figure 190 Bottoming tap

6. Use a Bottoming Tap (metric) (Table 12) to clean each tapped hole in crankcase top deck. Remove debris with filtered compressed air.
7. Thoroughly clean pushrods with a suitable solvent. Dry with filtered compressed air.

Cylinder Head Inspection – Valves Installed

NOTE: Inspect cylinder head for thickness, warping, cracks, and valve leakage.

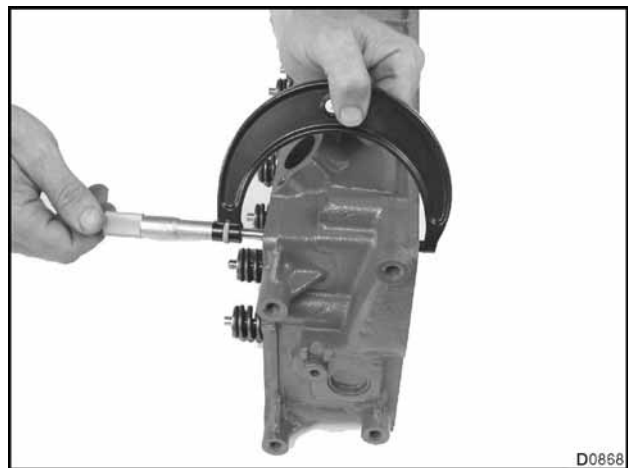


Figure 191 Measurement of cylinder head thickness

1. To determine if cylinder head has been resurfaced previously, use a 3-4 inch micrometer to measure deck thickness of cylinder head at four corner locations. If overall cylinder head thickness (deck-to-deck) specification is not met (Table 10), install new cylinder head.

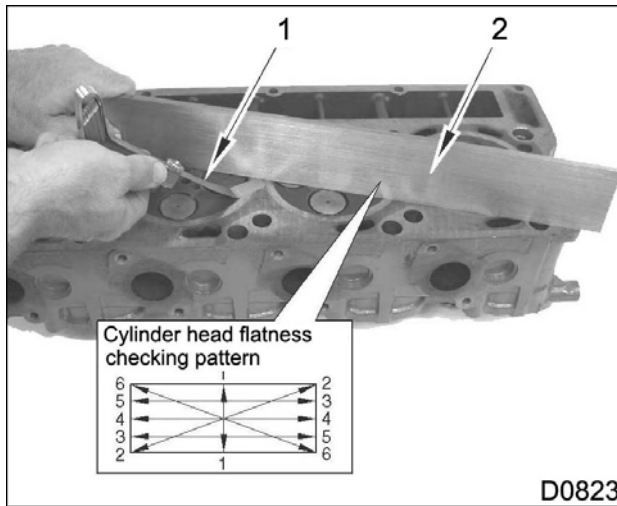


Figure 192 Check for gasket surface flatness

1. Feeler gauge
2. Straightedge
2. Use a straightedge and feeler gauge to check gasket surface of cylinder head for flatness. Check for flatness horizontally, diagonally, and transversely. If not to specifications (Table 10), install new cylinder head.

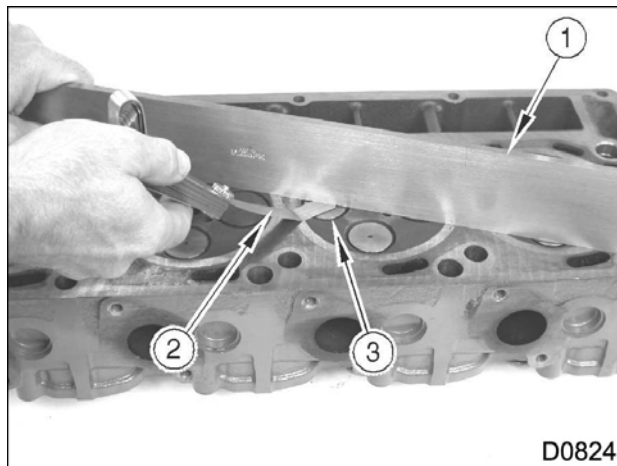


Figure 193 Checking valve recession

1. Straightedge
2. Feeler gauge
3. Valve head
3. Before removing valves, check valve head recession (relative to deck) as follows:

- a. Place a straightedge across each valve.
- b. Place a feeler gauge between straightedge and valve head.
- c. If out of specification (Table 10), replace valve. Do step 2 again, and if specifications are still not met, replace cylinder head.
4. Use the Dye Penetrant Kit (Table 12), to inspect for cracks in cylinder head

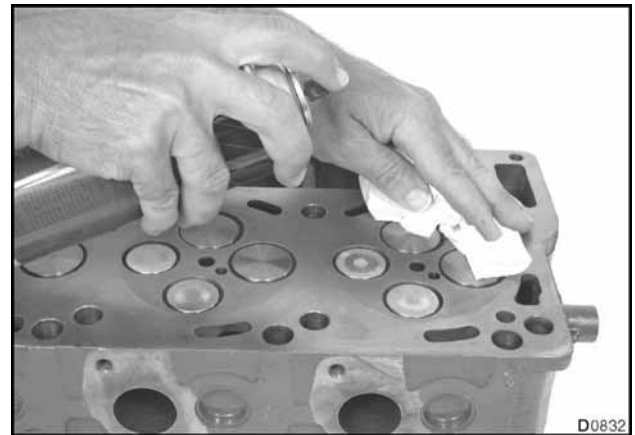


Figure 194 Cleaner sprayed on cylinder head

5. Spray cleaner on lower deck (gasket surface) of cylinder head and wipe dry.

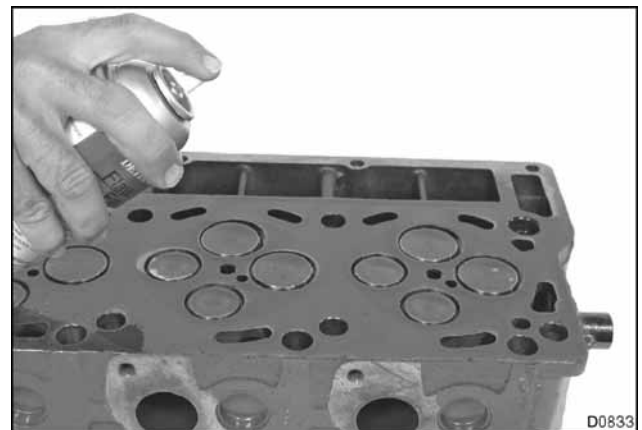


Figure 195 Dye penetrant sprayed on cylinder head

6. Spray dye penetrant on lower deck (gasket surface) of cylinder head and let dry for 5 to 15 minutes. Cracks will show up as purple lines against white developer.

7. Wipe dye off cylinder head surface.

NOTE: Dye will remain in cracks.

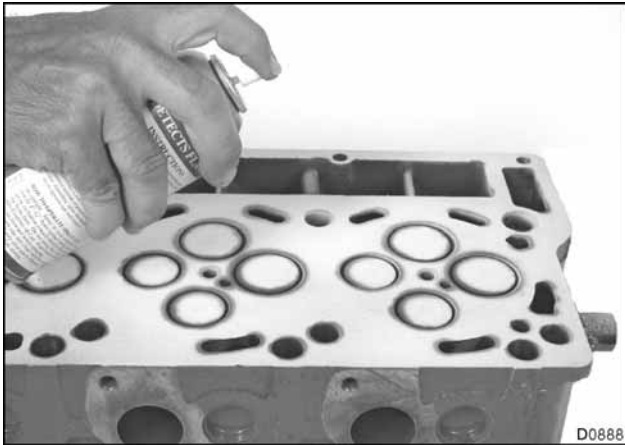


Figure 196 Spraying developer onto cylinder head

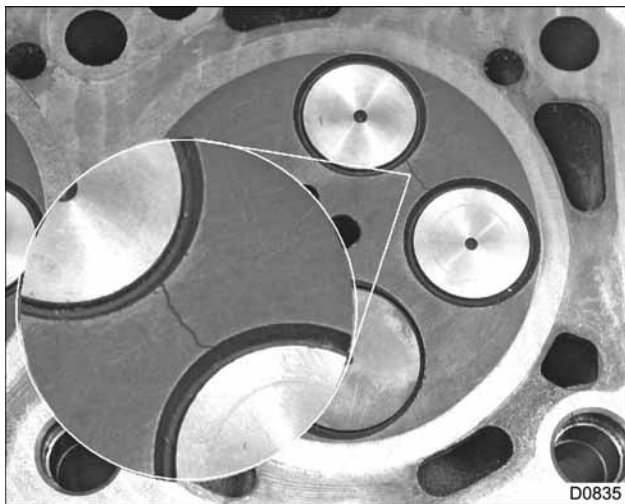


Figure 197 Cylinder head crack between intake and exhaust valves

8. Spray developer on lower deck (gasket surface) of cylinder head and let dry for 5 to 15 minutes. Cracks will show up as purple lines against white developer.

CAUTION: To prevent engine damage, replace the cylinder head if cracked.



Figure 198 Intake and exhaust ports sprayed with mineral spirits

9. Position cylinder head on wooden blocks with gasket surface facing down and spray mineral spirits into intake and exhaust ports.

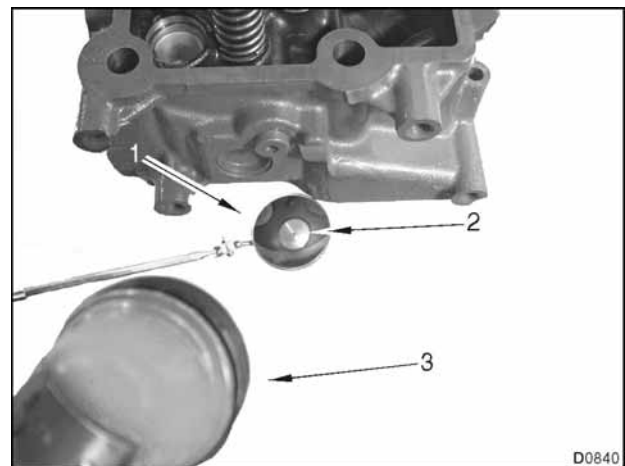


Figure 199 Leak inspection

1. Inspection mirror
2. Reflection of valve
3. Flashlight

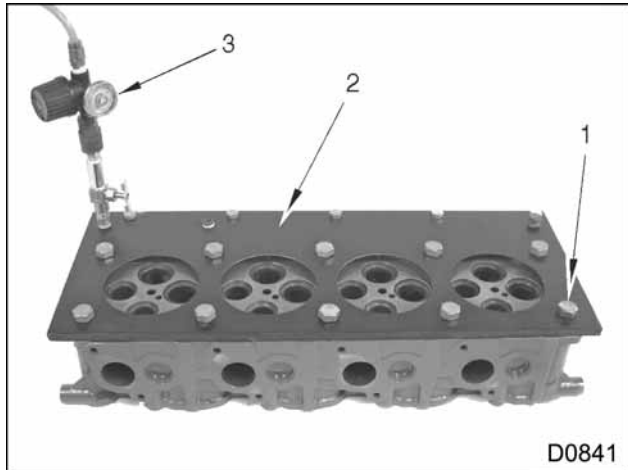
10. Wait five minutes. Use an inspection mirror to inspect valve seat area for leakage of mineral spirits.

NOTE: Valve seats must not leak. Valve seat reconditioning is not required, if the cylinder head passes the mineral spirits test. If valve seats leak, recondition the valves. See Removal in this section.

Cylinder Head Inspection – Valves Removed

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

1. Pressure testing the cylinder head will reveal cracks in ports or sleeve leakage which cannot be seen, using dye penetrant. Pressure test the cylinder head as follows:

**Figure 200 Cylinder head test plate**

1. Mounting bolt (15)
 2. Pressure test plate
 3. Pressure gauge and regulator
2. Fasten Cylinder Head Pressure Test Plate (Table 12) with rubber gasket attached to gasket side of cylinder head. Secure plate with ten M14 and five M8 mounting bolts.
 3. Immerse cylinder head in water. Apply air pressure and adjust to 124 to 138 kPa (18 to 20 psi) and inspect for leaks in the following places. If leaks are seen, install new cylinder head.
 - Ports
 - Upper cylinder head deck
 - Lower cylinder head deck
 - Nozzle sleeve area
 - Glow plug sleeve area

4. Install pressure test regulator and gauge assembly to cylinder head test plate (Table 12).
5. With the valves removed from the cylinder head, clean all valve guides using a nylon brush, soap and water. Blow out any residue with filtered compressed air.
6. Position an inspection light at the bottom of the valve guide bores and examine the walls for burning or cracking. Replace the cylinder head, if necessary.

**Figure 201 Measurement of Small Hole Gauge (valve guide ID)**

7. Measure each valve guide by using a small hole gauge (Table 12) and a 0-1 inch outside micrometer.
8. Record each valve guide inner diameter so valve-to-guide running clearance may be determined.
 - If valve guide inner diameter exceeds specifications (Table 10), replace cylinder head.
9. Using the valve guide inside diameter and valve stem diameter measurements, determine valve stem-to-guide running clearance. See Specifications (Table 10). Replace valve if necessary.
10. Clean valve seat area using suitable solvent, before inspection.

11. Inspect the exhaust valve seats for burned or cracked conditions. If any of these conditions exist, replace cylinder head.

Push Rods

1. Inspect pushrods for wear and deposits that may restrict oil flow into rocker arm assemblies. Replace pushrod if necessary.

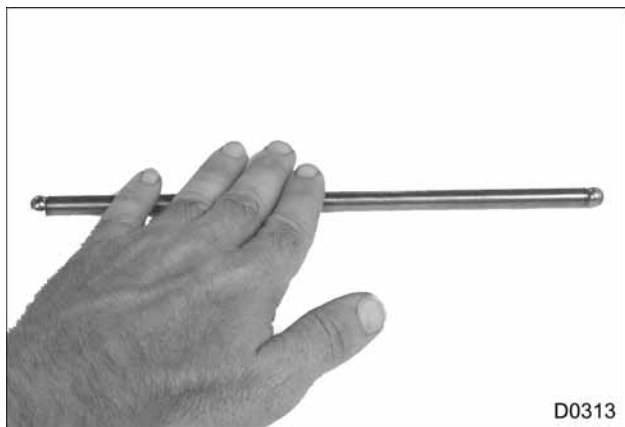


Figure 202 Push rod straightness

2. Roll pushrod on a flat surface to check straightness. If a pushrod is not straight, see Specifications for runout (Table 10). If specifications are exceeded, replace pushrod.

Valves

1. Remove all carbon from valve stems and heads, using a wire brush.
2. Inspect each valve. Replace valves having burn marks, warping, scuffing, bending or valve tip spalling.
3. Measure each valve stem diameter for wear using a 0-1 inch micrometer. Measure valves at three

locations 90° apart. See Specifications (Table 10). Replace valves that exceed the specification for minimum stem diameter.

NOTE: The intake valve has a larger diameter head.

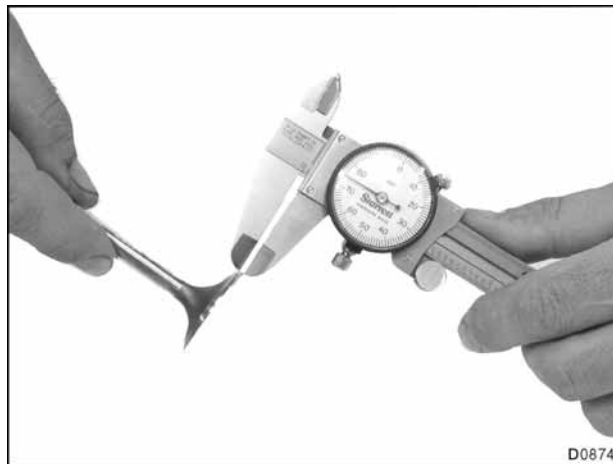


Figure 203 Measurement of valve face

4. Use a dial caliper to measure valve face margin at four locations (90° apart)

CAUTION: To prevent engine damage, minimum valve face margin must be maintained across the entire valve face. An insufficient margin will not provide correct heat dissipation and lead to valve warping or breakage. Intake and exhaust valve margins are different. Replace valve, if the margin is less than specified minimum. See Specifications (Table 10).

NOTE: If valves and seats are serviceable, they may be refaced to specified angles (Table 10).

Valve Springs

1. Clean all valve springs in a suitable solvent.
2. Inspect valve springs for rust, pitting, distortion, and cracks. If these conditions exist, replace the valve spring.



Figure 204 Flatness check of valve spring

3. Inspect to verify that spring ends are flat and square to prevent lateral loads on valve stem. Replace any springs if necessary.
4. Measure valve spring tension using a Valve Spring Tester (Table 12). Replace springs if necessary.



Figure 205 Measurement of valve spring free length

5. Measure valve spring free length. See Specifications (Table 10).



Figure 206 Measurement of valve spring free length under load

6. Apply correct test load to each spring and determine whether test length is achieved. See Specifications (Table 10).

Valve Spring Retainer Keys

1. Clean all valve spring retainer keys with a suitable cleaning solvent.
2. Inspect inside and outside of valve spring retainer keys for wear. Replace worn valve spring keys, if necessary.

Fuel Injector Sleeve Bore and Gallery

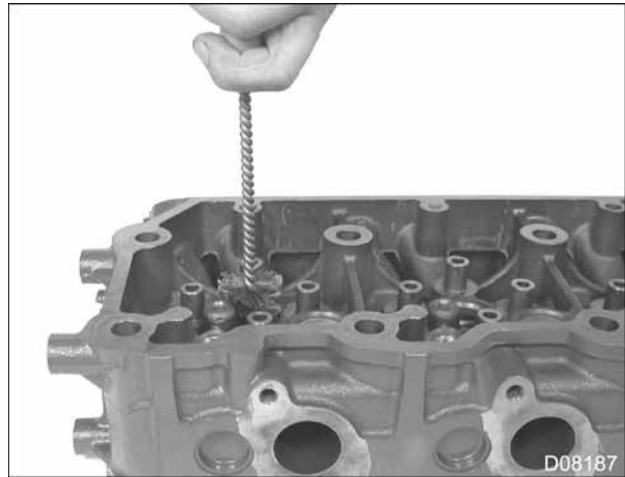


Figure 207 Injector bore

1. Insert an injector sleeve brush (Table 12) in the fuel injector bore and remove deposits and hardened sealant.
2. Remove fuel rail plug assembly (M12).

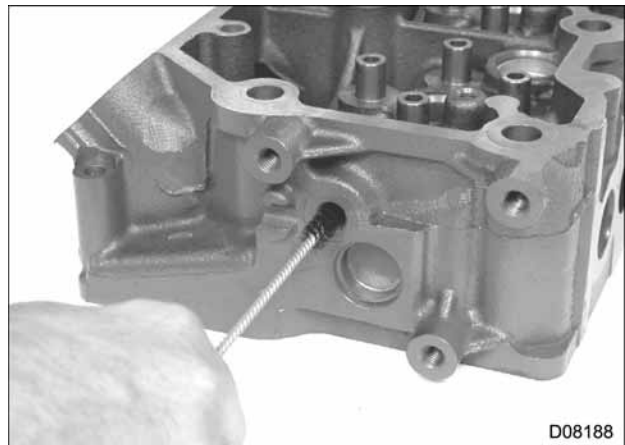


Figure 208 Fuel gallery

3. Clean the fuel gallery, using a Fuel Gallery Cleaning Brush (Table 12).

! 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).

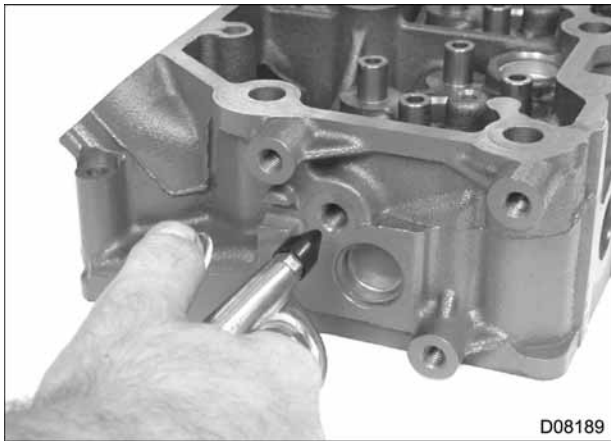


Figure 209 Fuel gallery

4. Use filtered compressed air to clean out debris from the fuel gallery port.
5. Install fuel rail plug assembly and tighten to the special torque (Table 11).

Glow Plug Sleeve Bore



Figure 210 Glow plug bore

1. Clean glow plug bore with Glow Plug Sleeve Seat Wire Brush (Table 12).

Rocker Fulcrums

! 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).

1. Clean parts with a suitable solvent. Use filtered compressed air to dry parts.
2. Inspect each rocker arm pivot foot and corresponding valve bridge for pitting or scuffing. Replace rocker arms and valve bridges, if necessary.
3. Inspect each rocker arm ball and socket for scuffing. Replace rocker arm ball and socket, if necessary.
4. Inspect rocker arm post ball socket for excessive wear. Inspect bolts for thread damage. Replace worn components, if necessary.
5. Inspect the valve cover gasket for damage or misalignment under compression. Under normal service conditions, the gasket can be reused.

Installation

Fuel Injector Sleeve

Do the following steps when installing a new fuel injector sleeve:

1. Verify injector bore is completely clean and dry.
2. Put fuel injector sleeve on Injector Sleeve Installer. (Table 12).

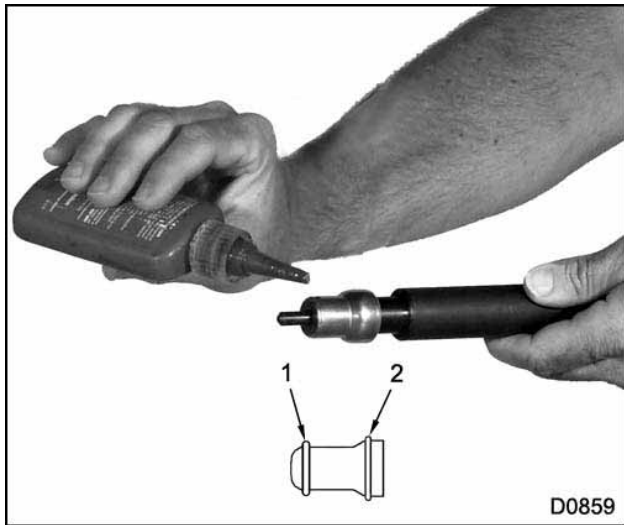


Figure 211 Application of liquid gasket to fuel injector sleeve

1. Wall (end)
2. Upper wall (top)
3. Apply Liquid Gasket (RTV) (Table 12) to fuel injector sleeve.
4. Carefully center the fuel injector sleeve in the injector bore.



Figure 212 Installation of fuel injector sleeve into bore

5. Use a hammer, drive Injector Sleeve Installer with fuel injector sleeve in fuel injector bore until the sleeve bottoms. If any liquid gasket gets in the inside of the injector sleeve, it must be cleaned out before it hardens.

Glow Plug Sleeve

! 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).

NOTE: Make sure the glow plug recess was cleaned out with the glow plug sleeve brush, rinsed with a suitable cleaning solution, and blown out with shop air.

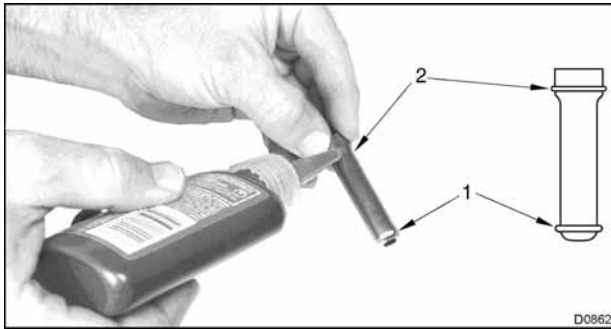


Figure 213 Application of liquid gasket to sleeve

1. Wall (end)
2. Upper wall (top)

1. Apply Liquid Gasket (RTV) (Table 12) to the wall and upper wall on the glow plug sleeve.

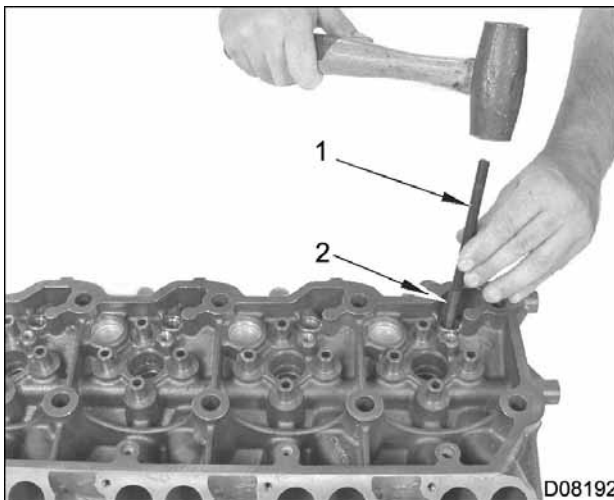


Figure 214 Installation of glow plug sleeve

1. Glow Plug Sleeve Installer
 2. Glow plug sleeve
2. Install glow plug sleeve in cylinder head with the Glow Plug Sleeve Installer (Table 12). Continue to tap the Glow Plug Sleeve Installer until the sleeve bottoms out in the recess.
 3. Clean glow plug sleeve with a Glow Plug Sleeve Brush (nylon) (Table 12) and solvent. Make sure liquid gasket is cleaned out before it hardens.

Cylinder Head Assembly

Install Valves

1. Clean valve faces and seats with a suitable cleaning solvent to remove all dirt or foreign material.

! 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).

2. Blow dry all new and used components.

NOTE: Guides must be clean.

3. Clean guides with valve guide brush.
4. Dry valve guides with filtered compressed air.
5. Lubricate the inside diameter of the new valve stem seal with clean engine oil and install valve seal over valve guide until it stops.

NOTE: Valve seal will not seat completely over valve guide by hand. Seals can be seated using a deep socket and a rubber mallet to provide a positive contact with the machined base.

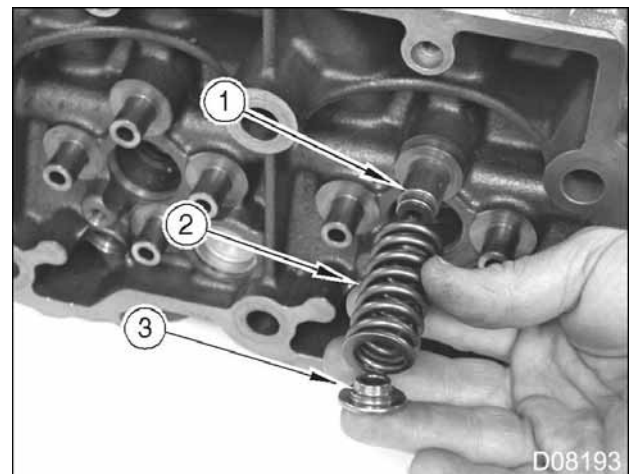


Figure 215 Installation of valve seal, spring, and retainer

1. Valve seal
 2. Valve spring
 3. Valve retainer
6. Place valve spring over valve stem seal.
 7. Install a valve spring retainer on top of spring.

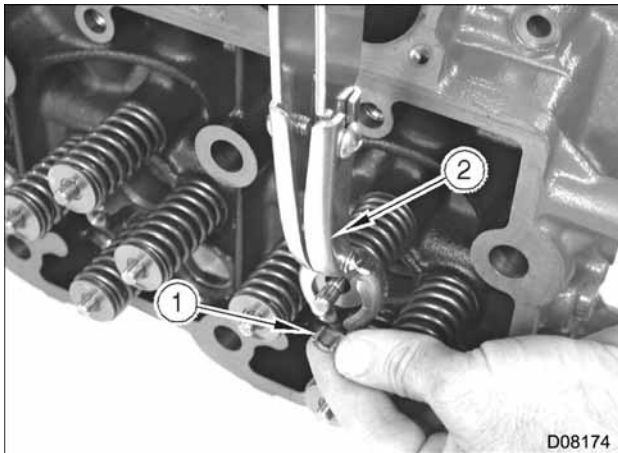


Figure 216 Installation of valve retainer key

1. Valve retainer key
2. Valve spring compression tool

8. Attach "C" Type Valve Spring Compressor (Table 12) and compress the valve spring. Install the retainer keys and release valve spring compression tool.

CAUTION: To prevent engine damage, make sure retainer keys are correctly seated in each valve stem.

9. After valve replacement, measure valve head recession relative to deck to confirm reconditioning. See Specifications (Table 10).

Rocker Arm Carrier Fulcrum Assemblies

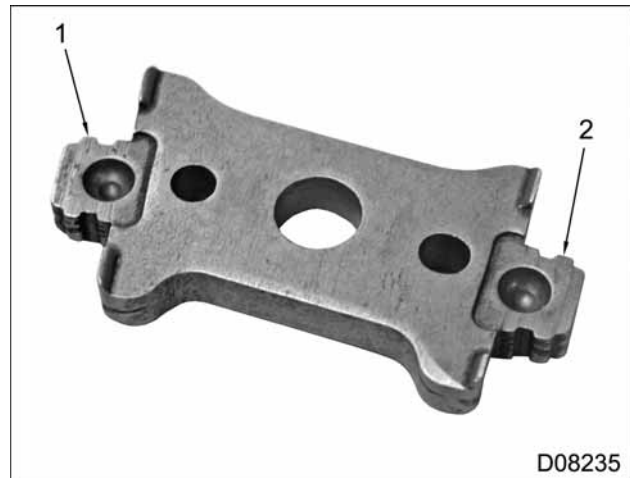


Figure 217 New rocker arm fulcrum (dual underside)

1. Exhaust end
2. Intake end

NOTE: Earlier rocker arm fulcrums are no longer serviceable; new rocker arm fulcrums and clips are required.

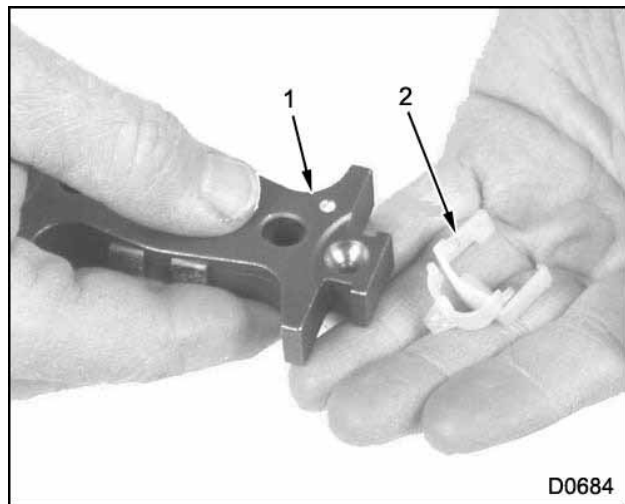


Figure 218 Installation of new rocker arm clip (typical)

1. Fulcrum plate
2. Rocker arm clip

1. Install a new rocker arm clip on new fulcrum plate.

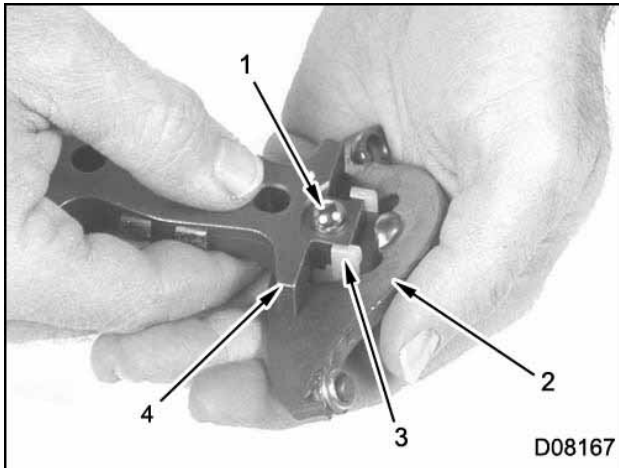


Figure 219 Installation of rocker arm ball (typical)

1. Rocker arm ball
2. Rocker arm
3. Rocker arm clip
4. Fulcrum plate

2. Insert rocker arm ball in detent in fulcrum plate.

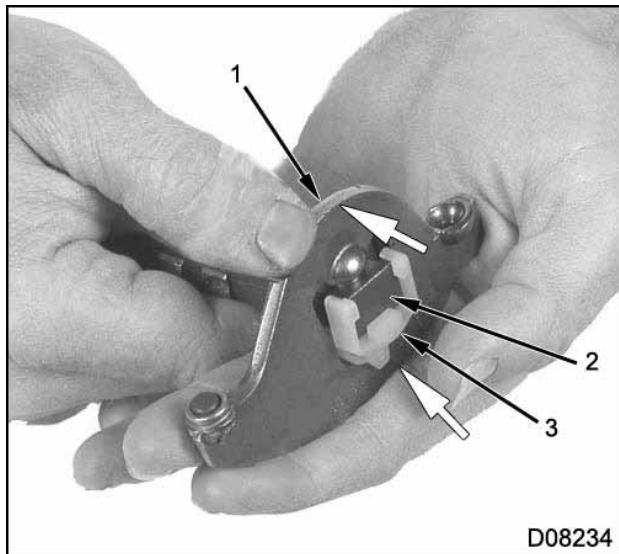


Figure 220 Installation of rocker arm (typical)

1. Rocker arm
2. Fulcrum plate
3. Rocker arm clip

3. Position lower part of rocker arm under rocker arm clip, push up with your palm, and use thumb back

to pull upper part of rocker arm over rocker arm ball.

4. Check for freedom of movement of rocker arm on fulcrum plate.

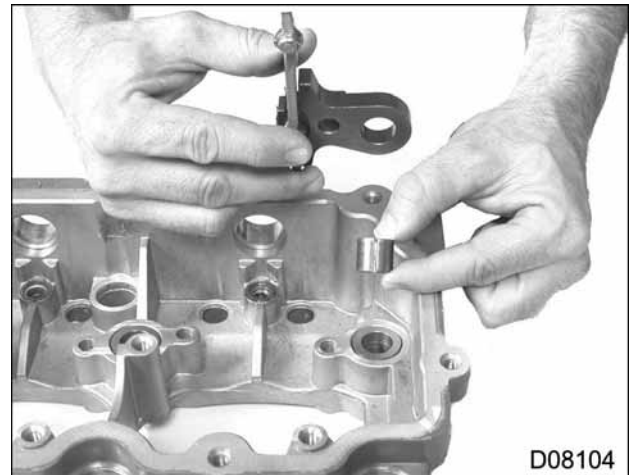


Figure 221 Installation of end fulcrum plate and dowel (typical)

5. Assemble intake and exhaust fulcrum plates to each end of the rocker carrier assembly by setting the fulcrum on the locating dowel and orienting the stamped **E** and **I** face up. Install an M8 x 65 bolt and spacer on each fulcrum and tighten to the special torque (Table 11).

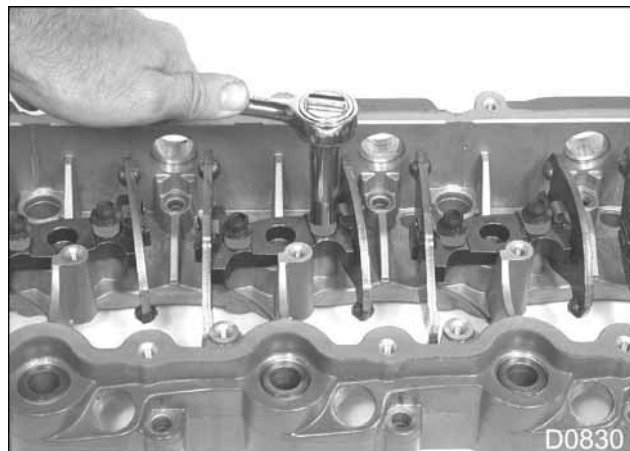


Figure 222 Installation of dual rocker fulcrum plates

6. Assemble the dual rocker fulcrum plates to carrier assembly by orienting the **E** and **I** up and

the casting branches toward the camshaft. Install six M8 x 65 bolts and spacers and tighten to the special torque (Table 11).

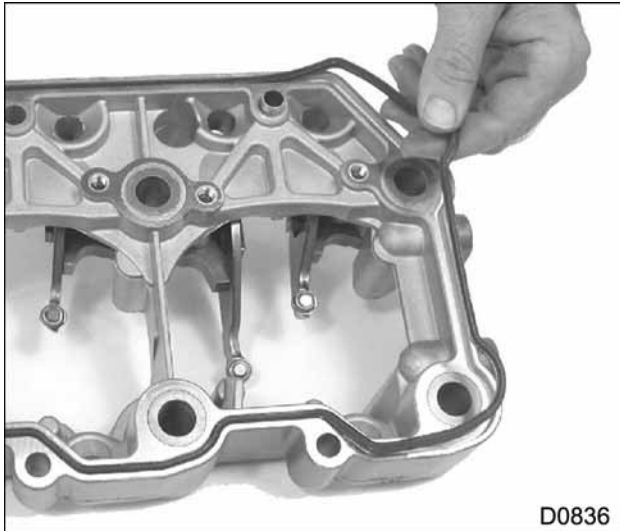


Figure 223 Cylinder head to rocker carrier gasket

7. Replace cylinder head to rocker carrier gasket.

Hydraulic Cam Follower

1. Clean hydraulic cam followers and roller follower guide. Use care to maintain roller follower identification and orientation.

NOTE: Identify orientation of each cam follower and guide during assembly.



Figure 224 Installation of cam follower in guide

2. Lubricate and put each hydraulic cam follower in its respective roller follower guide.

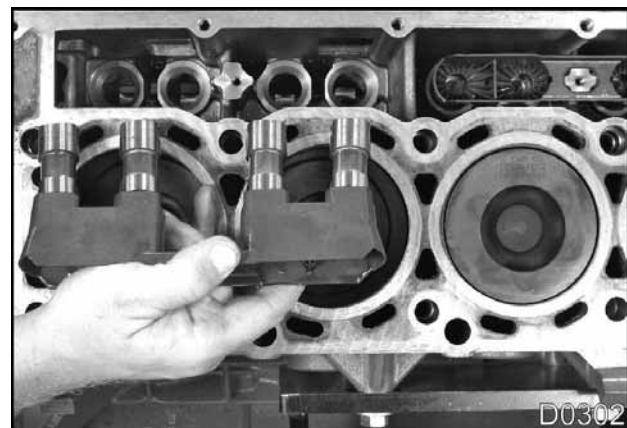


Figure 225 Installation of cam followers and guide

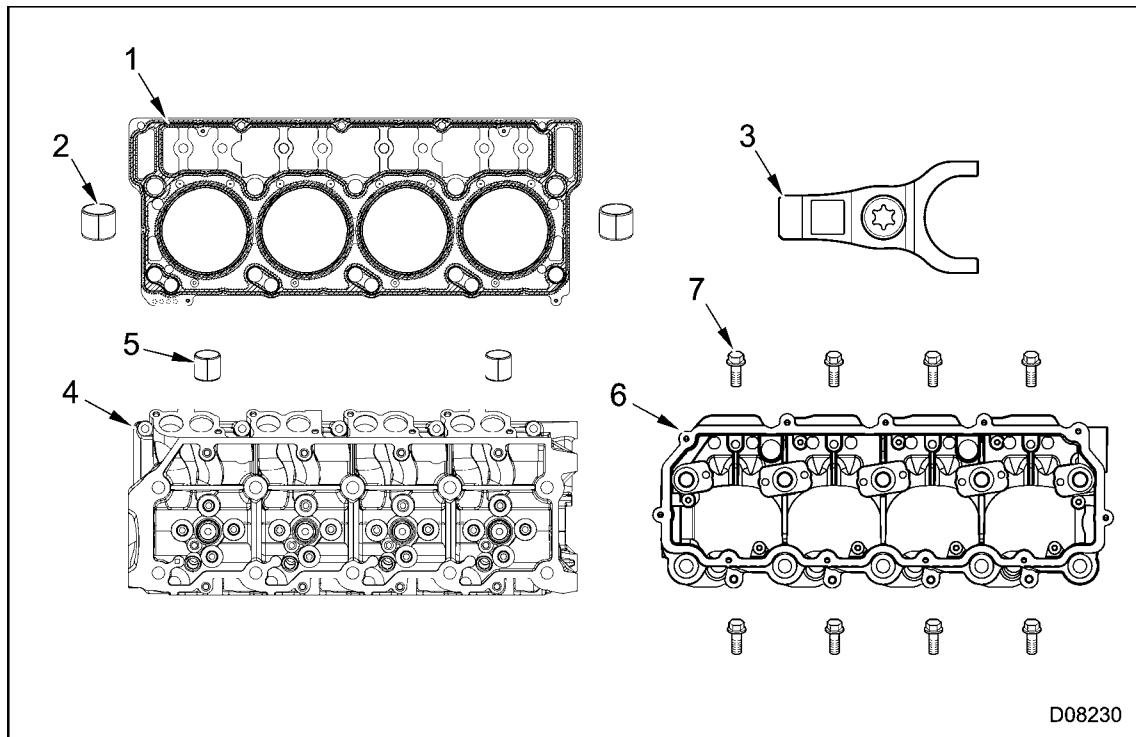
3. Lubricate cam followers with clean engine oil and install cam followers in correct bores.

NOTE: See "High-pressure Oil Pump" section, for procedure to mount branch tube assembly over rear cam follower guides.

to the standard value (Standard Torques, page 375).

4. Install an M6 x 15 bolt with washer on roller follower guides (front guides only) and torque bolt

Cylinder Head Applications

**Figure 226 2004 and 2005 Model Year (eight M8 mounting bolts for rocker arm carrier)**

1. Cylinder head gasket	3. Fuel injector hold down clamp	5. M8 dowel sleeve bushing (2)
2. 18 mm spring dowel pin (2)	(4)	6. Rocker arm carrier
4. Cylinder head	7. M8 bolt (8)	

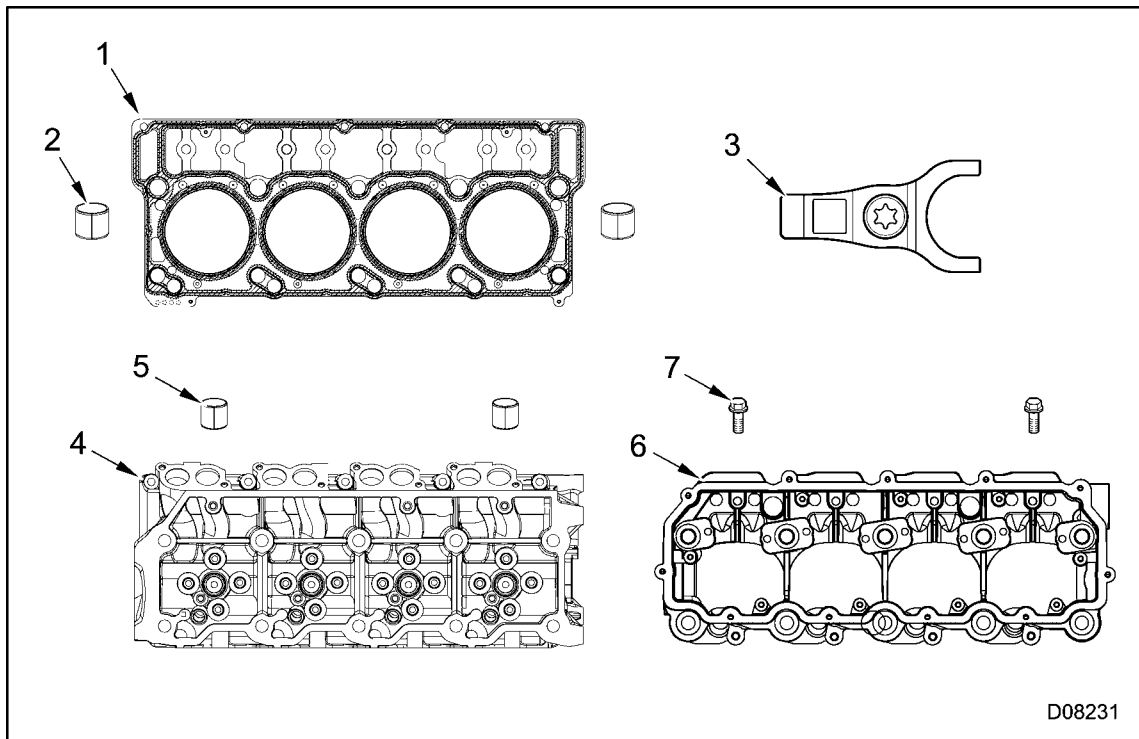


Figure 227 2005 Model Year (two M8 mounting bolts for rocker arm carrier)

1. Cylinder head gasket	3. Fuel injector hold down clamp	5. M10 dowel sleeve bushing (2)
2. 18 mm spring dowel pin (2)	(4)	6. Rocker arm carrier
4. Cylinder head	7. M8 bolt (2)	

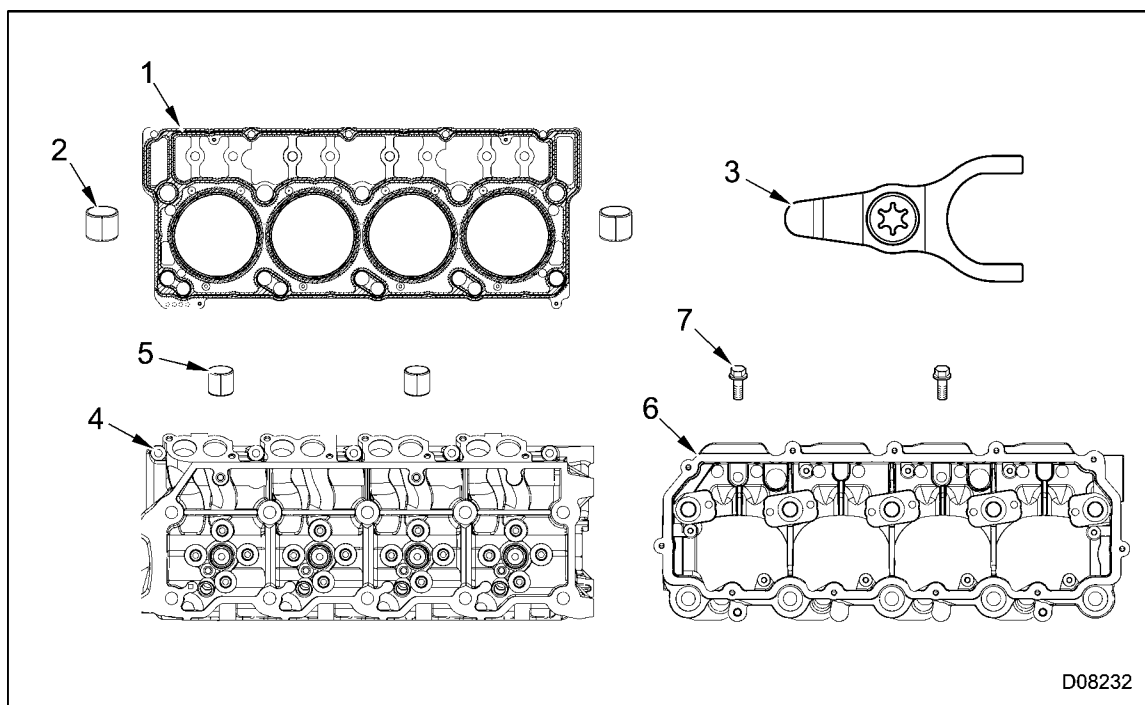


Figure 228 2006 Model Year (two M10 mounting bolts for rocker arm carrier)

1. Cylinder head gasket	3. Fuel injector hold down clamp	5. M10 dowel sleeve bushing (2)
2. 20 mm spring dowel pin (2)	(4)	6. Rocker arm carrier
4. Cylinder head	7. M10 mm bolt (2)	

NOTE: 2006 Model Year parts are not interchangeable with 2004 or 2005 Model Year applications.

1. If not done, clean all cylinder head bolt holes with a bottoming tap (Table 12) and remove debris with filtered compressed air.

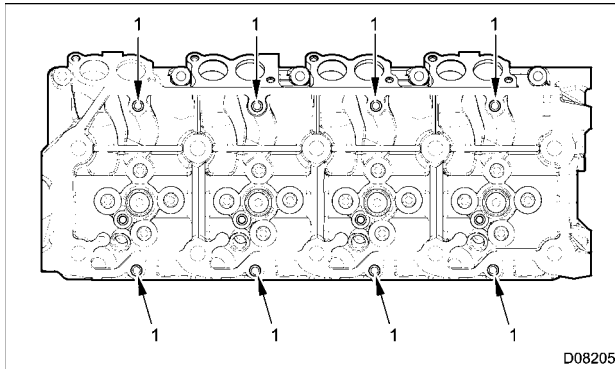


Figure 229 2004 and 2005 Model Year cylinder head (eight tapped M8 holes)

1. Tapped M8 bolt hole (8)

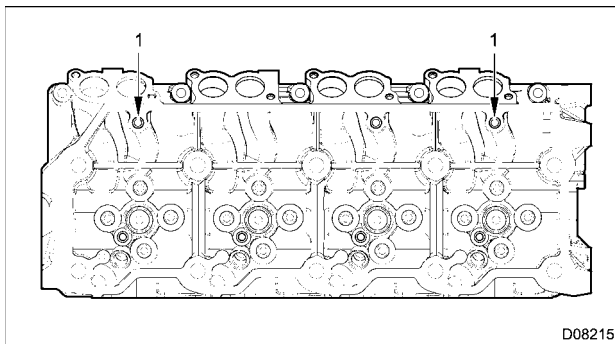


Figure 230 2005 Model Year cylinder head (two tapped M8 holes)

1. Tapped M8 bolt hole (2)

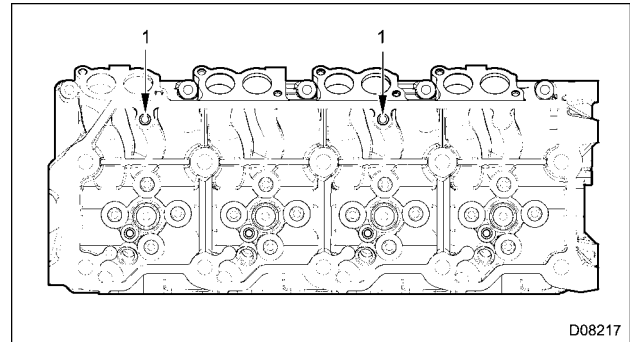


Figure 231 2006 Model Year cylinder head (two tapped M10 holes)

1. Tapped M10 bolt hole (2)

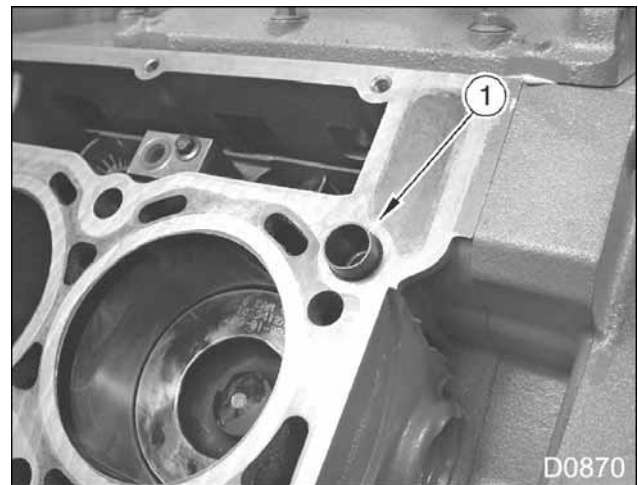


Figure 232 Cylinder head spring dowel pin in crankcase (typical)

1. Spring dowel pin (2)
2. Make sure two spring dowel pins are installed in crankcase.
 - For 2004 and 2005 Model Year cylinder heads, use 18 mm spring dowel pins.
 - For 2006 Model Year cylinder heads, use 20 mm spring dowel pins.

! 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: Threads in crankcase bolt holes must be clean and blown dry with filtered compressed air. Dirt or oil left in holes may cause binding or a false torque reading during assembly.

CAUTION: To prevent engine damage, make sure cylinder head and head gasket are clean and free of debris. A contaminated seal between the cylinder head and gasket can lead to oil, coolant, and compression leakage. Do not apply sealer to head gasket surfaces.



Figure 233 Installation of cylinder head gasket

1. Cylinder head gasket
2. Spring dowel pins (2)

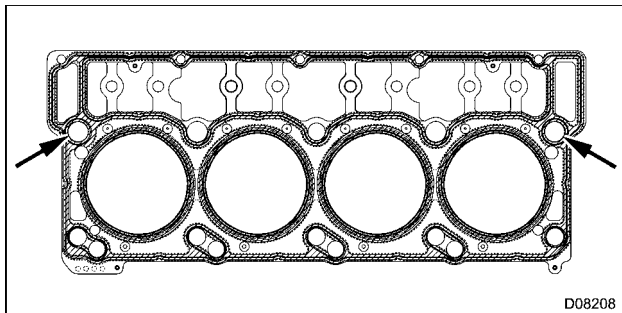


Figure 234 Clearance holes for spring dowel pins (typical)

CAUTION: To prevent engine damage, install the correct cylinder head gasket with part number facing up. Make sure the top five bolt holes and head gasket push rod holes line up.

NOTE: Use care to avoid scratching blue compound on cylinder head gaskets.

3. Align new cylinder head gasket with spring dowel pins and press to install.
 - For 2004 and 2005 cylinder heads, use cylinder head gasket with 18 mm with clearance holes for two spring dowel pins.
 - For 2006 cylinder heads, use cylinder head gasket with 20 mm with clearance holes for two spring dowel pins.

NOTE: Cam followers cannot be removed or replaced when cylinder head is bolted to the crankcase. Be sure to complete required work on cam followers, before installing cylinder head.

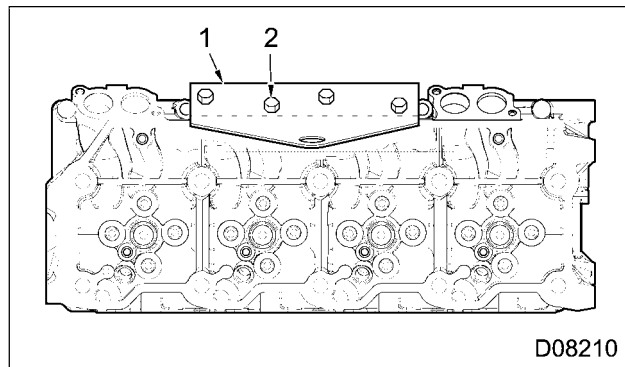


Figure 235 Installation cylinder head lifting bracket

1. Cylinder head lifting bracket
2. Lifting bracket mounting bolt (4)

4. Install Cylinder Head Lifting Bracket (Table 12) in center of cylinder head (if removed). Tighten bracket mounting bolts.

CAUTION: To prevent engine damage, do not drop or slide cylinder head on head gasket. Either action will damage the cylinder head gasket and spring dowel pins, resulting in leakage.

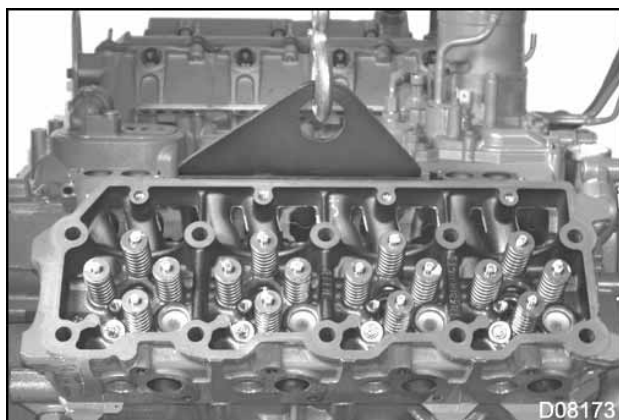


Figure 236 Attached hoist hook

5. Attach hoist hook or lifting sling to lifting bracket. Raise cylinder head and align with dowel sleeves previously installed in crankcase.

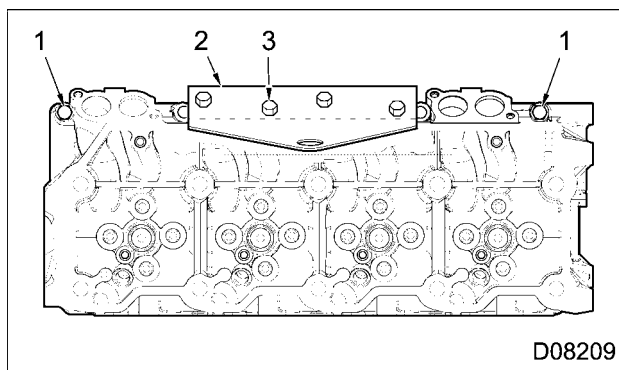


Figure 237 Installation of Cylinder head

1. M8 x 70 bolt – cylinder head to crankcase (2 of 5)
 2. Cylinder head lifting bracket
 3. Lifting bracket mounting bolt (4)
6. Install two outer M8 x 70 bolts – cylinder head to crankcase. Run threads down until finger tight.
 7. Remove cylinder head lifting bracket and hoist.

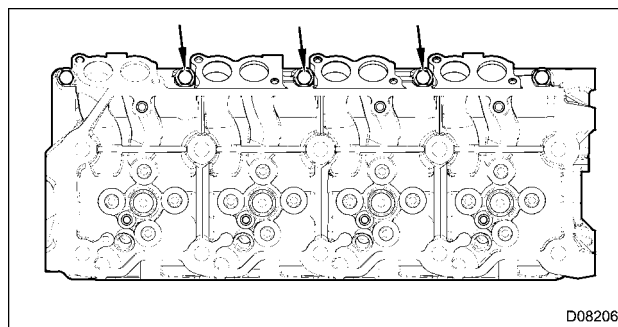


Figure 238 Installation of middle M8 x 70 bolts

8. Install three middle M8 x 70 bolts – cylinder head to crankcase. Run threads down until finger tight.

Valve Bridges and Push Rods

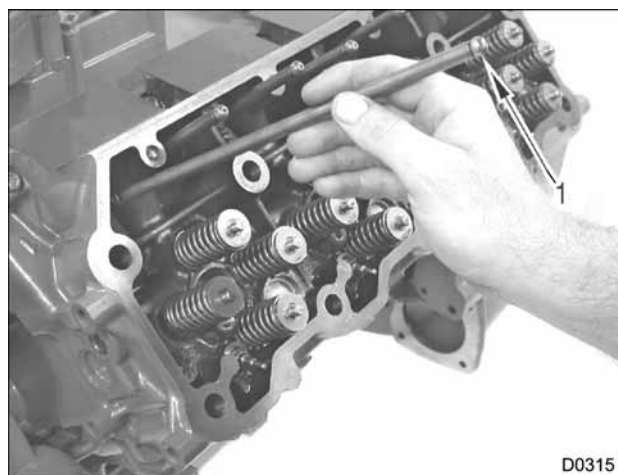


Figure 239 Pushrod

1. Pushrod
1. Apply clean engine oil to each end of pushrod and install to original locations.
 2. Coat the end of each valve stem with clean engine oil.

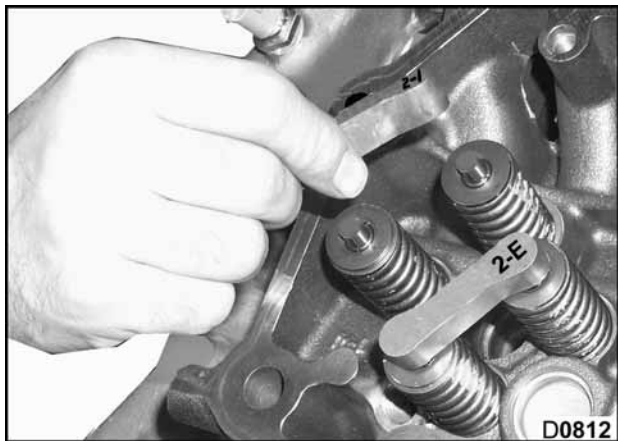


Figure 240 Valve bridges

3. Place each of the previously marked valve bridges on their respective valve stems.

Rocker Arm Carrier

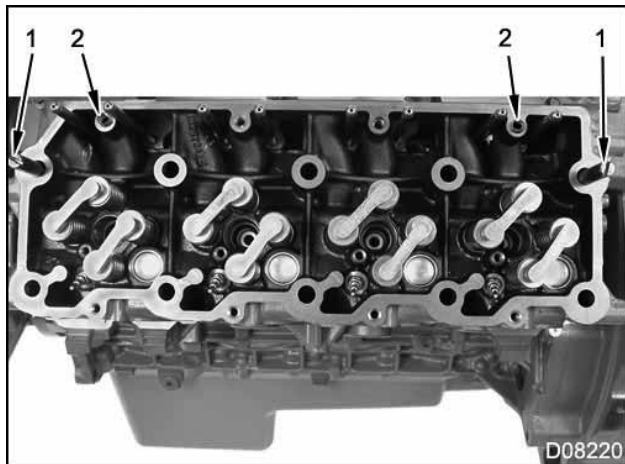


Figure 241 Alignment guides and dowel sleeve bushing in 2004 and 2005 Model Year cylinder head (Eight tapped M8 holes)

1. Alignment guide (2)
2. M8 dowel sleeve bushing (2)

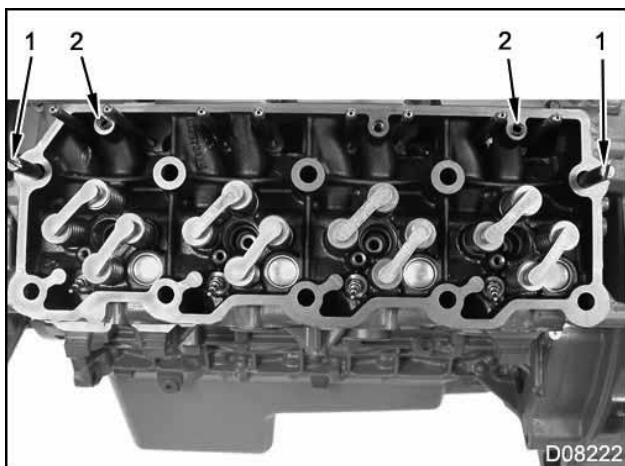


Figure 242 Alignment guides and dowel sleeve bushing in 2005 Model Year cylinder head (Two tapped M8 holes)

1. Alignment guide (2)
2. M8 dowel sleeve bushing (2)

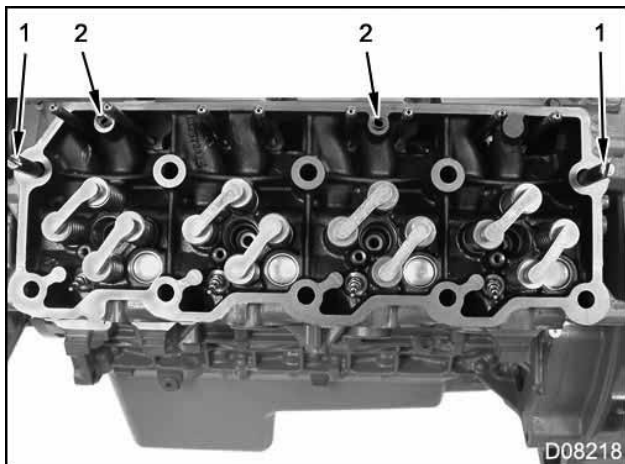


Figure 243 Alignment guides and dowels in 2006 Model Year cylinder head (Two tapped M10 holes)

1. Alignment guide (2)
2. M10 dowel sleeve bushing (2)

1. Install dowel sleeve bushings in cylinder head.

NOTE: Dowel sleeve bushings may still be attached to the cylinder head side of the rocker arm carrier.

2. Install cylinder head and rocker carrier alignment guides (make locally), before installing rocker arm carrier.

3. Rotate the crankshaft until damper locating dowel hole is in the six o'clock position. This positions all pistons below TDC, so the valves do not contact the pistons when tightening the rocker arm assemblies.
4. Apply engine oil to the top center of each valve bridge.

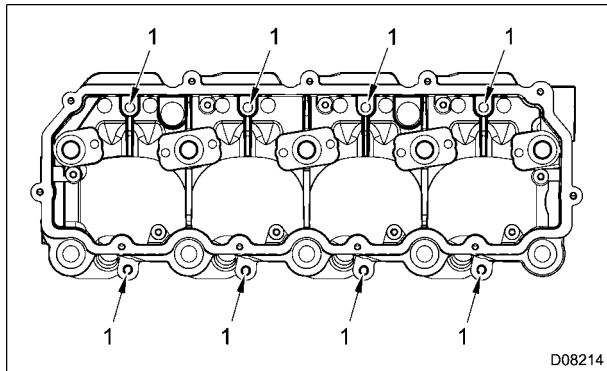


Figure 244 2004 and 2005 Model Year rocker arm carrier (Eight M8 clearance holes)

1. M8 clearance hole (8)

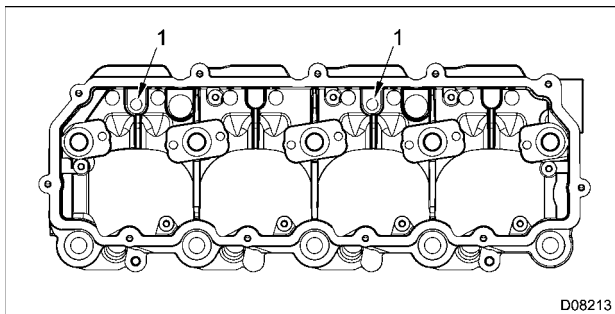


Figure 245 2006 Model Year rocker arm carrier (Two M10 clearance holes)

1. M10 clearance hole (2)

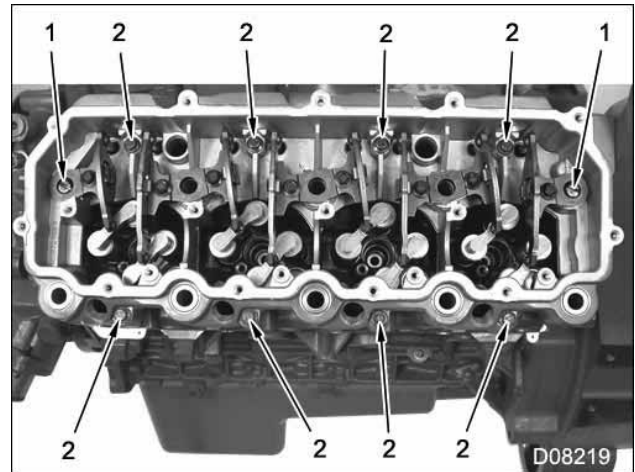


Figure 246 Installation of 2004 and 2005 Model Year rocker arm carrier (Eight M8 mounting bolts)

1. Alignment guides (2)
2. M8 x 50 bolt (8)

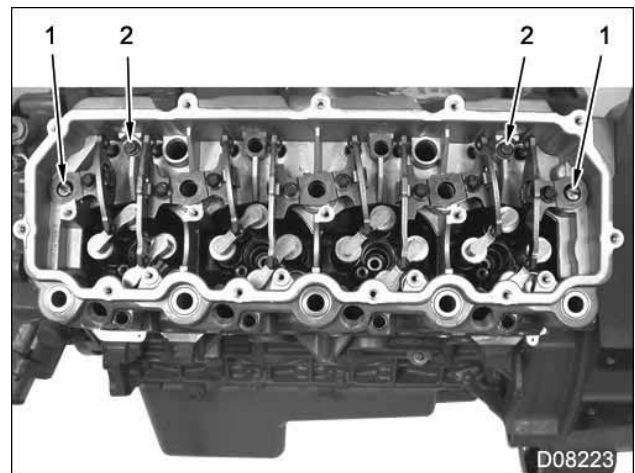


Figure 247 Installation of 2004 and 2005 Model Year rocker arm carrier (Two M8 mounting bolts)

1. Alignment guides (2)
2. M8 x 50 bolt (2)

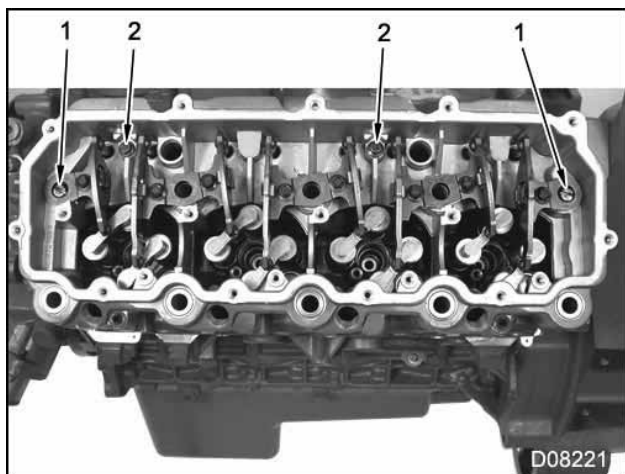


Figure 248 Installation of 2006 Model Year rocker arm carrier (Two M10 mounting bolts)

1. Alignment guides (2)
 2. M10 x 50 bolt (2)
5. Place rocker arm carrier on guides.
 6. Install M8 bolts and tighten to the standard torque (Standard Torques, page 375).
 - Eight M8 x 50 bolts or two M8 x 50 bolts are required for 2004 and 2005 rocker arm carriers.
 - Two M10 x 50 bolts are required for 2006 rocker arm carriers.

NOTE: If installing eight M8 x 50 bolts, pay close attention to rocker carrier alignment dowels when tightening down rocker arm carriers. It may be necessary to tighten the top four bolts first, then the lower bolts, to ensure correct engagement of dowels.

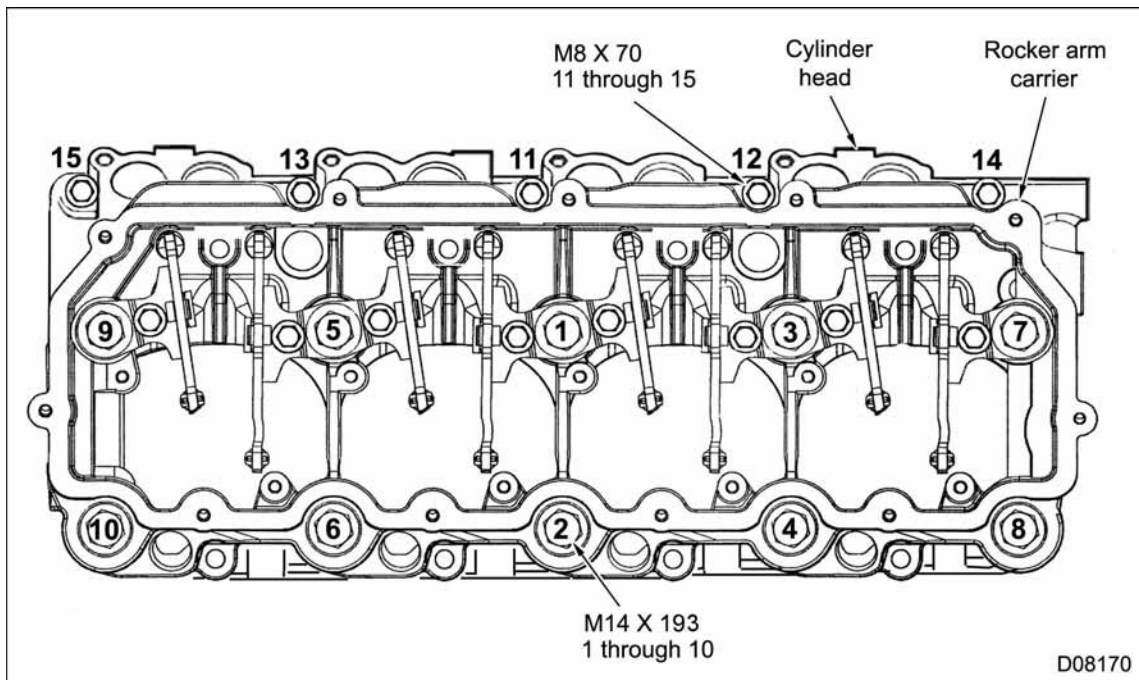
CAUTION: To prevent engine damage, use only permanent ink markers to identify bolt torque orientation.

CAUTION: To prevent engine damage, check to make sure push rod has seated in the rocker arm pocket.

CAUTION: To prevent engine damage, install new M14 x 193 head bolts. Lightly lubricate new bolt threads and mating surfaces of bolt flanges with clean engine oil. Too much oil will cause hydrostatic lock and give incorrect torque reading.

CAUTION: Do not use anti-seize, grease, or any other lubricant except engine oil. Other lubricants have an adverse effect on torque results.

7. Lightly lubricate 10 new M14 x 193 cylinder head bolts with clean engine oil.
8. Install the first eight bolts finger tight in the open positions.
9. Remove the two rocker arm carrier alignment guides and replace with the two remaining bolts finger tight.

Tightening Sequence for Cylinder Head Bolts**M14 x 193 Bolts****Figure 249 Special torque sequence for cylinder head mounting bolts (typical)**

NOTE: All M14 x 193 cylinder head mounting bolts must be torqued first, before torquing M8 x 70 bolts.

1. Torque new lubricated bolts in the sequence numbered 1 through 10 to 88 N·m (65 lbf·ft).
2. Torque bolts 1, 3, 5, 7 and 9 in sequence to 116 N·m (85 lbf·ft).
3. Torque all bolts in sequence numbered 1 through 10, clockwise 90°.
4. Torque all bolts in sequence numbered 1 through 10, a second time clockwise 90°.
5. Torque all bolts in sequence numbered 1 through 10, a third time clockwise 90°.
6. M14 x 193 torque sequence complete.
1. See Cylinder Head Mounting Bolt Special Torque Sequence (Figure 249) for the following steps:
2. Torque M8 bolts in the sequence numbered 11 through 15 to 24 N·m (18 lbf·ft).
3. Torque all M8 bolts in the sequence numbered 11 through 15 to 31 N·m (23 lbf·ft).
4. M8 x 70 torque sequence complete.

M8 x 70 Bolts

CAUTION: To prevent engine damage, do not lubricate the M8 x 70 bolts. Too much oil will cause hydrostatic lock and give incorrect torque reading. Lubricants have an adverse effect on torque results.

Fuel Injectors**Replace Copper Gasket and O-rings for Fuel Injector**

CAUTION: To prevent engine damage, do not use air tools when installing fuel injectors. Do not scratch injector surfaces.

CAUTION: To prevent engine damage, replace external O-rings and copper gasket each time a fuel injector is removed.

1. Remove the old copper gasket with a small hand tool. Wipe injector nozzle with a lint free cloth.

2. Install a new copper gasket injector onto injector tip.

NOTE: The copper gasket may be installed in either direction.

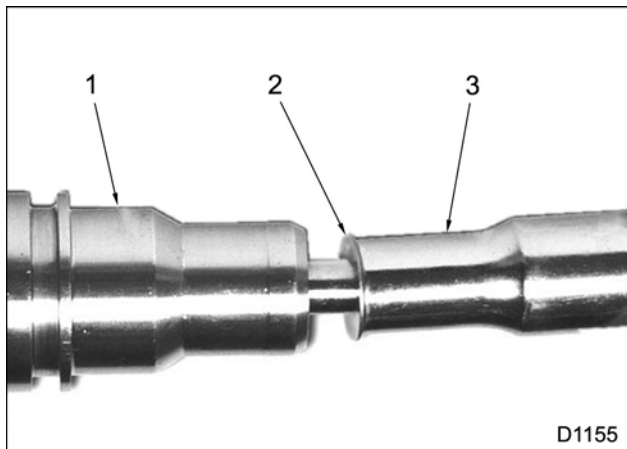


Figure 250 Seating copper gasket

1. Injector (nozzle end)
 2. Gasket (copper)
 3. Deep socket
3. To seat gasket, push on gasket with a deep socket.
 4. Use a nonmetallic hand tool to remove upper and lower O-rings from fuel injector. Discard O-rings.
 5. Install a new Teflon coated (white) O-ring (smaller diameter) in the lower recess just below the fuel inlet screens. Avoid contact with sharp machined surfaces.

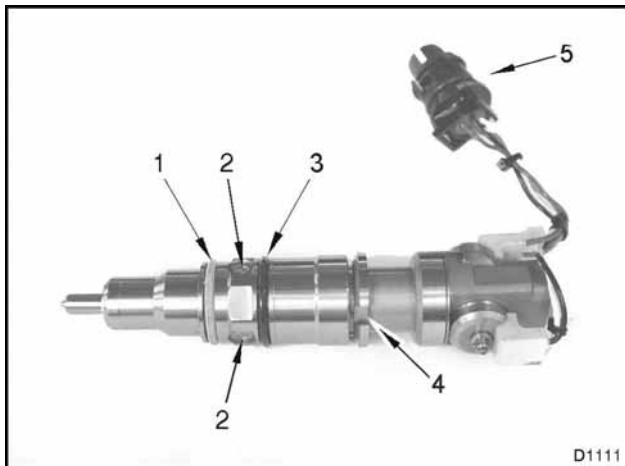


Figure 251 Fuel injector external O-rings

1. O-ring, lower (white Teflon coating) (smaller diameter)
 2. Fuel inlet screen (3)
 3. O-ring, upper (black Teflon coating) (larger diameter)
 4. Clamp alignment slot
 5. O-ring, harness connector (dark blue)
6. Install a new Teflon coated (black) O-ring (larger diameter) in the recess just above the fuel inlet screens. Avoid contact with sharp machined surfaces.



Figure 252 Lubrication of fuel injector O-rings

7. Lubricate upper and lower O-ring with clean engine oil.

Fuel Injector Assembly

CAUTION: To prevent engine damage, verify hold down bolt retainer is in position when installing injector hold down clamp assembly.

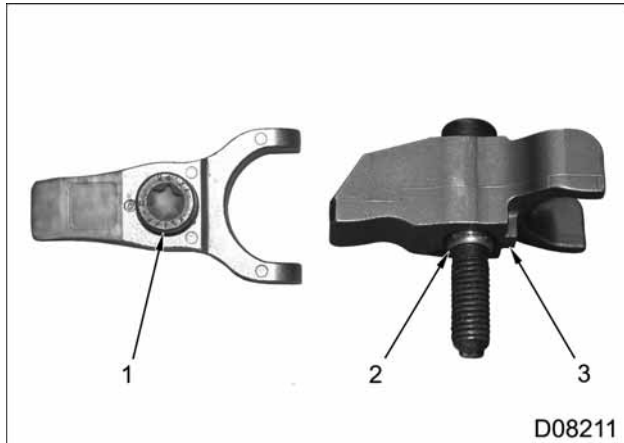


Figure 253 Fuel injector hold down clamp assembly (2004 and 2005 cylinder head applications)

1. Bolt, M8 X 45
2. Retainer
3. Clamp alignment index

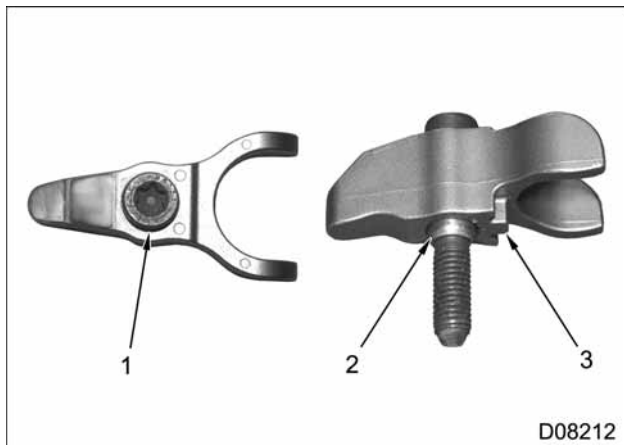


Figure 254 Fuel injector hold down clamp assembly (2006 cylinder head application)

1. Bolt, M8 X 45
2. Retainer
3. Clamp alignment index

1. Align injector assembly clamp alignment slot with hold down clamp alignment index. This aligns the injector correctly.

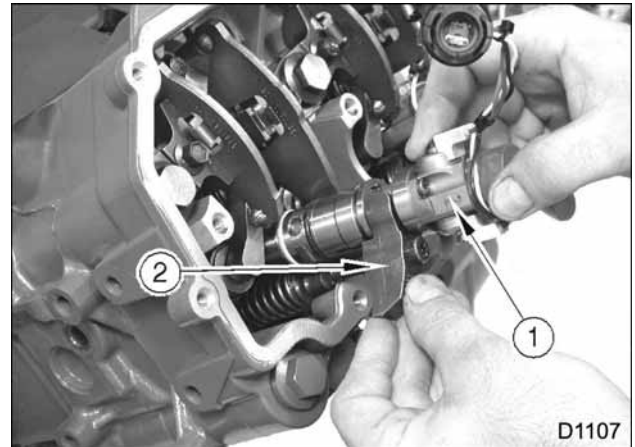


Figure 255 Installation of injector

1. Fuel injector
 2. Fuel injector hold down clamp assembly
2. Install fuel injector assembly by lowering fuel injector and hold down clamp assembly as one unit into injector bore.



Figure 256 Fuel Injector Hold Down Wrench



Figure 257 Fuel Injector Hold Down Wrench installed

1. Fuel injector assembly
2. Fuel injector hold down clamp assembly
3. Fuel Injector Hold Down Wrench

CAUTION: To prevent damage to fuel injector assemblies, do not use air power tools to remove or install injectors.

3. Use the Fuel Injector Hold Down Wrench (Table 12) to install the fuel injector hold down clamp assembly.
4. Tighten hold down clamp bolt to the special torque (Table 11).

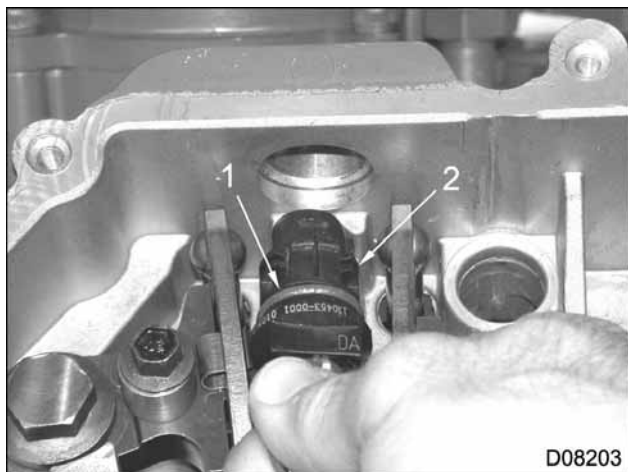


Figure 258 Installation of injector harness connector

1. O-ring
2. Injector harness connector

5. Replace O-ring on injector harness connector.
6. Position connector (identification marks face up) and push connector straight into mounting hole.

CAUTION: To prevent engine damage, be sure injector wiring is clear of moving parts.

High-pressure Oil Rail System



Figure 259 Lubrication of top D-ring

1. Lubricate the D-ring in the top of the injector cavity with clean engine oil.



Figure 260 Alignment of oil rail assembly to oil inlets

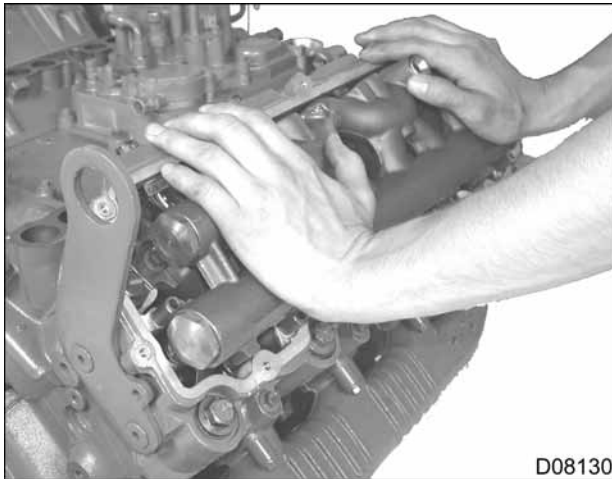


Figure 261 Oil rail assembly

2. Align oil rail assembly with oil inlets of each injector.
3. Tilt oil rail assembly toward engine, align oil rail assembly with case-to-head tube assembly, and push down evenly until oil rail assembly is firmly seated.
4. Hand start M6 x 25 oil rail assembly bolts 1, 2, and 3 until finger tight.

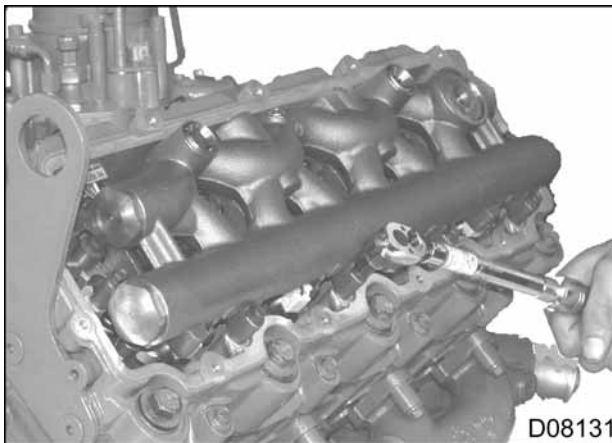


Figure 262 Oil rail assembly

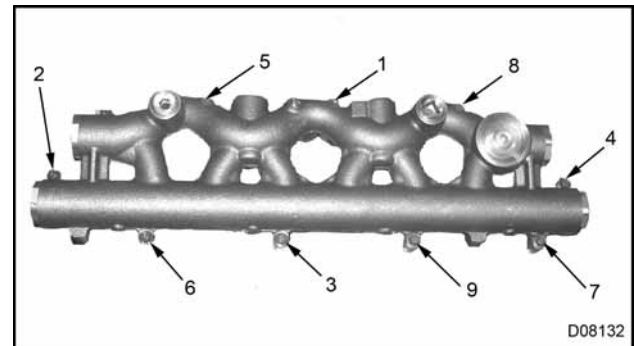


Figure 263 Torque sequence for oil rail bolts

5. Finish installing the remaining bolts finger tight. Torque bolts to the special torque (Table 11) following the sequence in (Figure 263).

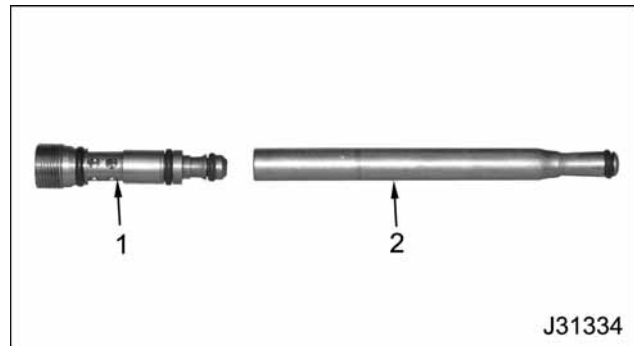


Figure 264 Crankcase-to-head tube assembly

1. Crankcase-to-head tube plug (long – with check valve)
2. Crankcase-to-head tube



Figure 265 Crankcase-to-head tube plug (hex head)

NOTE: The square socket short crankcase-to-head tube plug and crankcase-to-head tube assembly is not available for service.

CAUTION: To prevent engine damage, install new crankcase-to-head tube plug (long – with check valve) and crankcase-to-head tube. D-rings are not replaceable.

CAUTION: To prevent engine damage, make sure the new crankcase-to-head tube bottoms out in the branch tube assembly. This ensures that the oil rail, case-to-head tube assembly, and fuel injectors will function correctly.

6. Lubricate D-rings on new crankcase-to-head tube assemblies with clean engine oil.
 - Crankcase-to-head tube plug (long – with check valve)
 - Crankcase-to-head tube
7. Install new crankcase-to-head assemblies through high-pressure oil rail.
8. Torque crankcase-to-head assemblies to the special torque (Table 11) (Figure 263).

Glow Plugs



Figure 266 Installation of glow plug

1. Install glow plugs in cylinder head.
2. Tighten glow plugs to the special torque (Table 11).

ICP Sensor and Valve Cover Seal Ring for ICP sensor (right high-pressure oil rail)



Figure 267 Installation of valve cover seal ring for ICP sensor

1. Valve cover seal ring for ICP sensor
2. Oil rail ICP sensor opening

NOTE: If the valve cover was removed, a new valve cover seal ring is required.

1. Install valve cover seal ring for the ICP sensor and high-pressure oil rail.
2. Put new O-ring on ICP sensor.



Figure 268 ICP Sensor and O-ring

3. Install the ICP sensor and torque to the special torque (Table 11).



Figure 269 ICP sensor

4. Connect electrical connector to ICP sensor.

Valve Covers

Right Side Valve Cover

CAUTION: To prevent engine damage, do not use air powered tools, when installing valve covers.

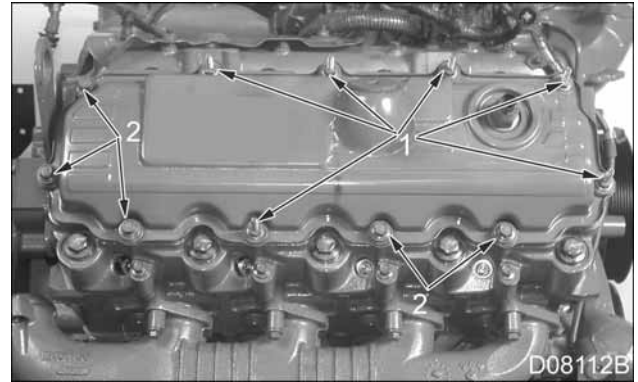


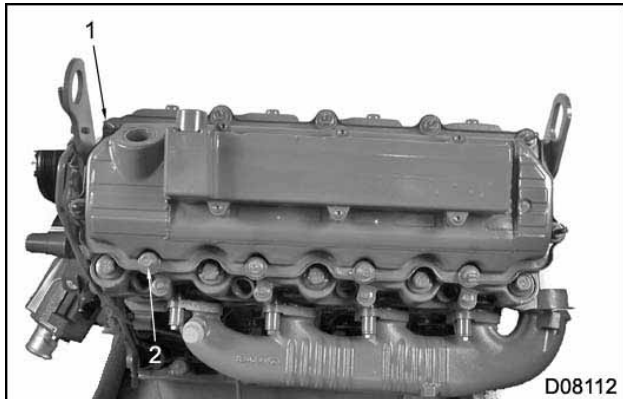
Figure 270 Valve cover mounting bolts and studs

1. Stud
2. Bolt

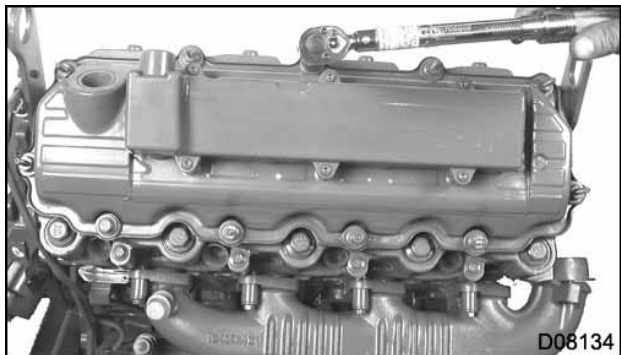
1. Install gasket.
2. Position valve cover on rocker arm carrier.
3. Install valve cover mounting bolts. Place stud bolts in correct locations to accommodate glow plug relay bracket and other harness routing hardware. Leave finger tight until bolts are started.
4. Continue installation of valve cover with remaining eight bolts. Tighten all mounting bolts to the special torque (Table 11).
5. Install the ICP sensor if not done.

NOTE: After the right side valve cover has been installed, the following parts can be installed. See "Engine Electrical" section for procedure.

- Glow plug relay bracket
- Tube assembly, filter to right hand cylinder head.

Left Side Valve Cover**Figure 271 Valve cover mounting bolts and studs**

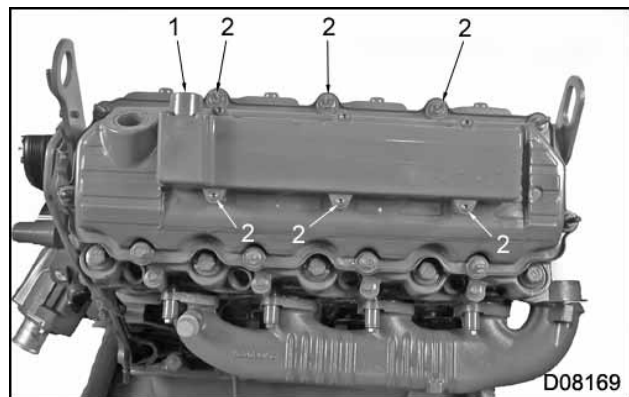
1. Bolt
2. Stud

**Figure 272 Valve cover mounting hardware**

1. Install gasket.
2. Position valve cover on rocker arm carrier.
3. Install valve cover mounting bolts. Place studs in correct locations to accommodate the ECM and

IDM bracket and other harness routing hardware. Leave finger tight until all bolts are started.

4. Tighten all bolts to the special torque (Table 11).
5. Install oil filler extension tube on valve cover.
6. If removed for any reason, install the lifting eyes on the rear of each rocker arm carrier and one on the left front carrier. Tighten bolts to the special torque (Table 11).

Breather Housing (If removed)**Figure 273 Breather housing bolts**

1. Breather opening
2. Bolt (6)

1. Install four breather housing opening gaskets
2. Install breather housing.
3. Install six bolts finger tight.
4. Tighten all bolts to the special torque (Table 11).

NOTE: After installation of left side valve cover, install the following parts. See section identified for installation procedure:

- Breather hose assembly with pitot tube
“ VGT Electronically Controlled Turbocharger“
 - Turbocharger air inlet duct
“ VGT Electronically Controlled Turbocharger“
 - Tube assembly, filter to left hand cylinder head.
 - Fuel filter assembly and lines
See “Fuel System.”
 - VGT assembly
See “Variable Geometry Turbocharger (VGT) Assembly.”
 - Electronic Control Module (ECM), Injector Driver Module (IDM), and mounting bracket
See “Engine Electrical.”
 - Exhaust Gas Recirculation (EGR) drive module and EGR drive module mounting bracket
See “Engine Electrical.”
 - Glow plug relay and bracket
See “Engine Electrical”
 - Intake manifold
See “Manifolds and Exhaust Gas Recirculation (EGR)”
 - Flywheel and rear cover (if cam followers were removed)
See “Rear Cover, Flywheel, and Power Steering Gear Drive.”
 - Branch tube assembly (if cam followers were removed)
See “High-pressure Oil Pump.”
1. Reinstall all safety guards, shields, and covers.
 2. Make sure all tools, cleanliness covers, loose parts, and service equipment are removed from the engine work area.

Specifications

Table 10 Cylinder Head and Valve Train

Exhaust Valves	
Stem diameter	6.947 to 6.965 mm (0.2735 to 0.2742 in)
Stem to guide clearance (max. allowable before replacement)	0.140 mm (0.0055 in)
Face to stem runout (T.I.R. max.)	0.038 mm (0.0015 in)
Valve face angle	37.5°
Valve margin (minimum)	1.35 mm (0.053 in)
Valve recession in head	0.50 ± 0.18 mm (0.020 ± 0.007 in)
Intake Valves	
Stem diameter	6.947 to 6.965 mm (0.2735 to 0.2742 in)
Stem to guide clearance (max. allowable before replacement)	0.140 mm (0.0055 in)
Face to stem runout (T.I.R. max.)	0.0038 mm (0.0015 in)
Valve face angle	30.0°
Valve margin (minimum)	1.40 mm (0.055 in)
Valve recession in head	0.50 ± 0.18 mm (0.020 ± 0.007 in)
Cylinder Heads	
Valve guide inside diameter	7.003 to 7.029 mm (0.276 to 0.277 in)
Valve guide bore runout	0.05 mm (0.002 in)
Valve guide taper (maximum)	0.10 mm (0.004 in)
Valve seat width (intake)	1.80 to 2.56 mm (0.071 to 0.101 in)
Valve seat width (exhaust)	1.48 to 2.24 mm (0.058 to 0.088 in)
Valve seat angle (intake)	30.0°
Valve seat angle (exhaust)	37.5°
Valve seat runout (T.I.R. max.)	0.035 mm (0.0014 in)
Gasket surface flatness	0.05 mm (0.002 in) per 51 mm (2 in)
	0.10 mm (0.004 in) per total surface area
Overall thickness of cylinder head (deck-to-deck)	95 mm (3.74 in)
Valve head recession relative to deck (surface of cylinder head)	0.32 to 0.68 mm (0.0126 to 0.0268 in)
Valve Spring:	
Free length	51.96 mm (2.045 in)
Solid height	36.1 mm (1.42 in)

Table 10 Cylinder Head and Valve Train (cont.)

Compressed*	46.30 mm @ 340 ± 17 N (1.82 in @ 76.5 ± 3.8 lbf)
Compressed*	38.30 mm @ 850 ± 43 N (1.51 in @ 191.1 ± 9.7 lbf)
* Spring must be compressed to a solid height before checking test loads.	
Push Rods	
Runout (maximum)	0.25 mm (0.01 in)

Special Torque

Table 11 Cylinder Head and Valve Train

Lifting eye, front, (M10 x 30)	41 ± N·m (30 ± 3 lbf·ft)
Lifting eye, rear, flat socket head (M10 x 35)	41 ± N·m (30 ± 3 lbf·ft)
Crankcase breather nuts	7 N·m (60 lbf·in)
Fuel rail plug assembly (12 mm)	27 ± 1 N·m (20 ± 1 lbf·ft)
Fuel injector hold down clamp bolt	33 N·m (24 lbf·ft)
Rocker arm fulcrum plate (M8 x 65)	31 N·m (23 lbf·ft)
Glow plugs	19 N·m (168 lbf·in)
Injection Control Pressure (ICP) sensor	12 ± 2 N·m (108 ± 18 lbf·in)
Oil rail assembly mounting bolts (M6 x 40)	13 N·m (120 lbf·in) (Figure 273)
Crankcase-to-head tube assembly	82 N·m (60 lbf·ft)
Valve cover bolts and studs	9 +1/-2 N·m (72 ± 12 lbf·in)
Oil fill extension	14 ± 1 N·m (120 - 132 lbf·in)
Rear heat shield (M10 x 1.5 x 16)	49 ± 5 N·m (36 ± 4 lbf·ft)

Special Service Tools

Table 12 Cylinder Head and Valve Train

DESCRIPTION	TOOL NUMBER
Bottoming Tap (metric)	ZTSE4508
Crankcase-to-head Removal Tool	ZTSE4694
Cylinder Head Lifting Bracket	ZTSE4535
Cylinder Head Pressure Test Plate	ZTSE4534
Dye Penetrant Kit	PT-7191
Fuel Gallery Cleaning Brush	ZTSE4541
Fuel Injector Hold Down Wrench	ZTSE4524
Fuel Injector Rack Holder	ZTSE4299B
Fuel Injector Tip Cleaning Brush	ZTSE4301
Glow Plug Sleeve Brush (nylon)	ZTSE4533
Glow Plug Sleeve Installer	ZTSE4532
Glow Plug Sleeve Remover (Both the tap and the bolt and sleeve adapter)	ZTSE4531
Glow Plug Sleeve Seat Wire Brush	ZTSE4589
Injector Connector Remover	ZTSE4650
Injector Sleeve Brush	ZTSE4304
Injector Sleeve Installer	ZTSE4529
Injector Sleeve Remover (Both the tap and the slide hammer adapter)	ZTSE4528
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Quick Release Tool	ZTSE4581
Quick Release Tool Kit	ZTSE4454
Slide Hammer Kit	ZTSE4398
Straightedge	Obtain locally
Valve Guide Gauge Tool	ZTSE4577
"C" Type Valve Spring Compressor	ZTSE1846
Valve Spring Tester	ZTSE2241

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Description

Front Cover Components

The front cover includes components for the cooling system, lube oil delivery, and vibration damper.

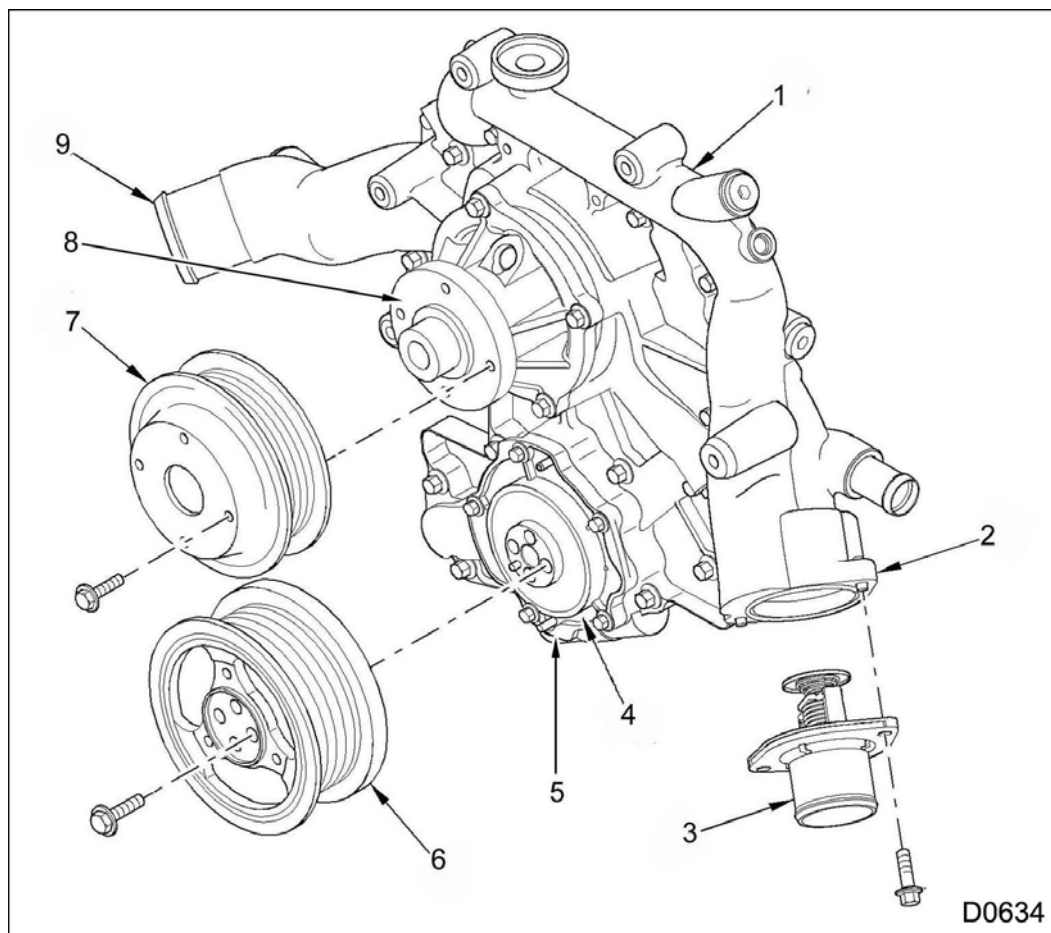


Figure 274 Front cover components

1. Front cover assembly	4. Gerotor oil pump assembly	7. Pulley
2. Front cover coolant outlet	5. Oil pressure regulating valve	8. Water pump assembly
3. Thermostat assembly	6. Vibration damper	9. Front cover coolant inlet

Removal

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

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

! WARNING: To prevent personal injury or death, 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: Engine fluids (oil, fuel and coolant) are a threat to the environment. Recycle or dispose of engine fluids according to local regulations. Never put engine fluids in the trash, pour fluids on the ground, in sewers or bodies of water.

Vibration Damper

1. Before removing vibration damper, inspect vibration damper for runout as follows:

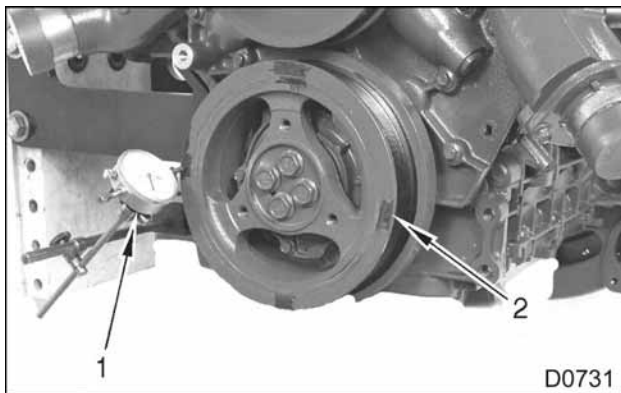


Figure 275 Vibration damper runout

1. Dial indicator with magnetic base
2. Paint removed, four points (90° apart)

- a. Remove paint from face of vibration damper at four points 90° apart.
 - b. Attach magnetic base dial indicator (Table 15) to front of crankcase. Position indicator point on unpainted surface.
 - c. Pry crankshaft forward and zero the dial indicator. This becomes the baseline.
- NOTE:** Pry only in one direction to eliminate possible error induced by crankshaft end play.
- d. Turn crankshaft 90°. Pry crankshaft forward and record reading.
 - e. Repeat at each unpainted surface. If run out exceeds specification (Table 13), replace vibration damper.

! WARNING: To prevent personal injury or death, support the vibration damper when removing bolts. The damper can easily slide off the end of the crankshaft.

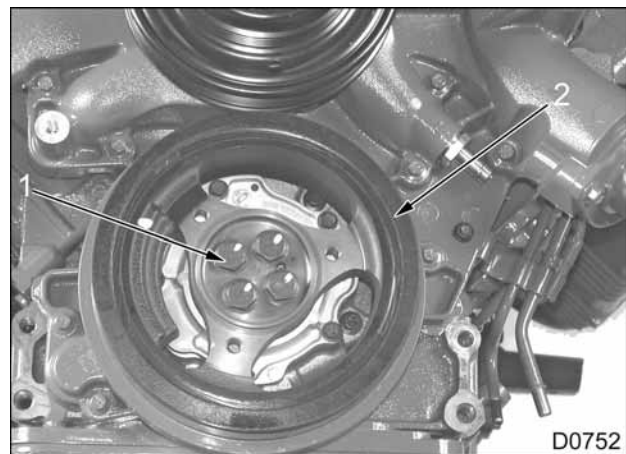


Figure 276 Vibration damper mounting bolts

1. Mounting bolts (4)
 2. Vibration damper
2. Remove and discard four M12 x 59 bolts that secure vibration damper to crankshaft. The vibration damper retaining bolts are not reusable.
 3. Remove vibration damper from crankshaft.

Front Oil Seal and Wear Sleeve

NOTE: The VT 365 is not equipped with a wear sleeve during factory production. Wear sleeves are available with an oil seal service kit.

NOTE: If removing only the seal, do steps 1 through 3. Otherwise, remove seal and wear sleeve doing steps 1 through 4.

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

CAUTION: To prevent engine damage, do not immerse damper in petroleum based solvents. Damage to rubber damping element may result.

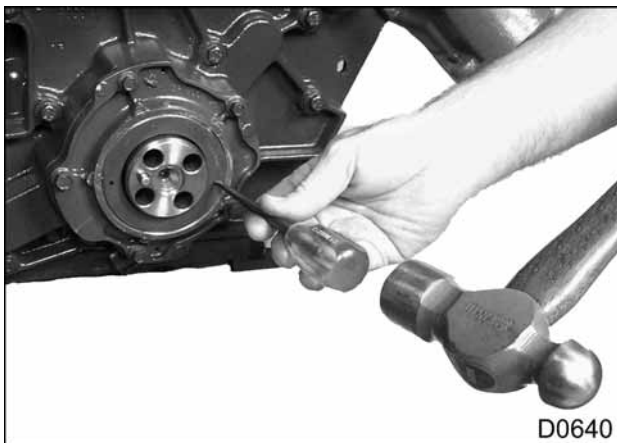


Figure 277 Holes for slide hammer

1. With an awl and hammer, punch two holes 180° apart in the front oil seal.

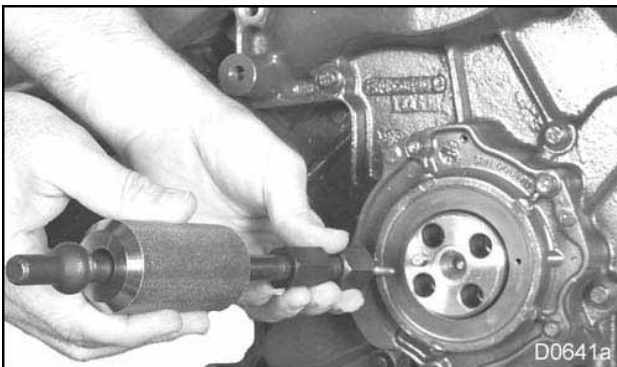


Figure 278 Slide hammer

2. Thread a slide hammer with correct size screw in one of the two holes.
3. Slide hammer until one side of the seal begins to pull out the gerotor cover. Move the slide hammer to the other hole and repeat until the front oil seal is removed completely.

NOTE: The following steps are necessary, if the engine has a front wear sleeve. Wear sleeves are only available in oil seal service kits.

4. Do the following steps to install the front wear sleeve remover (Table 15):

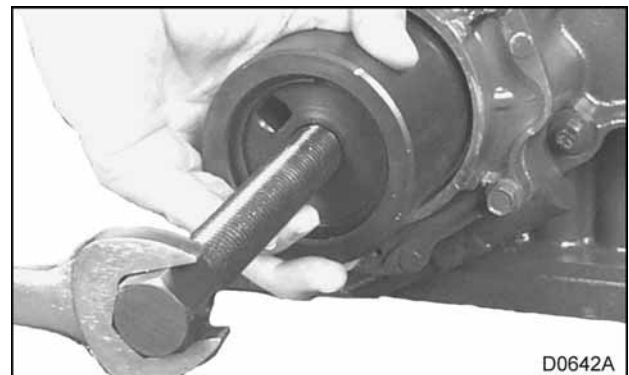


Figure 279 Removal of front wear sleeve

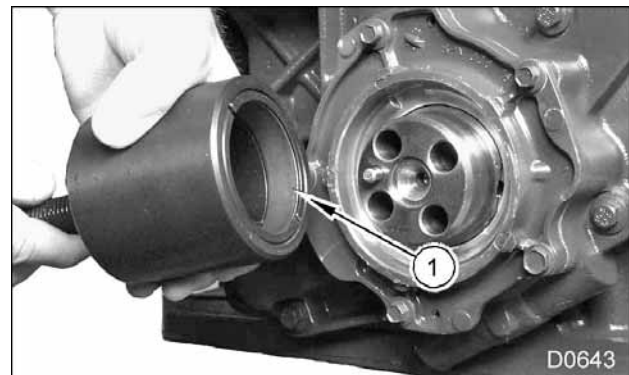


Figure 280 Front wear sleeve removed

1. Front wear sleeve
 - a. Install the tools two half shell ridges behind the front wear sleeve.
 - b. Place the threaded shaft and pulling flange inside the two shells while holding the shells together.

- c. Thread the shaft up to the crankshaft, and apply tension to the two half shells. Remove wear sleeve.

Gerotor Oil Pump

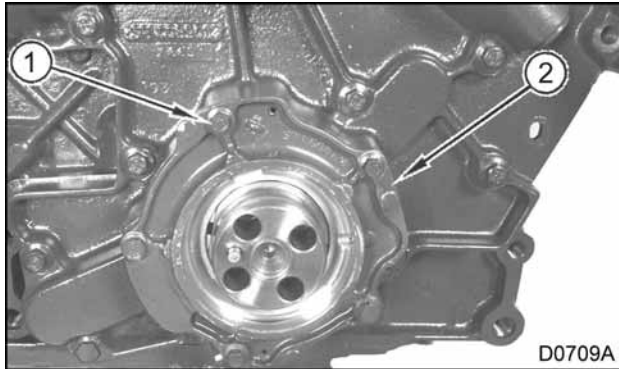


Figure 281 Gerotor oil pump cover

1. Gerotor oil pump cover mounting bolts (5)
 2. Gerotor oil pump cover
1. Remove five mounting bolts from gerotor oil pump cover.
 2. Carefully remove cover to expose gerotor.
 3. Use a permanent marker to mark the front of each gerotor for correct reassembly orientation.

CAUTION: To prevent engine damage, do not use paint to identify internal components or their orientation. Use a permanent marker only.

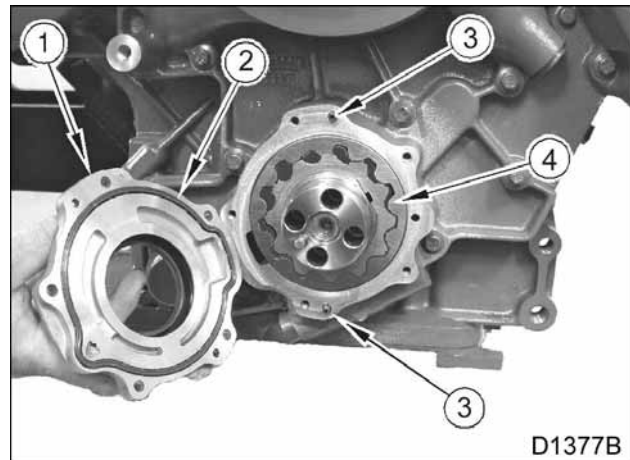


Figure 282 Gerotor components

1. Gerotor cover
2. O-ring
3. Dowel
4. Gerotor assembly

4. Remove gerotor gear set from housing.

Water Pump

NOTE: If removing the front cover, the water pump and thermostat do not need to be removed; however, the water pump pulley must be removed.

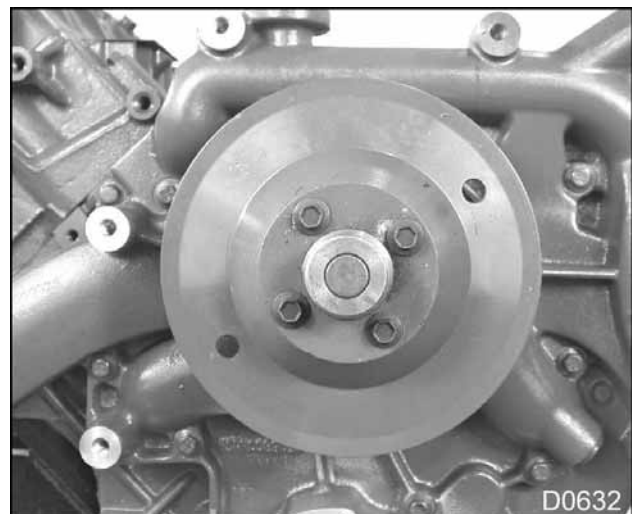


Figure 283 Water pump pulley

1. Remove four M8 x 12 bolts securing the pulley to the water pump.

NOTE: If not using a air impact wrench, use a holding device to lock the water pump pulley when removing the bolts.

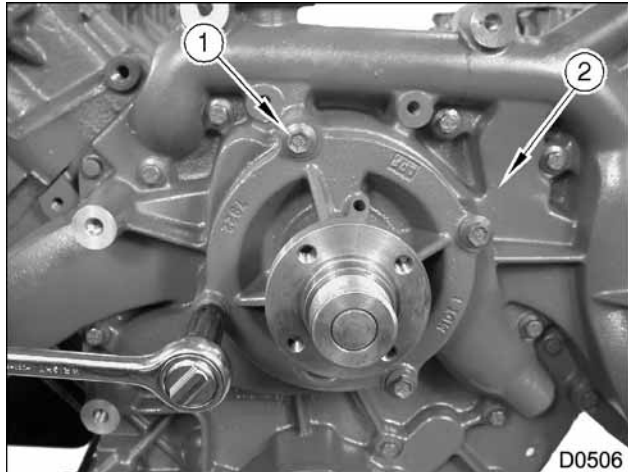


Figure 284 Water pump assembly

1. Water pump mounting bolts, M8 x 25 (4)
2. Front cover assembly

2. Remove four M8 x 25 bolts that secure water pump assembly to front cover.
3. Remove and discard water pump O-ring.

Thermostat

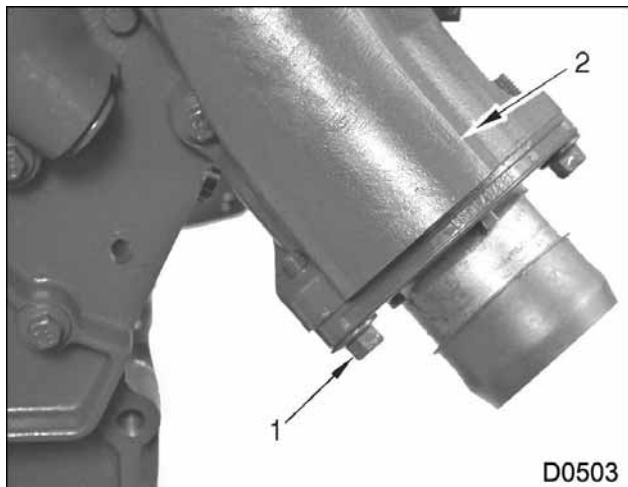


Figure 285 Thermostat assembly mounting bolts

1. Thermostat assembly mounting bolts, M8 x 30 (2)
2. Coolant outlet side of front cover (left side)

1. Remove two M8 x 30 bolts that secure thermostat assembly to left side of front cover.

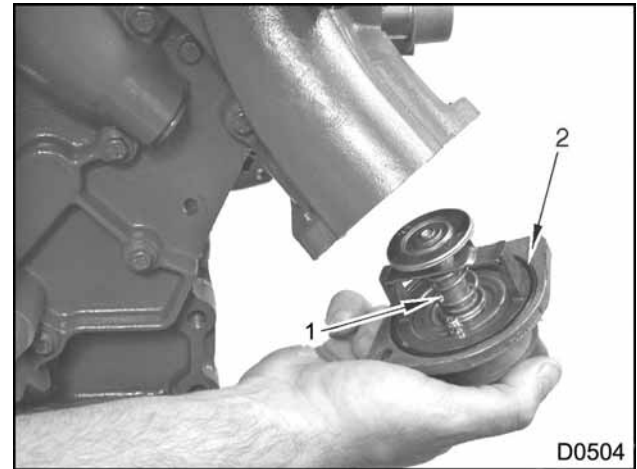


Figure 286 Thermostat assembly

1. Thermostat assembly
2. O-ring

2. Remove thermostat assembly from front cover. Remove and discard O-ring.

Front Cover

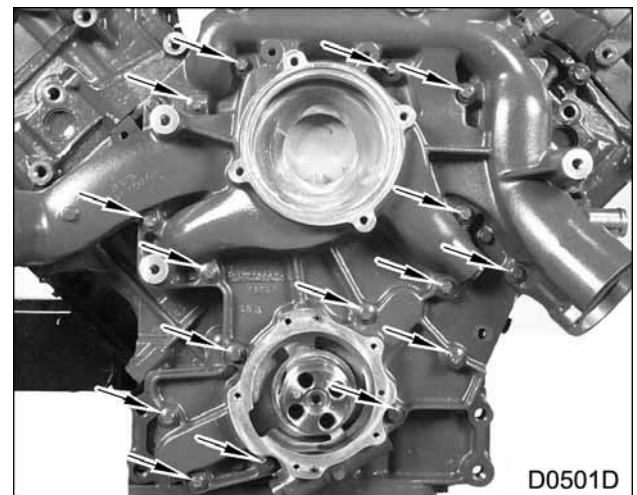


Figure 287 Front cover retaining bolts

1. Remove 16 retaining bolts (M8 x 35 hex flanged, dog point) from front cover.

CAUTION: To prevent engine damage, when removing the front cover, cut the sealant where the upper and lower crankcase meets.



Figure 288 Sealant between crankcase and lower crankcase joint

2. Use a thin blade scraper to cut sealant where crankcase and lower crankcase meet.

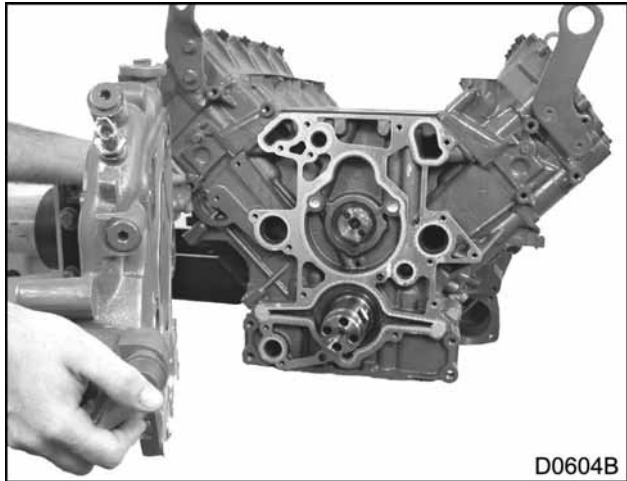


Figure 289 Removal of front Cover

3. Remove front cover.
4. Remove front cover gasket.

Cleaning, Inspection, and Testing

Vibration Damper

CAUTION: To prevent engine damage, do not immerse damper in petroleum based solvents. The rubber damping element could be damaged.

1. Clean vibration damper with soap, water, and a soft parts brush.

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

2. Dry damper with filtered compressed air.
3. Inspect vibration damper rubber compound for cracks, bulging or separation. Replace vibration damper if necessary.

Gerotor Oil Pump

1. Wash all parts thoroughly in a suitable solvent.

! 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).

2. Dry with filtered compressed air.
3. Lay front cover assembly on workbench.
4. Inspect gerotors and housing for nicks, burrs or scoring.
5. Replace any damaged components.

NOTE: The inner and outer gerotors are a matched set and cannot be replaced individually.

NOTE: If installing new gerotors, correct orientation is not necessary. If installing old gerotors, correct orientation is necessary.

6. Place inner and outer gerotors in oil pump housing.

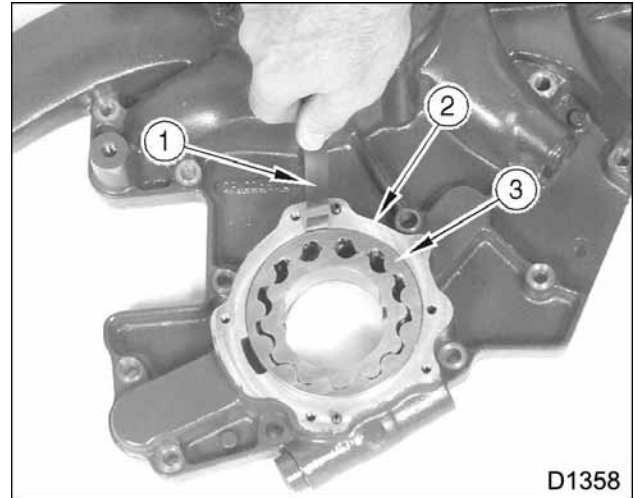


Figure 290 Gerotor inspection

1. Feeler gauge
 2. Front cover assembly
 3. Outer gerotor
7. Use a feeler gauge to inspect for wear by checking the radial clearance between outer gerotor and oil pump housing.

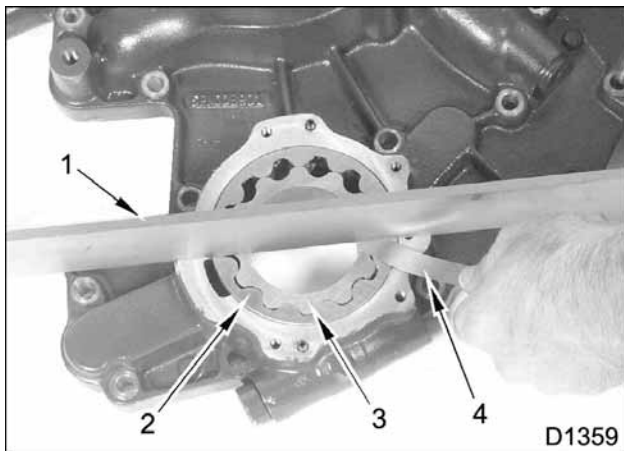


Figure 291 End clearance check for oil pump

1. Straightedge
2. Outer gerotor
3. Inner gerotor
4. Feeler gauge

8. Check oil pump end clearance as follows:
 - a. With the gerotors in place in the front cover, put straightedge across housing.
 - b. Insert feeler gauge under straightedge at inner and outer gerotors. Compare end clearance with specifications (Table 13).
 - c. If measurements are not within specifications, replace both gerotors (as a set).
9. Use a 12 mm internal hex wrench to remove oil pressure regulator.

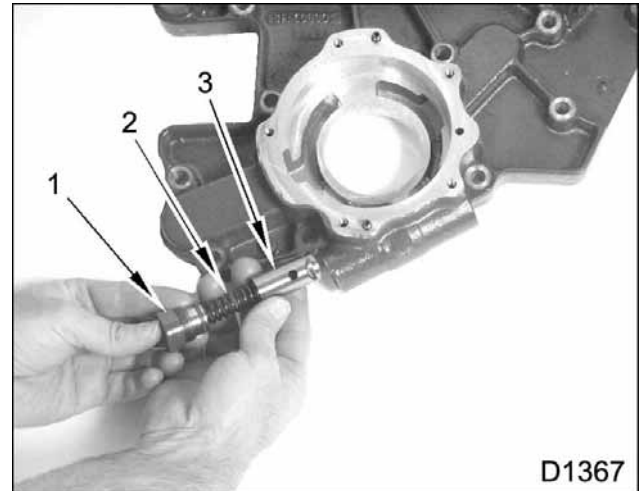


Figure 292 Oil pressure regulator components

1. End cap and O-ring
2. Oil pressure bypass spring
3. Piston poppet

10. Inspect oil pressure regulator components and bore for wear.

Front Cover and Water Pump

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

1. Wash thoroughly in a suitable cleaning solvent.
2. Dry with filtered compressed air.
3. Inspect front cover for cracks.
4. Inspect water pump for leaks, cracks, bearing failure, and problems with bearings or shaft seal. Replace if necessary.
5. Replace front cover if cracked.

Thermostat

! WARNING: To prevent personal injury or death, wear heat resistant gloves and appropriate eye protection during thermostat operation check.

CAUTION: To prevent engine damage when servicing thermostat, make sure the thermostat opens fully at the specified temperature to avoid overheating.

NOTE: Only genuine International® thermostats ensure correct coolant flow and positive sealing for correct engine cooling.

Check thermostat operation as follows:

1. Manually open the thermostat enough to insert a nylon ribbon under the valve seat.

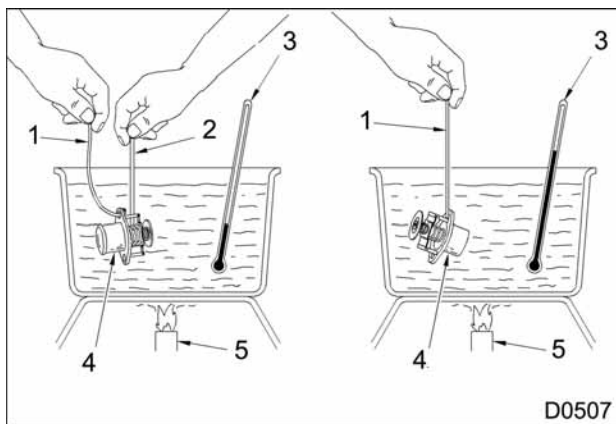


Figure 293 Thermostat operation test

1. Suspension line
2. Ribbon
3. Thermometer
4. Thermostat
5. Heat source

2. Suspend thermostat in a container so the thermostat does not touch the bottom of the container.
3. Heat the water filled container to the approximate Start-To-Open temperature of the thermostat. See specifications for temperature (Table 13).
4. Check thermometer and record the temperature as soon as the thermostat drops from the nylon ribbon. This is the Start-To-Open temperature.
5. Continue to heat the water to the Full-Open temperature of the thermostat. See Specifications (Table 13). Check movement of the thermostat sleeve.
6. While sleeve is off its seat, remove thermostat from container and inspect seat area for pitting and foreign deposits.
7. If the thermostat is damaged or operates incorrectly, replace thermostat.

Installation

Front Cover

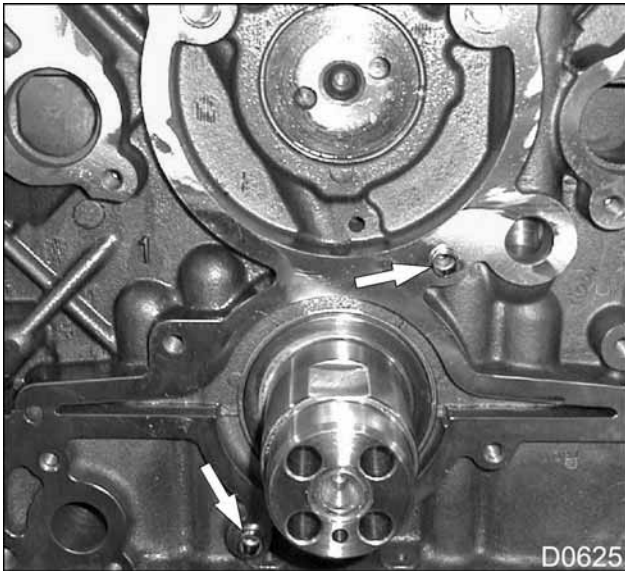


Figure 294 Front cover crankcase dowels

1. If removed, install front cover crankcase dowels.

NOTE: Dowels may become lodged in front cover. Remove dowels and install in crankcase, if necessary.

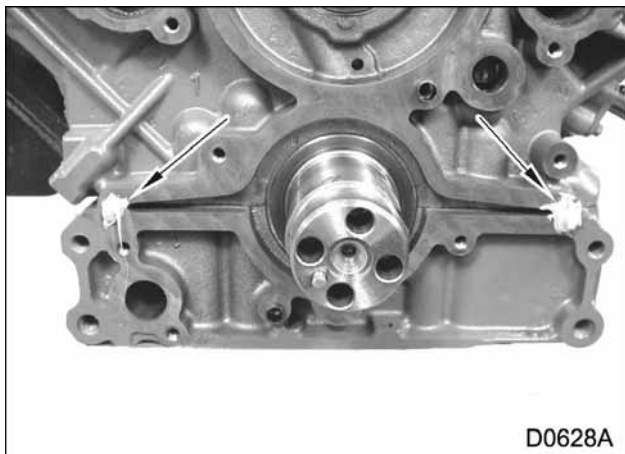


Figure 295 Liquid gasket applications

2. Apply Liquid Gasket (RTV) (Table 15) to joining surfaces of crankcase and lower crankcase.

NOTE: Install gasket and cover within five minutes before the liquid gasket forms a skin to ensure a leak proof joint.

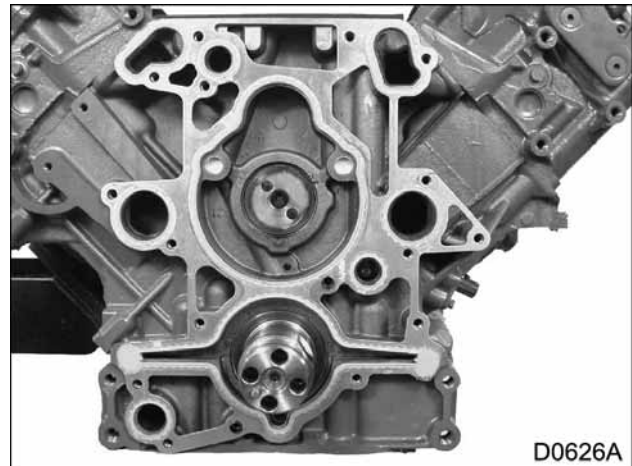


Figure 296 Front cover gasket installed

3. Position a new front cover gasket on the crankcase.

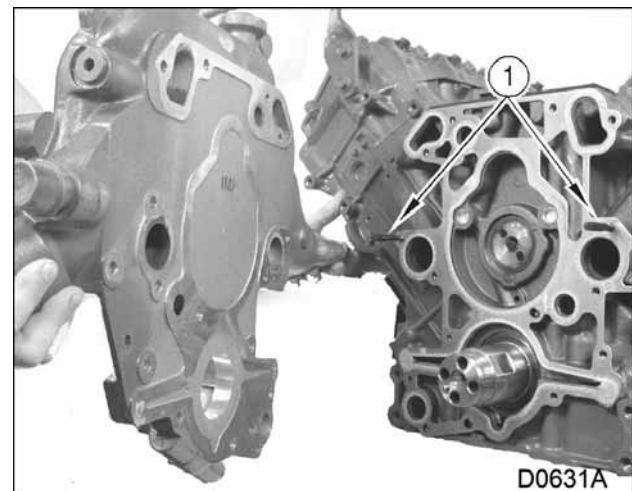


Figure 297 Front cover alignment

1. Alignment guides
4. Align front cover with crankcase dowels and alignment guides (made locally).

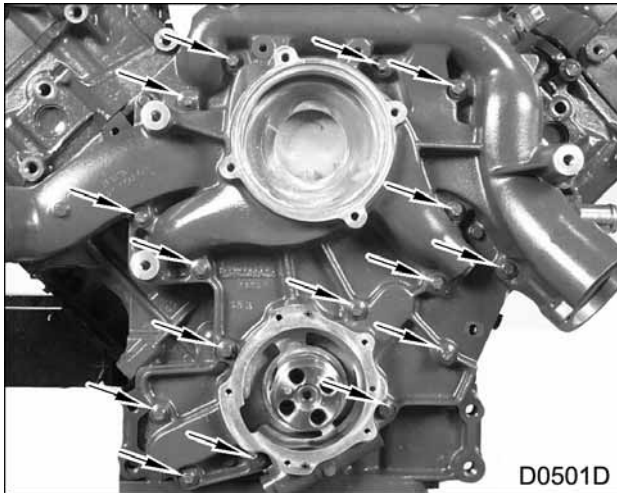


Figure 298 Front cover module retaining bolts

5. Fasten front cover assembly to crankcase with 16 bolts (M8 x 35 hex flanged, dog point). Tighten bolts to the special torque (Table 14).
6. If removed, install water pump on front cover with new O-ring. See (Water Pump, page 170).

Thermostat

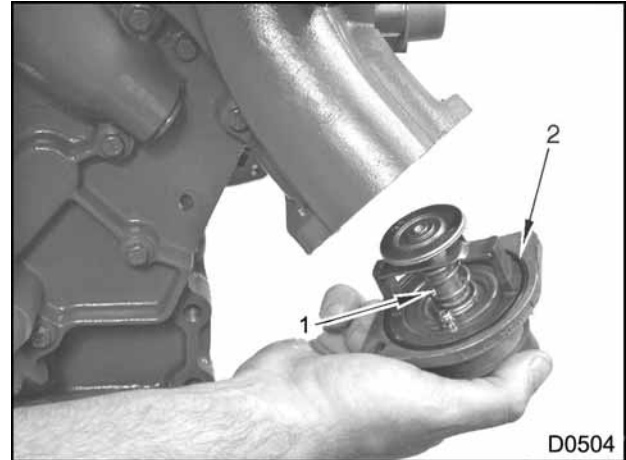
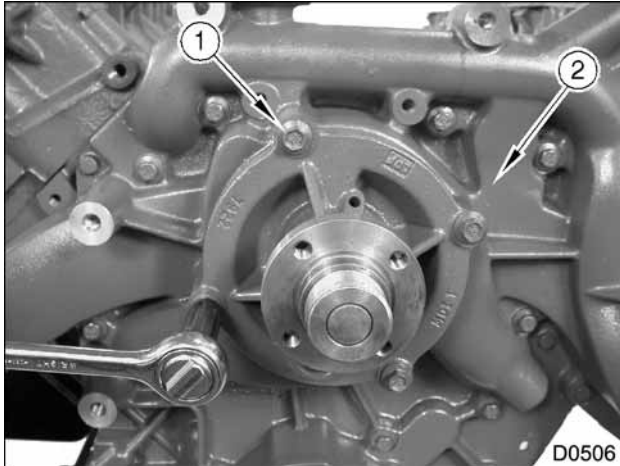


Figure 299 Thermostat assembly

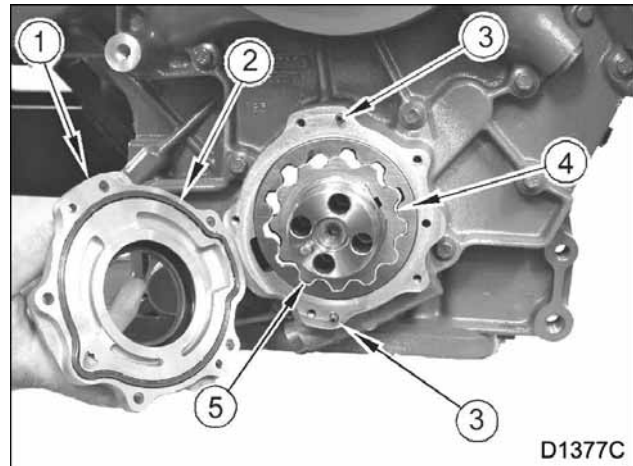
1. Thermostat
 2. Thermostat O-ring seal
1. Put new O-ring on thermostat housing and install assembly on front cover coolant outlet.
 2. Secure thermostat assembly with two M8 x 30 mounting bolts. Tighten bolts to the standard torque (Standard Torques, page 375).

Water Pump

1. Put a new O-ring on the front cover assembly. Use petroleum jelly to hold in place.

**Figure 300 Water pump**

1. Water pump mounting bolts
 2. Front cover
2. Install water pump assembly on front cover over the new O-ring and secure with four M8 x 25 mounting bolts. Tighten bolts to the special torque (Table 14).
 3. Install water pump pulley with four M8 x 12 bolts.

Gerotor Oil Pump**Figure 301 Outer gerotor gear**

1. Gerotor cover
 2. O-ring
 3. Dowel
 4. Gerotor assembly
 5. Lithium assembly grease
1. Lubricate inner gear with lithium assembly grease and install on crankshaft. Wipe off excess grease.
 2. Lubricate outer gear with lithium assembly grease and mesh with inner gear rotor in oil pump housing. Wipe off excess grease.

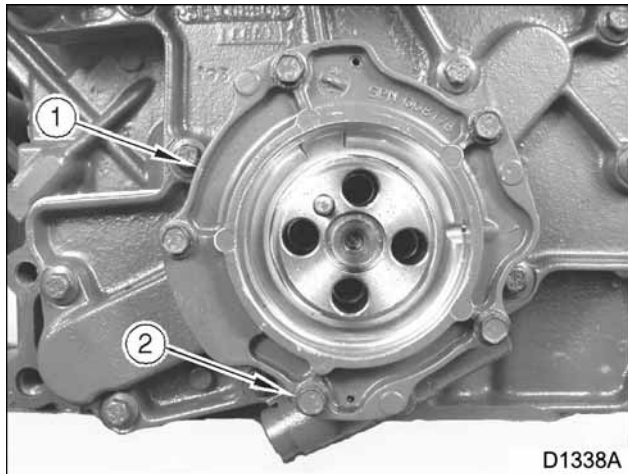


Figure 302 Oil pump housing

1. Oil pump cover
2. Oil pump cover retaining bolts
3. Align dowel pins and install oil pump cover on front cover.
4. Install five retaining bolts to oil pump cover and tighten to the standard torque (Standard Torques, page 375).

Front Oil Seal and Wear Sleeve

NOTE: A wear sleeve is not installed during engine production. The wear sleeve is required for rebuild and is supplied with the front oil seal, as a service part only.

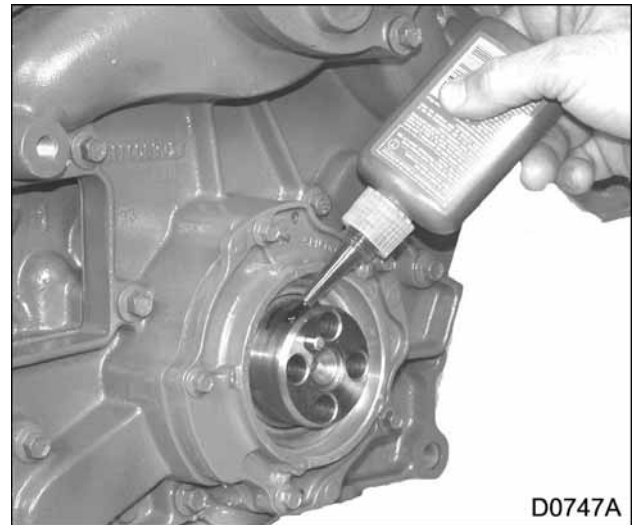


Figure 303 Liquid gasket application

1. Put a 360° bead of Loctite® Hydraulic Sealant (Table 15) on the leading edge of the crankshaft before wear sleeve installation.

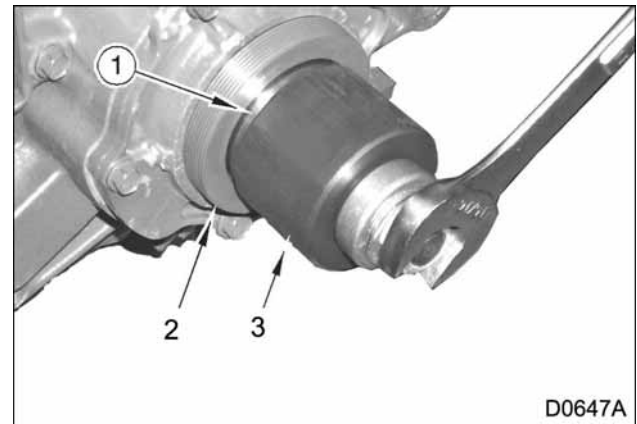


Figure 304 Front oil seal and wear sleeve

1. Wear sleeve
2. Front oil seal
3. Front Oil Seal/Wear Sleeve Installer
2. Use the Front Oil Seal/Wear Sleeve Installer (Table 15), to drive oil seal and wear sleeve assembly into the oil pump cover.

Vibration Damper

1. Align vibration damper with dowel pin on the front of the crankshaft.

⚠ WARNING: To prevent personal injury or death, install four new bolts to secure the vibration damper.

CAUTION: Do not use anti-seize compounds, grease or lubricants. Each has an adverse effect on torque results.

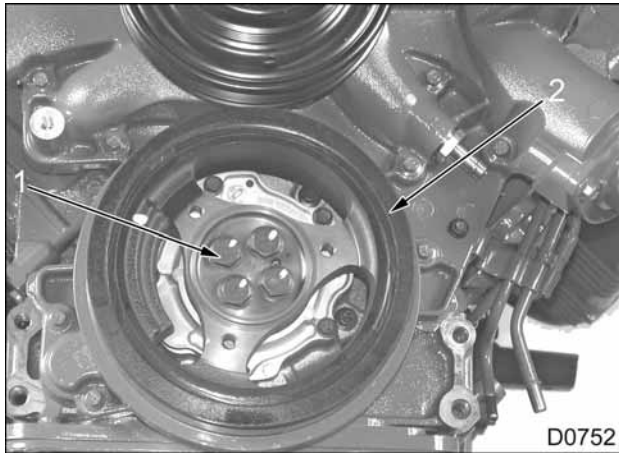


Figure 305 Vibration damper on crankshaft

1. Mounting bolts (4)
 2. Vibration damper
2. Install four new M12 x 59 bolts to secure vibration damper on crankshaft.

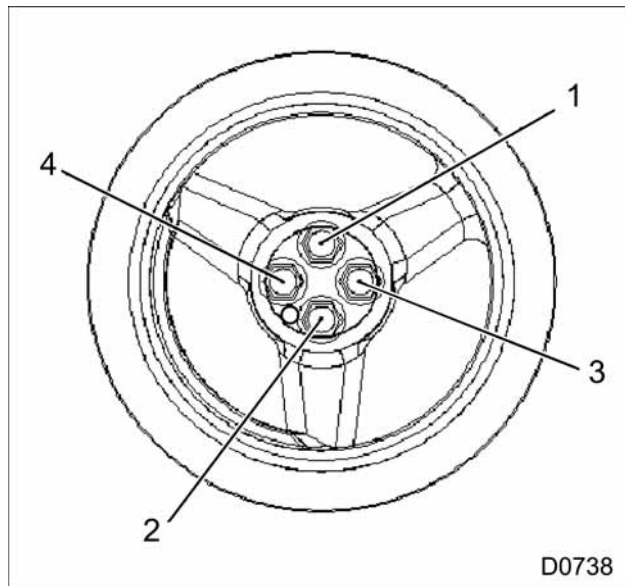


Figure 306 Torque sequence for vibration damper bolts

3. Vibration damper bolt torque sequence:
 - a. Tighten each bolt to the special torque (Table 14) using the above sequence.
 - b. Torque each bolt an additional 90° using the above sequence.
4. Reinstall all safety guards, shields, and covers.
5. Make sure all tools, cleanliness covers, loose parts, and service equipment are removed from the engine work area.

Specifications

Table 13 Vibration Damper, Lubricating Oil Pump, and Thermostat

Vibration Damper	
Face runout (maximum)	0.635 mm (0.025 in)
Rubber bulging (maximum)	1.5 mm (0.060 in)
Lubricating Oil Pump	
Type	Gerotor
Drive	Crankshaft
Location	Gerotor oil pump housing
Pressure Regulating Valve:	
Engine oil pressure, low idle (min. @ 110°C (230°F) oil temp.)	69 kPa (10 psi)
Engine oil pressure, high idle (min. @ 110°C (230°F) oil temp.)	276 kPa (40 psi)
Oil pump discharge pressure (2,500 rpm)	483 to 621 kPa (70 to 90 psi)
End clearance (inner and outer rotor to housing)	0.025 to 0.095 mm (0.001 to 0.004 in)
Radial clearance (between outer rotor and housing)	0.15 to 0.28 mm (0.006 to 0.011 in)
Thermostat	
Type	Balanced pressure, wax pellet
Minimum recommended coolant operating temperature	71°C (160°F)
Start-to-open temperature, 0.381 mm (0.015 in) stroke	87 to 91°C (188 to 196°F)
Full-open temperature, 8 mm (0.315 in) stroke	104°C (219°F)

Special Torque

Table 14 Front Cover, Vibration Damper, Water Pump, and Oil Pan Drain Plug

Oil pan drain plug	25 ± 5 N·m (18 ± 4 lbf·ft)
Front cover module bolts	24 N·m (18 lbf·ft)
Water pump mounting bolts	23 ± 1 N·m (17 ± 1 lbf·ft)
Vibration damper mounting bolts	New bolts only: 68 N·m (50 lbf·ft) + 90° rotation. (Figure 306)

Special Service Tools**Table 15 Front Cover, Vibration Damper, and Gerotor Oil Pump**

Description	Tool Number
Dial Indicator with Magnetic Base	Obtain locally
Fan Hub Wrench (2 inch)	ZTSE43972
Fan Wrench (pulley bolts)	ZTSE4587
Front Seal/Wear Sleeve Installer	ZTSE4516
Front Wear Sleeve Remover	ZTSE4517
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Loctite® Hydraulic Sealant	Obtain locally

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Removal

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

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

! WARNING: To prevent personal injury or death, 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: Engine fluids (oil, fuel and coolant) are a threat to the environment. Recycle or dispose of engine fluids according to local regulations. Never put engine fluids in the trash, on the ground, in sewers or bodies of water.

Lower Oil Pan

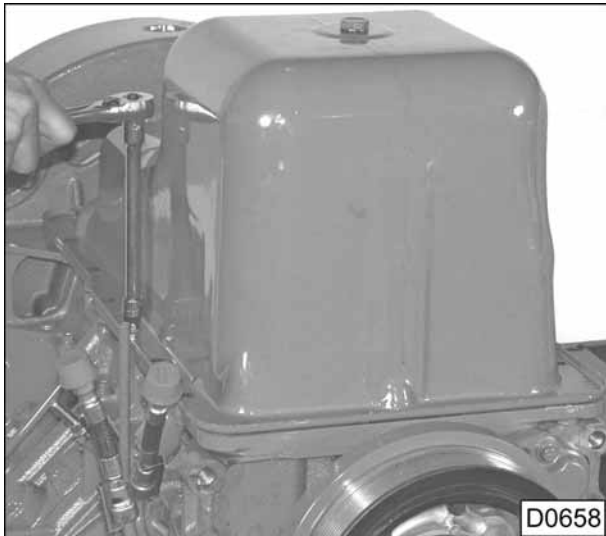


Figure 307 Mounting bolts for lower oil pan

1. Remove sixteen M6 mounting bolts from lower oil pan.



Figure 308 Lower oil pan

2. Remove lower oil pan.

Oil Pickup Tube

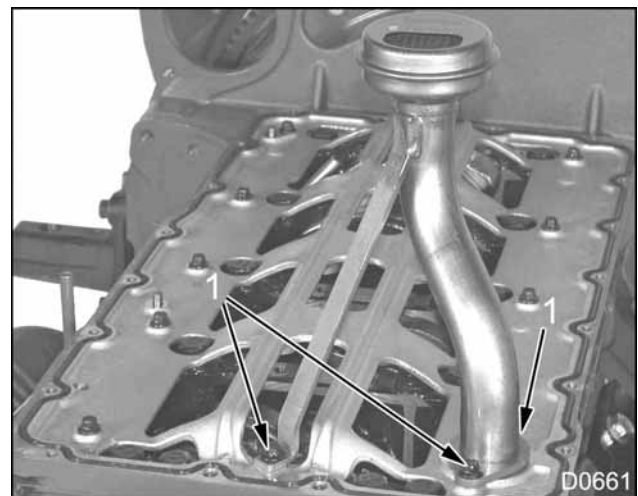


Figure 309 Oil pickup tube

1. Oil pickup tube mounting bolts, M6 X 16 (3)

1. Remove three oil pickup tube mounting bolts and oil pickup tube.

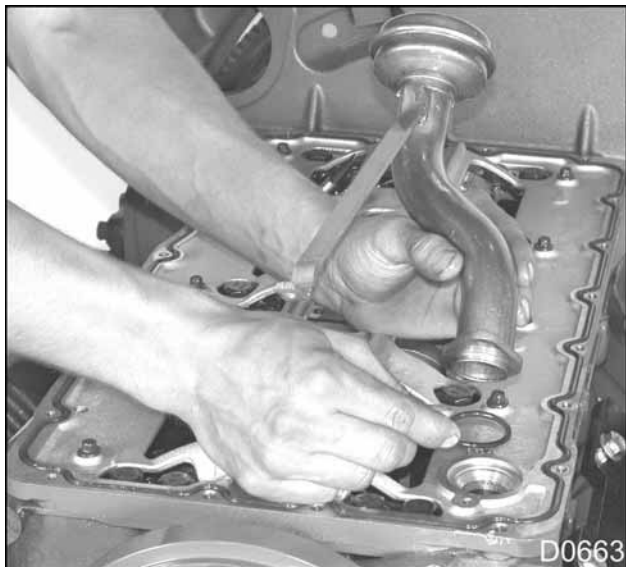


Figure 310 O-ring

2. Remove and discard oil pickup tube O-ring.

Upper Oil Pan

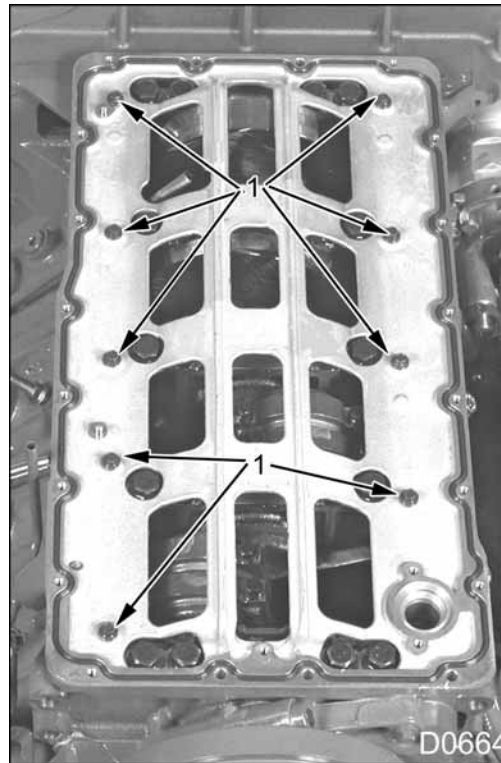


Figure 311 Mounting bolts for upper oil pan

1. M8 X 40 (9)

1. Remove nine mounting bolts from upper oil pan .
2. Remove upper oil pan.

Cleaning and Inspection

Lower Oil Pan

 **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).

1. Remove old gasket and discard.
2. Inspect bottom of oil pan for metallic debris or other evidence of engine damage. Investigate any abnormalities as required.
3. Clean oil pan with a suitable solvent.
4. Dry with filtered compressed air.
5. Look for warping, dents, and cracking. Replace the oil pan if necessary.

Oil Pickup Tube

1. Clean tube in a suitable solvent.

 **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).

2. Dry with filtered compressed air.
3. Inspect the oil pickup tube and bracket for cracking. Replace if necessary.

Upper Oil Pan

1. Clean oil pan in a suitable solvent.

 **WARNING:** To prevent personal injury or death, wear safety glasses with side shields to protect eyes from flying debris, when using compressed air for cleaning. Limit the air pressure to 207 kPa (30 psi).

2. Dry with filtered compressed air.
3. Inspect for warping or cracking. Replace if necessary.

Installation

Upper Oil Pan

1. Install new gaskets in upper oil pan.

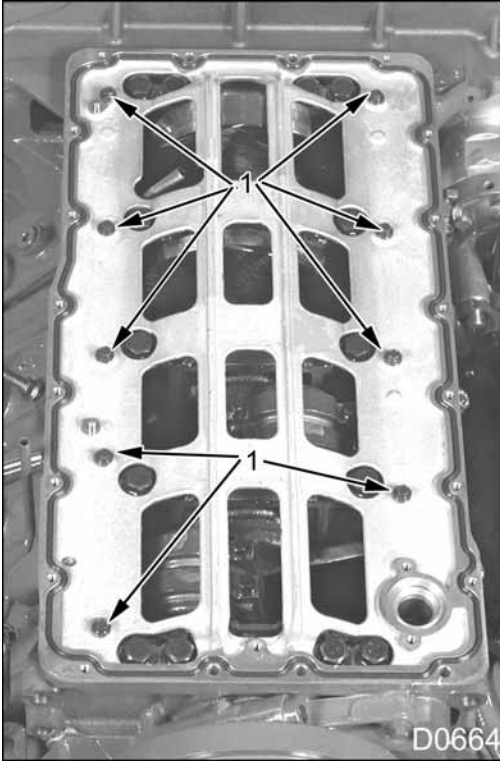


Figure 312 Mounting bolts for upper oil pan

1. M8 X 40 (9)
2. Install upper oil pan and nine mounting bolts. Tighten bolts to the standard torque (Standard Torques, page 375).

Oil Pickup Tube

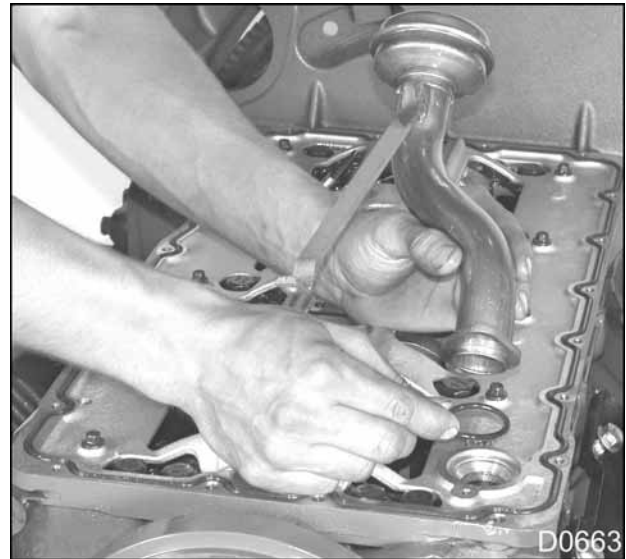


Figure 313 New O-ring

1. Install a new O-ring on oil pickup tube. Lubricate O-ring with clean engine oil.

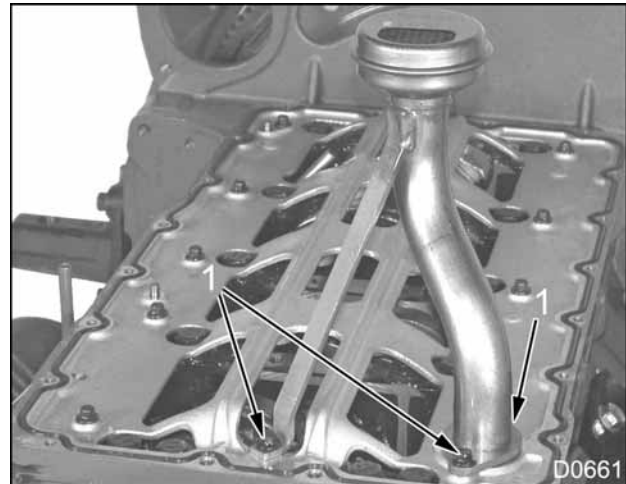


Figure 314 Oil pickup tube

1. Oil pickup tube mounting bolts, M6 X 16 (3)
2. Install oil pickup tube and three mounting bolts. Tighten bolts to the standard torque (Standard Torques, page 375).

Lower Oil Pan

1. Put a new gasket on upper oil pan (lower surface).



2. Place lower oil pan on upper oil pan mating surface.
3. Install 16 M6 lower oil pan mounting bolts. Tighten bolts to the standard torque (Standard Torques, page 375).
4. Reinstall all safety guards, shields, and covers.
5. Make sure all tools, cleanliness covers, loose parts, and service equipment are removed from the engine work area.

Figure 315 Lower oil pan

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Removal

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

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

 **WARNING:** To prevent personal injury or death, 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.

CAUTION: Replacement of the flywheel, flexplate, and vibration damper may also be necessary depending on engine serial number. Some engines have pistons with a greater mass, resulting in the need for a flywheel, flexplate and vibration damper with inertia values that compliment the additional mass. See your International® dealer for details.

NOTE: Engine fluids (oil, fuel and coolant) are a threat to the environment. Do not put engine fluids in the trash, pour fluids on the ground, in sewers or bodies of water.

NOTE: Before removing pistons, rings, and connecting rods, remove the following components:

- Fuel Filter and Lines
See “Fuel System.”
- VGT
See “VGT Electronically Controlled Turbocharger.”
- Electronic Control Module (ECM), Injector Driver Module (IDM) and Mounting Bracket
See “Engine Electrical.”
- Glow Plug Relay and Bracket
See “Engine Electrical.”
- Intake Manifold
See “Manifolds and Exhaust Gas Recirculation (EGR).”
- Cylinder Heads
See “Cylinder Head and Valve Train.”

Preliminary Checks

Piston and Connecting Rod

NOTE: Before removing any piston and connecting rod assemblies, piston protrusion should be evaluated. This will help identify bent or twisted connecting rods.

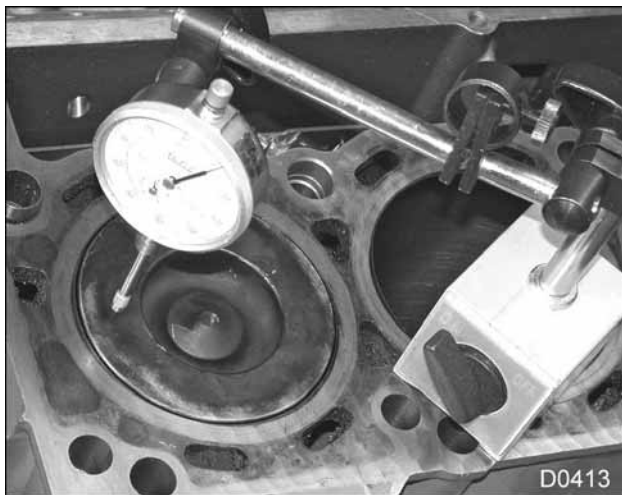


Figure 316 Checking piston protrusion

NOTE: Before checking piston protrusion, make sure the crankcase deck surface is flat and level. See (Crankcase Assembly, page 213).

NOTE: Piston protrusion readings are done at the 3 and 9 o'clock positions. These positions are in line with the piston pin, removing the rocking movement of the piston at any other position of measurement.

1. Check piston protrusion above crankcase as follows:
 - a. Zero dial indicator gauge (Table 18) on crankcase deck surface.
 - b. Position dial indicator tip over the piston head at 3 o'clock.
 - c. Bar the crankshaft around in the direction of normal rotation to raise the piston to its maximum outward protrusion at cylinder top dead center (TDC). Read this maximum protrusion on the dial indicator.
 - d. Record reading.
 - e. Reposition dial indicator tip on piston head at 9 o'clock.
 - f. Bar crankshaft around to raise the piston to its maximum protrusion. Read the maximum protrusion on the dial indicator.
 - g. Record reading, and then average the two readings. Replace piston and piston rod as required.

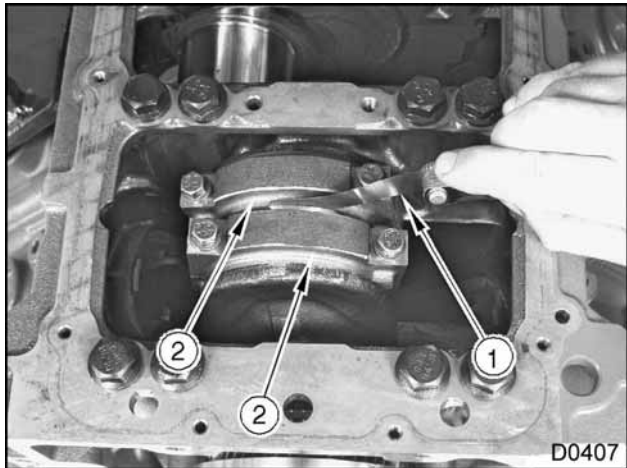


Figure 317 Side clearance check for connecting rod

1. Feeler gauge
 2. Connecting rods
2. Use a feeler gauge to check connecting rod side clearance as follows:
 - a. Pry apart a pair of connecting rods on a crankshaft rod journal. Insert largest possible feeler gauge between the connecting rods to check clearance.
 - b. Repeat for each pair of connecting rods on each crankshaft rod journal and compare with specification (Table 16).

NOTE: Lack of clearance could indicate a damaged rod or a rod bearing out of position. Excessive clearance may require replacement of rods or crankshaft. Correct as required.

Connecting Rod and Piston Assembly

CAUTION: To prevent engine damage, check for carbon ridge on top of the cylinder bore, before removing the rod and piston assemblies.

1. Scrape carbon ridge from top of cylinder bore, if necessary.

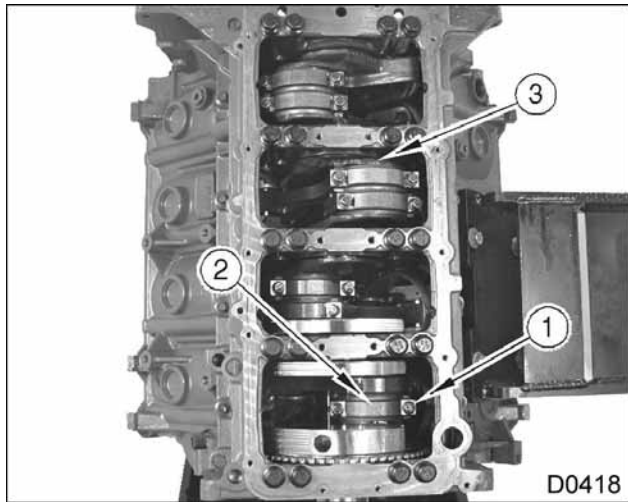


Figure 318 Connecting rods

1. Connecting rod bolts
 2. Connecting rod cap
 3. Crankshaft
2. Rotate crankshaft to position journals for removal of connecting rod assemblies. Mark connecting rod locations.

CAUTION: To prevent engine damage, check connecting rod bolts for binding. If bolts are binding, check thread condition during inspection.

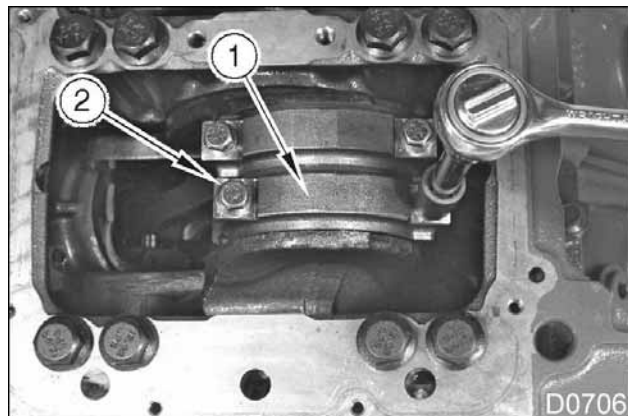


Figure 319 Connecting rod cap bolts

1. Connecting rod cap (8)
 2. Connecting rod bolt (16)
3. Remove two connecting rod bolts and connecting rod cap.

4. Remove piston and connecting rod assemblies from crankcase as follows:

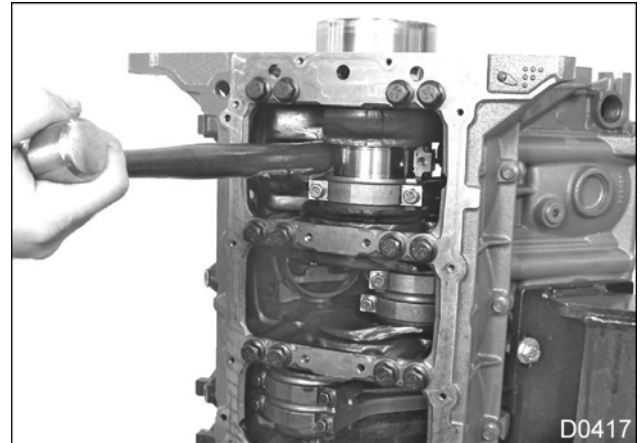


Figure 320 Piston and connecting rod assembly

- a. Rotate engine to a vertical position.
- b. Use a wooden or plastic handle and push piston and rod assembly from cylinder bore.
- c. Once piston rings are free of cylinder bore, remove piston and connecting rod assembly from crankcase.

CAUTION: To prevent engine damage, make sure each connecting rod and cap is stamped, marked, or tagged as a matched set.

CAUTION: This engine uses fractured connecting rods. Do not alter or damage the fractured mating surfaces of rod and cap.



Figure 321 Cap and rod numbers

1. Matching numbers

5. When removed, make sure matching connecting rod and cap numbers stay together as a set. A cap from one connecting rod is not interchangeable with any other connecting rod.

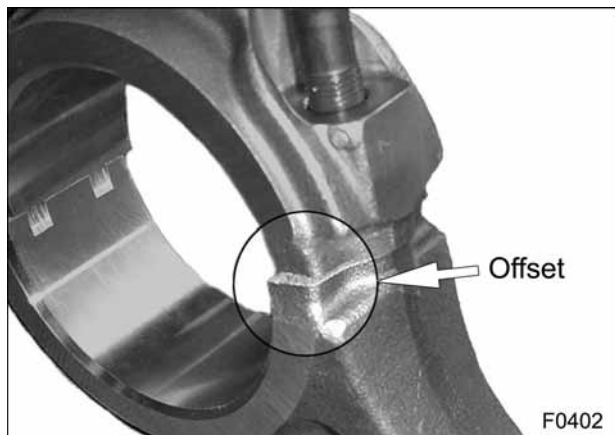


Figure 322 Offset for incorrect rod cap assembly

6. The rod cap can only be correctly installed on the connecting rod if it is oriented in the correct direction.
 - If the rod cap is reversed during assembly of the connecting rod, an obvious offset will be seen at the mating surfaces.
 - If the connecting rod assembly is installed on the crankshaft in this manner, the connecting rod must be replaced.
7. Check the crankpin fillets for damage.
 - If crankpin fillets are damaged, replace crankshaft.

Piston Disassembly

! WARNING: To prevent personal injury or death, wear safety glasses when removing retaining rings.

CAUTION: To prevent engine damage, mark the pistons with the cylinder number from which each was removed. If pistons will be reused, reinstall in correct cylinder bore.

CAUTION: To prevent engine damage, note the engine serial number (stamped on the crankcase pad, left side rear of the crankcase) and piston part number (stamped on the piston crown). Multiple pistons are available for service applications. Do not install pistons having different part numbers.

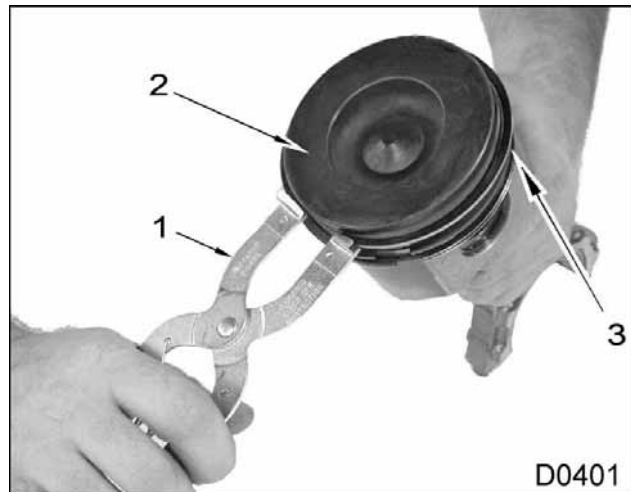
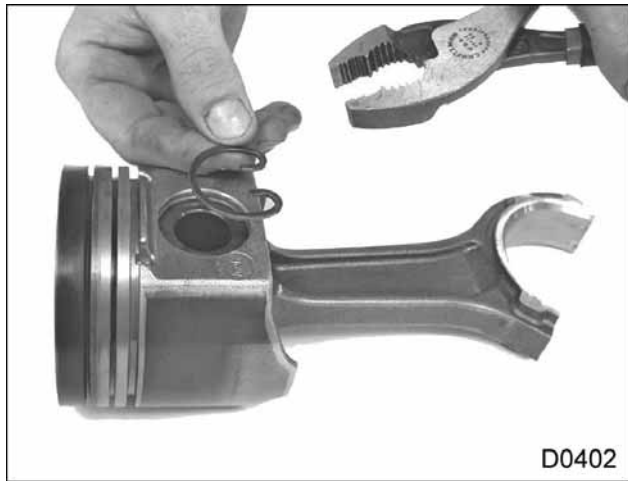


Figure 323 Piston ring removal

1. Piston ring expansion pliers
2. Piston
3. Piston ring

1. Use piston ring expansion pliers (Table 18) to remove the piston rings.
2. Remove top ring, intermediate ring, and oil control ring.



3. Use pliers to remove both piston pin retaining rings.
4. Remove piston pin from its bore by hand, and separate connecting rod from piston.

Figure 324 Piston pin retaining ring

Cleaning and Inspection

NOTE: Do not use a caustic solution, wire brush or bead blast material to clean aluminum pistons.

1. Use a soap and water solution to clean aluminum pistons. Soak piston first, and then clean piston with a nonmetallic brush.
2. Clean piston ring grooves thoroughly.
3. The following disassembled components may be cleaned using a suitable solvent:
 - Piston pins
 - Piston pin retainers
 - Connecting rods
4. Thoroughly clean connecting rod bolt holes and threads.

Pistons

1. Inspect pistons for scuffed or scored skirts, cracked or worn ring lands, and cracked or scuffed pin bores. Replace damaged pistons.
2. Check top compression ring groove for wear.

NOTE: Top compression ring groove is a keystone design which requires measurement over gauge pins to determine ring groove wear.

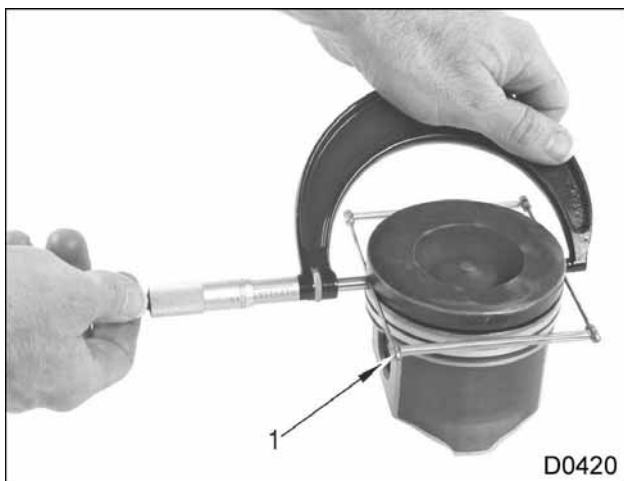


Figure 325 Top compression ring groove

1. Piston gauge pins (0.082 in)

3. Install the piston gauge pins (0.082 in) (Table 18) in the top ring groove. Piston gauge pins must be parallel.
4. Use a 3 - 4 inch outside micrometer to measure diameter over piston gauge pins.
5. If measurement over the gauge pin is not within specifications (Table 16), excessive piston groove wear exists. Replace piston.

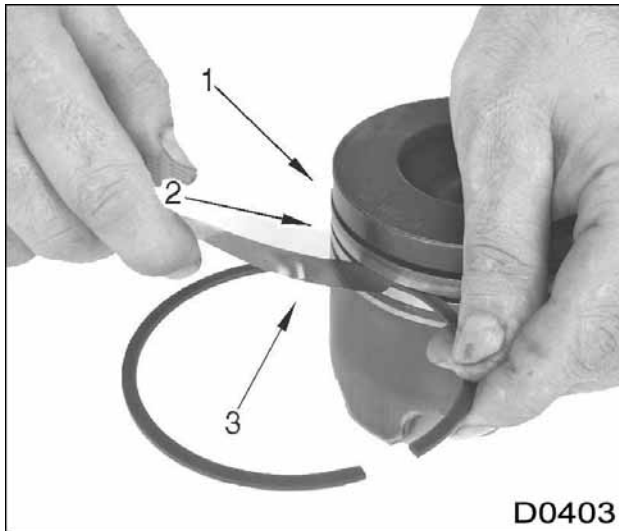


Figure 326 Ring groove clearance check (intermediate ring shown)

1. Compression ring groove
 2. Intermediate compression ring groove
 3. Feeler gauge
6. Check side clearance of intermediate ring groove as follows:
 - a. Place outer edge of new ring in its respective ring groove.
 - b. Roll ring entirely around piston in its respective groove. Make sure ring is able to move freely in its groove.
 - c. Use a feeler gauge to check side clearance of each ring in its respective groove (Table 16). Excessive side clearance indicates ring groove wear and requires piston replacement.
 7. Check side clearance of oil control ring groove as follows:

- a. Place outer edge of new ring in oil control ring groove.
- b. Roll ring entirely around piston in its respective groove. Make sure ring moves freely in groove.
- c. Use a feeler gauge to check side clearance of oil control ring in its respective groove. Excessive side clearance indicates ring groove wear and requires piston replacement.

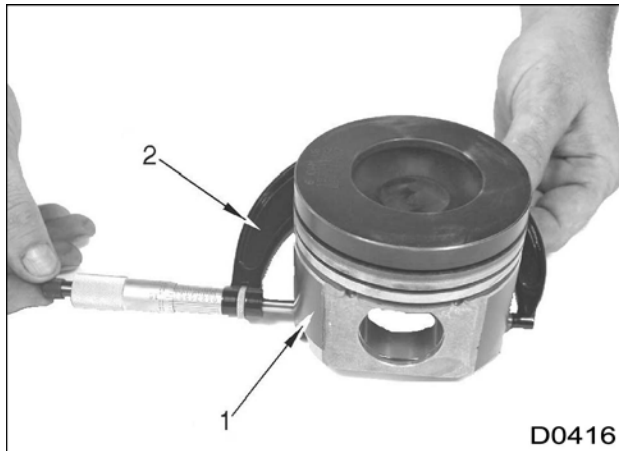


Figure 327 Piston skirt diameter

1. Piston skirt
2. 3 - 4 inch micrometer

8. When considering piston replacement, check cylinder bore out-of-round specifications.
9. See Specifications in (Table 16). Cylinder boring may be required. Bore reconditioning requires oversize service pistons. Verify piston size by measuring skirt diameter under conditions indicated in Specifications (Table 16).

NOTE: In addition to the standard size service piston, the following oversize pistons are available.

- 0.254 mm (0.010 in)
 - 0.508 mm (0.020 in)
 - 0.762 mm (0.030 in)
10. If cylinder walls have minor surface damage, but are otherwise within specification (out of round), it may be possible to remove such damage by honing.

If cylinder bore is suitable for use without reconditioning, deglaze bore using a glaze breaker brush, then reassemble.

11. See (Cylinder Deglazing, page 215) for the correct deglazing procedure.

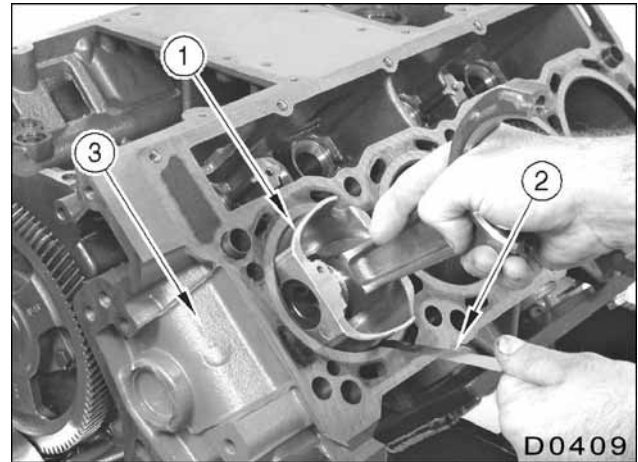


Figure 328 Piston skirt clearance check in cylinder bore

1. Piston
2. Feeler gauge
3. Crankcase

12. Check piston skirt clearance in the cylinder bore. Correct as required.

Piston Rings

NOTE: Faulty rings cannot always be detected by inspection; therefore, if a piston is removed, replace piston rings.

1. Inspect new piston rings for cleanliness.
2. Before installing new piston rings, check gap for each ring as follows:
 - a. Push piston ring down into cylinder bore. Make sure the piston ring is square with cylinder wall. An inverted piston head can be used to push piston ring to desired location of measurement (usually at the top of the piston stroke).
 - b. Use a feeler gauge to measure gap between ends of each piston ring.

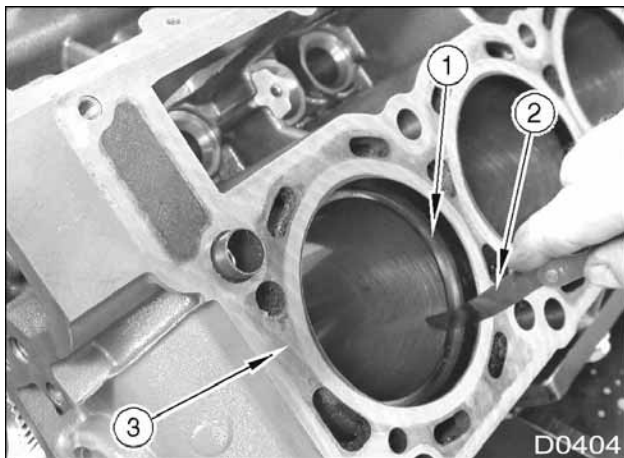


Figure 329 Piston ring end gap clearance in cylinder bore

1. Piston ring
2. Feeler gauge
3. Crankcase

- c. If gap does not meet specifications (Table 16), select another ring or recheck cylinder bore wear.

Connecting Rods

CAUTION: If the rod cap is reversed when assembled to the connecting rod or a rod cap is not installed on its original matching connecting rod, the fractured mating surfaces will be useless. The entire connecting rod assembly must be replaced.

CAUTION: To prevent engine damage, keep fractured mating surfaces clean and free of debris. Do not allow mating surfaces to rest on other surfaces. Do not bump mating surfaces or drop connecting rod or cap. This could cause wear and chipping of fractured surface, resulting in incorrect mating during installation.

1. Inspect connecting rod bolts 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 if necessary.

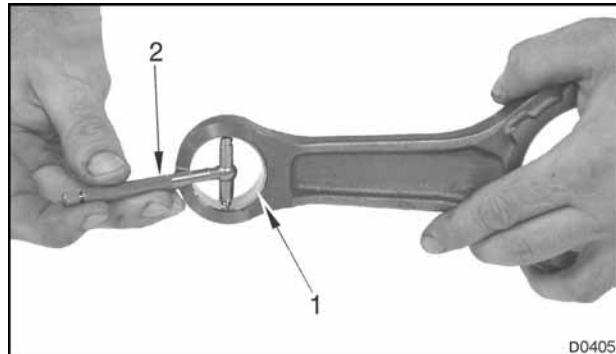


Figure 330 Inside diameter of piston pin bushing

1. Piston pin bushing
2. Telescoping gauge

3. Inspect connecting rod piston pin bushing for wear as follows:
 - a. Use a telescoping gauge (Table 18) and a 1-2 inch micrometer to measure pin bore at two locations 90° apart. Record both measurements.
 - b. If inside diameter of piston pin bushing exceeds specification (Table 16), replace connecting rod.

Connecting Rod Bore Out-of-round and Taper Check

CAUTION: To prevent engine damage, check connecting rod bolts for binding. Bolts should thread into connecting rod freely, when lubricated with clean engine oil. If not, discard the connecting rod. Connecting rod threads cannot be retapped, if binding. Check thread condition carefully during inspection.

1. Lubricate connecting rod bolts with clean engine oil. Assemble cap to rod without bearing insert. Tighten bolts to special torque (Table 17).

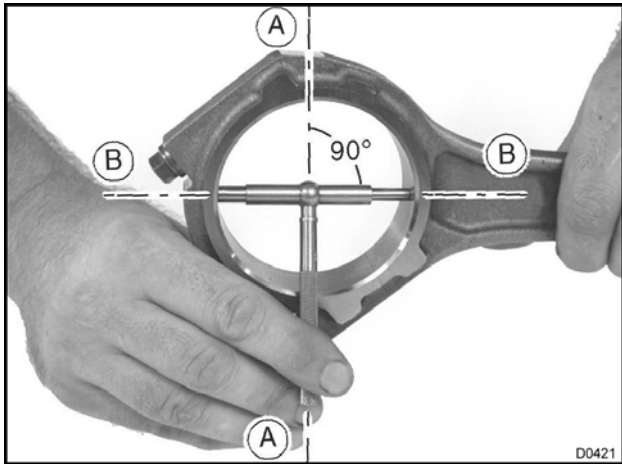


Figure 331 Measurement for out-of-round of bore of connecting rod bearing

2. Use a telescoping gauge (Table 18), measure connecting rod at two locations, 90° apart.
3. If the difference between dimension A and B exceeds out-of-round specifications (Table 16), replace connecting rod.

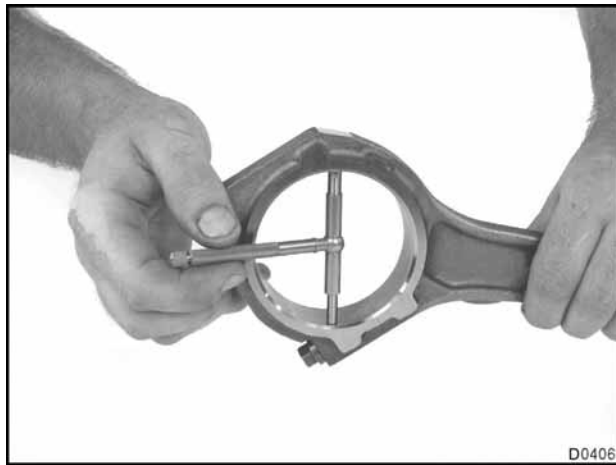


Figure 332 Measurement for bore taper of connecting rod

4. Measure connecting rod taper as follows:
 - a. Insert a telescoping gauge (Table 18) near chamfer on either side.
 - b. Measure inner diameter of connecting rod bearing bore near chamfer on other side.

The difference between the two readings is the connecting rod bore taper. If connecting rod bore taper exceeds specification (Table 16), replace connecting rod.

5. With connecting rod cap removed, inspect surface finish of connecting rod bearing bore. Bore must be smooth and free of scoring, nicks or burrs. Replace as required.

Connecting Rod Bearing Fit Check

NOTE: Bearing shells must fit tightly in the bore. When bearing shells are inserted into the connecting rod and cap, they protrude above the parting line. This protrusion is required to achieve "bearing crush."

Bearing shells across the open ends are slightly larger than the diameter of the connecting rod bore into which they are assembled. This condition is designed into the bearing shell, causing it to spread outward at the parting line when "bearing crush" load is applied by tightening the bolts. Some snap may be lost in normal use, but bearing replacement is not required because of a nominal loss of snap.

When the assembly is drawn up tight, the bearing is compressed, ensuring positive contact between the backside of the bearing and the bore.

1. Lubricate connecting rod bolts with clean engine oil. Assemble cap to rod with new bearing shells installed. Tighten bolts alternately and evenly to special torque value (Table 17).
2. Use a telescoping gauge (Table 18), measure inside diameter of connecting rod bearing at two locations 90° apart. Average the two inside diameters.
3. Use a micrometer to measure each crankshaft rod journal diameter.
4. Subtract the crankshaft rod journal diameter from the respective connecting rod bearing inside diameter to obtain bearing-to-crankshaft running clearance. Repeat for each crankshaft rod journal.
5. If bearing-to-crankshaft running clearances exceed specifications because of wear on crankshaft, replace or grind crankshaft and install under-size precision type bearing shells.

CAUTION: To prevent engine damage, grind or replace the crankshaft only. Do not rework bearing cap or bearings; this will reduce running clearance of journal-to-bearing.

NOTE: Plastigage® may be used as an alternate method, to determine running clearance.

Piston Pin Inspection

1. Inspect piston pins for corrosion or wear. Replace as required.

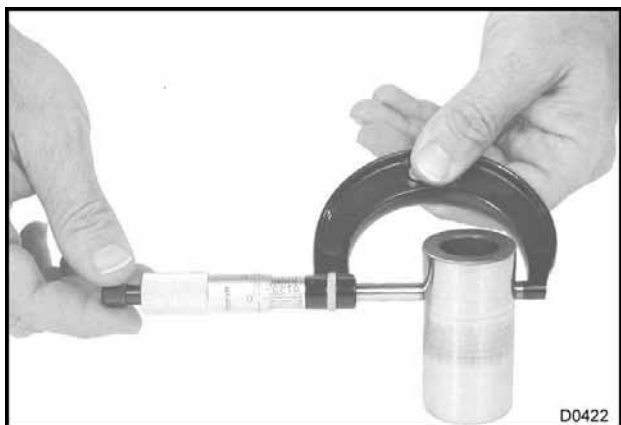


Figure 333 Piston pin wear

2. Use a 1-2 inch micrometer, measure piston pin outside diameter at two locations 90° apart.
3. Measure each end of the pin and record the range of readings.
- If piston pin wear exceeds specifications (Table 16), replace piston pin.



Figure 334 Inside diameter measurement of piston pin bore

4. Using a 1-2 inch telescoping gauge and micrometer, measure each piston pin bore inside diameter, at two locations 90° apart.
5. To check piston pin clearance, subtract outside diameter of the piston pin from the inside diameter of the piston pin bore.
 - If clearance exceeds specifications (Table 16), replace piston pin and check piston pin clearance using new piston pin.

Installation

Piston and Ring Assembly

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

CAUTION: To prevent engine damage, note the engine serial number (stamped on the crankcase pad, left side rear of the crankcase) and piston part number (stamped on the piston crown). Multiple pistons are available for service applications. Do not install pistons having different part numbers.

CAUTION: Some engines have pistons with a greater mass, depending on engine serial number. Inertia values of the flywheel, flexplate and vibration damper must compliment the greater mass pistons. Contact your International dealer for details.

CAUTION: To prevent engine damage, make sure the connecting rod and piston are assembled correctly.

1. Connect piston to connecting rod as follows:

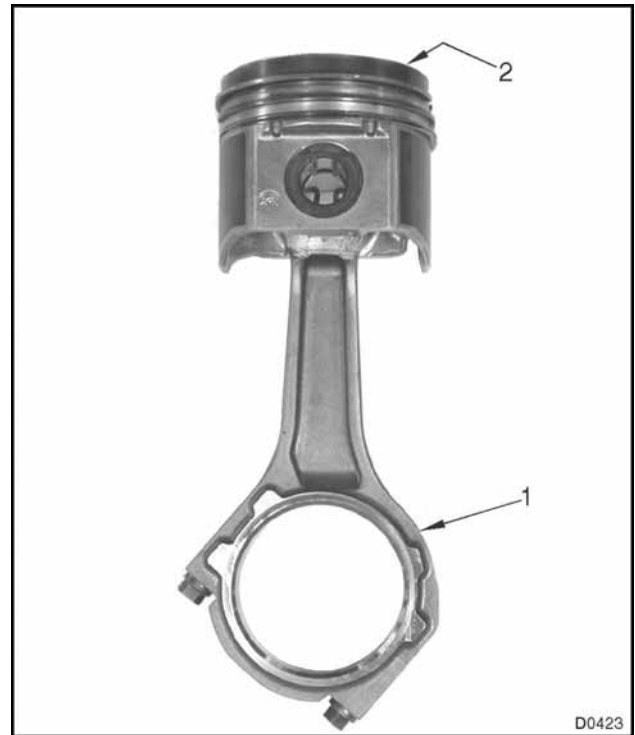


Figure 335 Correct position of installed connecting rod

1. Longer leg of connecting rod (cam side)
2. CAM V8 stamp on cam side of piston crown
 - a. Lubricate connecting rod piston pin bore, piston pin bore, and piston pin with clean engine oil.
 - b. Orient the longer leg of the connecting rod with the side of the piston bearing the CAM V8 stamped in its crown.

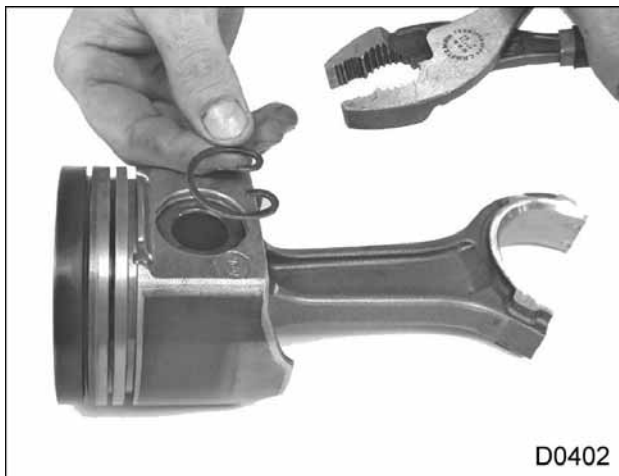


Figure 336 Piston pin retaining ring

- c. Using pliers, install retaining ring at one end of piston pin bore.
- d. Slide piston pin through bored holes, stopping at installed retaining ring.
- e. Use pliers to install second retaining ring.
- f. Check the piston pin end clearance (Table 16).

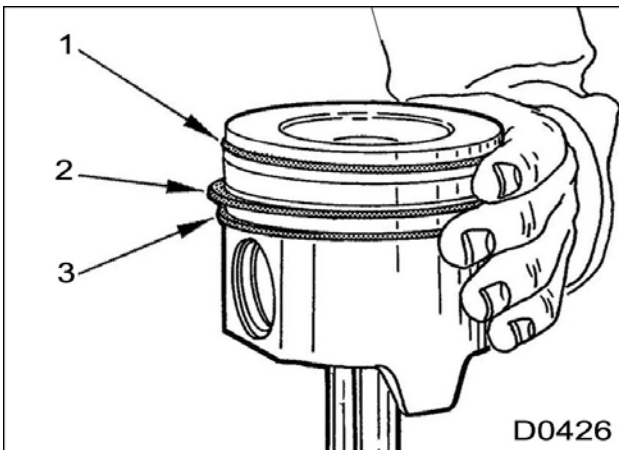


Figure 337 Piston rings

1. Top compression ring
 2. Intermediate compression ring
 3. Oil control ring
2. Use piston ring expansion pliers (Table 18), to install piston rings.

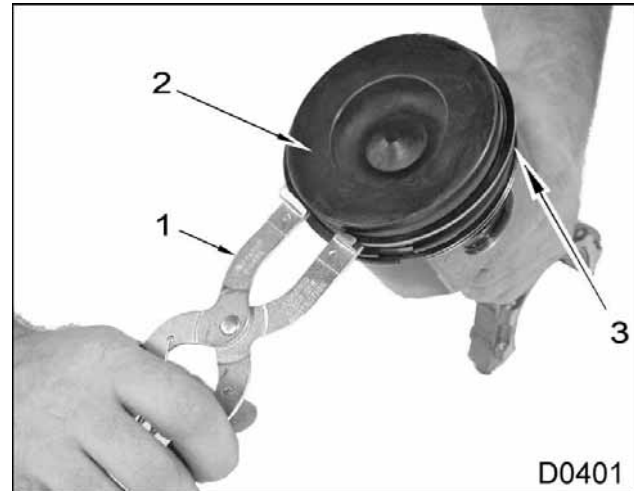


Figure 338 Piston rings installed

1. Piston ring expansion pliers
 2. Piston
 3. Piston ring (top compression shown)
- a. Install expansion spring component of two piece oil control ring into bottom piston groove.
 - b. Install oil scraper component of two piece oil control ring over expansion spring.

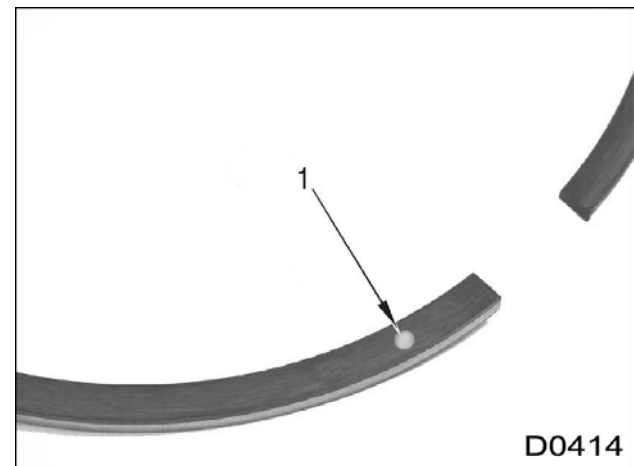


Figure 339 Piston ring identification mark (top ring)

1. Identification mark
- c. Install intermediate ring into middle piston groove. The intermediate ring is identified by two 'OO' marks on the top surface of the

- ring. Make sure the ring is installed with the identification mark facing up.
- d. Install compression ring into top piston groove. The compression ring is identified by the 'O' mark on the top surface of the ring. Make sure the ring is installed with the identification mark facing up.
3. Install intermediate and top compression rings with their identification marks facing up (to top of piston). Space ring gaps approximately 120° apart after ring installation.

Connecting Rod and Piston Assembly

1. Turn crankshaft so number 1 crank pin is at bottom of its stroke.



Figure 340 Piston and piston ring lubrication



Figure 341 Cylinder wall lubrication

2. Coat piston and piston rings with clean engine oil.
3. Coat cylinder walls, crankshaft journals, and piston cope with clean engine oil.

CAUTION: To prevent engine damage, CAM V8 stamped on top of the piston must be oriented towards the camshaft side of the crankcase or up position.



Figure 342 CAM V8 stamp on piston

NOTE: Before installing piston and connecting rod assembly, make sure all piston cooling tubes are installed.



Figure 343 Piston installed in piston cope

4. Place piston in piston cope (Table 18).
5. Install bearing shells in connecting rod and cap. Coat bearing shell in connecting rod with clean engine oil.
6. Carefully put piston and piston cope combination and connecting rod assembly in crankcase bore.

CAUTION: To prevent engine damage, when installing connecting rod and piston assemblies, do not damage piston cooling tubes.

CAUTION: To prevent engine damage, note the engine serial number (stamped on the crankcase pad, left side rear of the crankcase) and piston part number (stamped on the piston crown). Multiple pistons are available for service applications. Do not install pistons having different part numbers.

CAUTION: To prevent engine damage, install pistons in the correct cylinder bore.

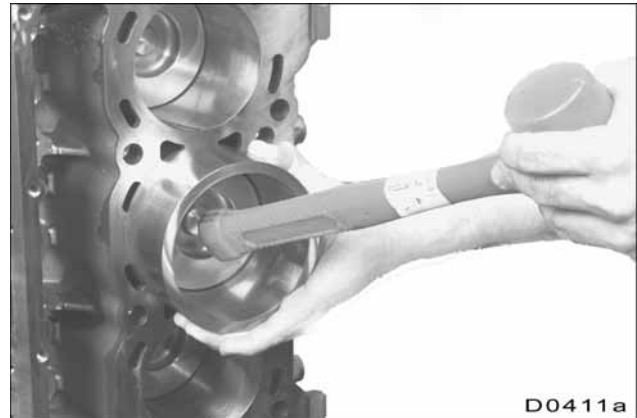


Figure 344 Installation of piston in cylinder bore

7. Once piston and connecting rod assembly have been inserted in cylinder bore, use the handle (wood or plastic) of a hammer to tap piston in crankcase bore. Guide connecting rod in place on crankshaft.
8. Apply clean engine oil to bolt hole threads for connecting rod and bearing shell in cap before installing bolts.

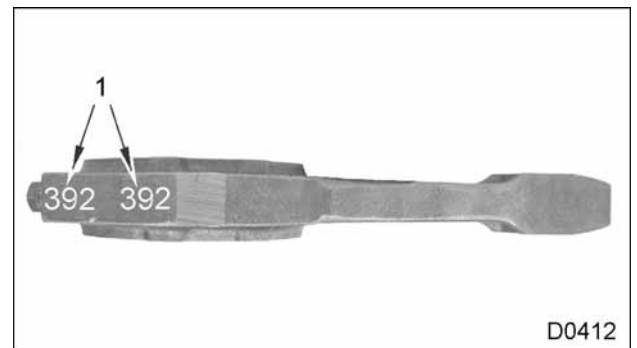


Figure 345 Connecting rod and cap

1. Matching numbers
9. Assemble cap to connecting rod with matching identification code on same crankshaft journal from which it was removed. Be certain that the longer leg of the connecting rod and the CAM V8 stamp on piston crown are oriented towards the camshaft.

CAUTION: To prevent engine damage, do not use air powered tools to install connecting rod bolts; this can seize rod bolts.

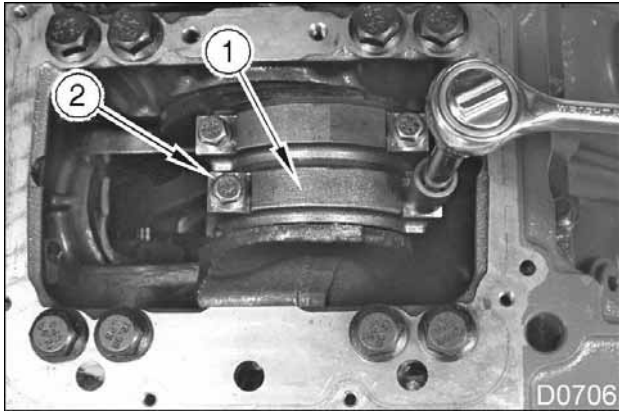


Figure 346 Connecting rod cap

1. Connecting rod bearing cap
2. Connecting rod bolt

10. Install and tighten connecting rod bolts evenly to initial and final torque values. See special torque (Table 17).
11. Repeat installation procedure for remaining connecting rod and piston assemblies.
12. Check connecting rod side clearance with feeler gauge. See procedure in removal section (Removal, page 185).
13. Reinstall all safety guards, shields, and covers.
14. Make sure all tools, cleanliness covers, loose parts, and service equipment are removed from the engine work area.

Specifications

Table 16 Connecting Rods and Pistons

Connecting Rods	
Connecting rod length (center to center)	176 mm (6.929 in)
Bushing bore diameter (pin end)	36.98 to 37.02 mm (1.456 to 1.457 in)
Piston pin bushing inside diameter	34.0140 to 34.0215 mm (1.3391 to 1.3394 in)
Material	I-Beam Section - Powdered
Bearing bore diameter (crankshaft end)	72.987 to 73.013 mm (2.8735 to 2.8745 in)
Bearing bore maximum out-of-round	0.013 mm (0.0005 in)
Bearing bore maximum taper per 25 mm (1 inch)	0.013 mm (0.0005 in)
Connecting rod bearing inside diameter	69.027 to 69.077 mm (2.7176 to 2.7196 in)
Connecting rod bearing running clearance (diameter)	0.0203 to 0.0837 mm (0.0008 to 0.0033 in)
Connecting rod side clearance	0.3 to 0.6 mm (0.012 to 0.024 in)
Weight (complete rod without bearing)	1201.5 to 1215.5 g (2.649 to 2.679 lb)
Pistons	
Material	Aluminum Alloy
Skirt diameter ¹	94.9460 to 94.9186 mm (3.737 to 3.738 in)
¹ Measure 14.68 mm (0.578 in) from bottom, at 90° to the piston pin. Measure only at room temperature of 19 to 21°C (66 to 70°F).	
Service Piston:	
Standard size	94.9460 to 94.9186 mm (3.737 to 3.738 in)
0.254 mm (0.010 in) oversize	95.1738 to 95.1992 mm (3.747 to 3.748 in)
0.508 mm (0.020 in) oversize	95.4278 to 95.4532 mm (3.757 to 3.758 in)
0.762 mm (0.030 in) oversize	95.6818 to 95.7072 mm (3.767 to 3.768 in)
Top compression ring groove width (measured over 2.08 mm (0.082 in) gauge pins):	
Upper limit	94.469 mm (3.7192 in)
Replacement limit	94.290 mm (3.7122 in)
Piston height above crankcase deck (protrusion)	0.900 mm (0.0354 in)
Piston skirt clearance (1 - 8)	0.0441 to 0.0909 mm (0.0017 to 0.0036 in)
Piston Pins	
Length	65.073 to 65.327 mm (2.5619 to 2.5719 in)
Diameter	33.9975 to 34.0025 mm (1.3385 to 1.3387 in)
Pin fit at room temperature of 19 to 21°C (66 to 70°F):	
Clearance in connecting rod (piston pin bushing)	0.0115 to 0.0240 mm (0.00045 to 0.00094 in)

Table 16 Connecting Rods and Pistons (cont.)

Clearance in piston	0.013 to 0.022 mm (0.0005 to 0.0009 in)
End clearance	0.24 mm (0.009 in)
Piston Rings	
Ring diameter (standard):	95 mm (3.74 in)
Fit in groove (side clearance in bore):	
Intermediate compression	0.051 to 0.102 mm (0.0020 to 0.0040 in)
Oil control	0.038 to 0.084 mm (0.0015 to 0.0033 in)
Ring gap in bore:	
Top compression	0.29 to 0.55 mm (0.011 to 0.021 in)
Intermediate compression	1.40 to 1.66 mm (0.055 to 0.065 in)
Oil control	0.24 to 0.50 mm (0.009 to 0.019 in)

Special Torque

Table 17 Connecting Rod Assembly

Connecting rod bearing bolts	Initial	45 N·m (33 lbf·ft)
	Final	68 N·m (50 lbf·ft)

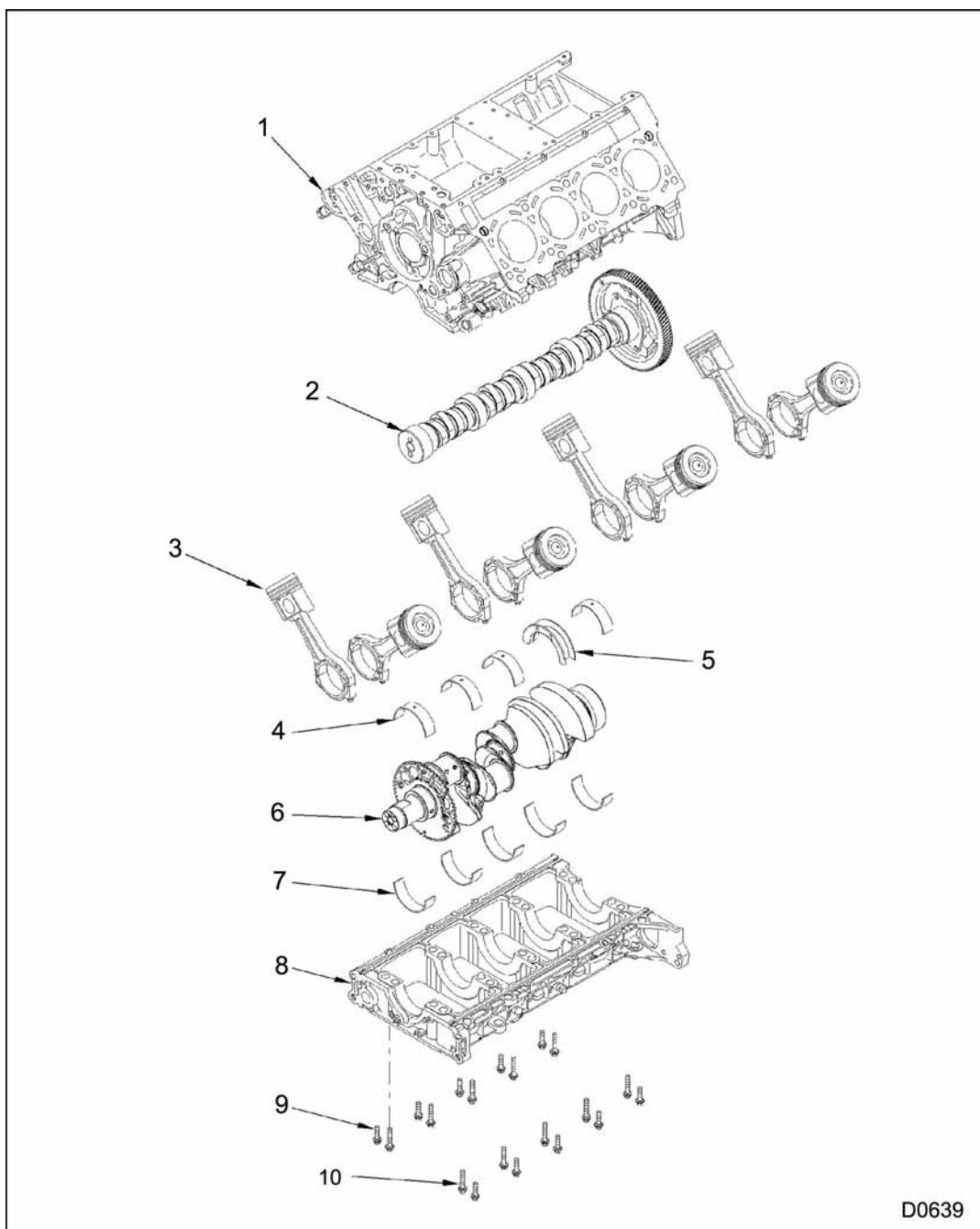
Special Service Tools

Table 18 Connecting Rods and Pistons

Description	Tool Number
Dial Indicator with Magnetic Base	Obtain locally
Piston Gauge Pins (0.082 in)	ZTSE4513
Piston Ring Compressor (Cope)	ZTSE4514
Piston Ring Expansion Pliers	Obtain locally
Telescoping Gauge Set	Obtain locally

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Figure 347 Crankcase and related parts

1. Crankcase assembly	5. Crankshaft upper main thrust bearing (1)	9. Main bearing bolt, M14 x 114 (10)
2. Camshaft assembly	6. Crankshaft assembly	10. Main bearing bolt, M14 x 127 (10)
3. Piston and connecting rod assembly (8)	7. Crankshaft lower main bearing (5)	
4. Crankshaft upper main bearing (4)	8. Lower crankcase assembly	

Removal

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

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

Before removing crankcase, crankshaft, bearings, camshaft, and bushings remove the following components:

- Flywheel and Rear Cover
See "Rear Cover, Flywheel, and Power Steering Drive Gear."
- Cylinder Heads
See "Cylinder Head and Valve Train."
- Intake Manifold and EGR
See "Manifolds and Exhaust Gas Recirculation (EGR)."
- Vibration Damper and Front Cover
See "Front Cover, Vibration Damper, and Gerotor Oil Pump."
- Turbocharger Assembly
See "VGT Electronically Controlled Turbocharger."
- Piston Assemblies
See "Pistons, Rings, and Connecting Rods."
- Upper and Lower Oil Pan
See "Oil Pan, Upper Oil pan, and Pickup Tube."

CAUTION: To prevent engine damage, do not remove the rear primary crankshaft flange bolts. If the flange is removed and reinstalled, engine vibration and premature wear of transmission components will occur.

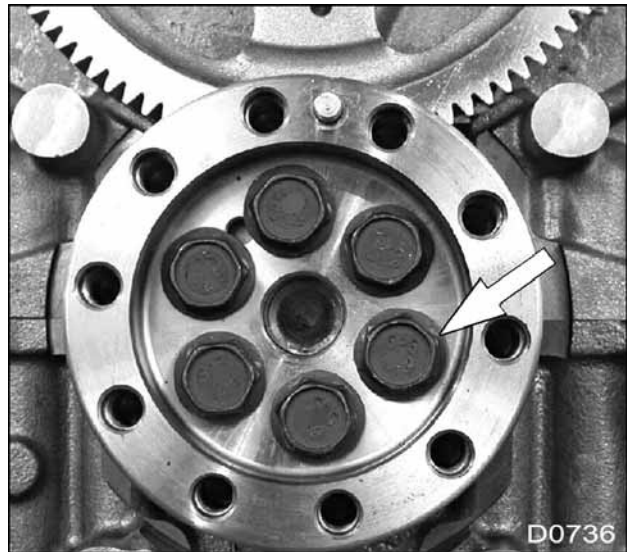


Figure 348 Rear primary crankshaft flange bolt (6)

Preliminary Checks

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

NOTE: Before removing components in this section, determine gear backlash (crankshaft gear to camshaft gear), camshaft end play, and crankshaft end play.

1. Check and record backlash for camshaft gear-to-crankshaft gear as follows (Figure 349):

NOTE: Crankshaft gear must be fixed and not allowed to rotate; the camshaft gear must rotate, for a correct reading.

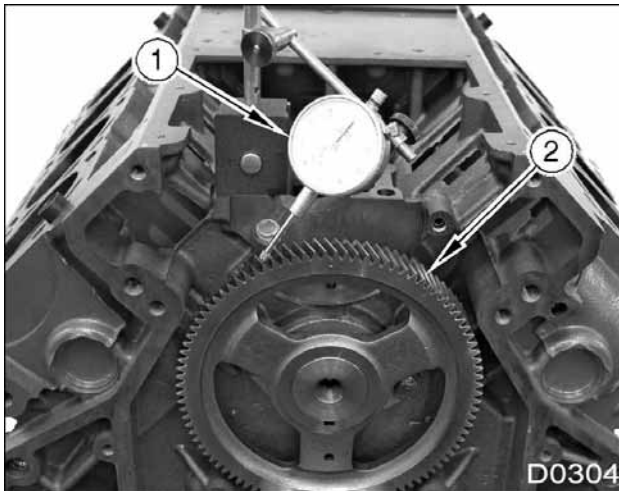


Figure 349 Gear Backlash check (camshaft gear to crankshaft gear)

1. Dial indicator
 2. Camshaft gear
- a. Mount dial indicator (Table 22) on rear of engine.
 - b. Position dial indicator tip on a gear tooth and remove lash.
 - c. Zero the dial indicator.
 - d. Rotate gear by hand and read indicator. Record backlash.
 - e. If backlash exceeds specified limits (Table 19), replace camshaft gear.
2. Reposition dial indicator and check camshaft end play as follows:

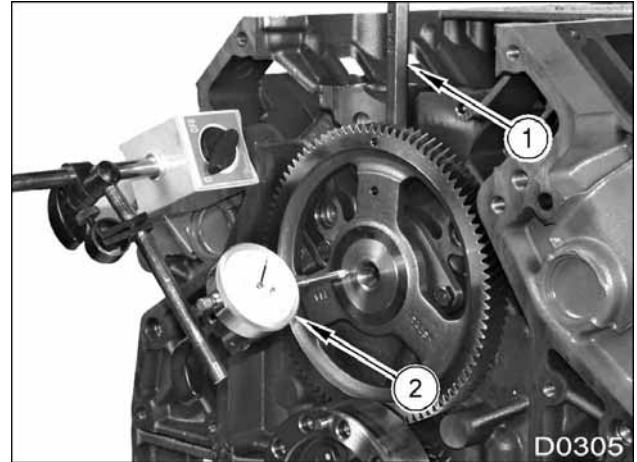


Figure 350 Camshaft end play

1. Pry bar
 2. Dial indicator
- a. Push camshaft to the front of the engine.
 - b. Zero the dial indicator.
 - c. Place a small pry bar between the camshaft gear and crankcase. Lightly pry camshaft forward. Compare dial indicator reading with specifications (Table 19).
 - If end play exceeds specified limits, replace camshaft thrust plate.
3. Check crankshaft end play as follows:

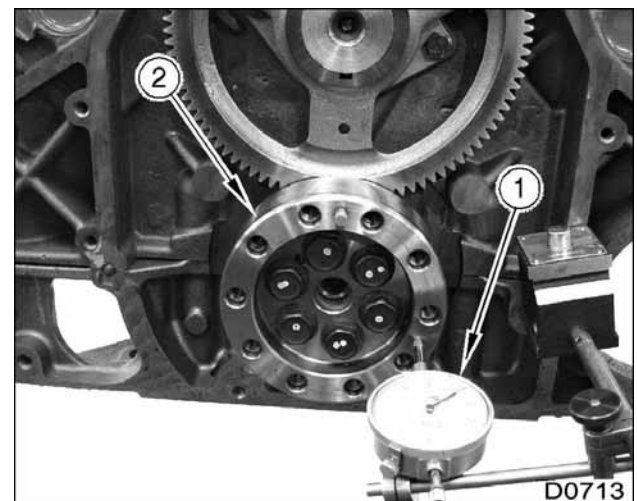


Figure 351 Crankshaft end play

1. Dial indicator
2. Crankshaft flange

- Mount dial indicator on crankcase with indicator tip on the end of crankshaft flange as shown.
- Pry crankshaft forward with pry bar and zero the dial indicator.
- Pry crankshaft back and forth while reading dial indicator.

Lower Crankcase

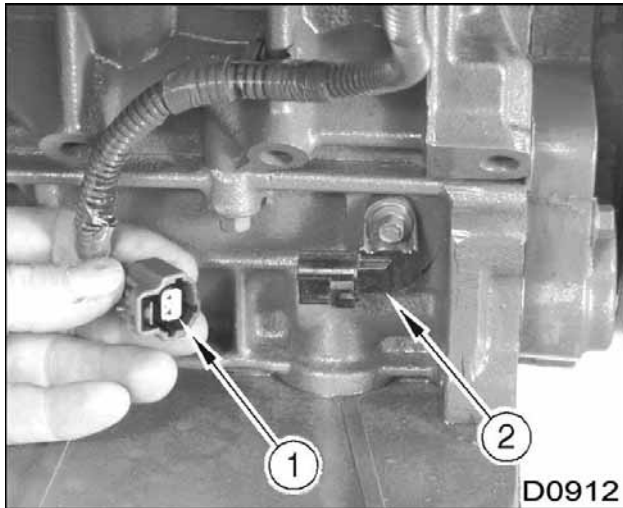


Figure 352 CKP sensor

- Sensor connector
- CKP sensor

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

- Disconnect the 2-pin electrical connector from Crankshaft Position (CKP) sensor.
- Remove the M6 x 14 retaining bolt from the CKP sensor on right lower front of the engine.
- Remove and discard O-ring.

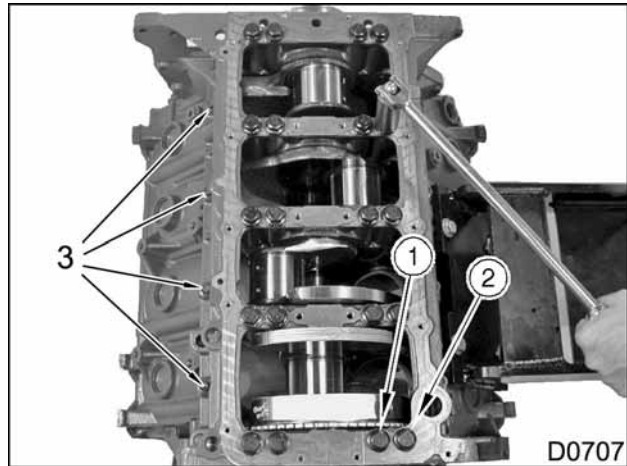


Figure 353 Main bearing bolts and outer lower crankcase bolts – 2004 Model Year

- Inboard main bearing cap bolt (M14 x 127) (10)
- Outboard main bearing cap bolt (M14 x 114) (10)
- Outer lower crankcase bolt (M8 x 30) (8)

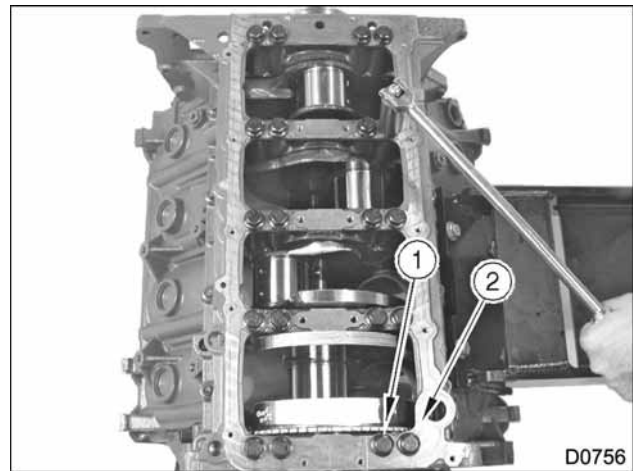


Figure 354 Main bearing bolts – 2005 and 2006 Model Years

- Inboard main bearing cap bolts (M14 x 127) (10)
- Outboard main bearing cap bolts (M14 x 114) (10)

- Remove 10 inboard main bearing cap bolts.
- Remove 10 outboard main bearing cap bolts.

NOTE: For 2004 Model Year, remove eight outer lower crankcase bolts.

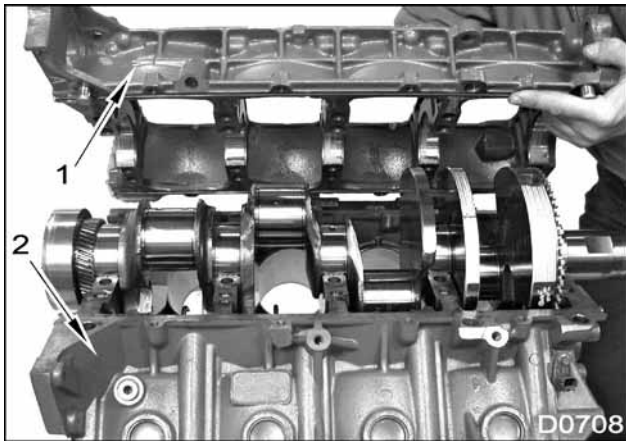


Figure 355 Lower crankcase assembly

1. Lower crankcase
2. Crankcase

6. Carefully lift lower crankcase from crankshaft.
7. Remove main bearing shells from lower crankcase by pushing bearing shells out of bearing saddles.
8. Mark lower shells with bearing number (1 to 5, beginning from the front) and put shells aside for inspection.

Crankshaft

! WARNING: To prevent personal injury or death, use a correct size lifting sling and hoist with a safety latch on hook.

1. Install a bolt in each end of crankshaft.

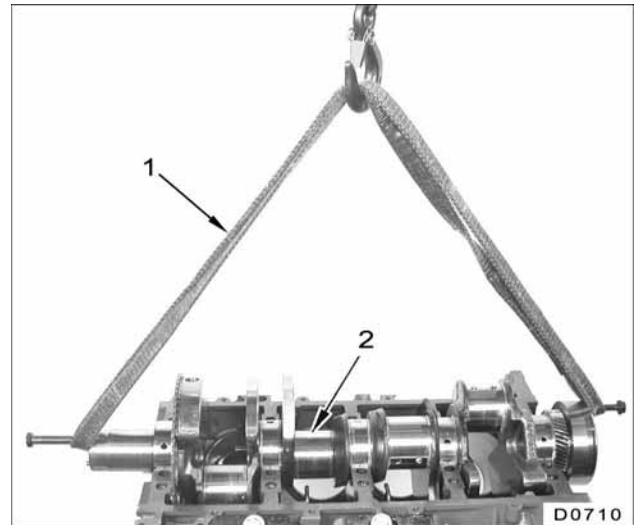


Figure 356 Lifting sling

1. Lifting sling
 2. Crankshaft
2. Attach lifting sling to crankshaft over bolts installed in the crankshaft. Lift crankshaft straight up and out of crankcase.

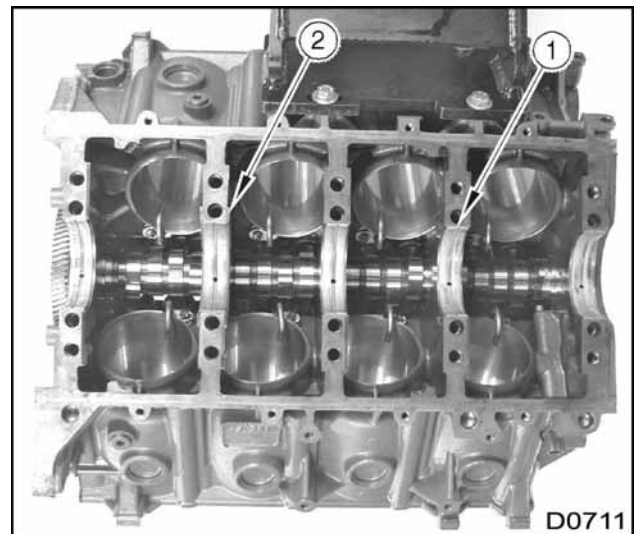


Figure 357 Main crankshaft upper bearings

1. Crankshaft upper bearing (4)
 2. Crankshaft upper thrust bearing (1)
3. Remove bearings from upper main bearing saddles by pushing bearings out.

4. Mark upper bearings to match lower bearings and put aside for inspection.

Piston Cooling Tubes

CAUTION: To prevent engine damage, the piston cooling tubes use a special patch type mounting bolt. Do not substitute.

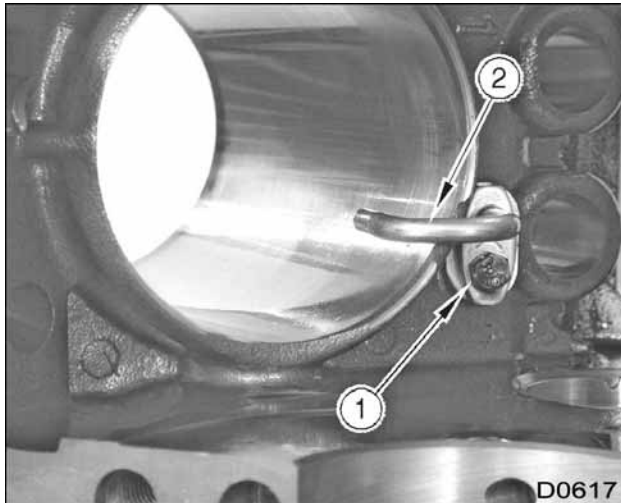


Figure 358 Piston cooling tube

1. Piston cooling tube mounting bolt (patch type) (M6 x 18)
2. Piston cooling tube

Remove each piston cooling tube by removing its special patch type mounting bolt (M6 x 18). The bolts are reusable, providing you clean and inspect the bolt, and add Liquid Gasket (RTV) (Table 22) to bolt threads before reinstallation.

Camshaft

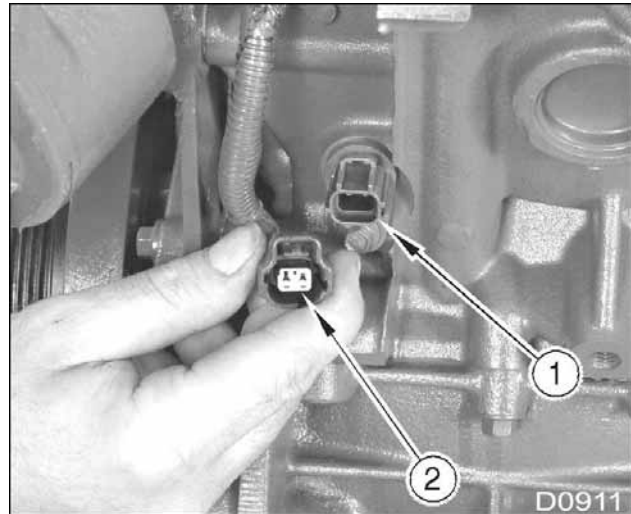


Figure 359 CMP sensor

1. CMP sensor
2. Sensor connector

1. Disconnect the 2-pin electrical connector from Camshaft Position (CMP) sensor.

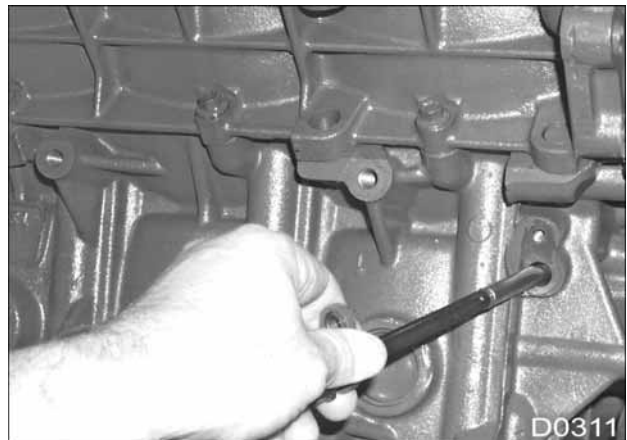


Figure 360 CMP sensor removal

2. Remove M6 x 14 retaining bolt from the CMP sensor in lower left engine block near the front cover.
3. Remove and discard both O-rings.

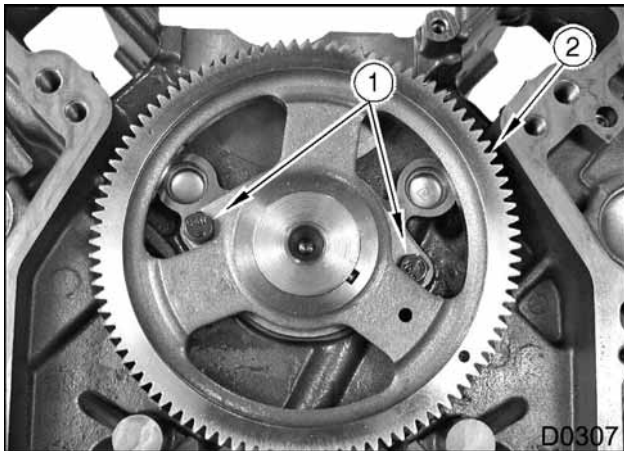


Figure 361 Mounting bolts for camshaft thrust plate

1. Camshaft thrust plate mounting bolts
2. Camshaft gear

4. Remove two M8 x 16 camshaft thrust plate mounting bolts.

NOTE: If the engine is mounted on a turn over stand, rotate engine face up, allowing for easy removal of camshaft assembly.

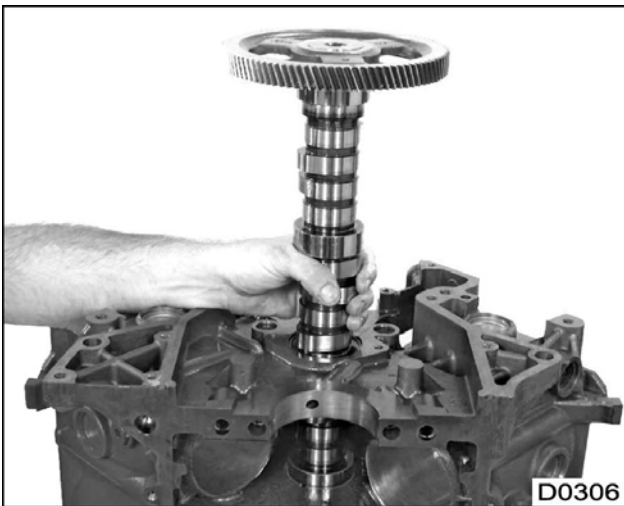


Figure 362 Camshaft assembly

5. Remove camshaft from crankcase by lifting assembly straight up and out.

NOTE: The camshaft gear, assembled to the camshaft with a shrink fit, can be removed with a hydraulic press, if required.

Camshaft Bushings

1. Determine necessity of replacing bushings based on running clearance (Measuring Camshaft Bushings, page 217).
2. Use existing camshaft bushing kit with Camshaft Bushing Remover/Installer (expanding collet) (Table 22) to remove all camshaft bushings. Install Camshaft Bushing Remover/Installer (expanding collet in collapsed state) in camshaft bushing.

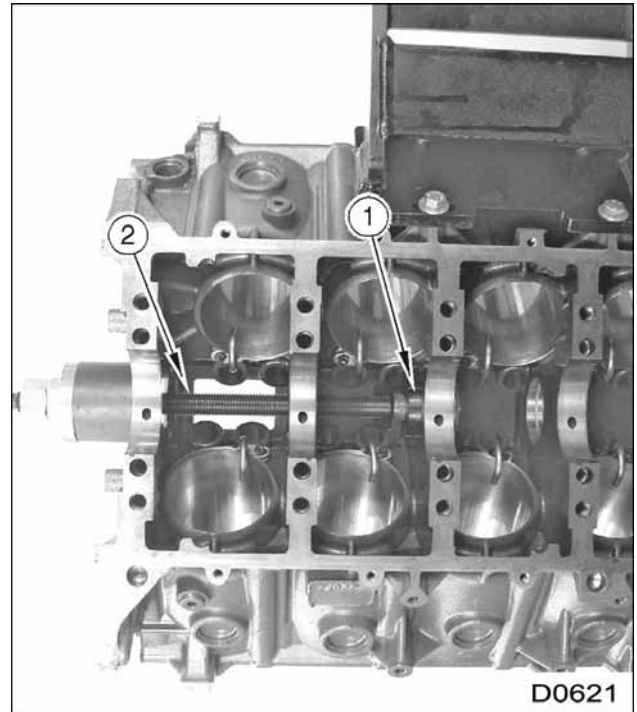
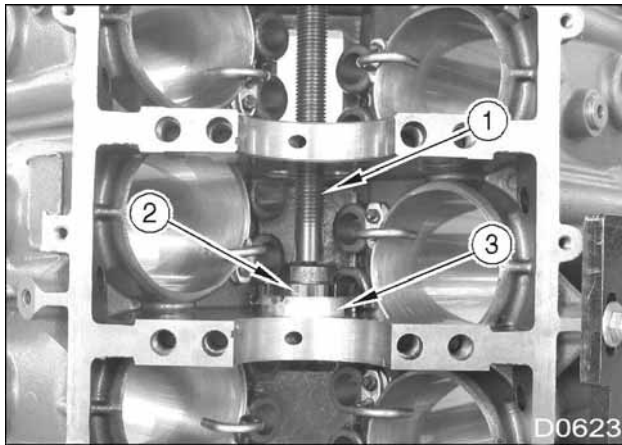


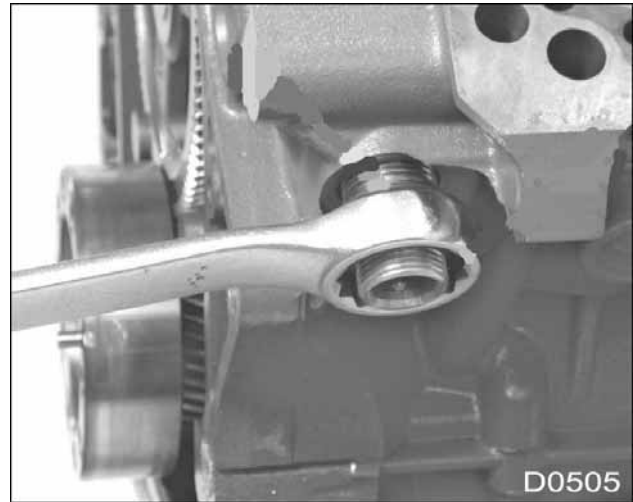
Figure 363 Camshaft bushing

1. Camshaft Bushing Remover/Installer (expanding collet)
2. Pulling screw (from camshaft bushing kit)
3. Assemble pulling screw in Camshaft Bushing Remover/Installer (expanding collet) and tighten backup nut until collet fits snug in camshaft bushing. To avoid nicks on bushings, be careful when inserting or removing threads of pulling screw.

NOTE: Hold a wrench on end of pulling screw to prevent screw from turning.

**Figure 364 Camshaft bushing**

1. Pulling screw
 2. Camshaft Bushing Remover/Installer (expanding collet)
 3. Camshaft bushing
4. Attach pulling plate, thrust bearing, and drive nut on pulling screw. Tighten nut against thrust bearing and pulling plate. Continue to thread nut on pulling screw until camshaft bushing is free from crankcase.

Coolant Heater**Figure 365 Coolant heater removal**

Remove coolant heater from right rear side of engine block.

Cleaning, Inspection, and Testing

Crankcase Assembly

Cleaning the Crankcase

NOTE: Clean the crankcase in a chemical bath or hot tank. This removes all carbonized material and mineral deposits in coolant passages.

- If a hot tank is not available, do the following steps:

NOTE: Thoroughly clean and inspect crankcase before and after reconditioning.

1. Use nonmetallic stiff bristle brushes and scrapers to clean gasket material from machined surfaces of crankcase.
2. Clean cylinder bore with soap, water, and a nylon stiff bristle brush.
3. Clean lower crankcase in solvent.

! 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).

4. Dry with filtered compressed air.



Figure 366 Removal of oil gallery cup plugs

1. Punch
2. Hammer
3. Oil gallery cup plug

5. To remove main oil gallery cup plug (in rear of crankcase), use a punch and hammer near edge of plug and strike with a hammer.
6. Remove plug from crankcase and discard.

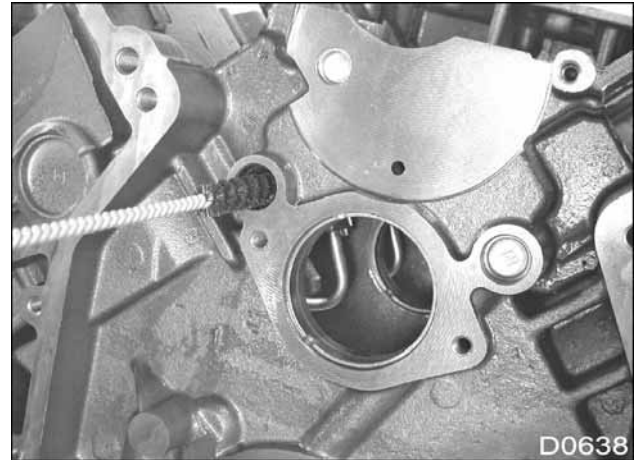


Figure 367 Main oil gallery

7. Clean main galleries with an Oil Gallery Cleaning Brush (Table 22).

NOTE: Use Liquid Gasket (RTV) (Table 22) before installing main oil gallery core plugs.

8. Coat edges of new oil gallery cup plugs with liquid gasket. Use an Oil Gallery Plug Driver (Table 22) and install new oil gallery cup plugs. The oil gallery plug driver installs the oil gallery cup plug to the correct depth. It should be flush with the crankcase surface to approximately 1.50 mm (0.060 in) below surface.

CAUTION: To prevent engine damage, threads in the crankcase bolt holes must be clean and blown dry with filtered compressed air. Dirt or oil left in holes may cause binding and a false torque reading during assembly.

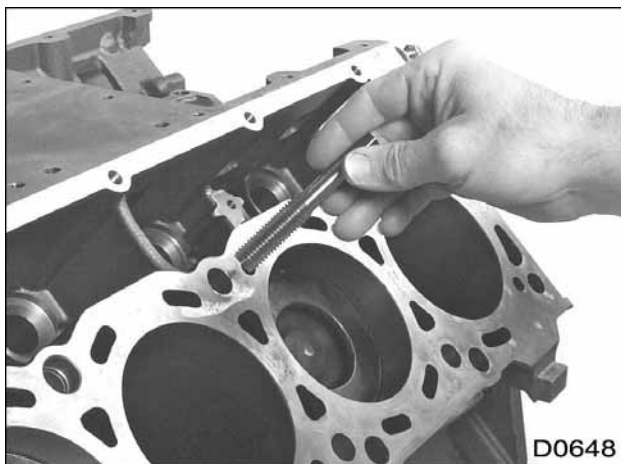


Figure 368 Cylinder head bolt holes

9. Clean cylinder head bolt holes with a head bolt bottoming tap (Table 22).

! 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).

10. Blow out chips with filtered compressed air.

Inspecting the Crankcase

1. After cleaning, inspect crankcase for cracks, scoring, roughness or wear at cylinder bores.

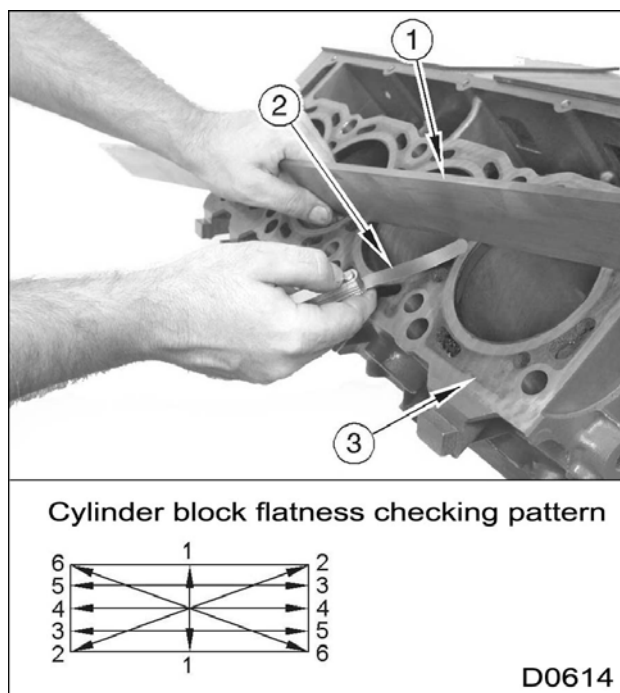


Figure 369 Flatness check for top surface of cylinder block

1. Straightedge
2. Feeler gauge
3. Cylinder block top surface

2. Use a straightedge (Table 22) to check the cylinder block top surface of crankcase (firing deck) for flatness. Insert a feeler gauge between straightedge and crankcase head surface.
 - a. Measure the whole deck surface. If the gap exceeds the specifications (Table 20), the crankcase must be replaced.
 - b. Divide the deck surface into 150 mm x 150 mm areas and measure each square area. If the gap exceeds the specifications (Table 20), the crankcase must be replaced.
 - c. Divide the deck surface into 25 mm x 25 mm areas and measure each square area. If the gap exceeds the specifications (Table 20), the crankcase must be replaced.

CAUTION: Do not resurface the crankcase. Surface defects beyond those listed above are not correctable.

3. If cylinder walls have minor surface damage, but are otherwise within out-of-round specifications, it may be possible to remove damage by honing.

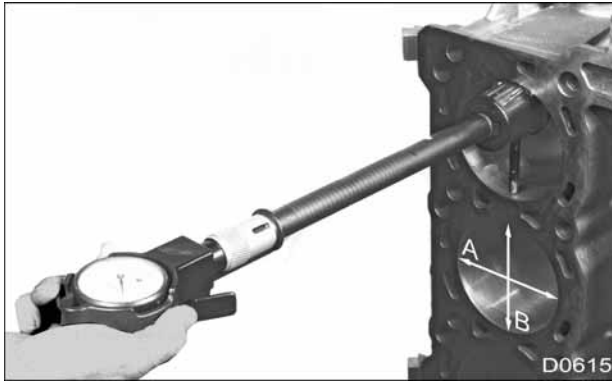


Figure 370 Out-of-round cylinder bore check

4. Use a cylinder bore gauge (Table 22) to check cylinder bore out-of-round conditions.
 - a. Measure diameter of cylinder bore at top of piston ring travel. Be sure to measure at a right angle to the center line of crankshaft (dimension A). Record reading.
 - b. Measure each bore so gauge reading coincides with center line of crankshaft (dimension B). Record reading.
 - c. The difference between dimension A and dimension B is the out-of-round condition at the top of the cylinder bore.
5. Repeat the same procedure at the bottom of ring travel to check for out-of-round condition.

CAUTION: To prevent engine damage, if cylinder bores are deeply scored, out-of-round or exceeds specifications, all cylinders must be bored out to an oversize dimension.

6. If cylinder bore is within specifications (Table 19), standard size pistons and rings may be used.
 - If cylinder bore is suitable for use without reconditioning, deglaze the cylinder bore before assembling. See Cylinder deglazing in this section for further details.

Cylinder Deglazing

NOTE: Piston cooling tubes must be removed before deglazing cylinder bores.

1. Use a Deglazing Hone (four-inch) (Table 22) to deglaze the cylinder bore. This silicone carbide-tipped nylon flexible brush quickly

deglazes cylinder walls and produces a crosshatch pattern on the cylinder wall surface in a single operation. The brush contours itself to the cylinder wall and conditions wall surface without altering cylinder bore.

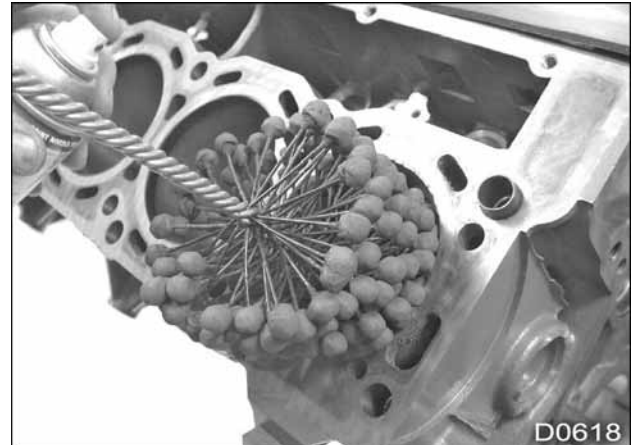


Figure 371 Deglazing Hone

2. Spray cylinder and Deglazing Hone with penetrating fluid or equivalent. This spray contains colloidal graphite and works well.
3. Attach Deglazing Hone to a variable speed electric or air powered drill.

NOTE: For a successful procedure 100 to 120 rpm is required.

4. Deglaze cylinder wall for about 15 seconds. Stroke bore up and down at a rate of one complete up and down stroke per second.
5. Withdraw deglazing hone from cylinder bore while rotating. Wipe portion of cylinder wall and inspect cross hatch pattern.

NOTE: The cross hatch pattern left by the abrasive tool should be approximately 45°.

- If pattern is "flatter" than required, increase up and down stroke speed or slow down drill rotation as required.
6. Continue deglazing cylinder bore for 10 to 15 seconds or 20 to 25 strokes.
 7. Wipe cylinder bore clean and inspect bore for correct 45° cross hatch pattern.
 8. After deglazing, thoroughly clean cylinder bores with soft bristle brush, soap and water.

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

9. Dry with filtered compressed air.
10. Lubricate bores with clean engine oil

Crankshaft

1. Clean and inspect the crankshaft and main bearings.
2. Clean crankshaft with a suitable solvent.

! 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).

3. Dry with 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 crankshaft main bearings for scratches, grooves, scoring, pitting, and inconsistent coloring.



Figure 372 Measurement for crankshaft main journal



Figure 373 Measurement for crankshaft connecting rod journal

8. Use a 3-4 inch micrometer to measure the diameter of each journal (main and connecting rod). Measure each journal at two points 90° apart. Move micrometer over entire width of journal (Table 19).

CAUTION: To prevent engine damage, the crankshaft must be reground or replaced, if journals exceed maximum out-of-round or taper specifications.

Piston Cooling Tubes

1. With the piston cooling tubes removed, run a correct size wire through the tube to ensure no blockage.

! 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).

2. Use dry filtered compressed air to blow out debris that remains from cleaning.
3. Replace any cracked or bent tubes.

Camshaft

1. Inspect camshaft. If any lobes are scuffed, scored or cracked, replace camshaft.

NOTE: This engine uses hydraulic valve tappets with roller followers; therefore, a roller follower guide is needed to maintain correct orientation of roller to cam lobe. Normal clearance between the valve tappet roller and guide allows for slight tracking of roller across cam lobe.

Tracking of the roller is normal when the roller accelerates and decelerates during engine operation. Consequently, a typical wear pattern on cam lobes will exhibit tracks from side to side, have wide and narrow areas from the loading, and unloading of the follower. The wear pattern (tracking) is normal and the camshaft does not require replacement.

2. After inspection, evaluate camshaft main journal and lobe condition as follows:

NOTE: When measuring the camshaft with a micrometer, always take two measurements 90° apart.



Figure 374 Measurement for camshaft bearing journal

- a. Use a 2-3 inch micrometer to measure journal diameter of camshaft bearing.
 - If bearing journals are worn beyond limits, install new camshaft.

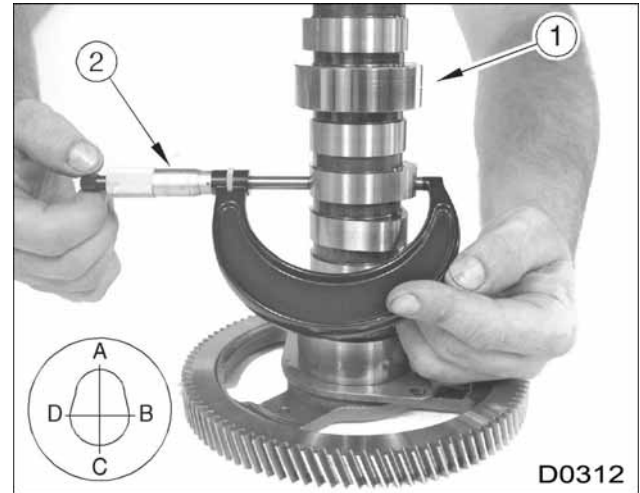


Figure 375 Measurement for camshaft intake and exhaust lobes

1. Camshaft assembly
2. Micrometer

- b. To check camshaft intake and exhaust lobes, measure across (A to C) and across (B to D). Subtract (B to D) from (A to C). This will give cam lobe lift. Replace camshaft if cam lobe wear exceeds specifications (Table 19).
3. Inspect thrust plate for wear, cracks or distortion. Use a micrometer to measure thrust plate thickness (Table 19). Replace thrust plate if worn or damaged.
4. Inspect camshaft drive gear for worn or damaged teeth.
5. Wash camshaft in cleaning solvent with a soft brush.

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

6. Dry with filtered compressed air.

Measuring Camshaft Bushings

Inspect the five camshaft bushings for wear and correct running clearance as follows:

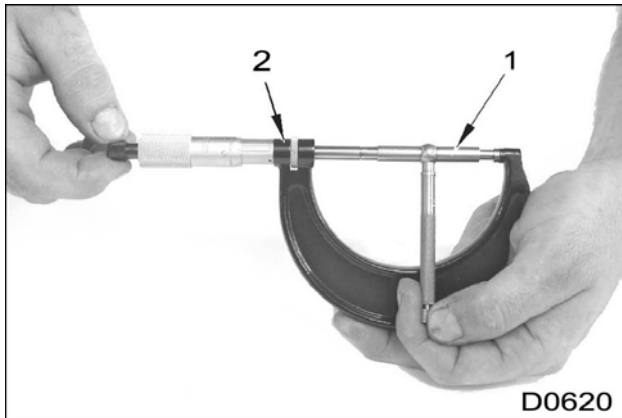


Figure 376 Measurement for inner diameter of camshaft bushing

1. Telescoping gauge
 2. Outside micrometer
-
1. Use a telescoping gauge (Table 22) and 2-3 inch micrometer to measure camshaft bushing inside diameters with bushings installed in crankcase.

2. To determine running clearance, subtract previous camshaft journal diameter readings from camshaft bushing inside diameter readings.
3. If maximum allowable running clearance is exceeded (Table 19), replace camshaft bushings. See camshaft bushing removal and installation procedures in this section.
4. Inspect each bushing bore in crankcase for burrs or debris that could damage new bushings.
5. Remove burrs and clean bores thoroughly before installing new camshaft bushings.

Coolant Heater

1. Inspect heater for continuity.
2. Check insulator at terminal for cracks.
3. Replace O-ring.

Installation

Camshaft Bushings

CAUTION: To prevent engine damage, use the correct camshaft bushing remover/installer (expanding collet).

1. Lubricate new camshaft bushings and crankcase bores with clean engine oil.

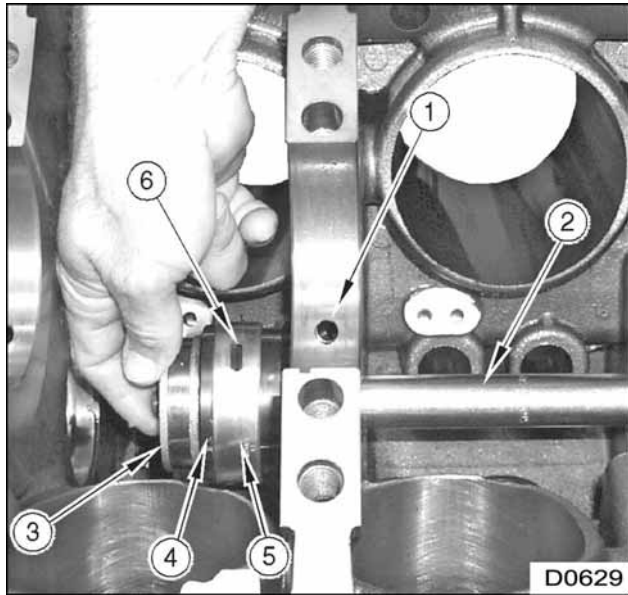


Figure 377 Installation of cam bushing

1. Oil supply hole
 2. Pulling screw
 3. Backup nut
 4. Camshaft bushing remover/installer (expanding collet)
 5. Camshaft bushing
 6. Camshaft bushing oil supply hole
2. Slide a new bushing on the Camshaft Bushing Remover/installer (expanding collet) (Table 22).
 3. Thread pulling screw, backup nut, and Camshaft Bushing Remover/Installer (expanding collet) together.
 4. Tighten expanding collet by turning backup nut until bushing is securely held on the Camshaft Bushing Remover/Installer (expanding collet).

CAUTION: To prevent engine damage, and to ensure correct oil circulation through the crankcase, make certain camshaft bushing oil holes are aligned with the corresponding oil supply holes in the crankcase.

5. To aid in alignment of bushing and crankcase oil holes, use a marker to indicate oil hole location on backup nut of installation tool. Repeat this step for each camshaft bushing.
6. Install all camshaft bushings through rear of crankcase. Pull bushings in place at rear of crankcase by turning pulling nut on pulling screw. Remove Camshaft Bushing Remover/Installer (expanding collet) and inspect oil hole alignment.

Camshaft

1. Coat camshaft lobes and bushing journals with clean engine oil.

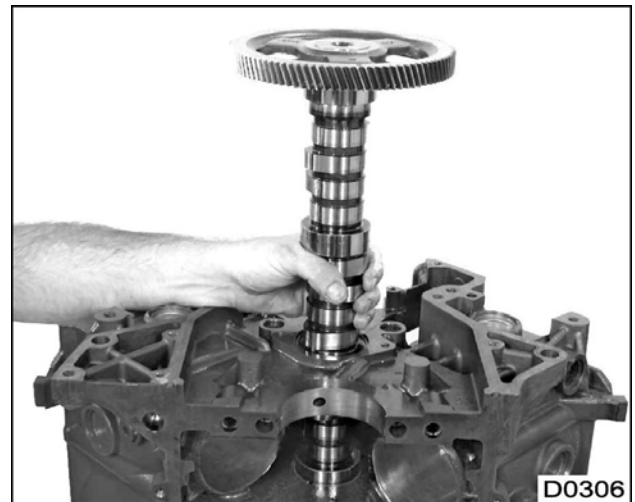


Figure 378 Camshaft assembly

2. Position crankcase with rear of engine facing up on engine stand and carefully install camshaft assembly.

NOTE: Do not nick or scratch camshaft bushings having cam lobes.

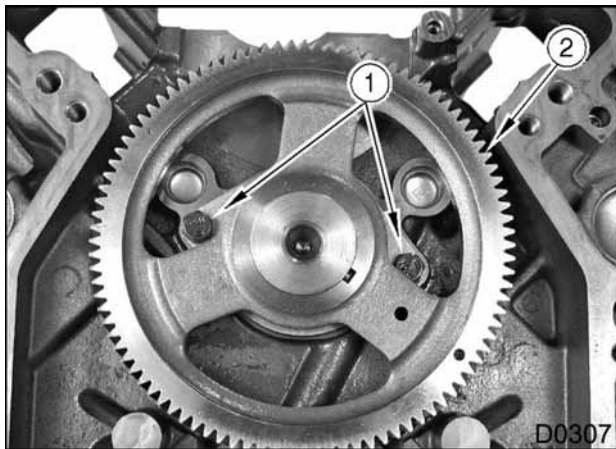


Figure 379 Camshaft thrust plate bolts installed

1. Camshaft thrust plate mounting bolt (M8 x 16)
 2. Camshaft gear
3. Install two M8 x 16 camshaft thrust plate mounting bolts. Tighten bolts to the standard torque (Standard Torques, page 375).
 4. Verify that camshaft end play is within specifications.

Piston Cooling Tubes

CAUTION: To prevent engine damage, the piston cooling tubes use a special patch type mounting bolt. Do not substitute.

NOTE: The bolt-on piston cooling tubes are self-aligning.

1. Place piston cooling tubes on crankcase mounting pad.
2. When installing piston cooling tube bolts, do one of the following:
 - a. Install new piston cooling tube mounting bolts (patch type).
 - b. Remove oil residue and apply Liquid Gasket (RTV) (Table 22) to the threads of existing piston cooling tube mounting bolts (patch type).

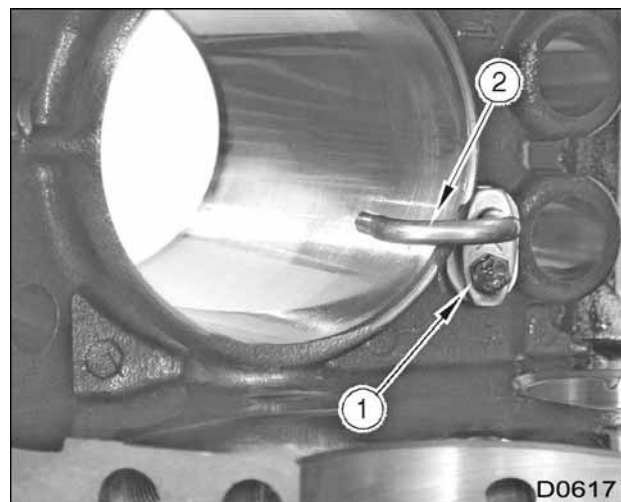


Figure 380 Piston cooling tube

1. Piston cooling tube mounting bolt (patch type) (M6 x 18)
 2. Piston cooling tube
3. Install and tighten bolts to the standard torque (Standard Torques, page 375).

Crankshaft

NOTE: Make sure the crankshaft has been inspected per instructions in this section before proceeding.

1. Use a lint-free cloth to wipe the crankcase bearing supports free of oil.
2. Inspect each bearing. Replace scored, chipped or worn bearings.

NOTE: When inserting main bearings, make sure oil is not between the back side of the bearing and the crankcase bearing saddles.

3. Place upper main bearings in the crankcase. Make sure locking tabs on bearings are snapped in the crankcase saddle and oil holes in bearings line up with oil holes in crankcase.

NOTE: Crankshaft thrust bearing is installed at the number 4 upper main bearing journal.



Figure 381 Upper main bearings lubrication

4. Lubricate bearings with clean engine oil.

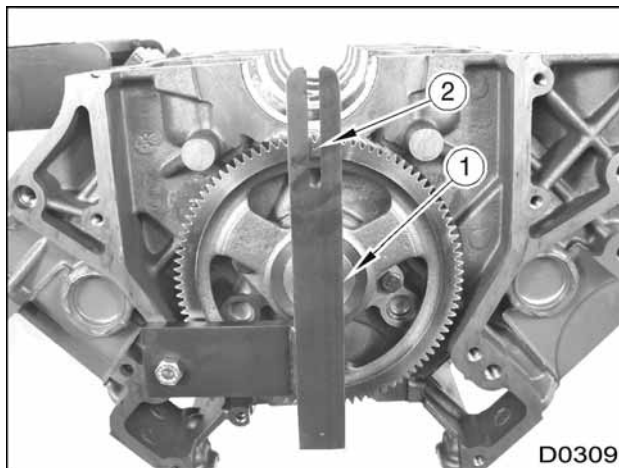


Figure 382 Crankshaft timing tool installed

1. Crankshaft timing tool
2. Camshaft index mark

5. Install Crankshaft Timing Tool (Table 22) so index mark on camshaft gear is visible between alignment slot of the crankshaft timing tool.

! WARNING: To prevent personal injury or death, use a correct size lifting sling and hoist with a safety latch on hook.

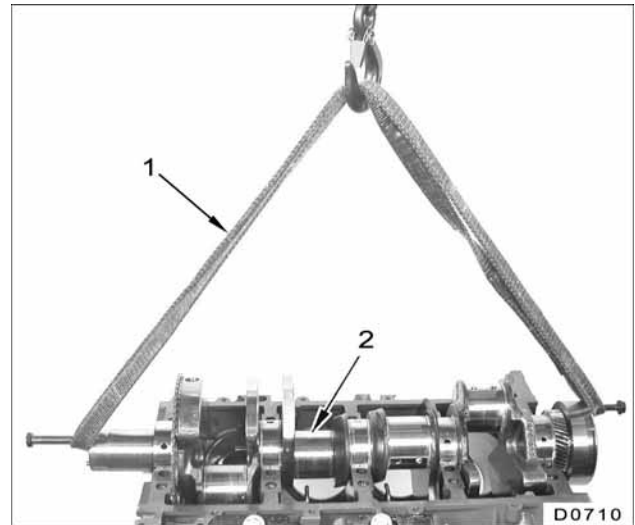


Figure 383 Lifting sling

1. Lifting sling
2. Crankshaft assembly

6. Install a bolt in each end of the crankshaft (if removed). Attach hoist and lifting sling around crankshaft bolts and carefully lower it on the five main bearings.

Crankshaft and Timing

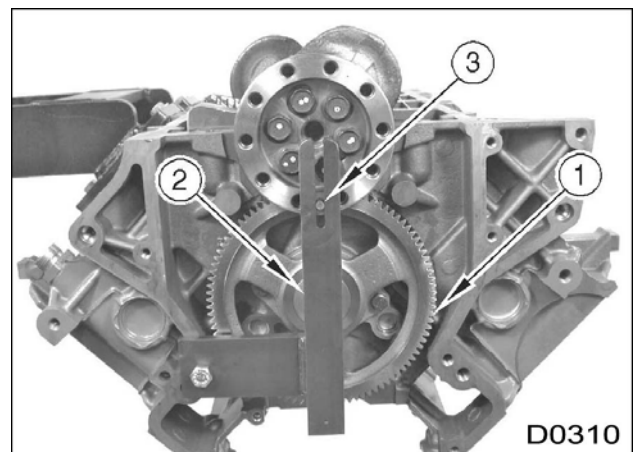


Figure 384 Crankshaft timing tool installed

1. Camshaft gear
2. Crankshaft timing tool
3. Crankshaft alignment pin

Install crankshaft so alignment pin falls between crankshaft timing tool alignment slot.

Lower Crankcase

With acceptable bearing clearance, install the lower crankcase as follows:

1. Install new lower crankcase seals.
2. Apply clean engine oil to lower bearing inserts, crankshaft journals, and lower crankcase bolts.

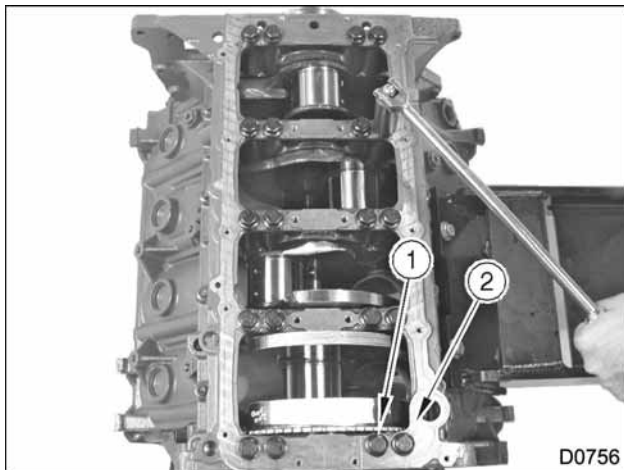


Figure 385 Main bearing bolts

1. Inboard main bearing cap bolts (M14 x 127) (10)
2. Outboard main bearing cap bolts (M14 x 114) (10)

CAUTION: To prevent engine damage, make sure that the longer main cap bolts (M14 x 127) are installed inboard and the shorter bolts (M14 x 114) are installed outboard.

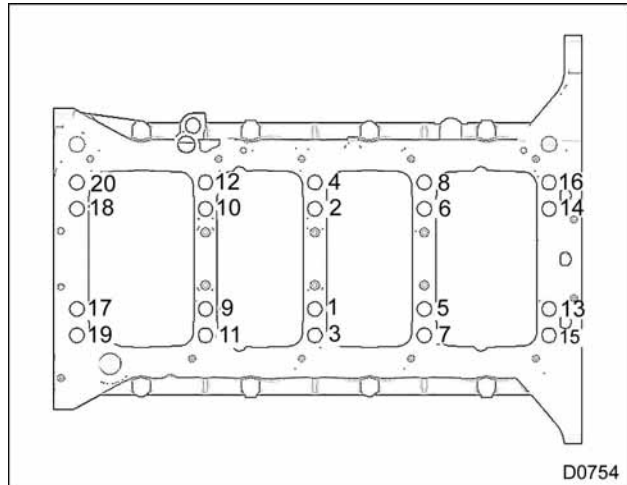


Figure 386 Torque sequence for main bearing mounting bolts to lower crankcase

3. Install 10 inboard main bearing cap bolts.
4. Install 10 outboard main bearing cap bolts.
 - Initially torque bolts to 122 N·m (90 lbf·ft).
 - Increase torque for bolts to 163 N·m (120 lbf·ft).
 - Finally, torque bolts to 231 N·m (170 lbf·ft).

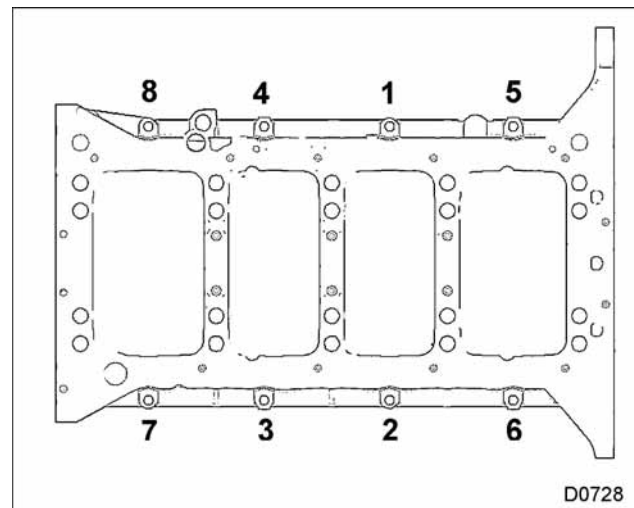


Figure 387 Torque sequence for outer lower crankcase bolts – 2004 Model year

NOTE: For 2004 Model Year, install eight M8 x 30 bolts around outside of lower crankcase and torque in sequence to 31 N·m (23 lbf·ft).

NOTE: Confirm that gear backlash between camshaft and crankshaft is within specifications.

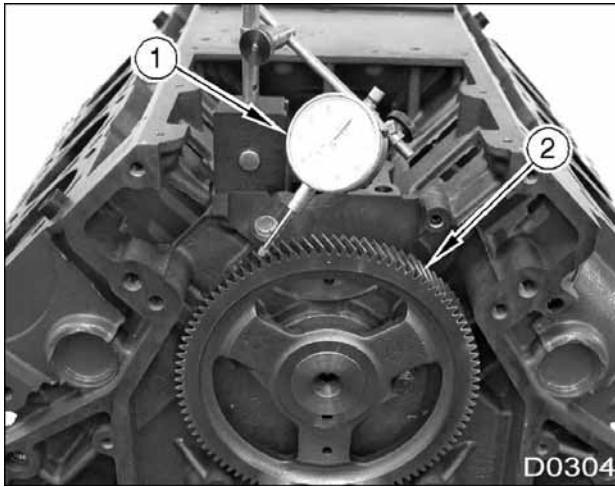


Figure 388 Gear backlash check (camshaft gear to crankshaft gear)

1. Dial indicator
 2. Camshaft gear
5. Check camshaft gear to crankshaft gear backlash as follows:
 - a. Mount dial indicator on rear of engine.
 - b. Position dial indicator tip on a gear tooth and remove lash.
 - c. Zero the dial indicator.
 - d. Rotate gear by hand and read indicator.
 - e. If backlash exceeds specified limits (Table 19), replace camshaft gear.

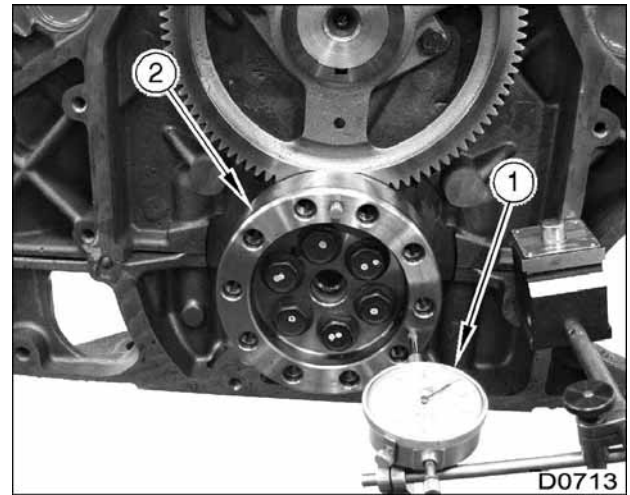


Figure 389 End play check for crankshaft

1. Dial indicator
 2. Crankshaft flange
6. Check crankshaft end play as follows:
 - a. Mount dial indicator on crankcase with indicator tip on the end of crankshaft flange as shown.
 - b. Pry crankshaft forward with pry bar and zero the dial indicator.
 - c. Pry crankshaft back and forth while reading dial indicator.

Crankcase Sensors and Coolant Heater

NOTE: See "Engine Electrical" section for engine sensors O-rings (Removal, page 257).

CMP Sensor

1. Put two new O-rings on CMP sensor.

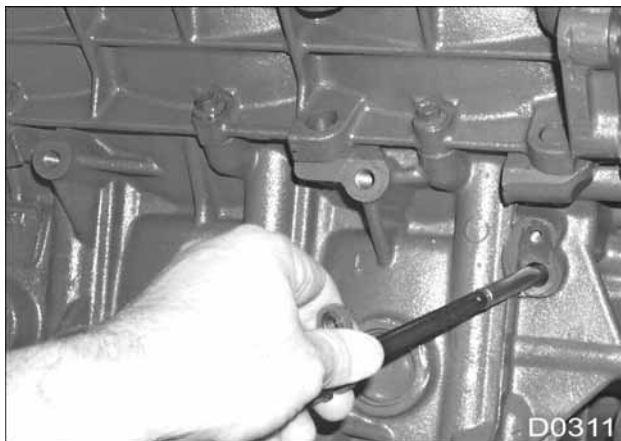


Figure 390 CMP sensor installation

2. Lubricate sensor O-rings with clean engine oil and install CMP sensor in crankcase.
3. Secure sensor with M6 x 16 bolt and tighten bolt to the standard torque (Standard Torques, page 375).

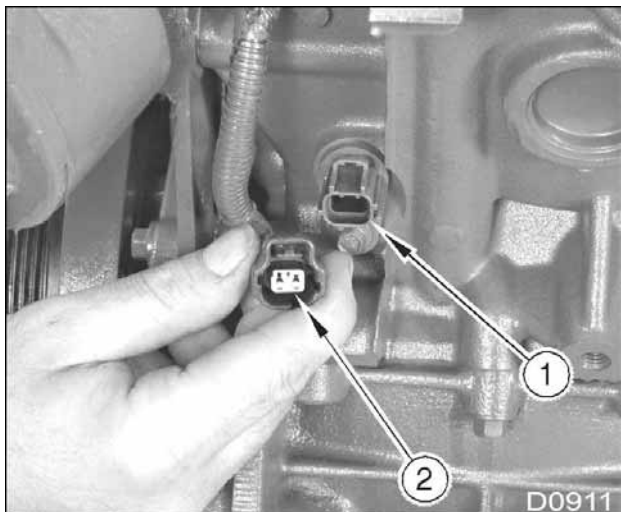


Figure 391 CMP Sensor

1. CMP sensor
2. CMP sensor connector

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

4. Connect electrical connector to CMP sensor.

CKP Sensor

1. Put new O-ring on CKP sensor.



Figure 392 Crankshaft Position (CKP) sensor installation

2. Lubricate O-ring with clean engine oil and install CKP sensor in lower crankcase.
3. Secure sensor with M6 x 16 bolt and tighten bolt to the standard torque (Standard Torques, page 375).

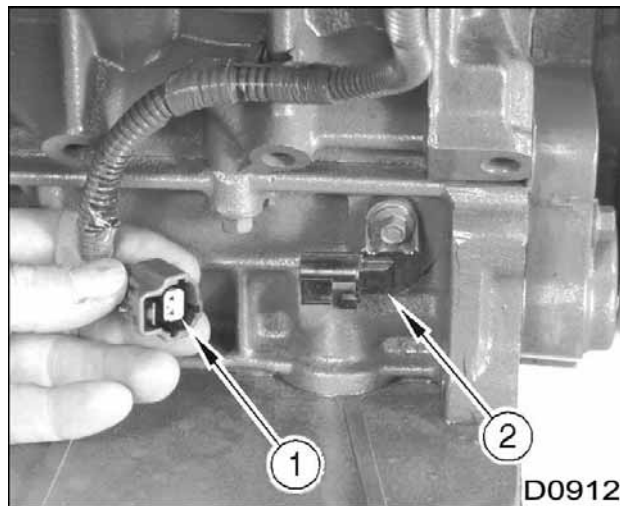


Figure 393 CKP sensor

1. CKP sensor connector
2. CKP sensor

4. Connect electrical connector to CKP sensor.

Coolant Heating Element

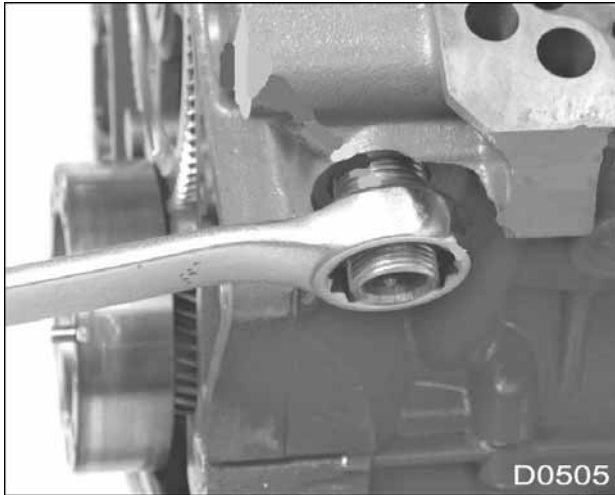


Figure 394 Installation of coolant heating element

1. Coolant heating element
2. Coolant heater O-ring

1. Lubricate a new O-ring and install on the coolant heater.
2. Install coolant heater element in the engine block and tighten to the special torque value (Table 21).
3. Connect electrical connector to coolant heating element.
4. Reinstall all safety guards, shields, and covers.
5. Make sure all tools, cleanliness covers, loose parts, and service equipment are removed from the engine work area.

Specifications

Table 19 Crankshaft, Camshaft, and Bushings

Crankshaft		
Main Bearing Journal Diameter:		
Standard size		80.9873 to 81.0127 mm (3.188 to 3.150 in)
0.254 mm (0.010 in) under size		80.7333 to 80.7587 mm (3.178 to 3.140 in)
0.508 mm (0.020 in) under size		80.4793 to 80.5047 mm (3.168 to 3.130 in)
0.762 mm (0.030 in) under size		80.2253 to 80.2507 mm (3.158 to 3.120 in)
Main bearing thrust face maximum runout		0.051 mm (0.002 in)
Oil seal journal maximum runout		0.025 mm (0.001 in)
Vibration damper mounting area maximum runout		0.05 mm (0.002 in)
Flywheel mounting surface maximum runout		0.05 mm (0.002 in)
Main bearing to crankshaft running clearance		0.020 to 0.086 mm (0.0008 to 0.0034 in)
Connecting Rod Journal Diameter:		
Standard size		68.99 to 69.01 mm (2.716 to 2.717 in)
0.254 mm (0.010 in) under size		68.73 to 68.75 mm (2.706 to 2.707 in)
0.508 mm (0.020 in) under size		68.48 to 68.50 mm (2.696 to 2.697 in)
0.762 mm (0.030 in) under size		68.23 to 68.25 mm (2.686 to 2.687 in)
Crankshaft end play (maximum)		0.222 mm (0.0087 in)
Camshaft		
Bearing journal diameter (all journals)		61.987 to 62.013 mm (2.440 to 2.441 in)
Bearing inside diameter		62.05 to 62.14 mm (2.443 to 2.446 in)
Journal and bushing running clearance		0.037 to 0.153 mm (0.0015 to 0.0060 in)
Camshaft end play		0.051 to 0.211 mm (0.002 to 0.008 in)
Camshaft gear backlash		0.179 to 0.315 mm (0.007 to 0.012 in)
Maximum permissible cam lobe wear		0.51 mm (0.02 in)
Camshaft thrust plate thickness		3.589 to 3.649 mm (0.1413 to 0.1436 in)
Camshaft lobe lift (maximum):		
Intake		5.820 mm (0.2291 in)
Exhaust		5.906 mm (0.2325 in)
Valve timing no. 1 cylinder (top of lobe):		
Intake open		16.2° BTDC
Intake closed		50.4° ABDC
Exhaust open		47.5° BBDC
Exhaust closed		14.9° ATDC

Table 20 Crankcase and Main Bearings

Crankcase	
	Total: 0.10 mm (0.004 in)
Cylinder block top surface of crankcase (firing deck) flatness	150 mm x 150 mm (6 in x 6 in) area: 0.05 mm (0.02 in) 25 mm x 25 mm (1 in x 1 in) area: 0.025 mm (0.001 in)
Crankcase main bearing bore diameter	85.99 to 86.01 mm (3.3854 to 3.3862 in)
Crankcase cam bearing bore diameter	65.98 to 66.02 mm (2.597 to 2.599 in)
Roller follower bore diameter	23.439 to 23.477 mm (0.9228 to 0.9243 in)
Roller follower outside diameter	23.391 to 23.411 mm (0.9209 to 0.9217 in)
Cylinder bore diameter	94.9905 to 95.0095 mm (3.7398 to 3.7405 in)
Cylinder bore maximum out-of-round	0.008 mm (0.0003 in)
Cylinder stroke	105 mm (4.13 in)
Main Bearings:	
Type	Precision replaceable
Material	Steel backed copper/lead
Number of main bearings	5
Thrust applied at	No. 4 main upper
Lower crankcase	Four bolts per main journal
Coolant heater element rating	1,000 watts, 120 volts

Special Torque

Table 21 Crankcase and Heater Element

Lower crankcase main bearing cap bolts	See tightening procedure and sequence (Figure 387)
Lower crankcase outer bolts	31 N·m (23 lbf·ft)
Coolant heater element	41 N·m (30 lbf·ft)

Special Service Tools

Table 22 Crankcase, Crankshaft and Bearings, Camshaft and Bushings

Description	Tool Number
Accessory Drive Gear Puller	ZTSE4520
Camshaft Bushing Kit	ZTSE2893A
Camshaft Bushing Remover/Installer (expanding collet)	ZTSE4489
Crankshaft Timing Tool	ZTSE4519
Cylinder Bore Gauge	Obtain locally
Deglazing Hone (four inch)	ZTSE4349
Dial Indicator with Magnetic Base	Obtain locally
Freeze Plug Installer	ZTSE4509
Front Seal/Wear Sleeve Installer	ZTSE4516
Front Wear Sleeve Remover	ZTSE4517
Head Bolt Bottoming Tap	ZTSE4508
Hot Plate	Obtain locally
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Oil Gallery Cleaning Brush	ZTSE4511
Oil Gallery Plug Driver	ZTSE4512
Piston Gauge Pins (0.082 in)	ZTSE4513
Straightedge	Obtain locally
Telescoping Gauge Set	Obtain locally

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Exploded Views and Details

Oil Cooler Cover and Filter Housing Assembly

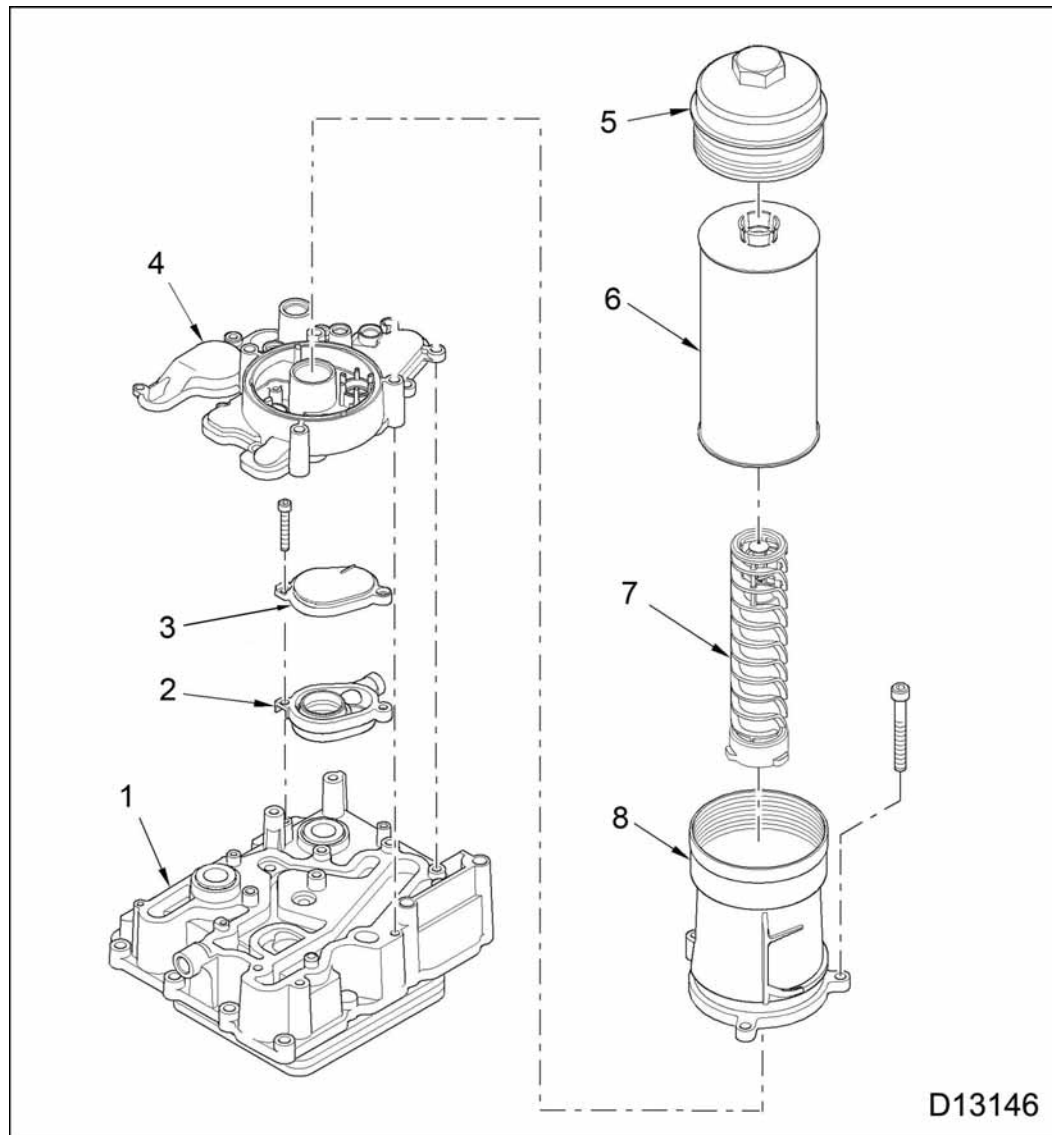


Figure 395 Oil cooler cover and filter housing assembly

1. Oil cooler and cover assembly	4. Oil filter base	7. Oil filter return tube
2. EGR coolant supply port	5. Oil filter cap and O-ring	8. Oil filter housing
3. EGR coolant supply port cover	6. Oil filter element	

Oil Cooler Cover and Oil Filter Base Location Details

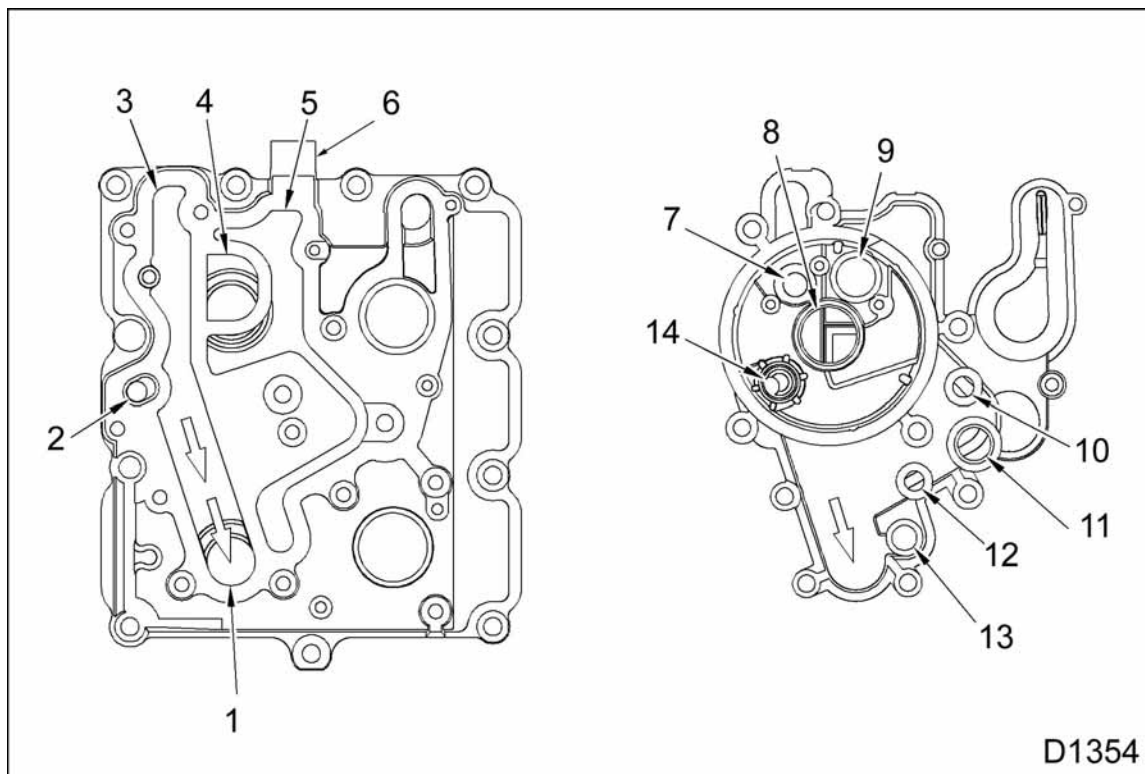


Figure 396 Oil cooler cover and oil filter base

1. Oil cooler inlet (oil)	7. Oil cooler bypass valve	12. Oil pressure sensor port
2. Oil drain to sump	8. Filtered oil to crankcase galleries and other components	13. Oil supply port for air compressor (optional)
3. Unfiltered oil flow from pump	9. Unfiltered oil inlet	14. Oil filter drain to sump
4. Oil cooler outlet (oil)	10. Oil temperature sensor port	
5. Filtered oil to reservoir	11. Turbocharger oil supply port	
6. Oil pressure test port fitting		

Removal

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

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

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

Oil Filter Base Assembly



Figure 397 Oil filter cap

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

1. Remove oil filter cap and filter element. Discard filter element and oil filter cap seal.

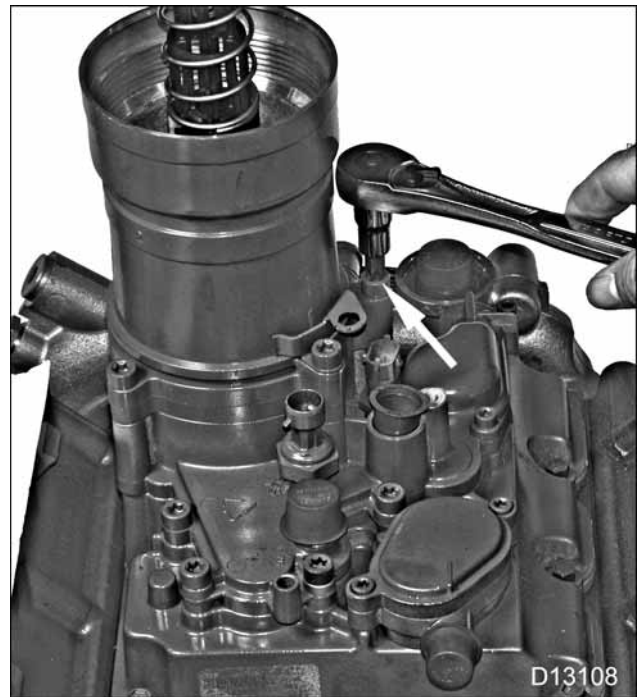


Figure 398 Oil filter housing mounting bolt (4)

2. Remove four M8 x 75 oil filter housing mounting bolts and remove housing. Remove and discard the filter housing base seal.

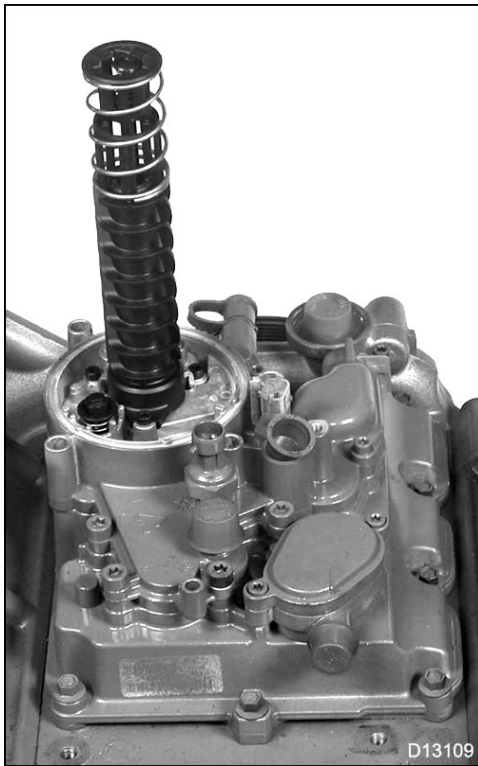


Figure 399 Oil filter return tube

3. To remove the oil filter return tube, loosen lock screw and turn tube counterclockwise and lift up.
4. Remove and discard oil filter return tube gasket.

NOTE: Oil filter base does not have to be removed to remove the oil cooler assembly.



Figure 400 EGR cooler coolant supply port cover bolts

5. Remove EGR cooler coolant supply port cover bolts (2), remove cover, and discard seal.

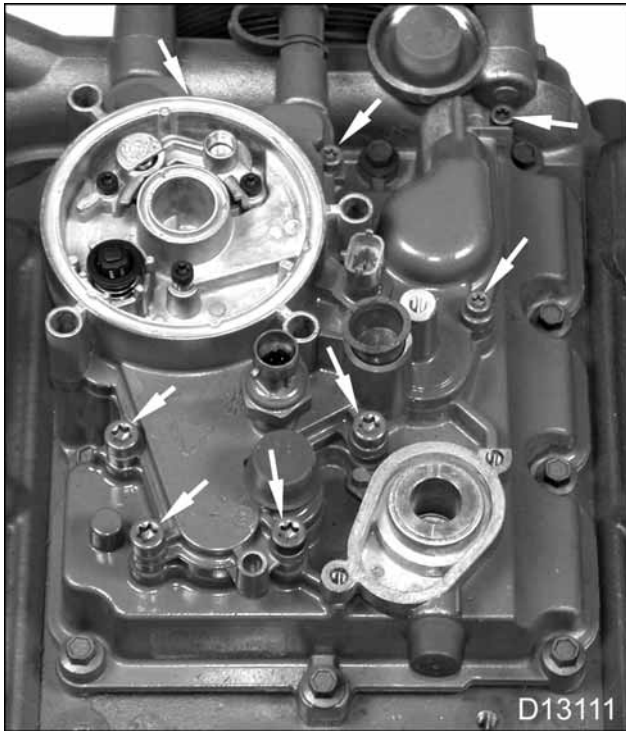


Figure 401 Oil filter base bolts

6. Remove eight mounting bolts from oil filter base assembly.

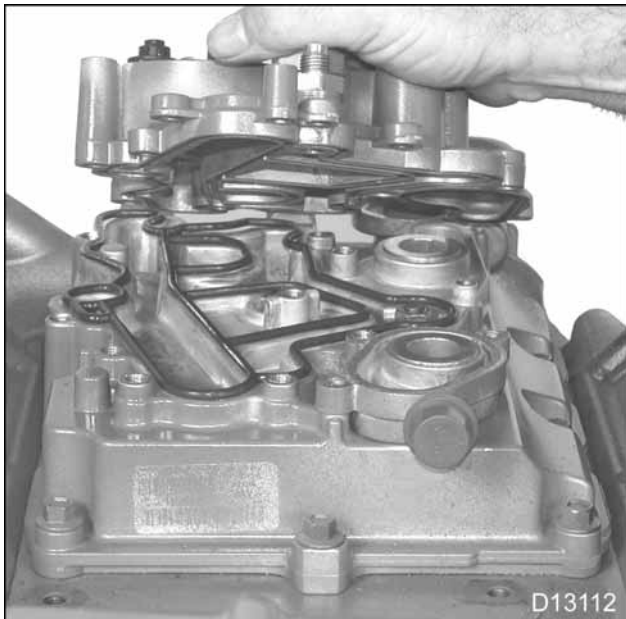


Figure 402 Oil filter base assembly

7. Lift oil filter base assembly off oil cooler cover assembly.
8. Remove and discard gasket.

Oil Cooler Cover Assembly

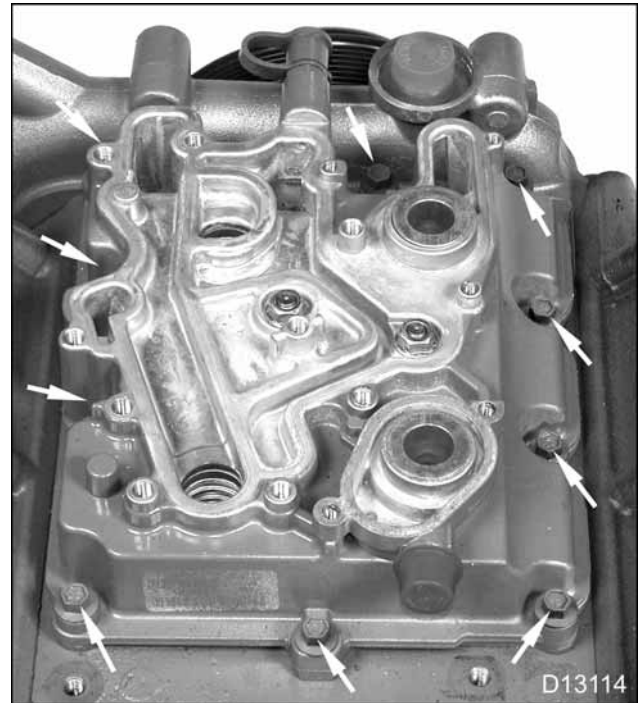


Figure 403 Mounting bolts for oil cooler cover assembly

1. Remove ten M8 x 30 oil cooler cover assembly mounting bolts.

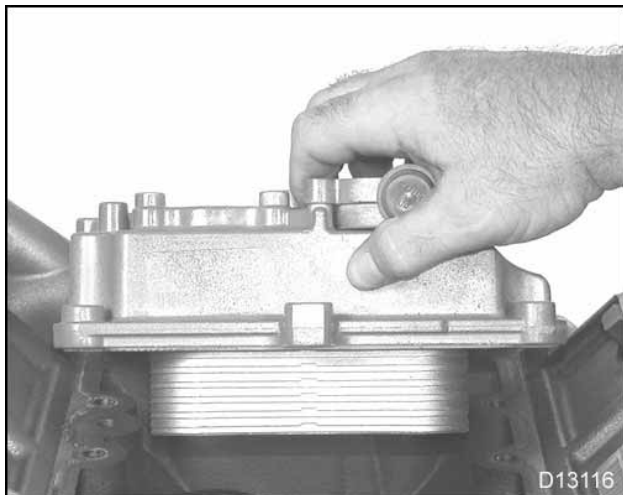


Figure 404 Cooler cover assembly

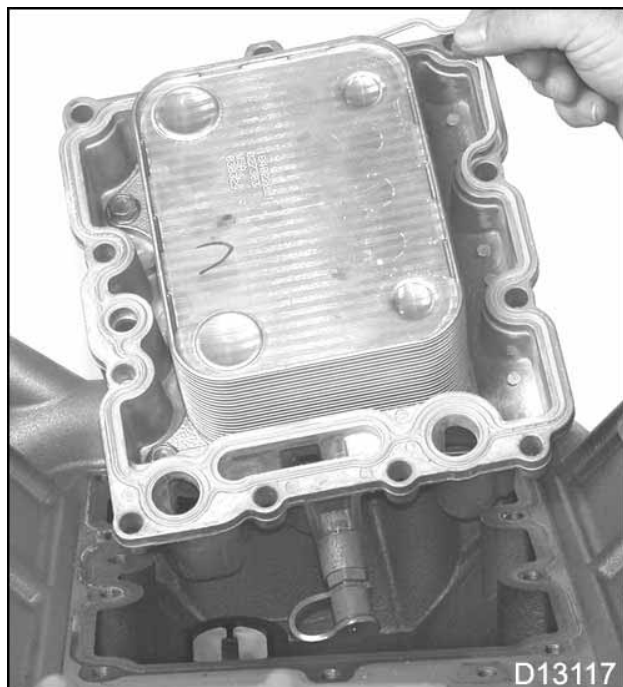


Figure 405 Reservoir cover gasket

2. Remove oil cooler cover assembly from crankcase.
3. Remove and discard reservoir cover gasket.
4. Remove oil from reservoir.

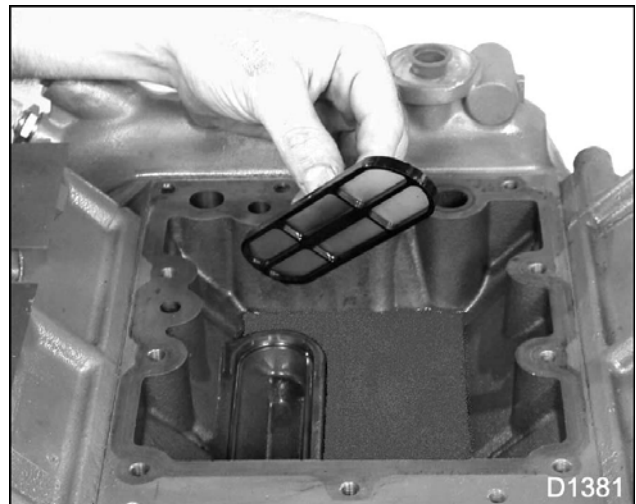


Figure 406 Pump inlet strainer

5. Remove pump inlet strainer from oil reservoir.

Oil Cooler Disassembly

CAUTION: If a catastrophic engine failure occurred, install a new oil cooler cover assembly and oil cooler. Debris cannot be removed from the oil cooler.

NOTE: Do the air pressure leakage test (Oil Cooler Cover Assembly, page 235).

- If the oil cooler test indicates leaking, replace the oil cooler cover assembly and oil cooler. Serviceable parts are not available.

Cleaning, Inspection, and Testing

Oil Cooler Cover and Oil Filter Base Assemblies

1. Drain and flush oil cooler cover, oil filter base, and housing to remove internal residue.

! 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).

2. Dry all components thoroughly with filtered compressed air.

Pump Inlet Strainer

Inspect the pump inlet strainer for tears or damage. Replace if necessary.

Oil Cooler Leaks (Coolant Side)

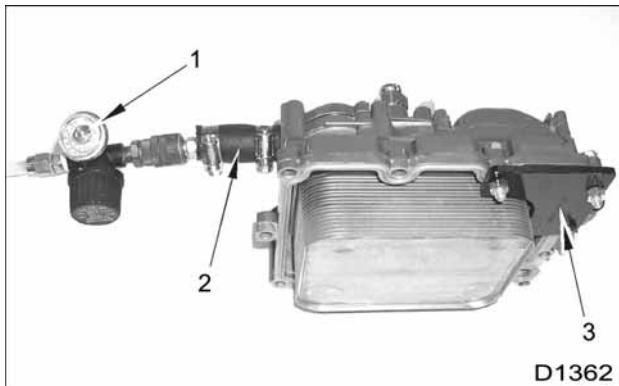


Figure 407 Air pressure leakage test

1. Air pressure regulator
2. Air adapter (make locally)
3. Test plate

NOTE: The oil filter base must be installed on the oil cooler cover assembly before a pressure test can be done.

1. Fasten Oil Cooler Test Plate (Table 25) to oil cooler.
2. Install air pressure gauge to EGR cooler coolant outlet port.

! 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).

3. Apply 207 kPa (30 psi).
4. Spray soapy water around the oil cooler and oil filter base.

CAUTION: To prevent engine damage, do not submerge the oil cooler in water. Submerging could allow water to be introduced into oil passages, causing engine damage during initial startup.

5. If leaking, bubbles will be seen between the oil cooler and cover. Replace assembly as required.
6. Remove soapy water residue and blow off with compressed air.

Installation

Oil Cooler Cover Assembly

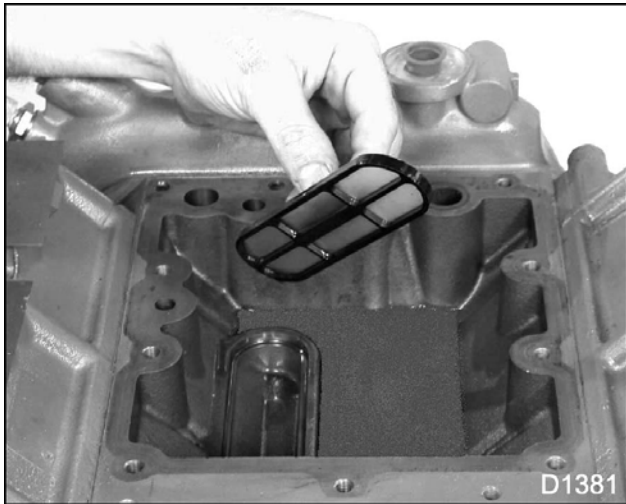


Figure 408 Pump inlet strainer (150 micron)

1. Install a clean pump inlet strainer in the oil reservoir.
2. Make sure dirt, sludge or debris does not restrict oil flow from crankcase to high-pressure oil pump.



Figure 409 Reservoir cover gasket

3. Add oil to correct level in oil reservoir.
4. Install a new reservoir cover gasket in the oil cooler cover assembly.

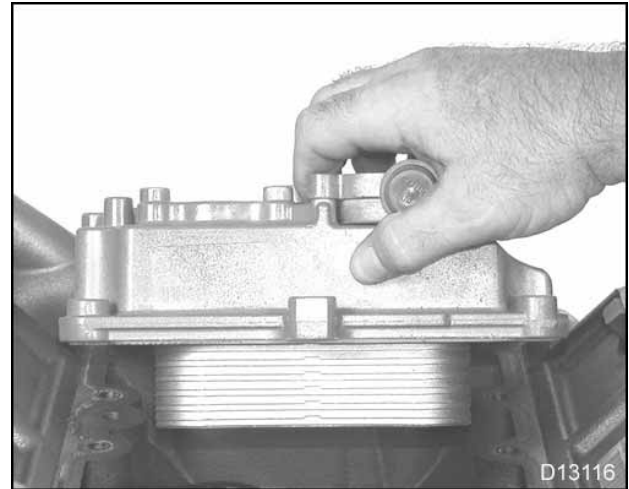


Figure 410 Oil cooler cover assembly

5. Lower oil cooler cover assembly on engine crankcase.



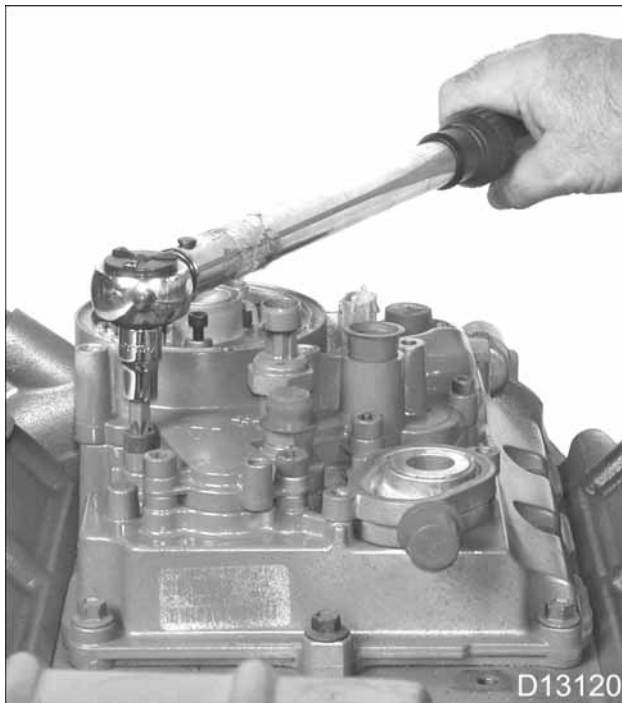
Figure 411 Mounting Bolts for oil cooler cover assembly

6. Install ten M8 x 30 oil cooler cover assembly mounting bolts. Tighten oil cooler cover assembly mounting bolts to the special torque (Table 24).

Oil Filter Base Assembly**Figure 412 Oil Filter Base Assembly Gasket**

1. Install a new gasket set on the oil filter base.
2. Install a new oil filter return tube gasket and filter housing to base seal. Coat gaskets and seals with clean engine oil.

3. Install oil filter base on oil cooler cover assembly.

**Figure 413 Oil filter base bolts**

4. Install five M8 x 23 bolts, and three M6 x 23 oil filter base assembly bolts. Tighten all oil filter base assembly bolts to the special torque (Table 24).



Figure 414 Cover gasket for coolant supply port in EGR cooler

5. Install a new gasket in coolant supply port for EGR cooler and secure with two M6 x 23 bolts.



Figure 415 Cover bolts for coolant supply port of EGR cooler

6. Tighten cover bolts to the special torque (Table 24).



Figure 416 Oil filter return tube gasket

7. Install new oil filter return tube gasket.

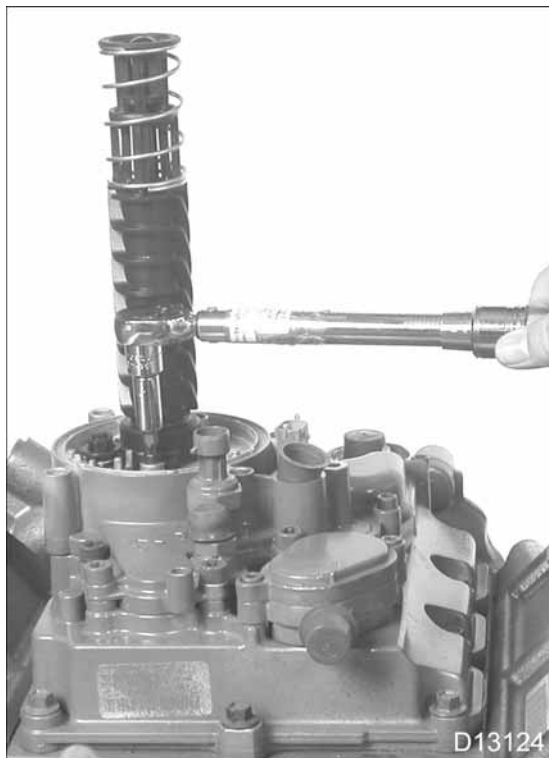


Figure 417 Oil filter return tube



Figure 418 Oil filter housing gasket

8. Install oil filter return tube by pushing in and rotating clockwise to lock in place, while aligning hold down tab with bolt hole in oil filter base. Tighten M5 x 18 lock screw to the special torque (Table 24).

9. Install new oil filter housing gasket.



Figure 419 Oil filter housing mounting bolts

10. Install oil filter housing and four M8 x 75 Oil filter housing mounting bolts. Tighten bolts to the special torque (Table 24).



Figure 420 Oil filter and cap

11. Install oil filter on cap with new seal and thread assembly in oil filter housing. Tighten cap to the special torque (Table 24).
12. Reinstall all safety guards, shields, and covers.
13. Make sure all tools, cleanliness covers, loose parts, and service equipment are removed from the engine work area.

CAUTION: To prevent engine damage, add oil to the engine before starting. See *Engine Operation and Maintenance Manual* for the engine oil and filter service interval. Correct maintenance will prolong service life.

CAUTION: Correct oil viscosity for diesel engines is important for satisfactory operation, especially in cold weather. See chart in the *Engine Operation and Maintenance Manual* to determine which oil viscosity is best suited for the expected temperature range.

14. Fill crankcase with oil. See *Engine Operation and Maintenance Manual* for correct refill capacity.

NOTE: Engine fluids (oil, fuel and coolant) are a threat to the environment. Do not put engine fluids in the trash, pour fluids on the ground, in sewers or bodies of water.

15. Start the engine and check for leaks. Fix leaks if necessary.
16. Shut down engine and check engine oil level. Add or drain oil to bring oil level to the FULL mark on oil level gauge. Do not overfill past the FULL mark.

Specifications

Table 23 Oil Cooler and Oil Filter

Oil Cooler	
Type	Full flow, fin
Location	Engine valley (forward)
Oil Filter	
Type	Cartridge, full flow - disposable
Location	Front, oil cooler mounted
Filter bypass location	Oil filter return tube assembly

Special Torque

Table 24 Oil Cooler and Oil Filter

EGR cooler coolant supply port cover (M6)	10 +1/-2 N·m (84 ± 12 lbf·in)
Oil cooler mounting bolts (M6 x 23)	10 +1/-2 N·m (84 ± 12 lbf·in)
Oil cooler cover mounting bolts (M8 x 23)	22 ± 2 N·m (17 ± 1 lbf·ft)
Oil filter housing mounting bolts (M8 x 75)	22 ± 2 N·m (17 ± 1 lbf·ft)
Oil filter return tube bolt	New base plate: 6 N·m (50 lbf·in)
	Reinstallation: 3 N·m (23 lbf·in)
Oil filter cap	25 N·m (18 lbf·ft)

Special Service Tools

Table 25 Oil Cooler

Description	Tool Number
Magnetic Cover	ZTSE4557
Oil Cooler Pressure Test Plate	ZTSE4525

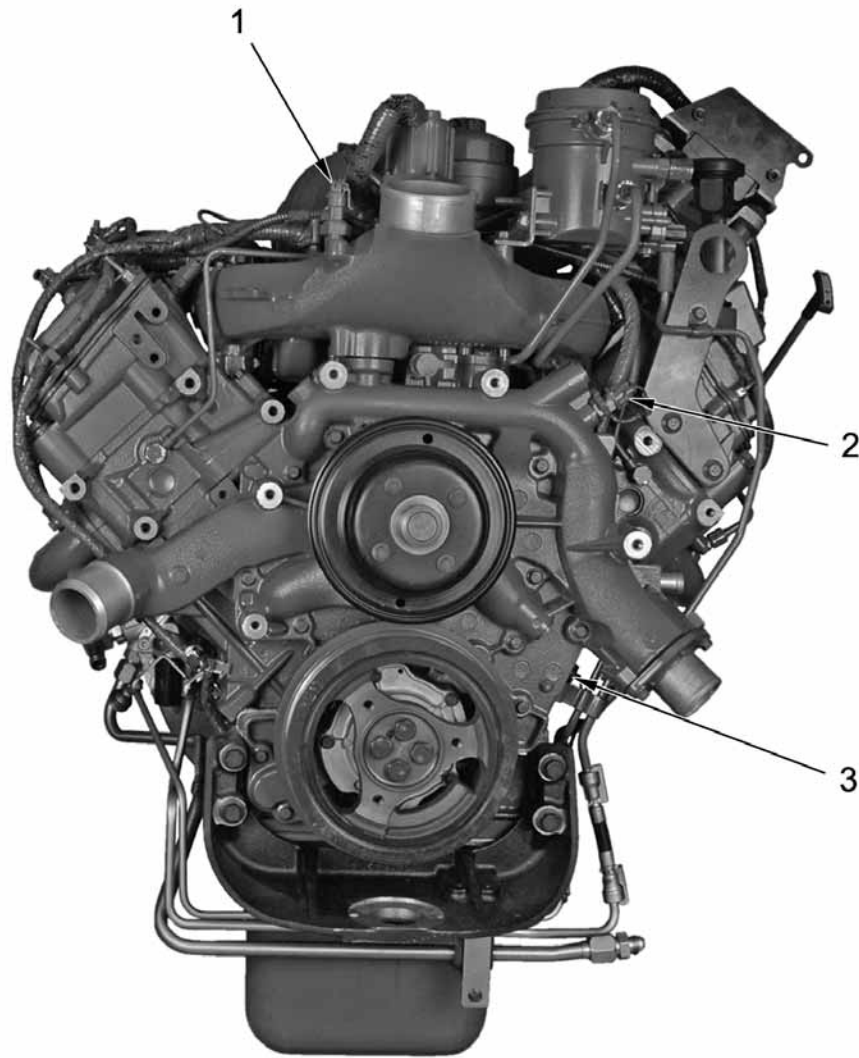
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Engine Electronic Components

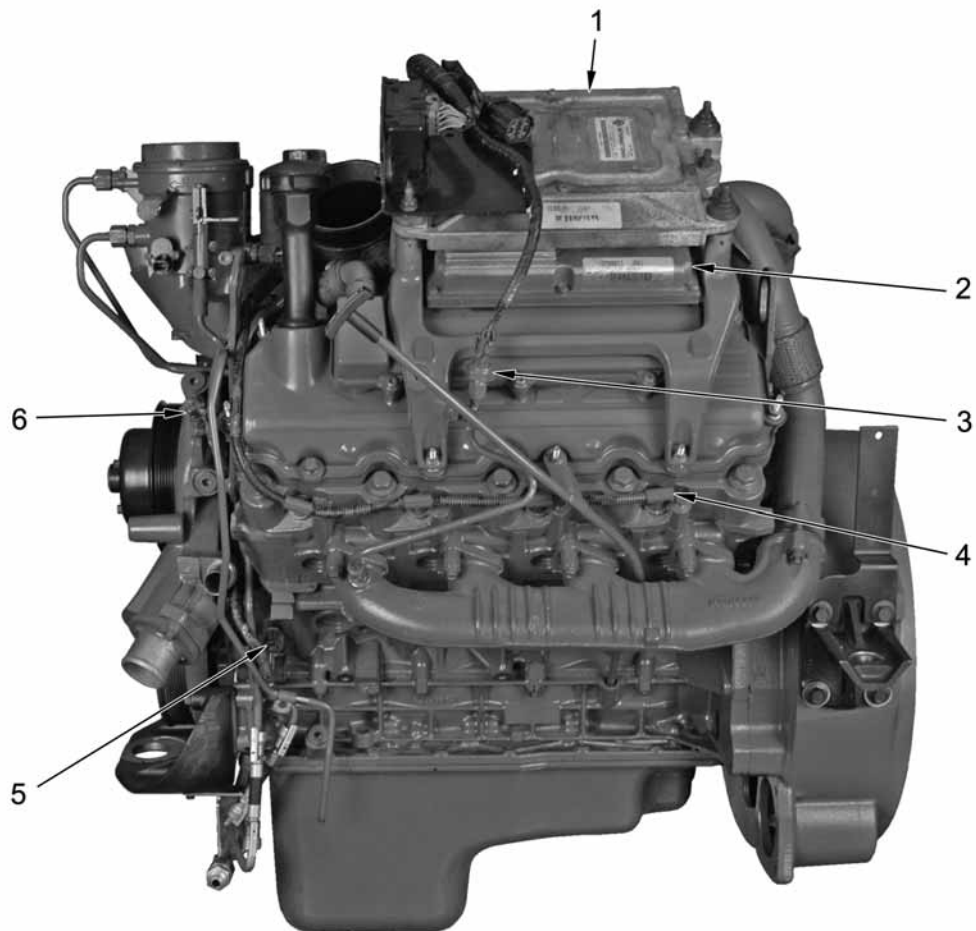
Electronic Components – Front



D31500

Figure 421 Electronic components – Front

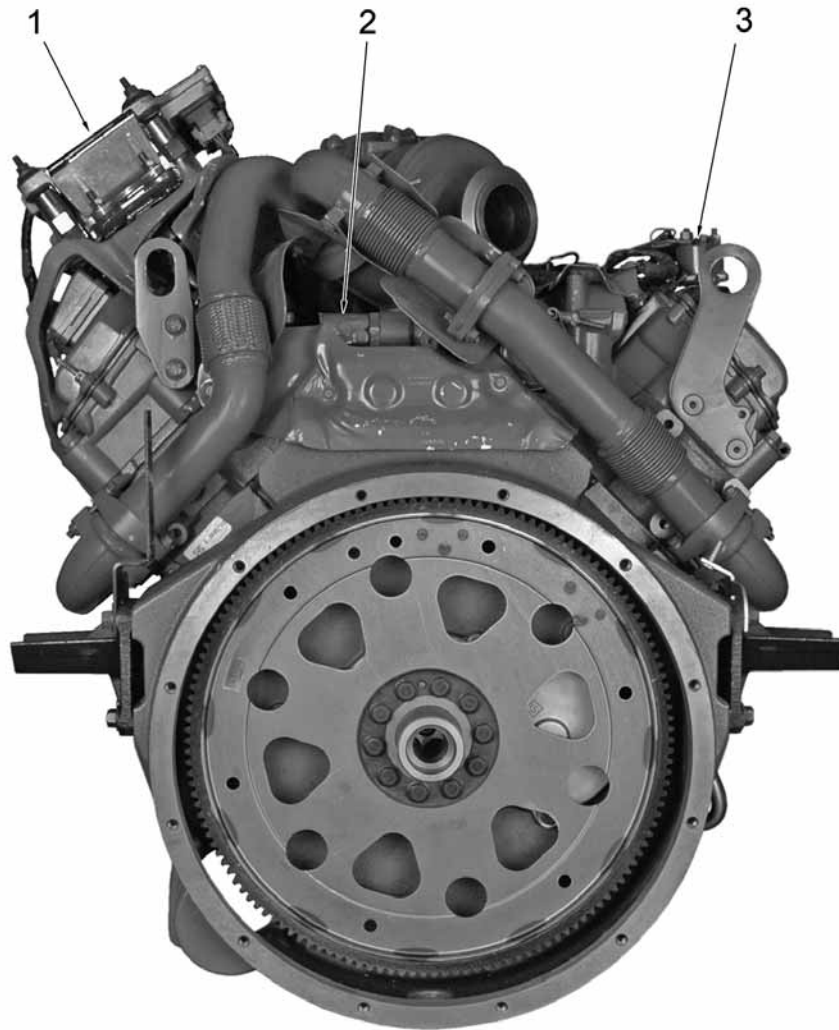
1. Manifold Absolute Pressure (MAP) sensor	2. Engine Coolant Temperature (ECT) sensor	3. Camshaft Position (CMP) sensor

Electronic Components – Left

D31488

Figure 422 Electronic components – Left

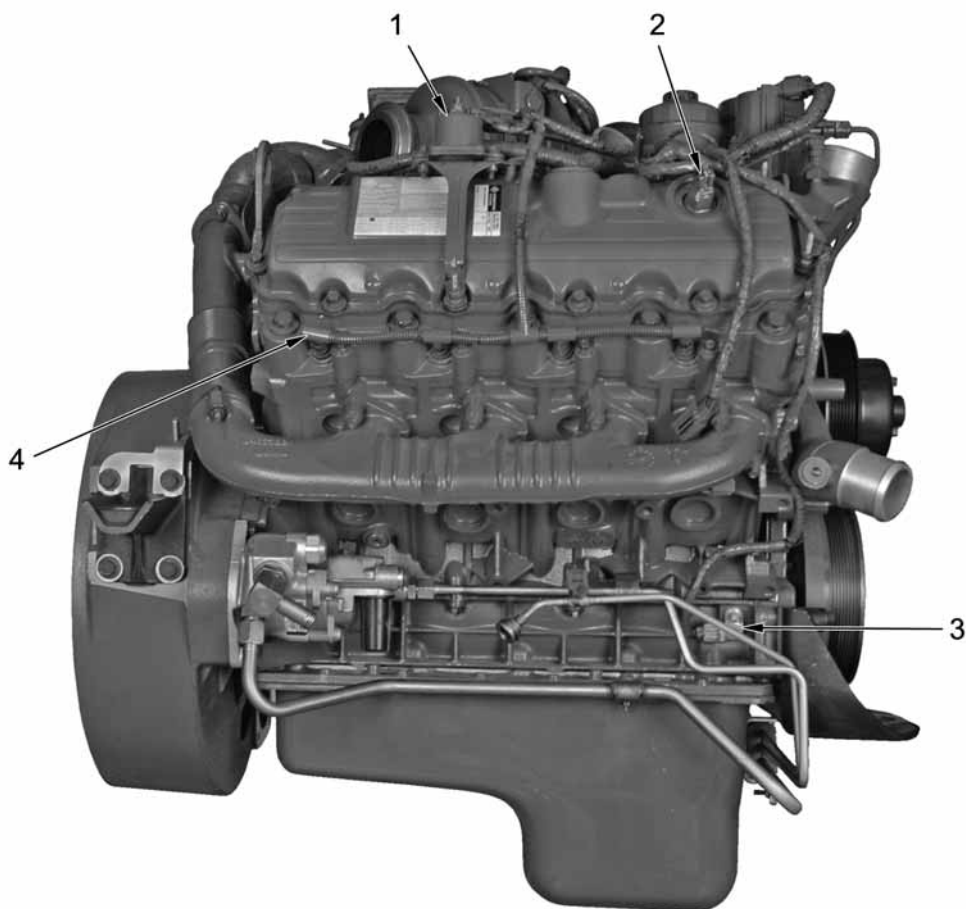
1. Electronic Control Module (ECM)	3. Exhaust Back Pressure (EBP) sensor	5. Camshaft Position (CMP) sensor
2. Injector Driver Module (IDM)	4. Glow plug harness	6. Engine Coolant Temperature (ECT) sensor

Electronic Components – Rear

D31501

Figure 423 Electronic components – Rear

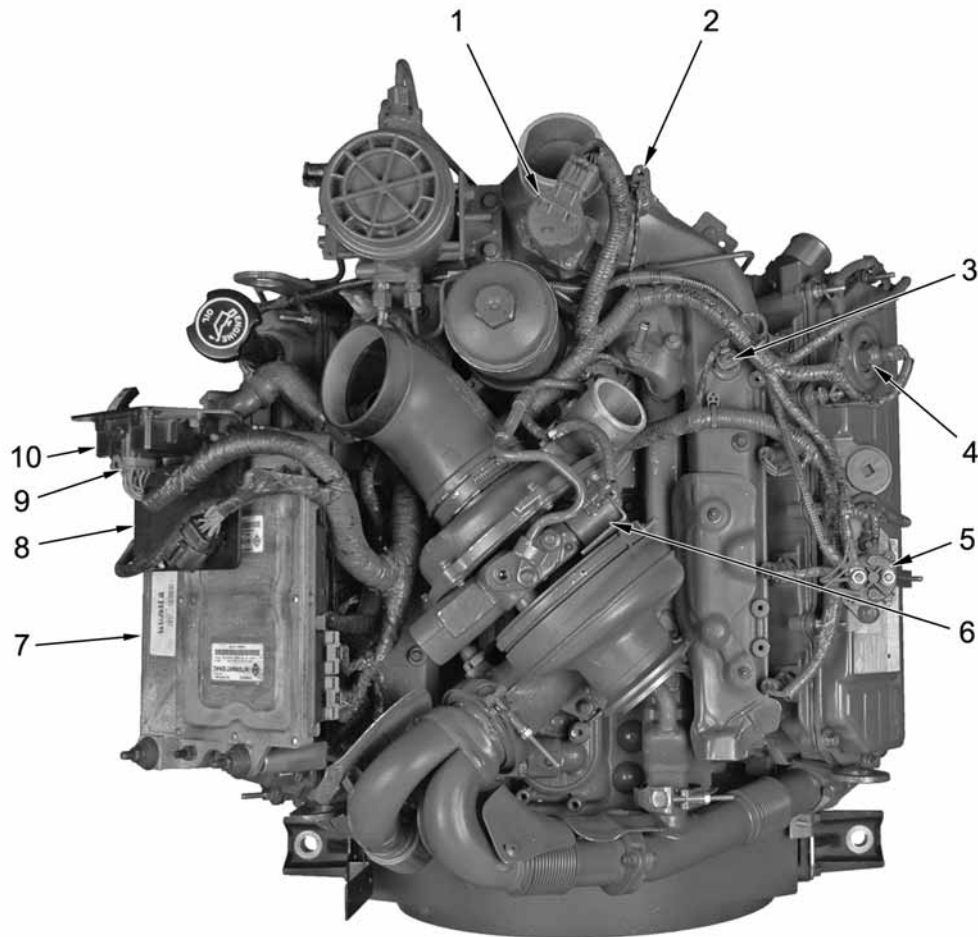
1. Electronic Control Module (ECM) and Injector Driver Module (IDM)	2. Injection Pressure Regulator (IPR) valve	3. Glow plug relay

Electronic Components – Right

D31487

Figure 424 Electronic components – Right

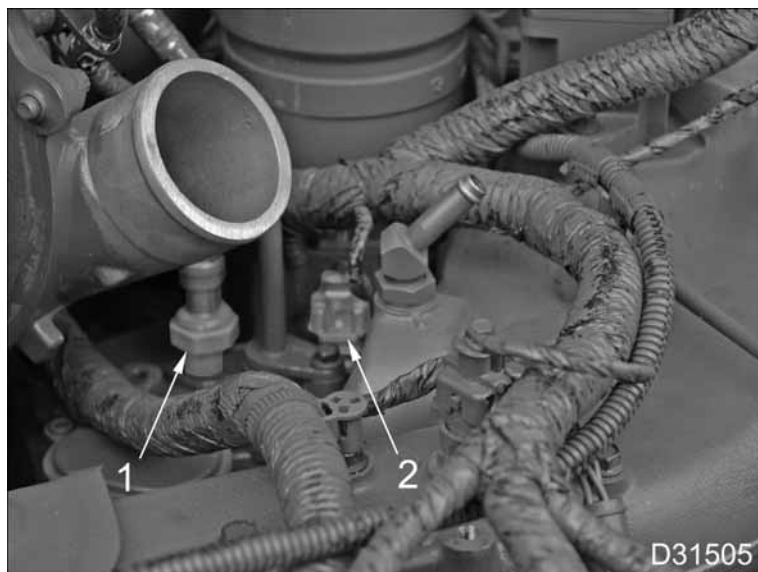
1. Glow plug relay	3. Crankshaft Position (CKP) sensor
2. Injector Control Pressure (ICP) sensor	4. Glow plug harness

Electronic Components – Top

D31486

Figure 425 Electronic components – Top

1. Exhaust Gas Recirculation (EGR) valve	5. Glow plug relay	9. Connector to (EGR) control module
2. Manifold Absolute Pressure (MAP) sensor	6. Variable Geometry Turbocharger (VGT) control valve	10. EGR control module
3. Manifold Air Temperature (MAT) sensor	7. Electronic Control Module (ECM)	
4. Injection Control pressure (ICP) sensor	8. Mounting bracket for EGR control module	

Electronic Components – Top (detail)**Figure 426 EOT and EOP sensors – Top**

1. Engine Oil Pressure (EOP) sensor	2. Engine Oil Temperature (EOT) sensor

Description of Engine Sensors and Valves

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

- EGES-240-1 VT 365 *Engine Diagnostic Manual*
- EGED-245 VT 365 Hard Start/No Start Diagnostic Form
- EGED-250 VT 365 Engine Performance Diagnostic Form
- EGED-320-1 VT 365 Electronic Control System Diagnostic Form

Crankshaft Position (CKP) Sensor



Figure 427 CKP sensor

The CKP sensor, a magnetic pickup sensor, reads a timing disk on the crankshaft.

The CKP sensor provides the ECM with a signal that indicates crankshaft speed and position. As the crankshaft turns the CKP sensor detects a 60 tooth timing disk on the crankshaft. Teeth 59 and 60 are missing. By comparing the CKP signal with the CMP signal, the ECM calculates engine rpm and timing requirements.

The CKP is installed in the front right side of the lower crankcase.

Camshaft Position (CMP) Sensor



Figure 428 CMP sensor

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

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

The CMP sensor is installed in the front left side of the crankcase.

Exhaust Back Pressure (EBP) Sensor

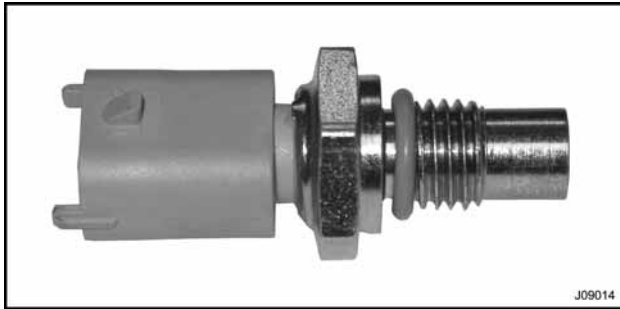


Figure 429 EBP sensor

The EBP sensor, a ceramic diaphragm sensor, measures exhaust back pressure before the turbocharger.

The EBP sensor provides feedback to the ECM for closed loop control of the VGT and for EGR position calculations.

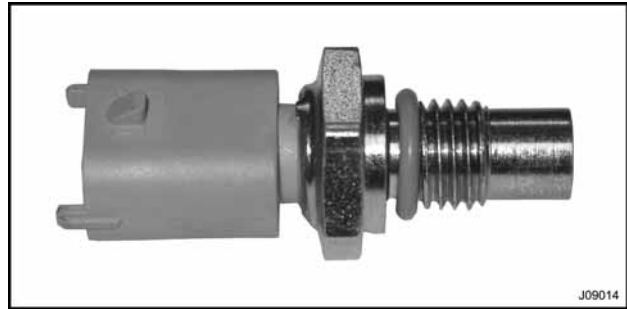
The EBP sensor is mounted on a bracket on the left side of the engine below the ECM.

Engine Coolant Temperature (ECT) Sensor**Figure 430 ECT sensor**

The ECT sensor, a thermistor sensor, detects engine coolant temperature.

The ECT signal is monitored by the ECM for operation of the instrument panel temperature gauge, coolant temperature compensation, optional Engine Warning Protection System (EWPS), glow plugs, and the wait to start lamp. The ECM will use ECT sensor input as a backup, if EOT sensor values are out of range.

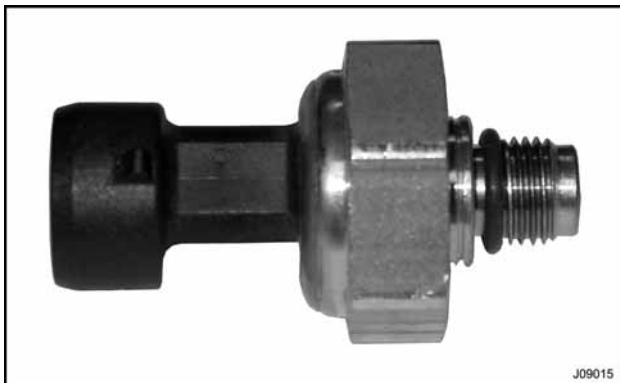
The ECT sensor is installed in the left side of the front cover.

Engine Oil Temperature (EOT) Sensor**Figure 432 EOT sensor**

The EOT sensor, a thermistor sensor, detects engine oil temperature.

The EOT signal is monitored by the ECM to control EGR, VGT, and for engine fueling calculations throughout the operating range of the engine. The EOT signal allows the ECM and IDM to compensate for differences in oil viscosity, due to temperature changes.

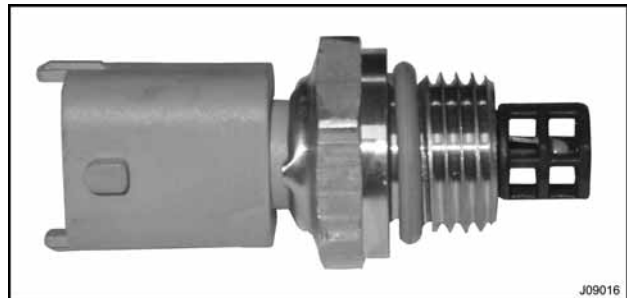
The EOT sensor is installed in the oil filter base.

Engine Oil Pressure (EOP) Sensor**Figure 431 EOP sensor**

The EOP sensor, a ceramic diaphragm sensor, detects engine oil pressure.

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

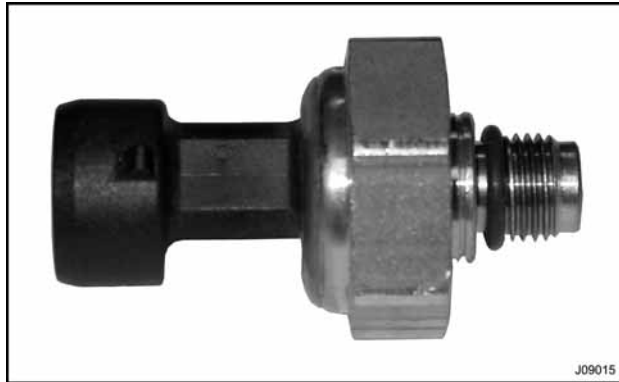
The EOP sensor is installed in the oil filter base.

Manifold Air Temperature (MAT) Sensor**Figure 433 MAT sensor**

The MAT sensor, a thermistor sensor, detects intake manifold air temperature.

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

The MAT sensor is installed in the right front of the intake manifold.

Manifold Absolute Pressure (MAP) Sensor**Figure 434 MAP sensor**

The MAP sensor, a ceramic diaphragm sensor, detects intake manifold boost pressure.

The MAP signal is monitored by the ECM for EGR position and engine fueling calculations.

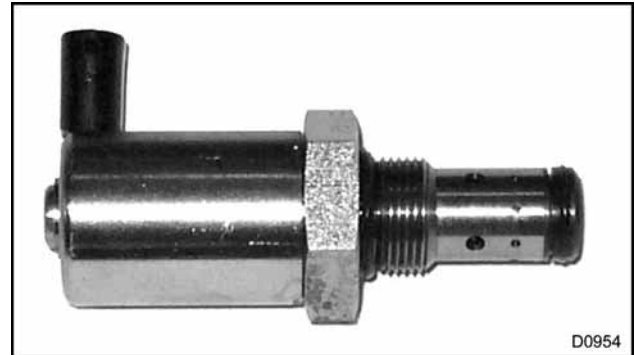
The MAP sensor is installed in the top front of the intake manifold.

Injection Control Pressure (ICP) Sensor**Figure 435 ICP sensor**

The ICP sensor, a micro-strain gauge sensor, measures injection control pressure.

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

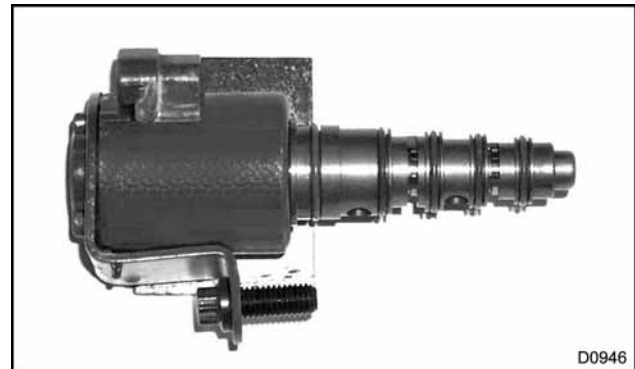
The ICP sensor is installed in the right high-pressure oil rail.

Injection Pressure Regulator (IPR) Valve**Figure 436 IPR valve**

The IPR valve, a variable position Pulse Width Modulated (PWM) valve, regulates injection control pressure, which actuates the fuel injectors.

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

The IPR valve is installed in the left rear side of the high-pressure oil pump.

Variable Geometry Turbocharger (VGT) Control Valve**Figure 437 VGT control valve**

The VGT control valve, a variable position duty cycle valve, controls turbocharger vane position.

The VGT valve is controlled by a pulse width modulated signal from the ECM in response to engine speed, required fuel quantity, boost, exhaust

back pressure, and altitude. Engine lube oil pressure is used to control the movement of vanes linked by a unison ring within the turbine housing. Turbine exhaust gas flow and VGT boost are modified by vane position. The ground circuit is supplied directly from battery ground at all times.

The VGT control valve is installed in the top right side of the VGT.

Exhaust Gas Recirculation (EGR) Valve

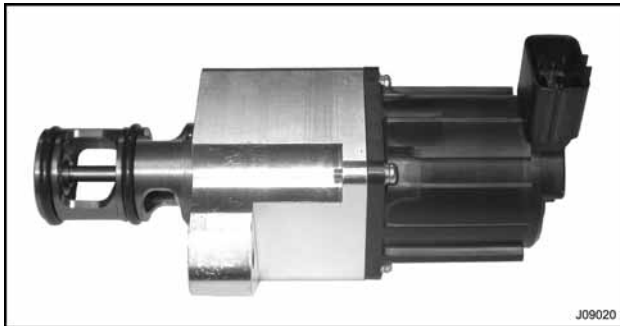


Figure 438 EGR Valve

The EGR valve, an electromechanical valve, recirculates cooled exhaust gases into the intake air stream to reduce NOx emissions.

The EGR valve has three major components: a two head valve assembly, a DC motor, and an Integrated Circuit (IC). The IC has three Hall effect position sensors that monitor valve movement.

The EGR valve is installed in the front of the intake manifold behind the air inlet.

The EGR drive module receives the desired EGR valve position from the ECM across the CAN 2 datalink to activate the EGR valve for exhaust gas recirculation. The EGR drive module provides feedback to the ECM on the valve position, interprets the ECM command, and sends the command using three pulse width modulated signals to the DC motor.

The EGR drive module is mounted on the EGR drive module mounting bracket above the ECM/IDM assembly.

Removal

Camshaft Position (CMP) Sensor

! 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.

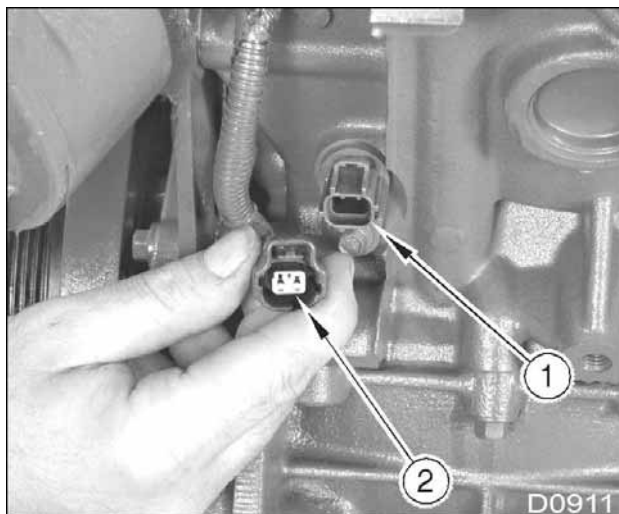


Figure 439 CMP sensor

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

Crankshaft Position (CKP) Sensor

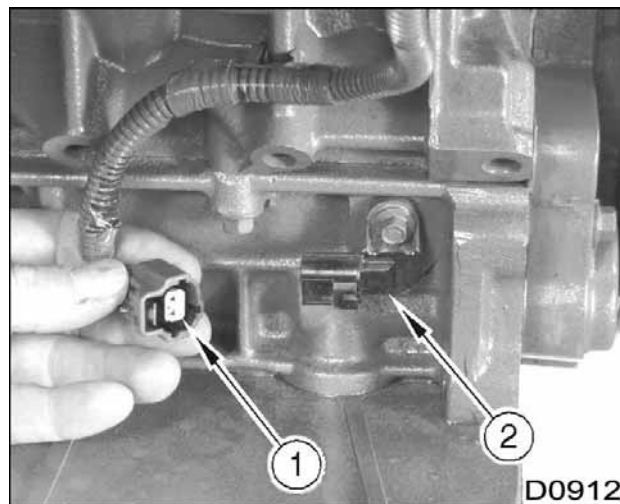


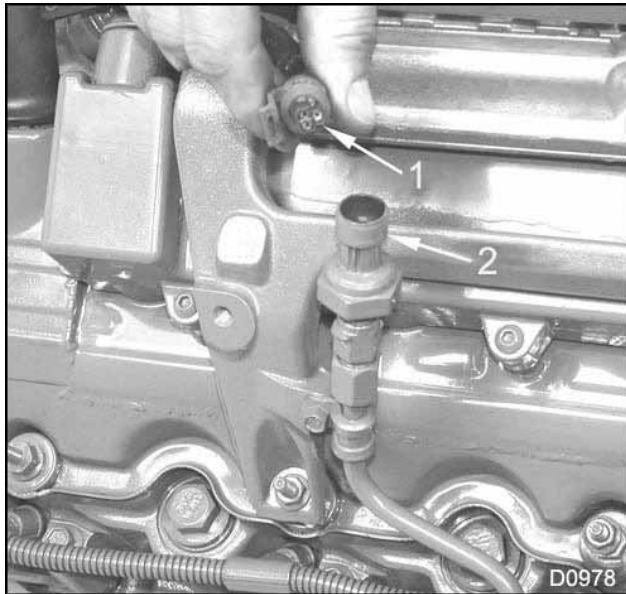
Figure 440 CKP sensor

1. Sensor connector
 2. CKP sensor
1. Disconnect 2-pin electrical connector from the CKP sensor installed in the front right side of the lower crankcase.

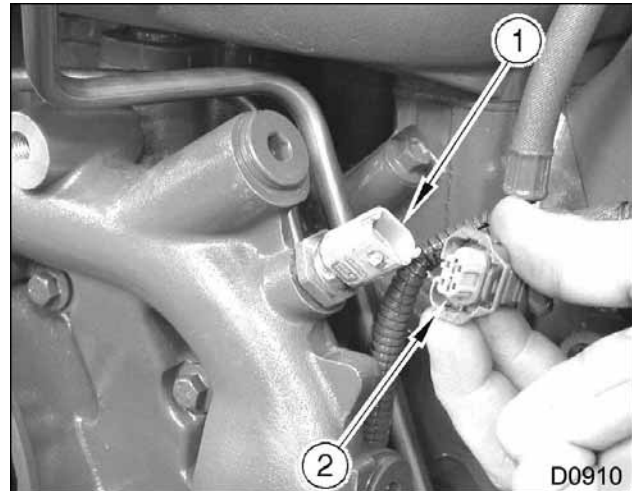


Figure 441 CKP sensor

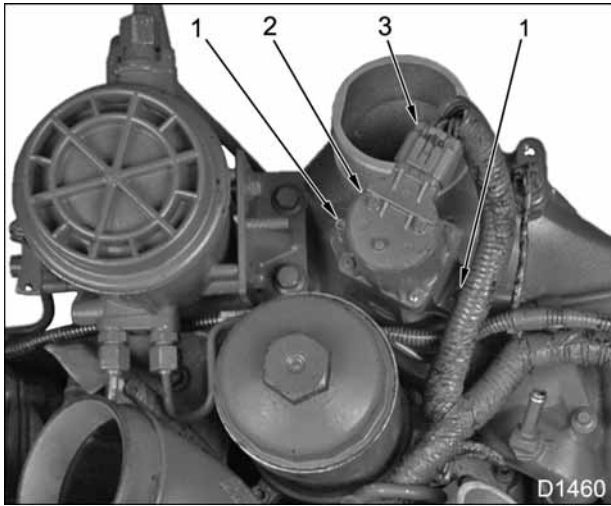
2. Remove the M6 x 14 retaining bolt from the CKP sensor.
3. Remove CKP sensor and discard O-ring.

Exhaust Back Pressure (EBP) Sensor**Figure 442 EBP sensor**

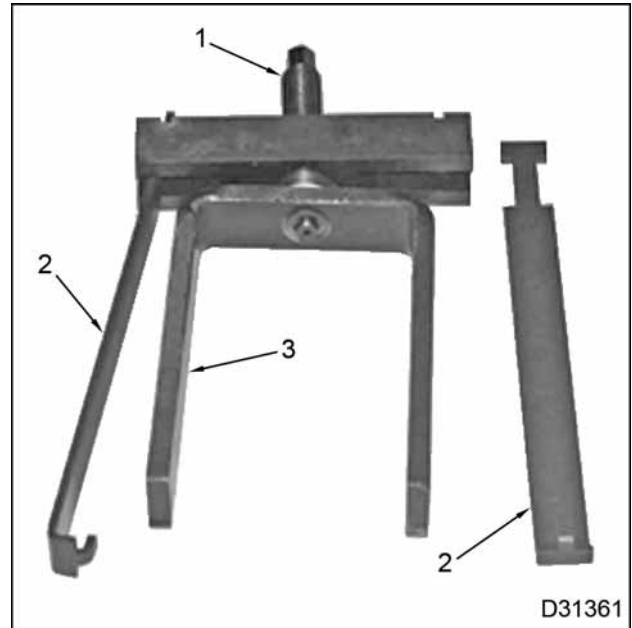
1. EBP sensor
 2. EBP sensor connector
1. Disconnect the 3-pin electrical connector from the EBP sensor mounted on the left side of the engine below the ECM.
 2. Remove EBP sensor.

Engine Coolant Temperature (ECT) Sensor**Figure 443 ECT sensor**

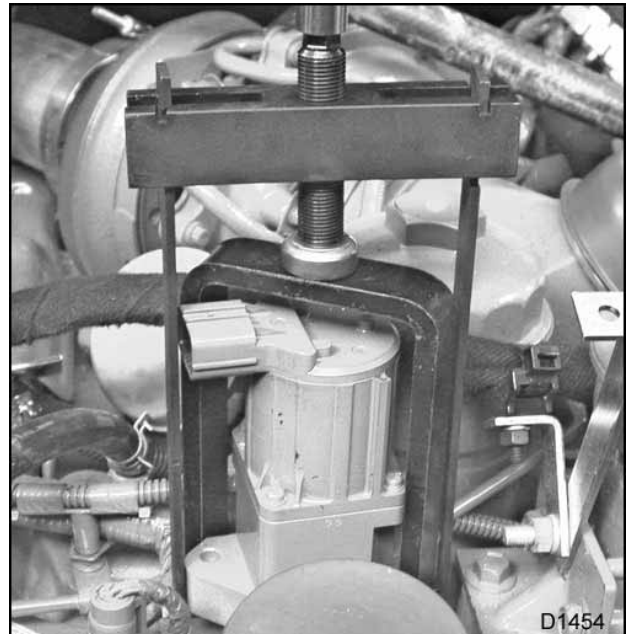
1. ECT sensor
 2. ECT sensor connector
1. Disconnect the 2-pin electrical connector from the ECT sensor installed in the left side of the front cover.
 2. Remove ECT sensor and discard O-ring.

Exhaust Gas Recirculation (EGR) Valve**Figure 444 Removal of mounting bolts for EGR valve**

1. M6 x 35 bolt (2)
 2. EGR valve
 3. 8-pin Electrical connector
1. Disconnect the 8-pin electrical connector from the EGR valve.
 2. Remove two M6 x 35 EGR valve retaining bolts.
 3. Turn the EGR valve counterclockwise.

**Figure 445 EGR Valve Puller**

1. Screw
 2. J arm with tab
 3. Puller legs
4. Install the EGR valve puller (Table 28).

**Figure 446 EGR valve puller installed**

5. Slip the pin of each J arm under and in the bolt hole of the EGR mounting flange and hook the top end in the puller beam.
6. Position the puller legs over the EGR bolt holes in the intake manifold.



Figure 447 Removal of EGR valve

7. Turn threaded shaft clockwise to remove EGR valve.

CAUTION: To prevent engine damage, after removing the EGR valve only, vacuum out deposits and debris inside the intake manifold.

8. Remove three O-rings.

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

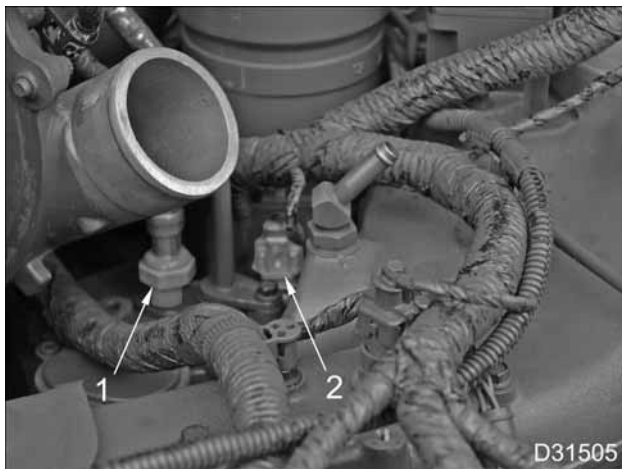


Figure 448 EOT and EOP sensors

1. EOP sensor
2. EOT sensor

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

Variable Geometry Turbocharger (VGT) Control Valve

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

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

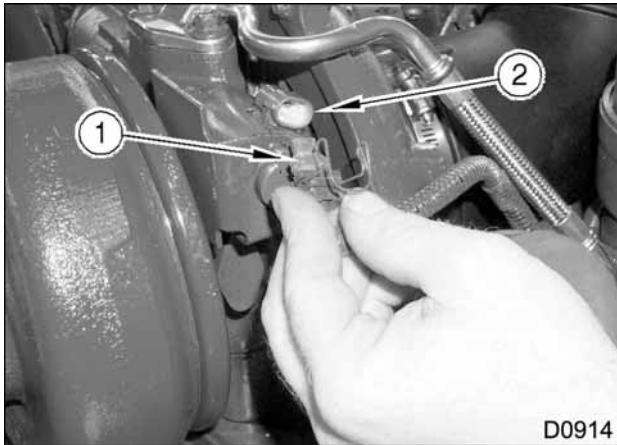


Figure 449 Turbocharger control valve

1. Turbocharger electrical connector
2. Turbocharger harness connection

1. Disconnect electrical connector from VGT control valve.

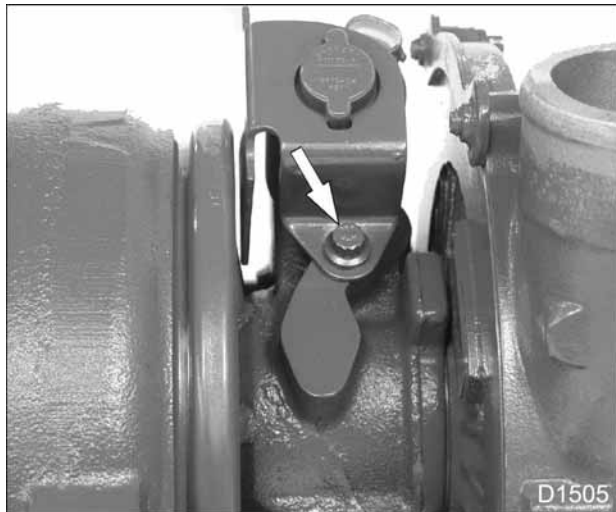


Figure 450 VGT control valve retaining bolt

2. Remove the M8 x 20 retaining bolt and bracket.



Figure 451 VGT control valve removed

3. Pull VGT control valve straight out from center housing.

Injection Pressure Regulator (IPR) Valve

NOTE: Some engines have a metal heat shield mounted over the IPR valve; others have an insulated snap cover on the IPR valve solenoid.

1. Remove three rear mounting bolts from exhaust heat shield and two bolts from heat shield for IPR valve (if installed).
2. Remove the insulated snap cover from IPR valve (if installed).

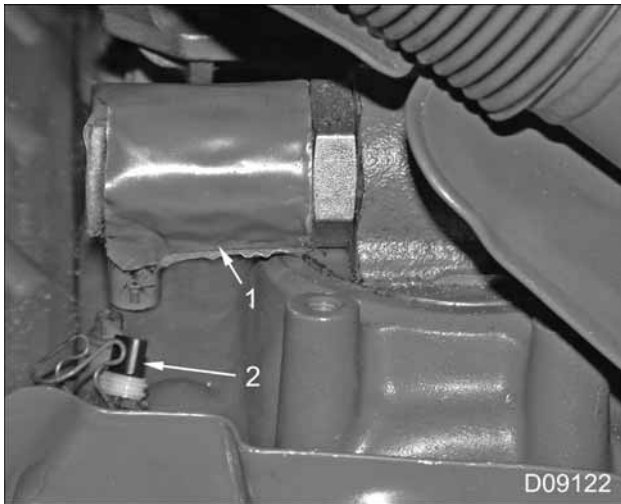


Figure 452 IPR valve

1. IPR valve
2. Engine harness connector
3. Disconnect engine harness connector from IPR valve.

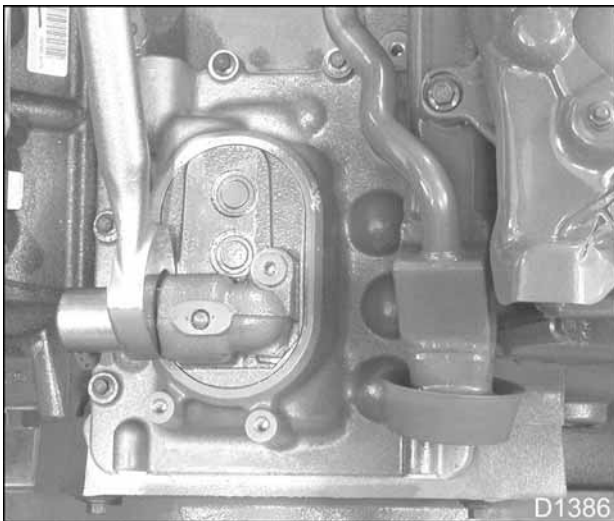


Figure 453 IPR valve removal

4. Remove IPR valve from top of the high-pressure pump.

5. Remove and discard body O-ring, end O-ring, and backup ring.

Injection Control Pressure (ICP) Sensor



Figure 454 Electrical connector removed from ICP sensor

1. Disconnect electrical connector from ICP sensor.



Figure 455 ICP sensor removal

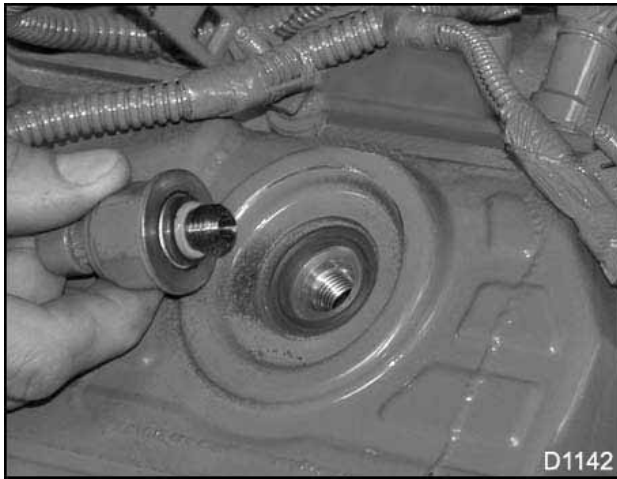


Figure 456 ICP sensor removed

2. Loosen and remove the ICP sensor from the right high pressure oil rail.
3. Remove O-ring from ICP sensor and discard O-ring.

NOTE: The ICP sensor may be removed before or after removing the right valve cover. The valve cover seal ring for the ICP sensor (under the valve cover) can be removed only after removing valve cover. If the ICP sensor is removed, for replacement or troubleshooting, the valve cover seal ring can be reused.



Figure 457 Valve cover seal ring for ICP

1. Oil rail ICP sensor opening
2. Valve cover seal ring

4. Remove and discard valve cover seal ring (if the valve cover is being or has been removed).

Manifold Absolute Pressure (MAP) Sensor

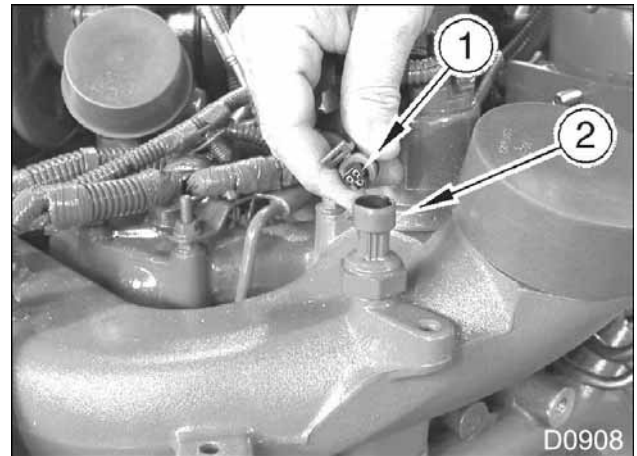


Figure 458 MAP sensor

1. MAP sensor connector
2. MAP sensor

1. Disconnect 3-pin electrical connector from the MAP sensor installed on top of the intake manifold.
2. Remove MAP sensor and discard O-ring.

Manifold Air Temperature (MAT) Sensor

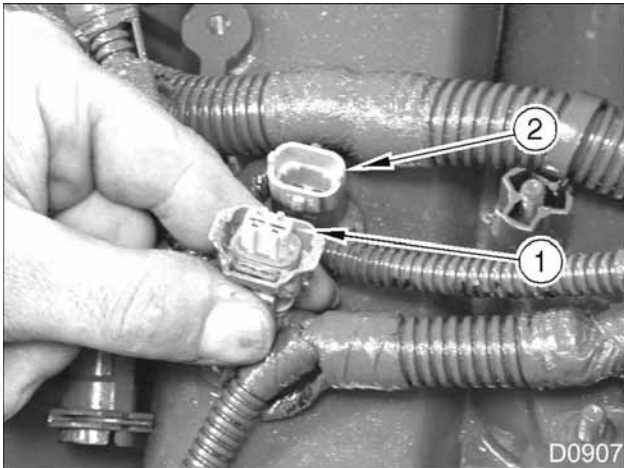


Figure 459 MAT sensor

1. MAT sensor connector
 2. MAT sensor
1. Disconnect 2-pin electrical connector from the MAT sensor installed in the right side of the intake manifold.
 2. Remove MAT sensor and discard O-ring.

ECM, IDM, and Mounting Bracket

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

1. Disconnect ground (-) terminal cable from battery.

NOTE: The ECM and IDM assembly can be removed without removing the support bracket.

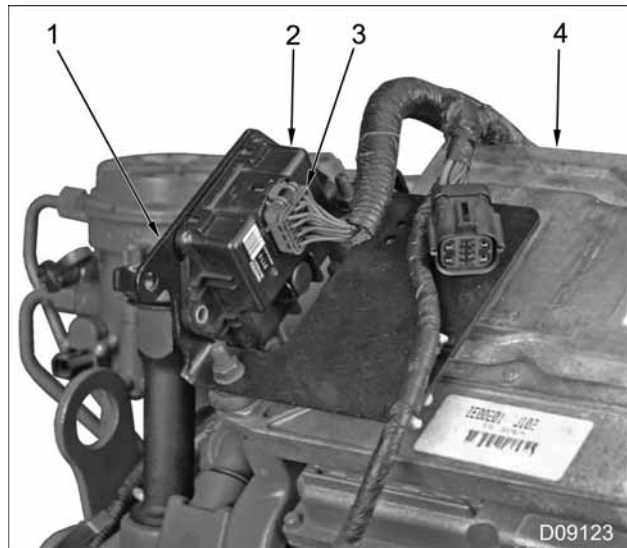


Figure 460 EGR drive module and ECM

1. EGR drive module mounting bracket
 2. EGR drive module
 3. EGR drive module electrical connector
 4. Electronic Control module (ECM)
2. Disconnect EGR drive module electrical connector.
 3. Remove nuts holding EGR drive module mounting bracket and remove mounting bracket.
 4. Remove four mounting bolts that secure ECM and IDM assembly to support bracket.



Figure 461 ECM harness connectors

5. Lift assembly and remove four ECM harness connections (two for engine and two for chassis).

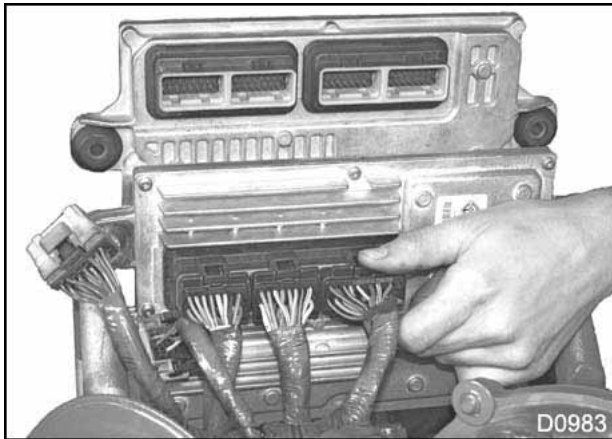


Figure 462 IDM harness connectors

6. Remove three harness connectors from IDM.

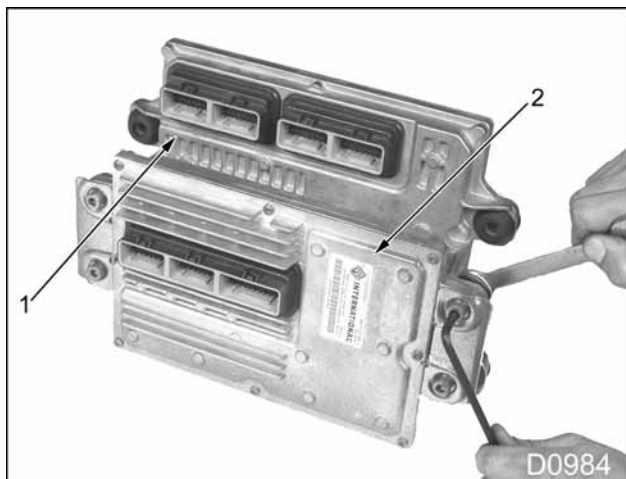


Figure 463 ECM and IDM Separation

1. ECM
2. IDM

7. Separate ECM and IDM by removing four bolts, nuts, and washers.

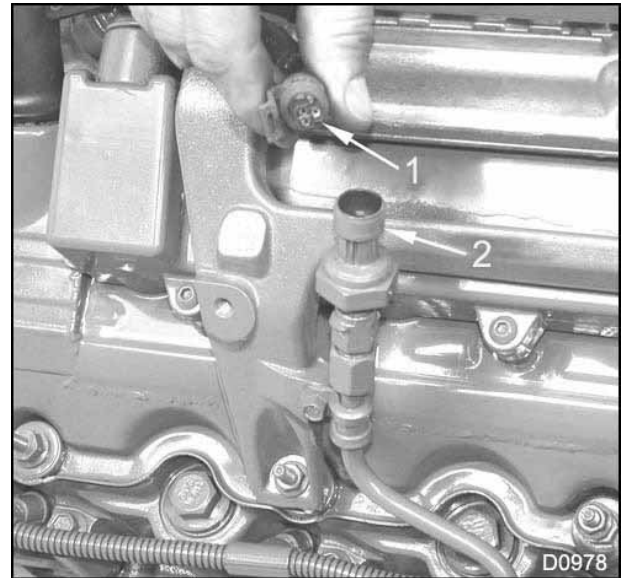


Figure 464 EBP sensor harness connector

1. EBP sensor harness connector
2. EBP sensor

8. Remove EBP sensor harness.

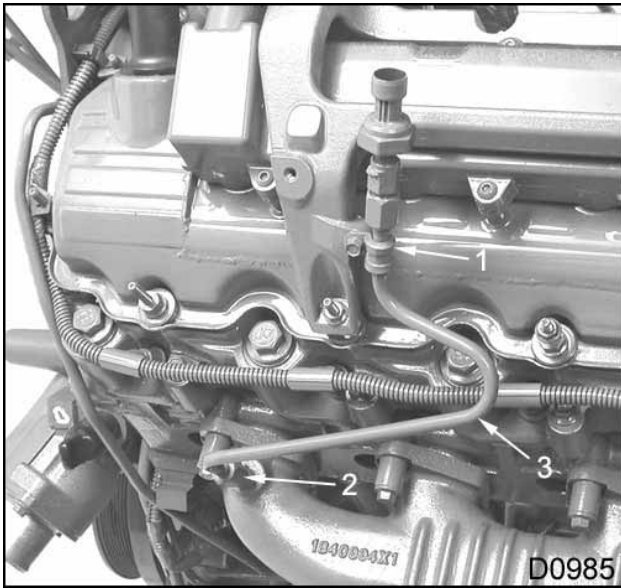


Figure 465 EBP sensor bracket and tubing

1. Bracket
 2. Tube fitting
 3. Tube
9. Remove EBP sensor bracket from the ECM and IDM assembly bracket and the tubing from exhaust manifold.

NOTE: Do not remove the ECM and IDM assembly bracket, if other engine repairs are not necessary.



Figure 466 Mounting Bracket Bolts for ECM and IDM

10. Remove six nuts and ECM and IDM assembly mounting bracket.

Main Engine Wiring Harness

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

NOTE: The electrical harness assembly does not need to be disconnected from the relay, unless the harness or relay is being replaced. Instead, two relay mounting bolts or three relay bracket bolts may be removed from the valve cover.

1. Disconnect ground (-) cable from battery.

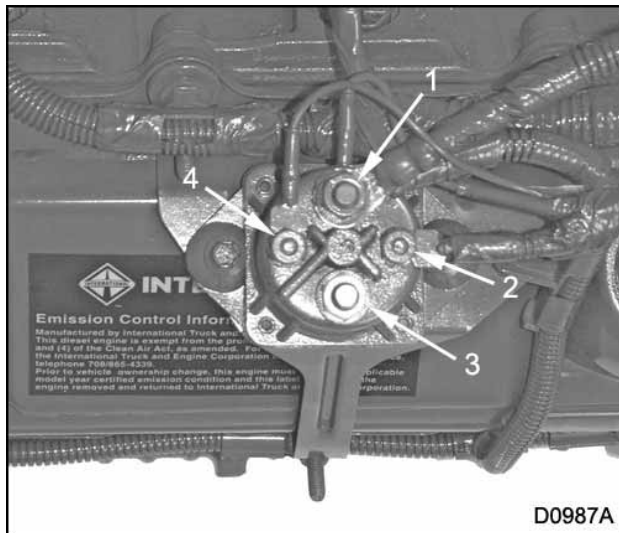


Figure 467 Glow plug relay terminals

1. To glow plug and ECM X1
 2. To ECM X1
 3. To battery (with fusible link)
 4. To ground
2. Disconnect electrical connections from glow plug relay terminals.
 3. If not removed, remove ECM and IDM assembly from support bracket (ECM, IDM, and Mounting Bracket, page 264).
 4. Disconnect main harness from sensors (Removal, page 257).
 5. Remove wiring harness clamps that secure wiring harness to cylinder heads and front cover.
 6. Disconnect electrical connectors from fuel injectors and glow plug harness assemblies.
 7. Remove ground wire attached at the left side of the rear of the intake manifold.
 8. Carefully lift main harness assembly from engine.

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

Glow Plug Harness Assemblies, Bracket, and Relay

Glow Plug Harness Assemblies

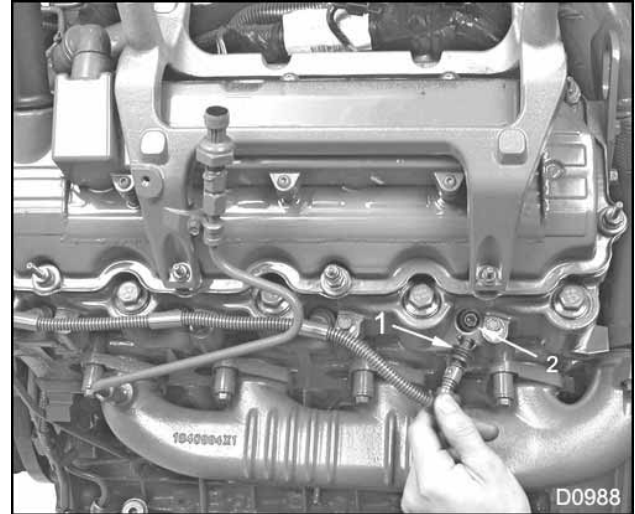


Figure 468 Removal of glow plug harness assemblies

1. Glow plug connector
 2. Glow plug
1. Disconnect ground (-) cable from battery.
 2. Remove harness assemblies from left and right glow plugs by releasing the clip on each glow using the Glow Plug Connector Remover/Installer (Table 28).
 3. Once glow plugs on each side are disconnected, pull the left and right harness assemblies to the front of the engine.

Glow Plug Relay and Bracket

1. Disconnect ground (-) cable from battery.



Figure 469 Glow plug relay nuts and bracket nuts

1. Glow plug relay bracket nuts
 2. Glow plug relay nuts
2. Remove two nuts for glow plug relay or three nuts for glow plug bracket.

NOTE: If removing the valve cover, leave the glow plug relay attached to the bracket. Remove only the three nuts securing the bracket to the valve cover studs.

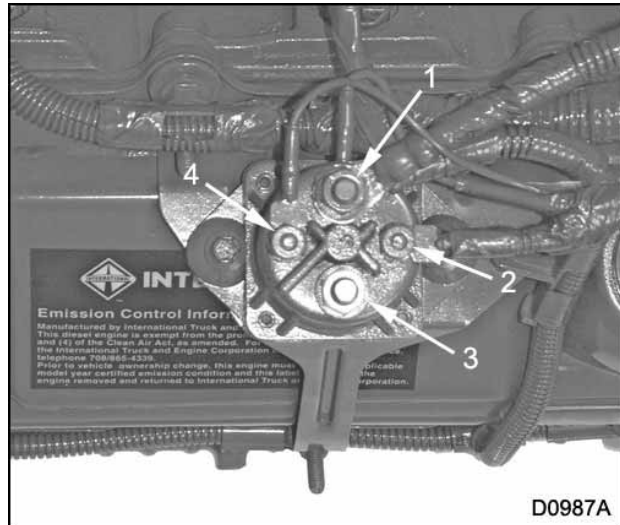


Figure 470 Glow plug relay terminals

1. To glow plug and ECM X1
 2. To ECM X1
 3. To battery (with fusible link)
 4. To ground
3. Remove plastic terminal cover for glow plug relay.
 4. Disconnect battery lead from glow plug relay terminal.
 5. Disconnect 12-V power wire, glow plug wire, and relay control harness connector.
 6. Remove two mounting screws for glow plug relay. Lift glow plug relay from engine.

Cleaning and Inspection

Main Engine Wiring Harness

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

Sensors and Valves

1. Check all connector pins on sensors or valves. If bent or corroded, replace that sensor.
2. If sensors or valves are removed, clean sealant from sensor or valve threads.
3. Remove scale or carbon build up.
4. Check for body cracks and leakage
5. If orifices or valves are plugged, replace sensors or valves.

Glow Plug Relay

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

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

Glow Plug Harness

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

ECM and IDM Assembly

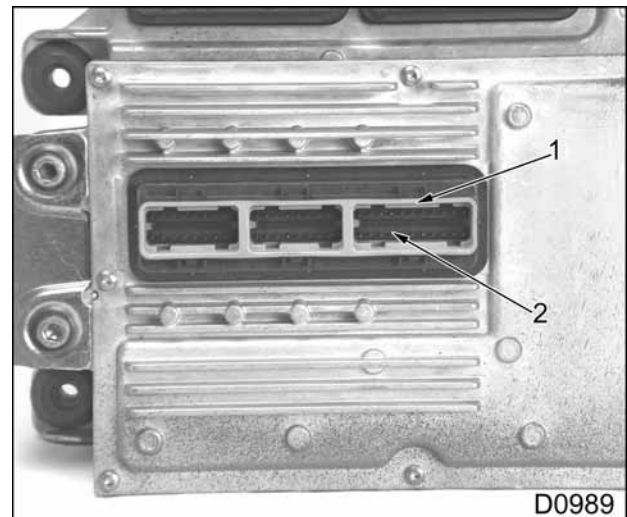


Figure 471 ECM and IDM assembly harness pin recesses (IDM shown)

1. Rubberized seal
2. Connector pins

1. Inspect rubber seal on harness connector and in ECM and IDM assembly pin recesses.

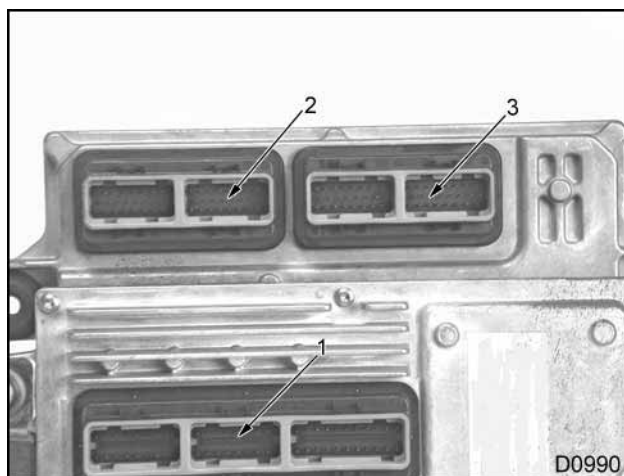


Figure 472 ECM and IDM assembly connections

1. IDM connection
2. ECM engine connections
3. ECM chassis connections

2. Check for bent pins in ECM and IDM assembly connections.

Installation

Engine Main Wiring Harness

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

1. Install engine wiring harness carefully align electrical connectors with sensors and valves (Figure 421).
2. Install wiring harness routing clips.
3. When each connector is installed in its mating socket in the appropriate procedural step, push each connector on its mating socket until locking tabs are fully latched.

Camshaft Position (CMP) Sensor



Figure 473 CMP sensor installation

1. Install two new O-rings on CMP sensor.
2. Lubricate sensor O-rings with clean engine oil and install CMP sensor in crankcase.
3. Secure sensor with M6 x 16 bolt and tighten bolt to the standard torque (Standard Torques, page 375).

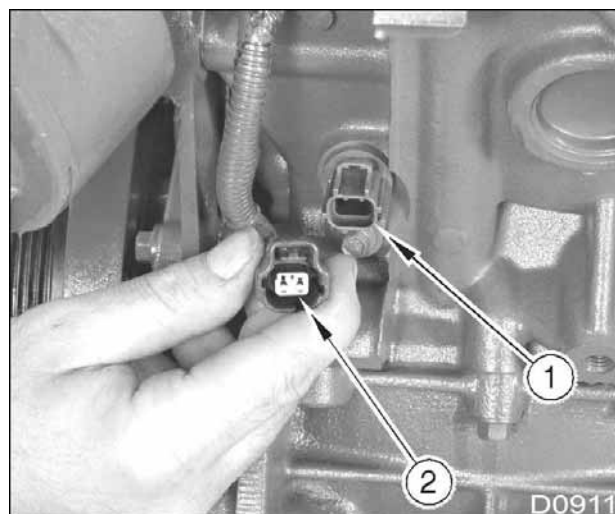


Figure 474 CMP Sensor

1. CMP sensor
2. CMP sensor connector

4. Connect electrical connector to CMP sensor.

Crankshaft Position (CKP) Sensor



Figure 475 CKP sensor installation

1. Install new O-ring on CKP sensor.
2. Lubricate O-ring with clean engine oil and install CKP sensor in lower crankcase.
3. Secure sensor with M6 x 16 bolt and tighten bolt to the standard torque (Standard Torques, page 375).

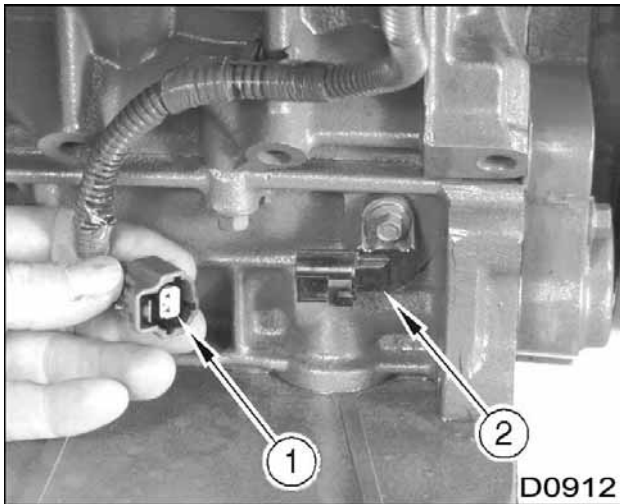


Figure 476 CKP sensor

1. CKP sensor connector
2. CKP sensor

4. Connect electrical connector to CKP sensor.

Exhaust Back Pressure (EBP) Sensor

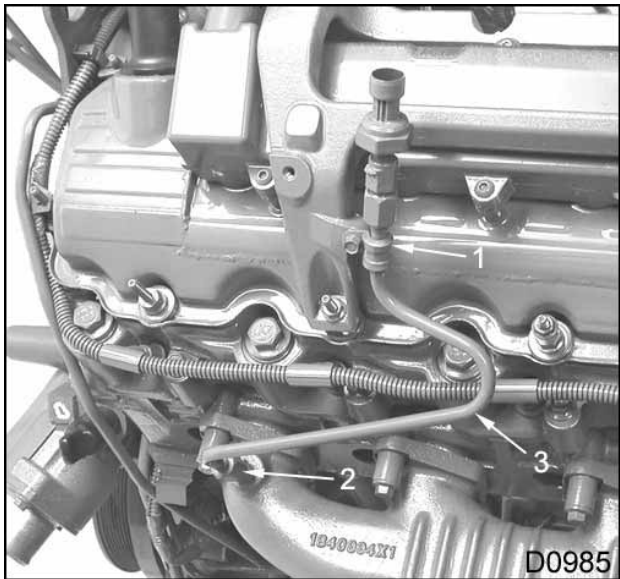


Figure 477 EBP sensor

1. EBP sensor bracket
2. Tube fitting
3. Tube

1. Install EBP sensor on sensor bracket.

2. Thread EBP tube fitting on sensor and tighten fitting to special torque (Table 27).

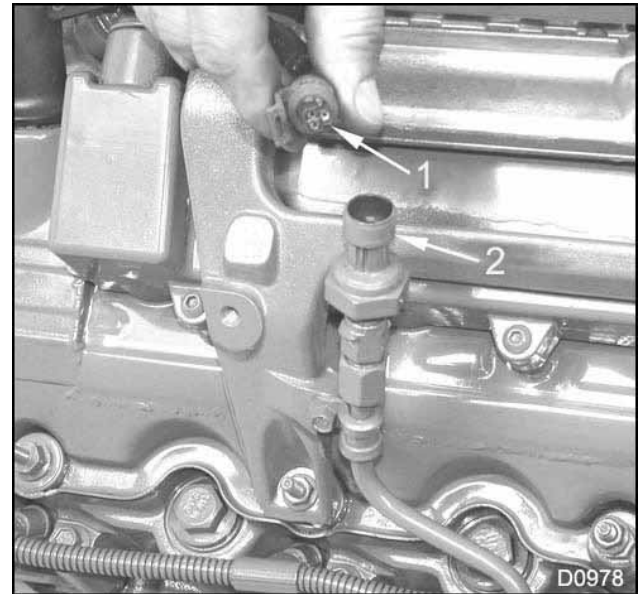


Figure 478 EBP sensor

1. EBP sensor
2. EBP sensor electrical connector

3. Connect electrical connector to EBP sensor.

Engine Coolant Temperature (ECT) Sensor

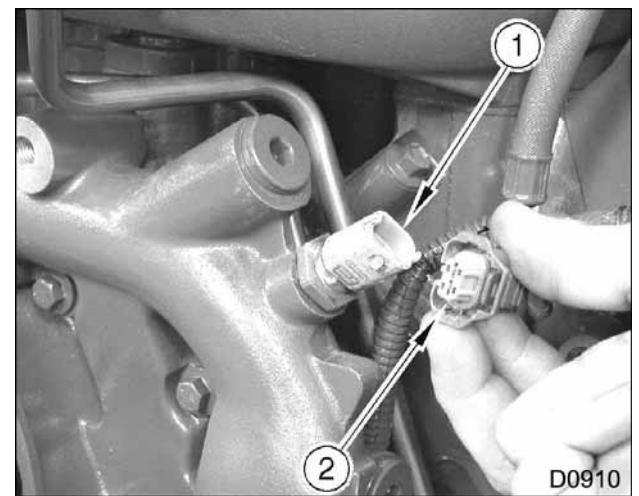


Figure 479 ECT sensor

1. ECT sensor
2. ECT sensor connector

1. Install new O-ring on ECT sensor.
2. Lubricate O-ring with clean engine oil.
3. Install ECT sensor in front cover and tighten sensor to special torque (Table 27).
4. Connect electrical connector to ECT sensor.

Exhaust Gas Recirculation (EGR) Valve

1. Install new gasket and two new O-rings on EGR valve.
2. Lubricate two O-rings with clean engine oil.



Figure 480 EGR installed

3. Install EGR valve in intake manifold, see (Exhaust Gas Recirculation (EGR) Valve, page 94).
4. When installing the EGR valve, make sure it is completely seated by hand before installing bolts.

NOTE: Failing to seat the EGR valve completely, could damage the EGR valve.

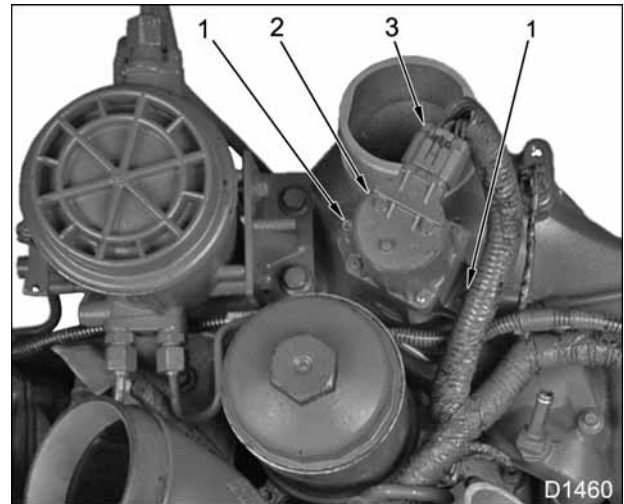


Figure 481 Installation of mounting bolts for EGR valve

1. M6 x 35 bolt (2)
2. EGR valve
3. Electrical connector
5. Thread two M6 x 35 bolts by hand, and tighten to the standard torque – alternating between both bolts (Standard Torques, page 375).
6. Connect electrical connector to valve.

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

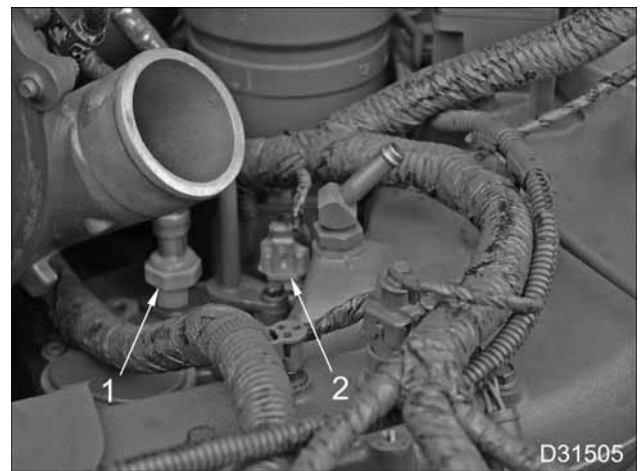


Figure 482 EOT and EOP sensors

1. EOP sensor
2. EOT sensor

1. Install new O-rings on EOT and EOP sensors.
2. Lubricate O-rings with clean engine oil.
3. Install and tighten EOT sensor to the special torque (Table 27).
4. Install and tighten EOP sensor to special torque (Table 27).
5. Connect electrical connector to EOT and EOP sensors.

Variable Geometry Turbocharger (VGT) Control Valve



Figure 483 Lubrication of control valve O-rings

1. Replace and lubricate O-rings with clean engine oil. Make sure that O-rings are correctly seated, not twisted or distorted.



Figure 484 Installation of control valve

2. Install control valve carefully to avoid twisting or cutting O-rings.

NOTE: Do not use the retaining bolt to draw the control valve into the housing. Push the control valve in by hand to seat securely, before installing bracket and bolt.

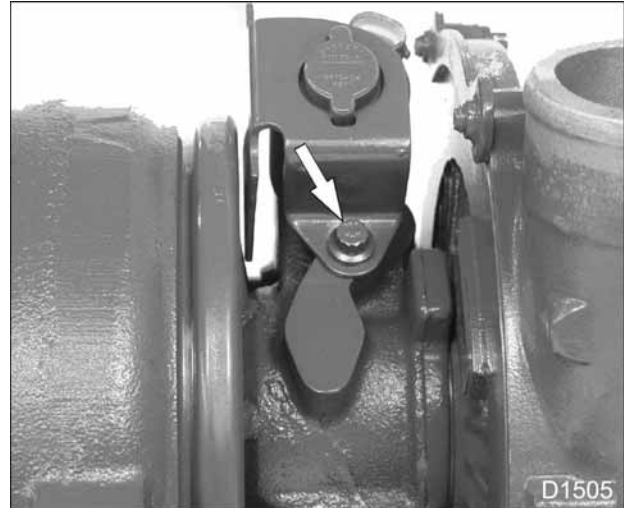


Figure 485 Control valve retaining bolt

3. Install control valve bracket and retaining bolt. Tighten bolt to standard torque (Standard Torques, page 375).

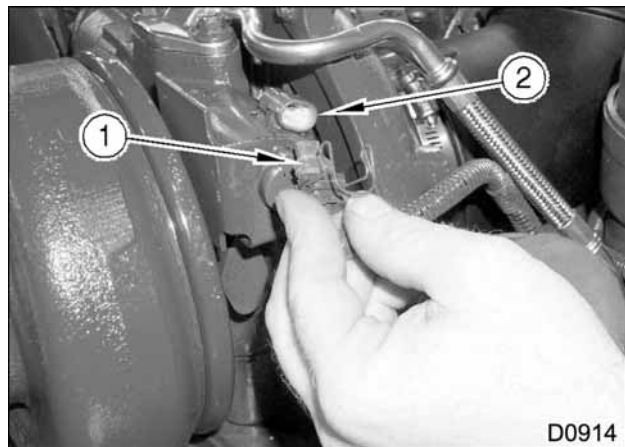


Figure 486 Turbocharger control valve

1. Turbocharger electrical connector
2. Turbocharger control valve connection

4. Connect electrical connector to control valve connection.

Injection Control Pressure (ICP) Sensor



Figure 487 Installation of valve cover seal ring for ICP sensor

1. Valve cover seal ring for ICP sensor
2. Oil rail ICP sensor opening

NOTE: If the valve cover was removed, a new valve cover seal ring is required.

1. Install valve cover seal ring between the right side valve cover and the oil rail.
2. Install new O-ring on ICP sensor.
3. Lubricate O-ring with clean engine oil.

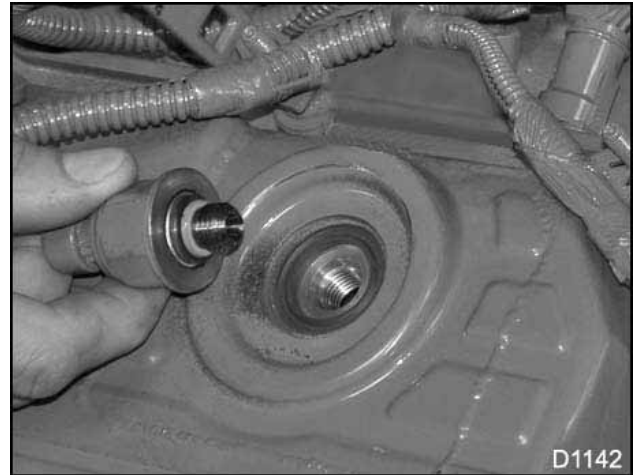


Figure 488 ICP Sensor and O-ring

4. Install ICP sensor in the right oil rail.
5. Tighten sensor to special torque (Table 27).



Figure 489 ICP sensor

6. Connect electrical connector to ICP sensor.

Injection Pressure Regulator (IPR) Valve

1. Install new O-rings and backup rings on IPR valve.
2. Lubricate O-rings with clean engine oil.
3. Install IPR valve and tighten to the special torque (Table 27).

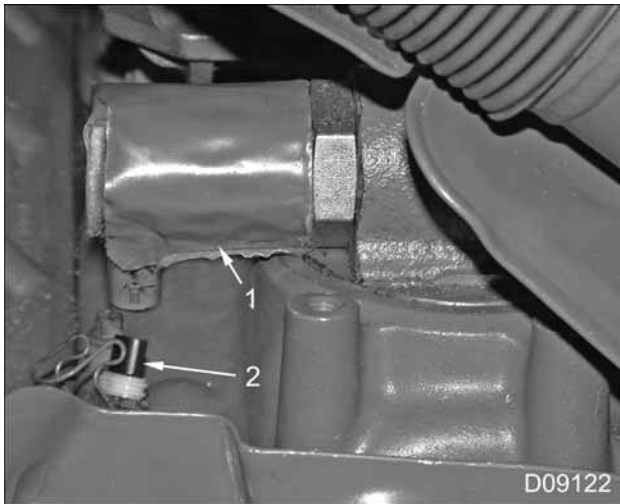


Figure 490 IPR valve and engine harness connector

1. IPR valve
 2. Engine harness connector
4. Connect engine harness connector to IPR valve.
 5. Install three rear mounting bolts for exhaust heat shield and two heat shield bolts (if equipped) for IPR valve. Tighten to the special torque (Table 27). If the stamped heat shield is not installed, install the special snap heat shield.

NOTE: Some engines have a metal heat shield mounted over the IPR valve; others have an insulated snap cover on the IPR valve solenoid.

Manifold Absolute Pressure (MAP) Sensor

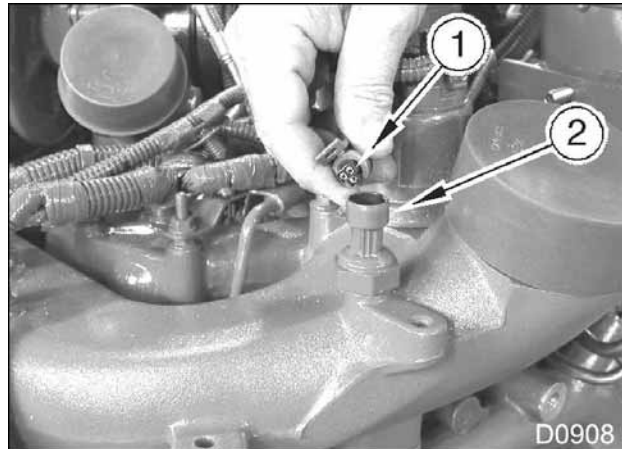


Figure 491 MAP sensor

1. 3-wire connector
 2. MAP sensor
1. Install new O-ring on sensor.
 2. Lubricate O-ring with clean engine oil.
 3. Install MAP sensor.
 4. Tighten sensor to special torque (Table 27).
 5. Connect electrical connector to MAP sensor.

Manifold Air Temperature (MAT) Sensor

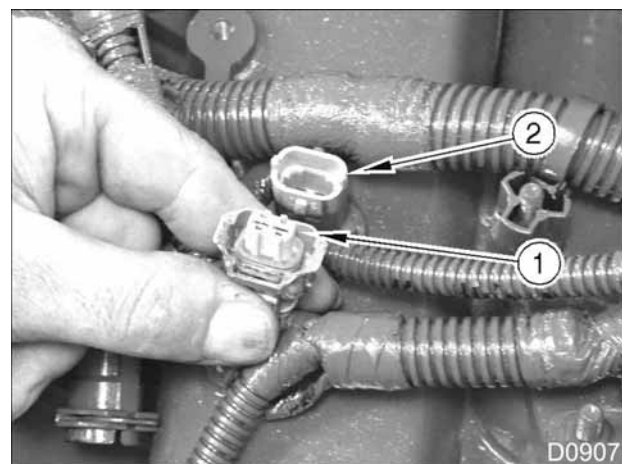


Figure 492 MAT sensor

1. 2-wire connector
2. MAT sensor

1. Install new O-ring on MAT sensor, and lubricate O-ring with clean engine oil.
2. Lubricate O-ring with clean engine oil.
3. Install MAT sensor.
4. Tighten MAT sensor to special torque (Table 27).
5. Connect electrical connector to MAT sensor.
3. If removed, install bracket and three nuts to valve cover studs. Tighten nuts to standard torque (Standard Torques, page 375).

Glow Plug Relay, Bracket, and Harness Assemblies

Glow Plug Relay and Bracket



Figure 493 Glow plug relay terminals

1. Glow plug relay bracket nuts
 2. Glow plug relay nuts
1. Install glow plug relay on bracket.
 2. Install and tighten two mounting nuts.

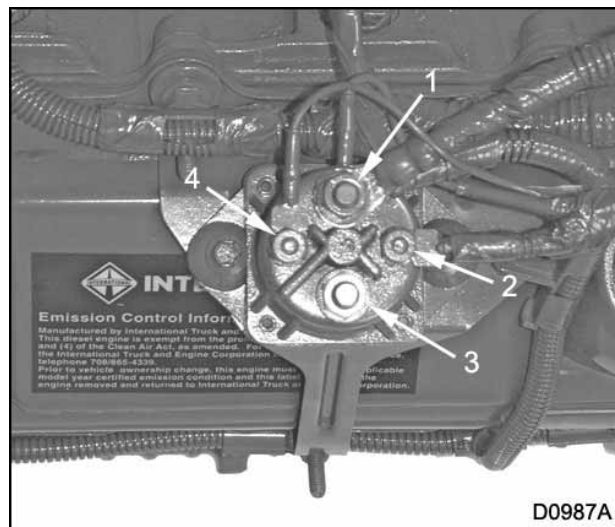


Figure 494 Glow plug relay terminals

1. To glow plug and ECM X1
 2. To ECM X1
 3. To battery (with fusible link)
 4. To ground
4. Connect glow plug wire and 12-V power wire to top of glow plug relay.
 5. Tighten terminal nuts.
 6. Connect wiring harness connector to glow plug relay.
 7. Reconnect batteries.

Glow Plug Harness Assemblies

1. Replace O-rings on the right and left side glow plug harness assemblies, if not done.



Figure 495 Installation of glow plug harness assembly

2. Install harness assemblies for left and right side glow plug by threading the harness assembly to the rear of the engine under the valve cover.
3. Using the Glow Plug Connector Remover/Installer, push on each cap to snap in place and compress O-ring (Table 28).

ECM and IDM Assembly



Figure 496 Nuts on valve cover studs for ECM and IDM bracket

1. Install six nuts on six valve cover studs to secure ECM and IDM bracket to engine.
2. Tighten nuts to standard torque (Standard Torques, page 375).

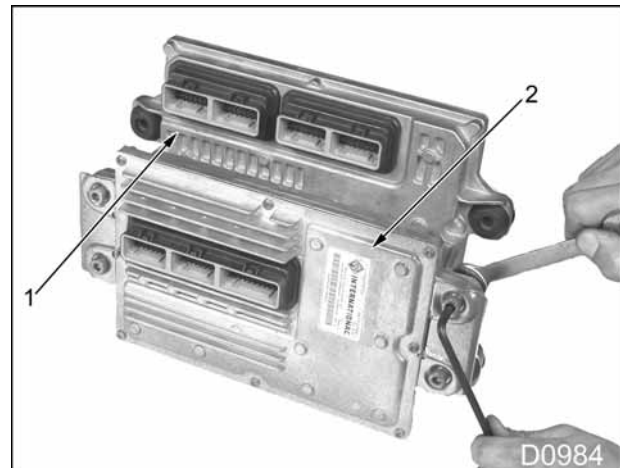


Figure 497 Connection of IDM to the ECM

1. ECM
2. IDM
3. Install four M8 x 70 bolts, washers, and nuts to join the ECM and IDM.

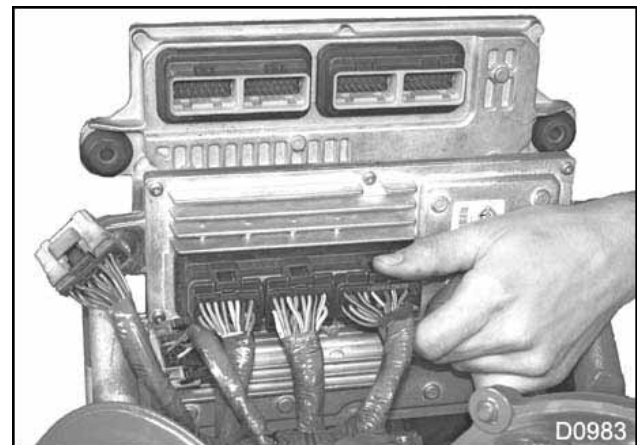


Figure 498 IDM harness connectors

4. Insert three IDM harness connectors.

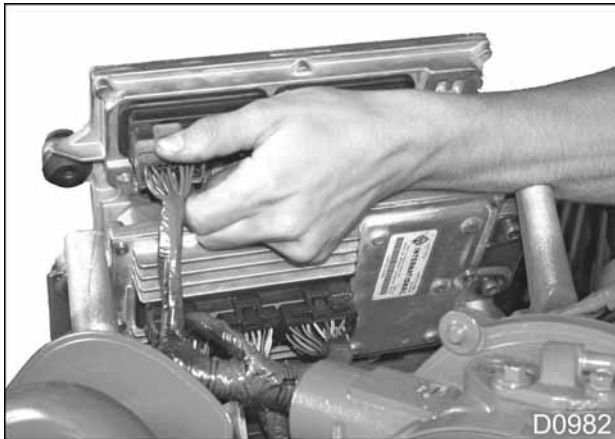


Figure 499 ECM harness connectors

5. Insert four ECM harness connectors (two for engine and two for chassis).

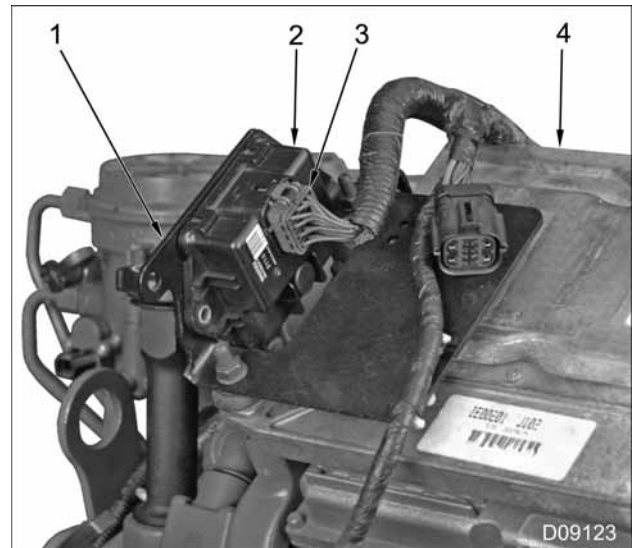


Figure 500 EGR drive module and ECM

1. Mounting bracket for Exhaust Gas Recirculation (EGR) drive module
 2. EGR drive module
 3. Connector to EGR drive module
 4. Electronic Control module (ECM)
-
6. Install ECM and IDM assembly on support bracket.
 7. Tighten four M6 x 25 nuts to the standard torque (Standard Torques, page 375).
 8. Reinstall all safety guards, shields, and covers.
 9. Make sure all tools, cleanliness covers, loose parts, and service equipment are removed from the engine work area.

Specifications

Table 26 Engine Electrical

Glow Plugs	
Location	Cylinder Head
Quantity	8
Camshaft Position (CMP) Sensor	
Location	Crankcase (left side)
Crankshaft Position (CKP) Sensor	
Location	Lower crankcase (right side)
Operating actuator speed	15 to 2,000 rpm
Operating temperature	-40 to +130°C (-40 to +266°F)
Injection Pressure Regulator (IPR) Valve	
Operating temperature range	-40 to +220°C (-40 to +428°F)
Maximum operating pressure	28 MPa (4,061 psi)

Special Torque

Table 27 Engine Electrical

Exhaust Back Pressure (EBP) sensor	12 + 2/-3 N·m (108 ± 12 lbf·in)
Engine Coolant Temperature sensor (ECT)	12 ± 2 N·m (108 ± 12 lbf·in)
Engine Oil Temperature sensor (EOT)	12 ± 2 N·m (108 ± 12 lbf·in)
Engine Oil Pressure sensor (EOP)	12 ± 2 N·m (108 ± 12 lbf·in)
Glow plug	19 N·m (168 lbf·in)
Injection Control Pressure (ICP) sensor	12 ± 2 N·m (108 ± 18 lbf·in)
Injection Pressure Regulator (IPR) valve	50 ± 5 N·m (37 ± 4 lbf·ft)
Manifold Absolute Pressure (MAP) sensor	12 ± 2 N·m (108 ± 12 lbf·in)
Manifold Air Temperature (MAT) sensor	18 + 2/-3 N·m (156 ± 24 lbf·in)

Special Service Tools

Table 28 Engine Electrical

Description	Tool Number
Cap Kit (All)	ZTSE4610
EGR Valve Puller	ZTSE4669
Glow Plug Connector Remover/Installer	ZTSE4670

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Exploded View and Flow Schematic

High-pressure Oil System

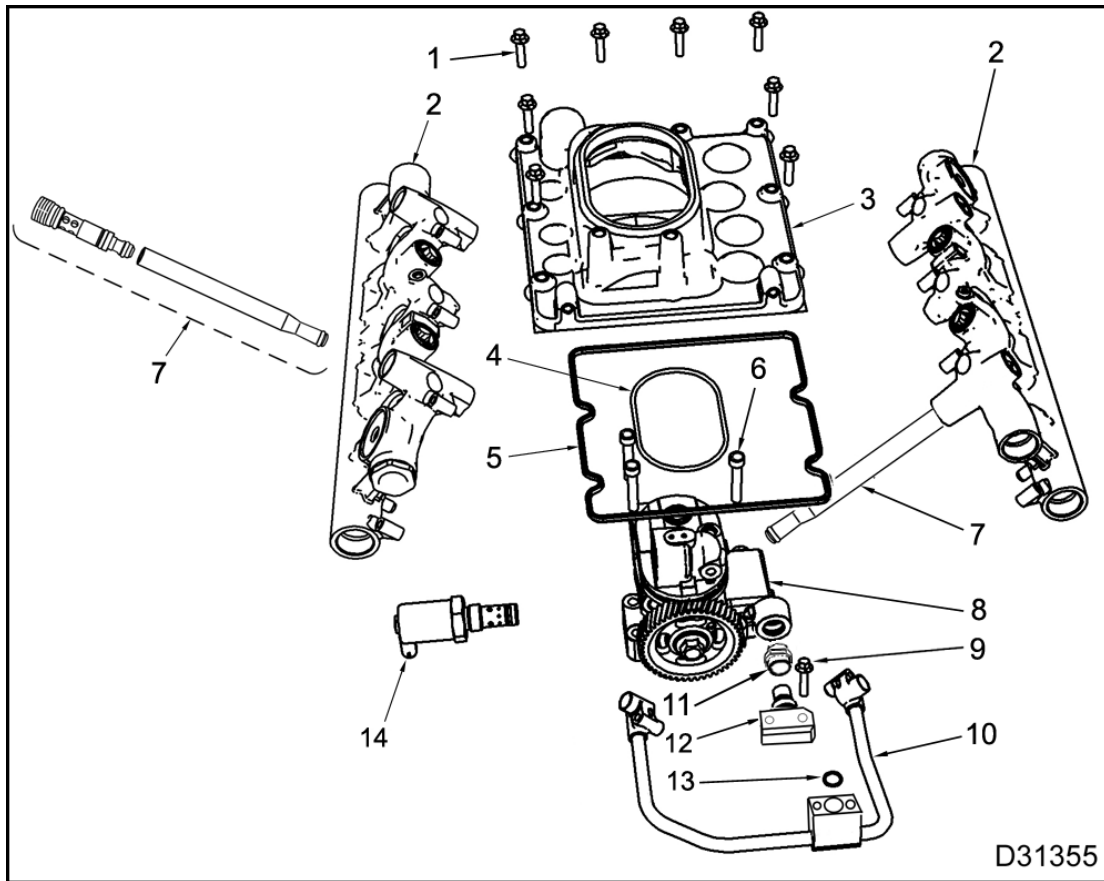


Figure 501 High-pressure oil system

1. High-pressure oil pump cover bolt (8)	7. Case-to-head tube assembly (2)	13. O-ring
2. Oil rail assembly (2)	8. High-pressure oil pump assembly	14. IPR valve
3. High-pressure oil pump cover	9. Branch tube adapter bolt (2)	
4. Pump-to-cover seal ring	10. Branch tube assembly	
5. High-pressure oil pump cover seal	11. Snap To Connection (STC) fitting	
6. High-pressure oil pump bolt (3)	12. Branch tube adapter	

High-pressure Flow Schematic

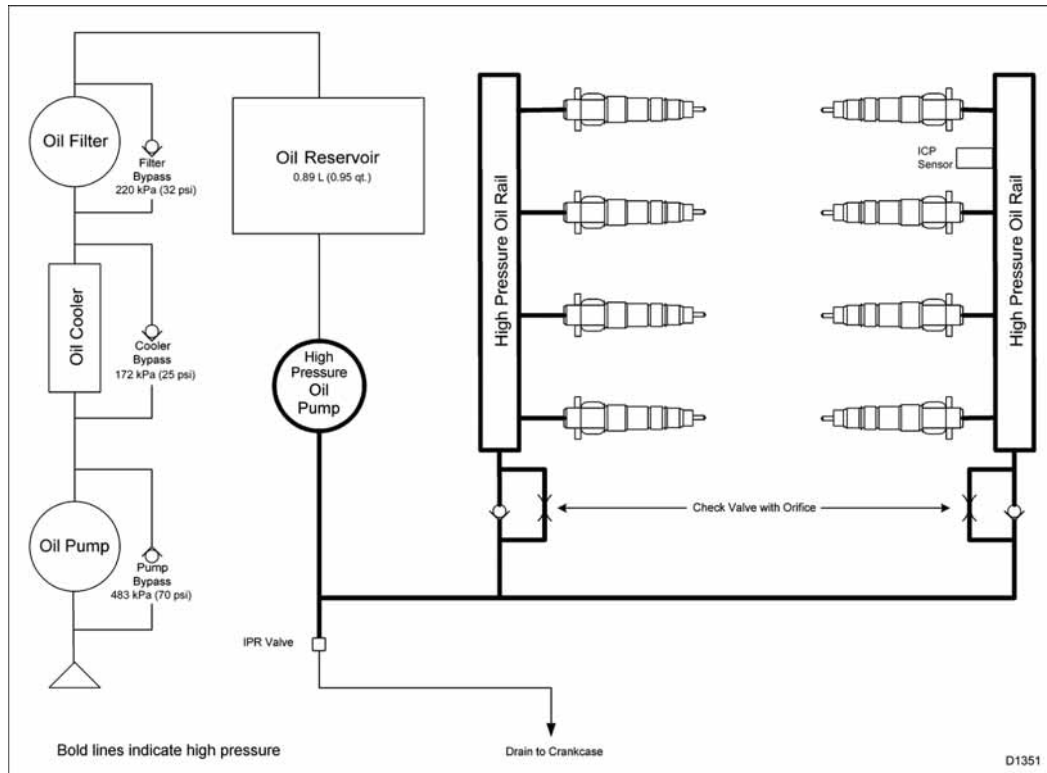


Figure 502 High-pressure flow

The bold flow lines indicate high-pressure oil flow from the high-pressure oil pump to the injectors. See Specifications for range of pressure. (Table 29)

Removal

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

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

NOTE: Before removing high-pressure oil system components, remove the following:

- Fuel filter assembly and lines
See "Fuel System."
- VGT assembly
See "Variable Geometry Turbocharger (VGT) Assembly."
- Electronic Control Module (ECM), Injector Driver Module (IDM), and mounting bracket
See "Engine Electrical."
- EGR drive module and mounting bracket
See "Engine Electrical."
- Glow plug relay and bracket
See "Engine Electrical."
- Exhaust Manifolds and the EGR cooler V-clamp.
See "Manifolds and Exhaust Gas Recirculation (EGR)."
- Rear cover
See "Rear Cover, Flywheel, and Power Steering Gear Drive."

High-pressure Oil Pump Cover

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

NOTE: The Injection Pressure Regulator (IPR) valve must be removed before removing the high-pressure oil pump cover.

NOTE: Some engines have a metal heat shield mounted over the IPR valve; others have an insulated snap cover on the IPR valve solenoid.

1. Remove three rear exhaust heat shield mounting bolts and the two IPR valve heat shield bolts (if installed).
2. Remove the IPR valve insulated snap cover (if installed).

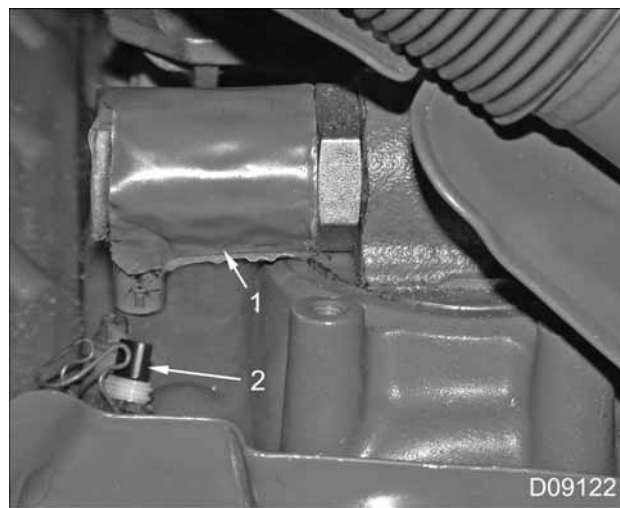


Figure 503 IPR valve disconnected

1. IPR valve
2. Engine harness connector

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

3. Disconnect engine harness connector from IPR valve.

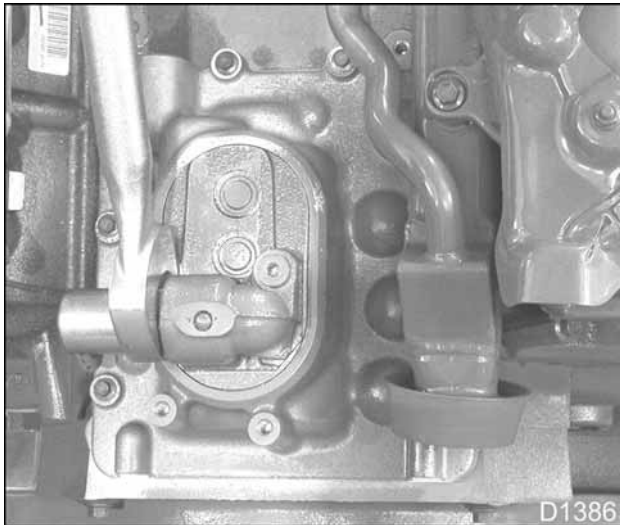


Figure 504 Removal of IPR valve

4. Remove IPR valve from high-pressure oil pump.
5. Remove and discard O-rings and backup ring.

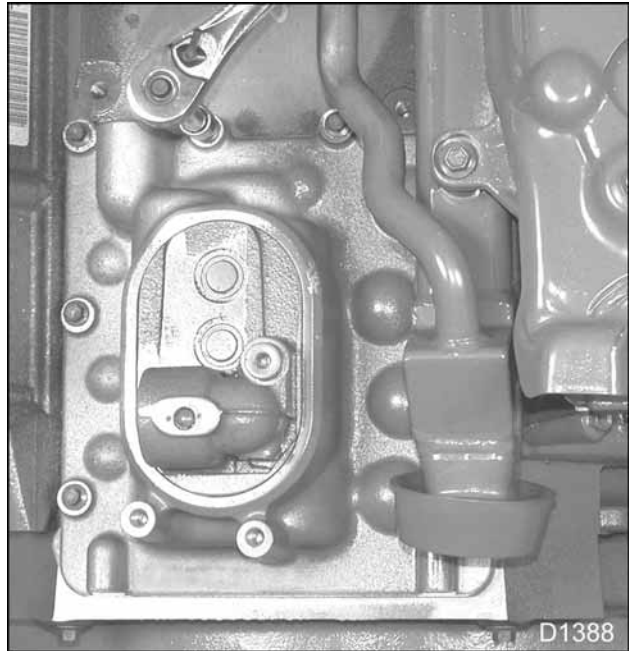


Figure 505 Removal of high-pressure oil pump cover

NOTE: The high-pressure oil pump can be replaced without removing the EGR cooler, if the exhaust pipe is loosened or removed.

6. Remove five M6 x 25 hex flange bolts from high-pressure oil pump cover.
7. Loosen and completely back out three M6 x 25 hex flange bolts under the EGR cooler. Leave these bolts loose in the cover

NOTE: These bolts will be removed after removal of oil pump cover.

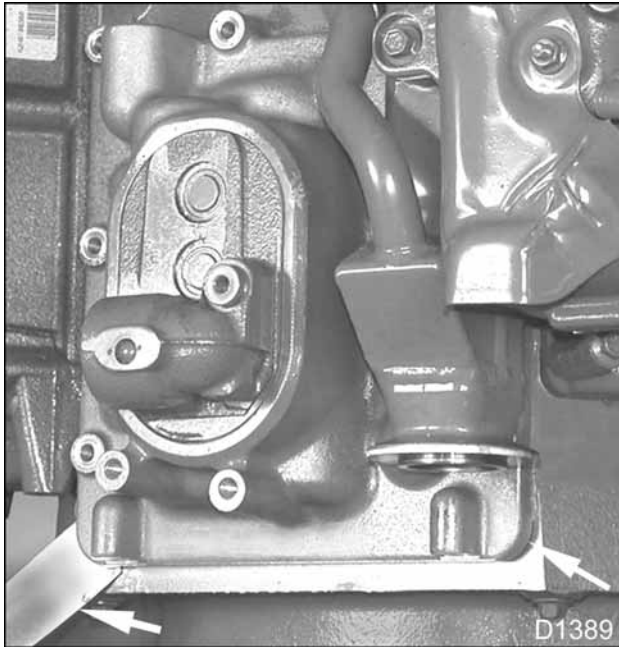


Figure 506 Separation of sealant with thin scraper

8. Use a thin gasket scraper to separate sealant between crankcase, rear cover seam, and high-pressure oil pump cover. Do this on both sides at the rear of the pump cover.

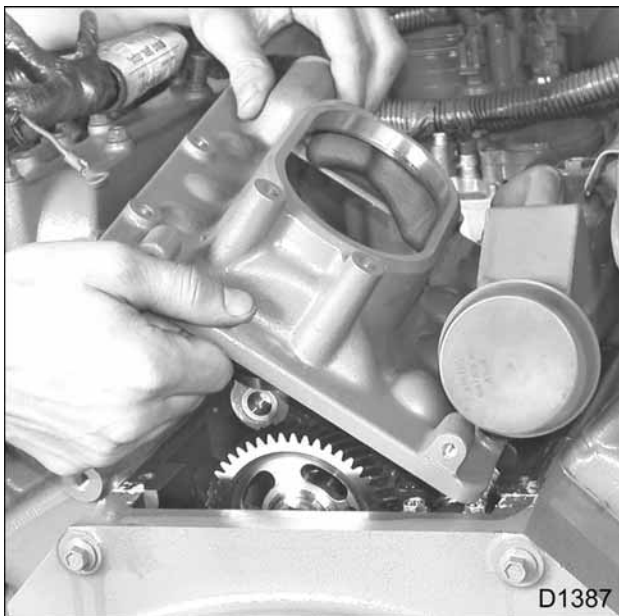


Figure 507 Removal of high-pressure oil pump cover

9. After breaking sealant, lift the pump cover side – opposite the EGR cooler – at an angle to clear pump gear, and lift cover from pump.

CAUTION: To prevent engine damage, do not lose or allow the three bolts in the cover to fall down into the crankcase.

High-pressure Oil Pump Assembly

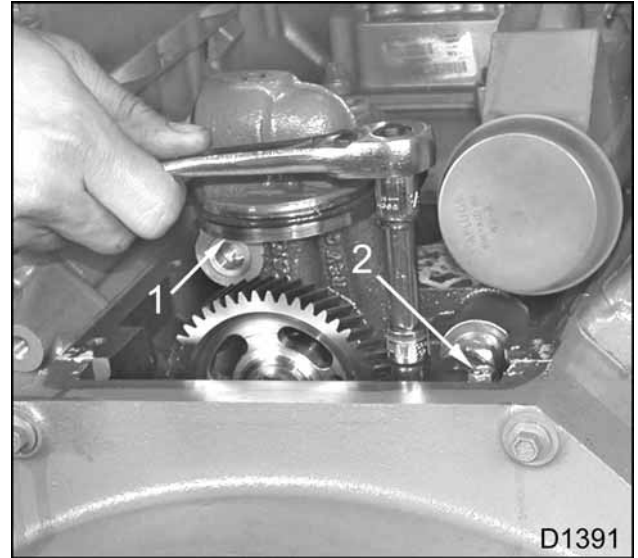


Figure 508 Removal of bolts from branch tube adapter

1. High-pressure oil pump assembly
2. M6 x 30 mounting bolt (2)

1. Loosen two M6 x 30 bolts connecting branch tube adapter to branch tube assembly.

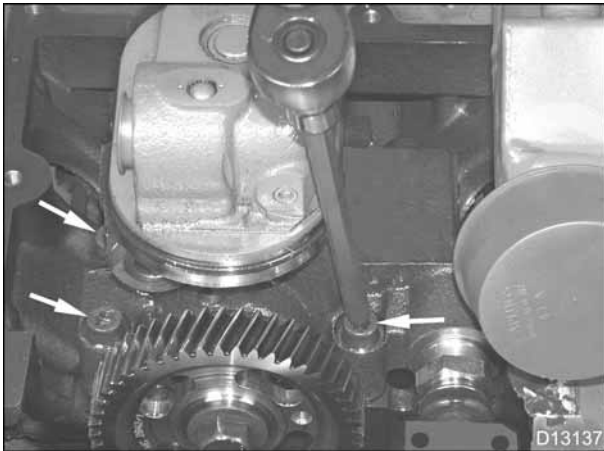


Figure 509 Removal of mounting bolts from high-pressure oil pump

2. Remove three M6 x 25 hex flange bolts from high-pressure oil pump.
3. Remove high-pressure oil pump and leave branch tube adapter attached.

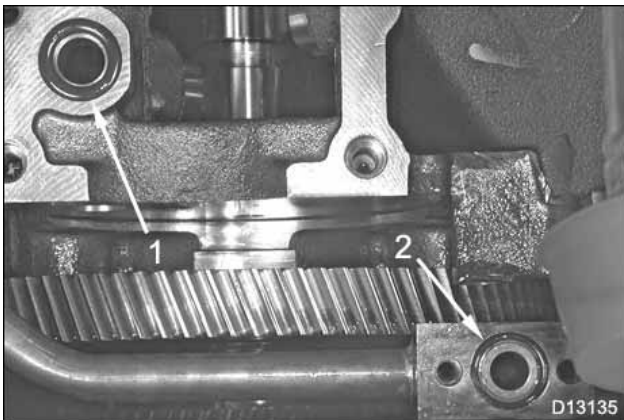


Figure 510 Removal of O-rings

1. O-ring for high-pressure oil pump inlet
 2. O-ring for branch tube adapter
4. Remove and discard O-ring for high-pressure oil pump inlet and O-ring for branch tube adapter.

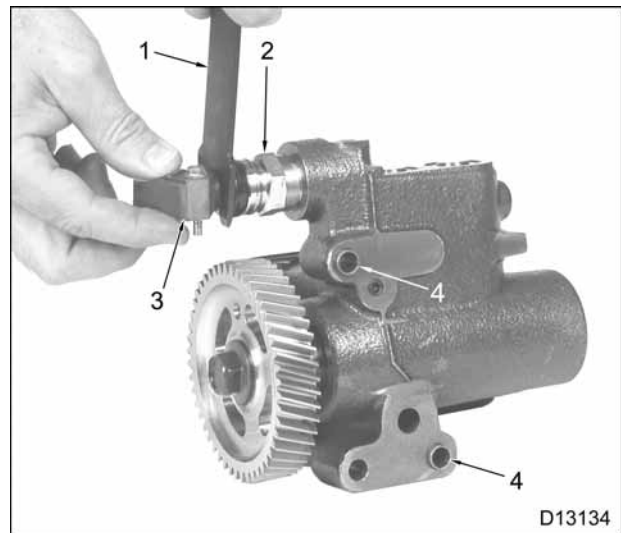


Figure 511 Removal of branch tube adapter

1. Quick release tool No. 10
2. Snap To Connect (STC) fitting
3. Branch tube adapter
4. High-pressure oil pump alignment pin (2)

5. If replacement of high-pressure oil pump assembly is necessary, disconnect branch tube adapter from high-pressure oil pump, using a No. 10 quick release tool (Table 31).
6. Remove STC fitting from high-pressure oil pump.

Branch Tube Assembly

NOTE: To remove the branch tube assembly, see the following sections:

- "Mounting Engine on Stand"
- "Rear Cover"
- "Flywheel, and Power Steering Gear Drive"
- "Cylinder Head and Valve Train"

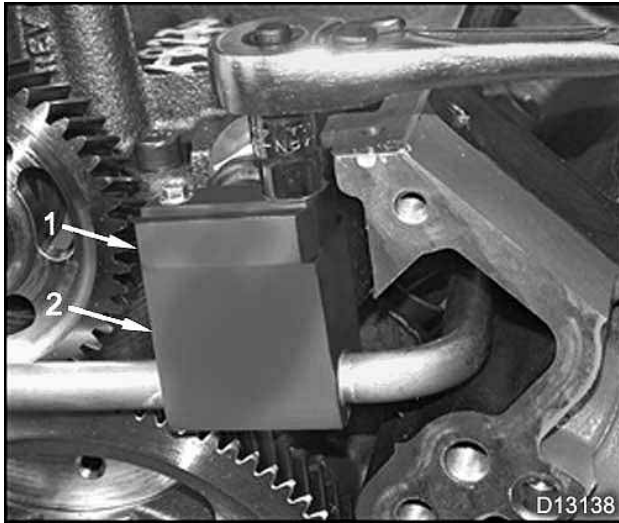


Figure 512 Removal of bolts from branch tube adapter

1. Branch tube adapter
2. Branch tube assembly

1. Remove two M6 x 30 bolts from branch tube adapter.

CAUTION: To prevent engine damage, do not drop mounting bolts into crankcase.

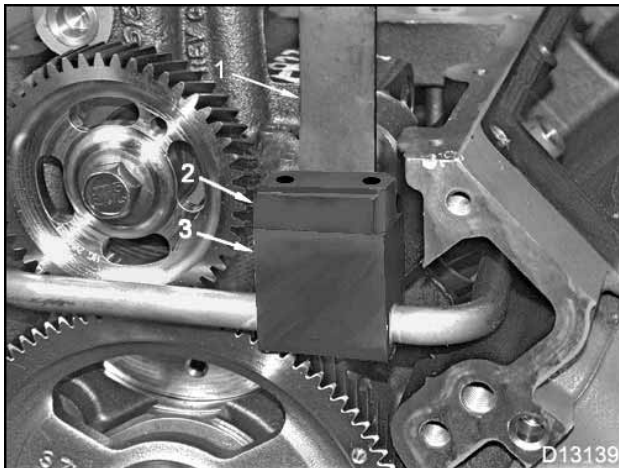


Figure 513 Disconnection of branch tube adapter

1. Quick release tool No. 10
2. Branch tube adapter
3. Branch tube assembly

2. If replacement of high-pressure oil pump assembly is required, disconnect branch tube adapter from the high-pressure oil pump, using a No. 10 quick release tool (Table 31).
3. Remove the branch tube adapter from the high-pressure oil pump assembly and the branch tube assembly.

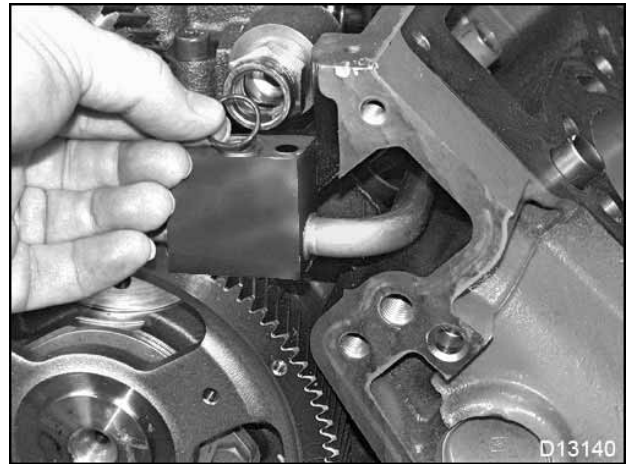


Figure 514 Removal of O-ring from branch tube assembly

1. O-ring
2. Branch tube assembly

4. Remove and discard O-ring from branch tube assembly.

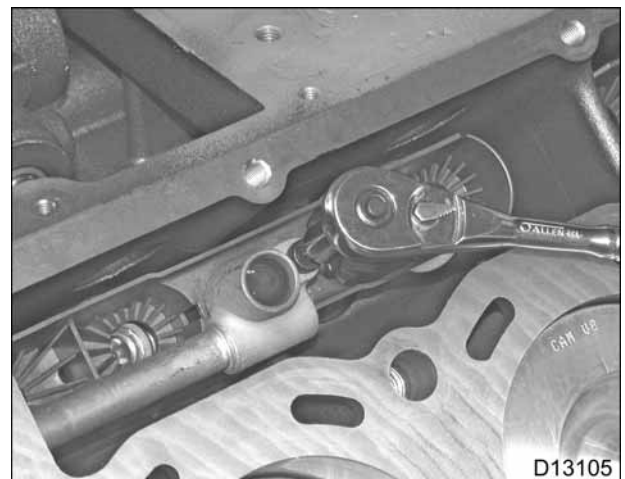


Figure 515 Removal of bolts from branch tube assembly (right side)

5. Remove M6 x 45 torx bolts from branch tube assembly (right and left sides)
6. Remove branch tube assembly.

Cleaning and Inspection

High-pressure Oil Pump Cover

1. Clean old sealant residue from the pump cover, crankcase cover, and rear cover mating areas.
2. Inspect the cover for the high-pressure oil pump assembly, the crankcase cover, and sealing surfaces of rear cover for dirt, raised metal or indications of seal failure. Correct defects, if necessary.
3. Clean and inspect the IPR valve for the following:
 - O-ring sealing surfaces for dirt, raised metal or other indications of seal failure. Correct defects, if necessary.
 - The electrical connector. See "Engine Electrical" for inspection criteria.
 - Valve openings for dirt or debris. Investigate causes and correct, if necessary.

High-pressure Oil Pump Assembly

NOTE: If oil pump assembly was removed, clean and inspect. The high-pressure oil pump is not a serviceable unit. The pump and gear are replaced as an assembly.

1. Clean and inspect sealing surfaces for the pump-to-cover O-ring for dirt, raised metal or seal failure. Correct defects, if necessary.
2. Clean and inspect inlet O-ring groove in the high-pressure oil pump for dirt, raised metal or seal failure. Correct defects, if necessary.

Branch Tube Adapter

1. Inspect outside and inside of the branch tube adapter connector to Snap To Connect (STC) fitting in high-pressure oil pump for debris, galling or damage. Install new branch tube adapter, if damaged.
2. Clean and inspect the branch tube adapter (if high-pressure oil pump assembly was not removed) O-ring groove for dirt, raised metal or seal failure. Correct any defects, if necessary.

Snap To Connect (STC) fitting

1. Clean and inspect STC fitting for debris, galling or damage.
2. Replace STC fitting, if damaged.

Installation

NOTE: If high-pressure oil pump assembly was replaced, but not the branch tube assembly, skip the branch tube assembly procedure.

Branch Tube Assembly

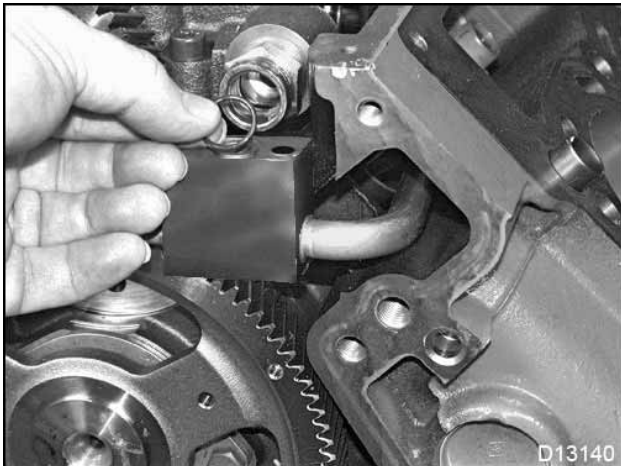


Figure 516 Installation of O-ring

1. Install new STC fitting in high-pressure oil pump
2. Install new O-ring in recess of branch tube assembly.

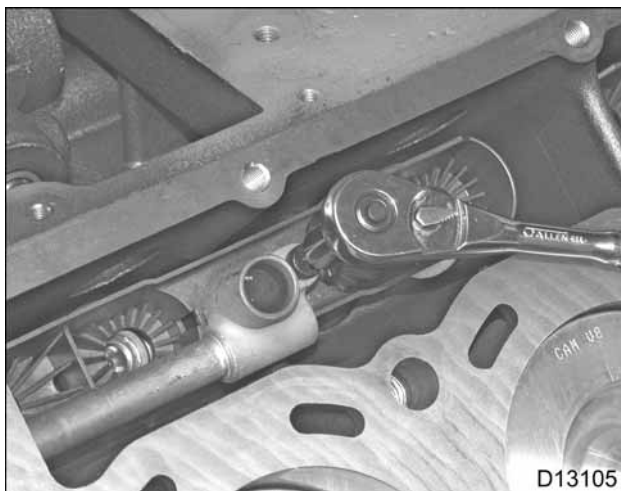


Figure 517 Installation of bolt for branch tube assembly (right side)

3. Install M6 x 45 torx bolts for branch tube assembly (right and left sides).
4. Tighten both M6 x 45 torx bolts the standard torque (Standard Torques, page 375).

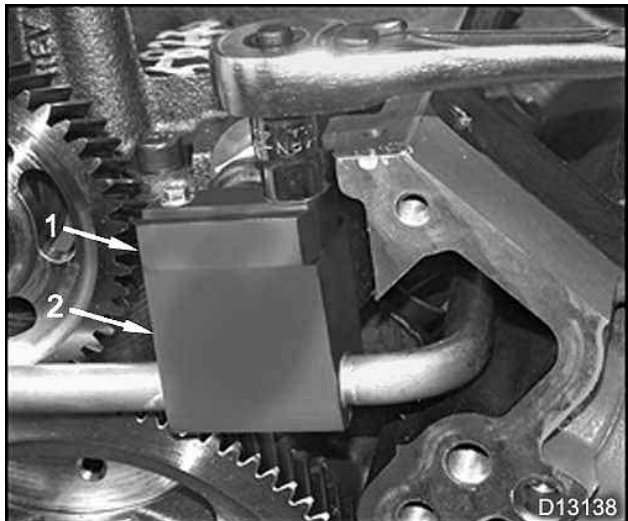


Figure 518 Removal of bolts from branch tube adapter

1. Branch tube adapter
2. Branch tube assembly

5. Install new branch tube adapter.
6. Install and tighten both M6 x 30 mounting bolts for the branch tube assembly to the standard torque (Standard Torques, page 375).

CAUTION: To prevent engine damage, do not drop mounting bolts into crankcase.

7. Install rear cover.

See "Rear Cover, Flywheel, Power Steering Gear Drive".

High-pressure Oil Pump Assembly

NOTE: Do the following procedure, if the high-pressure oil pump assembly was removed or the rear cover and cylinder heads were reinstalled after maintenance.

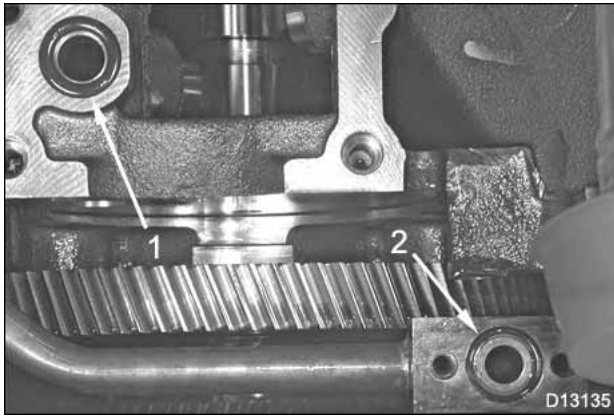


Figure 519 Installation of O-rings

1. O-ring in inlet recess of the high-pressure oil pump
2. O-ring in recess of the branch tube assembly

1. Lubricate recess in branch tube assembly.
2. Lubricate a new O-ring and put in branch tube recess.
3. Lubricate recess for high-pressure oil pump.
4. Lubricate a new O-ring and put in recess for high-pressure oil pump.

CAUTION: To prevent engine damage, use an approved seal for pump to cover. A substitution could damage the pump cover.

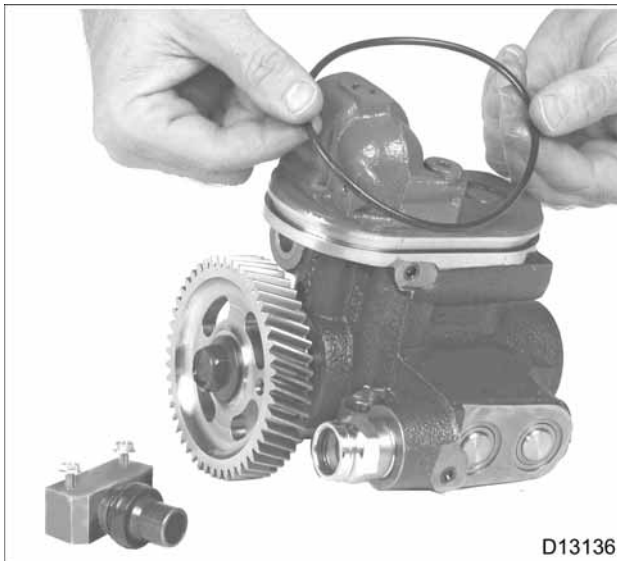


Figure 520 Installation of O-ring for high-pressure oil pump cover

5. Install a new O-ring on the high-pressure oil pump cover recess.
6. If removed, attach branch tube adapter to the high-pressure oil pump and install pump.

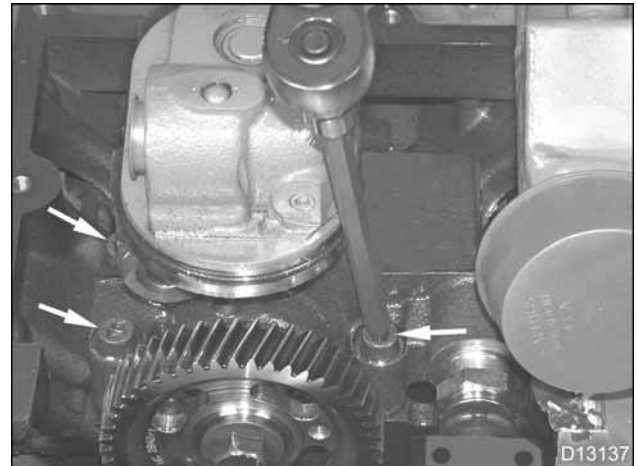


Figure 521 Installation of mounting bolts for high-pressure oil pump

7. Install three M8 x 35 socket bolts to secure the high-pressure oil pump to the crankcase. Tighten bolts to the standard torque (Standard Torques, page 375).

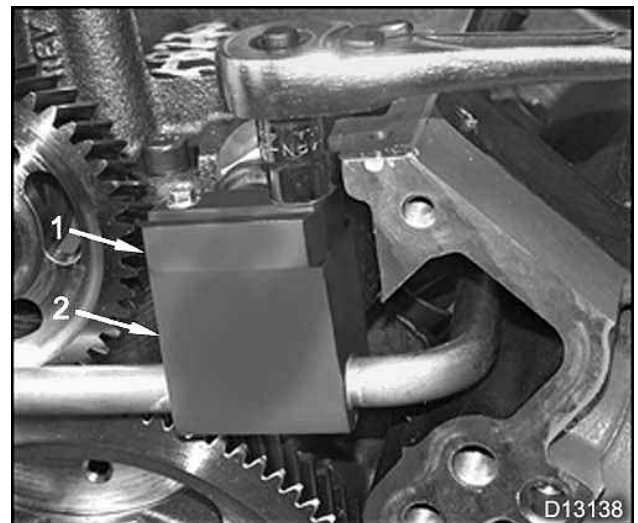


Figure 522 Removal of bolts from branch tube adapter

1. Branch tube adapter
2. Branch tube assembly

8. Install two M6 x 30 bolts to secure the branch tube adapter to the branch tube assembly and tighten to the standard torque (Standard Torques, page 375).

High-pressure Oil Pump Cover

1. Place a new gasket in the recess of cover for the high-pressure oil pump (if not already done).

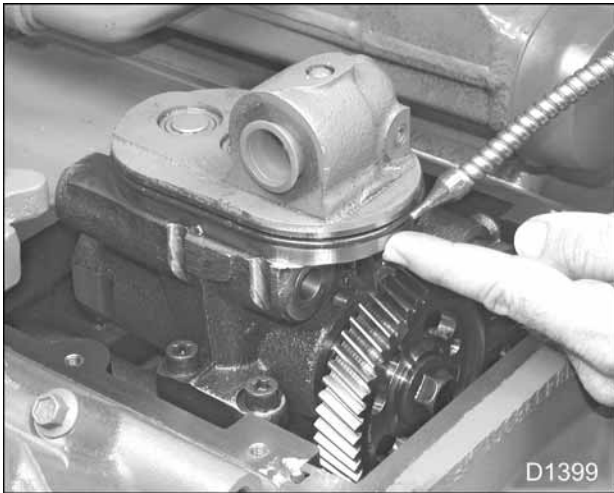


Figure 523 Lubricate O-ring in recess of cover for high-pressure oil pump

2. Lubricate O-ring in recess of cover for high-pressure oil pump.
3. Apply liquid gasket (Table 31) at two locations where rear cover and the crankcase meet.

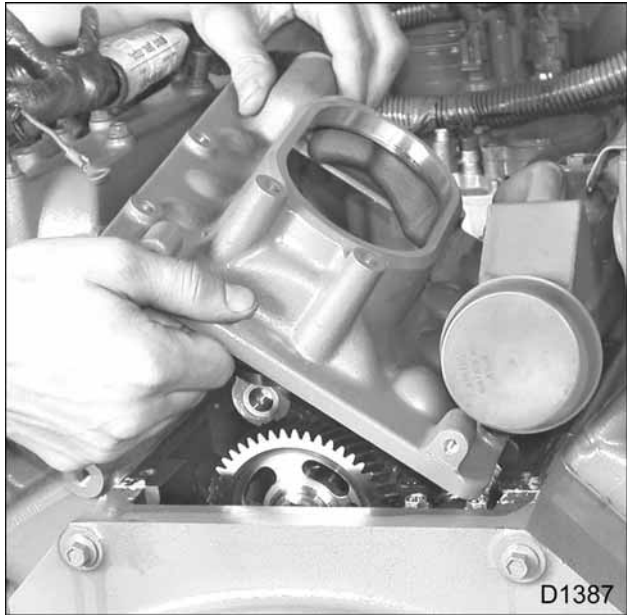


Figure 524 Installation of high-pressure oil pump cover

CAUTION: To prevent engine damage, do not drop the three mounting bolts inside high-pressure oil pump cover to be mounted under the EGR cooler.

4. Install three bolts in the part of the cover that will go under the EGR cooler.



Figure 525 Seating high-pressure oil pump cover

5. Apply firm even downward pressure to seat the high-pressure oil pump cover on O-ring.

CAUTION: To prevent engine damage and cracking the cover plate, the high-pressure oil pump cover must be firmly seated on the O-ring.

CAUTION: To prevent engine damage, do not misalign bolts – this will cause stripped threads, incorrect mounting of cover, and leakage.

6. Make sure bolts are aligned correctly with tapped holes in crankcase and in position for correct installation.



Figure 526 Torquing bolts for high-pressure oil pump cover

7. Install the other six M6 x 25 mounting bolts and tighten all eight bolts to the special torque (Table 30).
8. Install new O-rings and backup ring on the IPR valve.
9. Lubricate O-ring with clean engine oil.
10. Install IPR valve and tighten to the special torque (Table 30).

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

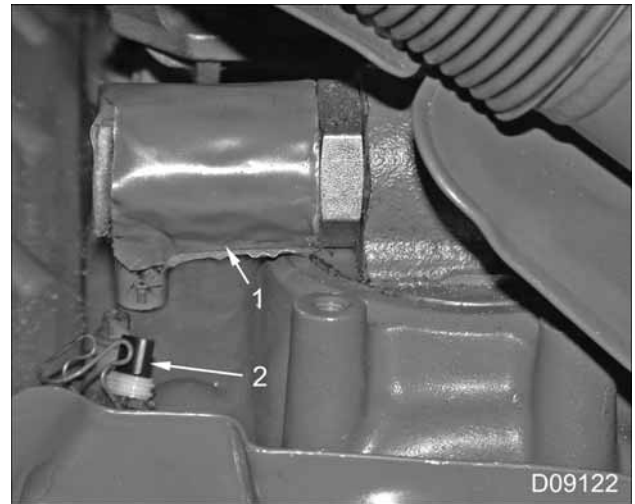


Figure 527 IPR valve and engine harness connector

1. IPR valve
2. Engine harness connector

11. Connect engine harness connector to IPR valve.

NOTE: Some engines have a metal heat shield mounted over the IPR valve; others have an insulated snap shield on the IPR valve solenoid.

12. Install the correct heat shield for IPR valve:

- **Metal heat shield** (Table 30).

Install three mounting bolts in rear of exhaust heat shield and the two bolts in IPR valve heat shield and tighten to the special torque

- **Snap heat shield**

Install shield around the IPR valve cap and electrical connection and snap to connect.

13. Reinstall all safety guards, shields, and covers.
14. Make sure all tools, cleanliness covers, loose parts, and service equipment are removed from the engine work area.

Specifications

Table 29 IPR Valve and ICP Sensor

Injection Control Pressure (ICP) Sensor	
Operating pressure range	0 to 30 MPa (0 to 4,350 psi)
Injection Pressure Regulator (IPR) Valve	
IPR valve cracking pressure	31 MPa (4,500 psi)
IPR valve maximum pressure	38 MPa (5,500 psi)

Special Torque

Table 30 Oil Pump, Cover, IPR, and Heat Shields

Snap To Connect (STC) fitting	53 ± 4 N·m (39 ± 3 lbf·ft)
Hydraulic pump cover bolts	14 N·m (120 lbf·in)
Branch tube adapter bolts (M6 x 30)	14 N·m (120 lbf·in)
Injection Pressure Regulator (IPR)	50 ± 5 N·m (37 ± 4 lbf·ft)
Rear exhaust heat shield, (M6 x 12)	11 ± 3 N·m (96 ± 24 lbf·in)
Rear heat shield, (M10 x 16)	49 ± 5 N·m (36 ± 4 lbf·ft)

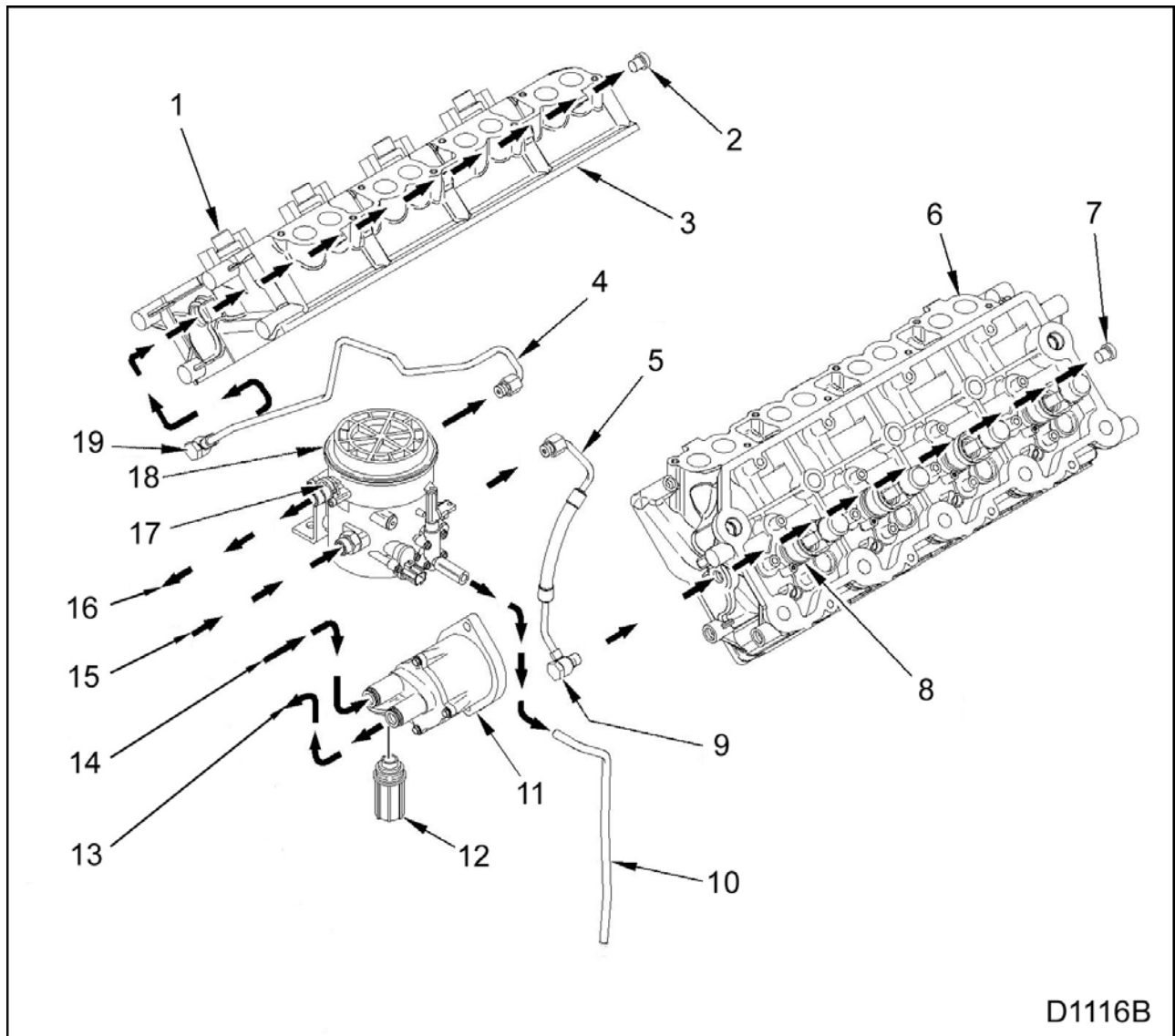
Special Service Tools

Table 31 High-pressure Oil Pump

Description	Tool Number
Cap Kit (All)	ZTSE4610
Dial Indicator with Magnetic Base	Obtain locally
IPR Valve Removal Tool	ZTSE4564
Liquid gasket (RTV) 6 oz. tube	1830858C1
Magnetic Cover	ZTSE4557
Quick Release Tool	ZTSE4581

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D1116B

Figure 528 Fuel system components

1. Fuel injector assembly (4)	8. Fuel injector assembly (4)	16. Fuel return to tank
2. Fuel rail plug assembly, right cylinder head	9. Banjo bolt, 12 mm with check valve, left cylinder head	17. Fuel filter regulator valve assembly
3. Cylinder head, right side	10. Fuel filter water drain tube assembly	18. Fuel filter housing assembly
4. Fuel supply line, right cylinder head	11. Fuel and power steering pump assembly (gear driven)	19. Banjo bolt, 12 mm with check valve, right cylinder head
5. Fuel supply line, left cylinder head	12. Filter strainer assembly	
6. Cylinder head, left side	13. Fuel from pump to filter	
7. Fuel rail plug assembly, left cylinder head	14. Fuel supply from tank	
	15. Fuel supply to filter from pump	

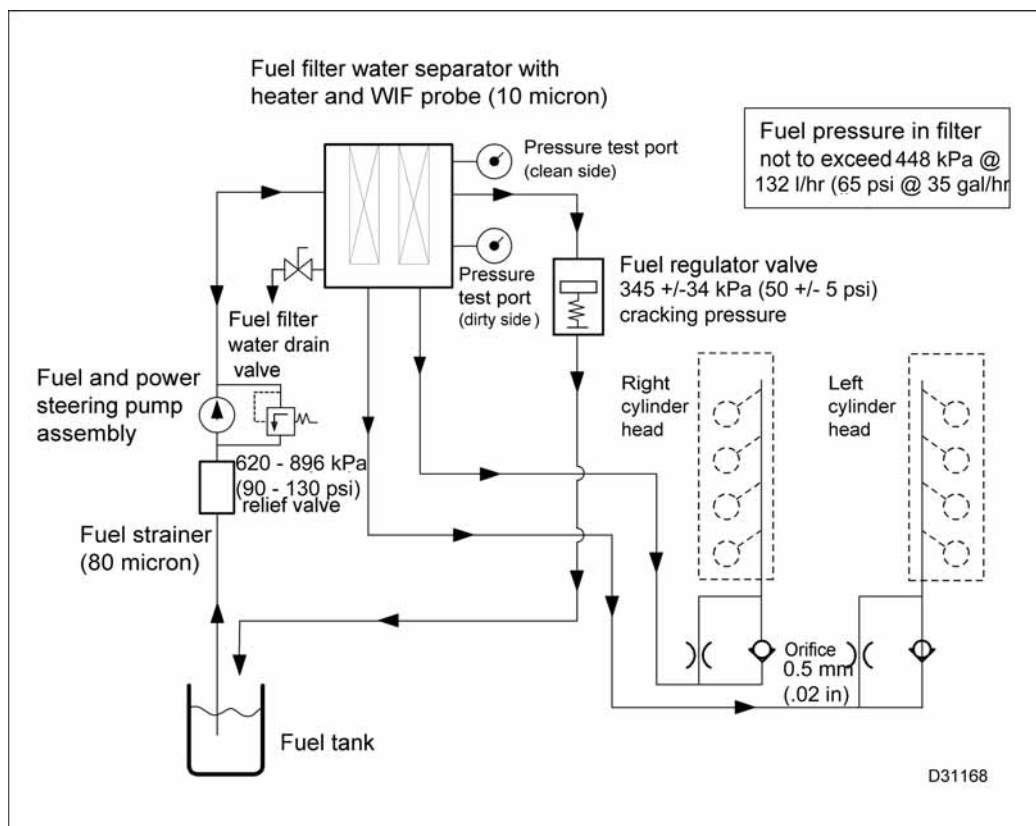


Figure 529 Fuel system schematic

Removal

Fuel Prescreen Element

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

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

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

CAUTION: Using propane or mixing propane with the recommended fuels specified in the *Engine Operation and Maintenance Manual* could cause engine damage. International Truck and Engine Corporation will not honor warranty claims against engines that have used fuels other than recommended fuels.

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

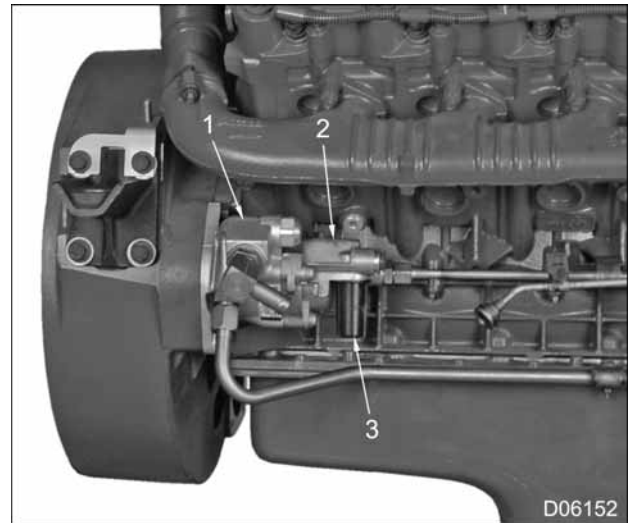


Figure 530 Removal of prescreen element

1. Power steering pump
2. Fuel pump
3. Prescreen bowl

1. Use a 30 mm box end wrench to remove prescreen bowl from fuel pump assembly.
2. Clean prescreen element after inspection or replace, if necessary.

Fuel Filter Element

1. Place a suitable container at end of fuel drain line to catch draining fuel.

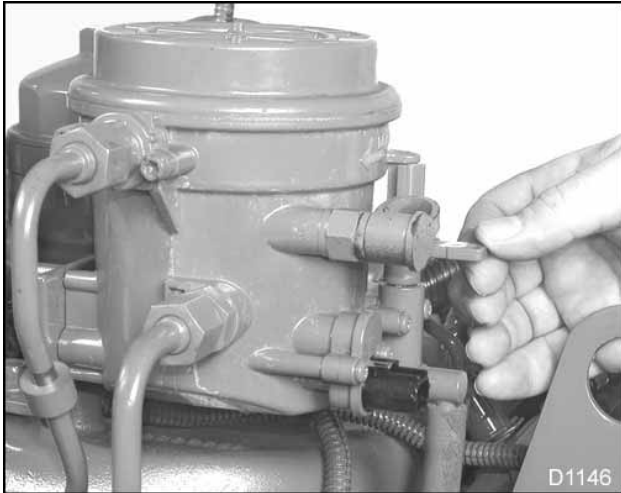


Figure 531 Fuel filter drain lever to DRAIN

2. Move fuel filter drain lever to DRAIN.
3. Remove fuel filter cap. Use an oil filter wrench if necessary.
4. Remove and discard the bevel cut gasket and clean mating surfaces.
5. Lift fuel filter element from housing.

Fuel Filter Assembly and Tubing

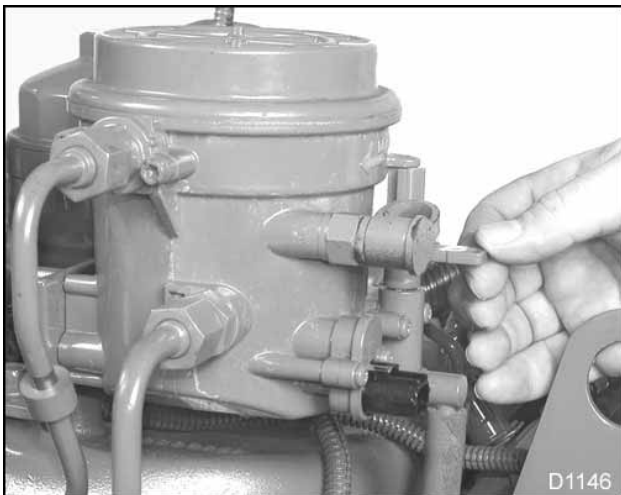


Figure 532 Fuel filter lever to DRAIN

1. Place a suitable container at end of fuel drain line to catch draining fuel.
2. Move fuel filter drain lever to DRAIN and shut drain lever when filter is empty.

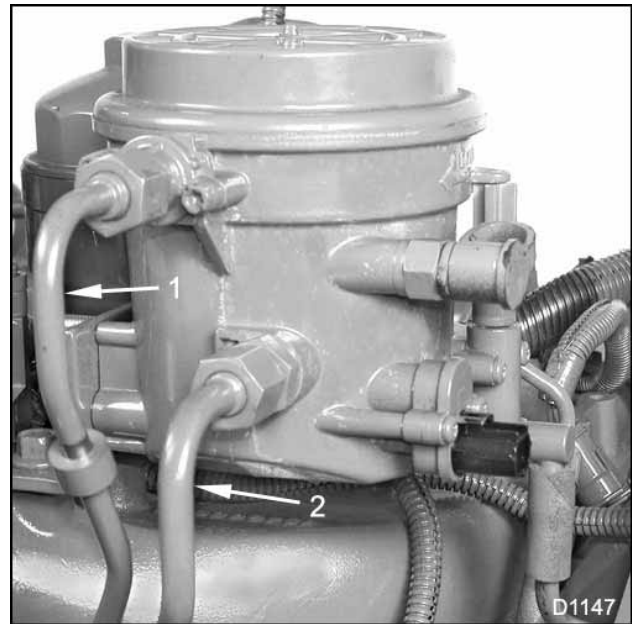


Figure 533 Fuel supply and return tubing

1. Fuel return tube
 2. Fuel supply tube
 3. Remove chassis fuel supply tube.
 4. Remove chassis fuel return tube.
 5. Remove fuel filter water drain tubing.
 6. Remove left cylinder head fuel supply tubing from fuel filter assembly.
- NOTE:** To remove the right cylinder head fuel supply tubing, it may be necessary to remove the oil filter cap assembly from the oil filter housing. This allows counterclockwise movement of the tube to be removed from the intake manifold.
7. Remove right cylinder head fuel supply tubing.
 8. Cap all openings to the fuel filter assembly.

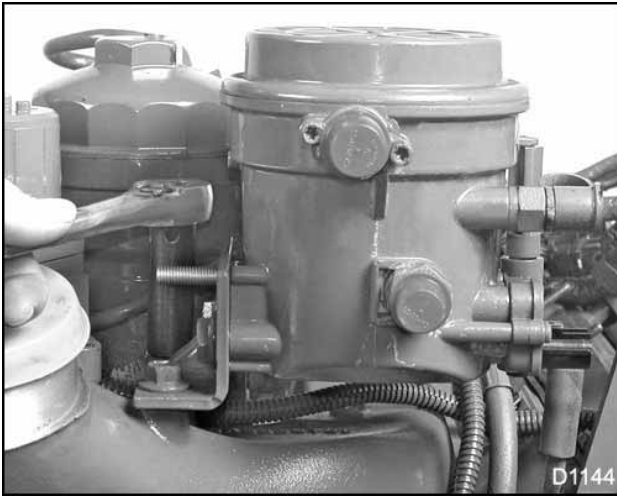


Figure 534 Removal of fuel filter support bracket

9. Remove two M10 x 20 bolts that secure fuel filter support bracket to intake manifold.

10. Remove fuel filter assembly.

Fuel Injectors

NOTE: See "Cylinder Head and Valve Train" section (Removal, page 106) for removal procedures.

Inspection

1. Inspect fuel lines for damage. Replace fuel lines if necessary.

Installation

Fuel Prescreen Element

1. Place cleaned prescreen element in the bowl or obtain a new precleaner assembly.

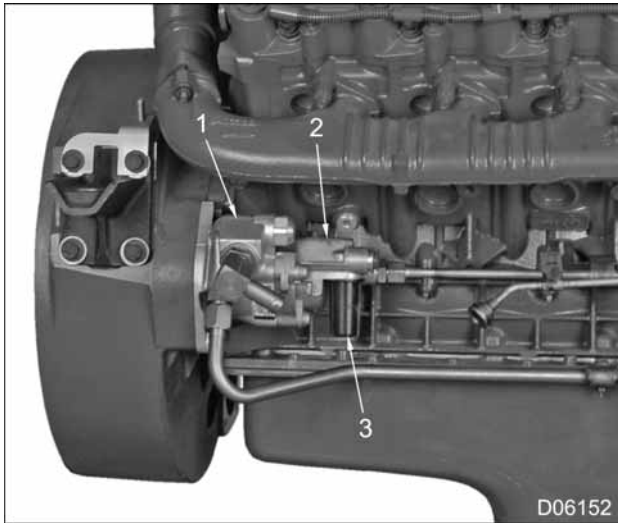


Figure 535 Installation of prescreen element and bowl

1. Power steering pump
 2. Fuel pump
 3. Prescreen bowl
-
2. Apply coating of diesel fuel on new strainer O-ring and prescreen bowl. Thread on fuel

transfer pump until hand tight and snug O-ring with 30 mm box end wrench.

Fuel Filter Assembly and Tubing



Figure 536 Fuel filter assembly

1. Install fuel filter assembly on intake manifold. Secure assembly with two M10 x 20 mounting bolts. Tighten bolts to the standard torque (Standard Torques, page 375).
2. Connect filter water drain tubing.



Figure 537 Fuel supply and return O-rings

1. Fuel return O-ring
 2. Fuel supply O-ring
3. Replace all O-rings in fuel return and supply fittings. Replace all banjo fitting copper washers in cylinder heads.



Figure 538 Filter drain and tubing for cylinder head fuel supply

1. Water drain tube assembly
2. Filter to left cylinder head tube assembly
3. Filter to right cylinder head tube assembly

4. Connect fuel tubing fittings to fuel filter assembly and leave hand tight. Connect banjo fitting ends to the left and right cylinder heads. Anchor right fuel tubing to EGR cooler stud. Tighten all fittings to the special torque (Table 33).

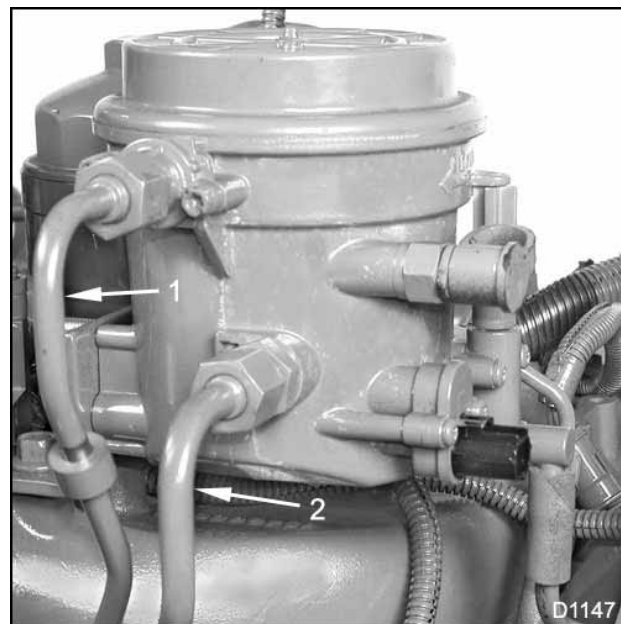


Figure 539 Connections for fuel supply and return tubing

1. Fuel return tube assembly
2. Fuel supply tube assembly

5. Connect chassis fuel supply and return tube assembly to fuel filter assembly and tighten fittings to the special torque (Table 33).

NOTE: Fuel filter drain lever must be closed.

Priming the Fuel System

Priming without Vacuum Source

NOTE: If the fuel system will not prime during diagnosis, the engine will exhibit white to black smoke and pulsating fuel pressure. See Combustion Leaks to Fuel in Section 4 of *Engine Diagnostics Manual* EGES-240.

If the engine is out of fuel, do the following steps:

1. Add fuel to tank. If equipped with dual tanks, add fuel to passenger side tank. Check fuel level in operator side tank to verify transfer pump is operating correctly.



Figure 540 Removal of fuel filter cap

2. Remove fuel filter cap using a band wrench. Leave filter in housing.
3. Fill fuel filter housing with diesel fuel up to the filter cap threads.
4. Replace fuel filter cap and tighten.
5. Engage starter for 30 seconds and allow starter to cool for two minutes.

NOTE: Return ignition key to RUN only between starts to decrease load on batteries. This will prevent glow plugs from recycling.

CAUTION: To prevent damage to the starter, if engine fails to start within 30 seconds, release ignition switch and wait 2 to 3 minutes to allow starter motor to cool. Repeat above procedure.

6. Repeat step 5 until engine starts and runs on its own.
 - Three to five cranking periods will be required to start vehicle. Additional cranking periods may be required if fuel filter is not primed.

NOTE: Engines in bus applications require more cranking time, since the rear tank is farther from the engine.

Priming with Vacuum Source

NOTE: If the fuel system will not prime during diagnosis, the engine will exhibit white to black smoke and pulsating fuel pressure. See Combustion Leaks to Fuel in Section 4 of *Engine Diagnostics Manual* EGES-240.

1. Add fuel to tank. If equipped with dual tanks, add fuel to passenger side tank. Check fuel level in operator side tank to verify transfer pump is operating correctly.



Figure 541 Unfiltered fuel pressure test port

2. Install fuel pressure test fitting in unfiltered fuel test port.
3. Attach vacuum source to fuel pressure test coupling and connect to fuel pressure test fitting.
4. Draw fuel from tank using vacuum source until level in fuel filter housing reaches fitting.
5. Disconnect vacuum source and fuel pressure test coupler from fuel pressure test fitting.
6. Engage starter for 30 seconds and allow starter to cool for two minutes.

NOTE: Return ignition key to RUN only between starts to decrease load on batteries. This will prevent glow plugs from recycling.

CAUTION: To prevent damage to the starter, if engine fails to start within 30 seconds, release ignition switch and wait 2 to 3 minutes to allow starter motor to cool. Repeat above procedure.

7. Repeat step 6 until engine starts and runs on its own.
 - Three to five cranking periods will be required to start vehicle. Additional cranking periods may be required if fuel filter is not primed.
8. After engine has been started and is running smoothly, stop engine and remove fuel pressure test fitting and reinstall plug in filter housing.

Fuel Filter Element

NOTE: If the fuel system has been completely drained, prime the fuel system to aid starting. Fill the filter housing with clean diesel fuel up to the filter cap threads, before installing the cap. Priming is not necessary, if only the filter housing was drained for regular filter replacement.

1. Apply coating of diesel fuel to new bevel gasket and install on fuel filter assembly.
2. Install new fuel filter element in fuel filter housing and tighten cap onto fuel filter assembly.

CAUTION: To prevent engine damage, tighten fuel cap on fuel filter assembly. The engine will not run, if the fuel filter element is not installed. The fuel filter element is required to open the valve in the center stand pipe, allowing fuel to flow into the filter.

3. Move fuel filter drain lever to close.

Fuel Injectors

NOTE: See the "Cylinder Head and Valve Train" section (Removal, page 106) for installation procedures.

Specifications

Table 32 Fuel Filter and Pressure Regulating Valve

Fuel Filter	
Type	10 micron with water separation
Normal fuel pressure (after fuel filter)	345 to 482 kPa (50 to 70 psi)
Fuel Pressure Regulating Valve	
Valve opening pressure	351 ± 31 kPa (51 ± 5 psi)
Heater element activates	3.6 to 10.8°C (38.5 to 51.5°F)
Heater element deactivates	19.1 to 29.6°C (66.5 to 83.5°F)

Special Torque

Table 33 Fuel System Components

Fuel supply tube assembly at filter	41 ± 4 N·m (30 ± 3 lbf·ft)
Fuel return tube assembly at filter	25 ± 2 N·m (19 ± 2 lbf·ft)
Left and right cylinder head supply tubing at filter	25 ± 2 N·m (18 ± 2 lbf·ft)
Banjo bolt, 12 mm	38 ± 4 N·m (28 ± 3 lbf·ft)
Fuel rail plug assembly, 12 mm (back of cylinder head)	27 ± 1 N·m (20 ± 1 lbf·ft)
Power steering pump inlet elbow fitting	90 ± 10 N·m (66 ± 7 lbf·ft)
Power steering pump outlet elbow fitting	45 ± 4 N·m (33 ± 3 lbf·ft)
Power steering tube	79 ± 4 N·m (58 ± 3 lbf·ft)

Special Service Tools

Table 34 Fuel System

Description	Tool Number
Cap Kit (All)	ZTSE4610
Fuel Gallery Cleaning Brush	ZTSE4541

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Removal

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

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

Preliminary Checks

Flexplate (Automatic Transmission)

1. Inspect flexplate for cracks around webbing and ring gear weldments.
2. Inspect all ring gear teeth for starter pinion damage.
3. Replace flexplate if necessary.

Flywheel (Manual Transmission)

1. Inspect flywheel for cracks around webbing and bolt holes.
2. Inspect flywheel for heat checks and extensive scoring.
3. Check for ring gear damage associated with the starter pinion
4. Replace flywheel if necessary.

Flywheel Surface Runout

CAUTION: To prevent engine damage, check runout of flywheel surface to ensure correct alignment of engine to transmission. Failure to ensure correct bore concentricity and face runout may reduce life of clutch or transmission.

NOTE: Keep crankshaft end play at zero in the same direction for all measurements.

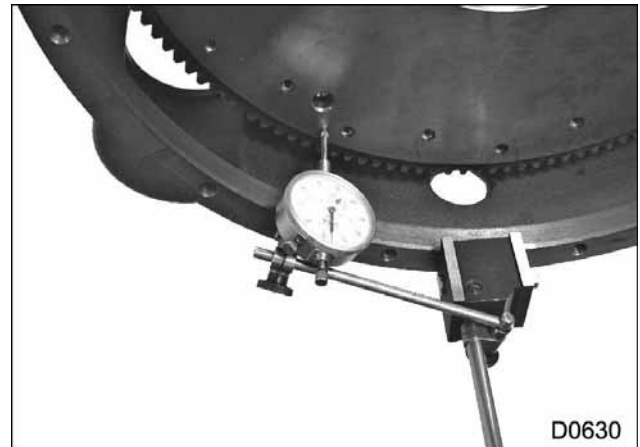


Figure 542 Flywheel surface runout

1. Attach dial indicator (Table 37) to rear cover. Place indicator tip against surface of flywheel.
2. Zero the dial indicator.
3. Rotate crankshaft slowly. (Table 35).

Rear Cover Runout

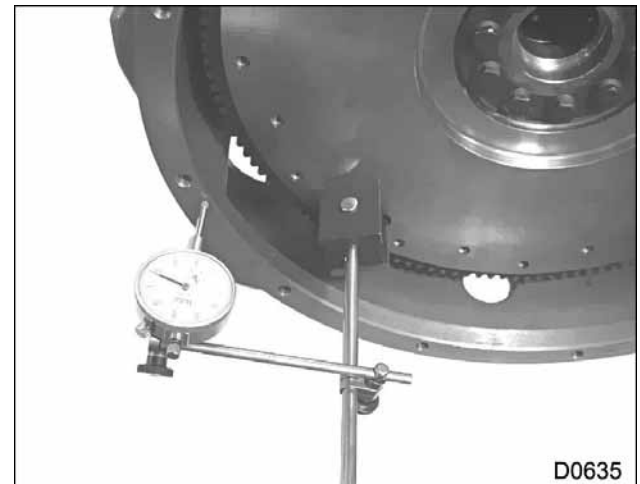


Figure 543 Rear cover runout

1. Attach dial indicator (Table 37) to surface of flywheel. Place indicator tip against rear cover.

NOTE: Keep crankshaft end play at zero in the same direction for all measurements.

2. Zero the dial indicator.

3. Measure at four points 90° apart for total face variation with (Table 35).

Backlash Test for Secondary Flange (Crankshaft Gear)

NOTE: Before doing this test, remove the power steering and fuel pump assembly. See (Secondary Flange, page 315) for procedure.

1. Attach dial indicator (Table 37) to rear cover.
2. Place indicator tip against secondary flange (crankshaft gear).
3. Lock the power steering idler gear. (For accurate measurement, the power steering idler gear must not move.)
4. Zero the dial indicator.
5. Move the secondary flange. Verify reading with the specification in (Table 35).

Backlash Test for Power Steering Idler Gear

NOTE: Before doing this test, remove the power steering and fuel pump assembly. See (Power Steering and Fuel Pump Assembly, page 316) for procedure.

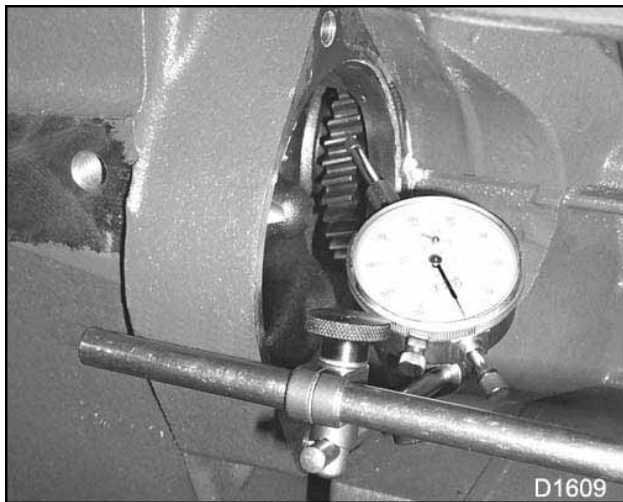


Figure 544 Idler gear backlash

1. Attach dial indicator (Table 37) to rear cover.
2. Place indicator tip against power steering idler gear.
3. Lock the power steering drive gear.

NOTE: The power steering drive gear must be locked for an accurate measurement.

4. Zero the dial indicator.
5. Move the power steering idler gear and record the dial indicator reading. Verify reading with the specification in (Table 35).

Flexplate (Automatic Transmission)



Figure 545 Flexplate hardware

1. Flexplate bolts (10)
2. Reinforcement ring
3. Flexplate adapter hub
4. Transmission side stamp (XMSN-SIDE)

1. Remove and discard ten M10 x 77 flexplate mounting bolts. Do not reuse these bolts.
2. Remove the reinforcement ring, flexplate, and adapter hub.

Flywheel (Manual Transmission)



Figure 546 Flywheel guides

1. Remove and discard two M10 x 77 flywheel mounting bolts at approximately 3 o'clock and 9 o'clock. Do not reuse these bolts.
2. Install two guide pins (make locally).
3. Remove and discard remaining eight flywheel mounting bolts. Do not reuse these bolts.

4. Remove reinforcement ring.

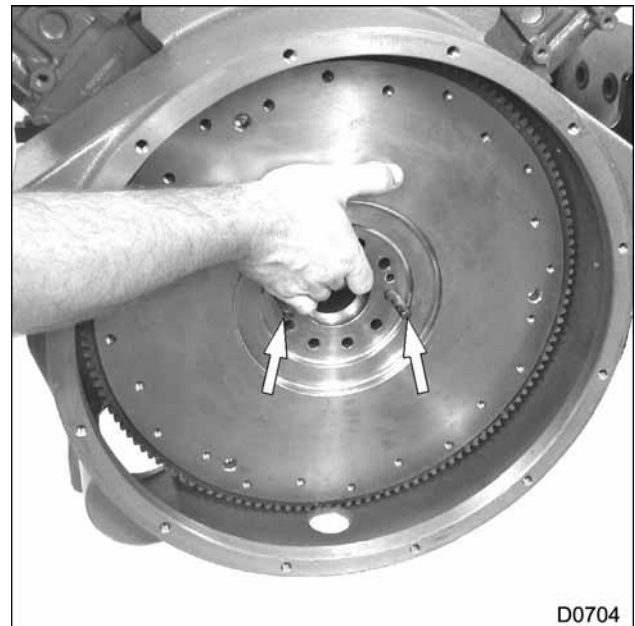


Figure 547 Flywheel guide pins

5. Slide flywheel off guide pins and out of housing.
6. Remove guide pins from secondary flange.

Rear Main Seal and Wear Sleeve



Figure 548 Starter holes

1. Starter hole
2. Rear main seal

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

1. Use an awl or 1/8 inch drill bit to make two small starter holes 180° apart in rear main seal.



Figure 549 Hammer screw in starter hole

2. Thread slide hammer screw into one of the starter holes.
3. To remove seal evenly, slide hammer on one side, and then alternate to other side.



Figure 550 Rear main oil seal removal

4. Remove and discard rear main oil seal from rear oil seal carrier.

NOTE: When replacing the rear main seal, note that production engines will not have a wear sleeve. Wear sleeves are only available as a service item included with the replacement rear main oil seal.

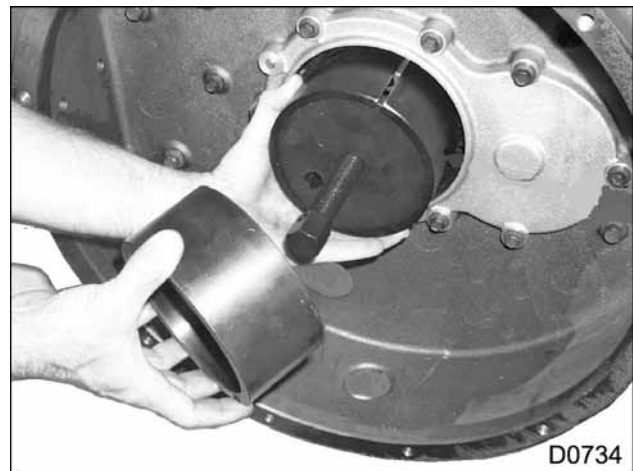


Figure 551 Wear sleeve removal tool

5. Install wear sleeve removal tool.

NOTE: Before applying force to threaded shaft, make sure the half shells of the wear sleeve removal tool are secured behind wear sleeve.

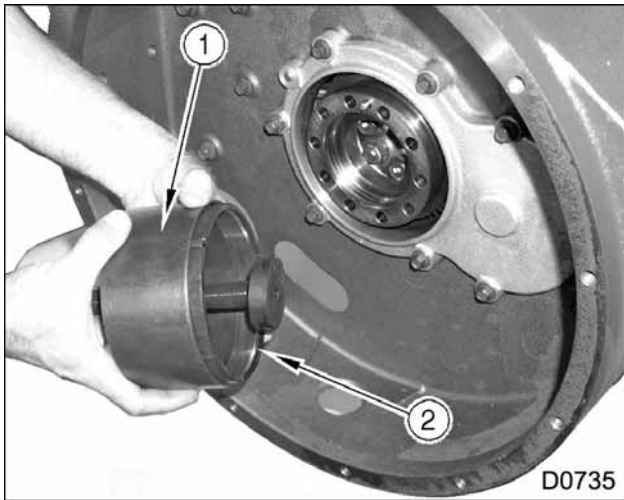


Figure 552 Wear sleeve

1. Wear sleeve removal tool
2. Wear sleeve

6. Turn the threaded shaft clockwise until the wear sleeve is free of the crankshaft flange.

Secondary Flange

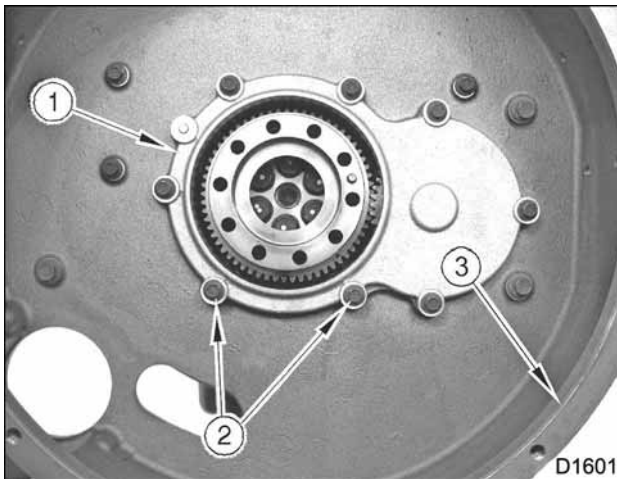


Figure 553 Rear cover and rear oil seal carrier

1. Rear oil seal carrier
2. Long bolts
3. Rear cover

1. Remove eight M8 bolts from rear oil seal carrier .



Figure 554 Rear oil seal carrier

2. Remove rear oil seal carrier and discard gasket.

NOTE: Do the backlash test for the secondary flange and power steering idler gear. See (Backlash Test for Secondary Flange (Crankshaft Gear) , page 312) before doing the following steps.

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

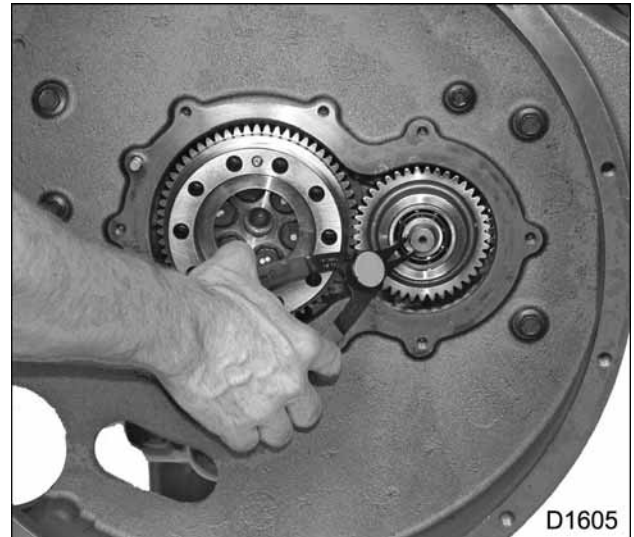


Figure 555 Snap ring on power steering idler gear

3. Remove snap ring from power steering idler gear.

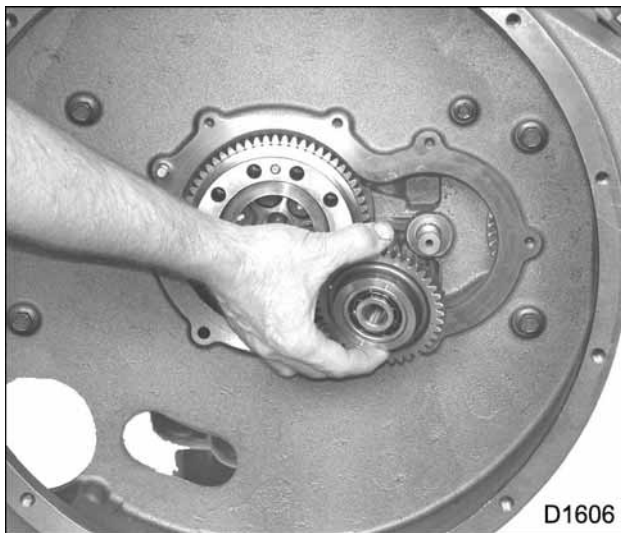


Figure 556 Power steering idler gear

4. Remove power steering idler gear.

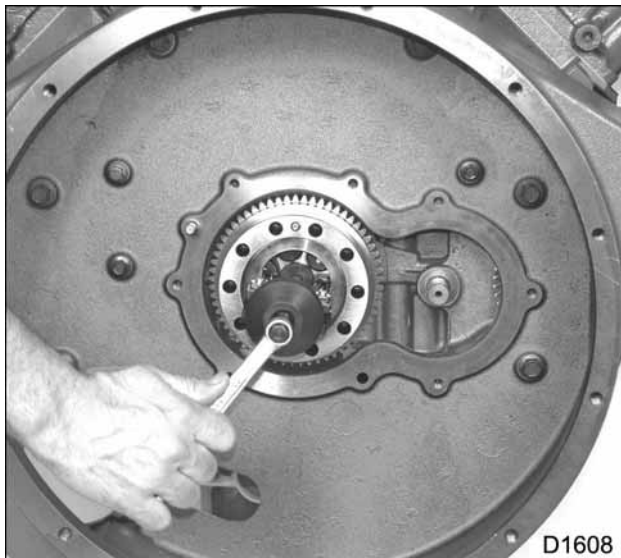


Figure 557 Secondary flange

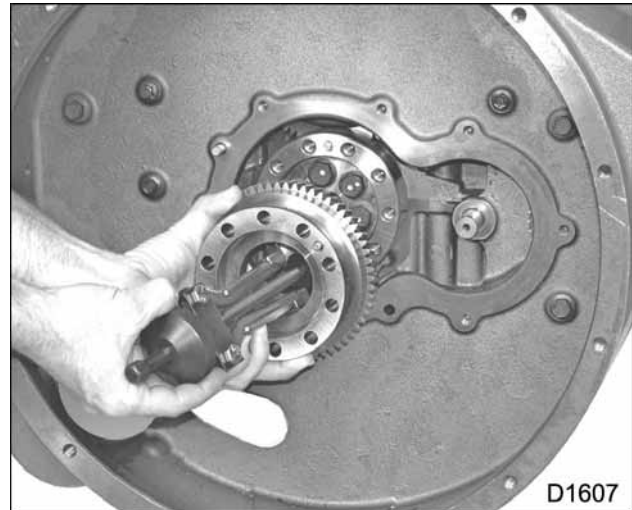


Figure 558 Gear puller

5. Use a gear puller to remove the secondary flange.

Power Steering and Fuel Pump Assembly

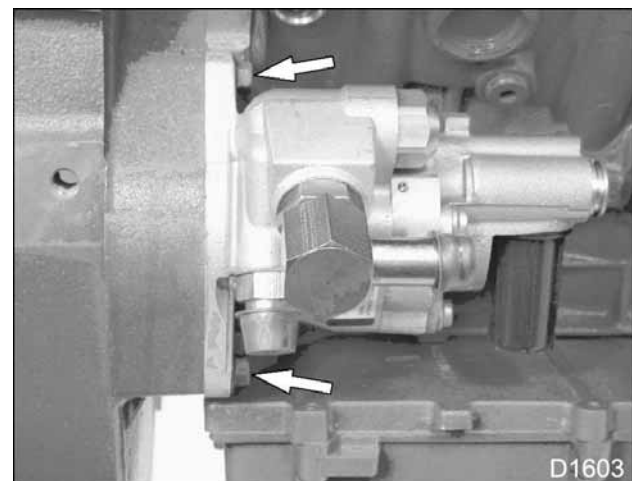


Figure 559 Mounting bolts for power steering and fuel pump assembly

1. Remove two M10 x 30 mounting bolts from power steering and fuel pump assembly.

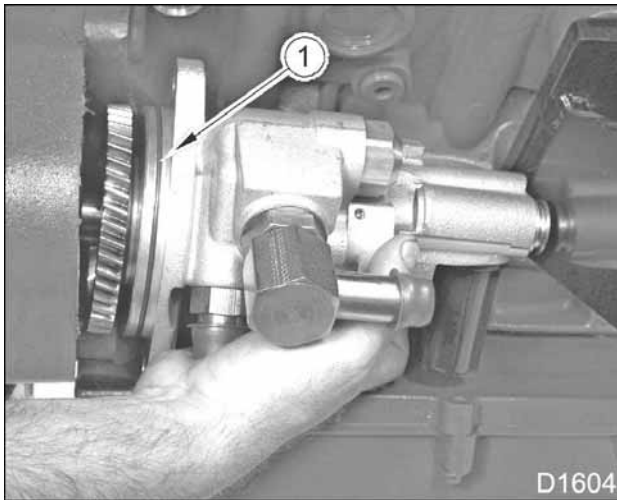


Figure 560 Power steering and fuel pump assembly

1. O-ring

2. Remove power steering and fuel pump assembly from rear cover and discard O-ring.

NOTE: The power steering and fuel pump assembly is serviced only as a single unit.

Rear Cover and Power Steering Idler Shaft

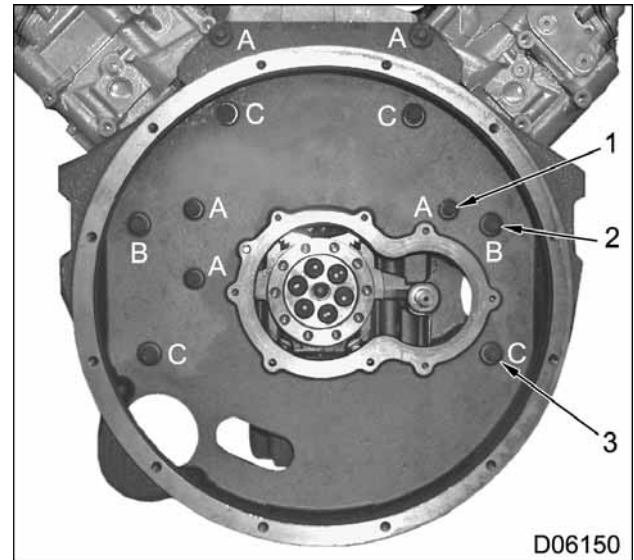


Figure 561 Rear cover mounting bolts

1. Bolts marked A, (M10 x 55) (5)
2. Bolts marked B, (M10 x 70) (2)
3. Bolts marked C, (M10 x 60) (4)

1. Remove eleven mounting bolts from rear cover.
2. Use a thin gasket scraper to separate sealant between rear cover joints listed below, to avoid pulling these gaskets out when removing the rear cover assembly.
 - Upper and lower crankcase
 - Rear cover assembly
 - Crankcase
 - High-pressure oil pump cover
 - Rear cover assembly

! WARNING: To prevent personal injury or death, get help when removing the rear cover.

3. Remove rear cover.

NOTE: If necessary, use a slide hammer to remove power steering idler shaft.

Cleaning

All Components

1. Clean foreign material from gasket surfaces of crankcase and rear cover. Use a scraper or wire brush to remove sealant from gasket surfaces.
2. Gasket surfaces must oil free for good adhesion of liquid gasket during assembly. Use a commercially available, non-caustic brake cleaner to clean gasket surfaces of crankcase and rear cover.
3. Remove sealant under the hydraulic oil pump cover while it is still in place.
4. Wash rear oil seal carrier, flywheel, flexplate, and rear cover. Dry all with filtered compressed air.
5. Wash secondary flange, power steering idler gear, and shaft with a stiff brush and suitable solvent. Dry all with filtered compressed air.



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).

Installation

Rear Cover and Power Steering Idler Shaft

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

1. If removed, install the power steering idler shaft into the rear cover. Make sure the bore of the idler shaft is clean.

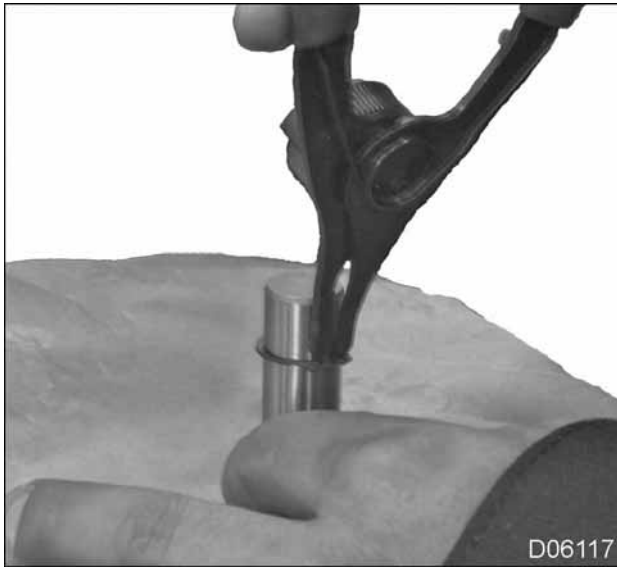


Figure 562 Retaining ring on idler shaft

2. Place a retaining ring on the end of the shaft without the threaded hole.



Figure 563 Idler shaft and retaining ring in installation tool

3. Put the threaded hole end of the idler shaft into the installation tool to set the correct height. $34.6 \pm 0.15 \text{ mm}$ ($1.362 \pm 0.006 \text{ in}$)

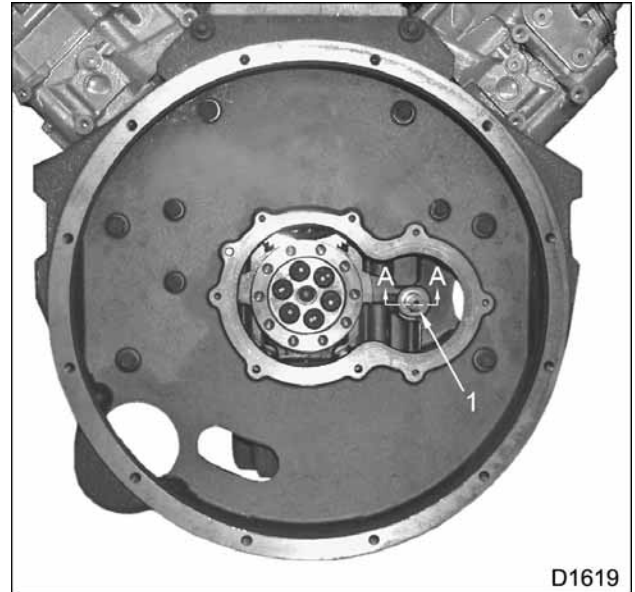


Figure 564 Power steering idler shaft in transmission side of rear cover

1. Power steering idler shaft (Section A-A)

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



Figure 565 Idler shaft in the rear cover assembly

CAUTION: To prevent engine damage, do not allow the retaining ring to contact the rear cover. Contact may distort the retaining ring, adversely affecting its performance as a gear thrust surface.

4. Align the idler shaft in the rear cover at the correct location. Using the installation tool, drive the idler shaft in the idler shaft bore in the transmission side of the rear cover, until the installation tool bottoms out.

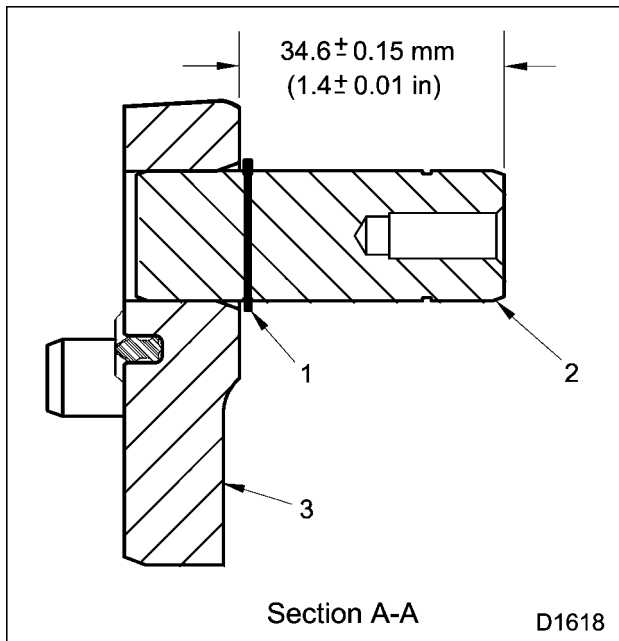


Figure 566 Power steering idler shaft installation height

1. Retaining ring
 2. Power steering idler shaft
 3. Rear cover assembly
5. If installation tool is not available, use brass drift to install the idler shaft in the rear cover to the correct height.

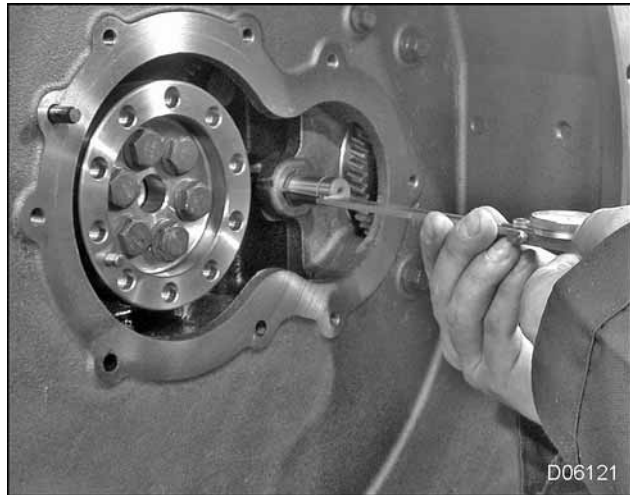


Figure 567 Idler shaft height measurement

6. Measure idler shaft height, using a dial caliper. Idler shaft height should be 34.6 ± 0.15 mm (1.362 ± 0.006 in).

CAUTION: To prevent engine damage, replace dowel pins in crankcase if damaged or missing.

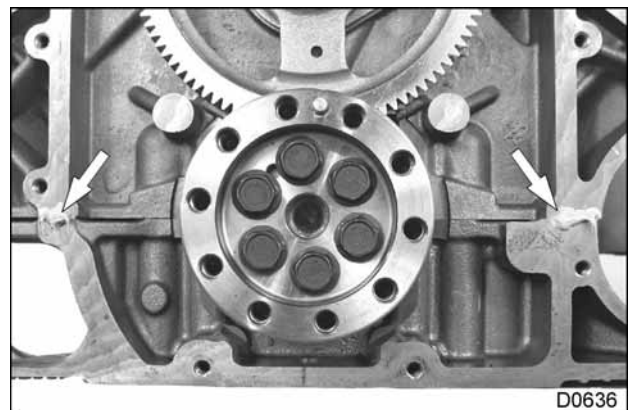


Figure 568 Application of sealant

1. Apply Liquid Gasket (RTV) (Table 37) at the ends, where the crankcase and the lower crankcase meet. Apply liquid gasket to the hydraulic oil pump cover joint, if the cover was not removed.

CAUTION: To prevent engine damage, do not allow the retaining ring to contact the rear cover. Contact may distort the retaining ring, adversely affecting its performance as a gear thrust surface.

2. Make sure that the rear cover gasket is in place, before installing the rear cover.

! WARNING: To prevent personal injury or death, get help when installing the rear cover.

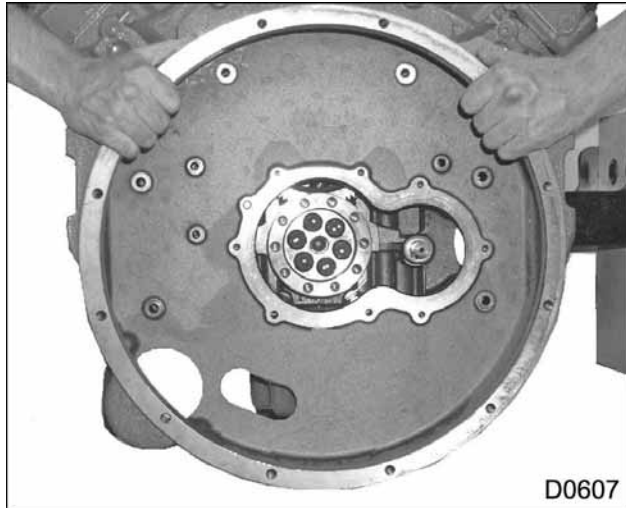


Figure 569 Rear cover

3. Install rear cover assembly with the aid of an assistant.

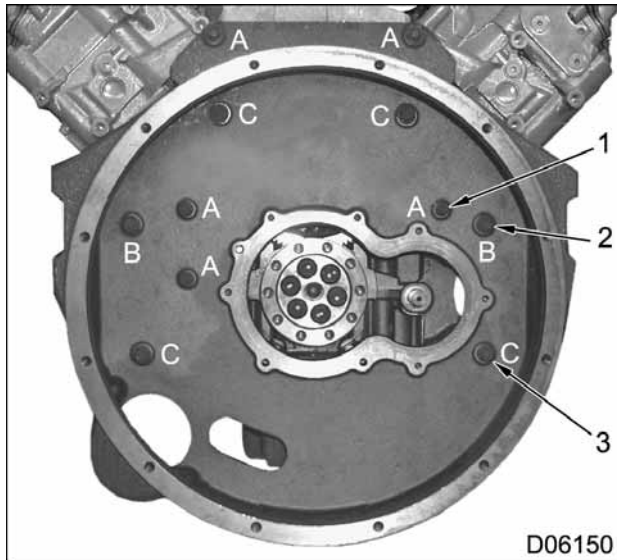


Figure 570 Rear cover mounting bolts

1. Bolts marked A, (M10 x 55) (5)
2. Bolts marked B, (M10 x 70) (2)
3. Bolts marked C, (M10 x 60) (4)

4. Install eleven rear cover mounting bolts. Tighten all bolts to the standard torque.

Secondary Flange

CAUTION: To prevent possible damage to the engine, transmission, or truck, correct dowel pin protrusion is critical when aligning the flywheel or flexplate and the reinforcement ring.

1. Install the dowel pin in the secondary flange gear.



Figure 571 Dowel pin in the secondary flange gear

2. Use a dial caliper to verify the protrusion height. Dowel pin protrusion should be 8.0 ± 0.25 mm (0.315 ± 0.01 in).
3. Clean the inside surfaces and the inner face surface of the secondary flange gear.

CAUTION: To prevent possible damage to the engine or truck, do not apply sealant on the face of the primary flange or the inner mounting surface of the secondary flange.

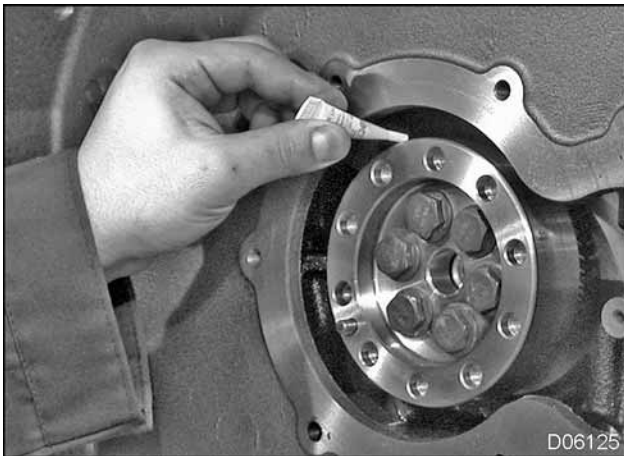


Figure 572 Application of Loctite® on the primary crankshaft flange

4. Apply Loctite® on the outside diameter of the primary crankshaft flange.

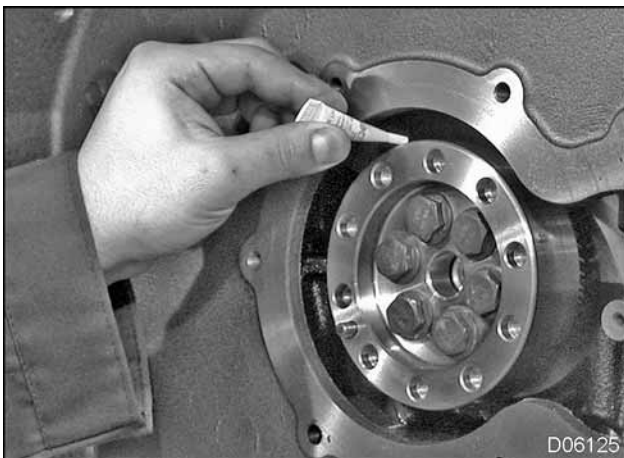


Figure 573 Application of Loctite® on the primary crankshaft flange

5. Spread the Loctite® evenly around primary crankshaft flange. Do not get any Loctite® on the face of the crankshaft flange.

CAUTION: To prevent damage to the engine, transmission, or vehicle, seat the secondary flange onto crankshaft in one step. When two surfaces are mated (air is removed) Loctite® sets up within 5 minutes. Installation after Loctite® has set will break the seal between the crankshaft flange and the secondary flange and cause leakage.



Figure 574 Crankshaft secondary flange installation studs (ZTSE4720)

6. Install two Crankshaft Secondary Flange Installation Studs, evenly spaced, into the crankshaft flange.
7. Align the dowel pin hole with the crankshaft dowel pin and slide secondary flange onto the studs.

NOTE: You have 5 minutes to fully draw the secondary flange onto the crankshaft flange.

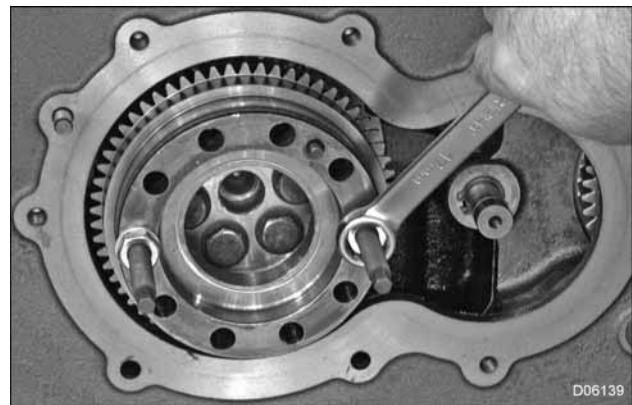


Figure 575 Secondary flange

8. Install two nuts and washers. Seat the flange by alternately tightening nuts on the studs.
9. Remove nuts, washers, and studs after flange has been seated.

CAUTION: To prevent possible engine or vehicle damage, do not drive the idler gear onto the shaft: this could damage the gear and gear teeth. For correct fit, rotate the gear for the power steering and fuel pump assembly .

CAUTION: To prevent possible engine or vehicle damage, ensure the circular witness groove is facing you. Installing the gear in backwards will cause abnormal wear and damage to the gear.

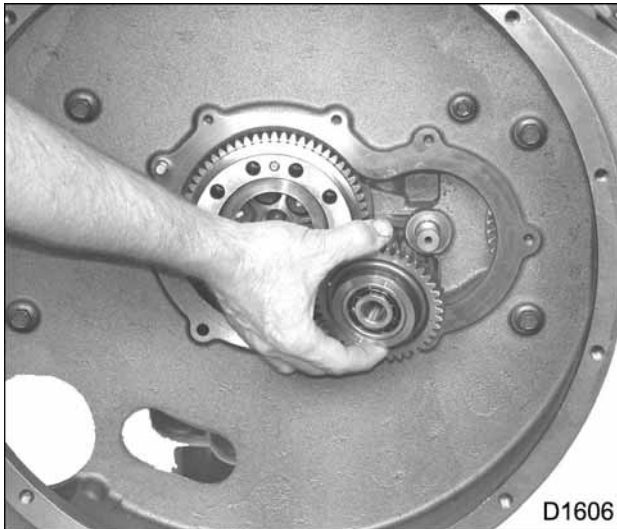


Figure 576 Power steering idler gear

10. Install power steering idler gear on shaft.

NOTE: The gear of the power steering and fuel pump assembly may have to be rotated for correct fit of the gears. Do not drive the gear onto the shaft.

11. Verify correct gear orientation and gear teeth engagement.

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

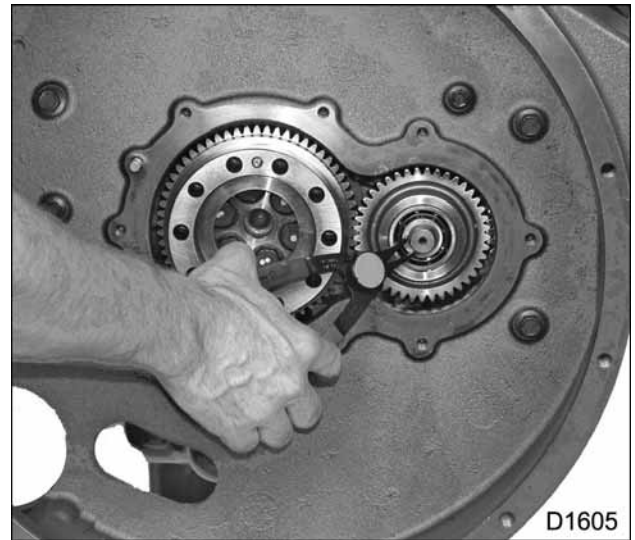


Figure 577 Power steering idler gear retaining ring on shaft

12. Install retaining ring onto the shaft for the power steering idler gear

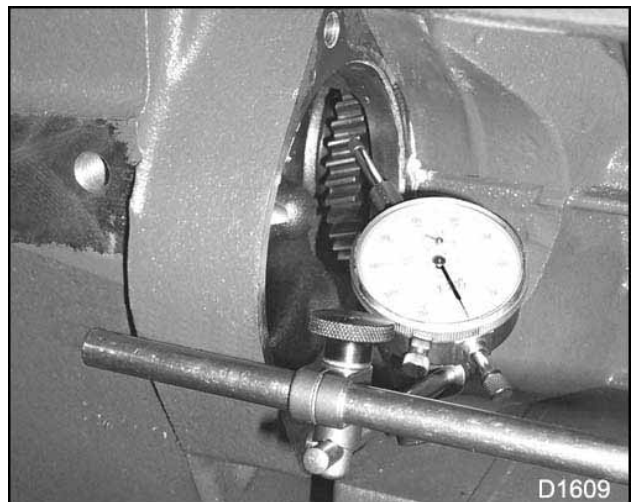


Figure 578 Idler gear backlash

13. Check the idler gear backlash. See (Figure 578).

14. Install new gasket on rear oil seal carrier.

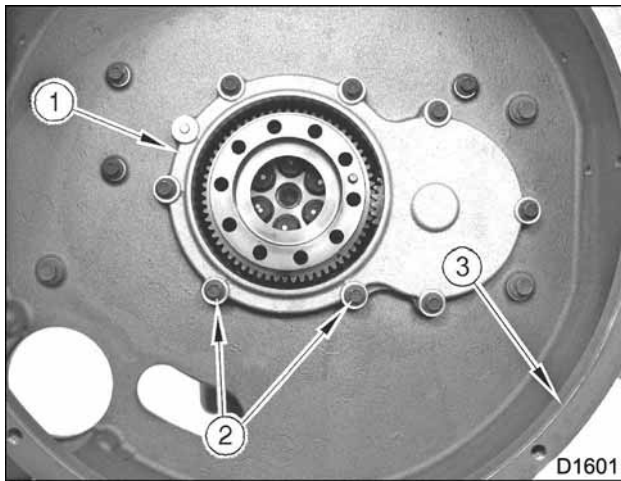


Figure 579 Rear cover and rear oil seal carrier

1. Rear oil seal carrier
 2. Longer bolts (M8 x 70)
 3. Rear cover
15. Install two M8 x 70 bolts in lower holes of rear oil seal carrier (Figure 579). Tighten bolts to the standard torque (Standard Torques, page 375).
 16. Install six remaining x 285 bolts M8 to secure rear oil seal carrier to rear cover.(Figure 579). Tighten bolts to the standard torque (Standard Torques, page 375).

Rear Main Oil Seal and Wear Sleeve

CAUTION: To prevent engine damage, do not separate wear sleeve from oil seal; this will damage the seal and engine.

NOTE: When replacing the rear main oil seal, note that production engines will not have a wear sleeve. Wear sleeves are only available as a service item included with the replacement rear main oil seal.

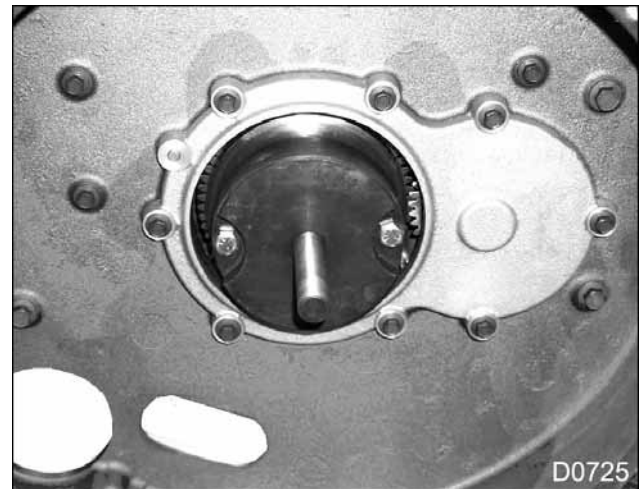


Figure 580 Rear/Wear Sleeve Installer

1. Bolt Rear/Wear Sleeve Installer (Table 37) on end of crankshaft. Make sure crankshaft alignment dowel fits in dowel recess hole in the rear/wear sleeve installer.

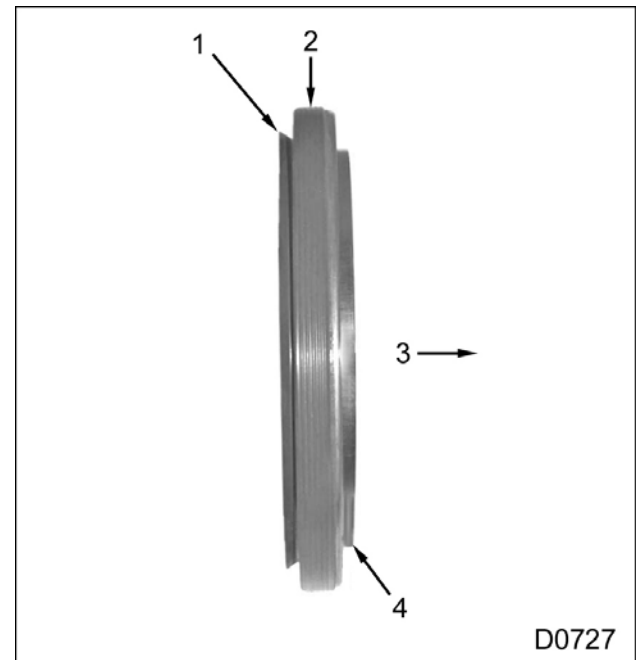


Figure 581 Orientation of rear main oil seal and wear sleeve

1. Dust seal lip
2. Rear main oil seal
3. Crankshaft side (forward)
4. Wear sleeve (internal bevel)

2. Position seal (Figure 581) and slide onto Rear/Wear Sleeve Installer.

NOTE: Before assembly, lubricate the outer diameter of rubber seal with a solution of dish washing soap and water (approximately 50/50 mix). Do not use other lubricants.



Figure 582 Sealant application to secondary crankshaft flange

3. Before installing wear sleeve and rear main seal oil, apply a 360° bead of Loctite® Hydraulic Sealant (Table 37) onto the rear edge of the secondary crankshaft flange.

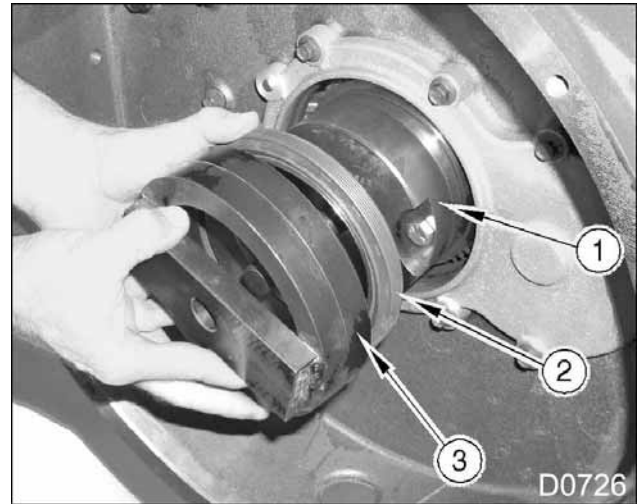


Figure 583 Rear/Wear Sleeve Installer

1. Base
2. Rear main oil seal and wear sleeve
3. Rear/wear sleeve installer
4. Position rear main oil seal and wear sleeve onto the rear/wear sleeve installer.

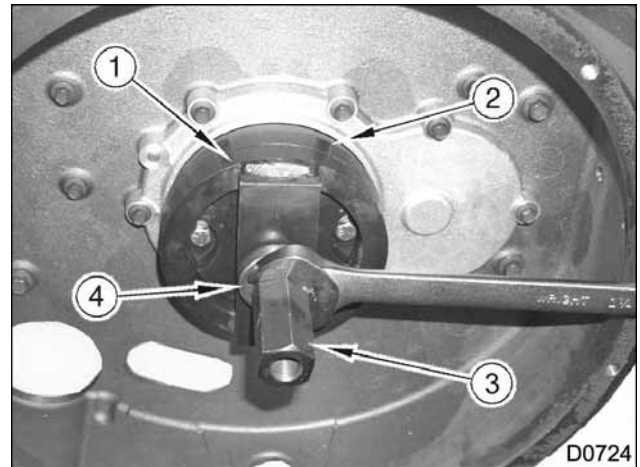


Figure 584 Rear main oil seal and wear sleeve combination on crankshaft

1. Rear/wear sleeve installer
2. Rear main oil seal
3. Drive nut
4. Thrust bearing
5. Place thrust bearing and drive nut on threaded shaft. Tighten nut until rear main oil seal bottoms out in rear oil seal carrier.

Power Steering and Fuel Pump Assembly

1. Check power steering and fuel pump assembly for cracks, leaks or other damage. Before installation, put a new O-ring on power steering and fuel pump assembly.

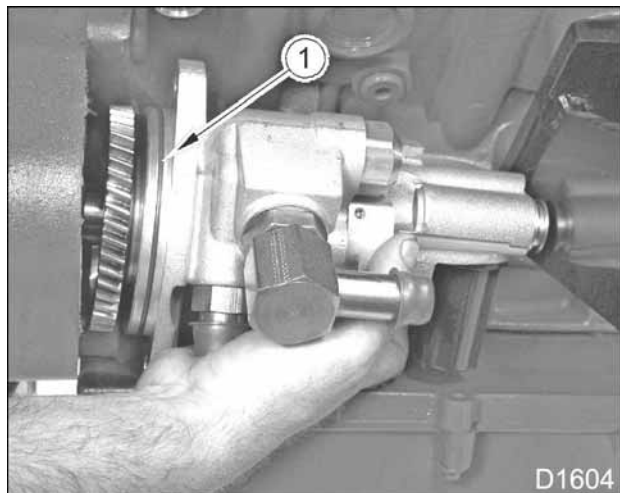


Figure 585 Power steering and fuel pump assembly

1. O-ring
2. Install power steering and fuel pump assembly in rear cover.

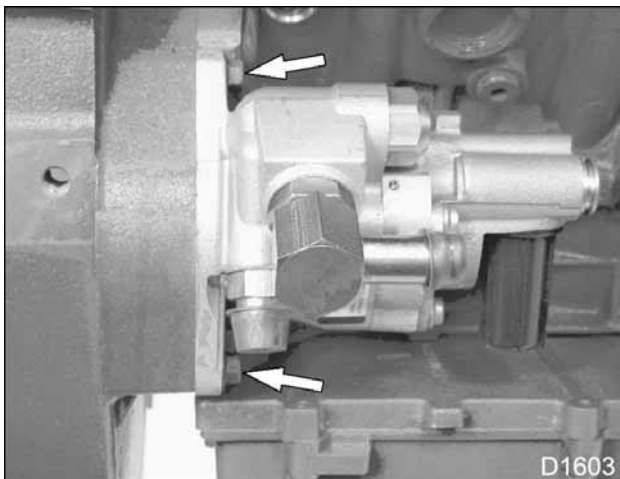


Figure 586 Mounting bolts for power steering and fuel pump assembly

3. Install two M10 x 30 mounting bolts for power steering and fuel pump assembly. Tighten bolts to the standard torque.

Flexplate

CAUTION: To prevent engine damage, use new bolts to install flexplate.

CAUTION: Do not use anti-seize compounds, grease or lubricants. Each has an adverse effect on torque results.

1. Position flexplate on adapter hub and align hub over the crankshaft secondary flange dowel. Make sure the XMSN-SIDE stamp is facing the transmission.



Figure 587 Flexplate

1. Flexplate bolts, M10 x 77 (10)
2. Reinforcement ring
3. Flexplate adapter hub
4. Transmission side stamp (XMSN-SIDE)
2. Make sure lip on outer circumference of reinforcement ring faces the transmission and align bolt holes to position reinforcement ring.
3. Install two M10 x 77 bolts for flexplate 180° apart through reinforcement ring, flexplate, and adapter hub.
4. Place flexplate assembly on crankshaft. Hand tighten two bolts to hold assembly.
5. Install eight remaining M10 x 77 mounting bolts.

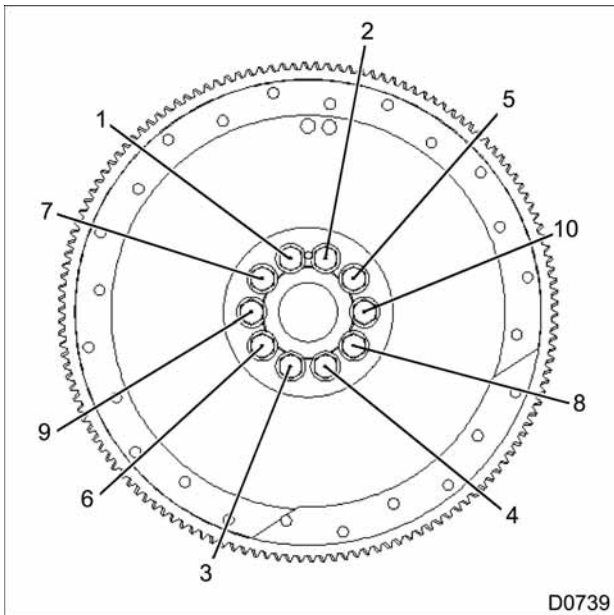


Figure 588 Torque sequence for flexplate

6. Snug all bolts in the sequence shown to 1 to 7 N·m (12 to 60 lbf·in).
7. Torque all bolts in the sequence to the special torque (Table 36).

Flywheel

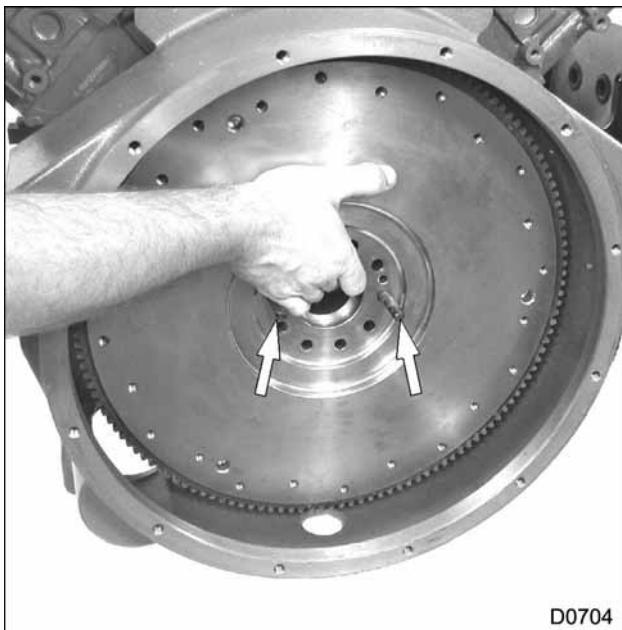


Figure 589 Flywheel on guide pins

1. Install two flywheel guide pins (made locally) in crankshaft flange at approximately 3 o'clock and 9 o'clock.
2. Align dowel hole in flywheel with crankshaft secondary flange dowel and slide flywheel onto guide pins.
3. Align reinforcement ring with dowel and slide over guide pins. Make sure lip on outer circumference of ring faces the transmission.

CAUTION: To prevent engine damage, use new bolts to install flywheel.

CAUTION: Do not use anti-seize compounds, grease or lubricants. Each has an adverse effect on torque results.

NOTE: New phosphate coated bolts do not require oil before torquing.

4. Install two new M10 x 77 bolts to secure flywheel to crankshaft. Remove both guide pins.
5. Install eight remaining M10 x 77 bolts.

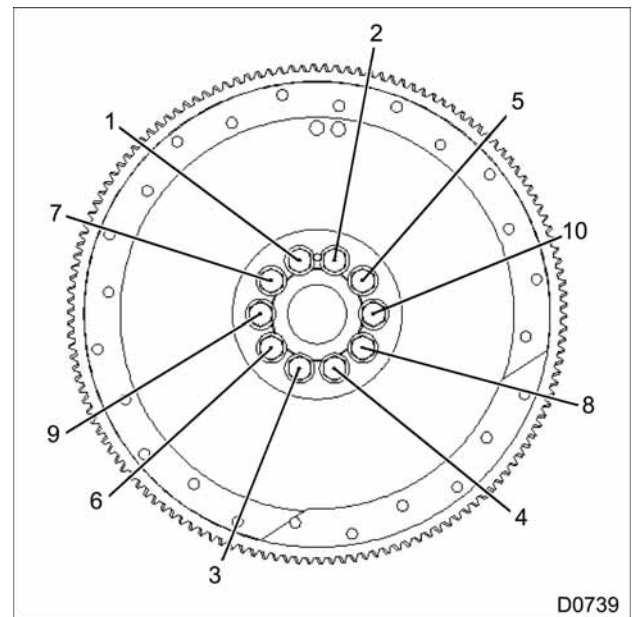


Figure 590 Torque sequence for flywheel

6. Snug bolts in the sequence to 1 to 7 N·m (12 to 60 lbf·in).
7. Torque all bolts in the sequence to the special torque (Table 36).
8. Reinstall safety guards, shields, and covers.

9. Make sure tools, cleanliness covers, loose parts, and service equipment are removed from the engine area.

Specifications

Table 35 Flywheel, Rear Cover, Power Steering and Fuel Pump

Flywheel		
Flywheel surface maximum runout (manual)		0.25 mm (0.010 in)
Flexplate ring gear T.I.R. runout (automatic)		1.27 mm (0.050 in)
Idler Gear		
Idler gear shaft height		36.4 ± 0.15 mm (1.4 ± 0.01 in)
Dowel Pin		
Dowel pin protrusion in secondary flange		8.0 ± 0.25 mm (0.315 ± 0.01 in)
Rear Cover		
Rear cover face maximum runout		0.51 mm (0.020 in)
Power Steering and Fuel Pump Drive Gear		
Backlash:		
Crankshaft to power steering and fuel pump idler gear		0.173 to 0.288 mm (0.0068 to 0.0113 in)
Power steering idler gear to power steering and fuel pump drive gear		0.173 to 0.288 mm (0.0068 to 0.0113 in)
Power Steering Pump		
Maximum operating pressure		17.5 MPa (2,538 psi)

Special Torque

Table 36 Flywheel, Flexplate and Power Steering Assembly

Flywheel mounting bolts, new bolts only	94 N·m (69 lbf·ft) (Figure 590)
Flexplate mounting bolts, new bolts only	94 N·m (69 lbf·ft) (Figure 590)
Power steering pump outlet pipe fitting	45 ± 5 N·m (33 ± 4 lbf·ft)
Power steering pump inlet pipe fitting	90 ± 10 N·m (66 ± 7 lbf·ft)

Special Service Tools**Table 37 Flywheel, Rear Cover and Power Steering and Fuel Pump**

Description	Tool Number
Cap Kit (All)	ZTSE4610
Dial Indicator with Magnetic Base	Obtain locally
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Rear/Wear Sleeve Installer	ZTSE4515
Rear Wear Sleeve Removal Tool	ZTSE4518
Power Steering Idler Shaft Installation Tool	ZTSE4719
Crankshaft Secondary Flange Installation Studs	ZTSE4720
Loctite® 290 Sealant	1847432C1
Loctite® Hydraulic Sealant	Obtain locally

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Branch Tube Assembly

Removal

 **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: Engine fluids (oil, fuel, and coolant) are a threat to the environment. Recycle or dispose of engine fluids according to local regulations. Never put engine fluids in the trash, pour fluids on the ground, in sewers or bodies of water.

 **WARNING:** To prevent personal injury or death, always disconnect main negative battery cable first. Always connect the main negative battery cable last.

1. Disconnect negative battery cable and Electronic Control Module (ECM) ground.
2. Drain air tanks, if equipped.
3. Remove inside engine cover from truck, if equipped. See *Truck Service Manual*.
4. Remove the right inner fender well, if required.

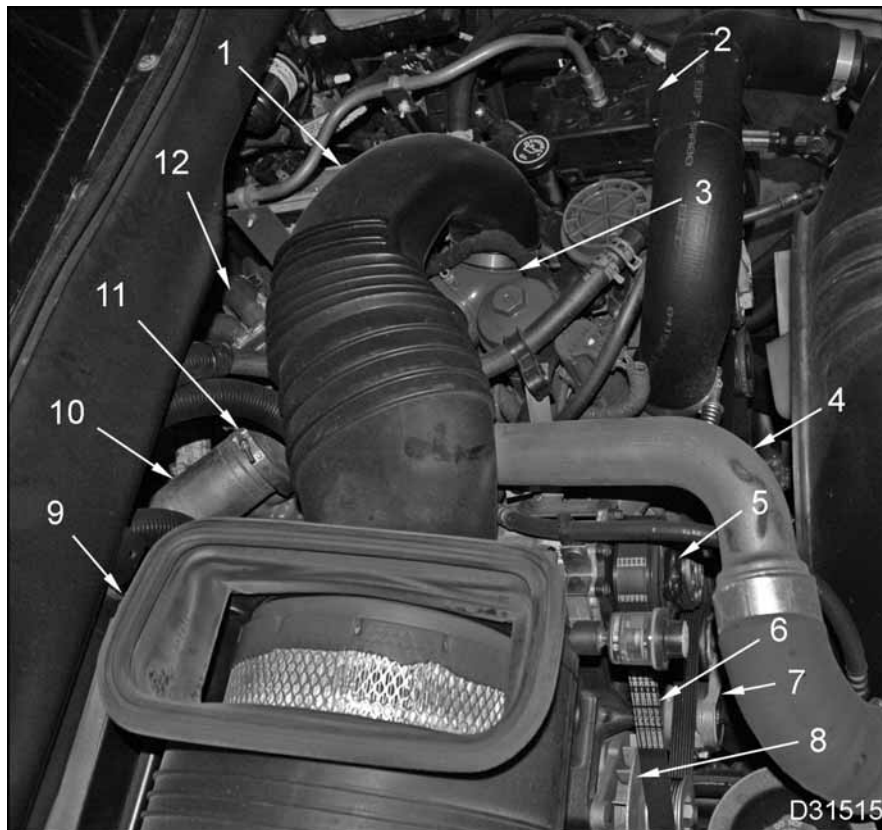


Figure 591 Parts for removal (Engine In-chassis – 4100 truck)

1. Air intake duct	5. Air conditioning compressor	9. Air filter housing
2. Air compressor	6. Serpentine drive belt	10. Exhaust down pipe
3. Turbocharger air inlet duct	7. Belt tensioner	11. Turbocharger exhaust clamp
4. Charge Air Cooler (CAC) pipe	8. Alternator assembly	12. Shielded tube exhaust assembly

5. Remove air intake duct, air filter housing, and mounting bracket.
6. Loosen CAC pipe clamps and remove CAC pipe.
7. Rotate belt tensioner clockwise to release belt tension and remove serpentine drive belts.
8. Remove alternator wiring and remove alternator assembly.

⚠ WARNING: To prevent personal injury or death, do not open pressurized air conditioning lines.

9. If truck is equipped with air conditioning, remove air conditioning compressor bolts from mounting bracket, but do not remove or disconnect pressurized air conditioning lines. Move

compressor out of the way and secure with a strap.

10. Remove mounting bracket for alternator and air conditioning compressor.
11. If truck is equipped with an air compressor, remove coolant supply line and pinch off hose. Remove two of three M10 air compressor mounting bracket bolts. Loosen third bolt and pivot or reposition air compressor out of the way.
12. If required to remove valve covers; remove oil dipstick, washer bottle, and bracket.
13. Loosen turbocharger exhaust clamp and remove exhaust down pipe from turbocharger exhaust flange.

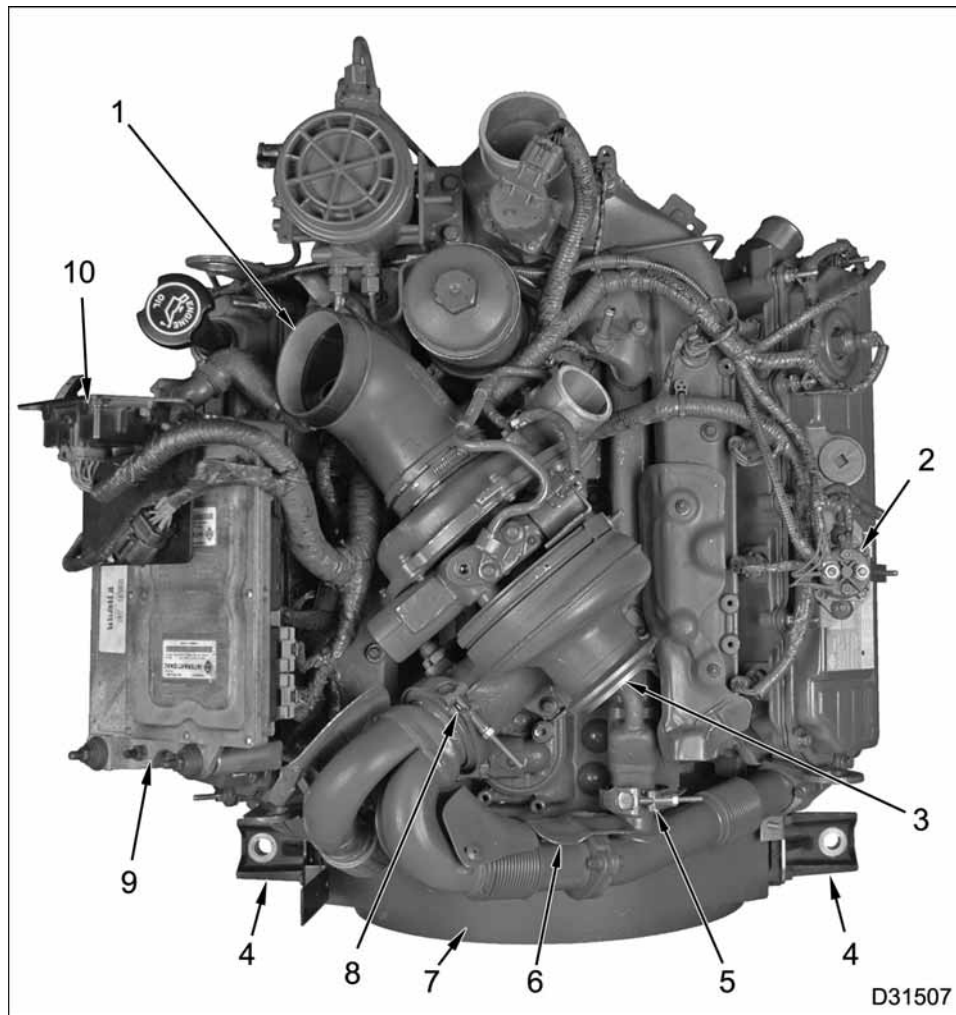


Figure 592 Parts for removal

1. Turbocharger air inlet duct	6. Pump gasket heat shield	10. EGR Drive Module
2. Glow plug relay	7. Rear cover	
3. Turbocharger exhaust flange	8. V-clamp (Shielded tube exhaust assembly to turbocharger)	
4. Rear engine mounting bracket (2)	9. Electronic Control Module (ECM) / Injector Drive Module (IDM)	
5. V-clamp (Right exhaust tube to EGR cooler)		

14. Loosen V-clamp connecting shielded tube exhaust assembly to turbocharger.	15. Loosen V-clamp connecting right exhaust tube to EGR cooler.

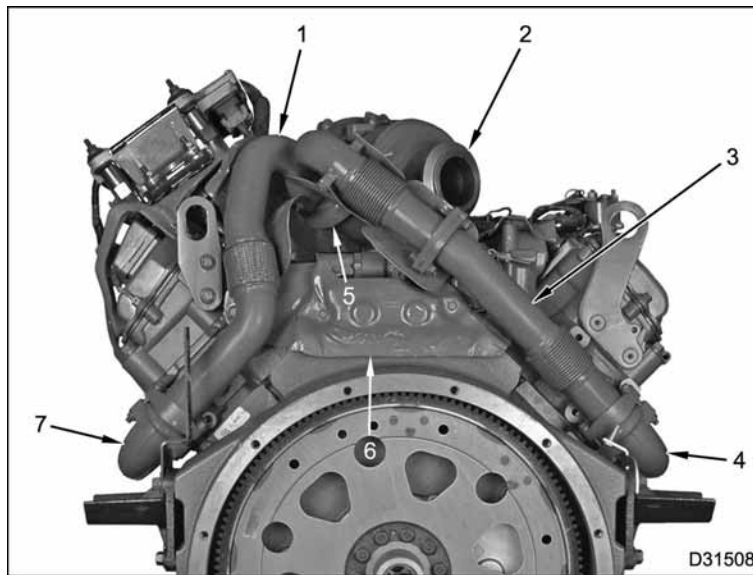


Figure 593 Air Management System parts

1. Shielded tube exhaust assembly	4. Exhaust manifold, right	6. Pump gasket heat shield
2. Turbocharger exhaust flange	5. V-clamp (Shielded tube exhaust assembly to turbocharger)	7. Exhaust manifold, left
3. Exhaust tube assembly, right		
-
16. Remove two M8 bolts and nuts connecting shielded tube exhaust assembly to left exhaust manifold.	23. See <i>Engine Service Manual</i> – “Electronically Controlled Variable Geometry Turbocharger (VGT)” to remove the following:
17. Remove two M8 bolts and nuts connecting right exhaust tube to right exhaust manifold.	• Turbocharger air inlet duct • VGT assembly
18. Leaving right exhaust tube attached, remove shielded tube exhaust assembly.	24. Remove the high-pressure oil pump cover. See <i>Engine Service Manual</i> – “High-pressure Oil Pump”.
19. Remove three bolts from pump gasket heat shield and remove heat shield.	25. See <i>Engine Service Manual</i> – “Cylinder Head and Valve Train” to remove the following:
20. Unplug the EGR drive module and remove module and mounting bracket.	• Valve covers • High-pressure oil rails • Case-to-head tube assemblies • Fuel injectors for cylinders 6, 7, and 8. • Rocker arm assemblies (intake and exhaust) for cylinders 7 and 8.
21. Unplug ECM and IDM electrical connectors.	
22. See <i>Engine Service Manual</i> – “Engine Electrical” to remove the following:	
• ECM, IDM, and mounting bracket. • Glow plug relay and bracket	

- Rocker arm assembly (exhaust) for cylinder 6.

! WARNING: To prevent personal injury or death, use a suitable lifting device to support and lower transmission assembly.

26. Remove transmission assembly.
27. Remove clutch assembly, if equipped with a manual transmission.
28. See *Engine Service Manual* – “Rear Cover, Flywheel, and Power Steering Gear Drive” to remove the following:
 - Flywheel or flex-plate
 - Oil seal carrier
 - Power steering idler gear
 - Crankshaft secondary flange
29. Remove two M10 x 30 bolts from power steering and fuel pump assembly, and support the power steering and fuel pump assembly.
30. Disconnect starter motor assembly wiring, remove M10 bolts from starter motor, and remove starter motor assembly.

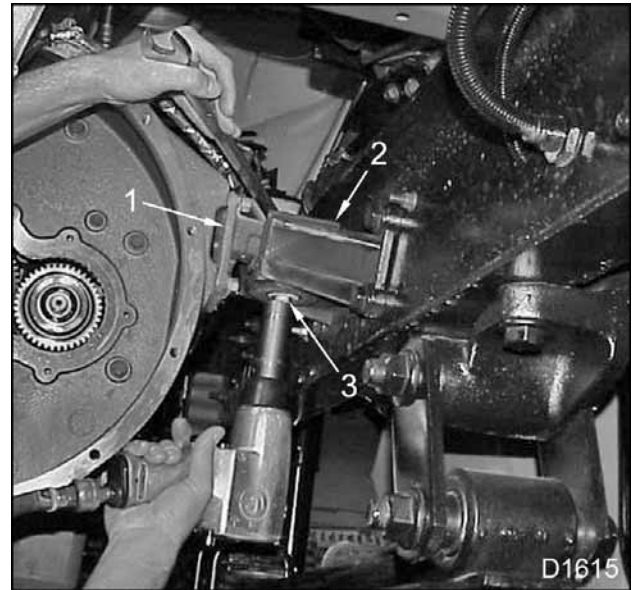


Figure 594 Removal of through bolt from rear engine mount in chassis mounting bracket

1. Rear engine mounting bracket
2. Chassis mounting bracket
3. Through bolt

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

31. Attach a hoist to support the engine.
32. Remove two M16 through bolts and nuts from rear engine mounts.
33. Raise engine with a hoist and support engine with a jack.
34. Remove eight M12 bolts from rear engine mounting brackets, and remove brackets from rear cover.
35. Remove wiring retaining clips from rear cover assembly, if installed.

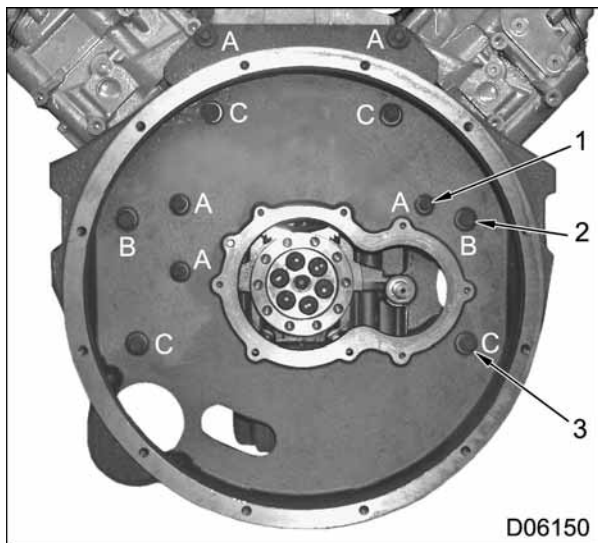


Figure 595 Rear cover mounting bolts

1. Bolts marked A, (M10 x 55) (5)
2. Bolts marked B, (M10 x 70) (2)
3. Bolts marked C, (M10 x 60) (4)

36. Remove rear cover mounting bolts marked A and C in figure.

! WARNING: To prevent personal injury or death, use a suitable lifting device or get help to lower rear cover.

37. Loosen rear cover mounting bolts marked B, but do not remove.

CAUTION: To prevent engine damage when removing the rear cover, avoid pulling out gasket between the upper and lower crankcase.

38. Use a thin gasket scraper to separate sealant between the upper and lower crankcase and the rear cover assembly.

39. Remove rear cover mounting bolts marked B and remove rear cover.

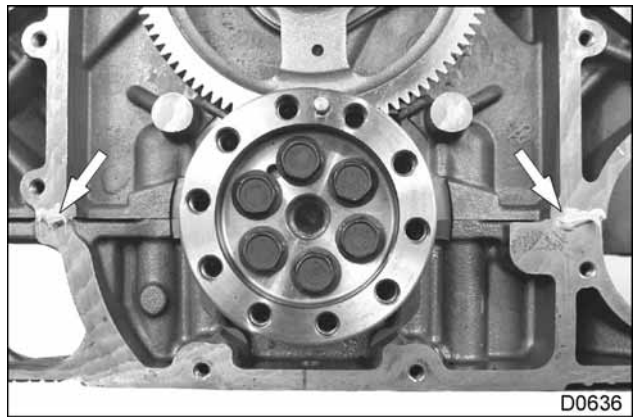


Figure 596 Sealant at upper and lower crankcase

CAUTION: To prevent engine damage, cut sealant at upper and lower crankcase.

40. Remove remaining sealant from upper crankcase, lower crankcase and rear cover, using a sharp gasket scraper or putty knife.

41. Remove intake and exhaust pushrods from cylinders 7 and 8.

42. Remove exhaust pushrod from cylinder 6.

43. Attach a No. 27 torx bit to a 1/4 x 10 inch extension.

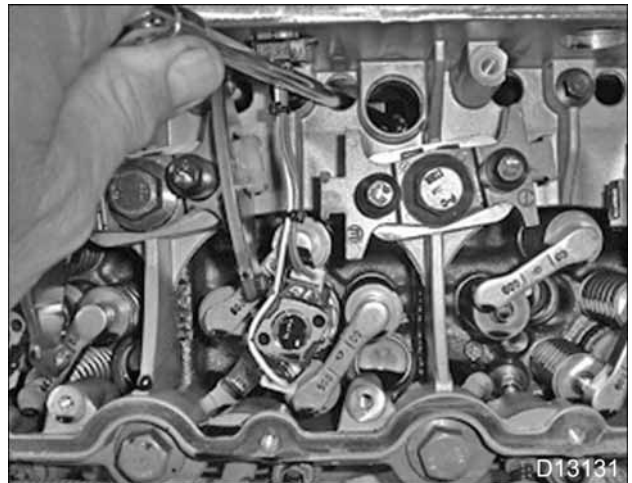


Figure 597 Extension in pushrod hole

44. Look through back of crankcase and insert extension through exhaust pushrod hole for cylinder 6 and push torx bit into M6 x 40 torx bolt in block of branch tube assembly.

CAUTION: To prevent engine damage, do not drop mounting bolts into crankcase.

45. Carefully loosen torx bolt to allow removal.
46. Remove extension from pushrod hole.
47. Look through back of crankcase and use a magnet to carefully remove torx bolt in one of three ways:
 - Magnet inserted through pushrod hole
 - Magnet inserted through hole for crankcase-to-head tube
 - Magnet inserted through back of crankcase
48. Insert extension through exhaust pushrod hole for cylinder 7 and push torx bit into M6 x 40 torx bolt in block of branch tube assembly.
49. Repeat steps 45 through 47.

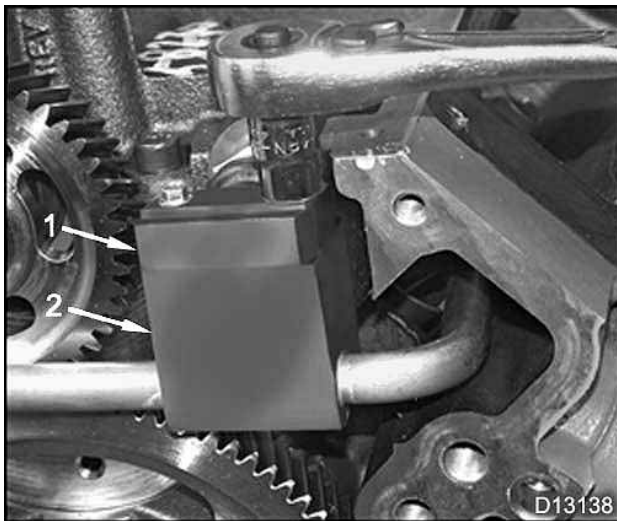


Figure 598 Removal of bolts from branch tube adaptor

1. Branch tube adaptor
2. Branch tube assembly

50. Remove two M6 x 30 bolts connecting branch tube adapter to branch tube assembly.

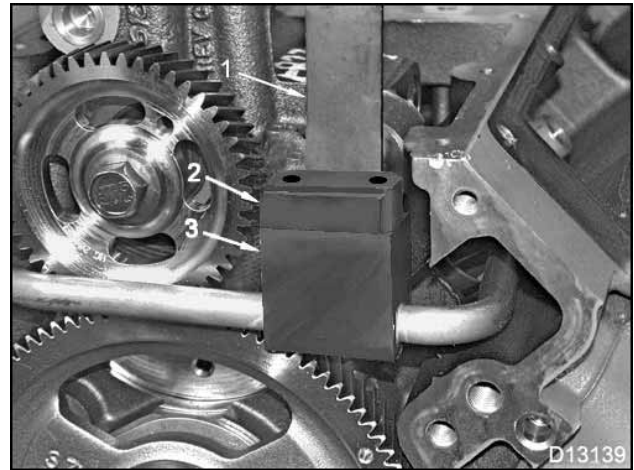


Figure 599 Removal of branch tube adapter

1. No.10 quick release tool
2. Branch tube adapter
3. Branch tube assembly

51. Remove branch tube adapter, using a No.10 Quick Release Tool (Table 39) .

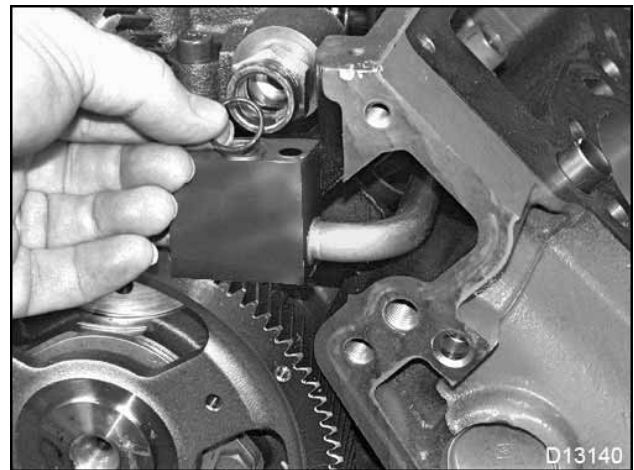


Figure 600 Removal of O-ring

52. Remove O-ring from recess in branch tube assembly.

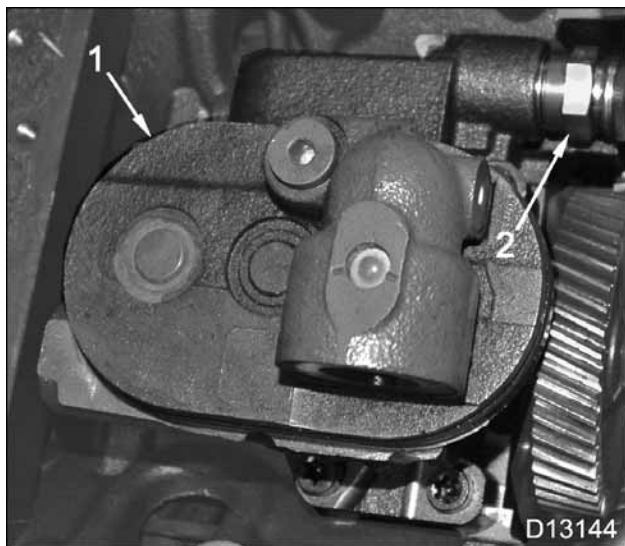


Figure 601 High-pressure oil pump assembly and STC fitting

1. High-pressure oil pump assembly
2. Snap To Connection (STC) fitting

53. Remove STC fitting.

54. Remove branch tube assembly.

Installation

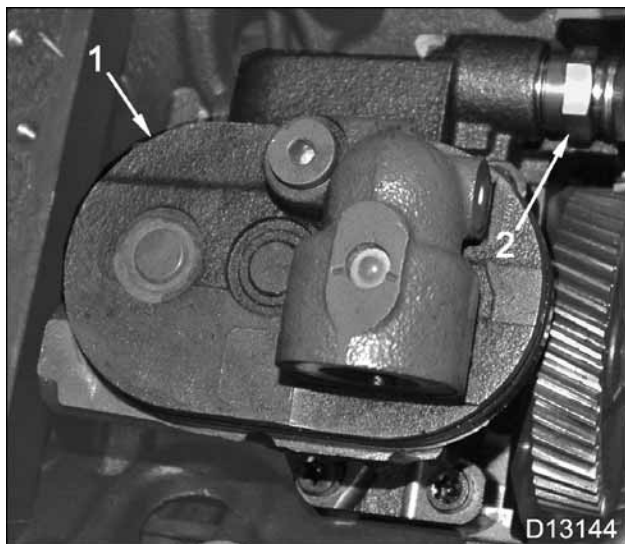


Figure 602 High-pressure oil pump assembly and STC fitting

1. High-pressure oil pump assembly
2. STC fitting

CAUTION: To prevent engine damage, a new STC fitting must be installed.

1. Install a new STC fitting for the high-pressure oil pump.

CAUTION: To prevent engine damage, do not over tighten the STC fitting; if over tightened, the STC fitting will fail.

2. Tighten new STC fitting to the special torque (Table 68).

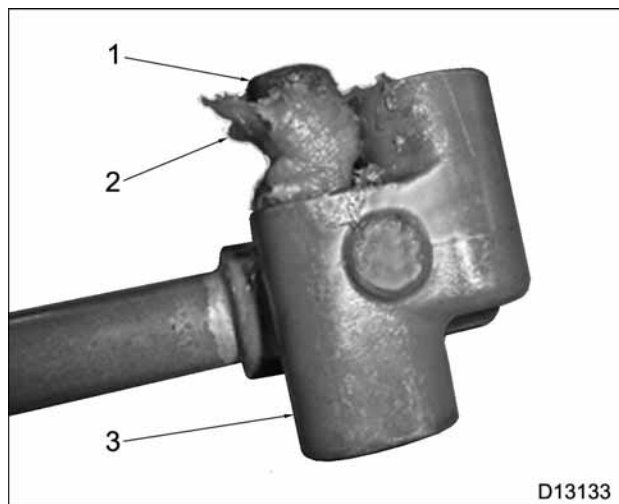


Figure 603 Mounting block on branch tube assembly

1. M6 x 40 torx bolt
2. Grease
3. Mounting block

CAUTION: To prevent engine damage, a new branch tube assembly must be installed.

3. Grease each M6 x 40 torx bolt and insert into mounting blocks of new branch tube assembly.

CAUTION: To prevent engine damage, do not drop mounting bolts into crankcase.

4. Position new branch tube assembly for mounting in crankcase.

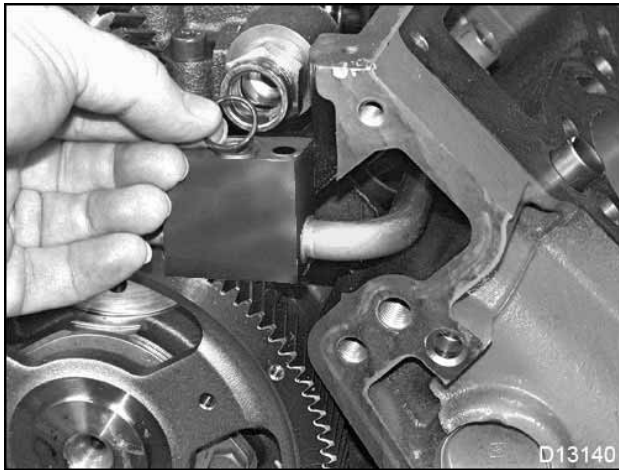


Figure 604 Installation of O-ring

CAUTION: To prevent engine damage, a new O-ring must be installed.

5. Install new O-ring in the recess of the branch tube assembly.

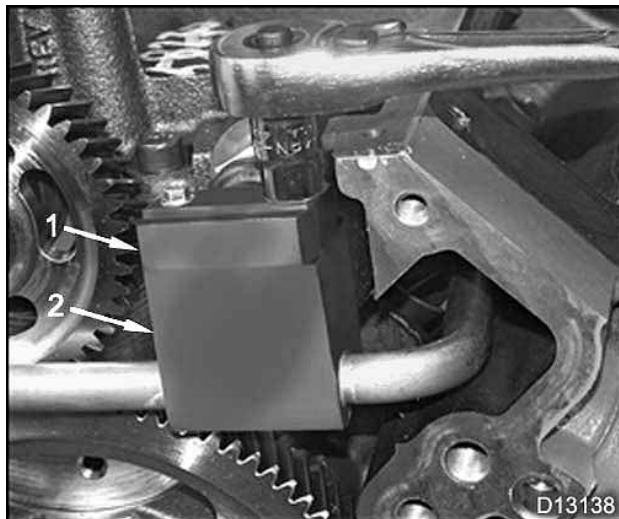


Figure 605 Installation of bolts for branch tube adapter

1. Branch tube adapter
 2. Branch tube assembly
6. Install and loosely tighten two M6 x 30 mounting bolts to connect new branch tube adapter to branch tube assembly.

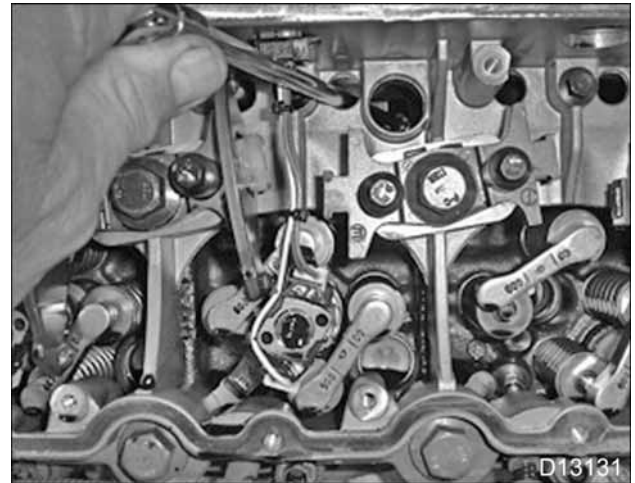


Figure 606 Extension in pushrod hole

7. Look through back of crankcase, insert extension – with No. 27 torx bit attached – through exhaust pushrod hole for cylinder 6, and install and loosely tighten M6 x 40 torx bolt.
8. Look through back of crankcase, insert extension – with No. 27 torx bit attached – through exhaust pushrod hole for cylinder 7, and install and loosely tighten M6 x 40 torx bolt.
9. Tighten both M6 x 40 torx bolts to the special torque (Table 68).
10. Torque both M6 x 30 mounting bolts to the special torque for the branch tube adaptor (Table 68).
11. Install exhaust pushrod for cylinder 6.
12. Install intake and exhaust pushrods for cylinders 7 and 8.
13. See *Engine Service Manual* – “Cylinder Head and Valve Train” to install the following:
 - Fuel injectors for cylinders 6, 7, and 8.
 - Case-to-head tube assemblies
 - High-pressure oil rails
 - Rocker arm assembly (exhaust) for cylinder 6.
 - Rocker arm assemblies (intake and exhaust) for cylinders 7 and 8.
 - Valve covers
14. Install high-pressure oil pump cover. See *Engine Service Manual* – “High-pressure Oil Pump”.

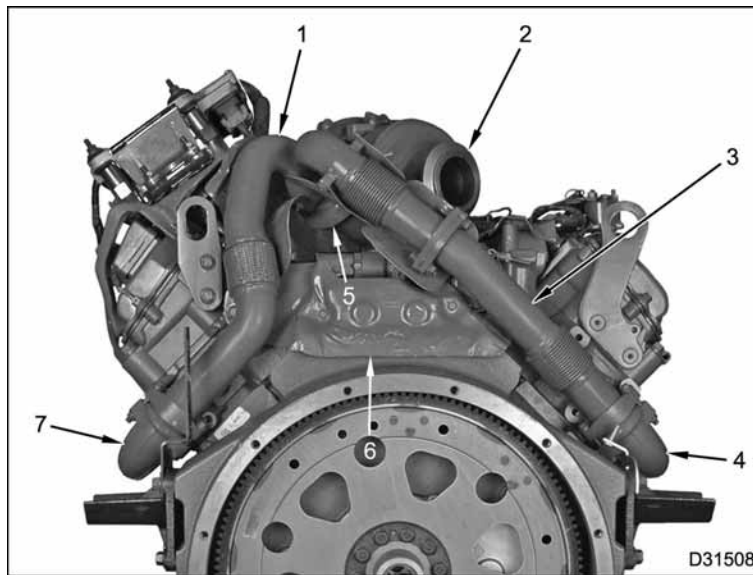


Figure 607 Air Management System parts

1. Shielded tube exhaust assembly	4. Exhaust manifold, right	6. Pump gasket heat shield
2. Turbocharger exhaust flange	5. V-clamp (Shielded tube exhaust assembly to turbocharger)	7. Exhaust manifold, left
3. Exhaust tube assembly, right		
-
15. Position pump gasket heat shield and install three bolts finger tight.
 16. Tighten two M6 x 12 heat shield bolts to the special torque (Table 68) and one M10 x 16 heat shield bolt to the special torque (Table 68).
 17. Position shielded exhaust tube assembly on engine with right exhaust tube and EGR cooler gasket attached. Install four M8 exhaust bolts and nuts finger tight to secure assembly to exhaust manifolds.
 18. Position V-clamp to connect shielded tube exhaust assembly to turbocharger and tighten V-clamp to the special torque (Table 68).
 19. Position V-clamp to connect right exhaust tube to EGR cooler and tighten V-clamp to the special torque (Table 68).
 20. Tighten M8 bolts securing shielded exhaust tube assembly (right exhaust tube attached) to the special torque (Table 68).
 21. See *Engine Service Manual* – “Rear Cover, Flywheel, and Power Steering Gear Drive” for installation of the following:
 - Rear cover assembly
 - Crankshaft secondary flange
 - Power steering idler gear
 - Rear oil seal carrier
 - Power steering and fuel pump assembly
 - Flex-plate or flywheel
 22. Reinstall wiring clips on rear cover, if necessary.
 23. Install rear engine mounting brackets on the rear cover assembly and tighten eight M12 x 40 bolts the special torque (Table 68).

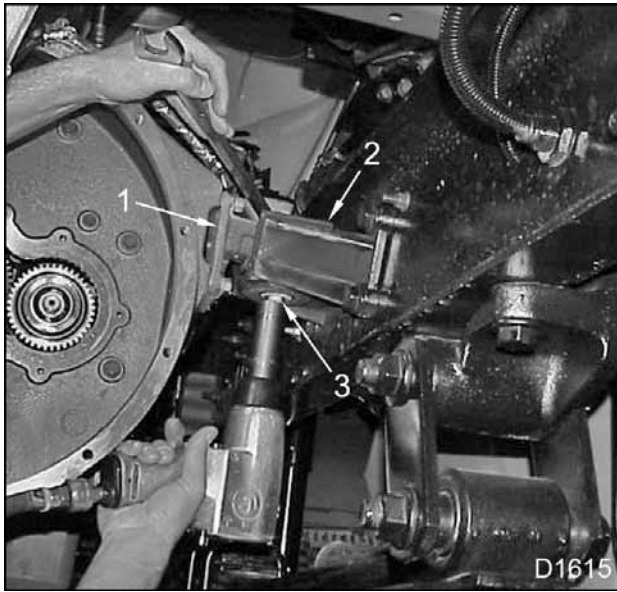


Figure 608 Installation of through bolt into rear engine mount

1. Rear engine mounting bracket
2. Chassis mounting bracket
3. Through bolt

! WARNING: To prevent personal injury or death, make sure the lifting hoist and hooks are secure – before lowering the engine.

24. Lower engine to set rear engine mounting brackets in chassis mounting brackets.
25. Install two M16 through bolts and nuts to secure rear engine mounts to chassis mounting brackets. Tighten nuts to the special torque (Table 68).
26. Remove chain hoist.
27. Install starter motor assembly and tighten M10 x 40 starter bolts to the special torque (Table 68).
28. Reconnect starter wiring.
29. Install clutch and pressure plate, if equipped with a manual transmission.

! WARNING: To prevent personal injury or death, use a suitable lifting device to support and raise transmission assembly.

30. Install transmission assembly.

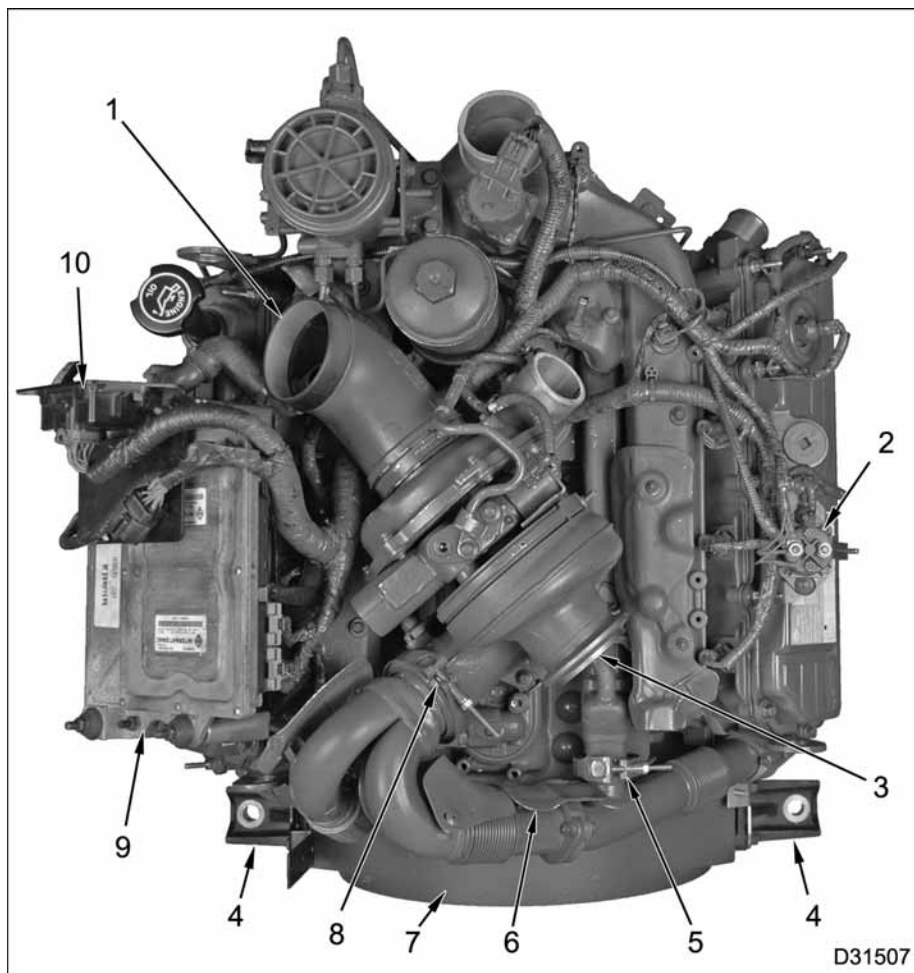


Figure 609 Parts for Installation

1. Turbocharger air inlet duct	6. Pump gasket heat shield	10. EGR Drive Module
2. Glow plug relay	7. Rear cover	
3. Turbocharger exhaust flange	8. V-clamp (Shielded tube exhaust assembly to turbocharger)	
4. Rear engine mounting bracket (2)	9. Electronic Control Module (ECM) / Injector Drive Module (IDM)	
5. V-clamp (Right exhaust tube to EGR cooler)		

31. See *Engine Service Manual* – “Electronically Controlled Variable Geometry Turbocharger (VGT)” to install the following:

- VGT assembly
- Turbocharger air inlet duct

32. Install exhaust down pipe onto turbocharger exhaust flange and tighten exhaust clamp to the special torque (Table 68).

33. See *Engine Service Manual* – “Engine Electrical” to install the following:

- Glow plug relay and bracket
- Electronic Control Module (ECM), Injector Driver Module (IDM), and mounting bracket.

34. Plug in ECM and IDM electrical connectors.

35. Install EGR drive module with mounting bracket and plug in electrical connector.

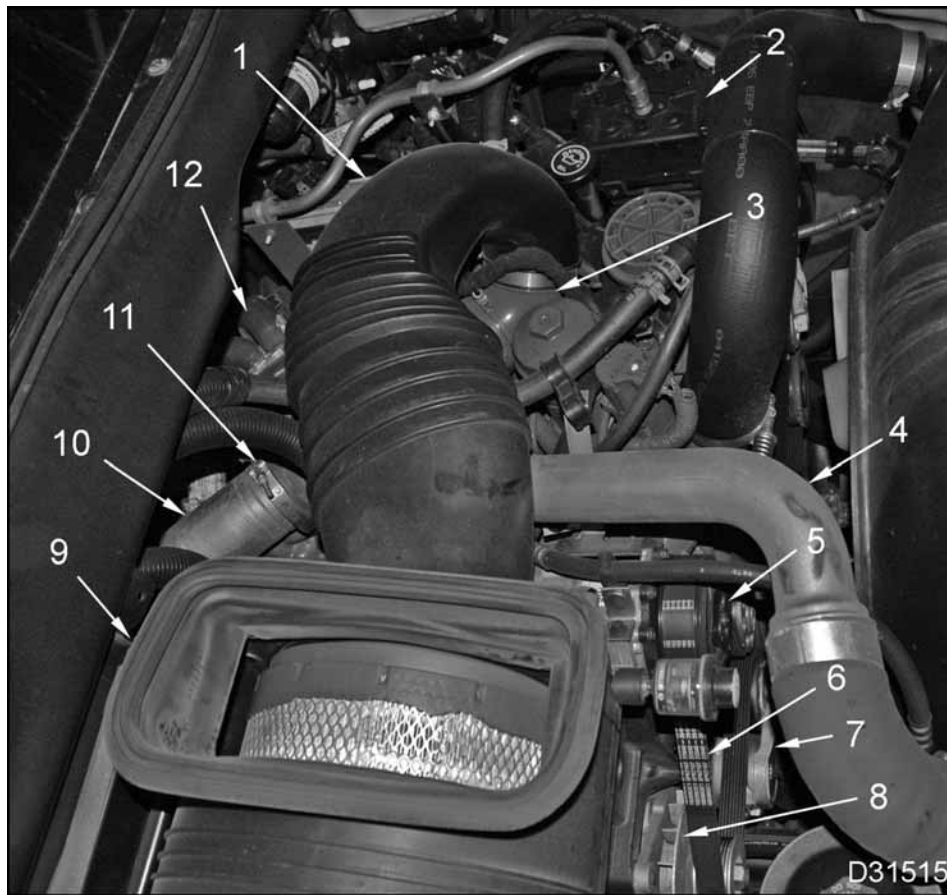


Figure 610 Parts for Installation – Engine In-chassis (4100 truck)

1. Air intake duct	5. Air conditioning compressor	9. Air filter housing
2. Air compressor	6. Serpentine drive belt	10. Exhaust down pipe
3. Turbocharger air inlet duct	7. Belt tensioner	11. Turbocharger exhaust clamp
4. Charge Air Cooler (CAC) pipe	8. Alternator assembly	12. Shielded tube exhaust assembly

36. Install oil dipstick, washer bottle, and bracket, if removed.	41. Reconnect air compressor lines and hoses.
37. Install alternator and air conditioning compressor mounting bracket and tighten M10 bolts to the special torque (Table 68).	42. Install serpentine drive belts.
38. Install alternator and reconnect alternator wiring.	43. Install CAC pipe and tighten clamps.
39. If removed, install air conditioning compressor.	44. Install air intake duct, air filter housing, and mounting bracket.
40. If removed, install air compressor and mounting bracket. Tighten three M10 x 100 air compressor mounting bracket bolts to the special torque (Table 68).	45. Install right inner fender well, if removed.
	46. Install inside engine cover in truck, if equipped. See <i>Truck Service Manual</i> .
	47. Reconnect Electronic Control Module (ECM) ground and negative battery cable.

Rocker Arm

Removal

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

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

! WARNING: To prevent personal injury or death, 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: Engine fluids (oil, fuel, and coolant) are a threat to the environment. Recycle or dispose of engine fluids according to local regulations. Never put engine fluids in the trash, on the ground, in sewers or bodies of water.

! WARNING: To prevent personal injury or death, always disconnect main negative battery cable first. Always connect the main negative battery cable last.

NOTE: Before doing the rocker arm removal procedure below, remove the following components:

- Turbocharger inlet air ducting
See "Electronically Controlled Variable Geometry Turbocharger (VGT)"
- Valve covers
See "Cylinder Head And Valve Train"
- High-pressure oil rails
See "Cylinder Head And Valve Train"

CAUTION: To prevent engine damage, insert clean shop towels (see TSI-02-12-16) or piece of rubber hose into oil drain holes in rocker arm carrier before removing fuel injectors. This will ensure that the following parts or pieces of these parts will not fall into the oil supply:

- 3/8" rocker arm pivot balls
- Rocker arm pivots and pivot retainers

NOTE: Account for all parts or pieces, before removing shop towels or rubber hoses after rocker arms have been replaced.

1. Find dowel hole in vibration damper between two of the four bolt heads.

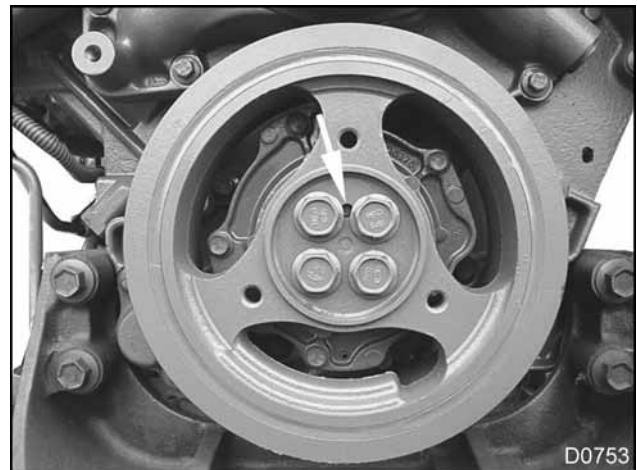


Figure 611 Dowel hole in vibration damper

2. Rotate crankshaft to position dowel hole at 12:00.
3. Wiggle both rocker arms for cylinder 1.

- If rocker arms feel free of valve train loading, the valves are completely closed. Rocker arms can be serviced for cylinders 1,2,7, and 8.

Do steps 4 through 16

- If rocker arms do not feel free, rotate crankshaft (360°) to put crankshaft in the correct position. Rocker arms can be serviced for cylinders 1,2,7, and 8.

Do steps 4 through 16

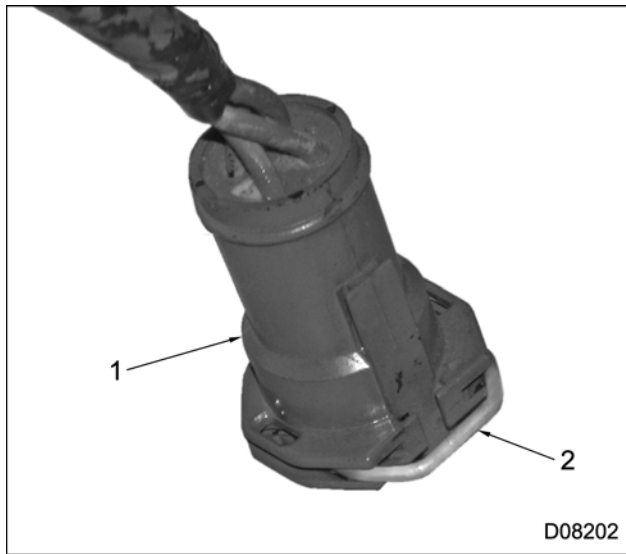


Figure 612 Engine harness connector to injector connector

1. Engine harness connector
 2. Spring loaded metal clip
4. Push in the spring loaded clip in the engine harness connector to the fuel injector connector and remove engine harness connector.

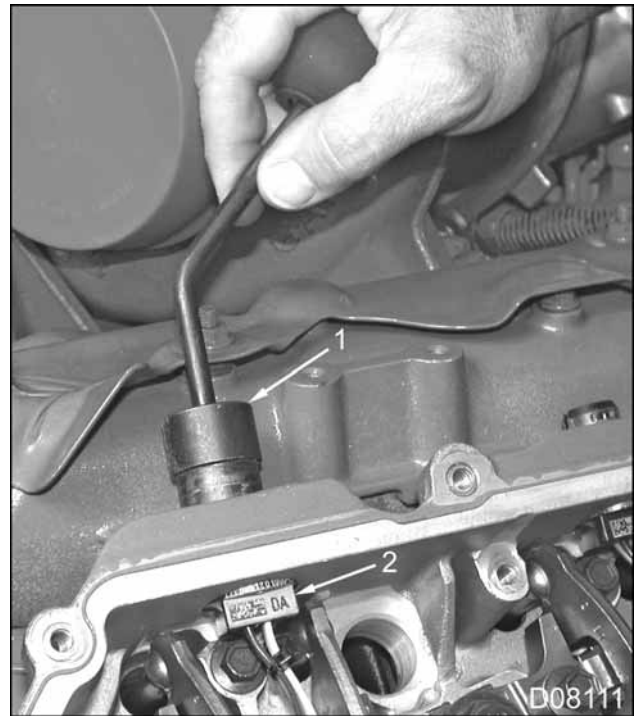


Figure 613 Injector connector removal

1. Injector Connector Release Tool
 2. Fuel injector connector
5. Install the Injector Connector Release Tool (Table 40).
6. Push Injector Connector Release Tool to pop loose spring clips on the injector connector and remove connector from the rocker arm carrier.



Figure 614 Fuel Injector Hold Down Wrench



Figure 615 Removal of fuel injector hold down clamp

1. Fuel injector assembly
2. Hold down clamp
3. Fuel Injector Hold Down wrench

7. Remove the fuel injector hold down clamp assembly, using the Fuel Injector Hold Down Wrench (Table 68).

8. Remove injector and place into injector cup.

CAUTION: To prevent engine damage, insert a clean paper towel inside injector sleeve to keep foreign material out.

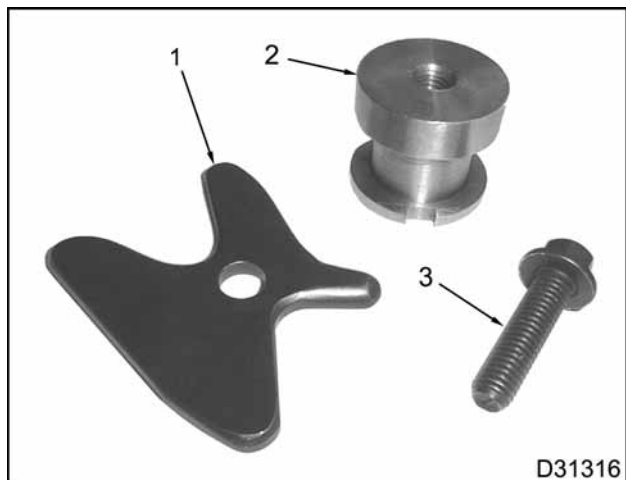


Figure 616 On-engine Valve Spring Compressor Tool

1. Valve spring compressor plate
2. Valve spring compressor base
3. Valve spring compressor bolt

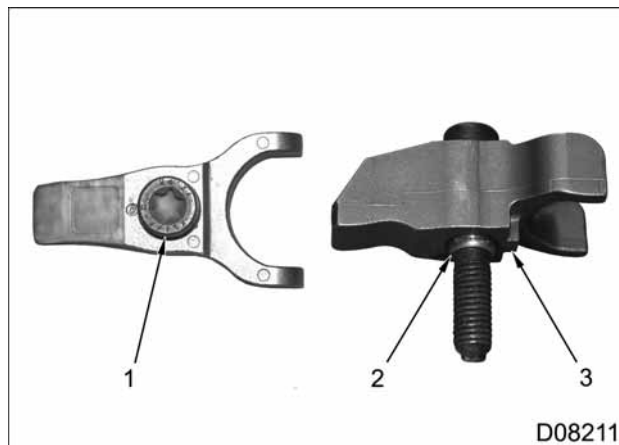


Figure 617 Fuel injector hold down clamp assembly

1. Bolt, M8 X 45
2. Retainer
3. Clamp alignment index

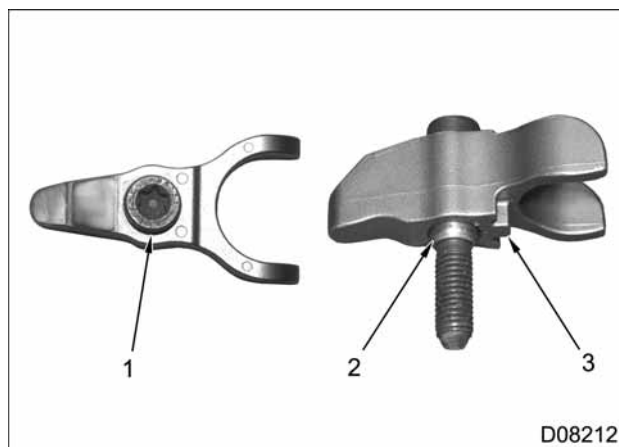


Figure 618 Fuel injector hold down clamp assembly

1. Bolt, M8 X 45
2. Retainer
3. Clamp alignment index

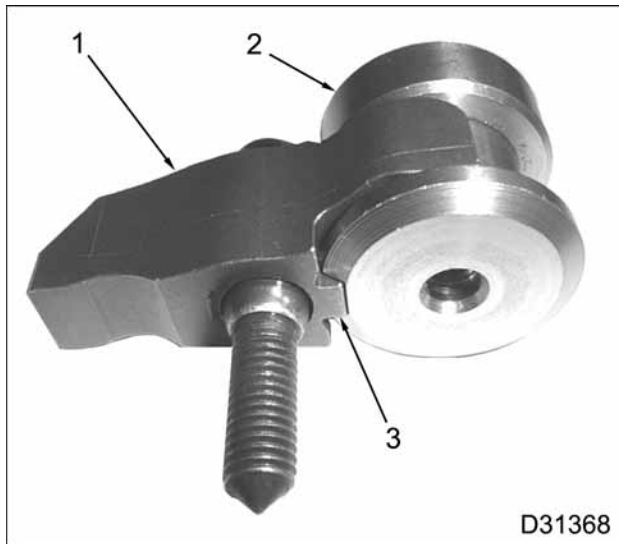


Figure 619 Hold down clamp and valve spring compressor base

1. Injector hold down clamp
 2. Valve spring compressor base
 3. Clamp alignment index
9. Install On-engine Valve Spring Compressor Tool (Table 40).

Insert valve spring compressor base into a new injector hold down clamp. Make sure the notch in the valve spring compressor base aligns with the alignment index tab on hold down clamp.

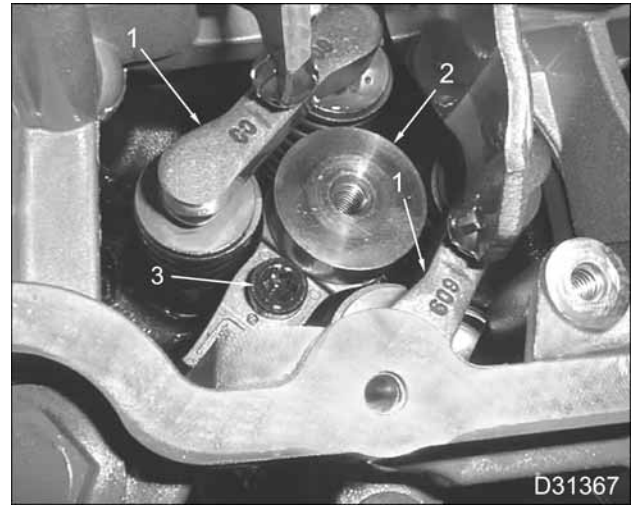


Figure 620

1. Valve bridge
2. Valve spring compressor base and hold down clamp
3. Hold down bolt

10. Install new hold down clamp and valve spring compressor base between valve bridges.

NOTE: While centering base between the two valve bridges, lightly tighten hold down bolt, but do not torque.

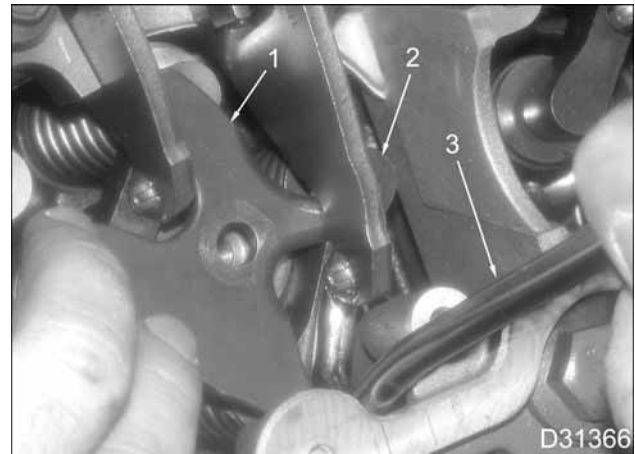


Figure 621 Clearance between rocker arm and valve bridge

1. Valve spring compressor plate
2. Valve bridge
3. Small pry bar

11. Install valve spring compressor plate onto top of valve bridge, inserting small point of plate between the exhaust rocker and valve bridge.

NOTE: If exhaust rocker is severely worn, insert a small pry bar between the exhaust rocker arm and valve bridge. Compress the valve bridge down to raise the rocker for enough clearance to rotate the small point of the compressor plate between the two components.

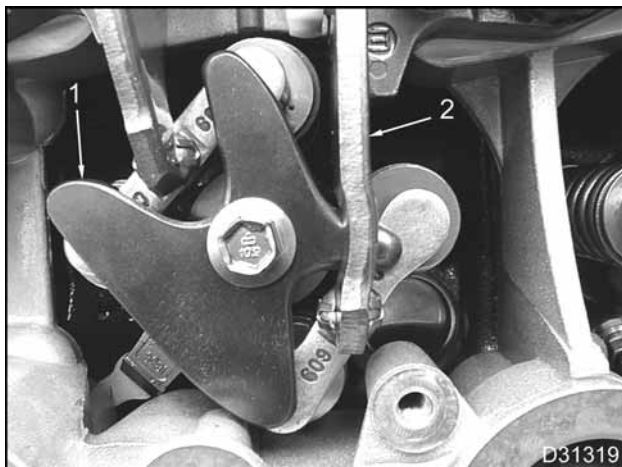


Figure 622 Valve spring compressor plate installed

1. Valve spring compressor plate
 2. Exhaust rocker arm
12. Once compressor plate is in position, install valve spring compressor bolt through plate and into valve spring compressor base.
 13. Using a hand wrench, tighten bolt to compress valve springs until plate contacts top of valve spring compressor base.
- CAUTION:** To prevent engine damage, do not use power tools.
14. Disengage rocker arm from push rod, while rotating rocker arm and compressing rocker arm clip simultaneously.
 15. Remove rocker arm and retaining clip.

CAUTION: To prevent engine damage, account for two 3/8" rocker arm pivot balls. If balls fall onto cylinder head, retrieve balls with magnet

CAUTION: To prevent engine damage, account for each rocker arm pivot and pivot retainer. Failure to account for broken pieces requires removal of oil pan to retrieve. .

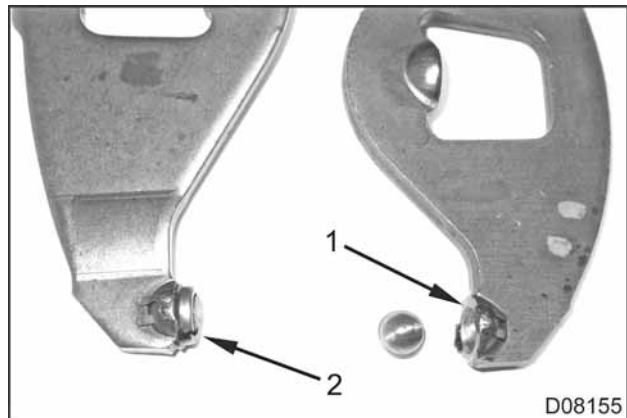


Figure 623 Damaged rocker arm pivot and retainer

1. Retainer partially missing (unaccounted for)
2. Retainer cracked (intact and accounted for)

16. With rocker arms removed, back out valve spring compressor bolt and remove valve spring compressor plate to access valve bridges.

Cleaning and Inspection

! 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).

1. Clean parts with a suitable solvent. Use filtered compressed air to dry parts.
2. Inspect each rocker arm pivot foot and corresponding valve bridge for pitting or scuffing. Replace rocker arms and valve bridges, if necessary.
3. Inspect each rocker arm ball and socket for scuffing. Replace rocker arm ball and socket, if necessary.
4. Inspect rocker arm post ball socket for excessive wear. Inspect bolts for thread damage. Replace worn components, if necessary.

5. Inspect the valve cover gasket for damage or misalignment under compression. Under normal service conditions, the gasket can be reused.

Installation

1. Following valve bridge replacement, place a dab of wheel bearing grease onto new rocker arm socket to hold new 3/8" ball in place, compress valves, and install new rocker arms.

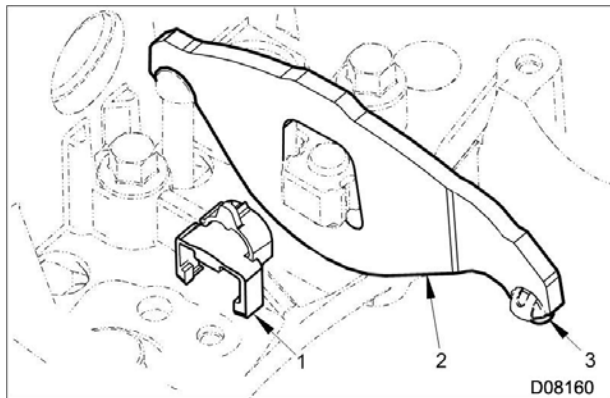


Figure 624

1. Rocker arm retaining clip
2. Fulcrum plate
3. 3/8" ball

2. Position 3/8" ball and rocker arm underneath fulcrum and rotate rocker arm into place, making sure push rod is seated within rocker arm.

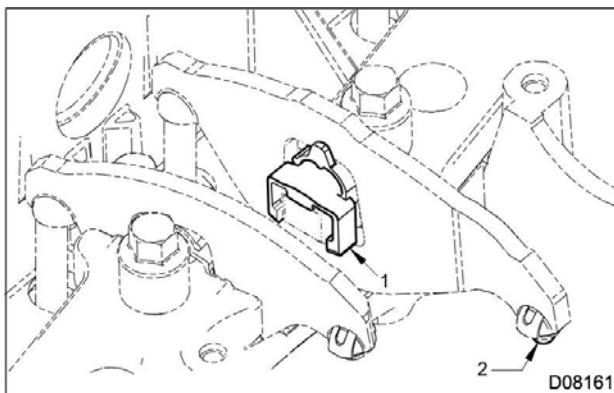


Figure 625 Retaining clip in correct position

1. Rocker arm retaining clip
2. Fulcrum plate

3. Install new plastic rocker arm retaining clip by positioning top of clip to top of rocker arm opening and rotating clip snapping into position around fulcrum plate.
4. Remove valve spring compressor bolt. Make sure the rocker arm and 3/8" ball are in place.

CAUTION: To prevent engine damage, do not use air tools when installing fuel injectors. Do not scratch injector surfaces.

CAUTION: To prevent engine damage, replace external O-rings and copper gasket each time a fuel injector is removed.

5. Remove the old copper gasket with a small hand tool. Wipe injector nozzle with a lint free cloth.

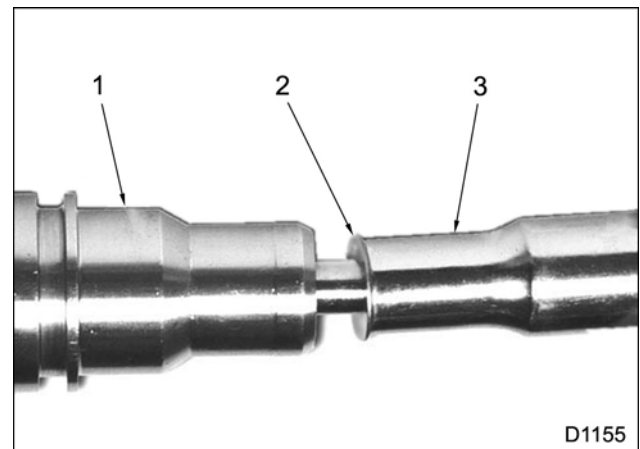


Figure 626 Seating copper gasket

1. Injector (nozzle end)
2. Gasket (copper)
3. Deep socket

6. Install a new copper gasket injector onto injector tip.

NOTE: The copper gasket may be installed in either direction.

7. To seat gasket, push on gasket with a deep socket.
8. Use a nonmetallic hand tool to remove upper and lower O-rings from fuel injector. Discard O-rings.

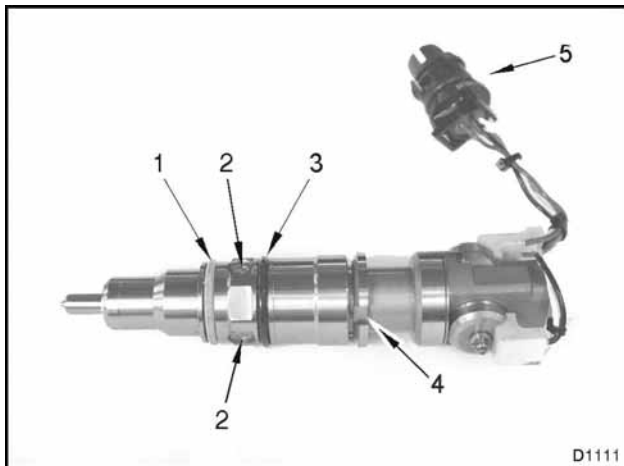


Figure 627 Fuel injector external O-rings

1. O-ring, lower (white Teflon coating) (smaller diameter)
 2. Fuel inlet screen (3)
 3. O-ring, upper (black Teflon coating) (larger diameter)
 4. Clamp alignment slot
 5. O-ring, harness connector (dark blue)
9. Use a nonmetallic hand tool to remove upper and lower O-rings from fuel injector. Discard O-rings.
 10. Install a new Teflon coated (white) O-ring (smaller diameter) in the lower recess just below the fuel inlet screens. Avoid contact with sharp machined surfaces.
 11. Install a new Teflon coated (black) O-ring (larger diameter) in the recess just above the fuel inlet screens. Avoid contact with sharp machined surfaces.



Figure 628 Lubrication of fuel injector O-rings

12. Lubricate upper and lower O-rings with clean engine oil.
13. Remove paper towels from injector bores and install injectors injector hold down clamp as outlined in the *Engine Service Manual*.
14. Check for small broken particles (using a magnet), before removing shop towels or rubber hose from oil drain holes.
15. Install the following components:
 - Crankcase-to-head tube assembly
See "Cylinder Head And Valve Train"
 - High-pressure oil rail
See "Cylinder Head And Valve Train"
 - Valve covers
See "Cylinder Head And Valve Train"
 - Turbocharger inlet air ducting
See "Electronically Controlled Variable Geometry Turbocharger (VGT)"

Special Torque

Table 38 Branch Tube Assembly

Bolts for branch tube mounting blocks	13 N·m (115 lbf·in)
Bolts for branch tube adapter	13 N·m (115 lbf·in)
STC fitting	53 ± 4 N·m (39 ± 3 lbf·ft)
Bolts for heat shield (M10 x12)	13 N·m (115 lbf·in)
Bolt for heat shield and M10 x 16)	62 N·m (45 lbf·ft)
V-clamp for shielded exhaust tube	12 N·m (106 lbf·in)
Bolts for right exhaust tube (shielded exhaust tube connected) to right exhaust manifold (M8)	27 ± 4 N·m (20 ± 3 lbf·ft))
Bolts for rear engine mounts (M12 x 40)	107 N·m (79 lbf·ft)
Nut for bolt through rear engine mounts and chassis mounts (M16)	294 – 325 N·m (216 – 239 lbf·ft)
Bolts for starter motor (M12 x 40)	47 –58 N·m (35–43 lbf·ft)
Turbocharger exhaust clamp for turbocharger down pipe	25 – 10 N·m (4 – 6 lbf·ft)
Bolts for alternator and air conditioning compressor bracket (M10)	72 N·m (53 lbf·ft)
Bolts for air compressor bracket (M10 x 100)	72 N·m (53 lbf·ft)

Special Service Tools

Table 39 Branch Tube Assembly

Description	TOOL NUMBER
No. 10 Quick Release Tool	ZTSE4581

Table 40 Rocker Arm

Description	TOOL NUMBER
Injector Connector Release Tool	ZTSE4650
Fuel Injector Hold Down Wrench	ZTSE4524
On-engine Valve Spring Compressor Tool	ZTSE4697

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Terminology

Accessory work – The work per cycle required to drive engine accessories (normally, only those essential to engine operation).

Actuator – A device that performs work in response to an input signal.

Aeration – The entrainment of air or combustion gas in coolant, lubricant, or fuel.

Aftercooler (Charge Air Cooler) – A heat exchanger mounted in the charge air path between the turbocharger and engine intake manifold. The aftercooler reduces the charge air temperature by transferring heat from the charge air to a cooling medium (usually air).

Ambient temperature – The environmental air temperature in which a unit is operating. In general, the temperature is measured in the shade (no solar radiation) and represents the air temperature for other engine cooling performance measurement purposes. Air entering the radiator may or may not be the same ambient due to possible heating from other sources or recirculation. (SAE J1004 SEP81)

Ampere (amp) – The standard unit for measuring the strength of an electrical current. The flow rate of a charge in a conductor or conducting medium of one coulomb per second. (SAE J1213 NOV82)

Analog – A continuously variable voltage.

Analog to digital converter (A/D) – A circuit in the ECM processing section that converts an analog signal (DC or AC) to a usable digital signal for the microprocessor.

American Trucking Association (ATA) Datalink – A serial datalink specified by the American Trucking Association and the SAE.

Boost pressure – 1. The pressure of the charge air leaving the turbocharger.

2. Inlet manifold pressure that is greater than atmospheric pressure. Obtained by turbocharging.

Bottom Dead Center (BDC) – The lowest position of the piston during the stroke.

Brake Horsepower (bhp) – The power output from an engine, not the indicated horsepower. The power output of an engine, sometimes-called flywheel horsepower is less than the indicated horsepower by

the amount of friction horsepower consumed in the engine.

Brake Horsepower (bhp) net – Net brake horsepower is measured with all engine components. The power of an engine when configured as a fully equipped engine. (SAE J1349 JUN90)

Calibration – The data values used by the strategy to solve equations and make decisions. Calibration values are stored in ROM and put into the processor during programming to allow the engine to operate within certain parameters.

Catalyst – A substance that produces a chemical reaction without undergoing a chemical change itself.

Catalytic converter – An antipollution device in the exhaust system that contains a catalyst for chemically converting some pollutants in the exhaust gases (carbon monoxide, unburned hydrocarbons, and oxides of nitrogen) into harmless compounds.

Cavitation – A dynamic condition in a fluid system that forms gas-filled bubbles (cavities) in the fluid.

Cetane number – 1. The auto-ignition quality of diesel fuel.

2. A rating applied to diesel fuel similar to octane rating for gasoline.

3. A measure of how readily diesel fuel starts to burn (autoignites) at high compression temperature.

Diesel fuel with a high cetane number autoignites shortly after injection into the combustion chamber. Therefore, it has a short ignition delay time. Diesel fuel with a low cetane number resists autoignition. Therefore, it has a longer ignition delay time.

Charge air – Dense, pressurized, heated air discharged from the turbocharger.

Charge Air Cooler (CAC) – See **Aftercooler**.

Closed crankcase – A crankcase ventilation that recycles crankcase gases through a breather, then back to the clean air intake.

Closed loop operation – A system that uses a sensor to provide feedback to the ECM. The ECM uses the sensor to continuously monitor variables and adjust to match engine requirements.

Cloud point – The point when wax crystals occur in fuel, making fuel cloudy or hazy. Usually below -12 °C (10 °F).

Cold cranking ampere rating (battery rating) – The sustained constant current (in amperes) needed to produce a minimum terminal voltage under a load of 7.2 volts per battery after 30 seconds.

Continuous Monitor Test – An ECM function that continuously monitors the inputs and outputs to ensure that readings are within set limits.

Coolant – A fluid used to transport heat from one point to another.

Coolant level switch – A switch sensor used to indicate low coolant level.

Crankcase – The housing that encloses the crankshaft, connecting rods, and allied parts.

Crankcase breather – A vent for the crankcase to release excess interior air pressure.

Crankcase pressure – The force of air inside the crankcase against the crankcase housing.

Current – The flow of electrons passing through a conductor. Measured in amperes.

Damper – A device that reduces the amplitude of torsional vibration. (SAE J1479 JAN85)

Deaeration – The removal or purging of gases (air or combustion gas) entrained in coolant or lubricating oil.

Deaeration tank – A separate tank in the cooling system used for one or more of the following functions:

- Deaeration
- Coolant reservoir (fluid expansion and afterboil)
- Coolant retention
- Filling
- Fluid level indication (visible)

Diagnostic Trouble Code (DTC) – Formerly called a Fault Code or Flash Code. A DTC is a three digit numeric code used for troubleshooting.

Digital Multimeter (DMM) – An electronic meter that uses a digital display to indicate a measured value. Preferred for use on microprocessor systems because it has a very high internal impedance and will not load down the circuit being measured.

Disable – A computer decision that deactivates a system and prevents operation of the system.

Displacement – The stroke of the piston multiplied by the area of the cylinder bore multiplied by the number of cylinders in the engine.

Driver (high side) – A transistor within an electronic module that controls the power to an actuator circuit.

Driver (low side) – A transistor within an electronic module that controls the ground to an actuator circuit.

Duty cycle – A control signal that has a controlled on/off time measurement from 0 to 100%. Normally used to control solenoids.

Engine lamp – An instrument panel lamp that comes on when DTCs are set. DTCs can be read as flash codes (red and amber instrument panel lamps).

Engine OFF tests – Tests that are done with the ignition switch ON and the engine OFF.

Engine rating – Engine rating includes **Rated hp** and **Rated rpm**.

Engine RUNNING tests – Tests done with the engine running.

Exhaust brake – A brake device using engine exhaust back pressure as a retarding medium.

Exhaust manifold – Exhaust gases flow through the exhaust manifold to the turbocharger exhaust inlet and are directed to the EGR cooler.

Fault detection/management – An alternate control strategy that reduces adverse effects that can be caused by a system failure. If a sensor fails, the ECM substitutes a good sensor signal or assumed sensor value in its place. A lit amber instrument panel lamp signals that the vehicle needs service.

Filter restriction – A blockage, usually from contaminants, that prevents the flow of fluid through a filter.

Flash code – See **Diagnostic Trouble Code (DTC)**.

Fuel inlet restriction – A blockage, usually from contaminants, that prevents the flow of fluid through the fuel inlet line.

Fuel pressure – The force that the fuel exerts on the fuel system as it is pumped through the fuel system.

Fuel strainer – A pre-filter in the fuel system that keeps larger contaminants from entering the fuel system.

Fully equipped engine – A fully equipped engine is an engine equipped with only those accessories necessary to perform its intended service. A fully equipped engine does not include components that are used to power auxiliary systems. If these components are integral with the engine or for any reason are included on the test engine, the power absorbed may be determined and added to the net brake power. (SAE J1995 JUN90)

Fusible link (fuse link) – A fusible link is a special section of low tension cable designed to open the circuit when subjected to an extreme current overload. (SAE J1156 APR86)

Gradeability – The maximum percent grade which the vehicle can transverse for a specified time at a specified speed. The gradeability limit is the grade upon which the vehicle can just move forward. (SAE J227a)

Gross Combined Weight Rating (GCWR) – Maximum combined weight of towing vehicle (including passengers and cargo) and the trailer. The GCWR indicates the maximum loaded weight that the vehicle is allowed to tow.

Gross brake horsepower – The power of a complete basic engine, with air cleaner, without fan, and alternator and air compressor not charging.

Hall effect – The development of a transverse electric potential gradient in a current-carrying conductor or semiconductor when a magnetic field is applied.

Hall effect sensor – Generates a digital on/off signal that indicates speed and timing.

High speed digital inputs – Inputs to the ECM from a sensor that generates varying frequencies (engine speed and vehicle speed sensors).

Horsepower (hp) – Horsepower is the unit of work done in a given period of time, equal to 33,000 pounds multiplied by one foot per minute. **1hp = 33,000 lb x 1 ft /1 min.**

Hydrocarbons – Unburned or partially burned fuel molecules.

Idle speed –

- Low idle is minimum rpm at no load.
- High idle is maximum rpm at no load.

Intake manifold – A collection of tubes through which the fuel-air mixture flows from the fuel injector to the intake valves of the cylinders.

International NGV Tool Utilized for Next Generation Electronics (INTUNE) – The diagnostics software for chassis related components and systems.

Low speed digital inputs – Switched sensor inputs that generate an on/off (high/low) signal to the ECM. The input to the ECM from the sensor could be from a high input source switch (usually 5 or 12 volts) or from a grounding switch that grounds the signal from a current limiting resistor in the ECM that creates a low signal (0 volts).

Lubricity – Lubricity is the ability of a substance to reduce friction between solid surfaces in relative motion under loaded conditions.

Lug (engine) – A condition when the engine is operating at or below maximum torque speed.

Manometer – A double-leg liquid-column gauge, or a single inclined gauge, used to measure the difference between two fluid pressures. Typically, a manometer records in inches of water.

MasterDiagnostics® (MD) – The diagnostics software for engine related components and systems.

Microprocessor – An integrated circuit in a microcomputer that controls information flow.

Nitrogen Oxides (NO_x) – Nitrogen oxides form by a reaction between nitrogen and oxygen at high temperatures and pressures in the combustion chamber.

Normally closed – Refers to a switch that remains closed when no control force is acting on it.

Normally open – Refers to a switch that remains open when no control force is acting on it.

Ohm (Ω) – The unit of resistance. One ohm is the value of resistance through which a potential of one volt will maintain a current of one ampere. (SAE J1213 NOV82)

On demand test – A self test that the technician initiates using the EST and is run from a program in the processor.

Output Circuit Check (OCC) – An On demand test done during an Engine OFF self test to check the continuity of selected actuators.

Output State Test (OST) – An On demand test that forces the processor to activate actuators (High or Low) for additional diagnostics.

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.

Positive On Shaft Excluder (POSE) – A Positive On Shaft Excluder is a separate piece from the rest of the front or rear seal used to keep out dust / debris.

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 Modulation (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.

Read Only Memory (ROM) – Computer memory that stores permanent information for calibration tables and operating strategies. Permanently stored information in ROM cannot be changed or lost by turning the engine off or when ECM power is interrupted.

Reference voltage (V_{REF}) – A 5 volt reference supplied by the ECM to operate the engine sensors.

Reserve capacity – Time in minutes that a fully charged battery can be discharged to 10.5 volts at 25 amperes.

Signal ground – The common ground wire to the ECM for the sensors.

Speed Control Command Switches (SCCS) – A set of switches used for cruise control, Power TakeOff (PTO), and remote hand throttle system.

Steady state condition – An engine operating at a constant speed and load and at stabilized temperatures and pressures. (SAE J215 JAN80)

Strategy – A plan or set of operating instructions that the microprocessor follows for a desired goal. Strategy is the computer program itself, including all equations and decision making logic. Strategy is always stored in ROM and cannot be changed during calibration.

Stroke – Stroke is the movement of the piston from Top Dead Center (TDC) to Bottom Dead Center (BDC).

Substrate – Material that supports the washcoating or catalytic materials.

Sulfur dioxide (SO_2) – Sulfur dioxide is caused by oxidation of sulfur contained in fuel.

System restriction (air) – The static pressure differential that occurs at a given air flow from air entrance through air exit in a system. Usually measured in inches (millimeters) of water. (SAE J1004 SEP81)

Tachometer output signal – Engine speed signal for remote tachometers.

Thermistor – A semiconductor device. A sensing element that changes resistance as the temperature changes.

Thrust load – A thrust load pushes or reacts through a bearing in a direction parallel to the shaft.

Top Dead Center (TDC) – The uppermost position of the piston during the stroke.

Torque – A force having a twisting or turning effect. For a single force, the cross product of a vector from some reference point to the point of application of the force within the force itself. Also known as moment of force or rotation moment. Torque is a measure of the ability of an engine to do work.

Truck Computer Analysis of Performance and Economy (TCAPE) – Truck Computer Analysis of Performance and Economy is a computer program that simulates the performance and fuel economy of trucks.

Turbocharger – A turbine driven compressor mounted to the exhaust manifold. The turbocharger increases the pressure, temperature and density of intake air to charge air.

Variable capacitance sensor – A variable capacitance sensor is measures pressure. The pressure forces a ceramic material closer to a thin metal disc in the sensor, changing the capacitance of the sensor.

Vehicle Electronic System Programming System – The computer system used to program electronically controlled vehicles.

Vehicle Retarder Enable/Engage – Output from the ECM to a vehicle retarder.

Vehicle Speed Sensor (VSS) – Normally a magnetic pickup sensor mounted in the tailshaft housing of the transmission, used to indicate ground speed.

Viscosity – The internal resistance to the flow of any fluid.

Viscous fan – A fan drive that is activated when a thermostat, sensing high air temperature, forces fluid through a special coupling. The fluid activates the fan.

Volt (v) – A unit of electromotive force that will move a current of one ampere through a resistance of one Ohm.

Voltage – Electrical potential expressed in volts.

Voltage drop – Reduction in applied voltage from the current flowing through a circuit or portion of the circuit current multiplied by resistance.

Voltage ignition – Voltage supplied by the ignition switch when the key is ON.

Washcoat – A layer of alumina applied to the substrate in a monolith-type converter.

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Variable Geometry Turbocharger (VGT)**Table 41 VGT Shaft**

Maximum turbine shaft axial end play	0.091 mm (0.0036 in)
Maximum turbine shaft radial shaft movement (play)	0.5 mm (0.02 in)

Manifolds and Exhaust Gas Recirculation (EGR)**Table 42 Intake and Exhaust Manifolds**

Exhaust Manifold	
Maximum allowable warpage	0.08 mm (0.003 in)
Intake Manifold	
Maximum allowable clearance	Between ports: 0.13 mm (0.005 in) Total: 0.25 mm (0.010 in)
Injection Control Pressure (ICP) Sensor	
Operating pressure range	3.5 to 20.7 MPa (500 to 3,000 psi)

Cylinder Head and Valve Train**Table 43 Cylinder Head and Valve Train**

Exhaust Valves	
Stem diameter	6.947 to 6.965 mm (0.2735 to 0.2742 in)
Stem to guide clearance (max. allowable before replacement)	0.140 mm (0.0055 in)
Face to stem runout (T.I.R. max.)	0.038 mm (0.0015 in)
Valve face angle	37.5°
Valve margin (minimum)	1.35 mm (0.053 in)
Valve recession in head	0.50 ± 0.18 mm (0.020 ± 0.007 in)
Intake Valves	
Stem diameter	6.947 to 6.965 mm (0.2735 to 0.2742 in)
Stem to guide clearance (max. allowable before replacement)	0.140 mm (0.0055 in)
Face to stem runout (T.I.R. max.)	0.0038 mm (0.0015 in)
Valve face angle	30.0°
Valve margin (minimum)	1.40 mm (0.055 in)
Valve recession in head	0.50 ± 0.18 mm (0.020 ± 0.007 in)

Table 43 Cylinder Head and Valve Train (cont.)

Cylinder Heads	
Valve guide inside diameter	7.003 to 7.029 mm (0.276 to 0.277 in)
Valve guide bore runout	0.05 mm (0.002 in)
Valve guide taper (maximum)	0.10 mm (0.004 in)
Valve seat width (intake)	1.80 to 2.56 mm (0.071 to 0.101 in)
Valve seat width (exhaust)	1.48 to 2.24 mm (0.058 to 0.088 in)
Valve seat angle (intake)	30.0°
Valve seat angle (exhaust)	37.5°
Valve seat runout (T.I.R. max.)	0.035 mm (0.0014 in)
Gasket surface flatness	0.05 mm (0.002 in) per 51 mm (2 in) 0.10 mm (0.004 in) per total surface area
Overall thickness of cylinder head (deck-to-deck)	95 mm (3.74 in)
Valve head recession relative to deck (surface of cylinder head)	0.32 to 0.68 mm (0.0126 to 0.0268 in)
Valve Spring:	
Free length	51.96 mm (2.045 in)
Solid height	36.1 mm (1.42 in)
Compressed*	46.3 mm @ 340 ± 17 N (1.82 in @ 76.5 ± 3.8 lbf)
Compressed*	38.3 mm @ 850 ± 43 N (1.51 in @ 191 ± 9.7 lbf)
* Spring must be compressed to a solid height, before checking test loads.	
Push Rods	
Runout (maximum)	0.25 mm (0.01 in)

Front Cover, Vibration Damper, and Gerotor Oil Pump

Table 44 Vibration Damper, Lubricating Oil Pump and Thermostat

Vibration Damper	
Face runout (maximum)	0.635 mm (0.025 in)
Rubber bulging (maximum)	1.5 mm (0.060 in)
Lubricating Oil Pump	
Type	Gerotor
Drive	Crankshaft
Location	Gerotor oil pump housing
Pressure Regulating Valve:	
Pressure, low idle (minimum @ 110°C (230°F) oil temperature)	69 kPa (10 psi)
Pressure, high idle (minimum @ 110°C (230°F) oil temperature)	276 kPa (40 psi)
Discharge pressure (2,500 rpm)	483 to 621 kPa (70 to 90 psi)
End clearance (inner and outer rotor to housing)	0.025 to 0.095 mm (0.001 to 0.004 in)
Radial clearance (between outer rotor and housing)	0.17 to 0.295 mm (0.007 to 0.012 in)
Thermostat	
Type	Balanced pressure, wax pellet
Minimum recommended coolant operating temperature	71°C (160°F)
Start-to-open temperature, 0.381 mm (0.015 in) stroke	87 to 91°C (188 to 196°F)
Full-open temperature, 8 mm (0.315 in) stroke	104°C (219°F)

Connecting Rods and Pistons

Table 45 Connecting Rods and Piston Assemblies

Connecting Rods	
Connecting rod length (center to center)	176 mm (6.929 in)
Bushing bore diameter (pin end)	36.98 to 37.02 mm (1.456 to 1.457 in)
Piston pin bushing inside diameter	34.0140 to 34.0215 mm (1.3391 to 1.3394 in)
Material	I-Beam Section - Powdered
Bearing bore diameter (crankshaft end)	72.987 to 73.013 mm (2.8735 to 2.8745 in)
Bearing bore maximum out-of-round	0.013 mm (0.0005 in)

Table 45 Connecting Rods and Piston Assemblies (cont.)

Bearing bore maximum taper per 25 mm (1 in)	0.013 mm (0.0005 in)
Connecting rod bearing inside diameter	69.027 to 69.077 mm (2.7176 to 2.7196 in)
Connecting rod bearing running clearance (diameter)	0.0203 to 0.0837 mm (0.0008 to 0.0033 in)
Connecting rod side clearance	0.3 to 0.6 mm (0.012 to 0.024 in)
Weight (complete rod without bearing)	1201.5 to 1215.5 g (2.649 to 2.679 lb)

Pistons

Material	Aluminum Alloy
Skirt diameter ¹	94.9460 to 94.9186 mm (3.737 to 3.738 in)

¹ Measure 14.68 mm (0.578 in) from bottom, at 90° to the piston pin. Measure only at room temperature of 19 to 21°C (66 to 70°F).

Service Piston:

Standard size	94.9460 to 94.9186 mm (3.737 to 3.738 in)
0.254 mm (0.010 in) oversize	95.1738 to 95.1992 mm (3.747 to 3.748 in)
0.508 mm (0.020 in) oversize	95.4278 to 95.4532 mm (3.757 to 3.758 in)
0.762 mm (0.030 in) oversize	95.6818 to 95.7072 mm (3.767 to 3.768 in)

Top compression ring groove width (measured over 2.08 mm (0.082 in) gauge pins):

Upper limit	94.469 mm (3.7192 in)
Replacement limit	93.290 mm (3.7122 in)
Piston height above crankcase deck (protrusion)	0.9000 mm (0.0354 in)
Piston skirt clearance (1 - 8)	0.0441 to 0.0909 mm (0.0017 to 0.0036 in)

Piston Pins

Length	65.073 to 65.327 mm (2.5619 to 2.5719 in)
Diameter	33.9975 to 34.0025 mm (1.3385 to 1.3387 in)

Pin fit at room temperature of 19 to 21°C (66 to 70°F):

Clearance in connecting rod (piston pin bushing)	0.0115 to 0.0240 mm (0.00045 to 0.00094 in)
Clearance in piston	0.013 to 0.022 mm (0.0005 to 0.0009 in)
End clearance	0.24 mm (0.009 in)

Piston Rings

Ring diameter (standard):	95 mm (3.74 in)
Fit in groove (side clearance in bore):	
Top compression	0.165 mm (0.0065 in)
Intermediate compression	0.051 to 0.102 mm (0.0020 to 0.0040 in)

Table 45 Connecting Rods and Piston Assemblies (cont.)

Oil control	0.038 to 0.084 mm (0.0015 to 0.0033 in)
Ring gap in bore:	
Top compression	0.29 to 0.55 mm (0.011 to 0.021 in)
Intermediate compression	1.40 to 1.66 mm (0.055 to 0.065 in)
Oil control	0.24 to 0.50 mm (0.009 to 0.019 in)

Crankcase, Crankshaft and Bearings, Camshaft and Bushings

Table 46 Crankshaft and Camshaft and Bushings

Crankshaft	
Main Bearing Journal Diameter:	
Standard size	80.9873 to 81.0127 mm (3.188 to 3.150 in)
0.254 mm (0.010 in) under size	80.7333 to 80.7587 mm (3.178 to 3.140 in)
0.508 mm (0.020 in) under size	80.4793 to 80.5047 mm (3.168 to 3.130 in)
0.762 mm (0.030 in) under size	80.2253 to 80.2507 mm (3.158 to 3.120 in)
Main bearing thrust face maximum runout	0.051 mm (0.002 in)
Oil seal journal maximum runout	0.025 mm (0.001 in)
Vibration damper mounting area maximum runout	0.05 mm (0.002 in)
Flywheel mounting surface maximum runout	0.05 mm (0.002 in)
Main bearing to crankshaft running clearance	0.020 to 0.086 mm (0.0008 to 0.0034 in)
Connecting Rod Journal Diameter:	
Standard size	68.99 to 69.01 mm (2.716 to 2.717 in)
0.254 mm (0.010 in) under size	68.73 to 68.75 mm (2.706 to 2.707 in)
0.508 mm (0.020 in) under size	68.48 to 68.50 mm (2.696 to 2.697 in)
0.762 mm (0.030 in) under size	68.23 to 68.25 mm (2.686 to 2.687 in)
Crankshaft end play (maximum)	0.222 mm (0.0087 in)
Camshaft	
Bearing journal diameter (all journals)	61.987 to 62.013 mm (2.440 to 2.441 in)
Bearing inside diameter	62.05 to 62.14 mm (2.443 to 2.446 in)
Journal/bushing running clearance	0.037 to 0.153 mm (0.0015 to 0.0060 in)
Camshaft end play	0.051 to 0.211 mm (0.002 to 0.008 in)
Camshaft gear backlash	0.179 to 0.315 mm (0.007 to 0.012 in)
Maximum permissible cam lobe wear	0.51 mm (0.02 in)
Camshaft thrust plate thickness	3.589 to 3.649 mm (0.1413 to 0.1436 in)

Table 46 Crankshaft and Camshaft and Bushings (cont.)

Camshaft lobe lift (maximum):		
Intake		5.744 mm (0.2261 in)
Exhaust		5.832 mm (0.2296 in)
Valve timing no. 1 cylinder (top of lobe):		
Intake open		7.22° BTDC
Intake closed		34.66° ABDC
Exhaust open		45.12° BBDC
Exhaust closed		6.24° ATDC

Table 47 Crankcase and Main Bearings

Crankcase		
		Total: 0.10 mm (0.004 in)
Cylinder block top surface of crankcase (firing deck) flatness	150 mm x 150 mm (6 in x 6 in) area:	0.05 mm (0.02 in)
	25 mm x 25 mm (1 in x 1 in) area:	0.025 mm (0.001 in)
Crankcase main bearing bore diameter		85.99 to 86.01 mm (3.3854 to 3.3862 in)
Crankcase cam bearing bore diameter		65.98 to 66.02 mm (2.597 to 2.599 in)
Valve tappet bore diameter		23.439 to 23.477 mm (0.9228 to 0.9243 in)
Valve tappet outside diameter		23.391 to 23.411 mm (0.9209 to 0.9217 in)
Cylinder bore diameter		94.999 to 95.001 mm (3.7401 to 3.7402 in)
Cylinder bore maximum out-of-round		0.05 mm (0.002 in)
Cylinder stroke		105 mm (4.13 in)
Rear oil seal face runout (T.I.R. maximum)		0.38 mm (0.015 in)
Front oil seal face runout (T.I.R. maximum)		0.25 mm (0.010 in)
Main Bearings:		
Type		Precision replaceable
Material		Steel backed copper/lead
Number of main bearings		5
Thrust applied at		No. 4 main upper
Lower crankcase		Four bolts per main journal
Coolant heater element rating		1,000 watts, 120 volts

Oil Cooler and Oil Filter**Table 48 Oil Cooler and Oil Filter**

Oil Cooler	
Type	Full-flow, fin bundle
Location	Engine valley (forward)
Oil Filter	
Type	Cartridge, full flow - disposable
Location	Front, oil cooler mounted
Filter bypass location	Oil filter return tube assembly
Oil filter bypass opening pressure	220 ± 41 kPa (32 ± 6 psi)

Engine Electrical**Table 49 Engine Electrical**

Glow Plugs	
Location	Cylinder Head
Quantity	8
Camshaft Position (CMP) Sensor	
Location	Crankcase (left side)
Crankshaft Position (CKP) Sensor	
Location	Crankcase (right side)
Operating actuator speed	15 to 2,000 rpm
Operating temperature	-40 to +130°C (-40 to 266°F)
Injection Control Pressure (ICP) Sensor	
Operating pressure range	3.5 to 20.7 MPa (500 to 3,000 psi)
Injection Pressure Regulator (IPR) Valve	
Operating temperature range	-40 to 220°C (-40 to 428°F)
Maximum operating pressure	28 MPa (4,061 psi)

High-pressure Oil Pump**Table 50 Injection Pressure Regulator (IPR) Valve**

Injection Pressure Regulator (IPR) Valve	
IPR valve cracking pressure	31 MPa (4,500 psi)
IPR valve maximum pressure	37 MPa (5,400 psi)

Fuel System**Table 51 Fuel Filter and Pressure Regulating Valve**

Fuel Filter	
Type	10 micron with water separation
Normal fuel pressure (after fuel filter)	345 to 482 kPa (50 to 70 psi)
Fuel pressure in filter not to exceed	448 kPa @ 132 L/h (65 psi @ 35 gal/h)
Fuel Pressure Regulating Valve	
Valve opening pressure	351 ± 31 kPa (51 ± 4.5 psi)
Heater element activates	3.6 to 10.8°C (38.5 to 51.5°F)
Heater element deactivates	19.1 to 29.6°C (66.5 to 83.5°F)

Rear Cover, Flywheel, and Power Steering and Fuel Pump**Table 52 Rear Cover, Flywheel, and Power Steering and Fuel Pump**

Flywheel	
Flywheel surface maximum runout (manual)	0.25 mm (0.010 in)
Flexplate ring gear T.I.R. runout (automatic)	1.27 mm (0.050 in)
Rear Cover	
Rear cover face maximum runout	0.51 mm (0.020 in)
Power Steering and Fuel Pump Drive Gear	
Backlash:	
Crankshaft to idler gear	0.173 to 0.288 mm (0.0068 to 0.0113 in)
Idler gear to pump drive gear	0.173 to 0.288 mm (0.0068 to 0.0113 in)
Power Steering Pump	
Maximum operating pressure	17.5 MPa (2,538 psi)

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Torque Guidelines

CAUTION: To prevent engine damage, do not substitute fasteners. Original equipment standard hardware is defined as Class 10.9 metric or Grade 8 standard coarse thread bolts and nuts and hardened flat washers (Rockwell "C" 38-45), all phosphate coated.

The standard torque charts provide the tightening torque for general application of standard hardware listed in the Parts Catalog for original equipment.

NOTE: Inspect parts for cleanliness and defects before assembly.

Standard Torques

Table 53 Standard Torques – Pipe Thread

Thread Size	Torque ¹
1/8 in NPT	11 N·m (90 lbf·in)
1/4 in NPT	14 N·m (120 lbf·in)
3/8 in NPT	20 N·m (180 lbf·in)
1/2 in NPT	34 N·m (25 lbf·ft)
3/4 in NPT	41 N·m (30 lbf·ft)

¹ Tolerances are ±10% of nominal value.

Table 54 Standard Torques — Class 10.9 Metric Bolts and Studs

Thread Diameter	Thread Pitch (mm/thread)	Torque ¹
6 mm	1	13 N·m (115 lbf·in)
8 mm	1.25	31 N·m (23 lbf·ft)
10 mm	1.5	62 N·m (45 lbf·ft)
12 mm	1.75	107 N·m (79 lbf·ft)
14 mm	2	172 N·m (127 lbf·ft)
15 mm	2	216 N·m (159 lbf·ft)
16 mm	2	266 N·m (196 lbf·ft)
18 mm	2.5	368 N·m (272 lbf·ft)
20 mm	2.5	520 N·m (384 lbf·ft)

¹ Tolerances are ±10% of nominal value.

Table 55 Standard Torques — Class 12.9 Metric Bolts and Studs

Thread Diameter	Thread Pitch (mm/thread)	Torque ¹
6 mm	1	15 N·m (132 lbf·in)
8 mm	1.25	36 N·m (27 lbf·ft)
10 mm	1.5	72 N·m (53 lbf·ft)
12 mm	1.75	126 N·m (93 lbf·ft)
14 mm	2	201 N·m (148 lbf·ft)
15 mm	2	252 N·m (186 lbf·ft)
16 mm	2	311 N·m (230 lbf·ft)
18 mm	2.5	430 N·m (317 lbf·ft)
20 mm	2.5	608 N·m (448 lbf·ft)

¹ Tolerances are ±10% of nominal value.

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		
10.8	10.8	Medium carbon, Medium carbon Alloy steel or low Carbon boron steel	Quench and tempered		

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Figure 629 Metric fasteners – Classification and identification

INTERNATIONAL designation	MATERIAL	THERMAL TREATMENT	HEAD MARKING	
			Preferred	Optional
CLASS	METRIC FASTENERS			
10.R	Medium carbon, Medium carbon Alloy steel	Quench and tempered, Roll threaded after heat treatment		
10.9	Medium carbon Alloy steel	Quench and tempered		
12.9R	Medium carbon Alloy steel	Quench and tempered, Roll threaded after heat treatment		

D31369

Figure 630 Special fasteners – Classification and identification

Many conditions affect torque and the results of torque applications. The major purpose in tightening a fastener to a specified torque is to obtain tension in the fastener (bolt and nut), which in turn develops a clamping load which exceeds any possible loading imposed on parts due to engine rpm or vibration.

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 the 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 maximum clamping effect 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. The fastener threads must have a film of clean lubricant (engine oil) to be considered lubricated.

Torque Wrench Extension and Adapters

An extension, crowfoot or adapter may be needed with a torque wrench to torque a bolt or line fitting that is difficult to reach. Adding adapters or extensions will alter the actual clamping force at the fastener. Use the following formula to determine the torque wrench setting to achieve the known standard or special torque value.

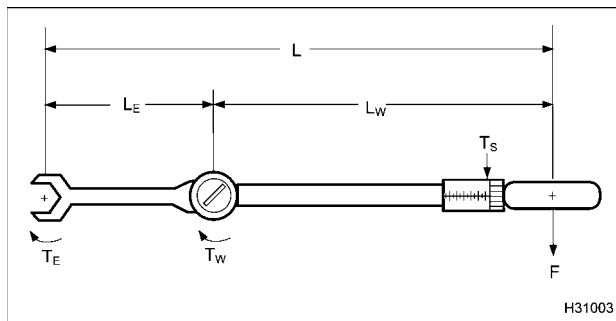


Figure 631 Torque wrench extension

- F – Force applied by technician
- L – Length through which force is applied to fastener
- L_E – Length of extension
- L_W – Length of torque wrench
- T_E – Torque applied at fastener
- T_W – Torque applied at end of torque wrench
- T_S – Torque wrench setting

$$T_S = T_E (L_W / (L_W + L_E))$$

Example:

A component has a known torque value of 88 N·m (65 lbf·ft) and an extension is required. What should the torque wrench setting be to compensate for the extension?

- Torque wrench = 12 inches
- Extension = 6 inches

$$T_S = 88 \text{ N·m (65 lbf·ft) [12 in / (12 in + 6 in)]}$$

$$T_S = 88 \text{ N·m (65 lbf·ft) [12 in / 18 in]}$$

$$T_S = 88 \text{ N·m (65 lbf·ft) [0.666]}$$

$$T_S = \mathbf{58.9 \text{ N·m (43.3 lbf·ft)}}$$

Special Torques

Mounting Engine On Stand

Table 56 Oil Pan Drain Plug

Oil pan drain plug	$25 \pm 5 \text{ N}\cdot\text{m}$ ($18 \pm 4 \text{ lbf}\cdot\text{ft}$)

Variable Geometry Turbocharger (VGT)

Table 57 VGT Bolts and Clamps

Air inlet duct hose clamp	$4 - 5 \text{ N}\cdot\text{m}$ ($36 - 48 \text{ lbf}\cdot\text{in}$)
VGT to mounting bracket bolts	$31 \pm 4 \text{ N}\cdot\text{m}$ ($23 \pm 3 \text{ lbf}\cdot\text{ft}$)
VGT exhaust adapter V-clamp	$12 \text{ N}\cdot\text{m}$ ($108 \text{ lbf}\cdot\text{in}$)

Manifolds and Exhaust Gas Recirculation (EGR)

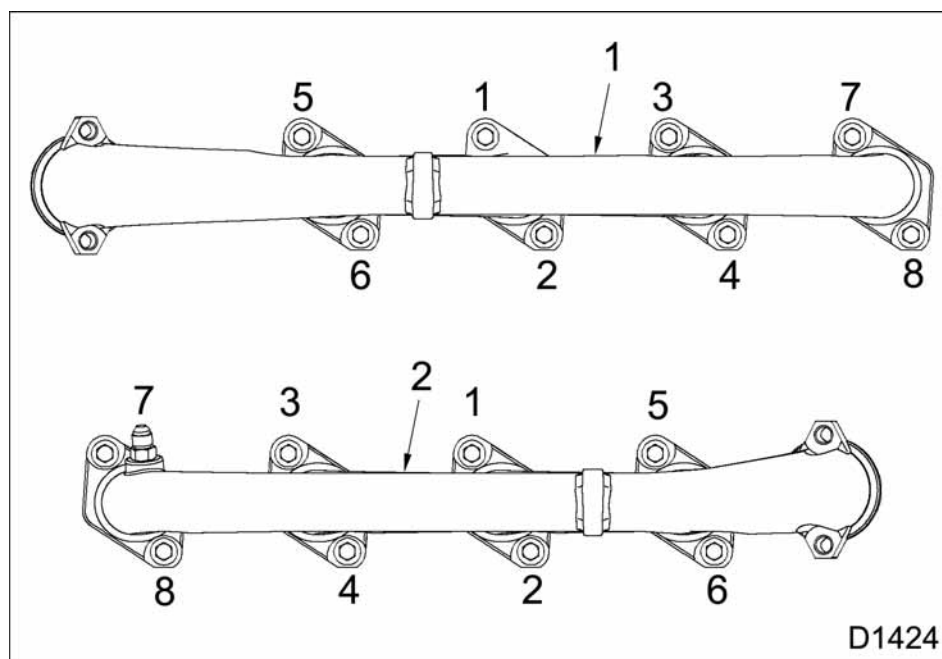


Figure 632 Tightening sequence for exhaust manifold mounting bolts

1. Right side exhaust manifold
2. Left side exhaust manifold

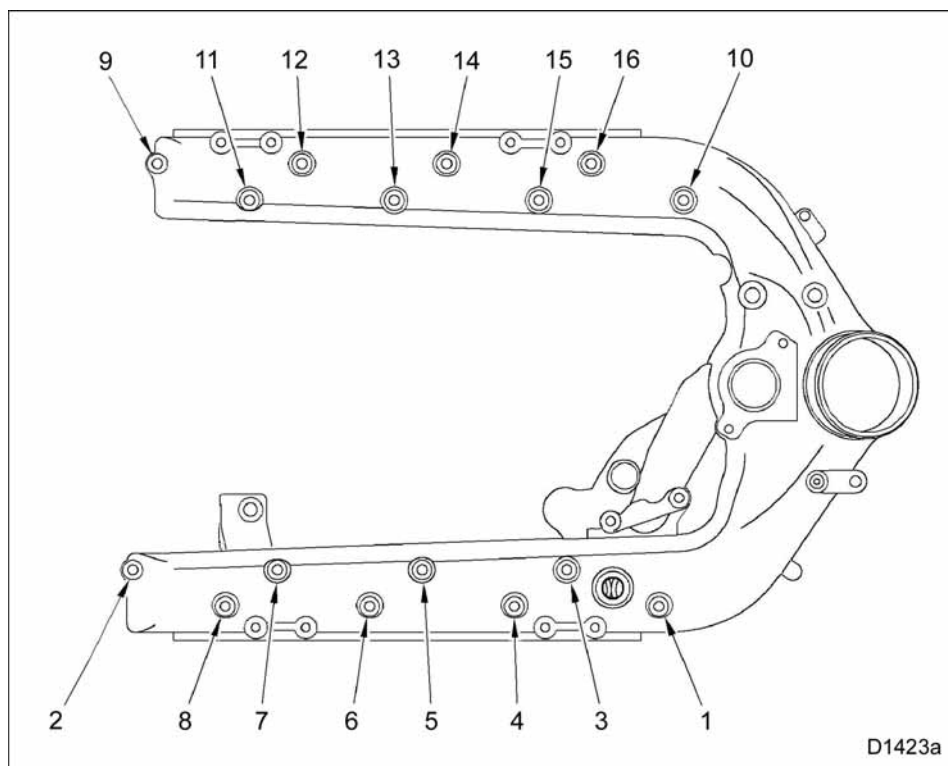


Figure 633 Tightening sequence for intake manifold mounting bolts

Table 58 Manifolds and Exhaust Gas Recirculation (EGR)

Intake manifold, M6 x 95 flange bolts	11 ± 1 N·m (96 ± 10 lbf·in) (Figure 633)
Intake heat shield, M6 nut	11 ± 3 N·m (96 ± 24 lbf·in)
Exhaust manifold flange bolts ¹	38 ± 4 N·m (28 ± 3 lbf·ft) (Figure 632)
EBP tube assembly ¹	30 ± 1 N·m (22 ± 1 lbf·ft)
EBP tube connector ¹	14 - 15 N·m (120 - 132 lbf·in)
Shielded exhaust tube to exhaust manifold (left side) ¹	27 ± 4 N·m (20 ± 3 lbf·ft)
Shielded tube exhaust to right side exhaust tube ¹	27 ± 4 N·m (20 ± 3 lbf·ft)
Exhaust tube to exhaust manifold (right side) ¹	27 ± 4 N·m (20 ± 3 lbf·ft)
VGT exhaust adapter V-clamp	12 N·m (108 lbf·in)
EGR cooler V-clamp	6 N·m (48 lbf·in)

¹ Apply anti-seize compound to bolt threads before assembly.

Cylinder Head and Valve Train

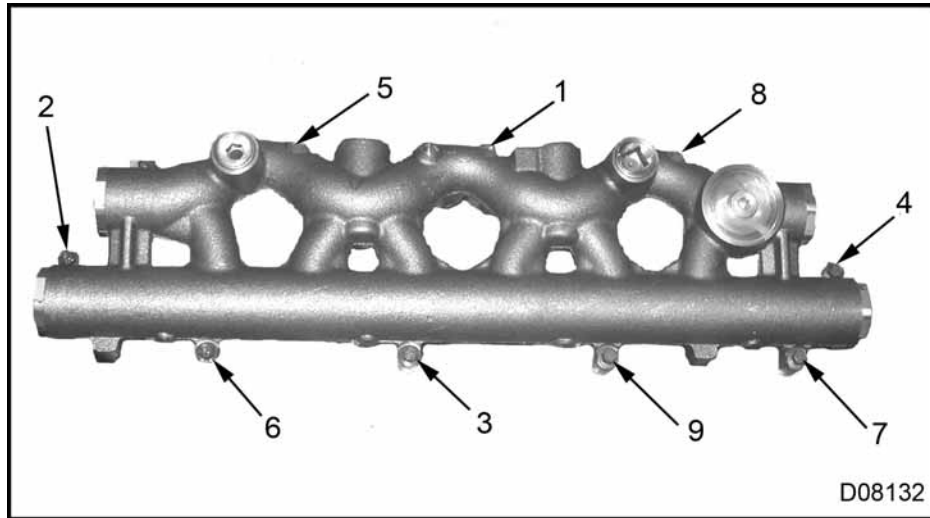


Figure 634 Torque sequence for oil rail bolts

Torque Sequence for Oil Rail Bolts

- A. Press rail down until seated. Thread remaining bolts finger tight.
- B. Torque bolts to the special torque in the sequence above.

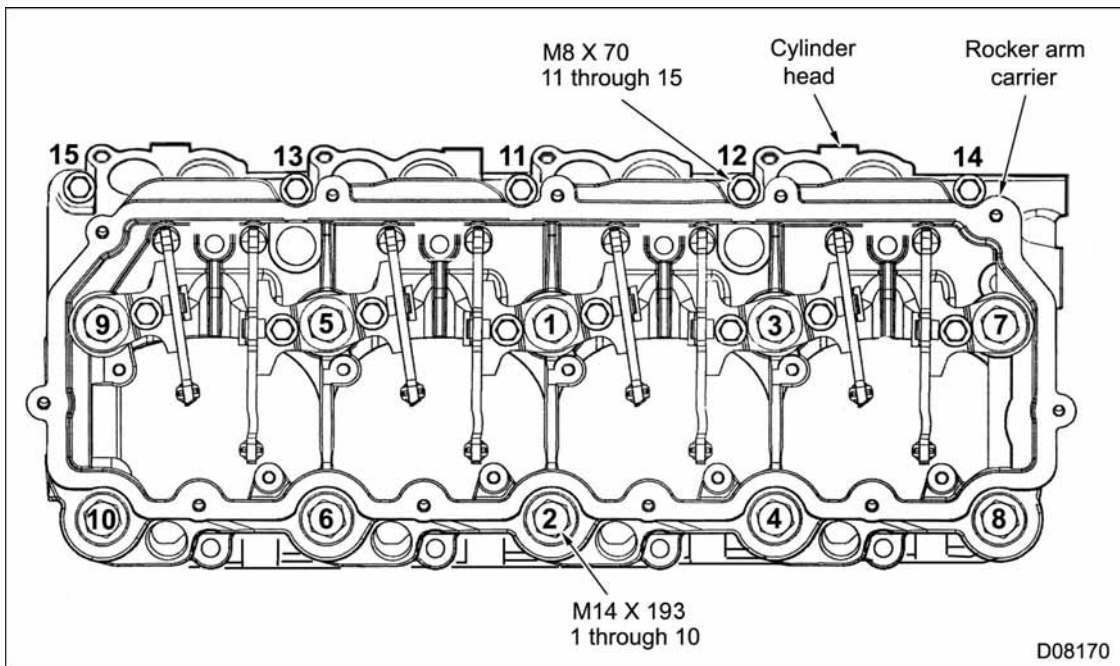


Figure 635 Tightening sequence for cylinder head mounting bolts

NOTE: All M14 x 193 cylinder head mounting bolts must be torqued first before torquing M8 x 70 bolts.

M14 x 193 Cylinder Head Mounting Bolts

- A. Lightly lubricate all bolts and torque in the sequence numbered 1 through 10 to 88 N·m (65 lbf·ft).
- B. Torque bolts 1, 3, 5, 7 and 9 in sequence to 116 N·m (85 lbf·ft).
- C. Torque all bolts in sequence numbered 1 through 10, clockwise 90°.
- D. Torque all bolts in sequence numbered 1 through 10, a second time clockwise 90°.
- E. Torque all bolts in sequence numbered 1 through 10, a third time clockwise 90°.
- F. M14 x 193 torque sequence complete.

M8 x 70 Cylinder Head Mounting Bolts

- A. Install all M8 bolts and torque in the sequence numbered 11 through 15 to 24 N·m (18 lbf·ft).
- B. Torque all M8 bolts in the sequence numbered 11 through 15 to 31 N·m (23 lbf·ft).
- C. M8 x 70 torque sequence complete.

Table 59 Cylinder Head and Valve Train

Lifting eye, front, (M10 x 30)	41 ± N·m (30 ± 3 lbf·ft)
Lifting eye, rear, flat socket head (M10 x 35)	41 ± N·m (30 ± 3 lbf·ft)
Crankcase breather nuts	7 N·m (60 lbf·in)
Cylinder head bolt torque and sequence	(Figure 635)
Fuel injector hold down bolt	33 N·m (24 lbf·ft)
Rocker arm fulcrum plate (M8 x 65)	31 N·m (23 lbf·ft)
Glow plugs	19 N·m (168 lbf·in)
Injection Control Pressure (ICP) sensor	12 ± 2 N·m (108 ± 18 lbf·in)
Oil rail assembly mounting bolts (M6 x 25)	13 N·m (120 lbf·in) (Figure 634)
Crankcase-to-head tube assembly	82 N·m (60 lbf·ft)
Valve cover bolts and studs	9 +1/-2 N·m (72 ± 12 lbf·in)
Oil fill extension	14 ± 1 N·m (120 - 132 lbf·in)
Rear heat shield (M10 x 16)	49 ± 5 N·m (36 ± 4 lbf·ft)

Front Cover, Vibration Damper, and Gerotor Oil Pump

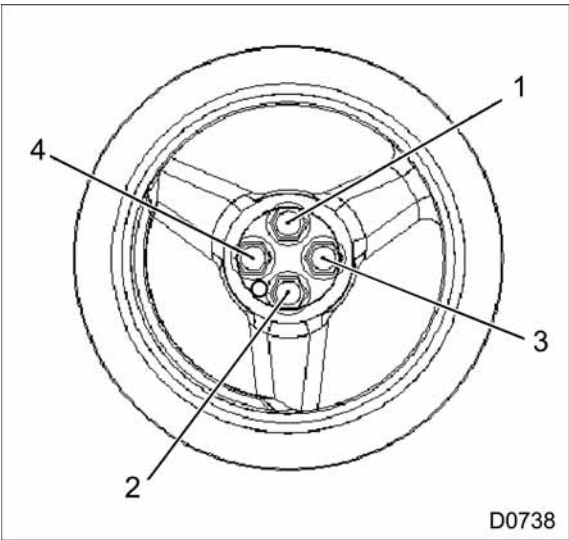


Figure 636 Torque sequence for vibration damper bolts

Table 60 Front Cover, Vibration Damper, Water Pump and Oil Pan Drain Plug

Oil pan drain plug	25 ± 5 N·m (18 ± 4 lbf·ft)
Front cover module bolts	24 N·m (18 lbf·ft)
Water pump mounting bolts	23 ± 1 N·m (17 ± 1 lbf·ft)
Vibration damper mounting bolts	New bolts only: 68 N·m (50 lbf·ft) + 90° rotation. (Figure 636)

Connecting Rods and Pistons

Table 61 Connecting Rod Assembly

Connecting rod bearing bolts	Initial	45 N·m (33 lbf·ft)
	Final	68 N·m (50 lbf·ft)

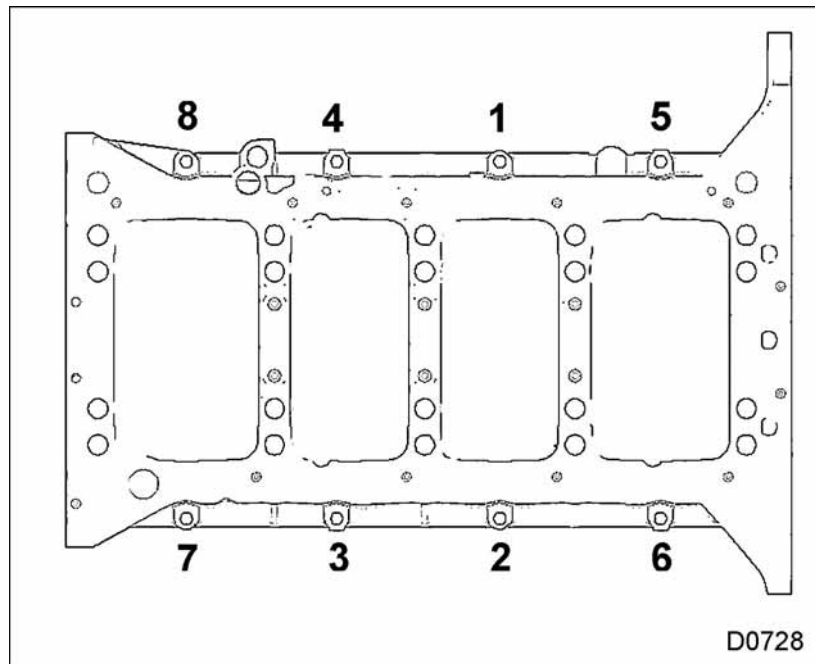
**Crankcase, Crankshaft and Bearings, Camshaft
and Bushings**

Figure 637 Torque sequence for outer lower crankcase bolts – 2004 Model Year

NOTE: For 2004 Model Year, install eight M8 x 30 bolts around outside of lower crankcase and torque in sequence to 31 N·m (23 lbf·ft).

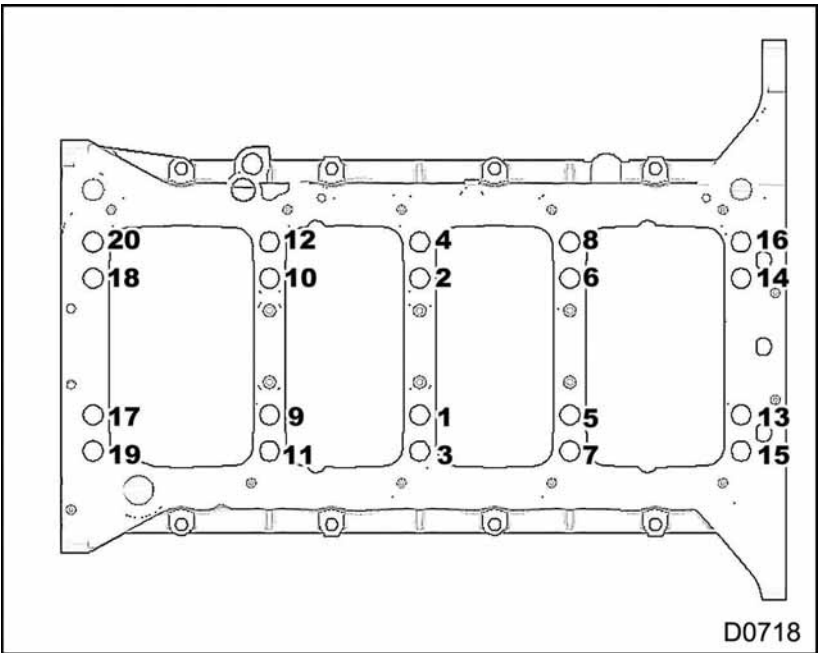


Figure 638 Tightening sequence for main bearing bolts in lower crankcase

1. Initially torque bolts to 122 N·m (90 lbf·ft).
2. Increase torque for bolts to 163 N·m (120 lbf·ft).
3. Finally, torque bolts to 231 N·m (170 lbf·ft).

Table 62 Crankcase and Heater Element

Lower crankcase main bearing cap bolts	See tightening procedure and sequence (Figure 637)
Lower crankcase outer bolts (M8 x 30), standard torque	
Coolant heater element	41 N·m (30 lbf·ft)

Oil Cooler and Oil Filter

Table 63 Oil Cooler and Oil Filter

EGR cooler coolant supply port cover (M6)	10 +1/-2 N·m (84 ± 12 lbf·in)
Oil cooler mounting bolts (M6 x 23)	10 +1/-2 N·m (84 ± 12 lbf·in)
Oil cooler cover mounting bolts (M8 x 23)	22 ± 2 N·m (17 ± 1 lbf·ft)
Oil filter housing mounting bolts (M8 x 75)	22 ± 2 N·m (17 ± 1 lbf·ft)
Oil filter return tube bolt	New base plate: 6 N·m (50 lbf·in) Reinstallation: 3 N·m (23 lbf·in)
Oil filter cap	25 N·m (18 lbf·ft)

Engine Electrical

Table 64 Engine Electrical

Exhaust Back Pressure (EBP) sensor	12 + 2/-3 N·m (108 ± 12 lbf·in)
Engine Coolant Temperature sensor (ECT)	12 ± 2 N·m (108 ± 12 lbf·in)
Engine Oil Temperature sensor (EOT)	12 ± 2 N·m (108 ± 12 lbf·in)
Engine Oil Pressure sensor (EOP)	12 ± 2 N·m (108 ± 12 lbf·in)
Glow plug	19 N·m (168 lbf·in)
Injection Control Pressure (ICP) sensor	12 ± 2 N·m (108 ± 18 lbf·in)
Injection Pressure Regulator (IPR)	50 ± 5 N·m (37 ± 4 lbf·ft)
Manifold Absolute Pressure (MAP) sensor	12 ± 2 N·m (108 ± 12 lbf·in)
Manifold Air Temperature (MAT) sensor	18 + 2/-3 N·m (156 ± 24 lbf·in)

High-pressure Oil Pump

Table 65 Oil Pump, Cover, IPR, and Heat Shields

High-pressure oil pump cover bolts	14 N·m (120 lbf·in)
Branch tube adapter bolts (M6 x 25)	14 N·m (120 lbf·in)
Injection Pressure Regulator (IPR)	50 ± 5 N·m (37 ± 4 lbf·ft)
Rear exhaust heat shield, (M6 x 12)	11 ± 3 N·m (96 ± 24 lbf·in)
Rear heat shield, (M10 x 16)	49 ± 5 N·m (36 ± 4 lbf·ft)

Fuel System

Table 66 Fuel System Components

Fuel supply tube assembly at filter	41 ± 4 N·m (30 ± 3 lbf·ft)
Fuel return tube assembly at filter	25 ± 2 N·m (19 ± 2 lbf·ft)
Left and right cylinder head supply tubing at filter	25 ± 2 N·m (18 ± 2 lbf·ft)
Banjo bolt, 12 mm	38 ± 4 N·m (28 ± 3 lbf·ft)
Plug assembly, 12 mm (back of cylinder head)	27 ± 1 N·m (20 ± 1 lbf·ft)
Power steering pump inlet elbow fitting	90 ± 10 N·m (66 ± 7 lbf·ft)
Power steering pump outlet elbow fitting	45 ± 4 N·m (33 ± 3 lbf·ft)
Power steering tube	79 ± 4 N·m (58 ± 3 lbf·ft)

Flywheel, Rear Cover, and Power Steering and Fuel Pump

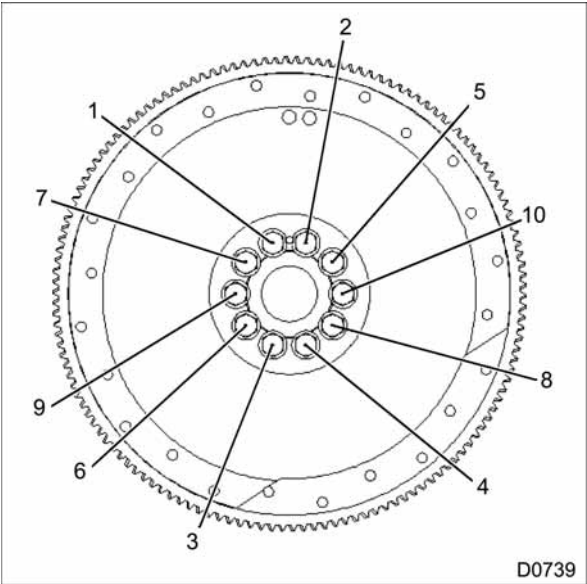


Figure 639 Torque sequence for flywheel and flexplate (typical)

Table 67 Flywheel, Flexplate and Power Steering Assembly

Flywheel mounting bolts (M10 x 77), new bolts only	94 N·m (69 lbf·ft) (Figure 639)
Flexplate mounting bolts (M10 x 77), new bolts only	94 N·m (69 lbf·ft) (Figure 639)
Power steering pump outlet pipe fitting	45 ± 5 N·m (33 ± 4 lbf·ft)
Power steering pump inlet pipe fitting	90 ± 10 N·m (66 ± 7 lbf·ft)

In-chassis Procedures**Table 68 Branch Tube Assembly**

Bolts for branch tube mounting blocks	13 N·m (115 lbf·in)
Bolts for branch tube adapter	13 N·m (115 lbf·in)
STC fitting	53 ± 4 N·m (39 ± 3 lbf·ft)
Bolts for heat shield (M10 x12)	13 N·m (115 lbf·in)
Bolt for heat shield and M10 x 16)	62 N·m (45 lbf·ft)
V-clamp for shielded exhaust tube	12 N·m (106 lbf·in)
Bolts for right exhaust tube (shielded exhaust tube connected) to right exhaust manifold (M8)	27 ± 4 N·m (20 ± 3 lbf·ft)
Bolts for rear engine mounts (M12 x 40)	107 N·m (79 lbf·ft)
Nut for bolt through rear engine mounts and chassis mounts (M16)	294 – 325 N·m (216 – 239 lbf·ft)
Bolts for starter motor (M12 x 40)	47 –58 N·m (35–43 lbf·ft)
Turbocharger exhaust clamp for turbocharger down pipe	25 – 10 N·m (4 – 6 lbf·ft)
Bolts for alternator and air conditioning compressor bracket (M10)	72 N·m (53 lbf·ft)
Bolts for air compressor bracket (M10 x 100)	72 N·m (53 lbf·ft)

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Special Tools

Special tools for the VT 365 engine can be ordered from the **SPX Corporation, 1-800-520-2584**.

Mounting Engine on Stand

Table 69 Mounting Engine on Stand

Description	TOOL NUMBER
Engine Stand Mounting Bracket	ZTSE4507

Variable Geometry Turbocharger (VGT)

Table 70 VGT

Description	Tool Number
Cap Kit (all)	ZTSE4610
Dial Indicator with Magnetic Base	Obtain locally
Intake Guard	ZTSE4548

Manifolds and Exhaust Gas Recirculation (EGR)

Table 71 Manifolds and Exhaust Gas Recirculation (EGR)

Description	Tool Number
Anti-Seize Compound	Obtain locally
Cap Kit (all)	ZTSE4610
EGR Cooler Pressure Test Plates	ZTSE4545
EGR Valve Puller	ZTSE4669
Feeler Gauge	Obtain locally
Injector Sleeve Brush	ZTSE43041
Intake Manifold Pressure Test Plates	ZTSE4527
Intake Manifold Pressure Test Plug (Replaces EGR Valve)	ZTSE4544
Intake Port Covers (cylinder heads)	ZTSE4559
Pressure Test Adaptor (intake)	ZTSE4554
Straightedge	Obtain locally

Cylinder Head and Valve Train**Table 72 Cylinder Head and Valve Train**

Description	TOOL NUMBER
Bottoming Tap (metric)	ZTSE4508
Case-to-head Removal Tool	ZTSE4694
Cylinder Head Lifting Bracket	ZTSE4535
Cylinder Head Pressure Test Plate	ZTSE4534
Dye Penetrant Kit	PT-7191
Fuel Gallery Cleaning Brush	ZTSE4541
Fuel Injector Hold Down Wrench	ZTSE4524
Fuel Injector Rack Holder	ZTSE4299B
Fuel Injector Tip Cleaning Brush	ZTSE4301
Glow Plug Sleeve Brush (nylon)	ZTSE4533
Glow Plug Sleeve Installer	ZTSE4532
Glow Plug Sleeve Remover (both the tap and the bolt and sleeve adapter)	ZTSE4531
Glow Plug Sleeve Seat Wire Brush	ZTSE4589
Injector Connector Remover	ZTSE4650
Injector Sleeve Brush	ZTSE43041
Injector Sleeve Installer	ZTSE4529
Injector Sleeve Remover (both the tap and the slide hammer adapter)	ZTSE4528
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Quick Release Tool	ZTSE4581
Quick Release Tool Kit	ZTSE4454
Slide Hammer Kit	ZTSE4398
Straightedge	Obtain locally
Valve Guide Gauge Tool	ZTSE4577
"C" Type Valve Spring Compressor	ZTSE1846
Valve Spring Tester	ZTSE2241

Front Cover, Vibration Damper, and Gerotor Oil Pump**Table 73 Front Cover, Vibration Damper, and Gerotor Oil Pump**

Description	Tool Number
Dial Indicator with Magnetic Base	Obtain locally
Fan Hub Wrench (2 inch)	ZTSE43972
Fan Wrench (pulley bolts)	ZTSE4587
Front Seal/Wear Sleeve Installer	ZTSE4516
Front Wear Sleeve Remover	ZTSE4517
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Loctite® Hydraulic Sealant	Obtain locally

Connecting Rods and Pistons**Table 74 Connecting Rods and Pistons**

Description	Tool Number
Dial Indicator with Magnetic Base	Obtain locally
Piston Gauge Pins (0.082 in)	ZTSE4513
Piston Ring Compressor (Cope)	ZTSE4514
Piston Ring Expansion Pliers	Obtain locally
Telescoping Gauge Set	Obtain locally

Crankcase, Crankshaft and Bearings, Camshaft and Bushings

Table 75 Crankcase, Crankshaft and Bearings, Camshaft and Bushings

Description	Tool Number
Accessory Drive Gear Puller	ZTSE4520
Camshaft Bushing Kit	ZTSE2893A
Camshaft Bushing Remover/Installer (expanding collet)	ZTSE4489
Crankshaft Timing Tool	ZTSE4519
Cylinder Bore Gauge	Obtain locally
Deglazing Hone (four inch)	ZTSE4349
Dial Indicator with Magnetic Base	Obtain locally
Freeze Plug Installer	ZTSE4509
Front Seal/Wear Sleeve Installer	ZTSE4516
Front Wear Sleeve Remover	ZTSE4517
Head Bolt Bottoming Tap	ZTSE4508
Hot Plate	Obtain locally
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Oil Gallery Cleaning Brush	ZTSE4511
Oil Gallery Plug Driver	ZTSE4512
Piston Gauge Pins (0.082 in)	ZTSE4513
Straightedge	Obtain locally
Telescoping Gauge Set	Obtain locally

Oil Cooler and Oil Filter

Table 76 Oil Cooler

Description	Tool Number
Magnetic Cover	ZTSE4557
Oil Cooler Pressure Test Plate	ZTSE4525

Engine Electrical

Table 77 Engine Electrical

Description	Tool Number
Cap Kit (all)	ZTSE4610
EGR Valve Puller	ZTSE4669
Glow Plug Connector Remover/Installer	ZTSE4670

High-pressure Oil Pump**Table 78 High-pressure Oil Pump**

Description	Tool Number
Cap Kit (all)	ZTSE4610
Dial Indicator with Magnetic Base	Obtain locally
IPR Valve Removal Tool	ZTSE4564
Liquid gasket (RTV) (6 oz. tube)	1830858C1
Magnetic Cover	ZTSE4557
Quick Release Tool	ZTSE4581

Fuel System**Table 79 Fuel System**

Description	Tool Number
Cap Kit (all)	ZTSE4610
Dial Indicator with Magnetic Base	Obtain locally
IPR Valve Removal Tool	ZTSE4564
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Magnetic Cover	ZTSE4557
Quick Release Tool	ZTSE4581

Flywheel, Rear Cover, and Power Steering and Fuel Pump**Table 80 Flywheel, Rear Cover, and Power Steering and Fuel Pump**

Description	Tool Number
Cap Kit (all)	ZTSE4610
Liquid Gasket (RTV) (6 oz. tube)	1830858C1
Rear/Wear Sleeve Installer	ZTSE4515
Rear Wear Sleeve Removal Tool	ZTSE4518
Loctite® Hydraulic Sealant	Obtain locally

In-chassis Procedures**Table 81 Branch Tube Assembly**

Description	TOOL NUMBER
No. 10 Quick Release Tool	ZTSE4581

Table 82 Rocker Arm

Description	TOOL NUMBER
Injector Connector Release Tool	ZTSE4650
Fuel Injector Hold Down Wrench	ZTSE4524
On-engine Valve Spring Compressor Tool	ZTSE4697

Special Tools

Essential Tools



Figure 640 "C" Type Valve Spring Compressor ZTSE1846

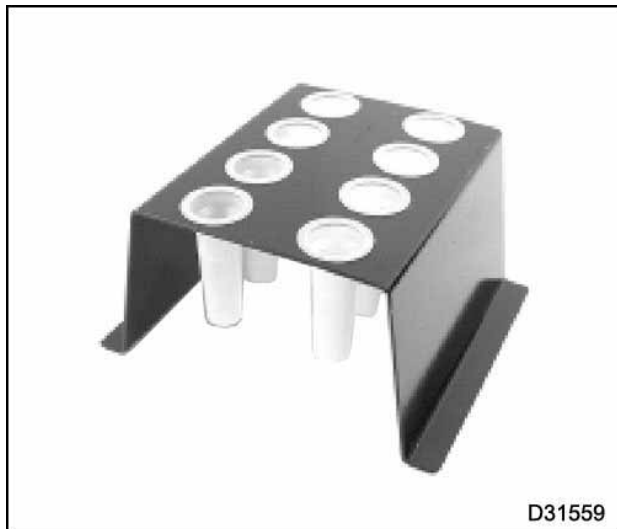


Figure 641 Fuel Injector Rack Holder ZTSE4299B



Figure 642 Slide Hammer Kit 5/8 in ZTSE4398

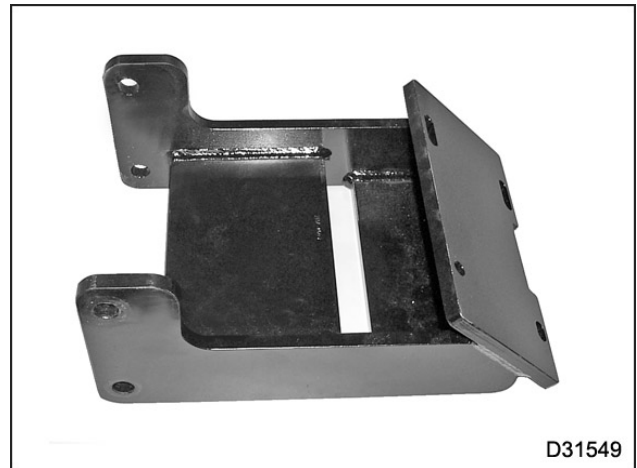


Figure 643 Engine Stand Mounting Bracket ZTSE4507

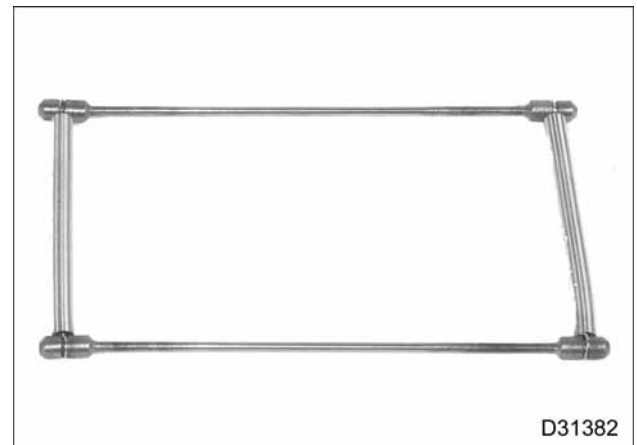
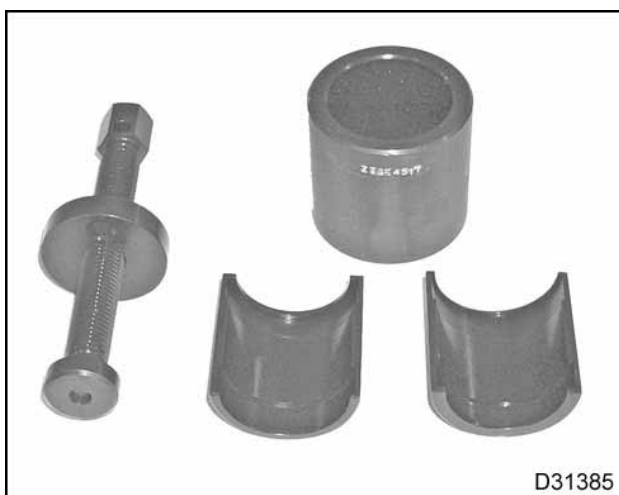


Figure 644 Piston Gauge Pins (0.082 in) ZTSE4513



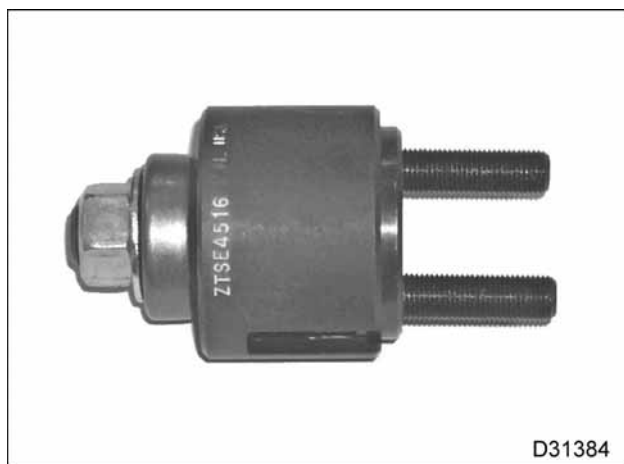
D31383

Figure 645 Crankshaft Rear Seal/Wear Sleeve Installer ZTSE4515



D31385

Figure 647 Front Wear Sleeve Remover ZTSE4517



D31384

Figure 646 Front Seal Installer/Wear Sleeve Installer ZTSE4516



D31386

Figure 648 Crankshaft Rear Wear Sleeve Remover ZTSE4518



Figure 649 Crankshaft Timing Tool ZTSE4519



**Figure 650 Fuel Injector Hold down wrench
ZTSE4524**



**Figure 651 Oil Cooler Test Plate/Pressure
Adapter ZTSE4525**

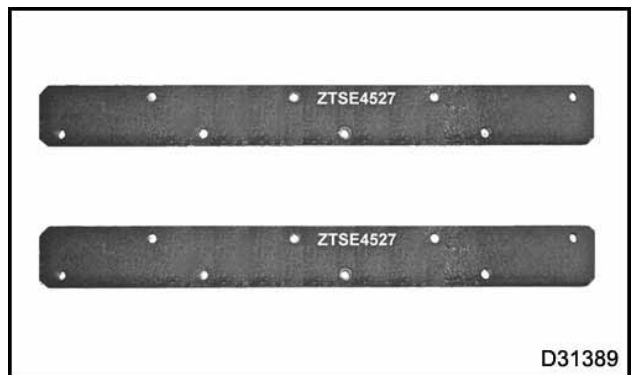


Figure 652 Intake Manifold Test Plates ZTSE4527



Figure 653 Injector Sleeve Remover ZTSE4528



Figure 654 Injector Sleeve Installer ZTSE4529

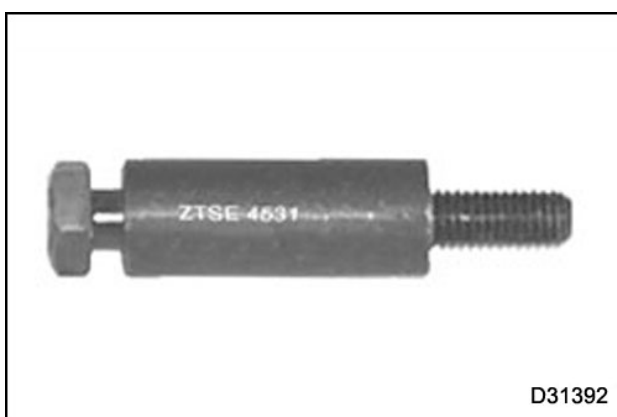


Figure 655 Glow Plug Sleeve Remover ZTSE4531



Figure 656 Glow Plug Sleeve Installer ZTSE4532

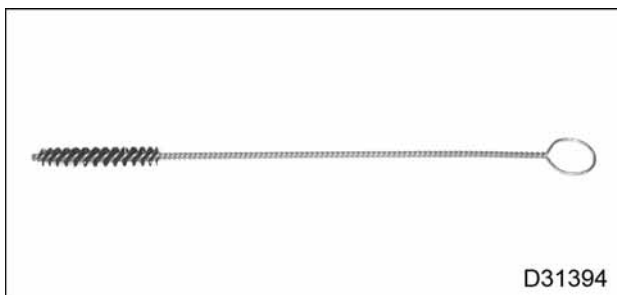


Figure 657 Glow Plug Sleeve Brush (nylon) ZTSE4533

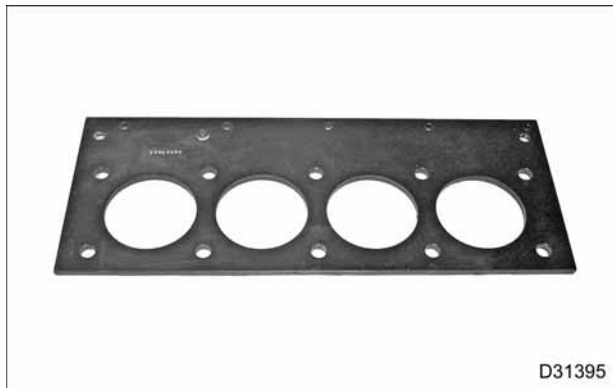


Figure 658 Cylinder Head Pressure Test Plate
ZTSE4534

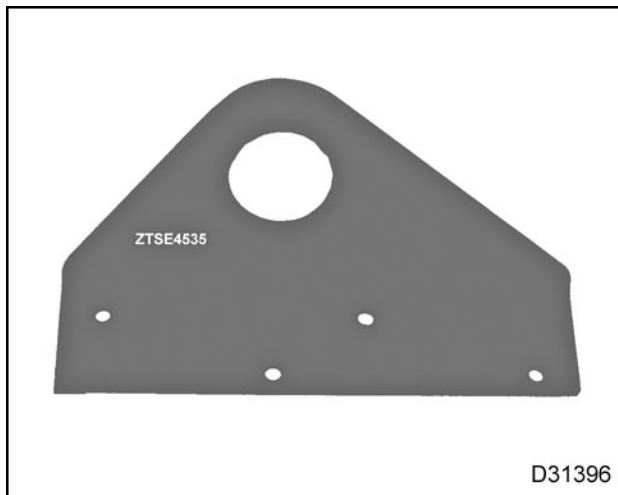


Figure 659 Cylinder Head Lifting Bracket
ZTSE4535



Figure 660 Intake Manifold Pressure Test Plug
(EGR Valve) ZTSE4544

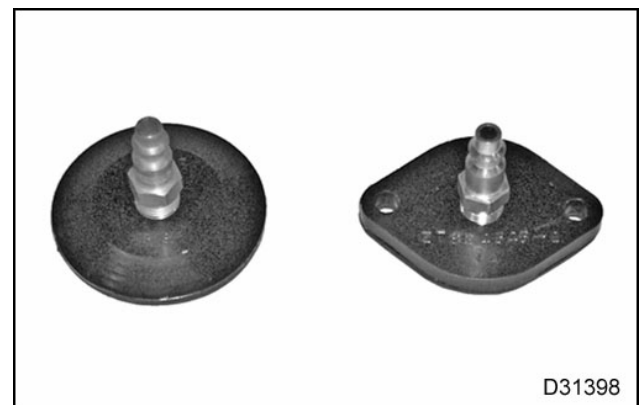


Figure 661 EGR Cooler Test Plates ZTSE4545



Figure 662 Intake Manifold Pressure Test Cap ZTSE4554

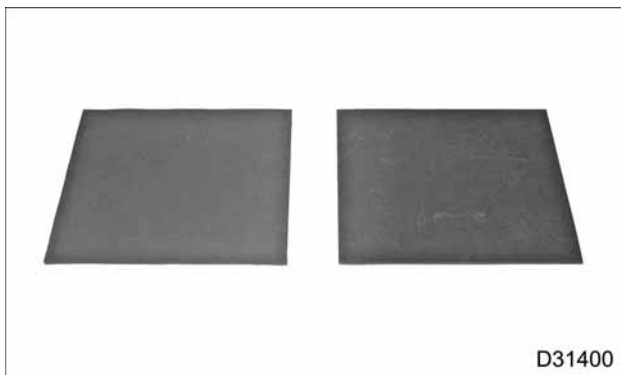


Figure 663 Oil Cooler Reservoir/High-pressure Pump Magnetic Covers ZTSE4557

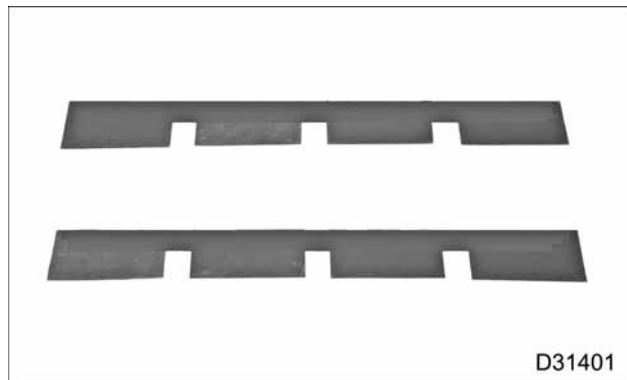


Figure 664 Magnetic Covers for Cylinder Head Intake Ports ZTSE4559



Figure 665 Quick Release Tool (No. 8 and No. 10) ZTSE4581



Figure 666 Fan Wrench (pulley bolts) ZTSE4587



Figure 667 Injector Connector Remover
ZTSE4650



Figure 669 Crankcase-to-head Removal Tool
ZTSE4694



Figure 668 EGR Valve Puller ZTSE4669



Figure 670 On-engine Valve Spring Compressor
Tool ZTSE4697



Figure 671 Idler Shaft Installation Tool ZTSE4719



Figure 672 Secondary Flange Installation Tool ZTSE4720

Photos of Essential Tools from T 444E Essential Tool Kit ZTSE4350

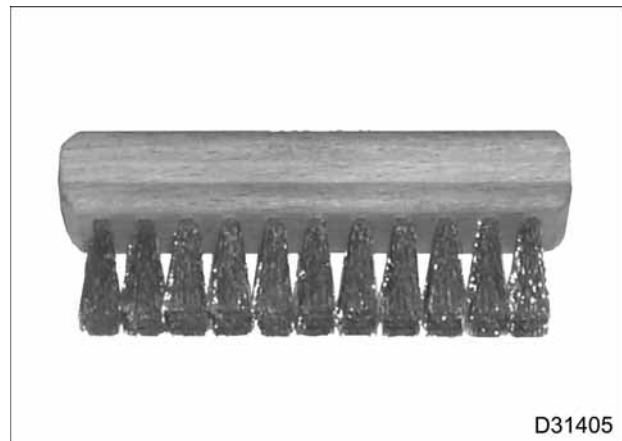


Figure 673 Injector Tip Cleaning Brush ZTSE4301

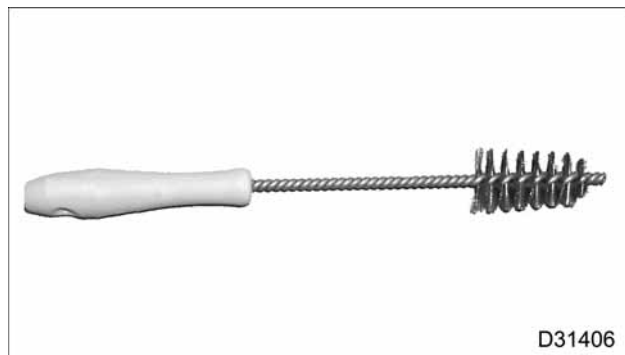


Figure 674 Injector Sleeve Brush ZTSE43041

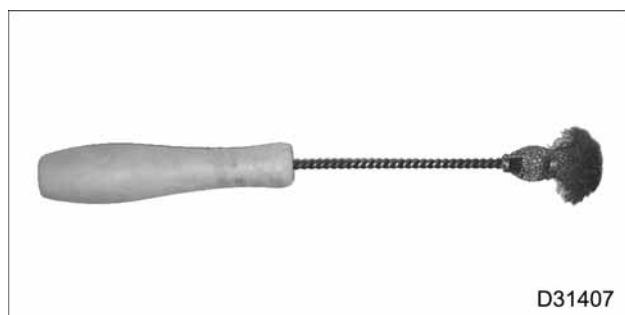


Figure 675 Injector Sleeve Flat Bottom Brush ZTSE43042



Figure 676 Fan Hub Wrench (2 inch) ZTSE43972

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