SERVICE MANUAL

INTERNATIONAL® VT 365

DIESEL ENGINE

2004-2006 Model Years

EGES-295-2

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Printed in the United States of America

Table of Contents

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	*VT 365 Engine Operation and Maintenance Manual*
EGES-295-2	*VT 365 Engine Service Manual*
EGES-240	*VT 365 Engine Diagnostic Manual*
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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C/O Moore Wallace North America
1750 Wallace Avenue
St. Charles, IL 60174
Telephone: 630-313-7507

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.

Table of Contents

Engine Identification

Engine Serial Number

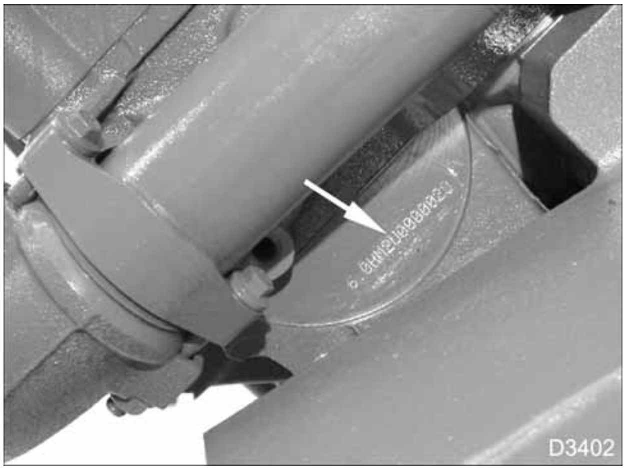


Figure 1 Engine serial number

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

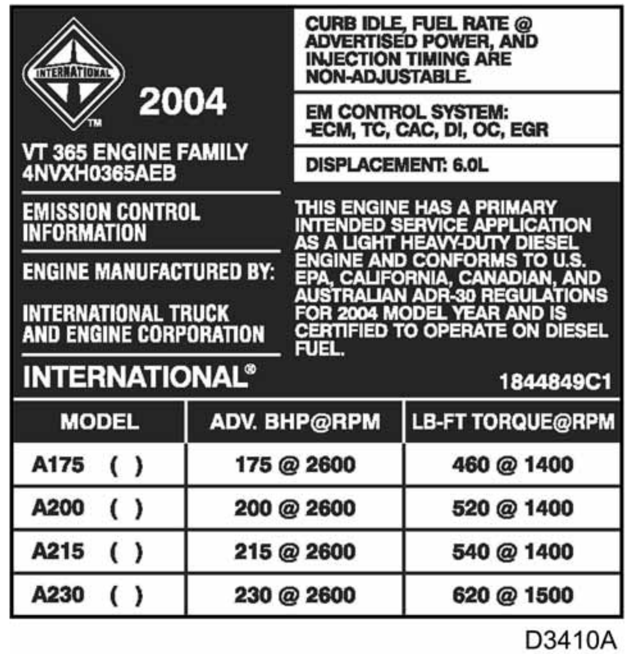


Figure 2 50 – State Exhaust Emissions Label (example)

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

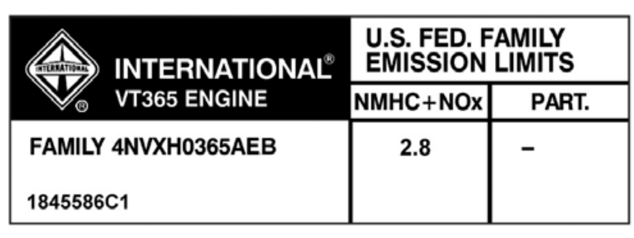


Figure 3 U.S. Federal Family Emission Limits label (example)

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.

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

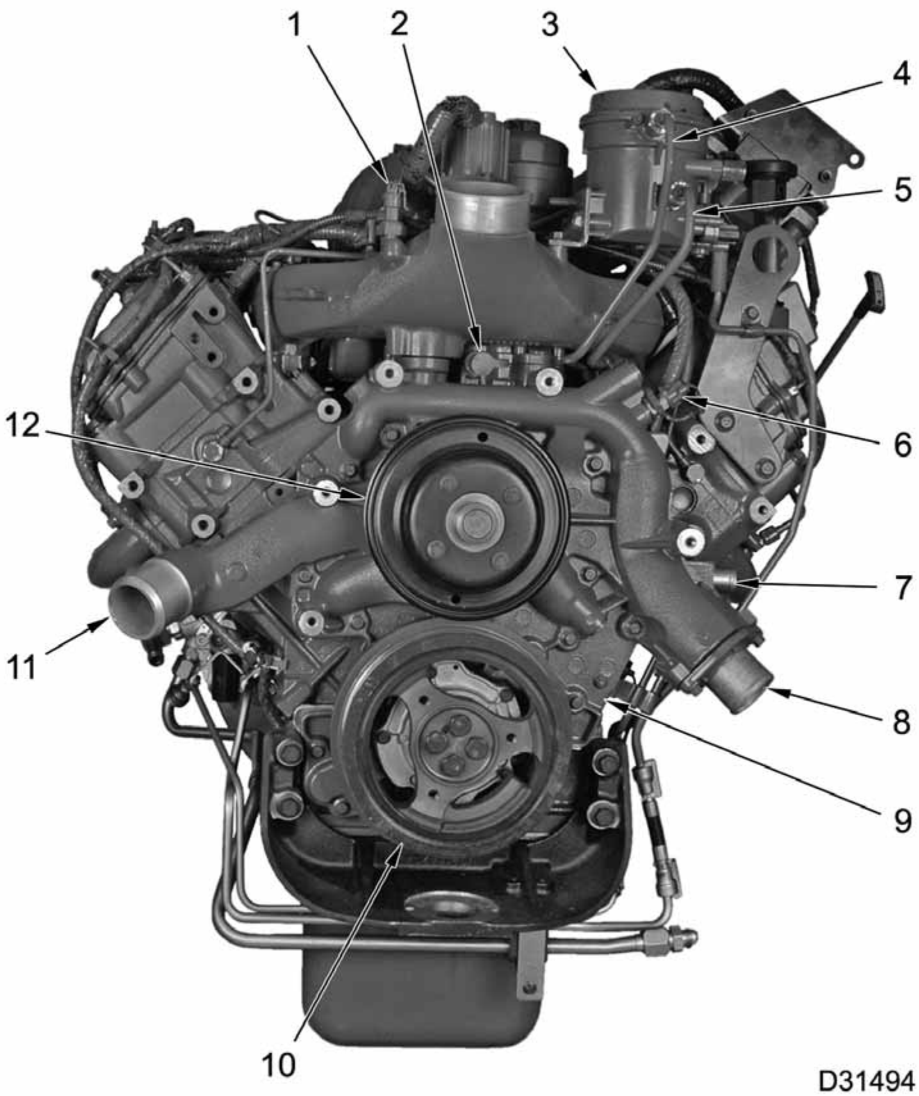


Figure 5 Engine components – Front

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

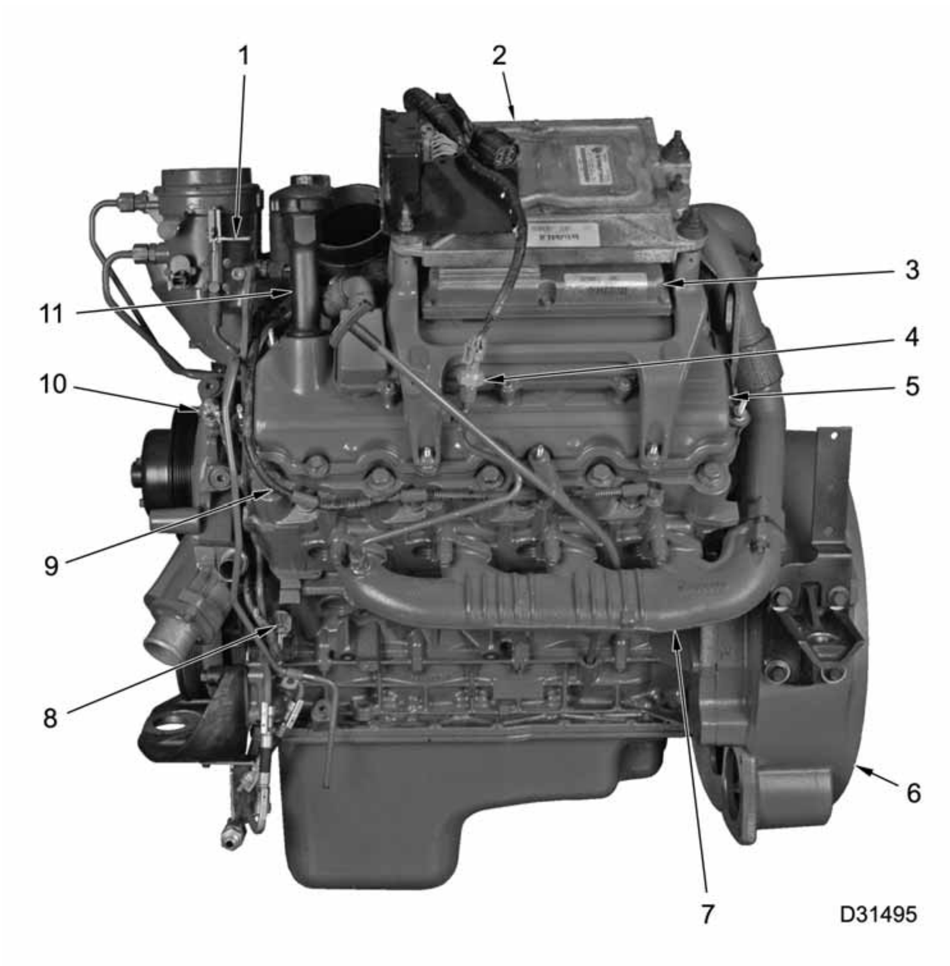


Figure 6 Engine components – Left

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

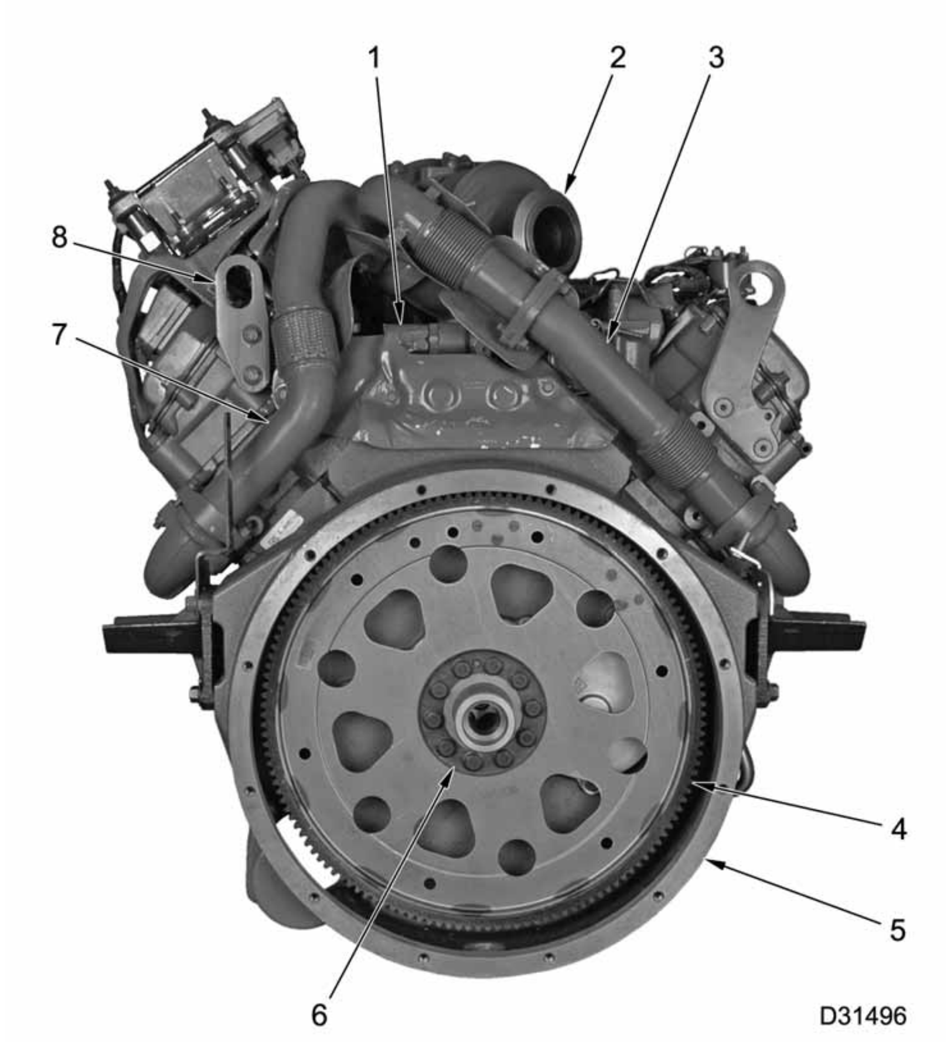


Figure 7 Engine components – Rear

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

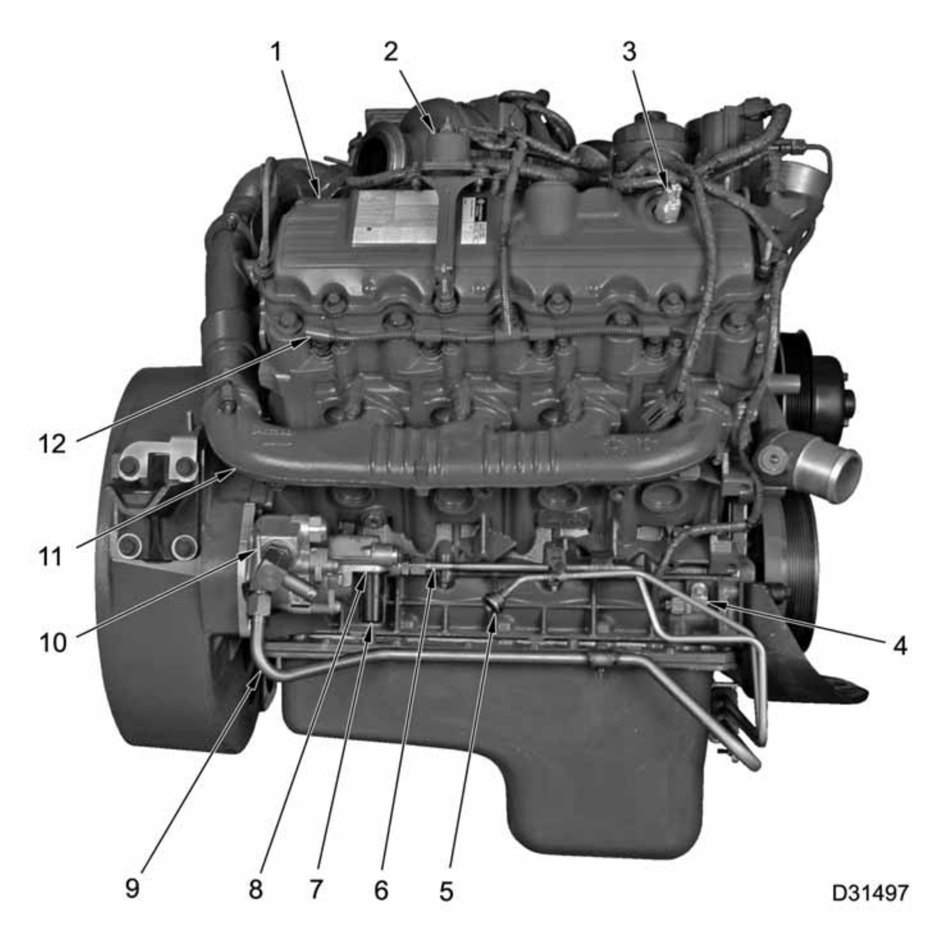


Figure 8 Engine components – Right

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

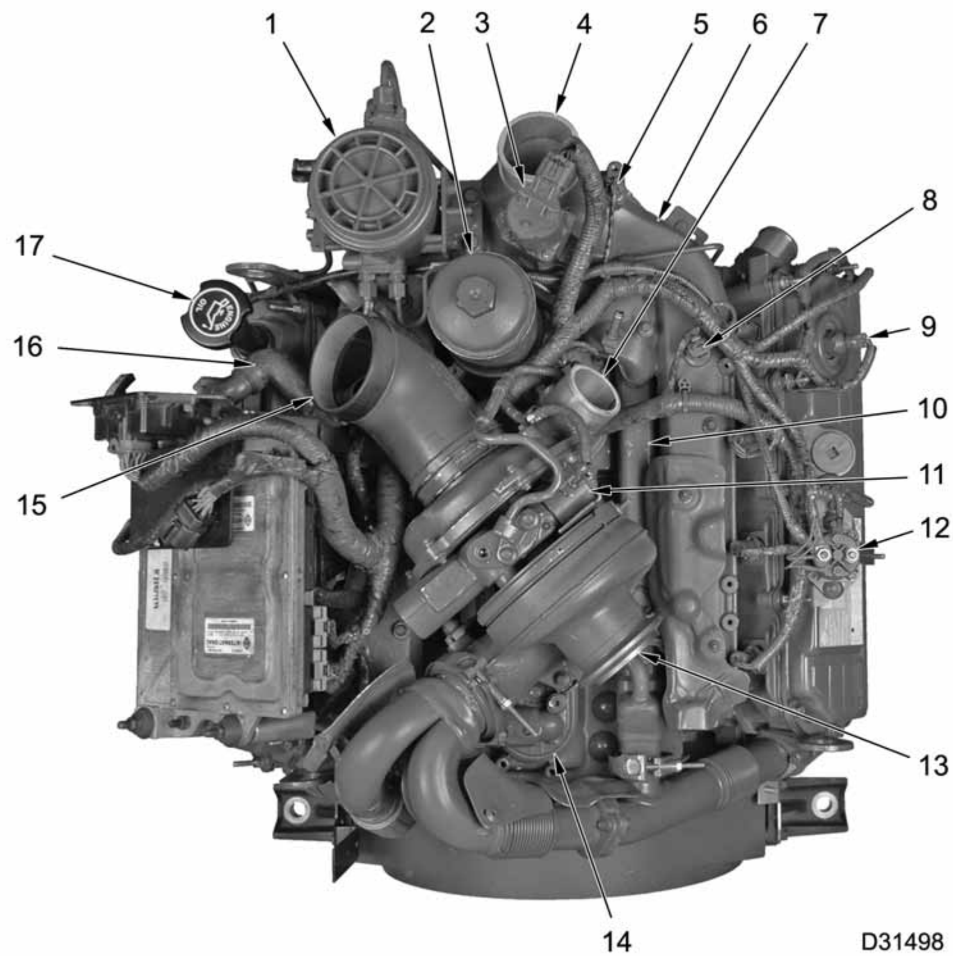
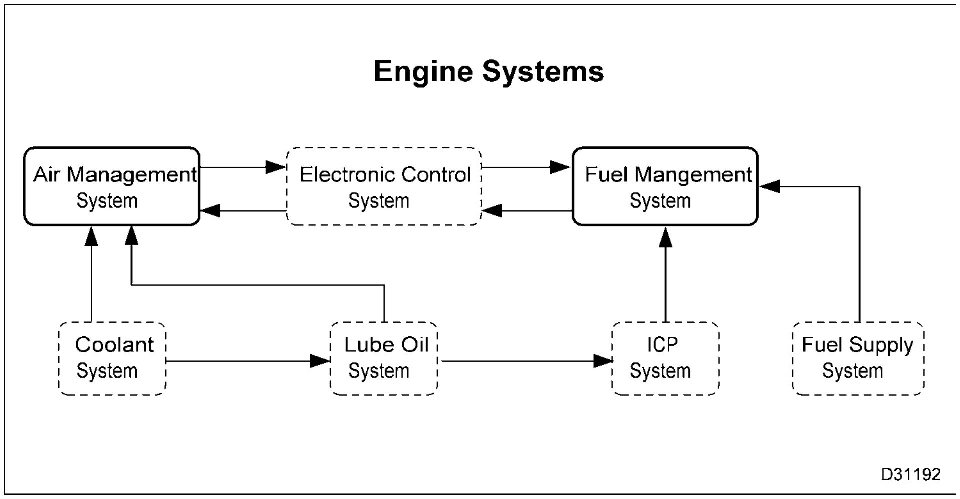


Figure 9 Engine components – Top

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

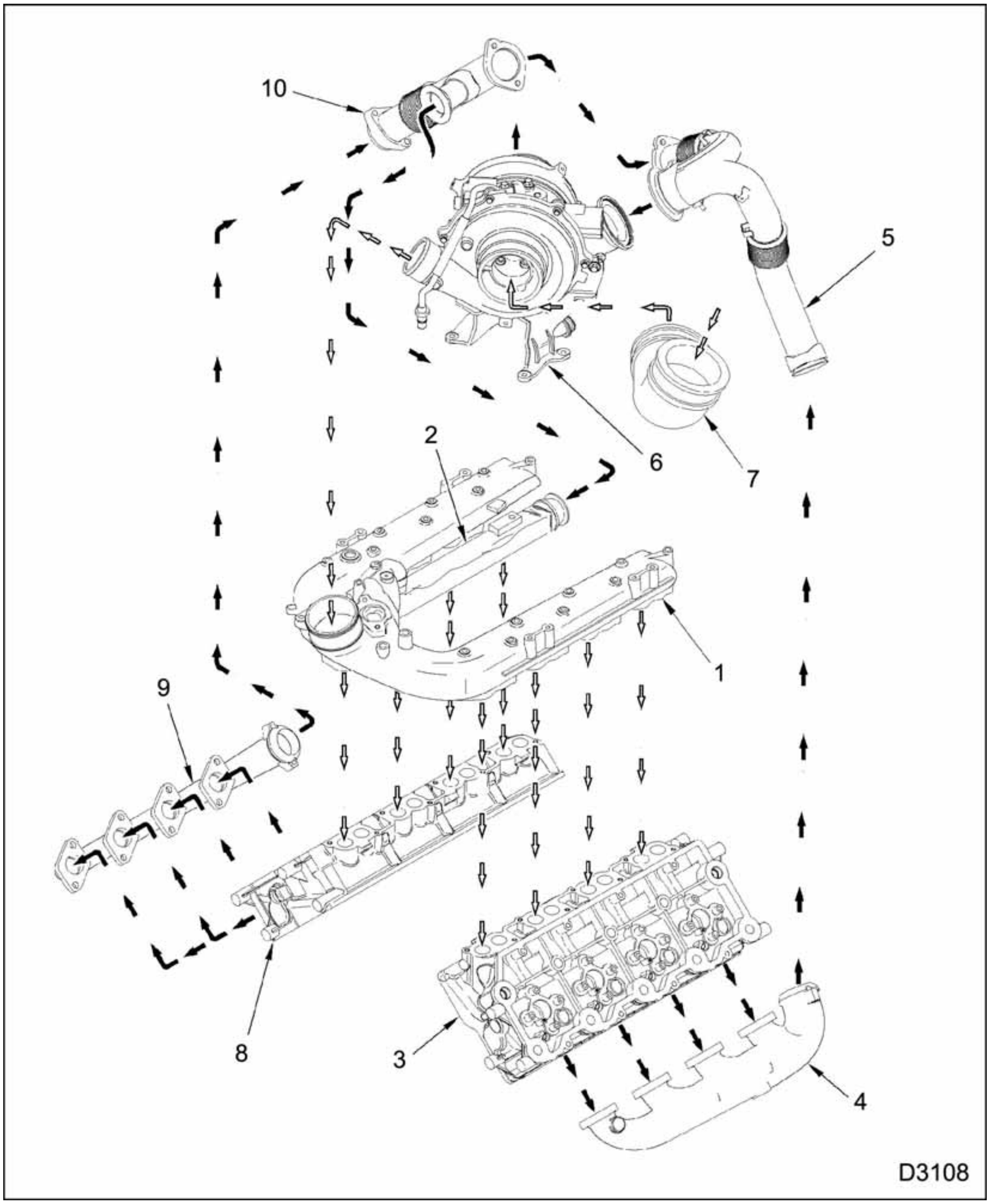


Figure 11 Air Management System (AMS)

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

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

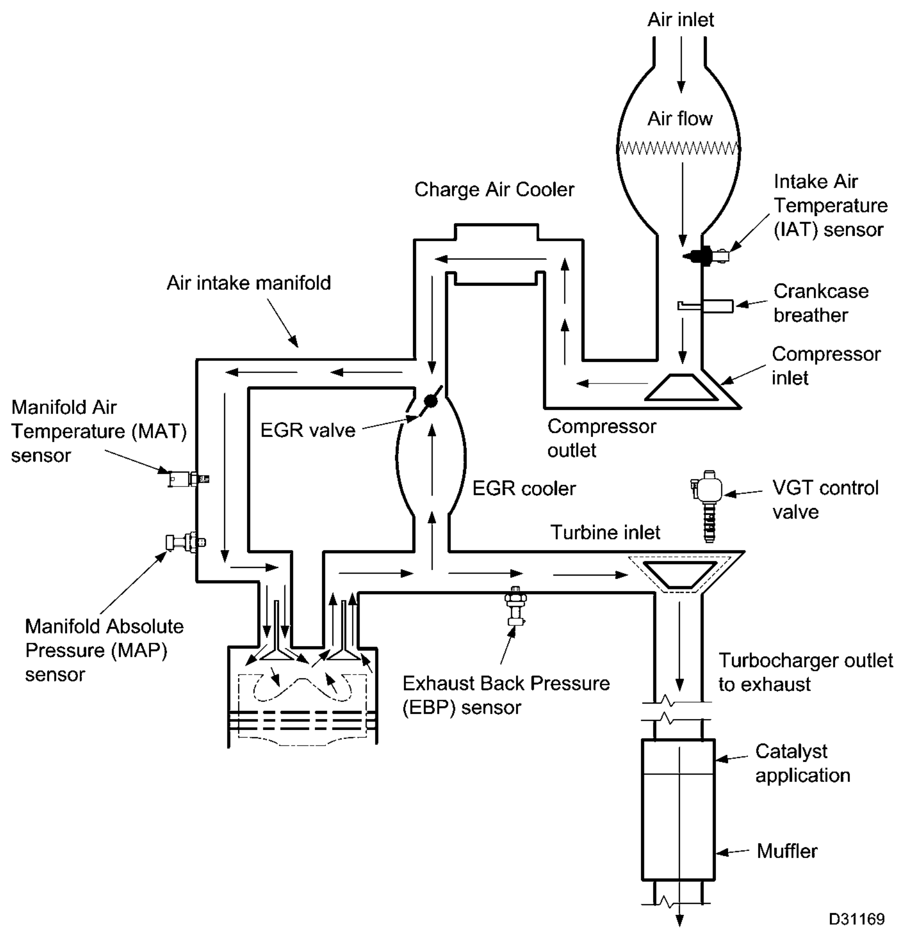


Figure 12 Air flow diagram

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)

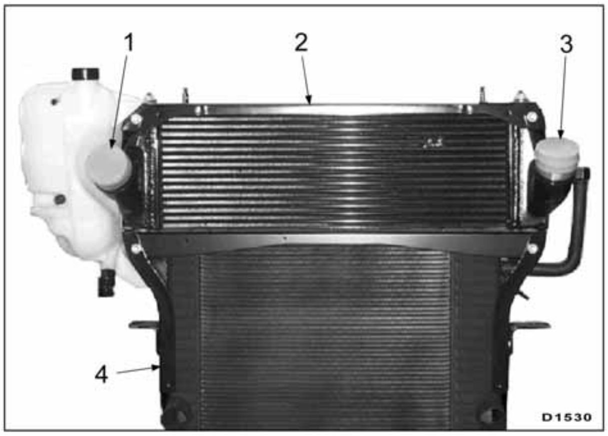


Figure 13 Charge Air Cooler

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)

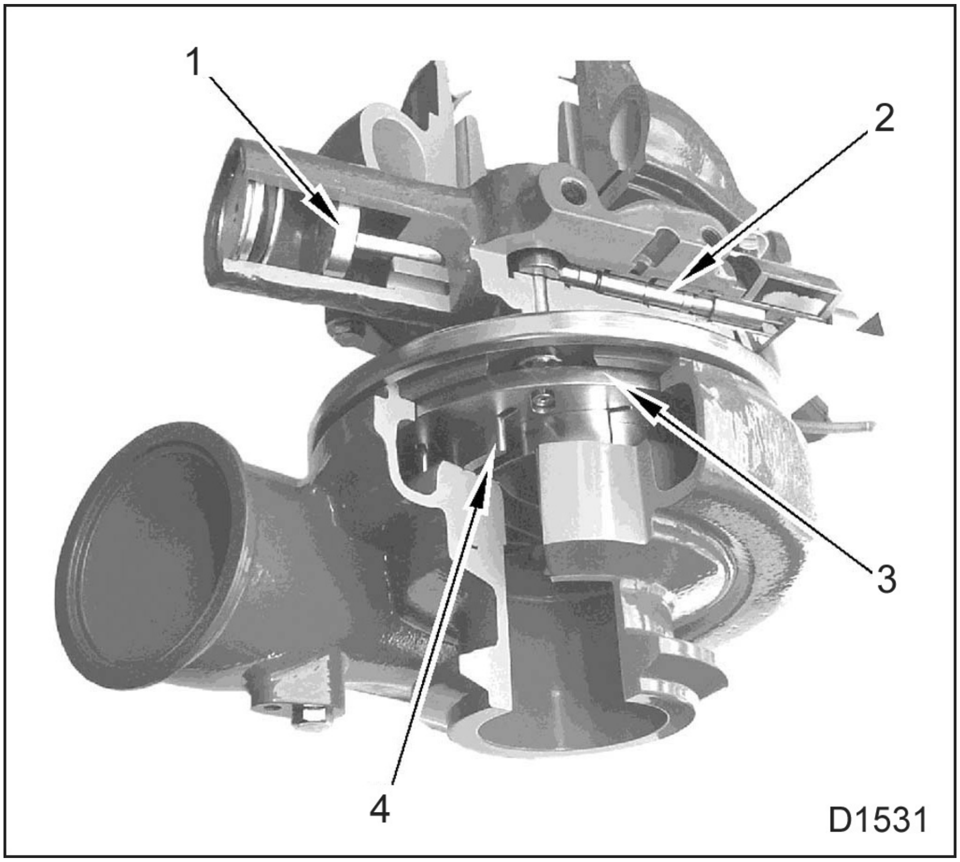


Figure 14 VGT

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

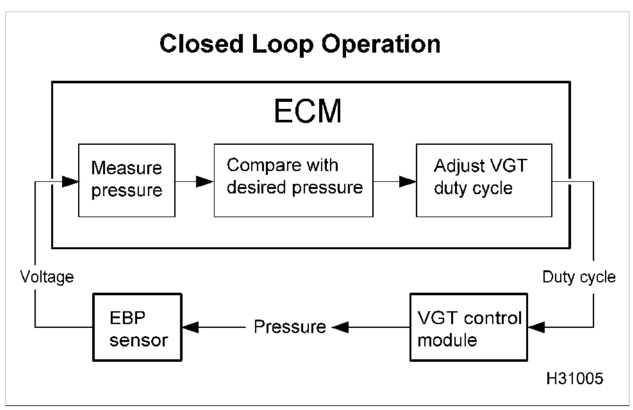


Figure 15 VGT closed loop system

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

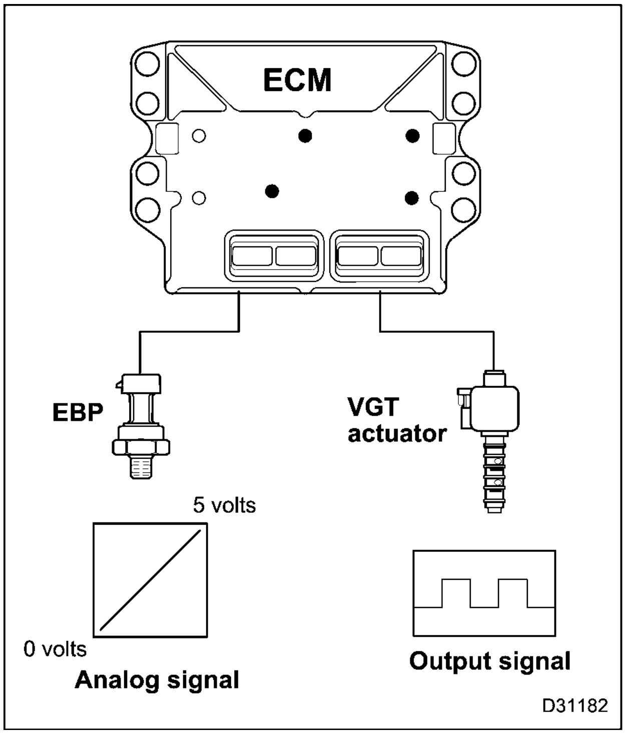


Figure 16 VGT control

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 (NOx) 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

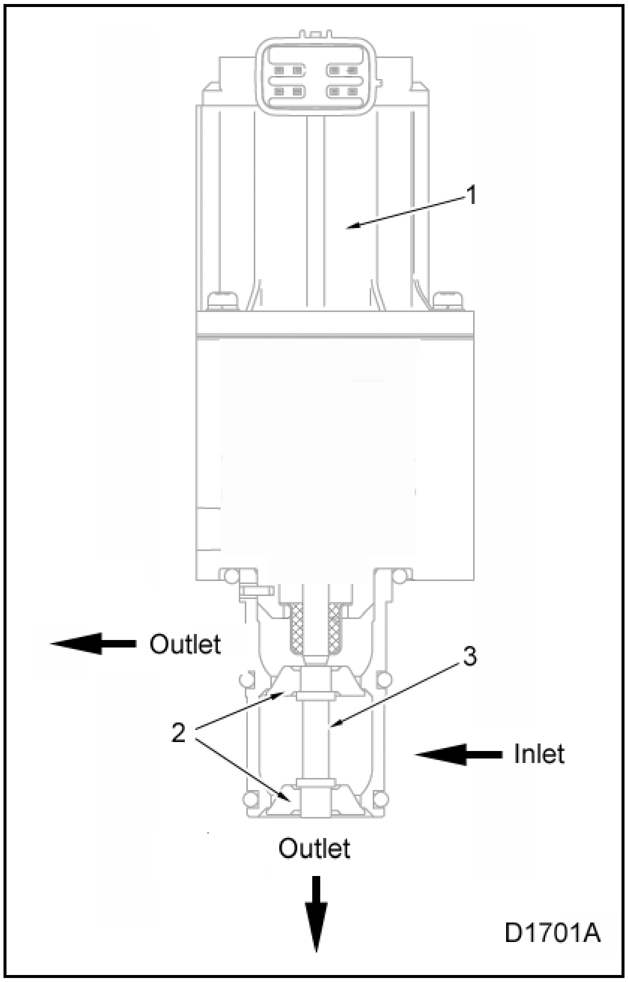


Figure 17 EGR valve

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.

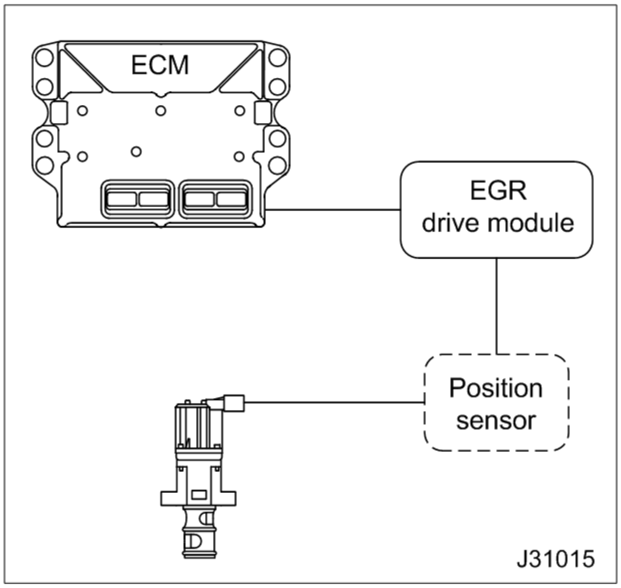


Figure 18 EGR control

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.

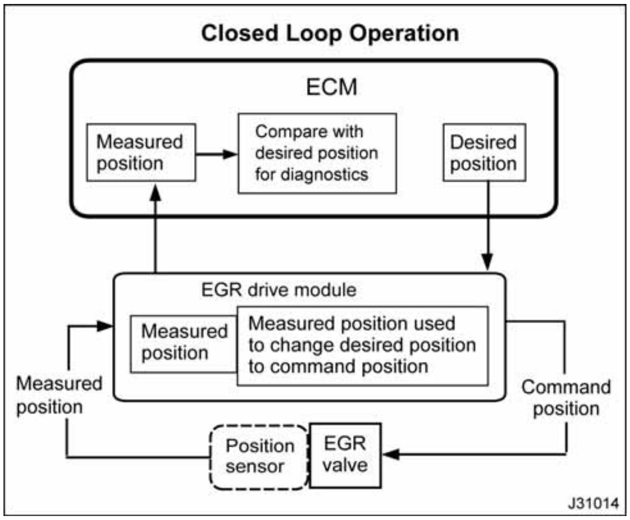


Figure 19 EGR closed loop operation

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

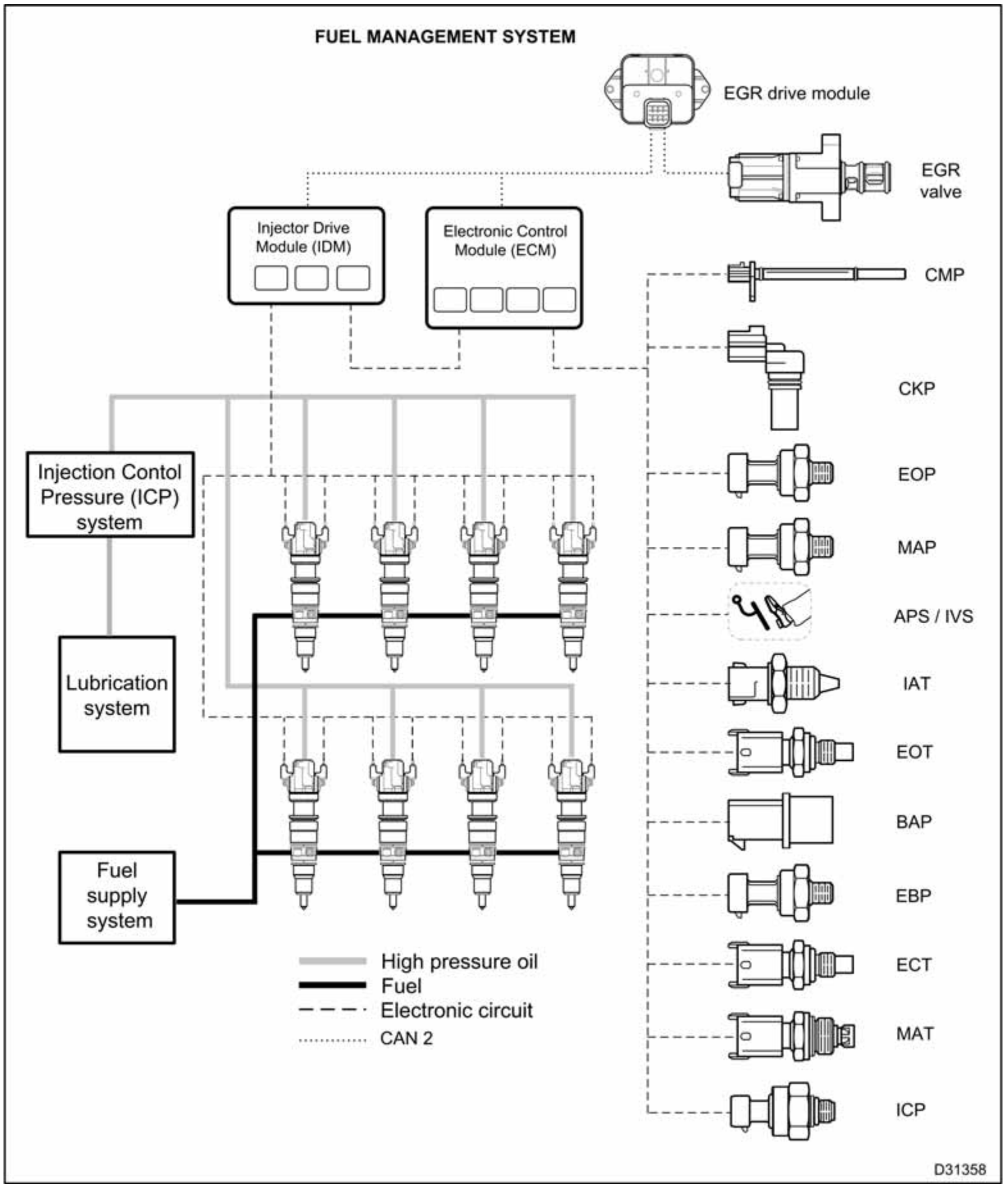


Figure 20 Fuel management system

The fuel management system includes the following:

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

Injection Control Pressure (ICP) System

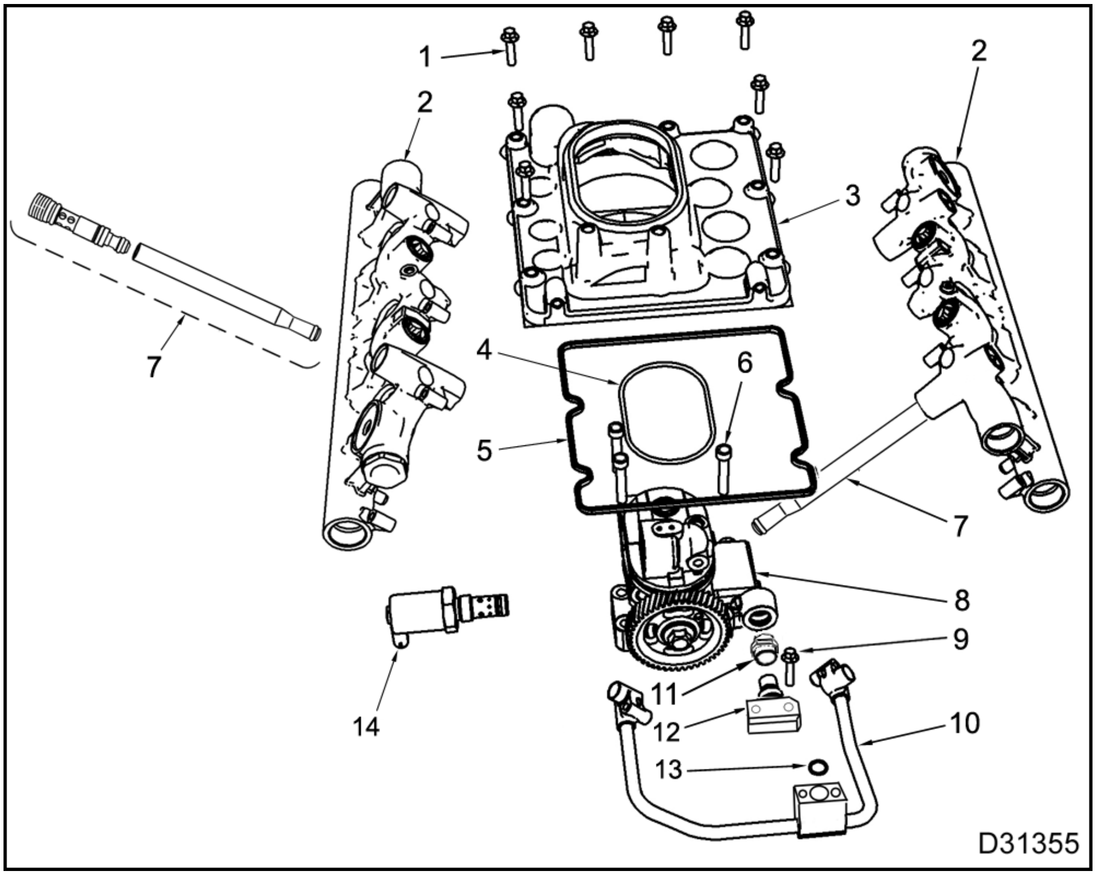


Figure 21 High-pressure oil system

1. High-pressure oil pump cover fasteners (8)
2. Oil rail assembly (2)
3. High-pressure oil pump cover
4. Pump-to-cover seal ring
5. High-pressure oil pump cover seal
6. High-pressure oil pump fasteners (3)
7. Case-to-head tube assembly (2)
8. High-pressure oil pump assembly
9. Branch tube adapter bolt (2)
10. Branch tube assembly
11. Snap to Connection (STC) fitting
12. Branch tube adapter
13. O-ring
14. IPR valve

High-pressure Oil Flow

A gear driven, high-pressure oil pump draws oil through a screen in the oil reservoir for the high-pressure oil pump. The oil reservoir, in the top of the crankcase below the oil cooler, is kept full by the engine lubrication system.

The IPR valve maintains the ICP pressure by dumping excess oil back to the crankcase.

High-pressure oil from the pump flows through a branch tube assembly to each case-to-head tube assembly to each high-pressure oil rail.

High-pressure oil in the oil rails enter the fuel injectors through sealed ports in the top of the fuel injectors.

When the OPEN coil for each injector is energized, the injector uses high-pressure oil to inject and atomize fuel into the combustion chamber. The CLOSE coils are energized to end injection. Exhaust oil exits through two ports in the top of the injector and drains back to the crankcase.

ICP Closed Loop System

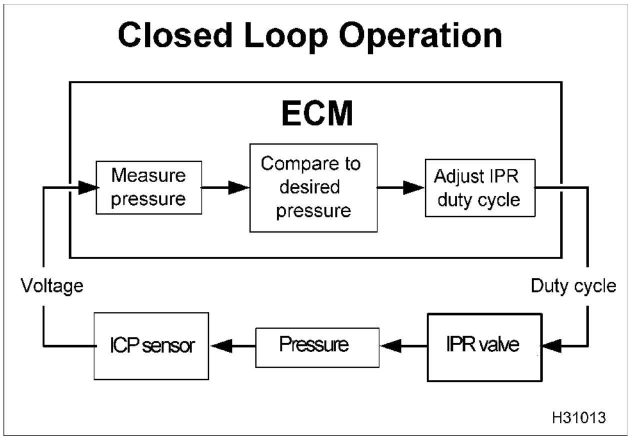


Figure 22 ICP closed loop system

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

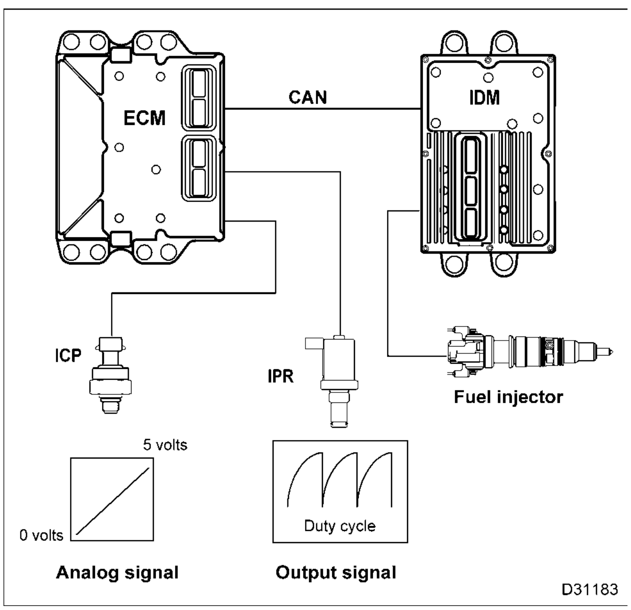


Figure 23 ICP control

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

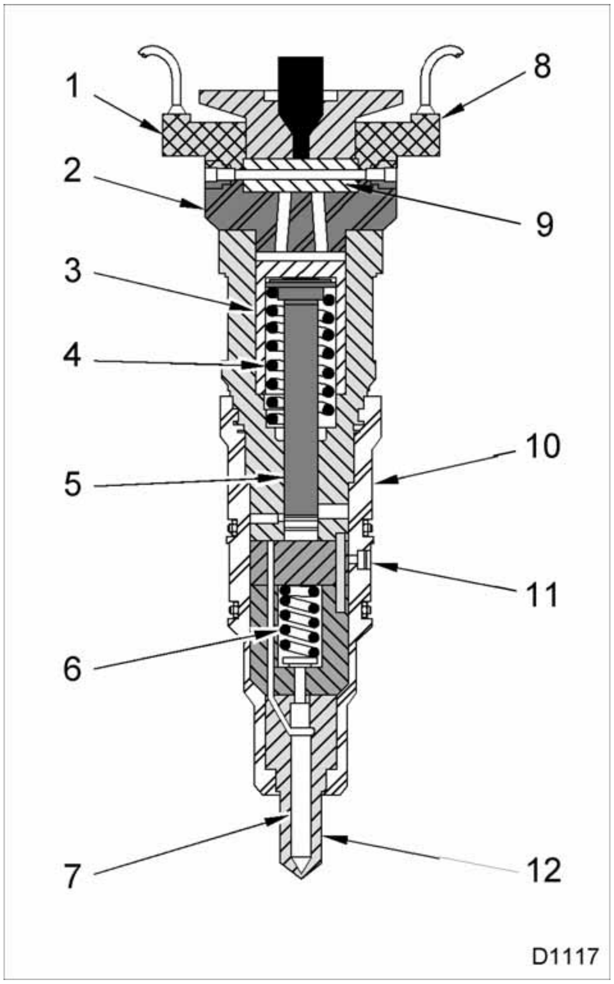


Figure 24 Fuel Injector

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

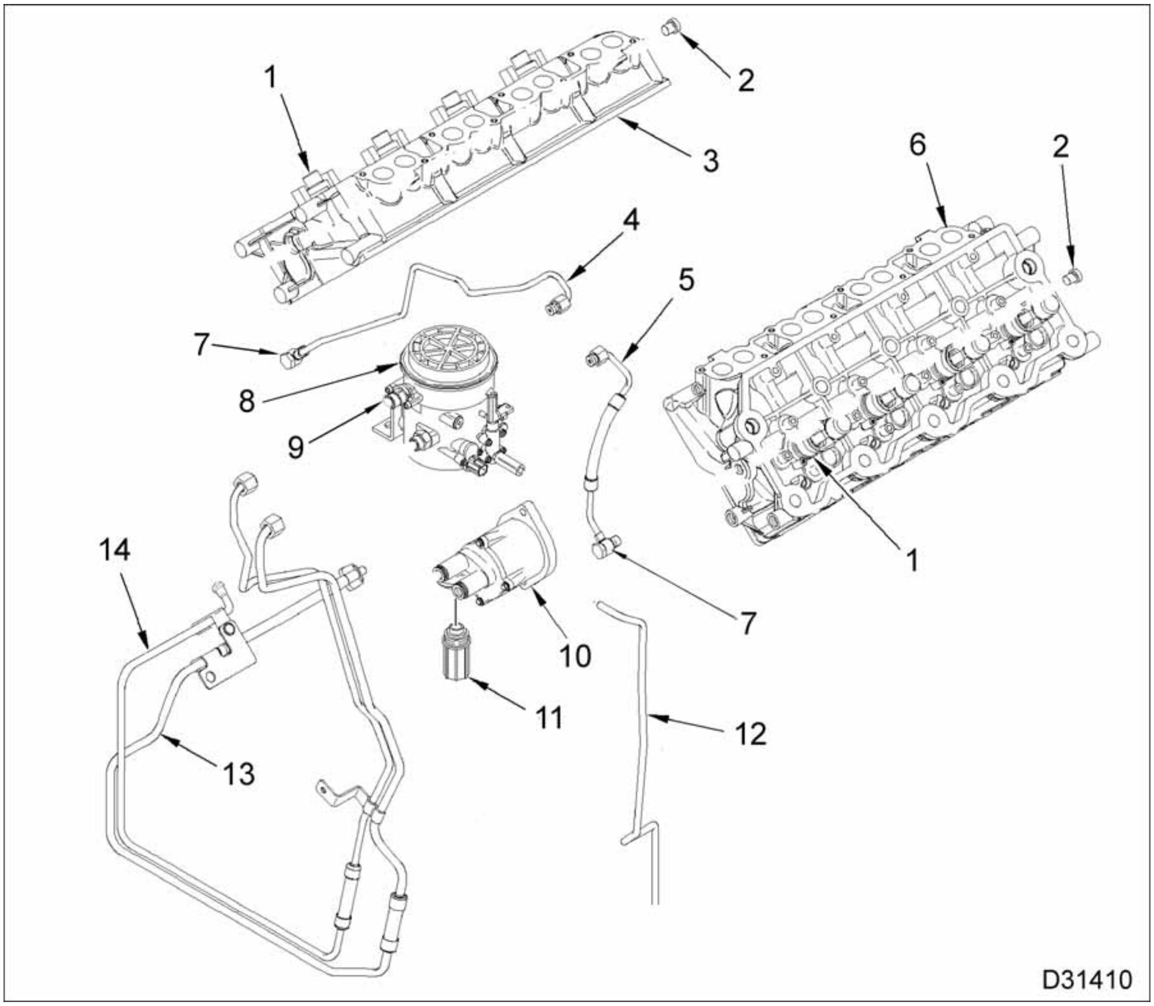


Figure 25 Fuel supply system

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

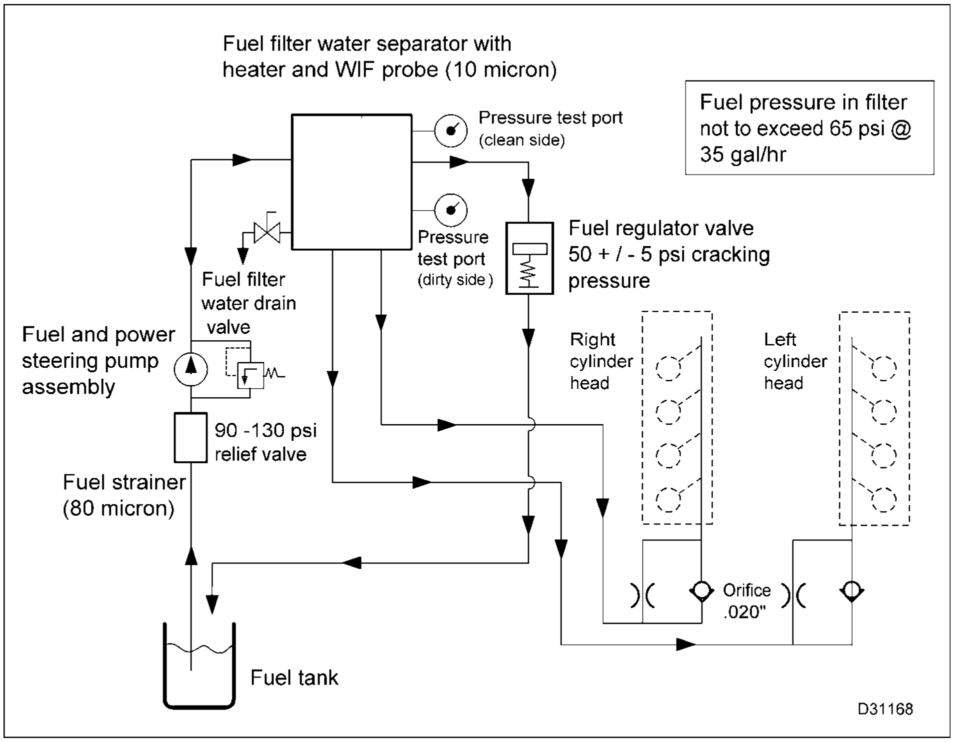


Figure 26 Fuel system schematic

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

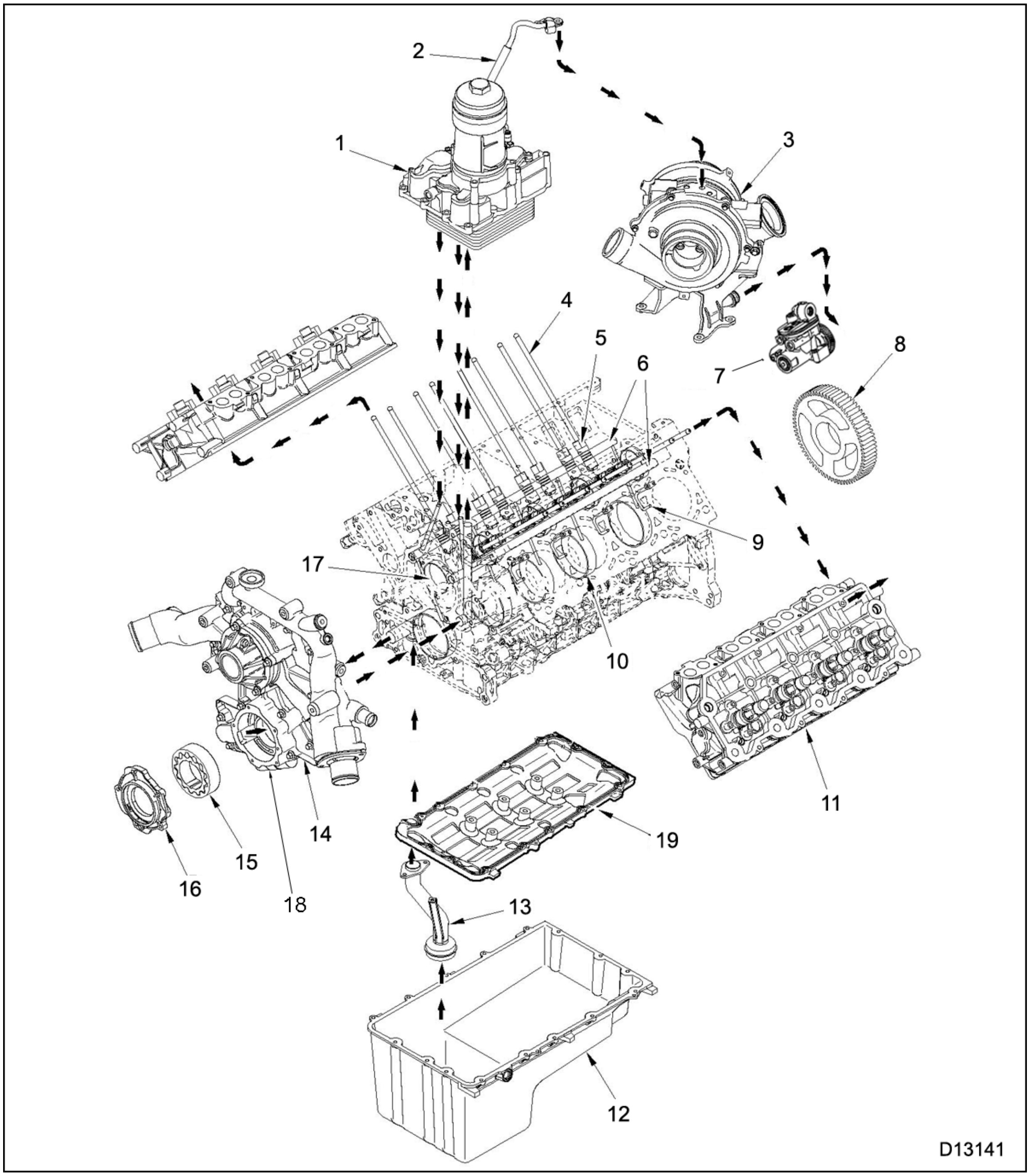


Figure 27 Lubrication system

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

Oil Flow

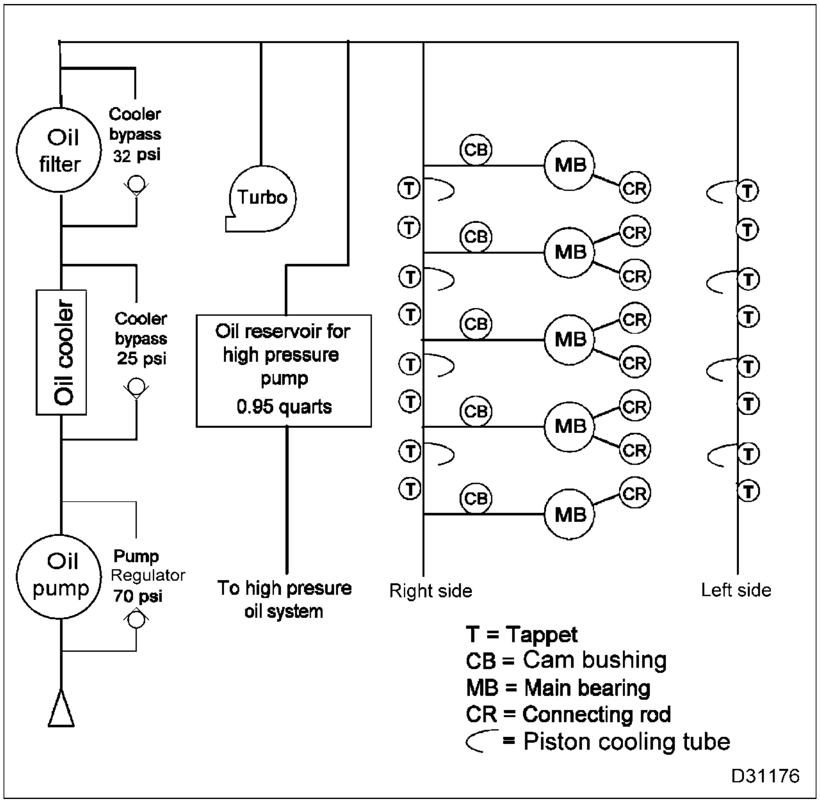


Figure 28 Lubrication system schematic

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.

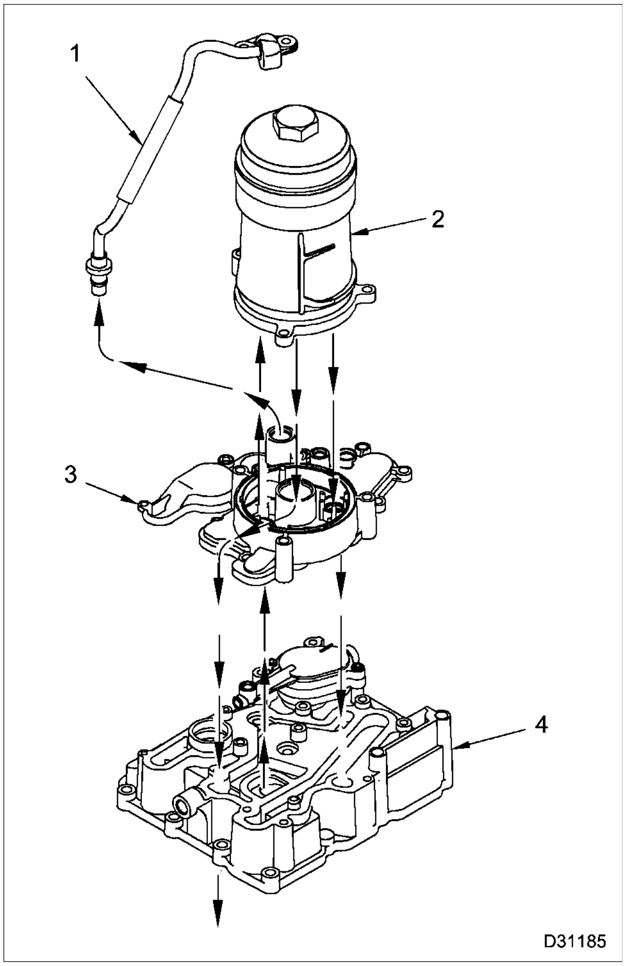


Figure 29 Oil cooler base and oil filter base

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).

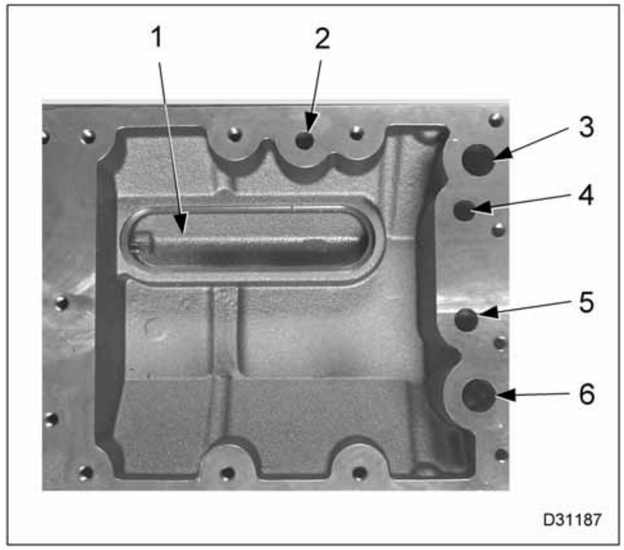


Figure 30 Oil reservoir in crankcase

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

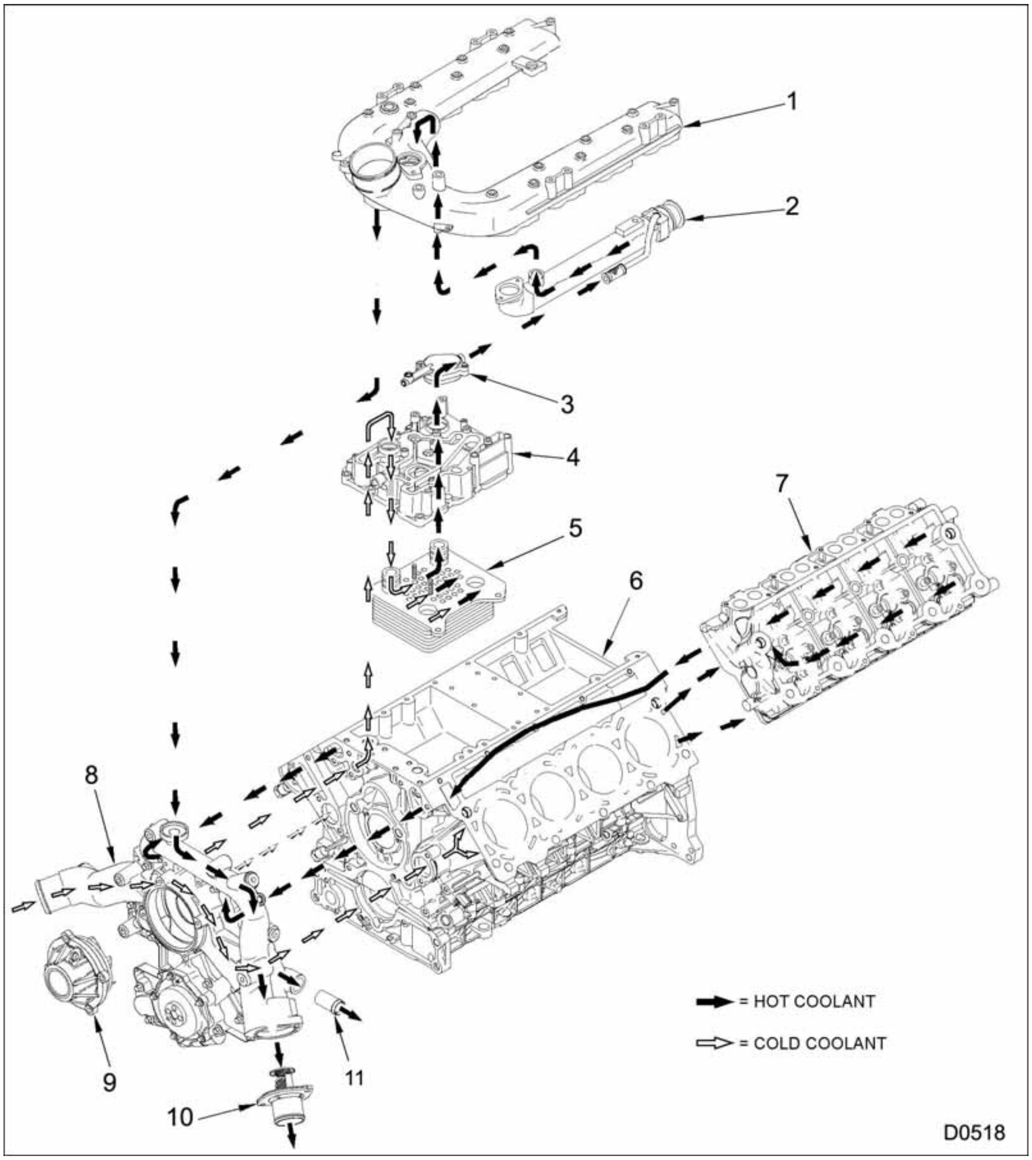


Figure 31 Engine cooling system components

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

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 though 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

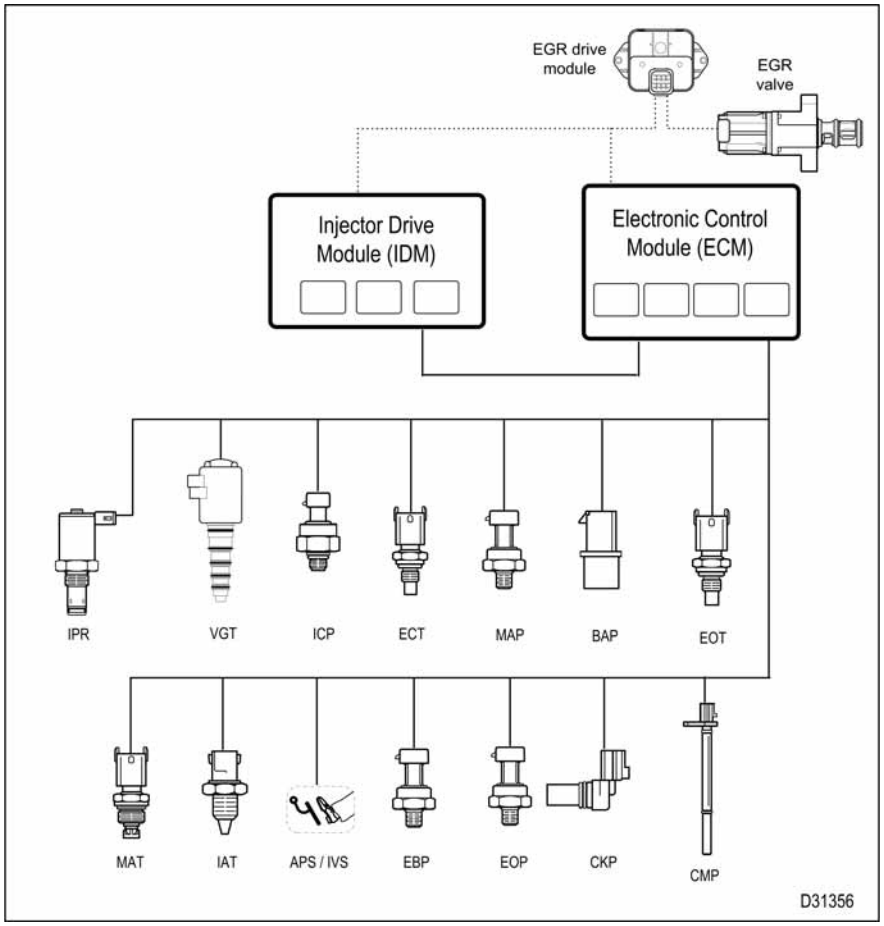


Figure 32

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)

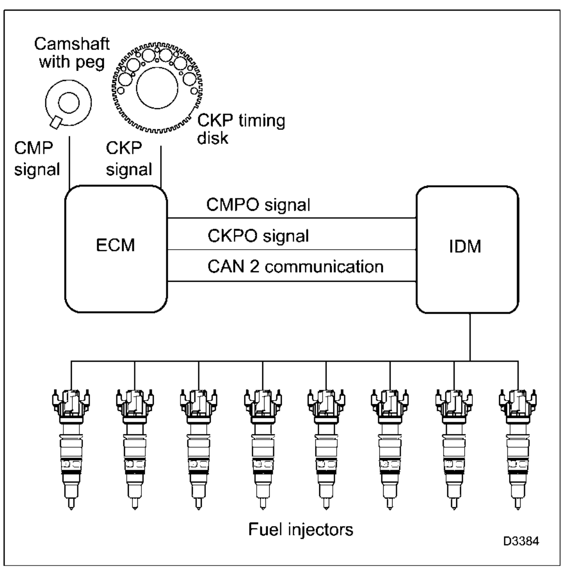


Figure 33 Injection Drive Module (IDM)

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

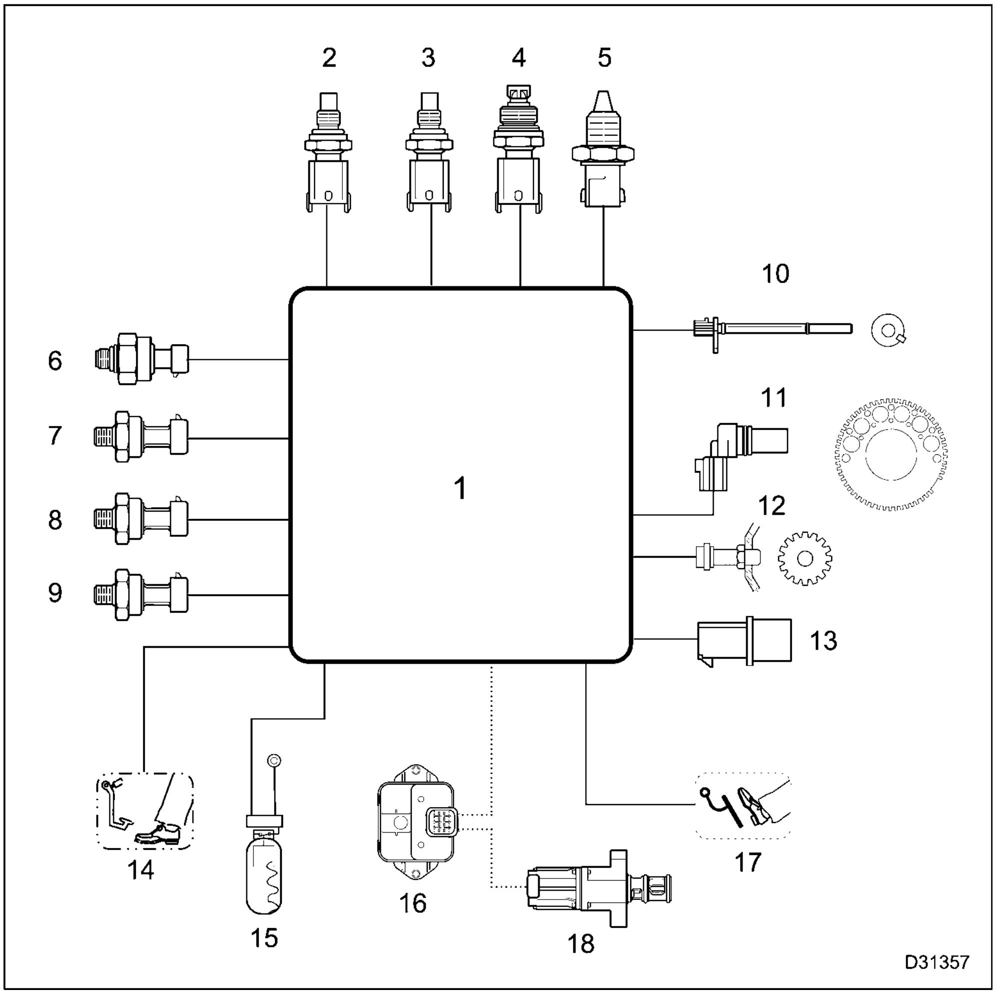


Figure 34 Engine and Vehicle Sensors

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

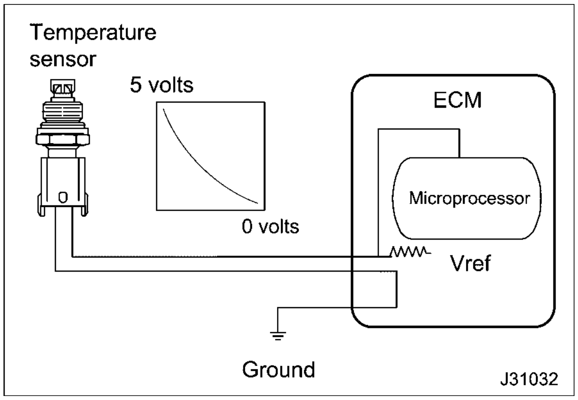


Figure 35 Thermistor

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.

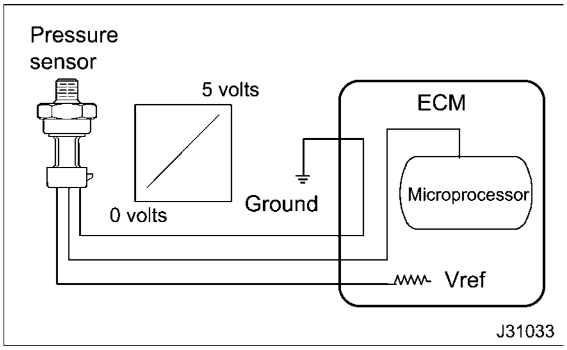


Figure 36 Variable capacitance sensor

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.

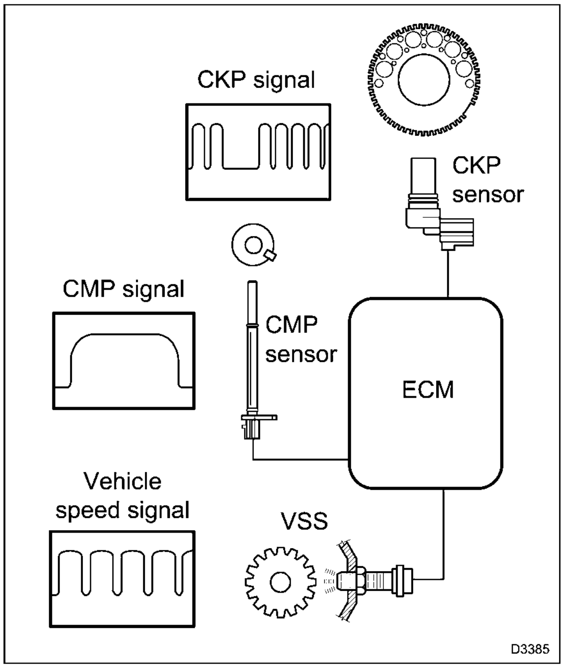


Figure 37 Magnetic pickups

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.

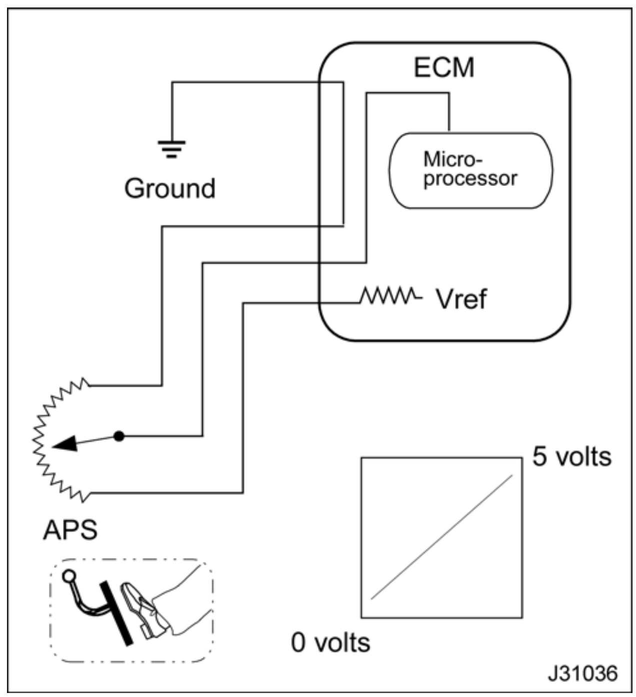


Figure 38 Potentiometer

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.

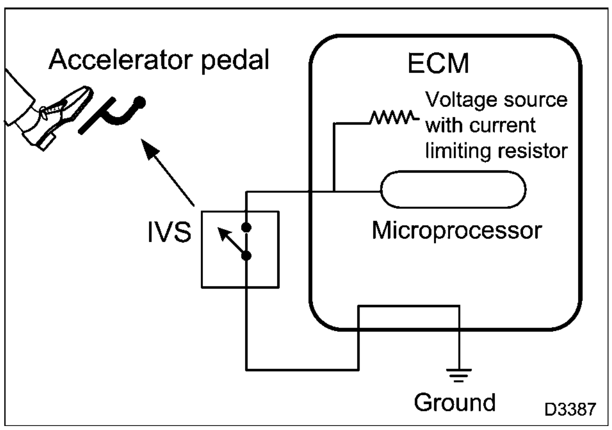


Figure 39 Switch

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

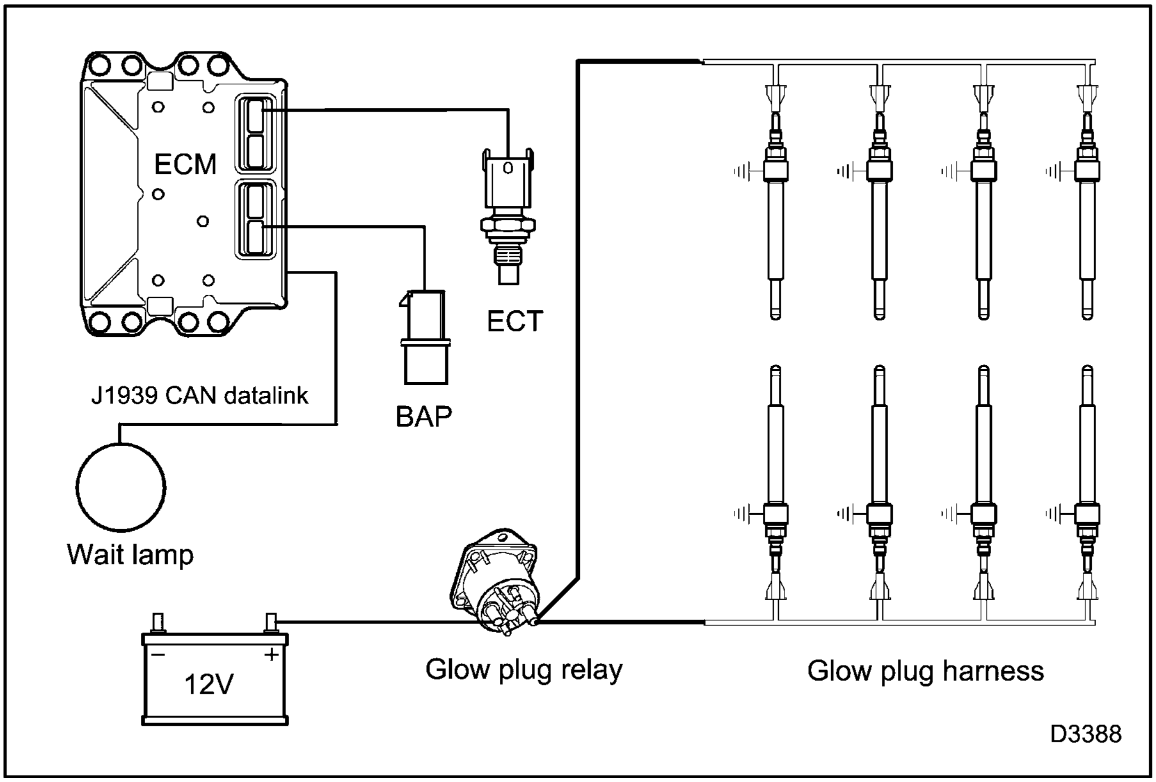


Figure 40 Glow plug control system

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.

Table of Contents

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.

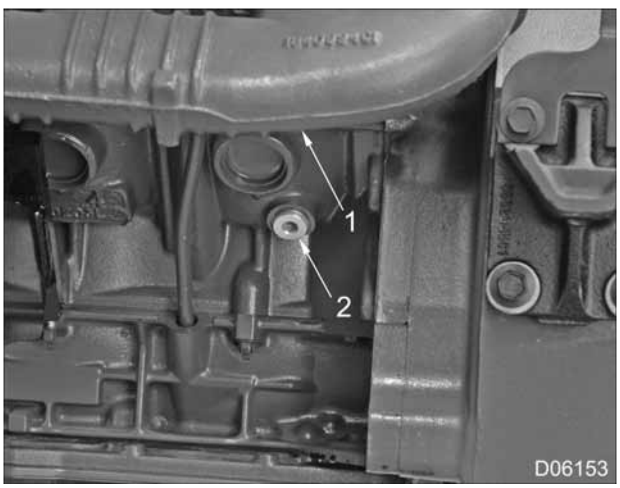


Figure 41 Left side coolant drain plug

1. Exhaust manifold
2. Coolant drain plug

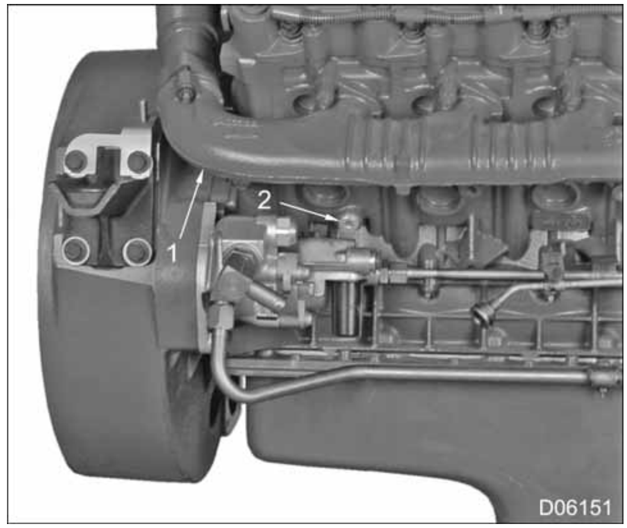


Figure 42 Right side coolant drain plug

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.

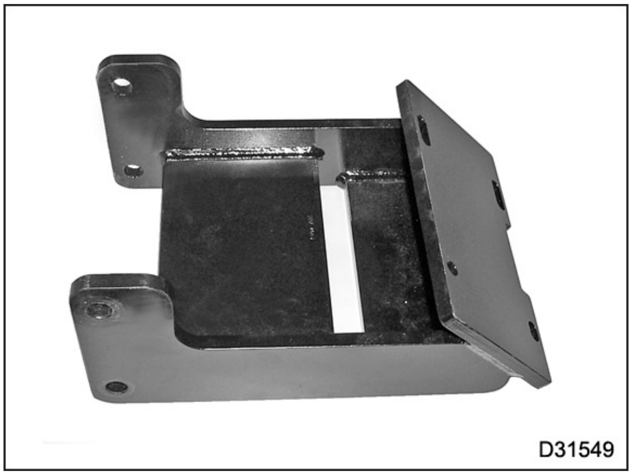


Figure 43 Engine Stand Mounting Bracket

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).

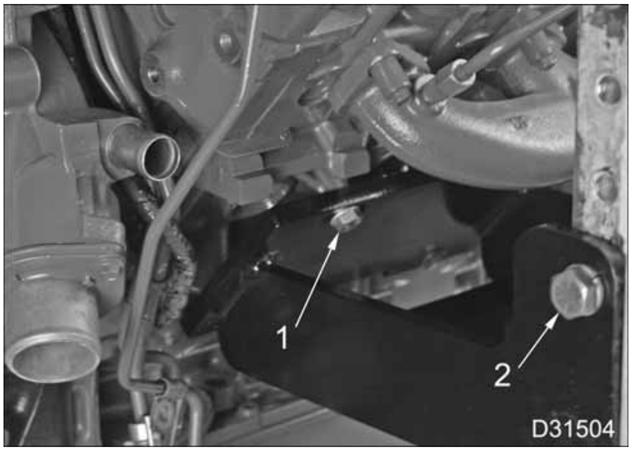


Figure 44 Mounting bolts for Engine Stand Mounting Bracket

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

Table of Contents

Description

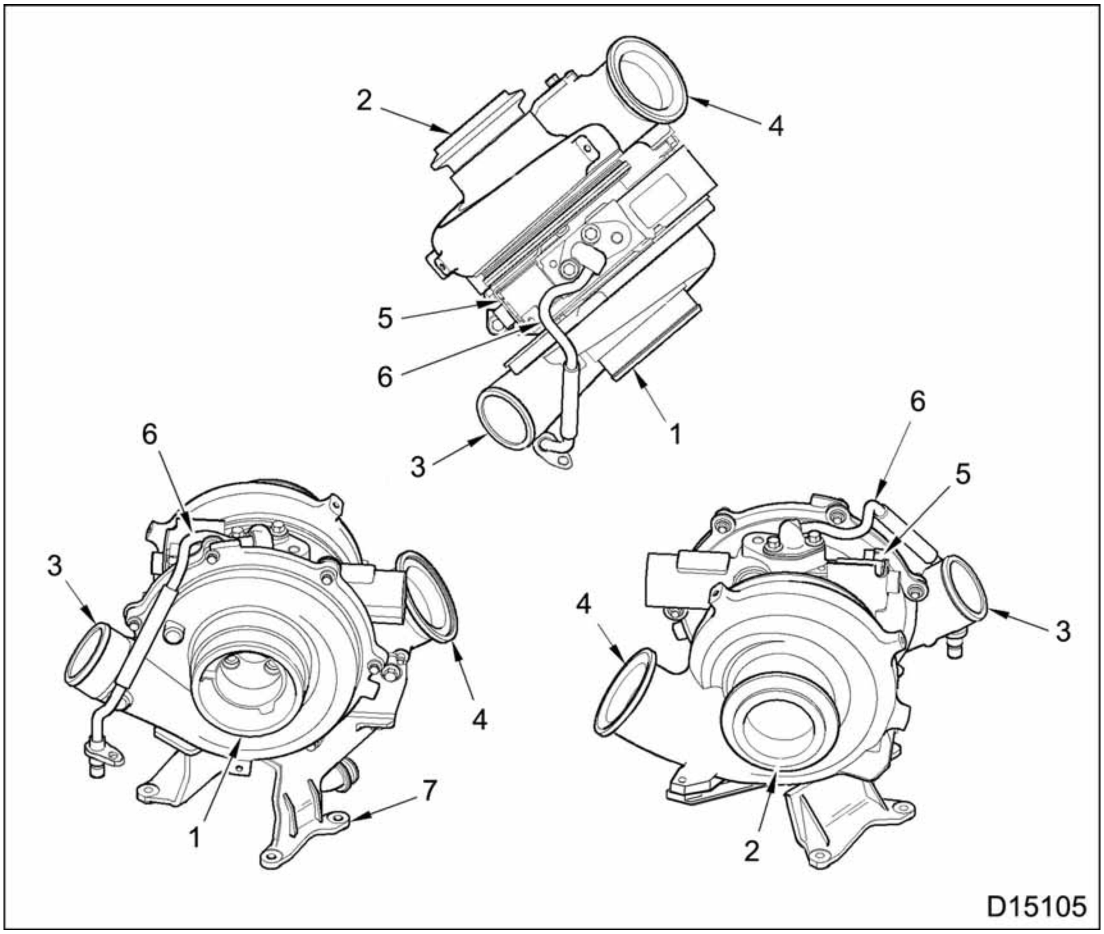


Figure 45 Turbocharger components

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

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 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.

Vanes 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.

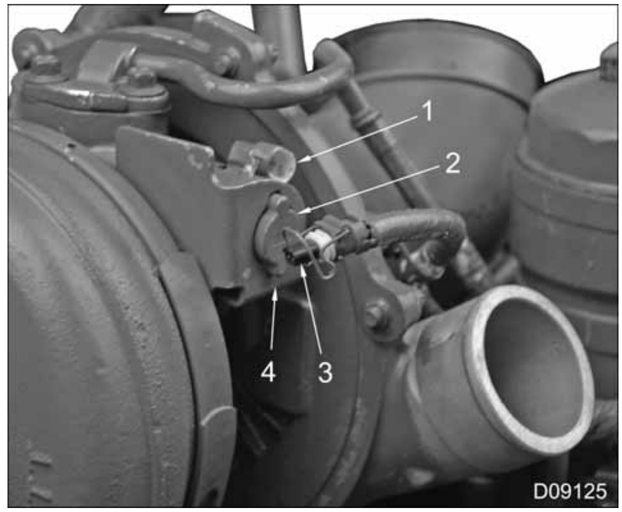


Figure 46 Disconnection of VGT control valve

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.

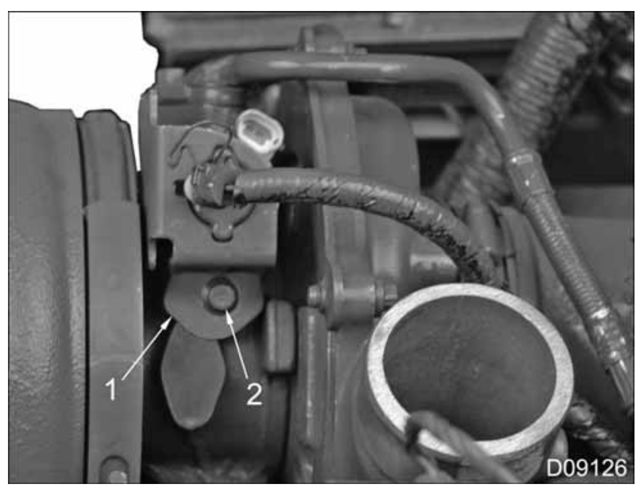


Figure 47 Retaining bolt for VGT control valve

1. VGT control valve bracket
2. Retaining bolt

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

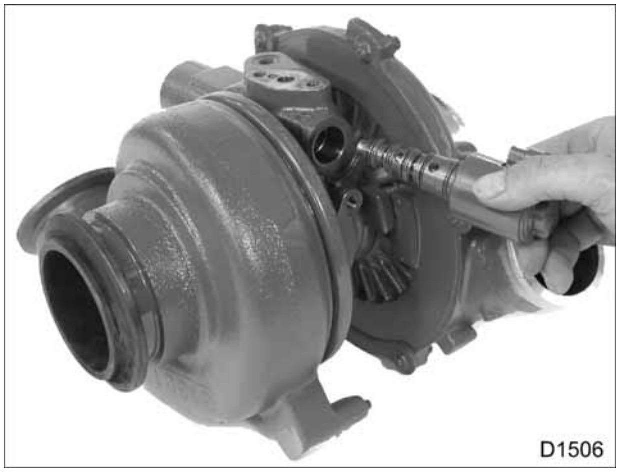


Figure 48 VGT control valve

2. Remove VGT control valve from turbocharger center housing.

VGT and Components

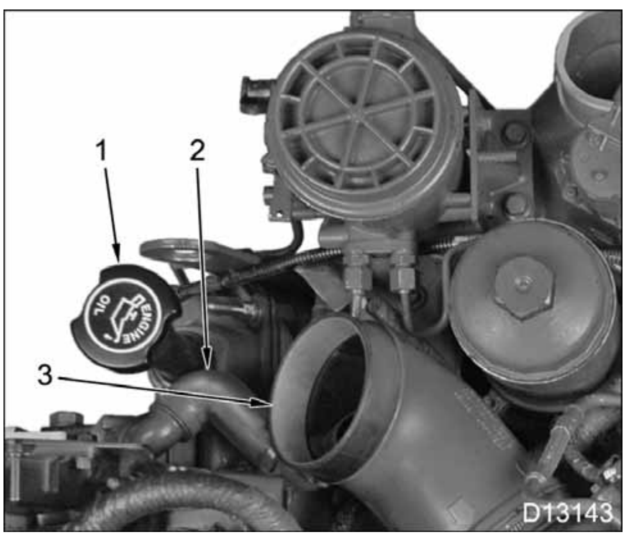


Figure 49 Air inlet duct

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.

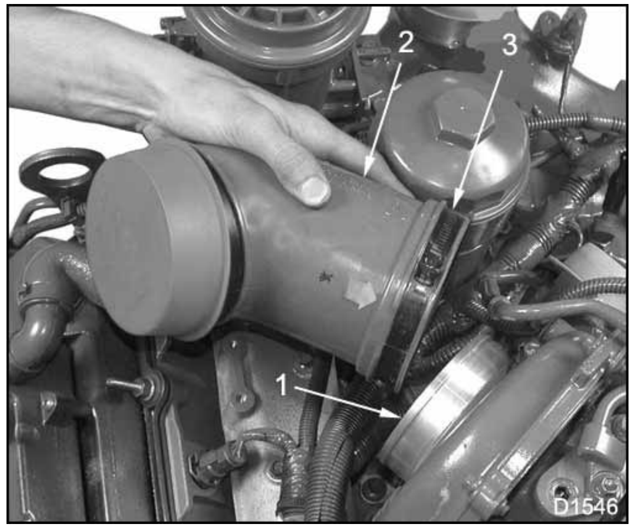


Figure 50 Air inlet duct

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.

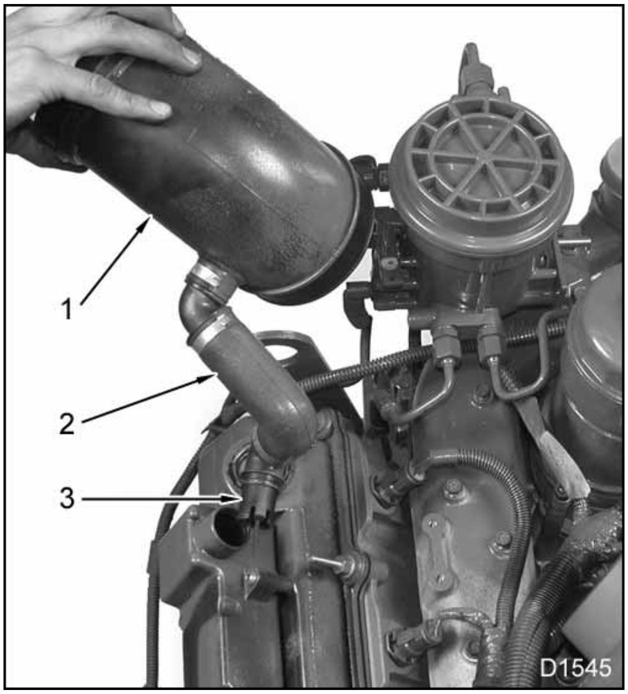


Figure 51 Breather tube and pitot tube

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.

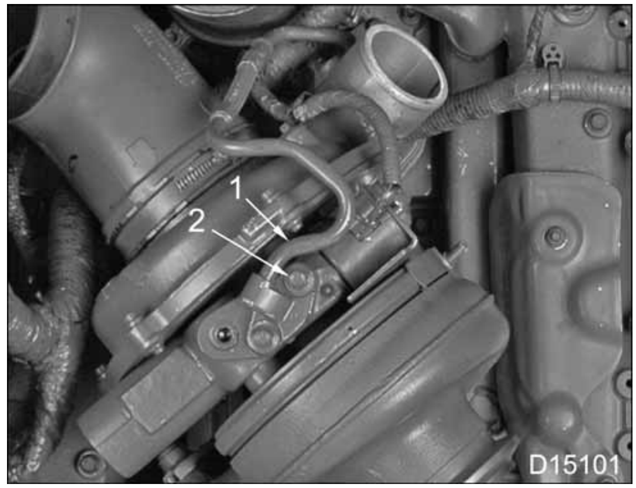


Figure 52 Oil supply tube to VGT

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

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.

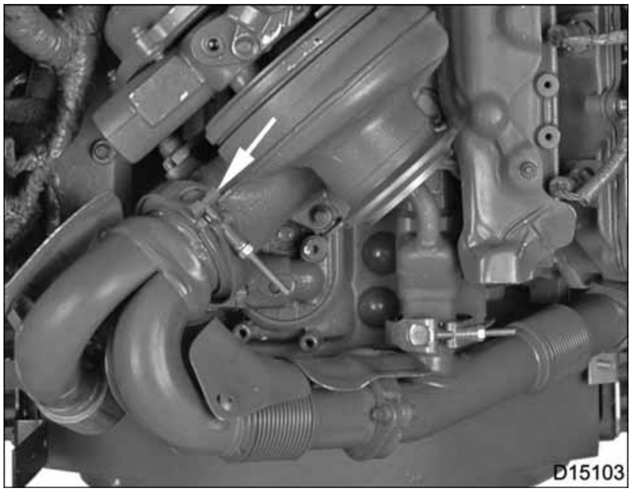


Figure 54 Exhaust adapter V-clamp for VGT

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

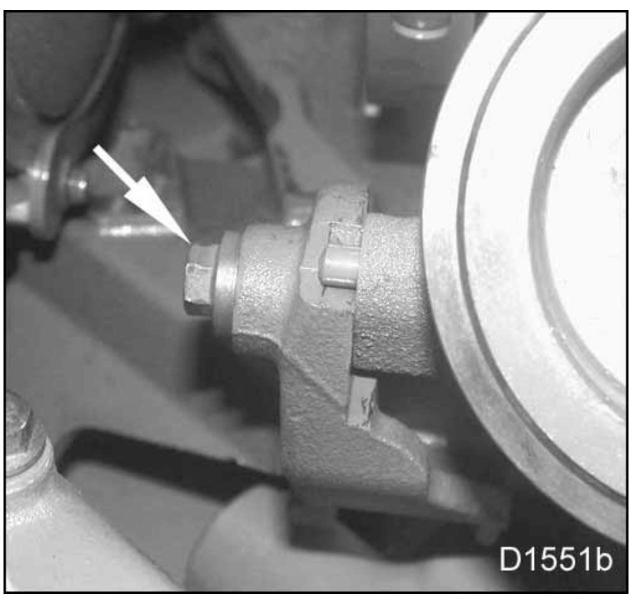


Figure 55 Center mounting bolt and spacer for VGT

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

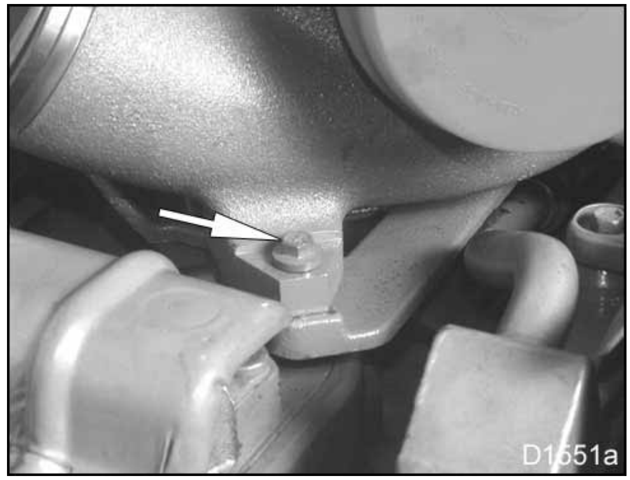


Figure 56 Rear mounting bolt for VGT

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

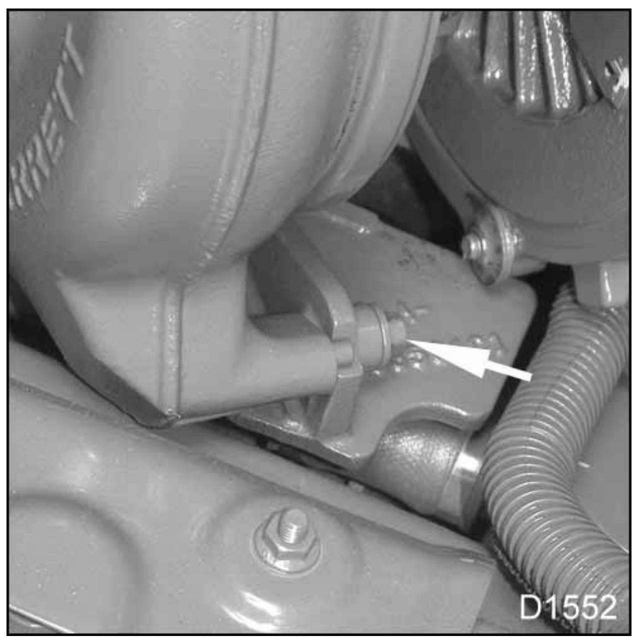


Figure 57 Front mounting bolt and spacer for VGT

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.

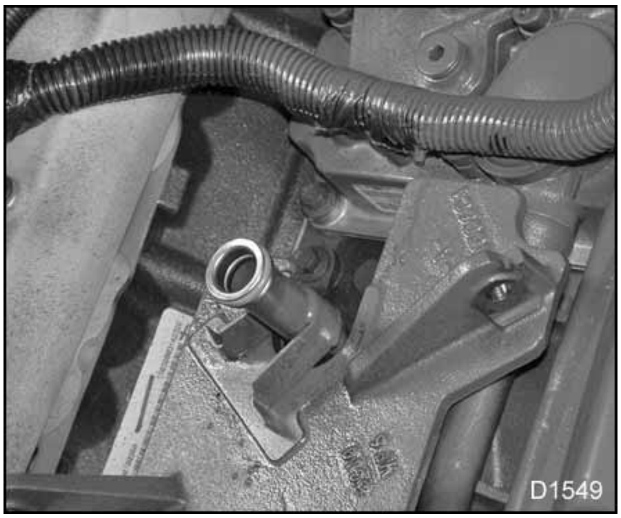


Figure 58 Oil drain tube for VGT

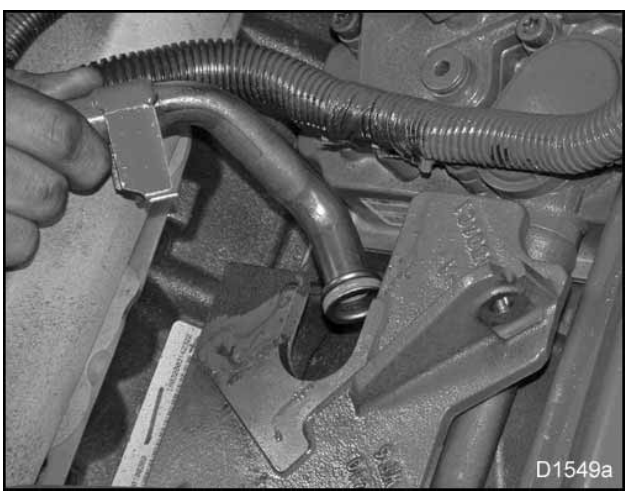


Figure 59 Removal of oil drain tube for VGT

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.

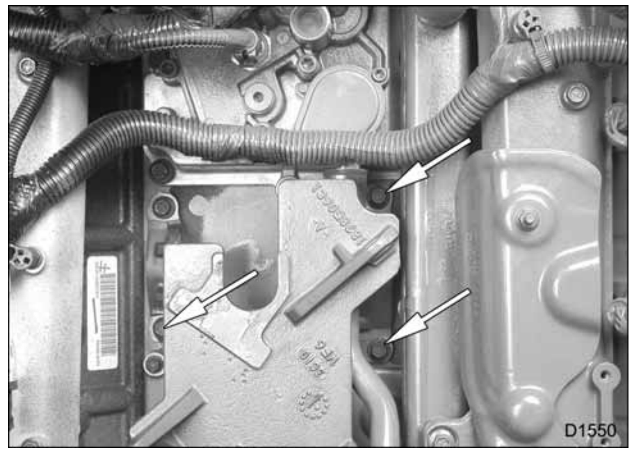


Figure 60 VGT bracket bolts

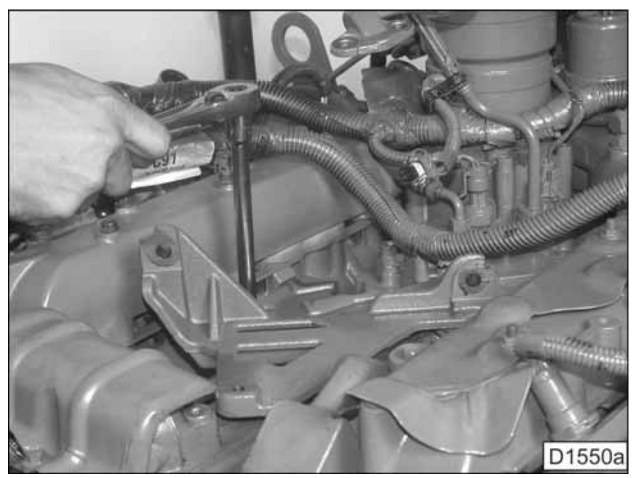


Figure 61 Removal of VGT bracket bolts

20. Remove four M8 x 20 VGT bracket bolts.

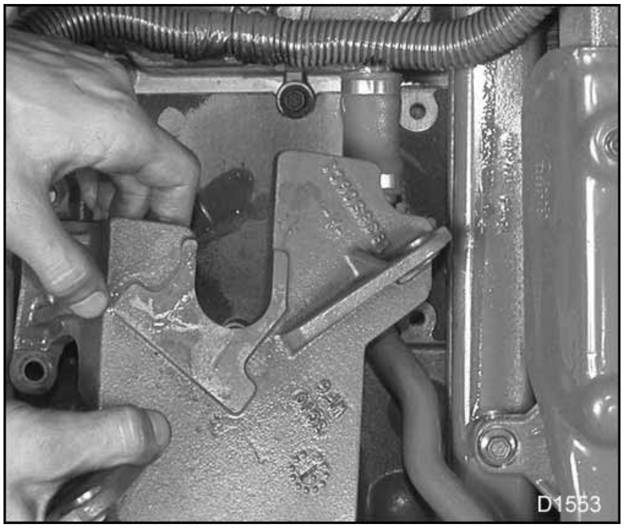


Figure 62 VGT mounting bracket

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

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.

Check Free Rotation and Housing Rub

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

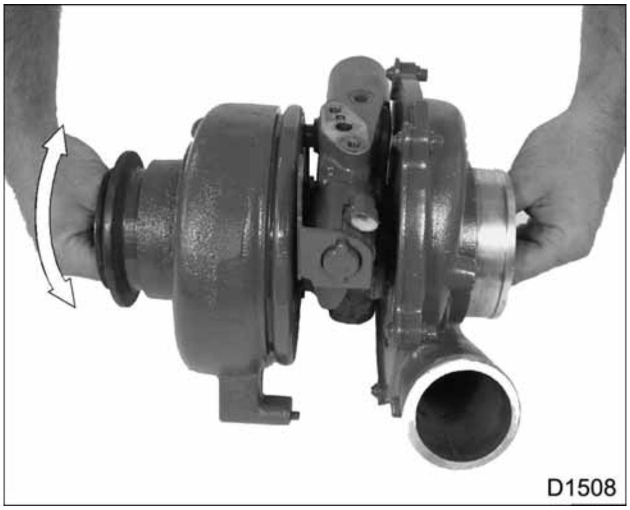


Figure 63 Free rotation of VGT shaft

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.

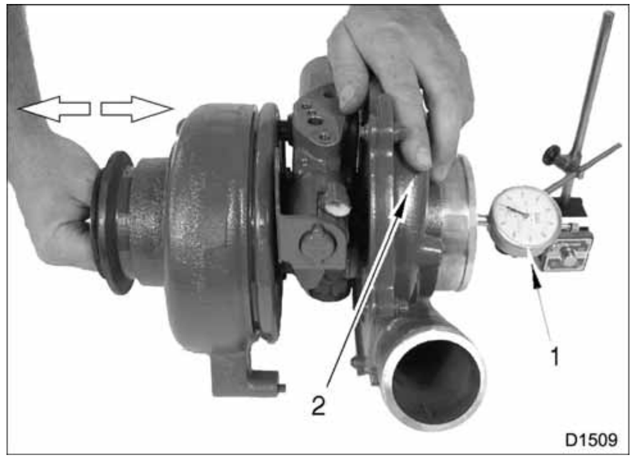


Figure 64 Axial end play

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

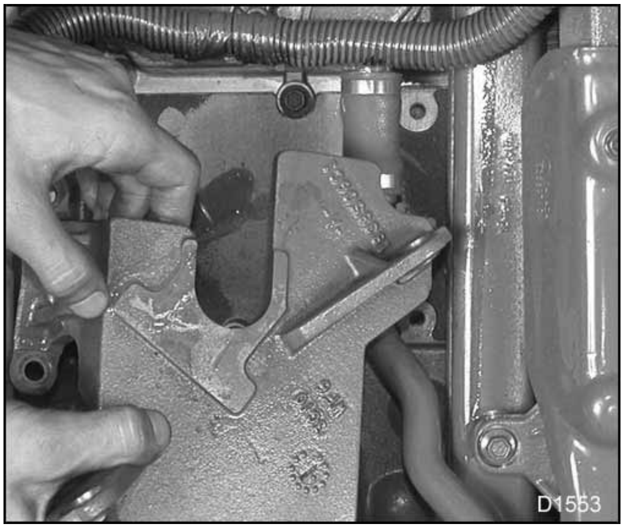


Figure 65 VGT bracket

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.

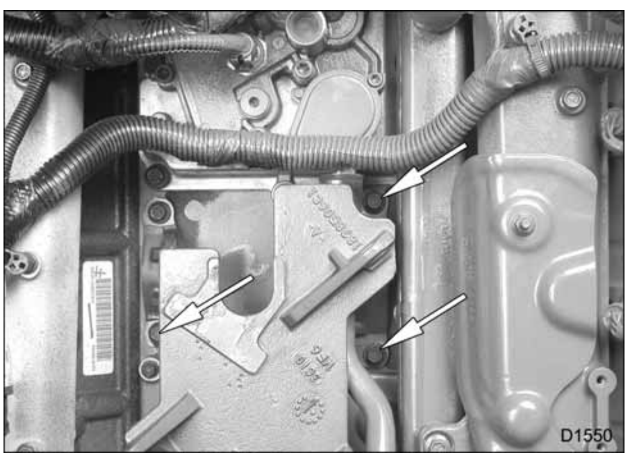


Figure 66 VGT bracket bolts

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

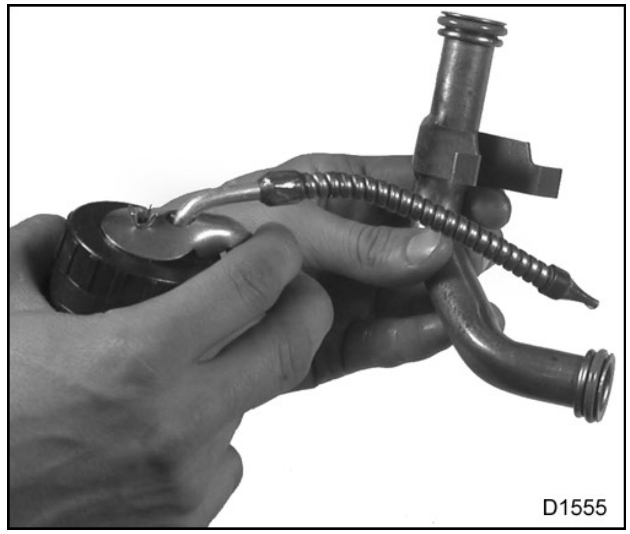


Figure 67 Lubrication for O-rings on oil drain tube for VGT

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.

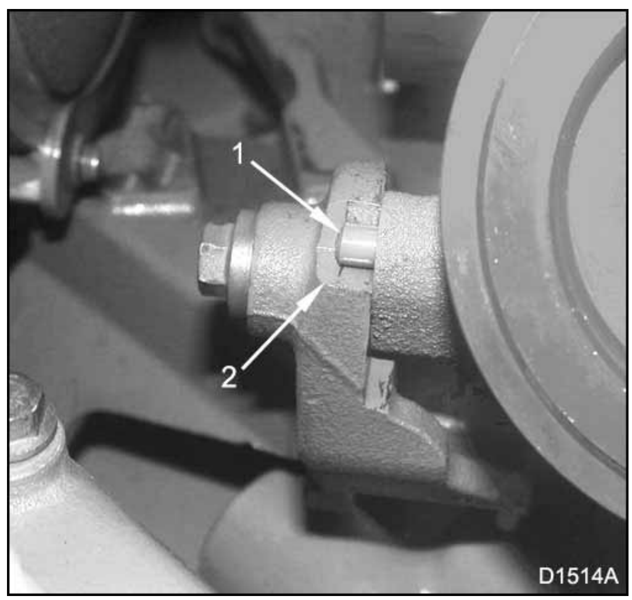


Figure 68 VGT alignment dowels and bosses

1. Alignment dowel
2. Alignment boss

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).

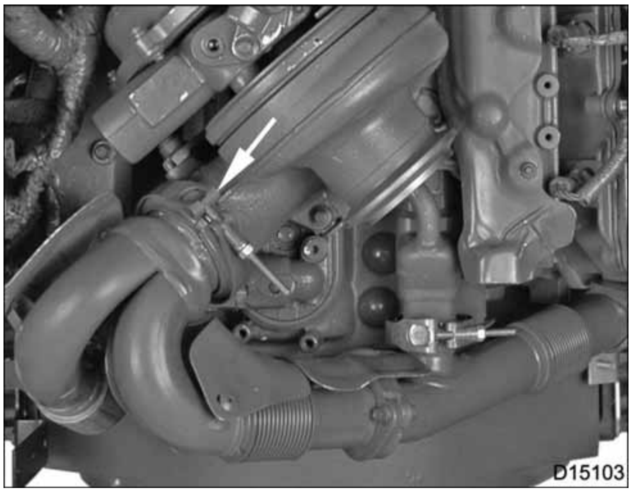


Figure 69 Exhaust adapter V-clamp for VGT

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).

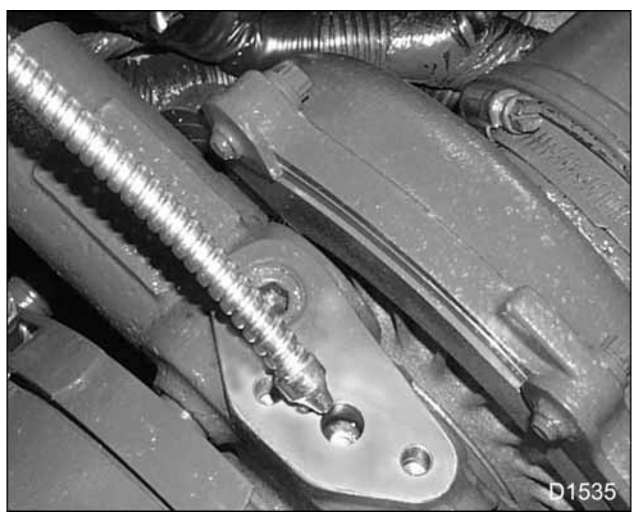


Figure 71 Prelubrication of VGT bearings

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.

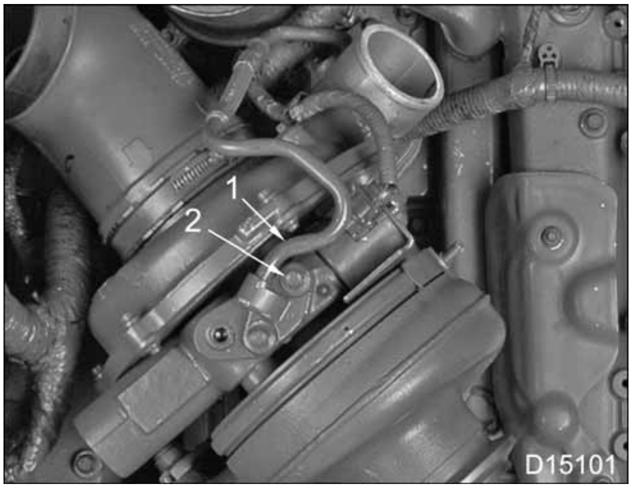


Figure 72 Oil supply tube for VGT

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

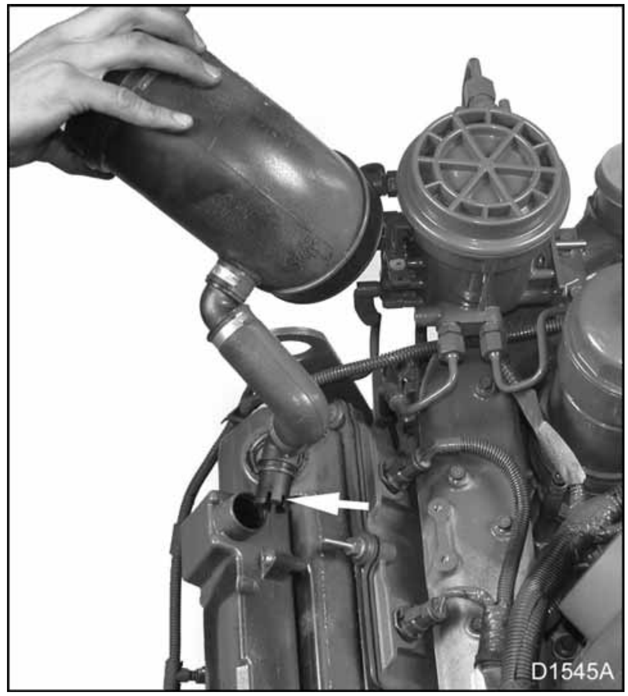


Figure 73 Breather tube with pitot tube in crankcase breather

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

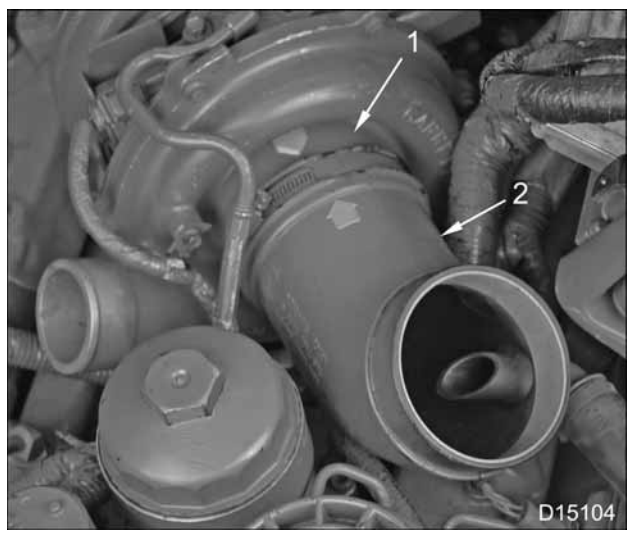


Figure 74 Air inlet duct to VGT

1. VGT
2. Air inlet duct

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).

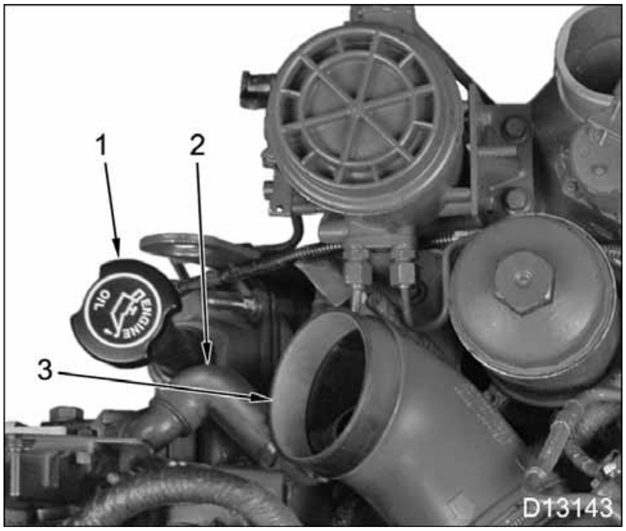


Figure 75 Air inlet duct

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)

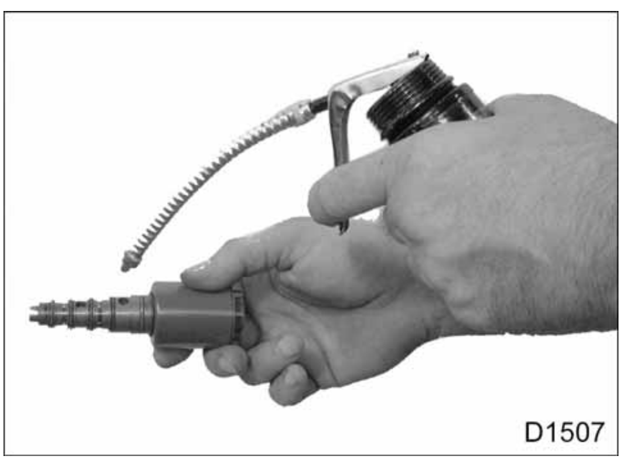


Figure 76 O-ring lubrication

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.

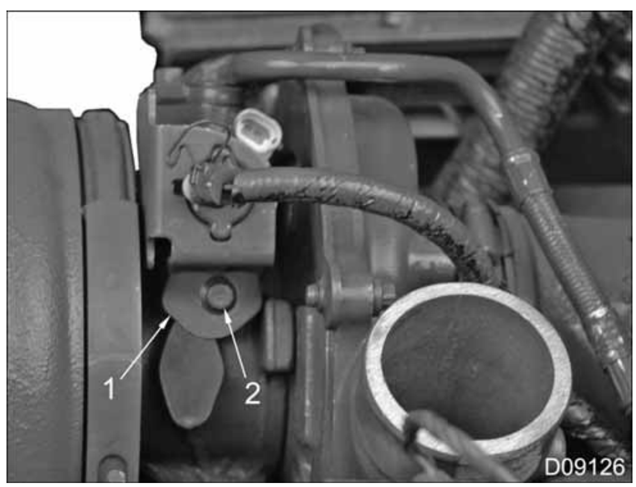


Figure 78 Retaining bolt for VGT Control valve

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).

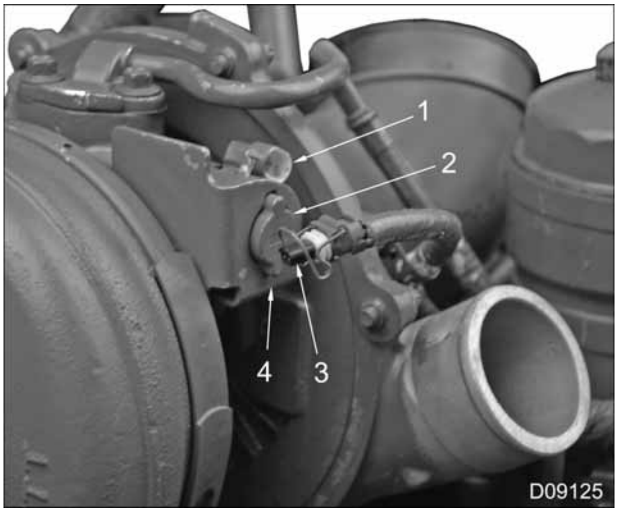


Figure 79 VGT control valve

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.

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

Table of Contents

Component Exploded Views

Intake Manifold

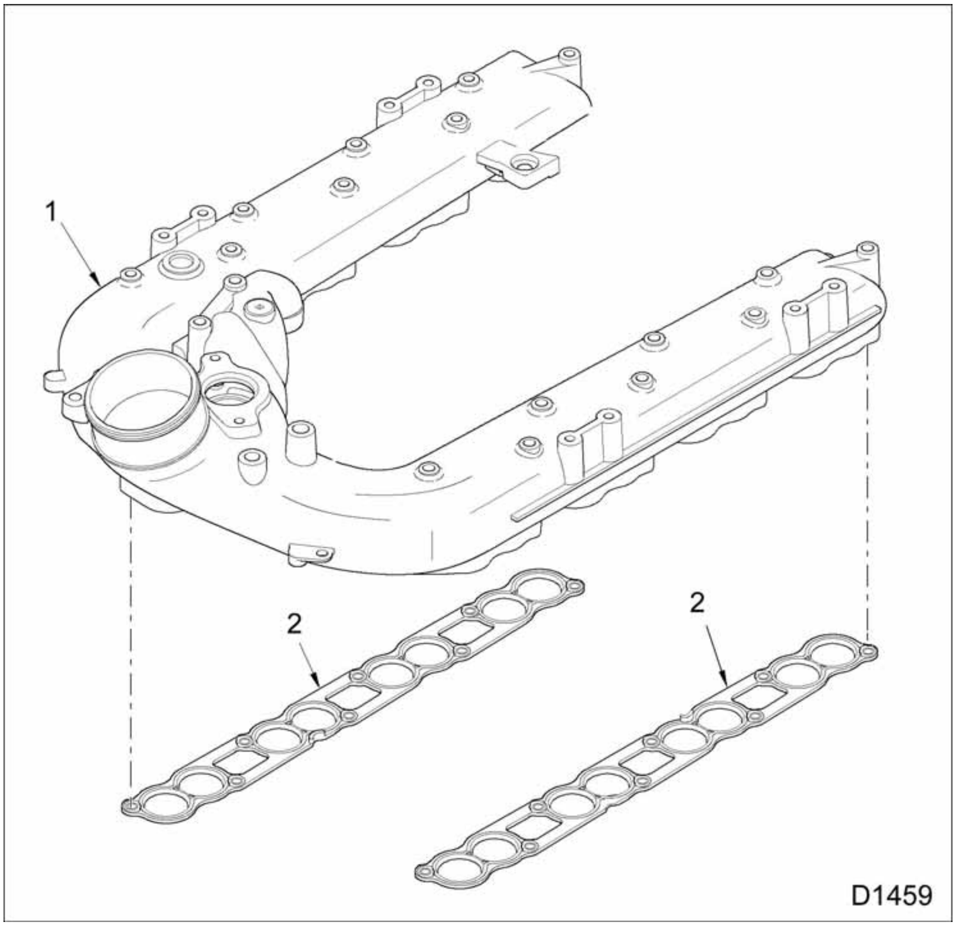


Figure 80 Intake manifold and gaskets

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

Exhaust Gas Recirculation Components

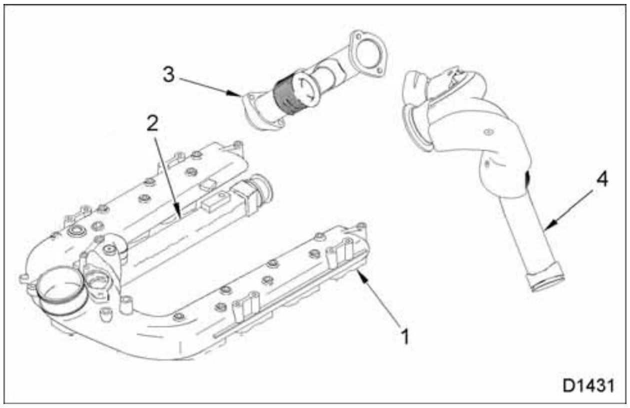


Figure 81 Exhaust Gas Recirculation Components (EGR)

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

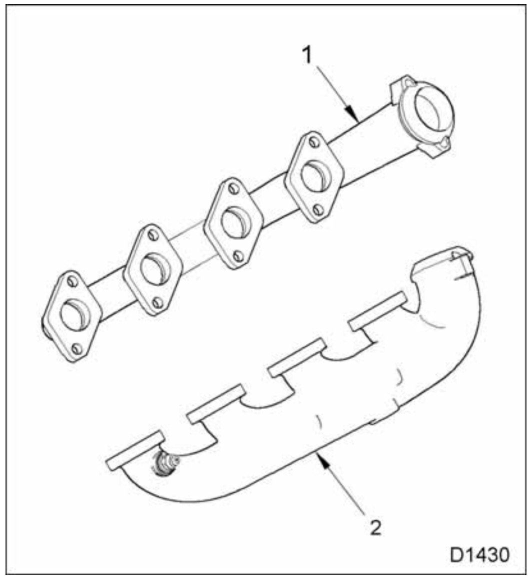


Figure 82 Exhaust manifolds

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.

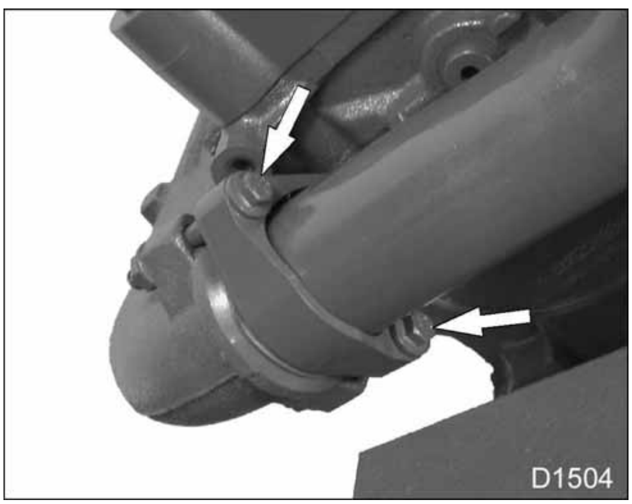


Figure 83 Manifold mounting bolts for shielded tube exhaust assembly

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.

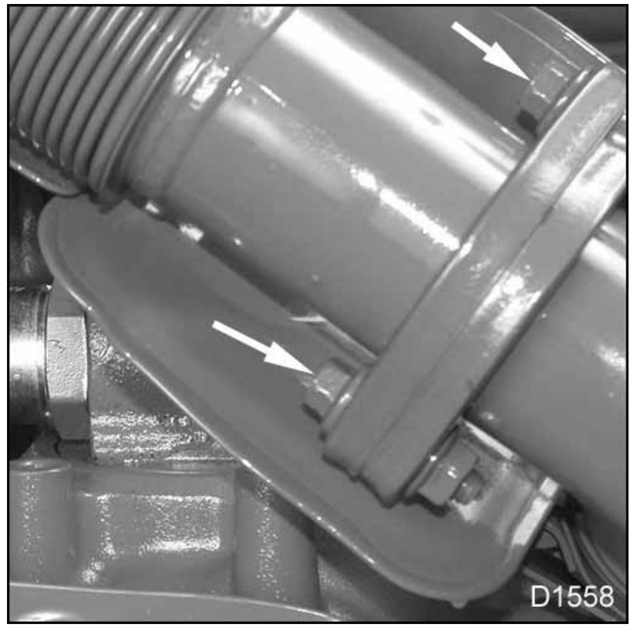


Figure 84 Exhaust tube bolts (upper right)

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.

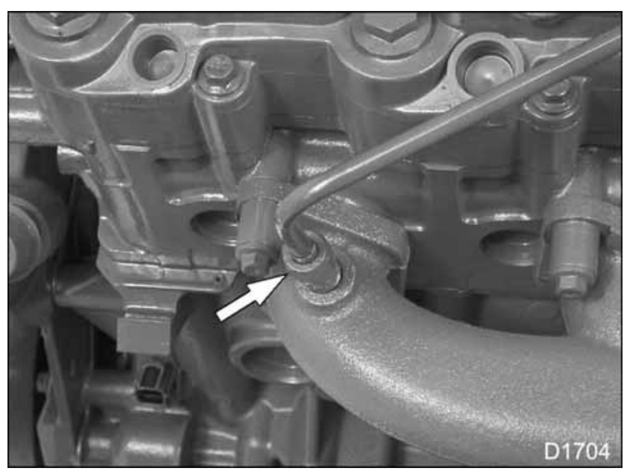


Figure 85 Tube fitting for EBP sensor

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

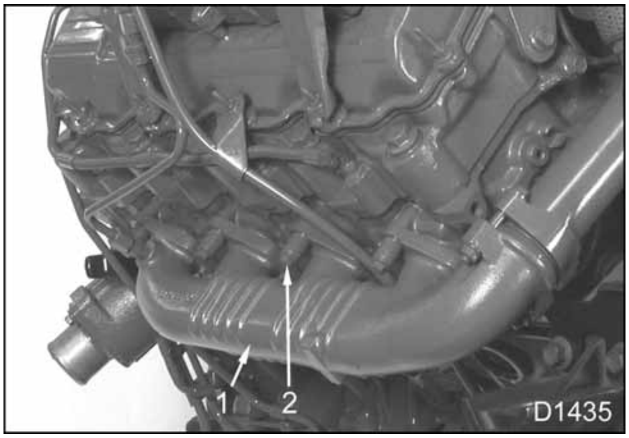


Figure 86 Mounting bolts and spacers for left exhaust manifold

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

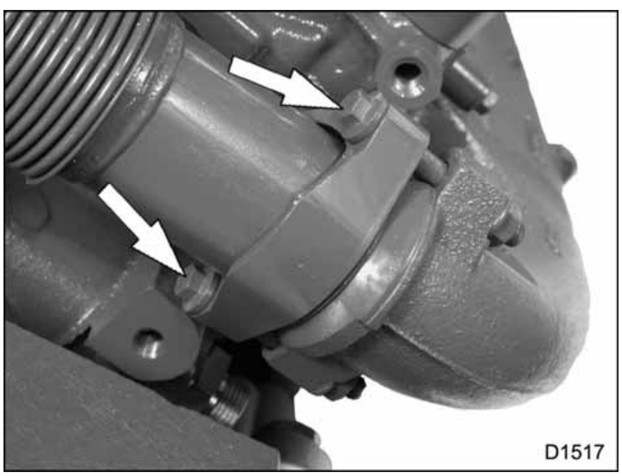


Figure 87 Right exhaust tube assembly

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

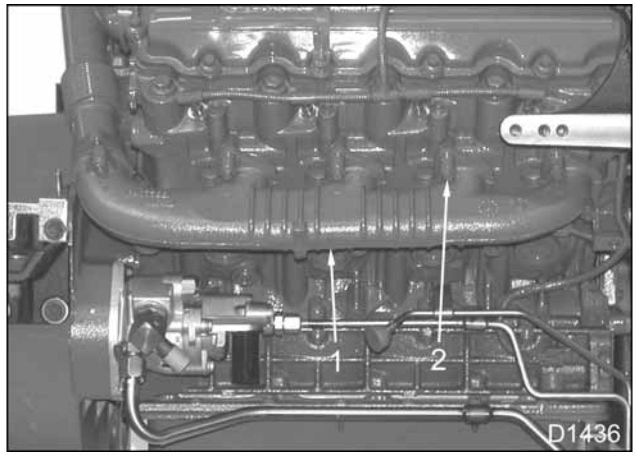


Figure 88 Mounting bolts and spacers for right exhaust manifold

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

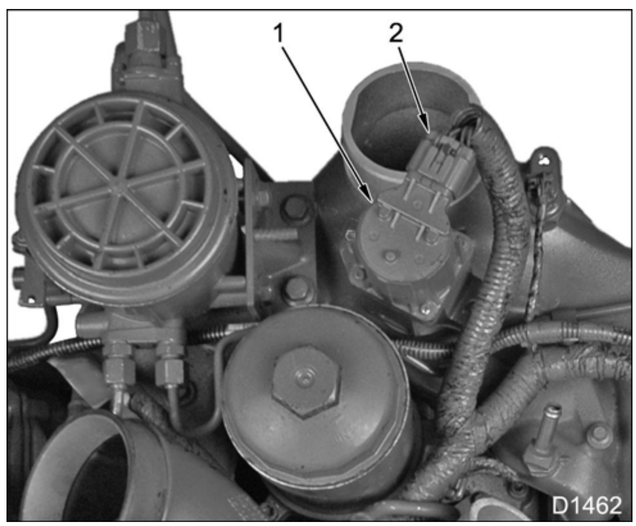


Figure 89 EGR valve and 8-pin electrical connector

1. EGR valve
2. 8-pin electrical connector

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

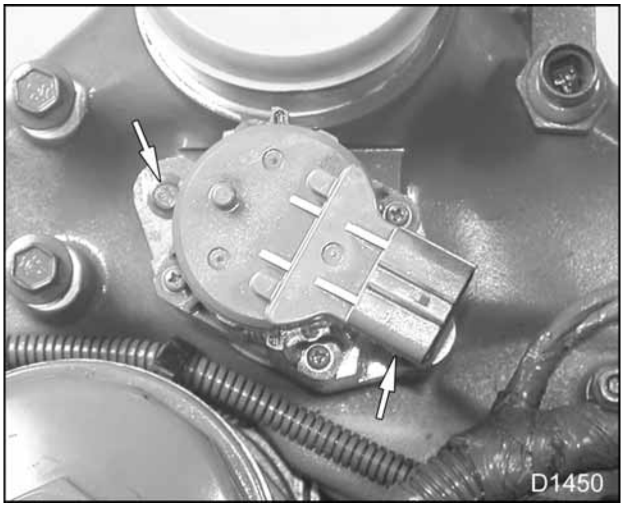


Figure 90 EGR valve retaining bolts

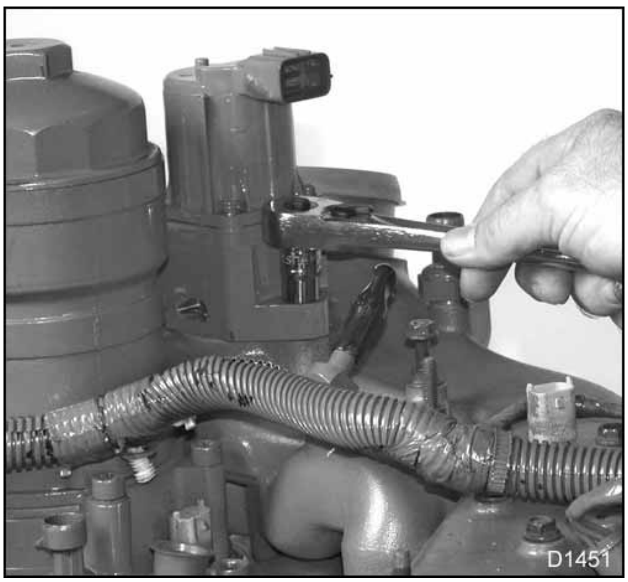


Figure 91 EGR valve retaining bolts

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

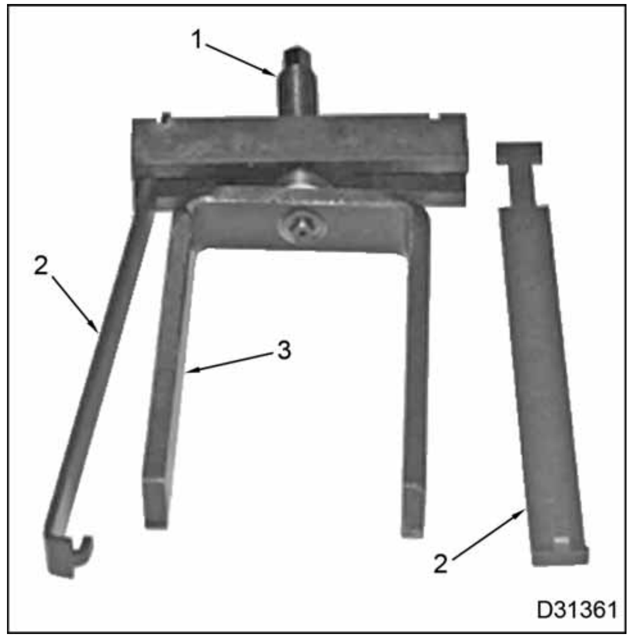


Figure 92 EGR Valve Puller

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

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

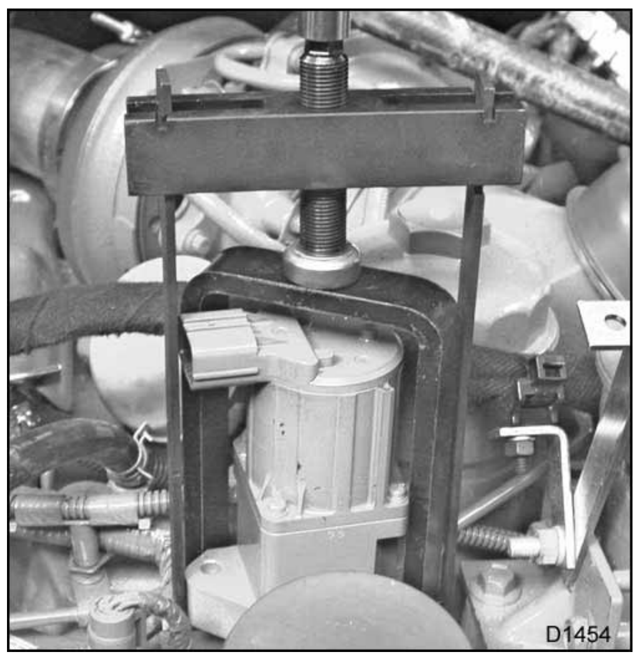


Figure 93 EGR valve puller installed

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.

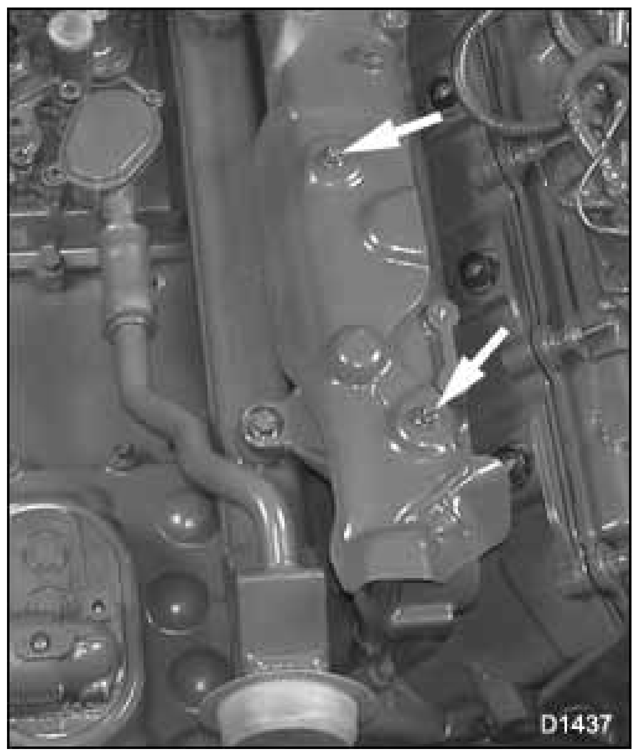


Figure 95 Intake heat shield mounting nuts (right side)

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

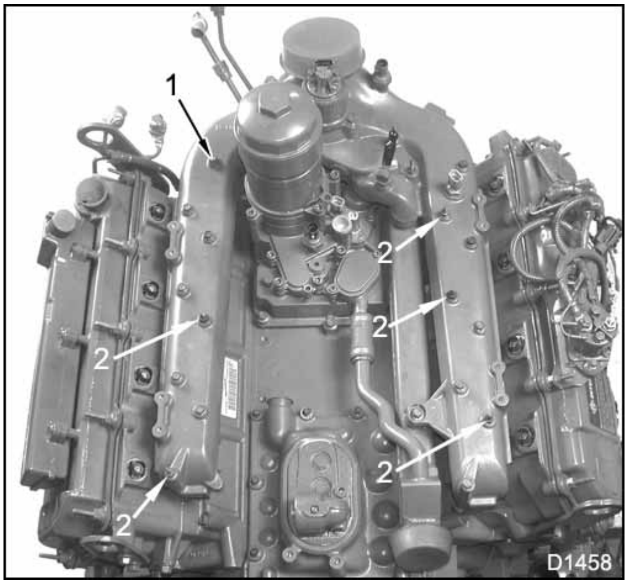


Figure 96 Dog point bolts stud bolts

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.

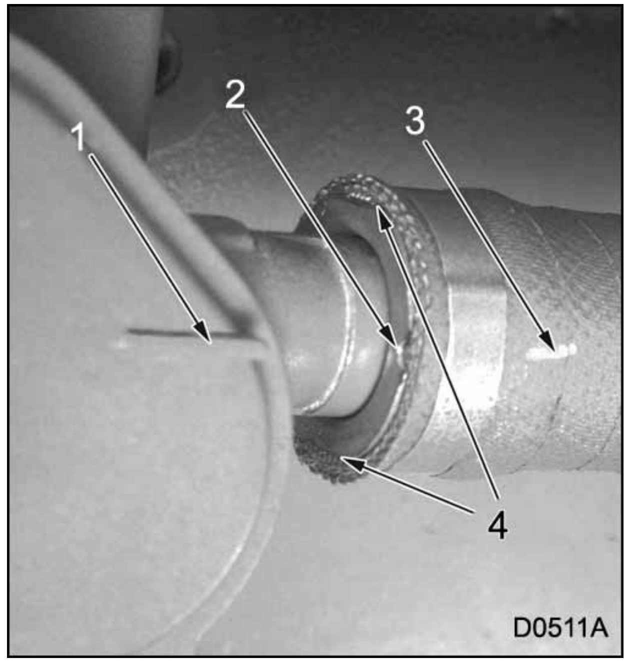


Figure 97 EGR coolant inlet coupling

1. Index feature on coolant supply port cover
2. Recess
3. Single index mark
4. Flat edge representing duel 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.

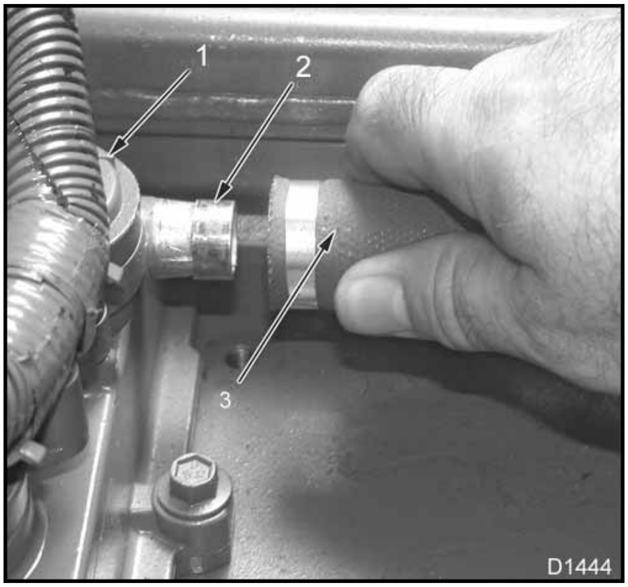


Figure 98 EGR coolant inlet coupling removal from coolant supply port

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.

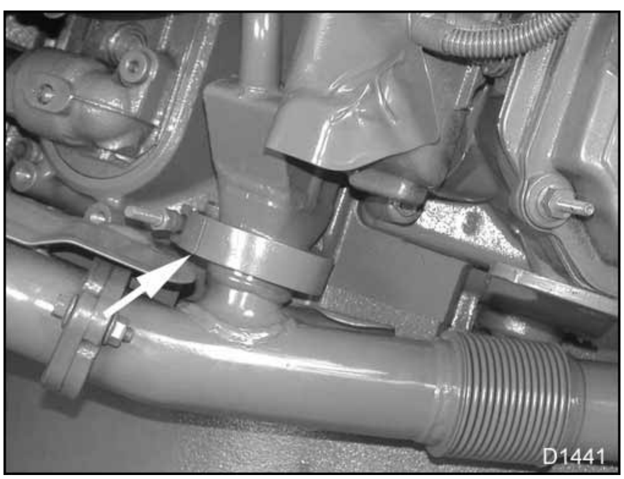


Figure 99 V-clamp on EGR Cooler

7. Remove V-clamp from EGR cooler.

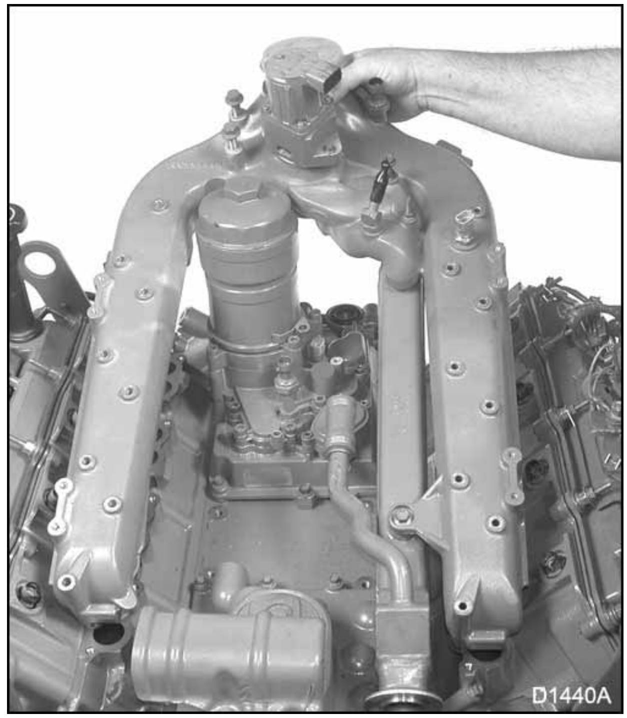


Figure 100 Intake manifold and EGR cooler

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

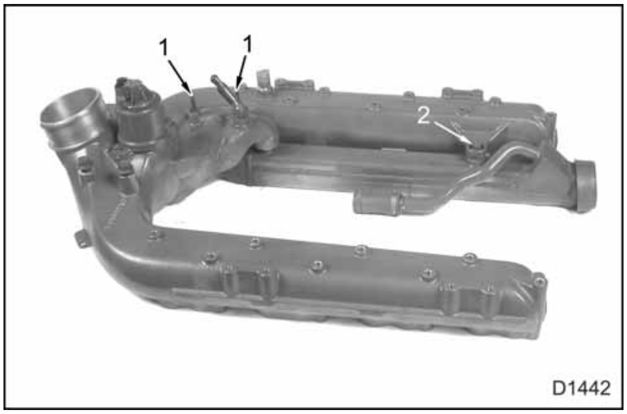


Figure 101 EGR cooler retaining bolts

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.

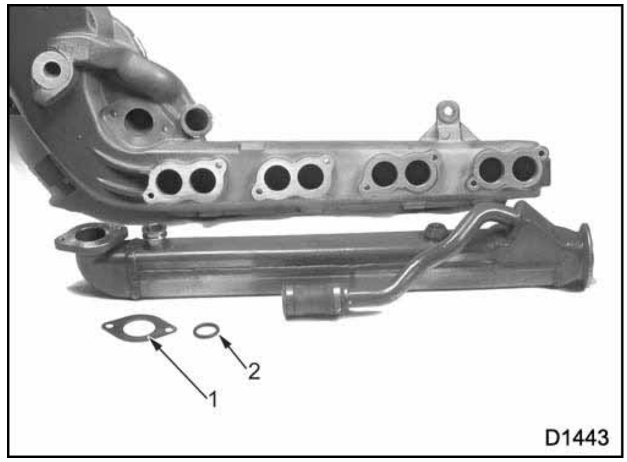


Figure 102 EGR cooler assembly

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

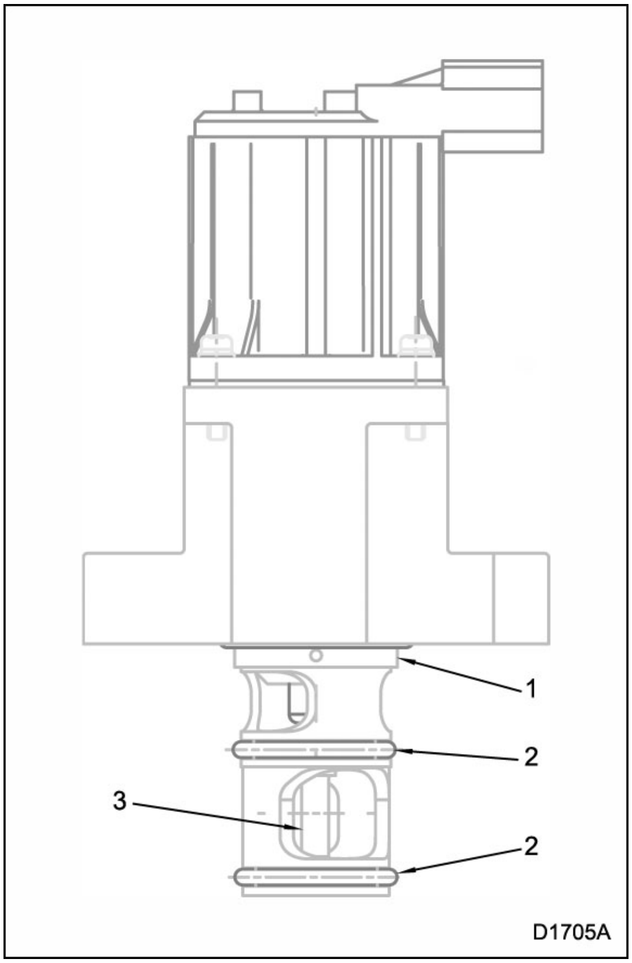


Figure 103 EGR valve assembly

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

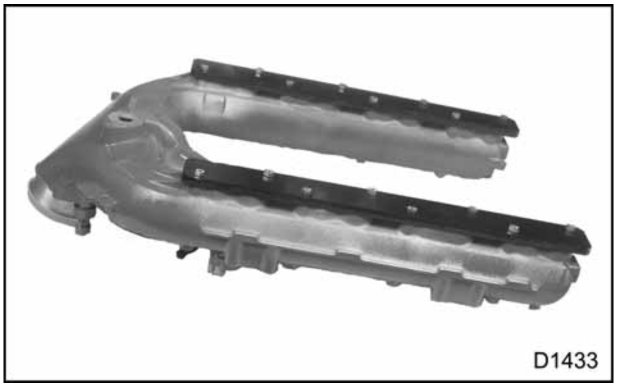


Figure 104 Test plates installed on intake manifold

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

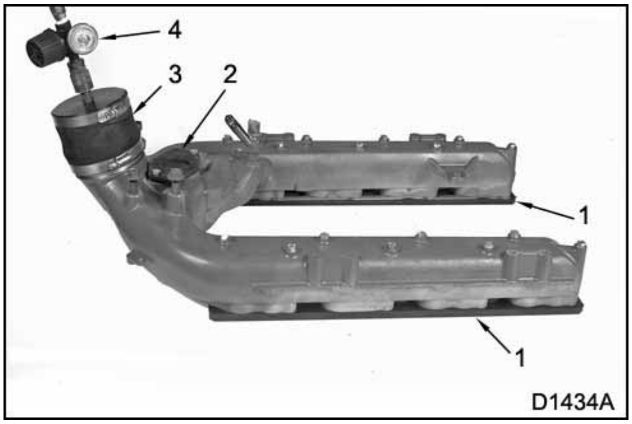


Figure 105 Set up for intake manifold pressure test

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

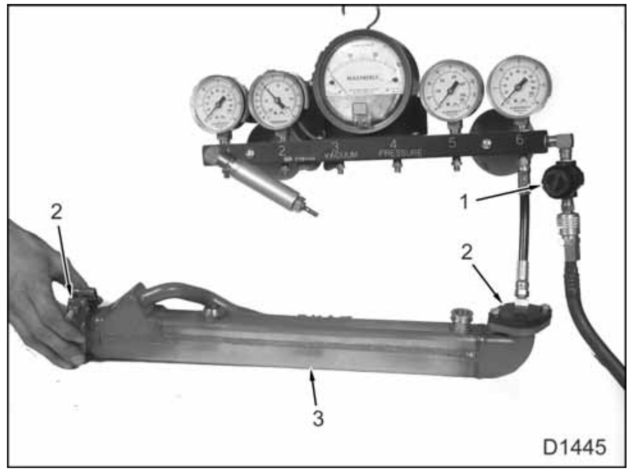


Figure 106 EGR cooler with pressure test plates installed

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.

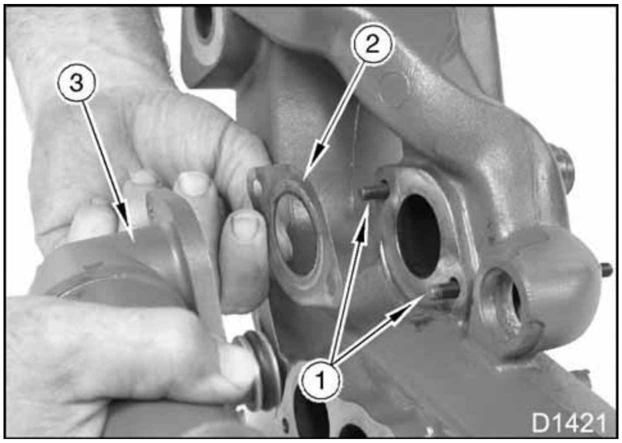


Figure 107 EGR cooler connection to intake manifold

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

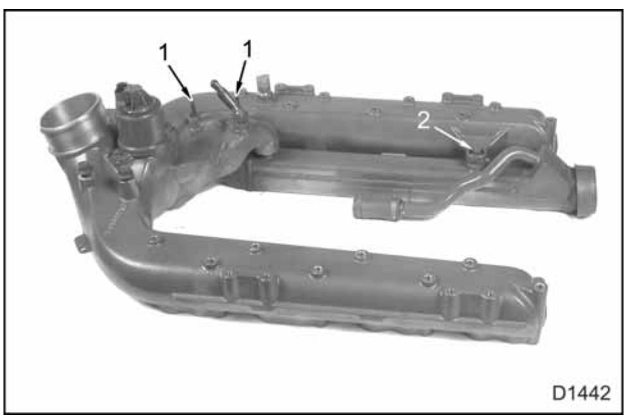


Figure 108 EGR cooler retaining bolts

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.

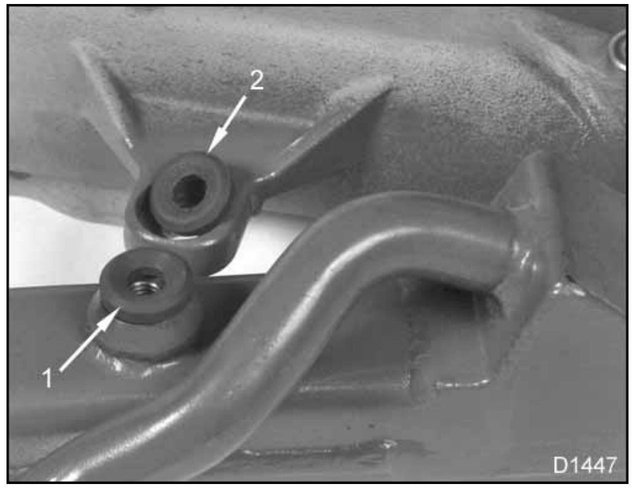


Figure 109 Bosses between EGR cooler and intake manifold

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.

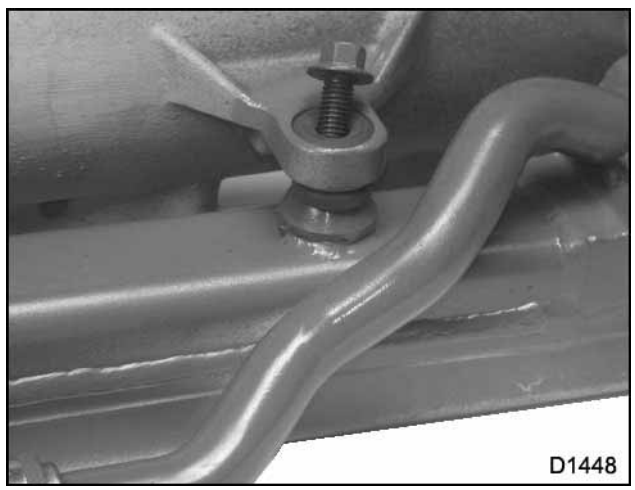


Figure 110 EGR rear mount bolt

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

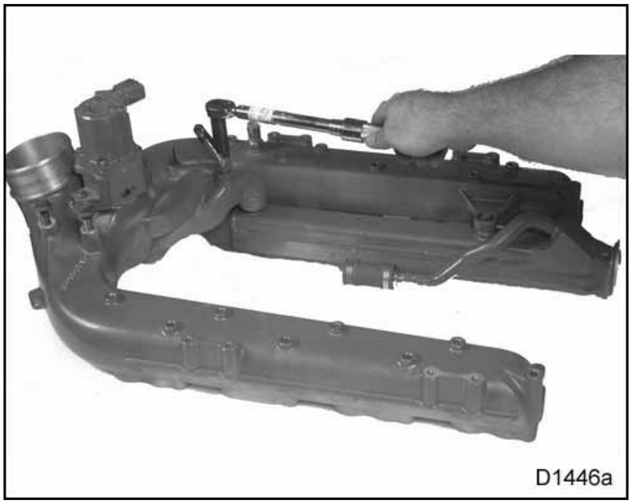


Figure 111 EGR cooler retaining bolts

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

Intake Manifold and EGR Cooler

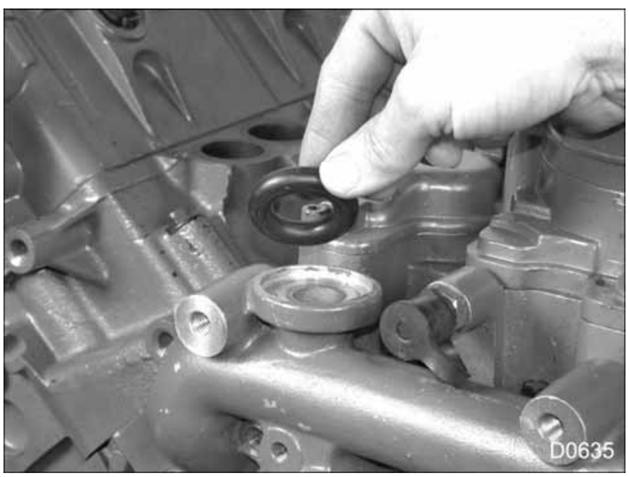


Figure 112 Front module seal

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

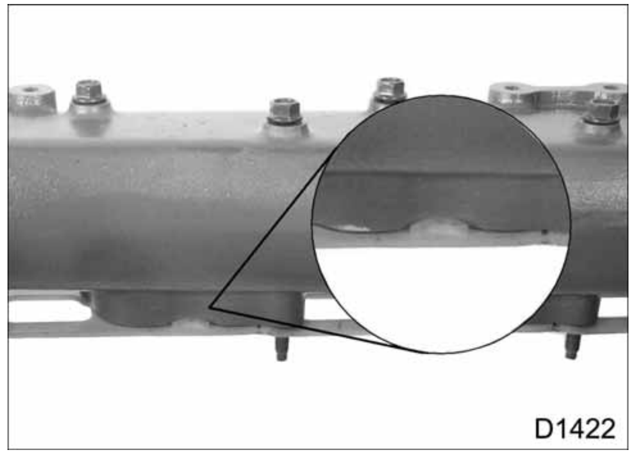


Figure 113 Intake manifold gasket with centering tab

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.

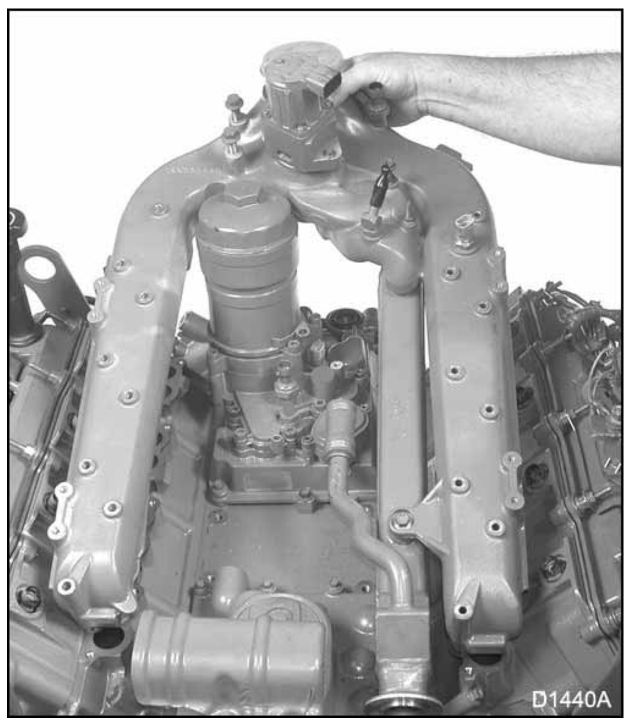


Figure 114 Intake manifold and EGR cooler assembly

4. Position intake manifold on cylinder heads.

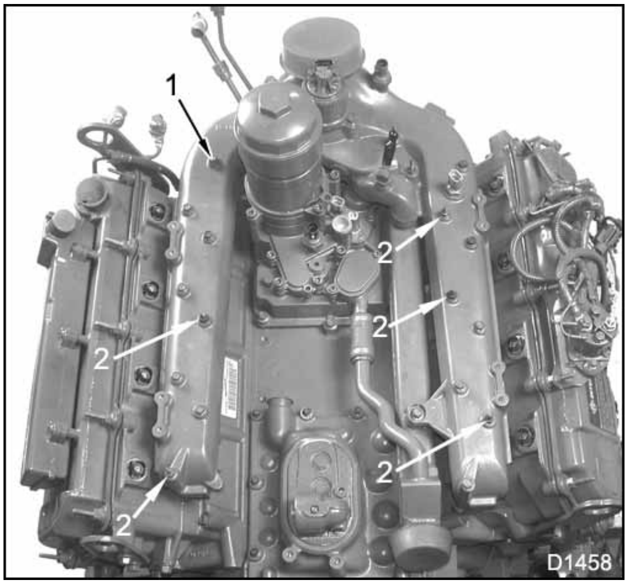


Figure 115 Dog point bolts and stud bolts

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

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

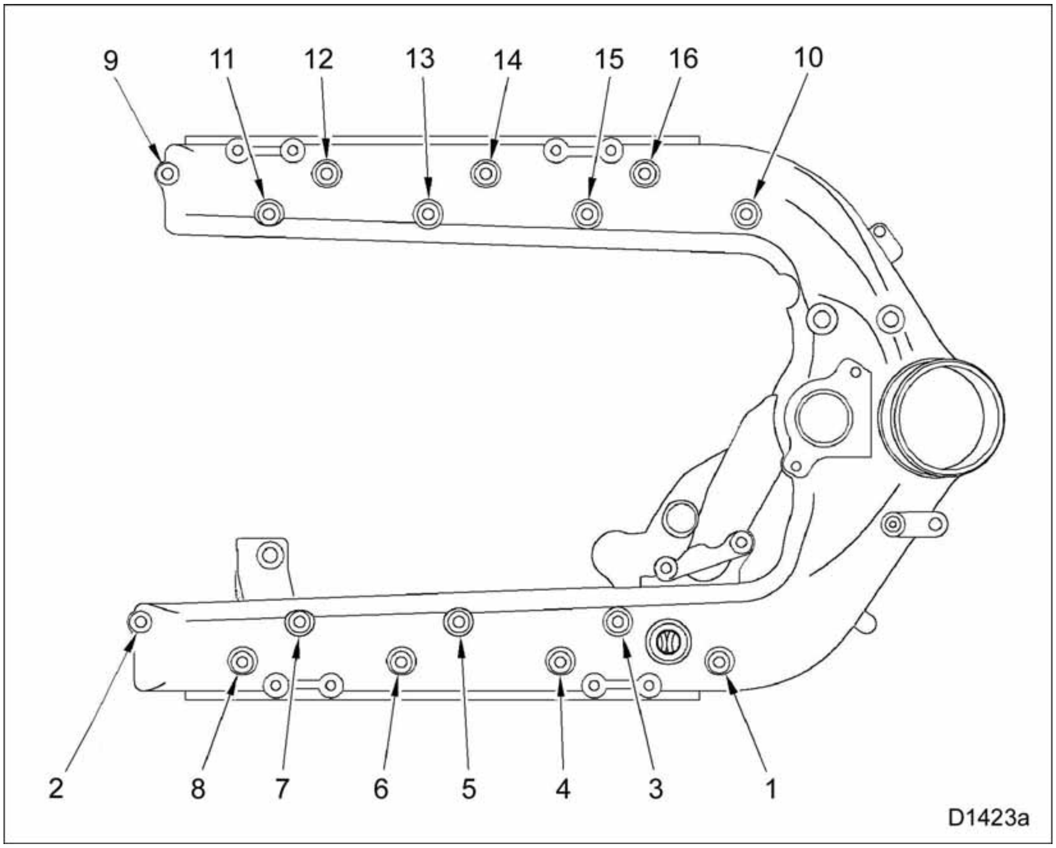


Figure 116 Torque sequence for intake manifold mounting bolts

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

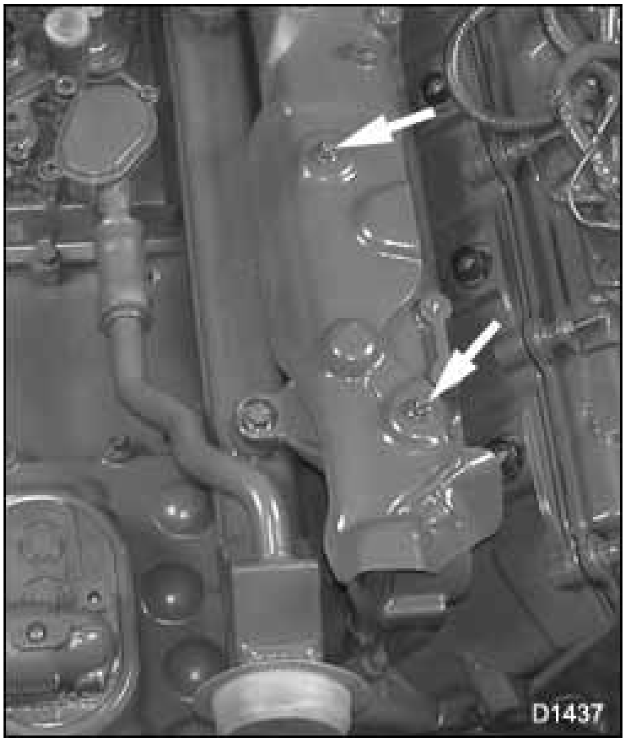


Figure 117 Heat shield mounting nuts (right side)

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).

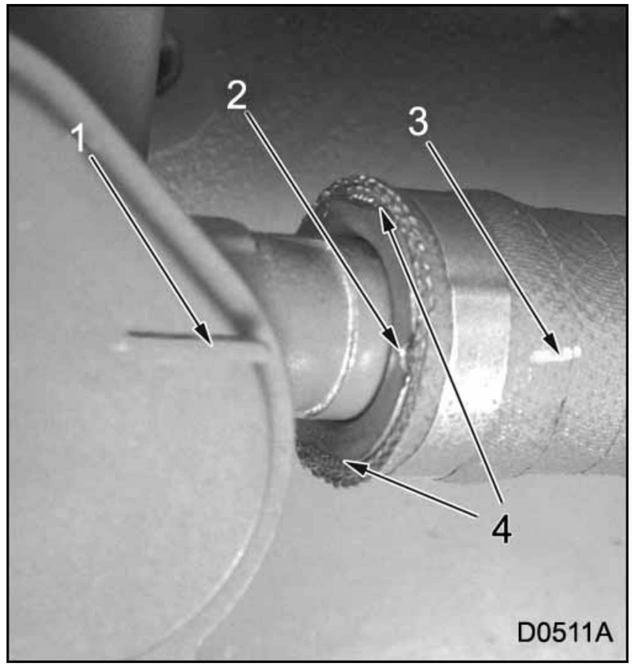


Figure 118 EGR coolant inlet coupling alignment (unlocked position)

1. EGR coolant supply port cover mark
2. Recess
3. Single index mark
4. Flat edge representing duel 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).

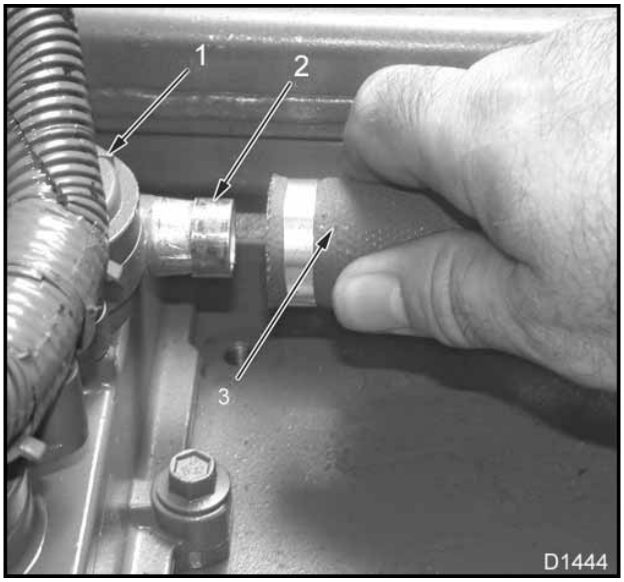


Figure 119 EGR coolant inlet coupling to coolant supply port

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.

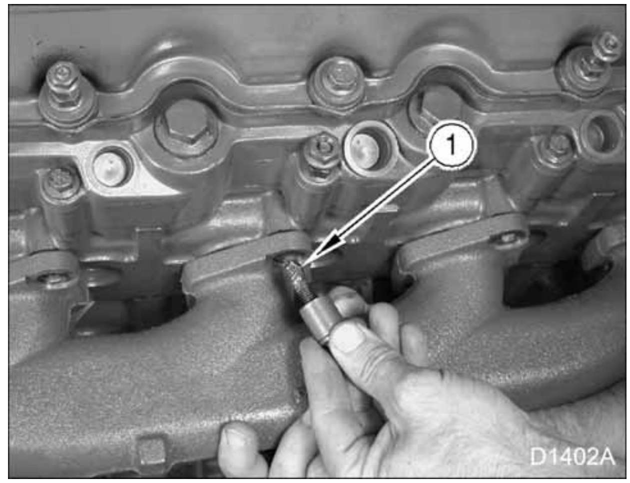


Figure 120 Right exhaust manifold bolt and spacer

1. Anti-seize compound

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

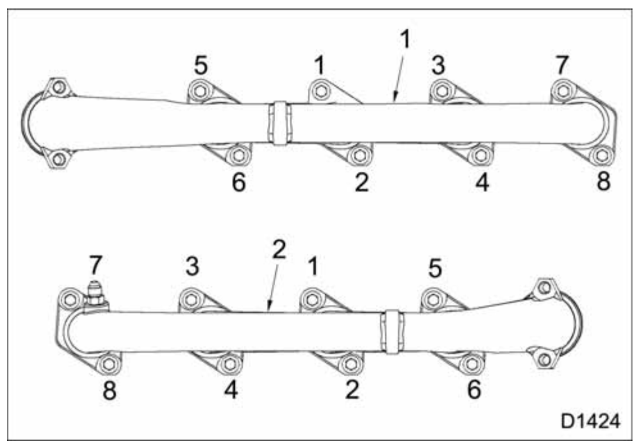


Figure 121 Torque sequence for exhaust manifold mounting bolts

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).

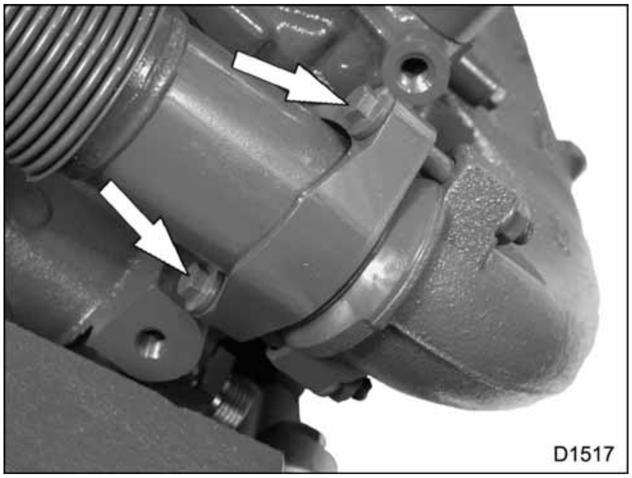


Figure 122 Mounting bolts for right exhaust tube

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.

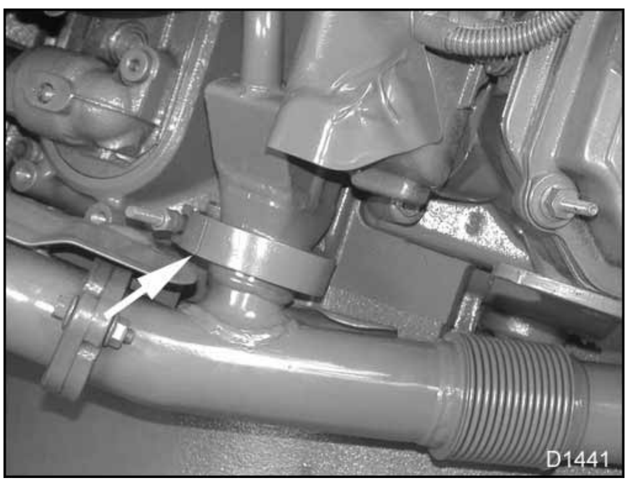


Figure 123 EGR cooler V-clamp

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

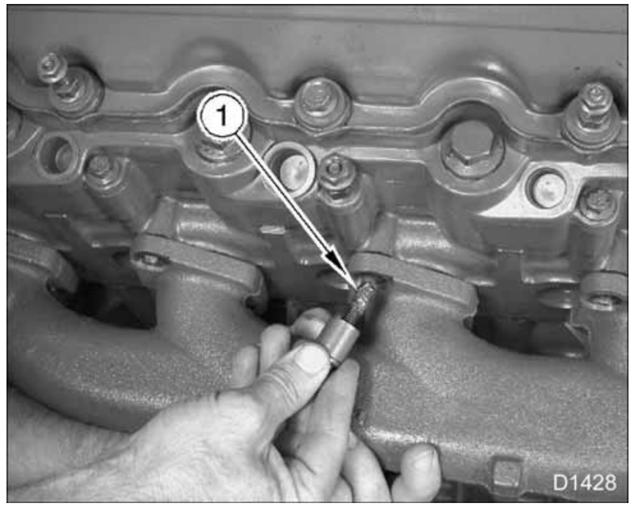


Figure 124 Bolt and spacer for left exhaust manifold

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).

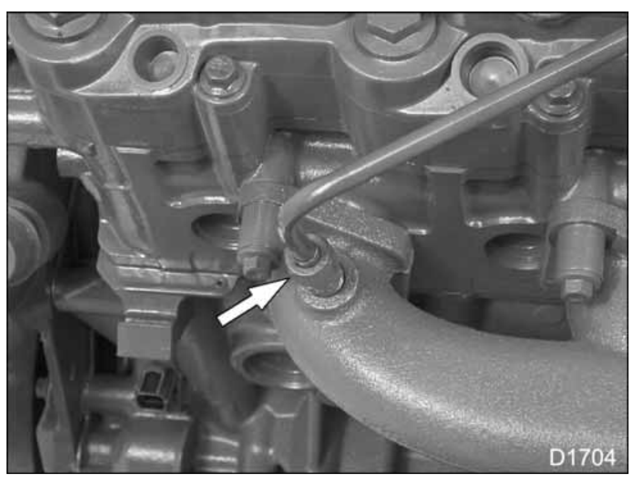


Figure 125 EBP sensor tube fitting

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).

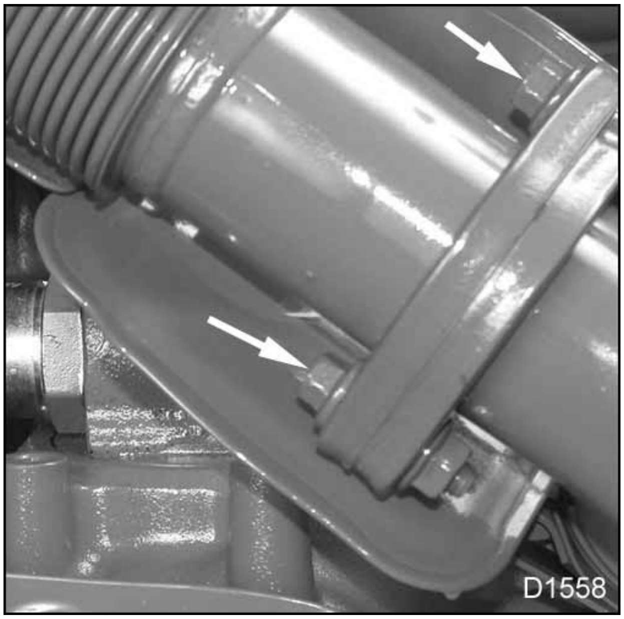


Figure 126 Exhaust tube bolts (upper right)

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.

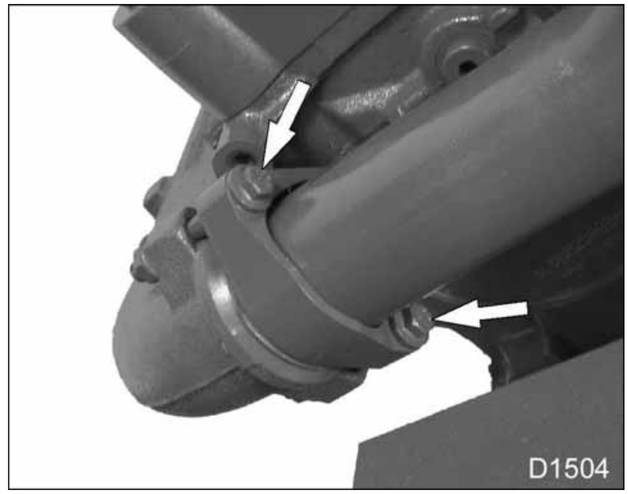


Figure 127 Mounting bolts for shielded tube exhaust assembly on left exhaust manifold

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

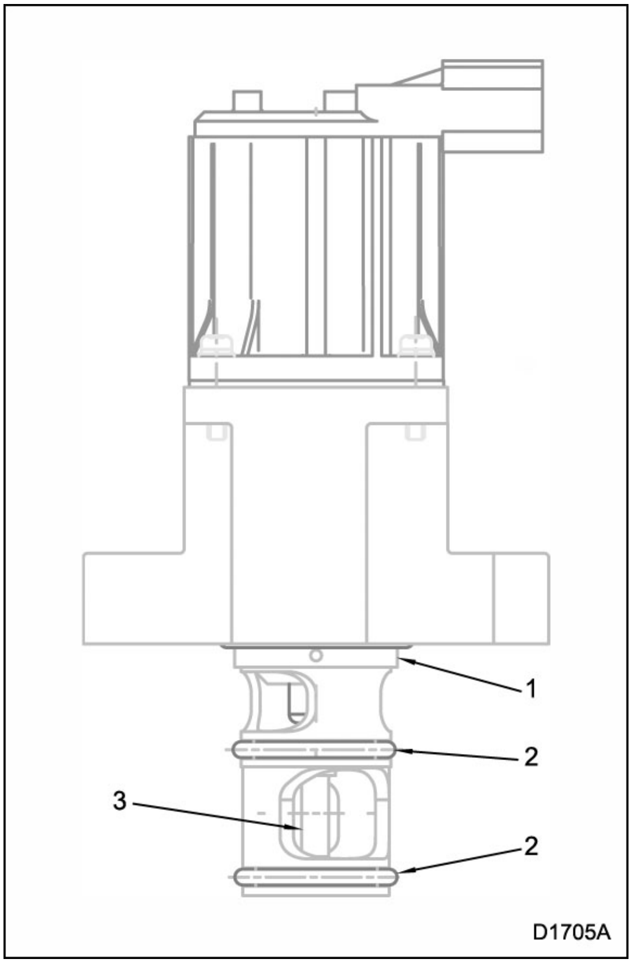


Figure 128 EGR valve assembly

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.

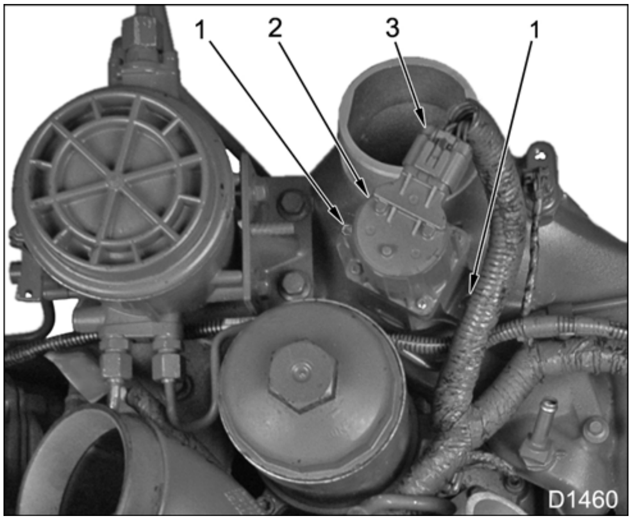


Figure 130 Insatallation of EGR valve

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